

4 The Small Pelagic Fishery in the southern Australian ecosystem

4.1 Small pelagic fish

There is little doubt that coastal pelagic fishes, as defined by Freon *et al.* (2005) to include small- and medium-sized pelagic fish, play a crucial role in marine food webs. Typically, they are an important linkage of energy and biomass between primary production and higher trophic levels; hence it is essential to understand the dynamics of these species if they are to be exploited sustainably.

Small pelagic species occupy a central role in the major upwelling regions worldwide, the most productive being the eastern boundary currents of the Benguela in the Atlantic Ocean off southern Africa, the Canary in the Atlantic Ocean off northern Africa, the Californian Current in the Pacific Ocean off North America and the Humboldt in the South Pacific off South America (Bulman *et al.* 2011). The high productivity in these regions (Carr and Kearns 2003) supports large biomasses of plankton-feeding fishes of which sardine and anchovy represent a large proportion and upon which massive fisheries are based. According to the Food and Agriculture Organization of the United Nations (FAO), 23 species of the 1600 for which it collects statistics contribute 40 per cent of total marine production and, of those, almost two-thirds are small pelagic species (FAO 2014a). In 2012, 14.32 million tonnes (t) of herrings, sardines and anchovies and approximately 447,000 t of Peruvian jack mackerel *Trachurus murphyi* were landed (FAO 2014b).

However, the extremely productive Benguela, Canary, Humboldt and Californian upwelling regions are quite unlike those in Australia (see section 4.3.1). Australian catches of these small pelagic species are magnitudes smaller. Total annual catches of Australian sardine *Sardinops sagax* and jack mackerel *Trachurus declivis* in the Eastern Zone of the Small Pelagic Fishery (SPF) (in both state and Commonwealth waters) are currently in the order of 2000 to 3000 t and 0 to 56 t respectively (Moore *et al.* 2013, Ward *et al.* 2014). In the Western Zone, South Australian Sardine Fishery (SASF) catches have been around 28,000 t since the early 2000s and jack mackerel catches have declined from less than 500 t to negligible (Ward *et al.* 2014). In addition, catches of blue mackerel *Scomber australasicus* have been around 400 to 500 t and less than 500 t in the Eastern and Western Zones respectively over the past few years (Ward *et al.* 2014). Yellowtail scad *Trachurus novaezelandiae* catches declined from 400 t in the late 1990s to approximately 200 t before a jump to around 700 t in 2010–11 and a decline to 500 t most recently (Ward *et al.* 2014). As discussed in Chapter 3, yellowtail scad is not assessed in this report. Redbait *Emmelichthys nitidus* was initially taken as bycatch in the jack mackerel purse seine fishery and actively avoided (Bulman *et al.* 2008), but since 2001 it has since been targeted by mid-water trawl. Catches of redbait from the Eastern Zone of the SPF peaked in 2003–04 at approximately 7000 t but have declined to only kilograms in recent years. Catches from the Western Zone peaked at approximately 3500 t in 2005–06 but have declined to zero in recent years (Ward *et al.* 2014) reflecting the effort trend in the SPF.

Changing oceanic conditions cause dramatic variability in small pelagic fish populations, particularly in the major upwelling current systems. The consequences of this on dependent predators and other species have been comprehensively reviewed by Cury *et al.* (2000). The small clupeid pelagic fishes such as anchovy, sardine, sardinella, herring and sprat are well-known for spectacular decadal fluctuations in biomass. Abundance regime shifts such as those between anchovies and sardines in the Humboldt Current can alter the entire ecosystem from phytoplankton to top predators (Alheit and Niquen 2004). These fluctuations have been associated with regime shifts of periods of warm or cold water driven by large-scale circulation shifts (Alheit *et al.* 2009). Warmer periods favour sardines while cooler water favours anchovy (Cury and Shannon 2004).

Locally, Australian sardines prefer to feed on small zooplankton favoured by warmer conditions while anchovy and jack mackerel prefer larger zooplankton including krill, favoured by cooler conditions. However, not all biomass fluctuations are related to environmental conditions. In the SPF, a mass mortality of Australian sardines occurred in 1995 and then again in 1998–99, caused by a herpesvirus (Whittington *et al.* 2008). Australian sardine biomass was reportedly reduced by

10–15 per cent and 70 per cent respectively (Ward *et al.* 2001a). Negative impacts of those reductions were documented for little penguins *Eudyptula minor* (Dann *et al.* 2000, Chiaradia *et al.* 2002, Chiaradia *et al.* 2003, Chiaradia *et al.* 2010), little terns *Sterna albifrons* in 1995–96 (Dann *et al.* 2000, Taylor and Roe 2004), crested terns *Sterna bergii* (McLeay *et al.* 2009) and Australasian gannets *Morus serrator* in 1998–99 (Bunce and Norman 2000, Bunce *et al.* 2002, Bunce 2004). This event, although dramatic, provides a good indication of how the ecosystem might respond to fishery- or climate-induced reductions of Australian sardines. See Section 6.7.4 for further discussion of this event.

4.2 Trophic role of small pelagic species

A technical review commissioned by the panel (Patterson *et al.* unpublished) collated dietary data, by numerical abundance, from 24 studies of six of the major central place forager (CPF) species in the Tasmanian region of the SPF, including eastern and western Bass Strait areas (Table 4.1). These data suggest that the SPF species are numerically important only for Australian fur seals *Arctocephalus pusillus doriferus* (redbait 31 per cent and jack mackerel 20 per cent) and for Australasian gannets (redbait 19 per cent and Australian sardine 20 per cent). However, the variances are very large and likely to mask and underestimate the importance of the SPF species. Furthermore, diet varies spatially and temporally again masking the importance that the SPF species may have at particular times for CPFs. These data were also based on a variety of methods including scat analysis (fur seals), regurgitates and DNA analyses, all of which have associated biases. Consequently, a single characterisation of the diet is very difficult to achieve resulting in the large variances seen (Patterson *et al.* unpublished) and is not particularly informative in the specific management of allocation of resources to dependent predators.

Table 4.1 Diet proportions and standard deviations (SD) of major central place foragers in the SPF by % numerical abundance

	LITTLE PENGUIN <i>EUDYPTULA MINOR</i>		AUSTRALIAN FUR SEAL <i>ARCTOCEPHALUS PUSILLUS DORIFERUS</i>		NEW ZEALAND FUR SEAL <i>ARCTOCEPHALUS FORSTERI</i>		AUSTRALASIAN GANNET <i>MORUS SERRATOR</i>		SHY ALBATROSS <i>THALASSARCHE CAUTA</i>		SHORT-TAILED SHEARWATER <i>ARDENNA TENUIROSTRIS</i>	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Redbait	0.01	1.41	0.31	0.71	0.13	0.77	0.19	1.66	0.02	1.25	0.04	1.77
Jack mackerel	0.0	–	0.20	0.76	0.01	1.00	0.06	0.64	0.03	0.59	0.04	1.77
Blue mackerel	0.0045	1.41	0.02	2.79	0.001	2.00	0.04	0.72	0.02	1.73	0.04	1.77
Australian sardine	0.06	0.24	0.01	2.06	0.004	1.21	0.20	1.32	0.02	1.73	0.04	1.77
Other	0.93	0.04	0.49	0.51	0.86	0.13	0.54	0.51	0.91	0.12	0.85	0.29

Source: Patterson *et al.* (unpublished)

For consumption modelling, as used by Patterson *et al.* (unpublished), or for ecosystem modelling, dietary data need to be input in terms of biomass (usually wet weight). Therefore, dietary data as a percentage of total biomass (or wet weight) were collated (Table 4.2) for a broader variety of small pelagic fish predators from a range of studies and sources including Patterson *et al.* (unpublished). SPF species are an important proportion of many predators' diets by biomass including the Australian fur seal; short-beaked common dolphins *Delphinus delphis*; several seabirds, some of which are CPF species that breed within the SPF; larger teleosts such as southern bluefin tuna (SBT) *Thunnus maccoyii*, and sharks. Importance varies widely as indicated by ranges for some studies over longer time periods or different life stages (Table 4.2). Some of the data are now quite old, e.g., the eastern Tasmania and eastern Bass Strait (EBS) data are all 20 to 30 years old. This creates uncertainty in assessing importance; shifts in diet have occurred when there have been species regime shifts, e.g. the temporary shift of anchovy and sardine following the mass mortality events and the apparent changes in abundance between jack mackerel and redbait reflected in changes in fur seal diet (see Figure 5.7 in Chapter 5) (Kirkwood *et al.* 2008, McLeod *et al.* 2012, Kirkwood and Goldsworthy 2013).

