The Commonwealth Small Pelagic Fishery: General background to the scientific issues

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There has been strong public interest in the management settings for the Commonwealth Small Pelagic Fishery (SPF). This general scientific background is intended to provide a summary of the fisheries science underpinning management.

Background – International scientific standards for sustainable fisheries on small pelagic fish species

Several groups of scientists worldwide, including from CSIRO and IMAS, have recently examined the effects of fisheries on small pelagic species (also sometimes called forage fish) and how they should be managed so as to avoid undesirable flow-on effects of these fisheries on the food web and ecosystem. There is now clear and widely agreed understanding about how these fisheries should be managed, and this understanding has a strong scientific basis (e.g. Smith *et al.* 2011). The latest and most comprehensive study and guidance comes from the Lenfest Forage Fish Task Force (Pikitch *et al.* 2012). This was supported by the Lenfest Ocean Program, a US conservation foundation, and brought together 13 eminent marine scientists including world experts in marine science, conservation science (e.g. specialists in penguins, seabirds, marine mammals and marine conservation) and fisheries science. During 2009-12, the Task Force reviewed all the major marine ecosystems and major forage fisheries in the world and examined where undesirable impacts had occurred in the past. They used both direct observations and modern ecosystem models to identify what was required of fishery management to protect the food web and ecosystem. Their requirements were designed so that, if followed, they would have protected all of the known food webs and ecosystems in the world that include fisheries for forage fish. This includes some ecosystems in which there are high levels of dependency between top predators and a small number of forage fish species. In contrast, the Australian food-web has a diverse range of species in this trophic level and top predators have lower dependency on particular prey species. The recommendations of the Lenfest Forage Fish Task Force were that:

- the fishing mortality is no more than half of the level that is usually considered to maximise the sustainable yield for an individual species;
- the average abundance of the forage fish is more than double the level usually considered to maximise the sustainable yield for an individual species; and

- fishing should be spread out so as to avoid localised depletions, especially in relation to any local ecological 'hotspots' where there is particularly strong local dependency between predators and prey (e.g. in the vicinity of some seabird rookeries).

The Task Force further expanded these requirements to take account of differences in the certainty of scientific understanding available about the quantity and dynamics of the forage fish species and about the food web and ecosystem. They provide rules so that fishery management is more conservative if there is less certainty in the scientific understanding. This more conservative management is necessary to protect the food web and ecosystems from the errors that could be made because of limited scientific understanding about the details of the particular fish species and ecosystem. The Task Force selected these rules so that they would be sufficient to protect all of the food webs and ecosystems known.

The recommendations of the Task Force have been accepted by NGO groups such as the Pew Foundation and conservation scientists who are often very critical of fishery management. The Marine Stewardship Council, the leading international ecolabel for sustainable seafood, has adopted equivalent requirements into its standard.

There is a strong scientific basis and understanding of what is required of fishery management to protect the food-web and broader ecosystem – and dependent fish, bird and marine mammal populations in particular – when conducting a fishery that targets the forage fish in that ecosystem. These requirements include that management be more conservative where there is more scientific uncertainty about the forage fish or the food web.

The basis of the catch limits set

Details on how the SPF is managed and how this compares with global scientific standards is given in Appendix 1.

The SPF Harvest Strategy uses a tiered approach that recognises the ecological importance of the small pelagic species and takes an explicitly conservative approach to setting harvest levels (i.e. proportion of spawning biomass) and hence TACs. The tiered approach recognises that harvest rates must be low when there is limited information available on the status of the stocks but can be increased as improved information becomes available.

> Tier 1 – applies to stocks for which spawning biomass estimates are no more than 5 years old, with harvest rates set between 10-20% of spawning biomass; the actual harvest rate is reduced as the 'age' of the biomass estimate increases. Spawning biomass is estimated using the Daily Egg Production Method (DEPM) which is a survey method that is independent of the fishery. It has been successfully applied nationally and internationally in other small pelagic fisheries to assess the size of spawning stocks.
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> Tier 2 – either set at a maximum of 7.5% of the most recent estimate of spawning biomass or where biomass has not been assessed at a level based on expert judgement that is

considered to be conservative when previous fishing history, species distributional range and life history characteristics are taken into account.

Tier 3 – applies to species for where there is limited information; TACs are set at very low levels but do not exceed 500 t for the species.

The SPF Harvest Strategy details, the DEPM surveys and biomass estimates (where available), the current tier level, the Recommended Biological Catch (RBC) and Total Allowable Catch (TAC) for 2012/13 by species and management subarea are as follows:

Sub-area	Species	DEPM surveys	Spawning biomass	Assessed tier level 2012/13 (harvest fraction)	RBC 2012/13	TAC 2012/13	Comments
Eastern	Redbait	NSW 2003 ETAS 2005 & 2006	NSW :20,500t TAS: 51,000t (2006) & 87,000t (2005) (av. 69,000t)	1 (10%)	6900t	6900t	NSW estimate imprecise but indicates ETAS values are likely under-estimates. Neira and Lyle (2011)
	Jack mackerel	NSW 2002	Best estimate (mid-range) approx. 140,000t	2 (7.5%)	10600t	10100t	RBC raised from 5000 t (2011/12) to take into account newly available information based on 2002 egg survey data. Neira *et al.* (2011)
	Blue mackerel	2004	Mid-range estimate of 40,000t	2 (7.5%)	3000t	2600t	Ward *et al.* (2009)
Western	Redbait	NA	NA	2	5000t	5000 t	RBC default - expert judgement
	Jack mackerel	NA	NA	2	5000t	5000t	RBC default - expert judgement
	Blue mackerel	2005	Best estimate 56,000t	2 (7.5% plus allowance for spawning outside survey area)	6500t	6500t	Spawning activity confirmed outside of the DEPM survey area. Ward & Rogers (2007), Ward *et al.* (2009)

Recognising that the reliability of biomass estimates will diminish if they are not updated over time, the SPF Harvest Strategy specifies that the harvest fraction (i.e. the RBC as a proportion of spawning biomass) will be reduced progressively and become more conservative as the age of the estimate increases. If no new estimate of spawning stock biomass is available after the original estimate has aged five years then the stock will default to Tier 2. So while spawning biomass estimates are available for a number of the SPF stocks, only redbait (eastern) was assessed at Tier 1 in 2012/13 and in line with the age of the DEPM estimate a harvest fraction of 10% (the lowest possible for Tier 1) of the spawning biomass was applied.

