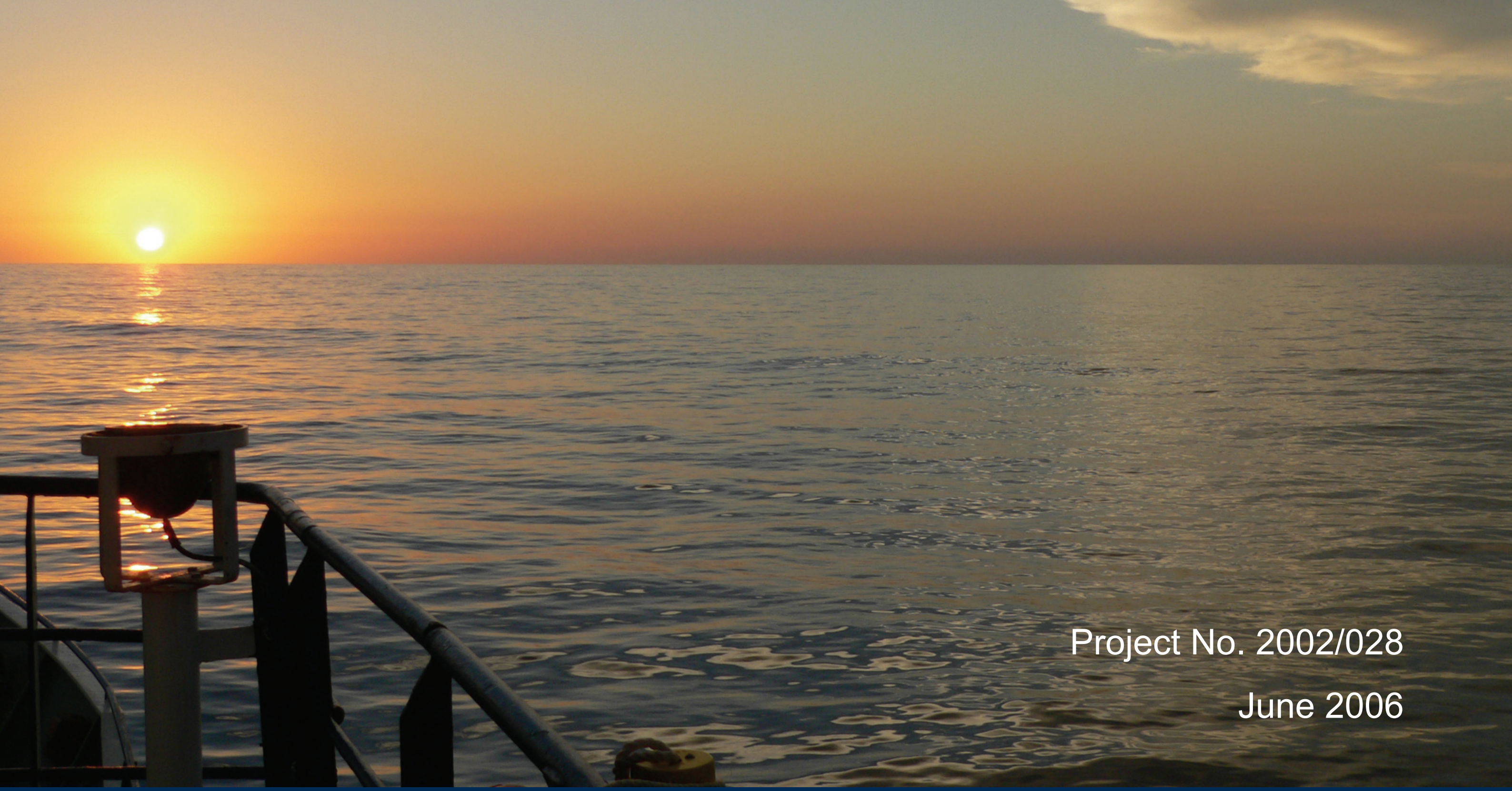

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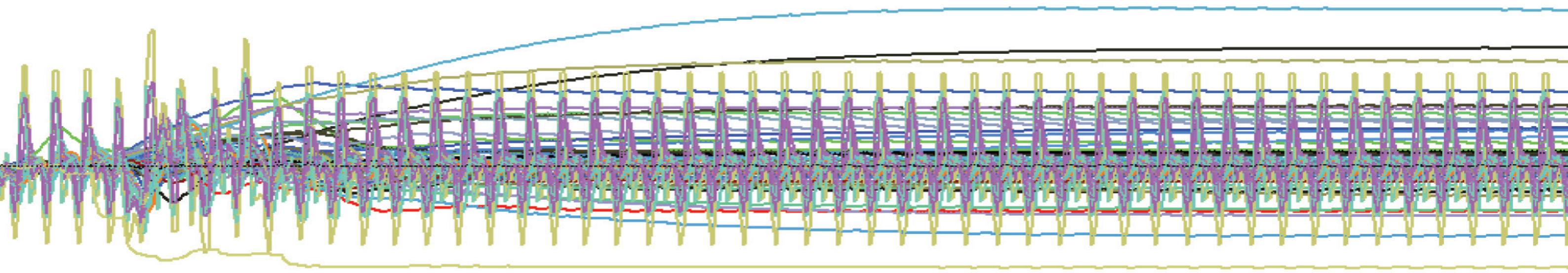

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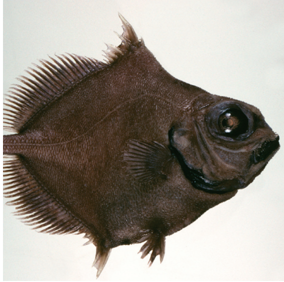

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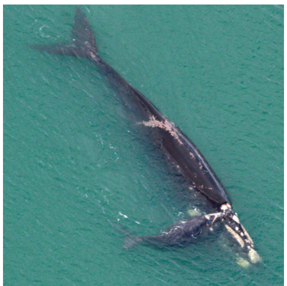

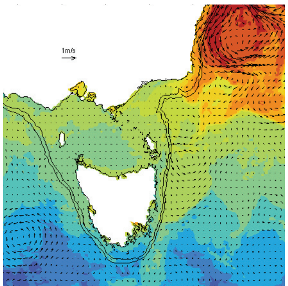

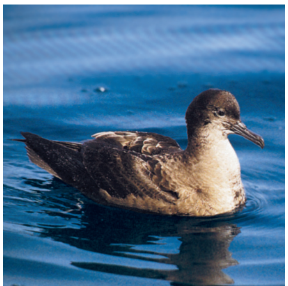

Trophic dynamics of the eastern shelf and slope of the South East Fishery: impacts of and on the fishery

C. Bulman, S. Condie, D. Furlani, M. Cahill, N. Klaer, S. Goldsworthy and I. Knuckey

Project No. 2002/028
June 2006

Final Report for Fisheries Research & Development Corporation

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NON TECHNICAL SUMMARY

2002/028	**Trophic dynamics of the eastern shelf and slope of the South East Fishery: impacts of and on the fishery**

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OBJECTIVES:

1. Develop circulation and trophic models to describe the past and present structure and dynamics of the food web on the eastern shelf and slope of the South East Fishery, the impacts of variability in primary production on catches, and to predict future changes in response to recovery of marine mammals and major reductions in discarding.
2. Provide a quantitative assessment of food web related risks, in support of strategic assessment of the fishery under the Environmental Protection and Biodiversity Conservation Act.
3. Contribute to a regional ecosystem model for use in the National Oceans Office's Regional Marine Plan for the South East, including detailed scoping and preliminary trophodynamic models for the Eastern Bass Strait Shelf.

NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED

1. A synthesis of existing knowledge about the trophic dynamics of the SEF ecosystem which was achieved through the collation of data from (i) targetted trophic studies and other physical, biological and oceanographic studies within the study area and broader South East Fishery zone; (ii) studies on the same or closely related species within other regions; and (iii) other ecosystem models with similar characteristics.
2. Identification of potential ecosystem responses to (i) changes in environmental conditions particularly through their impact on primary production; (ii) current trends in the recovery of seal populations; (iii) reductions in fishery bycatch; and (iv) changes in fishing effort.
3. Key tools and information to support the SEF in establishing an ecosystem-based approach to management of the fishery and satisfying EPBC requirements.

Until recently, trophic modelling and ecological risk assessment have not been utilised routinely in fisheries management. Two factors have limited the application of such methods: the first has been the paucity of data, understanding, and tools to undertake such assessments, and the second has been a lack of perceived importance of assessing the trophic impacts of fishing. Now the data and tools have improved, and there has been a general recognition of the need to extend assessment of impacts of fishing beyond the immediate impacts on target species. Of all the fisheries in Australia, the South East Fishery (SEF) is best placed to undertake such assessments, thanks mainly to a long history of ecological research that has gone beyond a focus on target species. Much of this work was summarized recently in a special edition of Marine and Freshwater Research (2001 Vol 52).

The overall objective of this study was to develop trophic models that describe the past and present structure and dynamics of the food web of the south-east Australian shelf around Eastern Bass Strait (EBS). Early results were provided to the National Oceans Office’s Regional Marine Plan for the South East Marine Region. The models were used to better understand the complex trophic interactions operating on the shelf and upper slope. While not yet capable of predicting precise magnitudes of change, they provide a means of identifying potential ecosystem responses to changes in environmental conditions or human activities.

At the foundation of any food web are the primary producers, which place an upper limit on the energy available to other trophic groups. We used satellite ocean colour data to estimate phytoplankton biomass and primary productivity in the EBS model area. These estimates were used to constrain the primary production parameters and impose patterns of seasonal and interannual variability onto the dynamics of the trophic model. Primary productivity in the area was found to support the modelled ecosystem without the need to rely on importation of organisms such as phytoplankton and zooplankton by ocean currents. The small mesopelagic fishes that support the slope and shelf break fishes were imported into the area largely through the process of diel vertical migration causing them to be washed up onto the shelf. While the model demonstrates the linkages between primary production and commercial fish species, the trophic pathways are complex and no strong direct correlation could be detected between satellite-estimated primary production and fishery catches.

The trophic model was developed primarily around the fishes of the commercial fisheries and the major vertebrate groups in the ecosystem including marine mammals and birds. Studies of the Australian seal populations suggest that they are doubling every 10 years, causing some fishers to express concern. We used the models to predict broad community responses to variations in the rate of seal population growth. Although seals are voracious feeders and highly visible, they are found to consume only a small proportion of the total consumption of fish in the system. Simulation results suggest that while higher seal numbers coincide with declines of their prey fish species, some target commercial species actually increase when seals increase.

We also investigated how the biological community might respond to increased or decreased fishing pressures. Nearly all fisheries were predicted to have lower catches in the future, even if the fishing rate was increased. This was because fishing rate, F, is the ratio of catch to biomass, therefore, if F is constant, catches will decline as biomass declines. If biomass continues to decline, then larger F rates might not result necessarily in larger catches. Effort has declined over the past 10 years in most fisheries except the Commonwealth trawl fishery where it has risen. This has released fishing pressure on many species allowing some recovery. However this recovery was not necessarily sufficient to result in bigger predicted catches in the future compared to the current catches even if effort was increased. This result suggests that some stocks are currently over-exploited.

Eliminating discarding by retaining all bycatch appeared to have little effect on the fish populations since the model assumed that bycatch whether discarded or landed was no longer part of the living system. We were not able to determine effects on the detrital sub-system.

Early last century, intensive sealing and whaling operations severely depleted these populations, while fish populations were largely unexploited. When the trophic model was recalibrated for these historical conditions with estimated pre-fishing abundances for flathead, morwong and Chinaman leatherjacket, and assumed pre-fishing abundances for the current commercial species based on stock assessment, the abundances of all other fish groups, many of which were prey of the previous groups, needed to be many times larger than today’s estimates. While the historical model described an ecosystem that might have been nearly twice as big overall as the present system, it could still be easily supported by the primary productivity estimated for present day conditions. The fate of the excess primary and secondary production in today’s system was indeterminable however there are several possibilities: excess primary production could be lost directly to the detrital cycle if not consumed; lost as secondary or higher level production if consumed and converted to next level production; advected out of the area; or a combination of both depending on the biomass of consumers.

The models we have developed for the Eastern Bass Strait have provided a good framework for ongoing exploration of the response of the eastern Australian marine ecosystem to environmental and anthropogenic disturbances. While the model captures some of the complexity of the trophic interactions that are fundamental to the ecosystem, there are still many gaps in our knowledge, particularly in relation to lower trophic levels. Filling these gaps will enable us to improve the model and its behaviour, and ultimately, its performance in response predictions. Discussion with and input from a wider range of experts would also be of great benefit to improvement of the model.

KEYWORDS: Trophic modelling, seal impacts, discarding, primary productivity, East Bass Strait, South East Fishery.

CONTENTS

1 PROJECT BACKGROUND

1.1 Acknowledgments

We gratefully acknowledge the Fisheries Research Development Corporation and the National Oceans Office, who funded the project; the Australian Fisheries Management Authority, the Commonwealth Scientific and Industrial Research Organization, and the New South Wales and Victorian state fisheries for providing fishery statistics data; and DIPWE for the providing the images of birds, seals and whales on the front cover. We also acknowledge many colleagues: Chris Rathbone for estimates of productivity from the remote sensing data; Robert Campbell and Mike Fuller (CSIRO Marine and Atmospheric Research) for helpful insights in interpreting the fisheries data,; Villy Christensen (Fisheries Centre, University of British Columbia) for facilitating a visit to the Fisheries Centre by CB to gain valuable experience and advice with the ecosystem software; Tony Smith, Beth Fulton and Tom Okey (CSIRO Marine and Atmospheric Research) for valuable modelling advice throughout the project and comments on the draft report. Our thanks also to Louise Bell for our cover design.

1.2 Background

The SEF is Australia’s oldest and most intensively fished fishery. Tilzey and Rowling (2001) describe the history of fishing since 1915, and Klaer (2001) describes some of the large changes in species composition over the first 50 years of the fishery. Other studies have demonstrated changes in the fish community in more recent years as fishing extended on to the upper and mid slope. Apart from long-term directional changes in the broad fish community, there are also large changes from year to year (and over longer time periods) in the availability of individual species, probably reflecting cyclical changes in the feed species due to changing water conditions (Prince and Griffin 2001). Fishers are very familiar with these changes, which also affect interpretations of catch rates and hence stock assessments. Other current changes in the broader ecology of the SEF region include the rapid recovery of seal populations, resulting in increased interactions with fishing operations and giving rise to the suspicion by some that seals may be competing increasingly with the fishery for fish.

The SEF is a quota-managed fishery, and considerable research and resources have gone into improving stock assessments for a number of quota species over the past 10 years. Much less effort has gone into assessing the broader ecological impacts of fishing in the SEF, although recent and current studies on bycatch and on fish habitats are improving this situation. There have also been a number of studies in the past 15 years addressing aspects of the feeding ecology and trophic structure of the fish communities of the SEF. These include studies of the upper slope (Bulman and Blaber 1986, Blaber and Bulman 1987, May and Blaber 1989, Young *et al*. 1986), the mid slope (Bulman *et al*. 2002, Koslow 1996) and the continental shelf (Bax and Williams 2000, Bax *et al*. 2001, Bulman *et al*. 2001, Williams and Bax 2001), together with a number of studies of the pelagic systems in the area (Young and Davis 1992, Young *et al*. 1993, 1996a, 1996b, 2001). Collectively, these studies represent an investment of millions of dollars, and provide a good basis for understanding many aspects of the trophic dynamics of the SEF. However there have been no previous attempts to synthesize this information, or to undertake any quantitative assessment of the trophic impacts of the fishery.

The most recent ecosystem studies in the SEF have pointed to some of the key interactions that might be very influential in the abundance and productivity of the fishery (FRDC 94/040). Bax and Williams (2000) concluded that the south-eastern shelf system was structured by the availability of food, unlike many other marine ecosystems, which are structured by predation. They also hypothesized that selective reduction of predators such as tiger flathead since the beginning of the fishery might have changed the structure of the fish community on the shelf. Removal of top predators due to selective fishing might be responsible for this apparent lack of structuring from predation. Selective fishing is thought to have caused a shift in the northeast Atlantic shelf system from a community dominated by commercial species to one that is now dominated by “trash” species. However, this has not occurred in the North Sea where fishing has been much less selective.

The SEF shelf ecosystem study also concluded that demersal fisheries were strongly linked to pelagic production (Bulman *et al*. 2001, Bax and Williams 2000). The major commercial and quota fish species within the SEF feed largely on pelagic and benthopelagic prey, particularly fish but a variety of invertebrates (Bulman *et al*. 2001). The prey fishes also rely on pelagic and benthopelagic invertebrates, particularly copepods and euphausiids but together with ostracods, hyperiid amphipods, crab larvae, pelagic gastropods and gelatinous zooplankton (Young and Blaber1986; Young *et al.*1996a).

In coastal upwelling regions, the production of zooplankton such as copepods and euphausiids is of great importance to fish production. The majority of transfer between phytoplankton and fish in these systems is via the pathways of diatom to meso- and macrozooplankton to fish (e.g. Robinson 1994). As a result of this transfer, the nutrient-rich shelf-break upwellings that occur on the area might have significant effects on fish distribution and production.

Other influences, such as the recovery of seals in the region, are also likely to be shaping the SEF ecosystem (Goldsworthy *et al*. 2003). Current proposals to reduce or even eliminate discarding in the trawl fishery are also likely to have implications for the trophic dynamics of the SEF. Total retention of catches will eliminate provisioning of scavengers forcing a reallocation of consumption of prey species. It will also change the calculated trophic level of catches by accounting for small “trash” fish of lower trophic level giving the appearance of fishing down the food chain (Pauly *et al*. 2000) although the total amount of fish “extracted” from the system remains the same whether fish are discarded or retained, because they are no longer part of the living system.

The aim of the present study is to synthesize the extensive ecological and environmental data available for the SEF, in particular for the southeast shelf and slope, and to develop preliminary trophic models of this system to begin to address the range of issues listed above. We chose an area of eastern Bass Strait to focus our model because it has been heavily fished over the past century causing an urgent need to understand the system for improved management and has also received considerable scientific attention providing a large amount of historical and current data.

1.2.1 Physical description of study area

The east Bass Strait (EBS) study area is situated on the southeast corner of mainland Australia from Wilsons Promontory on the southern Victorian coast to Bermagui on the NSW coast (Fig 1). The region has been the focus of a recent ecosystem study by CSIRO Marine Research (Bax and Williams 2000). The trophic model being developed covers the shelf and the slope to about 700m, where there is a major change in fish community composition. The shelf area within a depth range of 25 to 200 m is 26,150 km^2 while the slope from 200 to 700 m is 4,113 km^2, a total of 30,263 km^2. The shelf consists of soft and hard grounds interspersed with reefy outcrops that comprise nearly 10% of the total area (Bax and Williams 2000, 2001; Williams and Bax 2001).

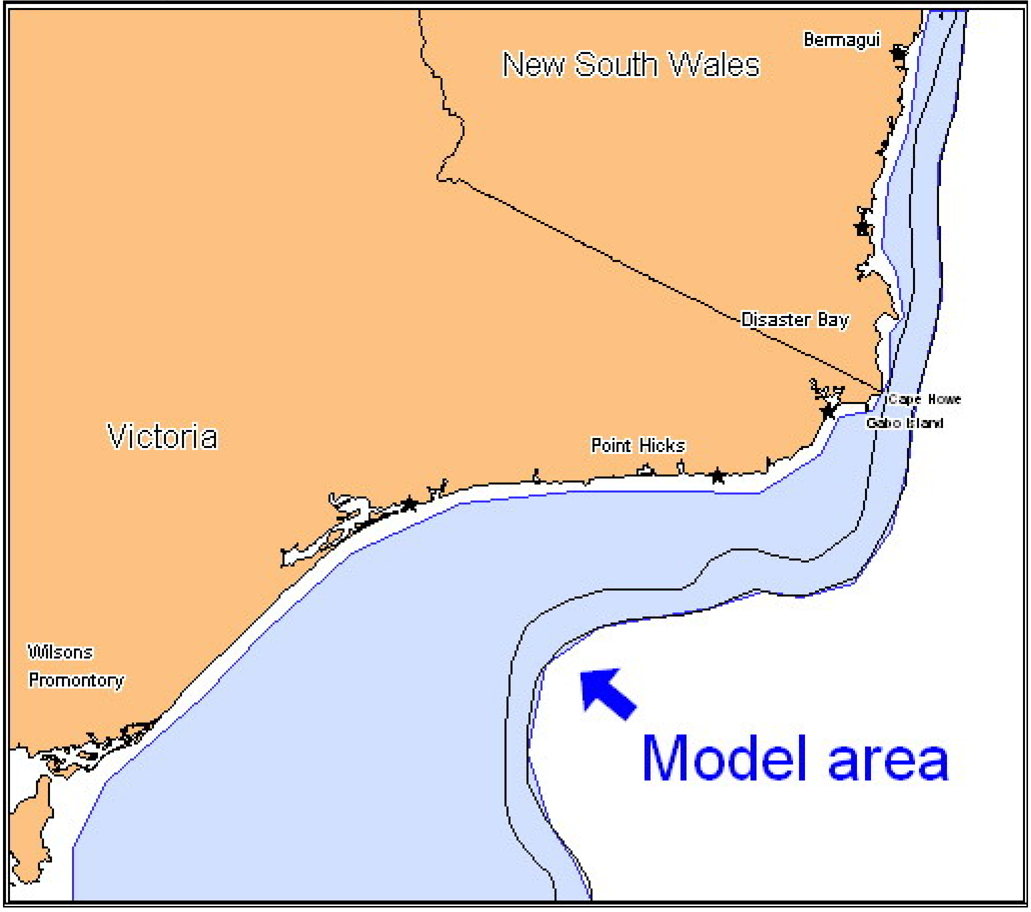

Figure 1. The East Bass Strait study area (light blue). The seaward boundary is the 700 m isobath, the middle isobath is 200 m and the inner isobath is 25 m.

The water influences are from the cool low-nutrient Bass Strait waters, the warm low-nutrient East Australian Current (EAC) intruding in summer and the cool nutrient-rich sub-Antarctic waters upwelling onto the outer shelf and slope areas more or less continually (Newell 1961, Bax and Williams 2000, Condie and Dunn unpublished manuscript.). A northward flowing counter current along the shelf-break brings slope water onto the shelf (Cresswell 1994). Nutrient enrichment of shelf waters is primarily by cool sub-Antarctic water uplifted from the slope, driven by EAC eddies, topography and wind, resulting in intermittent and seasonal events (Bax and Williams 2000).

The invertebrate communities are highly diverse and show high endemism (Bax and Williams 2001, National Oceans Office 2002). However, *Maoricolpus roseus*, the introduced New Zealand screw shell, now dominates the biomass of several of the inshore habitats.

1.3 Need

The change in focus of fisheries management towards ecosystem-based management (Pitcher 2001) is a worldwide trend. Within Australia it is particularly evident in the requirements of the Environmental Protection and Biodiversity Conservation (EPBC) Act, and in the development of regional marine plans (RMPs) under Australia's Oceans Policy. The former requires strategic assessment of the ecological impacts of fishing, including assessing trophic impacts. The latter seeks to integrate management of entire regions through an ecosystem approach that considers impacts from all uses of the marine environment (including impacts of other users on fishery ecosystems). The southeast region is the first to be evaluated under Oceans Policy.

Even without the "stick" of EPBC and RMP, there are good reasons to attempt to synthesize current data and understanding of the SEF ecosystem, and to model the impacts of and on the fishery. Specific questions that need addressing include:

What changes in the fish community have taken place in the past, and what are the consequences for current fishery production and value?

What further changes might be expected under planned reduction or elimination of discarding in the South East Trawl (SET)?

What are the implications for the fishery of current rapid recovery in seal populations?

What are the reasons for and impacts of year-to-year variability in the SEF ecosystem (including regional circulation and primary productivity) on distribution and catches of quota species?

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2 PROJECT OBJECTIVES

The overall objective is to develop conceptual trophic models that describe the present structure and dynamics of the food web of the eastern Bass Strait and southern NSW area (EBS). Specifically to:

- Develop circulation and trophic models to describe the past and present structure and dynamics of the food web on the eastern shelf and slope of the South East Fishery (SEF), the impacts of variability in primary production on catches, and to predict future changes in response to recovery of marine mammals and major reductions in discarding.
- Provide a quantitative assessment of food web related risks, in support of strategic assessment of the fishery under the Environmental Protection and Biodiversity Conservation Act.
- Contribute to a regional ecosystem model for use in the National Oceans Office’s Regional Marine Plan for the South East, including detailed scoping and preliminary trophodynamic models for the Eastern Bass Strait shelf.

3 OCEANOGRAPHIC ENVIRONMENT

3.1 Introduction

Critical inputs into the trophic model include estimates of the standing phytoplankton biomass and primary productivity in the model domain. In the Eastern Bass Strait (EBS) region, the only available estimates of these quantities with significant temporal or spatial coverage are derived from satellite ocean colour. This chapter describes the derivation of ocean colour products suitable for use in Ecopath with Ecosim (EwE).

In open systems, secondary production is supported not only by local primary production, but also by plankton carried into the region by ocean currents. The EBS system is open to Bass Strait to the west, the NSW shelf to the north, and the open ocean to the east, suggesting that phytoplankton exchanges might be significant. To test this hypothesis, an independent estimate of the net flux of phytoplankton into the EBS region was computed from satellite derived plankton concentrations and ocean currents. The results indicate that transport of phytoplankton into the EBS region is minor compared to primary productivity within the region.

3.2 Methods

3.2.1 Chlorophyll and phytoplankton biomass

Estimates of chlorophyll (approximately proportional to plankton biomass) were based on satellite ocean colour measurements from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) instrument taken from October 1997 to September 2002. The data are in the form of eight day composite images with 9 km spatial resolution, as provided by NASA. Since there are insufficient *in situ* data available to calibrate these datasets within the EBS region, errors in estimated chlorophyll concentration are yet to be quantified and may be significant in the coastal zone where other suspended material can contribute to the signal.

Chlorophyll represents only a small fraction of the mass of the phytoplankton cell, so that phytoplankton concentration must be estimated by multiplying the chlorophyll-*a* concentration estimated from the satellite data by a carbon to chlorophyll-*a* ratio of approximately 40 (e.g. Fasham *et al*. 1983, Harris 1986) and a wet weight to carbon ratio of 20 (McKinnon and Duggan 2003). However, in Ecopath, phytoplankton biomass is expressed not as a concentration (i.e. biomass per unit volume), but rather in depth-integrated form (i.e. biomass per unit area of ocean). To make this second conversion, we assume that the ocean colour signal is derived primarily from the surface mixed layer, which in the EBS region typically has a depth of around h = 40 m (Condie and Dunn, in press). Standing phytoplankton biomass in units of t km^{-2} is therefore given by:

$$B_{phy} = 40 \times 20 \times 10^{-3} \times h \times C_{chl} \qquad (1)$$

where h is the mixed layer depth (m), C_{chl} is the chlorophyll concentration (mg m^{-3}), and the factor of 10^{-3} coverts from mg m^{-2} to t km^{-2}.

3.2.2 Primary productivity

Primary productivity estimates were based on assumed relationships with quantities such as solar radiation, mixed layer depth, and satellite chlorophyll, and is therefore expected to be less reliable than chlorophyll itself. However, these products represent the best available information and provide a useful measure of temporal and spatial trends.

Depth integrated estimates of primary productivity within the euphotic zone were calculated using two alternate models. The Vertically Generalized Production Model (VGPM) of Behrenfeld and Falkowski (1997a – referred to here as Befa) relates surface chlorophyll to depth integrated euphotic zone primary productivity. It includes a measure of depth-integrated phytoplankton biomass, estimated by the product of surface chlorophyll and euphotic depth, as well as irradiance and photo-adaptive terms necessary to convert the estimated biomass into a photosynthetic rate (Behrenfeld and Falkowski, 1997b). The second primary production model requires similar parameters to the VGPM, but estimates primary productivity over the surface mixed layer depth, rather than the euphotic depth (Howard and Yoder 1997 – referred to here as Hoyo).

3.2.3 Phytoplankton immigration

The immigration rate of chlorophyll into the EBS domain (in units of mg s^{-1}) was estimated as the product of the local chlorophyll concentration at the boundary, the surface mixed layer depth, and the current normal to the boundary (u in units of m s^{-1}), all integrated around a path following the water portion of the model boundary (ℓ in units of m).

$$I_{chl} = \int u h C_{chl} \, d\ell \qquad (2)$$

For use in EwE, this quantity can be converted to the immigration of phytoplankton in tonnes per unit area of the model domain per year using:

$$I_{phy} = 40 \times 20 \times 0.031536 \times \frac{I_{chl}}{A} \qquad (3)$$

where A is the area of the model domain in km^2 and the factor of 0.031536 converts mg s^{-1} to t yr^{-1}.

3.2.4 Ocean current estimates

Currents in the upper water column were required to estimate *u* in equation (2). These were derived from a combination of satellite-derived sea-level measurements and modelled wind fields using the methodology described by Griffin *et al*. (2001) and Condie *et al*. (2005). Because the analysis was concerned with relatively long-term transport (> 8 days) tidal motions were neglected. However, low frequency sea-level and local wind fields were required to estimate the large-scale current velocity fields as described below. The currents were calculated for a nominal depth of 20 m, which was taken to be representative of a surface mixed layer with a depth of around 40 m (Condie and Dunn, unpublished manuscript).

The sea-level at each location consisted of a long-term mean component plus short-term fluctuations or anomalies. Data on sea-level anomalies were collected from (i) the Topex/Poseidon satellite altimeter (9.9 day global cycle), (ii) the ERS satellite altimeter (35 day global cycle), and (iii) tide-gauges around the EBS coastline. The effective spatial resolution of the combined dataset was quite variable, but generally adequate to resolve the major currents and mesoscale eddies. The coastal tide-gauge data were interpolated along the coastline to achieve coastal anomalies with comparable resolution to the altimetry. The long-term mean sea-level was calculated independently using the mean ocean density field. This mean was based on historical temperature and salinity measurements from a range of hydrographic data sources (NODC World Ocean Atlas 1994 hydrographic data, CSIRO RV Franklin, RV Southern Surveyor, SRV *Aurora Australis*) and mapped as part of the CSIRO Atlas of Regional Seas (Ridgway *et al*. 2002, Dunn and Ridgway 2002).

A time series of absolute sea-level was then computed on a regular 0.2° latitude-longitude grid by optimally interpolating the anomaly data from the coastal tide-gauges and two altimeters, then adding it to the mean sea-level field (Bretherton *et al.* 1976, Le Traon 1990). Large-scale current velocities were then computed from the sea-level fields using the geostrophic approximation, in which the velocity is proportional to the sea-level gradient divided by the Earth's rotation parameter. An example of the computed velocity field overlain on sea surface temperature is shown in Fig 1. On the inner-shelf, geostrophic currents tended to be small and unreliable, so that the geostrophic components of the currents were set to zero in waters shallower than 100 m, leaving only the wind-driven component described below.

In addition to the large-scale geostrophic component of the current, water movements are also influenced by local winds. Wind fields were interpolated in space and time from the NCEP-NCAR 40-year Reanalysis dataset (Kalnay *et al*. 1996), which provides twelve hourly winds on a 1.9° latitude-longitude grid (Fig 2). The wind forced component of the current was then calculated over the region based on the surface Ekman layer dynamics (Pollard and Millard 1970). A nominal depth of 20 m was used in this calculation, which was again taken to be representative of the surface mixed layer. However, this formulation ignored the effects of local bathymetry and bottom friction, and hence should be regarded as indicative rather than quantitative in water depths shallower than 50 m. Finally, the wind driven component and geostrophic component (> 100 m) were added together to provide estimated ocean velocities on a 0.2° grid.

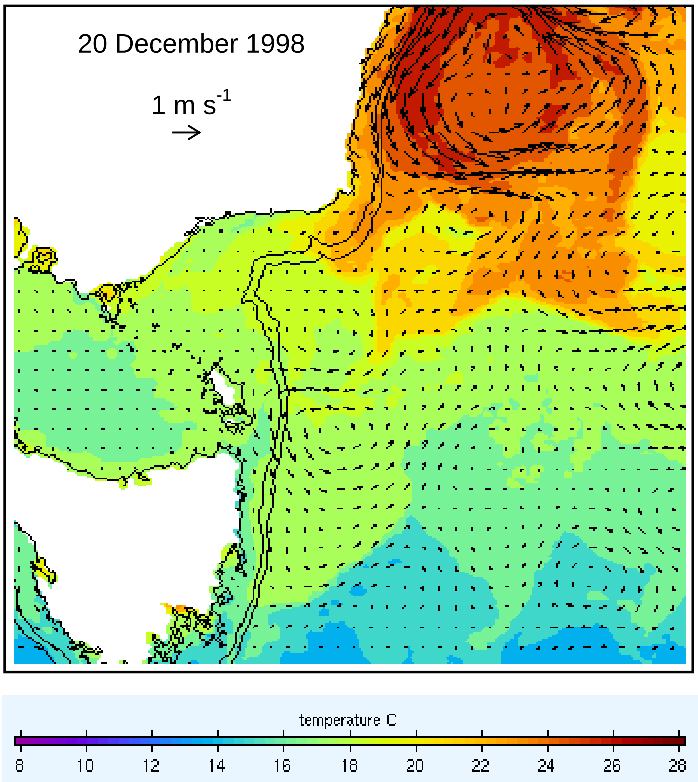

Figure 1. Example of computed velocity field (arrows) overlain on sea surface temperature. Note the consistency in the patterns of the two independently derived fields.

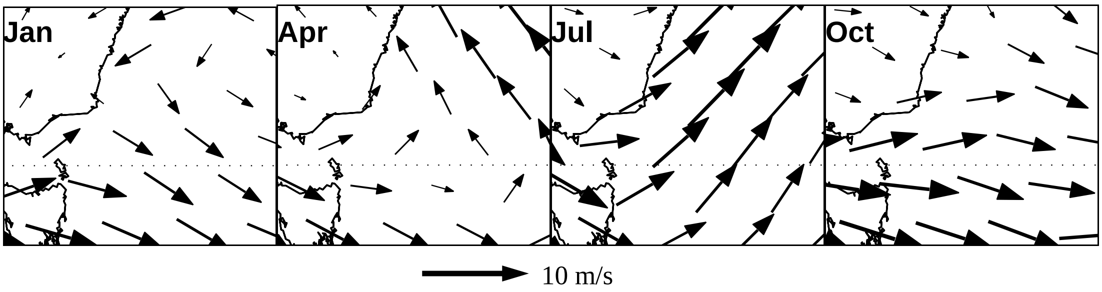

Figure 2. Average seasonal wind patterns in the EBS region computed from the NCEP-NCAR 40-year Reanalysis dataset.

3.3 Results

3.3.1 Mean quantities

Estimated phytoplankton biomass, primary productivity, and net phytoplankton immigration averaged spatially over the EBS model domain and temporally over the duration of the datasets (1997-2002) are summarised in Table 1. The mean chlorophyll of 0.60±0.20 mg m^{-3}

(corresponding to an approximate biomass of 19.0±6.3 t km^{-2}) is higher than most *in situ* measurements on the Australian shelf (Condie and Dunn, unpublished manuscript), although concentrations in excess of 2 mg m^{-3} have been measured off the east coast of Tasmania (Harris *et al*. 1987) and major upwelling systems can exceed 20 mg m^{-3} (e.g. Morales *et al*. 2001). While mean primary productivity levels in the EBS model domain are also higher than most Australian *in situ* measurements, estimates based on the Befa method are very similar to the closest available measurements off eastern Tasmania (Harris *et al*. 1987).

The net immigration rate of phytoplankton into the EBS model domain was usually positive, although local winds predominantly favoured emigration and periods of net emigration did occur (Table 1). However, the most important finding of this analysis was that net immigration is small compared to primary productivity, with mean ratios of less than 1%. Hence, despite the relatively strong flows in the region, primary productivity levels are high enough to dominate changes in phytoplankton biomass within the domain.

The critical phytoplankton characteristic used to balance the trophic model is the mean value of the ratio of primary productivity to phytoplankton biomass (*P/B* in Table 1). Values of P/B based on the satellite estimates are 517 yr^{-1} for the Befa method and 368 yr^{-1} for the Hoyo method. These values are higher than those used in most other temperate systems, which typically fall in the range 80 – 300 yr^{-1}. However, the average of *in situ* productivity measurements from a larger region around EBS and Tasmania (including regions of lower productivity) corresponds to *P/B* = 273 yr^{-1} (Harris et al. 1987), so the Hoyo estimate is entirely plausible.

Table 1. Estimated phytoplankton statistics within the EBS model domain (based on wet weight).

Quantity	Units	Mean value	Standard deviation	Minimum value	Maximum value
Chlorophyll	mg m^{-3}	0.60	0.20	0.26	1.98
Phytoplankton biomass: *B*	t km^{-2}	19.0	6.3	8.2	63.2
Primary productivity: *P* (Befa method)	t km^{-2} yr^{-1}	9321	2622	4702	28800
Primary productivity: *P* (Hoyo method)	t km^{-2} yr^{-1}	6929	2486	3092	18841
Net immigration: *I*	t km^{-2} yr^{-1}	37	185	-382	949
Immigration due to geostrophic currents	t km^{-2} yr^{-1}	63	176	-371	939
Immigration due to local winds	t km^{-2} yr^{-1}	-26	61	-268	280
P/B (Befa method)	yr^{-1}	517	165	240	1080
P/B (Hoyo method)	yr^{-1}	368	79	125	618

3.3.2 Seasonal trends

Seasonal variability in EBS is influenced by changes in both the East Australia Current (EAC) and local meteorological conditions. During summer, the warm nutrient-poor waters of the EAC extend south as far as Tasmania and winds tend to be light and variable. As winter approaches, the EAC withdraws to the north and strong southwesterly winds develop (Fig 2). The combination of surface cooling and wind and tidal stirring results in complete mixing of the water column in Bass Strait from May to October (Baines and Fandry 1983). This process produces a front along the shelf-break in EBS separating cold Bass Strait water from Tasman Sea water (Bruce *et al*. 2001). Wind conditions are favourable to upwelling on the offshore side of the front, eventually bringing higher nutrient waters from below (Fig 3). Observed nutrient levels east of the shelf break suggest that water is upwelled from at least 150 m depth (Gibbs *et al*. 1986, 1991).

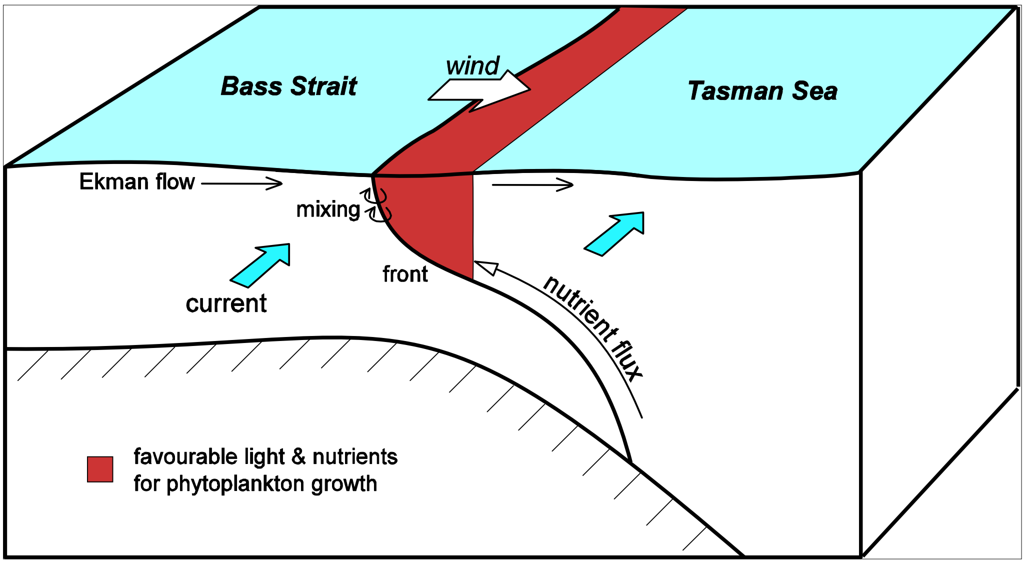

Figure 3. Schematic diagram of upwelling in the EBS region during winter and spring.

Chlorophyll shows a clear seasonal response to the physical processes operating in EBS (Figs 4 and 5). Thermal stratification over summer ensures low nutrient levels supporting limited phytoplankton. As vertical mixing increases over autumn, available nutrients on the shelf are entrained causing a modest autumn bloom. As winter ensues, the southerly wind component tends to suppress upwelling and primary productivity falls as the available nutrient pool is depleted across the region. Winds move to the west over spring (Fig 2) and upwelling supports a strong spring bloom (Figs 3 and 4). The occurrence of this bloom is consistent with Bax and Williams (2000) “pea soup” description of their August-September 1994 cruise. The bloom then dissipates over the following few months, with chlorophyll in the study region falling to an annual low around December. While not coincident in year, the seasonal levels based on SeaWiFS data are consistent with *in situ* measurements in the study area (Fig 5) made in April-May 1996 (0.51 ± 0.17 mg m^{-3}), August-September 1994 (0.62 ± 0.23 mg m^{-3}), and November-December 1996 (0.40 ± 0.23 mg m^{-3}) by Bax and Williams (2000).

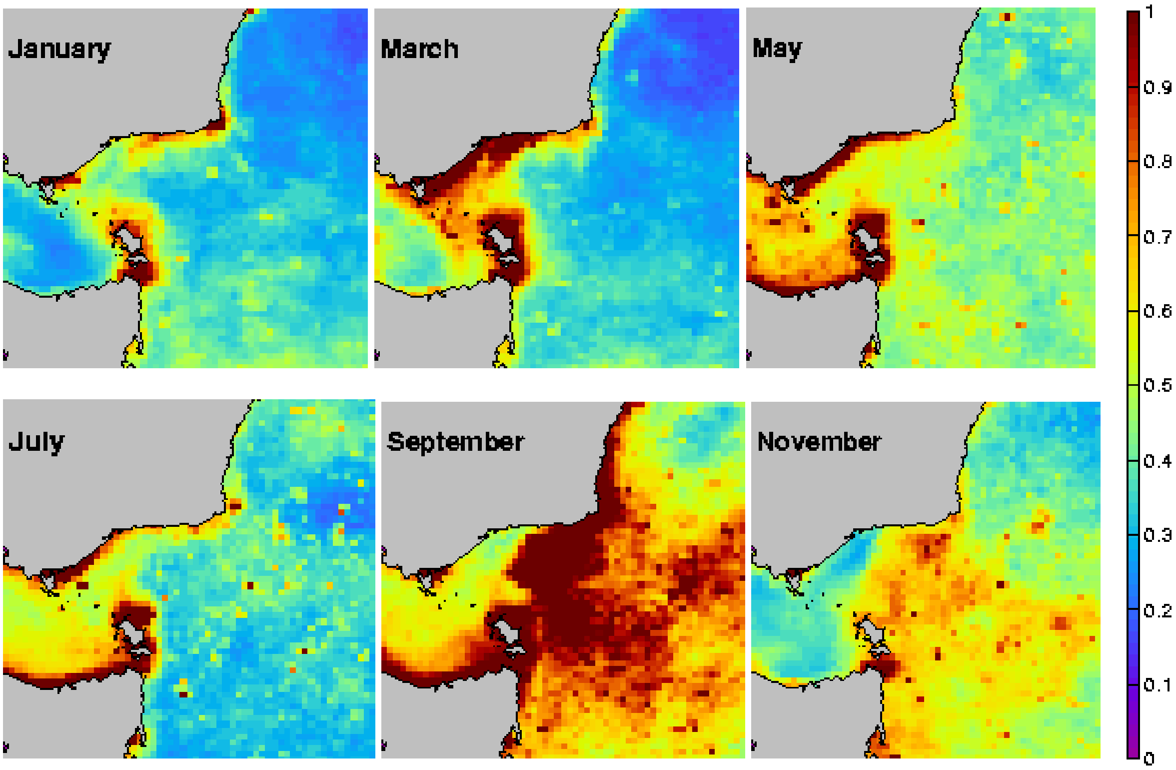

Figure 4. Monthly averaged chlorophyll concentrations based on SeaWiFS data (1997-2002) in units of mg m-3.

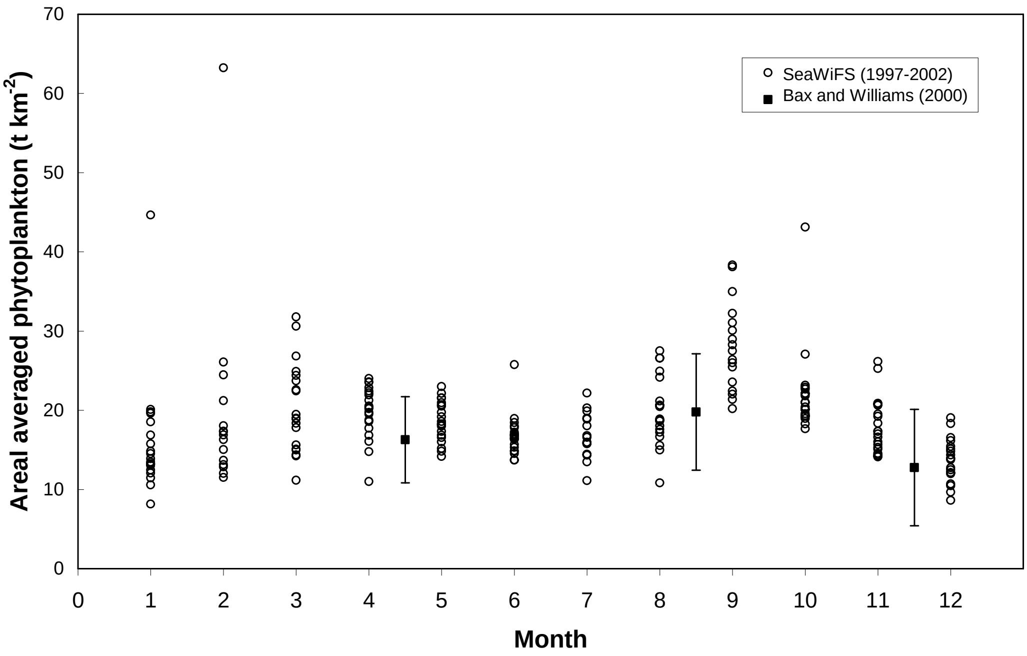

Figure 5. Average chlorophyll concentration in the EBS model domain grouped by month from SeaWiFS data (1997-2002) and from the 1994 and 1996 in situ measurements of Bax and Williams (2000). A mixed layer of depth of 40 m was assumed in both cases.

The difficulties associated with estimating primary productivity from satellite data without the aid of local calibration have already been noted. However, by utilizing NASA's two standard methods (calibrated in other parts of the world) and where possible making comparisons of the results with local in situ measurements, some indication of their reliability can be obtained for the EBS region. Examples from two standard algorithms are shown in Fig 6. The fundamental difference between the two algorithms is that the Hoyo method includes estimates of mixed layer depth in the computation of primary productivity. The spatial patterns are qualitatively similar to each other and similar to the chlorophyll concentrations (Fig 4). However, the inclusion of mixed layer depth is very significant over summer, where it typically reduces the primary productivity estimate by a factor of two.

The lower Hoyo estimates are generally more consistent with the earlier in situ measurements of Jitts (1966) and Harris *et al.*(1987), which over a similar domain to that shown in Fig 6 ranged from 0.12 to 1.05 kg C m^{-2} yr^{-1}, with an average of around 0.26 kg C m^{-2} yr^{-1}. The only measurement within the study region was taken by Harris *et al.* (1987) during the spring bloom and yielded an estimate of 1.04 kg C m^{-2} yr^{-1} or 2.07×10^4 t km^{-2} yr^{-1} wet weight.

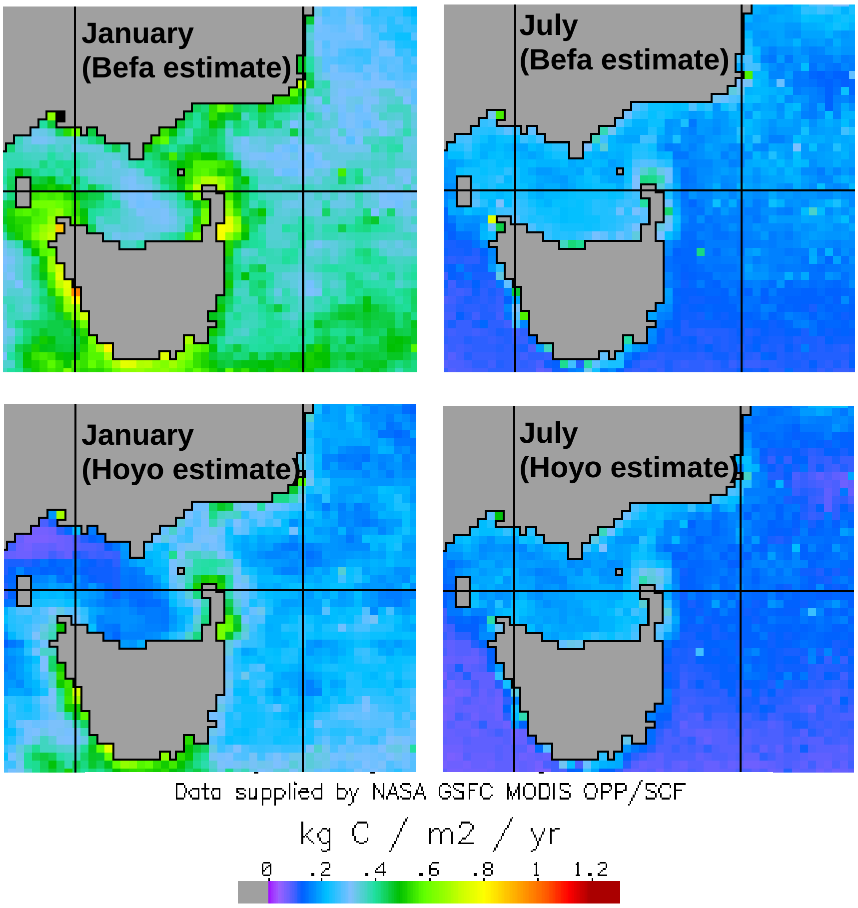

Figure 6. Monthly averaged primary productivity estimated from SeaWiFS chlorophyll concentrations and solar radiation levels (Befa estimate based on Behrenfeld and Falkowski 1997), or with these two quantities plus mixed layer depth (Hoyo estimate based on Howard and Yoder 1997). Note that the units are carbon weight rather than wet weight (conversion factor of approximately 20).

3.3.3 Interannual trends

While the seasonal cycle of primary productivity in the EBS region is relatively robust, there is also significant interannual variability associated with the system. Spatially averaged chlorophyll in the study region is largely dominated by regular autumn and spring blooms (Fig 7). However, following a strong spring bloom in 1997, the 1998 autumn bloom failed to develop. An extreme bloom in response to strong upwelling off Cape Howe during late summer in 1999 (Fig 8) was also followed by a meagre autumn bloom. In both instances, it seems likely that the anomalously large blooms severely depleted the nutrients at depth that would normally be available to drive the autumn bloom.

There is also considerable interannual variability in the estimated primary productivity (Fig 9). However, these trends tend to be overshadowed by shorter term variability and differences in the two productivity estimates, particularly over summer when inclusion of the effect of surface mixed layer shoaling strongly limits estimated primary productivity. Net immigration of phytoplankton is very small compared to primary productivity throughout the entire period.

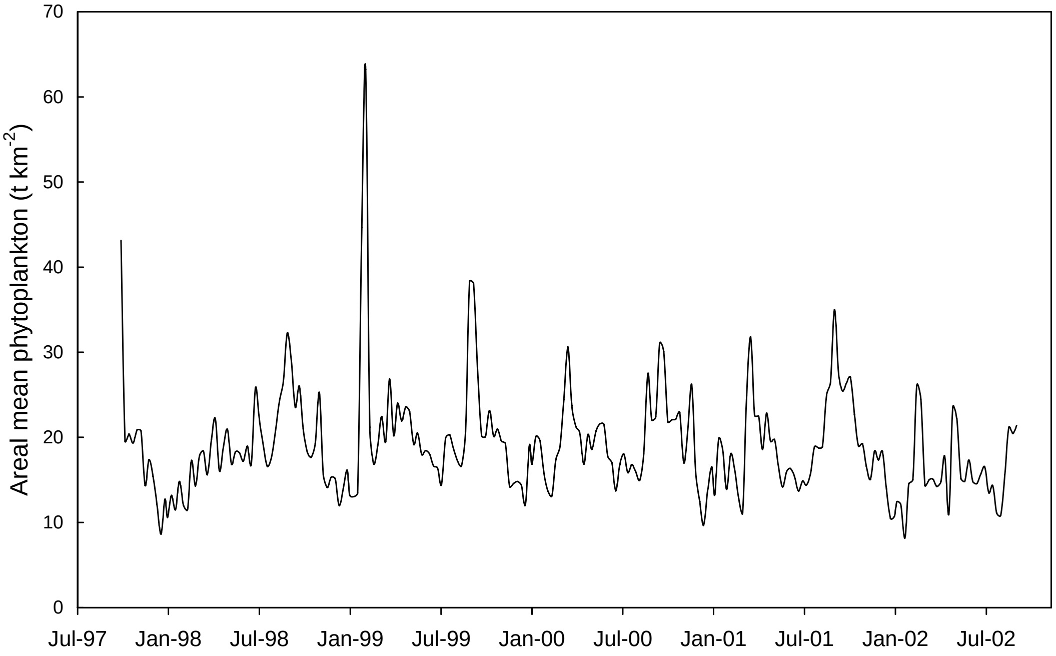

Figure 7. Time series of spatially averaged phytoplankton concentration in the EBS model region estimated from SeaWiFS satellite ocean colour.

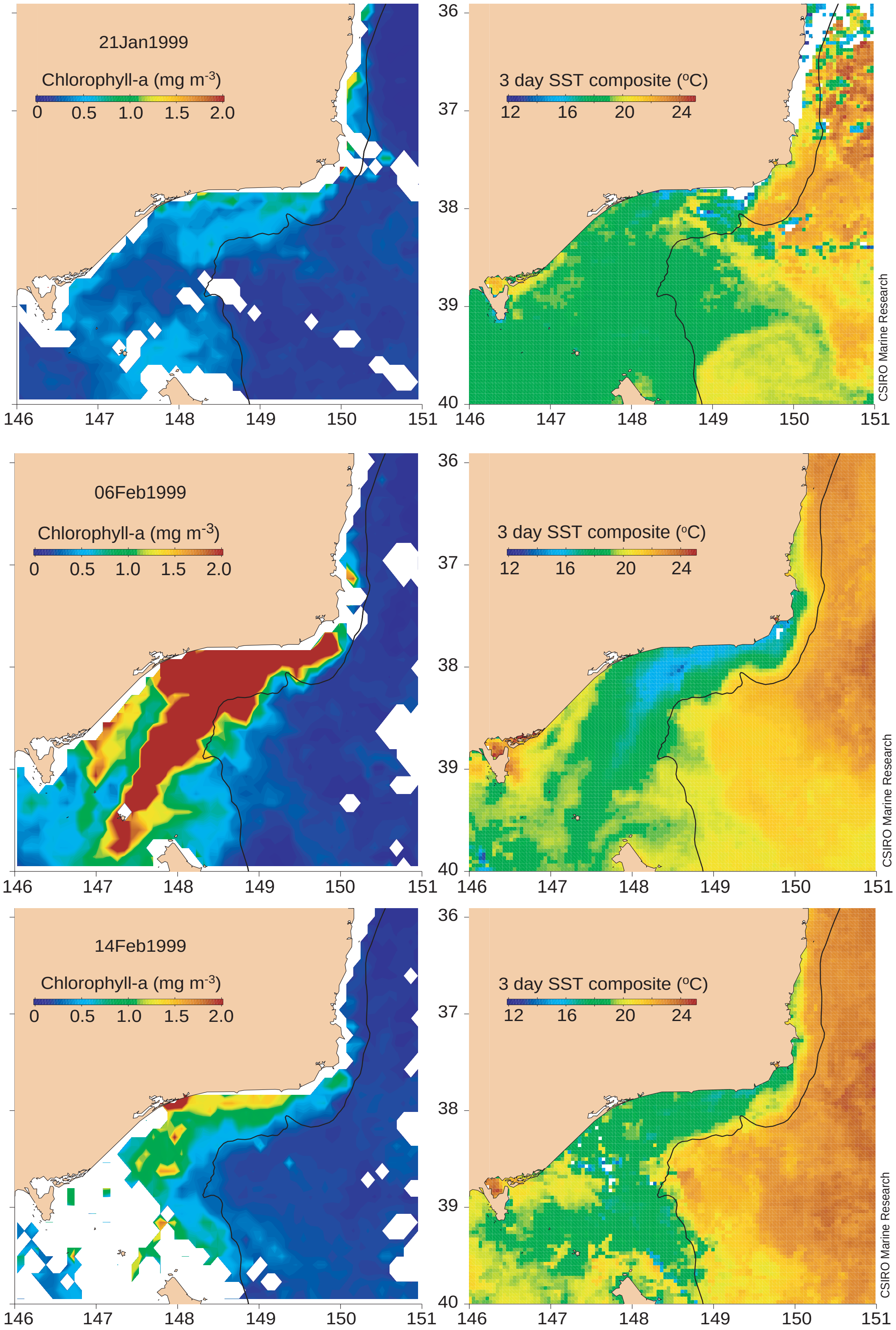

Figure 8. Chlorophyll concentration based on SeaWiFS data (left) and sea-surface temperature (right) during the development of an extreme bloom in late summer 1999. The extreme bloom around February 6 was clearly a response to upwelling of cold nutrient rich waters from depth.

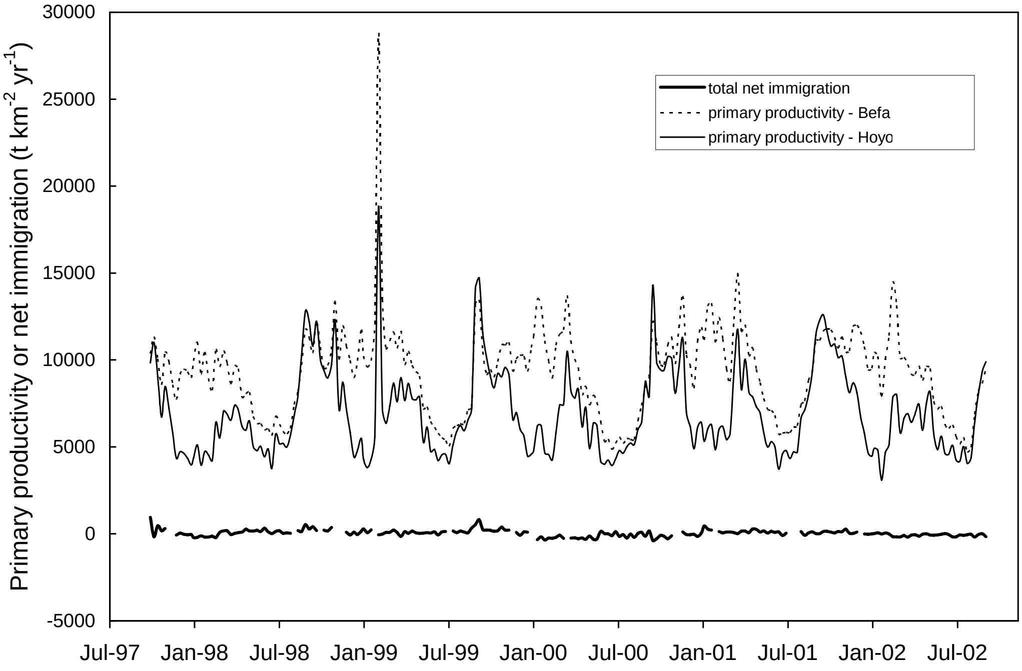

Figure 9. Time series of spatially averaged primary productivity in the EBS model region based on two estimation methods. The net immigration of phytoplankton biomass is also shown.