Table 4.2 Proportions of SPF species and anchovy in diets of major predators in the SPF expressed as % of total prey biomass i.e. proportion of the total prey weight unless otherwise specified (%FO = frequency of occurrence, %NA = numerical abundance)

PREDATOR	AUSTRALIAN FUR SEALS <i>ARCTOCEPHALUS PUSILLUS</i> <i>DORIFERUS</i>			NEW ZEALAND FUR SEALS A. <i>FORSTERI</i>		AUSTRALIAN SEA LIONS <i>NEOPHOCA CINEREA</i>		COMMON DOLPHIN <i>DELPHINUS</i>		BOTTLENOSED DOLPHIN <i>TURSIOPS TRUNCATUS</i>		LITTLE PENGUINS <i>EUDYPTULA</i> <i>MINOR</i>		SHORT-TAILED SHEARWATERS <i>ARDEMANNA TENUIROSTRIS</i>		LITTLE TERNS (ONLY BREEDING SEASON) <i>STERNA BERGII</i>		CRESTED TERNS <i>THALASSEUS</i> <i>BERGII</i>		AUSTRALASIAN GANNETS <i>MORUS</i> <i>SERRATOR</i>			SHY ALBATROSS <i>THALASSARCHE</i> <i>CAUTA</i>	
	Great Australian Bight (GAB)	W Bass Strait ¹	EBS ²	GAB	S Tas. ³ %FO	GAB	GAB	GAB	Bass Strait	GAB	Bass Strait ¹	GAB	Bass Strait ⁵ %NA	GAB	Port Phillip Bay ¹	South Tas. ⁷	GAB	Bass Strait ⁸	GAB					
Australian anchovy		0.1		0.1 ¹ , 0.2–1.3			43.3		22 ¹ (19–61) ³	61.6	8.5	13.7–19.4	30.7	4.9 ¹ (0–24) ⁶	1.8	9								
Australian sardine				0.4 ¹ , 0.9–2.1		0.1	20.8	2.1	7.3 ¹ (4–51) ⁴	3.5	1.4	0.9–1.1	78	22.9	0.6 ¹ (4–50) ⁶	16								
Jack mackerel	5.4	7.8	16	2.3 ¹ , 4.3–7.7	21–43	0.8	11.4	1.5	0.41		21.5	10.4–27.1	~28	0.2	36.6 ¹ (6–20) ⁶	13.1		43	46.8					
Blue mackerel				0.2 ¹ , 0.1–0.2			0.3	0.04		0.4		0.4–0.6				11		8.9						
Redbait	44.8	22.1	13.3	11.3 ¹ , 1.8–23.3	11–22				0.41	4.4	1	3.9–4.8			12.1 ¹	55.6		2.9	2.9					
Total SPF (exc. anchovy)	50.3	30	29.3	~16		0.9	32.5	3.6	8.1 (4–51) ⁴	8.3	23.9	21.75	Not calculated	23.1	49.3 ¹ (24–50) ⁶	68.7	27	45.9	58.6					

It is also important to note that while some species may have a high preference for some prey, the size composition of the prey species may not overlap with the size composition of the fishery. For example, the Australasian gannets near Pedra Branca off the south coast of Tasmania (Tas.) were catching redbait and jack mackerel of less than 200 millimetres (mm) fork length (FL), smaller than the fishery-caught jack mackerel, between 250 and 370 mm FL, and redbait, between 190 and 290 mm FL (Brothers *et al.* 1993). Little penguins were found to take Australian sardine and anchovy of 8 centimetres (cm) standard length (SL) (Cullen *et al.* 1991) which for sardine is smaller than size-at-maturity (approximately 14.5 cm FL: Rogers and Ward 2007) and smaller than the average fishery catch in New South Wales (NSW) and the SASF (approximately 12 to 20 cm FL: Ward *et al.* 2014, Ward *et al.* 2010 respectively). While fishery and bird foraging zones may not overlap, it is still important that the mature stock is of sufficient size to maintain adequate recruitment of juveniles for the dependent predators and for the stock itself.

Trophic data, such as those presented in Tables 4.1 and 4.2, underpin the models constructed for the southern Australian ecosystems; however, each model preferentially uses region-specific data where these are available. Bulman *et al.* (2006) used such data and models to investigate the trophic role of small pelagic fishes in the SPF and the control exerted by the SPF fishes (see section 4.3). Their generic diagram of the food web (Figure 4.1) based on the data available at the time, illustrates some of the complexity that is inherent in the SPF ecosystem. Not all minor linkages are represented nor does this representation explicitly account for differences between slope and shelf fish sub-systems, and regional and temporal differences.

The food web for the Great Australian Bight (GAB) generated by the corresponding Ecosim with Ecopath (EwE) model shows all linkages including minor ones (Figure 4.2).

	AUSTRALIAN SALMON <i>ARRIPIIS TRUTTA</i>	SOUTHERN BLUEFIN TUNA <i>THUNNUS MACCOYI</i>		THRESHER SHARK <i>ALOPIAS VULPINUS</i>	BRONZE WHALER <i>CARCHARHINUS BRACHYURUS</i>	COMMON SAWSHARK <i>PRISTIGORUS CIRRATUS</i>	SCHOOL SHARK <i>GALEORHINUS GALEUS</i>	BRIER SHARK <i>DEANIA CALCEA</i>	BLUE SHARK <i>PRIONACE GLAUCA</i>	BONITO <i>SARDA AUSTRALIS</i>	BARRACOUTA <i>THYRSITES ATUN</i>		RAY'S BREEM <i>BRAMA BRAMA</i>	LONG-FINNED PIKE <i>SPHYRAENA NOVAEHOllandIAE</i>	YELLOWTAIL KINGFISH <i>SERIOLA LALANDI</i>	STARGAZER <i>KATHETOSTOMA SP</i>	MIRROR DORY <i>ZENOPSIS NEBULOSUS</i>	JOHN DORY <i>ZEUS FABER</i>	GOULD'S SQUID <i>NOTOTODARUS GOULDI</i>	SOUTHERN CALAMARI <i>SEPIOTEUTHIS AUSTRALIS</i>
	GAB	GAB	Tas. ⁹	GAB	GAB	EBS ¹⁰	EBS ¹⁰	EBS ¹¹	GAB	GAB	GAB	EBS ¹⁰	EBS ¹¹	GAB	GAB	EBS ¹⁰	EBS ¹⁰	EBS ¹⁰	GAB	GAB
	18.6	21.4	0–0.5	75.7	0.3						7.5			15.4					3.6	
	9.5	37.4	0.1–0	17.1	35.4					100	42.8			12.7	5.3			0.5	11.8	11.2
		3.2	45.8–24.5			35.9	49	24.3			7.2	4.1			7.1	35.5	50.4	43.9	10	39.5
	0.6	0.7			0.1				28.4		6.1				8.9				0.2	
	4.1	12.1	30.5–1.4								18.2		2.2		8.7			0.9	4.7	
	14.2	53.4	76.4–26.4	17.1	35.5	35.9	49	24.3	28.4	100	74.3	4.1	2.2	12.7	30	35.5	50.4	45.3	26.7	50.7

