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Simulation analysis of jack mackerel stock sizes

Ecosystem model based plausibility study

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Executive summary

Two ecosystem modelling platforms have been used to model the south eastern waters of Australia. Both models contain jack mackerel as a modelled group. These models were used to explore the plausibility of a range of alternative spawning biomass estimates for the stock.

Both models indicated that values of 20,000-30,000t are implausibly low given the ecology captured in the models. The simulations run at this level are either numerically impossible (leading to numerical instability in Atlantis, or an imbalance in EwE) that could only be remedied by substantial restructuring of the models. Such large scale restructuring is not consistent with existing data sets. Although as these data sets are now more than a decade old only further diet data collection could test for sure whether such large scale changes have in fact occurred (though associated shifts in top predator biomasses have not been observed so shifts of sufficient magnitude are still unlikely). In contrast spawning biomasses of 130,000-170,000t are plausible given existing data sets and ecological understanding of the system.

If eastern jack mackerel is fished following the existing harvest strategy for the Small Pelagic Fishery (SPF) then some localised depletions are possible, but broad scale restructuring of marine ecosystems is very unlikely (it was not seen under any simulation using the plausible spawning biomasses).

Alternatively, if eastern jack mackerel biomass in the ecosystem models was ever moved to the standard target reference point used for many of Australia's federal fisheries (B_{48}) there are a number of possible knock-on trophic and ecological groups on other groups. While the exact form of these changes are complicated, in general they include the release of competitors, a reduction in predators who cannot find alternative prey as well as the prey of predators who increase as the system restructures. Some of these changes are beyond the natural level of variation in these species due to interannual environmental shifts, though they are not as large if spatial shifts can compensate for localised effects of system restructuring. 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).

1 Modelling Frameworks

1.1 Atlantis framework

1.1.1 GENERIC ATLANTIS FRAMEWORK

Atlantis (Fulton et al., 2004) is a modelling framework intended for use in management strategy evaluation (MSE) studies, where each part of the adaptive management cycle is represented (Jones 2009). It therefore includes the biophysical system, the human users of the system (industry), the three major components of an adaptive management strategy (monitoring, assessment and management decision processes) and socioeconomic drivers of human use and behaviour. Atlantis includes dynamic, two-way coupling of all these system components (summarized in Figure 1). The modelling framework includes many alternative model formulations for each major process and model component included (full documentation is available on a wiki at http://atlantis.cmar.csiro.au/). The choice of formulation is an application-specific decision made by the user, who has the freedom to set complexity at any desired level. This can range from a very simple model, through to complex models containing large parts of the system, as is the case for the model of southeastern Australian waters. This modular structure was deliberate given the model's intended use for MSE - where alternative candidate models are used to cover system uncertainty.

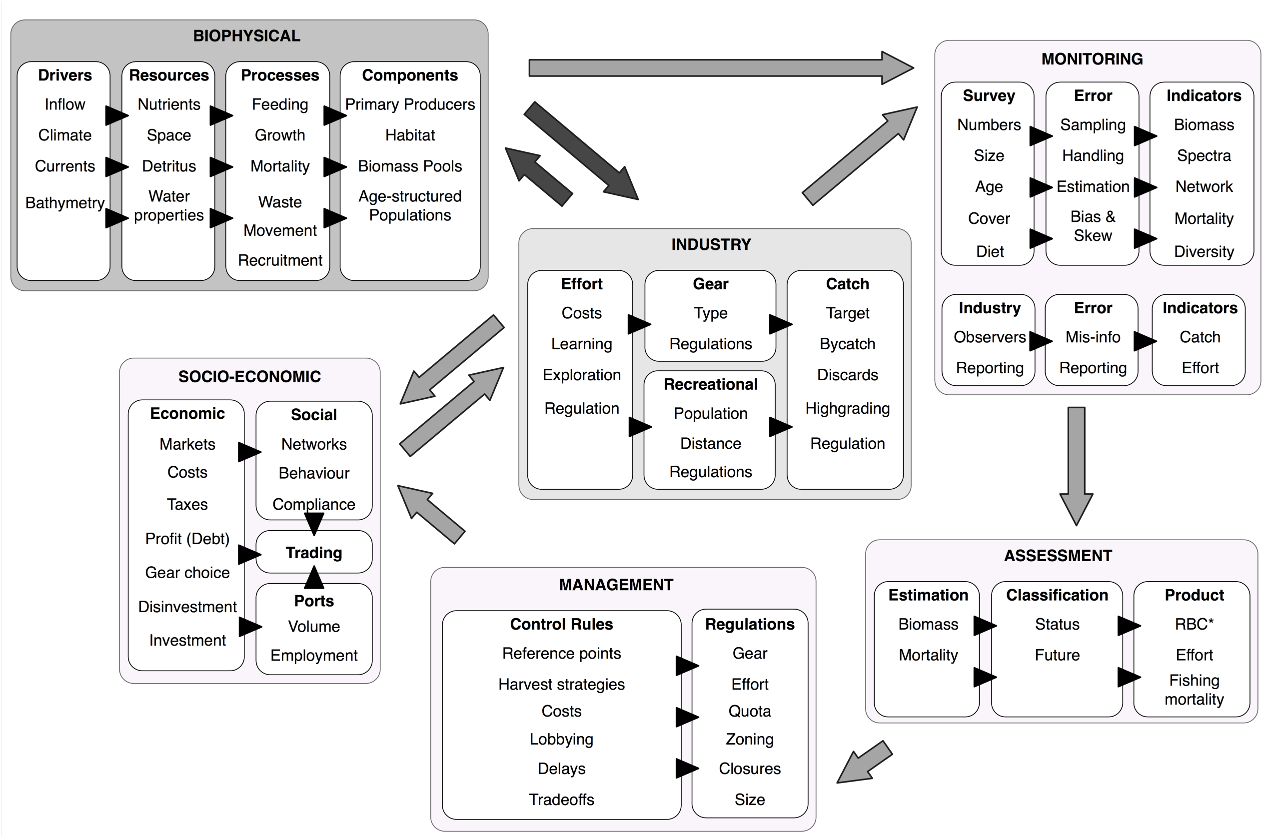

Figure 1: Schematic diagram of the connections, components and major processes included in the Atlantis modelling framework. *RBC stands for recommended biological catch (as of Fulton et al., 2011).

The Atlantis biophysical submodel is a three-dimensional model that tracks the flows of limiting nutrients (typically nitrogen and silica, although others are possible) through the main biological groups in the system. Time steps within the model are on a 6, 12 or 24h scale, while the average length of the run is 20-70 years long (so the potential future of the system is explored over that time frame). The primary ecological processes modelled are consumption, production, waste production, movement and migration, predation, recruitment, habitat dependency and mortality. Biological components are represented as either biomass pools (which are largely used for the lower trophic levels) or age structured populations (typically for vertebrates) where the average size and condition of individuals in each age class are tracked in each box. Representation of the physical environment occurs within the polygonal boxes, matched to the major geographical and bioregional features of the marine system, coupled with an oceanographic transport model. Seabed type (proportions of soft, rough and flat) and features such as canyons are represented in each box, as well as the vertical temperature, salinity, pH and oxygen profiles, advective and diffusive flows and the influence of eddies. The biological components may inhabit the substrate or any vertical layer of the water column according to environmental preferences.

The human impacts submodel deals primarily with the dynamics of fishing fleets – allowing for multiple fleets, each with its own characteristics (including gear selectivity, habitat association, targeting, effort allocation and management structures). The fleet dynamics model can be tailored to each fleet using formulations ranging from simple catch equations to forced effort, or catches, through to a quasi agent-based approach. In the latter, subfleets (boats of similar size with common home ports, socioeconomic backgrounds or other aggregate behavioural feature) explicitly step through effort allocation decisions based on a memory of past conditions, current economic conditions, distance to fishing grounds, management regulations and social networks. The more complex variants can include explicit handling of taxes, markets, compliance decisions, exploratory fishing, fuel prices, employment, learning, information sharing, quota trading and investment/disinvestment. The industry submodel can also include the impact of pollution, coastal development and broad-scale environmental change. However, at present, each of these is handled as a simple forced change or magnitude through time rather than as part of an adaptive management process.