The rationale for increasing the TAC for jack mackerel (eastern) from 5000 t in 2011/12 to 10,100 t for 2012/13 was new information arising from the re-examination of samples collected as part of ichthyoplankton surveys conducted off NSW in the early 2000s. Jack mackerel eggs were present in some samples and, using a range of plausible information about the spawning dynamics of related species, indicative estimates of spawning biomass were derived using the DEPM. Depending upon input parameters, spawning biomass off NSW was estimated to be in the range 50,000 to over 300,000 t. As evident from the wide range of values, there was considerable uncertainty associated with the estimates. Some of this uncertainty is because the surveys were not designed to estimate jack mackerel and so they were not optimal. Particularly they do not cover the full stock (e.g. did not include the waters adjacent to Tasmania where it is known that a large fraction of the jack mackerel population occurs) and they were not timed to cover the full/peak spawning season and consequently they gave under-estimates of true stock biomass. This makes the TAC levels more precautionary.

Two other pieces of information are relevant in determining whether these estimates are reasonable, and both are a form of 'cross check' with entirely independent information.

- The previous fishing history of jack mackerel off Tasmania gives an indication of stock size and potential productivity. For instance over 100,000 t was taken in three years during the 1980s and catches throughout the 1990s averaged over 10,000 t per annum. From this the unfished biomass of jack mackerel must have been well in excess of 100,000 t.

- The ecosystem models provide estimates of the population size for small pelagic species (see below) that are based on food-web structure, plankton productivity and mass-balance among the key components of the ecosystem (what must exist to be eaten to support the predators in the system). These estimates are similar to the estimates provided by the DEPM and expert judgement.

While there is uncertainty in all of these estimates their general consistency indicates that the population biomass estimates are not substantially incorrect. However, there will always be uncertainties in these estimates and the key issue is to ensure that the catch limits are set so that they are safe despite the uncertainty. This is exactly what the harvest strategy does. The harvest strategy has also been simulation tested using Management Strategy Evaluation methods that show the harvest strategy is conservative despite the uncertainties in the population estimation (and several other uncertainties).

The Daily Egg Production Method (DEPM) to estimate population size

The DEPM is used for stock assessment and management of some of the world's largest pelagic fisheries (see Stratoudakis *et al.* 2006, for a review). Over the last three decades, it has been applied to at least 18 species of small pelagic fishes worldwide (Stratoudakis *et al.* 2006, Neira *et al.* 2008, Dimmlich *et al.* 2009, Ward *et al.* 2009, Neira and Lyle 2011). The main reason that the method has been used so widely is that it is often the most practical option available for stock assessment of small pelagic species. In many circumstances the only real alternative to the DEPM is acoustic surveys, which often produce biased estimates of biomass and require more sophisticated and expensive infrastructure, higher levels of technical support and expertise, and have a longer developmental phase than the DEPM.

The DEPM relies on the premise that the biomass of spawning adults can be calculated by dividing the mean number of pelagic eggs produced per day throughout the spawning area, i.e. total daily egg production, by the mean number of eggs produced per unit mass of adult fish, i.e. mean daily fecundity (Lasker 1985).

Total daily egg production is the product of mean daily egg production (P_0) and total spawning area (*A*). Mean daily fecundity is calculated by dividing the product of mean sex ratio (by weight, *R*), mean batch fecundity (number of oocytes in a batch, *F*) and mean spawning fraction (proportion of mature females spawning each day/night, *S*) by mean female weight (*W*). Spawning biomass (*SB*) is calculated according to the equation:

$$SB = P_0.A/(R.F.S/W).$$

The DEPM can be applied to fishes that spawn multiple batches of pelagic eggs over an extended spawning season (e.g. Parker 1980). Data used to estimate DEPM parameters are typically obtained during fishery-independent surveys involving vertical plankton tows at sites located at regular intervals along parallel cross-shelf transects. Adult samples are often taken opportunistically during the survey and may be complemented by samples collected concurrently from commercial vessels (Stratoudakis *et al.* 2006).

The key assumptions of the DEPM are that: 1) surveys are conducted during the main (preferably peak) spawning season; 2) the entire spawning area is sampled; 3) eggs are sampled without loss and identified without error; 4) levels of egg production and mortality are consistent across the spawning area; and 5) representative samples of spawning adults are collected during the survey period (Parker 1980, Alheit 1993, Hunter and Lo 1997, Stratoudakis *et al.* 2006). Departure from assumptions 1 and 2 are likely if the survey is not optimal for the breeding of the species concerned and inevitably result in an underestimate of the true population biomass.

Estimates of spawning biomass based on optimal surveys are generally considered to be accurate (unbiased), but relatively imprecise (e.g. Lasker 1985, Piquelle and Stauffer 1985, Alheit 1993, Borchers *et al.* 1997, Hunter and Lo 1997, Jackson and Chen 2001, ICES 2004, Stratoudakis *et al.* 2006, Ward *et al.* 2009). This imprecision is mainly due to uncertainties associated with the estimation of total daily egg production, i.e. P_0 and *A*. (Fletcher *et al.* 1996, McGarvey and Kinloch 2001, Ward *et al.* 2001a,b, Gaughan *et al.* 2004). A range of analytical methods have been used to calculate these parameters and these have the potential to significantly affect estimates of spawning biomass. For example, egg age has been estimated using a range of models that combine information on daily spawning synchronicity and mean egg developmental rates in relevant temperature ranges (e.g. Lo 1985, Piquelle and Stauffer 1985, Ibaibarriaga 2007). P_0 (and hence spawning biomass) can be significantly under-estimated if the entire spawning area is not covered by the survey.