3.4 Discussion

The analysis of historical satellite ocean colour data has demonstrated a broad consistency with available in situ measurements of chlorophyll and primary productivity. The satellite product has therefore been used to estimate the spatially and temporally averaged phytoplankton biomass and mean primary productivity for input into the balanced Ecopath model. Similarly it has provided spatially averaged time-series information for input into the associated Ecosim model. The latter strongly suggests the need to resolve the seasonal signals in the phytoplankton dynamics and to a lesser extent the interannual signal. Combining these ocean colour data with altimeter and coastal sea-level data has also provided information on phytoplankton immigration rates, which can also be utilised directly in the trophic models. However, these rates are much smaller than the estimates of average primary productivity within the model domain or even the uncertainty associated with these estimates. This result implies that the EBS region chosen for the model domain may be approximated as a closed system for the purposes of phytoplankton supply into the food web.

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4 FISHERY PRODUCTION

4.1 Introduction

We had two reasons to compile time-series data from the fishery statistics for the Eastern Bass Strait region. Firstly, fisheries catch statistics, such as individual species catch per unit effort (CPUE) and catch and discard weights, are essential to initialise the fisheries defined in the model and then to refine parameters of the trophic model for which there are no measurements such as the vulnerabilities in predator–prey interactions. This process is more fully explained in following chapters but simply, time series data is used to “tune” the model to the actual observations of the system. Secondly, time-series data reflect population trends in catch and biomass within this region of the SEF which we compared directly to chlorophyll estimates derived from the satellite data in an attempt to identify any direct links between primary production and fishery production. This latter reason is investigated in this chapter.

4.2 Methods

4.2.1 Fishery datasets, gears used, and effort methodologies

Fishery database

Data from 1985 through to 2003 were obtained where available for the EBS study area using restricted latitude and longitude boundaries of 36.0° - 39.0° and 146.500° - 150.500° respectively. Catch data were from Commonwealth, Victorian and NSW state logbooks. Recreational fishing was not considered in this study. Discard data from 1992 through to 2002 were also obtained, where available, from logbooks and from the Integrated Scientific Monitoring Project (ISMP).

Commonwealth data includes logbooks SEF01, EFT01, GN01, GN01A, Squid (SQ04, SQ05), Jack mackerel, Small Pelagic and Tuna datasets (see Commonwealth logbook details, Table 1). SEF01, EFT01, GN01 and GN01A, Squid and Jack mackerel datasets only record retained catch, while the tuna data includes both retained and discarded catch details. Tuna datasets required conversions to the recorded catch weights to provide a standardised measure of fish weight, and has been documented under *Conversions for Commonwealth tuna data.*

Table 1. Commonwealth logbook details (1,184,386 data records)

Commonwealth logbooks	Logbook	Time frame	Fishing gears	Depths	No. of Records
	GN01	1/1997 -8/1999	Drop line Gillnet Fish trap Trot line Demersal longline	Minimum & maximum depth; Metres & fathoms – all converted to metres	15,472 rows includes 274 rows without effort
	GN01A	7/1999 -12/2003 *Effort data for 2000 incomplete	Drop line Gillnet Fish trap Handline Demersal longline	Minimum & maximum depth; Metres & fathoms – all converted to metres	28,767 rows includes 10,420 rows without effort
	#Jack Mackerel & Small Pelagic	9/1985 -2/2004 Effort predominantly as ‘search hours’	Pole and line Purse seine	Pelagic –bottom depth not stated	4,747 rows includes 108 rows without effort
	SEF01 & EFT01	10/1985 -12/2003 ** Effort data for 2000 incomplete	Pair trawl Otter trawl Dropline Danish seine Trawl Assumed	Average depth only	1,109,367 rows includes 39,378 rows without effort
	##Squid	1/1997 -12/2003	Squid jig and net	Minimum & maximum depth; Metres converted to average depth.	578 rows includes 6 rows without effort
	###Tunas	11/1982 -12/2003	Longline Pole and line Rod and reel Troll Handline ***	Pelagic –bottom depth not stated	25,455 rows

* Gear type was not recorded in 2000; as such, non-trawl effort is unavailable.

**Gear not given from 4/2000 – noted as TW_A (Trawl Assumed).

*** Where gear type is not given and hook count is large (>300), assume longline gear.

Includes JMF, OT03, PS01, TPB01 and TPB02.

Includes SQ04 and SQ05.

Includes AL02, AL04, AL05, JM04, NW01, OT01, SF05, TL02, TL04, TP03 and TP05.

Victorian state data came from a range of logbooks: Baitfish (BF), Danish seine (DS), General fishing (GF), Lakes Entrance scallop (LS), Otter trawl (OT), Prawn (PR), Rock lobster (RL), and Shark (SH) for data prior to March 1998, and Banded morwong (BM), Giant crab (GC), Ocean general (OF), Ocean purse seine (OP), Ocean scallop (OS), and Trawl-inshore (TR) for data recorded after the1998 logbook revisions (see Victorian state logbook details, Table 2). Because of the range of gears used, data were grouped by fishing method into Dredge, Hook and line, Miscellaneous nets, Seine and Mesh, Pump, Trap/Pot, Danish Seine and Trawl. Data were recorded daily and included retained catch only.

NSW state data can be obtained only as monthly records, and does not include longitude or depth data. Effort data until 1997 was restricted to number of days fished, and after 1997, contains limited effort in hours and shot numbers, particularly for trawl gear (see NSW state logbook details, Table 3). Catches were recorded as monthly summaries by species, and gear-types and fishing zones are provided. Data were grouped by fishing method into Dredge, Hook and Line, Miscellaneous nets, Seine and Mesh, Trap/Pot, Danish Seine and Trawl.
Each of these databases has been checked for consistency in reporting, particularly for gear type, fish weights, effort, and units recorded. Where assumptions were made to provide missing data, these have been included and identified as such in our database, eg. SEF01 and EFT01 fishing gear corrections have been made for misreporting of Danish Seine shot records, and omissions assumed to be trawl were denoted as TW_A (Trawl Assumed).

Datasets used, years covered, fishing gears reported, and number of records included, are tabled for Commonwealth (Table 1), Victorian (Table 2), and NSW (Table 3) state, respectively

Conversions for Commonwealth tuna data

The pelagic tuna data were reported in varying formats, including WWT (whole weight), CNT (actual numbers caught), and DWT (dressed weight, or headed and gutted weight), and included retained and discarded catch data. Data required species-specific manipulation to provide consistent reporting of catches. This included calculation of catch weights where only catch numbers were given, and conversion of dressed or gutted weights to whole weights of fish. Average fish weights and dressed-to-whole-fish-conversions were gained from the tuna database where sufficient whole weights, counts, and dressed weights were available for individual species. For discarded and retained fish where a count only was given, retained counts were multiplied by species average retained fish weight, and discarded counts were multiplied by the species minimum recorded weight for a retained fish. This allowed all data to be converted to weight for CPUE data calculation. Tuna catches within the Jack mackerel/Small Pelagic datasets did not require conversion.

Table 2. Victorian state logbook details (159,489 data records)

	Logbook	Time frame	Fishing gears	Depths	No. of Records
Victorian state logbooks	**Dredge**	1985 - 2003	Scallop dredge	Some depth data in fathoms – converted to metres	14,313 rows including 6,583 without effort
	Hook & Line	1985 - 2003	Hand line, (incl. hand squid jig)	Limited depth data	6,601 rows, no effort data
			Drop line	No depth data	1,082 rows, including 410 without effort
			Longline (Shark/Snapper)	Depths in fathoms-converted to metres	6,955 rows, including 1,660 without effort
			Troll line	No depth data	480 rows, no effort data
	Misc. Nets	1985 - 2003	Bait net Hoop/Ringing net Stake net	No depth data	2,770 rows, including 17 without effort
	Pump	1985 - 2003	Bait pump	No depth data	1,256 rows, including 40 without effort
	Seine & Mesh		Danish seine	Depths in fathoms-converted to metres	16,588 rows, including 855 without effort
			Deep sea (incl. mono- & multi-filament) mesh	No depth data	5,141 rows, including 1,877 without effort
			Purse seine (incl. garfish seine)	No depth data	2,298 rows, including 963 without effort
			Beach seine (mesh net)	No depth data	2,624 rows, no effort data
			Shark mesh	Depth data in fathoms – all converted to metres	57,522 rows, including 513 without effort
	Trap/Pot	1985 - 2003	Fish/Octopus trap Lobster pots	Depths in fathoms – all converted to metres	5,221 rows, including 468 without effort
	Trawl	1985 - 2003	Fish Trawl / Otter Trawl	Depths in fathoms-converted to metres	25,687 rows including 2,864 without effort
			Prawn Trawl		10,951 rows, no effort data

Table 3. NSW state logbook details (98,502 data records).

	Logbook	Time frame	Fishing gears	Depths	No. of Records
NSW state logbooks	**Dredge**	1984 - 2003	Dredge (scallop)	No depth data	69 rows
	Hook & Line	1984 - 2003	Dropline	No depth data	4,567 rows
			Handline		2,558 rows
	-main gears		Longline		2,911 rows
			Trotline		3,844 rows effort generally days, some Hrs
	-other gears		Driftline	No depth data	114 rows
			Poling		207 rows
			Setline		312 rows
			Troll		813 rows
	Misc. Nets	1984 - 2003	Misc. mesh	No depth data	577 rows
	Seine	1984 - 2003	Danish seine	No depth data	173 rows
			Purse seine		433 rows
	Trap/Pot	1984 - 2003	Fish trap	No depth data	2,228 rows effort generally days, some Hrs
			Lobster pot		105 rows
	Trawl	1984 - 2003	Fish Trawl	No depth data	53,295 rows effort generally days, some Hrs
			Prawn Trawl		1,647 rows effort generally days, some Hrs
	Unknown	1984 - 2003	Other/unspecified	No depth data	24,649 rows

Assumptions for effort calculations

Assumptions were made regarding the methods of fishing for individual gears where no documentation was available. It was assumed that gears are fished using the concept of saturation, i.e. the duration of fishing has been determined from experience to provide maximum catches over minimum time. This assumption allows hook-count or net-length alone to be used as a standard measure of effort where actual fishing times have not been recorded. Recorded measures of effort, for each gear type within each logbook, are tabled (Table 4).

Table 4. Effort measures for individual gear types within each dataset.

	Dataset	Effort	Gear
Commonwealth	**GN01** 1997 - 1999	1000Hks 1000m Hr	Dropline, Demersal longline Gillnet Fish trap
	GN01A 1999 - 2003	1000Hks 1000m Hr	Dropline, Demersal longline, Handline Gillnet Fish trap
	Jack mackerel/ Small pelagic 1985 - 2003	Hr, SHr*	Pole & line, Purse seine
	SEF01 / EFT01 1985 - 2003	Hr	Danish seine, Otter trawl, Demersal longline[#]
	Squid 1997 - 2000	Hr	Squid jig, Nets
	Tunas 1983 - 2003	1000Hks	All gears
Victoria	**Victorian state logbooks** 1985 - 2003	1000Hks 1000m Hr Lift	Dropline, Longline (shark, snapper) Shark mesh Danish/Purse seine, Fish Trawl, Dredge, Pump Trap/Pot
NSW	**NSW state logbooks** 1984 - 2003	N/A	

*SHr=Search Hours. [#]Assumed to have been recorded in wrong log book

CPUE calculations

To compare fishery production, i.e. the amount of fish caught from the region, with a proxy for primary productivity, fishery catches were standardised using appropriate effort units. Using the datasets, corrected where necessary with assumptions about fishing gears and calculated fish weights, catch per unit effort (CPUE) was calculated shot-by-shot, for each species caught within that shot. These values were converted to log values and geometric means were calculated wherever pooled of data were required. The resulting CPUE measures for each dataset (Table 5) were reported as kgs per unit of effort.

Calculation of annual catches per species

To provide comparable measures of annual catches when all data were amalgamated, gears needed to be grouped by similar methods of fishing (Table 6). These groupings also represented the fisheries in the trophodynamics model (chapter 5). Records were not used if fishing method was listed as ‘Other’, or was unspecified and ambiguous. Some assumptions made were logical, e.g. unspecified gear that caught tuna was assumed to be line fishing.

Table 5. CPUE units of measures for individual gear types within each dataset.

Dataset	CPUE	Gear
GN01	Kgs/1000Hks Kgs/1000m Kgs/Hr	Dropline, Demersal longline Gillnet Fish trap
GN01A	Kgs/1000Hks Kgs/1000m Kgs/Hr	Dropline, Demersal longline, Handline Gillnet Fish trap
Jack mackerel/ Small pelagic	Kgs/Hr	Pole & line, Purse seine
SEF01 / EFT01	Kgs/Hr	Danish seine, Otter trawl, Demersal longline#
Squid	Kgs/Hr	Squid jig, nets
Tuna	Kgs/1000Hks	All gears
Victorian state logbooks	Kgs/1000Hks Kgs/1000m Kgs/Hr Kgs/Lift (flesh wt)	Dropline, Longline (shark, snapper) Shark mesh Danish/Purse seine, Fish Trawl, Dredge, Pump Trap/Pot
NSW state logbooks	N/A	

#assumed to have been recorded in wrong log book

Table 6. Gear grouping by logbook and fishing method

Gear grouping	Logbook	Fishing method
Line	GN01, GN01A, Small pelagic Vic state**, NSW state	For all logbook sources, includes: Driftline, Dropline, Handline, Longline, Pole & line, Rod & reel, Setline, Troll, Trotline.
Net (Non Trawl)	GN01, GN01A Jack Mackerel, Small pelagic Vic state, NSW state	Gillnet Purse seine (incl. boat assisted) Mesh nets, Miscellaneous nets, Seine (excluding Danish)
Scallop	Vic state, NSW state	Scallop dredge
Squid	Squid	Squid jig
Trap	GN01, GN01A Vic state, NSW state	Fish trap Fish/octopus trap, Lobster/crayfish pot
Trawl_C'wealth	SEF01 / EFT01	Otter trawl, Trawl assumed
Trawl_NSW	NSW state	Otter trawl, Prawn trawl
Trawl_Vic	Vic state	Otter trawl, Prawn trawl
Tuna*	AL02, AL04, AL05, JM04, NW01, OT01, SF05, TL02, TL04, TP03, TP05	Longline, Pole & line, Rod & reel, Troll, Handline
Danish_C'wealth	SEF01 / EFT01	Danish seine
Danish_NSW	NSW state	Danish seine
Danish_Vic	Vic state	Danish seine

*Tuna data includes 'assumed line'

**Vic state Handline includes 'Hand squid jig

4.2.2 Comparing patterns of fishery production with ocean colour

The chlorophyll estimates described in Section 3.2.1 provide a surrogate for phytoplankton biomass, as well as general water colour characteristics. While it has often been suggested that fishery catches are related to water colour (i.e. “clear water” versus “dirty water”), this hypothesis has not previously been tested in the SEF using satellite data.

Chlorophyll estimates were compared with fisheries species catch weights and CPUE data recorded over the SeaWiFS period (October 1997 to September 2002) and slightly beyond (to the end of 2002) to allow for any lagged trophic response. Species to be considered initially were quota or commercial species, or those having close links to primary productivity, i.e. species that are zooplankton feeders or that directly feed upon other zooplankton feeders. Data used were shot-by-shot catch data, restricted to where CPUE was recorded as kgs/hr only. Predominantly, data from otter trawl catches were used as other gear types did not provide sufficient data to allow comparisons, or had used various measures of effort which precluded their use. Ultimately, the range of species was limited by the availability of sufficient data.

On the basis of commercial importance and data availability, sufficient records were available to allow comparisons initially for 12 SEF species: redfish *Centroberyx affinis*, silver dory *Cyttus australis*, pink ling *Genypterus blacodes*, blue eye trevalla *Hyperoglyphe antarctica,* blue grenadier *Macruronus novaezelandiae*, tiger flathead *Neoplatycephalus richardsoni,* latchet *Pterygotrigla polyommata*, blue warehou *Seriolella brama*, spotted warehou *Seriolella punctata*, eastern school whiting *Sillago flindersi*, mirror dory *Zenopsis nebulosus*, and john dory *Zeus faber*. For each species, 4-day and 8-day catch averages, log CPUE and CPUE as 4-day averages were calculated. Shot-by-shot catch data were plotted over the total study area as 8-day averages (Figs 1-12), as well as fisheries production in terms of catch, log CPUE and CPUE as 4-day averages (Appendix A1-12) for each year of the dataset. Total catch data, all species combined (Appendix A13), was also plotted.

These values were visually overlaid by plots of chlorophyll concentration data (8-day averages, Fig 13) to consider potential correlations. This method allowed varying time-lags between inferred phytoplankton biomass and fisheries uptake to be considered. Total catches of all species combined were also compared to mean chlorophyll concentration values.

4.3 Results

4.3.1 Correlations between fishery production and ocean colour

Fishery production data for the 12 SEF species considered above were compared directly with chlorophyll estimates. The only correlations that could be identified using the available data were weak and related to only two species. *M. novaezelandiae* peak catches correlate with the recorded chlorophyll peaks, with a lag of approximately 90-100 days. The largest catches occurred in 1999 following the largest chlorophyll peak in the records. *S. punctata* average catch weights also correlated weakly with chlorophyll, but with a lag of 30-40 days. While the largest catches of this species do occur in 1999, the lag was 150 days after the largest chlorophyll peak. Therefore, peaks in species catch do not consistently follow peaks in chlorophyll in this dataset. As catches for this species may also be interpreted as a strongly seasonal event, it is difficult to base this correlation directly on the individual chlorophyll events.

4.3.2 Seasonal and interannual variability in fishery production

The data show clear seasonality in catch and CPUE, with the two exceptions being *N. richardsoni* and *P. polyomata* (Figs 6 and 7). Five species (*C. australis, G. blacodes*, *H. antarctica*, *S. brama* and *S. punctata*) each show one period of peak abundance annually of 3-4 months. For *C. australis* and *H. antarctica*, these peaks are slight. Catches are notably higher during the peak period for *G. blacodes* (late autumn/early winter -April to June), and *S. brama* and *S. punctata* (late winter/spring -July to September/October) with the respective CPUE and log CPUE plots indicating that the increase is a result of increased availability as opposed to increased fishing effort.

The remaining five species (*C. affinis, M. novaezelandiae, S. flindersi*, *Z. nebulosus* and *Z. faber*: Figs 1, 5, 10-12 respectively) each exhibit two peaks per year, predominantly late summer/autumn and late winter/spring. The seasonal trend evident for *Z. nebulosus* catch weights is less evident in CPUE plots, which would imply that the increases in catch may be due to an increase in fishing effort rather than increased species availability.

Interannual variation in fisheries production was also considered for these twelve species. Trends were generally consistent between years for most species. Several species (*H. antarctica*, *M. novaezelandiae, S. punctata* and *Z. nebulosus*) recorded higher catches in 1999. Alternatively, catches for *S. flindersi* were predominantly confined to one seasonal peak during 1999, rather than the usual two.

The largest interannual variation was seen within *M. novaezelandiae*, *N. richardsoni* and *S. brama* trends. *M. novaezelandiae* catches follow a similar trend between years but with greatly increased catches recorded for the majority of the 1999 fishing year. *N. richardsoni* catches are highly variable, with 2000 being particularly anomalous. *S. brama* catches peaked only once in most years except in 1998 and 2000 when secondary peaks occurred. The 2000 secondary peak recorded higher catches than the primary peak. *G. blacodes* and *Z. faber* also recorded greater seasonal peaks in catch for the 2000 fishing year. While *S. brama* data showed a relatively minor fall in effort over the years considered for this fishery, catches fell at a greater rate.

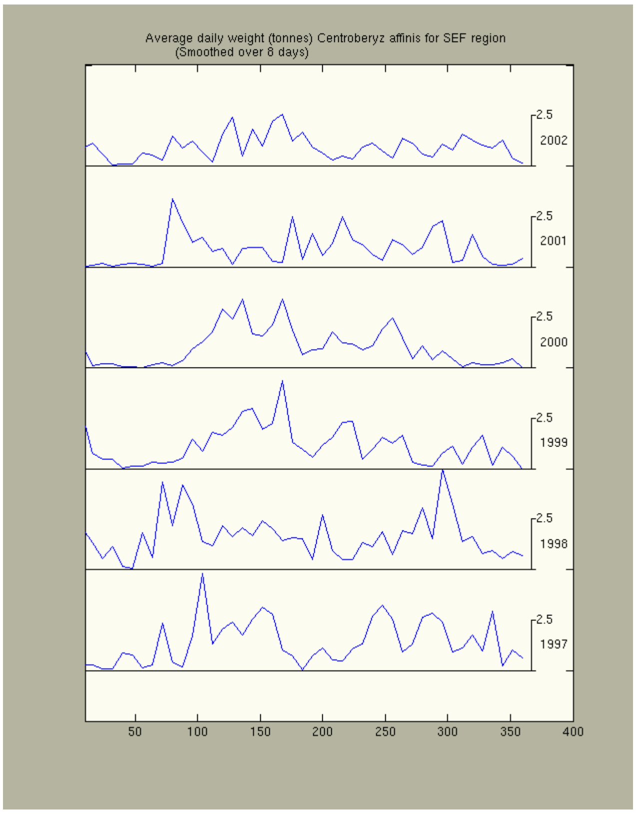

Figure 1. *Centroberyx affinis* 8-day average of catch weight plotted over years 1997 to 2002.

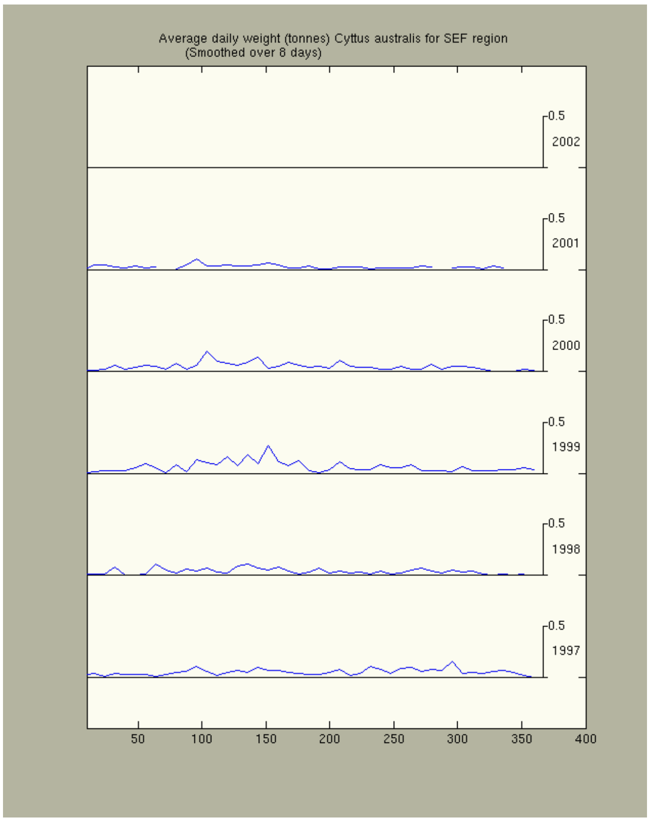

Figure 2. *Cyttus australis* 8-day average of catch weight plotted over years 1997 to 2002.

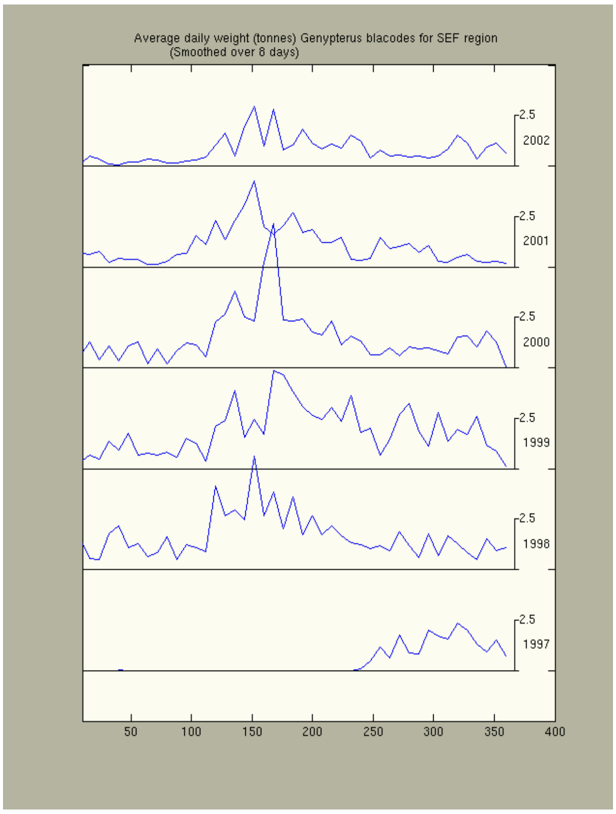

Figure 3. *Genypterus blacodes* 8-day average of catch weight plotted over years 1997 to 2002.

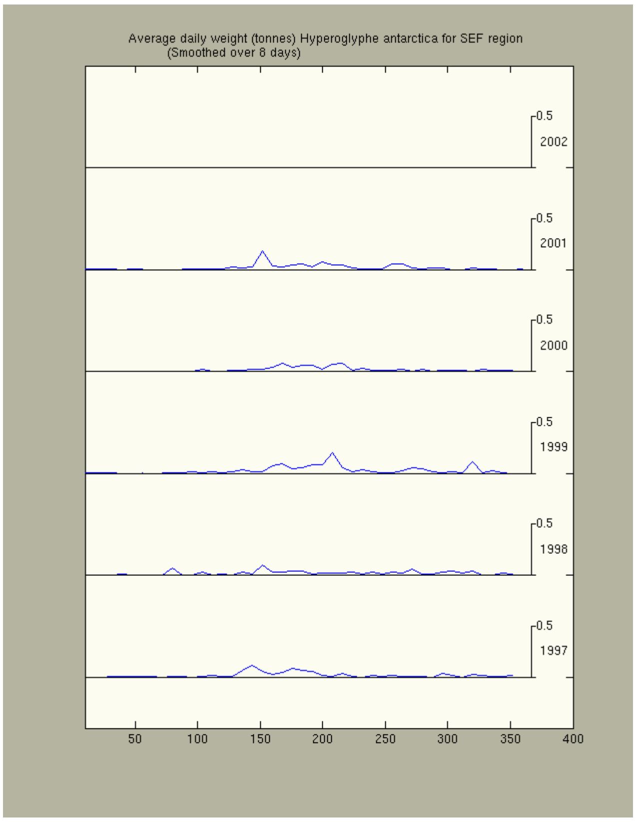

Figure 4. *Hyperoglyphe antarctica* 8-day average of catch weight plotted over years 1997 to 2002.

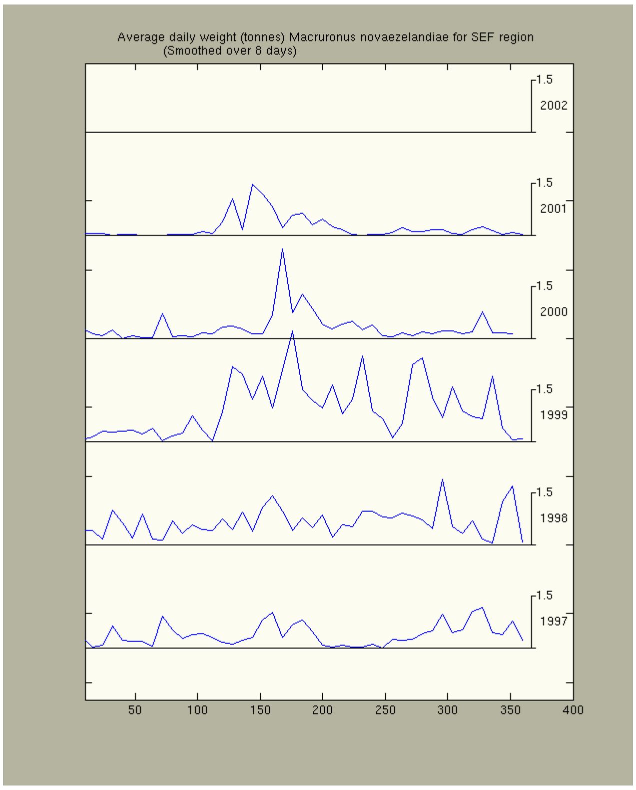

Figure 5. *Macruronus novaezelandiae* 8-day average of catch weight plotted over years 1997 to 2002.

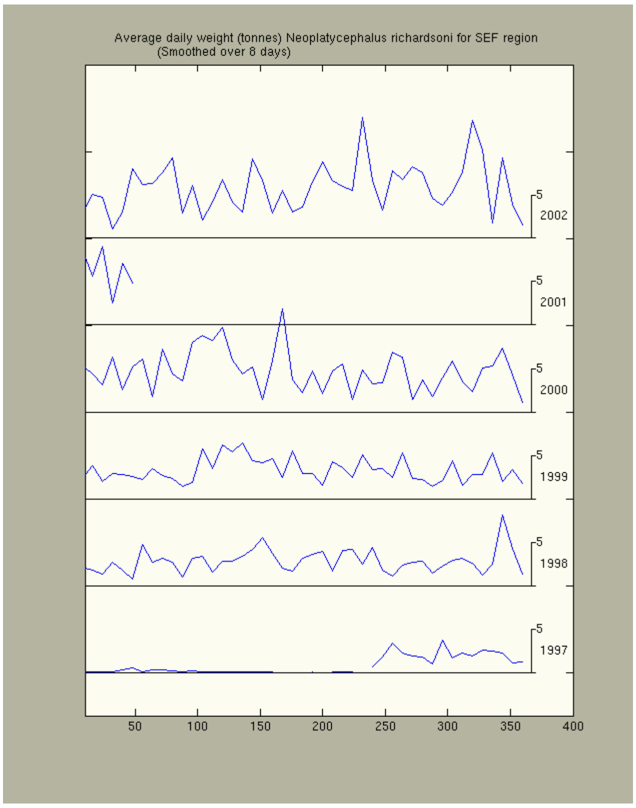

Figure 6. *Neoplatycephalus richardsoni* 8-day average of catch weight plotted over years 1997 to 2002.

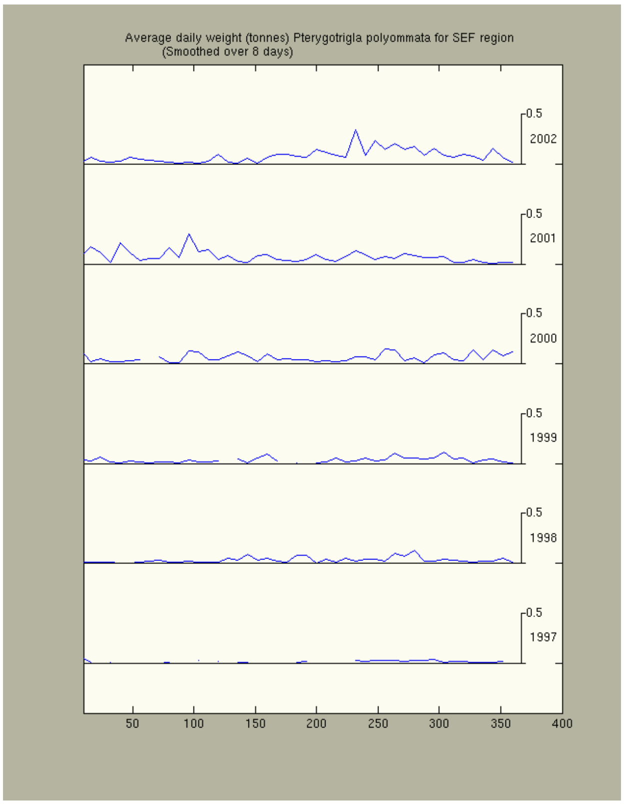

Figure 7. *Pterygotrigla polyommata* 8-day average of catch weight plotted over years 1997 to 2002

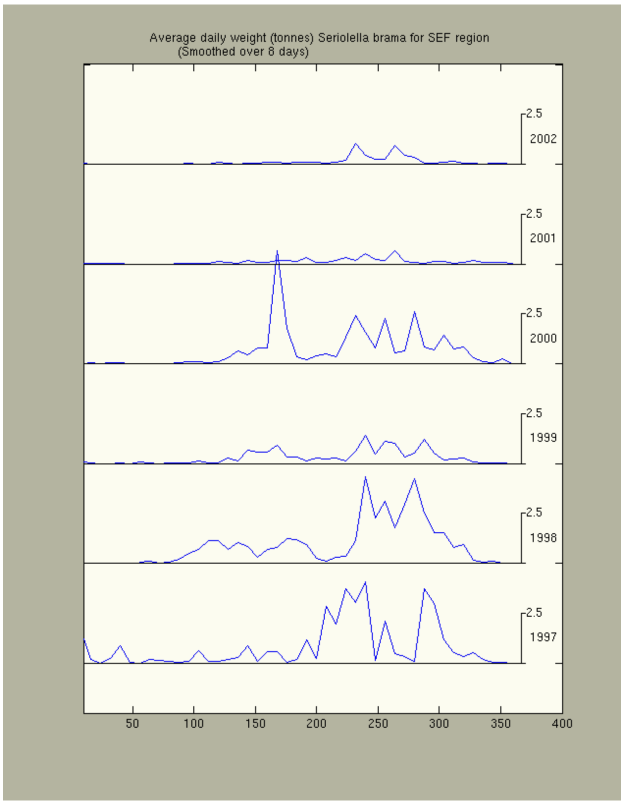

Figure 8. *Seriolella brama* 8-day average of catch weight plotted over years 1997 to 2002.

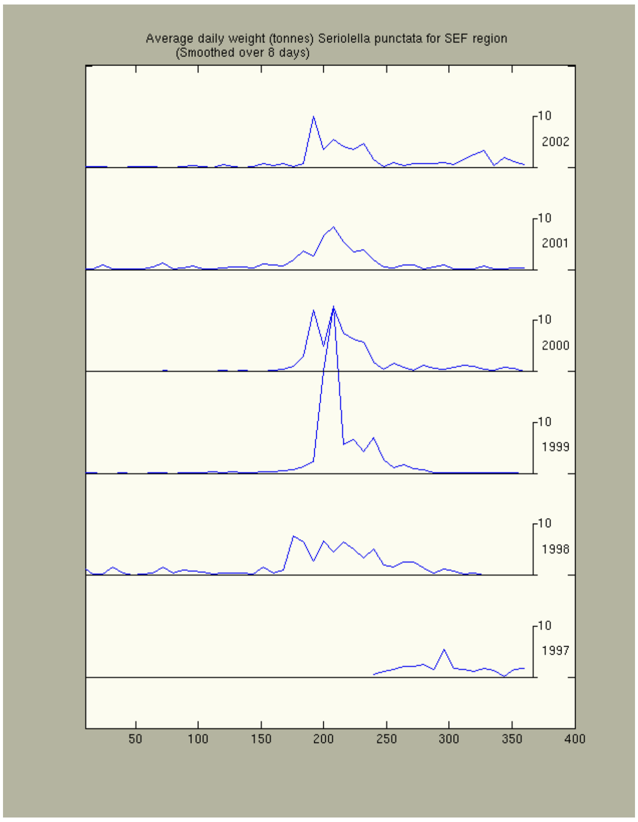

Figure 9. *Seriolella punctata* 8-day average of catch weight plotted over years 1997 to 2002.

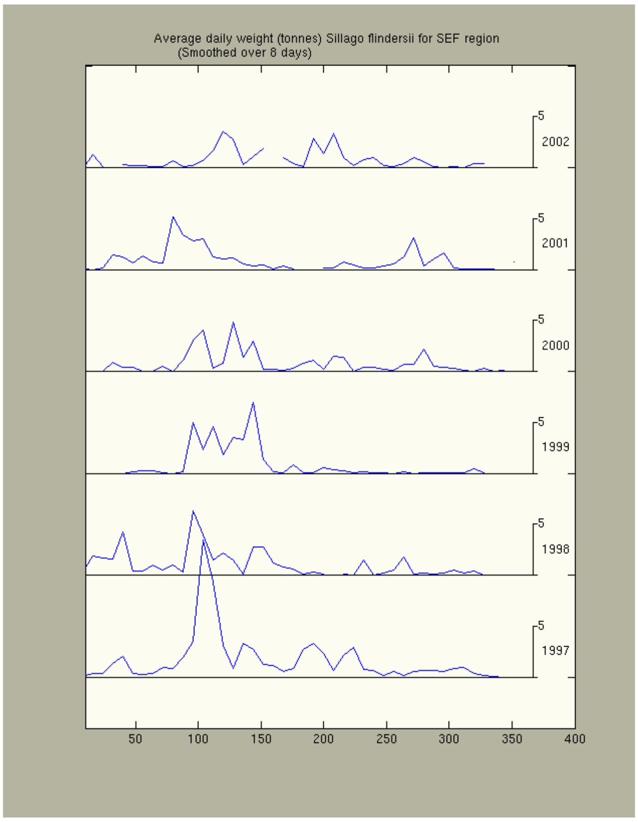

Figure 10. *Sillago flindersi* 8-day average of catch weight plotted over years 1997 to 2002.

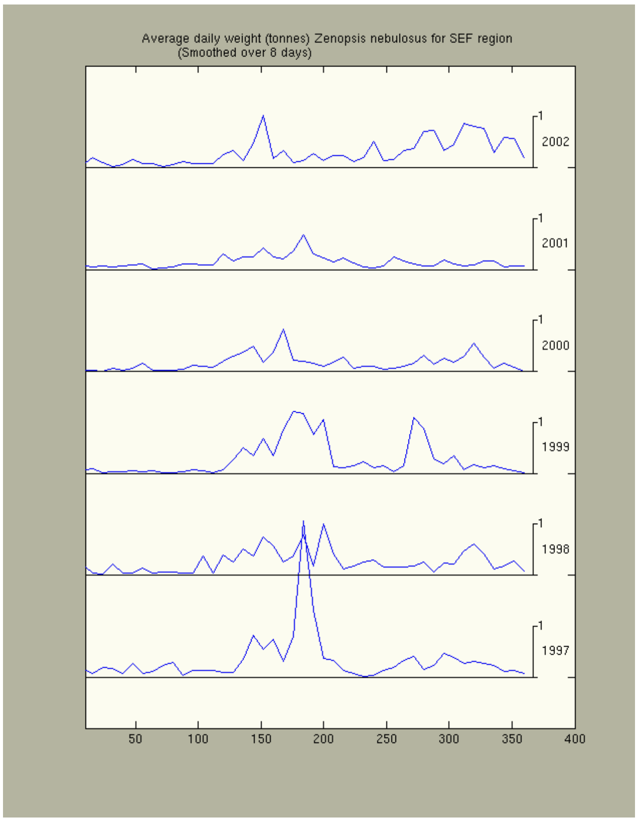

Figure 11. *Zenopsis nebulosus* 8-day average of catch weight plotted over years 1997 to 2002.

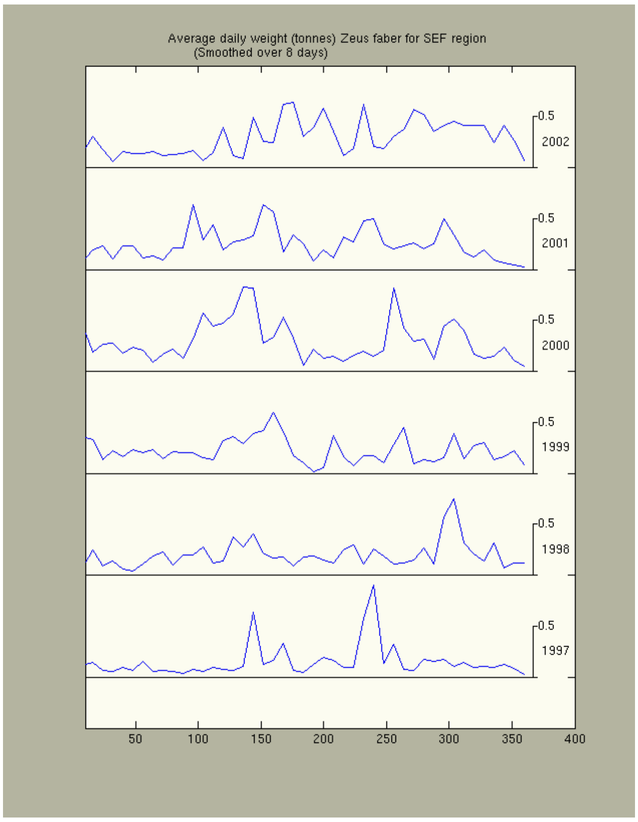

Figure 12. *Zeus faber* 8-day average of catch weight plotted over years 1997 to 2002.

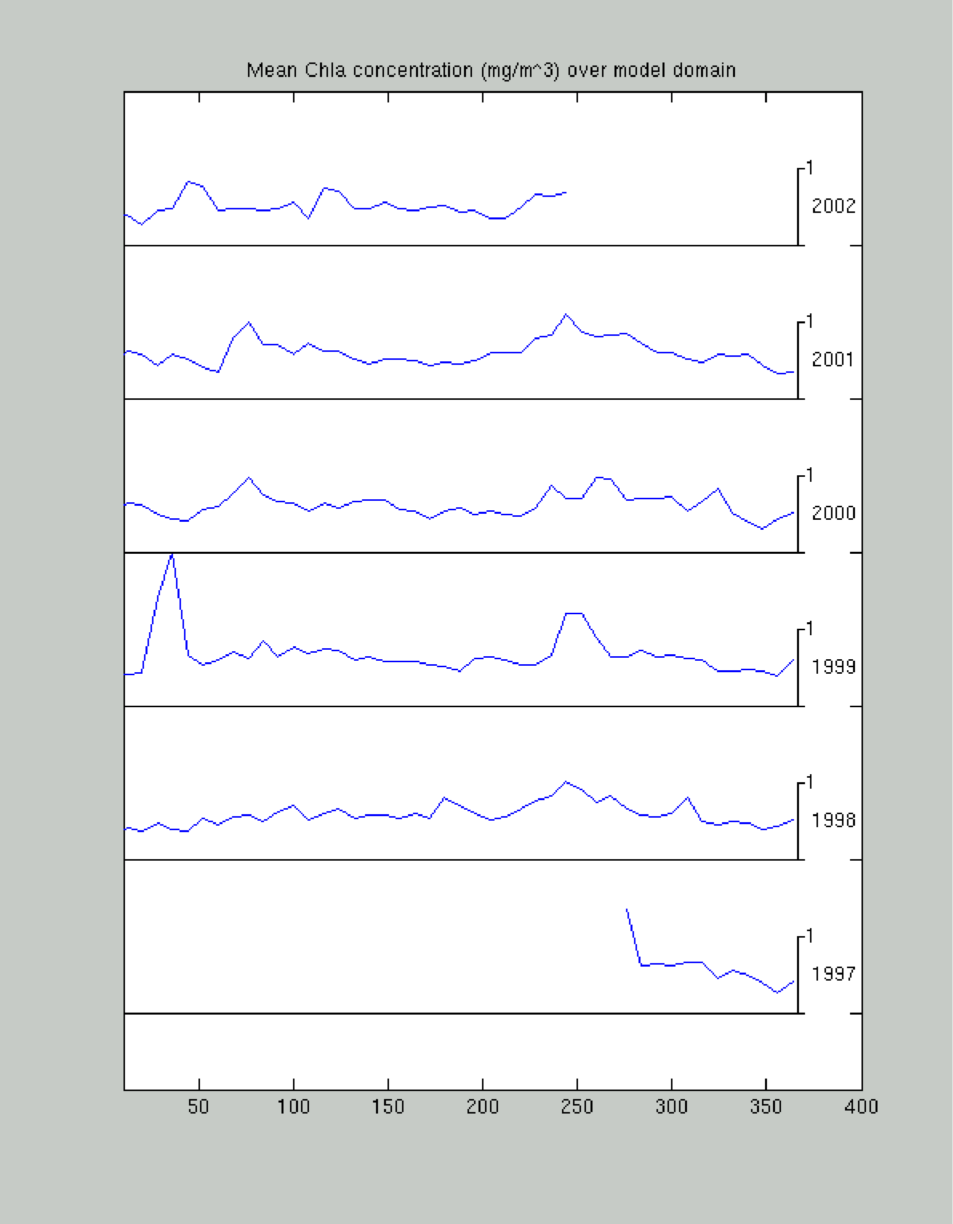

Figure 13. Mean chlorophyll concentration (8-day average) over the study area, years 1997 to 2002.

4.4 Discussion

The catch of a number of species in EBS (*C. affinis*, *M. novaezelandiae*, *S. flindersi*, *Z. nebulosus* and *Z. faber*) show a bimodal seasonal pattern similar to that observed in phytoplankton biomass (Section 3.3.2). However, there appears to be little consistent linking between annual catches and phytoplankton (at least at the scale of the data and analysis). While this result was expected for species feeding relatively high in the food web, such as carnivores (*Z. nebulosus* and *Z. faber)*, it was also true of those feeding directly on zooplankton or on other zooplankton-feeder species (*S. flindersi or Seriolella* species).

Fisheries production was generally consistent between years for most species. *H. antarctica*, *M. novaezelandiae*, *S. punctata* and *Z. nebulosus* recorded higher catches in 1999, the year in which the large upwelling event was observed (see section 3.3.3). Alternatively, catches for *S. flindersi* displayed only one seasonal peak during 1999, compared to its general trend for two seasonal peak fishing-periods, which may be a result of low nutrient levels remaining in the system following the unusually large summer upwelling event (Section 3.3).

The largest interannual variation was seen within *M. novaezelandiae*, *N. richardsoni* and *S. brama* trends. *M. novaezelandiae* catches followed a similar trend between years but with greatly increased catches in 1999. *N. richardsoni* catches are notably variable, but show particularly great variance in 2000, potentially demonstrating a years lag from the large upwelling event of 1999. *S. brama* catches move from a single peak abundance in most years to a secondary peak in 1998 and 2000, with the 2000 secondary peak recording higher catches than the primary peak. *G. blacodes* and *Z. faber* also recorded greater seasonal peaks in catch for the 2000 fishing year.

Variability in species abundances and catchability can be influenced by a broad range of environmental factors, including temperature, primary production, and the distribution of currents and fronts. These factors may have a direct impact on the distribution or catchability of species, or an indirect effect on abundance via trophic cascades or larval survival. For example, upwelling events have been found to sustain subsequent increases in mesozooplankton abundance and biomass, with potential impacts on fishery catches (Lehodey *et al.* 1997, Tenore *et al.* 1995, Young *et al.* 1996). Harris *et al.* (1992) reported the relative success of the jack mackerel fishery in Tasmania in years of greater upwelling due to fish biomass increases in areas of enhanced euphausiid aggregations. In other regions, it has been demonstrated that mesozooplankton production on feeding grounds and recruitment grounds has important implications for the biomass of small pelagic species such as Pacific hake (*Merluccius productus)* and herring (*Clupea pallasi*) (Ware and McFarlane 1994), and for the recruitment success of Pacific sardine (*Sagax sardinops*) through its effect on subsequent egg production (Ware and Thomson 1991).

In the EBS, the trophic structure may be more complex and the fisheries species are further removed trophically from primary production than is the case in small pelagic fisheries. For example, upwelling in EBS generally favours diatom production, forming a readily available food supply for copepods and euphausiids, followed by planktivorous fishes, and eventually through to carnivorous fishes. The uptake time from an initial phytoplankton bloom to increased macrozooplankton biomass will largely determine the lag time between bloom and initial fishery production, but this will be greatly increased for the higher trophic level species that comprise most of the fishery catch. As this trophic distance increases, the influence on recruitment to the fishery from primary productivity diminishes.

The long-term link between fishery production and primary production may be driven through enhanced recruitment success for spawning fishes, particularly where there is an extended lag time. As various herbivorous copepod stages are the main feeding resource for many pelagic fish larvae, a high spawning intensity coincident with the high primary productivity may be interpreted as an adaptive response for early life stages. Many of the SEF quota and commercial fisheries species are reported to spawn over the spring-summer months when primary productivity is greatest (Table 7). Matching egg and larval production with timing and location of primary productivity supports the success of breeding aggregations and enhances larval survival. This scenario would produce a notably greater lag time in terms of fishery production, with the resulting periodicity in the order of years, as successful cohorts are recruited to the fishery.

Table 7. Months of spawning/larval occurrence for selected species within the study area.

Species	Common name	Duration of spawning/larval occurrence
Centroberyx affinis	Redfish	November - May, off Sydney
Cyttus australis	Silver dory	(*unconfirmed September - February)
Cyttus traversi	King dory	(*unconfirmed September - February)
Engraulis australis	Anchovy	September - May
Genypterus blacodes	Pink ling	April - September, NSW
Hyperoglyphe antarctica	Blue eye trevalla	
Lepidoperca pulchella	Eastern orange perch	
Macruronus novaezelandiae	Blue grenadier	May - September, Tasmania
Neoplatycephalus richardsoni	Tiger flathead	December - April, Tasmania
Platycephalus bassensis	Sand flathead	(*unconfirmed November - March)
Pterygotrigla polyomata	Latchet	October - January, Tasmania
Rexea solandri	Gemfish	July - September, off Sydney
Sardinops neopilchardus	Pilchard	(*unconfirmed December - February)
Seriolella brama	Blue warehou	August - November, NSW - Tasmania
Seriolella punctata	Spotted warehou	July - October, NSW- Tasmania
Sillago flindersi	Eastern school whiting	(*unconfirmed September - February)
Thyrsites atun	Barracouta	September - April, NSW - Tasmania
Zenopsis nebulosus	Mirror dory	(*unconfirmed September - February)
Zeus faber	John dory	(*unconfirmed September - February)

Spawning/larval occurrence from Neira *et al*. 1998.
* based on data for other species within the genus.

This has also been supported in a recent study within the SEF area, where larval survival was observed to increase following the large 1999 upwelling event (Neira 2005), and has also been noted for the NSW eastern gemfish fishery (Prince *et al*. 1997, 1998).

A study of the spawning success of individual species between years, together with the chlorophyll measures over individual species spawning-periods and a measure of their success in recruitment to the fishery in following years, would be needed to further test this idea.

4.5 References

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5 TROPHIC MODEL

5.1 Overview of model software

The East Bass Strait shelf was modelled with the Ecopath with Ecosim (EwE) software. These models arose because the trend toward broader ecosystem-based management required representation of whole-of-ecosystem functioning and regulation upon which to test management or environmental options. The tools with which to achieve this are less well agreed upon. Walters *et al.* (1997) discussed three approaches that have been used with varying degrees of success: multi-species virtual population analysis (MSVPA); simpler differential equation models for biomass dynamics; and bioenergetic modelling. Jennings *et al.* (2001) reviewed several ecosystem modelling approaches including multi-species surplus production, MSVPA, and size spectra models. However many of these approaches resulted in outputs that were dubious or difficult to interpret. Further problems in using these methods include difficulties in parameterization, requirements for large amounts of data that were costly to obtain and a requirement for skilled modellers.

EwE is a simpler approach for ecosystem trophic analysis devised by Polovina (1984) and developed by Christensen and Pauly (1992) although the same difficulties still apply albeit to a lesser degree. Ecopath expresses the trophic flows between functional groups in a modelled ecosystem. Ecosim is the dynamic simulation extension of Ecopath that estimates how changes in environment or fishery will affect the ecosystem (Jennings *et al.* 2001). Ecospace is used to estimate spatially-explicit effects of changes in management. The resulting Ecopath modelling suite (Christensen and Pauly 1992, Pauly and Christensen 1993, Walters *et al.* 1998, Pauly *et al.* 2000) is now commonly used to summarize data on ecosystems, describe the system properties, and study responses to policy or ecosystem changes.

The first component of this approach, Ecopath, was developed by Polovina (1984). Biomass and food consumption of the various groups are estimated using mass-balance principles, and combined with an analysis of the flows between the groups by Ulanowicz (1986). The model describes an average state, rather than a steady state. The ecosystem is compartmentalized into groups of either single species, or many species base don the functional roles of the species. Descriptions of the model equations are given in Appendix B and more detailed accounts can be found in Walters *et al.* (1997) and Christensen *et al.* (2000). Once the model is parameterized, it can be used in the temporal and spatial components, Ecosim and Ecospace.

Ecosim was developed by expressing the Ecopath mass-balance equations as coupled differential and delay-difference equations into Ecopath, to allow for dynamic simulations (Walters *et al.* 1997). Biomass flux rates are expressed as a function of time, varying biomass and harvest rates (Christensen *et al.* 2000). Predator-prey interactions can be varied to emulate top-down or bottom-up control (Walters *et al.* 1998, Bundy 2001). Time series data on biomass, catch rates and fishing effort can be fitted which makes this program useful to explore options for management policies (Pauly *et al*. 2000). It has not been used extensively for fisheries management because most management is still concerned with single-species. However, this is changing with moves toward multi-species management. Christensen and Walters (2004) cite several recent applications of models to North American and Thailand marine ecosystems that have successfully evaluated the effects of fisheries and environmental changes.

Ecopath with Ecosim (EwE) has been used to examine a number of ecosystems including the Benguelan upwelling (Jarre-Teichmann *et al.* 1998, Shannon *et al*. 2000), the Eastern Bering Sea (Trites *et al*. 1999), the Central Pacific top predators (Kitchell *et al.* 1999), the Newfoundland-Labrador coast (Bundy 2001), and the Gulf of Thailand (Christensen 1998) and the list is increasing. In south-eastern Australia, EwE models were developed for the seamounts and midslope region off southern Tasmania (Bulman 2002, Bulman *et al*. 2002), to test the hypothesis of Koslow (1997) and Williams *et al*. (2001) that the large populations of orange roughy and oreo dories are supported by a constant advection of prey past the seamounts in the deeper currents. Goldsworthy *et al*. (2003) used Ecosim to model the impacts of increasing seal populations on fish stocks in eastern Bass Strait. An EwE model for the NSW fishery is currently being developed by R. Forrest (NSW Fisheries-UBC). The North West Shelf was modelled using EwE (Bulman 2006 in press). EwE models were developed for the Great Barrier Reef (Gribble 2001) and are currently being developed for Albatross Bay, the Gulf of Carpentaria and the Torres Strait by CSIRO.

Recent developments in ecosystem management increasingly require more spatial information. Traditional methods of stock assessment have not addressed spatial management options let alone indirect ecological impacts of policy alternatives (Walters *et al.* 1998). Responding to this need, the third module, Ecospace, represents the dynamical response of an ecosystem in two-dimensional space. Unlike other more conventional attempts, this new approach uses few additional data (Walters *et al.* 1998). Although it does not attempt to model all physical transport and migratory processes, the model may be able to provide insight into the effects of marine protected area policies on trophically linked species.

Ecospace was specifically developed to investigate the effects of protected areas on marine ecosystems. So far, it has not been as widely applied. Walters *et al.* (1998) presented results of a model of the shelf fishery of Brunei Darussalam with an MPA around the oilrigs and pipelines. The results showed that, although the fit could be improved by further manipulations, Ecospace could predict fish distributions quite similar to those observed while accounting for spatial variation of primary production, predation and fishing. Ecospace was applied to the Prince William Sound to aid scientists in understanding the implications of the Exxon Valdez oil spill on trophic interactions over large space-time scales (Okey and Pauly 1999); to fishing fleets in the Gulf of Thailand (Pitcher *et al.* 2002), to investigate the effects of MPAs on fishing fleets in British Columbia (Salomon *et al.* 2002) and to evaluate fisheries and conservation measures in the Galapagos (Okey *et al.* 2004).Within Australia, the penaeid prawn community in the far northern Great Barrier Reef was modelled with Ecospace by Gribble (2001) and a preliminary Ecospace model was built for the North West Shelf (Bulman 2006 unpublished report).

5.2 Model equation

The trophic model is based on two equations describing production and energy balance for each group:

> Production = catch + predation mortality + biomass accumulation + net migration + other mortality, and

Consumption = production + respiration + unassimilated food.

Ecopath also calculates:

Production utilized = catch + consumption by predators,
or mathematically,

$$B_i(PB^{-1})_i EE_i - \sum_{j=1}^{n} B_j (QB^{-1})_j DC_{ij} - Y_i - E_i - BA_i = 0 \qquad 1.$$

where:
B_i is the biomass of functional group i;
PB^{-1}_i is production/biomass ratio and can generally be input as total mortality rate (Z);
EE_i is the ecotrophic efficiency defined as the proportion of production of i that is utilized in the system;
B_j is biomass of predator j;
QB^{-1}_j is consumption rate for predator j;
DC_{ij} is the fraction of group i in the diet of predator j;
Y_i is the total fishery catch of group i;
E_i is the net migration of group i (emigration-immigration); and
BA_i is the biomass accumulation rate.

To parameterize the model three of the four terms, B, PB^{-1}, QB^{-1} or EE, must be supplied. If all four of the terms are entered, biomass accumulation or net migration can be estimated. Also required are diet composition, assimilation rate, net migration, catch, and biomass accumulation, the last three of which may be zero. More detail of the model equations are in Appendix B.

5.3 Model construction

5.3.1 Procedure

Okey and Mahmoudi (2002) documented the steps for the design, construction and balancing of an EwE model for the West Florida Shelf, USA. Briefly these were to:

- define the system in space and time (see section 1.2.1),
- define the functional groups in the model,
- estimate basic parameters for each functional group,
- estimate fisheries information,
- estimate additional parameters,
- enter parameters,
- characterise the pedigree of the parameters, and
- balance the model.

The EBS study area has been described previously in section 1.2.1 and in Chapter 2. The Ecopath model represents the area in 1994, when an extensive survey was conducted by CSIRO Marine Research. The Ecosim simulations use data through to 2003 and predictions were projected for a further 40 years.

5.3.2 Definition of groups

The fauna of the EBS was organized into functional groups based upon commercial fishery, life history traits and ecology such as size and growth, preferred depth and trophic function. For many species, categorization was complicated by increases in depth preference with increased size. Although this complication can be accommodated by creating stanzas or life stages that are linked, this version of the model does not account for ontogenetic changes in habitat preference.

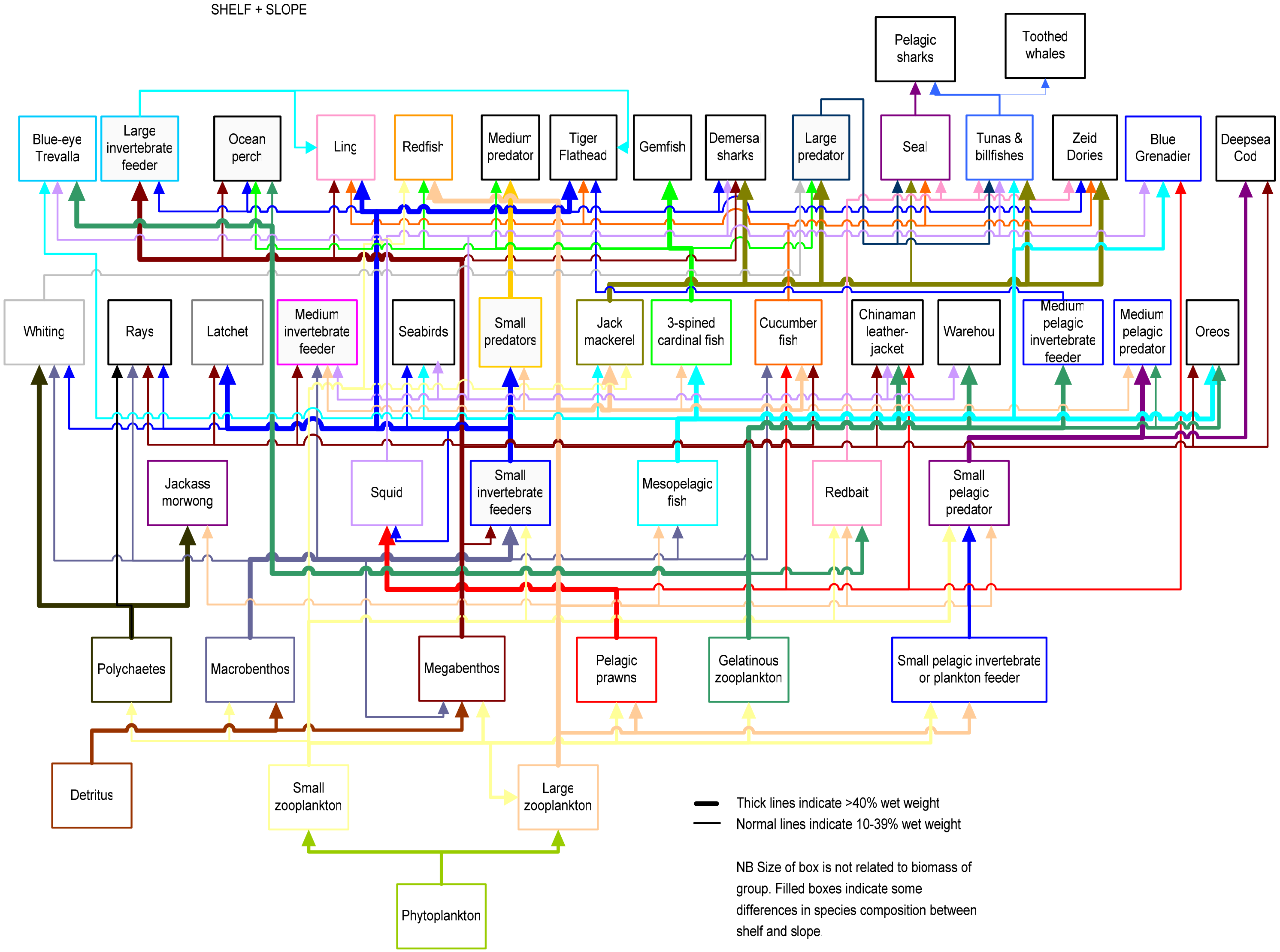
Further development of the Ecospace model could effectively deal with these changes. The aggregate groups of species were split according to average adult size (small=<30 cm, medium=30-50 cm, large= >50 cm) and preferred or major depth range of adults (shelf= 0-200m, slope>200m, pelagic= any depth not demersal).