To allow for evaluations of adaptive management options, 'simulated data' are generated from the biophysical and industry submodels. Given a user specified monitoring scheme, the sampling submodel generates fishery-dependent data (e.g. catch rates) and fishery-independent data (e.g. biomass surveys) with specified levels of measurement uncertainty (bias and variance). These data can be used to calculate 25 types of ecological indicators (e.g. relative biomass, size spectra and network-based indices) or can be fed directly into simulated assessment models. The output of the assessment submodel is fed into a management submodel, which is typically a set of decision rules and management actions that respond to the current assessed state of the system. Atlantis includes formulations for all major fishery management instruments (including gear restrictions, days-at-sea, quotas, spatial and temporal zoning, discarding restrictions, size limits, economic incentives and bycatch mitigation) as well as decision rules such as the tiered harvest decision rules used in Australian federal fisheries (Smith et al., 2008) and the within year revision of management regulations used by some US fishery councils.

1.1.2 DEVELOPMENT OF ATLANTIS-SE

The model for SE Australia is a modified form of Atlantis-SE (Fulton et al., 2007), which was originally developed as the basis for a whole-of-ecosystem management strategy evaluation in support of a strategic restructuring of SE Australian federal fisheries. The model has also been used to look at general fisheries and climate-related questions, such as the implications of fishing small pelagics to differing levels of depletion (Smith et al., 2011).

This model has broad spatial extent (covering 3.7 million km2), stretching from the WA border in the west around to the Fraser Island and out to Lord Howe (Figure 2). This covers the entire extent of the Southern and Eastern Scalefish and Shark Fishery, which has large overlap with the Small Pelagic Fishery (SPF). Within the model domain the extent of the fisheries (e.g. the SPF) matches the boundaries as defined by AFMA (though truncated a little in the west as the model only runs to the WA border whereas the SPF extends

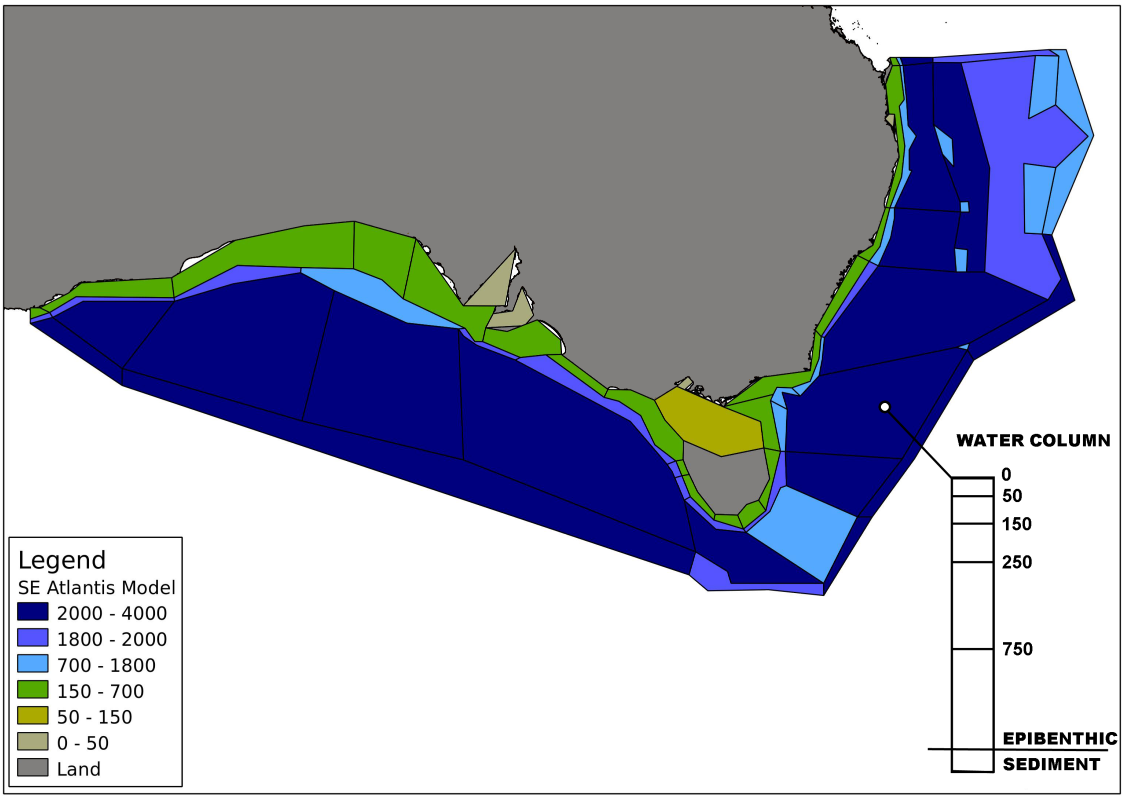

Figure 2: Map of the Atlantis-SE model domain (showing the spatial boundaries of each spatial box as well as the vertical layering - boxes shallower than 1800 are truncated as needed to represent the correct depth for that location).

further west). At present all fisheries represented in the model are constrained to operate only in the model domain.

Atlantis-SE includes quite complex ecology, including a size-resolved microbial web; nutrient, light, and space-based primary production; 37 age-structured ecological groups (from forage fish to top predators, see Tables in the Appendix), some resolved to the species level; multiple genetic stocks per group (in the case of mackerel the east-west stock split recognised by AFMA was used); and shifting climate-related environmental drivers of physiology and reproduction. Where species migrate beyond the ecosystem boundaries defined by the model domain, the model includes an explicit representation of this migration (i.e. species can move in/out of the model domain, with a simplified growth and mortality model applied to them when outside the explicit Atlantis-SE domain).

Atlantis-SE also has explicit representation of recreational and commercial fishing fleets, with the latter resolved to subfleets defined by homeports, crew, and vessel sizes; and driven by social and economic drivers that determine investment, disinvestment, quota trading, information updating, and effort allocation (listed in Tables in the Appendix). The fisheries regulation and assessment process employed by the Australian Fisheries Management Authority is also replicated in the model – including the use of gear restrictions, individual transferable quotas, spatial and temporal zoning, discarding restrictions, size limits, bycatch mitigation, and dynamic reference points and decision rules.

Uncertainty is a significant issue for such large models, which is why these models are used to provide strategic advice on possible futures not to set quotas on a year-to-year basis. It is quite difficult to find sufficient data to fit fully such large models, but in this case, there has been extensive calibration ecologically (vs. 36, 20–90-year catch history time-series and sporadic scientific surveys) and anthropogenically (though in this case only 7 years of data were available for initial testing, after removing the first 10-year section of the available effort time-series as a training dataset; comparison of predicted human behaviour over the period 2000-2010 has been undertaken since the publication of Fulton et al., 2007 as further validation of the model, to increase confidence in its use under climate change conditions). Using a simple implementation of pattern-orientated modelling (which simultaneously fits the entire model against data from multiple datasets; see Kramer-Schadt et al., 2007), bounding parameterisations were found that produce equally plausible modelled systems given the available data and alternative possible system structures. These parameterisations were then all carried forward in the various simulations done for the final analyses presented in following chapters.

1.1.3 DETERMINATION OF JACK MACKEREL BIOMASS IN ATLANTIS-SE

The 2000 initial conditions used for the simulations reported here were determined in a many step process by Fulton et al (2007). The first step was estimating the ecosystem state in 1910 (i.e. the total overall biomass per group), which was reached by

(i) taking estimates, where available for various groups in the model, from surveys and assessments (see full details in Fulton et al 2007), treating this as the unfished version of Atlantis-SE;
(ii) this starting point was repeatedly run, tuning the growth, clearance, non-predation mortality and trophic connection coefficients until the model predicted a plausible stable system state prior to fishing, sealing and whaling (this phase of the calibration captures the core ecological supply and demand drivers);
(iii) this ecologically-based calibration was then refined as the model was forced with known historical catch time series (such that the modelled system could give up observed survey time series and catches without any group going to extirpation, as this had not been observed been observed in reality);
(iv) for periods post 1990s the effort model was calibrated using log book effort data.