With respect to the application of the DEPM to jack mackerel in the SPF, the uncertainty associated with the estimation of total daily egg production is recognised explicitly (e.g. Neira 2011). The reason for fitting the mortality curve is to convert measures of egg density by age into an estimate of the number of eggs initially produced. The mortality curve and estimate of initial egg production presented by Neira (2011) are derived from a GLM with a negative binomial error distribution. Initial egg production was also estimated by fitting an exponential mortality model using non-linear least squares regression. Fits to egg densities by age are invariably poor due to strong over-dispersion of data, regardless of whether the exponential model (non-linear least squares regression), linear model or various GLMs are used (e.g. Ward *et al.* 2011). One alternative to estimating egg mortality is to ignore it, which introduces a significant negative bias into estimates of spawning biomass. McGarvey and Kinloch (1998) suggested an alternative approach that involved fitting assumed mortality rates based on prior knowledge. The paper by McGarvey and Kinloch (1998) showed that estimates of initial egg production are relatively insensitive to variations in mortality rates. Because of the insensitivity of estimates of initial egg production to variations in mortality rates, the potential effects of the poor fits on estimates of total egg production and biomass are low. These effects are particularly low in comparison to the identified sources of negative (conservative) bias in the biomass estimates. For example, the estimates of total egg production and biomass provided for jack mackerel are "highly likely to negatively biased" (i.e. under-estimate actual biomass) because they were "based on egg production confined to the northern distribution of the species" (Neira 2011, p 31). It is also likely that the surveys did not coincide with the peak spawning season. Similar levels of uncertainty in estimating mortality and egg production have been identified for other species (e.g. Ward *et al.* 2011). Based on knowledge of the species' spawning patterns, statistical sensitivity analyses and experience with similar pelagic fish it is considered that the potential effects of this uncertainty on the estimates of spawning biomass are low compared to the negative (conservative) bias resulting from the limited spatial coverage and sub-optimal timing of the surveys. The Recommended Biological Catch (RBC) for jack mackerel was also set at 7.5% of the estimate of spawning biomass. This conservative approach, explicitly specified for Tier 2 species in the SPF Harvest Strategy, is adopted to address the ecological importance of SPF species and uncertainties in estimates of spawning biomass. The RBC cannot be increased until another DEPM survey is conducted. It is also important to note that an ongoing program has been established for monitoring of catch, effort, catch-at-age and spatial and temporal distribution of fishing effort/catch. If this program provides evidence to suggest that catches are too high then in accordance with the SPF Harvest Strategy the RBC will be reduced.

Experience with similar Australian fisheries (South Australia)

The harvest strategy for the SPF has borrowed heavily from experience gained in the South Australian Sardine Fishery (SASF) where a similarly precautionary, adaptive approach to developing the fishery was taken (http://www.pir.sa.gov.au/). Importantly, the harvest strategies for both fisheries specify that the DEPM is the designated approach to stock assessment. Both harvest strategies also require annual monitoring of key fishery parameters (catch, effort and spatial and temporal distribution of fishing effort/catch). The information from these ongoing monitoring programs is used to assess the suitability of catch levels in years when DEPM surveys are not conducted.

In the SASF, low exploitation rates (10% of spawning biomass) were established initially and increased over time as more information became available about the stock. The current exploitation rate (or harvesting fraction) is about 18% (Ward *et al.* 2010). This conservative approach was adopted at the request of industry with the explicit objective to maximise stability in catches by forgoing potential yield and reducing the need for spatial management (zoning) in the fishery. A new harvest strategy is currently being developed for the SASF, which is likely to include a target harvesting fraction in the range of 15-25% of spawning biomass and an upper limit to the harvest fraction of 20-30%. The Commonwealth SPF Harvest Strategy specifies that the maximum harvest fraction that can be set for any species is 20%.

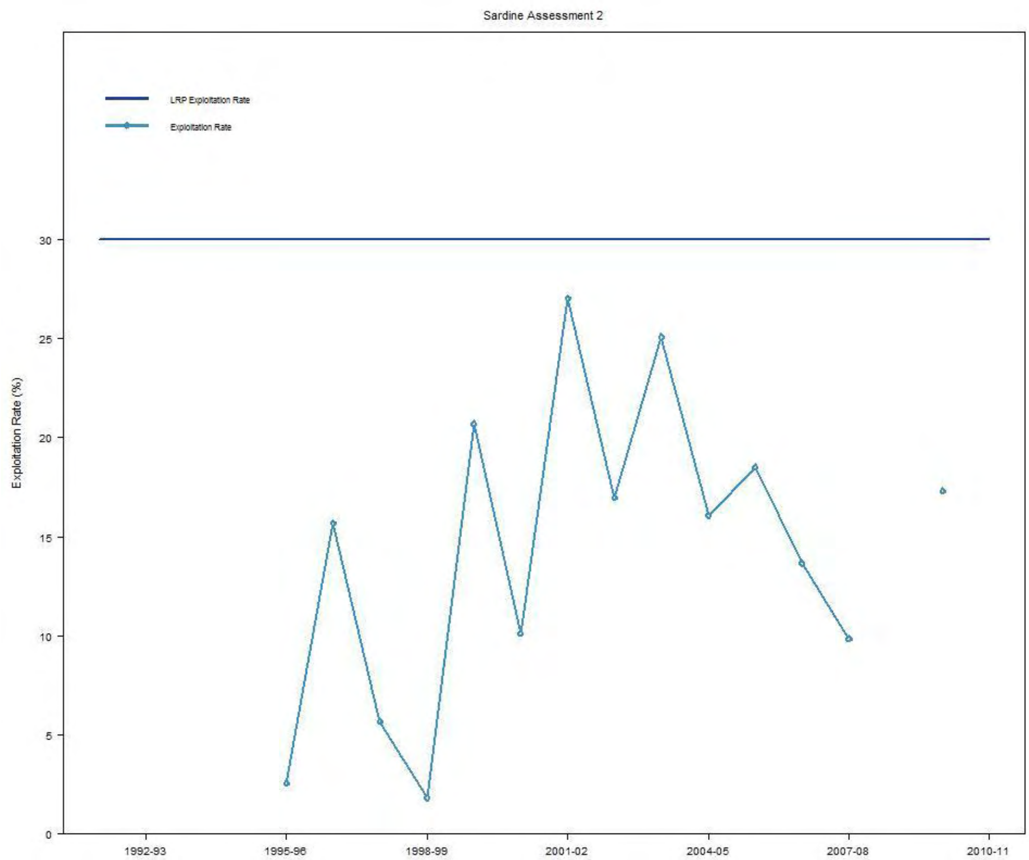

Figure: Exploitation rates (harvest fraction per year) in the SASF.