Table . Functional groups for the EBS model. Representative species in the groups are given in following section 5.4.6 and sub-sections and tables therein.

Functional Groups	
Toothed whale	Baleen whale
Seal	Seabirds
Penguins	Tunas and billfish
Pelagic sharks	Demersal sharks
Rays	Warehous
Redbait	Redfish
Ling	Dories
Jack mackerel	Jackass morwong
Flathead	Gemfish
Shelf ocean perch	Chinaman leatherjacket
Cucumberfish	Whiting
Cardinal	Shelf small invertebrate feeder
Shelf small predator	Shelf medium invertebrate feeder
Shelf medium predator	Shelf large invertebrate feeder
Shelf large predator	Blue-eye trevalla
Blue grenadier	Slope ocean perch
Deepsea cod	Oreos
Slope small invertebrate feeder	Slope small predator
Slope medium invertebrate feeder	Slope medium predator
Slope large invertebrate feeder	Slope large predator
Pelagic small invertebrate feeder	Pelagic medium invertebrate feeder
Pelagic medium predator	Pelagic large invertebrate feeder
Pelagic large predator	Mesopelagic fishes
Squid	Pelagic prawns
Macrobenthos	Megabenthos
Polychaeta	Gelatinous nekton
Large zooplankton	Small zooplankton
Primary producers	Detritus

5.3.3 Diets and food web

Wherever possible, dietary information was taken from local studies. Between 1993 and 1997, CSIRO Marine Research conducted intensive investigations of factors that affect fishery production on the south-eastern Australian shelf (FRDC 94/040: Bax and Williams 2000). The project was multi-faceted and investigated the association of fish assemblages with habitats, and the influences of physical and chemical variables of the habitat in the biological attributes of the assemblages. Within this project, the diets and trophic guilds of commercially important, and other ecologically important fish species, i.e. ones that were abundant or dominant in diets of commercial fish, were investigated. Specifically, the aims of the dietary analyses were: (1) to describe the diets of commercially and ecologically important fish species on the shelf; (2) to identify the trophic guild structure of the fish community; (3) to compare the relative importance of pelagic and benthic contributions to the fishery production by comparing pelagic and benthic prey sources of commercial species; and (4) to evaluate the magnitude of predation on commercially important (quota) species (Bulman *et al*. 2001). Details of the sampling locations and strategies are described in Bax and Williams (2000) and Williams and Bax (2001).


SHELF + SLOPE

NB Size of box is not related to biomass of group. Filled boxes indicate some differences in species composition between shelf and slope

Figure 1. Food web of the Eastern Bass Strait shelf and upper slope ecosystem used as the basis for the construction of the EwE model. Detritus also includes fishery discards. Fate of detritus is not shown.

The sampling design had two phases: broad scale surveys and focused area surveys. For the broad scale surveys, seven transects were sampled, each transect consisting of stations spaced at 25 m, 40 m, 80 m, 120 m, and 200 m depths across the shelf. For the focussed area surveys, sampling was focussed within six mesohabitats that were further defined at a finer scale into17 macrohabitats. Fish were caught by bottom trawls in the broad scale surveys or gillnets in the focused area surveys. Overall, 217 species were caught during the surveys. From the 102 species for which dietary samples were taken, 70 species had sufficient gut samples for further analysis (Appendix C).

In the original analysis, a cluster analysis was used to classify the 70 species into trophic guilds. To maximise our data, we pro-rated unknown fish or invertebrate prey categories. For instance, for any predator, unidentified fish were pro-rated across the identified fish species or groups in that predator’s diet. If no specific prey were identified, the aggregated diet group was re-apportioned across appropriate prey species according to the species’ proportions in the group, and the likelihood that that species would be available to the predator. This approach assumes that all prey fish in the same depth zone and of the same or smaller size would be equally vulnerable to predation, which may not necessarily be true for all species.

Based on the diet compositions and the guild structure of the 70 species, we constructed a food web to illustrate the most important trophic interactions in the shelf system, some of which might be of interest from a management, ecological or historical perspective. In addition to the fish species from the shelf dietary study, we added seals, whales, seabirds, pelagic species such as tunas, billfishes and large sharks and upper-slope species such as blue grenadier and blue-eye trevalla and aggregated groupings to the model (Fig 1). From this we developed the EwE ecosystem model.

The most fundamental information in the ecosystem model is the dietary matrix. The dietary composition data from the shelf study formed the basis of the matrix. As needed, we added dietary information from a study in the same area conducted 10 years earlier (Coleman and Mobley 1984) or used it to confirm or complement the more recent study. For slope species, data from a comprehensive trophic study off Maria Island, East Tasmania, we used (Bulman and Blaber 1986, Blaber and Bulman 1987, Young and Blaber 1986).When no data were available locally, we found data from the literature, or from FishBase sources, and the diets data were averaged.

In the trophic groups that consisted of many species, diets were weighted. For those species for which there were both dietary and biomass data, the components of their diets were weighted by the proportion of biomass they represented in their functional group. The weighted components per prey type were then summed over all species in the functional group to give a weighted diet composition for that functional group. The dietary matrix (Table 2), was entered into Ecopath, which we then balanced, in part, by adjusting various diet proportions. Even relatively large modifications are usually tolerable within the confidence limits of the diet compositions.

Table 2. Diet matrix for Ecopath model.

Prey \ Predator	Toothed whale	Baleen whale	Seal	Seabirds	Penguins	Tuna & billfish	Pelagic sharks	Demersal sharks	Rays	Warehou	Redbait	Redfish	Ling	Dories	Jack mackerel
Toothed whale	0.001														
Baleen whale															
Seal	0.002						0.025								
Seabirds	0.005						0.009								
Penguins	0.005						0.009								
Tuna/billfish	0.002						0.025								
Pelagic sharks	0.001						0.045								
Demersal sharks							0.135								
Rays							0.135	0.006							
Warehous			0.05		0.1		0.009								
Redbait		0.01	0.246	0.01		0.159		0.008						0.096	
Redfish			0.019				0.009	0.023						0.039	
Ling			0.012	0.005				0.001							
Dories			0.01				0.009	0.001							
Jack mackerel	0.078		0.309			0.228	0.045	0.206						0.245	
Jackass morwong			0.005					0.001							
Flathead			0.041					5E-04							
Gemfish			0.015				0.008								
Shelf Ocean Perch			0.005					0.001							
Chinaman leatherjacket								1E-04							
Cucumberfish								0.007				0.01	0.08	0.152	
Whiting			0.01					0.003	0.02					0.006	
Cardinal			0.002					0.037		0.018		0.253	0.192	0.16	0.006
Shelf Sm Invert Feeder			0.092					0.03	0.022			0.01	0.477	0.224	0.001
Shelf Sm Predator			0.051									0.01			
Shelf Med Invert Feeder				0.005				0.013				0.0006		0.019	
Shelf Med Predator			0.04	0.005				0.005						0.017	
Shelf L Invert Feeder					0.1										
Shelf L Predator								0.008							
Blue-eye trevalla	0.01							0.001							
Blue grenadier															
Slope Ocean Perch												0.001			
Deepsea Cod															
Oreos															
Slope Sm Invert Feeder		0.02							0.001						
Slope Sm Predator		0.01						0.006	0.004			0.001	0.01		
Slope M Invert Feeder								0.022	0.01			0.004			
Slope M Predator					0.1			0.006							
Slope L Invert Feeder								0.005				0.014	0.056		
Slope L Predator															
Pel Sm Invert Feeder	0.098	0.04		0.005	0.45	0.009		0.001							
Pel M Invert Feeder	0.049						0.01	0.005							
Pel M Predator	0.01					0.02	0.031	0.01							
Pel L Invert Feeder	0.025						0.045								
Pel L Predator							0.039								
Mesopelagic fish	0.098	0.02		0.125		0.005		.00005		0.002	0.065	0.068			0.313
Squid	0.148		0.019	0.265	0.1	0.07	0.1	0.212		0.046		0.049		0.007	
Pelagic prawns					0.05			0.029	0.084	0.00001		0.025	0.011	0.012	
Macrobenthos				0.025			0.045	0.005	0.114	0.021		0.00006		0.001	0.009
Megabenthos					0.05		0.018	0.267	0.342	0.005		0.053	0.103	0.008	0.011
Polychaeta								0.003	0.209	0.0004		0.0006			0.0002
Gelatinous nekton				0.005				0.0009		0.901	0.412	0.0007			0.011
L zooplankton		0.1			0.05	0.01		0.002	0.058	0.005	0.266	0.374	0.066	0.011	0.459
Sm zooplankton								0.026	0.126	0.002	0.256	0.126	0.006	0.003	0.19
Primary producers								0.0002		0.00007					
Detritus															
Discards			0.075	0.05				0.049	0.01						
Import	0.47	0.8		0.5		0.5	0.25								
Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 2. Diet matrix for Ecopath model (cont).

Prey \ Predator	Jackass morwong	Flathead	Gemfish	Shelf Ocean Perch	Chinaman leatherjacket	Cucumberfish	Whiting	Cardinal	Shelf Sm Inve Feeder	Shelf Sm Predator	Shelf Med Invert Feeder	Shelf Med Predator	Shelf L Invert	Shelf L Predator	Blue-eye trevalla
Toothed whale															
Baleen whale															
Seal															
Seabirds															
Penguins															
Tuna/billfish															
Pelagic sharks															
Demersal sharks												0.01		0.05	
Rays												0.01		0.05	
Warehous														0.01	
Redbait												0.05		0.01	
Redfish														0.001	
Ling		0.014													
Dories		0.01										0.03			
Jack mackerel		0.005										0.06		0.318	
Jackass morwong												0.02		0.01	
Flathead												0.01			
Gemfish															
Shelf Ocean Perch		0.002												0.002	
Chinaman leatherjacket															
Cucumberfish		0.128		0.08						0.11	0.053	0.04		0.04	
Whiting		0.06								0.099		0.002		0.083	
Cardinal	0.103	0.05	1	0.074					.00002	0.101		0.025		0.181	
Shelf Sm Invert Feeder	0.007	0.086		0.083	0.1	0.01	0.005		0.002	0.151	0.064	0.251		0.014	
Shelf Sm Predator					0.1	0.005			0.0006			0.012			
Shelf Med Invert Feeder	0.007	0.025		0.082		0.001	0.005		0.0006	0.005	0.001	0.025		0.01	
Shelf Med Predator		0.005													
Shelf L Invert Feeder															
Shelf L Predator		0.05		0.007								0.02			
Blue-eye trevalla															
Blue grenadier															0.01
Slope Ocean Perch														0.002	
Deepsea Cod															
Oreos															
Slope Sm Invert Feeder					0.1										0.01
Slope Sm Predator				0.014	0.1	0.001									0.01
Slope M Invert Feeder												0.0003			0.01
Slope M Predator															
Slope L Invert Feeder		0.106		0.068						0.005					
Slope L Predator															
Pel Sm Invert Feeder		0.24												0.002	
Pel M Invert Feeder															
Pel M Predator															
Pel L Invert Feeder															
Pel L Predator															
Mesopelagic fish	0.000006	0.038						0.837						0.1	0.05
Squid	0.007			0.021		0.018	0.007		0.002	0.000007	0.003	0.1			0.2
Pelagic prawns	0.017			0.014		0.006		0.01	0.027		.000007	0.05		0.1	0.01
Macrobenthos	0.06	0.006		0.029	0.1	0.139	0.48		0.215	0.091	0.091	0.05	0.36	0.0004	
Megabenthos	0.087	0.05		0.096	0.1	0.117	0.012	0.013	0.197	0.1	0.572	0.151	0.28	0.008	
Polychaeta	0.474	0.002		0.008		0.05	0.464	0.0005	0.144		0.05	.00005	0.21	.000002	
Gelatinous nekton	0.000009	0.024		0.347	0.4	0.074			0.003	0.056		0.00003		0.0005	0.7
L zooplankton	0.161	0.05		0.04		0.497	0.021	0.137	0.118	0.199	0.153	0.08	0.15	0.005	
Sm zooplankton	0.079	0.05		0.038		0.084	0.006	0.004	0.29	0.082	0.011	0.0002		0.003	
Primary producers									0.0005	0.00004	0.003				
Detritus															
Discards												0.003			
Import															
Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 2. Diet matrix for Ecopath model (cont).

Prey \ Predator	Blue grenadier	Slope Ocean Perch	Deepsea Cod	Oreos	Slope Sm Invert Feeder	Slope Sm Predator	Slope M Invert Feeder	Slope M Predator	Slope L Invert Feeder	Slope L Predator	Pel Sm Invert Feeder	Pel M Invert Feeder	Pel M Predator	Pel L Invert Feeder
Toothed whale														
Baleen whale														
Seal														
Seabirds														
Penguins														
Tuna/billfish														
Pelagic sharks														
Demersal sharks		0.057												
Rays										0.01				
Warehous										0.01				
Redbait													0.05	
Redfish														
Ling														
Dories														
Jack mackerel		0.06								0.25				
Jackass morwong														
Flathead														
Gemfish	0.016	0.059												
Shelf Ocean Perch														
Chinaman leatherjacket														
Cucumberfish		0.009						0.094						
Whiting														
Cardinal	0.015	0.001						0.249						
Shelf Sm Invert Feeder	0.009	0.023						0.036						
Shelf Sm Predator								0.171						
Shelf Med Invert Feeder								0.099						
Shelf Med Predator								0.05						
Shelf L Invert Feeder														
Shelf L Predator														
Blue-eye trevalla														
Blue grenadier	0.041													
Slope Ocean Perch		0.005						0.025						
Deepsea Cod								0.01						
Oreos								0.005						
Slope Sm Invert Feeder	0.018	0.004	0.05							0.16				
Slope Sm Predator			0.05					0.011		0.02				
Slope M Invert Feeder	0.118	0.207					0.006	0.02		0.2				
Slope M Predator										0.025				
Slope L Invert Feeder														
Slope L Predator	0.008													
Pel Sm Invert Feeder												0.05	0.01	
Pel M Invert Feeder														
Pel M Predator														
Pel L Invert Feeder														
Pel L Predator														
Mesopelagic fish	0.717	0.068		0.381	0.0005	0.534	0.251	0.179	0.061	0.025	0.024	0.2	0.318	0.152
Squid	0.03	0.001			0.0004	0.00006	0.012		0.003	0.1	0.003			0.02
Pelagic prawns	0.009				0.037	0.006	0.034	0.012		0.05				
Macrobenthos	0.002	0.079	0.7	0.09	0.189	0.052	0.002		0.404		0.003	0.1		0.01
Megabenthos	0.007	0.177	0.2	0.03	0.252	0.136	0.1	0.0003	0.525	0.15				
Polychaeta		0.008			0.367	0.137	0.014	0.039	0.004					
Gelatinous nekton	0.002	0.194			0.003	0.0000008		0.002				0.05	0.356	0.009
L zooplankton	0.009	0.045		0.399	0.059	0.053	0.581	0.00001	0.003		0.239	0.6	0.219	0.762
Sm zooplankton	0.0009	0.001		0.1	0.092	0.083	0.0006	0.000003			0.707		0.048	0.047
Primary producers											0.024			
Detritus														
Discards														
Import														
Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 2. Diet matrix for Ecopath model (cont).

Prey \ Predator	Pel L Predator	Mesopelagic fish	Squid	Pel. prawns	Macrobenthos	Megabenthos	Polychaeta	Gelatinous nekton	L zooplankton	Sm zooplankton
Toothed whale										
Baleen whale										
Seal										
Seabirds										
Penguins										
Tuna/billfish										
Pelagic sharks										
Demersal sharks										
Rays										
Warehous										
Redbait										
Redfish										
Ling										
Dories										
Jack mackerel										
Jackass morwong										
Flathead										
Gemfish										
Shelf Ocean Perch										
Chinaman leatherjacket										
Cucumberfish										
Whiting										
Cardinal										
Shelf Sm Invert Feeder										
Shelf Sm Predator										
Shelf Med Invert Feeder										
Shelf Med Predator										
Shelf L Invert Feeder										
Shelf L Predator										
Blue-eye trevalla										
Blue grenadier										
Slope Ocean Perch										
Deepsea Cod										
Oreos										
Slope Sm Invert Feeder										
Slope Sm Predator										
Slope M Invert Feeder										
Slope M Predator										
Slope L Invert Feeder										
Slope L Predator										
Pel Sm Invert Feeder	0.48		0.05							
Pel M Invert Feeder	0.02									
Pel M Predator										
Pel L Invert Feeder										
Pel L Predator										
Mesopelagic fish		0.06	0.2							
Squid	0.3	0.002								
Pelagic prawns										
Macrobenthos						0.5	0.05			
Megabenthos										
Polychaeta						0.05				
Gelatinous nekton										
L zooplankton	0.2	0.008	0.75		0.1					
Sm zooplankton		0.93		0.2	0.4	0.4	0.05	0.9	0.2	
Primary producers				0.8			0.5	0.1	0.8	1
Detritus					0.5	0.05	0.4			
Discards										
Import										
Sum	1	1	1	1	1	1	1	1	1	1

5.4 Parameters

5.4.1 Fish biomass estimates from survey data

Average annual swept-area abundances were calculated for the Southern Surveyor surveys for the period 1994-1996. A series of four surveys were conducted during this period to roughly coincide with season. Each survey comprised seven transects with a station at 5-6 depths per transect being occupied. Each station was allocated to a habitat type, based on transect and depth. At each station, a demersal trawl was deployed for about 30 minutes. The area swept was calculated as duration of the tow (hr) x vessel speed (knots) x 1.852 km (conversion of n miles to km) x net spread (km). Tow durations varied from 14-40 minutes, vessel speed from 2.5-3.7 knots and wingspread from 17-22 km. The abundance per species at each station or trawl site was calculated and averaged across all surveys (seasons). The averages for each species in each habitat type were calculated, weighted by that habitat's proportion of the total study area and totalled to give a total abundance per species in the study area.

Swept area abundances for small fishes were seriously underestimated due largely to their low catchability. To account for the underestimation of abundances of small species for which catch-at-age data were available, we developed specific size selectivity indices. For those species where catch-at-age data were not available but length frequency data were, we usually applied a generic mesh selectivity index. These size-selectivity factors were applied to all available length-frequency samples. Lengths were converted to biomass using length-weight relationships, specific where data available or generic where not, and thus length frequency distributions were converted to biomass distributions. The proportion of the population not sampled was then estimated from the difference between the expected and actual biomass distributions (Table 3). The swept-area abundance was scaled up accordingly.

Stock assessment procedures often use 0.5 as the catchability factor *q*; therefore we doubled our swept-area abundances. The final abundances for 1994 were entered as the initial parameters in the Ecopath model (Table 26).

Table 3. Estimated proportion of species' populations sampled by survey trawl net and scaling factor used to scale swept-area abundances.

Functional group	Species	Proportion of population sampled	Scaling factor
Cardinal fish	*Apogonops anomalus*	0.5790	1.727
Cucumber fish	*Chlorophthalmus nigripinnis*	0.2229	4.487
Dory	*Zeus faber*	0.9954	1.005
Flathead	*Neoplatycephalus richardsoni*	0.9809	1.019
Jack mackerel	*Trachurus declivis*	0.9239	1.082
Jackass morwong	*Nemadactylus macropterus*	0.9257	1.080
Shelf ocean perch	*Helicolenus percoides*	0.7469	1.339
Redfish	*Centroberyx affinis*	0.8868	1.128
School whiting	*Sillago flindersi*	0.5811	1.721
Shelf large predator	*Pseudocaranx dentex*	0.9885	1.012
Shelf medium invertebrate feeder	*Nemadactylus douglasi*	1.0000	1.000
Shelf small invertebrate feeder	*Allomycterus pilatus*	0.8322	1.202
Shelf small invertebrate feeder	*Lepidotrigla mulhalli*	0.1679	5.955
Shelf small invertebrate feeder	*Parika scaber*	0.7386	1.354

Functional group	Species	Proportion of population sampled	Scaling factor
Shelf small predator	*Caesioperca rasor*	0.9827	1.018
Warehou	*Seriolella brama*	0.9892	1.011
Warehou	*Seriolella punctata*	0.9950	1.005

5.4.2 Biomass data for invertebrate groups

Biomasses for prawns, gelatinous nekton, macrobenthos and megabenthos, polychaetes, large and small zooplankton were unobtainable; therefore we allowed the model to estimate them by parameterising *P/B*, *Q/B* from other models (see section 5.4.6 and relevant subsections therein for specific values) and using an *EE* of 0.8.

5.4.3 Production and consumption parameters

Production and consumption parameters were largely unknown from our specific areas so we used data from other areas if available, or data from FishBase (Froese and Pauly 2005) if available. Occasionally we were able to use estimates from stock assessments for a few of the commercial species. For aggregated groups we used data for the majority of species if not all. We weighted the mean of the values for aggregated groups based on the abundances of the species from our surveys.

5.4.4 Ecotrophic efficiencies

Ecotrophic efficiencies (*EE*s) are calculated by the model when *B*, *P/B* and *Q/B* were entered. However for a few groups we were unable to obtain a reasonable estimate of *B* therefore we used a default value of ecotrophic efficiency of either 0.95 for fishes or 0.8 for invertebrates based arbitrarily on those used for these groups in other models.

5.4.5 Commercial fishery catch

The large dataset from the Integrated Scientific Monitoring Program (ISMP) was used to extrapolate the catches and discards of non-target species from the commercial trawl catches. The data was recoded with current CAAB (Codes for Australian Aquatic Biota) codes and categorised to enable efficient analyses. As explained more fully in Chapter 4, data from the fisheries logbooks were obtained and collated into an annual catch and discard time series for the years from 1985-2002 or whenever available (Appendix F). Similar gears per jurisdiction were aggregated into 10 fleets: Commonwealth trawl, Danish Seine, NSW trawl, Victorian trawl, non-trawl nets, line, trap, scallop, squid and tuna longline. From the appropriate data for each fleet or fishery, we calculated the catch or discard rates (t km^{-2}) for each functional group or species in the model. We used the 1994 data sets to initialize the Ecopath model and the following years' data in the Ecosim model.

Annual effort for each fleet type was also calculated in units appropriate to the gear type and scaled relative to the 1994 value, the first year of the model simulations. These data were included in the time series to force the Ecosim model.

We did not incorporate recreational fishing into this version of the model. We assumed that much of it occurred outside the model domain, i.e. in less than 40 m depth, however the difficulty of obtaining accurate data was a major factor for excluding it. While we recognise that this assumption is ignoring a potentially important proportion of extracted fish we were unable to effectively incorporate it.

5.4.6 Model group data

The initial scoping phase of the project compiled a database of ecological parameters used in the initialisation of the model. The database and an extensive list of references were submitted in the final report to the National Oceans Office (Bulman *et al.* 2002b). The updated reference list is again listed at the end of this chapter. However not all references will be individually cited within the text but are referenced in the database or in the model itself. If not explicitly stated, the source of the production (*P/B*), consumption (*Q/B*)) parameters is from FishBase (Froese and Pauly 2005), and from as comparable an area as possible to the EBS.

Toothed and Baleen whales

Two whale groupings are included in the model: ‘toothed whales’ including the dolphins such as *Tursiops truncatus*, and ‘baleen whales’ such as the southern right whale, *Eubalaena australis*. The full list of whale species assumed to be within the broader Bass Strait area was derived from several sources; however only a few were thought to impact the study area significantly (Table 4). Many whale species feed predominantly in higher latitudes and would have a limited influence on the trophodynamics of this area. Estimates of biomass of whale species in the AUSE marine area of Longhurst (1995), an area off eastern Australia extending from northern Queensland to Wilson’s Promontory, were derived from global estimates of whale populations (Kaschner 2004). The model area was estimated to be about 3 % of this area and the estimates of whale abundances were reduced accordingly. The estimates for toothed and baleen whales were 0.014 and 0.006 t km^{-2} respectively. Following Trites *et al.* 1999, *P/B* was assumed to be 0.02. Also following Trites *et al.*1999 and Blanchard *et al.*2000, *Q/B* for each species was calculated from daily ration, $R=0.1*W^{0.8}$ where W is weight of the whale in kg. The *Q/B* for the groups was the average weighted by the biomass of the species in the groups and was calculated to be 3.9 for baleen whales and 5.8 for toothed whales, although this latter value was depressed by a relatively low *Q/B* for sperm whales and by excluding it from the calculation, *Q/B* could be raised to 9.7, closer to the values of Trites and Blanchard. Since the abundances used are very uncertain, a great deal of flexibility in these values could be expected.

Diets of the whale groups were assumed to be similar to the other studies but we modified them if specific information was available, e.g. it was reported that dolphins ate blue-eye trevalla *Hyperoglyphe antarctica* (Kailola *et al.* 1993).

Table 4. Species of whales known to occur in the AUSE marine area and those presumed to significantly impact the model area.

Group	Scientific Name	Common Name	Study area
Baleen Whales	*Megaptera novaeangliae*	Humpback whale	y
”	*Balaenoptera musculus*	Blue whale	y
”	*Eubalaena australis*	Southern Right whale	y
”	*Balaenoptera acutorostrata*	Dwarf minke whale	
”	*Balaenoptera edeni*	Bryde's whale	
”	*Balaenoptera physalus*	Fin whale	
”	*Balaenoptera borealis*	Sei whale	
Toothed Whales	*Physeter macrocephalus*	Sperm whale	y
”	*Globicephala melas*	Long-finned pilot whale	y
”	*Hyperoodon planifrons*	Southern bottlenose whale	y
”	*Delphinus delphis*	Short beaked common dolphin	y

Group	Scientific Name	Common Name	Study area
”	*Tursiops truncatus*	Bottlenose dolphin	y
”	*Pseudorca crassidens*	False killer whale	
”	*Globicephala macrorhynchus*	Short-finned pilot whale	
”	*Orcinus orca*	Killer whale	
”	*Peponocephala electra*	Melon-headed whale	
”	*Kogia simus*	Dwarf sperm whale	
”	*Kogia breviceps*	Pygmy sperm whale	
”	*Ziphius cavirostris*	Cuvier's beaked whale	
”	*Feresa attenuata*	Pygmy killer whale	
”	*Berardius arnuxii*	Arnoux's beaked whale	
”	*Mesoplodon hectori*	Hector's beaked whale	
”	*Mesoplodon layardii*	Strap-toothed whale	
”	*Mesoplodon densirostris*	Blainville's beaked whale	
”	*Mesoplodon ginkgodens*	Ginkgo-toothed beaked whale	
”	*Mesoplodon grayi*	Gray's beaked whale	
”	*Indopacetus pacificus*	Longman's beaked whale	
”	*Mesoplodon peruvianus*	Pygmy beaked whale	
”	*Delphinus capensis*	Long-beaked common dolphin	
”	*Grampus griseus*	Risso's dolphin	
”	*Lagenodelphis hosei*	Fraser's dolphin	
”	*Stenella attenuata*	Pantropical spotted dolphin	
”	*Stenella coeruleoalba*	Striped dolphin	
”	*Stenella longirostris*	Spinner dolphin	
”	*Steno bredanensis*	Rough-toothed dolphin	
”	*Tursiops aduncus*	Indian Ocean bottlenose dolphin	

Seals

Although New Zealand fur seals do occur within the study area, the Australian fur seal (*Arctocephalus pusillus doriferus*) makes up almost the entire seal biomass, and as such, for the purpose of this trophodynamics model, the group is considered to be monospecific. The biomass and consumption by seals within the study area was estimated through the development of population models based on life table data available for closely related species, and foraging distribution models that calculated the spatial distribution of foraging and consumption effort within a radius of all breeding colonies (Goldsworthy *et al.* 2003). Pup production estimates for seal breeding colonies were used as the basis for developing life tables to estimate the population size, biomass and prey consumption of each colony. Life tables were based on mean age-specific survival data available for other closely related species, and maximum age was set at 21 for females, and 18 for males. As very little data are available for age-specific survival rates of any male fur seals, female age-specific survival curves were scaled to the longevity of males. Mass-at-age data were then used to estimate the biomass of populations. Population biomass data were then used to estimate the energy and food requirements of each population. A mass-based regression equation of field metabolic rate based on seven otariid (fur seals and sea lions) species developed by BF Green ($\mathrm{MJd}^{-1} = 2.234M^{0.665}$, $r^2 = 0.89$, unpublished data) was modified to estimate the annual energy requirements of populations. Populations based energy requirements were converted to prey biomass using an average prey energy density of 4.985 MJkg^{-1}, based on the mean energy density of 21 species of fish and three species of cephalopod sampled off the east Tasmanian continental shelf (Blaber and Bulman 1987), after converting dry mass energy to wet mass using an average conversion factor of 5.

Simple distance-based foraging models using available (but limited) satellite tracking data were developed for male and female Australian fur seals to enable the spatial distribution of foraging and prey consumption to be determined for the study area. These models assumed that seals within a population forage within a set range (mean and standard deviation) from their colony of origin according to the normal probability density function. Due to paucity of data, no directional component to foraging was incorporated into the models. Males and females were designated to restrict their foraging from the shore to the continental shelf to 200 m isobath (Goldsworthy *et al.* 2003).

Dietary data for seals were based on 165 faecal and regurgitation samples obtained between 1999-2000 from the Australian fur seal colony at The Skerries, which was centrally located in the East Bass Strait study area (Littnan and Mitchell unpublished data). The biomass *B* of seals feeding in the East Bass Strait study area was estimated to be 0.051 t km^{-2}. *Q/B* was estimated from the population biomass and consumption models for the Australian fur seal as 41.356 year^{-1} (245,382 t /5,933 t), and *P/B* was estimated to be 1.163 year^{-1} (total production (live plus dead t)/ (total biomass t)) (Goldsworthy *et al.* 2003). Discard data from the Integrated Scientific Monitoring Program (ISMP) were available from fishing operations within the SEF and used to estimate the total discards (see section 5.4.5).

Birds

We derived two bird groups: seabirds comprising flying birds and penguins. All birds possibly occurring in the study area were compiled from literature, particularly Ganassin and Gibbs (2005). Birds from inshore to offshore waters were included but estuarine and coastal birds were excluded. Most species' reported distribution would cover the whole study area. About half were resident all year while a quarter was resident during winter including many of the albatrosses and petrels and the other quarter was resident during summer such as the shearwaters (Table 5). The dominant seabird in the area is the short-tailed shearwater (*Puffinus tenuirostris*): over a million pairs are resident for six months of the year. The only penguin species is the fairy penguin, *Eudyptula minor*. Reliable data were very limited for biomass estimates which were calculated from estimated numbers in the area and average body weight for the few species for which data were available. This estimate did not account for all species occurring in the study area, but it does account for the most numerically dominant species, the shearwaters. The biomass of seabirds was estimated to be 0.004 t km^{-2} of which 0.001 t km^{-2} were penguins. A *P/B* of 1.0 and *Q/B* of 80.0 was assumed for both bird groups based on a Barent's Sea model (Blanchard *et al.* 2002).

Diet of the fairy penguins was based on a study of birds at Phillip Island and consisted largely of small juveniles of species such as *Seriolella brama*, *Thyrsites atun*, *Sardinops sagax*, *Pseudophycis bachus*, and squid and krill (Chiaradia *et al*. 2003).

Diet of seabirds was based on that of shearwaters and albatrosses. Shearwaters eat predominantly krill, and fish and squid, and terns eat small pelagic fishes such as anchovies, jack mackerel and other small fishes and squid (Chiaradia *et al*. 2003). The partial residency of the seabirds, particularly of the shearwaters, reduces their annual consumption of local prey resources. This was accounted for by halving the proportions of prey and assigning half their diet to "import" in the model matrix. The diet proportions of any species foraging outside of the model area were treated similarly.

Albatrosses can dive up to 70m and are able to take a variety of fishes. The Royal albatrosses in New Zealand fed largely of squid, typically upper-slope fishes such as *Macrourus novaezelandiae*, *Genypterus blacodes*, *Lepidorhynchus denticulatus*, and macrourids. Shy albatross on Albatross Island feed mostly on fish (89% by weight) of which the majority are redbait and jack mackerel, squid (10%) and to a very small extent on tunicates and crustaceans (each <0.1%) (Hedd and Gales 2001). These albatrosses feed within a range of less than 200 km and therefore do not enter our study area specifically (Hedd *et al.* 2001);

however their diet was assumed to be representative of albatross species foraging in our study area.

Table 5. Birds most likely to be encountered in study area (compiled from Ganassin and Gibbs (2005). Those marked * were used to represent the penguins and seabirds groups and to parameterise the model.

Group	Species	Common name	Residency in area
Penguins	*Eudyptula minor**	Fairy penguins	all year
Seabirds	*Anous stolidus*	Common noddy	all year
Seabirds	*Catharacta maccormicki*	South polar skua	all year
Seabirds	*Diomedea gibsoni*	Gibson's albatross	all year
Seabirds	*Diomedea sanfordi*	Northern royal albatross	all year
Seabirds	*Pachyptila desolata*	Antarctic prion	all year
Seabirds	*Pachyptila turtur*	Fairy prion	all year
Seabirds	*Pelagodroma marina*	White-faced storm-petrel	all year
Seabirds	*Pelecanus conspicillatus*	Australian pelican	all year
Seabirds	*Phoebetria fusca*	Sooty albatross	all year
Seabirds	*Procelsterna albivittata*	Grey ternlet	all year
Seabirds	*Puffinus assimilis*	Little shearwater	all year
Seabirds	*Sterna bergii*	Crested tern	all year
Seabirds	*Sterna fuscata*	Sooty tern	all year
Seabirds	*Sterna striata*	White-fronted tern	all year
Seabirds	*Thalassarche bulleri*	Buller's albatross	all year
Seabirds	*Thalassarche salvini*	Salvin's albatross	all year
Seabirds	*Thalassarche steadi*	White-capped albatross	all year
Seabirds	*Larus novaehollandiae*	Silver gull	all year, peak May-Oct
Seabirds	*Thalassarche cauta*	Shy albatross	all year, peak May-Oct
Seabirds	*Morus serrator*	Australasian gannet	all year, Mar-Sept peak
Seabirds	*Puffinus bulleri*	Buller's shearwater	spring/autumn
Seabirds	*Puffinus gavia*	Fluttering shearwater	spring/autumn
Seabirds	*Puffinus griseus*	Sooty shearwater	spring/autumn
Seabirds	*Puffinus huttoni*	Hutton's shearwater	spring/autumn
Seabirds	*Puffinus tenuirostris**	Short-tailed shearwater	Sept-May, peak spring & autumn
Seabirds	*Puffinus carneipes*	Flesh-footed shearwater	Oct-April, peak spring & autumn
Seabirds	*Puffinus pacificus*	Wedge-tailed shearwater	August –April, peak spring & autumn
Seabirds	*Pterodroma cervicalis*	White-necked petrel	summer
Seabirds	*Pterodroma macroptera*	Great-winged petrel	summer
Seabirds	*Stercorarius longicauda*	Long-tailed jaeger	summer
Seabirds	*Stercorarius parasiticus*	Arctic jaeger	summer
Seabirds	*Stercorarius pomarinus*	Pomarine jaeger	summer
Seabirds	*Sterna hirundo*	Common tern	summer
Seabirds	*Diomedea exultans*	Wandering albatross	winter
Seabirds	*Thalassarche melanophris*	Black-browed albatross	winter
Seabirds	*Catharacta lonnbergi*	Brown skua	winter
Seabirds	*Daption capense*	Cape petrel	winter
Seabirds	*Diomedea antipodensis*	Antipodean albatross	winter
Seabirds	*Diomedea epomophora*	Southern royal albatross	winter
Seabirds	*Macronectes giganteus*	Southern giant-petrel	winter
Seabirds	*Macronectes halli*	Northern giant-petrel	winter
Seabirds	*Oceanites oceanicus*	Wilson's storm-petrel	winter
Seabirds	*Pterodroma solandri*	Providence petrel	winter
Seabirds	*Thalassarche carteri*	Indian yellow-nosed albatross	winter
Seabirds	*Thalassarche impavida*	Campbell albatross	winter

Tunas and billfishes

Fifteen species are included in the ‘Tunas and billfishes’ grouping (Table 6). Ecological and life-history data were available for all species. *Q/B* values from FishBase (Froese and Pauly 2005) range from 1.4 to 5.8, but were reported as high as 11.6 for yellowfin and 32 for skipjack tuna. An average value of 6.8 was used in the model. *P/B* values varied from 0.07 to 0.8, the average being 0.32 (FishBase: Froese and Pauly 2005). This range of values suggests that this group may be over-aggregated however the grouping of species is similar to that of Okey and Mahmoudi (2002) for the West Florida Shelf, where their ranges of estimates of P/B and Q/B were much narrower. Furthermore, their mean values were higher our values, affording us some justification when we adjusted the P/B in the balancing process. Local dietary data were available for yellowfin tuna, the most abundant of the tuna species and bluefin tuna (Young *et al*.1997, 2001). With the exception of swordfish, catch data were available for most species for most years. Limited logbook discard data were also available.

Table 6. Tunas and billfishes. Parameters of all species were averaged to represent this group in the model.

Representative species	
Xiphias gladius	*Thunnus albacares*
Katsuwonus pelamis	*Tetrapturus audax*
Thunnus alalunga	*Thunnus maccoyii*
Thunnus obesus	*Makaira indica*
Makaira mazara	*Scomberomorus commerson*
Scomberomorus munroi	*Euthynnus affinis*
Istiophorus platypterus	*Tetrapturus angustirostris*
Thunnus thynnus	

Pelagic sharks

There are 9 species of pelagic sharks that were identified from our area (Table 7). FishBase *P/B* values were between 0.08 and 0.26 and *Q/B* values range between 1.0 and 2.0, with the exception of the short-fin mako (*Isurus oxyrinchus*) calculated at 9.64 (FishBase: Froese and Pauly 2005). The P/B value for this species suggests that this species could perhaps be better placed with the tunas, and a congener was classified by Okey & Mahmoudi (2002) with tunas in the West Florida Shelf model however their P/B for the congener is also consistent with other sharks. We retained the mako in the shark group. No abundance data were available for these species thus unweighted arithmetic means of *P/B* and *Q/B* values were calculated. Diets were based on those reported by Cortés (1999) particularly that of *Carcharodon carcharias* which ate largely bony fishes, sharks, rays and seals, and small amounts of penguins, squid, crabs and carrion (=discards). Catch data were generally available post mid-90s from gillnet, longline and trawl catches. ISMP discard data were limited.

Table 7. Pelagic sharks. Parameters of all species were averaged to represent this group in the model.

Representative species	
Isurus oxyrinchus	*Lamna nasus*
Prionace glauca	*Sphyrna lewini*
Alopias vulpinus	*Carcharhinus brevipinna*
Galeocerdo cuvier	*Carcharodon carcharias*
Carcharhinus longimanus	

Demersal sharks

A total of 58 species were aggregated in the 'demersal shark' group (Table 8). We used 14 of those species for which we had the most survey abundance data and parameter. FishBase *P/B* values for these 14 species, ranged from 0.07 to 0.63, with a weighted average of 0.18 for the group. *Q/B* values range from 0.9 to 4.3, with a weighted average of 1.86. The gummy shark *Galeorhinus galeus* comprised the greatest individual component of catch data; often only a generic or family total was reported. Catch data were available for most species, particularly from the mid-90s, but ISMP discard data are minimal.

Table 8. Demersal sharks. Parameters of the first 14 representative species were averaged to represent this group in the model.

Representative species		
Galeorhinus galeus	*Squalus megalops*	*Pristiophorus nudipinnis*
Mustelus antarcticus	*Callorhinchus milii*	*Galeus boardmani*
Squatina australis	*Deania quadrispinosa*	*Asymbolus analis*
Heterodontus portusjacksoni	*Cephaloscyllium laticeps*	*Asymbolus rubiginosus*
Carcharhinus brachyurus	*Pristiophorus cirratus*	
Other species		
Asymbolus sp. A	*Etmopterus lucifer*	*Centrophorus harrissoni*
Carcharias taurus	*Cephaloscyllium sp. C*	*Harriotta raleighana*
Cephaloscyllium sp. A	*Oxynotus bruniensis*	*Asymbolus parvus*
Etmopterus granulosus	*Pristiophorus sp*	*Squalus sp. C*
Heptranchias perlo	*Squalus acanthias*	*Centrophorus uyato*
Heterodontus galeatus	*Deania calcea*	*Centroscymnus crepidater*
Hydrolagus lemures	*Orectolobus maculatus*	*Centroscymnus spp*
Hydrolagus ogilbyi	*Centrophorus moluccensis*	*Centroscymnus plunketi*
Isistius brasiliensis	*Rhinochimaera pacifica*	
Notorynchus cepedianus	*Squalus mitsukurii*	*Carcharhinus sorrah*
Odontaspis ferox	*Dalatias licha*	*Parascyllium collare*
Parascyllium ferrugineum	*Furgaleus macki*	*Asymbolus sp. B*
Pristiophorus sp. A	*Asymbolus vincenti*	*Cephaloscyllium fasciatum*
Sphyrna zygaena	*Hemitriakis falcata*	*Atelomycterus fasciatus*
Squatina sp A	*Centroscymnus owstoni*	*Chimaera sp.*

Rays

Twenty-nine skates, stingarees and rays were aggregated in this group however we used six to parameterise the group (Table 9). The average *P/B* value for 6 species from FishBase was 0.35 and the average *Q/B* value was 3.9. Catches at present were reported as family Rajiidae totals only. ISMP discard data were available.

Table 9. Rays. Parameters of the first six representative species were averaged to represent this group in the model.

Representative Species		
Narcine tasmaniensis	*Urolophus paucimaculatus*	*Pavoraja nitida*
Urolophus cruciatus	*Urolophus viridis*	*Raja sp. A*
Other species		
Urolophus bucculentus	*Hypnos monopterygium*	*Trygonorrhina sp. A*
Dasyatis thetidis	*Raja gudgeri*	*Aptychotrema vincentiana*
Urolophus sp. B	*Raja whitleyi*	*Notoraja sp. A*
Urolophus sufflavus	*Torpedo macneilli*	*Raja lemprieri*
Myliobatis australis	*Trygonoptera testacea*	*Urolophus expansus*
Raja australis	*Raja cerva*	*Trygonoptera sp. B*
Aptychotrema rostrata	*Trygonoptera mucosa*	*Trygonorrhina fasciata*
Dasyatis brevicaudata	*Urolophus sp. A*	*Urolophus bucculentus*
Trygonorrhina fasciata	*Trygonoptera sp. B*	

Warehous

Seriolella brama and *S. punctata* form a separate group because of their commercial importance. Catch data were available for all years. The FishBase *P/B* was reported as 2.8 for *S. brama* (FishBase: Froese and Pauly 2005), and 0.25 and 0.3 for *S. punctata* (Thompson and He 2001, Punt *et al*. 2001 respectively). *Q/B* values of 2.6 were estimated from FishBase (Froese and Pauly 2005). Some ISMP discard data were also available for both species. The warehous ate mostly pyrosomes, pelagic colonial tunicates.

Dories

The ‘Dories’ group is comprised of four piscivorous species: Z*eus faber, Zenopsis nebulosus, Cyttus australis* and *C. traversi.* Another dory *C. novaezelandiae* was included in the general aggregate grouping of small shelf invertebrate feeders because of its different diet (mostly pyrosomes) and different life-history parameters. For the four ‘dories’, an average *P/B* of 0.30 and *Q/B* value of 2.8 were estimated from all FishBase estimates. All years of trawl and non-trawl logbook catches (1986+) were available. ISMP discard data were also available for all species.

Single species fish groupings

There are eighteen single species groups in the model, separated because of their commercial or ecological importance: blue eye trevalla *Hyperoglyphe antarctica*, blue grenadier *Macruronus novaezelandiae*, cardinal fish *Apogonops anomalus*, Chinaman (currently known as ocean) leatherjacket *Nelusetta ayraudi*, cucumberfish *Chlorophthalmus nigripinnis*, deep-sea cod *Mora moro*, gemfish *Rexea solandri*, jackass morwong *Nemadactylus macropterus*, jack mackerel *Trachurus declivis*, pink ling *Genypterus blacodes*, ocean perch *Helicolenus percoides*, spiky oreo *Neocyttus rhomboidalis*, redbait *Emmelichthys nitidus*, redfish *Centroberyx affinis*, eastern school whiting *Sillago flindersi*, slope ocean perch *Helicolenus barathri*.

Q/B values were available for 16 species from FishBase. P/B data was from a variety of sources:

Hyperoglyphe antarctica: 0.2 based on Smith and Wayte (2004)
Macruronus novaezelandiae: 0.27 based on FishBase estimate on L_{inf} of 107 cm

(0.2-0.3 in Thompson and He 2001)
Apogonops anomalus: 0.77 (FishBase: Froese and Pauly 2005)
Nelusetta ayraudi: 0.36 (FishBase: Froese and Pauly 2005)
Chlorophthalmus nigripinnis: 0.52 (FishBase: Froese and Pauly 2005)
Mora moro: 0.25 (FishBase: Froese and Pauly 2005)
Rexea solandri: 0.44 average from Smith and Wayte (2004)
Nemadactylus macropterus: 0.22 average from Smith and Wayte (2004)
Trachurus declivis: 0.47 calculated in FishBase using an L_{inf} 46.3 cm (Webb and Grant 1973)
Genypterus blacodes: 0.22 calculated in FishBase based on L_{inf} of 122 cm
Punt et al. (2001)
Helicolenus percoides: 0.26 based on same as *H. barathri* from Smith and Wayte (2004)
Neocyttus rhomboidalis: 0.35 (FishBase: Froese and Pauly 2005)
Emmelichthys nitidus: 0.74 (FishBase: Froese and Pauly 2005)
Centroberyx affinis: 0.31 (FishBase: Froese and Pauly 2005) although Morison and Rowling (2001) report 0.7-1.2 which we decided were too high compared to other values used in the model
Sillago flindersi: 0.9 range 0.9-1.1 in Smith and Wayte (2004)
Helicolenus barathri: 0.26 from Smith and Wayte (2004)

Catch data from trawl was available for all species with the exception of cardinal fish, Chinaman leatherjacket, and redbait. Catch data from gillnet was available for nine species. ISMP discard data were not available for the leatherjacket, oreos or trevalla species, and was limited for grenadier, cardinal fish, redbait and school whiting, but were available for the remaining 10 species.

Flathead

Of seven flathead species identified from the study area, the two major commercial species, tiger flathead, *Neoplatycephalus richardsoni*, and sand flathead, *Platycephalus bassensis,* were aggregated into the flathead group. *P/B* for tiger flathead was 0.2 (Cui *et al.* 2001) while the FishBase value for sand flathead was estimated at 0.36. *Q/B* for tiger and sand flathead were 4.1 and 5.2 respectively. Catch data were available for all years from 1985 for gillnet and trawl gears. ISMP discard data were available.

Shelf small invertebrate feeder

This group were species that were identified as living primarily on the shelf, were reported to be less than 30cm in length, and ate more than 60% invertebrates. Eighty-five species were aggregated in this group, including whiptails, gurnards, globefish, *Sillago* and sweep (Table 10). Of the 85 species, dietary data were available for 14 species and they were selected as representative of the group. *P/B*s and *Q/B*s for these species were estimated from FishBase. Only 15 species were caught commercially including 3 *Sillago* species other than school whiting *S. flindersi*. Scientific survey data and ISMP data were available for about half of all the species identified.

Table 10. Shelf small invertebrate feeders. Parameters of the first 14 representative species were averaged to represent this group in the model.

Representative species		
Azygopus pinnifasciatus	*Allomycterus pilatus*	*Cyttus novaezelandiae*
Parequula melbournensis	*Lepidotrigla mulhalli*	*Macroramphosus scolopax*
Paramonacanthus filicauda	*Pseudolabrus psittaculus*	*Lepidotrigla modesta*
Arothron firmamentum	*Pempheris multiradiatus*	*Meuschenia scaber*
Parma microlepis	*Notolabrus tetricus*	
Other species		
Aracana ornata	*Anoplocapros inermis*	*Aracana aurita*
Chaunax endeavouri	*Bodianus vulpinus*	*Caesioperca lepidoptera*
Omegophora armilla	*Contusus richei*	*Neosebastes thetidis*
Ammotretis rostratus	*Parapercis allporti*	*Pseudorhombus jenynsii*
Bodianus sp	*Argentina australiae*	*Austrophycis marginata*
Hippocampus abdominalis	*Brachaluteres jacksonianus*	*Enoplosus armatus*
Maxillicosta whitleyi	*Lepidotrigla argus*	*Lophonectes gallus*
Parapercis binivirgata	*Meuschenia australis*	*Meuschenia venusta*
Pseudolabrus biserialis	*Parapriacanthus elongatus*	*Paratrachichthys sp 1*
Scobinichthys granulatus	*Reicheltia halsteadi*	*Repomucenus calcaratus*
Paratrachichthys sp. 1	*Thamnaconus degeni*	*Zebrias scalarias*
Bodianus sp. 1	*Upeneichthys lineatus*	*Sillago lutea*
Chaunax penicillatus	*Brachionichthys hirsutus*	*Callionymidae*
Halieutaea brevicauda	*Contusus brevicauda*	*Gaidropsarus novaezealandiae*
Lepidoperca occidentalis	*Hippocampus whitei*	*Lepidoperca brochata*
Parazanclistius hutchinsi	*Macrouridae*	*Metavelifer multiradiatus*
Prototroctes maraena	*Pegasus lancifer*	*Pleuronectidae*
Tetractenos glaber	*Pseudomugil gertrudae*	*Syngnathidae*
Acanthopagrus australis	*Tetradontidae*	*Torquigener pallimaculatus*
Phyllopteryx taeniolatus	*Girella tricuspidata*	*Pelates quadrilineatus*
Coryphaenoides serrulatus	*Sillago burrus*	*Sillago ciliata*
Haletta semifasciata	*Coryphaenoides subserrulatus*	*Foetorepus phasis*
Notolabrus fucicola	*Odax cyanomelas*	

Shelf medium invertebrate feeder

This is a large grouping containing 42 species, and includes grey morwong, scorpaenids, latrids and wrasses (Table 11). Reliable dietary data were available for six species therefore *P/B* and *Q/B* values were obtained from FishBase for those species and the weighted average of those values was calculated to be 0.36 and 3.4 respectively. Survey abundance data for 22 species was available. Catch data were available for all species, although was not comprehensive across all fisheries. ISMP discard data were limited to less than half.

Table 11. Shelf medium invertebrate feeders. Parameters of the first six representative species were averaged to represent this group in the model.

Representative species		
Nemadactylus douglasi	*Neosebastes scorpaenoides*	*Foetorepus calauropomus*
Diodon nicthemerus	*Meuschenia freycineti*	*Diodon nicthemerus*
Other species		
Pseudophycis barbata	*Scorpaena papillosa*	*Sillaginodes punctata*
Pentaceropsis recurvirostris	*Eubalichthys bucephalus*	*Eubalichthys mosaicus*
Gnathophis longicaudus	*Solegnathus spinosissimus*	*Upeneichthys vlamingii*
Gonorynchus greyi	*Muraenesox bagio*	*Acanthaluteres vittiger*
Neosebastes entaxis	*Ophisurus serpens*	*Pempheris klunzingeri*
Rhombosolea tapirina	*Nemadactylus valenciennesi*	*Acanthopagrus butcheri*
Serranidae spp	*Cephalopholis cyanostigma*	*Lotella rhacina*
Lotella rhacina	*Talismania longifilis*	*Cheilodactylus nigripes*
Dactylophora nigricans	*Mugil cephalus*	*Siganus nebulosus*
Sillaginidae	*Anguilla australis*	*Cookeolus boops*
Dicotylichthys punctulatus	*Diodon holocanthus*	*Gymnothorax sp.*
Meuschenia trachylepis	*Liza argentea*	*Myxus elongatus*

Shelf small predator

This grouping contains 16 species, including perch, cod, leatherjacket and gurnard, with life-history data available for most (Table 12). Dietary data were available for six of these species. The ranges of *P/B* and Q/*B* values were 0.45-0.59 and 4.1-4.7 respectively, with the averages been 0.55 and 4.46 respectively. Catch data were available for all years for five of these species and ISMP discard data were available for 11 species.

Table 12. Shelf small predators. Parameters of the first six representative species were averaged to represent this group in the model.

Representative species	
Lepidoperca pulchella	*Callanthias australis*
Caesioperca rasor	*Lepidotrigla vanessa*
Atypichthys strigatus	*Scorpis lineolatus*
Other species	
Gymnapistes marmoratus	*Lepidotrigla papilio*
Centropogon australis	*Neosebastes incisipinnis*
Scorpaena cardinalis	*Callanthias allporti*
Pleuroscopus pseudodorsalis	*Priacanthus macracanthus*
Scorpaena sp	*Uranoscopus bicinctus*

Shelf medium predator

This group contains 22 species, including stargazers, snapper, latchet, trumpeter and wrasse (Table 13). Survey abundance data were available for 15 species, but 5 species for which dietary data were available were chosen to represent this group. Weighted averages for *P/B* and *Q/B* values for the five species were 0.46 and 3.1 respectively (the specific values were from FishBase). Catch data were available for 9 species and ISMP data were available for 13 species.

Table 13. Shelf medium predators. Parameters of the first five representative species were averaged to represent this group in the model.

Representative species	
Chelidonichthys kumu	*Ophthalmolepis lineolatus*
Kathetostoma laeve	*Latridopsis forsteri*
Pterygotrigla polyommata	
Other species	
Aulopus purpurissatus	*Pseudophycis bachus*
Centroberyx lineatus	*Neosebastes pandus*
Platycephalus caeruleopunctatus	*Ichthyscopus barbatus*
Neoplatycephalus aurimaculatus	*Platycephalus arenarius*
Platycephalus longispinis	*Platycephalus marmoratus*
Satyrichthys lingi	*Centroberyx gerrardi*
Benthodesmus elongatus	*Acanthistius ocellatus*
Neosebastes nigropunctatus	*Salmo salar*
Satyrichthys moluccense	*Achoerodus viridis*
Platycephalus laevigatus	*Platycephalus speculator*

Shelf large predator

Seventeen species were categorised as ‘Shelf large predators’. Four species were chosen as representative species (Table 14) and their weighted average *P/B* was calculated to be 0.16 and average *Q/B* was 1.7. Catch data were available for all species. ISMP discard data were also available for about half of the species.

Table 14. Shelf large predators. Parameters of the first four representative species were averaged to represent this group in the model.

Representative species	
Latris lineata	*Pseudocaranx dentex*
Pagrus auratus	*Thyrsites atun*
Other species	
Seriola lalandi	*Seriola hippos*
Fistularia petimba	*Elegatis bipinnulata*
Pseudocaranx wrighti	*Epinephelus undulatostriatus*
Argyrosomus japonicus	*Glaucosoma scapulare*
Dinolestes lewini	*Notacanthus sexspinus*
Epinephelus septemfasciatus	*Polyprion americanus*
Fistularia commersonii	

Slope small invertebrate feeders

Nineteen species comprised this slope group but five had enough information available to be representative of the group (Table 15). For another 14 species there were varying abundance, catch and ISMP data. The weighted average *P/B* value for the four representative species was 0.52 and the *Q/B* was 4.28.

Table 15. Slope small invertebrate feeders. Parameters of the first four representative species were averaged to represent this group in the model.

Species	
Caelorinchus fasciatus	*Centriscops humerosus*
Epigonus denticulatus	*Epigonus lenimen*
Epigonus robustus	
Other species	
Notopogon lilliei	*Zanclistius elevatus*
Lepidotrigla grandis	*Notopogon fernandezianus*
Optivus sp 1	*Antigonia rhomboidea*
Hoplostethus intermedius	*Notopogon xenosoma*
Pentaceros decacanthus	*Pseudolabrus rubicundus*
Psychrolutes marcidus	*Tripterophycis gilchristi*
Ventrifossa nigromaculata	*Caelorinchus mirus*

Slope medium invertebrate feeder

This group comprised 17 species, however only 3 whiptails, *Lepidorhynchus denticulatus, Caelorinchus australis* and *Caelorinchus parvifasciatus,* were chosen to represent the group. Slope species were not well sampled in the 1994 survey data, which focussed only on the shelf. To approximate slope species assemblages and abundances, we used data from a similarly productive area off Maria Island surveyed in 1984 (May and Blaber 1989). The weighted average *P/B* was 0.19 and *Q/B* was 2.75, these values being heavily influenced by the dominance of *L. denticulatus* being about 95% of the biomass of this group. In addition, another 14 species were identified from commercial or ISMP data, although some identifications are questionable. Both catch and discard data were available but limited for the "other" species in Table 16.

Table 16. Slope medium invertebrate feeders. Parameters of the first three representative species were averaged to represent this group in the model.

Representative species	
Lepidorhynchus denticulatus	*Caelorinchus parvifasciatus*
Caelorinchus australis	
Other species	
Plagiogeneion macrolepis	*Sphoeroides pachygaster*
Pseudophycis breviuscula	*Caelorinchus acutirostris*
Caelorinchus kaiyomaru	*Caelorinchus matamua*
Caelorinchus sp. W5	*Caelorinchus innotabilis*
Hoplostethus latus	*Oplegnathus woodwardi*
Plagiogeneion rubiginosus	*Halargyreus johnsonii*
Plagiogeneion spp	*Scorpis aequipinnis*

Slope large invertebrate feeders

Three species were assigned to this group, two of which were members of the genus *Bassanago*, and another being *Cookeolus japonicus*. These species are long but slender; therefore their *P/B* and *Q/B* are similar to those of smaller species rather than larger species. The parameters for *B. bulbiceps*, i.e. 0.44 and 2.9 respectively, were used to represent this group. Survey data existed only for the shelf and none were available for the slope, therefore no biomass was entered for this group.

Slope small predator

Two macrourids represented this group (Table 17); *Caelorinchus mirus* and *C. maurofasciatus*, the latter dominating the group by biomass (May & Blaber 1989). The weighted *P/B* and *Q/B* were 0.40 and 0.32 respectively. Dietary data were available for these two species. Other species, of which at least one was potentially misidentified, were recorded only in ISMP information.

Table 17. Slope small predators. Parameters of the two representative species were averaged to represent this group in the model.

Representative species	
Caelorinchus mirus	*Caelorinchus maurofasciatus*
Other species	
Synagrops japonicus	*Trachyscorpia capensis*
*Uranoscopus cognatus**	

*possible misidentification

Slope medium predator

This group is represented by *Kathetostoma canaster* (Table 18*)*, for which we had life history and diet data. *P/B* and *Q/B* values were estimated to be 0.31 and 2.5 respectively (FishBase). Again survey data on the shelf were available for the first four species whose distributions extended onto the shelf but are not necessarily representative of their actual abundances. Only catch data for 5 species and only ISMP for 8 species were available.