This process produced a 1910 estimate of mackerel (all stocks combined) of approximately 124,500t, which had risen to about 224,000t by the early 1980s and was around 174,000t by 2000 in the simulations including the historical fishing pressure. This compound Mackerel group does include both *Trachurus declivis* and *Scomber australisicus*, but the *Trachurus declivis* dominates the biomass (making up over 85% of the biomass group).

Since 2007 extra information (for demersal fish) has been used to refine this calibrated model (using the same process described above). This information has also been used to create alternative parameterisations for use in future projections beginning in 2010 – referred to as the current set of "best estimate" parameterisations.

As the eastern jack mackerel stock is the focus stock for current discussions, only that component of the Atlantis-SE mackerel group will be reported in the rest of this document (i.e. the jack mackerel component of the eastern mackerel stock represented in the model). The current set of "best estimate" parameterisations for Atlantis-SE produce an eastern jack mackerel stock state in 2010 of between 90,000 and 200,000t. The spawning component of this total biomass is 87-98% (calculated by comparing the biomass of mature age classes and the total biomass). These values were used as the starting point for the analyses detailed below.

1.2 Ecopath with Ecosim (EwE) Modelling Framework

1.2.1 GENERIC EWE FRAMEWORK

The Ecopath with Ecosim (EwE) model is the most widely used marine ecosystem model internationally. It is composed of a mass balance model (Ecopath; Polovina 1984, Pauly et al. 2000, Christensen et al. 2005) from which temporal (Ecosim) and spatial (Ecospace) dynamic simulations can be developed (Walters et al. 1997). EwE has been used to describe aquatic systems and to explore the impacts of fishing ecosystems

(Christensen and Pauly 1992, Christensen et al. 2005). In particular, it has been used to further our understanding of ecosystem structure and functioning, explore hypotheses concerning ecosystem change (in response to a number of drivers, both environmental and fisheries), used as a basis for comparative studies (spatial and temporal), used to provide ecosystem indicators and used in various simulated perturbation experiments.

1.2.2 EWE-EBS MODEL

The Ecopath with Ecosim (EwE) model for Eastern Bass Strait was originally developed to represent a portion of the South East Fishery (SEF) off southeastern Australia that had been the subject of scientific surveys and trophic studies. Full details can be found in Bulman et al (2006). The model includes the shelf and the slope to about 700m, at which depth there is a major change in fish community composition. The fauna of the EwE-EBS was organized into functional groups based upon commercial fishery, life history traits and ecology such as size and growth, preferred depth and trophic function (see table in the Appendix). For many species, categorization was complicated by increases in depth preference with increased size. Although this complication can be accommodated by creating stanzas or life stages that are linked, this version of the model does not account for ontogenetic changes in habitat preference. The single species groups are groups of particular commercial interest at the time of the original model creation except cucumberfish and cardinal fish, which were of particular ecological interest. Jack mackerel is one of these single species groups.

The aggregate groups of species were split according to average adult size (small=<30 cm, medium=30-50 cm, large= >50 cm) and preferred or major depth range of adults (shelf= 0-200m, slope>200m, pelagic= any depth not demersal). Nearly all these groups contain species that are fished but are not the primary targets of the fishery or the most important commercially.

1.2.3 DETERMINATION OF JACK MACKEREL BIOMASS IN EWE-EBS

The estimates of jack mackerel used in EwE-EBS are taken from trawl surveys held in the region of the model (detailed in Bulman et al 2006). This provides an estimate of total biomass of jack mackerel of approximately 180,000t.

2 Modelling Steps

2.1 Atlantis Simulations

2.1.1 BIOMASS LEVEL TESTING

Atlantis simulations were initialised with spawning biomass values for eastern jack mackerel of: 20,000t, 30,000t, 130,000t and 170,000t (equating to total biomasses of approximately 23,000t, 34,000t, 145,000t and 190,000t respectively). The same relative age structure (i.e. proportional of biomass per age class) for the standard Atlantis parameterisations were retained, the numbers were simply scaled to give the new biomasses to test. In half of these runs the standard spawner-recruit curve used for jack mackerel was unmodified (i.e. only the starting biomasses are scaled) and in the other half the spawner-recruit curve was adjusted so that it is consistent with a long term eastern jack mackerel stock size equivalent to the four total biomasses 23,000-190,000t given above).

The model was then run for each parameterisation for 50 years to see if any group (particularly the jack mackerel stock) was extirpated. Diet compositions and mortality rates were also recorded to allow for interpretation of biomass trajectories and to check for consistency with trophic data.

As some of the new initial biomass values did not allow for numerically stable simulations a small number of additional runs were done iteratively raising the initial biomass values to find the minimum biomass levels that were numerically stable.

2.1.2 HARVEST STRATEGY TESTING – TIER 1, OPTION 2

Simulations were also run to explore the ecosystem implications of harvesting the jack mackerel with an exploitation rate of 0.15 – the rate specified under tier 1, option 2 of the SPF. To do this two methods were employed to represent the fishery. One was to replace the dynamic fishing model with an annual fishing mortality rate of 0.15 (applied only to the spawning stock in those spatial areas fished by the SPF in the dynamic fishing simulations). The second approach was to implement the harvest strategy in Atlantis so that the RBC and TAC for the Atlantis fisheries was set in line with the harvest strategy. This more dynamic form takes into account shifting spatial effort allocation and targeting, whereas the fishing mortality case is fixed spatially through time.

These simulations were carried out with 2010 spawning stock biomasses of 170,000t, 130,000t, 70,000t and 45,000t. It was not possible to trial it for 20,000-30,000t as these biomasses were not possible given the current system understanding (see discussion of results below).

2.1.3 B48 TESTING

The SPF harvest strategy does not employ the same kind of biomass targets (e.g. B_{48}) used in other of Australia's federal fisheries. For comparison purposes simulations were run to explore the implications of depleting jack mackerel to the target reference level of B_{48} (relative to 2010 values in this case). To do this two methods were employed to represent the fishery. One was to replace the dynamic fishing model with a blanket fishing mortality rate of 0.04-0.06 (which led to biomass levels ~ B_{48} in a much more extensive analysis of the implications of depleting lower trophic level species, Smith et al (2011)). The second was to update the economic and fishing parameters to replicate cost structures of potential forms of the SPF that could fish hard enough to deplete the stocks to this level – this was done using publically available information on fuel efficiency and variable costs of vessels of different size and cost structure information collated for use in the study by Fulton et al (2007). As mentioned above, the dynamic form of fishing takes into account shifting spatial effort allocation and targeting. In contrast, in this case the fishing mortality case is a blanket value applied across the entire spatial extent of the SPF.

Once again, the depletion experiments were carried out with 2010 spawning stock biomasses of 170,000t, 130,000t, 70,000t and 45,000t. It was not possible to trial it for 20,000-30,000t as these biomasses were not possible given the current system understanding (see discussion of results below).

2.2 Ecopath Analysis

2.2.1 BIOMASS LEVEL TESTING

The biomass estimates for jack mackerel was reset to 23,000t, 34,000t, 145,000t (equivalent to 20,000t, 30,000t, 130,000t spawning biomasses). The spawning biomass of 170,000t was not tried anew as this represents the baseline state of the EwE-EBS model. Where this biomass reset created a model imbalance the cause of this imbalance was noted and the steps required to achieve a new balance noted.

