Alternative Management Strategies for Southeast Australian Commonwealth Fisheries: Stage 2: Quantitative Management Strategy Evaluation

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Australian Fisheries Management Authority
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EXECUTIVE SUMMARY

Over the past decade, particularly in the early years following 2000, it became widely recognised that what is now known as the Southern and Eastern Scalefish and Shark Fishery (SESSF) was facing a swath of severe problems, including deteriorating economic performance of key sectors and declining ecological performance in terms of overfished species and other impacts of ecosystem services. The quota management system in place in the SESSF was proving to be unsuccessful in combating all of these problems and was inadequate for managing the fishery so that it simultaneously meet ecological and economic goals laid out under AFMA legislation, the Environment Protection Biodiversity Conservation (EPBC) Act 1999 and Australia's National Plan of Action for the Conservation and Management of Sharks. Recognition of this failing had led to general agreement among managers, industry, scientists and NGOs that a management rethink was required; and that interactions between sectors needed direct consideration.

This project reported here (formally known as the "Evaluation of alternative strategies for management of Commonwealth fisheries in south eastern Australia") was established during 2004 specifically to help rethink the broad basis for management of the SESSF. The project uses a management strategy evaluation (MSE) approach, where the major components of the adaptive management cycle are represented so that alternative options and potential problems can be evaluated in a realistic setting. In the first stage of the study the MSE was conducted using a qualitative method (Smith *et al* 2004); in the second stage Atlantis was used to complete a quantitative MSE analysis (reported here). Both stages provide insight into the potential consequences of applying alternative management scenarios and the trade-offs between them are explicitly considered.

This study should not be used as a strict assessment of the SESSF stocks nor should it be seen as a forecast of the exact future of the fishery. Instead it should be used to give strategic insights into the consequences and potential tradeoffs that are associated with a range of management strategies that could be used in the region. In no way should the results be considered as optimised or to give prescriptive management advice, instead they should be considered as information for strategic planning and decision support.

Stage 1 of the study identified and evaluated four scenarios for the future management of the SESSF: two variants of what was status quo at the time; an enhanced quota management scenario; and a mixed controls scenario. It was found in that stage that Scenario 4 (which involves the use of a combination of management measures, including quota, effort, gear and spatial management) achieved most closely the management objectives in the longer term, though at the cost of severe short-term disruption to the fishery. Management of the fishery has changed significantly in the intervening period, catalysed by the interest and thought generated by stage 1. Nevertheless it was decided that greatest understanding and benefit could be derived from stage 2 if it were still to consider one of the status quo scenarios, the enhanced quota management and mixed control scenarios considered in stage 1, as well as two more scenarios (one defined by AFMA staff members and another by an NGO after the release of the Stage 1 report). Each of these scenarios comprises an alternative mixture of quota management, spatial management, gear controls and effort controls; and range from what was largely "business as usual" during the late 1990s and 2000 through to more integrated packages that combine the use of all levers simultaneously.

The model used to perform the quantitative MSE is the southeast Atlantis model (hereafter Atlantis SE), which is one of the most detailed and comprehensive ecosystem models ever developed and implemented. It is a deterministic model that includes biophysical, industry, assessment, management and socioeconomic submodels. While it is focused on the commonwealth SESSF sectors and the groups it exploits and impacts, the model does include the activities off all fisheries in the region (including state fisheries and other commonwealth fisheries such as the tuna, small pelagic and squid fisheries) as well as some representation of all the major system components. The socioeconomic model is one of the first pure process based site choice models developed for a fishery at such a large scale.

General Results

The performance measures used in both stages of the MSE (qualitative and quantitative) were selected because they best reflect the combined list of stakeholder objectives, including AFMA's legislative objectives (Ecological Sustainable Development (ESD), maximising economic efficiency, and achieving cost-effective management) as well as industry's goals of profitability, minimal gear conflict, security of access to resources, stable management arrangements and a positive community acceptance.

Using these performance measures it was found that:

– Under the status quo scenario (Scenario 1) effort remains at around recent historically observed levels, and vessels push into more and more marginal areas, until economic pressure eventually proves too much and vessels exit each of the major sectors (except for the Great Australian Bight trawl sector). Any benefits from this reduction in effort are quickly dissipated and fishing sectors fish through the foodweb (targeting both higher trophic level chondrichthyans and lower trophic level squid and small pelagics), as traditionally targeted fin-fish resources prove less and less lucrative. This causes a degradation of the ecological system state (that would take many decades to recover) and poor public perception of the fishery.

– Initially under the enhanced quota management scenario (Scenario 3) effort also remains about the level observed historically. Within a decade however, economic pressure forces vessels out of the major sectors (particularly the southeast trawl and gillnet, hook and trop sectors) and contributes to a relocation and shift in behaviour in vessels that once fished deep waters (the spatial management components of this scenario make it difficult for that fleet to remain profitable). The use of TACs as a dominate management lever means problems with overcatch (when total landed catch of a species exceeds the TAC) are a significant issue in this Scenario[1]. Into the

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[1] In fact overcatch is an issue in many of the scenarios. It is typically no more than 30% of quota held and reflects the issues of searching and targeting in a multispecies fishery. It is precisely because of these issues that a 10-30% "overage" is allowed in the British Columbia groundfishery, where excess catch (up to 30% of the quota beyond this the boat must cease fishing in that BC region) can be carried over from one year and deducted from the next year's quota. No such carry over is allowed here (as it is no longer a feature of AFMA management in the SESSF) and with no direct penalties for overcatch there is no

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FOOTNOTE 1 CONTINUED:
explicit incentive in the model for fishers not to risk overcatch when pursuing the last little bit of quota each year. Inclusion of such incentives may be advisable in future forms of the model, but more

medium- and long-term there is some shift in targeting (to some of the chondrichthyans, the shallow demersal and forage fish, and squid), as many traditional target groups have constraining TACs and lower CPUE by this point. These changes lead to a strong economic performance for the trawl sectors in this Scenario, with variable performance in the non-trawl sectors. The variable performance of the later is reflected in port activity, public perception and the ecological status of the shallower system components. In contrast the deeper water components and overall diversity of the system is fairly good under this scenario.

- The integrated management scenario (Scenario 4) causes almost immediate shifts in the system, including a contraction in size of all sectors after just a few years (though the Great Australian Bight trawl sector and the longline sector do not see a substantial change in effort levels). Landed catches eventually stabilise and are often at lower levels than taken historically. TACs can be strongly constraining and it is not unusual for the TAC of a target species to go unfilled due to the lack of quota for a byproduct group. Overcatch and high grading are not completely eliminated and issues associated with spatial management also arise – without sufficient movement between locations it is possible for the available fish to be depleted even when the bulk of the population is doing well. Switching gears is also not as popular as predicted in the stage 1 analysis as costs can be prohibitive and even when that doesn't prevent switching this option is rarely as profitable as anticipated as the infrastructure associated with fishing (e.g. quota packages) are not optimal when changing from one gear to another. Nevertheless, this Scenario is much more consistent than the others – it is rarely "worst" at anything and is often in the middle to high end of the performance for the majority of the performance measures.
- The conservation scenario (Scenario 9) uses extensive spatial closures, which are very restrictive. This leads to a strong recovery in many groups, but at a significant industry and human cost. Effort and landed catches drop immediately with many vessels leaving the fishery from all the major sectors. Ultimately the industry is not economically viable, as there is insufficient returns (in absolute terms) to cover costs even with substantial increases in CPUE.
- Under the pragmatic management scenario (Scenario 10) fleets sizes are reduced relatively rapidly (within 5 years). While similar to the integrated management scenario in certain ways, the ban on discards in this Scenario has potentially the biggest impact of any single management action in any of the scenarios: it causes the fishers to shift grounds closer to port, which has habitat implications; the loss of discards as a food source also has ecological implications (that cascade through the ecological pathways to lead to a mixed and patchy system, with some species benefiting, mainly via increased food resources, and some suffering, primarily either through mortality or additional competition or predation by scavengers); there is the potential for increased overall mortality (if some individuals originally survived discarding but are now retained under the discarding ban); there is more gear conflict and more inclusive targeting is adopted, as there is less scope for "searching"; TACs become extremely constraining and overcatch (especially of byproduct species) is a persistent problem; there is a high volume of quota trading (especially for by-product species, a situation

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importantly this should be taken as a warning that incentives are needed in reality when trying to avoid overcatch in multispecies fisheries.

that has been observed in the British Columbia groundfishery and the New Zealand trawl fishery), causing substantial increases in associated costs or potentially dysfunctional operations (if trading can't be supported at the levels demanded quota hoarding behaviour can become prevalent in some sectors); there is also a loss of continuity with regard to indicators used historically, such as total landed catches and CPUE (though in absolute terms CPUE stabilises above historical lows). The economic performance of this Scenario is good, despite relatively high costs, although quality of the product may tarnish the returns and new operating costs materialise (e.g. trading associated costs become a significant component of the overall costs, as trading of quota, especially quota for byproduct groups, is prolific).

Similar results were found for Scenarios 1, 3 and 4 in the stage 1 analysis and overall there is a good deal of correspondence between the predicted trajectories in the qualitative and quantitative analyses. The quantitative trajectories contain more detail in the transitory dynamics however, and the qualitative analysis always predicted a single overall response, whereas the quantitative analysis had the potential to predict sector or gear specific performances. When the quantitative model did predict a split in performance, the qualitative prediction then either fell between these split quantitative trajectories or only matched one of them. The results of the qualitative and quantitative analyse only conflict in 1% of the comparisons (and are to do with species with slow recovery rates and behavioural uncertainty and unintended policy consequences, when management actions do not have the intended results). Such a high degree of congruence between the two stages of the study results does give some confidence in the general findings (though it must be emphasised that the success of the qualitative analysis is due to the immense experience of the project team in the fishery, it is doubtful a more general Delphic forum that convened for a day or so would have been as successful). This is not to say that either method exactly captures the dynamics of the real world in a precise and predictive sense, each is its own simplification of reality. Uncertainty was a crucial consideration in both analyses. While it was not feasible for a full and formal sensitivity analysis to be performed here the quantitative MSE was performed a cross a bounding set of parameters that covered the range of plausible biomasses and dynamics; with similar results regarding the relative performance of the alternative management options found across these parameterisations.

There are a number of other sources of uncertainty, including structural uncertainty; the impacts of changing larval supply (and some other potential impacts under climate change) and uncertainty of the handling of the socioeconomic components. Extensive experience with ecological and ecosystem modelling and the use of network analysis tools (specifically loop analysis and Johnson's regular colouration algorithm) in the developmental stages of this project mean that the first of these uncertainties has been minimised here and that we have an ever growing appreciation for the potential impacts of climate change. It is the final source of uncertainty that is potentially the greatest and most critical here (and probably in all fisheries management studies). This model is one of the most comprehensive dynamic fisheries models ever developed and is the first time the critical issue of behavioural uncertainty and the potential for unforeseen consequences due to that uncertainty has been considered in such detail. As such it required the development of many new model components and there is much scope for extra data collection and model refinement with regard to: the finer scale details of effort allocation; more sophisticated investment decisions (especially those involving major capital outlays); the market price models (the current representation completely lacks the feedback of recent landing levels and product quality on realised prices); and more sophisticated representation of management costs and their flow on effects into the industry decision making processes. Nevertheless as a pioneering step in the consideration of behavioural uncertainty the modelling work presented here has made significant advances in addressing one of the most critical uncertainties facing the successful use of management options. Unforeseen consequences of fishers' responses to management actions have been a significant factor in many of the fisheries management failures worldwide. It is the major reason for those differences that were observed between the results of the qualitative and quantitative results - the quantitative analysis predicted a behavioural response by the fishers that the qualitative analysis did not take into account (e.g. when used non-quota species to subsidise their efforts to pursue species under quota and this effectively circumvent the intent of the extensive use of quota management in scenario 3). Ultimately behavioural uncertainty also meant that there was no outstanding "best" scenario in the quantitative analysis, each had its drawbacks.

Conclusions and Recommendations

These scenarios considered in this study are not meant to cover all possible strategies nor provide prescriptive formulae for management reform. Reporting of relative performance are not statements of advocacy. All scenarios have their benefits and flaws and the evaluations presented here should be used in combination with other sources of advice to give insight and support decisions regarding the relative merits and trade-offs associated with use of different management levers. What this analysis does show is that successful management for a fishery such as the SESSF requires a balanced combination of a variety of input, output and technical management levers. Moreover for a fishery that is as large, complex and multifaceted as the SESSF (with such a broad set of management and industry objectives) no single management scenario can consistently return an optimal performance across the entire system. Tradeoffs have to be made. In addition to the trade-off in short term costs and long term payoffs highlighted in the Stage 1 report there are a number of other major tradeoffs and unanticipated outcomes of management decisions, including:

i) Economically viable fisheries and an unimpacted system are incompatible. Impacts can be reduced compared to the state of the late 1990s, but decisions regarding "acceptable levels of impact" need to be made. Given that such decisions would have implications for which fishing sectors could remain viable (healthy demersal stocks and a large scale small pelagic fishery may not be simultaneously possible) such decisions would need to be transparent.

ii) Banning discards has a wide range of effort distribution, targeting, habitat, trophic and mortality rate implications that may not lead to the desired management outcomes.

iii) There is the potential for fishing operators to effectively circumvent the intent of the management strategies if they are highly dependent on quotas (by using species yet to come under quota to subsidise the costs of taking of quota species).

iv) Companion TACs have ecological and economic implications. If a strong link companion TAC[2] and the companion with the lower relative biomass is used focus is on efficient exploitation of more productive and usually more valuable stocks, but this

[2] If a species pair is marked as a strong link companion TAC, then the lower TAC is scaled up so the ratio of the TACs matches the catch ratio. If a weak link TAC has been set then the higher TAC is scaled down so the resulting TAC ratio matches the catch ratio.

will be at the expense of those species that cannot withstand higher fishing pressure. Alternatively, if a weak link companion TAC is used (in an attempt to maintain all stocks and species at or above their individual target levels) there will be an economic cost as the exploitation of the more valuable and productive species is potentially heavily restricted.

v) Management measures (which may be put in place to protect deep water stocks) and rising costs see target shifting from deeper water groups to popular shelf species (like tiger flathead) which can then be potentially significantly impacted.

vi) To get the maximum potential benefit from a buyback it must be timed well. If timed well (where a number of commercially valuable species have been depleted to around their limit reference points and declining profit levels are pushing fishers to increase fishing power and fish in more distant or marginal grounds) there a significant benefits into the medium term, though to system inhabitants the majority of the benefits would appear to dissipate relatively quickly (within a decade). If a buyback is mistimed and is implemented too early (before there is significant economic decline) or too late (when the system is in a very poor state both ecologically and economically), then any benefits really do dissipate quite rapidly (within 3-5 years, if that) – this is because a buyback under those conditions has minimal impact on the future evolution of the system.

These findings are not only relevant for the SESSF, but could have broader implications (as this is one of very few studies world wide to consider alternative management strategies at a whole of fishery and whole of ecosystem level); this highlights the great potential that the management strategy evaluation approach. The two pronged approach provides greater confidence in the overall conclusions, but also helps to identify key processes and assumptions that deserve further detailed study. The tools developed in this study provide all the stakeholders with the first sound basis to evaluate integrated rather than piecemeal solutions to complex fishery management problems.

1. INTRODUCTION

1.1 The AMS study

The AMS (alternative management strategies) project (full title: Evaluation of alternative strategies for management of Commonwealth fisheries in south eastern Australia) was established during 2004 to help rethink the broad basis for management of the Southern and Eastern Scalefish and Shark Fishery (SESSF). At that time, the fishery was managed mainly using output controls (a quota management system comprising over 20 species and stocks) and with a largely sector by sector focus. The fishery was facing severe problems, including the economic performance of several key sectors and a wide perception of a deteriorating ecological performance, including a number of overfished species. The quota management system, introduced in 1992 and including use of individual transferable quotas (ITQs), was supposed to have solved these problems, but had clearly not been successful. There was general agreement among stakeholders, including managers, industry, scientists and NGOs, that interactions among sectors needed direct consideration and that it was time for a rethink of management directions and strategies.

The project was designed as a management strategy evaluation (MSE) study, evaluating a range of alternative management scenarios[3] for the fishery against a range of management objectives (including ecological, economic and social objectives). The key steps in an MSE study include (Smith *et al*., 1999):

1. Specifying management objectives
2. Developing performance measures for each objective
3. Identifying a range of management strategies or scenarios
4. Predicting the consequences of applying each management strategy
5. Evaluating trade-offs and communicating with decision makers

Normally the 4th step involves developing quantitative models to predict outcomes. However the AMS study was developed with a two-stage approach. Stage 1 involved undertaking a full MSE for the SESSF but with predictions made using expert knowledge rather than quantitative modelling. The results of the Stage 1 study were presented to stakeholders in 2005 and are reported in Smith *et al* (2004). Stage 2, which is the basis of this report, involved repeating much of the analysis from Stage 1 but using a quantitative modelling approach to predict the consequences of applying the alternative management scenarios.

The Stage 1 study identified and evaluated four scenarios for the future management of the SESSF. These were 1) status quo (pessimistic), 2) status quo (optimistic), 3) enhanced quota management, and 4) a mixed controls scenario. Scenario 4 involved use of a combination of

[3] Note that the nomenclature used here differs a little from the standard management strategy evaluation terminology. Due to the history of the project it was better to keep continuity with past names than to enforce standard nomenclature. Consequently, what would normally be termed a strategy is referred to as a scenario here and what is normally called a scenario (variations on biophysical assumptions) are called environmental or parameterisation variants in this report.

management measures, including quota management, effort management, gear controls, and spatial management. The Stage 1 MSE showed that Scenario 4 best achieved management objectives in the longer term, but at the cost of severe short-term disruption to the fishery.

There have been a number of significant changes in the management of the fishery since the presentation of the results of the Stage 1 study. Many of these changes have involved adopting elements of Scenario 4, particularly spatial management, although the current management arrangements in the fishery differ significantly from the package of measures envisaged in Scenario 4. It is difficult to determine how much influence the Stage 1 study had in effecting these changes, but the study did seem to capture the imagination of a range of stakeholders. For example, several fishers or groups of fishers put forward their own management scenarios after the Stage 1 report was released, as did one NGO and AFMA management. At the very least, the Stage 1 study was a significant catalyst for change in the SESS fishery.

This report presents the results of the Stage 2 study. In particular, it reports the results of the quantitative evaluations of five management scenarios. These include Scenarios 1, 3 and 4 from the Stage 1 study, together with the pragmatic scenario (Scenario 10) and the NGO scenario (Scenario 9) that were put forward subsequent to the release of the Stage 1 report. The remainder of this introduction describes the biophysical and human setting for the fishery. Chapter 2 describes the Atlantis model, the quantitative model used to predict the consequences of each management scenario. Chapter 3 describes how well this model fits the historical data from the fishery. Chapter 4 gives a descriptive overview of the evolution of each Scenario, with detailed comparisons of the results of the MSE analysis of the five management scenarios given in Chapter 5. Chapters 6 and 7 present the discussion and conclusions of the Stage 2 study, including a comparison of the results from this stage of the study with those from Stage 1.

1.2 The biophysical realm

The southeast regional ecosystem covers 3.7 million km^2 of the waters within Australia’s south eastern EEZ, from (117°48’ E, 46°51’ S) to (160°30’ E, 24°21’ S) (Figure 1.1). It spans large bays and gulfs, coastal waters, the continental shelf and slope, seamounts, submerged canyons and open ocean systems. The area includes tropical, subtropical, cool temperate and subantarctic environments. Geologically it is a quite diverse area, with a wide variety of bottom types (e.g. silts, oozes, material of terrestrial origin, gravel, rocky reefs, sands, and exposed limestone bedrock). Oceanographically, it is the seasonal changes in mixed layer depth and then pattern of current strength (Figure 3.2) – particularly the Zeehan and East Australian currents – that are the strongest forces in the system. Sea surface temperature, the strength and location of upwellings, the supply of nutrients, and the productivity and distribution of the biological components of the ecosystem are all heavily influenced by the current regime. Ecologically, the area includes some of the most productive of Australia’s waters; and it is also highly diverse, due at least in part to the influence of the Leeuwin and East Australian currents, which bring in biota from other areas. Another factor in this diversity is the sheer size and variability across the area, which provides for the existence of relic and endemic species, in addition to transient or migratory species and seasonal visitors. Biological diversity in the area is very high, particularly off the coast of eastern Victoria, (Zann, 1995, Coleman *et al*. 2007).

1.3 The human dimension

Greater than 77% of the Australian population (or more than 16 million people) live within 50km of the coastline in this southeast region (ABRS 2002). This concentration of population (and associated pressures, discussed below) in the area has meant that it has also received

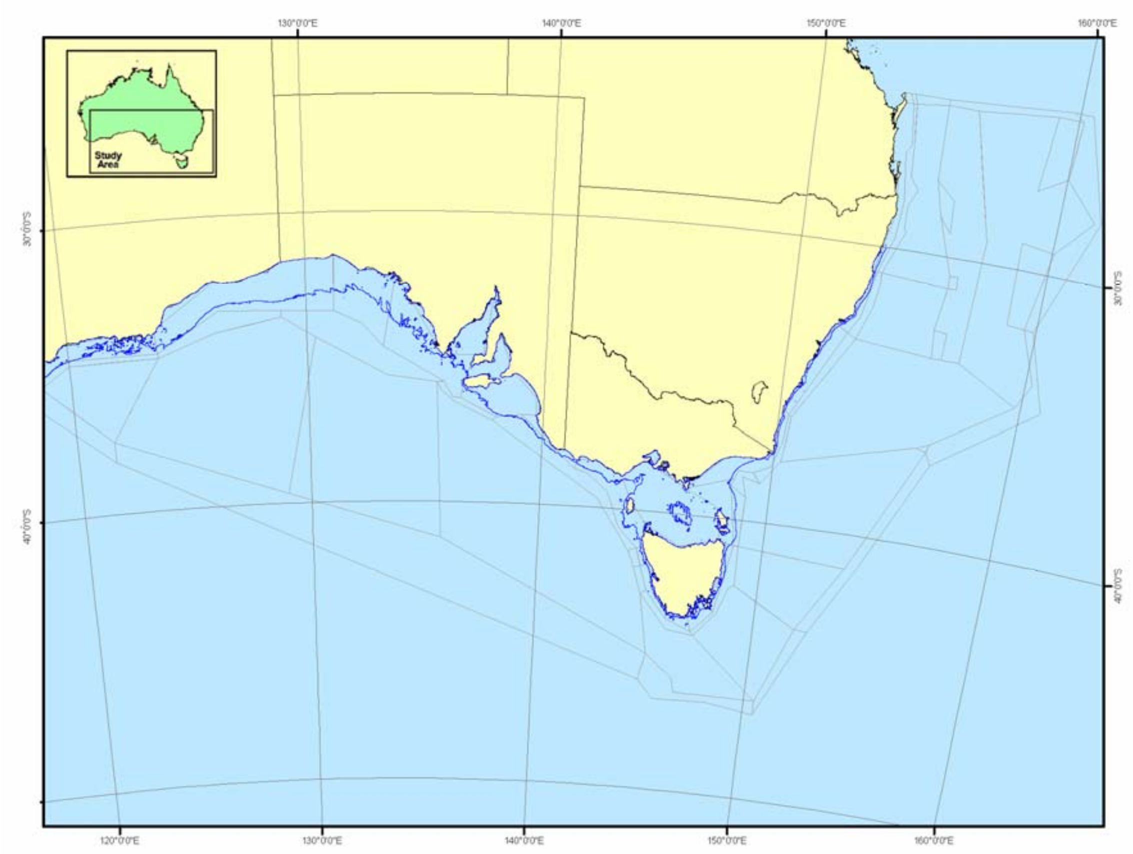


Figure 1-1: Map of the southeast region, for reference model geometry is shown in light gray

considerable research attention, at least in parts of the system (e.g. Harris *et al* 1996, Bax and Williams 2000, Bax *et al* 2001, AFFA 2002, Larcombe *et al* 2006). Unfortunately, as a whole it has never been systematically investigated in an integrated sense. To date the most integrated assessments of combined human impacts or pressures on the systems have been integrative modelling or reporting studies (such as the Ecological Risk Assessment – Hobday *et al* 2006a, Smith *et al* in press) that have drawn information from a wide variety of sources.

The natural resources and environment in the area have been under substantial pressure, due in the main to fishing (state and Commonwealth commercial fisheries as well as recreational fishing), industrial and agricultural contaminant release, pest and invasive species, and habitat modification due to urban and other coastal development. On the regional scale, fishing is probably one of the largest pressures. The area has been commercially exploited to varying degrees for over 150 years (rock lobsters have been fished commercially in the area since the 1850s). Australia's current largest fishery by weight is located in the southeast - the Great Australian Bight pilchard fishery, which had a peak TAC of 51,100 t in 2005. Some of Australia's most lucrative fisheries are also located in this area (e.g. the state abalone fisheries). In total, the area produces over 50% of the gross value of Australia's fisheries production

(ABARE and FRDC 2004), with the landed catch (of over 126,000t wet weight) worth in excess of $1 billion (Larcombe *et al* 2006).

At least 148 species are harvested commercially in the southeast region – including invertebrates (e.g. abalone, rock lobster, prawns and squid) and fin-fish. These species span a very wide range of life history strategies, from short lived Arrow Squid (*Nototodarus gouldi*), with a typical lifespan of about a year, to the very long-lived orange roughy (*Hoplostethus atlanticus*), which can live well over a century. It also includes species caught in shallow water (e.g. King George whiting captured in Port Phillip Bay) to those caught on the open ocean (e.g. broadbill swordfish).

Although only established under a single management plan in 2004, the SESSF has antecedents in three previously managed Commonwealth fisheries: the South East Trawl fishery, the Great Australian Bight Trawl fishery, and the Gillnet, Hook and Trap fishery. Prior to Commonwealth management (which commenced in 1985), many sectors of the fishery were managed under State legislation, including the trawl and Danish seine fleets in NSW and Victoria, and the shark longline and gillnet fleets in Victoria, South Australia and Tasmania. This evolution in the jurisdictional arrangements was matched by shifts in research, monitoring and assessments. A brief summary of this history of the fishery (and the current jurisdictional and sectoral boundaries, Figures 1.2) is given here, but a comprehensive description of the fishery and its management history may be found in Smith and Smith (2001) and the associated special issue of Marine and Freshwater Research.

The earliest phase of the fishery first began near the turn of the twentieth century (although harvesting of marine mammals and some fishing had obviously occurred before then) and extends to the early 1970s. During this time the fishery was primarily based on steam trawling and Danish seining, operating on the continental shelf off New South Wales and north-eastern Victoria. Management during this period was not highly constraining, as it was open-access with no formal stock assessment process and an *ad hoc* approach to research. The form of the management during this era allowed for its expansion both technologically (with the development of the non-trawl gill-net, trap, and line sectors) and spatially (where it pushed into upper- and mid-slope waters).

With this expansion came the realisation that more formal and structured approaches to management and research would be necessary. In response, during the 1980s-1990s the trawl fishery was brought under federal jurisdiction and in the mid-1980s limited entry was introduced. Around this time there was also an attempt to coordinate research (through bodies such as the Demersal and Pelagic Fisheries Research Group), with major programmes initiated by both State and Commonwealth agencies. Several quantitative stock assessments were performed at this time, with results presented to both industry and managers. This inclusion of industry was formalised during the end of this period of change in the perception and handling of what was now a significant and still growing fishery.

The 1990s were marked by initial high catches of species such as orange roughy, technologically driven shifts in fishing power (which contributed to an increase in bottom time despite some reduction in vessel numbers) and increasing regulation of the fishery. Other developments during this period included: many (but not all) of the non-trawl sectors were brought under federal management (species caught almost entirely within state waters as well as bay and estuarine fisheries remain under state jurisdiction); ITQs for 16 species were introduced in 1992; an inclusive (i.e. clear involvement of all stakeholders) assessment process was established that had a quantitative basis and spanned a number of species; the agreed introduction of some harvest strategies; and the development of fishery management plans. There was also an increased interest in fishery–ecosystem interactions. This interest was expressed in the form of integrated fishery-wide sampling (CAF and ISMP) that was co-ordinated through the Southeast Fishery Assessment Group, but also through national and international documents calling for an ecosystem-based approach to fisheries and sustainable development across sectors (e.g. FAO Code of Conduct for Responsible Fisheries (1995) and the Reykjavik Declaration (2001)).

The most recent phase of the fishery (over the last 5 years) is arguably one of the most tumultuous (something quite unexpected only 5 years ago when it was thought that the previous 15 years had seen the most dramatic changes in the fishery). During this last half decade (in fact during the life of this project) there have been substantial changes to the management of the fishery and to the region in which it occurs. Public opinion and legislation such as EPBC have thrown momentum behind moves to more environmentally ‘friendly’ fishing methods, better utilization of catch, and improved protection of protected species and habitats. Although always available in principle, a broader range of management levers is now used in practice, with spatial management featuring strongly both within but also beyond fisheries management. Industry has actively engaged in this process of change, putting forward proposals regarding alternative management approaches, and becoming increasingly directly involved in research and monitoring. Development of new scientific tools has also seen the early steps toward extension of the assessment related research to include (at least conceptually at this stage) a broader set of indicators and consideration of ecological impacts of fishing. A key event affecting all Commonwealth managed fisheries occurred in 2005 with the Ministerial direction to AFMA to take active steps to cease overfishing and recover overfished stocks, and with the Securing our Fishing Future package that included significant funds to reduce effort in a number of sectors, including several in the SESSF.

In addition to this fisheries management attention the shift in public attention and legislation lead to a regional marine plan being developed for the southeast by the National Oceans Office (now the Department of Environment and Water Resources) (NOO 2004). This plan was launched in 2004 and was aimed at ecologically sustainable development and use of the southeast region as a whole, across all sectors. As part of this plan a set of marine protected areas (MPAs) were proposed across the region in 2006 (Figure 1.3). These MPAs are distinct from fisheries management zones and are not used in all scenarios presented here – they are used in Scenario 10, which is a pragmatic representation of current fisheries and conservation management arrangements in the system (see section 2.8.5).

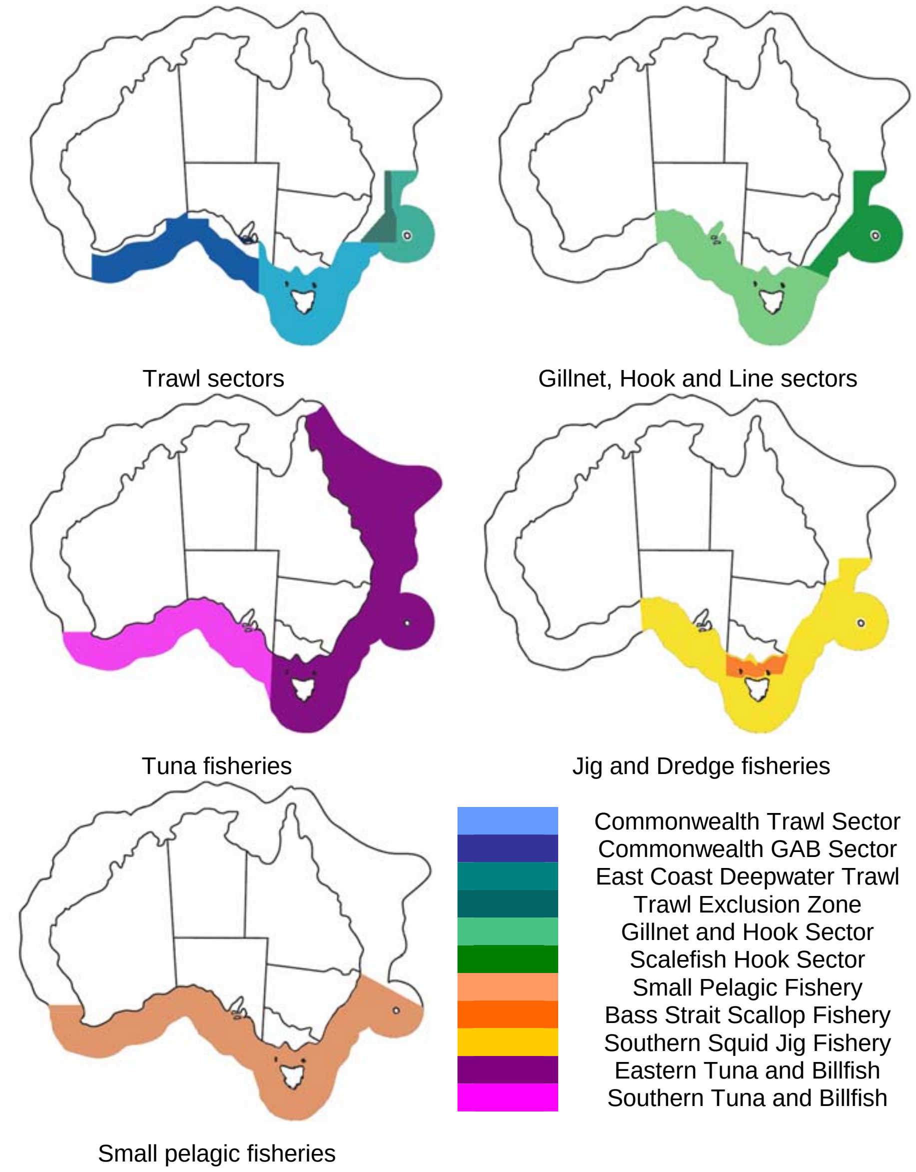


Figure 1-2: Schematic maps of jurisdictional and sectoral boundaries for fisheries active in the south east region of Australia (as of 2003), small scale modifications (such as small scale closures) have been made to this map, but it remains indicative.