Table 18. Slope medium predators. Parameters of the only representative species were used to represent this group in the model.

Representative species	
Kathetostoma canaster	
Other species	
Hoplichthys haswelli	*Pterygotrigla andertoni*
Beryx decadactylus	*Beryx splendens*
Dannevigia tusca	*Neoplatycephalus conatus*
Gadus morhua	*Hoplobrotula armata*
Hoplostethus gigas	*Lophiodes mutilus*
Malacocephalus laevis	*Peristedion picturatum*
Pterygotrigla picta	*Rexea antefurcata*
Gnathagnus innotabilis	

Slope large predator

The dominant species in this group was assumed to be *Lepidopus caudatus* (Table 19); on the shelf it was 20 times more abundant than *Polyprion oxygeneios*, the only other species in this group for which we had survey data. Abundance data for *L. caudatus* on the Maria Island slope were available so abundance was derived from both data sources. Commercial catch data were available for all species. The weighted *P/B* and *Q/B* for *L. caudatus* and *P. oxygeneios* were 0.2 and 2.35 respectively.

Table 19. Slope large predators. Parameters of the two representative species were averaged to represent this group in the model.

Representative species	
Lepidopus caudatus	*Polyprion oxygeneios*
Other species	
Trachipterus jacksonensis	*Ruvettus pretiosus*
Merluccius australis	*Polyprion spp*

Pelagic small invertebrate feeders

No survey data were available for this grouping although several species were allocated into this group (Table 20). Arithmetic means for *P/B* of 7.6 and for *Q/B* of 8.85 were calculated from Fish Base parameters for *E. australis* and *S. neopilchardus* which we assumed to be the most abundant species in this group. Catch data were available for all species but ISMP data were limited.

Table 20. Pelagic small invertebrate feeders. Parameters of all representative species were used to represent this group in the model.

Representative species	
Engraulis australis	*Sardinops neopilchardus*
Spratelloides robustus	*Hyperlophus vittatus*
Herklotsichthys castelnaui	*Sarda australis*

Pelagic medium invertebrate feeders

Six species are aggregated in this group (Table 21) however we had data for only one: *T. novaezelandiae*. *P/B* was 0.46 and *Q/B* was 3.4 for this species. Catch data were available for the scad and *S. caerulea* but only ISMP data were available for the remaining species.

Table 21. Pelagic medium invertebrate feeders. Parameters of the only representative species were used to represent this group in the model.

Representative species	
Trachurus novaezelandiae	
Other species	
Seriolella caerulea	
Arripis truttaceus	*Diretmichthys parini*
Tubbia tasmanica	*Decapterus russelli*

Pelagic large invertebrate feeders

This group is represented by Spanish mackerel *Trachurus murphyi*, which was caught in our surveys infrequently but does not appear in any commercial catch lists. *P/B* and *Q/B* were 0.16 and 3.0 respectively. This species was reported to feed on pelagic zooplankton and fish nekton.

Pelagic medium predators

This grouping contains 8 species of which we had survey data only for *S. australasicus* (Table 22). The biomass for *S. australasicus* was 0.7 t km^{-2}, but is unlikely to be representative of this grouping. The biomass of *B. brama* alone at Maria Island was 4.54 t km^{-2} (May and Blaber 1989). Therefore, we scaled up the survey value to around half the Maria Island estimate although we had no particular justification apart from balancing the model. The *P/B* and *Q/B* parameters for this species and *Brama brama* were averaged to 0.32 and 2.85 respectively. Catch and ISMP discard data were available for other species.

Table 22. Pelagic medium predators. Parameters of the two representative species were averaged to represent this group in the model.

Representative species	
Scomber australasicus	*Brama brama*
Other species	
Centrolophus niger	*Acanthocybium solandri*
Arripis georgianus	*Arripis trutta*
Auxis thazard	*Coryphaena hippurus*

Pelagic large predators

A number of species including tailor *Pomatomus saltatrix*, is contained in this group (Table 23) although survey data were available only for *Sphyraena novaehollandiae*. The arithmetic means for *P/B* and *Q/B* of the representative species for this group were 0.23 and 3.55 respectively. All species were taken in the line fisheries.

Table 23. Pelagic large predators. Parameters of two representative species were averaged to represent this group in the model.

Representative species	
Pomatomus saltatrix	*Sphyraena novaehollandiae*
Other species	
Lampris guttatus	*Rachycentron canadum*
Manta birostris	*Lepidocybium flavobrunneum*
Regalecus glesne	*Mola mola*

Mesopelagic fish

This group includes lantern fish and lighthouse fish but there are limited data available for our area (Table 24). Abundance data and dietary data were available from other studies of the same species in the SEF region (Young and Blaber 1986, Williams *et al*. 2001). Off Maria Island abundance of *L. hectoris* varied from 50 to 450 t km^{-2} (May and Blaber 1989). Average *P/B* and *Q/B* of 0.82 and 6 respectively were calculated for this group based on FishBase values.

Table 24. Mesopelagic species. Parameters of the all species were averaged to represent this group in the model.

Representative species	
Diaphus danae	*Lampanyctodes hectoris*
Maurolicus muelleri	*Neoscopelus macrolepidotus*
Idiacanthus sp.	*Phosichthys argenteus*

Prawns

The prawn group comprises the pelagic penaeid and carid prawns, and includes the commercial *Haliporoides sibogae*, the Royal red prawn (Table 25). Life-history and ecological data were largely from Jones and Morgan (1994). *P/B* and *Q/B* parameters for similar groups from the Bering Sea (Blanchard *et al.*2002), and the Azores (Guénette and Morato 2002) were reviewed, and averages of 1.6 and 10.0 were used in this model. Limited catch data were available from prawn trawling. Discard data were not available.

Table 25. Pelagic prawns. No data was available to use in representing this group.

Representative species	
Plesiopenaeus edwardsianus	*Plesiopenaeus cf. nitidus*
Haliporoides sibogae	*Haliporoides sibogae*
Sergia prehensilis	*Sergia potens*
Lucifer sp.	*Sergia* sp.
Oplophorus novaezelandiae	*Acanthephyra quadrispinosa*
Stylodactylus stebbingi	*Lipkius holthuisi*
Heterocarpus sp.	*Pasiphae sp.*
Chlorotocus crassicornis	*Chlorotocus* sp.
Chlorotocus novaezelandiae	

Macrobenthos

'Macrobenthos' is not strictly a size class but comprises an aggregate group of sessile epibenthos such asteroids, ophiuroids and echinoids and small mobile epifauna such as amphipods and small mysids. Parameters for groups containing these species were reviewed from various models (Trites *et al.* 1999, Blanchard *et al.* 2002, Okey and Pauly 1999, Bradford-Grieve 2002) and a *P/B* of 1.6 and a *Q/B* of 6.0 were used.

Megabenthos

The 'Megabenthos' comprises large mobile benthic fauna including the commercial species of crabs, bugs, benthic prawns, scallops, but also incudes non-commercial species such as mobile gastropods and bivalves, and benthic cephalopods (cuttlefish, four squid and eight octopus species). Some ecological data were available for this group, but life-history data are limited. *P/B* and *Q/B* values from Bundy 2001 were used after reviewing parameters from several models (Blanchard *et al.* 2002, Okey and Pauly 1999, Guénette and Morato 2002). Catch data were limited to bugs, prawns (eastern king and school), and scallop, squid and octopus, generally by family only. ISMP discard data were limited. No abundance data were available.

Squid

The 'Squid' group comprises all pelagic cephalopods of the study area, and contains six squid and three pelagic octopus species, including southern calamari and Gould's squid (Norman and Reid 2000). *P/B* and *Q/B* parameters were taken from the Azores model (Guénette and Morato 2002). We used an abundance value from our survey but scaled it up by 10 to 1.62 tkm^{-2} because we considered the trawl estimate to be particularly under-representative of squid abundance. While this is value is highly speculative it was not inconsistent with squid biomass for other systems and the system was easily balanced with this value. Catch data were restricted to Gould's squid and southern calamari. ISMP discard data were also limited.

Gelatinous zooplankton

‘Gelatinous zooplankton’ consists of pyrosomes and salps predominantly. The *P/B* of 4 and *Q/B* of 22 from the Barents Sea model (Blanchard *et al.* 2002) for salps and siphonophores were used. There was no abundance data available for this group.

Polychaeta

Data for ‘Polychaetes’ were unavailable from the local region. Data from other models were reviewed and an average *P/B* value of 2 was used similar to that used in a model for Newfoundland fishery (Bundy 2001). We also used a Q/B value of 22 from the Newfoundland fishery (Bundy 2001) although this is higher than the few other values for polychaetes that were found (e.g. 12 in a Coral reef system (Optiz 1993), 12 for Barents Sea (Blanchard *et al*. 2002)).

Large zooplankton

‘Large zooplankton’ included carnivorous plankton such as mysids, copepods, pelagic tunicates, chaetognaths and cnidarians, and larval fish. *P/B* parameters varied from 4-20 for other models however a value of 5 was chosen similar to that in the Azores model (Guénette and Morato 2002). Similarly, *Q/B* parameters varied from 17-57 and the Azores value of 32 was used.

Small zooplankton

‘Small zooplankton’ comprised euphausiids, large copepods and pelagic amphipods. Estimates of *P/B* parameters from the Azores, Prince William Sound models, Bering Sea (Guénette and Morato 2002, Okey and Pauly 1999b, Trites *et al.* 1999) ranged from 5-52, and for *Q/B* from 22-50. A median value of *P/B* of 20 with a gross efficiency of 0.3 was used in the model.

Phytoplankton

‘Phytoplankton’ includes all primary producers of a pelagic or oceanic origin. The average standing biomass, as estimated from satellite ocean colour data, was 19.0 t km^{-2} (Chapter 3, Table 1) and this appears to be consistent with the *in situ* measurements (Chapter 3, Fig 5). The satellite data also provided two estimates of *P/B* corresponding to 517 yr^{-1} using the Befa method for estimating *P* and 368 yr^{-1} using the Hoyo method (Chapter 3, Table 1). These estimates are relatively high compared to those from other systems, which range from a 30 yr^{-1} in a Philippines Sea (Alino *et al.* 1993), through 125 yr^{-1} in Monterey Bay (Olivieri et al.1993), to 290 yr^{-1} off the Azores (Guénette and Morato 2002). However, as discussed in Chapter 3, the Hoyo estimate is at least broadly consistent with *in situ* measurements and was used in model scenarios.

Detritus

‘Detritus’ comprised benthic detritus. No local standing biomass data were available for detritus. A value of 390 t km^{-2} was used on the West Florida Shelf (Okey and Mahmoudi 2002) and a similar value off Newfoundland (Bundy 2001). However detritus is variable and dependent on distance from shore. A value of 100 was input into the model but there is no particular reason to use that value.

Discards

This group was designed to account for discarded fish from the fishery, the fate of which can be varied. We estimated from the fisheries landings and ISMP statistics the total discarded fish in 1994 to be 0.36 t km^{-2}.

5.5 Balancing

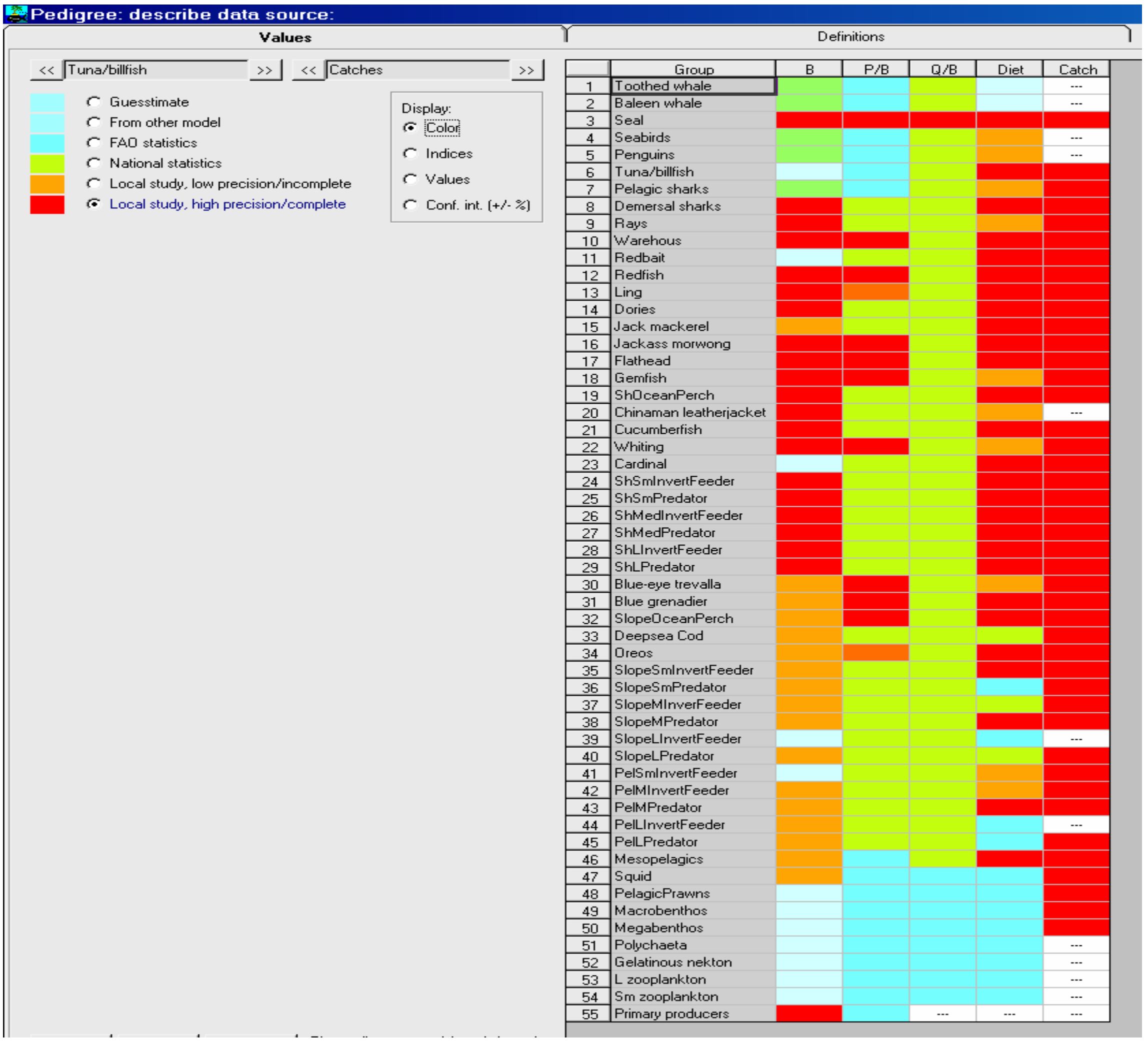
5.5.1 Strategy employed

Our general approach to balancing the model was that adjustments were made iteratively and were largely a balance of dietary and biomass values, with a few minor adjustments to production and consumption rates where necessary. The parameters were "pedigreed" by assigning a degree of confidence in each of the parameter values (Fig 2). This pedigree ranks the parameters according to the uncertainty of the value and is a useful tool in prioritising the amount of adjustment allowable. While the pedigree enables automated sensitivity routines to explore the implications of uncertainty around the input parameters within the confidences set by the model builder, manual adjustments can be made beyond that indicated by the data but must be reasonable in view of the system and the specific parameters.

Generally, it is thought that the largest uncertainty is in the diet (V. Christensen in Okey and Mahmoudi 2002) and slight adjustments in diet composition can relieve the demand on prey groups. Inspection of the consumption matrix revealed which predators placed the highest demand on a prey group whose EE was too high. Adjusting the diet composition to reduce the consumption of the prey species was regarded as preferable to inflating the biomass of the prey species. Wherever possible, dietary data specific to EBS were used, however where many species were aggregated, we sometimes had to rely on data from other studies or even systems which introduced a trophic interaction that was not indicated from the local data. While these decisions were often qualitative and subjective, they were made based on the applicability of the data suggesting the link and the feasibility of the link, and the confidence around them was lower.

Some species biomasses were estimated by the program initially because we had either poor or no information about them, but wherever possible, a biomass was entered. No biomass estimates for lower trophic groups such as the mega- and macrobenthos were available and the model was adjusted largely within the top groups. "Top-down" adjustment can often result in over-inflation of lower trophic groups if biomasses are unconstrained. However the primary producers' biomass was input, and therefore, constrained, thus restricting over-inflation of the benthos groups.

Mesopelagic fish biomass was initially unconstrained and the model estimated that a standing stock biomass of mesopelagic fish exceeding that found off eastern Tasmania (May and Blaber 1989) was required to support the consumption. This was regarded as improbable; therefore a standing biomass of 200 t km^{-2} was used to estimate an annual immigration rate, or the annual rate at which this group had to be advected into the model area to support the standing biomass of predators reliant on it. This value was 20% lower than the mean biomass at Maria Island and was chosen to reflect an assumed lower productivity than Maria Island (Alan Williams CSIRO pers. comm.). The rate required was calculated by the model to be 22 t km^{-2} yr^{-1} and this was put into the model for subsequent runs. This rate is relatively small when compared to the actual rate calculated for a midslope ecosystem supporting orange roughy off southern Tasmania (Bulman *et al.* 2001), where the annual advection rate of



Tuna/billfish

Catches

⬜ ○ Guesstimate
⬜ ○ From other model
🟦 ○ FAO statistics
🟨 ○ National statistics
🟧 ○ Local study, low precision/incomplete
🟥 ● Local study, high precision/complete

Display:
● Color
○ Indices
○ Values
○ Conf. int. (+/- %)

	Group	B	P/B	Q/B	Diet	Catch
1	Toothed whale	🟩	🟦	🟨	⬜	---
2	Baleen whale	🟩	🟦	🟨	⬜	---
3	Seal	🟥	🟥	🟥	🟥	🟥
4	Seabirds	🟩	🟦	🟨	🟧	---
5	Penguins	🟩	🟦	🟨	🟧	---
6	Tuna/billfish	⬜	🟦	🟨	🟥	🟥
7	Pelagic sharks	🟩	🟦	🟨	🟧	🟥
8	Demersal sharks	🟥	🟨	🟨	🟥	🟥
9	Rays	🟥	🟨	🟨	🟧	🟥
10	Warehous	🟥	🟥	🟨	🟥	🟥
11	Redbait	⬜	🟨	🟨	🟥	🟥
12	Redfish	🟥	🟥	🟨	🟥	🟥
13	Ling	🟥	🟧	🟨	🟥	🟥
14	Dories	🟥	🟨	🟨	🟥	🟥
15	Jack mackerel	🟧	🟨	🟨	🟥	🟥
16	Jackass morwong	🟥	🟥	🟨	🟥	🟥
17	Flathead	🟥	🟥	🟨	🟥	🟥
18	Gemfish	🟥	🟥	🟨	🟧	🟥
19	ShOceanPerch	🟥	🟨	🟨	🟥	🟥
20	Chinaman leatherjacket	🟥	🟨	🟨	🟧	---
21	Cucumberfish	🟥	🟨	🟨	🟥	🟥
22	Whiting	🟥	🟥	🟨	🟧	🟥
23	Cardinal	⬜	🟨	🟨	🟥	🟥
24	ShSmInvertFeeder	🟥	🟨	🟨	🟥	🟥
25	ShSmPredator	🟥	🟨	🟨	🟥	🟥
26	ShMedInvertFeeder	🟥	🟨	🟨	🟥	🟥
27	ShMedPredator	🟥	🟨	🟨	🟥	🟥
28	ShLInvertFeeder	🟥	🟨	🟨	🟥	🟥
29	ShLPredator	🟥	🟨	🟨	🟥	🟥
30	Blue-eye trevalla	🟧	🟥	🟨	🟧	🟥
31	Blue grenadier	🟧	🟥	🟨	🟥	🟥
32	SlopeOceanPerch	🟧	🟥	🟨	🟥	🟥
33	Deepsea Cod	🟧	🟨	🟨	🟨	🟥
34	Oreos	🟧	🟧	🟨	🟥	🟥
35	SlopeSmInvertFeeder	🟧	🟨	🟨	🟥	🟥
36	SlopeSmPredator	🟧	🟨	🟨	🟦	🟥
37	SlopeMInverFeeder	🟧	🟨	🟨	🟨	🟥
38	SlopeMPredator	🟧	🟨	🟨	🟥	🟥
39	SlopeLInvertFeeder	⬜	🟨	🟨	🟦	---
40	SlopeLPredator	🟧	🟨	🟨	🟨	🟥
41	PelSmInvertFeeder	⬜	🟨	🟨	🟧	🟥
42	PelMInvertFeeder	🟧	🟨	🟨	🟧	🟥
43	PelMPredator	🟧	🟨	🟨	🟥	🟥
44	PelLInvertFeeder	🟧	🟨	🟨	🟦	---
45	PelLPredator	🟧	🟨	🟨	🟦	🟥
46	Mesopelagics	🟧	🟦	🟨	🟥	🟥
47	Squid	🟧	🟦	🟦	🟦	🟥
48	PelagicPrawns	⬜	🟦	🟦	🟦	🟥
49	Macrobenthos	⬜	🟦	🟦	🟦	🟥
50	Megabenthos	⬜	🟦	🟦	🟦	🟥
51	Polychaeta	⬜	🟦	🟦	🟦	---
52	Gelatinous nekton	⬜	🟦	🟦	🟦	---
53	L zooplankton	⬜	🟦	🟦	🟦	---
54	Sm zooplankton	⬜	🟦	🟦	🟦	---
55	Primary producers	🟥	🟦	---	---	---

Figure 2. Colour-coded pedigree values for data input in to Ecopath model. Legend on LHS of window grades data quality from low confidence as pale blue to highest confidence in red.

similar mesopelagic fishes was calculated to be 1905 t km^{-2} based on a standing stock biomass of 30 t km^{-2} and current speed of 2.5 cm/sec. If the standing biomass of the other lower trophic groups was known, the emigration rate of those groups could also be modelled similarly. However, the model-estimated biomasses of lower trophic groups required to support the system do not appear to need additional input i.e. the biomass can be supported by the local primary production. However, since we have no values for standing biomass of the groups we cannot validate the estimates any further. The flux of phytoplankton in the model area was estimated to be very small (chapter 3) therefore that of zooplankton and other lower trophic groups is also likely to be low. The greatest input into the system of lower trophic groups was hypothesized to be from the vertically migrating mesopelagic nekton.

Production and consumption rates were generally not altered, or only by very small increments. The parameters for the aggregated groups were calculated by weighting each species' parameters according to their contribution to the group's composition and so, despite the constraint that the species should be of similar size and function and therefore have similar production and consumption parameters, a degree of flexibility would be expected. Also consumption rates *Q/B* were mostly derived from Pauly’s empirical formula which relied on an interpretation of the feeding style of the species.
Overall, adjustments were made with regard to the current knowledge of the system and the ecological sense of the resulting change. However, we do not presume to have perfect knowledge and much improvement should be made in consultation with experts.

5.5.2 Balanced Model

The resulting balanced model is just one possible solution that might fit the input parameters of the EBS area (Table 26). By constraining the parameters available to modify, the solution space becomes more limited and particularly so by assigning confidence levels to the parameters. While the higher trophic levels were well constrained by inputting biomass values for as many as possible, the lower trophic levels were not and therefore we do not presume that this part of the system is necessarily well-represented. On the other hand, primary production was well estimated, so that alone constrained the next higher trophic levels. Furthermore, the estimates for the lower trophic groups were consistent with other comparable groups in other shelf systems such as the Newfoundland-Labrador shelf (Bundy 2001), Yucatan (Arréguin-Sanchez *et al*. 1993), smaller values than for the West Florida Shelf system (Okey and Mahmoudi 2002), and similar to the Barents and Bering Sea models (Blanchard *et al*. 2002, and Trites *et al*. 1999 respectively). However, specific abundance data for the invertebrates would make a significant improvement to the model.

The total biomass of fish was 73 t km^{-2}, while that of higher vertebrates, birds and mammals was 0.06 t km^{-2} and that of lower trophic groups excluding primary producers was about 100 t km^{-2} and phytoplankton was 19 t km^{-2}, giving a total system biomass excluding detritus of 192 t km^{-2}. The Venezuelan shelf system has a total biomass of 257 t km^{-2} excluding marine mammals and birds, and a net system production of 1417 t km^{-2}year^{-1} (Mendoza 1993).

System statistics

Maturity of the system, *sensu* Odum (1969), can be inferred from a variety of system statistics calculated by Ecopath. Values of the ratio of primary production to respiration approaching 1 indicate a mature ecosystem, where the primary production of the system balances the respiration of the biomass (Christensen 1995). However, this term, which was derived for a “classical” equilibrium situation, is probably not appropriate for our system. The EBS system is probably the most severely disturbed system on the east coast of Australia and so is expected to return indices that suggest “immaturity” or, perhaps more correctly, a loss of maturity. The total primary production to respiration ratio for the EBS is 1.8 (Table 27), i.e. primary production exceeds respiration. This suggests that the system has moved away from maturity particularly if we consider the value for the historical value is 1.47 (see Chapter 7, Table 3). However, respiration is not reliably calculated by Ecopath and so the total primary production to respiration ratio is considered to be a less reliable measure of system maturity than the others discussed below (Christensen 1995).

The net system production for this system was 1694 t km^{-2}year^{-1} (Table 26) which is relatively high compared to most other systems (Christensen and Pauly 1993, Trites *et al.* 1999). While this is indicative of an immature system (Christensen *et al.*2000) it is highly dependent on primary production to respiration and not necessarily a good indicator of maturity (Christensen 1995). The biomass/throughput ratio should also increase as a system approaches maturity. Throughput is the sum of all flows in a system, i.e. total consumption + total export + total respiration + total flows to detritus. This value in itself is indicative of how large a system is, and the EBS system is larger than many. It was larger than the Peruvian

Table 26. Group parameters of East Bass Strait model after balancing. Bold values are estimated by the model; all others are input. Sh=shelf; Sm=<30 cm; M= 30-50 cm; L=>50 cm; Invert=invertebrate.

Group name	Trophic level	Habitat area (fraction)	Biomass in habitat. area (t/km²)	Biomass	*P/B*	*Q/B*	Ecotrophic efficiency	Growth efficiency
Toothed whale	4.34	1.00	0.0130	0.0130	0.02	13.00	0.6352	0.0015
Baleen whale	3.73	1.00	0.0060	0.0060	0.02	11.20	0.0000	0.0018
Seal	4.46	0.80	0.0510	0.0408	0.18	38.898	0.8623	0.0046
Seabirds	4.06	1.00	0.0030	0.0030	1.00	80.00	0.2893	0.0125
Penguins	4.31	1.00	0.0010	0.0010	1.00	80.00	0.8678	0.0125
Tuna/billfish	4.44	0.14	0.4614	0.0646	0.68	6.80	0.5000	0.1000
Pelagic sharks	4.72	1.00	0.0039	0.0039	0.20	1.20	0.9000	0.1667
Demersal sharks	4.24	1.00	1.2150	1.2150	0.18	1.80	0.7773	0.1000
Rays	3.60	1.00	1.2000	1.2000	0.35	3.50	0.3440	0.1000
Warehous	3.93	1.00	0.9000	0.9000	0.28	2.40	0.8840	0.1167
Redbait	3.49	1.00	**1.0162**	**1.0162**	0.74	2.80	0.9533	0.2643
Redfish	3.87	1.00	1.0700	1.0700	0.31	3.40	0.6888	0.0912
Ling	4.42	1.00	0.4400	0.4400	0.22	2.40	0.9825	0.0917
Dories	4.53	1.00	0.3901	0.3901	0.30	2.80	0.8813	0.1071
Jack mackerel	3.47	1.00	6.0000	6.0000	0.47	3.30	0.7594	0.1424
Jackass morwong	3.46	1.00	0.6280	0.6280	0.22	2.90	0.7025	0.0759
Flathead	4.33	0.86	0.4338	0.3731	0.52	3.50	0.9765	0.1486
Gemfish	4.94	0.60	0.2200	0.1320	0.44	2.10	0.9571	0.2095
Shelf Ocean Perch	4.19	0.66	0.2740	0.1808	0.26	2.60	0.7800	0.1000
Chinaman leatherjacket	4.20	0.47	0.0111	0.0052	0.36	2.30	0.1173	0.1565
Cucumberfish	3.44	1.00	2.4860	2.4860	0.52	4.70	0.8945	0.1106
Whiting	3.35	0.81	1.6905	1.3693	0.90	5.40	0.5029	0.1667
Cardinal	3.94	1.00	**3.8794**	**3.8794**	0.77	6.40	0.9600	0.1203
Sh Sm Invert Feeder	3.41	0.86	5.2000	4.4720	0.61	4.67	0.9137	0.1306
Sh Sm Predator	3.98	0.86	0.6162	0.5299	0.55	4.46	0.9745	0.1233
Sh Med Invert Feeder	3.95	0.86	1.3500	1.1610	0.36	3.40	0.8228	0.1059
Sh Med Predator	4.29	0.86	0.5000	0.4300	0.40	2.93	0.8193	0.1365
Sh L Invert Feeder	3.58	0.75	0.1200	0.0900	0.21	2.00	0.4469	0.1050
Sh L Predator	4.42	0.86	1.3000	1.1180	0.19	1.84	0.8282	0.1033
Blue-eye trevalla	4.04	0.14	0.3500	0.0490	0.20	1.40	0.6856	0.1429
Blue grenadier	4.23	0.19	0.7939	0.1508	0.27	2.90	0.9574	0.0931
Slope Ocean Perch	4.29	0.54	0.1800	0.0972	0.26	3.10	0.9579	0.0839
Deepsea Cod	3.77	0.14	0.4700	0.0658	0.25	2.20	0.2920	0.1136
Oreos	3.57	0.14	0.0839	0.0117	0.35	2.70	0.9822	0.1296
Slope Sm Invert Feeder	3.47	0.60	0.1850	0.1110	0.47	4.13	0.9746	0.1138
Slope Sm Predator	3.79	0.60	0.4525	0.2715	0.40	3.24	0.7305	0.1235
Slope M Invert Feeder	3.54	0.60	3.3000	1.9800	0.19	2.74	0.8422	0.0693
Slope M Predator	4.65	0.60	0.3000	0.1800	0.305	2.50	0.4568	0.1220
Slope L Invert Feeder	3.92	0.60	**1.2142**	**0.7285**	0.44	2.90	0.9500	0.1517
Slope L Predator	4.41	0.60	0.1200	0.0720	0.20	2.34	0.8602	0.0855
Pel Sm Invert Feeder	3.06	1.00	**1.7836**	**1.7836**	0.76	8.85	0.9500	0.0859
Pel M Invert Feeder	3.48	1.00	0.1310	0.1310	0.46	3.40	0.3253	0.1353
Pel M Predator	3.79	1.00	0.3200	0.3200	0.32	2.85	0.7800	0.1123
Pel L Invert Feeder	3.36	1.00	0.0393	0.0393	0.16	3.00	0.6985	0.0533
Pel L Predator	4.00	1.00	**0.0032**	**0.0032**	0.26	3.10	0.5000	0.0839
Mesopelagic fish	3.07	0.19	200.00	38.000	0.83	8.00	0.9840	0.1038
Squid	3.42	1.00	1.6230	1.6230	2.60	10.00	0.5502	0.2600
Pelagic prawns	2.20	1.00	**1.5242**	**1.5242**	1.60	10.00	0.8000	0.1600
Macrobenthos	2.52	1.00	**31.2638**	**31.2638**	1.60	6.00	0.8000	0.2667
Megabenthos	3.22	1.00	**6.7517**	**6.7517**	2.50	5.85	0.8000	0.4274
Polychaeta	2.13	1.00	**7.1167**	**7.1167**	2.00	22.00	0.8000	0.0909
Gelatinous nekton	2.90	1.00	**2.1150**	**2.1150**	3.00	10.00	0.8000	0.3000
L zooplankton	2.20	1.00	**16.4759**	**16.4759**	5.00	32.00	0.8000	0.1563
Sm zooplankton	2.00	1.00	**33.34**	**33.34**	20.00	70. 0	0.8000	0.2857
Primary producers	1.00	1.00	19.00	19.00	368.0	-	0.4047	-
Detritus	1.00	1.00	100.00	10.00	-	-	0.0313	-
Discards	1.00	1.00	0.36	0.36	-	-	0.8136	-

upwelling system of the 1970s (18800), the Venezuelan upwelling (5309), Monterey Bay (17513) (all cited in Trites *et al.* 1999), but not as large as the North West Shelf (23619: Bulman unpublished report). The total biomass supported by this flow is expected to increase as the system matures. The value for the EBS system of 0.012 is relatively small, and also supports the interpretation that this system has lost maturity (Table 27). It is similar to the value for the Venezuelan shelf system slightly higher than values for the Gulf of Mexico, Alaskan Gyre, and Brunei, but nearly an order of magnitude lower than that for the British Columbian shelf (Table 9 in Trites *et al.* 1999).

Primary production to biomass ratios are also difficult to compare since the primary production regimes in each system are different. However as a system matures, an accumulation of biomass would result in diminishing ratios (Christensen 1995). The value for the EBS system was four times greater for the Bering Sea models (4.9-5.5) and Monterey Bay (1.2) (Trites *et al.*1999).

Relatively simple linear food chains are characteristic of developing or immature ecosystems whereas more complex networks or food-webs are characteristic of mature systems (Odum 1969). The connectance index indicates the degree of web-like links between predator and prey. However it is dependent on the specification of the model i.e. the level of complexity of the model structure which relies to some degree on taxonomic resolution of the groups, and although it is possible to compare the same system with the same level of taxonomic detail at different times it is not always useful to compare between systems. Nevertheless, the system omnivory index was devised as an alternative and measures how the feeding interactions are distributed within trophic levels. It is the average omnivory index of all consumers weighted by the log of their food intake (Christensen *et al.*2000). An individual's omnivory index is zero if the predator is much specialised and feeds on a single trophic level but increases if it feeds on many. However, there appears to be no direct correlation with system maturity (Christensen and Pauly 1993).The omnivory index for the current model, 0.24, similar to systems that are reported to have complex web structure (Trites *et al.*1999).

5.5.3 Mixed trophic impacts

The Leontif matrix visually represents the effects of increasing the biomass of a trophic group on other groups and the fisheries, and as such, is a form of sensitivity analysis (Fig 3). The positive impacts extend above the bar and the negative below, and all are relative. The largest negative impacts in order of importance were:

- demersal sharks on Chinaman leatherjacket,
- penguins on shallow large invertebrate feeders,
- slope medium predators on deepsea cod,
- shallow large predators on pelagic sharks and rays,
- toothed whales on toothed whales, and
- mesopelagic fish on mesopelagic fish.

The largest positive impacts in order of importance were:

- squid on the squid fishery,
- cardinal fishes on gemfish,
- megabenthos on the scallop fishery,
- shelf medium predators on the trap fishery,
- primary producers on pelagic prawns, small and large zooplankton,
- macrobenthos on deepsea cod,
- gelatinous nekton on warehous,
- large zooplankton on pelagic large invertebrate feeders,
- shallow large predators on Chinaman leatherjacket,
- tuna and billfishes on the tuna longline fishery,

- pelagic small invertebrate feeders on the non-trawl fishery,
- small zooplankton on pelagic small invertebrate feeders, and

large zooplankton on squid and the squid fishery.

Table 27. System statistics from the balanced EBS model.

Parameter	Value	Units
Sum of all consumption	3747.093	t km^{-2}year^{-1}
Sum of all exports	4886.891	t km^{-2}year^{-1}
Sum of all respiratory flows	2105.819	t km^{-2}year^{-1}
Sum of all flows into detritus	5066.195	t km^{-2}year^{-1}
Total system throughput	15806	t km^{-2}year^{-1}
Sum of all production	7879	t km^{-2}year^{-1}
Mean trophic level of the catch	3.95	
Gross efficiency (catch/net p.p.)	0.000136	
Calculated total net primary production	6992	t km^{-2}year^{-1}
Total primary production/total respiration	3.320	
Net system production	4886.181	t km^{-2}year^{-1}
Total primary production/total biomass	36.337	
Total biomass/total throughput	0.012174	
Total biomass (excluding detritus)	192.423	t km^{-2}
Total catches	0.950	t km^{-2}year^{-1}
Connectance Index	0.174	
System Omnivory Index	0.241	

Apart from on Chinaman leatherjacket, increasing demersal sharks would have the greatest impact on the slope or pelagic groups: four negative (blue-eye trevalla, slope medium predators, pelagic medium invertebrate feeders and predators) and three positive (slope ocean perch, deepsea cod and oreos). Seals negatively impacted shelf species: redbait, gemfish, small and medium predators. They also had a negative impact on the trap fishery as a result of increased predation on medium predators which were the main target species of the fishery. Toothed whales had a strong negative impact on higher-order groups such as themselves, seabirds and penguins and pelagic medium and large invertebrate feeders, but also a positive impact on shelf large invertebrate feeders. All groups have a negative effect on themselves but the higher trophic groups had relatively much larger effects. The fisheries also had negative impacts on themselves but the greatest impact were between the tuna longline and line fisheries where competition for similar species would be high.

The tuna and billfish groups had strong positive impacts on tuna longline and line fisheries as might be expected from a highly targetted fishery. Flathead and whiting had a similarly positive impact on the Danish Seine fishery. Conversely, the NSW trawl had the greatest negative impacts on blue grenadier, oreos, slope large and medium predators and pelagic large predators as a consequence of direct capture. Likewise the greatest negative effect from the line fishery is on tunas and billfishes, and from the tuna longline fishery on pelagic sharks, and tunas and billfishes. The trawl fishery negatively impacted seals and slope predators while species such as redbait, gemfish, shelf medium predators were slightly benefited. Note that these small impacts are not all discernible in Fig 3.

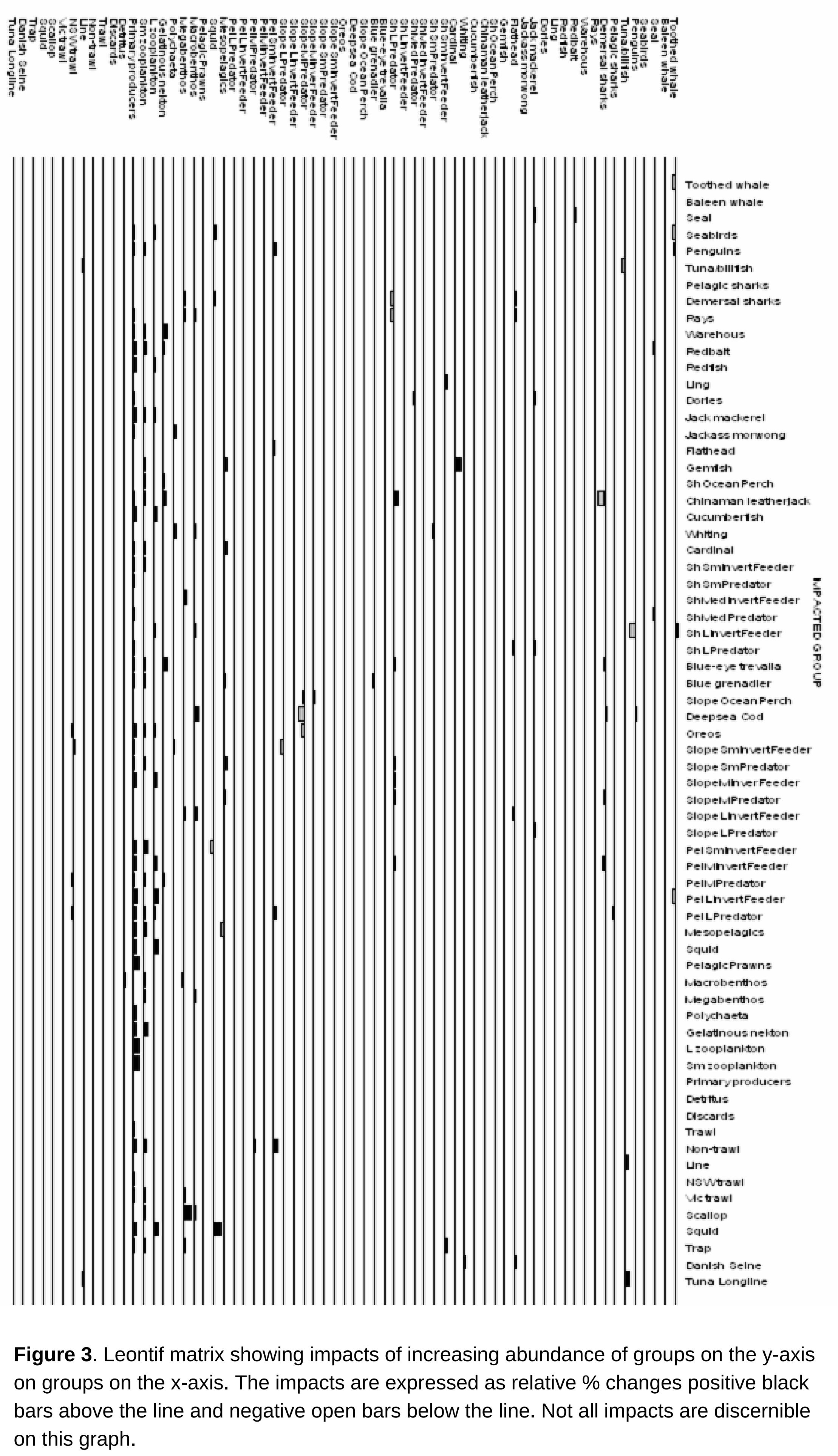


Figure 3. Leontif matrix showing impacts of increasing abundance of groups on the y-axis on groups on the x-axis. The impacts are expressed as relative % changes positive black bars above the line and negative open bars below the line. Not all impacts are discernible on this graph.

While most of the interactions are quite direct, this analysis also accounts for indirect effects that are less intuitive or obvious. For example, an increase in abundance of seals positively impacts ocean perch, deepsea cod and oreos. This occurs because the predation pressure on those species from slope medium predators is reduced as a result of a negative impact from the increased abundance of seals. Another example is the positive impact of toothed whales on shelf large invertebrate feeders, mentioned previously, which arises from the negative impact toothed whales have on penguins which eat them. However, it must be remembered that these interactions are complex and even though the impacts might indicate certain outcomes, it is the summation of all the impacts that we see in the simulation results (Chapter 6). Knowledge of these positive and negative impacts, as well as of actual diets and consumption, is essential to interpret the results.

5.5.4 Sensitivity analysis

The sensitivity of the model-estimated parameters to the impact of sequentially changing input parameters through a range of -50% to 50% was tested using the Ecopath sensitivity routine. This routine was used by Okey *et al.* (unpublished ms) to assess sensitivities of parameter estimates in the Prince William Sound model following Majkowski (1982 cited in Christensen *et al.* 2000). Of all the parameters tested, we present only the effects of changes in biomasses and consumption rates on the *EE*s and biomasses of the affected groups, which constitute about half of all the interactions tested. Percentage changes in *EE* or *B* of affected groups due to a 50% decrease or a 50% increase in *B* or *Q/B* of the impacting groups are averaged, and only changes greater than 10% are summarised here.

The imposed changes presented here are large, so the results are expected to cover the full range of potential system responses. Biomass and consumption changes in the higher trophic groups of toothed whales, penguins, demersal sharks, seals and larger predators including flathead resulted in the largest average changes in EE for other groups (Table 28). Of these, toothed whales, seals and demersal sharks affected the most groups. The changes in *EE* affected groups were mostly a direct result of increased or decreased predation pressure, and therefore demand, on prey species. This is also largely reflected in the changes to biomass although usually only one or two groups were affected. A notable exception was the shelf small invertebrate feeders which affected 4 other groups by an average of over 15%.

The relatively modest responses of the system to substantial changes in model parameters as summarised in Table 28 suggest the model results are not highly sensitive to parameter uncertainty. However, while this increases our confidence in the model, it does not provide any insight on the effect of model structure (i.e. the definition and population of the model groups and the presence or absence of interactions between them). While we are unable to quantify the sensitivity of the model to its underlying structure (without the huge effort needed to construct many balanced models) the structure adopted here is a technically feasible representation of the system consistent with observational data from the area and thermodynamic and ecological principles.

Table 28. Partial results of sensitivity analysis of model-estimated parameters of ecotrophic efficiency (*EE)* and biomass (*B*) to ± 50% variations in input parameters of biomass (*B*) and consumption rate (*Q/B*) of impacting trophic groups. The percentage change is averaged across all impacted groups (number = *n*) where the change is >10.

Input parameter	*B*			*Q/B*			*B*			*Q/B*		
	-50%	50%	n	-50%	50%	*n*	-50%	50%	n	-50%	50%	*n*
Output parameter impacted	*EE*						*B*					
Toothed whales	-35.7	35.9	5	-38.1	38.3	6	-16.6	16.7	1	-16.6	16.7	1
Seals	-15.7	15.7	8	-15.7	15.7	8	-27.2	27.2	1	-27.2	27.2	1
Penguins	-31.7	31.7	2	-31.7	31.7	2						
Pelagic sharks										-21.7	33.6	2
Demersal sharks	-20.5	20.5	8	-20.5	20.5	8						
Rays	-10.6	10.6	1	-10.6	10.6	1						
Warehous							-19.2	19.2	1	-19.2	19.2	1
Redbait										-11.6	11.6	1
Redfish	-11.2	11.2	1	-11.2	11.2	1	-16.1	16.1	1	-16.1	16.1	1
Ling	-10.1	10.1	1	-10.1	10.1	1						
Jack mackerel	-11.4	11.4	1	-11.4	11.4	1						
Flathead	-18.6	18.6	1	-18.6	18.6	1	-17.4	17.4	2	-17.4	17.4	2
Eastern school whiting							-15.1	15.1	1	-15.1	15.1	1
Cucumberfish	-10.2	10.2	1	-10.2	10.2	1						
Cardinal fish				-33.6	33.6	1						
Shelf small invertebrate feeders							-15.5	15.5	4	-15.5	15.5	4
Shelf small predators	-15.1	15.1	2	-15.1	15.1	2						
Shelf medium predators	-15.7	15.7	2	-15.7	15.7	2						
Shelf large predators	-21.7	21.7	5	-21.7	21.7	5						
Blue grenadier	20.6	-2.4	2	-18.1	18.1	2						
Slope ocean perch	-15.9	15.9	1	-15.9	15.9	1						
Slope medium predators	-27.1	27.1	4	-27.1	27.1	4						
Slope large predators	-26.5	26.5	1	-26.5	26.5	1						
Mesopelagic fishes	13.6	0.1	2	-21.7	21.7	2	-26.9	26.9	1	-26.9	26.9	1
Squid							-21.3	21.3	2	-21.3	21.3	2
Macrobenthos										-14.2	14.2	1
Megabenthos										-26.4	26.4	1

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6 TEMPORAL AND SPATIAL SIMULATIONS

6.1 Introduction

The Ecosim module of the EwE software that produces the dynamical simulations, is based on the static Ecopath model. It was developed by re-expressing the Ecopath mass-balance equations as coupled differential and difference equations to allow for dynamic simulations (Walters *et al.* 1997). Biomass flux rates are expressed as a function of time varying biomass and harvest rates (Christensen *et al.* 2000). Predator-prey interactions can be varied to emulate ‘top-down’ or ‘bottom-up’ control by altering the specific vulnerability settings of those interactions (Walters *et al.* 2000, Bundy 2001). Model predictions of biomass and catch can be fitted to time series data of abundance or biomass and catch by altering vulnerability and feeding time parameters thus verifying and tuning the model’s dynamic behaviour and making this program useful for exploring options for management policies. Groups can be split between juveniles and adults, each group having their own parameters but still linked, however we did not structure this model with split groups. For each time-step, equilibrium biomass is calculated for each group before updating the biomass estimates for the next time interval. Different time steps were used for fast groups (e.g. phytoplankton) and slow groups (e.g. fish and marine mammals) to increase computation speed as suggested by Walters *et al.* (1998). More details of Ecosim equations are provided in Appendix B.

The spatial extension of the software is Ecospace. It uses a defined rectangular grid of cells for which a system of differential equations and delay-difference equations are applied to split pools. The cells are assigned either land, or water and a habitat type. Preferred habitats are assigned to each functional group. Movement is allowed across the face of the cells but not across land or diagonally. While primary productivity, currents and migration patterns can be entered for each cell, it is not possible at this time to incorporate seasonal variation in system “forcing” i.e. physical mixing and plankton, and -migration behaviours, which were available in Ecosim. Restricted or closed fishing areas and seasonal closures can be assigned so that effects of MPAs can be investigated, one of the primary reasons for the development of Ecospace. Fisheries are assigned to habitats and MPAs or fishing areas. Fishing mortality for each cell can then be separated by gear type. More details of Ecospace equations are in Appendix B.

Walters *et al.* (1998) suggested that Ecosim and Ecospace are more useful as tools to synthesize information to design better management experiments and monitoring programs to evaluate policies rather than as tools for providing the quantitative predictions about the policies. Here we develop Ecosim scenarios for the EBS study area to explore possible effects of primary production variability, seal population increases, discard reductions in the fishery and changes in fishing effort. We also develop a preliminary Ecospace model based on the habitat structure in the model area to compare with corresponding Ecosim model scenarios.

6.2 Time series fitting

The parameters used in the dynamic model have been refined by comparing the model output to time series of actual observations over the period (1994-2003). The model parameters were adjusted to find the best fit between the model predictions and the fisheries data and observations. The observation series we used were annual CPUEs and total fishery catches while annual fishery effort values were used to derive fishing mortalities.

The CPUE series was derived for the majority of the fish groups from within our study area from the state and commonwealth fisheries and ISMP trawl data (see Chapter 7, Appendix E1). The trends in the CPUE data for the commercial quota species since 1994 were similar to those derived for the overall fishery over the same period (Caton and McLoughlin 2004). CPUE has been used here as an index of abundance of the species or groups, but there are many factors that might cause such an index to be biased including changes in fishing practices, gear, or changes in species distribution patterns. However, additional information on much of this bias is unavailable and we can only treat this data with caution.

The catch series data were collated for each trophic group, across all commercial fisheries for which we had data (Appendix E2). Unidentified fish were pro-rated across known fish species or groups. In this way, we accounted for all fish extracted from the system even if the resulting catch composition might not have been accurate because we assumed that the unidentified fish had the same species composition as the identified portion. While this was relatively small for most fisheries, in the case of the NSW data, the broadly unidentified group of ‘NSW ocean fish’ was often large; up to 67% of the 1997 annual catch and an overall average of 44% across all years from 1984-2003. Therefore, the species composition for the NSW fisheries could possibly have been more biased and less accurate than for other fisheries.

Effort in each fishery was calculated in appropriate units and this data series was the “driver” for the model (Table 1). Not all data could be used because of obvious misreporting, lack of reporting or the inability to combine some gear units appropriately. For example, for line fisheries, effort was sometimes reported as total hooks or as total line set in metres therefore some data had to be excluded. We did not consider this to be a significant problem because relatively few records were excluded. Of more concern, was the lack of effort data for NSW. The NSW catches were initially similar to the commonwealth trawl catches and relatively high compared to the Victorian trawl catches so effort was assumed to be an important driver for this fishery. Therefore, we derived a theoretical effort scenario based on the apparent decline of the annual NSW catches. This scenario was confounded by double reporting, which we were unable to resolve, during a period of jurisdictional change that came into effect from July 1997. Until then, fish caught in the Commonwealth-managed areas were very often also reported in the NSW logs (Rowling 2002) thus inflating the catches for NSW waters, and consequently our assumed effort. However, presuming that catch and effort were reduced proportionally once double-reporting ceased, a relatively steady catch was attained so we assumed effort was similarly steady. Therefore, from 1998 the effort for NSW was maintained at a rate about 20% of the original. A significant improvement to this model scenario would be a more accurate effort data series for NSW.

For each fishery type, annual efforts in the time series from 1994 to 2003 were scaled relative to the 1994 efforts, the first year of the model simulation. During a simulation, Ecosim then uses these relative effort values to scale the 1994 catches and discards in the corresponding years of the simulation. When the simulation projects beyond the period of the time series, the last value in the series is maintained for the remainder of the simulation.

The model was “tuned” by finding feeding and vulnerability parameters that reduced the least sums of squares difference between the model-predictions of biomass and catch, and the time series of CPUE and catch. Each time a simulation is run with the time series data loaded, Ecosim calculates a “goodness of fit measure as the weighted sum of squared deviations (SS) of log biomasses from log predicted biomasses, scaled in the case of relative abundance data by the maximum likelihood estimate of the relative abundance scaling factor *q* in the equation *y*=*qB* (*y*=relative abundance, *B*=absolute abundance)” (Christensen *et al.* 2000). Each time data series can be weighted according to how variable or reliable that data series is compared to the others used.

Table 1. Fishery effort data from 1985 through 2003. Data from 1994 on were used in model runs: all effort was scaled to the 1994 effort values used to initialise the model.

	Fishery (effort unit)									
Year	**Commonwealth trawl (hrs)**	**Net (non-trawl) (line set m)**	**NSW Trawl (days)**	**Vic Trawl (hrs)**	**Line (total hooks)**	**Scallop (hrs)**	**Squid (total hooks)**	**Trap (hrs)**	**Danish Seine (hrs)**	**Tuna (total hooks)**
1985	8867	7829388	168	6280	39301	2249		2249	11638	1200
1986	33915	6884234	174	1936	66706	1032		1032	12191	500
1987	27567	7658471	147	1053	84858	4321		4321	9750	44926
1988	33560	5536251		3133	124320	1854		1854	10758	48007
1989	29806	5357356		1622	188620	917		917	10577	65368
1990	28041	5812621		893	136040	3966		3966	12402	166226
1991	30377	6221816		1348	176025	3490		3490	10050	330603
1992	27937	5810151		2447	378484	7029		7029	10688	351326
1993	34096	6067351		2291	216052	21858		21858	9512	353818
1994	36741	5902810		2882	725454	807		807	10244	209779
1995	37575	6043206		2275	54820	0		0	8806	160580
1996	41579	6132832		2801	452397	1181		1181	8868	344254
1997	43552	7185825		1522	320297	910	44	954	10418	371270
1998	37867	5667595		521	221324	0	178	178	11461	399365
1999	39165	5927920			85352		3380	3380	8354	184956
2000	41454	5866630			91676		2558	2558	8226	241715
2001	38788	4473360			172438		9851	9851	7725	124570
2002	38566	4704320			159657		2868	2868	7522	116880
2003	43758	5181755			610436		5909	5909	6104	93310

6.2.1 Feeding parameters

Some parameters controlling feeding behaviour were modified following the arguments of Pitcher *at al.* 2002 in the Hong Kong marine system model (Appendix F1). The ‘maximum relative feeding time’ determines the level of predation risk a lower trophic level is willing to take to feed. For example, juveniles may be found hiding along food-deprived shorelines where both their prey and predators are more common offshore (Christensen et al. 2000). The model default is that the feeding time may at most double (i.e. a value of 2).

Another parameter that was modified was ‘feeding time adjustment’ factor, which determines how fast organisms adjust feeding times so as to stabilize consumption rate per biomass. A value of 0.0 maintains a constant feeding time (and exposure to predation risk), so that all changes in consumption per biomass will result in growth rate changes. A value of 1.0 reduces vulnerability to predation rather than increases growth rate when food density increases (Christensen *et al.* 2000). Model values were set to 0 for marine mammals and organisms that were sessile or moved very little, such as primary producers, infauna, macrobenthos, zooplankton and gelatinous nekton. All others groups were set to the default value of 0.5.

6.2.2 Vulnerabilities

Vulnerability settings in the model influence predator-prey interactions. Specifically, values less than 2 favour ‘bottom-up’ control, a value of 2 is ‘mixed’ control while values greater 2 favour ‘top-down’ control. The vulnerability setting procedure followed that recommended by (Christensen *et al.* 2000) and was as follows:

1. All groups were initially set to a level proportional to their trophic level as calculated by Ecopath.
2. The dynamical model was then run for an extended period beyond the initial 10 years of reference data with an iterative search for vulnerabilities that allowed the model to remain dynamically stable.
3. Fishing was then set to zero and vulnerabilities were again adjusted manually to ensure that no groups went extinct (Appendix F2).

The resulting vulnerabilities for many of the groups were relatively low, consistent with Bax and Williams (2000) assertion that the EBS is a bottom-up system. Heavily exploited stocks were usually given a very low vulnerability, indicating that in their depleted state relatively fewer predator-prey interactions occur.

6.3 Primary productivity forcing functions

Several time series of primary productivity were derived to force the model, most of which utilised the Befa or Hoyo estimates of primary productivity described in Chapter 3:

1. Primary productivity assumed to remain constant for 10 years at the value used in the balanced model (i.e. no seasonal or interannual anomaly).
2. The average seasonal pattern repeated for 10 years with no interannual anomaly based on (a) Befa and (b) Hoyo.
3. The average seasonal pattern, again based on (a) Befa and (b) Hoyo, superimposed on interannual anomalies estimated by Ecosim for each of the 10 years (interannual anomalies shown Fig 5).
4. As in 2 for the first 5 years, followed by the available 5 years of historical monthly averaged estimates from (a) Befa and (b) Hoyo (Chapter 3, Fig 9).
5. Both seasonal and interannual anomalies estimated by the Ecosim for 10 years so as to produce the best goodness of fit to the other time series.

The performance of the various forcing patterns, as measured by the sum-of-squares fit to historical data, was fairly similar in all cases (Table 2). Even when the model was allowed compute its own primary productivity for optimal fit (pattern 5), the sum-of-squares only fell by around 1%. The choice of forcing pattern for subsequent model runs was therefore based not on these statistics, but rather on judgement of how representative the pattern was of the real primary production rates in the EBS region. The Hoyo historical series (4b) was finally adopted because it made maximum use of the available satellite estimates and was most consistent with the limited available in situ data (see Chapter 3).

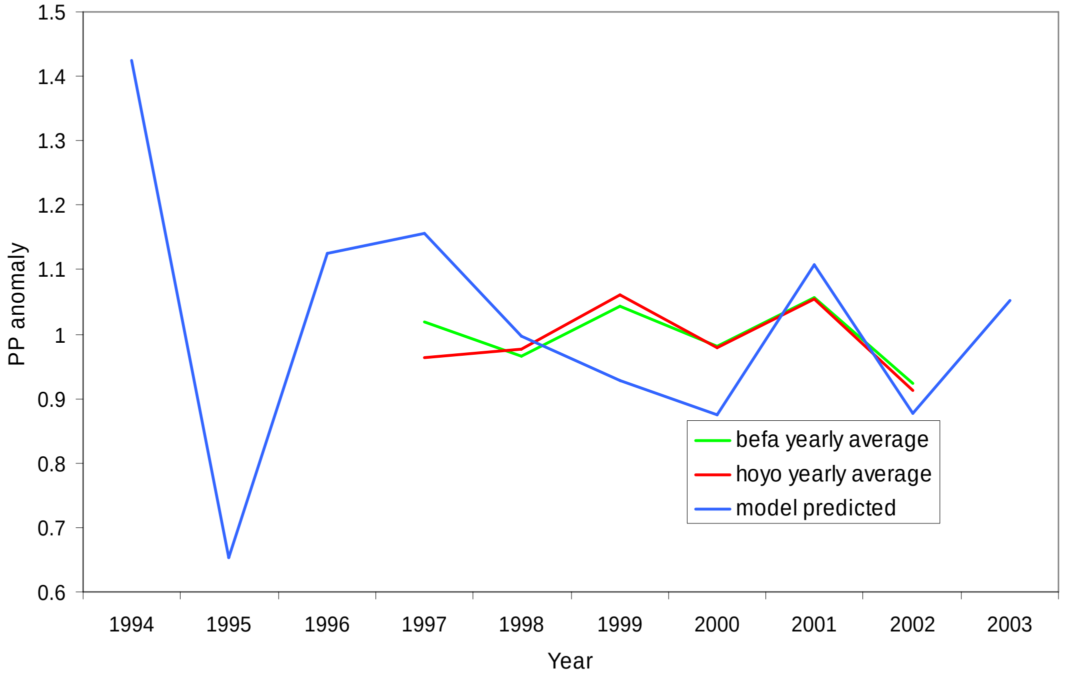


Figure 1. The annually averaged Befa and Hoyo primary productivity estimates used to force the temporal simulations compared with the primary productivity anomaly pattern predicted by the model to best fit the reference data. While the Befa and Hoyo methods produced disparate mean values (Table 1, Chapter 3), interannual anomalies were generally very similar.