Sources:

GAB: Goldsworthy *et al.* (2011a),1 Appendix 2 Patterson *et al.* (unpublished),2 Littnan *et al.* (2007),

3 Lake (1997),

4 Chiaradia *et al.* (2002), Chiaradia *et al.* (2003), Chiaradia *et al.* (2010), Deagle *et al.* (2010),

5 Taylor and Roe (2004),

6 Bunce (2004),

7 Brothers *et al.* (1993),

8 Hedd and Gales (2001),

9 inshore-offshore samples: Young *et al.* (1997),10 Bulman (unpublished data) and Bulman *et al.* (2001),

11 Blaber and Bulman (1987).

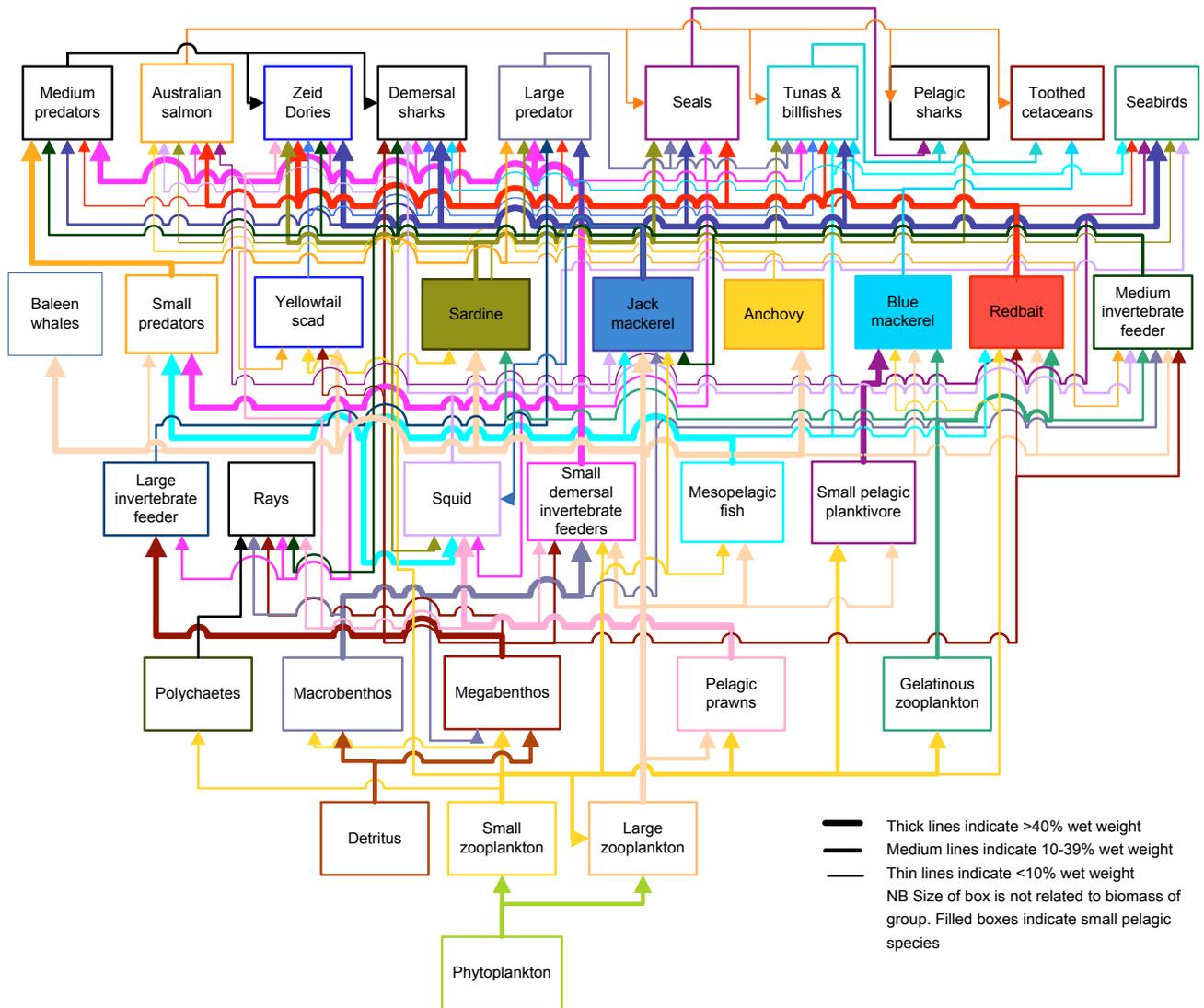


Figure 4.1 Generic small pelagic fish food web based primarily on dietary studies in southern Australia. Coloured boxes depict pelagic species of interest to this assessment. This representation does not explicitly differentiate between slope and shelf species. Source: C. Bulman (CSIRO)

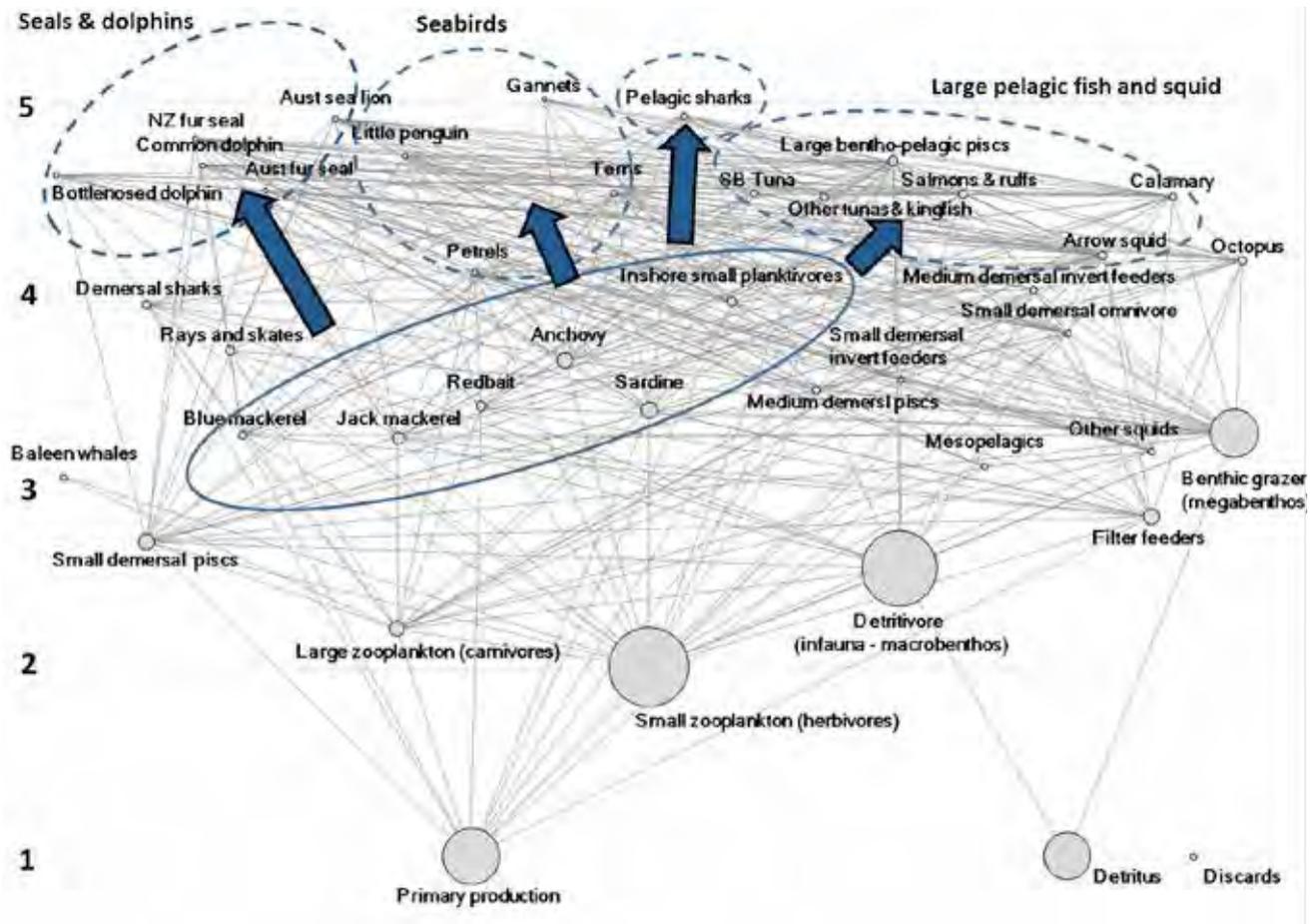


Figure 4.2 Food web for the Great Australian Bight EwE model. Source: S. Goldsworthy (South Australian Research and Development Institute)