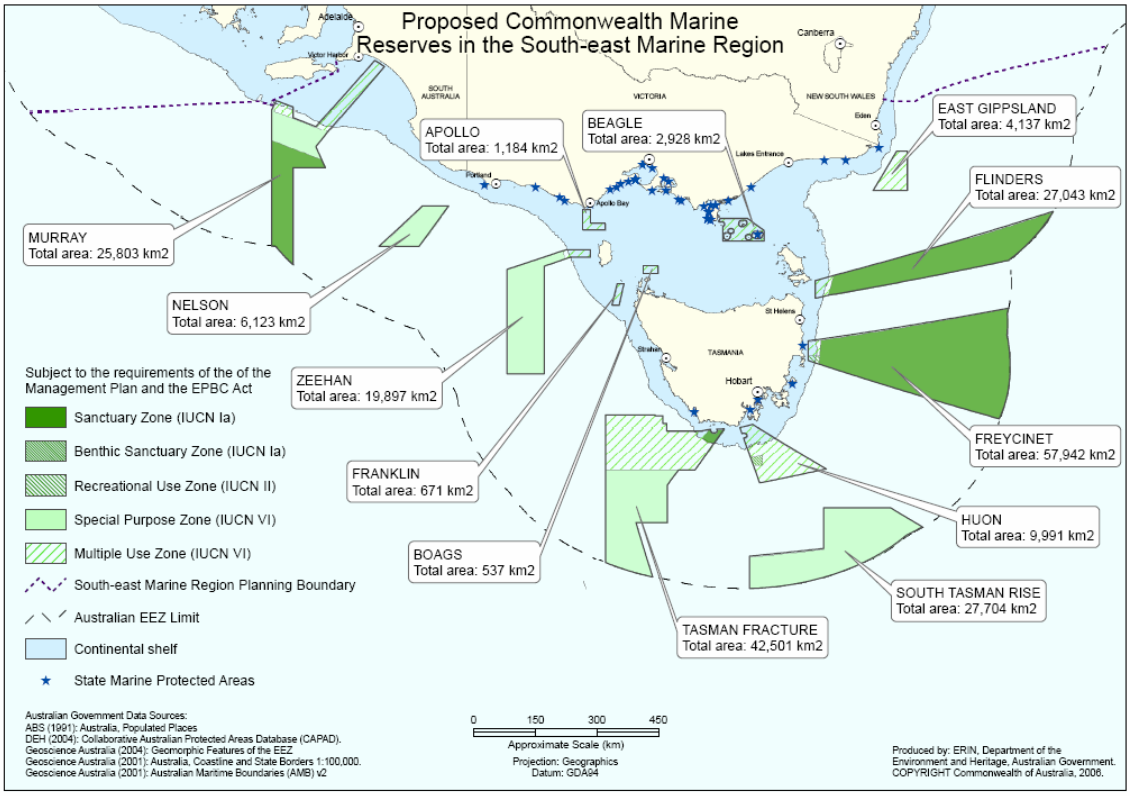


Figure 1-3: Map of marine protected areas introduced as part of the southeast regional marine plan (NOO 2004).

2. ATLANTIS MODEL

Atlantis is a deterministic biogeochemical whole of ecosystem model that includes modules for each of the major steps in the adaptive management cycle (Figure 2.1). This overall structure was used to make sure it was well suited for use in Management Strategy Evaluations.

Each of the modules will be described in more detail in the following sections, but to give a sense of the full model a brief overview will provided here. At the core of Atlantis is a deterministic biophysical sub-model, coarsely spatially-resolved in three dimensions, which tracks nutrient (usually Nitrogen and Silica) flows through the main biological groups in the system. The primary ecological processes modelled are consumption, production, waste production, migration, predation, recruitment, habitat dependency, and mortality. The trophic resolution is typically at the functional group level. Invertebrates are typically represented as biomass pools, while vertebrates are represented using an explicit age-structured formulation. The physical environment is also represented explicitly, via a set of polygons matched to the major geographical and bioregional features of the simulated marine system (e.g. Figure 2.2). Biological model components are replicated in each depth layer of each of these polygons. Movement between the polygons is by advective transfer or by directed movements depending on the variable in question.

Atlantis also includes a detailed industry (or exploitation) sub-model. This model deals not only with the impact of pollution, coastal development and broad-scale environmental (e.g. climate) change, but is focussed on the dynamics of fishing fleets. It allows for multiple fleets, each with its own characteristics of gear selectivity, habitat association, targeting, effort allocation and management structures. At its most complex, the model includes explicit handling of economics, compliance decisions, exploratory fishing and other complicated real world concerns such as quota trading and high grading. All forms of fishing maybe represented, including recreational fishing (which is based on the dynamically changing human population in the area).

The exploitation model interacts with the biotic part of the ecosystem, but also supplies ‘simulated data’ to the sampling and assessment sub-model. The sampling and assessment sub-model in Atlantis is designed to generate sector dependent and independent data with realistic levels of measurement uncertainty evaluated as bias and variance. These simulated data are based on the outputs from the biophysical and exploitation sub-models, using a user-specified monitoring scheme. The data are then fed into the same assessment models used in the real world, and the output of these is input to a management sub-model. This last sub-model is typically a set of decision rules and management actions (currently only detailed for the fisheries sector), which can be drawn from an extensive list of fishery management instruments, including: gear restrictions, days at sea, quotas, spatial and temporal zoning, discarding restrictions, size limits, bycatch mitigation, and biomass reference points.

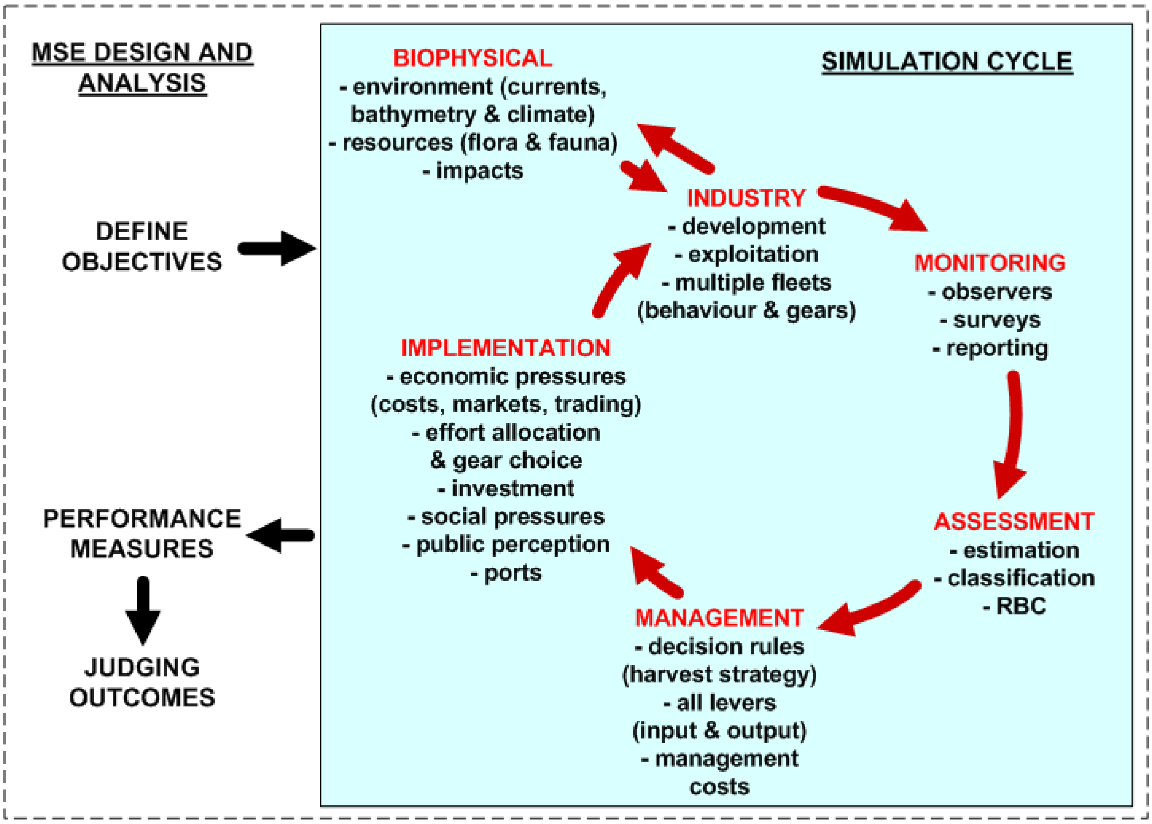


Figure 2-1: Management strategy evaluation cycle – showing the components included in each of the modules of Atlantis (which map to the different steps in the cycle).

2.1 Geography

The geography of the region is represented by 71 polygonal boxes (Figure 2.2) based on physical and ecological properties and distributions captured in the demersal bioregionalisation by IMCRA (1998), Butler *et al* (2001) and Lyne and Hayes (2005) and an independent pelagic analysis using the CSIRO's CARS (CSIRO Atlas of Regional Seas) data set and the same general Bioregionalisation approach. Within each box there are up to five layers, depending on the total depth of the box – shallower boxes have fewer layers. The nominal potential layer depths are shown in Figure 2.2. In the open ocean boxes (darkest blue boxes in Figure 2.2) the maximum depth represented was 1800m; waters below this depth were omitted and the bottom explicit layer was treated as having an open lower boundary with regard to exchanges.

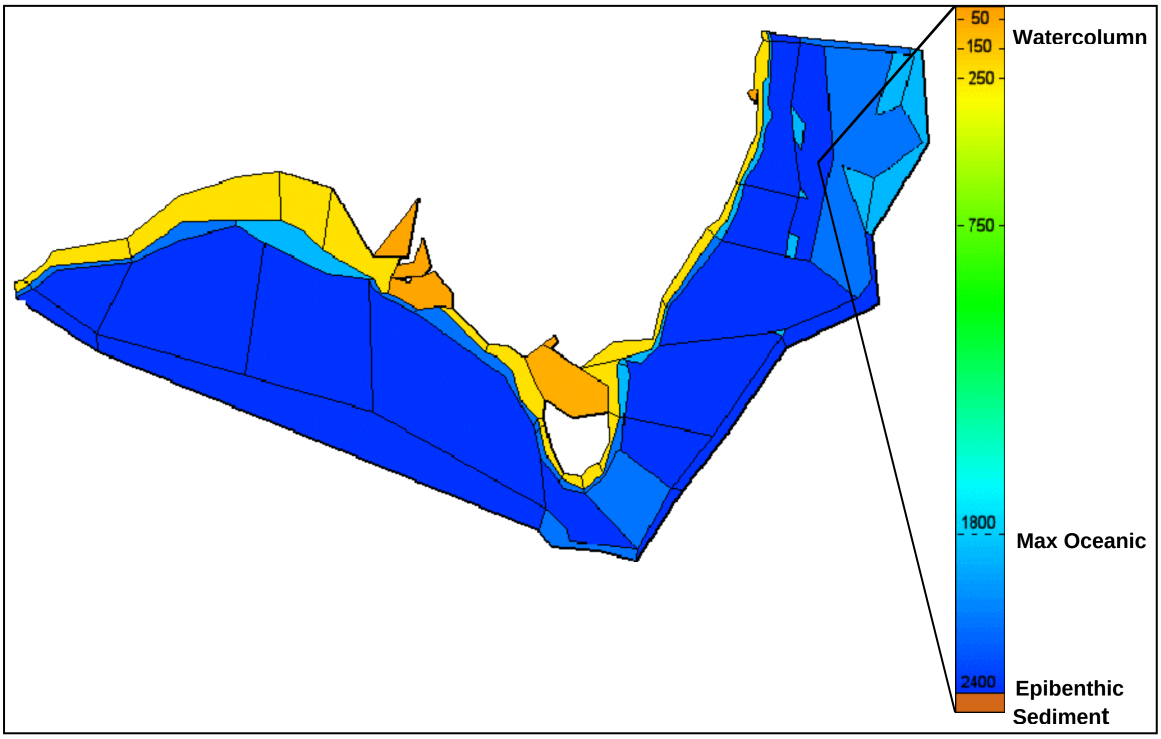


Figure 2-2: Map of model domain for south east Australian Atlantis model, depth key shown in metres. The vertical layers are grouped into those in the water column (depths below the maximum oceanic are omitted, see text), epibenthic (a 2D layer between the water column and the sediments) and the sediment layer(s).

2.1.1 Canyons

While the spatial resolution in Atlantis does not allow explicit representation of individual canyons, the proportional cover of each box that is canyon can be represented. This is not an independent habitat type itself, but for those species thought to aggregate in canyons (e.g. blue grenadier, eastern gemfish, and oreos; Yearsley *et al* 1999, Prince and Griffin 2001, Bruce *et al* 2002) the canyons in a cell act to enhance the biomass a habitat type in a cell can support. They can also (optionally) be used to condition production or vertical exchanges. The proportional cover of canyons (estimated from GIS bathymetry databases) in each box of the southeast Australian Atlantis model is given in Figure 2.3.

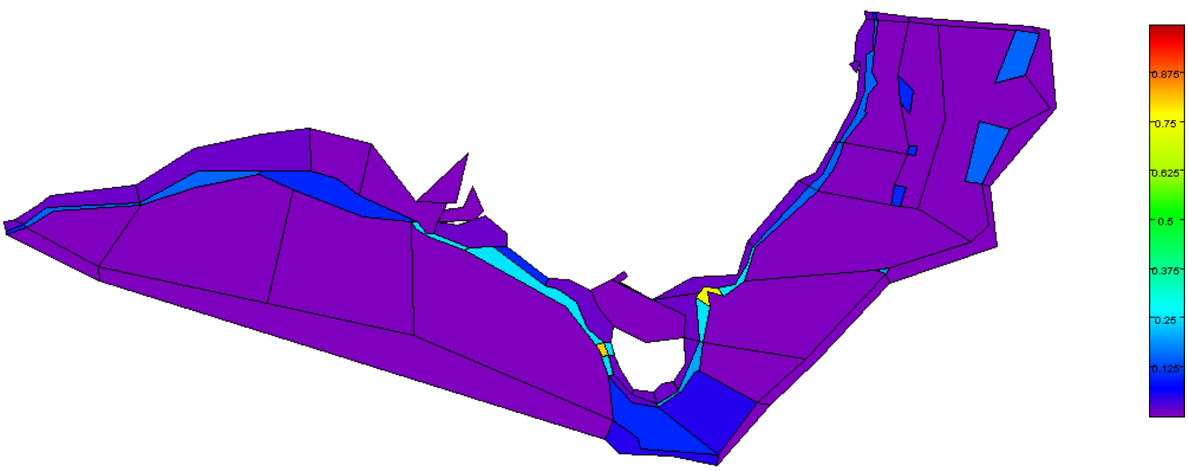


Figure 2-3: Proportional coverage of canyons per box (scale is from 0-1) in the southeast Atlantis model (taken from GIS analysis of bathymetry data)

2.2 Biophysical Environment

2.2.1 Physical Environment

Currents – Horizontal and Vertical Advection-Diffusion

Transports, both vertically and horizontally were calculated from 3D velocity fields from the ocean forecasting model (OFAM) developed by the BlueLink joint project between the CSIRO, Bureau of Meteorology and the Royal Australian Navy. A description of the Bluelink system can be found in Oke *et al* (2005). For the purposes of the transports used in the Atlantis model the flows were calculated from the Spinup 4 and 5 runs of OFAM by integrating the daily normal component of currents over each depth band of each box face (using realistic bathymetry to ensure face sectional areas are accurate.) These raw flows were then corrected for hyperdiffusion within boxes. To do this the east-west flows were divided by the width of the box in metres in that direction and north-south flows were divided by the length in metres of the box in that orientation. A conservative tracer is then used to check flows through the system, with tuned box specific flow scalars used to remove any remaining hyperdiffusion effects. If this combined correction is not made then flows within the larger boxes would be overstated by orders of magnitude as once in a box any tracer is assumed to be equally accessible through out the box which artificially inflates flows; this effect is removed by the correction. This is a fairly basic approach to correcting for hyperdiffusion, but to date not better method has been found for boxmodels of this type.

As an example of the quality of the flows and ocean dynamics predicted by the BlueLink model, a comparison between observed altimetric sea height and the sea height predicted by the BlueLink model for January 1st 1999 is given in Figure 2.4. The quality of the match is good and is typical of the quality of the BlueLink model output versus real current flow. Unfortunately the BlueLink model products are not available long-term and so for the model runs used in this study the flows were repeated without modification in a decadal loop. While this did not allow for long-term (>10 year) trends or cycles in properties such as current strength or water temperature it did produce seasonal and interannual variation, leading to a wide enough range of environmental forcing to capture the main conditions experienced in the southeast Australian marine region.

This limit on the availability of long term regional scale currents meant that any changes in currents over the last century were not captured. It was possible however, to use independent sources of upwelling strength (e.g. from CARS) to capture some known shifts in oceanography through the period. Together this means a representative, though not exact, form of the oceanography was used to force Atlantis SE. Importantly, the resultant transport model contains the forms of variation that cause non-linear responses in the system so that Atlantis SE has a solid environmental foundation for the management strategy evaluation.

The transport model was executed once per 12 hour time-step. There is variation in the strength of exchange between cells at this temporal resolution and from year to year. As a demonstration of the extent of this variability, snapshot examples from the BlueLink model output for different regions in each quarter of 1997 are given in Figure 2.5, which provide an indication of the gross change in the seasonal pattern of flows and upwelling strength. An example twenty year time series of net exchange from a single cell (box 43), both vertically and horizontally, is given in Figure 2.6. Note due to the inclusion of point source flows, like the upwellings in the Atlantis

SE oceanography, as well as the resolution of the saved output there is not an obvious exactly repeating cycle in this figure, even though the core currents are repeated. More finely resolved output (less than the 90 days per data point used here) would better capture the cycling (but has high storage requirements and so was not used in this case).

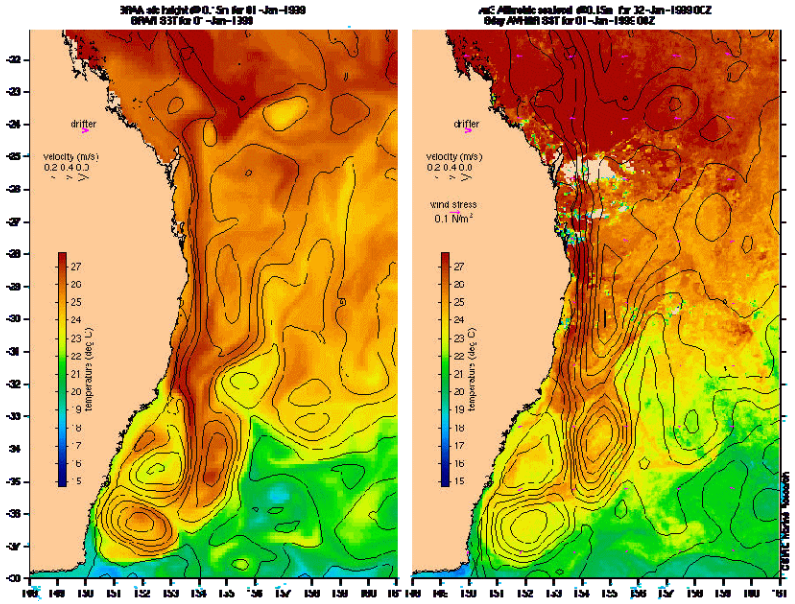


Figure 2-4: Comparison of observed altimetric sea height (on right) and sea height as predicted by the BlueLink model (on left). Source: www.cmar.csiro/ bluelink/exproducts.

Eddies

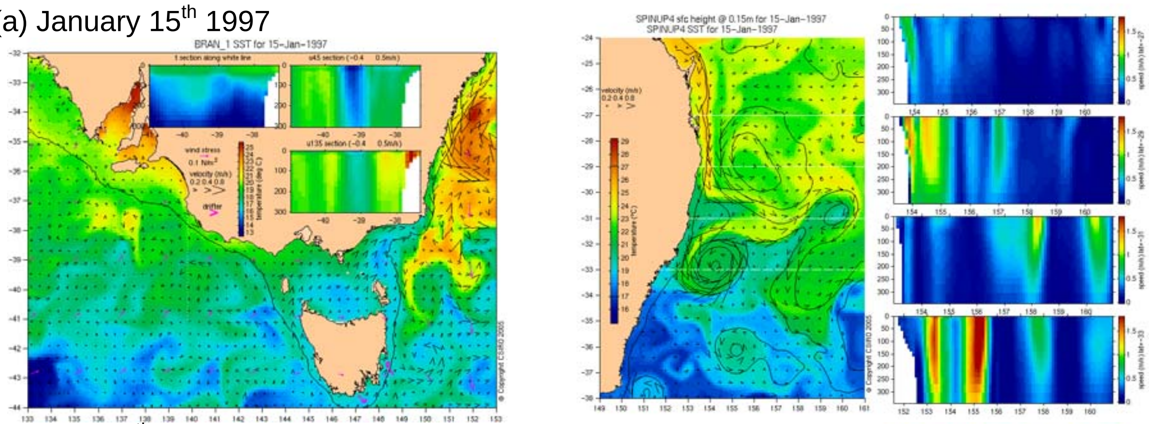
The spatial scale of Atlantis SE is not suitable for explicitly capturing oceanic eddies. These features have a strong influence on productivity however, and to better capture the cycles and distribution of production, eddies need to be represented in some form. While one possibility would be to increase vertical mixing, which should reflect the gross effects of eddies at the scale of the model boxes; the approach used here is to use an energy strength index (calculated from the ratio of homogeneity to heterogeneity in sea surface height and temperature) and condition primary production on that index using the following relationship:

$$P_g = B_g \cdot \mu \cdot \delta_N \cdot \delta_L \cdot \delta_S \cdot E \cdot \varepsilon \qquad (2.1)$$

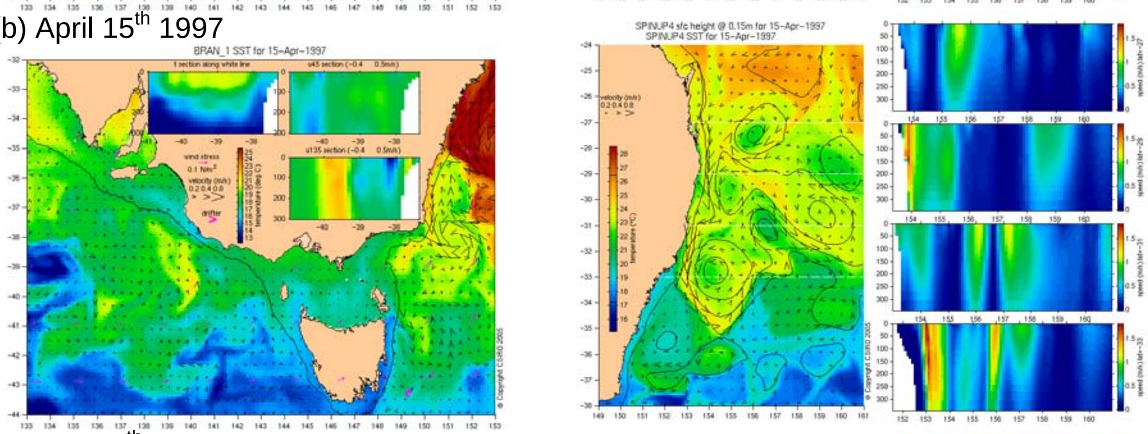
where P_g is the growth in the population of primary producers, B_g is the biomass of the primary producer, μ is the growth rate of the primary producer, δ_N is the limitation scalar due to ambient nutrient levels, δ_L is the limitation scalar due to ambient light levels, δ_S is the limitation scalar due to space limitation (for attached macrophytes only), E is the local strength of the energy index and ε is the energy coefficient (which is the key term for predicting the impact of eddies on primary productivity).

The energy fields were taken from a quarterly analysis completed as part of the pelagic bioregionalisation (Lyne and Hayes 2005). As the model runs through the course of a year it interpolates from one quarterly field to the next to get a smooth transition in eddy values at any one location through the year. The four quarterly distributions in Atlantis SE are shown in Figure 2.7.

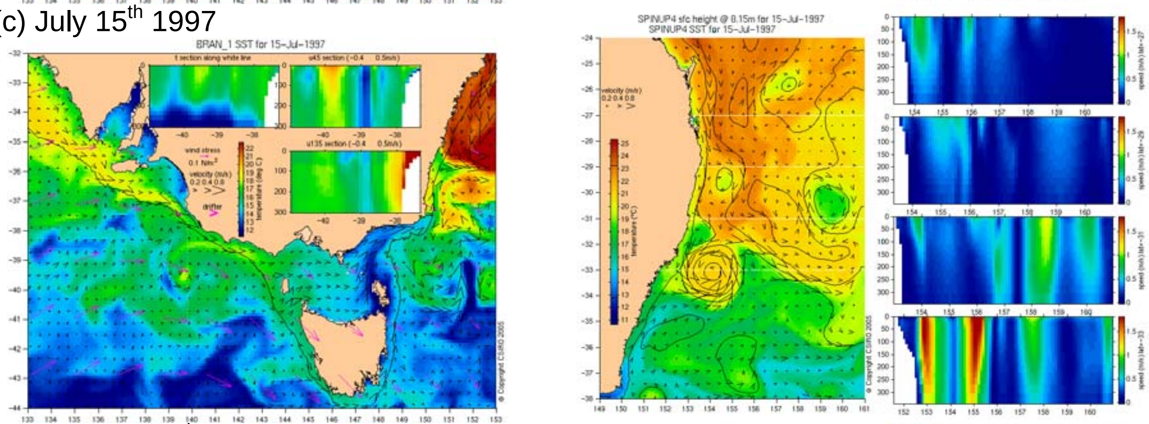
(a) January 15th 1997



(b) April 15th 1997



(c) July 15th 1997



(d) October 15th 1997

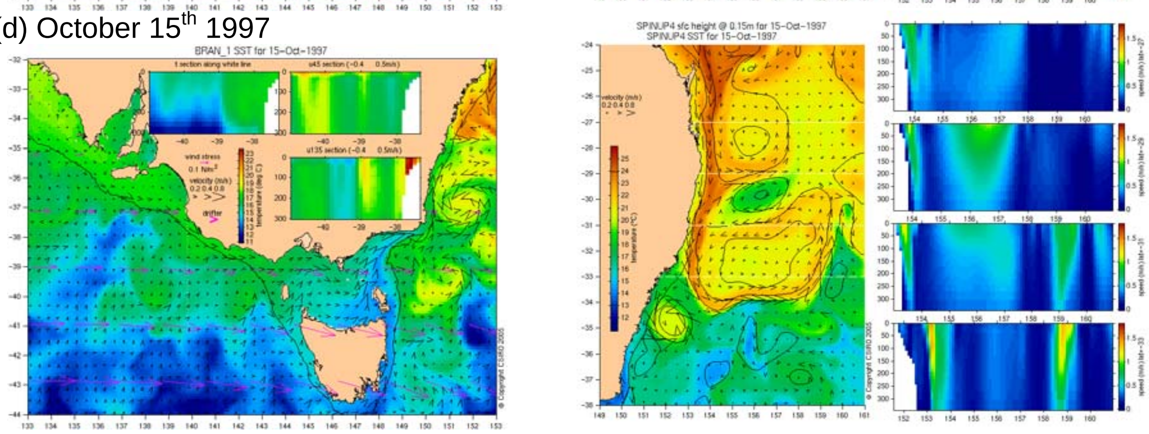


Figure 2-5: Snapshot examples of gross seasonal currents from BlueLink model for the Tasman and New South Wales regions in (a) Summer, (b) Autumn, (c) Winter and (d) Spring. Source: www.cmar.csiro/bluelink/exproducts.

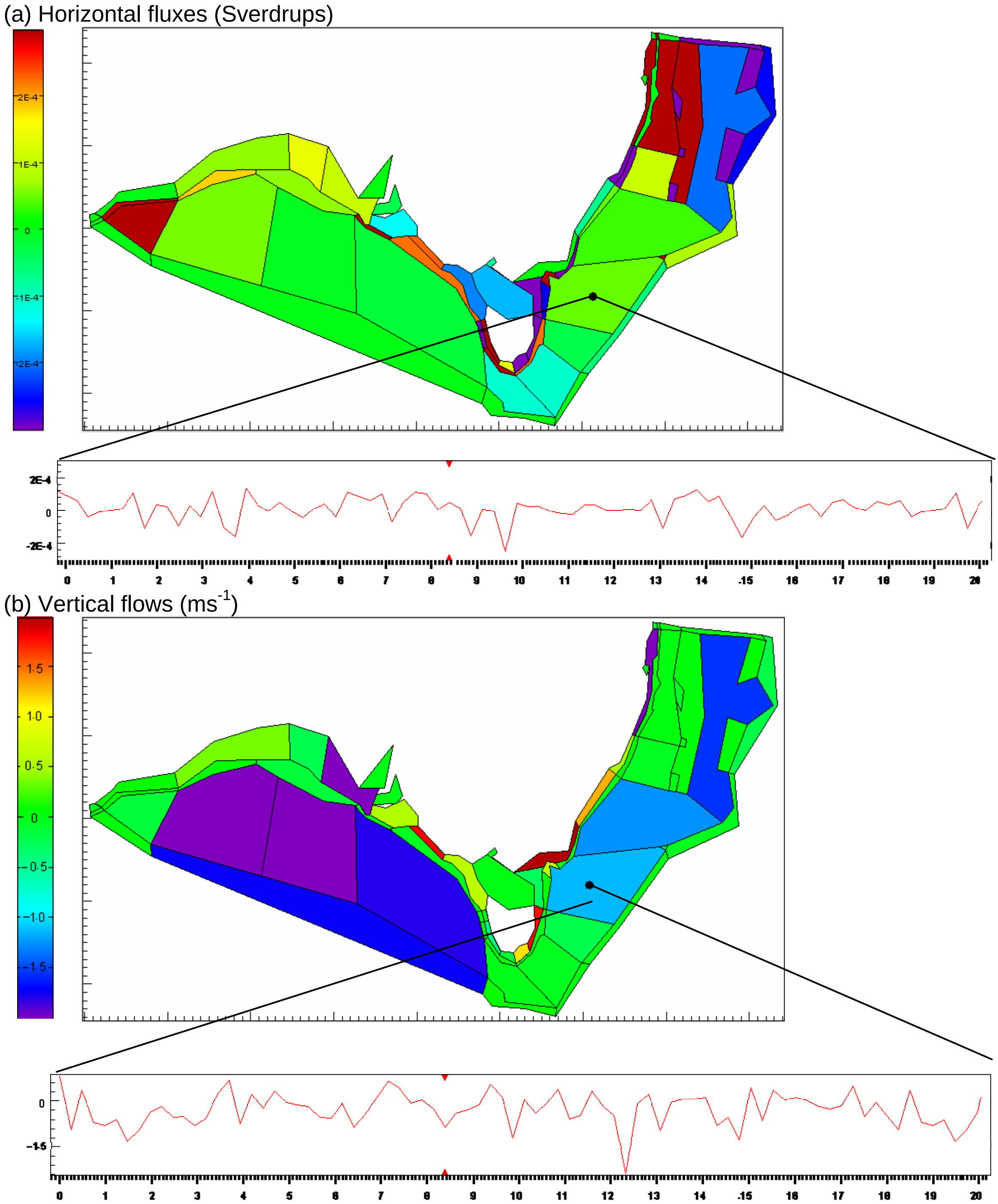


Figure 2-6: Example snapshot maps and twenty year time series of (a) net horizontal fluxes and (b) vertical exchange in box 43 of the southeast Atlantis model. Source: www.cmar.csiro/bluelink/exproducts.