2.2.2 HARVEST STRATEGY TESTING – TIER 1, OPTION 2

To look at the ecosystem implications of harvesting the jack mackerel with an exploitation rate of 0.15 a monthly fishing mortality rate of 0.0125 was used (a) for jack mackerel alone (with all other small pelagic species kept at the default rates in the EwE-EBS model) and (b) fishing all the SPF relevant groups at 0.0125.

2.2.3 B48 TESTING

As for Atlantis, simulations were run to explore the implications of depleting jack mackerel stocks to B_{48} levels (relative to 2010 values). To do this all landings and discards of jack mackerel were moved to a new fleet ("SPF"). This is a simplification, but allowed for greater control of the final depletion levels. To look at bycatch issues a quarter of the discards of the Seal group was moved from the general trawl fishery to this new SPF fishery. This is based on the high end of historical bycatch rates, which is a simplification that ignores improved excluder devices. This was done as it is a conservative assumption in terms of exploring the effects of the SPF fishing hard enough to deplete jack mackerel to B_{48}.

The depletion experiments were performed for model versions with initial jack mackerel spawning biomasses of 170,000t and 130,000t. It was not possible to explore cases with smaller initial biomasses (as they were incompatible with current system understanding – see the discussion of results below).

3 Results and Discussion

3.1 Atlantis Simulations

3.1.1 SUMMARY OF NEW SIMULATIONS

The simulations with new spawning biomasses of 130,000 and 170,000t ran to completion. The simulations with smaller biomasses either saw the extirpation of the jack mackerel group or were numerically unstable (which means the value is not consistent with data on the rest of the system, as to be possible it would require a very substantial restructuring of the entire system).

Starting at 30,000t and iteratively resetting the initial (2010) jack mackerel biomass values incrementally higher it was found that numerically stable parameterisations are only consistently possible once spawning biomasses are at approximately 50,000t or higher (see Table 1). At these biomass levels the model runs to completion with no extirpation and produces trajectories of catch and biomass consistent with known time series for the mackerel, top predators, invertebrates and demersal fish groups in the system. When spawning biomasses are initialised at values lower than roughly 50,000t, predation by large piscivorous fish (e.g. tuna), sharks, marine mammals and seabirds drives the group to extinction, which in turn can lead to declines in the biomasses of these predatory groups (with knock-on effects to other groups in the model).

It is possible to get some simulations that run to completion without extirpation with initial spawning stock sizes of 45000t, but these are very sensitive to environmental variation. That is, if they do not see runs of adverse years the stock can survive, but if poor conditions occur even for short periods of 2-3 years then the stock does not survive or the model becomes numerically unstable.

The Atlantis model parameterisations indicate that the most likely spawning biomass estimates consistent with the ecosystem model structure are 96,400t to 190,000t (Table 1).

Table 1: Jack mackerel spawning stock estimates from Atlantis - showing the mean and 95% confidence interval across the alternative parameterisations and the resulting plausible band for the minimum plausible and most consistent biomass estimates.

ESTIMATE OF JACK MACKEREL SPAWNING BIOMASS	PLAUSIBLE BAND	MEAN	95% CONFIDENCE INTERVAL
Minimum plausible (numerically stable)	45,000 – 73,000t	59,320t	± 13,700t
Most consistent with ecosystem model structure	96,400 – 190,000t	143,200t	± 46,800t

These ecosystem-modelling results indicate that the low biomass estimates are not plausible given the food web constraints and historical observations. Atlantis allows for quite plastic diets and a lot of uncertainty in diet connections is accounted for in the alternative parameterisations used in this study. Therefore, the results here should be robust unless there has been particularly large restructuring of south eastern Australian ecosystems within the last 10-15 years (the full set of trophic data used in Atlantis-SE was collected in the 1990s). The possibility that diets have shifted substantially cannot be ruled out without new dedicated trophodynamic studies, however it would have to be a **very large** restructuring to allow for total biomasses of Mackerel of the order of 20,000-30,000t without noticeably shifts in the biomasses of top predators in the area.

When following the harvest control rule for the SPF in Atlantis-SE most groups change by less than 5%. For some of the parameterisations some groups were more heavily impacted in the most intensively fished areas (see Table 2). The most commonly affected groups in this case were sharks, whales or seabirds.

Table 2: Atlantis-SE groups effected in boxes off the eastern states and Bass Strait when the SPF harvest strategy is implemented. All these effects are spatially constrained to these eastern areas and only effects with a magnitude > 5% are given.

INITIAL JACK MACKEREL SPAWNING BIOMASS	PARAMETERISATION	GROUPS THAT CHANGE >20%
170,000t	Low productivity system	**Shallow piscivorous fish increase** by roughly 6-10% (as predation on young of the year drops off); this and the reduction in the jack mackerel caused a **decrease in flathead biomass** by about 8-11%; although the **seabird biomass increased** by 20-22% on the back of the increase in numbers of the youngest age classes of piscivorous fish.
170,000t	Moderately productive system	**Baleen whales decrease** by 6% (there was one exception when there was a much higher drop in biomass, up to 18%, due to a combination of shifts in spatial distribution, but also a few accidental entanglements with fishing gear).
170,000t	Tightly connected system	**Gummy sharks and seabirds decrease** by 15-17%; with competition reduced **school shark increase** by up to 19%; and **baleen whales increase** by up to 16% in response to small increases in the other small pelagics.
130,000t	Low productivity system	The biomass of **shallow piscivorous fish, young blue grenadier and skates and rays decrease** by 10-13%. Flathead, gummy sharks and school sharks all increase by 10-20% due cumulative small increases in small pelagics, shallow invertebrates and young of the year for shelf dwelling fish.
130,000t	Moderately productive system	**Seabirds decrease** by up to 17%.
130,000t	Tightly connected system	**Baleen whales, young pink ling, skates and rays decrease** by up to 13%; while **seabirds increase** by up to 7% due to small increases in small fish relieved from competition or predation the jack mackerel.
70,000t	Low productivity system	**Baleen whales decrease** by up to 16%.
70,000t	Tightly connected system	**Seabirds decrease** by up to 23% locally, but (due to small increases in other small pelagics, shelf invertebrates and young age classes of shelf fish) **gummy shark increase** by up to 7-10%.
45,000t	Low productivity system	Small increases in the other forage species (small fish and invertebrates) allows for an **increase** of up to 17% **of gummy sharks, seabirds and baleen whales**.
45,000t	Moderately productive system	**Baleen whales increase up to 6-17%** (depending on levels of incidental entanglements and the increase of other forage species, especially zooplankton groups); **gummy sharks decline** up to 22%.
45,000t	Tightly connected system	**Seabirds decrease** by up to 40% (in this case it can have wider population implications, biomass drops 17-23%).

In terms of the effects of depleting the stock of eastern jack mackerel (or even the entire stock of mackerel) to approximately B_{48} Atlantis-SE suggested that there would be some (potentially complicated) knock-on effects. Few of the other groups in the system change by more than 20%, the majority of the other components changed by less than 5-10% (which they do anyway even in the absence of any changes in the eastern jack mackerel stock).

The exact groups impacted by a reduction in eastern jack mackerel biomass is dependent on the initial biomass level assumed for 2010 and the exact parameterisation used (Table 3). The groups most often impacted are mesopelagics and seabirds. The mesopelagics often increase as mackerel is depleted, due to a reduction in competition for planktonic prey. Whether predatory groups increase or decrease depends on whether they can switch pressure on to other prey species and whether their own predators increase/decrease (particularly for predators of juveniles).

Table 3: Atlantis-SE groups effected in boxes off the eastern states and Bass Strait by a reduction in eastern jack mackerel stocks to B_{48}. In those cases where a group decreased in the eastern boxes but showed less of a change in biomass overall (due to shifting to new spatial locations chasing redistributed prey etc.) the group is marked with a * or #. Also note that only those runs where an effect were observed are listed below – if a run is not listed no group changed by > 10%.