Table 2. Results of fitting primary productivity forcing functions to reference data in model. More detailed definitions of the forcing functions are given in the text.

Pattern #	Primary productivity forcing functions	Sum of squares
1	constant	506.1186
2a	repeated seasonal - Befa	506.5485
2b	repeated seasonal - Hoyo	507.4218
3a	seasonal with interannual anomaly - Befa	523.9617
3b	seasonal with interannual anomaly - Hoyo	505.2073
4a	historical (1997-2002) - Befa	510.2202
4b	historical (1997-2002) - Hoyo	511.0832
5	model prediction	494.3104

6.4 Ecosim scenarios

Nine scenarios were devised to investigate potential consequences of:

1. Reduced levels of primary productivity in the future (scenarios 2 and 3 below).
2. Expected continuation of the growth in seal populations (scenarios 4 and 5 below).
3. Elimination of discarding from the fishery (scenario 6 below).
4. Changed rates of fishing in the region (scenarios 8 and 9 below).

Various combinations of these conditions were investigated over a 50 year period: the first 10 years of the simulation from 1994 to 2003 used all observed data time series and the remaining 40 years assumed the rates of the last year of real observations (i.e. 2003). The scenarios are described briefly below.

Scenario 1: Status quo

The scenario that we considered to best represent the current conditions in the model domain assumed that the rate of change in the Australian fur seal abundances is doubling every 10 years (Goldsworthy *et al.* 2003). We used an annual biomass accumulation rate of 0.105 for seals that would produce that rate of increase for the first 10 years of the model run. Primary productivity was based on the historical Hoyo series for the first 10 years (pattern 4 in section 6.3) followed 40 years of a repeating seasonal pattern with a constant annual mean (identical to pattern 2) (Fig 2). This scenario assumed no change to current discarding practices and fishing effort.

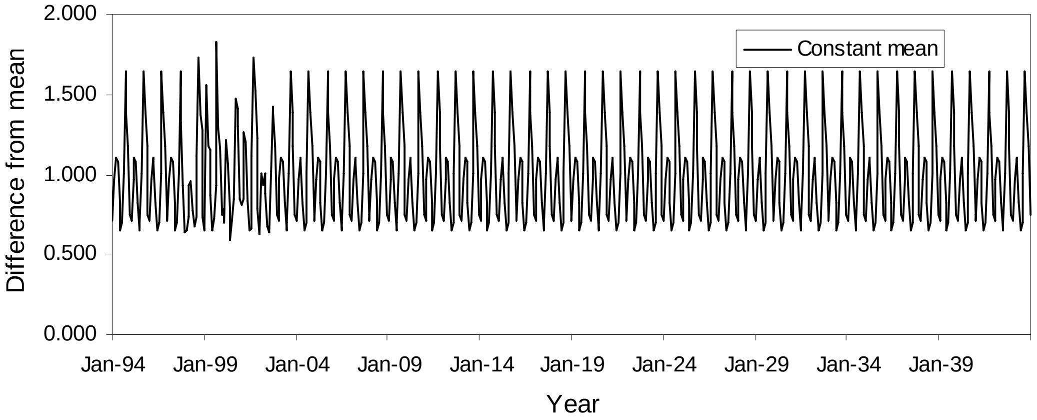


Figure 2. 50 year primary productivity data series with constant mean primary productivity over last 40 years.

Scenario 2: Productivity reduced to 80%

Current climate predictions suggest a strengthening of the EAC, which may carry more warm low nutrient water into the EBS region and reduce primary productivity levels. For this scenario, we gradually reduced the mean productivity over the final 40 years to 80% of the current levels (Fig 3). All other conditions of the status quo scenario (1) were maintained.

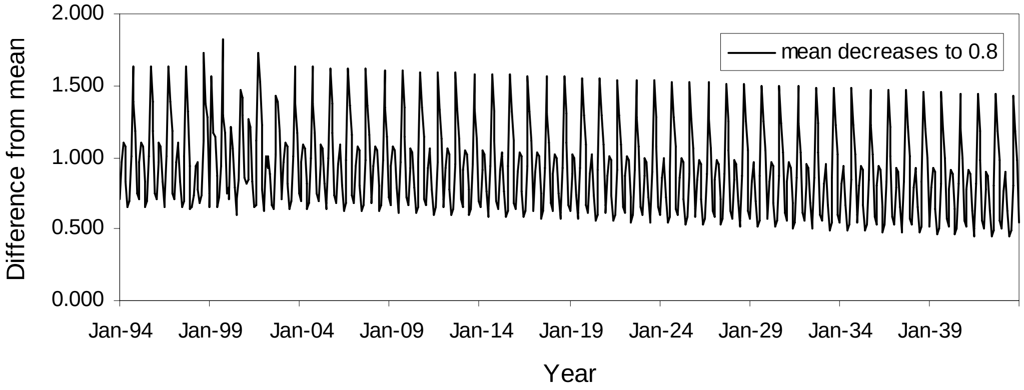


Figure 3. 50 year primary productivity data series with mean primary productivity over last 40 years declining to 80% of initial value.

Scenario 3: Productivity reduced to 60%

As for scenario 1, all conditions of the status quo scenario were maintained but with the mean primary productivity declining to 60% of current levels (Fig 4).

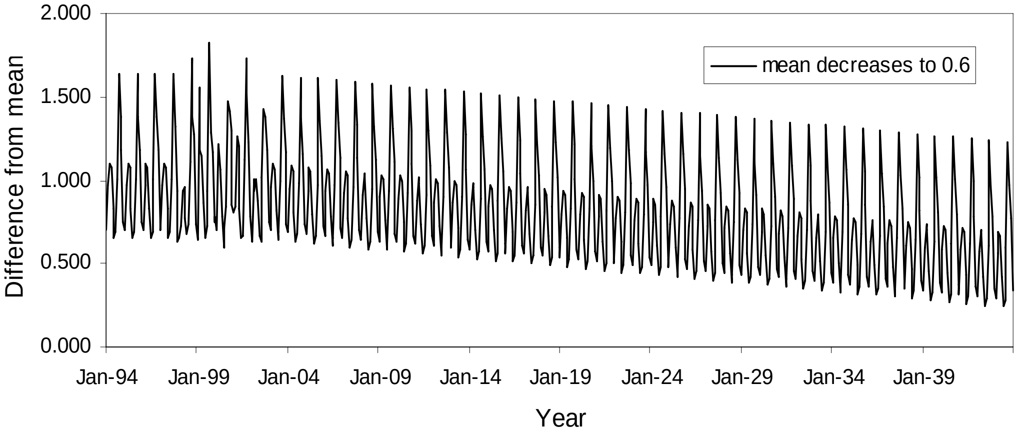


Figure 4. 50 year primary productivity data series with mean primary productivity over last 40 years declining to 60% of initial value.

Scenario 4: Seal biomass accumulation halved

As for scenario 1 but the seal biomass accumulation rate was halved to 0.053 so that the population was forced to increase at only half of its estimated present rate.

Scenario 5: No seal biomass accumulation

This scenario was as for scenario 1 but with no seal biomass accumulation.

Scenario 6: No discarding

In the non-discarding scenario, all previously discarded fish were retained. We modelled this scenario from 1994 where all the estimated discards were added to the landings for all fisheries for all years. The 2003 landings rates were used to simulate the next 40 years of the simulation. The discard portions of the diets of all relevant predators were removed and compensated by proportional increases in all non-discard components of their diets. To balance this system, it was also necessary to marginally reducing the proportion gemfish and flathead in the diets of seals and flathead.

Scenario 7: No discarding and no seal biomass accumulation

This scenario was as for scenario 6 but with no biomass accumulation term for seals.

Scenario 8: Fishing effort increased 25%

The last two scenarios investigated changes in total fishing effort. These scenarios do not represent any current management proposals, but were included in our scope of investigation to evaluate potential responses of the system to such measures

The first of the two fishing scenarios assumed all conditions of scenario 1 but with a 25 % increase in effort above the 2003 level across all fisheries over the last 40 years of the 50 year simulation.

Scenario 9: Fishing effort decreased 25%

This scenario was as for scenario 1 but with a 25% decrease in fishing effort across all fisheries.

6.5 Scenario results

Predictions based on complex trophic interactions can often be unexpected and therefore need careful interpretation. The model predictions are very dependant on the underlying assumptions of diet composition, and on the parameter settings. The following comparisons of results of the scenarios (Table 3 and following figures) aim to illustrate some of the more important interactions but in no way adequately characterizes all of them. The results report the difference between the starting conditions in 1994 and the end conditions 50 years later.

6.5.1 Status quo scenario

This scenario simulated the effects of a continuing increase in seal populations with no changes to other conditions. The effects were variable: more seals caused some declines particularly for prey species but also some increases for higher predators such as sharks. Overall, total fishery catches declined although two sectors appeared to benefit slightly. This scenario was complicated by actual changes in effort in the fisheries during the early stages of the simulation; nevertheless, the decline in catches from 2003 to those predicted suggested that the 2003 fishing rates were unsustainable.

Seal biomass increased by nearly 270% during the 50 year simulation (Fig 5). This had the greatest negative effect on prey species such as warehous, and shelf small and medium predators, all of which declined by more than 40% (Table 3, section 5.3.3). Jack mackerel declined by more than 10% at least partly as a result of direct predation of seals. However, jack mackerel were impacted by an increase of demersal sharks almost as much as by the simulated increase of seals. Predation by seals also contributed to the decline of gemfish, dories and ling, although other predators contributed to their overall decline, e.g. flathead had a relatively large negative impact on ling.

Pelagic shark biomass doubled, due to the increase of biomass of seals, demersal sharks and most pelagic fish groups, all of which are important prey, and despite the decrease in other important prey such as rays and jack mackerel. Increased predation from pelagic sharks probably contributed to the decline of penguins and seabirds in the model. However, toothed whales had the greatest negative impact on the bird groups (section 5.3.3), and while their increase was minimal they probably contributed largely to the declines in seabirds and penguins. The pelagic sharks had the greatest negative impact on the tuna and billfish and pelagic large predators (see section 5.3.3) but neither of these groups actually declined (no change and 50% increase respectively) because the total effects of all impacts were positive.

Demersal sharks increased due largely to the positive impact of an increase of biomass of flathead, shelf ocean perch and pelagic medium-sized groups. An increase in demersal sharks impacted Chinaman leatherjacket negatively which declined and blue-eye trevalla, slope medium predators, pelagic medium invertebrate feeders and predators, all of which declined.

Rays changed very little over the 50 year simulation (Table 3) but is more difficult to interpret. While pelagic sharks are a major predator, their increased biomass actually has a positive impact whereas increased biomass of demersal sharks (also a predator) and seals had negative impacts. However, biomasses of the prey of rays increased and might offset negative impacts.

Large positive changes in biomass were found for blue-eye trevalla which increased more than 50%. This increase accompanied increases in seals and shelf large predators both of which have net positive impacts on blue-eye and neither of which are predators. Larger positive effects resulted from increased biomasses of blue-eye prey e.g. gelatinous nekton, perhaps accounting for the overall increase in blue-eye. We were unable to estimate gelatinous nekton biomass directly and allowed the model to estimate it. Therefore while this result may be misleading, it does not diminish the importance of gelatinous nekton as prey component in the diet of this species. Seal increase has positive impacts on blue-eye trevalla and blue grenadier biomass, the latter also having a positive impact on blue-eye.

The increase of blue grenadier largely arises from an increase in biomass of one of its prey, slope large predators Indirect effects such as increased availability of mesopelagic fishes released from predation pressure by a decline in its other predators, might be benefiting blue grenadier, one of the highest consumers of mesopelagic fishes. The predators which might contribute to this release of predation pressure were cardinal fish, jack mackerel, and squid, all of which declined in biomass whereas there were no similarly high consumers that increased.

Slope species such as slope ocean perch, deep-sea cod and oreos all increased in biomass from 11-26% (Table 3). Increasing demersal shark biomass has a strong positive impact on all three, particularly deepsea cod (see section 5.3.3) probably because demersal sharks feed on slope medium predators, a common predator of the three groups, thus releasing predation pressure. Slope large predators and pelagic medium and large predators also increased more than 50%, partly due to increases in biomass of some of their respective prey despite decreases in many others. Similarly to blue grenadier, they might also be taking advantage of a release in predation pressure on some of their prey such as mesopelagic fish, particularly in the case of pelagic medium predators, whose diet is about one third mesopelagic fish, and to a lesser degree, slope large predators.

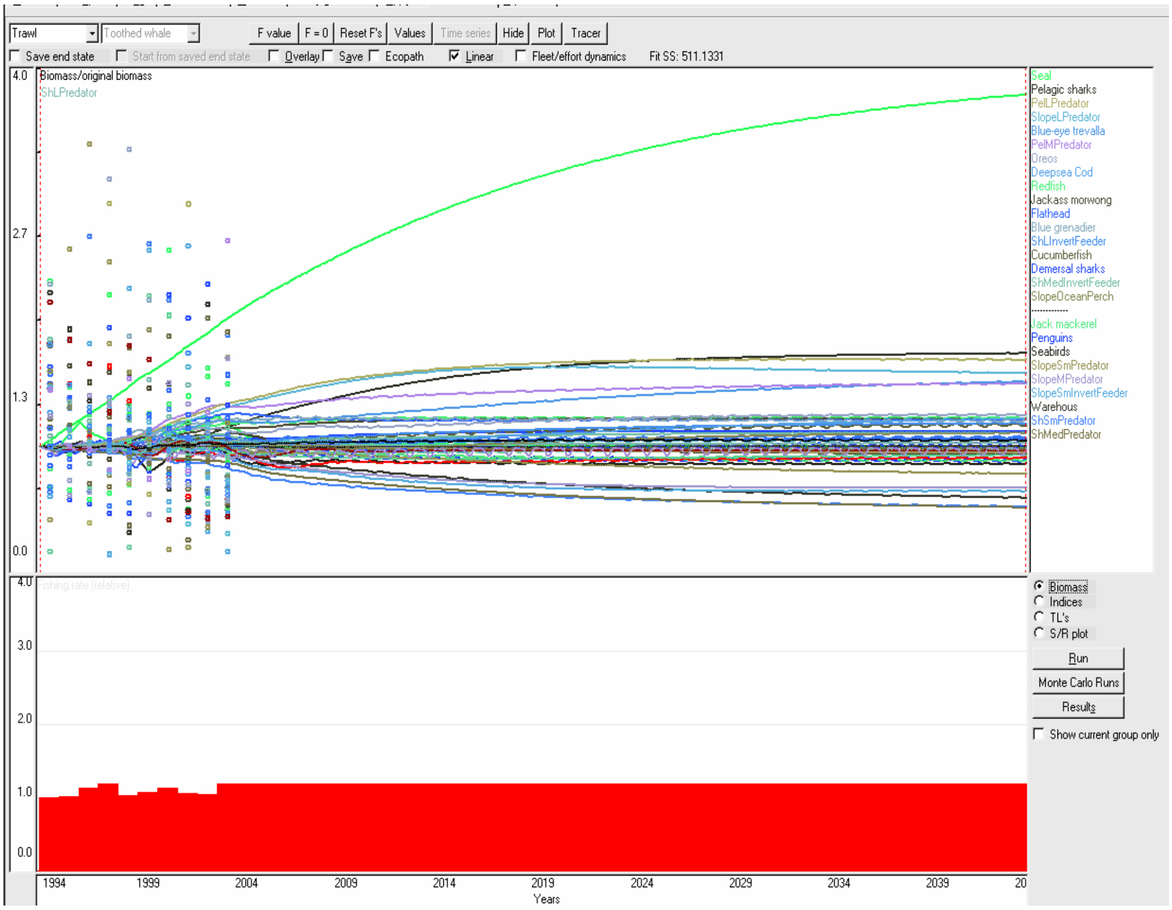
All the pelagic groups except for the small invertebrate feeders, increased in biomass. The Leontif trophic impacts predicted from an increasing shelf large predator group were positive, particularly for the pelagic medium invertebrate feeders (section 5.3.3). However, bigger positive impacts were expected from increased zooplankton and gelatinous nekton groups, major prey groups.

Typically, the small fish and lower invertebrate groups that are heavily predated declined. The exceptions were cucumberfish, school whiting, and gelatinous nekton, zooplankton and phytoplankton (primary producers). Cucumberfish populations increase probably due to the release from predation pressure from the declining biomass of shelf small predators which are eaten by seals. Similarly, school whiting biomasses increase even though they are also eaten by seals unlike cucumberfish. The zooplankton groups follow closely the dynamics of the imposed primary productivity forcing function and vulnerability settings for these groups were set for bottom-up control. Therefore, these lower trophic groups increased coincident with primary production. As there was no biomass data for these groups, it is not possible to determine whether these results are justifiable. This is an area of model definition and development that would benefit by better and quantitative data.

Overall, the fishery catches were predicted to decline over the period 1994 to 2043. Much of this decline was due to decreasing effort in the fisheries from 1994 to 2003. In contrast to the general trend, the commonwealth trawl catches were predicted to increase (Table 3). The reason for this is complex. The decreasing efforts in the other fisheries meant that the 2003 effort, used in the forward projections were lower than in 1994 and so the fishing pressure on of many of the target species decreased thus allowing their biomasses to increase. This outcome combined with an F rate for the Commonwealth trawl which was 20% higher in 2003 than in 1994 resulted in higher catches for that fishery. Catches in all the other fisheries declined particularly in the case of NSW trawl fishery, which we assumed had declined to just 10% of its initial value (Table 1). Scallop and squid effort data were too variable to present. The 2003 trap effort data is very low compared to previous years and the results should be viewed with caution. The release from fishing pressure, particularly from the NSW fishery, probably accounts for not only the apparent recovery of the target fish biomass, but the subsequent decline of the prey fish biomasses. So while this result appears to be beneficial to the commonwealth trawl fishery, the total catch, summed across all fisheries, actually declined by 39% from the initial 1994 catch (Table 3). But because effort declined it was not clear whether current fishing rates were supportable into the future.

To disentangle changes in effort during the first 10 years of the simulation, we compared the catches from 2003 to 2043 during which time effort remained constant at the 2003 rates (Table 4). It must be stressed that the 2003 parameters used for the forward projections were not intended as a true reflection of possible or real behaviour of the fishing fleet in the future. Catchabilities were also assumed to remain constant. The release from fishing pressure in the previous 10 years, particularly from the NSW fishery largely accounted for the apparent recovery of some of the target fish biomass, and the decline of some of the prey fish biomasses. Nevertheless, during the time period 2003-2043, the catches still declined by 5% (Table 4). Most of the specific changes were relatively minor. Interestingly, the trend of the commonwealth fishery catches was reversed and declined by 7% from the 2003 levels, tuna longline declined by 12% and line fisheries declined by 9%. Danish Seine and the non-trawl net catches increased by 1-2%. Because effort was constant over the final 40 years of the simulation, these changes must reflect the biomass changes for target species. The biomasses of main target species of the trawl fisheries were nearly all lower than the 2003 level, the lowest being warehous and gemfish at only 63% and 85% respectively of their 2003 biomasses levels. Other target species were only less than 5% lower e.g. dories, flathead, gemfish, and jack mackerel. On the other hand, whiting biomasses increased by 10% coincident with increased Danish Seine predicted catches. Redfish and jackass morwong biomasses increased a few percent while the slope species biomasses such as blue-eye trevalla, blue grenadier, oreos and cod increased more than 10-20% over the final 40 years of the simulation.

In conclusion, the 2003 fishing rates were not beneficial to the fisheries or the fish stocks, and therefore should be considered unsustainable.



Trawl | Toothed whale

☐ Save end state ☐ Start from saved end state ☐ Overlay ☐ Save ☐ Ecopath ☑ Linear ☐ Fleet/effort dynamics

Fit SS: 511.1331

Figure 5. Ecosim output of relative change in biomass from 1994 to 2043 for the higher trophic levels assuming *status quo* conditions (scenario 1). The lower trophic groups were not shown because noise from the oscillations which closely followed the primary productivity patterns masks the other results. The RHS legend indicates the trophic groups represented by the trajectories. The top-most green line is the seal trajectory. The dots represent the reference catch and CPUE time series data used in the first 10 years to tune the model. Fishing effort for the trawl fishery is shown in lower screen in red. Beyond 2002 fishery effort is maintained at the 2002 level.

Table 3. Summary of relative changes in biomass of trophic model groups from 1994 to 2043 for all scenarios. Scenario 1 is the status quo scenario against which the other scenarios are compared. Red boxes are declines >10%, blue boxes are increases >10% and grey boxes are between -10 and 10% changes.

	Scenario								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	Status quo	**80% mean PP**	**60% mean PP**	**0.5 seal BA**	**no seal BA**	**no discard-ing**	**no discard-ing, 0 seal BA**	**decrease F 25%**	**increase F 25%**
Toothed whales	0.01	-0.03	-0.07	0.00	0.00	0.01	0.00	0.01	0.01
Baleen whales	0.00	-0.02	-0.03	0.00	0.00	0.00	0.00	-0.01	0.00
Seals	2.69	1.89	1.21	0.84	0.08	2.81	0.14	3.13	2.55
Seabirds	-0.13	-0.55	-0.89	-0.13	-0.13	-0.03	-0.03	-0.12	0.01
Penguins	-0.10	-0.29	-0.46	-0.10	0.00	-0.10	0.00	-0.13	-0.05
Tunas & billfish	0.00	-0.29	-0.55	0.04	0.11	-0.02	0.09	0.09	-0.14
Pelagic sharks	0.74	0.08	-0.39	0.64	0.59	0.77	0.62	1.10	0.43
Demersal sharks	0.12	-0.47	-0.82	0.15	0.20	0.19	0.26	0.23	0.11
Rays	0.00	-0.61	-0.91	0.01	0.01	0.01	0.02	0.00	0.00
Warehous	-0.41	-0.69	-0.88	-0.13	0.05	-0.46	0.03	-0.35	-0.51
Redbait	0.02	-0.29	-0.57	-0.03	-0.05	0.03	-0.05	-0.01	0.07
Redfish	0.23	-0.15	-0.44	0.24	0.25	0.20	0.24	0.34	0.06
Ling	-0.06	-0.20	-0.33	0.03	0.06	-0.04	0.06	-0.05	-0.09
Dories	-0.03	-0.21	-0.37	-0.02	-0.01	-0.04	-0.02	-0.04	-0.02
Jack mackerel	-0.11	-0.41	-0.65	-0.05	0.01	-0.13	0.00	-0.11	-0.12
Jackass morwong	0.22	-0.16	-0.43	0.27	0.30	0.22	0.30	0.34	0.07
Flathead	0.21	-0.09	-0.37	0.27	0.37	0.22	0.37	0.40	-0.04
Gemfish	-0.09	-0.06	-0.04	-0.17	-0.23	-0.06	-0.21	-0.19	0.07
Shelf ocean perch	0.06	-0.21	-0.47	0.04	0.00	0.06	0.00	0.06	0.06
Chinaman leatherjacket	-0.08	-0.50	-0.83	-0.17	-0.23	-0.06	-0.23	-0.16	0.07
Cucumberfish	0.17	-0.22	-0.54	0.05	-0.03	0.20	-0.02	0.16	0.22
Eastern school whiting	0.08	-0.22	-0.47	0.05	0.03	0.08	0.03	0.09	0.07
Cardinal fish	-0.02	-0.12	-0.21	-0.07	-0.11	0.00	-0.10	-0.07	0.06
Shelf small invertebrate feeders	0.00	-0.30	-0.57	-0.01	-0.02	-0.01	-0.02	-0.02	0.01
Shelf small predators	-0.48	-0.66	-0.80	-0.20	-0.04	-0.52	-0.05	-0.54	-0.42
Shelf medium invertebrate feeders	0.12	-0.35	-0.73	0.05	0.01	0.12	0.00	0.11	0.12
Shelf medium predators	-0.48	-0.67	-0.82	-0.18	0.02	-0.54	0.00	-0.51	-0.49
Shelf large invertebrate feeders	0.18	-0.38	-0.72	0.18	0.17	0.18	0.17	0.22	0.13
Shelf large predators	0.03	-0.17	-0.34	-0.01	-0.02	0.03	-0.02	0.03	0.05
Blue-eye trevalla	0.52	0.02	-0.42	0.22	0.01	0.54	0.01	0.52	0.50
Blue grenadier	0.20	0.12	0.02	0.22	0.23	0.19	0.22	0.29	0.10
Slope ocean perch	0.11	-0.17	-0.43	0.02	-0.04	0.15	-0.06	0.17	0.07
Deepsea cod	0.23	-0.50	-0.86	0.18	0.15	0.25	0.17	0.30	0.18
Oreos	0.26	0.11	-0.01	0.24	0.23	0.27	0.25	0.65	0.09
Slope small invertebrate feeders	-0.35	-0.50	-0.63	-0.35	-0.36	-0.35	-0.35	-0.46	-0.18
Slope small predators	-0.22	-0.31	-0.43	-0.18	-0.16	-0.26	-0.20	-0.28	-0.19
Slope medium invertebrate feeders	-0.05	-0.19	-0.34	-0.04	-0.03	-0.06	-0.04	-0.07	-0.03
Slope medium predators	-0.33	-0.46	-0.59	-0.29	-0.25	-0.35	-0.28	-0.42	-0.22
Slope large invertebrate feeders	-0.03	-0.31	-0.58	-0.05	-0.08	-0.03	-0.08	-0.07	0.04
Slope large predators	0.58	0.03	-0.41	0.68	0.77	0.53	0.74	0.87	0.15

	Scenario								
	1	2	3	4	5	6	7	8	9
	Status quo	**80% mean PP**	**60% mean PP**	**0.5 seal BA**	**no seal BA**	**no discarding**	**no discarding, 0 seal BA**	**decrease F 25%**	**increase F 25%**
Pelagic small invertebrate feeders	-0.04	-0.27	-0.44	-0.06	-0.08	-0.02	-0.06	-0.04	0.02
Pelagic medium invertebrate feeders	0.05	-0.17	-0.37	0.04	0.03	0.05	0.04	0.06	0.04
Pelagic medium predators	0.50	0.18	-0.11	0.37	0.28	0.51	0.28	0.57	0.39
Pelagic large invertebrate feeders	0.05	-0.31	-0.58	0.06	0.07	0.05	0.07	0.07	0.03
Pelagic large predators	0.69	0.07	-0.42	0.63	0.53	0.70	0.53	0.81	0.61
Mesopelagic fish	-0.03	-0.30	-0.46	-0.02	-0.02	-0.03	-0.02	-0.02	-0.04
Squid	-0.01	-0.35	-0.63	-0.01	-0.02	-0.02	-0.03	-0.02	-0.01
Pelagic prawns	-0.01	-0.26	-0.51	-0.01	-0.01	-0.01	-0.01	-0.02	0.03
Macrobenthos	0.01	-0.23	-0.44	0.01	0.00	0.02	0.01	0.02	0.04
Megabenthos	-0.01	-0.44	-0.76	-0.01	0.00	-0.01	-0.01	-0.02	0.00
Polychaeta	-0.02	-0.24	-0.39	0.01	0.03	-0.02	0.03	-0.01	0.02
Gelatinous nekton	0.25	-0.14	-0.51	0.03	-0.11	0.29	-0.09	0.18	0.45
Large zooplankton	0.05	-0.20	-0.40	0.06	0.07	0.06	0.07	0.07	0.17
Small zooplankton	0.18	-0.10	-0.31	0.18	0.18	0.18	0.18	0.18	0.46
Primary producers	0.18	-0.01	-0.18	0.18	0.18	0.17	0.17	0.18	0.29
Detritus	0.14	-0.09	-0.26	0.14	0.14	0.14	0.14	0.14	0.32
Discards	-0.58	-0.67	-0.73	-0.55	-0.51			-0.37	0.13
Total	-0.951	0.87	-0.33	0.05	0.05	0.05	0.05	0.05	0.13
Fishery									
Trawl	0.19	-0.16	-0.45	0.27	0.33	0.18	0.32	-0.18	0.43
Non-trawl	-0.09	-0.34	-0.53	-0.10	-0.10	-0.08	-0.09	-0.33	0.05
Line	-0.18	-0.42	-0.64	-0.13	-0.07	-0.20	-0.09	-0.38	-0.04
NSW trawl	-0.89	-0.92	-0.95	-0.89	-0.88	-0.89	-0.88	-0.92	-0.87
Vic trawl	-0.76	-0.83	-0.89	-0.74	-0.73	-0.76	-0.73	-0.82	-0.70
Trap	-0.80	-0.88	-0.93	-0.80	-0.80	-1.00	-1.00	-0.86	-0.77
Danish Seine	-0.34	-0.57	-0.74	-0.34	-0.33	-0.34	-0.33	-0.49	-0.20
Tuna Longline	-0.54	-0.68	-0.80	-0.52	-0.51	-0.55	-0.51	-0.64	-0.45
Total	-0.39	-0.57	-0.71	-0.36	-0.33	-0.39	-0.34	-0.57	-0.27

Table 4. Relative differences in fishery catches from the beginning of the forward projection in 2003 to the end in 2043. Catches are in tkm^{-2}.

Fishery	Catch 2003	Catch 2043	Relative difference
Trawl	0.3982	0.3719	-0.07
Non-trawl	0.0903	0.0915	0.013
Line	0.0183	0.0160	-0.12
NSW trawl	0.0462	0.0446	-0.03
Vic trawl	0.0038	0.0036	-0.08
Trap	0.0001	0.0001	-0.03
Danish Seine	0.0513	0.0522	0.018
Tuna Longline	0.0034	0.0031	-0.10
Total	0.6122	0.5835	-0.05

6.5.2 Primary productivity scenario results

The results of showed that decreasing productivity would cause ubiquitous declines in the system (Table 3; Fig 6) except for gemfish whose decline is lessened slightly probably due to an easing of predation pressure because its predators are declining. Under all scenarios, seals increased as expected because of the biomass accumulation term however the increase decreased with decreasing mean productivity. They were the only species to increase at all in scenario 3 when mean productivity was reduced to only 60%. Pelagic sharks also increase, coincident with seal population (prey) increases except under productivity scenario 3.

Although not reported here in detail, a simulation removing the biomass accumulation term for seals indicated that their populations would decline by 36 to 68% under either productivity scenario, similarly to other groups. Also gemfish would experience a bigger decline but the reversed pattern remained i.e. reduction in decline with decreased productivity mean compared to all other groups which experienced increased declines with decreased productivity mean.

Many of the vulnerabilities of the predator-prey interactions were set to low values i.e. below 2, thus creating a bottom-up control. Therefore, the effect of reducing mean productivity emanates strongly through to higher trophic levels and causes quite serious detrimental effects on nearly all groups in the model with some groups nearing collapse. In reality, these effects could be offset by a net migration into the system of primary and secondary production i.e. phytoplankton, zooplankton and other groups likely to be advected. However our results of potential advection of primary production into the model domain (Chapter 3) suggest that this is minimal and therefore unlikely to be able to support the system, even in its presently depleted state.

6.5.3 Seal abundance scenario results

Overall, seals facilitate some species and hinder others. They have a direct influence on prey species as expected but also many indirect effects became evident by varying the rates of increase.

The reduction or complete removal of seal biomass accumulation (scenarios 4 and 5) resulted in very large reductions in the seal biomass from a 269% increase down to 84% and 8% respectively (Table 3, Fig 7). Other species also increased in biomass some of which can be explained, at least in part, by a reduction in predation pressure from seals, e.g. the increase in warehous, jack mackerel, and shelf small and medium predators. However, a further consequence of the increase of those groups is greater competition with seals for a common prey thus contributing to a decline in that prey. For example, the decline in cardinal fish, increased from 2% to 9% as seal biomass was reduced (Table 3). Another notable prey species which continued to decline even when the seal biomass accumulation term was removed completely was gemfish. While the predation on gemfish from seals was not entirely removed, the decline of gemfish was expected to have been arrested with the reduction in seal biomass. However, the principal prey item of gemfish was also cardinal fish which declined, as mentioned previously, as a result of increased predation by seal competitors.

Similar to cardinal fish, redbait continued to decline even though the pressure of predation from seals was lessened. This was because seals also ate all but two of the other redbait predators therefore predation pressure from seals on them was also reduced. Consequently, biomasses of those species, i.e., dories and shelf medium predators, increased as did their predation pressure on redbait. Predation pressure on redbait also increased when the decline of the demersal sharks was reduced because the lower biomasses of seals reduced competition for redbait.

Figure 6. Relative changes in biomass of species and groups from 1994 to 2043 with underlying primary productivity forcing functions of Hoyo-derived primary productivity estimates. The scenarios are: *status quo* means productivity, mean productivity declining to 0.8 or declining to 0.6.

Figure 7. The relative changes in species abundances predicted from 1994 to 2043 for the three seal population increase scenarios. The actual fishery effort rates were used for the first 10 years of the simulation and then the 2003 rates were maintained for the forward projections.

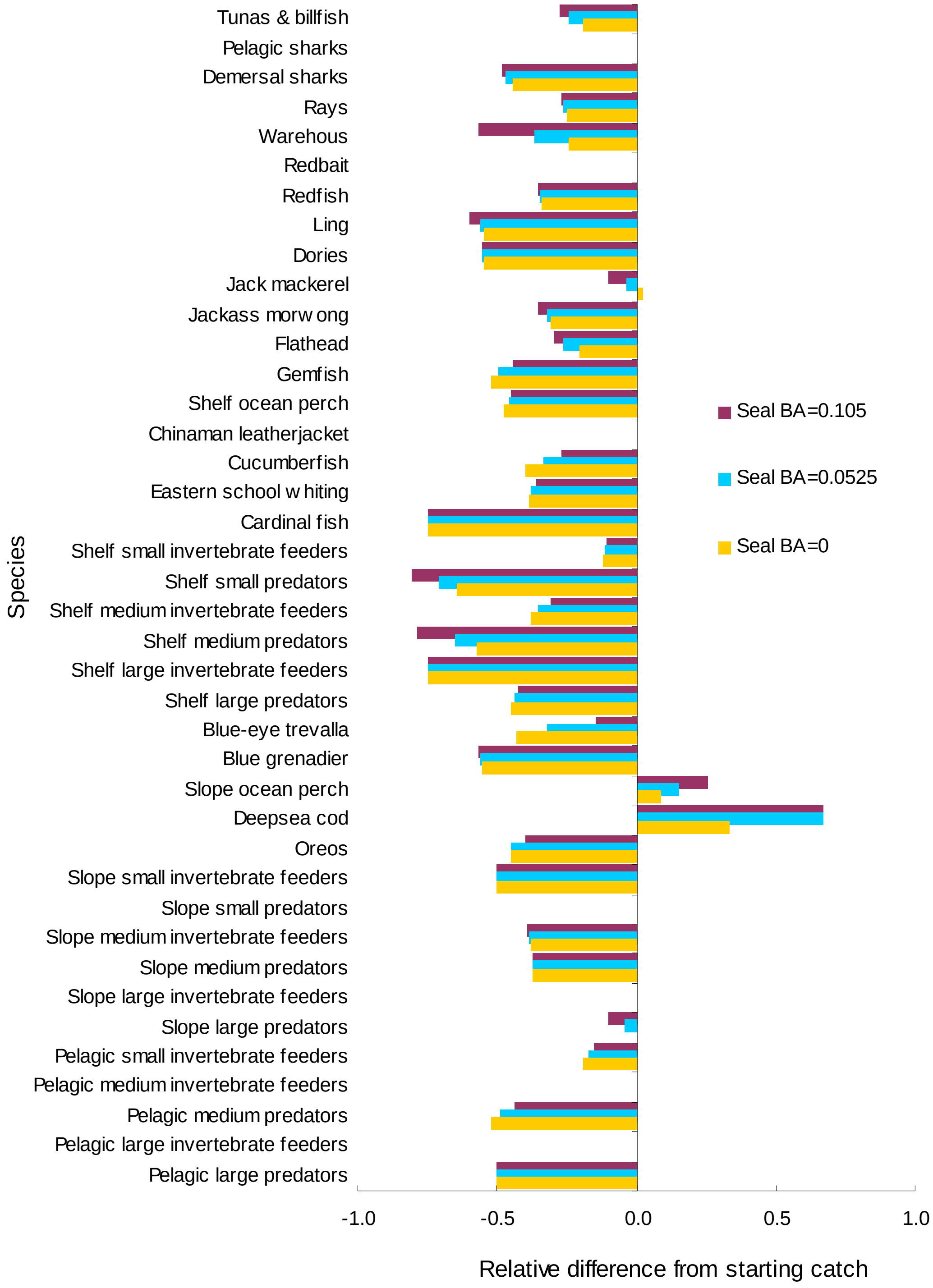


Figure 8. Relative changes in catch per species or group from 1994 to 2043 for the three scenarios of seal increase: no biomass increases, population doubling in 20 years and population doubling in 10 years.

Overall, the total fishery catches still decreased even when seal populations were not increasing (Tables 3 & 4), but to a lesser extent. Relatively small differences in most fishery catches were found between the three seal increase scenarios (Fig 9) and overall, there was a 3 to 6% improvement. As before, the commonwealth trawl catch was the only fishery catch to increase by nearly double if seals did not (Table 3; Fig 9), because of the higher effort used in the forward projections combined with increased slope ocean perch and deepsea cod biomasses and, consequently, higher catches (Fig 8). Jack mackerel catches also increased slightly if seal biomass accumulation was removed.

However, the improved commonwealth trawl catches were not solely attributable to the decreased consumption of fish by the seals. At the end of the 50 year simulation, the consumption of fish by seals was 50% less if they were not increasing (1.67 *cf* 2.43 t $km^{-2}yr^{-1}$) whereas the fishery catch was more than 70% higher (0.19 *cf* 0.33 t $km^{-2}yr^{-1}$) but the overall catch was only 6% better (-0.39 *cf.* -0.33) (Table 3). Considering that the total consumption of fish in the system was 68 t $km^{-2}yr^{-1}$, and consumption of fish by seals was relatively minor at only 2.5%, Changes in consumption from other predators of the target species are likely to account for this increase. Since fishing mortalities and catchabilities remained constant in forward projections, the catches were a reflection of biomass changes of the target species. For example, the biomasses of target species, e.g. ling, redfish, jack mackerel, flathead, morwong, dories, and warehous (Fig 8) increased because decreases in biomasses of all predators, not just seals, resulted in an overall reduction in predation pressure on the targets. On the other hand, catches of gemfish, shelf ocean perch and school whiting declined further if seals declined although the changes were small.

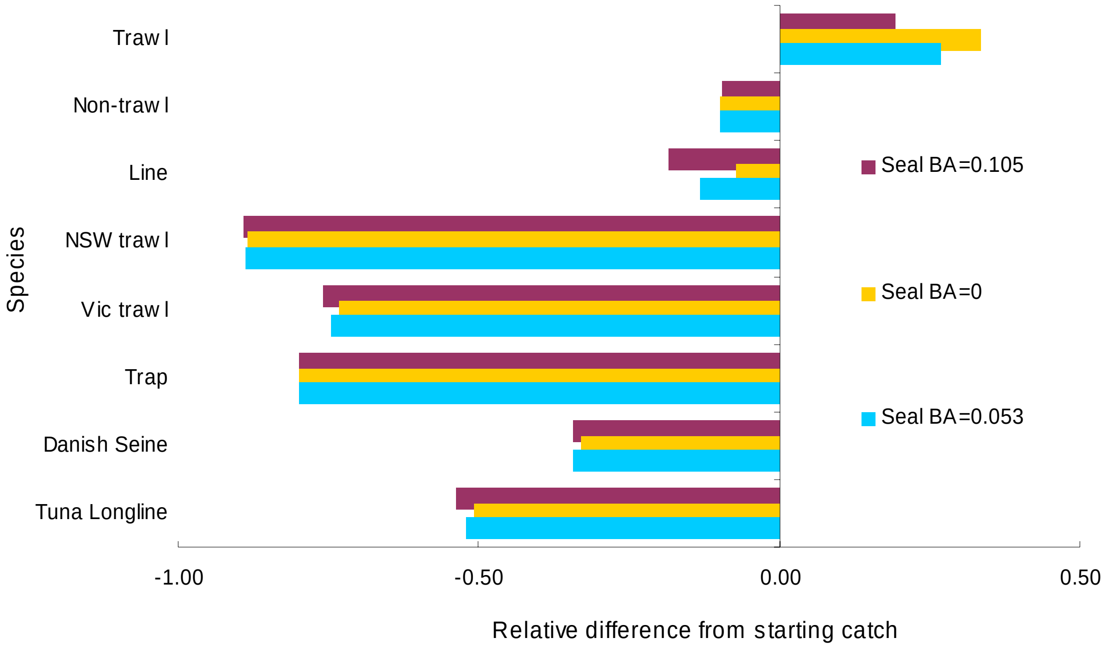


Figure 9. The relative changes in fishery output predicted from 1994 to 2043 for the three seal population increase scenarios. The actual fishery effort rates were used for the first 10 years of the simulation and then the 2003 rates were maintained for the forward projections.

6.5.4 Discard scenario results

Eliminating discarding (scenario 6) had the largest benefit for seals which increased by 12% in biomass (Table 3; Fig 10) in both scenarios of biomass accumulation. It also benefited 18 other groups most changes were only 1 or 2 %. Fewer groups were negatively affected. Similarly minor differences were found if the seal biomass accumulation was removed (compare scenarios 5 and 7). In fact the largest variations between these four scenarios were due to the biomass accumulation of seals discussed previously. While it seems counter-intuitive that by eliminating a source of prey, a predator would increase, the redistribution of diet for the four species in which discards occurred may account for the increase. Seal diet was redistributed over groups including redfish, jackass morwong and flathead all of which increased. Similarly for seabirds that fed on shelf medium invertebrate feeders, pelagic sharks that fed on seals and redbait, and demersal sharks that fed on many groups all of which increased. The larger biomasses of these top predators therefore increased predation pressure on their prey accounting for some of the groups that declined further. For other groups, the differences were so small, that the variations in biomasses of or caused by these four groups could easily account for them.

The changes in the total fishery catches with elimination of discarding were due mostly to the inclusion of all previously discarded species (Fig 11). The largest difference was the greater decrease in the trap fishery catches. Slight disadvantages were seen in the line and tuna longline fisheries if discarding was eliminated. Overall, the difference in total fishery catches after 50 years between the discarding or non-discarding scenario was 0.03 to 0.05 $tkm^{-2}yr^{-1}$ for the doubling or non-doubling seal population increase scenarios respectively in favour of non-discarding.

Again the commonwealth trawl fishery catches increased (Fig 11). As in the scenarios of seal abundance, slope ocean perch and deep-sea cod catches increased in all discarding scenarios (Fig 12). Similarly, jack mackerel catches increased very slightly in the non-doubling seal biomass scenarios regardless of discarding or not. The cause of the increase in catches is the same as in the preceding scenarios.

Overall, we were unable to determine any significant change to the system by eliminating discarding, using the present model structure. There are several reasons why these results might be misleading. Firstly, a proportional rescaling of prey across prey groups to account for the removal of discards from the diets of the relevant predators might be unrealistic. If the proportion of discards was high and if the predator had particular prey preferences which were not reflected in the remaining portion of its diet, we could assume an incorrect diet composition. However since the highest proportion of discards was 10 % in seabirds, we did not think that this was a major concern.

Another factor which might have also masked the effects of non-discarding, is the decline in the hypothetical NSW fishery effort. All scenarios (Table 3) showed a marked decline in discards up to about 60% due to the effort in the fishery declining. The rates of discarding for the state fisheries were both based on the rates for the Commonwealth trawl sector so if the real rates and compositions of the discard portions are considerably different, the results might also be different.

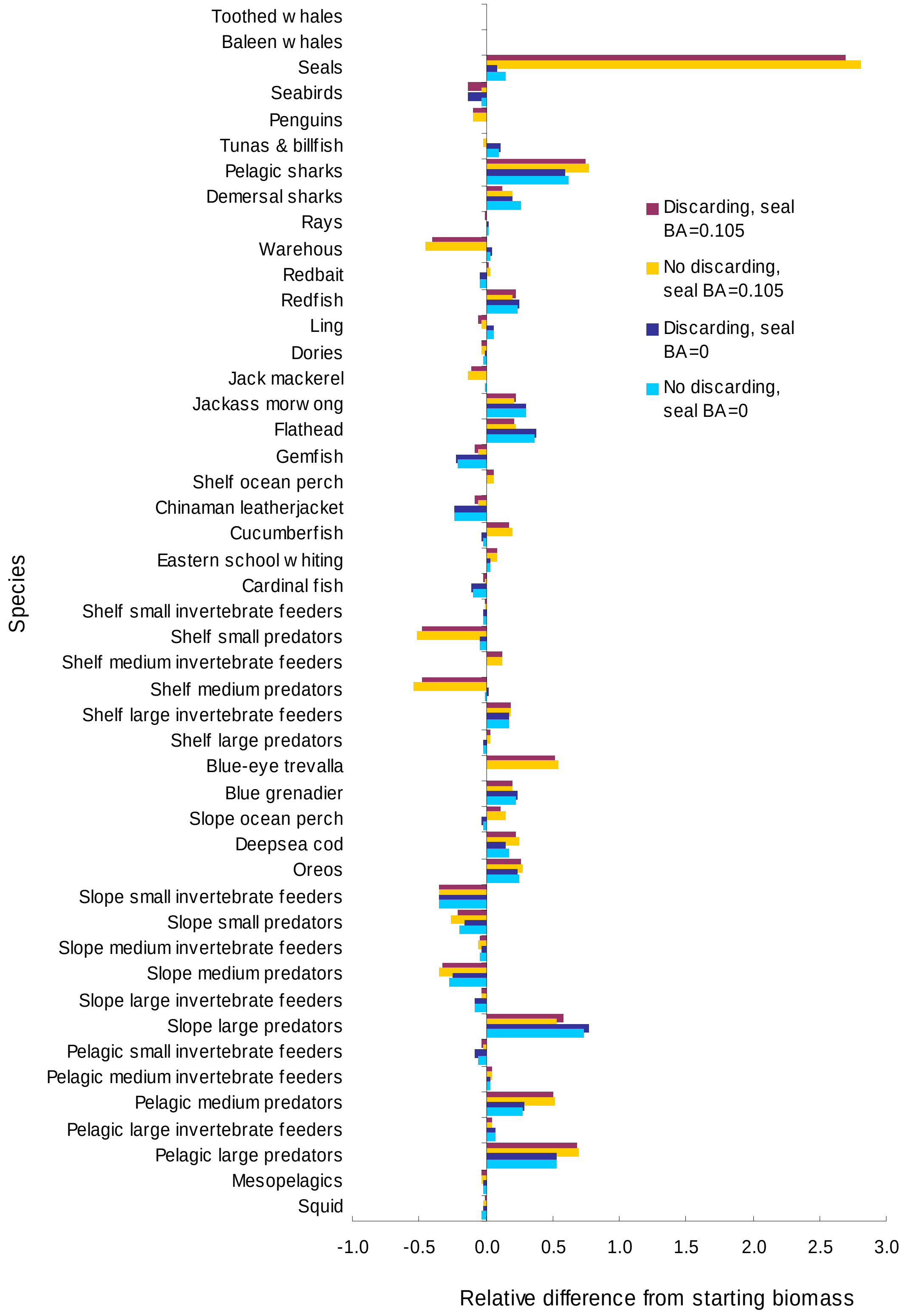


Figure 10. Relative changes in species biomasses from 1994 to 2043 with discarding or with no discarding, and seal biomasses doubling or not doubling.

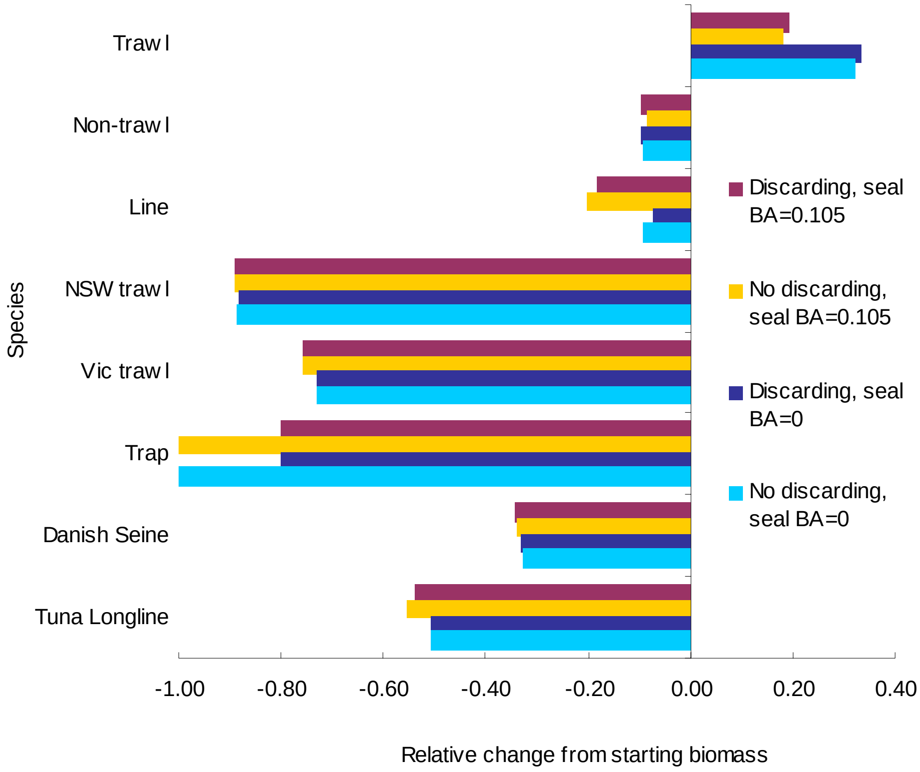


Figure 11. Relative changes in fishery catches from 1994 to 2043 with or without discarding, and with or without seal biomass accumulation.

Figure 12. Relative differences in catches from 1994 to 2043 under the discarding and seal biomass accumulation scenarios.

Figure 13. Relative changes in biomass from 1994 to 2043 for scenarios where fishing is reduced from the 2003 rate by 25% across all fisheries, and increased by 25%, compared to no change in 2003 fishing rate.

6.5.5 Fishing effort scenario results

Decreasing or increasing fishing pressure generally produced expected results: decreased effort benefited the target species and their predators because catches were lower while increased fishing effort had the opposite effect, in most cases. Comparison of present day catches (2003) to the predicted future catches reflected an overall decline in biomasses of the target species.

A reduction in fishing effort (scenario 8) resulted in increases in biomass of seals, pelagic sharks, and the commercial fisheries species particularly tunas and billfishes, redfish, jackass morwong, flathead, oreos, blue grenadier, deepsea cod, slope ocean perch, and other groups such as slope large predators, pelagic medium and large predators (Fig 13).The decline of warehous was lessened. In contrast, penguins, gemfish, Chinaman leatherjacket, shelf small and medium predators, slope small and medium invertebrate feeders and predators and large invertebrate feeders and pelagic small invertebrate feeders all declined probably due to increased predation from seals and sharks largely but also from increased competition from increased biomass of the recovering target species.

On the other hand, all these trends were reversed when fishing effort was increased by 25%.Target species declined but prey species such as shelf small and medium predators and all the slope small and medium groups either increased or their decline was lessened as predation pressure from those target species was released by increased fishing on them. Lower trophic groups increased with increased fishing pressure due to a release in predation pressure by the removal of predators. Generally, the changes were relatively small.

The increased fishing effort scenario (scenario 9) had the best outcome for all fisheries’ catches except the Commonwealth trawl fishery (Fig 14), where the status quo scenario had a better outcome. Danish seine and non-trawl fisheries catches actually increased slightly while the declines in catches were lessened for other fisheries. The general reduction in fishery output in most scenarios is obviously related to a decline in target species biomass (Fig 15). In the increased fishing effort scenario, catches of pelagic sharks, slope ocean perch and deep-sea cod increased most, and slightly for several other species (Fig 15).

However, as in the *status quo* scenario results (section 6.5.1), by using 2003 as the starting point we obtained more informative indication of the system response to present fishing practices (Table 5). While all fishery catches declined, the decline was less pronounced because the largest reductions in effort in most fisheries actually occurred prior to 2003. Similarly, the increases in catches were less pronounced. The 25 % increase in effort resulted in less than that magnitude in catch. The commonwealth trawl catch increased only by 11% with increased effort, compared to a 7 % decline over the same period in the *status quo* scenario, reflecting the decline in target species biomass as previously discussed (section 6.5.1). Similarly, other fisheries increased their catch from as little as 1% in the Victorian trawl fishery (*c.f.* 8% decline in Table 4), nearly 17% in the NSW trawl and non-trawl net fisheries (*c.f.* 3% decline and 1% increase respectively) and nearly 24% in the Danish Seine (*c.f.* 2% increase). Squid and scallop are not presented here because of their highly variable effort data, and trap effort data is also dubious due to the 2003 effort data.

Therefore, while effort was increased by 25 % across all fisheries the overall increase in fishery catch from the present day catch was only 13% higher compared to 5% lower if effort remained constant (Table 4). Presumably, this increase arises from a recovery of target species from the release of fishing pressure imposed by the higher fishing rates that operated in some of the fisheries in 1994.

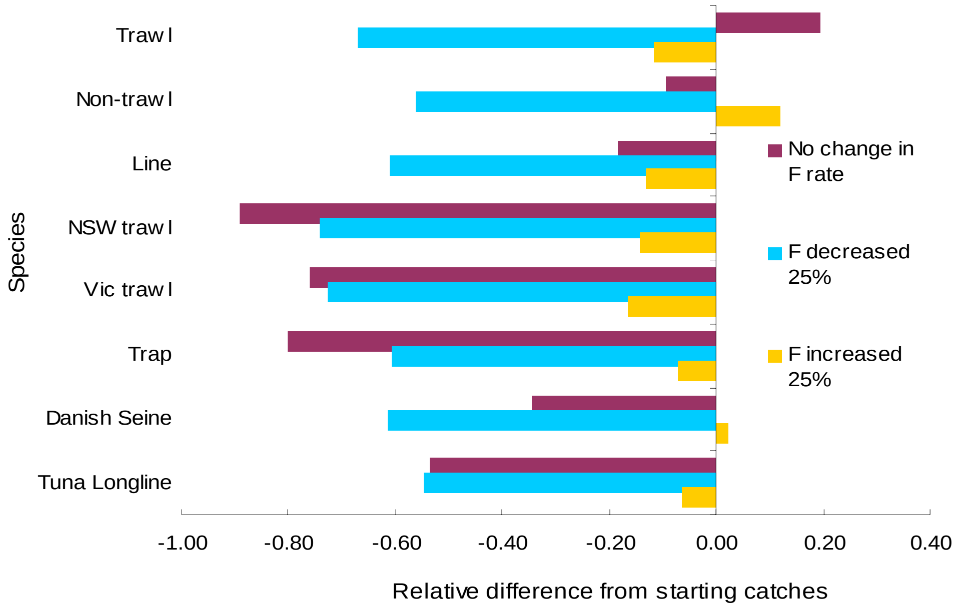


Figure 14. Relative changes in fishery catches from 1994 to 2043 where fishing is reduced from the 2003 rate by 25% across all fisheries, and increased by 25%, compared to no change in 2003 fishing rate.

Table 5. Relative changes of fishery catches over the period from 2003 to 2043 when the 2003 effort is decreased or increased by 25% across all fisheries.

		Decrease effort 25%		Increase effort 25%	
Fishery	**Catch 2003**	**Catch 2043**	**Relative difference**	**Catch 2043**	**Relative difference**
Trawl	0.3982	0.2546	-0.3620	0.4423	0.1107
Non-trawl	0.0903	0.0663	-0.2556	0.1046	0.1656
Line	0.0183	0.0122	-0.3333	0.0190	0.0357
NSW trawl	0.0462	0.0323	-0.3016	0.0538	0.1650
Vic trawl	0.0038	0.0026	-0.3312	0.0039	0.0104
Trap	0.0001	0.0001	-0.2736	0.0001	0.1776
Danish Seine	0.0513	0.0404	-0.2070	0.0635	0.2382
Tuna Longline	0.0034	0.0025	-0.2751	0.0037	0.0976
Total	0.6122	0.4113	-0.3273	0.6915	0.1307

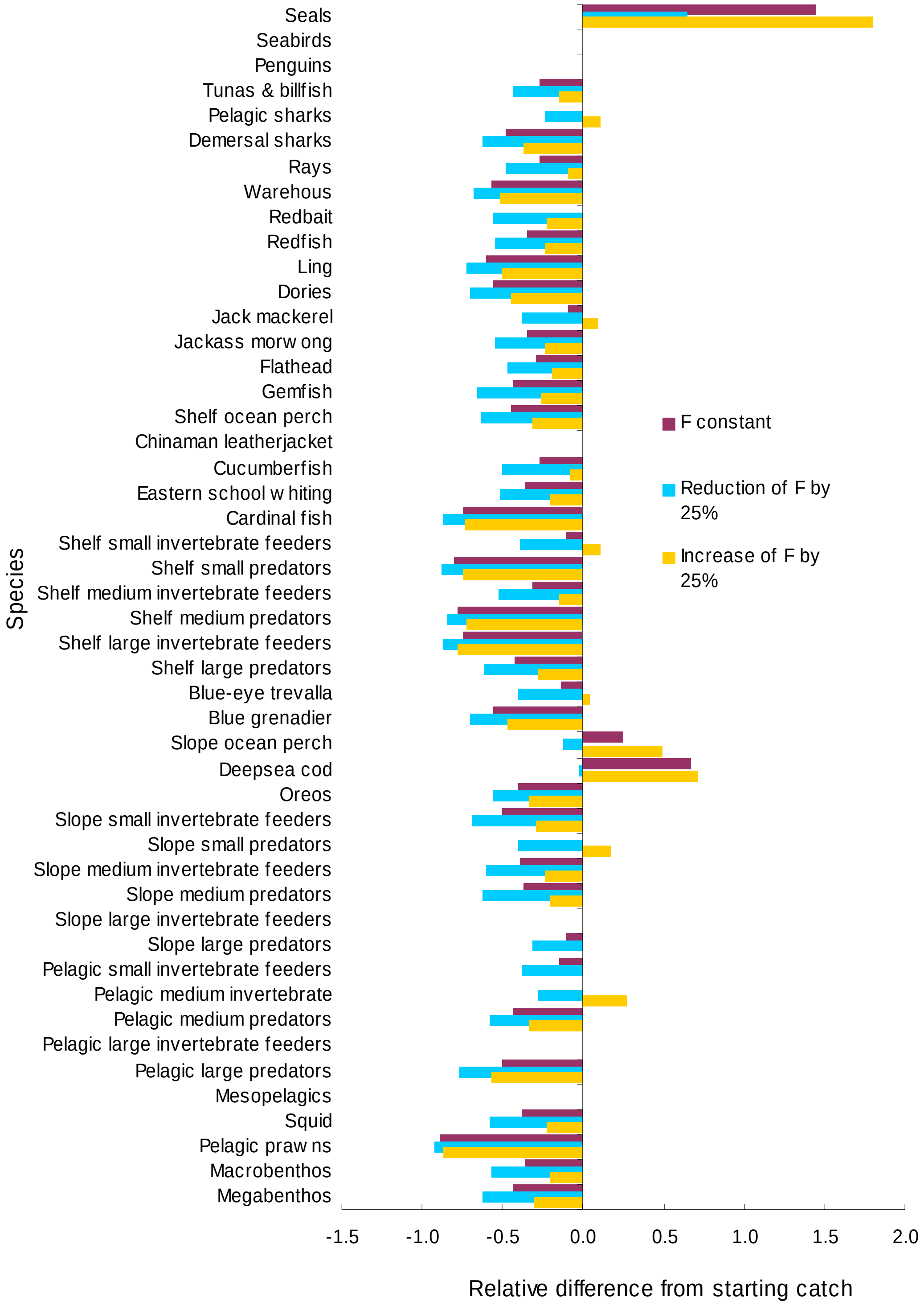
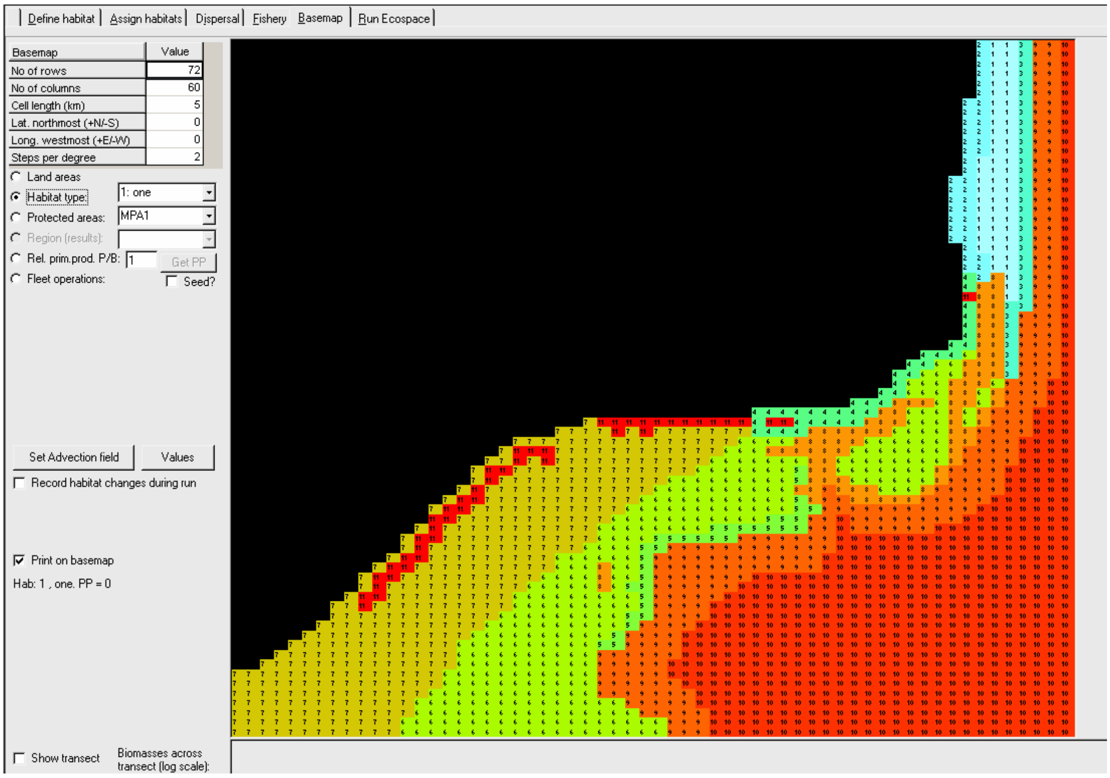


Figure 15. Relative changes in catch per species from 1994 to 2043 for scenarios where fishing is reduced from the 2003 rate by 25% across all fisheries, and increased by 25%, compared to no change in 2003 fishing rate.