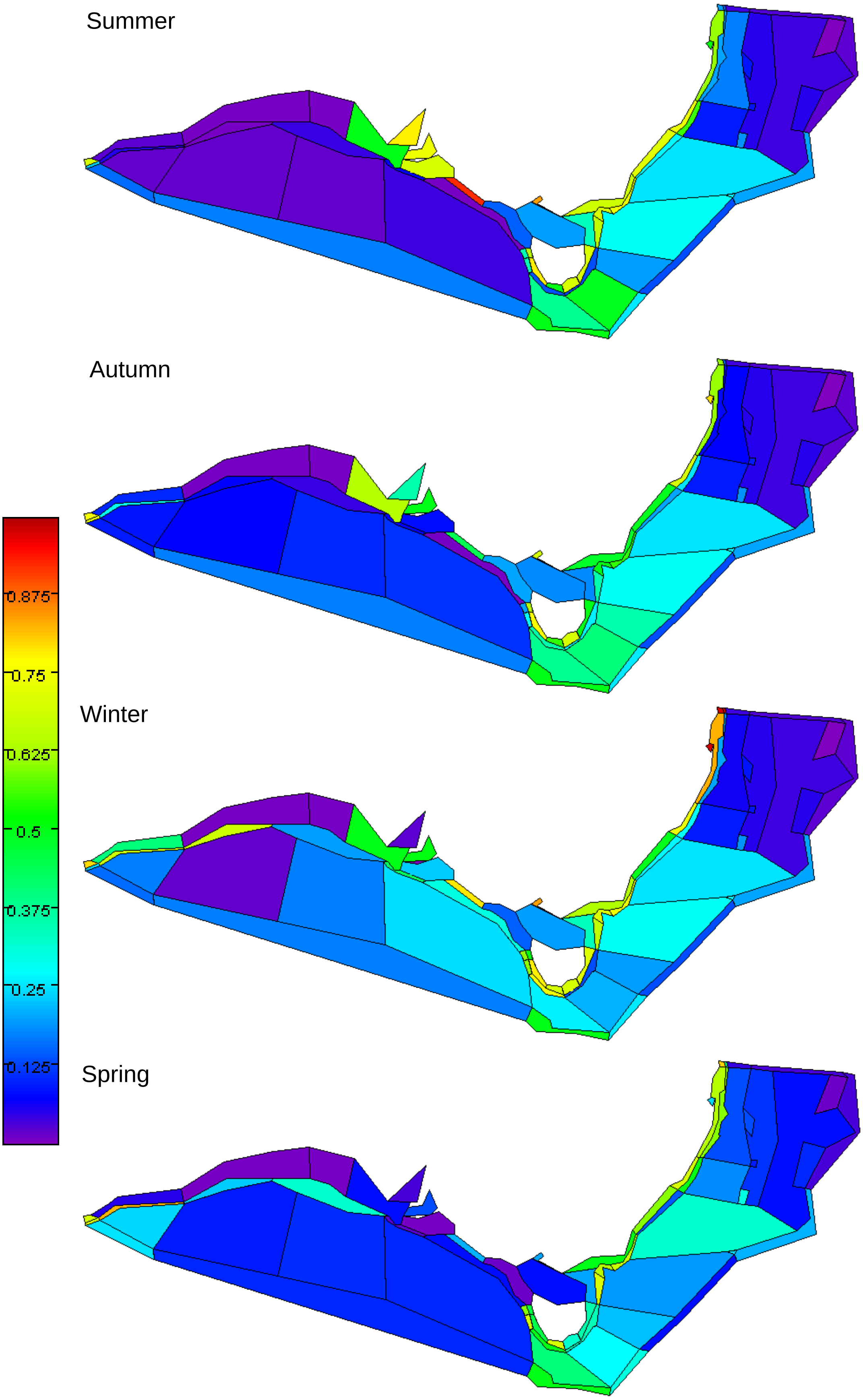


Figure 2-7: Quarterly energy fields (scaled 0-1) used to represent eddy strength in the southeast Atlantis model.

Temperature and Salinity

The same BlueLink model outputs used to provide advection and diffusion for Atlantis SE were also used to provide time series of temperature and salinity in every cell of the model. In the same way the currents were recycled through time (as only limited length time series were available) the time series of temperature and salinity were also recycled through the course of any individual Atlantis run. An example of the resulting time series (in this case for temperature) is given in Figure 2.8.

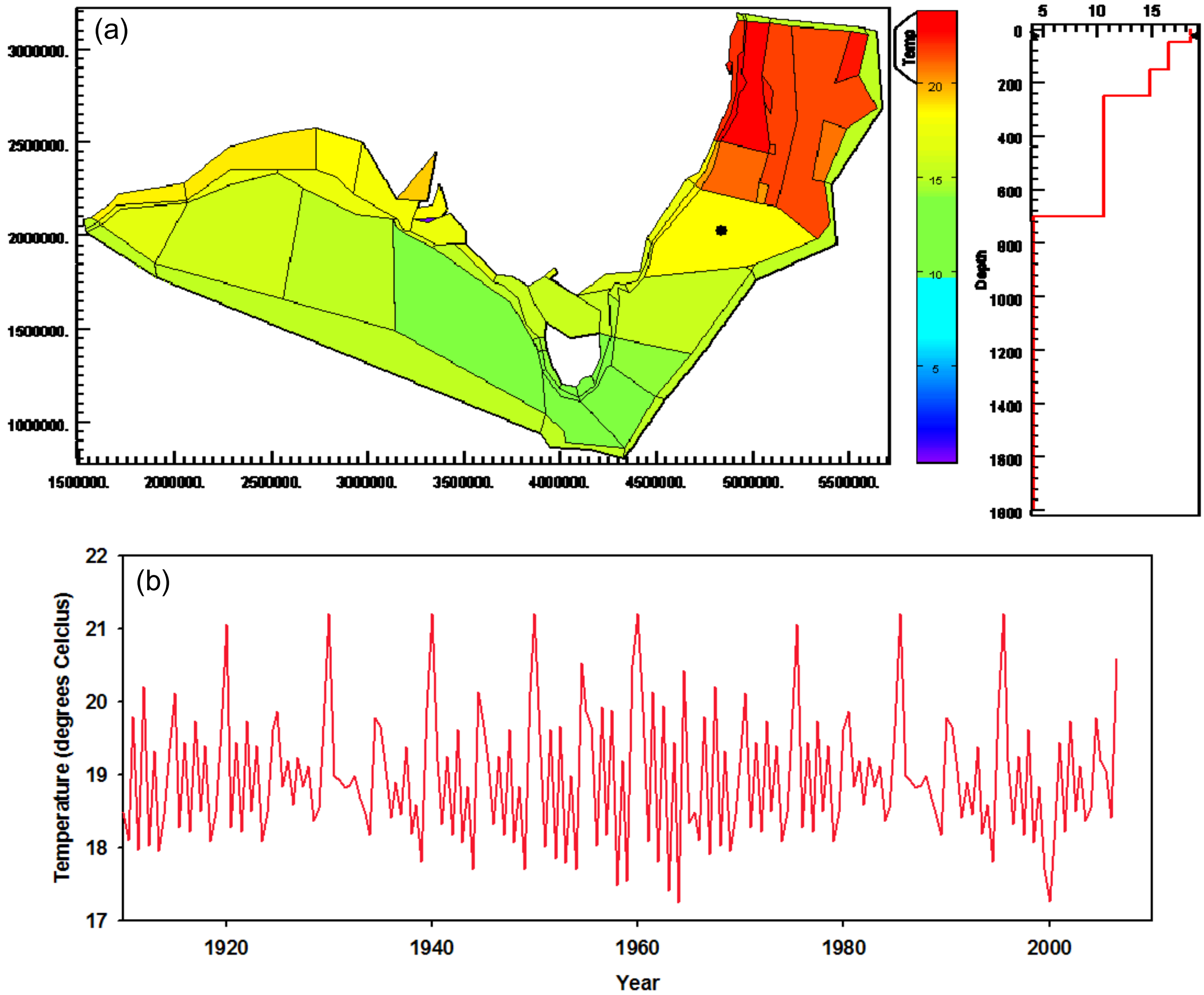


Figure 2-8: Example (a) temperature (in ºC) map and static depth profile and (b) time series (from box marked with black dot in the map) from Atlantis SE, based on BlueLink model output. Note that the long-term cyclic pattern in this figure is due to aliasing between the resolution of the 90 day frequency of Atlantis SE output and the seasonal cycle, the actual BlueLink data (used to force Atlantis SE on a 12 hourly timestep) cycles once every 10 years (Atlantis SE output can be saved on more finely resolved periods, right down to once every timestep, but this has high storage overheads and so has not typically been done to date).

Sediments

As Atlantis SE is a shelf and deep water model there is no call for fine scale sediment patchiness and dynamics. Moreover as the bottom layers are thick (50m or more) it is not sensible to represent resuspension as an explicit mechanism in this case. It is important however, to represent bulks sediment types and sediment biogeochemistry in the shallow and shelf waters. In boxes shallower than 1800m sediment biochemistry is represented explicitly, but it is not represented in boxes deeper than this - where it is assumed an open (water) boundary is at the base of the column of boxes.

With regard to sediment types the sediment environment has been characterised as the proportion of ground in each cell that is rough, flat and soft (see Figure 2.9 – 2.11). The three sediment types are used as they are the simplest division that captures: substrate preferences of epibenthos; the accessibility of an area to fishing gear that reaches the bottom; different rates of sediment biogeochemistry. The sediment data used to parameterise this in the southeast model were taken from a data set that is now part of the draft Sediment Type (Folk classification) of the Australian EEZ (National Geoscience Dataset) – reachable via the Neptune data directory reference (http://neptune.oceans.gov.au/index.html) and from data on the auSEABED data

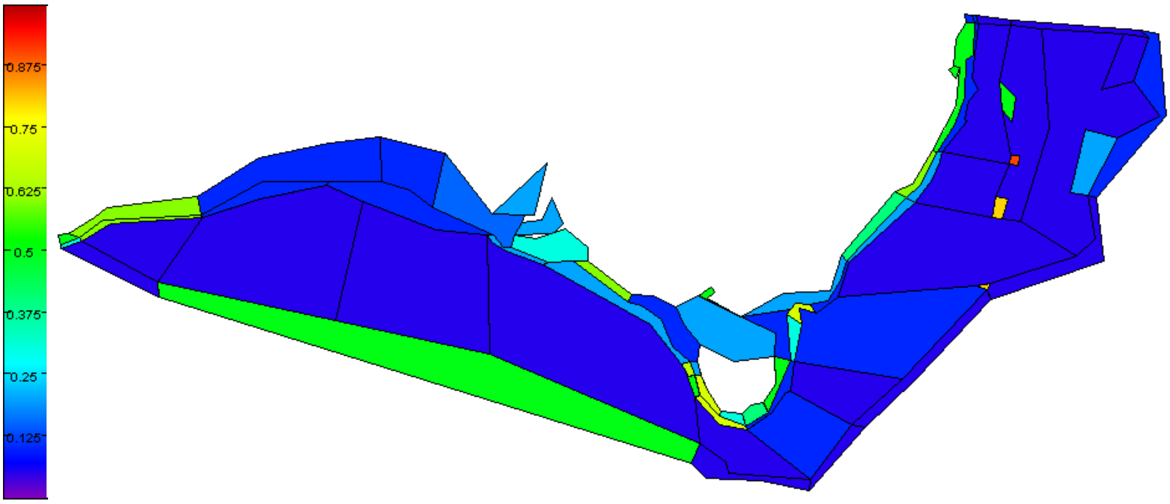


Figure 2-9: Proportional cover of rough ground per box (scale is 0-1), used to dictate sediment properties in the southeast Atlantis model.

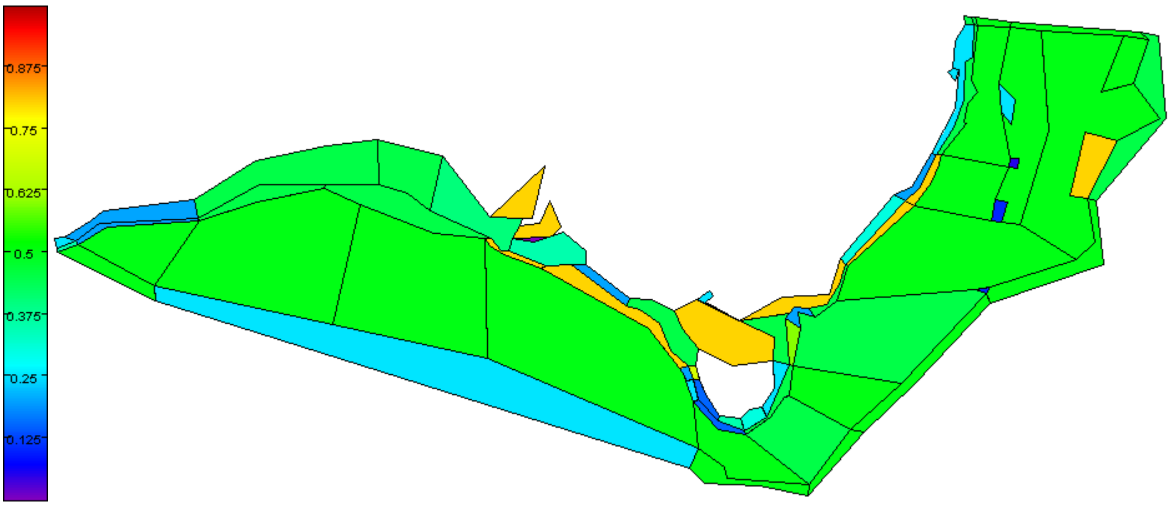


Figure 2-10: Proportional cover of flat ground per box (scale is 0-1), used to dictate sediment properties in the southeast Atlantis model.

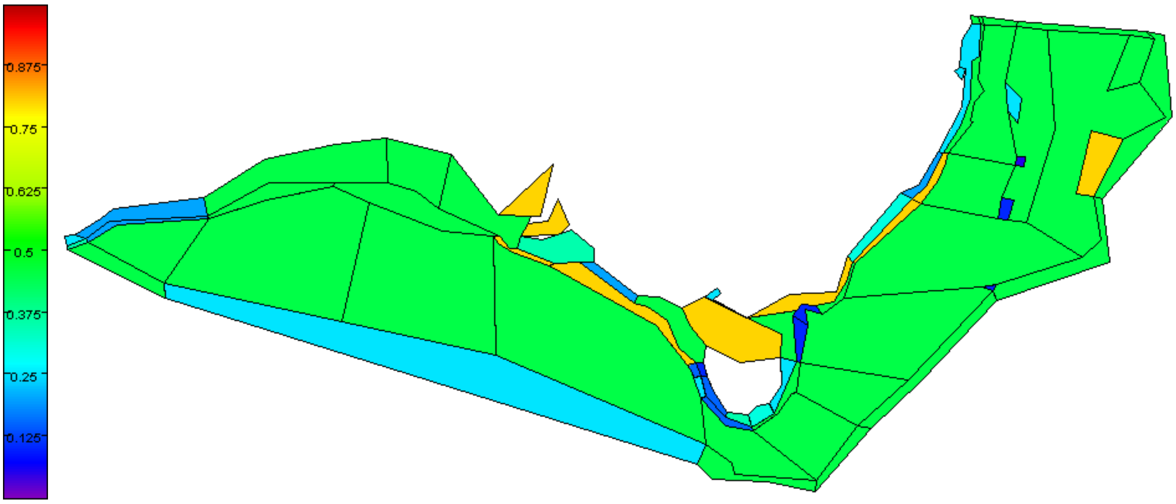


Figure 2-11: Proportional cover of soft ground per box (scale is 0-1), used to dictate sediment properties in Atlantis SE.

repository (http://instaar.colorado.edu/~jenkinsc/dbseabed/auseabed/auseabed.html). Habitat degradation scenarios can be used to modify these values, but typically they are constant throughout a single Atlantis run.

2.2.2 Ecological Components

Functional Groups

The biological groups included in Atlantis SE (listed in Tables 2.1 and 2.2) were made up of functional groups (aggregate groups of species with similar size, diet, predators, habitat preferences, migratory patterns and life history strategy) and dominant target species in the SESSF. The list of groups and species broadly matches the list identified in the trophic analysis and Ecosim model by Bulman *et al* (2006) and an independent grouping of the entire trophic web using the turn-over rate weighted regular colouration equivalence measure (Everett and Borgatti 2002, Dr Jeff Dambacher, CSIRO, *pers. com.*) and the Johnson hierarchical clustering algorithm (Johnson and Kargupta 1999). The invertebrate groups are represented using biomass pools, while the cephalopods, prawns and vertebrates are presented as age structured stocks.

In addition to these living biological groups, pools of ammonia, nitrate, silica, carrion, labile and refractory detritus are also represented dynamically. A “simple” network diagram of the complete food web is given in Figure 2.12.

Stock Structure

Atlantis SE allows for the vertebrate groups to have multiple stocks, though this feature is not used for all vertebrate groups. For some groups these stocks represent reproductive stocks, which were guided by: the definition of stocks for assessment purposes (though for assessments the stocks are not necessarily treated as reproductively isolated, which they are in Atlantis SE); or by experts on the species – in particular Ross Daley advised on all the shark distributions. For other groups they denote that different species are being represented in different parts of

Table 2-1: List of invertebrate functional groups included in Atlantis SE.

Model Component	Group Composition	Model Component	Group Composition
Pelagic invertebrates		*Benthic invertebrates*	
Large phytoplankton	Diatoms	Sediment bacteria	Aerobic and anaerobic bacteria
Small phytoplankton	Picophytoplankton	Carnivorous infauna	Polychaetes
Small zooplankton	Heterotrophic flagellates	Deposit feeders	Holothurians, echinoderms, burrowing bivalves
Mesozooplankton	Copepods	Deep water filter feeders	Sponges, corals, crinoids, bivalves
Large zooplankton	Krill and chaetognaths	Shallow water filter feeders	Mussels, oysters, sponges, corals
Gelatinous zooplankton	Salps (pryosomes), coelenterates	Scallops	*Pecten fumatus*
Pelagic bacteria	Pelagic attached and free-living bacteria	Herbivorous grazers	Urchins, *Haliotis laevigata*, *Haliotis rubra*, gastropods
Squid	*Sepioteuthis australis*, *Notodarus gouldi*	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*

Table 2-2: List of vertebrate groups and species in Atlantis SE.

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*

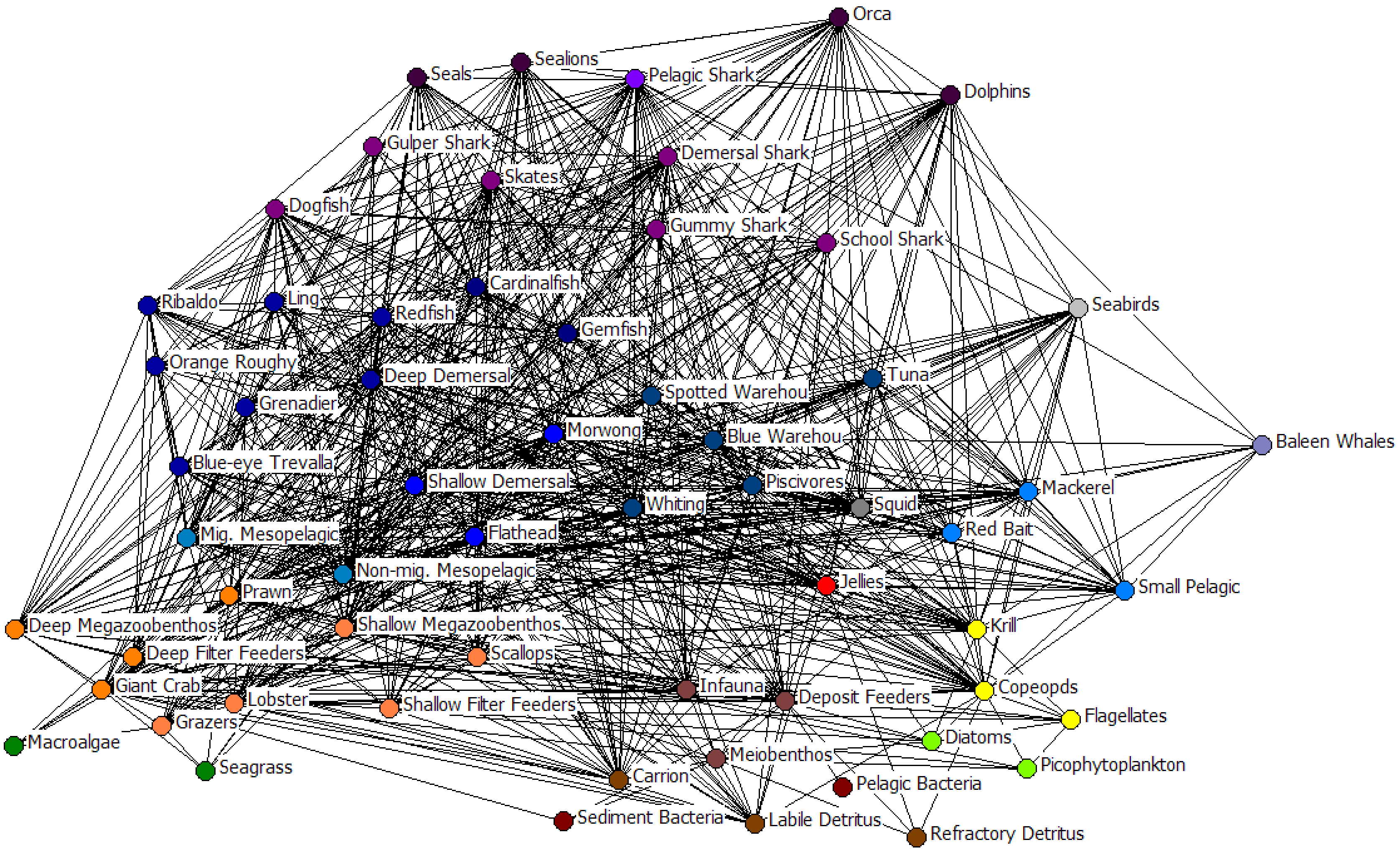


Figure 2-12: Food web used in Atlantis SE – as an interpretation aid, groups with similar trophic levels, habitat and depth preferences are coloured similarly.

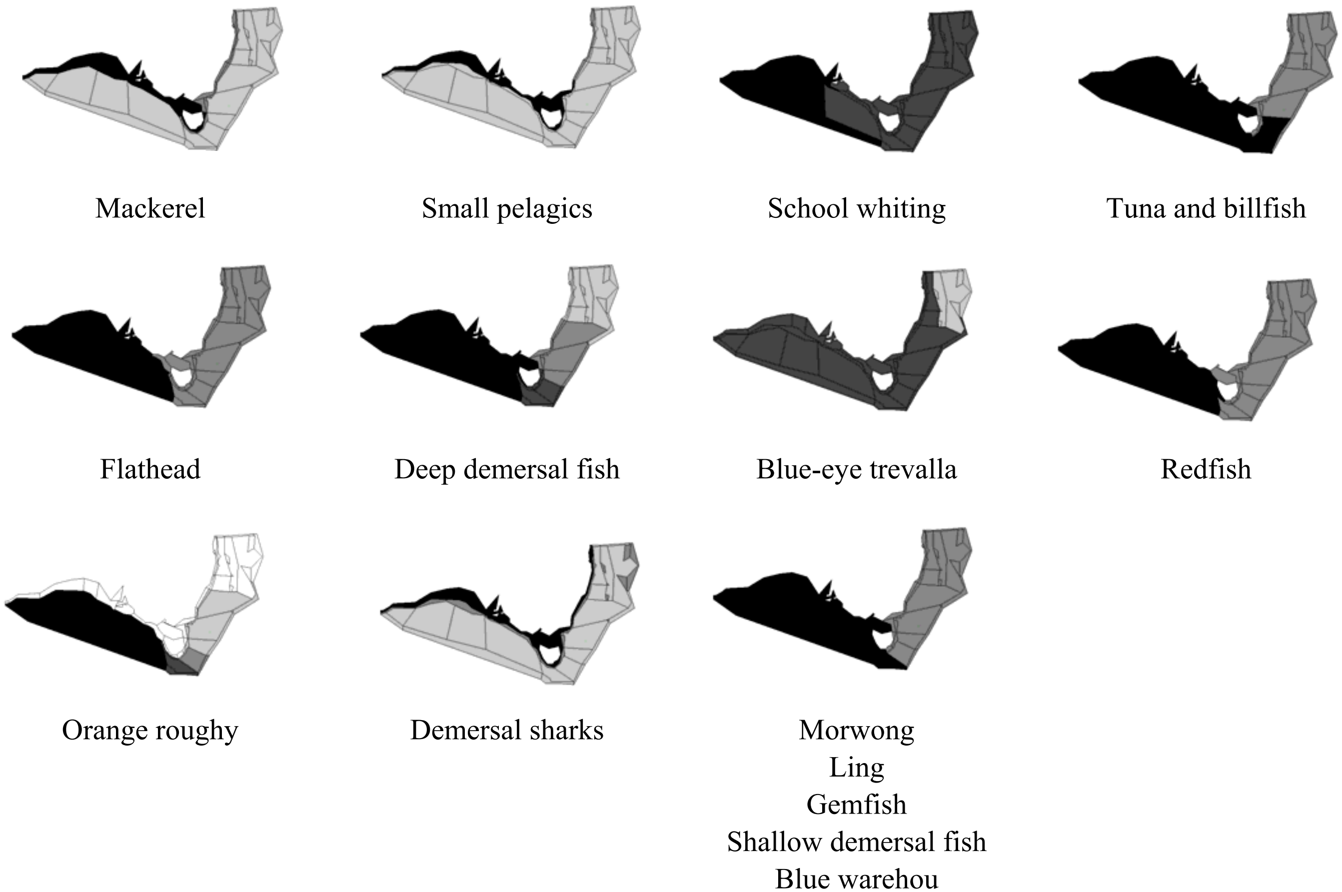


Figure 2-13: Stock structure patterns for the vertebrate groups in Atlantis SE that have multiple stocks. Note that for flathead, redfish and demersal sharks the stocks actually represent different species rather than genetic stocks.

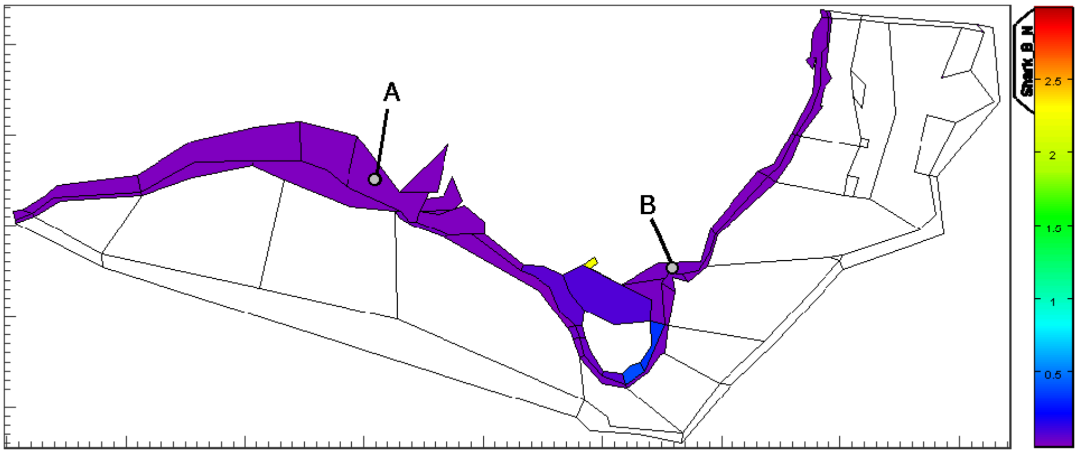
the model domain (e.g. tiger flathead in the SET and deepwater flathead in the GABT fisheries). Those groups with multiple stocks and the distribution of those stocks are given in Figure 2.13. All other vertebrate species and groups are considered to have a single stock which stretches across their entire range within the model.

Trophic Connections

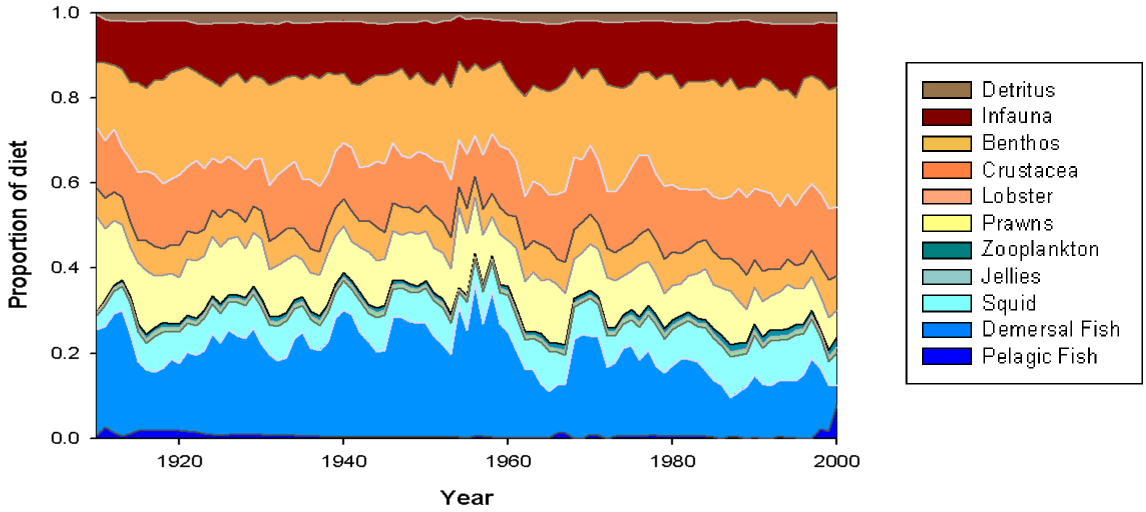
The potential trophic connections between groups are given in Appendix A (Tables A.1-A.4). These trophic connections are broken up based on maturity; represented as a juvenile-juvenile connection matrix, a juvenile-adult matrix, and adult-juvenile and adult-adult matrices. These matrixes are not a diet composition in the typical observable sense (they are not a set of gut contents or a percentage composition of the diet). What these trophic connection matrices are is the set of **maximum potential** proportion of the prey population that a predator can access at any one time. That is, the interaction (availability) parameters (the values in each cell of the matrices given in Tables A.1-A.4) are defined as the maximum proportion of prey that are accessible by predators – where predators and prey are of the appropriate maturity status, so if it's a juvenile prey-adult predator matrix then the parameters refer to the maximum availability of juveniles of the prey group to adults of the predator group. There is still further differentiation by age for some of the vertebrate predatory interactions with invertebrates – as the strength and rapidity of ontogenetic diet shifts can vary quite considerably from group to group. This division of the trophic connections allows for more flexibility with changing behaviours and size through the life history of both predator and prey.

As the values in these matrices are the maximum proportion of the prey population available to that predator at any one location at any one time, the effective proportion of available food taken may differ substantially from this depending on the overlap of predator and prey, habitat preferences and habitat state, the amount of forage available, and for vertebrates the relative size of predator and prey (as this determines whether gape limitation is occurring). All of these factors are included in the Atlantis calculations and the realised diets look quiet different depending on which predator and prey are actually in the same location at the same time (meaning their can be seasonal shifts in diet as groups move in to or out of an area) and the abundance of the various prey items. This means that, unlike other ecosystem models, the existence of a connection does not guarantee that predation will always occur. First, both predator and prey must be present in the cell for an interaction to take place (so if they are in different boxes or layers the interaction is impossible). Second, for vertebrate prey the predator must have a suitable gape to capture the prey - the prey must either be smaller than the gape or the predator must be identified as a group that can bite chunks out of prey that are too large to fit in their mouth whole. This last stage means that as fish grow they can pass through various predation refuges and windows. In combination this representation of the trophic linkages allows for great flexibility in realised diet as the biomasses of the different groups change through time. No additional explicit diet preference is included in the model, but the shift in diet composition through time may be referred to here as a shift in diet preference.

This representation of trophic connections means that an interaction term in the parameter matrix can be quite high but the realised contribution to the diet may be quite low, or may change substantially through time (capturing some degree of diet switching or shifts in trophic and network pathways as the system changes). For instance, two examples of the predicted realised diets for large adult gummy shark are given in Figure 2.14. The year to year variation is



(A)



(B)

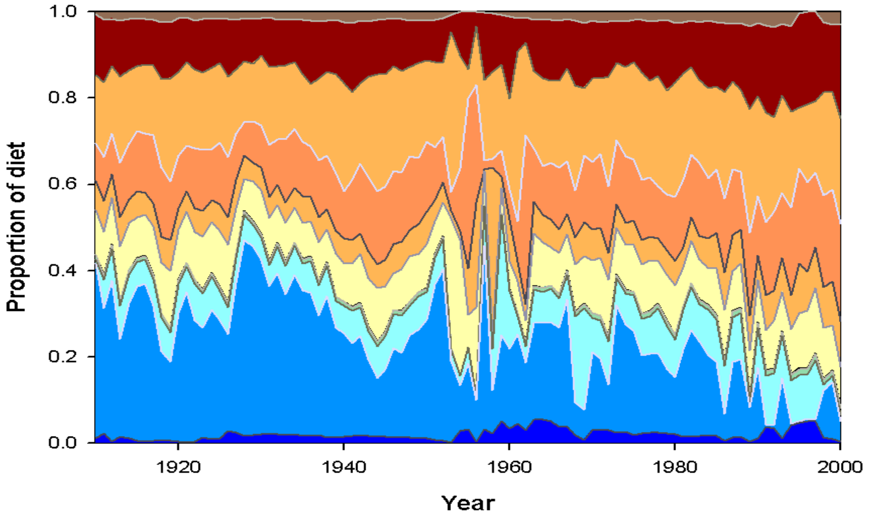


Figure 2-14: Example predicted diets for gummy sharks from different regions of Atlantis SE for the period 1910-2000: (a) in the Great Australian Bight (box 4) and (b) Eastern Victoria (box 17). For spatial reference, the location of the boxes is shown on the initial biomass distribution for gummy shark (at the start of 1910), scale is in t/km2.

obvious in both plots (seasonal variation has been omitted as snapshots on an annual basis were used to construct the plots). The greatest variation occurs in the example from the box in Eastern Victoria. In this case there are strong changes in diet through the late 1950s, due to fluctuations in the relative proportions of benthic groups in that box, and an apparent decline in the contribution of fish to the diet in the 1990s. While data to verify the temporal trends in these predictions is not currently available the diet composition does match well with that seen in actual diet studies – a quartile plot comparing observed and predicted diet composition for gummy shark is given in Figure 2.15. For most prey groups the range and median predictions by the model compare well with observed values; though the model tends to inflate the contribution by infauna and the has the potential to allow for quite high lobster contributions (though the median value is closer to observed values).