INITIAL JACK MACKEREL SPAWNING BIOMASS	PARAMETERISATION	GROUPS THAT CHANGE >20%
170,000t	Low productivity system	**Mesopelagics increase**, particularly the non-migratory component which increases (due to a reduction in competition with mackerel) by up to 60%; **small pelagics decline** by 14% (due to increased competition with mesopelagics out weighing the release in competition with jack mackerel); **seabirds* decline** by up to 32% **and school sharks** by up to 11% (due to a reduction in available prey like the small pelagics and a slight increase in predators).
170,000t	Moderately productive system	**Gummy shark, school shark and seabirds increase** by 13-16% due to small increases in forage fish and invertebrate prey groups, particularly in inshore.
170,000t	Tightly connected system	**Seabird** biomass **increase** by up to 30%, while the **baleen whales and school shark increase** in biomass by 15-16% all in response to increasing biomass of small pelagics and red bait (which increase a little as competition is reduced, the small pelagics also move to more accessible points in the water column). **Gummy shark decrease** by 16% in response to small increases in the numbers of pup predators (in turn in response to the increased biomass of other forage fish).
130,000t	Low productivity system	**Non-migratory mesopelagics increase** up to 72% (due to a reduction in competition with jack mackerel), while **migratory mesopelagics decline** by 11% as they compete and are consumed by the non-migratory mesopelagics; **seabirds increase** by 14%, **carrion, school and gummy sharks** all **increase** by 22-26% (fed by production coming through the increased mesopelagic biomass; seabird predators also shift).
130,000t	Moderately productive system	**Baleen whales increase** by 18% due to small increases in other forage fish and zooplankton (and a slight shift in behavior of predators on juveniles); whereas the **shallow piscivorous fish*** and **juvenile blue grenadier** decrease 11-12%. **School shark* and gummy shark***

INITIAL JACK MACKEREL SPAWNING BIOMASS	PARAMETERISATION	GROUPS THAT CHANGE >20%
		locally **increase** by up to 16% in response to small increases in other forage fish, juvenile fish and invertebrates that were the fish groups that decreased in biomass.
130,000t	Tightly connected system	**Baleen whales* and school sharks* decrease** by 17-18% as the increase in biomass of other available prey groups does not sufficiently compensate for the decrease in jack mackerel biomass (there is also a slight increase in predation on juvenile whales).
70,000t	Low productivity system	**Small pelagics and non-migratory mesopelagics increase** by 24 % and 175% respectively (due to a release from competition for plankton prey); while **migratory mesopelagics decrease** by 14% due to competition with the other mesopelagics. **Seabirds decline** by 17% and **school sharks decrease**[#] by 33% due to an overall reduction in available prey and **carrion** (which also **declines** by 13%) – the increase in the other forage fish does not offset the loss of jack mackerel for these predators.
70,000t	Moderately productive system	**Seabirds increase** in biomass by up to 18% and **gummy shark** by up to 14% due to localized increases in the other forage fish and a small reduction in predator biomass.
70,000t	Tightly connected system	**Seabirds decline** by up to 21% while the baleen **whales increase** by 12% - both in response to shifts in the prey fields (the depletion of jack mackerel releasing zooplankton and some of the other forage fish, which the whales benefit form, but the overall available prey field is lower for seabirds provisioning chicks who decline in response).
45,000t	Low productivity system	The biomass of **zooplankton, small pelagic fish and non-migratory mesopelagics all decline** by 11-30% as predators shift pressure onto them as the jack mackerel decline. **Flathead and school shark** also **decline** by 19-21% as their prey declines. **Blue warehou increase** in biomass by up to 16% as their predators and competitors decline.
45,000t	Tightly connected system	**Gummy shark decline** by up to 27%; while **shallow piscivorous fish*, seabirds* and baleen whales* increase** by up to 11-16% as other forage fish and plankton increase a little. In addition there is a shift in predators of key age groups – a slight decrease in adult predators for juvenile whales and adult seabirds.

* System wide the decline is <5-10%
# Note that the system wide decline is <8-15%

Note that the only real difference between considering the effects of a reduction of the jack mackerel stock to B_{48} (relative to 2010 values) and considering the reduction in biomass of the entire mackerel group was that the effects on other groups were more spatially extensive. For the depletion of eastern jack mackerel the effects are seen in the boxes off New South Wales, Victoria, Tasmania and eastern Bass Strait. When considering the depletion of the entire mackerel stocks similar effects are seen over the spatial extent of the entire population.

The other important observation from the depletion simulations is that for the lower initial biomasses the rate of depletion was important. If the eastern initial jack mackerel spawning biomass was 70,000t and the depletion took less than 5-10 years it could make the simulation numerically unstable. Similarly if the simulation with initial spawning biomass of 45,000t was depleted in less than 8-15 years.

Comparing the results for the harvest strategy and B_{48} simulations it is clear that the dynamics of the system do not change linearly with increasing pressure on jack mackerel. There is an overlap in the groups effected in each case, but more pressure does not simply equate to bigger effect. Indeed in the biomasses of jack mackerel predators (e.g. seabirds), or the predators of other forage species (e.g. baleen whales), seen under the harvest strategy can be smaller than under the B_{48} depletion. This is because the drop in jack mackerel biomass is enough to impact the available prey field, but not sufficient to release the other forage species (especially the mesopelagics or zooplankton) to the extent that they more than compensate for the losses. In constrast, this release often happened for the B_{48} case. In terms of system restructuring however, the greatest changes were always seen under the B_{48} case.

3.1.2 SUMMARY OF OTHER RELEVANT ATLANTIS WORK

The discussion of other relevant modelling work given in this section was originally made available in a 2012 briefing document entitled "Summary of Atlantis Work Relevant to Australia's Small Pelagics Fishery".

Across the different standard parameterisations of the Atlantis-SE model there are a range of possible biomasses for Australian small pelagics based on trophic interactions in the system and what can be supported by the plankton production of the system and the level of likely predation in the system. The total biomass estimates for the small pelagic species from the Atlantis-SE model are:

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.

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). Simulations run forward from 1900 (using known historical fishing pressure) have all of these species increase in biomass in the model over the 20th century. This is due to reductions in biomass of their predators. Based on the trophic flows in Atlantis-SE, the predatory species (e.g. finfish, sharks, mammals etc) can put significant pressure on the small pelagic groups. For example, the 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
With total annual consumption: 250,000 to 500,000t

While 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
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 importance of predator biomass for the trajectory of the prey does not mean that the biomass of the individual prey species is critical to predator biomass. The trophic dynamics captured in Atlantis-SE allow for shifting diets if some prey are hard to find at a particular location or time. This means that substantial declines in predator population biomass is only observed if the very large biomass groups, like the mesopelagics, decline. The simulations summarized for 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 concluded that at the current exploitation rates in the SPF (<10%) the ecosystem impacts of fishing on small pelagic fish populations (even in systems with large dependence on these species) and their predators are low. The study compared models in classical "upwelling" ecosystems (e.g. Southern Benguela, Humboldt current, California current), the North Sea and Southeast Australia. In each model the small pelagic groups were intentionally depleted to differing degrees, regardless of the level of fishing actually pursued in the system currently. The impacts of fishing the pelagic target species in SE Australia (redbait, mackerel, sardines and anchovy) were generally low (<5-10%) changes (increases or decreases) in predatory fish, marine mammals and seabirds. If mackerel are depleted by 60% (well beyond current limits in the harvest control rules) shifts in the ecosystem seabird biomass is projected to increase by more than 40%. As counterintuitive as it sounds, it is possible for a predator species to show an increase in biomass with the depletion of a prey species if the other prey species, which compete with the depleted species, benefit. If anchovy and sardines are depleted by 60% mackerel, seabirds, seals and sealions all decline by more than 40%. In contrast, depletion of mesopelagics had significant ecological consequences that cascade through slope and shelf food webs leading to changes in biomass of pelagic bacteria, diatoms, kelp, copepods, krill, arrow squid, meiobenthos, sardines and anchovies, mackerel, red bait, morwong, cardinalfish, gemfish, shallow piscivorous fish, tunas, school whiting, deep demersal finfish, shallow demersal finfish, redfish, blue-eye trevalla, deepwater dogfish and pelagic sharks. No fishery currently targets mesopelagic fish in Australia.