4.3 Ecosystem modelling in the SPF

All models are simplifications of the systems they represent and it stands to reason that they have not been used for tactical purposes such as setting of catch quotas. They are, however, useful to investigate management or conservation strategies. Spatial issues can be addressed with spatially explicit models such as Atlantis, and Ecospace, the spatial module of the Ecopath modelling suite, but they do need to be developed at the appropriate scale. Testing harvest strategies at the ecosystem-scale will inform understanding of the consequences that could be expected at finer spatial scales, i.e. unsustainable harvest would imply similar or worse impacts at a finer scale, but they have not been used to inform understanding of localised depletion specifically. Modelling has an obvious advantage: even severe impacts can be explored without having to expose the system to the stress of severe fishing rates or climate regimes. Such explorations, particularly of exploitation levels, are frequently used in management strategy evaluations (MSE), e.g. Fulton *et al.* (2007). Various climate change implications have been investigated using a variety of the models available for Australia (Bulman *et al.* 2006, Brown *et al.* 2010, Fulton 2011).

Ecosystem models have been developed for the southern Australian region, encompassing either most or parts of the SPF (Bulman *et al.* 2006, Fulton *et al.* 2007, Savina *et al.* 2008, Goldsworthy *et al.* 2013a, Johnson *et al.* 2011a, Watson *et al.* 2013). Some of these have been used in the evaluation of the role of small pelagic species in the ecosystem and the broader ecosystem consequences of exploitation. While they all suffer from a lack of detailed information such as

abundance and diet about many species, particularly the higher predators such as the seabirds and marine mammals, they do offer a way to investigate the potential effects of various impacts such as fishing and climate change.

The three EwE models that are most relevant to the SPF are the East Bass Strait Ecosystem (EBSE) model (Goldsworthy *et al.* 2003a), the EBS model (Bulman *et al.* 2006, Bulman *et al.* 2011) which is an updated and expanded version of the previous model, and the GAB model (Goldsworthy *et al.* 2013a) (Figure 4.3). While none of these models encompass the whole area of the SPF, they can be considered representative of their respective SPF Zones (Eastern or Western). The EBSE and EBS model domains extend from southern NSW to Wilsons Promontory, Victoria covering the shelf and slope to 700 metres (m), areas of approximately 40,000 and 30,500 square kilometres (km²) respectively. The objectives of these models were to investigate the effects of fishing, climate change and the impact of fur seals in this area. The GAB model domain includes Investigator Strait and the lower portions of Gulf St Vincent and Spencer Gulf, South Australia, to 200 m, an area of approximately 154,000 km². The objectives for this model were to investigate the SASF impacts on the higher trophic level predators such as seals and seabirds. Details of the model construction, data and results can be found in the reports (Goldsworthy *et al.* 2011, Goldsworthy *et al.* 2013a). The dietary data collated in Table 4.2 and depicted in Figures 4.2 and 4.3 were just some that were used in the construction of the regional models. A major shift in diet might have occurred in the past decade or so, at least for higher predators, as discussed in section 4.2. However, a recent CSIRO dietary study re-sampled a subset of the fish species from the 1994–1996 South East Fishery shelf study (Bax and Williams 2000). The preliminary results of that study suggest minor differences for some species, but it is not yet certain whether they are significantly different from the natural variability of the diets (Dr C. Bulman, CSIRO unpublished data). It is necessary to monitor and update diets to maintain model relevance and performance.

The Atlantis South East model (Atlantis-SE) covers the majority of the SPF. Atlantis-SE was developed to provide insight into alternative integrated management solutions for the Commonwealth fisheries in south-east Australia (Fulton *et al.* 2007) (Figure 4.3). The model has also been used to identify robust indicators of the effects of fishing with simple indices such as relative biomass proving the most reliable (Fulton *et al.* 2004, Fulton *et al.* 2005). The original Atlantis-SE model covers 3.7 million km² of the waters within Australia's south-eastern Exclusive Economic Zone. Other versions of this model exist for eastern Victoria, Bass Strait and Tasmanian waters and the NSW coastal waters (Savina *et al.* 2008, Johnson *et al.* 2011b). A version of the Atlantis-SE model was used in a comparison with the EwE EBS model in a global investigation of exploitation on low trophic level (LTL) species by Smith *et al.* (2011). This model covers approximately 640,000 km² (Figure 4.3). A range of SPF issues has therefore been addressed by these models and are discussed below.

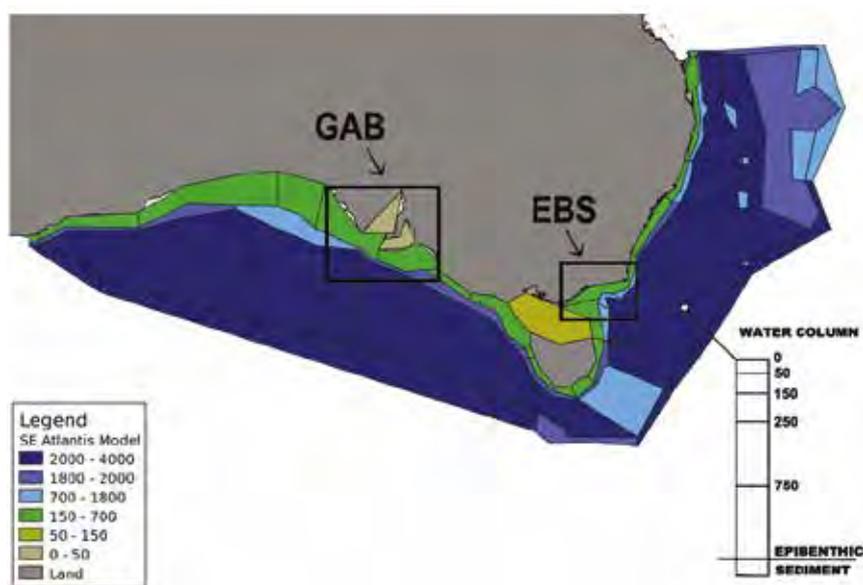


Figure 4.3 Atlantis-SE model domain also showing the indicative area of the EwE EBS and GAB models. Source: Dr E. Fulton (CSIRO)

4.3.1 Food web control

Bulman *et al.* (2011) note that “ecosystem dynamics differ among systems depending on the type of trophic control operating in the food web. Understanding the type of control in a system is fundamental not only to determining sustainable levels of harvest of pelagic fishes but could also help to determine the impacts on higher predators and their fisheries”. Bottom-up controlled systems are those where large predators respond to changes in abundance of their prey, which is generally influenced by the environment. Top-down systems are those where higher predators control their prey. Wasp-waisted systems (Rice 1995) are those where small pelagic species exert top-down control on lower trophic levels such as zooplankton, but also a bottom-up control on their predators such as large pelagic fishes, birds, mammals and fishers. Freon *et al.* (2005) illustrated these types of control in their comprehensive review of small pelagic fishes (Figure 4.4).