The connections defined in the Tables presented in Appendix A are based on diet information from data collected in the area (Coleman and Mobley 1984, Wingham 1985, Bulman and Blaber 1986, Skira 1986, Young and Blaber 1986, Blaber and Bulman 1987, May and Blaber 1989, Jones and Morgan 1994, Young *et al* 1997, Cortes 1999, Norman and Reid 2000, Hedd and Gales 2001, Hedd *et al* 2001, Harris *et al* 2002, Young and Davies 1992, Young *et al* 1993, Koslow 1996, Young *et al* 1996, Bulman *et al* 2001, Williams *et al* 2001, Young *et al* 2001, Bulman *et al* 2002a, Chiaradia *et al* 2003, Bulman *et al* 2006), from consultation with experts on species in the area (Ross Daley, Dr John Stevens, Dr Cathy Bulman, Dr Jock Young, CSIRO Hobart) and from the literature (Kailola *et al* 1993, Prince 2001, Fishbase www.fishbase.org). The final values used were the result of estimates from these sources modified through model calibration so that the resultant realised diet composition matched the available data and the biomass dynamics predicted by the model matched the best understanding of the changes in system state (from assessments and surveys) through the period 1910 to 2005, though the calibration was based primarily on the period 1910 to 2000 (which is the period presented in chapter 3).

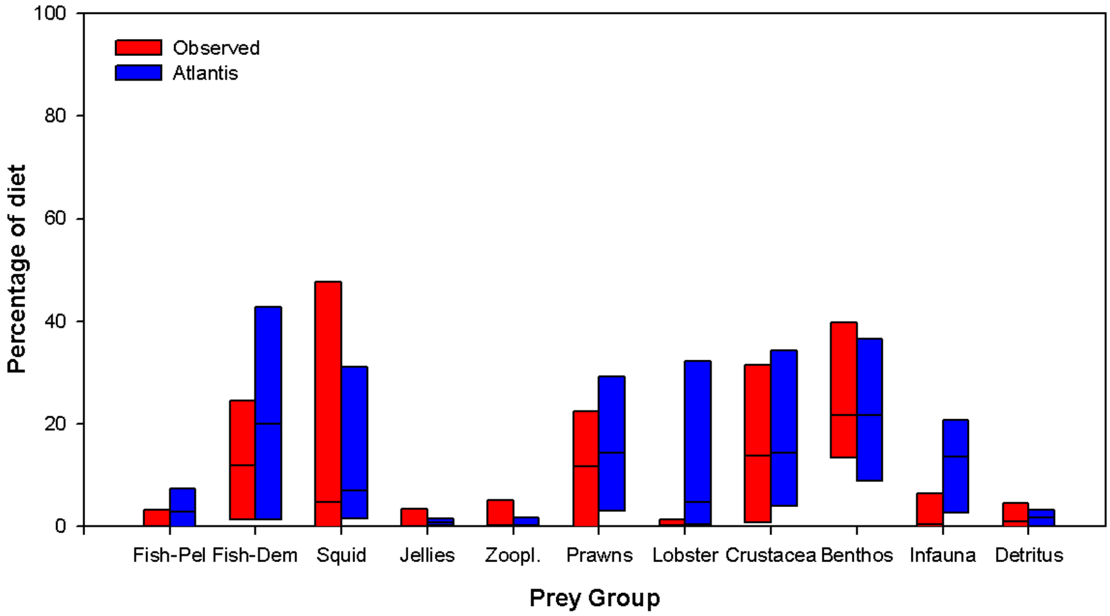


Figure 2-15: Box-plot showing observed and predicted diet composition for gummy shark – data for observations from Coleman and Mobley (1984), Bax and Williams (2000), Bulman *et al* (2001) and Simpfendorfer *et al* (2001).

Habitat Dependencies

To represent the fact that in reality the large areas covered by single Atlantis boxes would not be homogeneous, a sub-grid scale model is used to capture the effects of finer scale habitat patchiness. To date this is only done for benthic and biogenic habitat usage and dependencies. The parameterisation of this usage and dependency (given in Table 2.3) was calculated from information on biomass and distribution in Bax and Williams (2000, 2001) and Williams and Bax (2001). Where information was not available in these publications information was taken from more general sources (e.g. Kailola *et al* 1993 and FishBase http://www.fishbase.org).

Usage simply reflects whether a group can access an area containing a habitat type (it is not a proportional distribution across the habitat types). If a group can't access a habitat type, then it is also not possible for it to access any prey biomass associated with that habitat type. Given the typical data available on the majority of groups this simple on-off usage is the most effective means of establishing this non-trophic connection; and hence there is no relative strength of the term as in the trophic connections. During trophic interactions the habitat usages of predator and prey are compared to see if the two groups can be in the same small scale patches and thus able to interact directly. During a fishing event a similar comparison is made between the habitat preferences (and thus fine scale distribution) of fish and the types of habitat a fishery can access. Note that this dependency is only in effect in the bottom water column layer (where it contacts the epibenthic and sediment layers), once up off the bottom the groups could move over all habitat types (as they were physically above them) – this allows for differing behaviour with vertical movements, such as feeding on mesopelagic feed layers.

Habitat dependency is a group characteristic that is in addition to its habitat usage (it is quite feasible for a group to use habitat, but not be dependent upon it). Habitat dependency can also modify the trophic interactions. A simple theoretical non-linear curve (Figure 2.16) relates the quality of the habitat to the amount of structural refuge it could supply to a species dependent upon it. The trophic interaction terms for prey dependent on that habitat are then scaled by the value from this curve during any feeding interactions in that box – this means that good quality habitat provides more cover for prey groups dependent upon it, whereas degraded habitat allows predators to access more of their prey. This representation is an optional feature in Atlantis SE and may be omitted as it is open to criticism on three fronts. First, the curve does not have a final inflection that would match the case where even good quality habitat has become saturated and fails to provide any refuge for a larger proportion of the total population. Second, the curve is deterministic and time invariant so there is no explicit dynamic trade-off between predation risk and hunger-driven searching in open ground as there is in Ecosim (Walters *et al* 1997). Third, it ignores the use of cover by predators, where improved cover can actually lead to more successful predation interactions (e.g. Lynx using grass to hide from Snow-shoe hares in Canada). These are all valid criticisms, but for the purposes of Atlantis SE they were put to the side and the habitat dependency weighting of trophic interactions was used as it allowed for a wider range of system dynamics that better matched collective scientific understanding of the fine scale dynamics in the southeast of Australia (Alan Williams and Cathy Bulman *pers. com.*). The model would be sensitive to strong changes in the form of the curve. Unfortunately the resources required to fully validate the form of the model are beyond this study. The current form was used as it best matched current understanding and data; results under alternative forms that fit the data nearly as well show there is no shift in the relative ranking of the alternative management strategies (and so will not be presented separately here).

Table 2-3: Potential habitat use and dependency by the ecological groups in the southeast Atlantis model (filter feeders, macroalgae and seagrass are considered biogenic habitat forming groups as they form reefs and other three dimensional structures other groups can use as habitat). Note that because a group is marked as potentially using a habitat doesn't mean it has to use it if the other dictates of their behaviour never sees a group enter a cell containing that habitat type. Also note that pelagic groups are marked as being able to access all habitat types because they swim over all types as they pass above them in the water column. For benthic habitat, this only applies when they are in the bottom water column layer. Dependencies are drawn from information in Kailola *et al* (1993), Williams and Bax (2001) and Fishbase (www.fishbase.org).

Group \ Habitat	Habitat dependent	Shallow filt. feeder	Deep filt. feeder	Macroalgae	Seagrass	Rough	Flat	Soft	Canyons
Small pelagics	0	1	1	1	1	1	1	1	0
Red bait	0	1	1	1	1	1	1	1	1
Mackerel	0	1	1	1	1	1	1	1	0
Mig. mesopelagics	0	1	1	1	1	1	1	1	1
Non-mig. Mesopel.	0	1	1	1	1	1	1	1	1
School whiting	1	0	0	0	0	0	1	1	0
Shallow piscivores	0	1	1	1	1	1	1	1	0
Blue warehou	0	1	1	1	1	1	1	1	1
Spotted warehou	0	1	1	1	1	1	1	1	1
Tuna and billfish	0	1	1	1	1	1	1	1	0
Gemfish	0	1	1	1	1	1	1	1	1
Shallow demersal fish	1	1	1	1	1	1	1	1	0
Flathead	1	0	0	0	1	0	1	1	0
Redfish	1	1	1	0	1	1	0	1	1
Morwong*	1	1	0	1	1	1	1	1	0
Ling	1	1	1	1	0	1	1	1	1
Blue grenadier*	1	1	1	0	0	1	1	1	1
Blue-eye trevalla	1	1	1	1	1	1	0	0	1
Ribaldo	1	1	1	0	0	1	1	1	1
Orange roughy	1	1	1	0	0	1	1	1	1
Dories and oreos	1	1	1	0	0	0	1	1	1
Cardinalfish	0	1	1	1	1	1	1	1	1
Gummy shark	1	0	0	0	0	0	1	1	0
School shark	1	0	0	0	0	1	1	1	0
Demersal sharks	1	1	1	1	1	1	1	1	1
Pelagic sharks	0	1	1	1	1	1	1	1	1
Dogfish	1	1	1	1	1	1	1	1	1
Gulper sharks	1	0	1	0	0	1	0	0	1
Skates and rays	0	1	1	1	1	1	1	1	1
Seabirds	0	1	1	1	1	1	1	1	1
Seals	0	1	1	1	1	1	1	1	1
Sea lion	0	1	1	1	1	1	1	1	1
Dolphins	0	1	1	1	1	1	1	1	1
Orcas	0	1	1	1	1	1	1	1	1
Baleen whales	0	1	1	1	1	1	1	1	1
Large zooplankton	0	1	1	1	1	1	1	1	1
Gelat. zooplankton	0	1	1	1	1	1	1	1	1
Squid	0	1	1	1	1	1	1	1	1

Group \ Habitat	Habitat dependent	Shallow filt. feeder	Deep filt. feeder	Macroalgae	Seagrass	Rough	Flat	Soft	Canyons
Carnivorous infauna	0	1	1	1	1	1	1	1	1
Deposit feeders	0	1	1	1	1	1	1	1	1
Deep filter feeders	1	1	1	0	0	1	1	1	1
Shallow filter feeders	1	1	1	0	0	1	1	1	1
Scallops	1	1	1	0	0	1	1	1	1
Herbivorous grazers	1	1	1	0	0	1	1	1	1
Deep megazooben.	0	1	1	1	1	1	1	1	1
Shallow megazooben.	0	1	1	1	1	1	1	1	1
Rock lobster	0	1	1	1	1	1	1	1	1
Macroalgae	1	0	0	1	1	1	1	0	0
Seagrass	1	0	0	0	1	0	1	1	0
Prawns	0	1	1	1	1	1	1	1	1
Giant crab	0	1	1	1	1	1	1	1	1

* Combined adult and juvenile dependencies shown here, juvenile and adult dependencies actually differ. For both these species the Morwong the adults are found in all habitats adults may be found in any habitat that is present at the depths they inhabit; whereas the juveniles have more restricted distributions (for Blue Grenadier juveniles are restricted to flat and soft ground or ground covered by biogenic (filter feeder formed) habitat, while Morwong are more reef associated as juveniles than as adults).

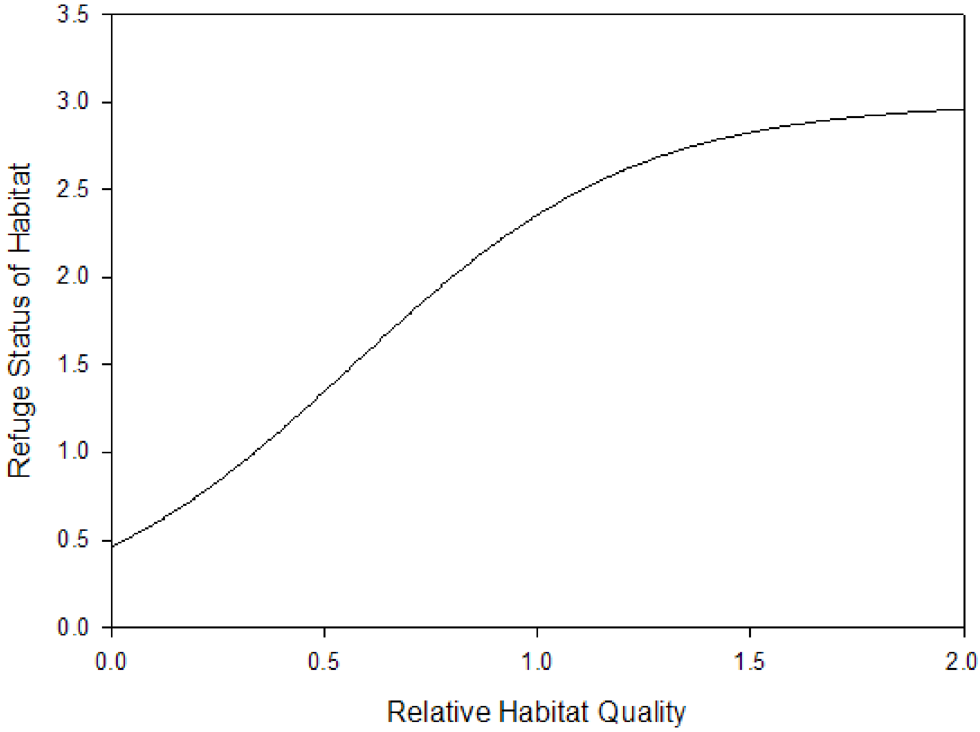


Figure 2-16: Relationship between relative habitat quality and refuge status proffered used to condition habitat dependent trophic interactions in Atlantis SE.

2.3 Fishing Fleets

Based on targeting and gear use[4], all fisheries (including State fisheries) were grouped into fleets and further divided into “fleet components” (using essentially the same approach as was used to determine the ecological groups). As the focus of the model is on Commonwealth fisheries, these were handled dynamically and were resolved in more detail - including the representation of sectors which were active historically, but have declined more recently, so that the past fisheries activities could be represented explicitly. In contrast State fleets were aggregated more heavily and their distribution, gear use (including the form of the selectivity function) and effort levels were set as fixed scenarios in all runs. Recreational fishing was also represented with a simple tithe (flat rate per person fishing recreationally) rather than using a detailed dynamic effort allocation model. A list of all fleets and fleet components used in the model and their gear, target and effort allocation details are given in Table 2.4 and their potential connections with the ecological groups in the model is shown in Figure 2.17.

The Commonwealth fisheries fleet definitions were drawn from previous work on the topic by Klaer and Tilzey (1994), Klaer (2004) and an independent analysis of AFMA’s logbook data. In the logbook analysis, boats were sorted based on size, areas fished, gear and reported landings. This analysis was performed using the year 2000 as a reference year (as that was to be the first year of the management strategy evaluation runs) and also across all years (1985 – 2004), so that (i) it could be judged how representative the year 2000 was of the general patterns (simple summary statistics and pattern matching was used to compare the year 2000 with available data before and after that year) and (ii) to see if there were any other large scale events or trends that needed to be kept in mind when using the logbook data to calibrate the dynamic fisheries model. This last point is particularly important as the model was calibrated (or trained) using the data from the mid-late 1990s so that it was not using the same 2000 onwards data that would ultimately be used as a check of the model against reality in the early years of the period covered by the management strategy evaluation projections. However, substantial changes in the fleet dynamics either side of 2000 would be problematic as the model would not have been trained using current effort allocation behaviours. While changes did occur during the late 1990s through the early 2000s, these were not considered large enough (as they did not see a complete restructuring or relocation of the majority of effort in the region) to jeopardise the model’s performance given that it contained the explicit kinds of behaviours (gear switching and effort shifts) that were seen in the data.

For those familiar with the Commonwealth fisheries the division of the fleets into fleet components may seem disconcerting, but it is necessary for capturing the correct overall fleet dynamics given the effort allocation models available in Atlantis. The various fleet components are more finely divided than in SESSF assessment models and they may represent what would be considered a single fleet in reality, but more aggregated forms fail to capture some of the fisheries behavioural changes through time. The fleet components are differentiated to a large degree by the primary target species (as recorded in the logbook data), but can still hold quota

[4] The specification of gear used is quite important as it is a significant factor in determining catchability, accessibility (based on whether a gear type can access a specific habitat type – like trawls avoiding particularly rough ground), selectivity (which can also change as a result of gear modifications like bycatch reduction devices) and escapement or incidental mortality.

Table 2-4: 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).

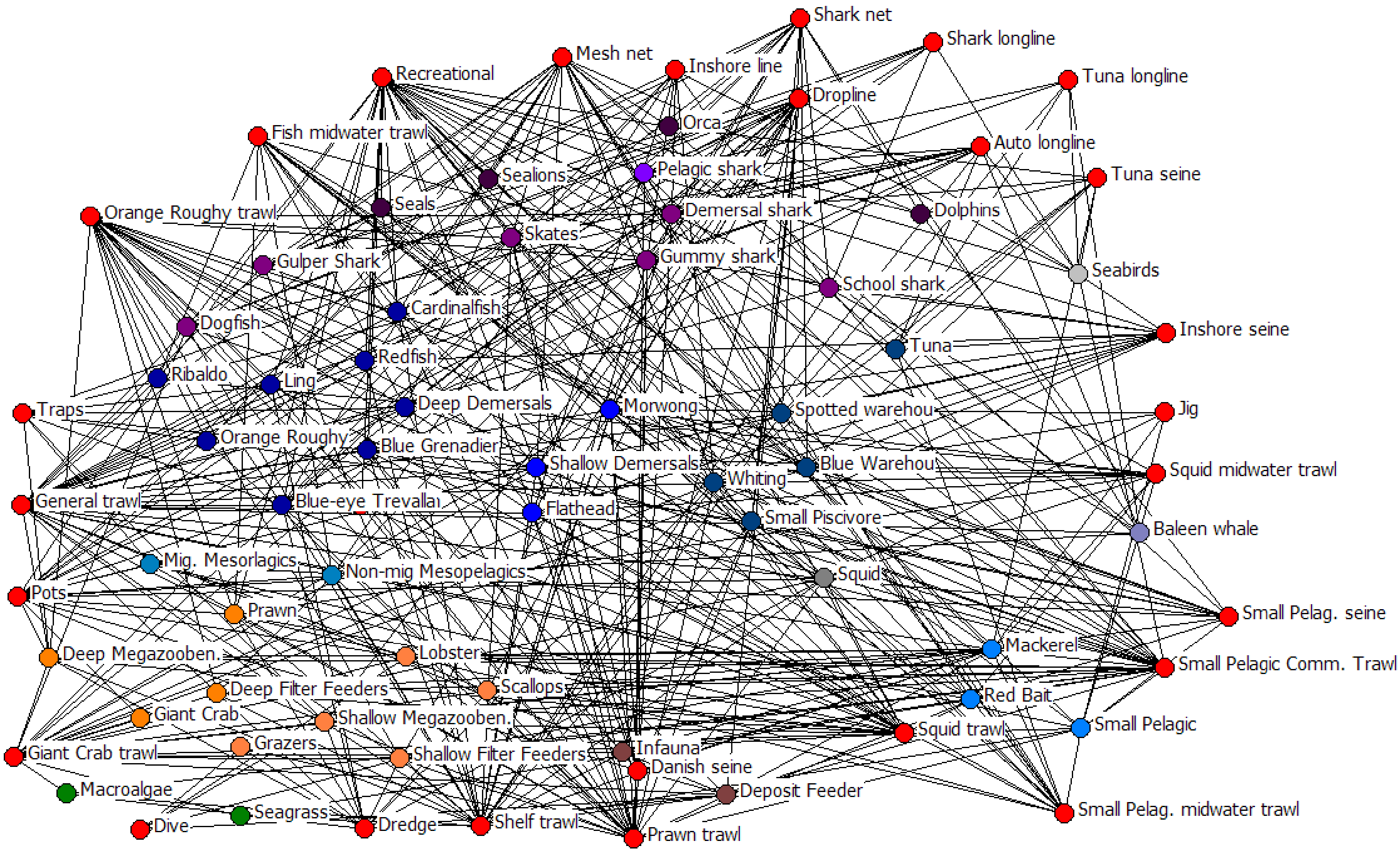


Figure 2-17: Fisheries connections in Atlantis SE, colouring of ecological groups shown here is as of Figure 2.12; all fisheries are coloured red here.

and fish target groups beyond that primary target species. The division into fleet components is simply a characterisation division based on their behaviour as reported in the logbooks. This is the best way of capturing the range of behaviour shown by these large multi-behavioural fleets. When reporting results in the following chapters, to reduce confusion for those considering the results, these fleet components have been recombined to form the overall trawl fleets traditionally reported.

2.4 Socio-economics

Previous implementations of Atlantis used simple aggregate fleet models to represent the fisheries and their effort allocation (e.g. Fulton *et al* 2005a). This kind of model was not sufficiently resolved to capture the processes and dynamics of interest in this study, where system state and proposed management methods could have differential impacts not only across gears, but also across vessel classes with different cost structures and vessel characteristics. Consequently a new socio-economics model was implemented that saw the larger fleets subdivided based on size and operational behaviours (subfleet divisions for each fleet are provided in Table 2.4).

A detailed description of the socio-economics model is given in Appendix B, but a brief description is provided here. There are four main parts to the current socio-economic model in Atlantis:

(i) Calculation of economic indicators (some of which are then used within the rest of the economic model, while others are reported as performance statistics)

(ii) Fleet tracking (including investment, disinvestment and switching between fleets and gear types), and resulting port activity status

(iii) Effort allocation (spatial and temporal) by fleet based on socio-economic factors

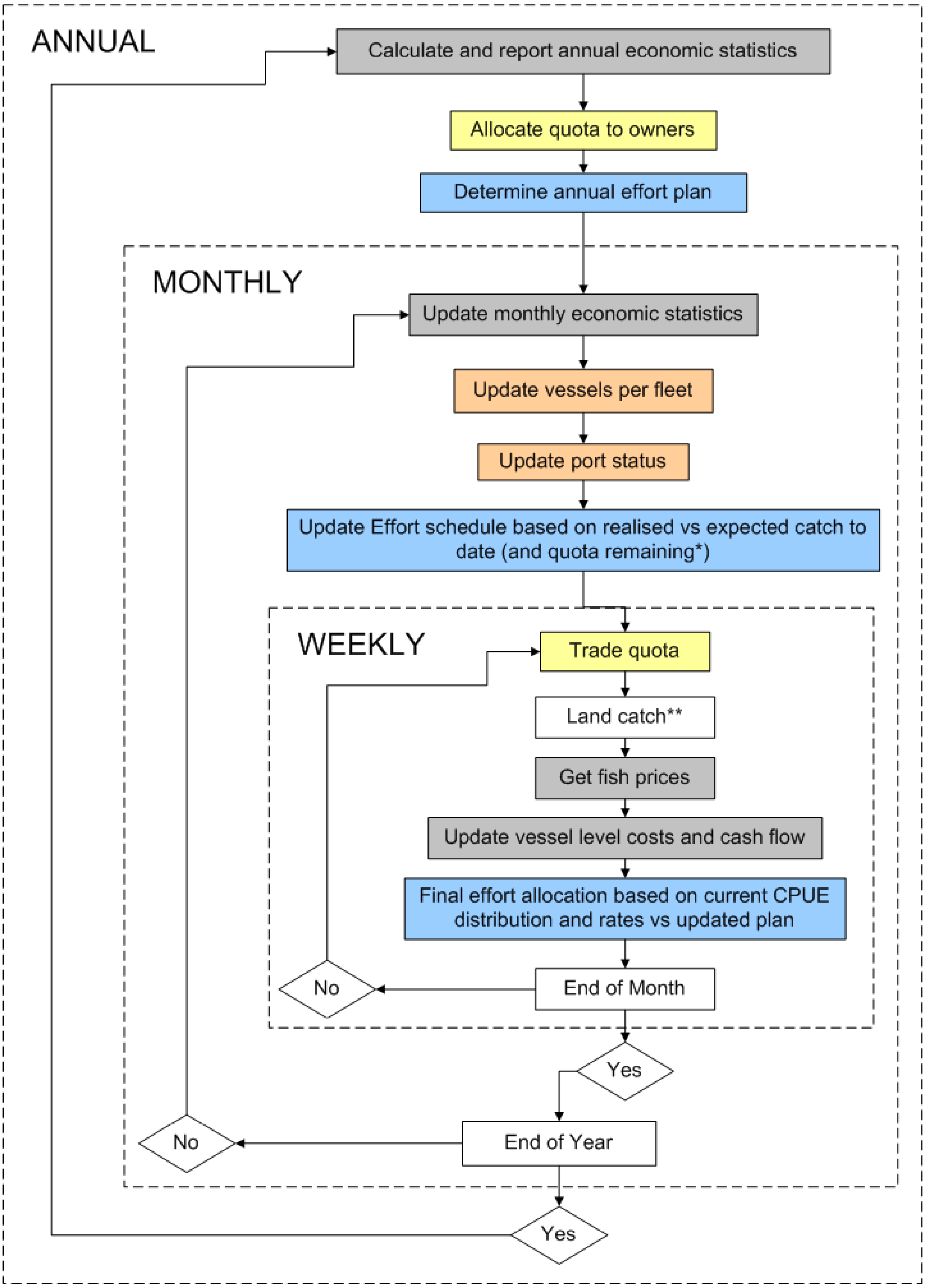
(iv) Quota trading

A flow diagram of the steps in the socio-economic model is given in Figure 2.18 and details of the different components described briefly below are more fully described in the appropriate sections of Appendix B.

2.4.1 Economic indicators

The economic indicators calculated and reported in Atlantis SE are drawn from two sources. The first is the list of economic indicators in the final report of the qualitative phase (Stage 1) of the project (Smith *et al* 2004). The second was those economic variables that were needed as part of the broader economic model (e.g. variable costs, prices and rents).

For those indicators taken from the Stage 1 report, the form of the relationship used to calculate the indicator in Stage 2 was based on the descriptions given in the narrative explanation of the economic performance measures (Smith *et al* 2004). The simplest curve that matched this shape was used for the quantitative relationship. For instance simple proportional relationships – such as that between cost per day and total yield were represented by a linear relationship of the



* If quota limiting

** If trip complete, multi-week trips are possible and catch will not be landed until the trip is complete.

Figure 2-18: Schematic diagram of the flow of the economics model in Atlantis SE. Blue indicates effort allocation steps, grey indicates economic indicator or value calculation and reporting steps, yellow indicates quota allocation and trading, and orange indicates steps dealing with fleet and port status determination.

form y = ax +b, with the coefficients taken from existing economic data or expert opinion. These calculations are straight forward at the boat or subfleet level but needed to be aggregated to produce overall aggregate values. It is possible to use additive, average and multiplicative combinations of these values across subfleets to give overall values per fleet. In the case of the results reported here, additive combinations are used (on advice from fisheries economists Dr Gerry Geen (FERM) and Dr Tom Kompas (ANU, ABARE)).

The indicators calculated per fleet are:

- number of boats switching between fleets or gears
- average boat size
- total marginal rent (or profit)
- gross value of the landed catch
- value of leased quota
- extent of quota trading
- cash flow per boat
- return on investment
- profit per tonne
- profit per effort
- profit per boat

The indicators calculated per subfleet (either for later aggregation to fleet or for use directly in the economics model) are[5]:

- number of vessels in the subfleet
- overall landed catch per unit effort
- total discards
- average size of the landed catch
- composition of the landed catch
- gross value of the landed catch
- costs per day (including fuel, capital, gear, unloading and fixed costs)
- costs per ton
- profit per day
- profit per ton landed
- profit per boat
- return on investment (adjusted to full equity)
- capital utilisation
- extent of spatial management affecting the subfleet
- number of within gear changes (including selectivity, swept area, discarding, access and escapement) per year
- management and research costs associated with the subfleet
- trading extent

[5] As alternative socioeconomic models are developed during future studies additional indicators, such as a measure of marginal net return (the contribution to profit of extra catch or effort in the next week to month) will be added (such an indicator would have value in its own right, but would also prove useful as an alternative means of determining whether or not to lease quota; at present this decision is based on the ratio of used: remaining quota vs behavioural trigger levels, see Appendix B for more details).

- total quota held (either owned or leased permanently or temporarily) by the subfleet
- sale value of quota

2.4.2 Fleet and port status

This section of the socio-economic model tracks fleet and port status. The membership of each subfleet is checked monthly, with the number of vessels in the subfleet updated based on whether any existing vessels in the subfleet have been decommissioned, forced from the fishery by debt, sold in a buyback scheme, or switched to alternative fisheries. If spare licences exist, new vessels may also enter a fishery.

Investment, disinvestment and switching between fleets are based on the model by Thébaud *et al*. (2006). This constructs a probability of leaving a fishery (or buying into a fishery if spare licences are available) based on long-term net returns vs short term payouts. A random number draw is then compared against this probability to determine how many (if any) boats take up this option. The switching between fleets is dealt with in the same manner – with boats shifting to the fishery that had the best trade-off of potential returns vs cost of boat modification. Boats joining a fishery in this way would enter the subfleet matching their vessel size, if available licences existed. If there are no available licences then the boats cannot switch and so remain in their original fleet.

Boats forced from a fishery due to debt could number beyond those that purposefully choose a decommission payout (or participate in a buyback scheme). Boats will leave a fishery if their total debt is beyond the maximum acceptable threshold (based on banking industry business fore-closure policies (Business Centre, Commonwealth Bank of Australia, pers. com.)) and the costs of maintaining a shore-based household for a year (Commonwealth of Australia 2006), or the vessel has opted to tie up rather than fish (due to expected marginal rents being less than the acceptable level, typically a substantial loss) for x months of the previous year (in this case the boat could lease out all its quota, if there was demand for that quota). In the results presented here x was set to 12 (i.e. an entire year of not fishing) as this presented a plausible maximum based on a current fisher's ability to accept debt loading and subsidise fishing activities with other sources of income. Further calibration of these facets of the model, which are currently based on plausible instances and expert judgement rather than fine scale data, would be beneficial, but would require access to data not currently available in the public domain.

Port activity is based on the number of vessels that considered a port to be their home port and the amount of landings channelled through a port. This port activity index is then used to calculate the dynamic (human) population of the port, which can also be scaled based on prescribed overall population changes (which capture population shifts due to activities other than fishing). In turn, this population influences recreational fishing pressure and can also contribute to coastal habitat degradation and pollution (though these latter two features can also be forced independent of population if desired).

2.4.3 Effort allocation

Black-books

In reality fishers build up knowledge of the system, both through personal experience and by sharing information (potentially disinformation) with others. The concept of "Black-books" (records of critical or cumulative historical knowledge stored by operators[6]) is used in Atlantis SE to capture this knowledge. These are subfleet-level arrays of CPUE and effort per area per month. The model is initialised with arrays created by averaging over the more recent historical catch and effort data (particularly the logbook data 1995 – 2000). As the model runs these historical data are updated with the model generated CPUE and effort data. A heuristically tuned weighting parameter dictates the subfleet's willingness to weight the most recent catch and effort data over longer term patterns, which captures the degree to which the fishers in the subfleet are "risk takers" or "traditionalists". Explicit data for parameterising this weighting term was not readily available. Instead during the training of the effort allocation model these weighting parameters were tuned to reproduce the shifts in allocation and targeting seen during the 1990s. While this feature of the model works as is, future collaboration with social scientists would lead to a much deeper understanding of the forces expressing through this mechanism and potentially a much richer repertoire of behaviours.

Information sharing is not dealt with explicitly in Atlantis SE, though as the model acts at the fleet and subfleet levels some of this sharing is implicitly incorporated into the model. The related issue of disinformation is not dealt with in this model at all, though others have looked into the topic (McCay 1978, Smith *et al* 1982, Allen and McGlade 1986, Thorlindsson 1994, Drefus-Leon and Gaertner 2006, Little and McDonald in press). Into the future it may be possible to include consideration of the topic as the model contains a simple friendship network representation.

Effort Allocation Tiers

After consultation with industry members it was clear that a hierarchical effort allocation and planning scheme is used to decide effort distributions and magnitude in the SESSF. A three tiered dynamic effort allocation sub-model is included in the economics model at the level of the subfleet to capture this hierarchical process (a summary is presented here, but for more detail please consult Appendix B). The three tiers are:

(i) Annual – Changes in targeting are made based on expected returns per species that the fishery can access; using annually updated expected returns per month, the available quota per target group (if quota is constraining), and the knowledge stored in the subfleet level monthly Black-books (see above), a plan is made for effort per box per month.