In simulations run to explore the implications of climate change and ocean acidification through until 2070 in south eastern Australia (Fulton et al., 2012), potential future trajectories for the SPF were explored using a range of vessel sizes (from the size of the vessels used in the past up to 100m trawlers capable of staying at sea for up to 50 days). These simulations found that medium to large vessels were the only ones able to remain economically viable (i.e. consistently profitable) and environmentally sustainable as climate change driven shifts in the system accumulated. The shifting environment and cumulative effects of management strategies across all fisheries in the region can lead to shifts of >40% (increase or decrease) in 50-60% of the groups in the system. In contrast, shifts due to full exploitation of the SPF alone were less than 5-10% for all groups interacting with the fishery. The single exception is for red bait. Under low productivity parameterisations of the system, with tight trophic links, red bait declined by > 20%. This parameterisation is only one of 10 ecological parameterisations explored in the simulation suite.

3.2 EwE Results

Resetting the biomass of jack mackerel in EwE-EBS to be consistent with a spawning biomass of 20,000-30,000t sees the model fail to balance (so the sum of mortality and losses does not equal production for all groups). Specifically the ecotrophic efficiency (the proportion of production accounted for by mortality, migration etc in the model) exceeds 1.0 for the jack mackerel group (it is 3.76). This means there is insufficient biomass (and thus new production annually) to support the predation and fisheries mortalities as defined by the landings, discards and diet data included in the model. Looking into the different mortality sources, it is predation by seals, tunas and demersal sharks that do not allow for such a low biomass level. Trying to rebalance the model with a spawning biomass of 20,000t would not be an easy task (in fact it seems effectively impossible) as the alternative prey for these groups are already close to fully accounted for in the model (i.e. ecotrophic efficiency is > 0.95 and so can not support additional mortality moved away from the jack mackerel). It is not simply a matter of increasing production or biomass for these other prey as that has cascading effects through their prey and substantially modifies the entire model (taking it away from observed values). As with Atlantis it is possible that there has been substantial diet restructuring since the time when the data underlying diet matrix at the heart of the model was collected. However only dedicated diet sampling could identify with a sufficiently large shift in diet (and system structure) has occurred. The lower biomass values for jack mackerel are not consistent with the current "best understanding" as captured in the model.

In contrast, setting biomasses of jack mackerel consistent with a spawning biomass of 130,000-170,000t allows for a balanced model even without modification of any other parameters.

Fishing the jack mackerel group with an annual F of 0.15 (monthly rate of 0.0125) saw the biomass for the group drop to 50-55% of starting values. When all SPF relevant groups are fished at this level the jack mackerel biomass stabilised at roughly 80% of starting values; red bait shows almost no change from starting values (varying between 95-105% of starting values); and the small pelagics stabilised at about 90% of the starting values. Under these fishing levels of fishing pressure none of the other groups in the model changed by more than 5% from the baseline cases.

The Ecosim B_{48} simulations do not have a spatial component so many trophic effects are greater than seen in Atlantis-SE. The patterns of increases/decreases are identical in this model regardless of whether initial biomasses are 130,000 or 170,000t – see Table 3; results for the 130,000t case within 2-5% of the results for 170,000t; typically the changes under 130,000t are slightly smaller than for 170,000t.

The majority of changes were small increases or decreases of <2-5%. Of those groups that change by 5% or more only the predators seals and tuna and billfish decline (due to a reduction in prey). All other groups that change increase either (i) due to small increases in prey groups due to reduced competition or (ii) due to the reduction of predator biomass.

Table 4: EwE-EBS groups which change > 5% when jack mackerel is decreased to B_{48}.

MAGNITUDE OF CHANGE	INCREASES	DECREASES
5-10%	Seabirds Penguins Jackass morwong Chinaman leatherjacket	Tuna and billfish
10-20%	Warehous Redfish Ling Gemfish Shallow small predators Deep sea cod Pelagic medium predator	Seals
20-30%	Shallow medium predators	

3.3 Conclusions

Using the Atlantis and EwE models for the south eastern Australia as a "plausibility testing" platform for alternative eastern jack mackerel spawning biomasses, shows that values of 20,000-30,000t are too low given the ecology captured in the models. In contrast spawning biomasses of 130,000-170,000t are plausible.

If eastern jack mackerel are fished according to the current SPF harvest strategy some localised depletions are possible, but broad scale restructuring of marine ecosystems is very unlikely (it was not seen under any simulation using the plausible spawning biomasses). If instead the eastern jack mackerel biomass in the ecosystem models is reduced to approximately B_{48} there are a number of possible knock-on trophic and ecological groups on other groups. The exact form of these changes are complicated but in general are the release of competitors, a reduction in predators who cannot find alternative prey, as well as the reduction in biomass of prey of predators who increase as the system restructures. Some of these changes are beyond the natural level of variation in these species due to interannual environmental shifts, though they are not as large if spatial shifts can compensate for localised effects of system restructuring. 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).

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Appendix – Model Structures

Atlantis-SE Components

Table 5: List of biological components in Atlantis-SE

MODEL COMPONENT	GROUP COMPOSITION
Pelagic invertebrates	
Large phytoplankton	Diatoms
Small phytoplankton	Picophytoplankton
Small zooplankton	Heterotrophic flagellates
Mesozooplankton	Copepods
Large zooplankton	Krill and chaetognaths
Gelatinous zooplankton	Salps (pryosomes), coelenterates
Pelagic bacteria	Pelagic attached and free-living bacteria
Squid	*Sepioteuthis australis*, *Notodarus gouldi*
Benthic invertebrates	
Sediment bacteria	Aerobic and anaerobic bacteria
Carnivorous infauna	Polychaetes
Deposit feeders	Holothurians, echinoderms, burrowing bivalves
Deep water filter feeders	Sponges, corals, crinoids, bivalves
Shallow water filter feeders	Mussels, oysters, sponges, corals
Scallops	*Pecten fumatus*
Herbivorous grazers	Urchins, *Haliotis laevigata*, *Haliotis rubra*, gastropods
Deep water megazoobenthos	Crustacea, asteroids, molluscs
Shallow water megazoobenthos	Stomatopods, octopus, seastar, gastropod, and non-commercial crustaceans
Rock lobster	*Jasus edwardsii*, *Jasus verreauxi*
Meiobenthos	Meiobenthos
Macroalgae	Kelp
Seagrass	Seagrass
Prawns	*Haliporoides sibogae*
Giant crab	*Pseudocarcinus gigas*

MODEL COMPONENT	GROUP COMPOSITION
Fin-fish	
Small pelagics	*Engraulis*, *Sardinops*, sprat
Red bait	Emmelichthyidae (*Emmelichthys nitidus*)
Mackerel	*Trachurus declivis*, *Scomber australisicus*
Migratory mesopelagics	Myctophids
Non-migratory mesopelagics	Sternophychids, cyclothene (lightfish)
School whiting	*Sillago*
Shallow water piscivores	*Arripis*, *Thyrsites atu*, *Seriola*, leatherjackets
Blue warehou	*Seriolella brama*
Spotted warehou	*Seriolella punctata*
Tuna and billfish	*Thunnus*, *Makaira*, *Tetrapturus*, *Xiphias*
Gemfish	*Rexea solandri*
Shallow water demersal fish	Flounder, *Pagrus auratus*, Labridae, *Chelidonichthys kumu*, *Pterygotrigla*, *Sillaginoides punctata*, *Zeus faber*
Flathead	*Neoplatycephalus richardsoni*, *Platycephalus*
Redfish	*Centroberyx*
Morwong	*Nemadactylus*
Ling	*Genypterus blacodes*
Blue grenadier	*Macruronus novaezelandiae*
Blue-eye trevalla	*Hyperoglyphe Antarctica*
Ribaldo	*Mora moro*
Orange roughy	*Hoplostethus atlanticus*
Dories and oreos	Oreosomatidae, Macrouridae, *Zenopsis*
Cardinalfish	Cardinalfish
Sharks	
Gummy shark	*Mustelus antarcticus*
School shark	*Galeorhinus galeus*
Demersal sharks	*Heterodontus portusjacksoni*, Scyliorhinidae, Orectolobidae
Pelagic sharks	*Prionace glauca*, *Isurus oxyrunchus*, *Carcharodon carcharias*, *Carcharhinus*
Dogfish	Squalidae
Gulper sharks	*Centrophorus*
Skates and rays	Rajidae, Dasyatidae
Top predators	
Seabirds	Albatross, shearwater, gulls, terns, gannets, penguins
Seals	*Arctocephalus pusillus doriferus*, *Arctocephalus forsteri*
Sea lion	*Neophoca cinerea*
Dolphins	Delphinidae
Orcas	*Orcinus orca*
Baleen whales	*Megaptera novaeangliae*, *Balaenoptera*, *Eubalaena australis*