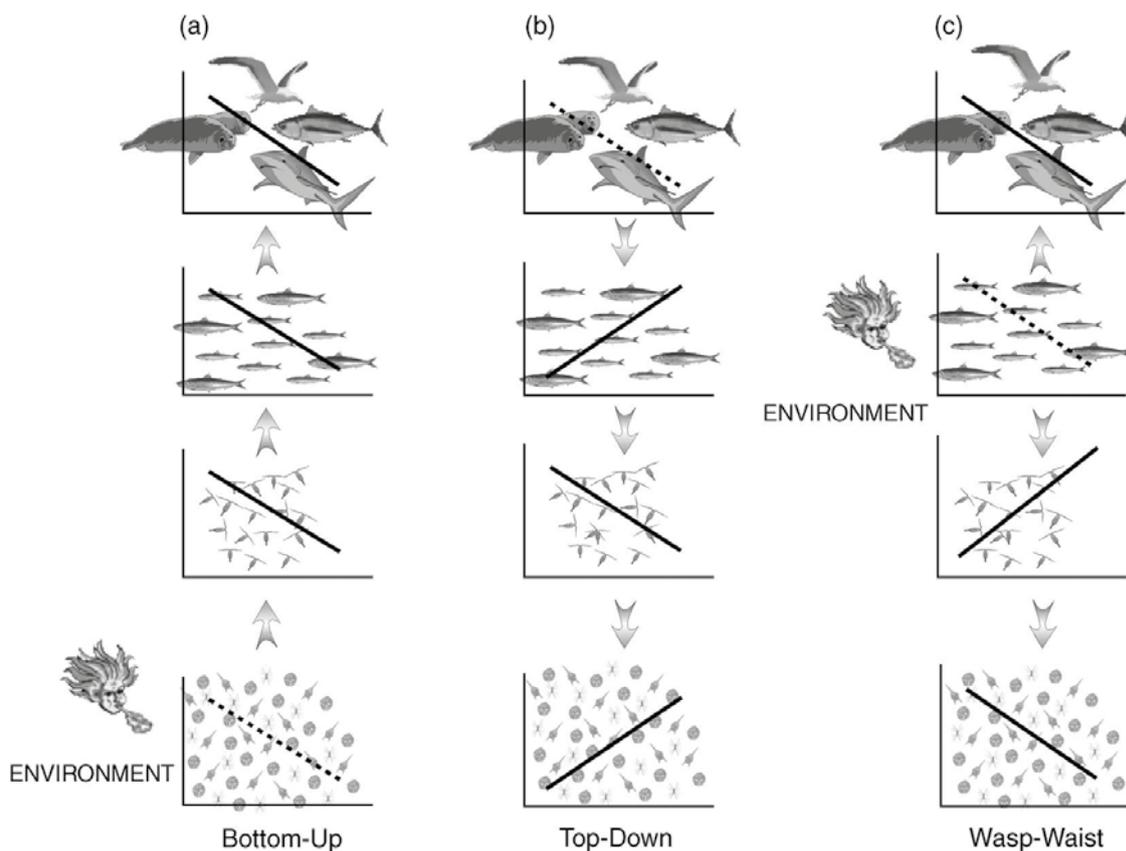


Figure 4.4 Types of potential trophic controls in linear pathways from phytoplankton through to large predators such as pelagic fishes, marine mammals and seabirds. The dotted line is the controlling factor and the solid lines represent the direction of responses of the impacted groups’ biomass over time. Note that no fishing pressure responses are depicted. Source: Freon *et al.* (2005), reproduced with permission from the Bulletin of Marine Science. Image derived in part from Cury *et al.* (2003) in Sinclair and Valdimarsson (Eds). Copy right FAO.

Bulman *et al.* (2011) investigated the dynamics of food web control of the EBS and GAB EwE models and found that these systems are largely bottom-up forced, i.e. the abundance of the prey has a direct influence on the predator but that the more heavily fished EBS has more top-down controlling interactions. They also found that different pathways of the food web could show different control particularly in the EBS model, i.e. control isn’t ‘across-the-board’ for all interactions in an ecosystem. Switching between bottom-up and top-down control may indicate pressures such as climate change and fishing.

The evidence for the classic wasp-waist control by any of the SPF target species was not particularly strong. Australian sardines (and anchovies) were involved in only two of the 25 most sensitive predator–prey interactions in the GAB and one in the EBS compared to one quarter to one half of those in the large upwelling system of the Benguela Current in a similar investigation (Shannon *et al.* 2008). Typically, ‘wasp-waist’ species are the small pelagic or ‘forage fish’ species and they dominate their trophic level with high biomass, channelling the energy flow through the mid-trophic level from plankton to large fish, seabirds and marine mammals. As discussed above, the pelagic fish biomass is much less dominant in the Australian ecosystem compared to those that support huge fisheries elsewhere. This is an important consideration in modelling the predator–prey interactions accurately and understanding the dynamics of these species in the food web.

A common factor in both the GAB and the EBS models was the dominance by both the New Zealand fur seal *Arctocephalus forsteri* and Australian fur seals respectively, despite their relatively low biomasses in the ecosystem (Bulman *et al.* 2011). In the GAB the interactions between fur seals and their prey were mostly bottom-up controlled for both species, i.e. if there was an increase in seal biomass the effect on their prey would not be particularly significant. However, in the EBS, fur seal interactions were largely top-down controlled, i.e. the fur seals would be more influential on their prey abundances. Specifically, important findings relevant to this assessment were that:

- the Australian fur seal–redbait interactions were bottom-up controlled in both models but the New Zealand fur seal–redbait interaction was not amongst the ‘top 25’ sensitive interactions
- the interactions of jack mackerel with both the Australian and New Zealand fur seals in the GAB were bottom-up controlled but in the EBS the jack mackerel–Australian fur seal interaction was top-down controlled.

The SPF species were also involved in other predator–prey interactions in the ‘top 25’ interactions. Relevant interactions were SBT–redbait and SBT–jack mackerel in the EBS; arrow squid–jack mackerel, pelagic sharks–Australian sardine and SBT–anchovy in the GAB, noting that anchovy is not an SPF species but is a small pelagic forage fish. These were all bottom-up controlled interactions apart from the squid–jack mackerel interaction. SBT predation on redbait and jack mackerel in the EBS ecosystem is probably ‘under-played’ in the Eastern Zone SPF since the data were averaged across inshore and offshore data for the purposes of the model; the ‘inshore’ dependence on jack mackerel and redbait combined was greater than 75 per cent (Table 4.2). Nevertheless, SBT in the Eastern Zone clearly have a preference for the medium-size pelagics (and squids) whereas they prefer the small-sized pelagics, sardines and anchovy, in the GAB.

One of the interesting findings in the EBS ecosystem and the Atlantis–SE modelling studies was that mesopelagic fishes and krill produced the most significant results, i.e. reducing their abundance affected more groups to a greater extent than reductions in small pelagic fishes (Bulman *et al.* 2011, Smith *et al.* 2011). The combination of a high initial biomass and heavy predation pressure on a group generally resulted in a higher likelihood of that group playing a central role in the functioning of the ecosystem, as occurred for krill in the Atlantis–SE model and for krill and mesopelagic fishes in the Ecosim–EBS model (Smith *et al.* 2011). A similar response was found in an oceanic model for the Eastern Tuna and Billfish Fishery where mesopelagic fish and squid had the significant wasp-waist role with effects cascading up and down the food web upon their removal (Griffiths *et al.* 2010).