Extensive ecological studies have been conducted to investigate potential ecosystem impacts of the SASF (Goldsworthy *et al.* 2011). Ecosystem monitoring and modelling have provided strong evidence that: i) no predatory species feeds exclusively or even predominately on sardine; ii) food availability is not negatively impacting on the foraging behaviour or reproductive success of any predatory species; iii) that ecosystem function has not been negatively impacted by the relatively rapid growth of the fishery; and iv) ecological effects from local depletion have not occurred. There is some empirical evidence to support declines in seabirds due to depletion of sardines during the extreme sardine die offs in the mid-1990s (Dann *et al.* 2000, Bunce *et al.* 2002, Taylor and Roe 2004, Chiarardia *et al.* 2010), which shows that at extreme sardine depletion there can be an effect on dependent predators. But such effects have not been caused by the SASF (Goldsworthy *et al.* submitted), which applies a similar maximum exploitation rate to the SPF.

Localised depletion

Localised depletion is where fishing reduces the abundance of fish in a local area and for a period of time. For fish that are not highly mobile localised depletion can persist for a long time (e.g. scallops, abalone, and some site-resident groupers). For highly mobile fish such as small pelagic and tuna species localised depletion can be temporary because they are replaced by fish from a wider area – so long as the overall catch in the wider area is low enough to maintain sufficient fish numbers to replenish the local area. Natural predation can also cause localised depletion. Localised depletion can be caused by recreational or commercial fishing. Localised depletion is of particular concern in small pelagic fisheries because it could disrupt predator feeding behaviour. Predators usually feed intensively on schools of small pelagic fish in localised areas wherever they occur, and sometimes there are spatial fixed 'hotspots' where prey schools and their predators commonly congregate. Localised depletion could disrupt these feeding interactions if it was large and persistent enough.

The recent scientific guidelines on management of small pelagic fisheries provide rules to avoid food-web impacts on predators, including through the effects of localised depletion, based on the experience of more than 20 ecosystems worldwide. The rules would avoid food-web impacts on predators, including through local depletion, even in ecosystems that have food-webs that are much more vulnerable to such impacts than is the case for the ecosystems in SE Australia. The catch quotas set for the small pelagic species in the SPF are more conservative than the catch quotas allowed under these rules.

There are five reasons why the SPF is unlikely to cause food-web impacts on predators, including through localised depletion:

1. The catch quota is set low and, even accounting for uncertainties in the population estimates, it is lower than the rules provided by recent scientific guidelines to avoid food-web impacts on predators – including through local depletion.
2. The food-web in this SE Australian marine ecosystem is well understood by world standards, and the structure of the food-web makes this ecosystem less vulnerable to the effects of either widespread or localised depletion of small pelagic fish.
3. Both the predators (e.g. tuna, marine mammals) and their small pelagic fish prey are highly mobile which reduces the scope for localised depletion.
4. There is broad spatial zoning of the catch quotas to help spatially spread the catch. All areas inside 3 nautical miles of the coast are closed to the fishery (which includes key 'hotspots' such as the Hippolyte Rocks and a significant part of the foraging range of many marine mammals and birds). There are some state managed fisheries inside 3 nautical miles, and where these occur the catches are deducted from what is available to the SPF.
5. Direct evidence from the 20 year history of the South Australia Sardine Fishery is that there has been no local depletion and no ecological effect on predators. This SA fishery takes a larger catch and from a smaller area than the eastern zone of the Commonwealth SPF, it operates in an area that is well known for its populations of predators (SBT, marine mammals, penguins), the catch quota is set using similar rules as are applied in the SPF, and the ecosystem has been well

studied and monitored. There has been no sign of localised depletion of the sardine or the predators, and no sign of food-web impacts on any of the predators.

These 5 factors taken together give confidence that food-web impacts of the SPF on predators and the SPF species themselves, including through localised depletion, are unlikely.

Knowledge of the SE Australian marine ecosystem and the role of small pelagic fish

The trophic dynamics of ecosystems in southern and eastern Australia have been well studied over many years by CSIRO, IMAS, SARDI and others and are well understood by world standards (Bulman &Blaber 1986, Young & Blaber 1986, Blaber and Bulman 1987, Bulman & Koslow 1992, Young & Davis 1992, Young *et al.* 1993, 2001, 2010, Bulman *et al.* 2000, 2001, 2002, 2006, Ward *et al.* 2001, Williams *et al.* 2002, Bulman 2002, Goldsworthy *et al.* 2003, 2011, McLeod 2005, Watson *et al.* 2012). This understanding has been synthesised in a number of ecosystem models that summarise the trophic dynamics of the region and provide an ability to forecast the impacts on other parts of the ecosystem of fishing forage species (Bulman *et al.* 2006, 2010, Smith *et al.* 2011, Goldsworthy *et al.* 2012, Watson *et al.* 2012). The Atlantis ecosystem model developed for southern and eastern Australia (Fulton *et al.* 2008) provides the best regional coverage for the SPF. Atlantis has been recognised internationally as the best available model to test the broad ecological effects of fishing (Plagányi 2007).