(ii) Monthly – The existing expected plan (originally defined annually) is updated based on realised catch vs expected catch and the available quota (if quota is

[6] The name comes from the colloquial reference to the notes and records kept by fishers (independent of mandatory logbook requirements). Some operators only keep this information in their head, but the majority will have some form of notes on where past catches (particularly good or poor ones) were taken. This is updated through time and is used to guide their decisions on which sites to fish and which to avoid.

constraining) per species; required down time for maintenance and profitability (or losses) of the operations constrain the maximum planned effort per month (e.g. if losses are higher than can be tolerated the boat will tie up rather than fish)

(iii) Weekly – Check to see whether available quota (if constraining) or planned effort for the month is already used up; if permissible effort remains, allocate it based on planned distribution of effort and the current realised spatial distribution of CPUE weighted by costs of reaching these boxes and the preference of the subfleet for using pre-determined plans rather than the current CPUE distribution.

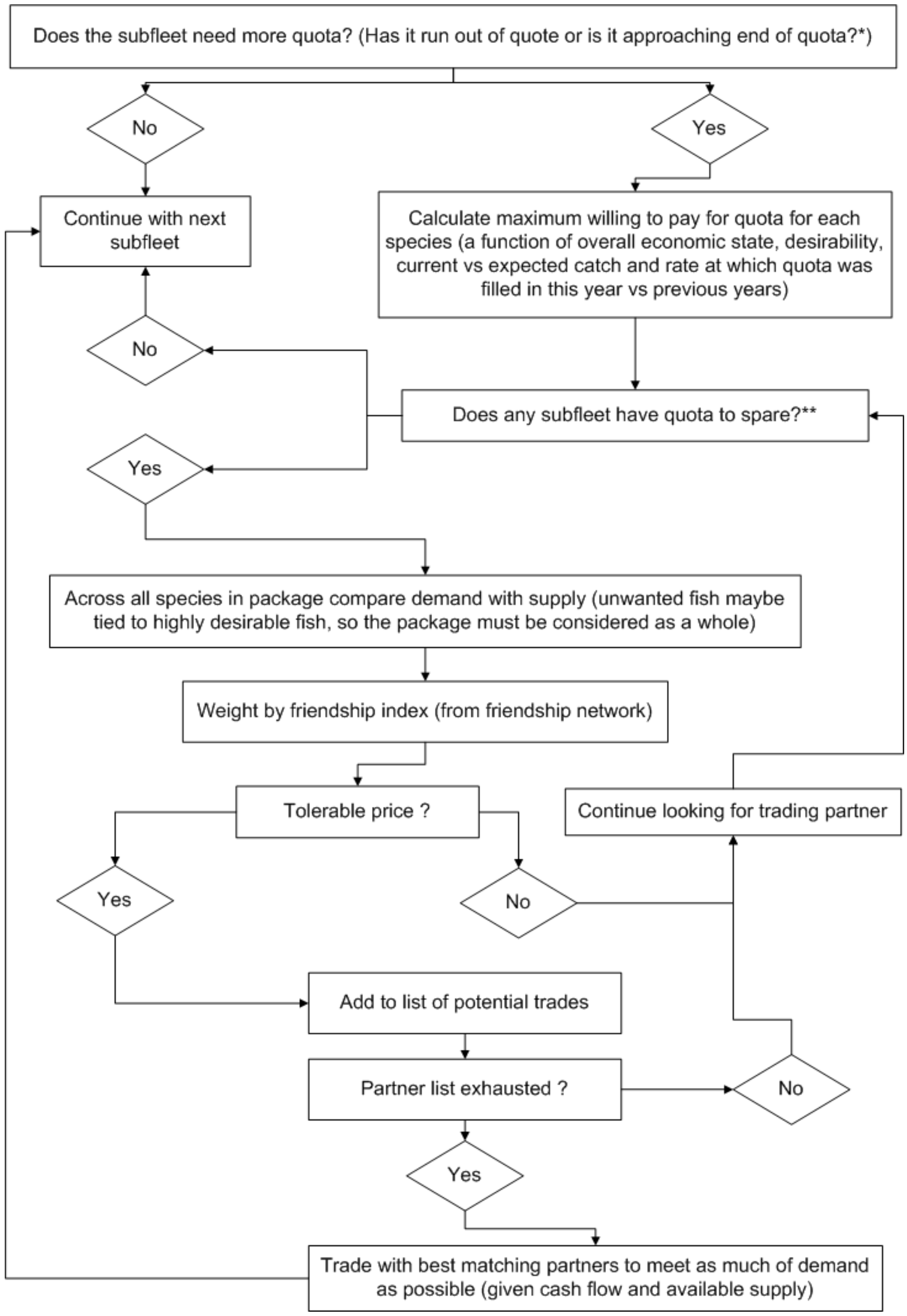
If catch rates in the boxes fished fall below a threshold level[7], then exploratory fishing is undertaken in boxes adjacent to cells fished in the previous year. An alternative formulation had return of effort to historically fished boxes that had not recently been fished as well as exploratory fishing in boxes adjacent to the boxes in the Black-Books with recorded historical effort. While this alternative exploration model is appropriate in well-established or widely distributed fisheries, which the SET would appear to be, the changes in targeting and effort distributions through the last 15 years of the fishery mean that the effort distribution and shifts of the current fishery more closely match that of a fishery which hasn’t thoroughly exploited all spatial areas it overlaps. This means that the former exploration model out performs the alternative in this case and so was used in Atlantis SE. It was also the exploration model that best fits the nature of the GAB fisheries.

2.4.4 Quota trading

Atlantis SE can model quota trading in fisheries with individual transferable quotas (ITQs). However because the model represents fleets and sub-fleets rather than individual vessels, quota trading is limited to trade between fleets and sub-fleets. This representation proved suitably flexible to allow for changing quota needs with changing fishing practices (as vessels moved west or east out of traditional grounds or from deep to shallow water quota held by the subfleets shifted as their targeting and landings shifted). Nevertheless it does underestimate the bulk level of trades because it does not capture trades between the vessels within a subfleet (which effectively have a shared quota pool in this case; if the subfleets were reduced to the size of a single vessel each then it would be a direct match with reality).

Quota trading is typically only active when quota is constraining. Other quota trading models are dealt with species-by-species (e.g. Little in prep), but as quota packages are traded in the SESSF a dynamic quota trading model had to be developed for the SESSF. This model involves both a price model and an actual trading model. The price model is a reparameterised version of the quota price model developed by Newell *et al*. (2005) for New Zealand (see Appendix B for the formulation used). The steps in the quota trading model are given in Figure 2.19 and details of the formulations used can be found in Appendix B.

[7] Here this threshold level of CPUE was set to be unconstraining, so exploration was free to occur at any time. Whether fishers then acted to consolidate an effort shift to that new location was dictated by the realised catch rates at that location versus costs of fishing there and catch rates and costs of fishing elsewhere.



* This occurs when the catch has come within a threshold % of filling the subfleet's quota for a species. The base % is 10% but this reduces as the year progresses, so that there is not excessive overrun or undercatch due to quota availability.

** A subfleet will put up quota for sale if they have caught less than a threshold % of the subfleet's quota for a species. The base % is 10% but it increases substantially as the year progresses so that the subfleet is not left with a lot of unused quota at year end (and does not forgo the income gained from trading it). The combination of quota across species is known as a package.

Figure 2-19: Flow diagram of steps in the quota trading model used in Atlantis SE.

2.4.5 Compliance

It is not an absolute requirement of Atlantis SE that operators are 100% compliant with management regulations. The model can be parameterised to allow for a proportion of the fleet to disregard the regulations (either habitually or opportunistically as pressures clashed with economic or other incentives) – and alternative levels of compliance were run as part of the alternative parameterisations of the model. Results produced under these alternative parameterisations showed that short of a complete breakdown in compliance and enforcement the level of compliance made little substantive difference to the relative outcome of the management strategy evaluation (the ranking of the strategies remained the same even if the absolute value of the indicators was shifted). Lower rates of compliance, particularly with regard to the boundaries and integrity of spatial management zones, diluted the impact of management and frequently lead to lower biomass levels of the target and vulnerable groups. This drop in biomass was not substantial unless infringement was high (in which case all results converged on those where with the weakest effective management, Scenario 1). While this potential for the management measures to be undercut must be kept in mind, it was judged that the advent of VMS makes such levels of non-compliance unlikely and so levels of compliance in the runs presented in the body of this report were set fairly high (95% or more).

2.4.6 Community and Operator perception

An understanding of public perceptions of fisheries and management is necessary if public concerns are to be addressed, both with regard to knowing what they are and to act to correct them (in cases where perception is erroneous the action may be educating the public). This is particularly true if co-management is a significant component of the management system or if public opinion can impact fisheries policy via a political feedback. The Bureau of Rural Science Australia report on community perceptions of the fisheries showed how important awareness an understanding of public perception can be for the marketability and sustainability of the industry (Aslin and Byron 2003). Moreover, it gave some insight into some of the factors which dictate public perception of fisheries, including: effectiveness of management, compliance and enforcement, monitoring, regulatory activities; behaviour (whether the fishers act responsibly), resource conservation, sustainability of current activities, by-catch, discarding; competition between sectors, and quality of product. An earlier review of Australian attitude surveys (Lothian 1994) showed that environmental concern (particularly regarding biodiversity and pollution, but also sustainability of natural resources) combined with economic (economy, job creation and export earnings) considerations to shape the Australian public's perception of industries. The hardest facet of this to capture in indicators is the lifestyle component and the AMS study has not found an easy solution to this. Instead it has followed Chesson and Clayton (1998) who used simple indices, such as the number of boats active in the fishery, as crude proxies for the lifestyle component. This remains an area where more detailed social survey work that examining attitudes and values of different components of the public and the industry could make a significant contribution to our understanding and management of fisheries (via gaining public and industry support and understanding of specific actions or decisions). One path for future research in this area may be through the use of focus groups, which could provide insight into people's attitudes, perceptions, behaviour, and knowledge base. While typically providing qualitative data, such groups are an incredibly useful source of information for use in deciphering the complex process of forming an attitude and for allowing the interpretation of previous social survey studies. As no social survey work was explicitly included in the AMS project it was necessary to use quite simple proxy measures that combine the many factors identified by Aslin and Byron (2003) in a simple and straightforward manner (e.g. an average across factors). This leaves much scope for increased sophistication or modification, but has the advantage that short of the kind of focus group work identified above the composite index would be transparent and have value for comparisons (the relative value across scenarios having comparative value even of the absolute value and formulation of the index could be refined further).

Community perception was one of these social performance measures used in the management strategy evaluation. This measure was calculated as a running average of perception based on standardised economic value of the fishery, port activity (as a measure of employment and social contributions), discard rates and the inverse of the TEP and habitat impacts. That is the value for each of these factors is standardised versus the 2000 value (so that all are of a similar order of magnitude) and then these are combined in the final running average (so that there are not sharp discontinuities year-to-year, as people tend to have a lag or inertia in the shift of their perception).

The other major social measures used were port activity (which is proportional to the volume of catch moving through the port and is a measure of employment and infrastructure) and the operator's perception of the situation. These measures were continuously updated by only reported annually. In the final formal MSE analysis the operator perception was not included as a formal performance measure (as it was not one of the measures used in the qualitative analysis), but was a useful indicator of how the mix of economic, access and workload pressures could be perceived by someone active in the fishery. The operator perception was calculated as a running average of the normalised values of: port activity level, frequency of return to home port; the stability and access of the fishery; the transparency of the decision setting process (a binomial based on whether the lobby-based rules or harvest strategies were in use); effort levels; CPUE rates; GVP; costs and marginal profits (i.e. profits after crew costs are removed).

2.5 Assessment

A wide range of sampling and assessment models are available as part of the harvest strategy component in Atlantis. The sampling models include representations of fisheries dependent, observer-based and fisheries independent data collection methods and data handling procedures. The assessment models span the range of most commonly used fisheries assessment models, including: the most common variants of the Schaefer production model (Haddon 2001); Virtual Population Assessment (ADAPT VPA, Lassen and Medley 2000); Multi-Species VPA (MSVPA, Magnusson 1995); and integrated assessment models such as CAB (Cope *et al* 2004) and Stock Synthesis (Methot 1990). The first two types of assessment model have been directly incorporated into Atlantis, while the latter two sit outside the Atlantis modelling framework and are called as needed (usually annually) from within the Atlantis assessment module. In these cases, the data files needed to run the assessment models are outputs from the Atlantis monitoring sub-model (within the fisheries sub-model).

Early versions of Atlantis SE used data generated by the fisheries sub-model and the CAB model to assess the target species and groups represented in the model and to recommend quotas. It quickly became obvious however that this approach was computationally prohibitive, particularly in combination with the already high demands of the Atlantis model itself. The alternative approach adopted was to use a "pseudo-assessment" to derive the estimates of biomass, fishing and natural mortality that are subsequently used in the harvest control rule to determine the quotas. This was done by taking the actual (Atlantis model) available biomasses and numbers lost to predation and fishing, and adding error to represent the uncertainties in the assessment process[8]. These values were then treated as “data” and “parameter estimates” when calculating the appropriate F_{ref} (e.g. F_{40}) for use in the final harvest control rule calculations, which determined the RBCs (recommended biological catches). A series of trials were run comparing the assessments and resulting quotas from the full integrated assessment and the pseudo-assessments (Figure 2.20). There were differences in the estimates (by as much as 15%), but more importantly the differences in the recommended RBCs were less than 10%. Given the buffering in rate of TAC change (TACs were not allowed to increase by more than 20%, or decrease by more than 50% in one step[9]) and the other sources of error and variation in the model, this level of divergence in the RBC was considered acceptable – especially as the resulting effort dynamics produced in the fisheries and economics model were not markedly different under TACs produced by the full and pseudo-assessments.

Beyond the harvest strategies, which focus on management of quota species, Atlantis SE includes the ability to assess and manage other ecological impacts of fishing, including impacts on bycatch species, on threatened, endangered and protected species, and on benthic habitats. The assessment models for these ecological components are not yet well developed, and mostly rely on the use of “triggers” (when the estimated biomass or coverage drops below a limit reference point of 20% of the estimate of unperturbed levels) associated with key species and habitat indicators to identify the need for management action.

(a)

(b)

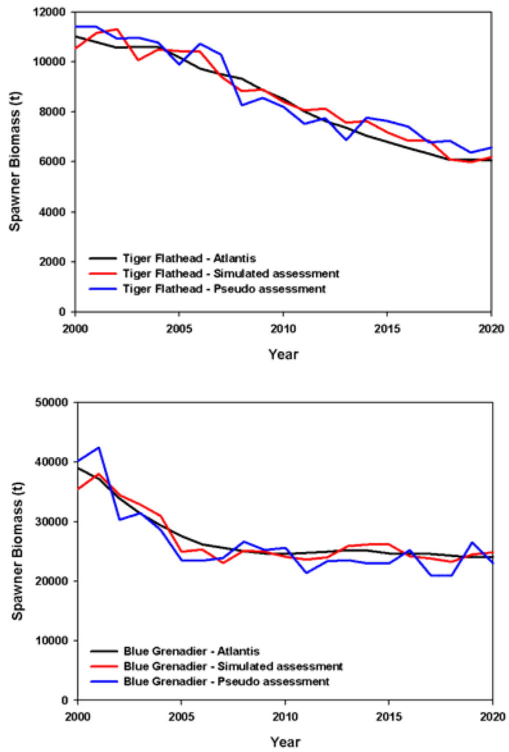


Figure 2-20: Comparison of assessments and pseudo-assessments – examples given are (a) Tiger Flathead and (b) Blue Grenadier.

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[8] Note that to ensure consistency, the level of error was generated and saved for each species and applied in the same sequence in any all scenarios where that species was assessed.
[9] This buffering was used to reflect the mediating effects of the AFMA TAC setting process.

2.6 Management

The Management sub-model in Atlantis adjusts the settings of all the management levers based on the results from various assessment models. The principal assessments are those for target and quota species, but as noted in section 2.5, impacts on other components of the ecosystem are also considered. In the results presented in this report, the management levers that were explicitly considered were:

- gear size (which impacts selectivity, accessibility and escapement)
- discarding
- spatial management (zoning, spawning, TEP-based and total closures)
- seasonal closures
- quotas (including basket, companion and regional TACs)
- trip limits

Of these, quotas and spatial management were the most frequently used measures.

The costs of management were also explicitly considered. A very simple costs model was constructed to capture the gross changes in costs through time under each Scenario. The costs were broken down into general, research, compliance, monitoring and other (buyback) costs. The initial values for the costs were provided for the major sectors by AFMA, based on the values from 2006. The annual values were then calculated for each simulated year using the following equations:

$$K_{gen,t} = K_{gen,0} \tag{2.2}$$

$$K_{res,t} = K_{res,0} \cdot \left(\phi_{Q,t} \cdot \kappa_Q + \phi_{res,t}\right) \tag{2.3}$$

$$K_{com,t} = K_{com,0} \cdot \left(1 + N_Z \cdot \kappa_{com} + \kappa_{TAC} \cdot N_{Q,i}\right) \tag{2.4}$$

$$K_{mon,t} = K_{mon,0} \cdot \frac{N_{Q,i}}{N_{Q,hist}} \cdot \frac{\phi_{Q,t}}{\phi_{Q,0}} \tag{2.5}$$

where $K_{gen,t}$ is general costs in year t; $K_{res,t}$ is research costs in year t; $K_{com,t}$ is compliance costs in year t; $K_{mon,t}$ is monitoring costs in year t; $\phi_{Q,t}$ is the proportion of species under quota that are assessed (and have TAC updated) in year t; $\phi_{res,t}$ is the contribution of fisheries ecological research to the overall research costs (including tagging and other spatial studies as well as life history research); κ_Q the scalar of costs for each additional species assessed (set to 1.15 on advice from AFMA and CSIRO financial officers); κ_{com} the cost scalar associated with each extra spatial management area to be enforced (set to 0.007 on advice from AFMA); κ_{TAC} the cost scalar associated with each extra species included in the quota management system (set to 0.005); N_Z is the number of spatial management areas implemented under the Scenario; $N_{Q,i}$ is the number of species included in the quota management system for the Scenario; $N_{Q,hist}$ is the number of species under quota management in reality in the year 2000.

2.6.1 Harvest strategies and RBCs

The way in which the RBC was set depended on the decision making method employed in each scenario. In runs where quotas were not a major management lever (i.e. the NGO specified scenario, Scenario 9) the method of RBC setting was irrelevant. Of more interest are the two main RBC setting methods used in those cases where quotas did form a major part of the management regulations. The first method attempted to replicate the “negotiated” method of setting TACs during the period of the late 1990s and early 2000s. If the catch rates had been increasing for more than five years then the TAC was raised by 20%. If on the other hand, catch rates had been decreasing for five years and the current rates were below a critical level (set at 5% peak levels) then the TAC was decreased by 50%.

The second method of RBC setting uses the harvest strategy framework (HSF) recently introduced to the SESSF (Smith and Smith 2005, Smith 2006). The form of the HSF used here was the proposed form as of August 2006, this does not exactly match the final form of the Commonwealth Fisheries Harvest Strategy (DAFF 2007); for instance, F_{TARG} used here is higher than given in DAFF (2007). The HSF used here assigns each quota species to one of four tiers depending on the amount of information available for that species. Tiers 1 and 2 have the most information (a quantitative stock assessment). Tier 3 has information on the age or size structure of the catch. Tier 4 uses catch per unit effort data only. Each tier has a harvest control rule that takes information from the assessment to determine the RBC for each species.

Tier 1 – The recommended biological catch (RBC) is calculated by applying the allowable fishing mortality (F_{ADJ}) to the current estimated biomass (B_{CUR}) using the agreed base case assessment model. The allowable fishing mortality is calculated using:

$$F_{ADJ} = \begin{cases} F_{TARG} & \text{where} \quad B_{TARG} \le B_{CUR} \\ F_{TARG} \cdot \left(\dfrac{B_{CUR} - B_{LIM}}{B_{TARG} - B_{LIM}} \right) & \text{where} \quad B_{LIM} \le B_{CUR} < B_{TARG} \\ 0 & \text{where} \quad B_{LIM} < B_{CUR} \end{cases} \tag{2.6}$$

with F_x the fishing mortality rate that would cause the spawning biomass (not absolute biomass) to decline to x% of its unfished levels; B_x is the biomass at x% of unfished levels. In this case F_{TARG} is set to F_{48}, B_{TARG} is B_{40} and B_{LIM} is B_{20}.

Tier 2 – as for Tier 1, but with F_{TARG} is set to F_{60}, B_{TARG} is B_{50} and B_{LIM} is B_{20}.

Tier 3 – this is a catch based tier where the RBC is set at some defined fraction of recent average catches. The fraction is based on the ratio of current fishing mortality to natural mortality rates as follows:

$$RBC = \begin{cases} 1.2 \cdot C_{CUR} & \text{where} \quad F_{CURR} \le 0.5 \cdot M \\ 1.1 \cdot C_{CUR} & \text{where} \quad 0.5 \cdot M < F_{CURR} \le 0.75 \cdot M \\ C_{CUR} & \text{where} \quad 0.75 \cdot M < F_{CURR} \le M \\ 0.9 \cdot C_{CUR} & \text{where} \quad M < F_{CURR} \le 1.25 \cdot M \\ 0.8 \cdot C_{CUR} & \text{where} \quad 1.25 \cdot M < F_{CURR} \le 1.5 \cdot M \\ 0.5 \cdot C_{CUR} & \text{where} \quad 1.5 \cdot M < F_{CURR} \le 2.0 \cdot M \\ 0 & \text{else} \end{cases} \tag{2.7}$$

Tier 4 – this is also a catch based tier where the RBC is set based on recent trends in catch rate using:

$$RBC = \left(1 + R_{\alpha} \cdot C_{S}\right) \cdot C_{CUR} \tag{2.8}$$

where R_{α} is the scaling coefficient (set to 1.0 in this case); C_S is the trend in catch rates over the last five years; and C_{CUR} is the average catch over the last five years.

When these tier rules were in use, the majority of quota groups were treated as tier one or two for the results reported here (see Table 2.5).

The final TAC is the set based on the calculated RBC after (potentially) taking a number of other considerations into account. This means the final TAC need not be set equal to the RBC, though there were fairly strict constraints on when the TAC could exceed the RBC. For the case where the "negotiated" method of setting TACs was being used these extra considerations where not included and so the TAC matched the RBC. For the tiered RBC calculations the following other considerations were taken into account when setting the final TAC:

- Level of companion TACs (see below)
- Discards (the F rate is calculated including discards and expected discards are subtracted from the RBC to give the new TAC)
- Whether spatial management is being traded off against any TAC reduction (see the description under the "Integrated Management" scenario in section 2.8.6)
- Need to transition from last TAC to new TAC that would be set under the harvest strategy, where the two are very different. In this case the following rule was used:

$$TAC_{final} = \begin{cases} \rho_{low} \cdot TAC_{old} & TAC_{new} < \rho_{low} \cdot TAC_{old} \\ \rho_{hi} \cdot TAC_{old} & TAC_{new} > \rho_{hi} \cdot TAC_{old} \\ TAC_{new} & \text{otherwise} \end{cases} \tag{2.9}$$

Where TAC_{new} is the new TAC set using the RBC and other considerations (like companion status and discards); ρ_{low} is the proportional decrease in TAC that would be likely to be implemented in any one step (set to 0.5 here); and ρ_{hi} is the proportional increase in TAC that would be likely to be implemented in any one step (set to 1.2 here).

It has been acknowledged that in reality other considerations when setting a TAC are: whether multi-year TACs are in place; and that there may be justification in setting TACs slightly above RBCs in a multi-species fishery if there is only a very small probability that the resulting TAC would ever be fully taken. As rules on how to treat either of these cases were not available during the development of the Atlantis SE model they were not considered explicitly here. The later issue was instead subsumed into the handling of companion TACs within Atlantis SE. While the impact of the former issue was considered only post hoc, by examining how often it would have lead to an alternative regime of TACs under the methods used here.

Table 2-5: Harvest strategy tier used for each potentially fished group in each scenario (note a zero tier indicates a "negotiated" method of setting TACs and a "-" entry indicates no TAC set for that group).

Group	Scenario 1	Scenario 3	Scenario 4	Scenario 9	Scenario 10
Deposit feeders	-	-	-	-	-
Deep water filter feeders	-	-	-	-	-
Shallow filter feeders	-	1	-	-	-
Scallops	-	1	-	-	-
Herbivorous grazers	-	1	-	-	-
Deep megazoobenthos	-	-	-	-	-
Shallow megazoobenthos	-	1	-	-	-
Rock lobster	-	1	-	-	-
Macroalgae	-	-		-	-
Prawns	0	1	1	0	1
Giant crab	-	1	-	-	-
Large zooplankton	-	-	-	-	-
Squid	-	1	-	-	-
Small pelagics	-	-	-	-	-
Red bait	-	1	-	-	-
Mackerel	-	1	-	-	-
Migratory mesopelagics	-	-	-	-	-
Non-mig. mesopelagics	-	-	-	-	-
School whiting	-	1	1	-	1
Shallow water piscivores	-	-	-	-	-
Blue warehou	0	1	1	0	0
Spotted warehou	0	1	1	0	1
Tuna and billfish	-	-	-	-	-
Gemfish	0	1	1	0	1
Shallow demersal fish	0	2	2	0	2
Tiger flathead	0	1	1	0	1
Deepwater flathead	0	1	1	0	1
Redfish	0	1	1	0	1
Bight redfish	0	1	1	0	1
Morwong	0	1	1	0	1
Ling	0	1	1	0	1
Blue grenadier	0	1	1	0	1
Blue-eye trevalla	0	1	1	0	1
Ribaldo	-	1	-	-	-
Orange roughy	0	1	1	0	1
Dories and oreos	0	1	1	0	1
Cardinalfish	-	1	-	-	-
Gummy shark	0	1	1	0	1
School shark	0	1	1	0	1
Demersal sharks	-	1	1	-	-
Pelagic sharks	-	1	-	-	-
Dogfish	0	1	1	0	1
Gulper sharks	-	1	0	-	0
Skates and rays	-	1	-	-	-
Seabirds	-	-	-	-	-
Seals	-	-	-	-	-
Sea lion	-	-	-	-	-
Dolphins	-	-	-	-	-
Orcas	-	-	-	-	-
Baleen whales	-	-	-	-	-

2.6.2 Regional, Companion and Basket TACs

Some scenarios included regional, companion and basket TACs. Regional TACs used the same methods outlined above, but were based on the status of the stock in each region rather than the total overall biomass[10]. Companion TACs were also initially set separately for each species using the standard methods described above, but were then revised (rescaled) based on the ratio of the catches of the companion species. Whether TACs were scaled up or down depended on whether weak or strong link companions were identified. If a species pair was marked as a strong link companion, then the TAC for species A is compared with the value returned if the TAC for species B is scaled by the catch ratio of the two species - i.e. the amount of species A caught for each unit (e.g. tonne) of species B. If the TAC is less than the scaled value then the TAC is raised to the scaled value. If the TAC is greater than the scaled value then the process is repeated in reverse (the TAC for species B scaled based on the catch ratio with species A). This set of calculations for a companion TAC for species A is captured in the following expression:

$$TAC_{A,co} = \begin{cases} TAC_{A,\,final} & TAC_{A,\,final} \geq \rho_{A:B} \cdot TAC_{B,\,final} \\ \rho_{A:B} \cdot TAC_{B,\,final} & \text{otherwise} \end{cases} \tag{2.10}$$

where $TAC_{A,final}$ is the TAC as given by the negotiated method of setting a TAC or the harvest strategy framework; and $\rho_{A:B}$ is the catch ratio of species A and B (i.e. C_A / C_B). If a weak link TAC had been set then a similar process is followed, but with the higher TAC scaled down based on the catch ratio, such that:

$$TAC_{A,co} = \begin{cases} TAC_{A,\,final} & TAC_{A,\,final} \leq \rho_{A:B} \cdot TAC_{B,\,final} \\ \rho_{A:B} \cdot TAC_{B,\,final} & \text{otherwise} \end{cases} \tag{2.11}$$

Most of the basket TACs currently used in the SESSF were best represented in Atlantis SE by a more standard TAC on a single group, as the group membership included all species in the basket. Other deepwater demersal sharks and the gulper shark group needed to be represented by a combined (basket) TAC in the runs discussed here. In that case the TAC was not substantially modified during the course of the run and the landed catches of both groups were combined when checking if the basket had been exceeded. If the basket quota had been exceeded, it was marked as tripped and no more of those groups could be retained for the remainder of the fishing year regardless of the make-up of the landed catch that originally filled the basket quota (i.e. all of the landed catch could come from one of the groups and still cause the quota to be filled; it was not necessary to have landed catch from both groups). This was the simplest means of implementing baskets that could be easily transferred between sectors. The transfer would have been much more complicated if contribution to the basket was more strongly prescribed – which may have been the case if the species in other baskets did not end up in a single group in Atlantis SE. The specifics of the transfer of baskets between sectors is something that would have to be considered carefully.

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[10] Note that the same level of error used in the pseudo-assessment at the regional level as was used when dealing with the total biomass for the entire model domain. It is possible for error levels in reality (and theory) to vary with each stock, as some may be more effectively sampled than others, but this issue was not considered in Atlantis SE to date.

2.6.3 Spatial management

Spatial management was one of the main management levers used in several of the scenarios. In some cases, fixed zoning was applied (so the proportion of each box accessible by the fishery remained constant throughout the course of the run), but in others rolling and dynamically applied spatial zoning and closures were used (the specific zonings for each scenario are given in detail with the scenario descriptions below). When rolling or seasonal closures were used a time series of proportional access per box per fishery was read-in from a pre-generated file. However, in the case of seasonal spawning closures and trade-offs between spatial management and TAC reductions, the zoning was dynamically set from within the management model. The way in which this is done will be detailed in the scenarios that use these approaches, but in both of these cases the proportional box access was adjusted for particular specified boxes. In contrast, the smaller spatial closures on the scale of aggregations were represented by temporarily resetting the catchability of the aggregating group to much lower levels. This solution has its drawbacks, but given the spatial resolution of the aggregations compared with the box sizes it was the most computationally efficient means of addressing the problem. Targeted trials using a more complex agent-based model (*InVitro*) indicated that the end result of explicit small scale closures and the catchability adjustment were very similar at the population level (particularly for groups that aggregate to spawn). Therefore this approach was deemed acceptable for use in the runs considered here.

2.7 Performance Measures

The performance measures used to evaluate the performance of each management scenario were the same as those adopted in the final report of the qualitative phase (Stage 1) of this study (Smith *et al* 2004). Several additional performance measures to describe system state were also included based on recommendations from the work of Fulton *et al* (2005a) on robust indicators of the ecological effects of fishing. A complete list of all performance measures and their definitions is given in Table 2.6. It was not possible to tease out some of the social or management measures as much as in the qualitative report. Similarly it was not possible to generate innovation or sector confidence measures dynamically from within Atlantis so they were omitted here.

2.7.1 Integrated Measures

It is always difficult to present comparisons across multiple performance measures. Integrated Indices and multivariate methods (such as PCA) have been used in the past to try and simplify this potentially daunting task. In this instance kite plots were used to present results based around topical groupings of the performance measures listed in Table 2.6. Instead of aggregating all the performance measures into a single index the measures were grouped in broad topic areas. The performance measures were then converted into relative measures versus the "best" value for that measure across all years in all scenarios. These relative measures were then averaged and the final values normalised so that they could all be compared on kite diagrams. In cases where a high value for a performance measure indicated poor performance the measure was inverted during the calculation of the integrated topical performance measure. The following performance measure groupings (and whether the performance measure was inverted or not in the calculation) were used to derive the integrated performance measures:

- Industry: Overall discards (inverted), habitat-impact (inverted), total effort (inverted), CPUE, total catch, average size of the catch and catch composition (in terms of species/groups)
- Management: Access, stability and quota trading
- Management costs: Overall management costs (inverted), research costs (inverted), compliance costs (inverted), monitoring and assessment costs (inverted)
- Social: Public image, gear conflict (inverted), port activity
- Economics: Gross value of landed catch, revenue per tonne, revenue per effort, costs (inverted), profits[11]
- Ecology: Biomass of bycatch groups, biomass of target species, habitat cover, pelagic:demersal biomass ratio (inverted), piscivore:planktivore biomass ratio, change in BSS-slope (inverted), biomass of TEP groups, microfauna biomass (inverted), shark and skate and ray biomass

Once average values were calculated the final values were normalised over all years and scenarios before being plotted. A slightly different procedure was followed when plotting individual performance measures in kite diagrams. In that case relative values were calculated and if a performance measure would have been inverted in the combined measures then the following equation was used to calculate the final value of the performance measure ($I_{fin,t}$) in year t:

$$I_{fin,t} = 1 - \frac{I_{raw,t}}{I_{raw,\max}}$$

where $I_{raw,t}$ is the raw value of the performance measure and $I_{raw,max}$ is the maximum value of the measure over all years and scenarios. As with the overall performance measures, the individual measures were normalised over all years and scenarios before being plotted.