6.6 Spatial model

We developed a preliminary spatial scenario in Ecospace based on the habitats determined by Williams and Bax (2001) for the EBS shelf area (Fig 16). A slope habitat from the shelf-break to 700 m was added and the open water border was bounded by an offshore habitat. From the results of the abundances and occurrences of fishes caught in the CSIRO surveys, we were able to assign habitat preferences as presence or absence to each of the species and groups. Where we had no specific data, we used data from other surveys or from the literature. Fishing effort was assigned to specific habitats based on presence or absence. A base map of spatial primary productivity anomalies was also calculated and input into the model. The forcing functions used in Ecosim were no longer operable on the Ecospace primary productivity base map therefore the results are not directly comparable to the temporal model.



Basemap	Value
No of rows	72
No of columns	60
Cell length (km)	5
Lat. northmost (+N/-S)	0
Long. westmost (+E/-W)	0
Steps per degree	2

○ Land areas
● Habitat type: 1: one
○ Protected areas: MPA1
○ Region (results):
○ Rel. prim.prod. P/B: 1
○ Fleet operations: ☐ Seed?

☐ Record habitat changes during run

☑ Print on basemap

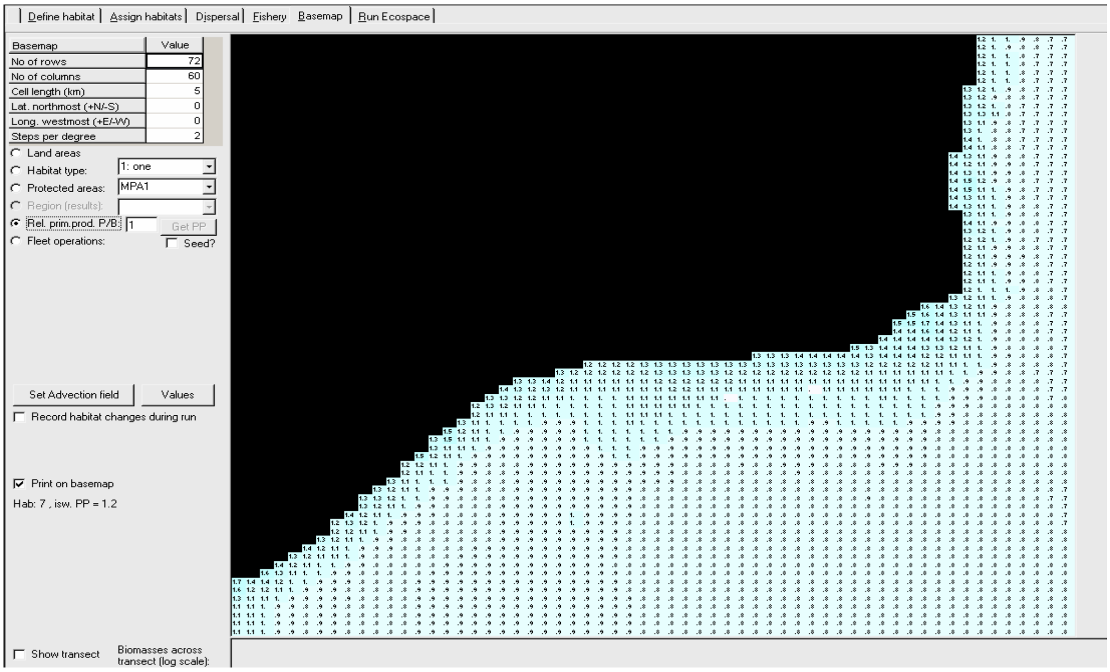
Hab: 1 , one. PP = 0

☐ Show transect Biomasses across transect (log scale):

Figure 16. Habitat base map defined for the Ecospace model simulation based on the habitats determined by Williams and Bax (2001). Habitat types are depicted as different colours with corresponding numbers superimposed. These numbers are also superimposed on other base maps. Species and fisheries are assigned a preference for habitats.

The spatial models were run with some of the underlying temporal scenarios, as before in section 8.3, which ran for 50 years using the actual fishery effort data for the first 10 years and then maintained the 1993 effort for the last 40 years of the projection. The Ecospace output window at the beginning of the simulation (Fig 18) represents the spatial density of all the groups in the model in their preferred habitat. The scale on the right of the window is a relative scale and most groups begin with median value (green). As the simulation progresses colours change to reflect their relative density.

We compared the scenarios of discarding and seal increases to determine whether spatially–resolved distributions differed from the previous Ecosim predictions and whether they gave a better representation.



Basemap	Value
No of rows	72
No of columns	60
Cell length (km)	5
Lat. northmost (+N/-S)	0
Long. westmost (+E/-W)	0
Steps per degree	2

○ Land areas
○ Habitat type: 1: one
○ Protected areas: MPA1
○ Region (results):
● Rel. prim.prod. P/B: 1
○ Fleet operations:
☐ Seed?
☐ Record habitat changes during run
☑ Print on basemap
Hab: 7 , isw. PP = 1.2
☐ Show transect
Biomasses across transect (log scale):

Figure 17. Ecospace primary productivity anomaly base map based on mean value of 19 tkm^{-2} phytoplankton biomass. The numbers are the differences from the mean and are used to rescale the primary productivity in each cell.

Figure 18. Initial spatial representation of biomasses. Scale on the right indicates relative density in the habitat.

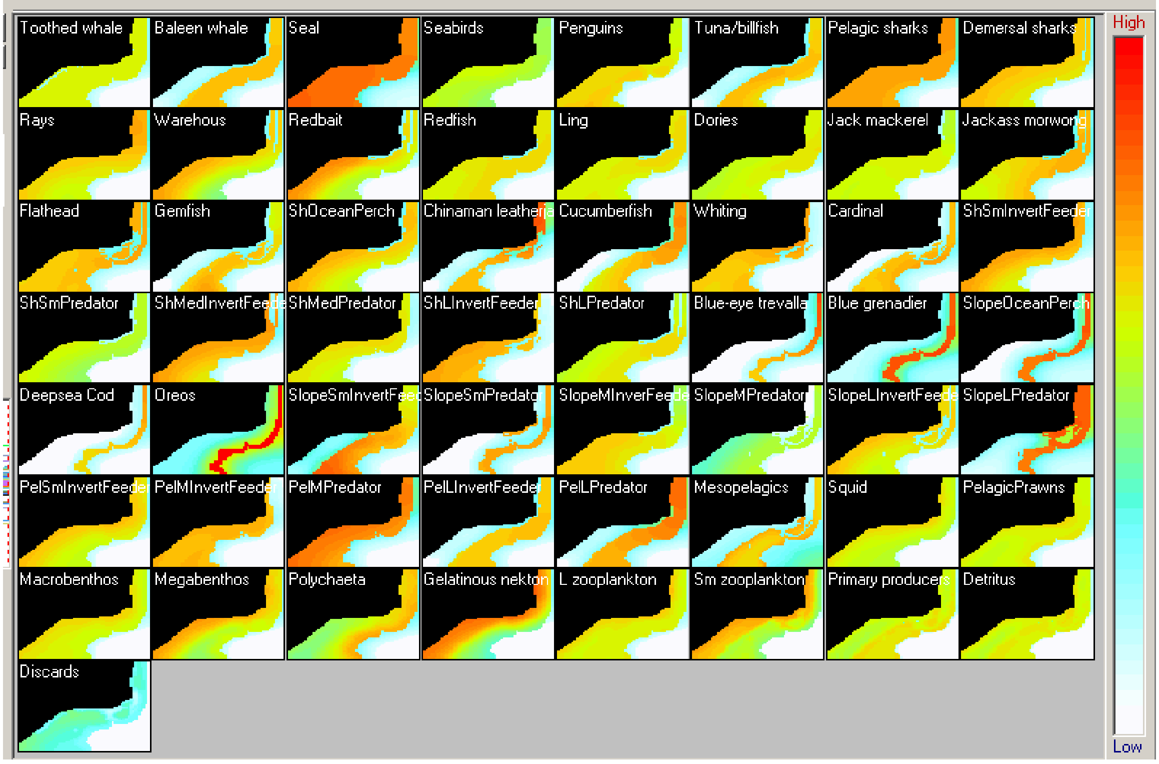


Figure 19. Final Ecospace output after simulation from 1994 to 2043 where there is discarding and a doubling in seal biomass at the rate of about double in 10 years (compare to Fig 18).

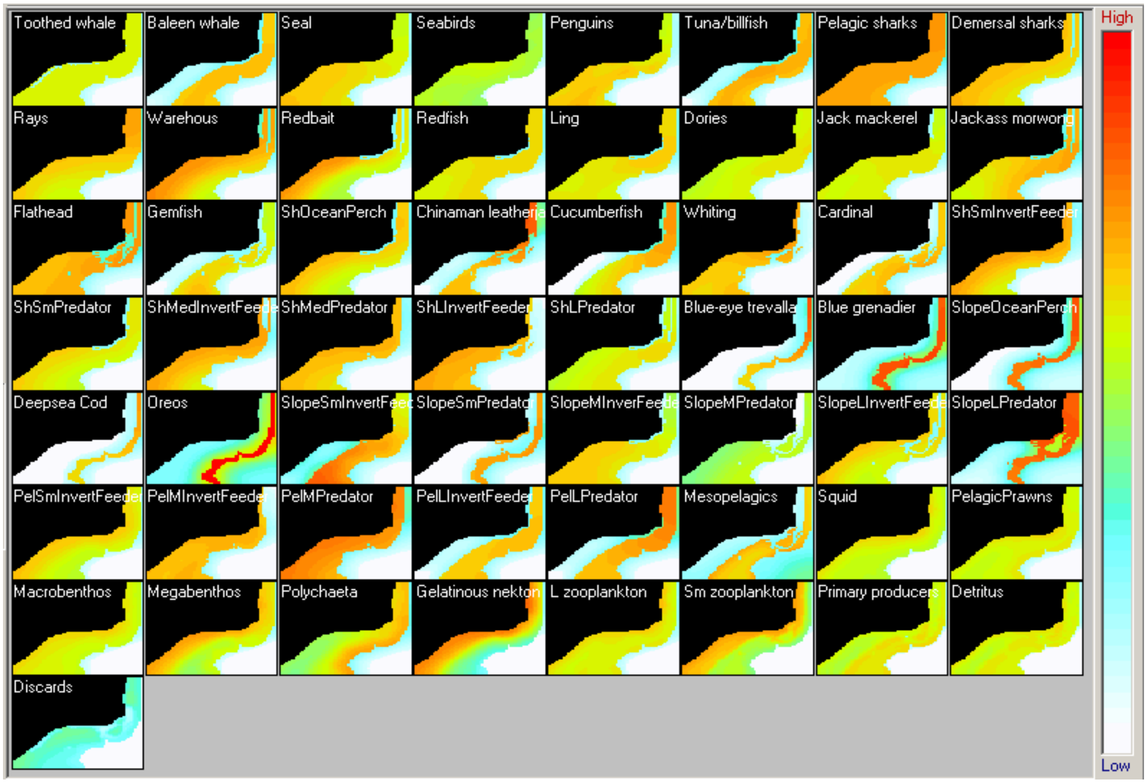


Figure 20. Final Ecospace output after simulation from 1994 to 2043 where there is discarding but no seal biomass accumulation. Note for example the intensity of colour of seals has lightened from that in Fig 18 indicating a lower abundance.

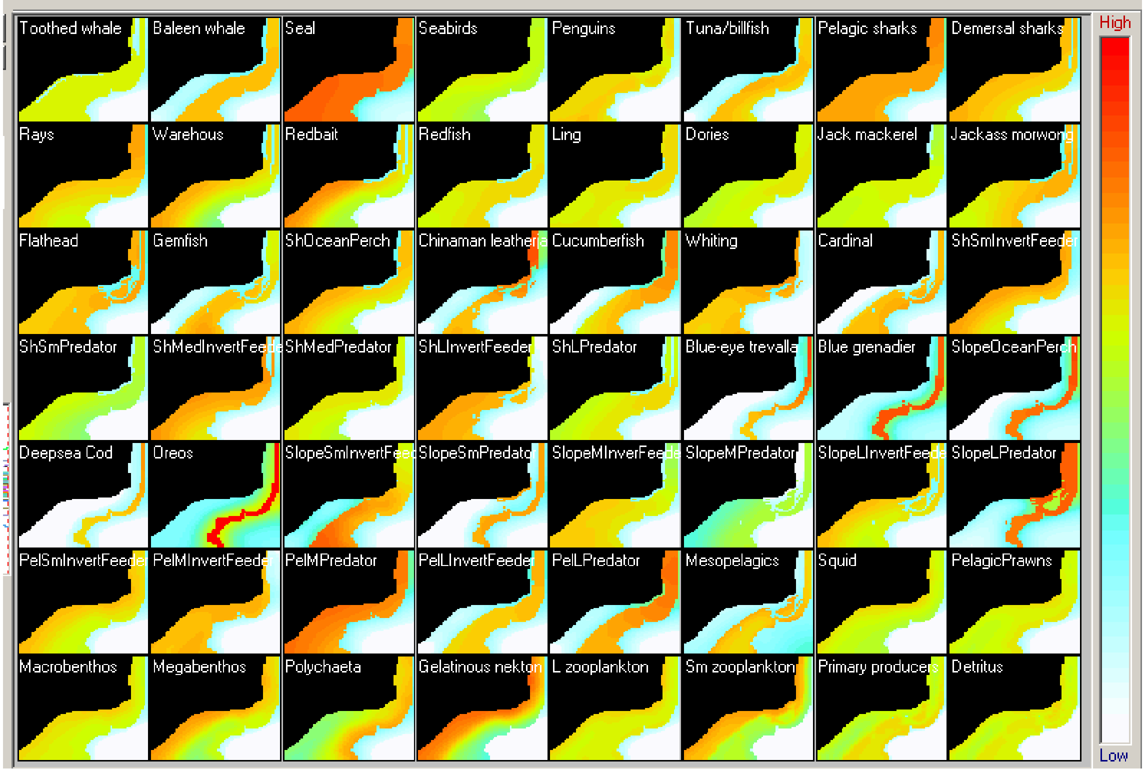


Figure 21. Final Ecospace output after simulation from 1994 to 2043 where there is no discarding and a doubling in seal biomass at the rate of about double in 10 years.

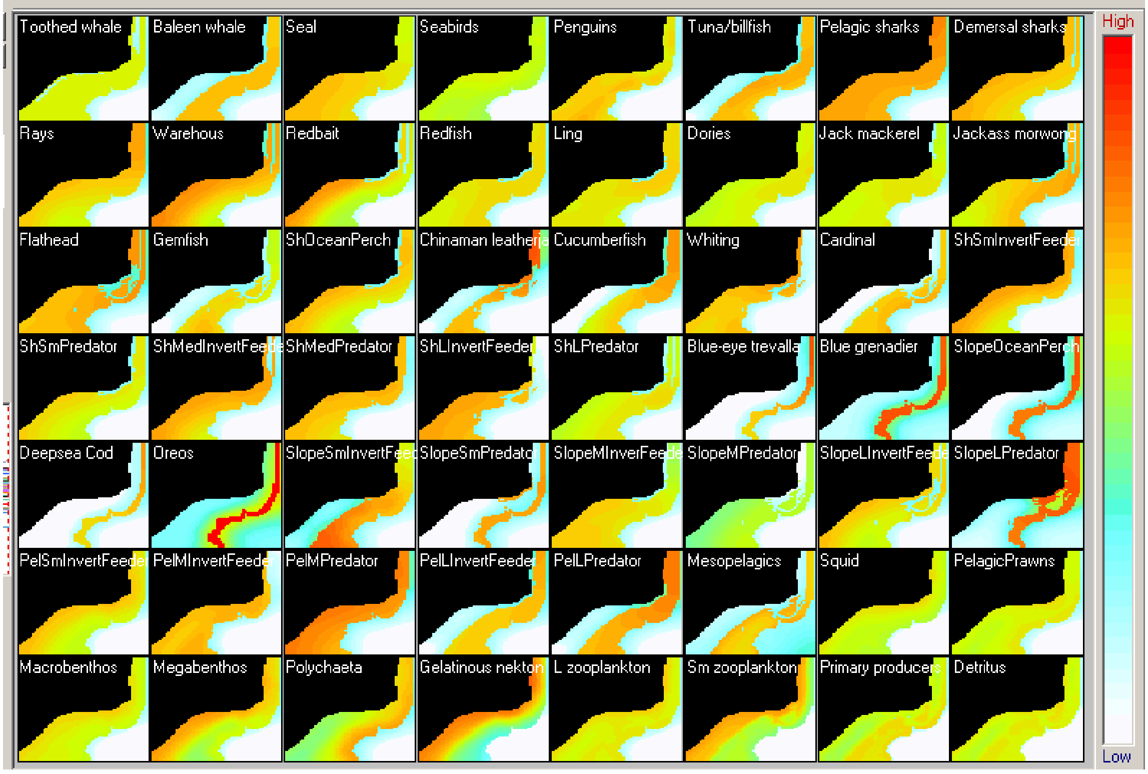


Figure 22. Final Ecospace output after simulation from 1994 to 2043 where there is no discarding and a doubling in seal biomass at the rate of about double in 10 years.

There were major differences between the non-discarding and discarding scenarios, for either seal biomass accumulation condition. However, as in the Ecosim simulations, there were also some differences between the seal biomass accumulation scenarios. The results of these scenarios can also be summarised as relative changes in biomass and represented graphically (Fig 23) as for the temporal simulations (Fig 10).

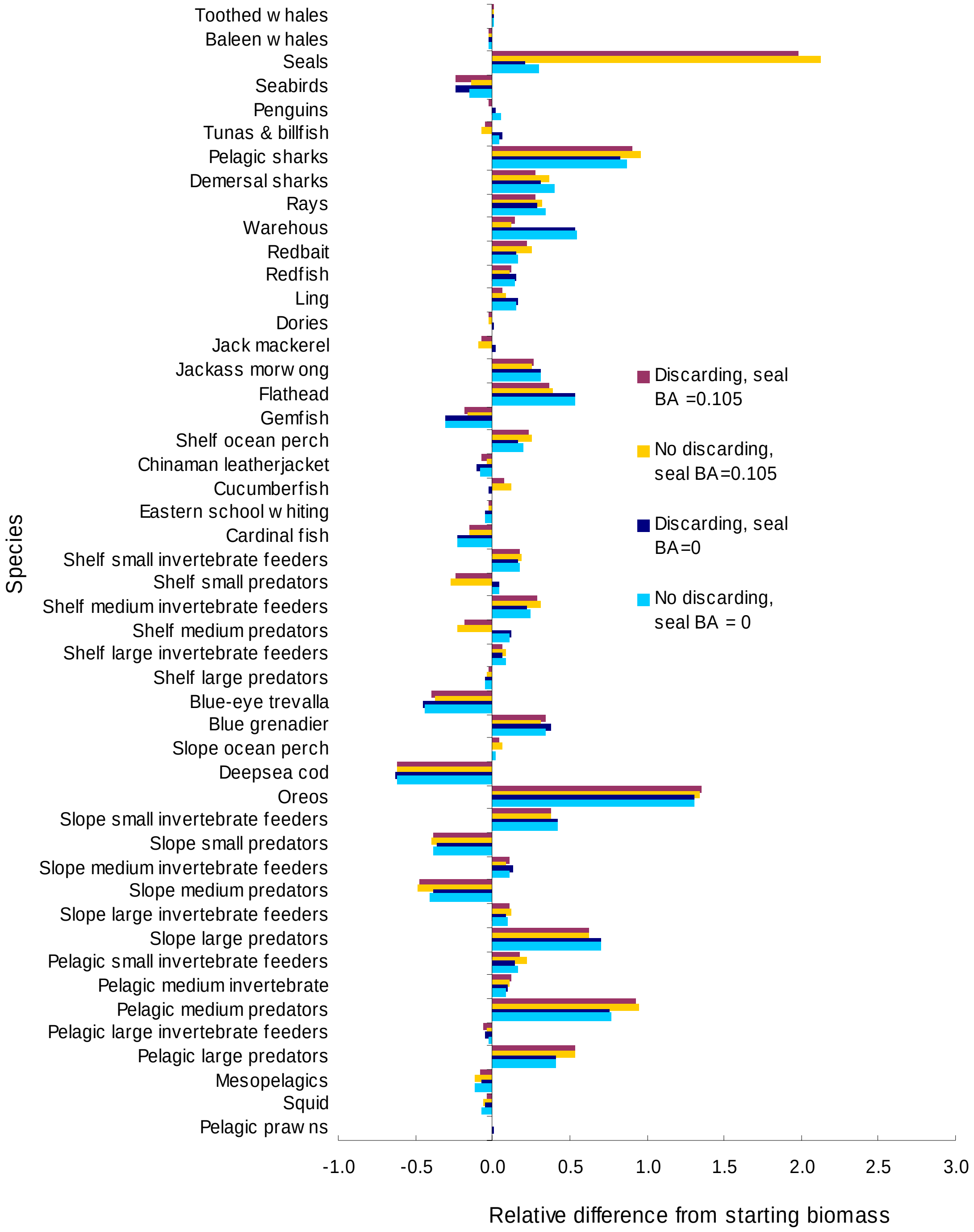


Figure 23. The relative changes in biomasses of species and groups from 1994 to 2043 using Ecospace model (spatially adjusted). Compare with the Ecosim results in Fig 10 where only the temporal dynamics are considered.

Comparing the spatial model results in Fig 23 with the temporal model results in Fig 10 for the four scenarios, we found that trends that were either stronger or weaker than in the temporal model and some complete reversals of trend. The spatial model predicted similarly small differences between the discarding or non-discarding scenarios but bigger differences between the seal biomass accumulation scenarios. A major difference between the models was that the spatial model more often predicted higher biomasses but on the other hand, some decreases were enhanced. Some important examples of these trends were an increased gemfish decline and a larger oreo increase. In the spatial model, the biomass of seals did not increase as much as in the temporal and pelagic sharks increased. Similarly, the demersal sharks and rays also appeared to be benefited by spatial treatment.

Complete reversals of trends are probably the most significant differences between the spatial and temporal models. For example, the spatial model predicted that warehous increased in all scenarios compared to a decline under the ‘seal doubling’ scenario and a very small increase under the ‘seal not doubling’ scenario. Similar positive reversals of trends were found for redbait, ling, slope ocean perch, all slope invertebrate feeders, shelf small invertebrate feeders and predators although many are very small. Negative reversals were found for whiting, shelf large predators, deepsea cod, and blue-eye trevalla. The latter two were relatively large changes.

6.7 Discussion

In an attempt to make a credible dynamic model that would reflect the actual dynamics of the system, we fitted the model predictions to the actual observations from the fishery under what is considered the most likely scenario of seal population increase. While it was possible to achieve a good fit of the predictions to the data for many of the species using default vulnerabilities, we chose to modify vulnerabilities to reflect better the actual relationships of the predators and prey. It was also important to have a stable and robust model that could operate under extreme conditions therefore parameter settings were modified which sometimes decreased the goodness of fit. While the fits to observed CPUE data were not always good, it must also be considered that CPUE is not necessarily a good indicator of species abundance (for example Harley *et al.* 2001). Overall, model parameters such as vulnerabilities and feeding parameters settings could be explored further and adjusted to improve model dynamics. This is particularly relevant for the spatial model settings most of which were not altered from the default settings in this preliminary version. There is considerable opportunity to improve the performances of both temporal and spatial models.

The scenarios we investigated suggest that while seals might be a dominant force in the ecosystem they account for only a very small portion of the consumption of fish. The fishery is competing with seals to a large extent but is also benefiting slightly from seals eating the predators of some of the target fishery species. Similar effects of seal predation on hake species were modelled by Punt and Butterworth (1995). They predicted that culling of seals would have a minimal or at worst a detrimental effect on the bottom-trawl fishery catches. Seals ate the deep-water hake species that ate the shallow-water hake therefore its removal would result in increased predation of shallow-water hake species by deep-water species, and a subsequent decrease in catch.

Parallel with the modelled increase in seals was an increase in pelagic sharks, which are currently considered positive indicators of ecosystem health (Fulton *et al.* 2004). Fulton *et al.*

(2004) discussed several studies that examined the effects of removal of top predators. One such study is that by Stevens *et al.* (2001) who modelled removal of sharks in three ecosystems, one of which being the Venezuelan shelf, a system quite similar to the EBS. Their modelled consequences of shark removal were often large and could indirectly affect species not eaten by sharks. Increase in pelagic sharks in our system can be linked directly to the increase in availability of seals, one of their prey, but did have negative consequences for their prey such as penguins, demersal sharks, warehous, redfish dories, and jack mackerel.

The practice of discarding or not discarding does not seem to have a great effect on the system as modelled. The changes in biomass of trophic groups are all minor and there are no reversals of trends. While discards provide an opportunity for scavengers to get an easy meal and attract the attention of fishers, these species are able to support themselves readily as they do in the pre-fishing (historical) scenario. However, we acknowledge that the model predictions are sensitive to dietary composition, not only in this scenario, therefore any major differences in diet from that modelled, might alter the outcomes significantly.

The effect of overall reductions or increases of fishing pressure produced predictable results. However, the increased fishing mortality scenario predicted that smaller prey fish such as cardinal fish and cucumberfish would increase leading to an increase in gemfish. Increased abundance of small prey species as a result of increased fishing pressure has also been found in other systems (Okey *et al.* unpublished ms).

The spatial model is only preliminary and needs further investigation but was included here to illustrate its potential. Ecospace was developed for the purpose of investigating the effects of marine protected areas and fishery closures but has not yet been used widely used as yet. In this case, we found that differences between the two types of models were informative with respect to some of species inhabiting some of the smaller habitats such as the slope habitat and it highlighted the value of obtaining good quality data. Reversals of trends were found when the system was modelled spatially implying that for some species we will need to consider the dynamics between the species and their habitats and changes that have occurred to the habitat over time.

6.8 References

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7 HISTORICAL MODEL

7.1 Introduction

Commercial trawling in the SEF commenced in 1915, and the history of the development is described by Tilzey and Rowling (2001). Klaer (2001) describes some of the large changes in species composition over the first 50 years of the fishery where steam trawling was a principal fishing method. This chapter describes the development of an Ecopath model for ecosystem components at the commencement of commercial fishing that can then be compared to the contemporary model presented in previous chapters.

Estimates of initial biomass levels for main commercial fish species caught on the SE shelf have been developed and presented by Klaer (Submitted). An Ecopath scenario can be developed using those biomass values and assuming that some inputs such as diet matrices are applicable to the unexploited system.

The notion of an “unexploited” SE marine ecosystem requires further examination. The work here examines changes in the demersal marine fish community of the SE region during the period 1915 to the present, and attempts to quantify some of those changes. However, to interpret and judge the significance of changes during that period also requires an understanding of changes that might have occurred prior to 1915. While 1915 marks the commencement of commercial fishing in the region, natural and human-induced changes were operating before that, causing considerable change to the SE shelf ecosystem. The following section documents known changes that can be attributed to human influence that occurred before 1915.

7.2 Change in the SE shelf ecosystem prior to 1915

There are several sources of community or ecological change that may have been operating prior to 1915:

(a) natural ecosystem fluctuations
(b) human extraction of marine organisms
(c) human assisted invasions of exotic species
(d) human alteration of the physical environment (through pollution, movement of substrates or human-induced global climate change)

7.2.1 Natural fluctuations

The notion that ecosystems undergo constant cycles and changes was first expressed in 1960 by Ramon Margalef: “Ecosystems result from the integration of populations of different species in a common environment. They rarely remain steady for long, and fluctuations lie in the very essence of the ecosystems and of every one of the ... populations [that comprise the system]” (Smith 1994). On a geological time-scale, ecosystems change greatly, leading to both the evolution of the physical environment as well as the biological components.

There are many sources of long-term change or cycles in natural systems that existed previously and outside of human influence. Examples include global temperature change, sea level changes and long-term changes in marine water chemistry. Such changes ensured that over long periods of time ecosystems were never in a steady state. Natural fluctuations also occur on shorter time frames due to, for example, large scale weather events such as El Niño, or fluctuations in the characteristics of the SE Australian current.

7.2.2 Human extraction of marine organisms

Human activities have influenced the status of fish communities on the SE Australian continental shelf since well before 1915. Aboriginals have probably harvested marine animals primarily in near-shore waters in the region since they first arrived more than 30,000 years ago. There was a period of sea level rise of about 120m that extended from the peak of the last ice age 20,000 years ago to 6,000 years ago. Coastal areas that may have been occupied prior to 6,000 years ago were flooded or covered with sedimentation. Therefore, current archaeological evidence provides information about marine exploitation by aboriginals only during the last 6,000 years, and particularly the last 2,000-3,000 years (Mulvaney and Kamminga 1999). Shelf trawl grounds shallower than 120m depth were dry land during the time of aboriginal colonisation, indicating the enormous natural changes that have taken place in the shelf ecosystem during the period of potential human influence.

Archaeological evidence of marine exploitation by aboriginals in the region comes primarily from excavations of rock shelters and shell middens. Rock shelters in the Sydney region show evidence of occupation only for the last 2,500 years. Shell middens in the area contain remains of molluscs, fish, and large marine mammals such as whales. The molluscs came from estuaries and rock platforms, the fish were caught by spear, hook and line, and possibly scoop net, and the mammals were probably found stranded (Mulvaney and Kamminga 1999). Fishing with hook and line appears to be a more recent development between 700 and 1100 years ago, based on imprecise dating of hooks and stone files from shell middens throughout the SE region. An increase in the relative quantity of mussels has been noticed in some middens that correspond with the advent of line fishing (Mulvaney and Kamminga 1999). It is not known whether the two are related, or whether this was due to a change in shellfish distribution or abundance.

Diaries from members of the First Fleet describe aboriginal men fishing with spears and women fishing with hook and line from canoes. Most of the fish catch was snapper (*Chrysophrys auratus*) (Mulvaney and Kamminga 1999).

In contrast to the mainland, Tasmanian aboriginals were not observed to catch marine fish. They restricted their marine activities to collecting shellfish and crayfish in near-shore waters (Roughley 1953).

It is likely that the impact on the shelf ecosystem of extractions by aboriginals was low, due to the relatively low aboriginal population numbers, and the apparent sustainability of the resources.

The first direct European influence on SE Australian marine fauna would have been due to whaling. In 1642 Abel Tasman of the Dutch East India Company became the first European to sight the SE coast of Australia in Tasmania. One of the activities of the Dutch East India Company was whaling, primarily in the northern hemisphere, although the company had a monopoly on whaling throughout the Pacific in the 1700s (Bach 1976). British whaling ships were permitted to exploit Australian and New Zealand waters after 1798, using the ports of Sydney and Hobart. In 1809 the British government imposed a prohibitive duty on colonial oil to protect British whalers, effectively limiting the development of a substantial domestic whaling and sealing industry. In any case, in the early 1800s the colonists did not have the commercial or industrial capacity to equip and supply an offshore whaling industry. Small and localised bay and estuary whaling enterprises did develop in, for example, the Derwent estuary and Twofold Bay.

There were 164 British and 130 American whaling ships operating in the south Pacific in 1821 mostly targeting sperm whales. By 1849, the year when British duties were finally abolished, there were 21 British and 659 American ships operating in the south Pacific (Bach 1976). Between 20 and 76 whaling vessels operated from Sydney in the years from 1830 to 1848, while in 1849, 37 such vessels operated from Hobart (Bach 1976).

While there was substantial whaling activity in the southern hemisphere prior to 1900, the scale greatly increased in the 20th century. Between 1904 and 1980 approximately two million whales were killed there. It is probable that between 80 and 95% of the pristine populations of humpbacks, blue whales and sperm whales was killed during this period, while southern right whales were depleted in the 19th century and protected by international agreement in the 1930s (Baker and Clapham 2002).

It is likely therefore, that the number of whales in the SE region of Australia had been substantially changed by 1915, and continued to be affected by major whaling activity through to about 1980.

Sealing is an activity related to whaling in that oil is one of the major products. Large numbers of seals on islands and shores of Bass Strait were recorded as discovered in 1797 by Matthew Flinders in the small vessel *Francis* while on a voyage to rescue castaways from the Wreck of the vessel *Sydney Cove* on Preservation Island. Commercial sealing soon commenced, with Captain Bishop in the brig *Nautilus* returned to Sydney in 1799 from sealing in the region of Cape Barren Island with 9,000 sealskins and a quantity of oil. A rush to participate in the industry then took place, and between 1800 and 1806 over 100,000 sealskins were brought to Sydney alone. By 1832 sealing in Bass Strait was no longer profitable, and was all over by 1838 (O’May 1973).

Prior to exploitation there were four species of seals breeding in Bass Strait, and two of these have not returned since: Australian sea lions (*Neophoca cinerea*) and Southern elephant seals (*Mirounga leonina*) (Warneke and Shaughnessy 1985). New Zealand fur seals (*Arctocephalus forsteri*) have recently extended their breeding range back to Bass Strait (Pemberton and Gales 2004), but pre-exploitation population numbers are unknown.

Warneke and Shaughnessy (1985) estimated the Australian fur seal (*Arctocephalus pusillus doriferus*) population prior to exploitation to be about 200,000 individuals. Various population estimates from 1945 to 1991 are in the order of 40,000 (Pemberton and Gales 2004). Pemberton and Gales (2004) estimate the current population at about 70,000 individuals. In 1915 the Australian fur seal population was likely to have been less than the estimate of 40,000 for 1945.

After European settlement in the late 1700s and until about 1915, fishing activity particularly in the Sydney region consisted of netting enclosed or semi-enclosed waterways, beach netting and line fishing (Tenison-Woods 1882). Fishing was mainly concentrated in near-shore waters less than about 50m in depth. A primary target species for line fishing in the deeper near-shore waters was snapper. Snapper are a species found in deeper shelf waters to 200m (May and Maxwell 1986), so early fishing for them may have directly influenced the demersal fish community composition of the shelf waters. Young snapper live in estuaries until they move to sea where they remain as adults (Roughley 1953).

Tenison-Woods (1882) described the snapper as remarkably regularly distributed along the whole of the NSW coast, and perhaps the most abundant fish species in inshore waters. He also describes the exhaustion of fishing grounds close to Sydney prior to 1882 due to pollution and disturbance, but mainly because of high levels of net fishing in the region:

> “The wholesale destruction within the harbour caused by stake nets and seines with meshes almost small enough for a naturalist’s hand-net has of course produced its natural effect on the outside grounds, where schnapper can now only be taken in very small quantities, and without any degree of certainty. The evidence given by fishermen, who can remember the large hauls of fish once taken from the beaches of North and Middle Harbour, Rose and Double Bay, not to speak of the flats up the Parramatta River, affirms this.”

The lakes in the region north of Sydney (e.g. Lake Macquarie, Tuggerah Lakes) are described by Tenison-Woods as chief nursery areas for snapper. He also describes the destructive use of nets of unlimited length and small mesh where one haul frequently brought to shore a ton or more of small fish that was left to rot. While there were still considerable amounts of snapper caught off NSW since 1915, it is probable that the population was altered considerably because of such fishing practices in the 1800s. Snapper catches prior to 1915 may have had a direct influence on the demersal fish communities of the wider SE shelf, as the depth range occupied by them overlaps considerably with the main commercial trawl species considered in this study.

7.2.3 Human-assisted invasions of exotic species

There are more than 300 species that have been identified as invasive to the Australian marine environment in a list maintained by the CSIRO Centre for Research on Introduced Marine Pests. Although an estimated date of introduction is unknown for many species, there are currently 22 marine species listed as having been introduced prior to 1915 (K Hayes *pers. comm.*). Those species include algae, amphipods, barnacles, bryozoans, bivalves and crabs. Bax *et al.* (2003) noted that introduced marine pests have caused a considerable amount of environmental and economic damage in nearshore waters, but have not had the same effect further offshore on the open continental shelf. Only one introduced marine gastropod, the New Zealand screw shell *Maoricolpus roseus*, has been identified as having an impact in shelf waters of SE Australia, and its distribution has expanded from southern Tasmania to Sydney in the past 70 years or so. While it is unlikely that this species had an influence on the Australian SE shelf prior to 1915, its abundance in areas where it now occurs, and its expanding distribution suggest that its current and future influence may be substantial.

7.2.4 Human alteration to the physical environment

The impact on fish populations of pollution and disturbance by the traffic of a large number of vessels in the waters of Port Jackson was recognised very early by Tenison-Woods (1882). The siting of population centres close to the sea does have at least a localised effect on the marine environment of the region due in particular to disposal of industrial waste and sewerage into the sea, siltation from soil exposure from development, and physical changes caused by construction of structures such as break walls. In addition, increases in agricultural activity leads to increases in nutrients, agricultural chemicals and silt in the estuaries of the catchment area, and perhaps changes to the amount and nutrient mix of wind-borne dust settling on the ocean.

However, stable isotope and photo-reactive pigment analyses have shown that estuarine and terrestrial sources of production have little influence in the food webs of the SE Australian continental shelf. The main source of production was found to be pelagic plankton and micronekton transported to the shelf from the open ocean by deep upwelling (Bax *et al.* 2000).

This suggests that while physical changes due to human activities have obvious localised effects, there has been a low impact on the wider shelf communities. The effect of human-induced climate change on the SE marine system has not been investigated, although there are several current CSIRO projects with that focus.

7.3 Methods

As for the current ecosystem model presented in earlier chapters, Ecopath (Christensen and Pauly 1992, Christensen *et al*. 2000) was used to model the mass-balance of the SE shelf demersal ecosystem before the commencement of the trawl fishery. As the fishery began in 1915, the system before commercial fishing is represented here using the year 1914.

Biomass estimates for 1914 were available for the main commercial fish species caught on the continental shelf (Klaer Submitted). Densities were estimated assuming that the species occupy the whole shelf area in the SE Australian region, and also just the trawl grounds. The region modelled here represents a sub-region of that used by Klaer (Submitted), and consists mainly of trawlable grounds, so the estimates for trawl ground densities for flathead, jackass morwong and Chinaman leatherjacket were used for further modelling (Table 1).

Table 1. Density of fish biomass per species assuming distribution of the 1914 population was confined to trawl fishing grounds alone, or across the whole SE Australian shelf area.

Species	1914 B_0 (t)	Density	
		Trawl grounds	Whole shelf
Flathead	49,350	6.86	2.60
Morwong	29,400	4.09	1.55
Leatherjacket	9,300	1.29	0.49

Estimates of initial biomass prior to exploitation were also available from fisheries assessments (Caton and McLoughlin 2004), so for the commercial fish species of warehous, ling, gemfish, whiting and blue grenadier the input biomass values used to model the current system were adjusted upwards accordingly. Account was also taken of the relative density of the species within the study area, leading to, for example, only a modest increase in the estimated 1914 biomass for blue grenadier.

To construct the 1914 scenario, the diet composition matrix from the current model was largely used. Discards did not exist in 1914 because there was no fishery, so discards were removed from the diet composition of all trophic groups and compensated by proportional increases in all non-discard components of their diets.

There were no available biomass estimates for trophic groups other than commercial fish species for 1914, so values for other fish groups identified in the contemporary model were adjusted upwards by hand during the process of balancing the model. Generally, the contemporary model values were doubled initially and then adjusted either up or down as needed to achieve a balanced model.

The only input biomass value that was lower than current was for seals, recognising that the seal population was considerably lower in 1914 than at present.

We assumed that the abundance of mesopelagic fish would not have been substantially different from the current model in which we used a value of 200 tkm^{-2} in the slope and shelf-break habitat. We also assumed that primary production was similar and we input the same values of biomass for phytoplankton as used in the current day model.

7.4 Results

An Ecopath scenario for the SE shelf demersal ecosystem in 1914 was mass-balanced and gross systems statistics were calculated and compared with those obtained from the current model (Table 2). In order for the model to be balanced, additional biomass for mesopelagic fish was required and assumed to be advected into the area. The additional biomass required annually for this group was 121 $t\ yr^{-1}$. The process of advection from offshore and the deeper slope is assumed to be primarily an impingement of mesopelagic fishes and nekton on the upper slope and shelf break from diel vertical migration and current regimes.

Using the same value of *P/B* for phytoplankton the model could not be balanced without an additional 719 $t\ yr^{-1}$ of small zooplankton. However, with the higher *P/B* values of 368 or 500, net migration into the area was unnecessary. We are unable to determine which scenario is most feasible without additional estimates of standing stocks of zooplankton and other invertebrates however the results are little affected.

This 1914 scenario suggests that the overall biomass (excluding detritus) was greater than the current biomass by a factor of almost 2 (Table 2). Total overall consumption, respiratory flows, total system throughput, sum of all production and total net primary production were greater in the 1914 scenario versus the current model. Flows to exports, detritus, and net system production were all lower for the 1914 scenario than for the current model.

Parameter estimates were obtained for each trophic group (Table 3). Estimated biomass densities for all diet composition groups were then compared on a log-scale (Fig 1). Most groups show a decline over the period, but of the higher trophic level groups with biomass values estimated by the model only pelagic sharks show an increase. Seals form part of the diet of pelagic sharks, so it is plausible that they would show similar trends. The biomass of commercial fish species (gemfish, dories, tuna/billfish, ling, flathead, blue grenadier, ocean perch, blue-eye trevalla, Chinaman leatherjacket, warehous, redfish, deepsea cod, oreos and whiting was more than 4 times greater for the 1914 scenario compared to current. Therefore it is not surprising that the 1914 system requires larger biomasses of lower trophic groups. Only the redfish biomass was estimated by the model for the 1914 scenario, so most of the relative change in commercial fish species biomass is determined by the values we input into the model.

Table 2. System statistics from the balanced EBS model for 1914 compared to those from the current model.

Parameter	1914	Current	Units
Sum of all consumption	7399.434	4062.542	t/km²/year
Sum of all exports	2919.97	4655.699	t/km²/year
Sum of all respiratory flows	4193.741	2280.016	t/km²/year
Sum of all flows into detritus	3354.816	4832.303	t/km²/year
Total system throughput	17868	15831	t/km²/year
Sum of all production	8719	7900	t/km²/year
Mean trophic level of the catch	-	3.95	
Gross efficiency (catch/net p.p.)	-	0.000137	
Input total net primary production			
Calculated total net primary production	6992	6935	t/km²/year
Unaccounted primary production			
Total primary production/total respiration	1.6672	3.041645	
Net system production	2798.259	4654.984	t/km²/year
Total primary production/total biomass	17.4437	34.04073	
Total biomass/total throughput	0.0224	0.012869	
Total biomass (excluding detritus)	400.8327	203.7265	t/km²
Total catches	-	0.949908	t/km²/year
Connectance Index	0.1812	0.173884	
System Omnivory Index	0.2279	0.240742	

Table 3. Diet composition group parameters of East Bass Strait model for 1914 after balancing. Bold values are estimated by the model; all others are input. Sh=shelf; Sm=<30 cm; M= 30-50 cm; L=>50 cm; Invert=invertebrate.

Group name	Habitat area (fraction)	Biomass in habitat. area (t/km^2)	Biomass	P/B	Q/B	Ecotrophic efficiency	P/Q
Toothed whale	1	0.013	0.013	0.02	13	**0.6401**	**0.0015**
Baleen whale	1	0.006	0.006	0.02	11.2	**0**	**0.0018**
Seal	0.8	0.005	0.004	0.18	38.898	**0.627**	**0.0046**
Seabirds	1	0.003	0.003	1	80	**0.2817**	**0.0125**
Penguins	1	0.001	0.001	1	80	**0.8452**	**0.0125**
Tuna/billfish	0.14	1	0.14	0.68	6.8	**0.0047**	**0.1**
Pelagic sharks	1	**0.00122**	**0.00122**	0.2	1.2	0.95	**0.1667**
Demersal sharks	1	1.22	1.22	0.18	1.8	**0.8839**	**0.1**
Rays	1	1.5	1.5	0.35	3.5	**0.846**	**0.1**
Warehous	1	1.8	1.8	0.28	2.4	**0.2072**	**0.1167**
Redbait	1	**1.3263**	**1.3263**	0.74	2.8	0.9533	**0.2643**
Redfish	1	**6.7392**	**6.7392**	0.1	2	0.95	**0.05**
Ling	1	0.88	0.88	0.22	2.4	**0.8855**	**0.0917**
Dories	1	0.8	0.8	0.3	2.8	**0.8876**	**0.1071**
Jack mackerel	1	12	12	0.47	3.3	**0.9577**	**0.1424**
Jackass morwong	1	4.09	4.09	0.22	2.9	**0.6263**	**0.0759**
Flathead	0.86	6.86	5.8996	0.27	3.5	**0.7728**	**0.0771**
Gemfish	0.6	2.2	1.32	0.44	2.1	**0.2779**	**0.2095**
ShOceanPerch	0.66	0.85	0.561	0.26	2.6	**0.85**	**0.1**
Chinaman leatherjacket	0.47	1.29	0.6063	0.36	2.3	**0.756**	**0.1565**
Cucumberfish	1	**12.0302**	**12.0302**	0.52	4.7	0.98	**0.1106**
Whiting	0.81	3	2.43	0.5	5.4	**0.884**	**0.0926**
Cardinal	1	**19.4438**	**19.4438**	0.77	6.4	0.96	**0.1203**
ShSmInvertFeeder	0.86	15	12.9	0.61	4.67	**0.97**	**0.1306**
ShSmPredator	0.86	3.4	2.924	0.55	4.46	**0.9514**	**0.1233**
ShMedInvertFeeder	0.86	2.7	2.322	0.36	3.4	**0.9513**	**0.1059**
ShMedPredator	0.86	1.41	1.2126	0.4	2.93	**0.9301**	**0.1365**
ShLInvertFeeder	0.75	0.1	0.075	0.21	2	**0.5079**	**0.105**
ShLPredator	0.86	5	4.3	0.19	1.84	**0.877**	**0.1033**
Blue-eye trevalla	0.14	0.7	0.098	0.2	1.4	**0.9064**	**0.1429**
Blue grenadier	0.19	0.85	0.1615	0.27	2.9	**0.9894**	**0.0931**
SlopeOceanPerch	0.54	1.25	0.675	0.26	3.1	**0.9816**	**0.0839**
Deepsea Cod	0.14	0.47	0.0658	0.25	2.2	**0.406**	**0.1136**
Oreos	0.14	0.0839	0.0117	0.35	2.7	**0.4926**	**0.1296**
SlopeSmInvertFeeder	0.6	0.38	0.228	0.47	4.13	**0.9931**	**0.1138**
SlopeSmPredator	0.6	0.49	0.294	0.4	3.24	**0.8934**	**0.1235**
SlopeMInverFeeder	0.6	3.3	1.98	0.19	2.74	**0.9571**	**0.0693**
SlopeMPredator	0.6	0.3	0.18	0.305	2.5	**0.7126**	**0.122**
SlopeLInvertFeeder	0.6	**2.406**	**1.4436**	0.44	2.9	0.95	**0.1517**
SlopeLPredator	0.6	0.12	0.072	0.2	2.34	**0.7729**	**0.0855**
PelSmInvertFeeder	1	**3.3246**	**3.3246**	0.76	8.85	0.95	**0.0859**
PelMInvertFeeder	1	0.131	0.131	0.46	3.4	**0.5884**	**0.1353**
PelMPredator	1	0.32	0.32	0.32	2.85	**0.4831**	**0.1123**
PelLInvertFeeder	1	0.055	0.055	0.16	3	**0.9664**	**0.0533**
PelLPredator	1	**0.0654**	**0.0654**	0.26	3.1	0.5	**0.0839**
Mesopelagics	0.19	200	38	0.83	8	0.8	**0.1038**
Squid	1	**2.3419**	**2.3419**	2.6	10	0.8	**0.26**
PelagicPrawns	1	**4.5517**	**4.5517**	1.6	10	0.8	**0.16**
Macrobenthos	1	**86.3455**	**86.3455**	1.6	6	0.8	**0.2667**
Megabenthos	1	**18.9331**	**18.9331**	2.5	5.85	0.8	**0.4274**
Polychaeta	1	**19.349**	**19.349**	2	22	0.8	**0.0909**
Gelatinous nekton	1	**5.7451**	**5.7451**	3	10	0.8	**0.3**
L zooplankton	1	**41.9765**	**41.9765**	5	32	0.8	**0.1563**
Sm zooplankton	1	**58.9362**	**58.9362**	20	70	0.8	**0.2857**
Primary producers	1	19	19	368	-	**0.7803**	-
Detritus	1	10	10	-	-	**0.1296**	-
Discards	1	-	-	-	-	**0**	-

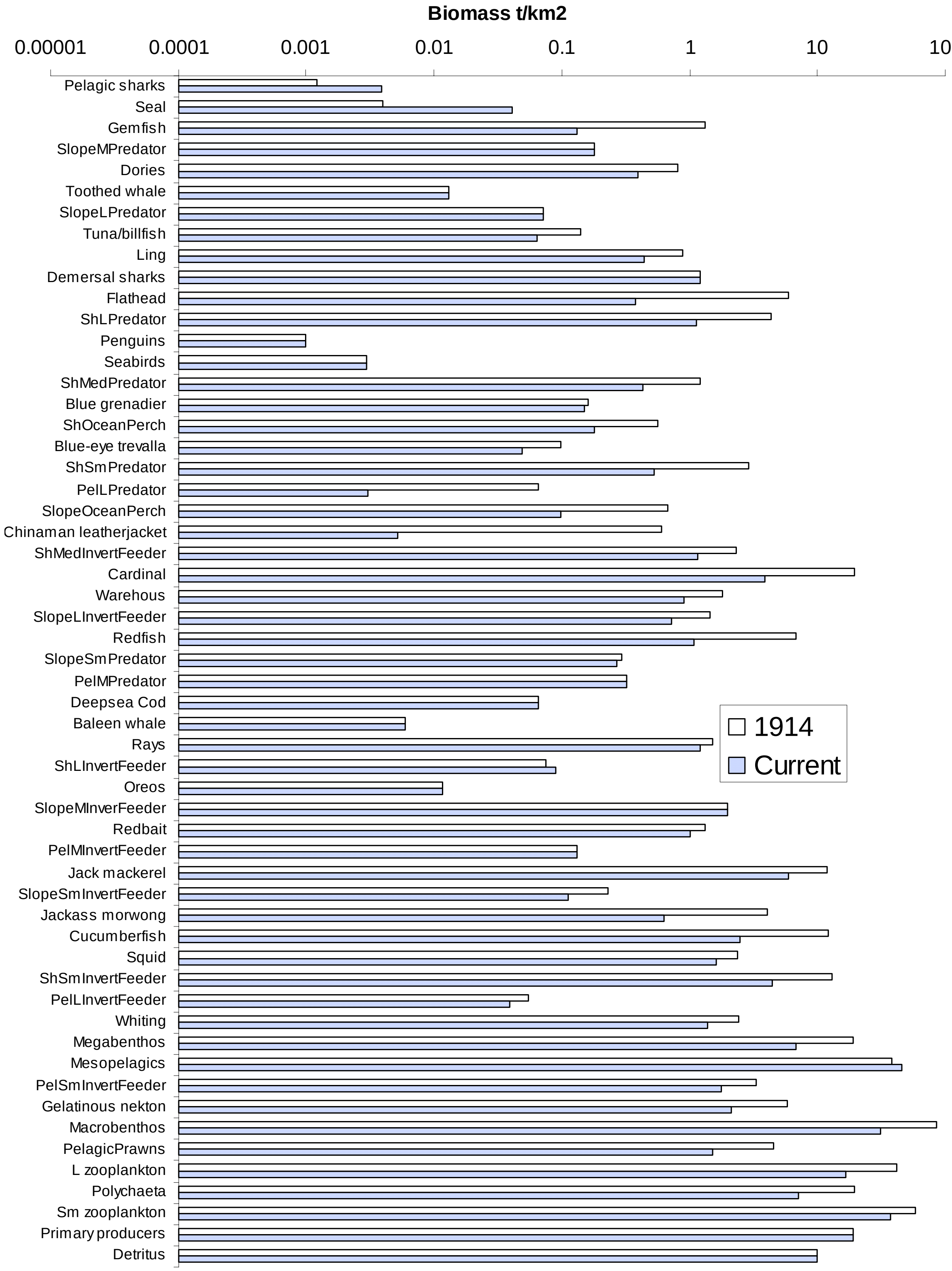

Figure 1. Comparison of estimated biomass values by functional group for 1914 and current (ordered by trophic level in 1914).

7.5 Discussion

The results here have shown firstly that a mass-balanced ecosystem model can be built using available estimates of the biomass of certain trophic groups for 1914. The 1914 model presented here should be considered as one of many possible models that may be constructed. There are no direct estimates of 1914 biomass values for many of the trophic groups that have been entered as input values. Sensitivity of the results to alternative assumptions about such input values has not been tested.

The substantial reduction in the relative biomass of the main commercial fish species from 1914 to present is also reflected in reductions in groups at lower trophic levels. For example, the largest absolute difference in total biomass for any group was a reduction in macro- and megabenthos from 1914 to present. The 1914 scenario as presented generally has increased biomass in lower trophic groups to support larger biomass in the higher levels. Assuming that primary production in the system was similar in 1914 to current, a considerable proportion of those larger biomasses at lower trophic levels were required to be imported. However, higher P/B values easily account for the estimated requirement of the higher predation. Irrespective of which phytoplankton scenario we use, the model-estimated biomasses for the zooplankton groups and other invertebrates were greater. However, because the model estimates those biomass values, we can only regard them as the requirement of the higher trophic levels to balance the system and not necessarily a true indication of biomass.

Biomass values for important species such as flathead have been estimated using different means for the 1914 and current scenarios. The 1914 values were estimated using single-species population dynamics models (Klaer Submitted), while current values have been estimated by direct survey (see Chapter 5). For flathead, the current biomass was 0.434 t/km^2 compared to 6.86 t/km^2 for the 1914 model. Recent fisheries stock assessment for flathead (e.g. Punt 2005) suggest that current biomass is about 40% of the unexploited level. Similarly, the current biomass in the Ecopath model for jackass morwong is 0.628 t/km^2 compared to 4.09 t/km^2 for the 1914 model. Recent stock assessments for that species (e.g. Fay *et al.* 2004) suggest that the current biomass is about 40% of the unexploited level. Values used in the Ecopath models here indicate a much greater decline for both species, so further work is required to create consistency between values used for ecosystem models and those produced by current fisheries stock assessments. Some of the differences may be explained by the survey estimates being made specifically for the region being modelled, while the fisheries assessment biomass estimates were for the larger area of distribution of the stocks.

The use of two mass-balanced ‘snapshots’ has limitations. It is recognised that the system is probably not in balance, particularly currently where catches from the trawl fishery vary considerably from year to year. Therefore, it is also important to investigate whether it is possible to construct dynamic Ecosim (Walters *et al.* 1997) models that can test the consistency of the Ecopath scenarios and fishery catches and biomass trajectories from 1914 to present.

7.6 References

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8 CONCLUSIONS

The primary objective of the study was to develop trophic models that describe the structure and dynamics of the food web of the south-east Australian shelf and slope to 700m between eastern Bass Strait and southern NSW. This was achieved through the development of oceanographic models and two trophic ecosystem models, one historical and one current, for the area of interest. The results of the oceanographic modelling were incorporated into the trophic model and used to develop several primary productivity scenarios. They were also used to investigate any possible correlation with fish production or catches. The preliminary results were used to inform the development of the National Oceans Office’s Regional Marine Plan for the South East Marine Region (SEMR). Scenarios for investigating the effect of different rates of seal population increases, and discarding practices were also developed and evaluated. As a direct outcome of this investigation, we have developed a tool which, with further validation and supplemented with more or improved data, can be used to investigate food-web related risks within the framework of a risk assessment of the fishery as required by the Environmental Protection and Biodiversity Conservation Act (EPBC).

A fundamental benefit and outcome of developing these models is a better understanding of the complex trophic interactions operating on the shelf. While not yet capable of quantitative predictions, they do provide a means of identifying potential ecosystem responses to changes in environmental conditions and human activities. The models also represent a coherent framework for describing the large amount of data available and help identify data-poor components and data gaps.

We developed scenarios that: (i) accounted for documented changes in the fish community that have taken place (ii) simulated possible effects of planned elimination of discarding in the South-East Trawl fishery; (iii) simulated effects on the ecosystem and fishery from current recovery rates in seal populations; and (iv) simulated the impacts of year-to-year variability in regional circulation and primary productivity. We also developed a spatial model and applied the discarding and seal recovery scenarios for comparison with the temporal model.

Several conclusions arose from our investigations. Firstly, there was little flux of phytoplankton biomass into the model domain relative to the local primary production within the domain. Therefore, in terms of primary productivity, the system operates as a “closed” system implying that either the standing stock of phytoplankton is able to support the system, or that secondary and/or tertiary production is advected into the area to support the higher trophic levels. We found that the level of primary production could easily support a system larger than the contemporary one, such as the hypothetical “1914” system.

Secondly, there were no strong correlations between primary productivity anomalies and fish catches apart from weak lagged responses of blue grenadier catch lagging primary productivity by 90-100 days and of blue warehou catch lagging by 30-40 days. However, we were unable to resolve our analysis to a fine enough temporal and spatial scale to explore the possibilities further. We suggest that periodic upwellings, such as the one that occurred during the Feb 1999, might increase the chances of larval survival and strengthen subsequent recruitment.