The panel noted that these ecosystem models suggest that the GAB ecosystem, which is more dependent on the sardine and anchovy food base, is largely bottom-up controlled and so the predators have less effect on abundances of their prey than might other factors such as environmental conditions. By comparison, the EBS ecosystem does not have the same dependence on Australian sardine, with jack mackerel and redbait being more important and the Australian fur seals are particularly dominant and influential on their prey. Therefore, the roles that the SPF species play in each system are different as are the roles of the top predators, and may be important to consider for management and allocation of resources with respect to the ecosystem requirements (see Chapter 6).

4.3.2 Climate change

Ecosystem models found that climate change was very likely to have major impacts in any system, particularly in top-down systems already sensitive to fishing pressure (Bulman *et al.* 2011). A range of climate-change scenarios has been explored using a collection of EwE models for a dozen ecosystems around Australia including the EBS model, with generally linear responses to system productivity, although individual model specification and structure also influenced outcomes (Brown *et al.* 2010).

Fulton (2011) suggested that mid-trophic level species, particularly mesopelagic and small pelagic fishes, may be at the centre of a future oceanographic regime shift in waters off eastern Tasmania and Bass Strait. She used a collection of Atlantis models for north-east, north-west and south-east Australia to predict outcomes from climate-change scenarios. In the south-east model, plankton, other pelagic invertebrates, and pelagic fish all increased, while the demersal fish decreased. The modelled regime shift in the waters off eastern Bass Strait and Tasmania predicted a change from a demersal and mesopelagically dominated system to a more pelagically driven one. While primary production was predicted to increase, the plankton community shifted to a smaller sized plankton assemblage similar to the actual shift observed during 1988–89 (Harris *et al.* 1991, Harris *et al.* 1992). Such a shift was proposed by McLeod *et al.* (2012) to explain the apparent switch in dominance between jack mackerel and redbait since the early 2000s. They found that jack mackerel reliance on krill was about 60 per cent by weight compared to nearly total reliance in the 1980s (Young *et al.* 1993). Jack mackerel also ate myctophids, similar to the jack mackerel studied by Blaber and Bulman (1987) on the upper shelf off Maria Island, suggesting they fed deeper. Redbait had a higher dependence on krill than jack mackerel but also ate copepods so perhaps could take advantage of a more copepod-dominated assemblage. Macleod *et al.* (2012) suggested that a permanent shift to a smaller-sized plankton base mediated by warmer, less productive water would better support the small copepod–redbait pathway. Bulman *et al.* (2011) stated that a permanent regime shift “may lead to large-scale restructuring of the role of small pelagic fishes” which may “lead to a radically different context to the fishery than exists today”.

4.3.3 Sustainable harvest and indicators

A challenge for management of the SPF is to not only maintain the target stocks at a sustainable level but at a level that avoids broader ecosystem impacts. Pikitch *et al.* (2012) point out that it is possible to manage a stock so that it is not overfished but still cause negative ecosystem effects, i.e. ecosystem overfishing, by not considering predator-prey relationships. Several modelling studies have explored sustainable harvest rates and indicators of relative importance of the SPF species.

Goldsworthy *et al.* (2003a) explored the consequences of fishing redbait and jack mackerel on the Australian fur seal populations in the East Bass Strait, a relatively small area of the SPF. They found that at a harvest of jack mackerel of 5000 t, equivalent to a fishing mortality (F) of 0.05 (of the whole biomass), the fur seal biomass would decline by about 10 per cent and a redbait harvest of 5000 t would cause a fur seal decline of around 2 per cent. It should be noted that this study did not model environmental variability, therefore biomass changes of this order due to fishing may either be added to that caused by environmental variability or absorbed by the population’s ability to cope with a certain degree of change. In either case, low levels of change would be indiscernible from natural variability. At higher levels of exploitation, however, biomass changes are likely to be discernible.

Smith *et al.* (2011), in a study for the Marine Stewardship Council (MSC), explored the broader ecosystem effects of fishing LTL species in five ecosystems: three of the eastern boundary currents, i.e. northern Humboldt, southern Benguela, and Californian current; and two non-upwelling dominated systems, i.e. the North Sea and south-east Australian shelf. The LTL species in that study included small pelagic ‘forage’ fish such as anchovy, sardine, herring, mackerel and capelin, but also mesopelagic fishes and invertebrate species such as krill. Krill has been the focus of concerns in the Antarctic ecosystem in relation to increased harvesting and potential localised depletion effects (Constable *et al.* 2000, Plagányi and Butterworth 2012, Pikitch *et al.* 2014). The LTL investigation used three model structures to avoid model-specific structural assumptions. The two southeastern Australian ecosystem models included jack mackerel, Australian sardine and redbait as well as krill, squid and mesopelagic fishes (Atlantis-SE: Johnson *et al.* 2010, EwE EBS: Bulman *et al.* 2011).

The strategy of Smith *et al.* (2011) was to investigate the responses of all ecosystem model groups to a range of exploitation rates for each of the LTLs up to extirpation. They found impacts were widespread, and increasing exploitation rates tended to involve increasing numbers of groups (see Figure 2 in Smith *et al.* (2011)). The individual response of a species also varied: some species were more responsive even at low fishing rates. Marine mammals and seabirds were most often negatively impacted although not highly.

Indicators

The variability across the species and the potential implications for management prompted Smith *et al.* (2011) to look at generic properties that might explain and predict the variability observed. They calculated a connectance index (the number of connections a prey has in the model diet matrix relative to the total number of connections in the model), as an indicator of the importance of particular prey in the ecosystem. Prey with values greater than a threshold of 0.04 were considered highly connected. They found that abundant groups had consistently greater impacts as did the more highly connected groups.

This theme of connectedness was explored further by Plagányi and Essington (2014). They proposed a way to identify critical forage fish species in an ecosystem using the proportion of a predator's diet that the forage fish constitutes (by biomass) as well as the number of connections it has with other groups in the matrix. The supportive role to fishery ecosystems (SURF) index is similar to the connectance of Smith *et al.* (2011) but also considers the strength of those interactions. The primary motive for this development was to provide a quick but robust indicator to identify those key species whose removal might have the largest indirect impacts. The connectance of each of the EwE models was investigated in one or other of the studies mentioned, i.e. the MSC connectance index for EBS model (and Atlantis-SE model) (Smith *et al.* 2011) and the SURF (and connectance but values not given) for the GAB model (Plagányi and Essington 2014). In order to compare both indices for each of the models, the panel calculated the relevant 'missing' indices for the EwE models only (Table 4.3). As both of these indices were proposed to identify critical links in the food web it was useful to determine whether the Australian SPF species have a significant role using both methods.

Connectance for the EBS had been calculated by Smith *et al.* (2011) and none of the SPF species met the threshold, although jack mackerel was close, suggesting that none of these species is particularly critical in the system. However, the small pelagic group used in this study was an aggregated group of small pelagic species including Australian anchovy and sprats (as a minor component). Anchovy alone might produce a significant result since it comprises more than 20 per cent of some age classes of marine mammal diets in age-structured Atlantis models (Dr E Fulton, CSIRO pers. comm. 29 September 2014). In contrast, in the GAB model, all SPF species were above the threshold, with Australian sardine having the highest connectance, noting that Australian sardine in the GAB is managed in the SASF rather than in the SPF.

The SURF index identified no SPF species as being above the threshold in the EBS, whilst in the GAB, only Australian sardines were identified as above the threshold, as was anchovy. The SURF index uses the actual prey proportion and therefore gives a more quantitative indication of importance and this makes the model structure quite important in interpreting the results. Therefore, in the EBS model where the 'small pelagic' group was an aggregated group, as noted previously splitting out sardines was necessary in order to calculate the index. Anchovy, being dominant in little penguins' diets, might well have produced a significant result. While indices are useful they should be used only with careful interpretation and knowledge of the systems. It is worth noting that in the EBS model, krill and mesopelagic fishes produced above threshold values for both connectances (0.049 and 0.056 respectively: Smith *et al.* 2011) and SURF indices (0.002 and 0.004 respectively: this study). In the GAB model, krill had a high connectance index (0.063) but not SURF index (0.0003). The difference in results between the two models reflects the difference in the ecosystem characteristics they represent as shown in the earlier section on food web control.