[11] While all other indicators were treated as having a weight of 1.0, profits were weighted as 10.0. This was done to create a penalty function on negative profits. Without this oddities (such as high revenue per tonne, but insufficient tonnes captured to cover costs returning a "good" indicator result) arose.

Table 2-6: Performance measures used to evaluate the various management strategies and scenarios

Performance Measure	Definition
Fishery measures	
Catch of fished groups	Landed catch time series (tonnes per year) for each fished group (target or byproduct)
Catch of bycatch groups	Catch time series (tonnes per year) for each bycatch group
Size of catch	Average size of the fish caught per fishery
Total landed catch	Landed catch time series across all landings
Catch composition	Proportional make-up (by identity) and number of groups landed per fishery
Effort per fishery	Effort time series (days fished per year) per fishery (or subfleet)
Fleet size	Number of vessels per fishery (or subfleet)
Average size of vessel	Average size of the vessel in the fishery (this is a index of fishing power)
Area fished	Total square kilometres fished through the year (both as a simple overall footprint and also as an intensity map, where the footprint is scaled by the effort applied per box)
Distance travelled	Kilometres steamed during the year (sum of distances from home port to midpoint of boxes fished)
Catch per unit effort	Total landed catch / Total effort per fishery
Discards per group	Time series of discards (tonnes per year) for each group impacted by fishing
Total discards	Time series of total discards
Management measures	
Management costs	Compliance costs (spatial management, gear and TAC monitoring/enforcement/administration) plus costs of assessments plus data management/collection/collation costs
Research costs	Costs of fisheries independent surveys and science in support of assessments
Management access	Access to fishing sites per fishery (this index is a simple binomial that is assigned per site and fishery once annual fisheries decisions have been made in the management model)
Management stability	Number of changes to management per year per fishery (this index is a simple counter which is iterated every time a management lever is modified, like a TAC is changed, or an area opened or closed)
Gear conflict	Overlap of effort distributions of conflicting gears (calculated both in terms of absolute area of the overlap and as a proportion of the area fished by each fishery)
TEP interactions	Interactions (count of contacts) with TEP groups per fishery
Economic measures	
Trades	Number of quota trades per fishery
Proportion of quota traded	Proportion of quota held by fishery that was traded
Total quota holdings	Total quota held by a fishery across all groups
Value of quota traded	Total value of quota sold and leased
Gross value of production	Sum of landed catch * market value across all groups fished
Costs per tonne landed	Total costs (fuel, capital, gear, unloading and fixed) per tonne landed per fishery (across all groups caught)
Costs per day fished	Total costs (fuel, capital, gear, unloading and fixed) per day fished per fishery
Total profits	Total profit (GVP minus costs) per fishery
Profit per tonne landed	Total profit per tonne landed per fishery (across all groups caught)

Performance Measure	Definition
Profit per day fished	Total profits (fuel, capital, gear, unloading and fixed) per day fished
Boat cash income	Total profit per boat per fishery
Return on investment	Revenue per dollar invested in the fishery (calculated as profit as percentage of capital value, including licences, quota and spending on new vessels or gear switching)
Capital utilisation	Revenue per dollar invested in new boats and new gears if switch fisheries
Number of vessels switching	Number of vessels from this fishery that switched fisheries or gears
Ecological measures	
Biomass of each group	Biomass[1] (or relative biomass) of each group (or stock)
Habitat cover	Proportional cover by biogenic habitat forming groups
Pelagic:demersal biomass ratio	Ratio of total pelagic : demersal biomass (this is an index of system structure, it was calculated per cell per quarter, but also overall for the GAB, east coast waters and entire model domain per year)
Piscivore:planktivore biomass ratio	Ratio of total piscivore : planktivore biomass (this is an index of food web structure and integrity, it was calculated per cell per quarter, but also overall for the GAB, east coast waters and entire model domain per year)
Infauna:epifauna biomass ratio	Ratio of total infauna:epifauna biomass per box (index of benthic fauna integrity)
Diversity	Count of groups (and age stages) present
Biomass size spectra slope	Slope of biomass size spectra (index of system state change)
Social (and Port) measures	
Community perception	Running average of perception based on economic value, activity, discard rates and the inverse of the TEP and habitat impacts.
Port status	Index of activity (catch) flowing through port (which is an index of the employment generated by fishing in the port due to unloading, processing, transport and services/infrastructure)

1. For the age structured groups both total biomass and the spawner biomass were considered.

2.8 Scenarios

Of the four management scenarios[12] evaluated in Stage 1 of this study, three were selected for detailed quantitative evaluation (Scenarios 1, 3 and 4). After release of the Stage 1 report, a number of additional management scenarios were identified and discussed, most of them arising from submissions from groups of interested stakeholders in the fishery. Of these additional scenarios, two were selected for detailed quantitative analysis at Stage 2. Not all additional scenarios were evaluated as subsequent changes in the management of the fishery and more recent policy directions from government have effectively eliminated certain scenarios from contention – though the qualitative evaluation of these additional scenarios was

[12] Note that the nomenclature used here differs a little from the standard management strategy evaluation terminology. Due to the history of the project it was better to keep continuity with past names then to enforce standard nomenclature. Consequently what would normally be termed a strategy is referred to as a scenario here and what is normally called a scenario (variations on biophysical assumptions) are called environmental or parameterisation variants in this report.

Table 2-7: Summary of management strategies used in the Scenarios tested. Evolving indicates the gear control is changing through time in the course of the simulation (through variable uptake or staged implementation), while increasing indicates a relaxation (an increase) in the number of hooks allowed for use by auto longline.

Management Control	Scenario 1	Scenario 3	Scenario 4*	Scenario 9	Scenario 10
TACs					
TACs constraining (with harvest strategies)	No	Yes	Yes	Yes	Yes
Additional quota species	No	Yes (more)	Yes (few)	No	No
Non-quota species	No	Baskets	Baskets	No	Gulper basket
Companion TACs	No	Yes	Yes	Yes	Yes
Accounting for discards (qs)	No	No	Yes	Yes	Yes (Banned)
Regional TACs	No	Yes	Yes	Yes	Yes
Fishing without quota	Yes	Yes	Yes	Yes	No
Spatial management					
MPAs (SERMP)	Yes (largely ineffective)	Yes	Yes	Yes	Yes
Fishery closures (no take)	No	No	Yes	Yes	Yes
Sectoral closures (by method)	Existing	Additional	Extensive	Yes	Extensive
Industry closures	No	No	No	No	Yes
Gear controls					
Trawl – mesh size	Existing (ineffective)	Additional	Additional	Yes	Existing
Trawl – ground gear	None	Additional	Additional	Yes	Existing
Gillnet – length, height, mesh size	Existing	Existing	Existing	Yes	Existing
Auto longline – no. hooks/licence	Increasing	Existing	Existing	Yes	Existing
Shark longline	Existing	Existing	Existing	Yes	Existing
Drop line	Existing	Existing	Existing	Yes	Existing
Trap	Existing	Existing	Existing	Yes	Existing
On new methods of fishing being introduced	No restrictions	Restrictions	Restrictions	Yes	No restrictions
BRDs	Evolving	Evolving	Evolving	Yes	Evolving
Input controls					
Limited entry	Yes	Yes	Yes	Yes	Yes
Choice of gear	No	No	Yes	Yes	No
Vessel length (GABTF)	Yes	No	No	Yes (ALL)	Yes

* Note: The variant of this Scenario with modified shark fishery uses the same set of management strategies.

still very informative as they present a broad range of management options covering a large swath of policy space. It was important that they be considered before focusing more intensively on a subset for future research and policy directions.

The following is a sketch of the five main scenarios evaluated to date using Atlantis SE (a summary of which can be found in Table 2.7). Analysis of the Scenario 10 has been further refined to explore in more detail the possible costs and benefits of certain more specific management tools. Scenarios 1, 3 and 4 retain the same numbering as used in the Stage 1 report and Scenario 9 uses numbering from the additional scenarios evaluated towards the end of Stage 1. Variants of the scenarios (to allow more extensive investigation of specific aspects of the basic scenarios) are listed in Table 2.8.

2.8.1 Scenario 1

This scenario retains the management arrangements (quota, closed areas etc) that represented *status quo* in 2003.

Quota Management

All species under quota in 2003 continue under quota in this scenario. The list of the species under quota in this scenario and the initial quotas set for the first year of the run (2000) are given in Table 2.9. Where possible initial TACs were set based on actual TACs from the year 2000, but for those species that come under quota after 2000 the TAC of their first full year under quota (the year 2002) was used. As quotas in Atlantis are constraining (if landed catch > quota then excess catch is discarded or fishery closure occurs), all quotas applied in this scenario were set slightly above the actual quotas to capture the fact that quotas were effectively unconstraining in Scenario 1. During the course of the run, if the assessments lead the management models to reset the TACs then these could potentially become constraining. TACs are for commercial species only and they are set based on trends in catch rates over multiple years; no formal harvest strategies are in place.

There were no companion TACs used in this scenario; and apart from pre-existing regional (stock-based) TACs for orange roughy and gemfish, there were no new regional TACs in this scenario. Fishing without quota was allowed, though quota reconciliation had to occur before the end of the fishing year.

Gear Controls

Gear transferability is not permitted in this scenario, but many gear types have existing restrictions on gear dimensions. There are mesh size restrictions for gillnet (150-165mm), Danish seine (38mm) and trawl codends (90mm for all trawl methods, except prawn which must be between 40-60mm). These restrictions are represented in the model as a lower selectivity for smaller sized animals. There is also a maximum hook limit (15,000 hooks per set) for auto-longline vessels, which limits the potential maximum realised effort allocation and “swept area” per effort for the gear.

Table 2-8: Summary of variant management strategies used in the Scenarios tested – for variants marked with * multiple alternate levels of the settings were used.

Management Control	**Scenario 3 – Worst Case**	**Scenario 3 – Discard Accounting**	**Scenario 4 – Reduced Costs (x2)**	**Scenario 4 – Buybacks (x2)**	**Scenario 9 – No Climate Change**
TACs					
TACs constraining (with harvest strategies)	Yes	Yes	Yes	Yes	Yes
Additional quota species	Yes (more)	Yes (more)	Yes (few)	Yes (few)	No
Non-quota species	Baskets	Baskets	Baskets	Baskets	No
Companion TACs	Yes	Yes	Yes	Yes	Yes
Accounting for discards (qs)	No	Yes	Yes	Yes	Yes
Regional TACs	Yes	Yes	Yes	Yes	Yes
Fishing without quota	Yes	Yes	Yes	Yes	Yes
Spatial management					
MPAs (SERMP)	No	Yes	Yes	Yes	Yes
Fishery closures (no take)	No	No	Yes	Yes	Yes
Sectoral closures (by method)	Additional	Additional	Extensive	Extensive	Yes
Industry closures	No	No	No	No	No
Gear controls					
Trawl – mesh size	Additional	Additional	Additional	Additional	Yes
Trawl – ground gear	Additional	Additional	Additional	Additional	Yes
Gillnet – length, height, mesh size	Existing	Existing	Existing	Existing	Yes
Auto longline – no. hooks/licence	Existing	Existing	Existing	Existing	Yes
Shark longline	Existing	Existing	Existing	Existing	Yes
Drop line	Existing	Existing	Existing	Existing	Yes
Trap	Existing	Existing	Existing	Existing	Yes
On new methods of fishing being introduced	Restrictions	Restrictions	Restrictions	Restrictions	Yes
BRDs	Existing	Evolving	Evolving	Evolving	Yes
Input controls					
Limited entry	Yes	Yes	Yes	Yes (+Buyback*)	Yes
Choice of gear	No	No	Yes* (subsidised)	Yes	Yes
Vessel length (GABTF)	No	No	No	No	Yes (ALL)

Table 2-8: Continued.

Management Control	**Scenario 10 – Integrated Management**	**Scenario 10 – Strong Link**	**Scenario 10 – Weak Link**	**Scenario 10 – Gulper Closures**	**Scenario 10 – Buyback**
TACs					
TACs constraining (with harvest strategies)	Yes	Yes	Yes	Yes	Yes
Additional quota species	No	No	No	No	No
Non-quota species	Gulper basket	Gulper basket	Gulper basket	Gulper basket	Gulper basket
Companion TACs	Yes	Yes (Strong)	Yes (Weak)	Yes	Yes
Accounting for discards (qs)	Yes (Banned)	Yes (Banned)	Yes (Banned)	Yes (Banned)	Yes (Banned)
Regional TACs	No	No	No	No	No
Fishing without quota	No	No	No	No	No
Spatial management					
MPAs (SERMP)	Yes	Yes	Yes	Yes (+Gulper)	Yes (+Gulper)
Fishery closures (no take)	Yes (Tradeoff vs TAC)	Yes	Yes	Yes	Yes
Sectoral closures (by method)	Extensive	Extensive	Extensive	Extensive	Extensive
Industry closures	Yes	Yes	Yes	Yes	Yes
Gear controls					
Trawl – mesh size	Existing	Existing	Existing	Existing	Existing
Trawl – ground gear	Existing	Existing	Existing	Existing	Existing
Gillnet – length, height, mesh size	Existing	Existing	Existing	Existing	Existing
Auto longline – no. hooks/licence	Existing	Existing	Existing	Existing	Existing
Shark longline	Existing	Existing	Existing	Existing	Existing
Drop line	Existing	Existing	Existing	Existing	Existing
Trap	Existing	Existing	Existing	Existing	Existing
On new methods of fishing being introduced	No restrictions	No restrictions	No restrictions	No restrictions	No restrictions
BRDs	Evolving	Evolving	Evolving	Evolving	Evolving
Input controls					
Limited entry	Yes	Yes	Yes	Yes	Yes (+Buyback)
Choice of gear	No	No	No	No	No
Vessel length (GABTF)	Yes	Yes	Yes	Yes	Yes

Table 2-9: Groups (species) under quota and initial quotas (in 2000) used in Scenario 1. Note that the initial TAC was larger than the actual observed TAC to allow for the fact the actual TACs were unconstrained in effect.

Group	Initial TAC (t)	Actual TAC (t)
School whiting	1900	1870
Blue warehou	1950	1907
Spotted warehou	4850	4829
Gemfish	200 + 350	200 + 336
Shallow water demersals[1]	15500[1]	1502
Tiger flathead	3750	3742
Redfish	2100	2097
Morwong	1550	1536
Ling	2900	2820
Blue grenadier	12000	11937
Blue-eye trevalla	750	733
Orange roughy	1950 + 710 + 1650 + 1600	1944 + 700 + 1613 + 1600
Dories and oreos	1000	977
Gummy shark	4520[2]	1800 (in 2002)
School shark	300	292 (in 2002)
Dogfish	450	434 (in 2002)
Prawns	600	561

1. This group represents a large number of inshore species, so to allow for state fisheries and the catch of these other aggregated groups the allowed TAC was artificially inflated to match the total take from this group.
2. The quota for gummy was set this high to allow for unconstrained dynamics of all fleets which interact with this group, tighter TACs could artificially constrain some of the gears (especially bycatch gears like trawl) in the early years of the simulation. The implications of this decision on the results are discussed further in the main body of the results.

Spatial Management

Spatial closures that already existed or were intended for introduction as of 2005 were included in the zoning for this scenario. As spatial management is a form of zoning (differential access based on gear type and location in the water column that is fished) a single closure map was not used for all fisheries. Rather fisheries specific spatial closure maps were used (Figure 2.21). These maps were static throughout the course of each run for this scenario.

Other Regulations

The 2003 limits on the number of licences and vessel length were maintained throughout the course of the run for this scenario. This regulation has implications for the size of vessels allowed in the different subfleets used in the socioeconomic sub-model (and their associated characteristics such as costs or flexibility of effort allocation).

Monitoring of the fisheries in this scenario was via (i) industry-based logbooks and landing records and (ii) observers. The observers were on commercial boats (i.e. not fisheries independent) and recorded information on catch as well as discards. Note that while discards were monitored they were not deducted from individual quota holdings. The observer coverage on longline vessels was simplified to a fixed coverage of 25% of all trips (which in turn could influence the error rates assumed in the assessment method and rates of compliance).

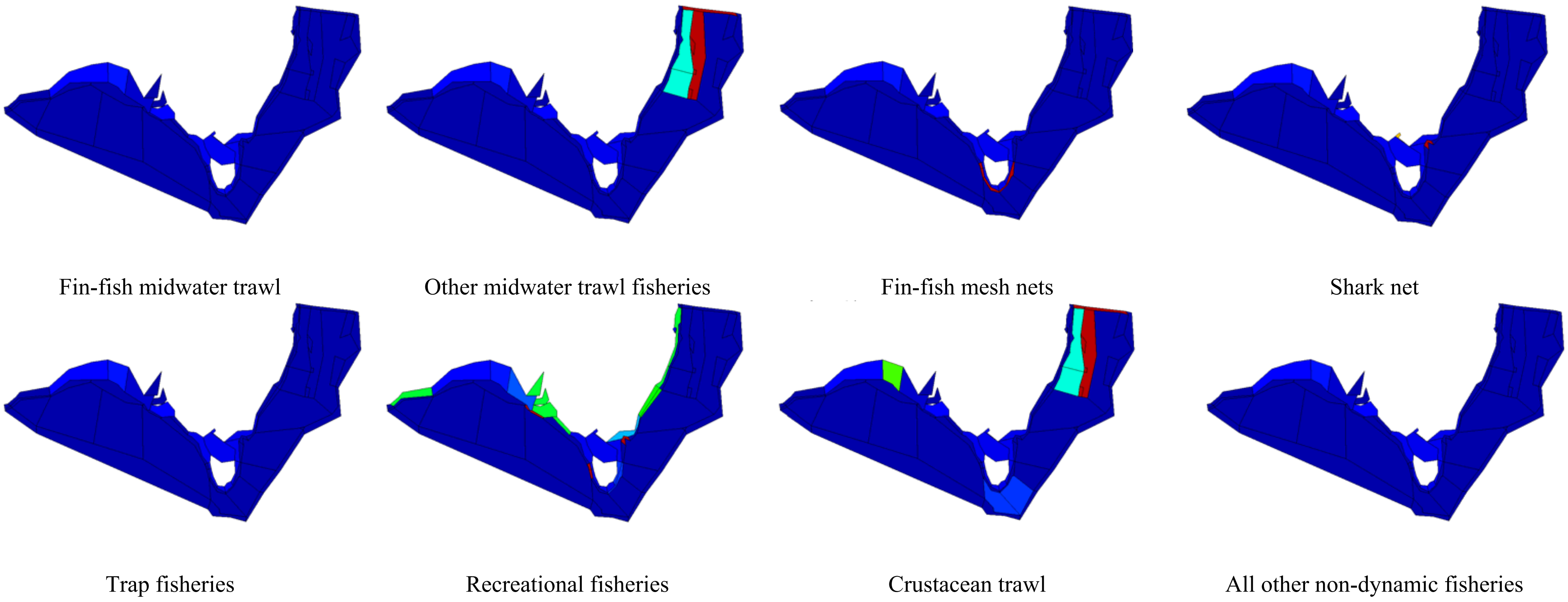

Figure 2-21: Spatial management maps for fisheries in Scenario 1 (colour key indicates the proportion of the box zoned open for that fishery). Note that while inshore, shelf and state fisheries have a non-zero value in offshore and oceanic boxes shown here, they do not access those boxes in practice due to fishing operation preferences and constraints.

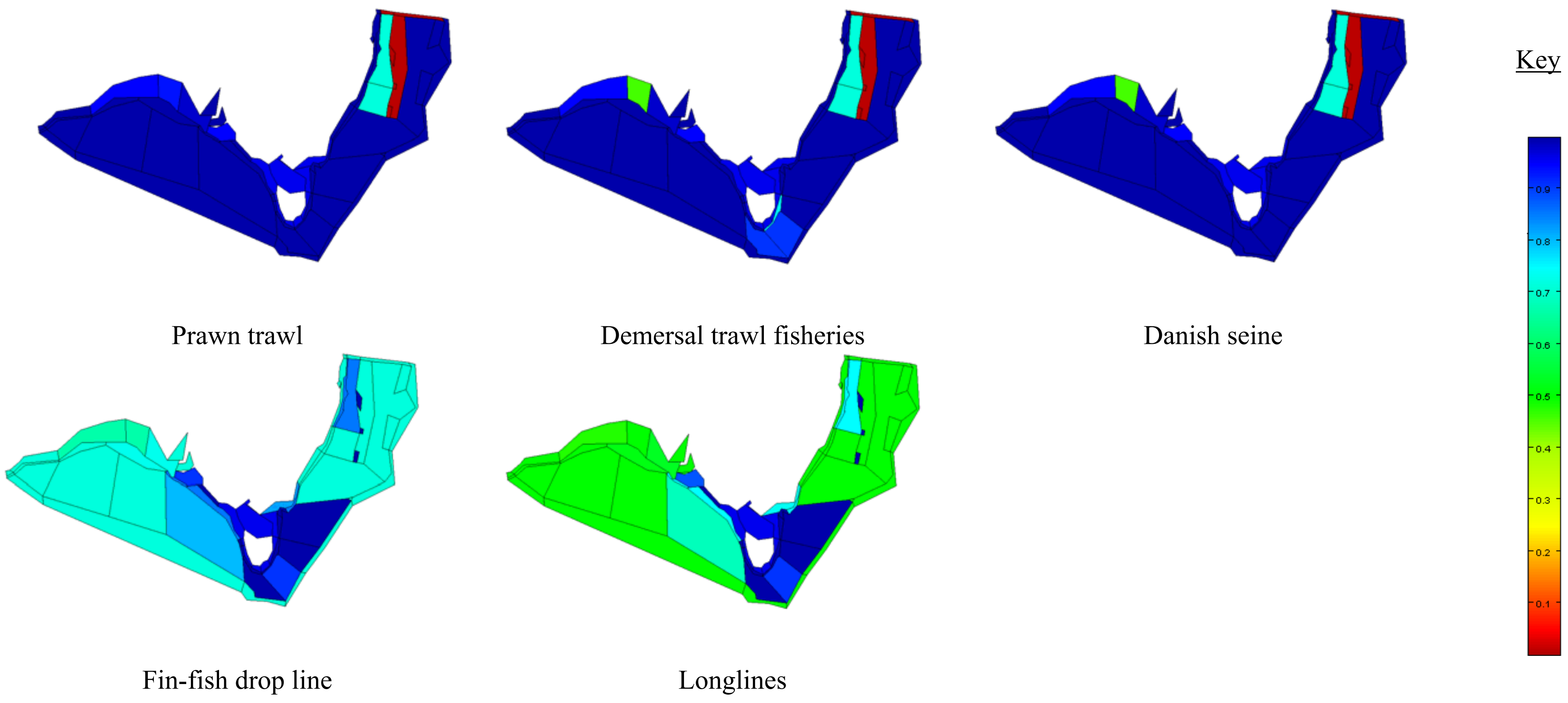

Figure 2-21: Continued.

2.8.2 Scenario 3

Compared to Scenario 1, this scenario involves a much greater emphasis on quota management though in the standard form presented here it still includes some spatial and seasonal management. Variants where these practices were discontinued were also considered (see Table 2.8).

Quota Management

The major emphasis of management in this scenario is through TACs, with eight more groups brought under quota, and the various demersal shark groups coming under a basket quota. The Stage 1 scenario included the provision for a group to shift from a basket to individual TAC should they consistently make up a given proportion of the landed catch or if there was concern expressed about the status of the stock. However the aggregate nature of some of the biological groups in Atlantis SE meant that this trigger was effectively tripped for all groups to come under individual quotas from the start of the run, so in effect this transition was never seen dynamically within a run. As for Scenario 1, the initial quotas were set based on actual historical quotas in the year 2000 (or first full year under quota), so for the groups under quota in both scenarios the starting TACs matched in the two cases. For those extra groups under quota in Scenario 3 (mackerel, cardinalfish, school whiting, red bait, ribaldo, demersal sharks, pelagic sharks, skates and rays, gulper sharks, other filter feeders, abalone, lobster, crustaceans and squid), year 2000 TACs were set based on the actual initial quotas; otherwise the starting TACs were set based on existing catches (so that the first year of the model run would reproduce the unconstrained catches for these groups in 2000). After 2000, the dynamic assessments from within the model were used to set TACS that could be constraining. The quotas that are specific to Scenario 3 are given in Table 2.10. Initial quotas for all other groups are given in Table 2.9 above. In a variant of this scenario discards are accounted for in the TAC setting process (see Table 2.8).

Companion TACs were used in Scenario 3, with the weaker stocks being limiting[13]. The companions used were:

- flathead, morwong and school whiting
- gummy sharks and school sharks
- spotted warehou, blue warehou, ling and blue-eye trevalla
- redfish and “dories and oreos”
- blue grenadier, blue-eye trevalla and spotted warehou
- orange roughy, dogfish, “dories and oreos”
- gemfish with “dories and oreos”
- ling and ribaldo
- ling and gulper sharks

Note that in reality the companions of redfish and gemfish would be the upper slope dories, while for orange roughy it would be the deepwater oreos. The vertical spatial structure used in

[13] Note that weak stocks were not identified a priori. Instead companion stocks and ratios of catch were identified and the model determined the weak stock and appropriate TAC’s using expression (2.11).

this model saw the deepwater oreos and upper slope dories aggregated to form a single group and so the various companion TACs had to be set against the "dories and oreos" group.

Regional (stock-based or east-west) TACs were also a major feature of the management used in this scenario. Regional TACs were used for orange roughy, gemfish, ling and blue warehou.

Formal harvest strategies are in place in this scenario, with all assessed groups set at tier-1 or 2 (and assessments occurring every 1-3 years). An attempt was made to replicate the Stage 1 Scenario 3 strategy and only have a few groups assessed at a tier-1 level year to year with the rest assessed via key indicators or alternative tiers – so that the level of investment in fisheries science and management matched the level of risk and TACs were set relative to the uncertainty of the assessment. Unfortunately work remains to be done within advisory groups on how to determine "key" species year-to-year, how to assess and make TAC decisions of alternative key indicators and how to trade off risk vs cost. Therefore it was not possible to model these aspects of this scenario at this time. Once the basis for making these choices has been formalised, this scenario can be revised and updated.

Fishing without quota is allowed, but there has to be reconciliation (for quota species) before landing.

Table 2-10: Groups (species) under individual or basket quotas and the initial quotas used in Scenario 3

Group	Initial TAC (t)	Actual TAC (t)
Red bait	7400	
Mackerel	450	
Ribaldo	150	100
Cardinalfish	40	
Demersal sharks[1]	750	108 + 92
Pelagic sharks	120	
Gulper sharks	220	
Skates and rays	160	

1. This group has inshore components as well (its stocks are structured with depth to represent different species at different depths), so the TAC was inflated to allow for shallow water take. A "regional" TAC was used to restrict the take of deepwater sharks to that intended by the 2005 TAC on deepwater sharks.

Gear Controls

Gear transferability was not permitted in this scenario.

The same gear restrictions as specified for Scenario 1 were also used in this scenario (i.e. restrictions on mesh size for gillnet, Danish seine and trawl, and a restriction on the maximum number of hooks per snood for automatic longliners). These more prescriptive gear restrictions were motivated by a desire to: aid the maintenance of sustainable stocks of quota species by protecting pre-recruits and aggregations of breeding animals; maximise yields; reduce take of bycatch species and discarding; minimise benthic habitat impacts; and increase the economic quality of the product. These changes were implemented as shifts in the selectivity curve to match the new gear sizes.

Bycatch reduction devices were also represented by reducing selectivity (and thus impact) on bycatch and benthic biogenic habitat groups – the reduction was between 1 and 80% depending on the group, age class and gear considered. The discard rates of the gears were also reduced (by 50-80%) in an attempt to consider the effects of improved targeting, which was a suggested in the Stage 1 analysis to be a result of changing mindsets within the fisheries under this scenario. The value of an MSE is that the relative contribution of levers and strategies can be accessed by trialing options that are beyond the realms of what is permissible in the real world situation. In this spirit a variant of the scenario which dropped the spatial and seasonal management aspects also had this decline in discard rates removed in order to facilitate a "worst case" evaluation of how this scenario's intentions could be derailed via behavioural uncertainty and unforeseen consequences of responses to management actions.

Spatial Management

The spatial management included in the standard form of this scenario was parameterised to make it directly comparable with the intended closures outlined in the Stage 1 version of the scenario. In particular:

- spatial closures that already existed or were intended for introduction as of 2005 were included in the zoning for this scenario
- no gillnetting in waters deeper than 200m
- no trawl in waters shallower than 170m west of King Island
- no autolongling in waters shallower than 200m

As with the zoning and spatial closures in the other scenarios the spatial management levers lead to differential access based on gear type. The resulting fisheries-specific spatial closure maps are given in Figure 2.22. These maps were static throughout the course of the run for this scenario. As noted above in the caption for Figure 2.21, inshore, shelf and state fisheries can have a non-zero value in offshore and oceanic zonings but they do not access those boxes in practice, due to fishing operation preferences and constraints (such as boat and hold sizes). A variant of this scenario with no spatial management for the dynamic (Commonwealth) fishery components was also run (Summarised in Table 2.8), where all boxes could potentially be fished by any of these Commonwealth fishery components. This was done to allow for an evaluation of whether TAC management alone is sufficient to manage a fishery of the complex and varied nature of the SESSF.

Other Regulations

The 2003 limits on the maximum number of licences and vessel length were maintained throughout the course of the run for this scenario.

Monitoring of the fisheries in this scenario was via (i) industry-based logbooks and landing records; (ii) VMS; (iii) observers; and (iv) fishery independent surveys (largely acoustic). The observers were deployed on commercial boats and recorded catch as well as discards, though the discards were not then deducted from individual quota holdings. As with Scenario 1, observer coverage on longline vessels was set at 25% of all trips. As mentioned above the level of observer coverage could influence the error rates assumed in the assessment method and rates of compliance.

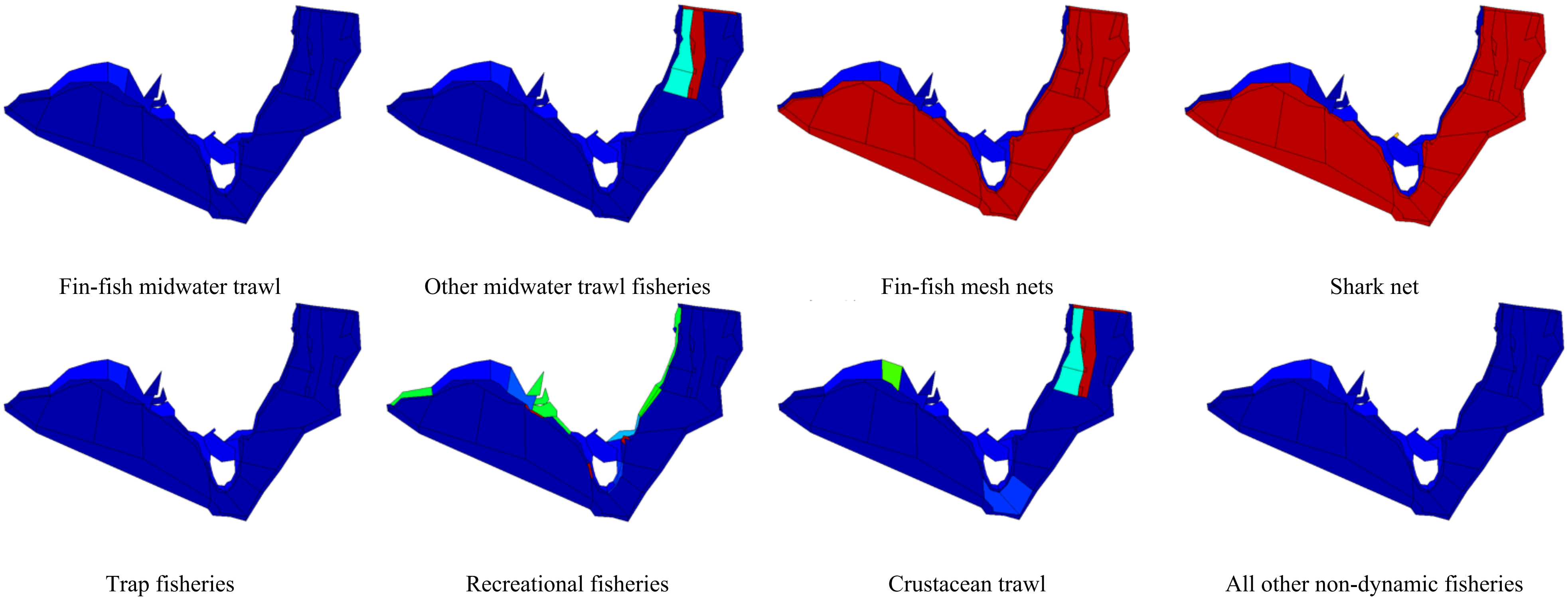

Figure 2-22: Spatial management maps for fisheries in Scenario 3 (colour key indicates the proportion of the box zoned open for that fishery).. Note that while inshore, shelf and state fisheries have a non-zero value in offshore and oceanic bozes in the zonings given here they do not actually access those boxes in practice due to fishing operation preferences and constraints.