Thirdly, consumption of fish by seals is several times higher than the fishery catch but very small compared to the total consumption of fish by fish in the system. Higher biomasses of seals impacted negatively on most of its prey species, but they also coincided with increased abundances of some target commercial species. Seals may have benefited the target species by reducing their competitors for the same resources. While we found that seals were influential on the structure of the present ecosystem, flathead were probably a more influential predator in the historical system, when seal populations were lower than current levels and much lower than pristine levels.

Fourthly, eliminating discards appears to have little impact on the overall structure of the system. The slightly larger biomasses of four top predators increased predation pressure on their prey accounting for some of the declining groups while changes in other parts of the food web were negligible. However, evaluation of this scenario may have been limited by the model structure. For example, detritivores and other lower trophic groups might be significantly influenced by present day discarding practices but were not explicitly modelled here. Therefore, we were unable to draw any conclusions about the effects of reducing the detritus input into the lowest trophic levels of the system by eliminating discarding. Major modifications or a different modelling technique will be needed to investigate this further.

Fifthly, most fishery catches for the period 1994-2043 declined in all scenarios. However, with the exception of the Commonwealth trawl, the largest reductions in effort, and therefore catch, occurred prior to 2003. The predicted commonwealth trawl fishery catch increased by nearly 20% from 1994 to 2003 but that was due to the 2003 fishing rate being 20% higher than that in 1994. However, from 2003 to 2043, it actually declined by 7 % without any change in effort and increased only by 11% if effort were increased 25%. When effort was increased by 25% across all fisheries the overall increase in fishery catch from the present day catch was only 13% compared to 5% lower if effort remained constant. Presumably, this increase arises from a recovery of target species from the release of fishing pressure imposed by higher fishing rates that operated in some of the fisheries in 1994.

Lastly, the 1914 system, prior to fishing, probably had a significantly larger total biomass than the current system. Our knowledge of the size and composition of lower trophic groups is poor and these groups are not parameterised at all well in either of the models. We hypothesize that advection of the mesopelagic fishes is required to support the system as in the contemporary model but to a larger degree. We were unable to determine the rate of advection but based on similar models of southern Tasmanian seamounts we concluded that the required rate was feasible. However, this remains a significant gap in our knowledge and limits the validation of both models. Furthermore, we recognise that the pre-fishing model of 1914 does not represent the pristine system because in 1914 seals and whales were at a very low population levels following exploitation during the previous century.

Overall, the trophic model predictions reflected the complexity of the underlying structure. The predictions were not always intuitive and required careful interpretation based on sound ecological principles. While simple sensitivity analyses revealed the trophic groups and their parameters that were liable to cause significant variations in other groups. We were not able to systematically address the uncertainty within the model structure i.e. the definition and population of the model groups and the presence or absence of interactions between them. However, this model presents a feasible representation of the system consistent with observational data from the area and thermodynamic and ecological principles. As such, it represents the best available tool to address specific issues associated with trophic interaction in the EBS region.

9 BENEFITS

The major beneficiaries of this research will be the Commonwealth, Victorian and NSW state fisheries but also all other commercial fisheries operating in the eastern Bass Strait area. Ecosystem models such as we have developed here are part of the range of tools that will be used in the future to predict the outcomes of management scenarios. This model is just one type of model that is being developed, but will contribute to the development of broader more comprehensive models such as Atlantis currently being developed and used by CSIRO. At the very least it has synthesised data ranging from dietary, ecological, biological and fishery. While we do not presume to have utilised all data that are available, the data we have assimilated into the model are extensive. At best we have provided an ecosystem model that, even without further improvements, is useful to explore or develop hypotheses about the natural system and about the response of the system to effects of fishing. Many of the examples we have described, illustrate just how complex trophic interactions are, and how this complexity causes results in predictions that were not intuitive or expected. This model is a tool to understanding how this ecosystem might behave and will be useful to other model developers by providing alternative results for comparison.

10 FURTHER DEVELOPMENT

Our investigations have highlighted many areas for further research. They include:

- In situ surveys of primary production to ground-truth remote sensing techniques
- Maintenance or establishment of longer time series of observations for oceanographic and primary production, and secondary producers such as zooplankton.
- Develop methods to correlate primary production with fish larval and recruitment processes.
- Improved fisheries data i.e. validation of data and collection of missing data (e.g. effort).
- Incorporation of recreational fishing effort
- Incorporation of data for those under-researched groups particularly the lower trophic groups.
- Development of pre-whaling and -sealing model to suggest a possible pristine ecosystem structure.
- Develop more relevant scenarios of fishing rate variations.

11 PLANNED OUTCOMES

We have synthesised a large amount of existing knowledge about the trophic dynamics of the SEF ecosystem which was achieved through the collation of a considerable amount of data from targetted trophic studies and many other physical, biological and oceanographic studies within the area and more broadly in the South East Fishery zone. In addition, to the specific local data, we gleaned and collated data from the literature pertaining to the same or similar species, and from other similar ecosystem models where appropriate. We also collated a vast amount of fisheries statistics of variable quality to fit the model to the observed data. Because much of this data are of dubious quality, we also took into account, as far as we knew, the current hypotheses of the states of the stocks. The resulting model is indeed a synthesis of all this knowledge, and while still imperfect and capable of much more development and tuning, is a significant step towards a better understanding of the ecosystem in which the fisheries operate.

We identified potential ecosystem responses to changes in environmental conditions and specific fisheries management issues in the SEF of concern to managers, fishers and the general public such as impacts of seal recovery and reductions in discarding examined in this report. We achieved this through the development of simple scenarios and tested them on our model. The results are not intended to be quantitative predictions but are indicators of possible responses. But even more importantly, our results represent the development of more hypotheses and directions for future work. The area of our model has being heavily exploited over most of last century, particularly during the latter half, and while there is a wealth of data as a result of this, some key parameters are still poorly known or unknown. Unfortunately we could not be exhaustive in our search for data for all parts of the system and the likelihood that this data exists is quite high. A first step in improving this model would be to unearth and incorporate this knowledge and review existing data by involving a wider panel of expertise.

However, we provided a serious attempt to consider ecosystem-wide responses to issues of concern in the management of the fishery, which will supplement a quantitative risk assessment of the fisheries, enabling the fishery to meet the requirements of the EPBC Act. We have provided an historical reference, or at least one possibility, and a wealth of possibilities for further work in this area. We have provided a current reference for comparison with larger and more complex ecosystem models, and is useful from that view alone. While the modelling technique appears to be deceptively simple, it is still a complex modelling suite, operating on a very simplified representation of a complex system. Therefore, we cannot hope to successfully model all elements with this particular model but we have provided a foundation model from which to build other models focussed on specific questions.

PROJECT STAFF

Name	Position	Qualification	%
Catherine Bulman	Fisheries biologist	PhD	60
Scott Condie	Oceanographic modeller	PhD	20
Xi He	Fisheries Modeller	PhD	30(to 30/4/02)
Dianne Furlani	Fisheries biologist	B.Sc.(Hons)	30
Madeleine Cahill	Oceanographic modeller	PhD	30
Neil Klaer	Fisheries biologist	M.App.Sc	20
Chris Rathbone	Remote sensing specialist	B.Sc.(Hons)	10
Ian Knuckey	Fishwell Pty Ltd	PhD	-
Simon Goldsworthy	Marine mammal ecologist	PhD	-

INTELLECTUAL PROPERTY

The intellectual property arising from this works is the property of CSIRO and FRDC.

12 COMMUNICATIONS

Bulman, C., Condie, S. Furlani, D., He, X., Rathbone, C., Knuckey, I., and Goldsworthy, S. (2002). 'Trophodynamic modelling of the Eastern Bass Strait shelf.' Final Report for the National Oceans Office. (CSIRO, NOO and FRDC: Hobart.) This was completed in September 2002 as fulfilment of requirements of objective 3.

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Klaer, N. Presentations of SE shelf historical work to the History of Marine Animal Populations (HMAP) sub-project of the Census of Marine Life (10 participating countries)

August 2003 (Durham, New Hampshire, USA)

August 2004 (Esbjerg, Denmark)

October 2005 (Kolding, Denmark) Final results to be presented.

Klaer, N. (2004). Presentation of the work trying to link fish catch with oceanographic conditions to a Shelf Assessment Group meeting. May 2004. Eden. (Industry, AFMA, State fisheries, CSIRO)

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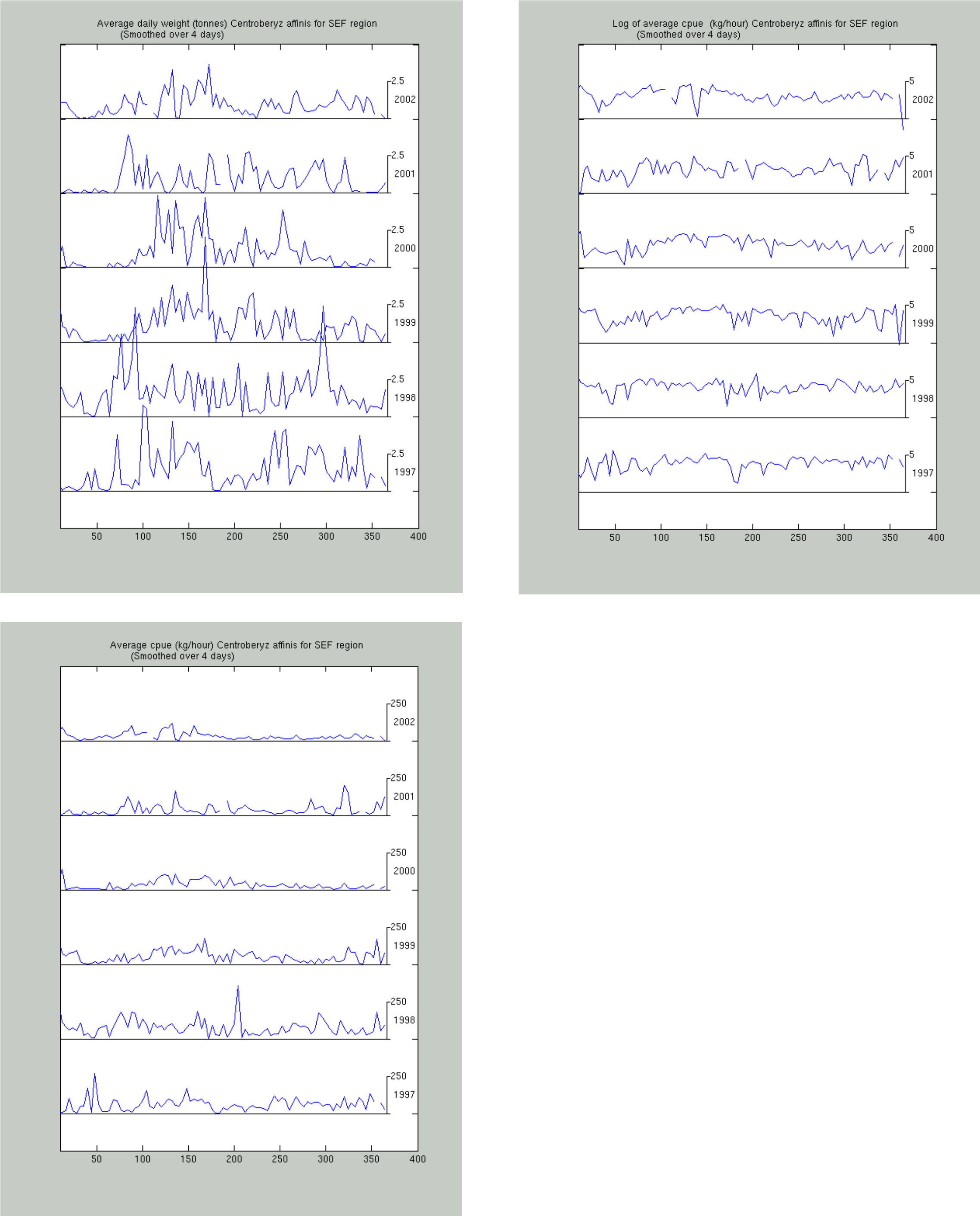
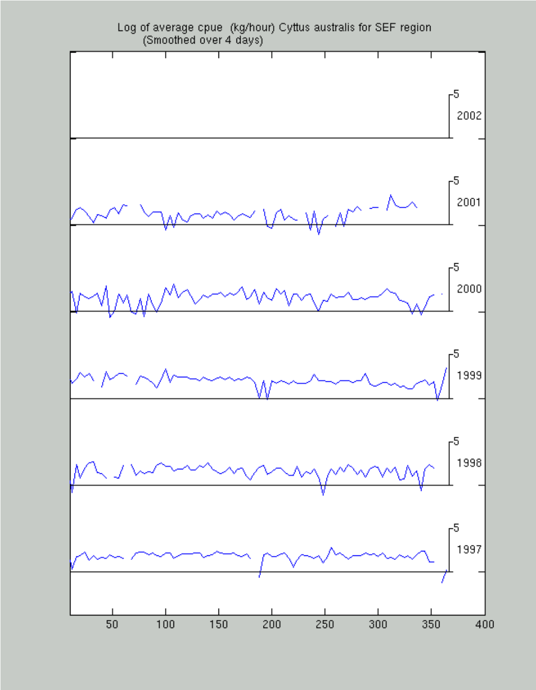
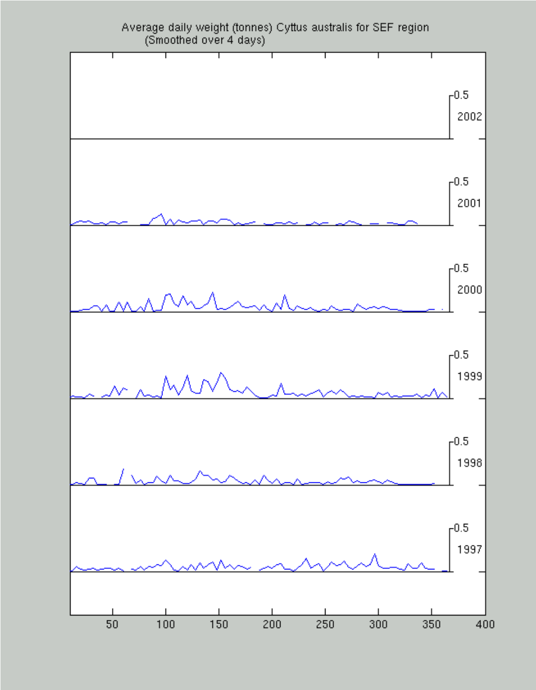
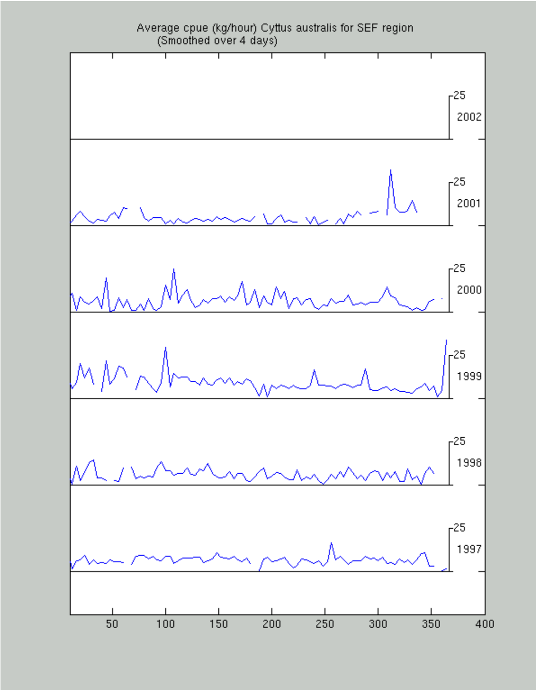
APPENDIX A: FISHERY PRODUCTION PLOTS



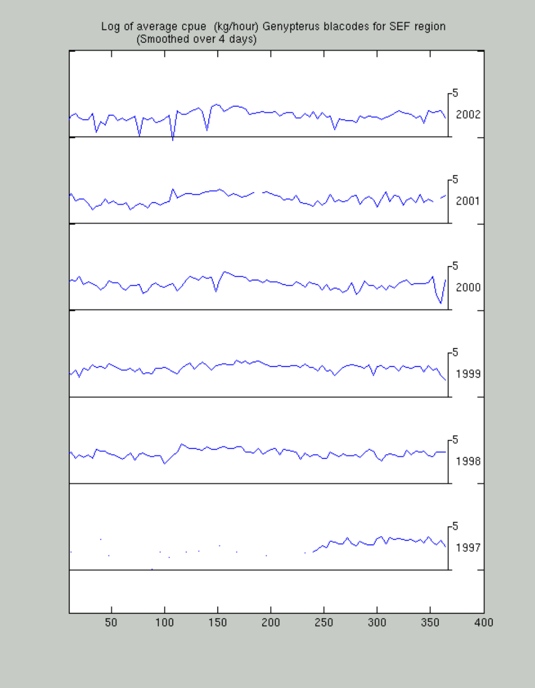
A1. *Centroberyx affinis* 4-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.

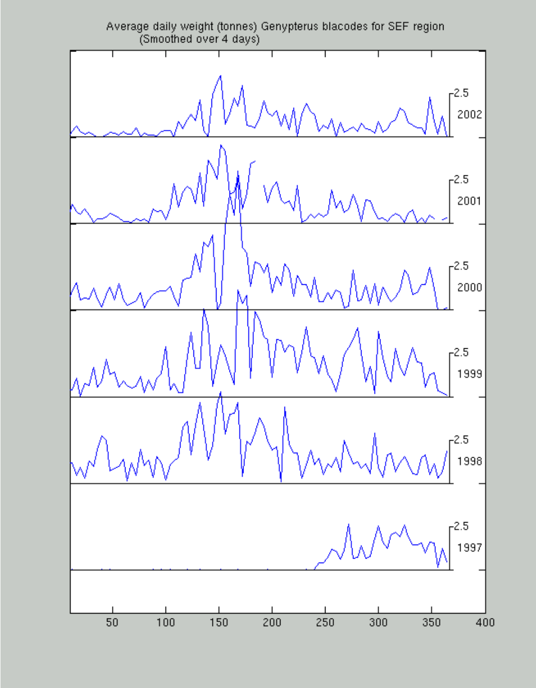


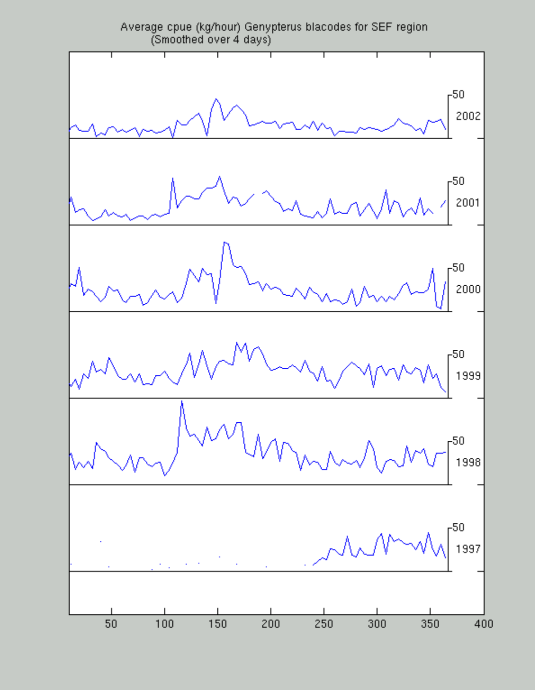




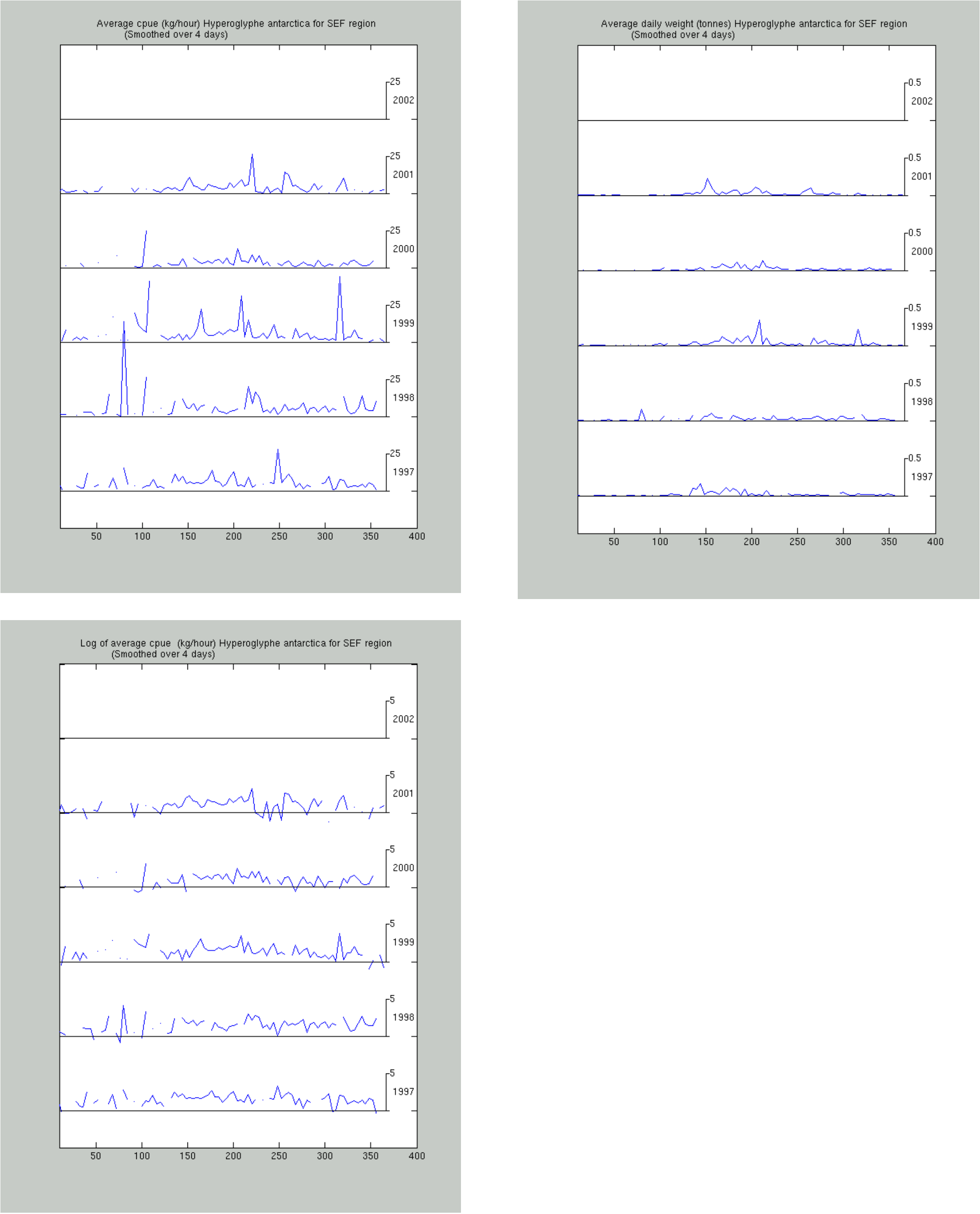
A2. *Cyttus australis* 4-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.



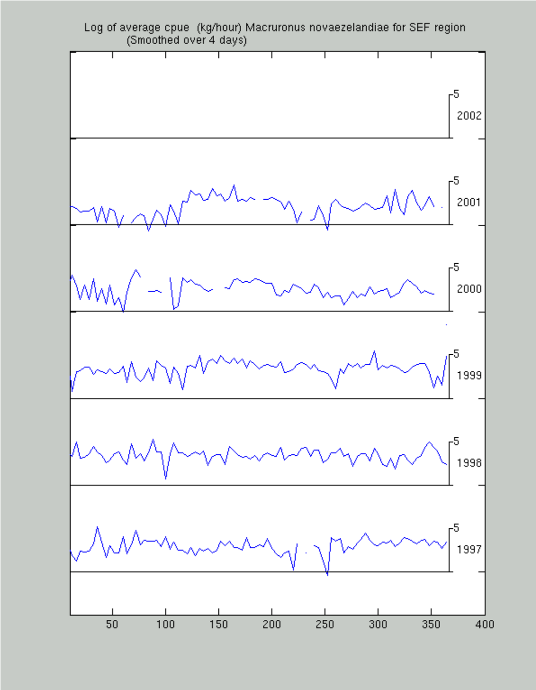


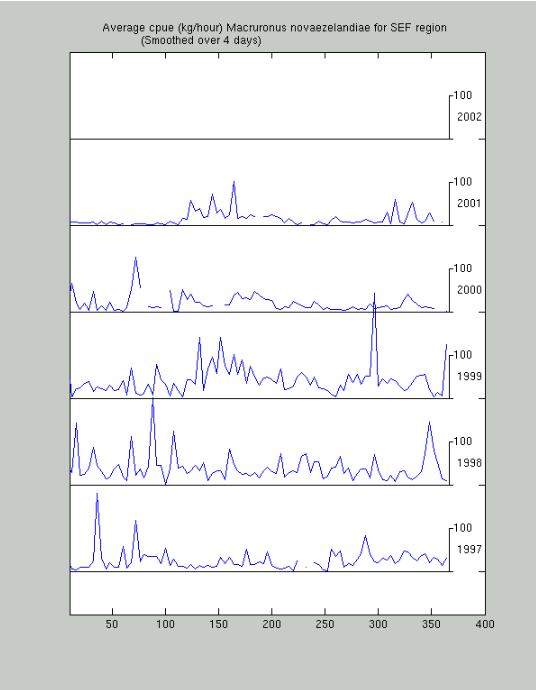


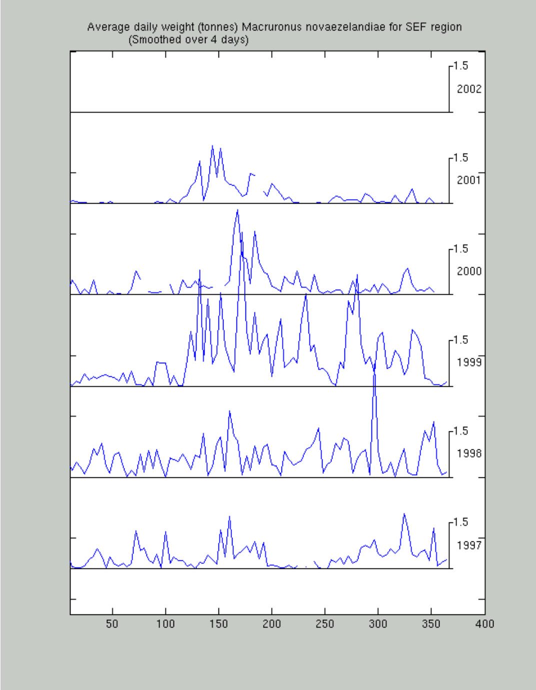
A3. *Genypterus blacodes 4*-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.



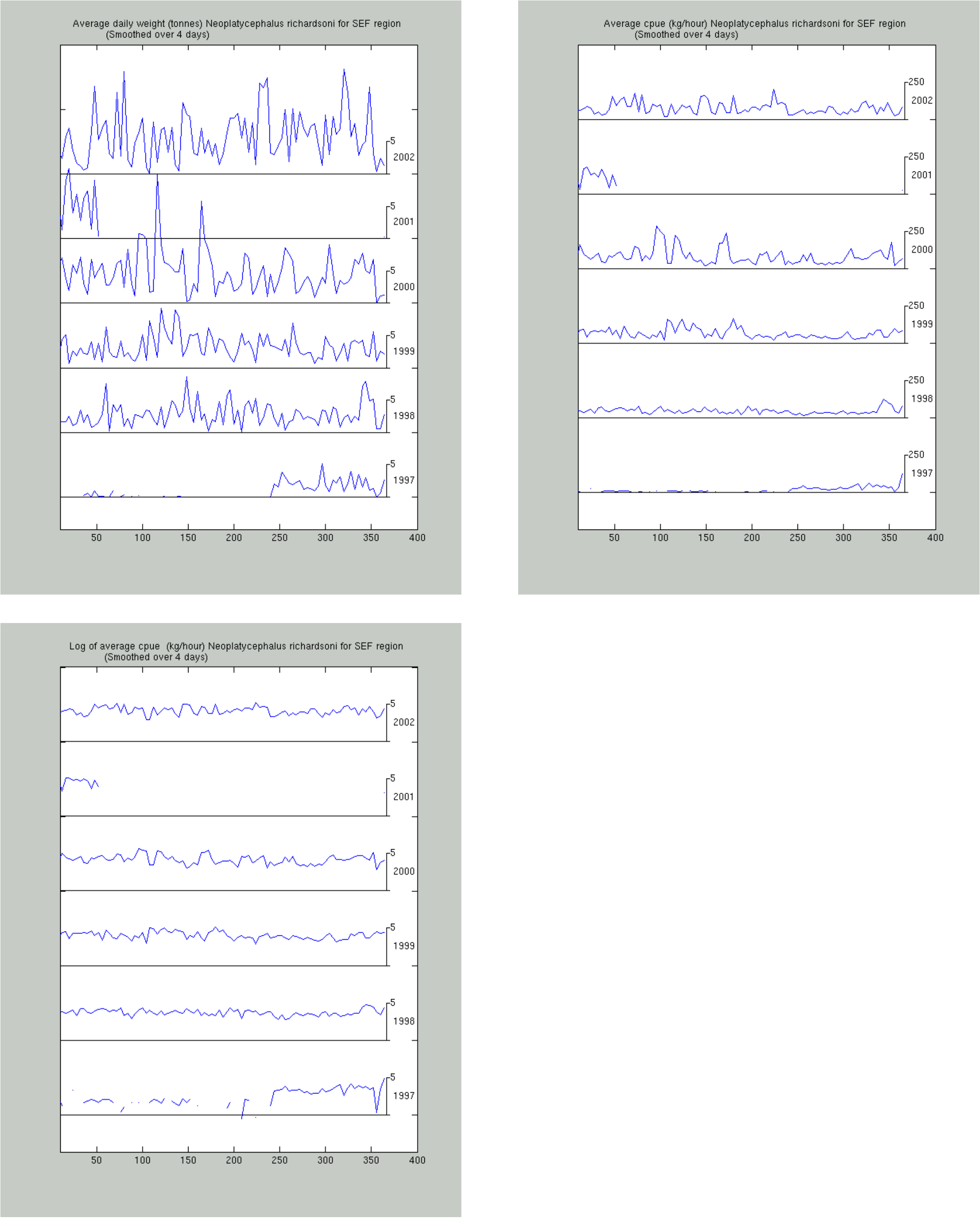
A4. *Hyperoglyphe antarctica* 4-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.



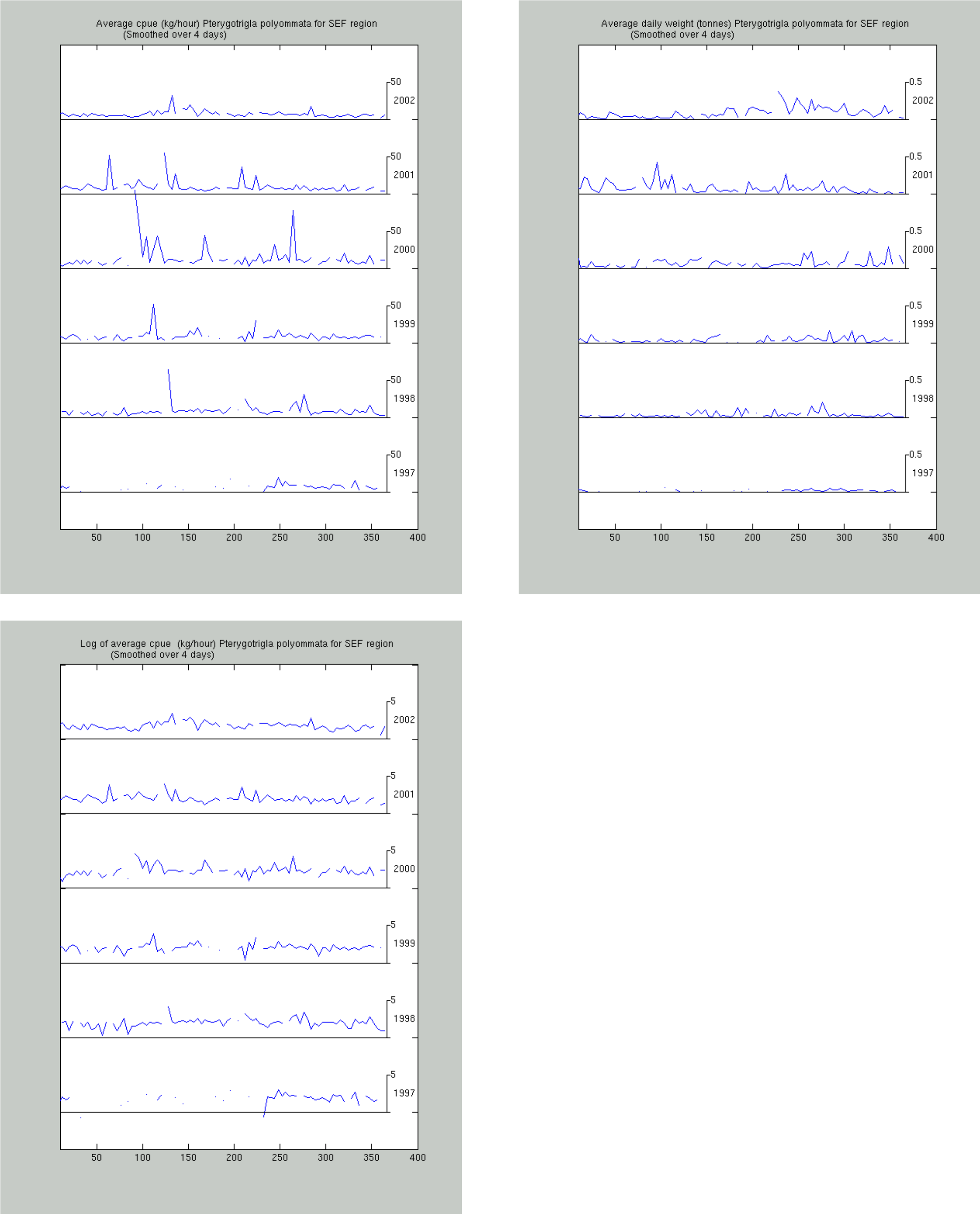




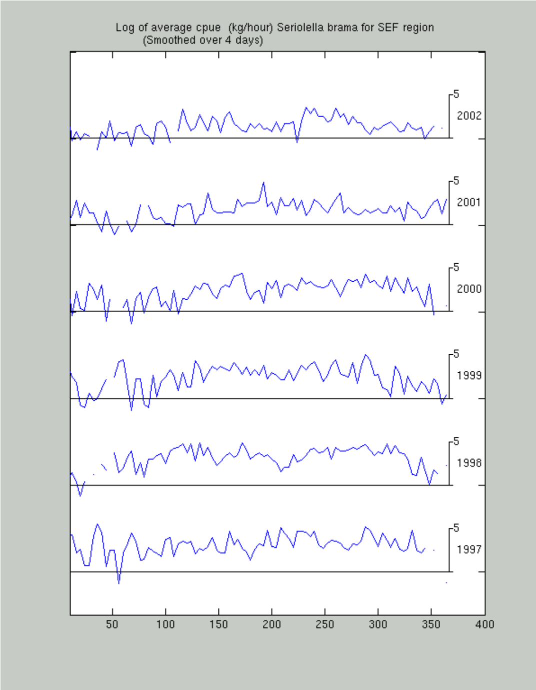
A5. *Macruronus novaezelandiae 4*-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.

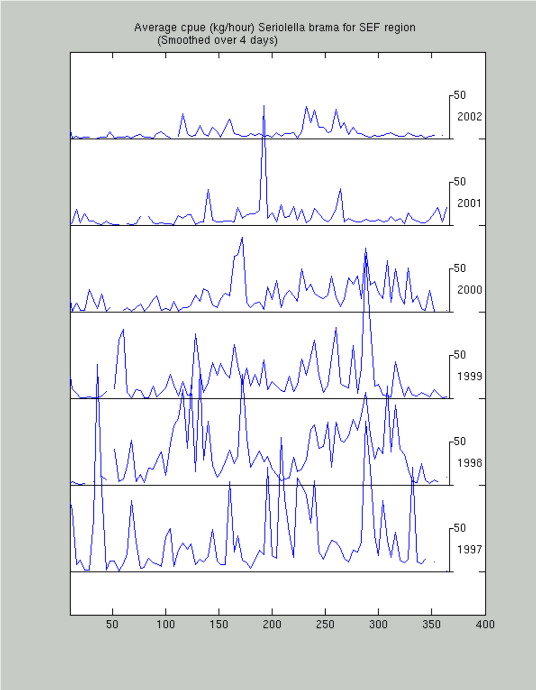


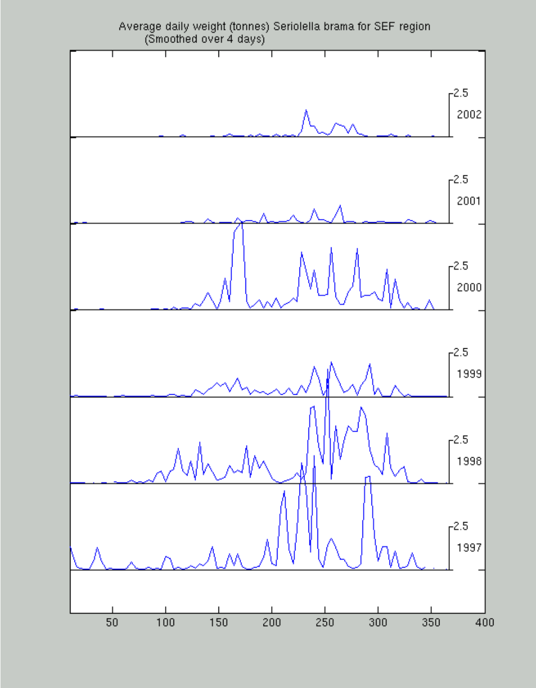
A6. *Neoplatycephalus richardsoni* 4-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.



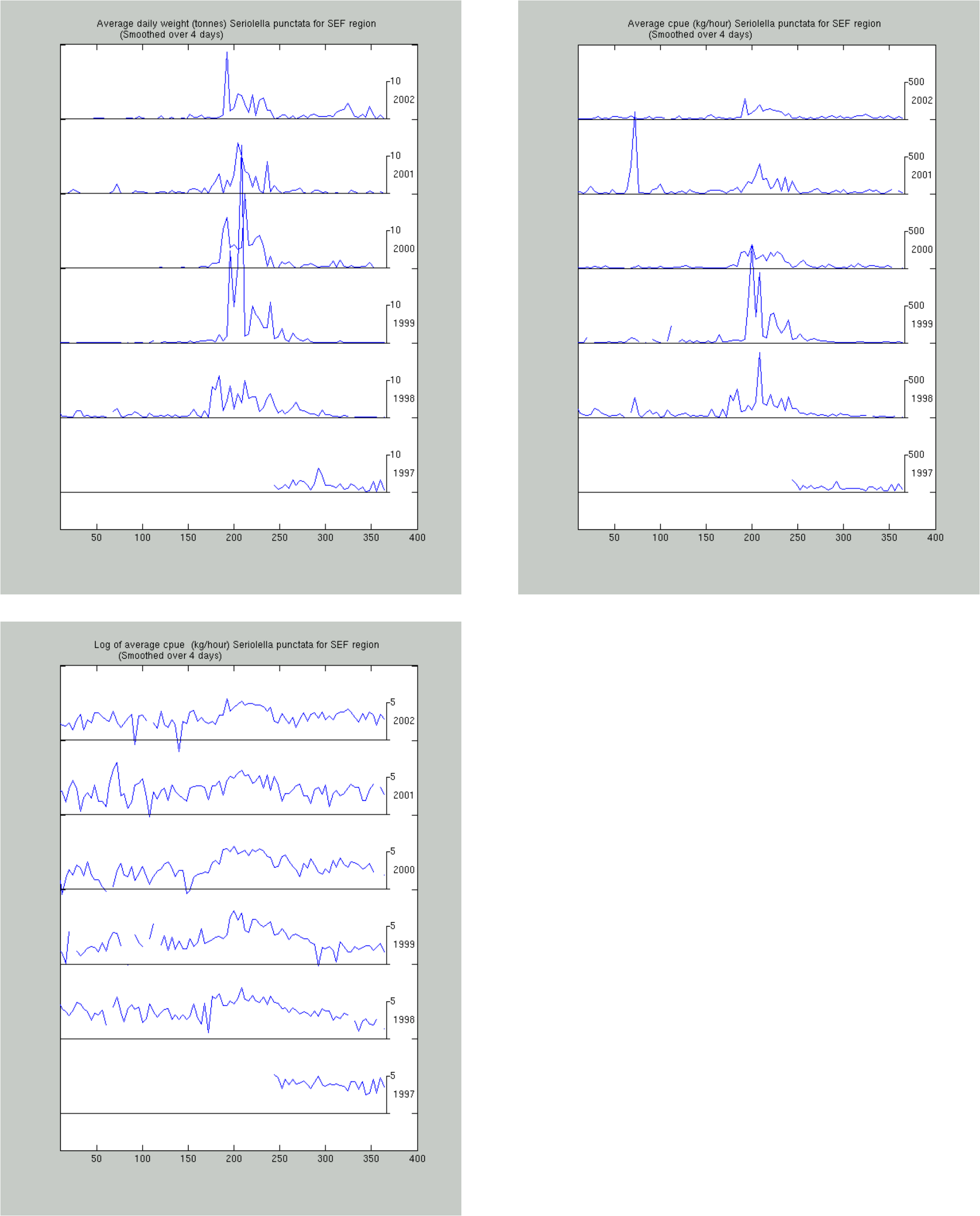
A7. *Pterygotrigla polyommata* 4-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.



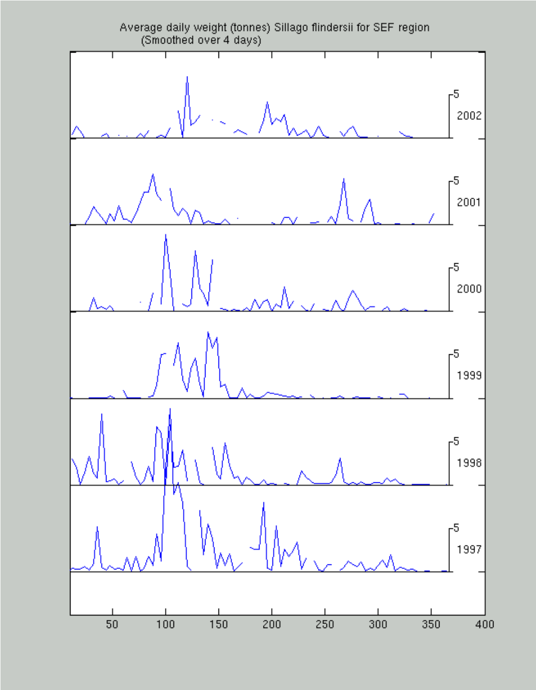


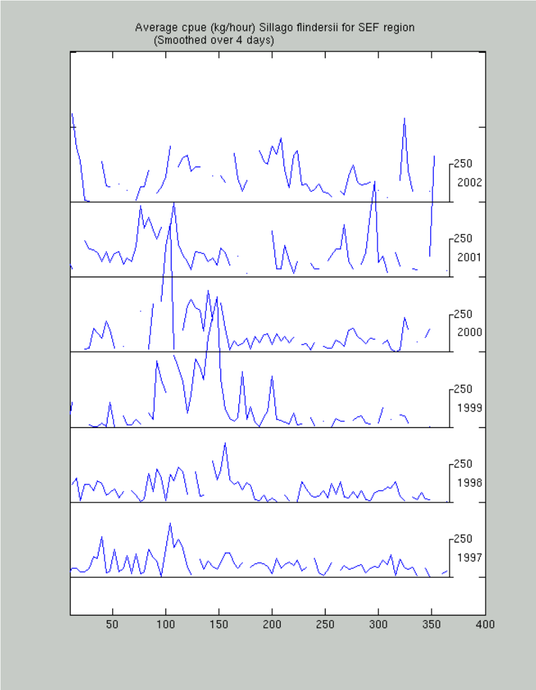


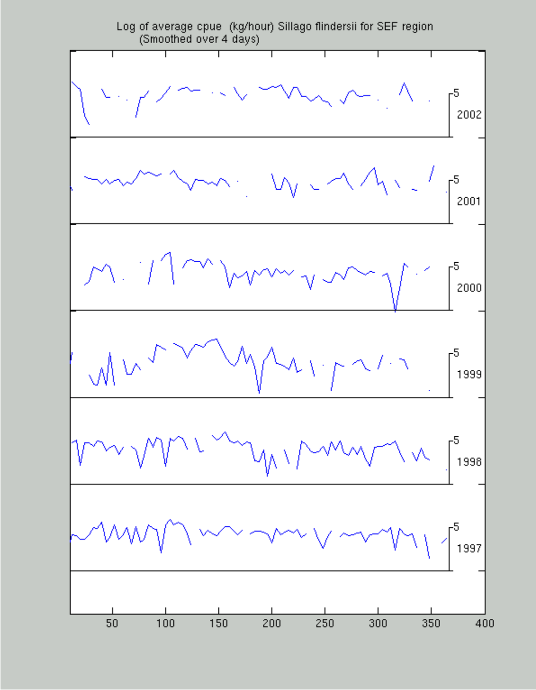
A8. *Seriolella brama* 4-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.



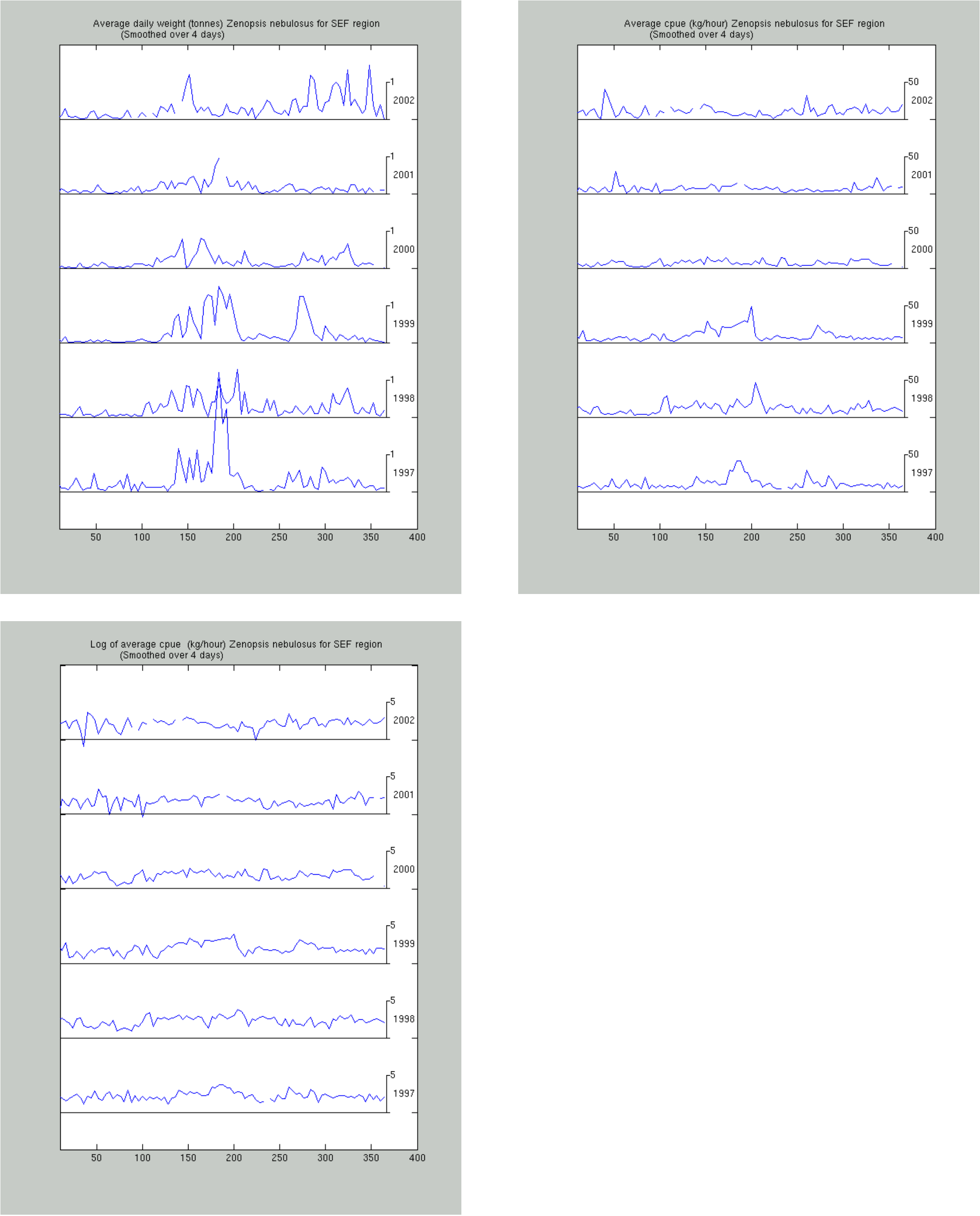
A9. *Seriolella punctata 4*-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.



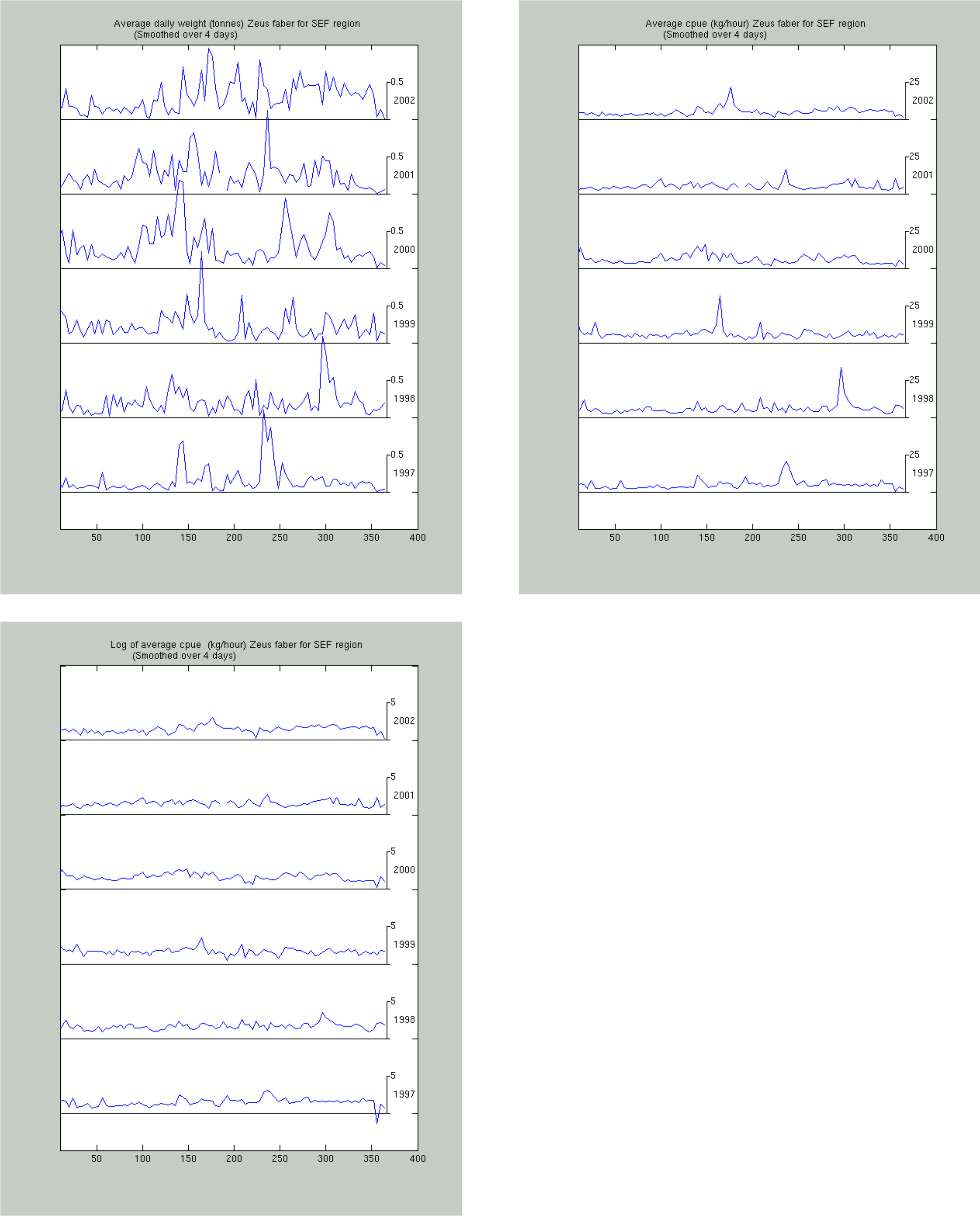




A10. *Sillago flindersi 4*-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.



A11. *Zenopsis nebulosus* 4-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.



A12. *Zeus faber* 4-day averages of catch weight, log CPUE and CPUE plotted over years 1997 to 2002.

APPENDIX B: ECOPATH MODEL EQUATIONS

Ecopath

Ecopath was based on the approach developed by Polovina (1984) where biomass and food consumption of the various groups are estimated using mass-balance principles, and combined with an analysis of the flows between the groups by Ulanowicz (1986). The model describes an average state, rather than a steady state [? Again this is not clear to me]. Once the model is parameterized, it can be used in the temporal and spatial components, Ecosim and Ecospace. The ecosystem is compartmentalized into groups of either single species, or of many species, grouped functionally based on taxonomy or ecology of the species. There are two master equations describing production and energy balance for each group.
Production = catches + predation mortality + biomass accumulation + net migration + other mortality. This can be expressed mathematically as:

$$P = Y_i + B_i M2_i + E_i + BA_i + P_i(1 - EE_i) \tag{1}$$

where, for group *i*, P_i is the total production; Y_i is the total fishery catch; $M2_i$ is the total predation mortality on group i, and $M2_i = \sum_{j=1}^{n} Q_j DC_{ji}$; Q_j is consumption of predator *j*; B_i is the biomass; E_i is the net migration (emigration-immigration); BA_i is the biomass accumulation rate; and $P_i(1\text{-}EE_i)$ = other mortality rate, $M0_i$, and where *EE*, the ecotrophic efficiency, is the proportion of production of *i* that is utilised in the system. This can be re-expressed as:

$$B_i(PB^{-1})_i EE_i - \sum_{j=1}^{n} B_j (QB^{-1})_j DC_{ij} - Y_i - E_i - BA_i = 0 \tag{2}$$

where PB^{-1} is production/biomass ratio and can generally be input as total mortality rate *Z* estimated in stock assessment models , QB^{-1} is consumption/biomass ratio, and DC_{ij} is the fraction of prey *i* in the diet of predator *j*. For a system of n groups this gives n linear equations that can be solved simultaneously

$$a_{1,1}X_1 + a_{1,2}X_2 + \ldots a_{1m}X_m = Q_1$$

:

:

$$a_{n1}X_1 + a_{n2}X_2 + \ldots a_{nm}X_m = Q_n \tag{3}$$

where *n* is the number of equations and m is the number of unknowns. In matrix notation this is

$$\left[A\right]_{nm}\left[X\right]_m = \left[Q\right]_m \tag{4}$$

and

$$\left[X\right]_m = \left[Q\right]_m \left[A^{-1}\right]_{nm} \tag{5}$$

The series of simultaneous equations is solved by a generalised inverse method. If the equations are over-determined i.e., there are more equations than unknowns and the equations are not consistent with each other, a least squares estimate will minimise the discrepancies. If they are under-determined, i.e., number of equations is less than the number of unknowns, non-unique solutions consistent with the data are found.

In the Ecopath model, the energy input and output of each box is balanced. The second master equation balances production with other flows so that:

consumption = production + respiration + unassimilated food.

This is based on the Winberg (1956) concept of the sum of somatic and gonadal growth, metabolism and waste. However, the Ecopath function differs in that it estimates losses and doesn't explicitly include gonadal growth, which is included in the predation mortality term. Respiration is determined by the difference between consumption, and production and unassimilated food, however it can be input. Energy is the currency used in all three programs but nutrients can also be used in Ecopath.

To parameterise the model three of the four terms, *B*, *P/B*, *Q/B* or *EE*, must be supplied. If all four of the terms are entered, the program will ask if biomass accumulation or net migration is to be estimated. Also required are diet composition *DC*, assimilation rate, net migration *E*, catch *Y*, and biomass accumulation *BA*, the last three of which may be zero.

Uncertainty within parameters can be addressed in Ecopath by using the EcoRanger module. This allows entry of a mean and range for basic parameters and random input variables are drawn from a frequency distribution. The best model from a range of models is chosen based on a criterion such as the minimum residual. This therefore allows for a statistically based approach to fitting models within given constraints. [EcoRanger was not used, so is it useful to describe it here?]

Ecosim

Ecosim was developed by incorporation of coupled differential and difference equations into Ecopath, to allow for dynamic simulations (Walters *et al.* 1997). Biomass flux rates are expressed as a function of time varying biomass and harvest rates (Christensen *et al.* 2000). Predator-prey interactions can be varied to emulate top-down or bottom-up control (Walters *et al.* 2000, Bundy 2001). Time series data on biomass, catch rates, fishing effort etc. can be fitted and makes this program useful to explore options for management policies.

The basic equation modified from the basic Ecopath equation 2 is:

$$dB_i / dt = g_i \sum_i Q_{ij} - \sum_j Q_{ij} + I_i - (M_i + F_i + e_i) B_i \qquad 6$$

where dB_i/dt is the growth rate of group i in biomass, g_i is the net growth efficiency or production/consumption ratio, Qij is the consumption of prey j by predator i, M_i is the other mortality, F_i is the fishing rate, e_i is emigration rate, and I_i is the immigration rate. The first summation is the total consumption by group i and the second is the total consumption on group i. The biomasses of groups are split into vulnerable and invulnerable and it is the transfer rate, v_{ij}, between them that determines the type of control over the interactions, i.e. bottom-up donor driven or top-down Lotka-Volterra type. Mixed control is also possible.

The Lotka-Volterra assumption has usually been used to predict flows, $c_{ij}(B_i, B_j)$, so that:

$$c_{ij}(B_i, B_j) = a_{ij} B_i B_j \qquad 7$$

where a_{ij} is the instantaneous rate of mortality on i by j and c_{ij} (formerly Q_{ij} in Ecopath) is consumption. The problems with this equation are that satiation by a predator is not accounted for, but is thought to be minor, and that the vulnerability of prey to predators, determined by behavioural factors or physical factors such as habitat. For example, diel vertical migration of mesopelagic fishes might make them unavailable to predator fishes for part of the day. This is a critical concept in Ecosim (Walters *et al.* 1999) and in Ecosim it is possible to vary the amount of biomass of prey i available to predator j. Consumption rate, c_{ij}, is then derived by;

$$c_{ij} = v_{ij} a_{ij} B_j B_i / (2 v_{ij} + a_{ij} B_j) \qquad 8$$

The available biomass, V_{ij} , exchanges with the unavailable biomass B_i-V_{ij} according to:

$$dV_{ij} / dt = v_{ij}(B_i - V_{ij}) - v_{ij}V_{ij} - a_{ij}V_{ij}B_j \quad 9$$

The available biomass is added to from the unavailable pool at the rate of v_{ij}, and biomass is returned at the rate $v_{ij}V_{ij}$. Biomass is also being removed from the available biomass by predators at the rate, $a_{ij}V_{ij}B_j$, the mass-action encounter rate (Walters *et al.* 1997). Low values of v_{ij} and high values of a_{ij} imply a ratio-independent interaction leading to bottom-up control, whereas high values imply a mass-action interaction leading to top-down control (Walters *et al.*1997).

Functions also exist for computing flows between split-pools i.e. between juveniles and adults, each group having their own parameters, but stock recruitment relationships are accounted for by using delay-difference equations. Functions for either computing flows where prey or predator biomass levels increase to high levels and for handling detritus are also added. The differential equations are solved using an Adams-Basforth integration routine or a Runge-Kutta 4th order routine

Failures of the Ecosim model to predict flows when there are large changes in prey or predator biomass could occur due to predator satiation during high abundance of prey, prey-switching when prey abundance is low or when predation risk increases due to changes of behaviour or vulnerability.