Table 4.3 Ecosystem model connectance and SURF indices for SPF species and anchovy in EBS and GAB EwE models

INDEX	MODEL	AUSTRALIAN ANCHOVY	AUSTRALIAN SARDINE	REDBAIT	JACK MACKEREL	BLUE MACKEREL
Connectance	EBS	-	0.0315	0.0264	0.0368	0.021
	GAB	0.0443*	0.0601*	0.0506*	0.0570*	0.0538*
SURF	EBS	~0.0004	~0.0006	0.0002	0.0005	<0.0001
	GAB	0.0023#	0.0022#	0.0008	0.0006	<0.0001

Bolded values > thresholds; * threshold > 0.04 (MSC), # threshold > 0.001 (SURF).

Sustainable harvest

Smith *et al.* (2011) concluded that considerable impact could be mitigated by a reduction in exploitation levels of LTL species from maximum sustainable yield (MSY), i.e. from about 60 per cent depletion to approximately 25 per cent depletion (see Figure S1 in supporting online material: Smith *et al.* 2011). They also concluded that this target could be achieved with a much lower fishing effort and may be close to long-term economic optimum return. Two further strategies were proposed that might be effective in managing these fisheries: using thresholds or 'set-asides', i.e. an allocation of the resource specifically to ensure against impacts such as those on central place foragers and broader ecosystem requirements, and spatial closures.

An important outcome of the Smith *et al.* (2011) study was a concern about the species-specific variability in response to the same exploitation rates and the implications that may have for using a 'blanket' target as in the SPF Harvest Strategy (Australian Fisheries Management Authority [AFMA] 2008). This concern is the focus of a current investigation (Fisheries Research and Development Corporation [FRDC] 2013/028) that is also assessing the ecosystem impacts of fishing simultaneously across all target species in the SPF (see Section 4.3.5). The earlier Smith *et al.* (2011) study assessed the impacts of only fishing one target species at a time (although all other fisheries and non-target species were modelled at status quo levels).

The outcomes of the Smith *et al.* (2011) study were supported by the Lenfest Forage Fish Task Force research (Pikitch *et al.* 2012). Its objective was to provide "practical, science-based advice for the management of forage species because of these species' crucial role in marine ecosystems and because of the need for an ecosystem-based approach to fisheries management". This comprehensive examination of forage fish ecosystems, their fisheries and management resulted in the development of specific management measures and general rules.

One of the findings from the Lenfest analysis of 72 ecosystem (EwE) models was that three-quarters of them had at least one predator that was highly dependent on forage species, i.e. ate 50 per cent or more forage species; 29 per cent had at least one predator that was extremely dependent (i.e. that ate 75 per cent or more), and 25 per cent had no predators that ate 50 per cent or more (Pikitch *et al.* 2012). Applying those criteria to observed diet data in Table 4.2, i.e. not modelled diet data, both ecosystems (GAB and EBS) had species that were extremely dependent on SPF species: bonito in the GAB, little terns in Bass Strait, and inshore SBT in eastern Tasmania. Of these, bonito and little terns were dependent on sardines and the SBT dependent on jack mackerel and redbait. Another five species in both areas were highly dependent when summing their diet across all forage species: Australian fur seal in the GAB and EBS; Australasian gannets in Port Phillip Bay; shy albatross in Bass Strait and GAB; SBT in the GAB; and school shark, barracouta and mirror dory in the EBS. However, if these criteria were applied to the model group data as Lenfest did, rather than observed data, the results were slightly less outstanding, i.e. only the Australian fur seal, SBT and the 'other tuna' group from the GAB model would rank as highly dependent and the last two results were as a result of inclusion of Australian sardine which is managed by South Australia in the GAB. This is because species aggregation within the model, a common necessity in modelling, hides specific species interactions as seen in the calculation of connectance indices. In addition, if a predator's diet is highly variable, it may have not been sampled adequately to have captured that variability. Even if it were adequately sampled, as discussed previously, the single characterisation of a highly variable diet for inclusion into a 'model diet' will smooth over those critical times when SPF species may be highly important.

The indicators and guidelines derived from the MSC and Lenfest studies are in general agreement with original conclusions about the dynamics of the model systems, but the models point to other species and groups in each ecosystem that might also be important. It still remains necessary to 'drill down' to species-specific information to inform issues of ecological dependence and allocation, particularly for protected species of predators and other predator species of high commercial value.

4.3.4 South-east case study

Notwithstanding the problems of model specificity and architecture, ecosystem models do provide valuable insights into the dynamics of ecosystems under pressure. All of the models, particularly the Atlantis models, have been used to predict changes in ecosystem groups under various fishing scenarios. The two Australian models used in the MSC study were reported more fully in Johnson *et al.* (2010) and Bulman *et al.* (2011). As discussed in the previous section, for the broader

MSC study, Johnson *et al.* (2010) investigated the responses of the EwE-EBS and Atlantis-SE ecosystem model groups to a range of exploitation rates for each of the LTL species up to extirpation.

In the small pelagics simulations, they found that exploitation rates (F) of 0.1 in the EwE-EBS model and 0.05 in the Atlantis-SE model reduced the biomass to 75 per cent of unfished biomass (B_{75}). This biomass is close to the 80 per cent level recommended by the Lenfest task force for forage fisheries on a low information tier (Pikitch *et al.* 2012). In both EwE-EBS and Atlantis-SE, the level of biomass at which maximum sustainable yield can be achieved (B_{MSY}) was predicted to be similar to B_{40} (40 percent of biomass (usually spawning stock or available biomass)) and attained with $F=0.33$ and 0.15 respectively.

In the jack mackerel simulations, F_s of 0.01 and 0.02 were found to reduce the biomass to B_{75} in the EwE-EBS and Atlantis-SE models respectively. B_{MSY} (at slightly above B_{40}) was attained with F_s of 0.05 and 0.06 respectively.

The red bait simulations for Atlantis were not reported due to inappropriate calibration at the time and those for the EwE-EBS model were not representative of the eastern Tasmanian stock (Bulman *et al.* 2011) and so will not be discussed further here. It should be noted that the current Atlantis model being used in the FRDC Project 2013/028 has an appropriate red bait calibration (Dr E. Fulton, CSIRO pers. comm. 22 September 2014).

The responses of the model groups for a reduction of jack mackerel to B_{75} were small (Table 9; Figures 33 and 34 of Johnson *et al.* 2010). The largest adverse effects were decreases in abundance of approximately 5 per cent for tunas and seals, and less for sharks and dorries in the EwE-EBS, and even smaller decreases in Atlantis-SE. The majority of the responses were small increases in biomass particularly in seabirds and baleen whales in Atlantis-SE. This is broadly consistent with Goldsworthy *et al.* (2003a) who found that an F equal to 0.01 of jack mackerel, i.e. catch of 1000 t, was predicted to result in an approximate 2 per cent decline of fur seals.

Both negative and positive responses to reductions of small pelagic species to B_{75} or less were far more wide-reaching in the EwE model compared to the Atlantis model (Table 12, Figures 12 and 13 of Johnson *et al.* 2010). Atlantis produced little response and some of the largest ones were actually positive increases in biomass. In the EwE-EBS model, little penguins declined by 20 per cent; however the small pelagic group was a combination of Australian anchovy and sardine and the little penguin's diet consists predominantly of anchovy (Tables 4.1 and 4.2), therefore it is the reduction in the anchovy, rather than the sardine, to which the little penguins might be responding. This might also apply to some of the other fish groups that showed strong responses.