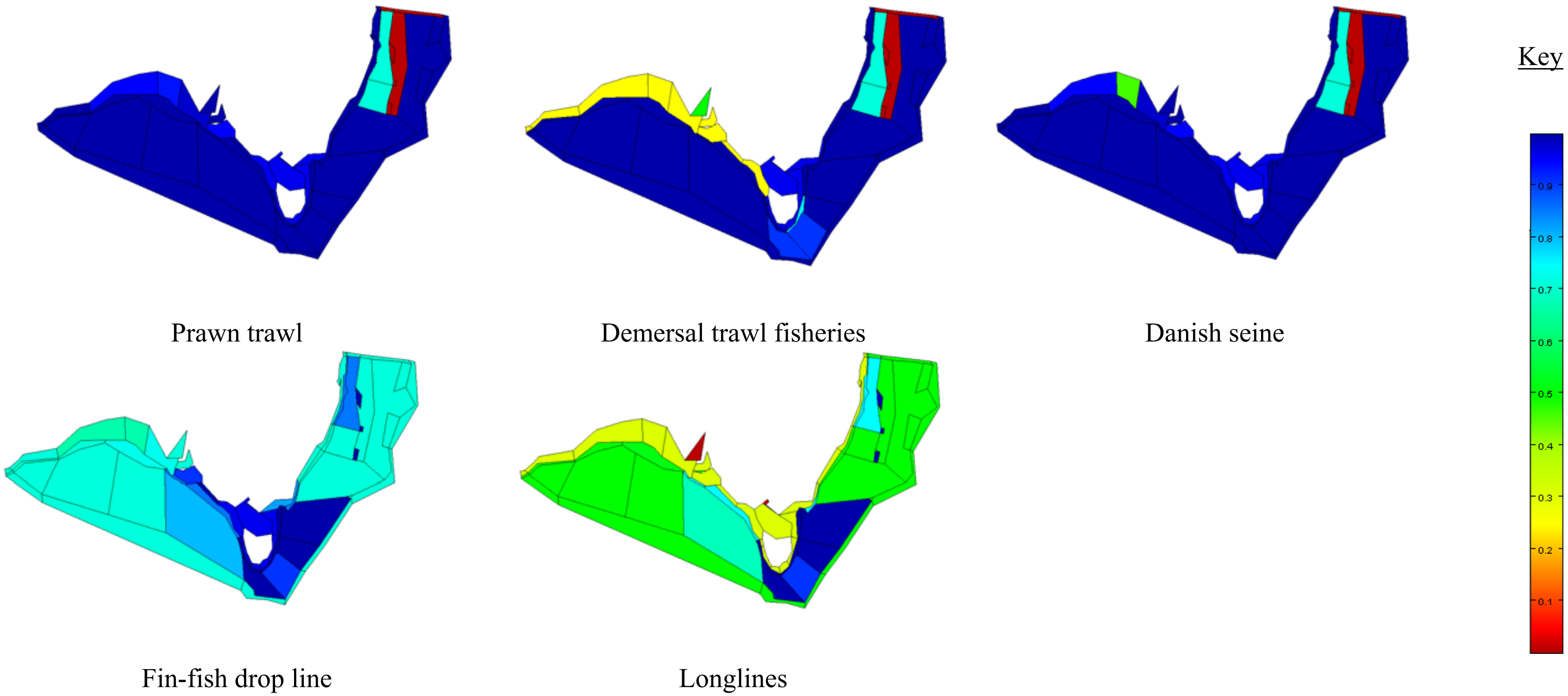

Figure 2-22: Continued.

2.8.3 Scenario 4

This scenario tries to use an integrated combination of many different management levers (zoning, quotas and other regulatory methods such as the provision for gear switching). When this scenario was first proposed in Stage 1 it was a radical departure from the way the system had been managed. Changes to the management of the system since mean that this scenario no longer seems so drastic.

Quota Management

The basic list of groups under quota (and initial quotas) matches that in Scenario 1, with the addition of gulper sharks (with initial TAC of 220t). Gulper sharks are also included in a basket trip limit with other demersal sharks (meaning that for gulper sharks there is an overall limit on what can be taken per annum plus a further limit on what can be taken per trip) – this serves to avoid local depletion, which this species is particularly susceptible to (Daley *unpublished*). The same set of companion and regional TACs implemented in Scenario 3 are also used here (the differences in the numbers of these more complicated quotas brought out in the qualitative analysis of Scenarios 3 vs 4 was not possible here due to the resolution of the biological groups). One major difference in the handling of quota in this scenario is that discards are included in the TAC setting process. They are included in the assessment, but the TAC allocation to the subfleets (quota holders) is reduced in proportion to the quantity of fish discarded – this provides an incentive for the subfleets to reduce discards.

Harvest strategies are in place in this scenario, with all assessed groups managed at tier 1. Fishing without quota is allowed, but quota is needed for landing.

Gear Controls

The gear restrictions on gillnet, Danish seine, and automatic longliners that were used in Scenarios 1 and 3 were also used in this scenario. For trawl fisheries minimum cod end mesh size is set at 100mm (i.e. larger mesh than for scenarios 1 and 3), which modifies the selectivity curve for this gear (reducing its take of smaller bodied groups and age classes). Bycatch reduction devices (as specified for Scenario 3) were also represented in this scenario – again this was done by reducing selectivity (and thus impact) on bycatch and benthic biogenic habitat groups.

One significant modification to gear controls in this scenario is that gear specific access entitlements are removed. While the 2003 limits on number of licences are maintained throughout the course of the run, limits on size of vessels are removed (so boats can be "upgraded" to larger sizes[14]) and gear transferability is allowed. During the vessel updating stage of the economics and fleet model, the probability of switching gears (and thus fleet within the model) or sizes is calculated based on expected returns under the different gears and the immediate cost of switching gears (i.e. fishery specific cost of installing the new gear, see

[14] This is represented in the model as the loss of a boat from one (smnall boat) subfleet and the addition of a boat in another (laregr boat) subfleet, with concommittant shift in characteristics, costs, fishing power and the like.

Appendix B for details). This means that it is possible to switch between any of the dynamic gears (those defining fleets with dynamic effort allocation) and to do so every month if desired (i.e. if probabilities of switching are high). Similarly the decision to change the size of the vessel can be made in any month, though the much higher costs involved mean it is much less likely to happen (and in fact happened only once during the course of the simulations for this scenario). These changes may not be made mid trip, only between trips. This is a simplified representation of gear switching, as in reality not all vessels could be re-equipped with other gears. For instance, gillnet vessels could not switch to either mid-water or bottom trawl. Likewise some of the smaller shelf trawl vessels would be incapable of trawling in the deeper waters. This complexity was omitted in this study, but if gear transferability is considered in any detail in future analyses these restrictions should be taken into consideration.

A couple of variants of this scenario (summarised in Table 2.8) were run with greatly reduced costs (i.e. no cost) of switching gears to assess sensitivity of the results (and potential impacts) of alternatives in prevalence of this behaviour. In one of these variants any boats switching gears switched only to the most profitable alternative gear (if any gear was more profitable than their current gear). In the other variant boats switching gear did so across all gears that were more profitable than their current gear (with the number of boats switching directly related to how much more profitable the alternative gear was). There was a strong seasonal signature to this switching, as the vessels switched gear to best match the peak species for that month (e.g. ling in the spring quarter).

Spatial Management

Zoning is a significant management lever in this scenario, with inshore, shelf, slope and deepwater zones all defined using the following rules:

- except for established Victorian Inshore Trawl grounds all waters within 3nm will be closed to all methods
- outside of established grounds (and a few developing GABTF sites) all fishing methods are banned in waters 90-200m
- 30% of all canyons (in waters 200-700m) are closed to fishing
- except for established fishing grounds waters deeper than 700m is banned

These zones are defined with the goals of preventing: excessive fishing of spawning aggregations, nursery areas and juvenile age classes and exceptionally vulnerable groups (e.g. gulper sharks); interactions with the TEP groups (e.g. seals, seal lions, whales, large pelagic sharks and seabirds); a loss of a large proportion of the diverse habitats that provide feeding, refuge and aggregation sites for a wide range of mid-trophic level fish and demersal sharks in the region.

As with the zoning and spatial closures in the other scenarios using spatial management levers, zoning often leads to differential access based on gear type and depth in the water column fished by a gear. The resulting fishery specific spatial closure maps are given in Figure 2.23. These maps were static throughout the course of the run for this scenario - Atlantis SE has the facility to allow adaptive management using spatial controls, but this would require specification of decision rules to determine the changes, and these have yet to be developed.

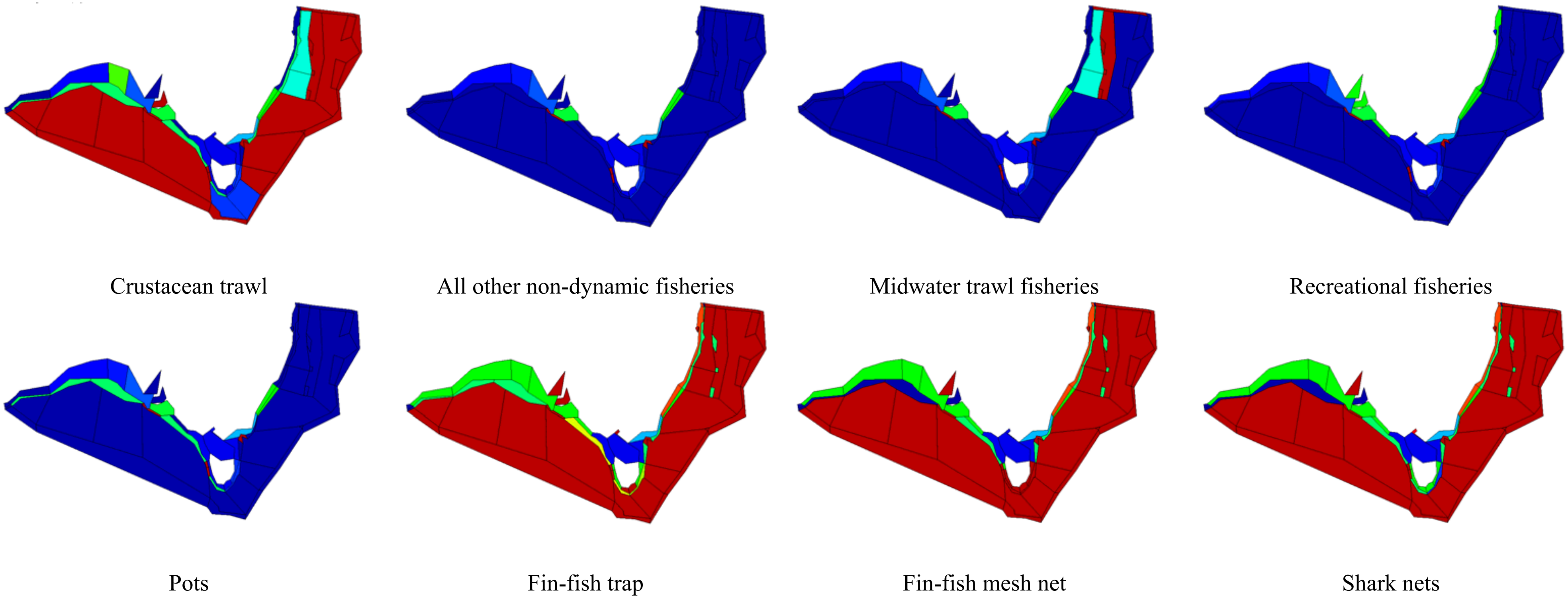

Figure 2-23: Spatial management maps for fisheries in Scenario 4 (colour key indicates the proportion of the box zoned open for that fishery).. Note that while inshore, shelf and state fisheries have a non-zero value in offshore and oceanic bozes in the zonings given here they do not actually access those boxes in practice due to fishing operation preferences and constraints.

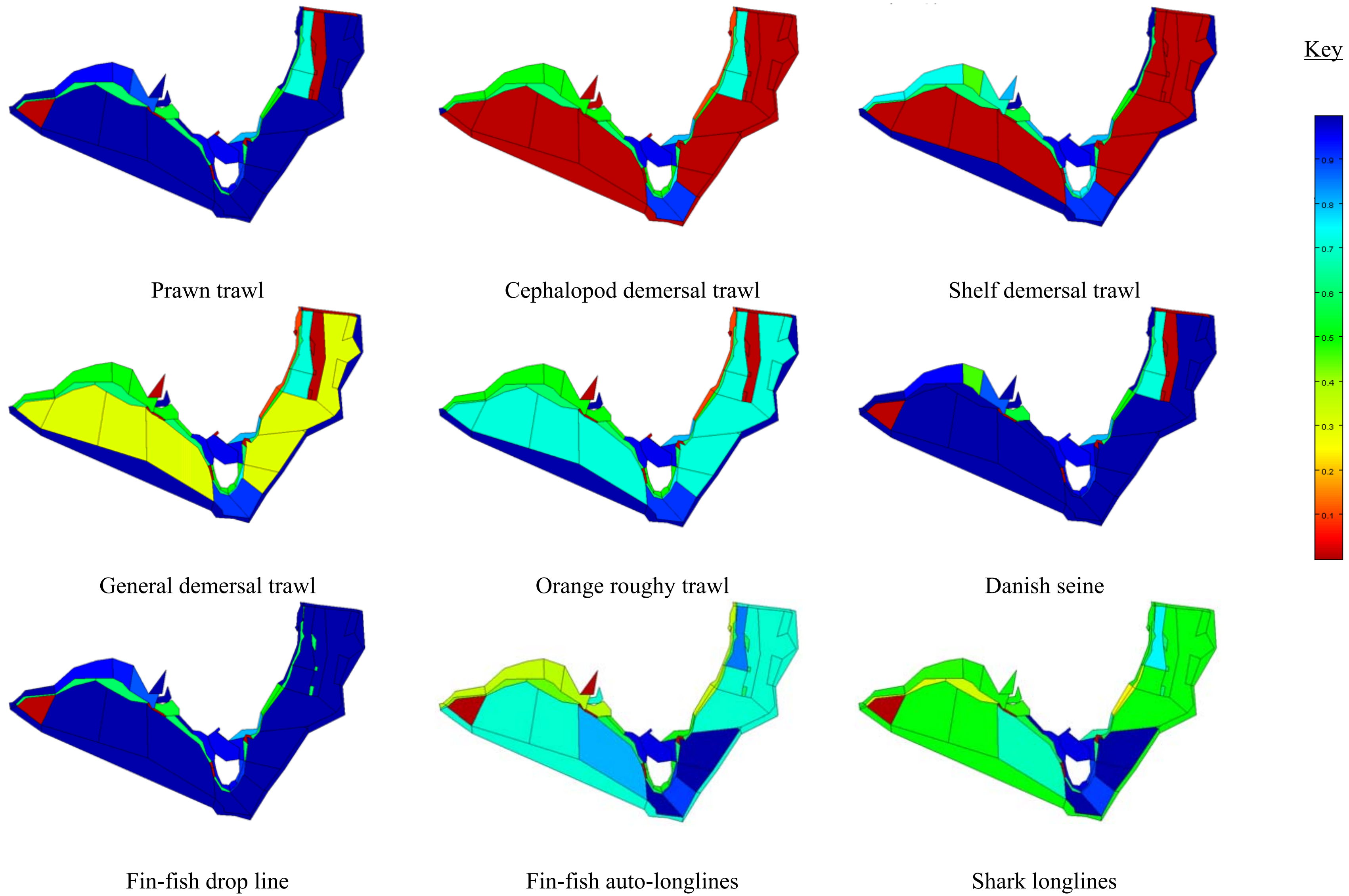

Figure 2-23: Continued.

Other Regulations

The 2003 limits on the maximum number of licences and maximum vessel length were maintained throughout the course of the run for this scenario (though variants which had 25-50% and 50-75% buyback of effort after 5 simulated years were also run – these are summarised in Table 2.8).

Monitoring in this scenario was via: (i) industry-based logbooks and landing records; (ii) VMS; and (iii) observers (with a relatively high coverage of 20-25% in all fisheries, though again automatic longliners are assigned a fixed % coverage rather than the variable levels currently specified in the fishery). Note that in this scenario discarding rules are vigorously monitored and enforced.

2.8.4 Scenario 4 – Modified Shark Fishery

In response to the pattern of shark catches seen under the standard Scenarios, a variant of Scenario 4 was run to explore the impact (i) of high initial TACs and (ii) the spatial resolution of the model on the model predictions.

TACs were initially set high to be unconstraining (given quotas were not introduced until 2001), but the reduction in quotas in the standard runs do not occur as quickly as seen in reality. To consider the impact of that quota level (and the higher than observed catches it allows) the initial quotas for gummy shark was reduced to 2200 in this scenario.

Another issue with the standard forms of the Scenarios is that the resolution of the model means the longliners are allowed to access a small proportion of the shelf boxes. The box break-line is at the shelf break not the depth contour defined in the qualitative definition of the Scenarios (or the actual regulations) where the exclusion depth is shallower than the shelf break. This means that in the standard scenarios auto-longliners access a small proportion of the shelf boxes. In combination with the rates of shark movement within boxes there is a constant turnover of fish moving into those sections of the box that the auto-longliners can access. This appears to potentially allow for the availability of the gummy shark stock to the auto-longline sector to be over stated. It was not possible in this instance to explicitly represent more boxes (and pull out the depth contours used as jurisdictional boundaries), though that would be a sensible approach for future work. Instead this variant of Scenario 4 had auto-longliners excluded from all shelf boxes (and in fact any boxes gummy shark enter).

2.8.5 Scenario 9

As defined in Stage 1 this scenario was drawn up by the Australian Marine Conservation Society based on the precautionary principle and emphasising the recovery of overfished and threatened marine species and minimising the impacts of fishing on protected and bycatch species to acceptable levels. Compared to the other management strategies (and management as it stood 2000-2006) it is a radical recasting of the fishery, so many current measures are removed (such as restriction of auto-longlining access to shelf waters) with new ones put in their place (described below). Moreover, the scenario attempts to capture some of the basic implications of the threat of human-induced climate change on ocean ecosystems. This was modelled by forcing a trend in water temperature – specifically a 1°C increase in the surface waters and a half degree decrease at depth, in line with observation and global climate model projections for the area in the next twenty years (Hobday *et al* 2006b). Other potential impacts such as the frequency of catastrophic events, wind patterns and large scale current redirections required climatology forcing that is currently unavailable. Once this becomes available then these facets of this scenario could be revisited and re-examined. A version of this scenario was also run without any temperature changes so that the impacts of climate change could be distinguished from the impacts of the spatial management approach used. The basic version was reported in the results, but there was little difference under the no-climate change variants (see section 4.6.1), as this version of Atlantis SE is not really focused on addressing climate change questions. Further development on this aspect of the model is under development, which would allow for a comparison of all the scenarios under a more rigorous representation of climate change conditions (including those aspects listed above which were unavailable for the management strategy discussed here).

Quota Management

The list of species under quota and the initial quota settings are as for Scenario 1. All assessed groups are managed under a tier 1 harvest strategy in this scenario. There are no basket quotas in this scenario, but there are regional TACs for orange roughy, gemfish, ling and blue warehou. Fishing, but not landing, without quota is allowed.

Gear Controls

Gear transferability was not permitted in this scenario.

While gear restrictions are specified for this scenario, they differ from those in other scenarios. There is no limit on the number of hooks per set for auto longliners (allowing for an increase in effective effort and “swept area”) for this fleet; and while the mesh restriction of 150-165mm is in place for gillnets the total amount of net allowed is extended up to 6000m (allowing an increase in maximum potential effort in the model for the gillnet using fleets). Cod end mesh sizes are increased to 110mm and Danish seine mesh sizes are set to 38mm or greater. Prawn trawl mesh sizes must be between 40-60mm with bycatch reduction devices (BRDs) in use (which reduce selectivity on bycatch and incidentally impacted groups).

Spatial Management

The spatial management and zoning in this scenario is quite complex. Effectively all waters within the 3nm State waters are a no-take fishing reserve with no dynamic fishery effort allowed within it (the forced fisheries are allowed to fish in these waters as they have State fishery components). Outside 3nm a series of fishing ‘paddocks’ define where fishing can occur. These paddocks are designed to:

- minimise gear impacts on benthic habitats
- enhance the productivity in areas outside the paddocks
- maximise fisheries returns inside the fishing paddocks
- promote the recovery of overfished species

- protect non-quota and TEP groups as well as areas of critical importance to fish stocks[15]
- avoid vulnerable species, such as chondrichthyans and deepwater species, and the habitats they are dependent upon.

The percentage of hard and soft grounds made available through this paddock system to the fisheries is dependent on the gear type used and the water depths.

'Soft bottom paddocks' are designated so that they prevent encroachment of bottom-impacting methods onto hard bottom habitats. They are also set-up to reserve significant areas of consolidated or structured soft bottom habitats adjacent to the paddocks in an attempt to enhance the long term productivity of groups using these habitats and thus maximise the spill over potential into the fished areas. On the shelf, non-trawl methods (with the exception of gill netting for sharks) are excluded from the soft-bottom paddocks so that competition and gear conflicts are minimised (or even eliminated). Gillnetting for shark is permitted in soft-bottom shelf paddocks to maximise the viability of the fishery, as it is restricted to the continental shelf in this scenario to avoid impacts on deepwater chondrichthyan groups. Line and trap methods may also access the soft bottom paddocks on the upper slope.

'Hard bottom paddocks' are accessible by gears with low benthic habitat impacts (e.g. hook, trap, gillnet and seine nets). Danish seining can also be used over rubble habitat on the shelf, but auto longlining is only permitted in 50 per cent of the 'hard bottom shelf paddocks' (due to their potential impacts on vulnerable shelf groups using those habitats).

Fishing by any means is not permitted on seamounts. Variable compliance with this assumption was allowed under alternative parameterisations, but for the standard parameterisation it was assumed that VMS would ensure high levels of compliance with this regulation.

The percentages of the habitat types accessible in the different paddock types at each depth band are summarised in Table 2.11. The resulting spatial zoning maps are given in Figure 2.24. Note that methods, such as midwater trawling, that do not contact the bottom are allowed to continue fairly unrestricted in depths down to 500 m. It is assumed that effective use of monitoring and observers will prevent them from encroaching into demersal realms.

Spawning closures were also implemented for blue grenadier, blue eye trevalla and ling. This was modelled by the use of a zoning time series read-in and applied in specific locations known to be the location of spawning aggregations (particularly in the boxes representing the canyons off eastern Victoria and western Tasmania). In addition smaller spatial closures were represented by temporarily reducing the catchability of the aggregating group by 20-80% (depending on available information regarding spawning behaviour for the groups in question) in selected boxes (catchability was reset to non-spawning levels with the cessation of the spawning period, which was a parameterised period taken from life history data).

A time series of closures was also read-in for the east coast boxes so that rolling block closures could be implemented to protect the eastern gemfish stock. These closures involve complete closure of the shelf break and slope north of 40°S during June to August each year.

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[15] The spatial resolution of Atlantis means that some of these critical features are only implicitly represented. The most important features (and regions) of critical fish habitat are explicitly represented in the model via the habitat model in Atlantis SE and the use of habitat dependencies and preferences.

Table 2-11: Summary of the percentage of hard, soft and canyon habitats accessible by trawl and non-trawl gears in each depth band in Scenario 9.

Depth	Soft	Hard	Canyon
< 3nm	No take all gears	No take all gears	No take all gears
3nm – 150m	30% of area open to bottom trawl and shark gillnets	15% of area open to auto-longlining; 30% of area open to other non-trawl gear and Danish seine	As dictated by habitat type in the canyon (hard or soft)
150 – 500m	80% of soft-bottom open in 2005 remains accessible to all bottom contacting gears; 100% of area open to midwater trawl (so long as it does not contact the bottom at any time)	70% of hard-bottom open in 2005 remains accessible to trap and line; 100% of area open to midwater trawl (so long as it does not contact the bottom at any time)	70% of canyons remain accessible (other 30% are closed to all gears; this 30% was selected based on expert information)
500 – 800m	20% of area remains open to all gears	No take all gears	As dictated by habitat type in the canyon (hard or soft)
> 800m	No take all gears	No take all gears	No take all gears
Offshore seamounts	No take all gears	No take all gears	No take all gears

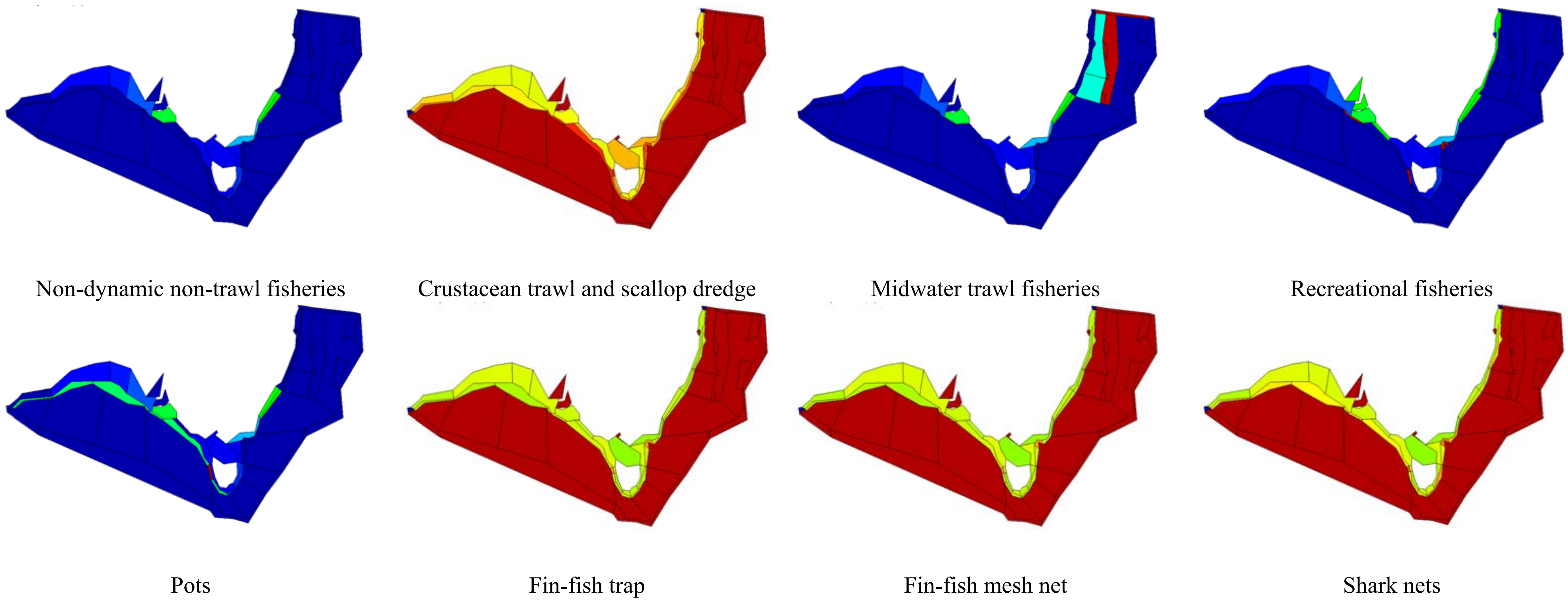


Figure 2-24: Spatial management maps for fisheries in Scenario 9 (colour key indicates the proportion of the box zoned open for that fishery). Note that while inshore, shelf and state fisheries have a non-zero value in offshore and oceanic bozes in the zonings given here they do not actually access those boxes in practice due to fishing operation preferences and constraints.

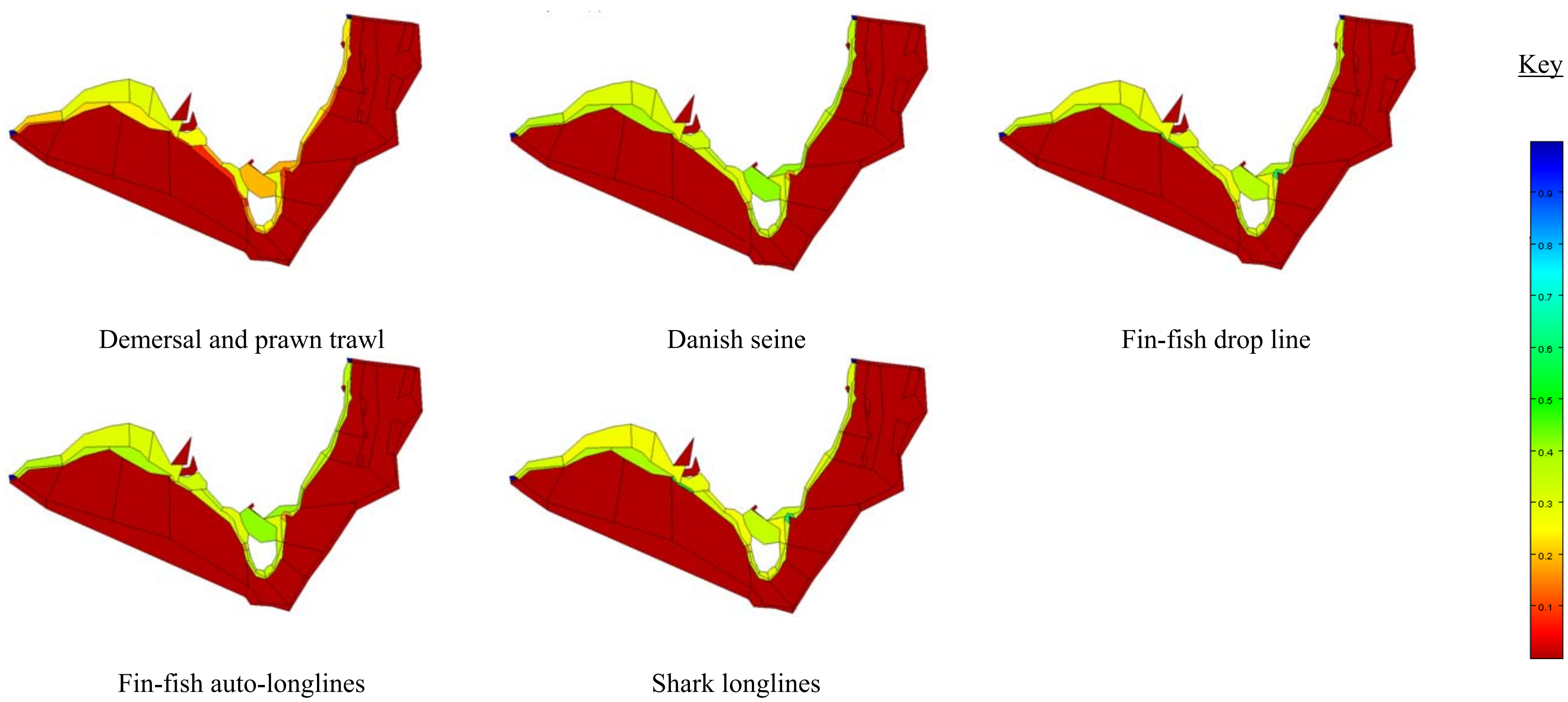


Figure 2-24: Continued.

Other Regulations

The 2003 limits on the maximum number of licences and vessel length were used at the start of the run, but after five simulated years a restructuring buyback of licences was implemented. This removed 25 - 50% of the effort in the dynamic fisheries at that point.

Monitoring in this scenario uses: (i) industry-based logbooks and landing records; (ii) VMS; (iii) observers (with a relatively high coverage of 20-25% in all fisheries, with automatic longliners again assigned a fixed % coverage rather than the variable levels currently specified in the fishery); and (iv) fishery independent surveys (largely acoustic). Note that in this scenario it is assumed that monitoring of compliance with the paddock system is effective and there is little infringement. Fishing creep (which impacts accessibility, selectivity, swept area and effective effort) is also assumed to be estimable and is taken into the decision making process.

2.8.6 Scenario 10 – Basic

All of the variants of Scenario 10 were developed in conjunction with AFMA staff and try to capture the current state of management (whether existing or planned for future introduction as of November 2006). A variant of this basic scenario included a buyback after 5 years.

Quota Management

All groups under quota as of 2006 are under quota in this scenario, though for comparative purposes the same starting quota levels used in other scenarios are used here rather than 2006 quota levels. There are also regional TACs for orange roughy, gemfish, ling and blue warehou. Fishing without quota is not allowed and the dynamic fisheries also have to land all of their catch of quota groups (i.e. no discarding of quota groups is permitted).

Harvest strategies are fully implemented for this scenario, though as for the other scenarios all are managed as tier 1 species in the present analysis.

Gear Controls

All gear restrictions specified in AFMA (2005) are in effect: 150-165mm mesh for gillnets, 38mm mesh for Danish seine, 90mm for trawl codends, 40-60mm mesh for prawn trawl and a maximum of 15,000 hooks per set for auto-longline vessels.

Spatial Management

All Department of the Environment and Water Resources (Department of the Environment and Heritage) and fisheries closures existing or planned as of November 2006 are implemented. The resulting zoning maps are given in Figure 2.25. Seasonal voluntary closures (running through September and October) were also implemented in ling spawning areas, as were the seasonal closures outlined in the Ministerial directive of September 2006. A map of the location of these closures is given in Figure 2.26.