The Atlantis model for southern and eastern Australia (Fulton *et al.* 2008) does not use as inputs any of the biomass estimates that are used in the SPF Harvest Strategy (e.g. the DEPM estimates). Rather the Atlantis model estimates population sizes based on food-web structure, the diets of key ecosystem groups, the life-history and physiological characteristics of the various key ecosystem groups, and planktonic productivity. The Atlantis model estimates of the population sizes are thus totally independent from the DEPM estimates. Model estimates of abundance are indirect and so the absolute quantities estimated are not expected to be highly accurate. However the ecosystem model results provide a reliable portrayal of general dynamics and relative change in the ecosystem, including the ecological effects of changes in the abundance of the small pelagic species.

The following are the total biomass estimates for the small pelagic species from the Atlantis model, which covers a very similar area to that of the SPF:

- Jack mackerel: 90,000 to 200,000t
- Redbait: 50,000 to 100,000t
- Sardines and anchovy: 600,000 to 1,200,000t
- Mesopelagics (lanternfish, myctophids, etc.): 750,000 to over 2.5 milliont.

These biomass estimates of target species from Atlantis are independent of the DEPM estimates and expert judgements used in the SPF Harvest Strategy to set the TAC. The model estimates are of total biomass whereas the DEPM estimates are for spawning biomass. However the values are similar, which imparts confidence in both, and indicates a large quantity of small pelagic fish in the ecosystem.

The much lower biomass and importance of jack mackerel and redbait relative to mesopelagics is both predicted by the ecosystem model and confirmed by dietary studies of predators (Young *et al.* 2010). Smith *et al.* 2011 and Pikitch *et al.* 2012 show that ecosystems are more reliant on the small pelagic species that have large population sizes than on species with small populations.

All these species showed an increase in biomass in the model over the 20th century, thought to be due to reductions in biomass of their predators.

The study by Smith *et al.* (2011) examined the impacts on other parts of the food chain of fishing low trophic level (LTL) species at varying intensities. The study examined five ecosystems globally, including SE Australia. In comparison with classical “upwelling” ecosystems such as the Benguela, Humboldt and California currents, impacts of fishing SPF species in SE Australia were generally low – the exception being in relation to the mesopelagics for which significant ecological consequences are predicted if their abundance were to be significantly reduced. The greatest impacts in the model occurred when the mesopelagic species were harvested. These are not currently subject to any targeted fishing in the SPF.

These ecosystem modelling studies have concluded that at the current exploitation rates in the SPF (<10%) the ecosystem impacts of fishing on small pelagic fish populations and their predators is low. Even at higher exploitation rates, corresponding to “Maximum Sustainable Yield” and more than double the exploitation rate applied in the SPF, the food-web impacts were limited. This is because the food web in this ecosystem has many different forage species and so it is not as sensitive as some to fishing. At these higher exploitation rates the predicted impact varied across models used, and so those predictions are considered uncertain.

To put the scale of the SPF catches into ecological perspective the current catch levels can be compared with model-derived consumption by some predator groups. For the Atlantis model, annual consumption by seals is estimated as:

Redbait: 25,000 to 40,000t
Mackerel: 10,000 to 25,000t
Other small pelagics (including sardine): 40,000 to 150,000t
Other species consumed: other small fish, cephalopods, benthic invertebrates
Total annual consumption: 250,000 to 500,000t

For tunas and billfish, the annual consumption estimates are:

Redbait: 6,000 to 10,000t
Mackerel: 5,000 to 10,000t
Small pelagics (including sardines): 10,000 to 45,000t

Other groups consumed by tunas and billfish include:

Mesopelagics: 10,000+t
Squid: 1000+t
Benthic invertebrates (crustacea): 500+t
Pelagic invertebrates (e.g. krill): 66,000+t
Other small piscivores: 40,000+t
Cannibalism: 2,000+t

The state of the forage fish stocks and the effects of past fishing

These stocks are not overfished or subject to overfishing as determined by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES). The most recent ABARES assessment is:

Fishery status	2008–09		2009–10		Comments
Biological status	Fishing mortality	Biomass	Fishing mortality	Biomass	
Australian sardine (*Sardinops sagax*)	Not subject to overfishing	Not overfished	Not subject to overfishing	Not overfished	SPF Tier 1 assessment (DEPM survey). Low catches indicate overfishing is not occurring.
Blue mackerel—east (*Scomber australasicus*)	Not subject to overfishing	Not overfished	Not subject to overfishing	Not overfished	SPF Tier 1 assessment (DEPM survey). Low catches indicate overfishing is not occurring.
Blue mackerel—west (*Scomber australasicus*)	Not subject to overfishing	Not overfished	Not subject to overfishing	Not overfished	SPF Tier 1 assessment (DEPM survey). Low catches indicate overfishing is not occurring.
Jack mackerels—east (*Trachurus declivis, T. murphyi*)	Not subject to overfishing	Not overfished	Not subject to overfishing	Not overfished	High historical catches, predator/prey studies and anecdotal evidence suggest a sizeable stock. Low catches indicate overfishing is not occurring.
Jack mackerels—west (*Trachurus declivis, T. murphyi*)	Not subject to overfishing	Not overfished	Not subject to overfishing	Not overfished	High historical catches, predator/prey studies and anecdotal evidence suggest a sizeable stock. Low catches indicate overfishing is not occurring.
Redbait—east (*Emmelichthys nitidus*)	Not subject to overfishing	Not overfished	Not subject to overfishing	Not overfished	SPF Tier 1 assessment (DEPM survey). Low catches indicate overfishing is not occurring.
Redbait—west (*Emmelichthys nitidus*)	Uncertain	Uncertain	Not subject to overfishing	Uncertain	No DEPM, therefore estimate of biomass is uncertain. Low catches indicate overfishing is not occurring.
Economic status (Fishery level)	Net economic returns not available				Little economic incentive to participate in the fishery given current prices and costs.

DEPM = daily egg production model; SPF = Small Pelagic Fishery

	Green	Red	Yellow
Fishing mortality	Not subject to overfishing	Subject to overfishing	Uncertain
Biomass	Not overfished	Overfished	Uncertain

The previous significant fishing for jack mackerel off Tasmania occurred in the 1980s and 1990s. Over 100,000 t was taken in three years during the 1980s and catches throughout the 1990s averaged over 10,000 t per annum. This fishery was highly localised off eastern Tasmania because of limitations on the vessel range and the port facilities. The fishery substantially reduced in scale and catch during the 2000s and 2010s because it was very marginal economically.