The differences in the model responses were due to 'model architecture' and formulation and are discussed more fully in Johnson *et al.* (2011b). The issues to do with model structure, i.e. the aggregation of groups, have been addressed in the more recent Atlantis-SPF being used in the FRDC Project 2013/028. However, Johnson *et al.* (2011b) also specifically mention factors related to size structuring such as gape limitation, ontogeny and prey-switching that allow more flexible trophic connections in the Atlantis model than in the EwE configuration. The gape limitation and prey preference mechanisms used in Atlantis allow for prey switching if suitable alternative prey can be found, and therefore buffer predators from declines in their primary prey. This kind of switching has been seen in other ecosystems and is suggested by all the Atlantis model results as likely in this region for the SPF species but possibly not as simply for anchovy (Dr E. Fulton, CSIRO pers. comm. 26 September 2014).

4.3.5 Explorations of biomass and harvest strategy

Irrespective of model architecture, both the EwE and Atlantis models are calibrated to real observations including biomasses of the model groups. While these models are not used for setting total allowable catches (TACs), their value in evaluating scenarios such as those discussed above depends upon the models being either balanced, in the case of EwE, or numerically stable, in the case of Atlantis. The biomass used in the EwE-EBS model for jack mackerel was initially estimated from survey data (Bulman *et al.* 2006) from surveys of the South East Fishery (Bax and Williams 2000) which was consistent with the estimates of Neira (2011). Similarly, the biomass of redbait was estimated from estimates derived from daily egg production methods for redbait (Neira *et al.* 2008, Neira *et al.* 2009, Neira and Lyle 2011).

Fulton (2013) explored the hypothesis that the TAC for jack mackerel was too high by simulating a range of spawning biomass estimates between 20,000 and 170,000 t and evaluating the model's performance with each estimate. Biomasses of 20,000 to 30,000 t caused both models to 'fail'. The best performances for Atlantis were achieved for biomasses between 96,000 and 190,000 t with a mean of 143,000 t (Fulton 2013) similar to the mean of Neira (2011). For the EwE model, spawning biomasses of 130,000 and 170,000 t, equivalent to total biomasses of 145,000 t and 180,000 t (the current baseline value) that were input into the model, were the only values that would balance the model. It was concluded that very low biomass values, i.e. 20,000 to 30,000 t of jack mackerel, are not consistent with the current observations and knowledge of the ecology of the system.

Fulton (2013) also compared the current SPF Tier 1 Option 2 harvest control rule (HCR) of exploitation rate of 0.15 (the maximum harvest rate allowable in the three-tier system: see Section 3.2.2) with the more commonly used target of B_{48} across the range of most plausible jack mackerel biomasses. Some localised depletion was possible under the SPF Harvest Strategy (AFMA 2008) but most changes were less than 5 per cent, however, under the B_{48} strategy a number of complicated 'knock-on' effects were likely. The conclusion from this investigation was that "if smaller ecological footprints are desired, target reference points for jack mackerel should be increased to a high level, e.g. B_{75} as recommended by Smith *et al.* (2011)" (Fulton 2013). In other words, a target of B_{48} , i.e. a reduction to 48 per cent of the (usually spawning stock) biomass (SSB), is not an appropriate target reference point for jack mackerel and that the Tier 1 Option 2 HCR of $F_{0.15}$ (i.e. a harvest rate of 15 per cent of SSB) broadly satisfies ecosystem requirements.

The current SPF Harvest Strategy is the focus of an investigation (FRDC 2013/028) lead by Dr Tony Smith (CSIRO). The two issues being examined are: Should exploitation rates be lowered to account for potential trophic impacts of fishing these species? And does the current strategy comply with the Commonwealth Harvest Strategy Policy (Department of Agriculture, Fisheries and Forestry, 2007) for each target species and stock? Preliminary results communicated to the panel (Dr A. Smith, CSIRO *in litt.* 6 June 2014) suggest that the impacts on predators and other groups of fishing the SPF stocks are low across the range of exploitation rates including the current rate. The changes in abundance of all other species and trophic groups were less than 20 per cent and mostly negligible and this was true even when all the SPF target species were simultaneously depleted. The model results predict that predators would switch diets to other species or groups when SPF species abundance is low which they found consistent with other model results for the region. The preliminary conclusion is that, "based on current evidence, the biomass targets and corresponding exploitation levels in the SPF harvest strategy need not be adjusted specifically to account for trophic impacts of fishing", i.e. the ecological allocation to maintain the predators and ecosystem as a whole is not impinged upon by the exploitation rate. Model simulations of the present TAC were shown to be even more conservative than the harvest strategy rule implying that fishing in recent years should not have been harmful (Dr E. Fulton, CSIRO pers. comm. 1 September 2014). Preliminary results from the MSE analysis confirmed that the current SPF harvest strategy settings are generally appropriate, and that the Tier 1 harvest strategy meets the Commonwealth Harvest Strategy Policy requirement that there be less than a 10 per cent chance of the stock falling below 20 per cent of unfished levels (Dr A. Smith, CSIRO *in litt.* 6 June 2014).

In the SASF, Goldsworthy *et al.* (2013a) found that the current level of harvest for Australian sardines of about 10 to 20 per cent of the estimated spawning biomass was conservative and that no broad ecosystem effects were evident. This exploitation rate is in accord with the recommendations of the Lenfest Fish Task Force (Pikitch *et al.* 2012) and the MSC study (Smith *et al.* 2011). However, Goldsworthy *et al.* (2013a) also note that the SASF is concentrated in a relatively small area, approximately 7 per cent of the model domain and broader area over which the fish are found and connectivity between the fish within the two areas is assumed to be high. If this assumption is incorrect, "localised depletion cannot be discounted as a meso-scale issue" (Goldsworthy *et al.* 2013a).

4.4 Conclusions

The predator-prey interactions are generally well-known for many of the main species in the SPF although some of the trophic data particularly in the Eastern Zone are at least 20 years old. While a major shift in diet might have occurred in the past decade or so, preliminary results from a recent study into diets of a small sub-set of the original South East Fishery shelf study (Bax and Williams 2000) fish species in the Eastern Zone, do not suggest large changes (Dr C. Bulman, CSIRO unpublished data). However, dietary information for Australian fur seals and little penguins from Victoria in the Eastern Zone are more current and do suggest diet changes indicative of an oceanographic regime shift (Kirkwood *et al.* 2008, Chiaradia *et al.* 2010 respectively). The data collected for GAB species is also recent and also includes diets for large predators and central place foragers. While the spatial coverage of the diet studies is relatively small when compared to the SPF, it is assumed to be representative of each Zone. There remains a lack of distributional and biological data for many higher predators, particularly seabirds, and particularly in the Eastern Zone. Therefore, some uncertainty remains about the nature and extent of ecosystem impacts that might arise if the main fishing effort in the SPF was to be again concentrated off eastern Tasmania, although the panel noted that the historical exploitation levels of jack mackerel in that area were higher than the present harvest strategy allows.

The ecosystem modelling studies in the SPF appear to have captured the dynamics of the systems reasonably well. The SPF species are apparently not as influential as small pelagic species in other upwelling systems. There is general agreement across model types and ranges of scenarios that exploitation under the current harvest strategy is unlikely to cause adverse environmental impacts to the broader ecosystem although some predator groups may decline slightly. The 'ecological allocation' to predators and the broader ecosystem is apparently adequate based on model simulations of the Tier 1 exploitation rate (greater than the present TACs). There is, however, the potential for localised depletion that might lead to adverse environmental impacts if fishing effort were spatially concentrated. Localised depletion is discussed further in Chapter 6.