Table 6: Summary table of fisheries (fleets and fleet components) represented in Atlantis-SE - recreational fishing includes fishing from charter boats. Forced = fixed effort level and distribution as of 2000, dynamic = uses a dynamic effort allocation model to execute fishing. Depths represents potential depths fished, fisheries did not automatically fish all potential depths at any one time or even during the course of an entire run. Note that fisheries could target many more groups than just the primary target and that the primary target group is for the start of the dynamic runs, within a run the identity of the primary target group could change as a result of decisions made by the dynamic fisheries.

FISHERY (FLEET)	FLEET COMPONENT	GEAR	DEPTHS (M)	PRIMARY TARGET GROUP(S)	EFFORT MODEL	SUBFLEETS
Dive	-	Dive	< 35	Grazers, lobster, deposit feeders	Forced	All size boats together
Fin-fish auto-longline	-	Auto-longline	150 - 600 [A]	Ling, blue grenadier, blue-eye trevalla	Dynamic	All size boats together
Fin-fish drop line	-	Drop lines	150 - 650	Blue-eye trevalla	Dynamic	All size boats together
Fin-fish mesh net	-	Mesh nets	150 - 250	Warehou	Dynamic	All size boats together
Fin-fish trap	-	Traps	150 - 550	Ling and demersals	Forced	All size boats together
Inshore line	-	Drop and hand lines	< 200	Shallow piscivores	Forced	All size boats together
Pots	-	Traps	< 250	Lobster, shallow megazoobenthos	Forced	All size boats together
Recreational (represented as a tithe)	-	Multiple	< 200	multiple	Dynamic	Individuals Charter boats
Scallop dredge	-	Dredge	< 150 [B]	Scallops	Forced	All size boats together
Shark net	-	Mesh nets	< 150 [C]	Gummy shark, school shark	Dynamic	< 30m 30 – 40m > 40m
Shark longline	-	Longline	< 150 [C]	Gummy shark, school shark	Dynamic	All size boats together
Small pelagic state fisheries	-	Net, seine	< 250	Small pelagics, mackerel	Forced	All size boats together
Small pelagic Commonwealth fishery	-	Midwater trawl	< 300	Mackerel, red bait	Dynamic	All size boats together
Small pelagic purse seine	-	Purse seine	< 250	Small pelagics, mackerel	Forced	All size boats together
Squid jig	-	Jig	< 200	Squid	Forced	All size boats together
Tuna longline	-	Pelagic longline	> 50	Tuna and billfish	Forced	All size boats together
Tuna purse seine	-	Purse seine	> 50	Tuna and billfish	Forced	All size boats together

FISHERY (FLEET)	FLEET COMPONENT	GEAR	DEPTHS (M)	PRIMARY TARGET GROUP(S)	EFFORT MODEL	SUBFLEETS
Trawl (with state, SET and GABT divisions) [D]	Cephalopod trawl	Bottom trawl	< 300	Squid	Dynamic	All size boats together
	Crustacean trawl	Bottom trawl	50 – 250	Crustaceans [E]	Forced	All size boats together
	Prawn trawl	Bottom trawl	300 - 500	Royal red prawns	Dynamic	All size boats together
	Fin-fish midwater trawl	Midwater trawl	50-400	Demersals	Dynamic	All size boats together
	Squid midwater trawl	Midwater trawl	< 500	Squid	Dynamic	All size boats together
	Danish seine	Danish seine	< 200	Flathead	Dynamic	< 30m > 30m
	General demersal (slope) trawl [F]	Bottom trawl	< 650	Ling, blue grenadier	Dynamic	< 30m 30 – 40m 40 – 50m > 50 m
	Shelf demersal trawl	Bottom trawl	< 250	Flathead	Dynamic	< 30m 30 – 40m > 40m
	Orange roughy trawl	Bottom trawl	< 1250	Orange roughy	Dynamic	< 30m 30 – 40m > 40m

A. In reality auto-longline is between 183-600m, but the resolution of the model meant that it had to be represented as either 150-600 or 250-600. It was decided in this case to use 150-600, but in the future sensitivity to this decision (or better still resolving the model so it can represent say 180-600) needs to be considered – see discussion of the gillnet and auto-longline and shark catch results for further exploration of this topic.

B. This depth was set to capture historical catches and because of the vertical resolution of the model, more recently the majority of observed scallop dredging is in waters <80m.

C. This depth was set to capture historical catches and because of the vertical resolution of the model, since the adoption of quota management for gummy and school shark most observed effort is in waters <80m.

D. The state fishery components were really only active for Crustacean trawl and Shelf demersal trawl components.

E. For state fisheries the primary target groups are prawns and giant crab, while for the Commonwealth fisheries the target group is “non prawn crustaceans”.

F. While active on the upper slope this trawl fleet ranges more widely and can be found fishing the shelf break and on the shelf (changing its targeting appropriately).

EwE-EBS Components

Table 7: Model groups in the EwE-EBS model. Representative species upon which the parameters were based are listed per group, but note that the species listed in multi-species groups do not necessarily represent all the species that could be attributable to that group.

MODEL COMPONENT	GROUP COMPOSITION
Detritus	
Discards	Contains the fishery discards
Detritus	Benthic detritus
Primary producers	
Phytoplankton	All phytoplankton including diatoms of pelagic and oceanic origin
Macrophytes	Macroalgae
Pelagic invertebrates	
Small zooplankton	Planktivorous plankton such as heterotrophic flagellates, euphausiids, large copepods and pelagic amphipods
Large zooplankton	Carnivorous plankton such as mysids, copepods, pelagic tunicates, chaetognaths and cnidarians, and larval fish
Gelatinous zooplankton	Pyrosomes, salps and coelenterates
Krill	*Euphausia* spp.
Squid	Southern calamary *Sepioteuthis australis*, Arrow squid *Notodarus gouldi*
Pelagic prawns	Pelagic penaeid and carid prawns
Benthic invertebrates	
Polychaetes	Mostly infaunal polychaetes
Megabenthos	Large mobile benthic fauna including the commercial species of crabs, bugs, benthic prawns e.g. Royal red prawn *Haliporoides sibogae*, scallops and non-commercial species such as mobile gastropods and bivalves, and benthic cephalopods (cuttlefish, four squid and eight octopus species)
Macrobenthos	Aggregate group of sessile epibenthos such asteroids, ophiuroids and echinoids and small mobile epifauna such as amphipods and small mysids
Pelagic Fishes	
Small pelagic fishes	Australian Anchovy *Engraulis australis*, Australian sardine *Sardinops sagax*, Blue sprat *Spratelloides robustus* and also Sandy sprat *Hyperlophus vittatus*, Australian bonito *Sarda australis*, Southern herring *Herklotsichthys castelnaui*
Jack mackerel	Jack mackerel *Trachurus declivis*
Mesopelagic fishes	Hector's lantern fish *Lampanyctodes hectoris*, Dana lanternfish *Diaphus danae*, Pennant pearlside *Maurolicus australis*, Silver lightfish *Phosichthys argenteus*, Black dragonfishes *Idiacanthus* spp., Largescale neoscopelid *Neoscopelus macrolepidotus*
Medium pelagic fishes	Yellowtail scad *Trachurus novaezelandiae*, Eastern Australian salmon *Arripis trutta*, White warehou *Seriolella caerulea*, Indian scad *Decapterus russelli*
Medium pelagic predators	Blue mackerel *Scomber australasicus*, Ray's bream *Brama brama*
Large pelagic fish	Peruvian mackerel *Trachurus murphyi*
Large pelagic predators	Tailor *Pomatomus saltatrix*, Snook *Sphyraena novaehollandiae*
Tuna and billfish	Swordfish *Xiphias gladius*, Yellowfin tuna *Thunnus albacores*, Albacore *T. alalunga*, Southern bluefin tuna *T. maccoyii*, Bigeye tuna *T. obesus*, Skipjack tuna *Katsuwonus pelamis*, Black marlin *Makaira indica*, Blue marlin *M. nigricans*, Spanish mackerel *Scomberomorus commerson*, Spotted mackerel *S. munroi*, Mackerel tuna *Euthynnus affinis*, Sailfish *Istiophorus platypterus*, Striped marlin *Tetrapturus audax* and Shortbill spearfish *T. angustirostris*
Demersal fishes	