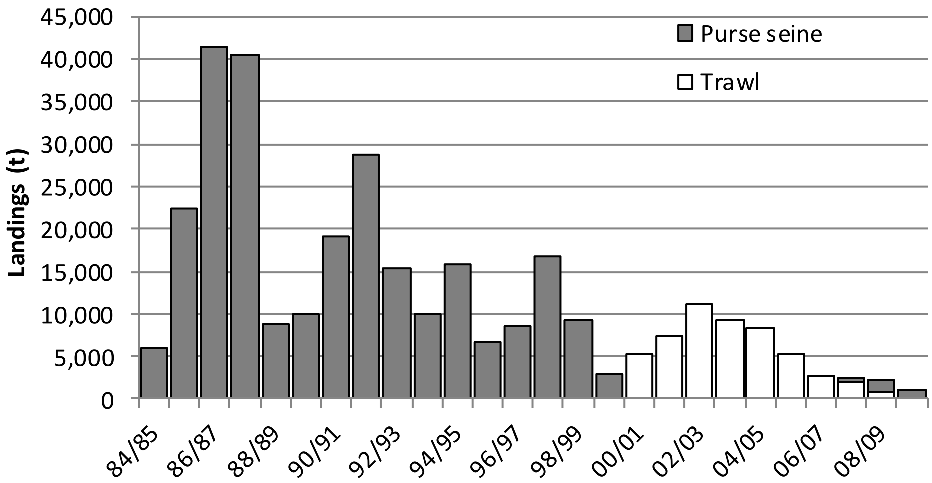

Figure: The catch history, by capture method, of small pelagic fish from waters adjacent to Tasmania.

It has been claimed that fishing in the 1980s and 1990s caused overfishing of jack mackerel, with a subsequent loss of surface schools of jack mackerel which have never recovered. Scientific interpretation of these events (e.g. Young *et al.* 1993, Hobday *et al.* 2008, Poloczanska *et al.* 2008, McLeod *et al.* 2012, Watson *et al.* 2012) suggest that it was not overfishing that caused the loss of jack mackerel surface schools rather it was due to changes in the plankton caused by the warming that has been observed in waters off eastern Tasmania over the past 40 years. This warming has caused many ecological changes, including increase in the redbait population and changes in the zooplankton composition. This warming has changed the structure of the zooplankton in many ways, including greatly reducing the surface schooling of Australian krill. The surface schools of jack mackerel targeted in this earlier fishery were aggregations feeding on the surface schools of krill. When the krill stopped surface schooling so did the jack mackerel (Young *et al.* 1993). This change appeared not to be related to the SPF, though the timing was coincidental. The jack mackerel were still present but they were subsurface – where they could still be detected acoustically and as a result the fishery switched from surface capture (purse seine) to mid-water capture (pelagic trawl).

Similarly it has been claimed that the recently improved recreational fishery for southern bluefin tuna (SBT) off eastern Tasmania is due to cessation of trawling for small pelagic fish since the late 2000s. These correlations and interpretations of causation are not clear. However, there is information from the global stock and Australian-wide SBT abundance that match these changes but are related to global management of SBT rather than the local effects of the SPF. During the 1990s, the SBT population and number of juveniles in Australian waters were decreasing because of excessive international catches. The abundance of SBT remained low through the 2000s, again because of large international catches. In recent years the international SBT catches have been reduced and there are increasing numbers of SBT in Australian waters – fuelling a significant increase in the recreational catch in many states. This global change in the SBT population is scientifically interpreted through the relevant international Commission as having been due to reduced international catches. The same recent increases are being seen in many areas in addition to eastern Tasmania, in areas with and without local fisheries for small pelagic species.