Ecospace

Ecospace uses a defined rectangular grid of cells for which a differential equation system of equations based on Equation 6 and 8 and delay-difference equations for split pools. The cells are assigned either land or water and a habitat type. Movement is allowed across the face of the cells but not land or diagonally. Areas or cells of higher primary productivity, and restricted or closed fishing areas, can be assigned.

Immigration I_i for each cell is made up of four components, the emigration flows across each face of the cell from the surrounding cells (except on the boundary). These flows are represented by:

$$e_i = m_i B_i \quad 10$$

where m_i is the instantaneous movement rate. The rate will be affected by the way in which the organism is transported i.e. by itself or reliant on advective process; whether an organism prefers specific habitats thus increasing the emigration rate from non-preferred habitat type cells; and the response of the organism to predator risk relative to prey abundance. Emigration rate is calculated from the average speed of movement of the organism and is proportional to the speed and inversely proportional to the cell size. A problem with this is the fact that organism’s movements are likely to be made up of two types: many short movements within a home range and a few longer movements such as migrations. Most movements are non-random but the Eulerian approach does not allow a history to be attached. Cells on boundaries are therefore vulnerable to exploitation. Another problem is the fact that organisms might have preferred habitats thus the probability of moving in the direction of that habitat is increased. Feeding efficiencies and predation risk are likely to be affected also.

Fishing mortality for each cell can be separated by gear where a variety of gear is used. This allows for situations where effort might be higher such as on the boundary of an MPA. For each gear in the initial Ecopath analysis, a gravity model represents spatial distribution of fishing mortality. The proportion of total effort E is proportional to the sum over all groups of biomass x catchability x price of target groups. If there are N cells, each gear k can exert a total mortality rate NF_k over the whole grid. This rate is distributed over cells c in proportion to gravity weights G_{kc}:

$$G_{kc} = O_{kc}U_{kc}(P_{ki}q_{ki}B_{ic}) \quad 11$$

where O_{kc} is 1 if open to the fleet or 0 if not, U_{kc} is 1 if gear k can fish the habitat type assigned to the cell, p_{kc} is relative price, q_{kc} is catchability, B is the current biomass, and c is the relative cost of fishing in the cell. Total mortality NF_k is distributed among cells by:

$$F_{kc} = Nf_{kc}G_{kc} / \sum G_{kc} \qquad 12$$

The differential equations of Ecosim/Ecospace have a structure that is exploited to develop efficient algorithms. For any B, i.e. in any cell at any time t:

$$dB / dt = (I + gC) - (Z + E)B \qquad 13$$

where I is total immigration rate and E is total instantaneous emigration rate. If the rate components were constant over time, B would move toward equilibrium,

$$B_e = (I + gC)/(Z + E) \qquad 14$$

along a time trajectory,

$$B_{t+\Delta t} = W_t B_t + (1 - W_t)B_e \qquad 15$$

where the exponential weight, $W_t = e^{-(Z+E)\Delta t}$. Therefore, W is pre-computed for each group by using movement parameters m and mortality rates Z. For each time step, equilibrium biomass B_e is calculated for each group, before updating the biomass estimates for the next time interval. Walters *et al.* (1999) found that by splitting the fast, e.g., phytoplankton, and slow, e.g., fish and marine mammals, variables, computation was sped up enormously. They found that fast variables generally tracked the moving equilibria of slow variables. However, the speed of computation has been facilitated at the expense of being able to incorporate seasonal variation in system "forcing" i.e. physical mixing and plankton, and dispersal-migration behaviours, which were available in Ecosim. In addition, the preservation of persistent time lag structure might dampen or lose the cyclical behaviour of predator-prey interactions (Walters *et al.* 1999). Ecospace is therefore capable of providing general indications of biomass responses to MPAs and should not be expected to provide more. Walters *et al.* (1999) suggested that it is as a useful tool to synthesize information, to design better management experiments and monitoring programs to evaluate policies rather than for providing the quantitative predictions about the policies.

APPENDIX C: DIETS FROM 1994 SEF STUDY

Dietary data from the 1994 CSIRO survey of the shelf (Bax and Williams 2001) for all available species were used in the construction of the trophic model. This data were modified to account for the aggregate groupings of species. For each species within an aggregate group, the proportions of prey were weighted by that species’ proportion, in terms of biomass, in the group. The overall diet for the aggregate grouping was obtained by adding the species’ contributions to each prey.

For species where dietary data were not locally available data there was a hierarchical procedure used to first search and then assign a level of confidence to the data in the model. Data would be sought first from within the SEF region, then from different regions for the same species, from FishBase where data confidence could vary from high to low according to the source, and then, as a last resort, from other models, where the data were inevitably from different regions and therefore the confidence low. A level of confidence in the dietary data were assigned within the Pedigree module of the model.

Predators		Prey by Trophic group																																				
Trophic Group	Predator species	Abundance (final)	Ppn of diet group abundance	demersal shark	ray	redbait	redfish	ling	jack mackerel	flathead	ocean perch	cucumber fish	school whiting	cardinal fish	shelf small invertebrate feeder	shelf small predator	shelf medium invertebrate feeder	shelf medium predator	shelf large invertebrate feeder	shelf large predator	slope ocean perch	Slope small predator	slope medium invertebrate feeder	slope medium predator	pelagic small invertebrate feeder	pelagic medium invertebrate feeder	mesopelagic	squid	prawns	macrobenthos	megabenthos	polychaeta	Gelatinous nekton	large zooplankton	small zooplankton	Primary producers	other	unidentified fish (for pro-rating)
Cardinal fish	*Apogonops anomalus*	0.811	1																								0.83		0.01		0.01	0		0.14	0		0.01	0.6
Cucumberfish	*Chlorophthalmus nigripinnis*	2.486	1												0.04		0.05					0.01						0.02	0	0.09	0.1	0.03	0.06	0.39	0.07		0.13	0.08
Demersal sharks	*Cephaloscyllium laticeps*	0.725	0.25		0.02		0.03	0.03	0.44			0.02			0.03		0	0.01		0.01							0	0.07	0.02	0.01	0.29	0			0		0.00	0.12
	Galeorhinus galeus	0.211	0.07						0.81						0.14													0.02		0	0.02			0.01	0			0.37
	Mustelus antarcticus	1.065	0.36						0.1									0										0.41	0.06	0	0.37				0.05			0.01
	Squalus megalops	0.669	0.23	0.21						0		0.01		0.16	0.02		0.03	0.03	0					0.05	0.01		0	0.18	0	0.01	0.24	0.01	0	0	0.01		0.01	0.28
	Squatina australis	0.257	0.09			0.07	0.16						0.14		0.2		0.06	0.02	0.05				0.25					0.01	0	0	0	0		0	0.02	0	0.00	0.69
	Total Demersal sharks	0.603		0.05	0.01	0.01	0.02	0.01	0.2	0		0.01	0.01	0.04	0.04		0.01	0.01	0.01	0			0.02	0.01	0		0	0.21	0.03	0.01	0.26	0	0	0	0.03	0	0.00	0.19
Dories	*Cyttus australis*	0.108	0.51									0.21	0	0.29	0.37		0.03	0.03	0									0	0.02	0	0.02			0.02	0.01		0.00	0.05
	Zenopsis nebulosus	0.028	0.13			0.45			0.52					0.01													0.02				0				0		0.00	0.03
	Zeus faber	0.074	0.35			0.1	0.11		0.49		0	0.12	0.01	0.02	0.1		0.02	0.01							0.01			0.02		0	0	0	0	0	0		0.00	0.11
	Total Dories	0.537				0.1	0.04		0.24		0	0.15	0.01	0.16	0.22		0.02	0.02	0						0		0	0.01	0.01	0	0.01	0	0	0.01	0		0.00	0.07
Flathead	*Neoplatycephalus richardsoni*	0.262	0.6					0.02	0.01			0.21	0.07	0.05	0.12		0.15	0.01	0.17	0					0.01	0.06	0.06	0	0	0	0.01	0	0	0.02	0.01		0.00	0.19
	Platycephalus bassensis	0.172	0.4										0				0.91													0.01	0.01	0	0.06	0				0.25
	Total Flathead	1						0.01	0.01			0.13	0.04	0.03	0.08		0.45	0	0.1	0					0.01	0.04	0.04	0	0	0.01	0.01	0	0.02	0.01	0.01		0.00	0.22
Gemfish	*Rexea solandri*	0.088	1											0.94																							0.06	0.79

Predators		Prey by Trophic group																																				
Trophic Group	Predator species	Abundance (final)	Ppn of diet group abundance	demersal shark	ray	redbait	redfish	ling	jack mackerel	flathead	ocean perch	cucumber fish	school whiting	cardinal fish	shelf small invertebrate feeder	shelf small predator	shelf medium invertebrate feeder	shelf medium predator	shelf large invertebrate feeder	shelf large predator	slope ocean perch	Slope small predator	slope medium invertebrate feeder	slope medium predator	pelagic small invertebrate feeder	pelagic medium invertebrate feeder	mesopelagic	squid	prawns	macrobenthos	megabenthos	polychaeta	Gelatinous nekton	large zooplankton	small zooplankton	Primary producers	other	unidentified fish (for pro-rating)
Jack mackerel	*Trachurus declivis*	6.23	1											0.01	0		0	0									0.3		0	0.01	0.01	0	0.01	0.44	0.18	0	0.02	0.13
Jackass morwong	*Nemadactylus macropterus*	0.628	1											0.09	0.01		0.01	0		0							0	0.01	0.02	0.05	0.08	0.43	0	0.15	0.07	0	0.08	0.05
Ling	*Genypterus blacodes*	0.064	1								0	0.08			0.47		0.2		0.06			0.01					0		0.01	0	0.1	0		0.07	0.01		0.00	0.02
Pelagic medium predator	*Scomber australasicus*	0.069	1																						0.38				0	0		0	0.35	0.22	0.05		0.01	0.38
Rays	*Narcine tasmaniensis*	0.052	0.06																										0	0.12	0.01	0.84		0.02	0		0.01	
	Raja australis	0.015	0.02												0.01														0.14		0.83	0		0	0.01		0.01	0.01
	Raja sp A	0.248	0.28												0.07		0.4			0								0.01	0.02	0	0.45	0		0	0.03		0.01	0.04
	Urolophus cruciatus	0.119	0.14																										0.02	0.2	0.15	0.44	0	0.05	0.06		0.08	
	Urolophus paucimaculatus	0.254	0.29												0													0	0.2	0	0.29	0.19		0.08	0.16		0.07	0
	Urolophus sp A	0.023	0.03																										0.2	0	0.7	0		0.06			0.04	
	Urolophus viridis	0.165	0.19														0.03												0.02	0.02	0.3	0.16		0.12	0.3		0.06	0.03
	Total Rays	0.174													0.02		0.12			0								0	0.08	0.04	0.32	0.2	0	0.05	0.12		0.05	0.02
Redbait	*Emmelichthys nitidus*	0.53	1																								0.04	0	0	0	0	0	0.26	0.17	0.16		0.37	0.04
Redfish	*Centroberyx affinis*	1.745	1									0		0.26	0.01		0		0.02		0.01	0	0				0.07	0	0.03	0	0.06	0	0	0.4	0.14		0.00	0.03
School whiting	*Sillago flindersi*	1.69	1														0.25											0.01		0.21	0.01	0.43		0.02	0.01		0.07	0.22
Shelf large predator	*Latris lineata*	0.029	0.01								0.16	0.08		0.13	0.35		0.15				0.06									0.02	0		0.04	0				0.2

Predators		Prey by Trophic group																																				
Trophic Group	Predator species	Abundance (final)	Ppn of diet group abundance	demersal shark	ray	redbait	redfish	ling	jack mackerel	flathead	ocean perch	cucumber fish	school whiting	cardinal fish	shelf small invertebrate feeder	shelf small predator	shelf medium invertebrate feeder	shelf medium predator	shelf large invertebrate feeder	shelf large predator	slope ocean perch	Slope small predator	slope medium invertebrate feeder	slope medium predator	pelagic small invertebrate feeder	pelagic medium invertebrate feeder	mesopelagic	squid	prawns	macrobenthos	megabenthos	polychaeta	Gelatinous nekton	large zooplankton	small zooplankton	Primary producers	other	unidentified fish (for pro-rating)
	Pagrus auratus	0.242	0.1											0.89			0.07													0	0.04		0	0	0			0
	Pseudocaranx dentex	0.08	0.03									0.02		0.58	0															0	0.12	0		0.01	0		0.25	0
	Thyrsites atun	2.151	0.86			0.05	0		0.69			0.02	0.1	0.08	0		0.05				0				0						0		0	0.01	0		0.00	0.19
	Total shelf large predator	0.968				0.04	0		0.59		0	0.02	0.08	0.18	0		0.05				0				0					0	0.01	0	0	0.01	0		0.01	0.16
Shelf medium invertebrate feeder	*Nemadactylus douglasi*	0.1	0.33												0.05														0	0.02	0.83	0.03		0.02	0.01	0	0.03	0.05
	Latridopsis forsteri	0.029	0.1																											0.04	0.02	0.01		0.06	0.07	0.03	0.78	
	Neosebastes scorpaenoides	0.172	0.57												0.07		0.06	0.08										0		0.12	0.43			0.22	0			0.03
	Total shelf medium invertebrate feeder	0.262													0.06		0.03	0.05										0	0	0.08	0.52	0.01		0.14	0.01	0	0.08	0.03
Shelf medium predator	*Chelidonichthys kumu*	0.095	0.5									0.02			0.38		0.45	0.04										0.01		0.04	0.02	0		0			0.04	0.01
Latchet	*Pterygotrigla polyommata*	0.072	0.38									0.04	0.01	0.01	0.7			0.04					0					0			0.21				0			0.12
	Kathetostoma laeve	0.017	0.09						0.43			0.11			0.29		0.16											0	0	0	0.01			0				0.18
	Ophthalmolepis lineolatus	0.004	0.02												0.34	0.34														0.15	0.1				0		0.06	0.69
	Scorpis lineolatus	0.002	0.01												0.4	0.4																0.02	0	0.18	0	0		0.8
	Total shelf medium predator	0.374							0.04			0.03	0	0	0.49	0.01	0.24	0.03					0					0.01	0	0.02	0.09	0	0	0	0	0	0.02	0.09
Shelf ocean perch	*Helicolenus percoides*	0.236	1	0								0.08		0.07	0.08		0.08	0	0.07	0.01		0.01					0	0.02	0.01	0.03	0.09	0.01	0.34	0.04	0.04	0	0.01	0.12

Predators		Prey by Trophic group																																				
Trophic Group	Predator species	Abundance (final)	Ppn of diet group abundance	demersal shark	ray	redbait	redfish	ling	jack mackerel	flathead	ocean perch	cucumber fish	school whiting	cardinal fish	shelf small invertebrate feeder	shelf small predator	shelf medium invertebrate feeder	shelf medium predator	shelf large invertebrate feeder	shelf large predator	slope ocean perch	Slope small predator	slope medium invertebrate feeder	slope medium predator	pelagic small invertebrate feeder	pelagic medium invertebrate feeder	mesopelagic	squid	prawns	macrobenthos	megabenthos	polychaeta	Gelatinous nekton	large zooplankton	small zooplankton	Primary producers	other	unidentified fish (for pro-rating)
Shelf small invertebrate feeder	*Allomycterus pilatus*	0.194	0.08																										0.15	0.36	0.28		0.01	0	0.2			0
	Arothron firmamentum	0.046	0.02																										0	0.16	0.05	0.03	0	0.18	0.23	0.02	0.33	
	Azygopus pinnifasciatus	0.001	0												0.01	0.01														0.83	0.04	0.08		0.01	0.01		0.01	0.01
	Caelorinchus parvifasciatus	1E-04	0												0.01	0.01														0.07	0.05	0.8		0.01	0.03		0.03	0.02
	Cyttus novaezelandiae	0.023	0.01																															0.95	0.05			
	Diodon nicthemerus	0.316	0.13																											0.48	0.4	0.03	0.01	0.07		0	0.01	
	Lepidotrigla modesta	0.143	0.06														0.01												0.1	0	0.65	0.01		0.12	0.07		0.04	0
	Lepidotrigla mulhalli	0.258	0.11												0.01														0.05	0.01	0.27	0	0	0.49	0.15		0.01	0.01
	Macroramphosus scolopax	0.104	0.04												0.01														0	0.04	0.03	0.04		0.16	0.55		0.17	0
	Meuschenia freycineti	0.036	0.01											0.01														0.03		0.62	0.15	0.04	0.05	0.01	0.05	0	0.04	0.01
	Notolabrus tetricus	0.008	0												0.03	0.03												0.32		0.45	0.1				0.02		0.05	0.07
	Paramonacanthus filicauda	0.422	0.17																											0.01		0		0.03	0.97		0.00	
	Parequula melbournensis	0.376	0.15																											0.18	0	0.66		0	0.02		0.13	
	Parma microlepis	2E-04	0																											0.16		0	0	0.01		0	0.83	

Predators		Prey by Trophic group																																				
Trophic Group	Predator species	Abundance (final)	Ppn of diet group abundance	demersal shark	ray	redbait	redfish	ling	jack mackerel	flathead	ocean perch	cucumber fish	school whiting	cardinal fish	shelf small invertebrate feeder	shelf small predator	shelf medium invertebrate feeder	shelf medium predator	shelf large invertebrate feeder	shelf large predator	slope ocean perch	Slope small predator	slope medium invertebrate feeder	slope medium predator	pelagic small invertebrate feeder	pelagic medium invertebrate feeder	mesopelagic	squid	prawns	macrobenthos	megabenthos	polychaeta	Gelatinous nekton	large zooplankton	small zooplankton	Primary producers	other	unidentified fish (for pro-rating)
	Pempheris multiradiatus	0.022	0.01																												0	0.2	0	0.76	0.03		0.01	
	Pseudolabrus psittaculus	0.005	0												0.13	0.13														0.32				0.01	0.17		0.23	0.27
	Foetorepus calauropomus	0.483	0.2												0	0													0.01	0.29	0.16	0.1		0.03	0.11	0	0.31	0
	Total shelf small invertebrate feeder	0.61												0	0	0	0											0	0.02	0.2	0.18	0.13	0	0.1	0.26	0	0.10	0
Shelf small predator	*Caesioperca rasor*	0.374	0.78												0.7															0.05			0.07	0.04	0.1		0.04	0.7
	Atypichthys strigatus	0.008	0.02												0.83															0	0		0.08	0.02	0	0	0.07	0.83
	Callanthias australis	0.002	0												0.9	0.1																			0			1
	Lepidoperca pulchella	0.076	0.16												0.88	0.1														0.01	0		0	0.01	0		0.00	0.98
	Lepidotrigla vanessa	0.021	0.04												0.37		0.35		0.12									0		0	0.11			0.04	0.01		0.00	0.13
	Total shelf small predator	0.761													0.72	0.02	0.02		0.01									0		0.04	0		0.05	0.03	0.08	0	0.04	0.72
Slope medium invertebrate feeder	*Caelorinchus australis*	0.007															0.21											0.01	0.02	0	0.25	0.23	0.09	0.14	0.06			0.01
Slope medium predator	*Kathetostoma canaster*	0.268	1									0.09		0.27	0.04	0.37	0.16					0	0.01					0.01		0	0.04	0			0		0.00	0.03
	Total slope medium predator	0.85										0.09		0.27	0.04	0.37	0.16					0	0.01					0.01		0	0.04	0			0		0.00	0.03

Predators		Prey by Trophic group																																				
Trophic Group	Predator species	Abundance (final)	Ppn of diet group abundance	demersal shark	ray	redbait	redfish	ling	jack mackerel	flathead	ocean perch	cucumber fish	school whiting	cardinal fish	shelf small invertebrate feeder	shelf small predator	shelf medium invertebrate feeder	shelf medium predator	shelf large invertebrate feeder	shelf large predator	slope ocean perch	Slope small predator	slope medium invertebrate feeder	slope medium predator	pelagic small invertebrate feeder	pelagic medium invertebrate feeder	mesopelagic	squid	prawns	macrobenthos	megabenthos	polychaeta	Gelatinous nekton	large zooplankton	small zooplankton	Primary producers	other	unidentified fish (for pro-rating)
Slope ocean perch	*Helicolenus barathri*	0.15												0.25	0.06		0.05	0				0.12					0.01			0.03	0.1	0.05	0.01	0.26	0.05		0.00	0.09
Slope small invertebrate feeder	*Caelorinchus fasciatus*	0.038	0.97																										0.03	0.17	0.22	0.32	0	0.05	0.08		0.13	0
	Centriscops humerosus	0.001	0.03																			0						0	0	0.11	0.05	0.13	0.01	0.02	0.2		0.47	0
	Total slope small invertebrate feeder	0.795																				0						0	0.03	0.16	0.22	0.32	0	0.05	0.08		0.14	0
Slope small predator	*Caelorinchus maurofasciatus*	0.042	0.57																								0.45			0.04	0.15	0.22		0.14				
	Caelorinchus mirus	0.032	0.43																								0.6	0	0.01	0.01	0.1	0.01	0	0.05	0.1		0.13	0.6
	Total slope small predator	0.074																									0.51	0	0.01	0.03	0.13	0.13	0	0.1	0.04		0.05	0.26
Warehous	*Seriolella brama*	0.307	0.17											0.09	0													0.21		0.1	0	0	0.42	0.02	0	0	0.15	0
	Seriolella punctata	1.551	0.83																								0	0	0	0	0	0	0.82	0	0	0	0.17	0
	Total warehous	1												0.02	0												0	0.04	0	0.02	0	0	0.75	0	0	0	0.16	0

APPENDIX D: BIOMASSES FROM 1994 SEF STUDY

Table D1. Mean weighted abundances per trophic group in each habitat type and overall proportion of study area inhabited per group.

Trophic group	**Weighted mean abundance per habitat (before scaling for selectivity and catchability)**								**[1]ppn of model area inhabited**
Habitat type	ISW	IC	INE	OSW	ONE	SBS	SBN	USL	
Proportion of model area	0.341	0.033	0.026	0.353	0.057	0.042	0.012	0.136	
Blue grenadier	-	-	-	-	-	0.001	0.001	-	[2]0.19
Blue-eye trevalla	-	-	-	-	-	-	-	0.006	0.14
Cardinal fish	-	0.000	0.000	0.016	0.002	0.126	0.035	0.055	0.66
Chinaman leatherjacket	-	0.000	0.000	0.005	0.000	-	-	-	0.47
Cucumber fish	0.000	0.000	0.000	0.202	0.008	0.005	0.010	0.052	1.00
Deepsea cod									[2]0.14
Demersal shark	1.035	0.061	0.022	0.621	0.030	0.094	0.004	0.353	1.00
Dory	0.022	0.002	0.001	0.059	0.006	0.014	0.005	0.006	1.00
Flathead	0.076	0.002	0.003	0.104	0.018	0.003	0.002	0.008	1.00
Gemfish	-	-	-	0.008	0.001	0.032	0.001	0.003	0.60
Jack mackerel	1.856	0.038	0.019	0.585	0.076	0.088	0.046	0.169	1.00
Jackass morwong	0.010	0.000	0.000	0.070	0.029	0.042	0.001	0.138	1.00
Latchet	0.001	0.000	-	0.027	0.006	0.001	-	-	0.83
Ling	0.005	0.000	0.002	0.010	0.003	0.003	0.002	0.008	1.00
Macrobenthos	-	-	-	0.054	-	-	-	-	1.00
Megabenthos	0.161	0.007	0.002	0.300	0.001	0.001	0.003	0.005	1.00
Mesopelagic	-	-	-	0.009	-	-	-	-	0.60
Shelf ocean perch	-	0.000	0.001	0.037	0.020	0.014	0.006	0.011	0.66
Oreo									[2]0.14
Pelagic large invertebrate feeder	-	-	-	0.010	-	0.004	0.001	0.004	0.54
Pelagic large predator	-	-	0.000	-	-	-	-	-	0.03
Pelagic medium invertebrate feeder	0.057	0.000	0.003	0.004	-	-	-	-	0.75
Pelagic medium predator	0.009	0.001	0.001	0.018	0.002	-	0.003	-	0.82
Pelagic shark	0.067	0.007	0.004	0.092	0.026	0.005	0.008	-	1.00
Pelagic small invertebrate									[2]

Trophic group	**Weighted mean abundance per habitat (before scaling for selectivity and catchability)**								**[1]ppn of model area inhabited**
Habitat type	ISW	IC	INE	OSW	ONE	SBS	SBN	USL	
Proportion of model area	0.341	0.033	0.026	0.353	0.057	0.042	0.012	0.136	
feeder									
Prawns									[2]1.00
Ray	1.174	0.074	0.070	1.003	0.114	0.032	0.030	0.023	1.00
Redbait	0.005	0.001	0.001	0.044	0.021	0.121	0.001	0.026	1.00
Redfish	0.026	0.004	0.026	0.319	0.239	0.051	0.043	0.067	1.00
School whiting	0.344	0.045	0.010	0.092	0.000	-	0.000	-	0.81
Shelf large herbivore									[2]0.40
Shelf large invertebrate feeder	0.003	0.000	0.000	0.002	-	-	-	-	0.75
Shelf large predator	0.856	0.005	0.012	0.326	0.034	0.023	0.001	0.034	1.00
Shelf medium herbivore									[2]0.40
Shelf medium invertebrate feeder	0.497	0.020	0.007	0.203	0.013	0.004	0.008	0.004	1.00
Shelf medium predator	0.120	0.005	0.008	0.084	0.011	0.001	0.001	-	0.86
Shelf small invertebrate feeder	0.894	0.032	0.022	0.369	0.058	0.046	0.004	0.014	1.00
Shelf small predator	0.112	0.001	0.001	0.058	0.014	0.060	0.005	0.006	1.00
Slope large invertebrate feeder	-	0.000	0.000	-	0.002	0.000	0.000	0.002	[3]0.14
Slope large predator	-	-	-	0.019	0.003	0.003	0.005	0.001	0.60
Slope medium invertebrate feeder	0.003	-	0.000	0.004	0.000	0.002	0.002	0.001	0.97
Slope medium predator	0.077	0.001	-	0.006	0.002	0.011	0.007	0.053	0.97
Slope ocean perch	-	-	-	0.042	-	0.011	0.003	-	0.54
Slope small invertebrate feeder	0.000	0.001	0.001	0.002	0.000	0.000	0.003	0.026	[3]0.14
Slope small predator	-	0.000	-	-	-	0.000	0.000	-	0.22
Small zooplankton	-	-	-	0.000	-	-	-	-	[3]1.00
Squid	0.115	0.002	0.005	0.064	0.005	0.005	0.004	0.033	1.00
Tuna & billfishes									[3]0.60
Warehou	0.071	0.017	0.000	0.045	0.018	0.053	0.005	0.715	1.00

1 Derived from occurrence in habitat type and assumed distribution if data unavailable.

2. Assumed occurrence

3. Modified from observations based on knowledge or literature.

Table D2. Total mean abundance of trophic groups from survey data.

Trophic group	Biomass in study area	Biomass in habitat area
Blue grenadier	0.794	4.178
Blue-eye trevalla	0.211	1.548
Cardinal fish	0.811	1.230
Chinaman leatherjacket (ocean jacket)	0.011	0.024
Cucumber fish	2.486	2.486
Demersal shark	4.851	4.855
Dory	0.390	0.390
Flathead	0.434	0.434
Gemfish	0.088	0.147
Jack mackerel	6.230	6.230
Jackass morwong	0.628	0.628
Ling	0.064	0.0638
Macrobenthos	0.107	0.107
Megabenthos	0.754	1.257
Mesopelagic	0.018	0.032
Pelagic large invertebrate feeder	0.039	1.513
Pelagic large predator	0.00004	0.00006
Pelagic medium invertebrate feeder	0.129	0.157
Pelagic medium predator	0.069	0.069
Ray	5.040	5.040
Redbait	0.530	0.530
Redfish	1.745	2.155
School whiting	1.690	2.245
Shelf large invertebrate feeder	0.010	0.010
Shelf large predator	2.584	2.584
Shelf medium invertebrate feeder	1.145	1.326
Shelf medium predator	0.503	0.763
Shelf ocean perch	0.236	0.358
Shelf small invertebrate feeder	3.992	3.992
Shelf small predator	0.632	0.632
Slope large invertebrate feeder	0.010	0.017
Slope large predator	0.064	0.066
Slope medium invertebrate feeder	0.023	0.024
Slope medium predator	0.315	0.581
Slope ocean perch	0.150	0.277
Slope oreo	0.084	0.617
Slope small invertebrate feeder	0.049	0.221
Slope small predator	0.032	0.032
Small zooplankton	0.001	0.001
Squid	0.162	0.162
Warehou	1.858	1.858
Deepsea cod	0.474	3.483
Grand Total	39.444	48.840

APPENDIX E: TIME SERIES

Appendix E1. CPUEs derived for species and species groups from the EBS area from available fishery statistics from 1985 through 2002. The series from 1994 on was used in the model fitting procedure to determine the best vulnerabilities and feeding parameters to best fit it.

Trophic group	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Tuna & billfishes	-	6.71	17.39	7.52	10.49	40.00	3.33	4.44	-	-	-	-	12.50	7.09	6.11	6.58	2.86	8.81
Pelagic sharks	-	-	-	-	-	-	-	-	-	-	-	-	-	12.80	39.79	60.32	40.76	85.89
Demersal sharks	48.90	61.02	51.55	45.80	53.80	52.75	47.64	63.35	67.35	146.69	56.47	53.32	45.89	46.23	79.19	215.55	197.62	224.29
Rays	4.87	5.85	13.83	14.88	12.16	14.92	15.84	13.77	15.38	15.78	15.40	13.50	14.72	16.27	26.01	59.79	32.75	38.04
Warehou	39.16	51.24	51.41	74.68	65.21	88.47	45.65	51.37	47.85	52.93	46.01	32.43	30.55	31.86	23.83	15.76	11.82	11.32
Redbait	-	-	-	-	-	-	-	-	-	-	-	-	22.16	-	-	-	8.24	9.11
Redfish	14.37	23.83	22.72	29.36	17.61	21.04	26.14	26.41	30.91	29.16	18.54	15.78	16.99	19.34	15.92	10.00	8.35	7.62
Ling	16.65	17.13	21.50	17.65	19.78	20.92	18.69	16.83	17.81	16.24	16.45	13.09	12.67	22.41	20.63	13.39	16.74	9.44
Dories	36.32	47.55	39.47	44.70	50.78	45.32	30.74	27.63	34.74	29.69	25.16	19.95	19.13	17.15	19.21	12.61	19.46	12.07
Jack mackerel	9.49	44.40	17.64	32.80	12.81	11.59	10.77	14.71	15.12	19.07	17.15	19.40	20.62	19.21	20.74	24.62	21.94	13.91
Jackass morwong	27.17	24.17	31.75	29.81	27.43	21.29	19.43	15.51	17.75	16.56	14.88	13.68	14.40	11.07	9.92	7.49	5.26	5.85
Flathead	30.03	31.14	40.64	35.47	48.26	42.27	34.54	30.47	30.37	20.31	20.11	15.44	23.39	27.06	29.16	34.61	30.08	32.82
Gemfish	11.12	42.04	43.50	47.11	35.14	19.40	14.04	12.04	10.48	7.27	6.00	4.32	6.55	5.45	4.08	3.03	2.42	1.82
Ocean perch	15.20	11.77	9.96	11.14	11.63	12.03	12.40	11.10	11.87	11.13	9.66	9.02	8.17	7.87	8.63	5.54	6.15	4.47
Chinaman's leatherjacket	-	-	-	-	-	-	-	-	-	-	-	10.00	-	14.43	-	30.52	13.89	16.94
Cucumber fish	-	56.25	-	-	22.50	27.18	27.79	15.69	31.14	21.33	-	-	-	-	-	-	10.81	-
School whiting	71.90	78.30	45.90	53.95	78.99	93.31	101.93	62.01	128.37	4.97	9.07	20.83	4.15	4.32	20.35	16.86	3.49	3.76
Cardinal fish	-	-	-	16.67	-	-	-	0.67	71.75	2.00	-	-	-	2.35	25.71	-	120.00	-
Shelf small invertebrate feeder	5.03	7.52	4.03	7.36	12.03	14.07	37.86	30.34	18.56	16.93	13.63	8.26	14.41	4.36	12.05	21.86	3.06	23.52
Shelf small predator	29.50	19.75	19.12	27.56	21.16	20.54	22.13	24.46	28.36	25.43	28.84	24.74	22.48	17.53	19.52	15.73	23.52	17.08
Shelf medium invertebrate feeder	23.73	31.87	28.66	42.76	36.88	48.10	139.40	26.48	14.91	17.45	10.62	11.33	10.70	11.40	9.58	11.63	6.54	5.15

Trophic group	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Shelf medium predator	26.54	37.07	49.51	32.25	29.86	25.81	24.81	26.23	29.71	28.98	31.84	24.29	16.21	42.44	20.55	19.64	15.71	20.90
Shelf large invertebrate feeder	3.32	6.42	5.04	3.61	5.88	3.36	2.90	3.35	6.00	2.40	5.22	4.09	3.52	2.94	3.99	4.55	6.11	3.32
Shelf large predator	36.05	49.10	81.06	61.46	54.04	58.62	58.57	53.15	62.55	47.92	59.95	38.27	42.75	34.62	67.88	39.74	65.82	29.08
Blue-eye trevalla	5.72	7.41	6.67	10.83	7.81	9.67	6.91	6.06	4.17	4.66	4.75	3.38	3.58	3.19	2.84	1.88	2.02	1.62
Blue grenadier	8.54	20.70	26.65	24.94	26.76	33.92	18.22	12.43	15.38	14.58	6.42	6.48	8.70	11.99	13.78	6.05	5.30	2.60
Deep-sea cod	7.14	-	8.26	9.77	7.87	9.21	5.39	13.66	12.41	13.67	11.63	10.53	14.07	13.98	11.65	10.49	8.98	8.63
Oreos	-	57.75	43.56	44.40	7.21	40.72	7.14	25.25	39.85	27.86	13.97	12.13	59.34	63.78	17.30	13.35	13.25	21.26
Slope small predator	-	22.30	25.85	-	58.22	7.08	2.59	15.87	6.75	7.86	12.66	16.75	12.16	7.83	5.23	0.90	0.99	1.77
Slope medium invertebrate feeder	-	-	-	3.93	7.50	13.06	-	-	-	4.79	-	11.92	20.57	-	-	-	-	8.87
Slope medium predator	-	-	-	33.67	13.17	5.00	8.45	7.43	12.19	13.07	6.49	14.80	14.10	7.70	4.90	15.90	14.12	4.47
Slope large invertebrate feeder	-	3.29	6.09	9.81	6.98	7.42	7.41	3.93	8.04	8.87	7.65	6.85	5.28	7.45	6.99	1.75	2.00	1.79
Slope large predator	47.09	59.55	66.57	59.81	73.65	69.41	76.28	69.27	61.78	46.41	35.81	32.64	30.40	40.76	37.54	34.78	51.40	23.99
Pelagic medium invertebrate feeder	-	5.00	12.03	24.14	24.49	13.09	6.90	15.41	-	-	-	3.24	3.55	105.56	2.01	1.56	4.74	1.26
Pelagic medium predator	-	-	6.32	24.24	23.41	68.03	9.07	24.18	42.77	29.42	28.79	24.03	45.41	21.93	26.48	23.78	37.38	77.52
Pelagic large predator	8.00	-	-	-	-	10.67	-	-	-	-	-	0.75	5.57	1.34	1.19	-	5.56	-
Squid	26.64	29.35	34.41	30.27	24.86	28.28	35.07	11.71	14.90	12.59	14.68	11.42	9.83	11.88	12.06	11.99	9.08	11.01
Prawns	3.77	10.90	17.20	16.20	13.90	12.92	11.41	7.15	11.67	12.54	11.32	33.09	35.98	22.24	10.89	10.17	38.56	47.55
Megabenthos	83.80	74.99	46.24	22.98	18.82	23.76	16.95	68.65	115.78	54.90	37.04	42.12	16.11	29.40	31.85	47.49	20.54	33.60

Appendix E2 (1985-93). Total catch (landings) combined over all fisheries assessed for 1985 through 1993 (t km^{-2}).

Species	1985	1986	1987	1988	1989	1990	1991	1992	1993
Toothed whale	-	-	-	-	-	-	-	-	-
Baleen whale	-	-	-	-	-	-	-	-	-
Seal	-	-	-	-	-	-	-	-	-
Seabirds	-	-	-	-	-	-	-	-	-
Penguins	-	-	-	-	-	-	-	-	-
Tuna & billfishes	0.008	0.005	0.003	0.008	0.022	0.031	0.036	0.022	0.028
Pelagic shark	0.0001	0.00003	0.0002	0.0003	0.0004	0.0005	0.001	0.0005	0.001
Demersal shark	0.018	0.024	0.019	0.021	0.018	0.020	0.018	0.019	0.029
Rays	0.001	0.003	0.002	0.004	0.002	0.003	0.003	0.001	0.003
Warehou	0.008	0.024	0.029	0.052	0.046	0.088	0.092	0.057	0.075
Redbait	-	-	-	-	-	-	-	-	-
Redfish	0.019	0.039	0.026	0.040	0.017	0.026	0.060	0.069	0.079
ling	0.017	0.025	0.026	0.026	0.024	0.027	0.025	0.027	0.041
dory	0.013	0.020	0.013	0.022	0.024	0.018	0.017	0.015	0.026
Jack mackerel	0.004	0.019	0.005	0.039	0.002	0.009	0.007	0.015	0.015
Jackass morwong	0.031	0.035	0.043	0.050	0.045	0.025	0.032	0.021	0.026
Flathead	0.056	0.073	0.091	0.095	0.093	0.088	0.094	0.090	0.083
Gemfish	0.063	0.127	0.081	0.101	0.054	0.028	0.012	0.011	0.007
Shelf Ocean Perch	0.005	0.007	0.005	0.008	0.008	0.007	0.008	0.008	0.013
Chinamans leatherjacket	-	-	-	-	-	-	-	-	-
Cucumber fish	-	0.00001	0.00017	-	0.00024	0.00003	0.00019	0.00028	0.00005
School Whiting	0.027	0.080	0.056	0.073	0.032	0.062	0.050	0.019	0.040
Cardinal fish	-	-	-	-	-	-	-	-	-
Shelf Small Invertebrate Feeder	0.001	0.004	0.003	0.005	0.004	0.004	0.004	0.002	0.004
Shelf Small Predator	0.0000	0.0002	0.0003	0.0002	0.0004	0.0001	0.0002	0.0003	0.001
Shelf medium Invertebrate Feeder	0.013	0.005	0.004	0.009	0.007	0.006	0.005	0.004	0.009
Shelf medium predator	0.010	0.013	0.011	0.020	0.014	0.009	0.008	0.016	0.010
Shelf large invertebrate Feeder	0.0002	0.0004	0.001	0.003	0.000	0.001	0.001	0.001	0.001
Shelf large Predator	0.035	0.029	0.026	0.045	0.037	0.042	0.022	0.041	0.039
Blue-eye trevalla	0.002	0.002	0.003	0.003	0.002	0.002	0.002	0.001	0.002
Blue grenadier	0.003	0.008	0.012	0.012	0.014	0.028	0.015	0.006	0.011
Slope Ocean Perch	0.001	0.004	0.003	0.005	0.003	0.003	0.003	0.002	0.004
Deep-sea Cod	0.00001	0.00001	0.000002	0.00003	0.00001	0.00003	0.00002	0.0001	0.0004
Oreo	-	-	0.00010	0.000003	0.000004	0.00002	0.00024	0.0001	0.002

Species	1985	1986	1987	1988	1989	1990	1991	1992	1993
Slope Small Invertebrate Feeder	0.000002	0.00001	0.00001	0.00002	0.00001	0.00001	0.00001	-	-
Slope Small Predator	0.000004	0.00003	0.00002	0.00003	0.00002	0.00002	0.00002	-	0.00002
Slope Medium Invertebrate Feeder	0.00005	0.00031	0.00025	0.00061	0.00024	0.00024	0.00023	0.001	-
Slope Medium Predator	0.00015	0.001	0.001	0.001	0.001	0.001	0.001	0.0002	0.002
Slope Large Invertebrate Feeder	0.000004	0.00003	0.00002	0.00003	0.00002	0.00002	0.00002	-	-
Slope Large Predator	0.00041	0.001	0.001	0.001	0.001	0.002	0.003	0.006	0.005
Pelagic Small Invertebrate Feeder	0.00033	0.0003	0.001	0.022	0.021	0.028	0.034	0.050	0.032
Pelagic medium Invertebrate Feeder	0.00005	0.0003	0.0002	0.0007	0.0003	0.0003	0.0003	0.0001	0.0001
Pelagic medium Predator	0.004	0.011	0.008	0.010	0.004	0.008	0.009	0.011	0.020
Pelagic large Invertebrate Feeder	-	-	-	-	-	-	-	-	-
Pelagic large Predator	0.00004	0.0001	0.00003	0.0002	0.001	0.0001	0.0001	0.0001	0.0001
Mesopelagic	0.0000001	0.0000005	0.0000004	0.000001	0.0000004	0.0000004	0.0000003	-	-
Squid	0.013	0.016	0.015	0.018	0.011	0.014	0.015	0.007	0.023
Prawns	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.0003	0.001
Macrobenthos	0.0002	0.0004	0.0001	0.0001	0.00005	0.001	0.003	0.003	0.001
Megabenthos	0.019	0.015	0.040	0.019	0.009	0.024	0.023	0.245	0.317

Appendix E2 (1994-2003). Total catch (landings) combined over all fisheries assessed for 1994 through 2003 (t km^{-2}) the period over which the model was run.

Species	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Toothed whale	-	-	-	-	-	-	-	-	-	-
Baleen whale	-	-	-	-	-	-	-	-	-	-
Seal	-	-	-	-	-	-	-	-	-	-
Seabirds	-	-	-	-	-	-	-	-	-	-
Penguins	-	-	-	-	-	-	-	-	-	-
Tuna & billfishes	0.021	0.013	0.022	0.019	0.009	0.130	0.351	0.030	0.008	0.002
Pelagic shark	0.0003	0.0004	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0004
Demersal shark	0.017	0.015	0.017	0.012	0.012	0.014	0.007	0.015	0.018	0.015
Rays	0.002	0.002	0.002	0.001	0.001	0.004	0.004	0.002	0.003	0.002
Warehou	0.087	0.079	0.060	0.052	0.040	0.039	0.024	0.016	0.016	0.014
Redbait	-	-	-	-	-	-	-	-	0.005	0.003
Redfish	0.052	0.026	0.036	0.023	0.021	0.015	0.012	0.011	0.011	0.007
ling	0.034	0.031	0.025	0.028	0.024	0.028	0.019	0.015	0.011	0.016
dory	0.019	0.012	0.011	0.008	0.007	0.008	0.007	0.006	0.007	0.011
Jack mackerel	0.009	0.005	0.024	0.001	0.001	0.065	0.392	0.028	0.025	0.014
Jackass morwong	0.028	0.019	0.020	0.021	0.013	0.011	0.011	0.009	0.010	0.007
Flathead	0.084	0.085	0.059	0.065	0.060	0.128	0.071	0.064	0.066	0.065
Gemfish	0.004	0.003	0.003	0.006	0.002	0.002	0.002	0.001	0.001	0.001
Shelf Ocean Perch	0.010	0.006	0.007	0.005	0.004	0.005	0.004	0.004	0.004	0.005
Chinamans leatherjacket	-	-	0.000001	-	0.00001	-	0.00004	0.0000005	0.001	0.001
Cucumber fish	-	-	-	-	-	-	-	0.00017	-	0.00000
School Whiting	0.020	0.025	0.016	0.012	0.009	0.051	0.010	0.012	0.011	0.011
Cardinal fish	-	-	-	-	-	-	-	-	-	-
Shelf Small Invertebrate Feeder	0.001	0.001	0.001	0.001	0.002	0.004	0.005	0.003	0.002	0.003
Shelf Small Predator	0.002	0.001	0.001	0.0004	0.0002	0.0001	0.0002	0.0002	0.0005	0.0001
Shelf medium Invertebrate Feeder	0.008	0.008	0.006	0.001	0.001	0.005	0.001	0.001	0.002	0.001
Shelf medium predator	0.007	0.005	0.005	0.003	0.003	0.006	0.003	0.002	0.003	0.003
Shelf large invertebrate Feeder	0.0004	0.0003	0.0001	0.0001	0.0001	0.0002	0.0002	0.0002	0.0003	0.0002
Shelf large Predator	0.032	0.026	0.087	0.015	0.007	0.005	0.008	0.008	0.008	0.012
Blue-eye trevalla	0.003	0.002	0.002	0.005	0.003	0.004	0.001	0.001	0.001	0.002
Blue grenadier	0.013	0.004	0.003	0.005	0.008	0.012	0.004	0.003	0.001	0.001
Slope Ocean Perch	-	0.0002	0.003	0.002	0.002	0.006	0.002	0.002	0.003	0.002
Deep-sea Cod	0.0003	0.0003	0.0003	0.0004	0.0003	0.0004	0.0001	0.0001	0.0002	0.0003

Species	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Oreo	0.001	0.0004	0.0002	0.0003	0.0005	0.0002	0.0001	0.0001	0.0002	0.0001
Slope Small Invertebrate Feeder	0.00007	-	-	0.000005	0.00001	-	0.00001	0.0000003	-	0.00001
Slope Small Predator	0.00021	-	-	-	0.00001	-	-	0.000002	-	0.00001
Slope Medium Invertebrate Feeder	0.000002	-	0.00001	0.00001	0.001	0.0004	0.000004	0.00002	0.000002	0.0002
Slope Medium Predator	0.00042	0.001	0.003	0.002	0.001	0.001	0.0005	0.0003	0.0005	0.0006
Slope Large Invertebrate Feeder	-	-	0.001	0.000	-	-	-	-	0.000003	0.00002
Slope Large Predator	0.005	0.004	0.004	0.003	0.003	0.003	0.002	0.002	0.001	0.001
Pelagic Small Invertebrate Feeder	0.058	0.054	0.012	0.026	0.012	0.016	0.002	0.007	0.067	0.046
Pelagic medium Invertebrate Feeder	0.0001	0.001	0.0003	0.003	0.001	0.003	0.002	0.001	0.001	0.007
Pelagic medium Predator	0.032	0.011	0.061	0.047	0.087	0.519	0.708	0.042	0.041	0.036
Pelagic large Invertebrate Feeder	-	-	-	-	-	-	-	-	-	-
Pelagic large Predator	0.0001	0.0002	0.0001	0.0001	0.0002	0.001	0.001	0.001	0.0004	0.0002
Mesopelagic	-	-	-	0.000005	-	-	-	-	-	0.0000003
Squid	0.007	0.012	0.005	0.010	0.006	0.031	0.015	0.007	0.007	0.006
Prawns	0.001	0.001	0.0002	0.0001	0.001	0.001	0.001	0.001	0.005	0.0004
Macrobenthos	0.001	0.002	0.002	0.0003	-	0.000003	0.00001	0.0004	0.0004	0.0002
Megabenthos	0.021	0.009	0.020	0.014	0.005	0.007	0.042	0.039	0.034	0.014

APPENDIX F: TEMPORAL MODEL PARAMETERS

Table F1. Feeding rate parameters used in temporal simulations.

Group	Max rel. P/B	Max rel. feeding time	Feeding time adjust rate [0,1]	Fraction of 'other' mortality sens. to changes in feeding time	Predatoeffect on feeding time [0,1]	Density-dep. catchability: *Qmax/Qo* [>=1]	*QB*max/*QBo* (for handling time) [>1]	Switching power parameter [0,2]
Toothed whale		2	0	1	0	1	1000	0
Baleen whale		2	0	1	0	1	1000	0
Seal		2	0	1	0	1	1000	0
Seabirds		2	0.5	1	0	1	1000	0
Penguins		2	0.5	1	0	1	1000	0
Tuna/billfish		2	0.5	1	0	1	1000	0
Pelagic sharks		2	0.5	1	0	1	1000	0
Demersal sharks		2	0.5	1	0	1	1000	0
Rays		2	0.5	1	0	1	1000	0
Warehous		2	0.5	1	0	1	1000	0
Redbait		2	0.5	1	0	1	1000	0
Redfish		2	0.5	1	0	1	1000	0
Ling		2	0.5	1	0	1	1000	0
Dories		2	0.5	1	0	1	1000	0
Jack mackerel		2	0.5	1	0	1	1000	0
Jackass morwong		2	0.5	1	0	1	1000	0
Flathead		2	0.5	1	0	1	1000	0
Gemfish		2	0.5	1	0	1	1000	0
ShOceanPerch		2	0.5	1	0	1	1000	0
Chinaman leatherjacket		2	0.5	1	0	1	1000	0
Cucumberfish		2	0.5	1	0	1	1000	0
Whiting		2	0.5	1	0	1	1000	0
Cardinal		2	0.5	1	0	1	1000	0
ShSmInvert Feeder		2	0.5	1	0	1	1000	0
ShSmPredator		2	0.5	1	0	1	1000	0
ShMedInvert Feeder		2	0.5	1	0	1	1000	0
ShMed Predator		2	0.5	1	0	1	1000	0
ShLInvert Feeder		2	0.5	1	0	1	1000	0

Group	Max rel. P/B	Max rel. feeding time	Feeding time adjust rate [0,1]	Fraction of 'other' mortality sens. to changes in feeding time	Predatoeffect on feeding time [0,1]	Density-dep. catchability: *Qmax*/*Qo* [>=1]	*QB*max/*QBo* (for handling time) [>1]	Switching power parameter [0,2]
ShLPredator		2	0.5	1	0	1	1000	0
Blue-eye trevalla		2	0.5	1	0	1	1000	0
Blue grenadier		2	0.5	1	0	1	1000	0
Slope Ocean Perch		2	0.5	1	0	1	1000	0
Deepsea Cod		2	0.5	1	0	1	1000	0
Oreos		2	0.5	1	0	1	1000	0
SlopeSmInvertFeeder		2	0.5	1	0	1	1000	0
SlopeSm Predator		2	0.5	1	0	1	1000	0
SlopeMInvert Feeder		2	0.5	1	0	1	1000	0
SlopeM Predator		2	0.5	1	0	1	1000	0
SlopeLInvert Feeder		2	0.5	1	0	1	1000	0
SlopeL Predator		2	0.5	1	0	1	1000	0
PelSmInvert Feeder		2	0.5	1	0	1	1000	0
PelMInvert Feeder		2	0.5	1	0	1	1000	0
PelMPredator		2	0.5	1	0	1	1000	0
PelLInvert Feeder		2	0.5	1	0	1	1000	0
PelLPredator		2	0.5	1	0	1	1000	0
Mesopelagics		2	0.5	1	0	1	1000	0
Squid		2	0.5	0	0	1	1000	0
Pelagic Prawns		2	0.5	0	0	1	1000	0
Macrobenthos		1	0	0	0	1	1000	0
Megabenthos		2	0.5	0	0	1	1000	0
Polychaeta		2	0	0	0	1	1000	0
Gelatinous nekton		2	0	0	0	1	1000	0
Large zooplankton		2	0	0	0	1	1000	0
Small zooplankton		2	0	0	0	1	1000	0
Primary producers	2							

Table F2. Vulnerabilities used in temporal simulations.

Prey \ predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Toothed whale	2														
Baleen whale															
Seal	2						2								
Seabirds	2						2								
Penguins	2						2								
Tuna/billfish	2						2								
Pelagic sharks	2						2								
Demersal sharks							2								
Rays							2	7.9							
Warehous			8.6		1.2		2								
Redbait		2	2	2		1.2		2						1.2	
Redfish			2				2	2						2	
Ling			8.6	2				7.9							
Dories			8.6				2	7.9							
Jack mackerel	2		2			1.2	2	2						1.2	
Jackass morwong			8.6					2							
Flathead			2					2							
Gemfish			1.2				2								
ShOceanPerch			8.6					2							
Chinaman leatherjacket								1.2							
Cucumberfish								2				6.6	1.2	1.2	
Whiting			1.2					2	6.3					1.2	
Cardinal			2					2		7.7		6.6	1.2	1.2	2
ShSmInvertFeeder			8.6					7.9	6.3			6.6	1.2	1.2	2
ShSmPredator			8.6									6.6			
ShMedInvertFeeder				2				7.9				6.6		1.2	
ShMedPredator			8.6	2				7.9						1.2	
ShLInvertFeeder					2										
ShLPredator								7.9							
Blue-eye trevalla	2							2							
Blue grenadier															
SlopeOceanPerch												6.6			
Deepsea Cod															
Oreos															
SlopeSmInvertFeeder		2							6.3						
SlopeSmPredator		2						7.9	6.3			6.6	1.2		
SlopeMInverFeeder								7.9	6.3			6.6			
SlopeMPredator					1.2			7.9							
SlopeLInvertFeeder								7.9				6.6	1.2		
SlopeLPredator															
PelSmInvertFeeder	2	2		2	1.2	1.2		7.9							
PelMInvertFeeder	2						2	2							
PelMPredator	2					1.2	2	2							
PelLInvertFeeder	2						2								
PelLPredator							2								
Mesopelagics	2	2		2		1.2		7.9		7.7	1.2	6.6			2
Squid	2		8.6	2	1.2	1.2	2	7.9		7.7		6.6		1.2	
PelagicPrawns					1.2			7.9	6.3	7.7		6.6	1.2	1.2	
Macrobenthos				2			2	7.9	6.3	7.7		6.6		1.2	2
Megabenthos					1.2		2	7.9	6.3	7.7		6.6	1.2	1.2	2
Polychaeta								2	2	2		2			2
Gelatinous nekton				2				2		2	1.2	2			2
L zooplankton		2			2	2		2	2	2	1.2	2	2	2	2
Sm zooplankton								2	2	2	1.2	2	2	2	2
Primary producers								2		2					
Detritus															

Table F2 (cont).

Prey \ predator	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Toothed whale															
Baleen whale															
Seal															
Seabirds															
Penguins															
Tuna/billfish															
Pelagic sharks															
Demersal sharks												1.5		1.2	
Rays												1.5		1.2	
Warehous														1.2	
Redbait												1.5		1.2	
Redfish														2	
Ling		2													
Dories		2										1.5			
Jack mackerel		2										1.5		1.2	
Jackass morwong												1.5		1.2	
Flathead												1.5			
Gemfish															
ShOceanPerch		2												1.2	
Chinaman leatherjacket															
Cucumberfish		2		1.2						1.8	2	1.5		1.2	
Whiting		2								1.8		1.5		1.2	
Cardinal	6.1	2	1.1	1.2					1.2	1.8		1.5		1.2	
ShSmInvertFeeder	6.1	2		1.2	2	2	1.2		1.2	1.8	2	1.5		1.2	
ShSmPredator					2	2			1.2			1.5			
ShMedInvertFeeder	6.1	2		1.2		2	1.2		1.2	1.8	2	1.5		1.2	
ShMedPredator		2													
ShLInvertFeeder															
ShLPredator		2		1.2								1.5			
Blue-eye trevalla															
Blue grenadier															2
SlopeOceanPerch														1.2	
Deepsea Cod															
Oreos															
SlopeSmInvert Feeder					2										2
SlopeSmPredator				1.2	2	2									2
SlopeMInverFeeder												1.5			2
SlopeMPredator															
SlopeLInvertFeeder		2		1.2						1.8					
SlopeLPredator															
PelSmInvertFeeder		2												1.2	
PelMInvertFeeder															
PelMPredator															
PelLInvertFeeder															
PelLPredator															
Mesopelagics	6.1	2						2						1.2	2
Squid	6.1			1.2		2	1.2		1.2	1.8	2	1.5			2
PelagicPrawns	6.1			1.2		2		2	1.2		2	1.5		1.2	2
Macrobenthos	6.1	2		1.2	2	2	1.2		1.2	1.8	2	1.5	6.2	1.2	
Megabenthos	6.1	2		1.2	2	2	1.2	2	1.2	1.8	2	1.5	6.2	1.2	
Polychaeta	2	2		1.2		2	2	2	2		2	1.5	2	2	
Gelatinous nekton	2	2		1.2	2	2			2	1.8		1.5		2	2
L zooplankton	2	2		1.2		2	2	2	2	1.8	2	1.5	2	2	
Sm zooplankton	2	2		1.2		2	2	2	2	1.8	2	1.5		2	
Primary producers									2	1.8	2				
Detritus															

Table F2 (cont).

Prey \ predator	31	32	33	34	35	36	37	38	39	40	41	42	43	44	31
Toothed whale															
Baleen whale															
Seal															
Seabirds															
Penguins															
Tuna/billfish															
Pelagic sharks															
Demersal sharks		2													
Rays										4					
Warehous										4					
Redbait													1.2		
Redfish															
Ling															
Dories															
Jack mackerel		2								4					
Jackass morwong															
Flathead															
Gemfish	2	2													2
ShOceanPerch															
Chinaman leatherjacket															
Cucumberfish		2						2							
Whiting															
Cardinal	1.2	2						2							1.2
ShSmInvertFeeder	1.2	2						2							1.2
ShSmPredator								2							
ShMedInvertFeeder								2							
ShMedPredator								2							
ShLInvertFeeder															
ShLPredator															
Blue-eye trevalla															
Blue grenadier	1.2														1.2
SlopeOceanPerch		2						2							
Deepsea Cod								2							
Oreos								2							
SlopeSmInvert Feeder	2	2	6.5							4					2
SlopeSmPredator			6.5					2		4					
SlopeMInverFeeder	1.2	2					1.2	2		4					1.2
SlopeMPredator										4					
SlopeLInvertFeeder															
SlopeLPredator	1.2														1.2
PelSmInvertFeeder												1.2	1.2		
PelMInvertFeeder															
PelMPredator															
PelLInvertFeeder															
PelLPredator															
Mesopelagics	1.2	2		1.01	1.2	6.7	1.2	2	1.2	4	1.2	1.2	1.2	5.3	1.2
Squid	1.2	2			1.2	6.7	1.2		1.2	4	1.2			5.3	1.2
PelagicPrawns	1.2				1.2	6.7	1.2	2		4					1.2
Macrobenthos	1.2	2	6.5	1.01	1.2	6.7	1.2		1.2		1.2	1.2		5.3	1.2
Megabenthos	1.2	2	6.5	1.01	1.2	6.7	1.2	2	1.2	4					1.2
Polychaeta		2			2	2	2	2	2						
Gelatinous nekton	2	2			2	2		2				1.2	2	2	2
L zooplankton	2	2		1.01	2	2	2	2	2		2	1.2	2	2	2
Sm zooplankton	2	2		1.01	2	2	2	2			2		2	2	2
Primary producers											2				
Detritus															

Table F2 (cont).

Prey \ predator	45	46	47	48	49	50	51	52	53	54	55
Toothed whale											
Baleen whale											
Seal											
Seabirds											
Penguins											
Tuna/billfish											
Pelagic sharks											
Demersal sharks											
Rays											
Warehous											
Redbait											
Redfish											
Ling											
Dories											
Jack mackerel											
Jackass morwong											
Flathead											
Gemfish											
ShOceanPerch											
Chinaman leatherjacket											
Cucumberfish											
Whiting											
Cardinal											
ShSmInvertFeeder											
ShSmPredator											
ShMedInvertFeeder											
ShMedPredator											
ShLInvertFeeder											
ShLPredator											
Blue-eye trevalla											
Blue grenadier											
SlopeOceanPerch											
Deepsea Cod											
Oreos											
SlopeSmInvert Feeder											
SlopeSmPredator											
SlopeMInverFeeder											
SlopeMPredator											
SlopeLInvertFeeder											
SlopeLPredator											
PelSmInvertFeeder	7.2		5.4								
PelMInvertFeeder	2										
PelMPredator											
PelLInvertFeeder											
PelLPredator											
Mesopelagics		4.4	5.4								
Squid	7.2	4.4									
PelagicPrawns											
Macrobenthos						4.9	2				
Megabenthos											
Polychaeta						2					
Gelatinous nekton											

L zooplankton	2	2	2		2						
Sm zooplankton		2		2	2	2	2	2	2		
Primary producers				2			2	2	2	2	2
Detritus					2.8	4.9	2.7				