MODEL COMPONENT	GROUP COMPOSITION
Red bait	Redbait *Emmelichthys nitidus*
School whiting	Eastern school whiting *Sillago flindersi*
Cucumberfish	Blacktip cucumberfish *Paraulopus nigripinnis*
Cardinalfish	Threespine cardinalfish *Apogonops anomalus*
Ocean jacket	Ocean jacket *Nelusetta ayraud*
Shelf ocean perch	Reef ocean perch *Helicolenus percoides*
Warehous	Blue warehou *Seriolella brama*, Silver warehou *Seriolella punctata*
Dories	John dory *Zeus faber*, Mirror dory *Zenopsis nebulosus*, Silver dory *Cyttus australis* and King dory *C. traversi*.
Gemfish	Gemfish *Rexea solandri*
Flathead	Tiger flathead *Neoplatycephalus richardsoni*, Sand flathead *Platycephalus bassensis*
Redfish	Redfish *Centroberyx affinis*
Jackass morwong	Jackass morwong *Nemadactylus macropterus*
Ling	Pink ling *Genypterus blacodes*
Small shelf fishes	Banded-fin flounder *Azygopus pinnifasciatus*, Australian burrfish *Allomycterus pilatus*, New Zealand dory *Cyttus novaezelandiae*, Silverbelly *Parequula melbournensis*, Roundsnout gurnard *Lepidotrigla mulhalli*, Cocky gurnard *Lepidotrigla modesta*, Common Bellowsfish *Macroramphosus scolopax*, Threadfin Leatherjacket *Paramonacanthus filicauda*, Velvet leatherjacket *Meuschenia scaber*, Rosy wrasse *Pseudolabrus mortoni*, Bluethroat wrasse *Notolabrus tetricus*, Starry toadfish *Arothron firmamentum*, Bigscale bullseye *Pempheris multiradiata*, White-ear *Parma microlepis*
Small shelf piscivores	Eastern orange perch *Lepidoperca pulchella*, Splendid perch *Callanthias australis*, Barber perch *Caesioperca rasor*, Butterfly gurnard *Lepidotrigla vanessa*, Mado *Atypichthys strigatus*, Silver sweep *Scorpis lineolata*
Medium shelf fishes	Grey morwong *Nemadactylus douglasi*, Common gurnard perch *Neosebastes scorpaenoides*, Common stinkfish *Foetorepus calauropomus*, Globefish *Diodon nicthemerus*, Sixspine leatherjacket *Meuschenia freycineti*
Medium shelf piscivores	Red gurnard *Chelidonichthys kumu*, Southern Maori wrasse *Ophthalmolepis lineolatus*, Common stargazer *Kathetostoma laeve*, Bastard trumpeter *Latridopsis forsteri*, Latchet *Pterygotrigla polyommata*
Large shelf piscivores	Striped trumpeter *Latris lineata*, Silver trevally *Pseudocaranx dentex*, Snapper *Pagrus auratus*, Barracouta *Thyrsites atun*
Slope ocean perch	Bigeye ocean perch *Helicolenus barathri*
Blue grenadier	Blue grenadier *Macruronus novaezelandiae*
Blue-eye trevalla	Blue-eye trevalla *Hyperoglyphe antarctica*
Ribaldo	Ribaldo *Mora moro*
Small slope fishes	Banded whiptail *Coelorinchus fasciatus*, White deepsea cardinalfish *Epigonus denticulatus*, Robust cardinalfish *E. robustus*, Bigeye cardinalfish *E. lenimen*, Banded Bellowsfish *Centriscops humerosus*
Small slope piscivores	Gargoyle fish *Coelorinchus mirus*, Falseband whiptail *Coelorinchus maurofasciatus*
Medium slope fishes	Toothed whiptail *Lepidorhynchus denticulatus*, Little whiptail *Coelorinchus gormani*, Southern whiptail *Coelorinchus australis*
Medium slope piscivores	Speckled stargazer *Kathetostoma canaster*
Large slope fishes	Conger eels *Bassanago* spp., Longfin bigeye *Cookeolus japonicus*
Large slope piscivores	Southern frostfish *Lepidopus caudatus*, Hapuku *Polyprion oxygeneios*
Sharks and rays	

MODEL COMPONENT	GROUP COMPOSITION
Pelagic sharks	Blue *shark Prionace glauca*, Shortfin mako *Isurus oxyrinchus*, White shark *Carcharodon carcharias*, Porbeagle *Lama nasus*, Oceanic whitetip shark *Carcharhinus longimanus*, Spinner shark *C. brevipinna*, Scalloped hammerhead *Sphyrna lewini*, Tiger shark *Galeocerdo cuvier*, Thresher shark *Alopias vulpinus*
Demersal sharks	School shark *Galeorhinus galeus*, Gummy shark *Mustelus antarcticus*, Spikey dogfish *Squalus megalops*, Elephantfish *Callorhinchus milii*, Longsnout dogfish *Deania quadrispinosa*, Draughtboard shark *Cephaloscyllium laticeps* , Port Jackson shark *Heterodontus portusjacksoni*, Common sawshark *Pristiophorus cirratus*, Southern sawshark *P. nudipinnis*, Sawtail catshark *Figaro boardmani*, Grey spotted catshark *Asymbolus analis*, Orange-spotted catshark *A. rubiginosus*, Bronze whaler *Carcharhinus brachyurus*
Skates and rays	Tasmanian numbfish *Narcine tasmaniensis*, Sparsely-spotted stingaree *Urolophus paucimaculatus*, Banded stingarees *U. cruciatus*, Greenback stingarees *U. viridis*, Peacock skate *Pavoraja nitida*, skate *Dipturus confusus*
Top predators	
Seabirds	Short-tailed shearwater *Puffinus tenuirostris* but also includes Albatrosses *Thalassarche* spp., gulls *Larus* spp., terns, gannets,
Penguins	Fairy penguins *Eudyptula minor*
Seals	Australian fur seal *Arctocephalus pusillus doriferus*, New Zealand fur seal *Arctocephalus forsteri*
Baleen whales	Humpback whale *Megaptera novaeangliae*, Blue whale *Balaenoptera musculus*, Southern Right whale *Eubalaena australis*
Toothed whales	Sperm whale *Physeter macrocephalus*, Long-finned pilot whale *Globicephala melas*, Southern bottlenose whale *Hyperoodon planifrons*, Short beaked common dolphin *Delphinus delphis*, Bottlenose dolphin *Tursiops truncatus*

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