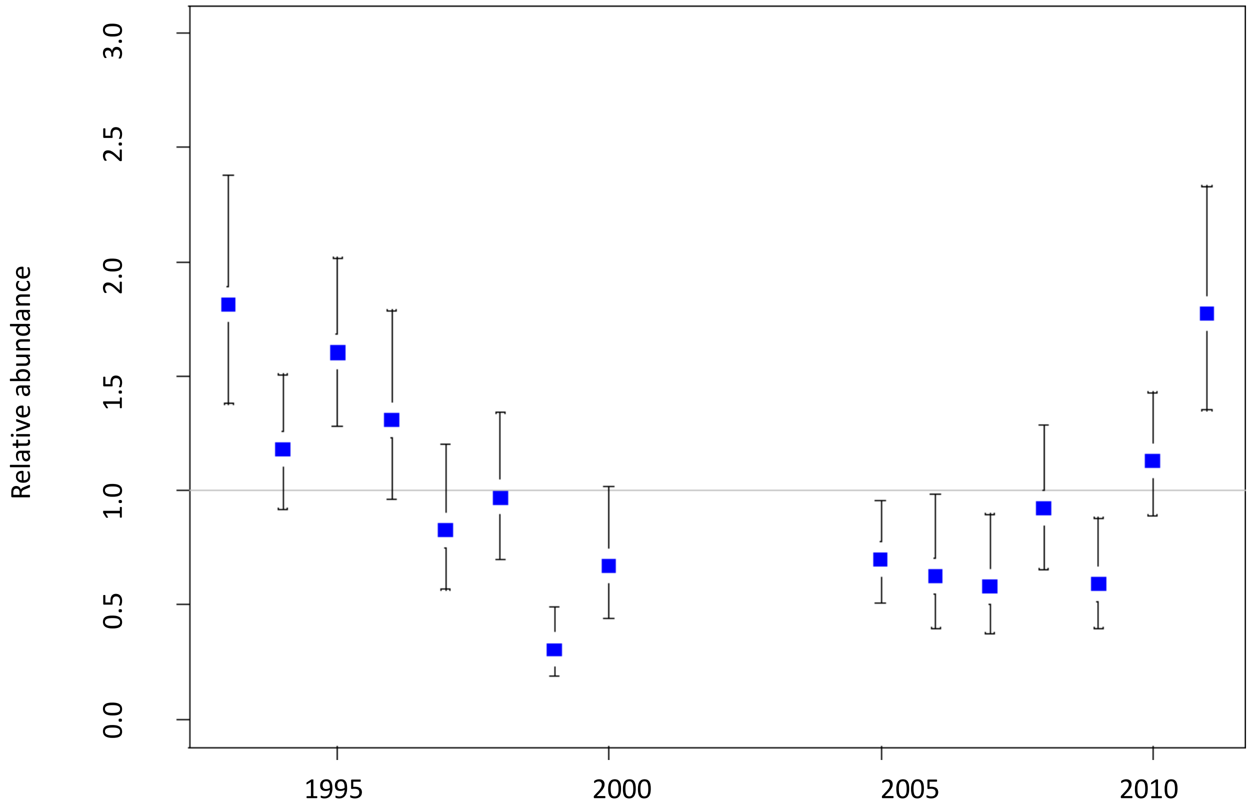

Figure: Scientific aerial survey index of relative abundance of juvenile SBT by year in the Great Australian Bight. Eveson *et al.* (2011)

By-catch and excluder devices on the nets

Fish by-catch

On board catch sampling conducted by IMAS researchers and AFMA observers between 2001 and 2006 found that mid-water trawl operations adjacent to Tasmania had minimal levels of catch of non-target species. The main non-target species were barracouta and spotted warehou; with a range of other fish and squid either captured very occasionally or taken in extremely low numbers. SPF operators must hold quota to cover by-catch of species that are subject to quota management in other Commonwealth fisheries (e.g. spotted warehou).

Marine mammal by-catch

Mid-water trawl operations in the SPF have resulted in instances of seal and dolphin mortalities, highlighting the need for ongoing and effective observer coverage to monitor such interactions along with strategies that reduce capture and mortality rates. AFMA has committed to 100% observer coverage to monitor by-catch and other aspects of fishery operations for the factory trawler (http://www.afma.gov.au/2012/06/super-trawler-faqs/).

In response to the capture of dolphins in the SPF in 2004 and 2005 a high level of observer coverage was implemented by AFMA and voluntary avoidance measures were identified and implemented.

The measures are simple – 'move on' rules that stop fishing and move the vessel to a different location if dolphins are sighted. There have been no further reports of dolphin captures since mid-2005, and this is corroborated by observers and trawl net video cameras. There remains some ongoing risk of dolphin capture and management of this risk will require ongoing mitigation measures.

In addition, SPF vessels are required to use a seal exclusion device (grid) and associated escape hole on all trawl nets to stop the passage of marine mammals into the codend and to provide a means by which the animals can escape the net. Underwater camera technology has been used to study the nature and frequency of interactions between marine mammals and trawl net. The study established that seals regularly entered the trawl net and that while most exited safely some mortalities did occur (Lyle and Willcox 2008). The study recommended that the exclusion device be modified from a bottom opening configuration to a top opening one; the bottom opening configuration resulted in mortalities dropping out of the net and would not have been obvious to on board observers.

In future the SPF vessels will use a top opening seal exclusion device, as recommended by the research. This style of excluder device has been well tested on similar nets and its effectiveness is well established. The basic design (including a 'hood' at the escape hole) has been tested and used successfully in the Australian blue grenadier trawl fishery off western Tasmania and several New Zealand pelagic trawl fisheries. Importantly, this configuration retains any individuals that die in the net and therefore any mortality will be observed and reported.

Ongoing measures and monitoring will be required to assess excluder devices and manage the ongoing risk of marine mammal interactions and capture.

Summary

- The Total Allowable Catch (TAC) is a low fraction of the population size for both the mackerel and redbait populations that are targeted by the fishery and for the ecosystems of which they are a part.

- Several large scientific studies have recently examined the world's main fisheries for small pelagic species (also known as forage fish), and their ecosystems. They have developed clear advice about how to set TACs and manage such fisheries so that the food-web and dependent predators are protected. This advice includes how the safety margin should increase if there is greater uncertainty about the fish stocks or the ecosystem. The methods used to set the TAC in the Commonwealth managed Small Pelagic Fishery (SPF) are consistent with this scientific advice.

- There are uncertainties in the population estimates and these are recognised. The TAC setting rules have been scientifically evaluated andare determined to be sufficiently precautionary and that the populations would be protected even if there were large errors in the population estimates.

- There is a practical demonstration that this management approach works. The South Australian Sardine Fishery uses a similar precautionary approach to set the TAC, which is also consistent with the recent global scientific advice. The TAC in the SA Sardine Fishery (34,000 t) is about double the combined SPF quota for jack mackerel and redbait off the eastern Australian coast (17,000 t) and is taken from a much smaller area. After 20 years of fishing and close ecological monitoring the conclusion from a recent study by SARDI, CSIRO, SA universities, and consulting scientists is that ”despite the rapid growth of the sardine fishery since 1991, there have likely been negligible fishery impacts …. suggesting that current levels of fishing effort are not impacting negatively on the ecosystem function”. This provides an Australian example where the rules are working in practice.

- By-catch is very low in the SPF and catch of species that are subject to catch quotas in other Commonwealth fisheries, such as warehou, needs to be covered by quota from the other fishery.

- Voluntary rules to stop fishing and relocate the vessel if dolphins are seen were implemented in 2004 following the incidental capture of dolphins; there have been no reported or observed dolphin mortalities since mid-2005. In addition a seal excluder device is required on all nets.. Ongoing measures and monitoring will be required to manage the ongoing risk of marine mammal interactions and capture.

- Localised depletion is evaluated as unlikely with the proposed harvesting fractions applied in the SPF because most small pelagic species, and their predators, are highly mobile and local areas replenish quickly provided the overall stocks are not depleted. This has been the experience with small pelagic fisheries that have been similarly managed in Australia. However given uncertainties about detailed movement patterns of several of the species targeted in the SPF, it would be prudent to distribute catches to minimise the chance of local depletion. This is consistent with global scientific advice on best practice for managing such species.

Disclaimer

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Appendix 1 How the Commonwealth Small Pelagic Fishery is managed and how this compares with the world's best practice scientific standards

The Small Pelagic Fishery (SPF) is managed by the Commonwealth through the Australian Fisheries Management Authority (AFMA). AFMA is a Statutory Authority responsible for the day-to-day management of fisheries under Commonwealth jurisdiction (http://www.afma.gov.au/ and Smith *et al.* 1999). AFMA uses an extensive advisory structure and encourages the participation of stakeholders (typically scientists, industry, conservation NGOs, recreational fishers, and State and Commonwealth government departments) in these advisory processes. Decision making is by the AFMA Commission. Commissioners cannot hold any executive position in a fishing industry association, nor can they have a controlling interest or executive role in any entity holding a Commonwealth fishing concession.

The SPF extends from Western Australia to the NSW/QLD border (http://www.afma.gov.au/managing-our-fisheries/fisheries-a-to-z-index/small-pelagic-fishery/). The SPF Management Plan was enacted in late 2009, with Statutory Fishing Rights issued in early 2012. Management is based on output controls – that is the fishery is managed by annually setting Total Allowable Catches (TACs), which are then allocated to fishers according to their holdings of Individual Transferable Quota (ITQ) units. ITQ units, with their catch entitlements, can be bought, sold or leased among fishers but this does not change the total catch. The TACs are defined by management sub-areas (east and west of Tasmania) and species. The main target species for which quotas are allocated are jack mackerel, redbait, blue mackerel and Australian sardine (other species that can be taken include yellowtail scad).

A harvest strategy sets out the management actions that are needed to achieve defined biological and economic objectives for a single fish stock or group of fish stocks. This includes specifying (i) 'control rules' that regulate the level of fishing activity, and (ii) monitoring and assessment processes to inform both setting and progress of the harvest strategy objectives.

The SPF Harvest Strategy provides the rules for setting the TAC, including the need for increased precaution when scientific uncertainty is greater, and the monitoring required for the fishery. (http://www.afma.gov.au/managing-our-fisheries/fisheries-a-to-z-index/small-pelagic-fishery/publications/small-pelagic-fishery-harvest-strategy/). The SPF Harvest Strategy is the operationalisation for this fishery of the requirements of the over-arching Commonwealth Government's Harvest Strategy Policy (HSP) (http://www.daff.gov.au/__data/assets/pdf_file/0004/397264/HSP-and-Guidelines.pdf). Harvest strategies for individual AFMA fisheries such as the SPF are continuously under review to take account of recent scientific advances, and the HSP is currently under formal review by the Commonwealth Government. The SPF Harvest Strategy includes decision rules on how the scientifically based Recommended Biological Catch (RBC) is calculated by the SPF Resource Assessment Group. The RBC is used by the AFMA Commission to determine the TACs. Decision rules are a relatively recent development in fishery management world-wide, and their use is considered best management practice (FAO 1995, para 7.5.3). The use of decision rules ensures that the TAC decisions are clearly based on specific evidence about stock status. Also decision rules can be scientifically tested to determine that they can achieve management objectives. The SPF Harvest Strategy uses a tiered approach that recognises the ecological importance of the small pelagic species and takes an explicitly conservative approach to setting harvest levels (i.e. proportion of spawning biomass) and hence TACs. The tiered approach recognises that harvest rates must be low when there is limited information available on the status of the stocks but can be increased as improved information becomes available.

> Tier 1 – applies to stocks for which spawning biomass estimates are no more than 5 years old, with harvest rates set between 10-20% of spawning biomass; the actual harvest rate is reduced as the 'age' of the biomass estimate increases. Spawning biomass is estimated using the Daily Egg Production Method (DEPM) which is a survey method that is independent of the fishery. It has been successfully applied nationally and internationally in other small pelagic fisheries to assess the size of spawning stocks.
>
> Tier 2 – either set at a maximum of 7.5% of the most recent estimate of spawning biomass or where biomass has not been assessed at a level based on expert judgement that is considered to be conservative when previous fishing history, species distributional range and life history characteristics are taken into account.
>
> Tier 3 – applies to species for where there is limited information; TACs are set at very low levels but do not exceed 500 t for the species.

The information about stock status and the TAC is reviewed annually. For Tier 1 and 2 stocks this is fishery (catch and effort) and biological information from catches (size and age structure), while for Tier 3 stocks this is only fishery data. This process allows the TACs to be revised if there are changes in stock status.

In the current year all stocks in the SPF except the eastern redbait stock are managed at Tier 2 which has a maximum harvest fraction of 7.5%. The eastern redbait stock is managed as Tier 1 and the actual harvest fraction applied for 2012/13 is 10%.

The harvest fractions for Tier 2, and the applied harvest fraction for Tier 1, are very low and meet the recommended scientific standards regarded as best practice to protect both the target stock and the dependent predators. The SPF Harvest Strategy also explicitly reduces the TAC when the information available becomes older or less reliable, as recommended in the scientific standards.

The SPF Harvest Strategy is currently being reviewed, as part of the review of the Commonwealth fisheries Harvest Strategy Policy and consistent with the HSP.

In summary, management of the SPF is consistent with world's best practice scientific standards for fisheries that target small pelagic species in that:

- the catch limit gives a fishing mortality and stock abundance that is more conservative than recommendations of the recent scientific reviews and the requirements of the Marine Stewardship Council;

- the catch limit is more cautiously set when there is increased uncertainty in the estimates of population size;
- the combination of management measures in the SPF, and practical experience with similar management in small pelagic fisheries elsewhere and elaborated below, gives scientific confidence that food-web effects on predators, including through localised depletion, are unlikely; and
- Australian fishery management has been recognised as among the best in the world (Pitcher *et al.* 2008, 2009). This assessment covered compliance, the balance of conservation and economic aims, use of precaution, reference points, discards, by-catch and socio-economics. Australia ranked 4th of the 53 countries behind Norway, the United States and Canada.