Other Regulations

The number of licences and vessel size limitations current in 2006 are retained for the foreseeable future. No gear switching between fisheries is allowed.

2.8.7 Scenario 10 – Integrated Management

This is as for Scenario 10 above in all respects, except when TACs are flagged for a reduction. If the TAC of one of the groups listed immediately below is to drop by more than 30% then the TAC is reduced by only 30% and spatial closures on all "known" spawning sites (i.e. currently known based on expert knowledge) for that group are instituted instead of a larger reduction in the TAC (alternative cases where the "known" sites covered all spawning sites used in the model and where they only covered a proportion of the spawning sites were considered to check for the range in effectiveness of this strategy). These extra closures are only in place during the spawning period of the group. The list of groups treated in this way is: morwong, gemfish, blue warehou, spotted warehou, deep demersal fish, shallow demersal fish, flathead, ling, orange roughy, blue grenadier, blue-eye trevalla, redfish, ribaldo, demersal sharks, dogfish, gulper sharks, gummy sharks and school sharks.

Other Regulations

The number of licences and size limitations current in 2006 are retained throughout the course of the run. No gear switching between fisheries is allowed.

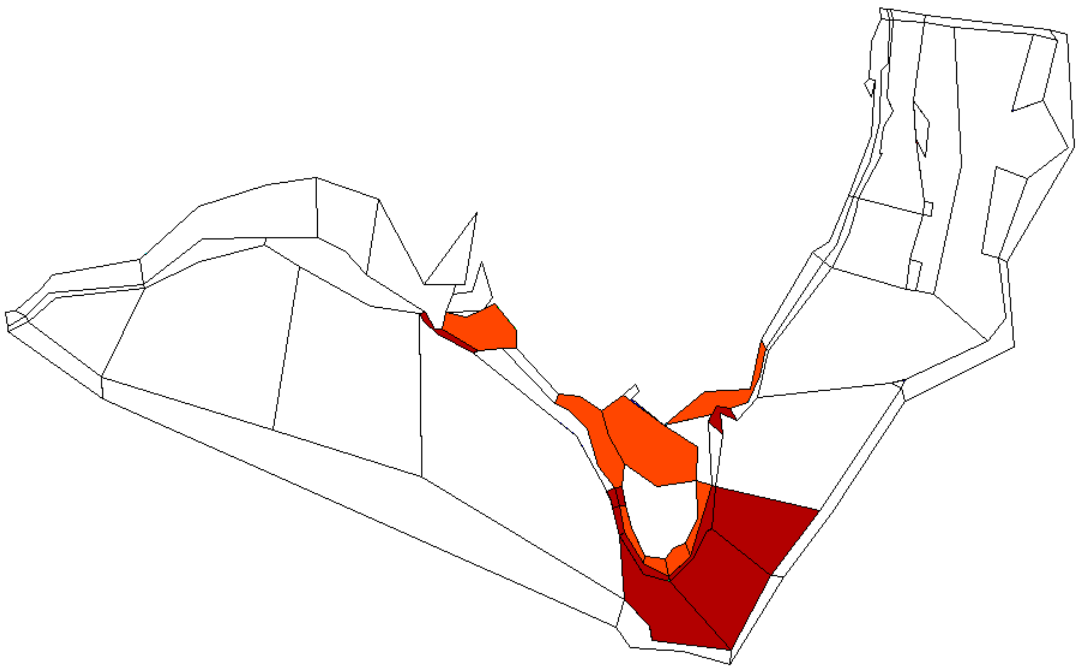


Figure 2-25: Sites of seasonal closures in Scenario 10. Red indicates a box that is completely closed to one or more gear types at some point in the year (either formally or voluntarily) and orange marks partially closed boxes.

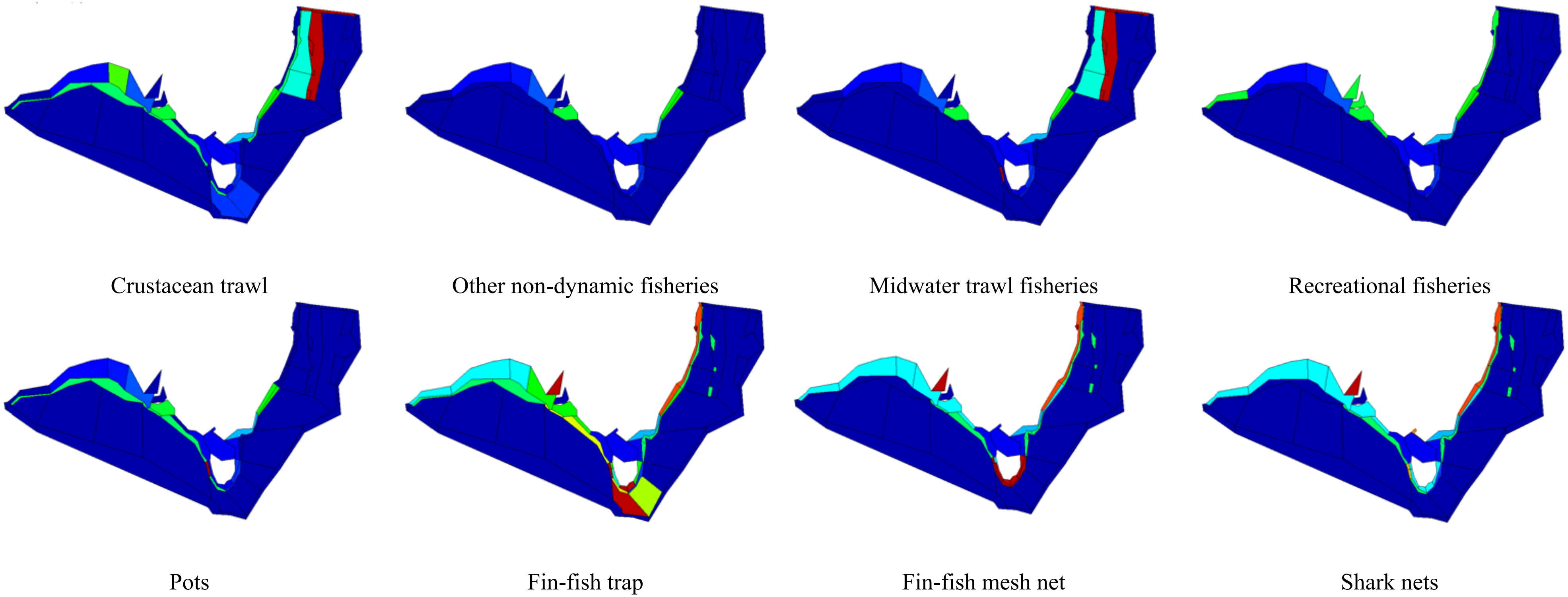


Figure 2-26: Spatial management maps for fisheries in Scenario 10 (colour key indicates the proportion of the box zoned open for that fishery). Note that while inshore, shelf and state fisheries have a non-zero value in offshore and oceanic boxes they do not access those boxes in practice due to fishing operation preferences and constraints.

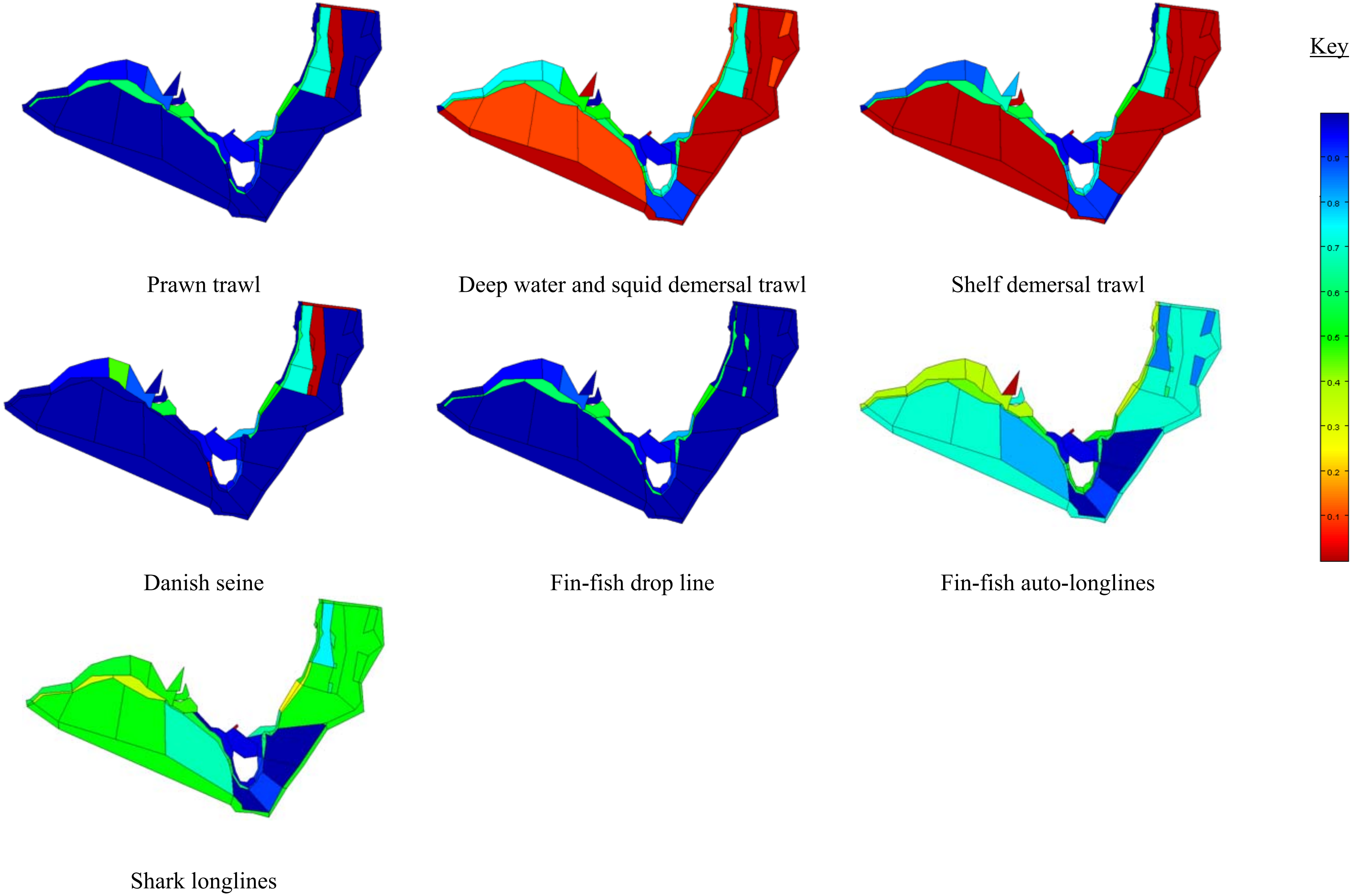


Figure 2-26: Continued.

2.8.8 Scenario 10 – Strong Link Companion TACs

The only difference between this scenario and the basic form of Scenario 10 is the application of companion TACs. The set of companions is as defined for Scenario 3. The groups are defined as “strong-link” companions (in that the more productive stock dictates the quota rescaling, as given by expression (2.10)).

2.8.9 Scenario 10 – Weak Link Companion TACs

This scenario has the same set of companions as for Scenario 3 and the “strong-link” variant of Scenario 10, but in this case the “weak-link” companions (less productive groups) dictate the quota rescaling.

2.8.10 Scenario 10 – Gulper shark Closures

This scenario is again only different from the basic form of Scenario 10 in one aspect. In this scenario, permanent year-round closures to protect gulper shark habitat are adopted. The already identified AFMA gulper shark closures are included, but have been extended spatially. Note that these additional closures were **not** defined in consultation with AFMA and should not be considered any indication of AFMA’s future intentions on this issue. A map showing their location is given in Figure 2.27.

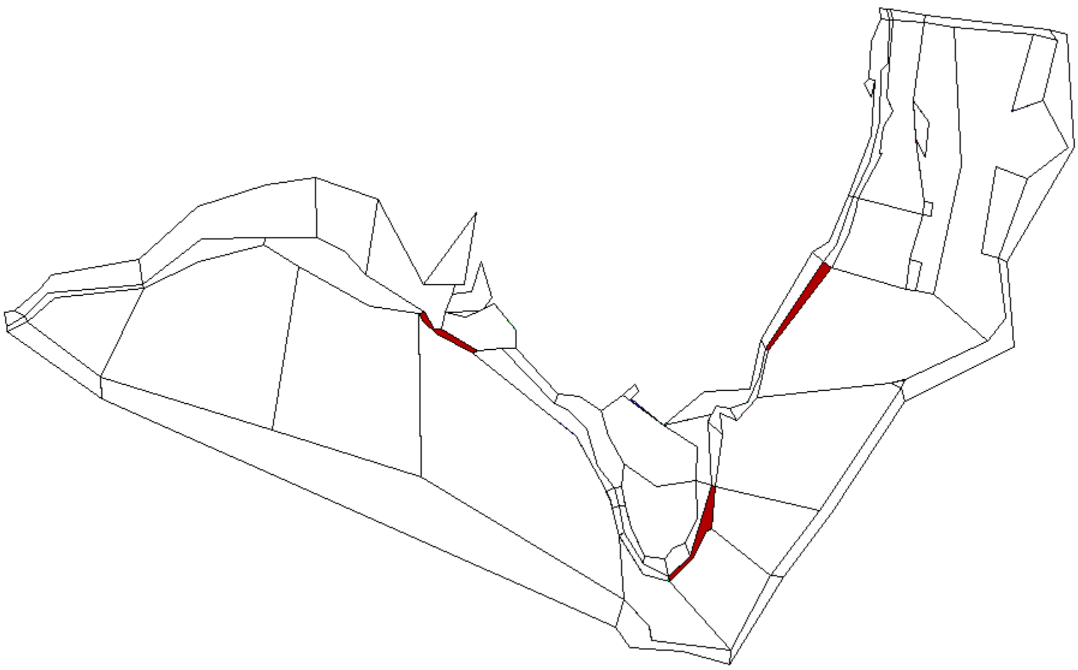


Figure 2-27: Location of gulper shark closures (entire box closed to all bottom gears).

3. HISTORICAL MODEL TIME SERIES

3.1 Virgin Biomasses

The initial (1910) total overall biomass per group was reached in a semi-iterative way. Initial estimates were taken from surveys (Williams 1981, May and Blaber 1989, Chapman *et al* 1992, Young *et al* 1993, Smith *et al* 1995, Koslow 1996, Young *et al* 1996a, Andrew *et al* 1997, Williams and Koslow 1997, Stevens and Wayte 1999, Bax and Williams 2000, Rowling 2000, Bax *et al* 2001, Bulman *et al* 2001, Williams and Bax 2001, Young *et al* 2001, Daley *et al* 2002, Graham 2005, Neira 2005, Walker *et* al 2005, Bulman *et al* 2006) and assessments (Tilzey 1994, Punt 2000, Punt *et al* 2000, Thomson 2002, Welsford and Lyle 2003, Fay *et al* 2004, Smith and Wayte 2004, Taylor and Smith 2004, Tuck *et* al 2004, Tuck and Smith 2004, Basson *et al* 2006, Klaer and Day 2006, Tuck 2006) and used to initialise an unfished version of the southeast Atlantis model. This 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.

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 catches without any group going to extirpation (as this has not been observed at a system scale in reality) and matched any observed biomass time series (of which there were very few and mainly for target or charismatic species and for restricted or patchy time periods). This calibration draws in the non-ecological mortality drivers for each group. An alternative method of historically calibrating the model would have been to impose historical effort and tune until that effort produced historically recorded catches. While this approach was taken when calibrating the dynamic fisheries effort model from the 1990s onwards (see section 3.6) it was not a viable alternative for earlier periods as those effort data were not available.

The final set of 1910 biomasses reached at the end of this iterative calibration is given in Table 3.1 and a comparison of the 1910 biomasses with those the year before fishing began on a group are given in Table 3.2. Initial age distributions were reached in the same way, but these will not be presented here. The non-stationary nature of the system, and the potential impacts of trophic interactions on the system, is indicated by the fact that the 1910 biomasses do not always match the pre-fishing biomasses in table 3.2; this is because changes due to environmental and fisheries induced shifts in the system can see biomass shift even before direct fishing pressure is felt by a group.

Interestingly, regional specific trophic connection coefficients and stock specific recruitment parameters were required when finding the original unfished stable state (without this a stable, plausible system state could not be found overall). This requirement was only strengthened during the second (forcing with catches) phase of the calibration. Based on this parameterisation it appears that waters off eastern Victoria and northeast Tasmania are much more productive as far as the demersal fish community goes, than elsewhere in the southeast region of Australia (despite the fact that major upwellings occur elsewhere, like the Bonnie coast), which may be related to the canyon features in the area. In addition, shelf break and upper slope demersal habitat plays a greater role in mitigating predation interactions, with predators finding it harder to access prey in this area. In contrast it is the shelf groups that find more protection amongst rough habitat through the Great Australian Bight.

As discussed in the next section there is a good deal of uncertainty associated with these biomasses and distributions. In particular, the biomasses of the pelagic components of the model may require significant revision and recalibration. Data available for use in state-based assessments were not all available for use in model calibration and so there can be significant divergence with some of those assessments. In particular, the biomass of red bait may actually be 1.2-1.5x the unfished value given in Table 3.2 (based on the recent assessment by TAFI). Implications of this uncertainty are discussed explicitly when dealing with results for these groups in chapter 5.

Table 3-1: Initial (1910) total biomasses (juveniles and adults) for all biological groups in the southeast Atlantis model. Due to their importance, two entries are given here for flathead and redfish, one for each species that makes up the group in the east and west - all other groups are reported as single totals even if they contain multiple stocks. The source of initial estimates used as starting points for model iterations are also given. Note that (i) more recent assessments may now be available for some groups, but the references given are those used during the model initialisation and calibration phase (which began in 2004) and (ii) "Model derived" means that there was no reliable biomass information available for the group and the value is the predicted value from Atlantis SE (constrained indirectly by the information used for other groups).

Group	Biomass (t)	Source
Pelagic invertebrates		
Large phytoplankton	237,732,337	Jitts (1966); Harris *et al* (1987); Bax *et al* (2001)
Small phytoplankton	742,771,809	Gibbs *et al* (1991); Behrenfeld and Falkowski (1997)
Small zooplankton	1,987,692,000	Model derived
Mesozooplankton	181,305,918	Young *et al* (1996a); McKinnon and Duggan (2003)
Large zooplankton	419,172,984	Young *et al* (1996a)
Gelatinous zooplankton	376,968,097	Deibel (1985); Bulman *et al* (2002b)
Pelagic bacteria	1,101,008,000	Model derived
Squid	864,511	Bulman *et al* (2002b)
Benthic invertebrates		
Sediment bacteria	108,060,800	Model derived
Carnivorous infauna	60,040,310	Bax and Williams (2000)
Deposit feeders	1,372,670,931	Bax and Williams (2000)
Deep water filter feeders	245,070,942	Bax and Williams (2000)
Shallow filter feeders	28,158,256	Bax and Williams (2000)
Scallops	46,2976	Malcolm Haddon pers. com.
Herbivorous grazers	16,082,580	Bax and Williams (2000); PIRSA (2003a)
Deep megazoobenthos	11,586,143	Bax and Williams (2000)
Shallow megazoobenthos	1,741,955	Bax and Williams (2000)
Rock lobster	27,780	PIRSA (2003b)
Meiobenthos	3,574,663,882	Model derived
Macroalgae	12,500,000	Model derived
Seagrass	6,425,000	Model derived
Prawns	379,119	PIRSA (2003c)
Giant crab	32,946	SARDI (2005)
Fin-fish		
Small pelagics	479,297	Ward *et al* (2001); Ward *et al* (2002)
Red bait	46,280	Bulman *et al* (2006)
Mackerel	124,534	Bulman *et al* (2006)
Migratory mesopelagics	502,823	Bulman *et al* (2002b)
Non-mig. mesopelagics	393,466	Bulman *et al* (2002b)

Group	Biomass (t)	Source
School whiting	31,608	Tony Smith pers.com.
Shallow water piscivores	412,346	Bulman *et al* (2006)
Blue warehou	35,003	Tuck and Smith (2004)
Spotted warehou	34,772	Tony Smith pers.com.
Tuna and billfish	61,075	Young *et al* (2001)
Gemfish	24,224	Prince *et al* (1997, 1998); Prince (2001)
Shallow demersal fish	217,532	Bulman *et al* (2006)
Tiger flathead	42,436	Punt (2005)
Deepwater flathead	27,377	Klaer and Day (2006)
Redfish	17,804	Klaer (2005)
Bight redfish	27,250	Klaer and Day (2006)
Morwong	29,483	Fay *et al* (2004)
Ling	33,335	Tuck and Smith (2004)
Blue grenadier	102,083	Tuck and Smith (2004)
Blue-eye trevalla	12,334	Tony Smith pers. com.
Ribaldo	4,774	Bulman *et al* (2002b)
Orange roughy	326,416	Smith and Wayte (2000); Wayte (in prep)
Dories and oreos	182,805	Bulman *et al* (2002b)
Cardinalfish	129,301	Bulman *et al* (2002b)
Top predators		
Seabirds	1,426	Reid *et al* (2002)
Seals	6,956	Pemberton and Gales (2004); Goldsworthy *et al* (2003)
Sea lion	1,573	Goldsworthy *et al* (2003)
Dolphins	4,253	NSW Marine Mammal Database
Orcas	6,509	NSW Marine Mammal Database
Baleen whales	522,992	NSW Marine Mammal Database IWC (http://www.iwcoffice.org /Estimate.htm)
Sharks		
Gummy shark	18,491	Tuck and Smith (2004)
School shark	40,336	Punt *et al* (2000)
Demersal sharks	240,581	Tuck and Smith (2004)
Pelagic sharks	256,847	Bulman *et al* (2006)
Dogfish	18,617[A]	Daley *et al* (2002)
Gulper sharks	15,808	Daley *et al* (2002)
Skates and rays	125,640	Model derived
Detritus		
Labile detritus	55,200,000	Model derived
Refractory detritus	415,000,000	Model derived

A. Information that has come to light since the model development was complete suggests that this value is appropriate for the slope dogfish biomass, but would need to be increased (even doubled) to cover shelf dogfish (Terry Walker *pers. com.*). This should be taken into consideration in future modelling exercises.

Table 3-2: Initial (1910) and year before fishing ("Pre-fishing") total biomasses (juveniles and adults) for the exploited biological groups in the southeast Atlantis model. Due to their importance, two entries are given here for flathead and redfish, one for each species that makes up the group in the east and west – all other groups are reported as single totals even if they contain multiple stocks.

Group	1910 Biomass (t)	Pre-fishing Biomass (t)	Pre-fishing Year	Pre-fishing / 1910 Biomass
Invertebrates				
Squid	864511	901718	1963	1.04
Shallow filter feeders	28158256	28686134	1963	1.02
Scallops	462976	310685	1964	0.67
Herbivorous grazers	16082580	20235513	1963	1.26
Shallow megazoobenthos	1741955	1675174	1940	0.96
Rock lobster	27780	27635	1940	0.99
Prawns	379119	396183	1940	1.05
Giant crab	32946	33121	1988	1.01
Fin-fish				
Small pelagics	479297	529316	1950	1.10
Red bait	46280	61867	1979	1.34
Mackerel	41411	39104	1950	0.94
School whiting	31608	31887	1940	1.01
Shallow water piscivores	495469	593800	1915	1.20
Blue warehou	35003	47196	1985	1.35
Spotted warehou	34772	51799	1979	1.49
Tuna and billfish	61075	67727	1950	1.11
Gemfish	24224	25696	1948	1.06
Shallow demersal fish	217532	217532	1918	1.00
Tiger flathead	42436	42436	1915	1.00
Deepwater flathead	27377	25972	1985	0.95
Redfish	17804	17335	1915	0.97
Bight redfish	27250	27002	1984	0.99
Morwong	29483	25859	1915	0.88
Ling	33335	32686	1972	0.98
Blue grenadier	102083	107444	1977	1.05
Blue-eye trevalla	12334	13198	1965	1.07
Ribaldo	4774	4454	1989	0.93
Orange roughy	326416	237484	1984	0.73
Dories and oreos	182805	182806	1974	1.00
Cardinalfish	129301	160536	1989	1.24
Sharks				
Gummy shark	18491	17637	1926	0.95
School shark	40336	40241	1926	1.00
Demersal sharks	240581	282608	1938	1.17
Pelagic sharks	256847	239616	1969	0.93
Dogfish	18617	18361	1965	0.99
Gulper sharks	15808	14942	1989	0.95
Skates and rays	125637	125637	1918	1.00
Top predators				
Seals	6956	6956	1910	1.00
Sea lion	1573	1573	1910	1.00
Baleen whales	522992	522992	1910	1.00

3.2 Parameter Sensitivity and Model Uncertainty

Model uncertainty is always a significant issue with ecosystem models, especially in one with the size and degree of interconnectedness of Atlantis SE. The “best fit” parameterisation presented above (and other refinements mentioned below) is undoubtedly only one of many parameterisations that would be judged acceptable under the calibration criteria used (which were that they must allow for all observed catches to be sustained without pushing any group to extinction and that the resulting biomass trajectories must match observed time series, if available, or be plausible given known system dynamics, if no observations were available for that group). To address this multiple parameterisations that all comply with the historical fitting criteria and span the plausible range of biomasses and dynamics were saved during the calibration phase of the study and used for the remainder of the management strategy evaluation. In addition, an evaluation of a broader ensemble of parameter sets (sitting around the final bounding set used) was checked to see how sensitive the model was to parameterisation of the various model components. The results of this investigation showed that there was a reasonable degree of sensitivity, with model performance falling off substantially as the parameterisation moved further from this final bounding set.

To explain this process more fully, the bounding parameterisations found during calibration are alternative results of a simple implementation of pattern-oriented modelling (see Kramer-Schadt *et al* 2007 for a more detailed description of the method). This is where previous work (such as dedicated factor analyses and the last decade of experience with the Atlantis modelling framework) is used to identify critical parameters which are then simultaneous varied and the resulting output judged against multiple datasets. These datasets are drawn from different sources (such as logbook data and independent scientific surveys) and capture different facets of the system at different spatial and temporal scales. Given the breadth of sources and scales of the data it is consequently more likely that the best performing parameterisations do represent “structurally realistic” parameters, at least in the local region of phase space, than if single-factor or even two- or three-factor sensitivities had been considered. The sensitivities to a smaller group of parameter adjustments is a more traditionally used approach, but is not as useful for large models with a large number of feedbacks as simultaneously constraining the parameterisations with multiple data sources of different types.

The sheer number of runs involved in a systematic sensitivity analysis of the classical form (e.g. as discussed in Saltelli *et al* 2004) or a more formal application of the inverse method of pattern-oriented modelling (Kramer-Schadt *et al* 2007) makes it infeasible for a model this size. Hence it is not possible to say with absolute certainty that a local (or global) optimum has been found for the parameters. Moreover, the pattern or performance does not rule out better parameter sets (which more closely fit observed time series) sitting at a distant point in parameter space; nor does it guarantee that the parameter set used was “right for the right reasons”. Nevertheless, as time precluded a broader search, and the bounding set of parameterisations covered the plausible spread of biomass values historically and other available data on system status and dynamics; it was agreed (after showing the biomass trajectories to experts in the region) that they provided a suitable basis for the remainder of the management strategy evaluation (the implications of this and other forms of uncertainty for the final analysis are discussed further in chapter 6).

Another aspect of model uncertainty is structural uncertainty. Extensive work using qualitative and network tools went into the developmental stages of the project to minimise potential impacts of this form of uncertainty. Loop analysis (Puccia and Levins, 1985) is a very useful tool for addressing uncertainty in how ecological systems are structured. They are very rapid techniques that allow for the exploration of alternate hypotheses about key processes and interactions among species. This form of analysis focuses on the simple connections between system components (e.g. between 2+ species or between species and a physical resource) and whether those connections are positive, negative or neutral - it ignores the strength or magnitude of interactions. Based on this structure (summarised in a connection or community matrix) matrix algebra is used to provide predictions about how species abundance will respond to a sustained, or “press”, perturbation when the system is at or near equilibrium. It is even possible to check for ambiguity in predictions due to the combined effect of many competing feedback mechanisms. The simplicity of the approach is its strength; by ignoring the magnitude of interactions (which can be incredibly hard to determine empirically with any degree of accuracy), the analyses can focus on structural uncertainty in any models built using that community matrix as a foundation. In this way it facilitates the rapid exploration of the consequences of alternate community and model structures (Dambacher et al., 2002; 2003; Ramsey and Veltman, 2005). These methods were used to consider a range of different community matrices for the southeast system and check for consistency of response in simplified (aggregated) foodwebs (defined using Johnson’s algorithm for regular colouration). In this way a model structure was selected that was of the simplest form without being so simple as to create erroneous responses to perturbation and structural error. Excessive aggregation as well as excessive detail will both result in a degradation of performance and should be avoided

Despite the effort put into considering core structural uncertainty during model development there will nevertheless remain some structural uncertainty (particularly pertaining to rare links or behaviourally moderated links and the membership of some of the aggregate groups, which may shift if the system were very highly perturbed).Given the resources necessary to develop a large number of quantitative models with alternate representations (e.g. trying alternative biophysical models or trophic linkages and observing whether the results changed) it has not been possible to give structural uncertainty any further explicit consideration (beyond what was done during model development). The network analysis tools suggest that the impacts of structural uncertainty should be relatively small in this case, but this has not been verified using the full quantitative model.

Despite existing uncertainty regarding the model’s form and parameterisation, in comparison with the socioeconomic assumptions and parameterisation, the biological uncertainties seem fairly small. The greatest uncertainties in the Atlantis SE model as a whole reside in the recently developed socioeconomic modules. There are many decades of experience with ecological models and over a decade of experience with ecosystem models now, but socioeconomic models that are process based, such as the one developed here are newer and fewer in number and so there is much more uncertainty associated with their use (as there is much less available experience). Alternative parameterisations were determined for the socioeconomic components of the model (using the same conceptual foundation of pattern-oriented modelling that was used to parameterise the biophysical components), but the sparser nature of data for this section of the model would mean that the process was not as constraining and that greater uncertainty persists, particularly with regard to the finer details of effort allocation and investment decisions and the market price models (where feedback based on supply and demand and product quality would have a significant impact on realised prices that are not explicitly represented here). Management costs are also fairly simply represented here and so a good deal of uncertainty would be associated with not only their magnitude but also their flow-on effects into the industry decision making processes. Despite all this there is immense value in the attempt to address how socioeconomic pressures can lead to unexpected responses to management measures. This is the first studies the authors know of that have given such attention to what is a very difficult, but critical, factor to the ultimate success of management strategies. Consequently, even with all the uncertainty the effort is justified (particularly if it is built upon in future work).

3.3 Landed catch time series

The historical commercial landed catches (1910 – 2000) were collected for each group from: logbooks (AFMA and operator held logbooks, 1977 onwards); the Australian Department of Agriculture, Fisheries and Forestry's National Fisheries Production database (by species by state per year from 1964, available from http://www.edaff.gov.au/nfpd/index.cfm); the New South Wales Department of Primary Industries (Pease and Grinberg 1995, Rowling 2000); Primary Industries and Resources South Australian (PIRSA 2003, Ward *et al* 2001, 2002); Victoria's Fisheries Division (NRE 2002); Department of Primary Industries, Water and Environment Tasmania (Tarbath *et al* 2002, Gardner *et al* 2004, Lyle *et al* 2004, Mills *et al* 2005); the Queensland Department of Primary Industries (Leigh and O'Neill 2004, Bell *et al* 2005); the Western Australia Department of Fisheries (WADF 2003); steam trawler data collected in the doctoral thesis of Klaer (2006a) and Klaer (2001); the International Whaling Commissions whaling records (IWC 1942, 1956, 1960, 1964, 1970, 1978, 1984); and SESSF stock assessment reports. Note that for some groups, Mackerel and the chondrichthyans, these aggregate catches may be an underestimate. In the case of the Mackerel, catches in state waters (which exceeded 40,000t in some years of the late 1980s; Gerry Geen pers. com.) have not been captured in the data available during model development (the correct catch data only came to the authors attention in the final stage of the project and there was insufficient resources to correct the omission at that point, but it should be an important consideration in future work). For the chondrichthyans the issue with the data was that much of the catch of these groups was either discarded or reported as "other species". There was some effort to capture this via bycatch rules (see Table 3.3), but recent dedicated analysis of the ISMP data (Walker and Gason 2007), which was not available at the time the model was being run, indicates that these rules may still substantially underestimate the actual historical catch and discards (by as much as a factor 2-3 or even more for skates and rays). Future work with Atlantis SE would benefit from a sensitivity analysis considering the impact of a time series matching the ISMP-based estimates on system state and subsequent dynamics.

The aggregate catches (landings) were spatially allocated to the model boxes based on their associated locations (if known from logbooks or other records) or based on more general descriptions of the distribution of historical fishing (this admittedly devolved to somewhat anecdotal accounts for some groups and in more remote areas). These spatially allocated landed catches were then used to force the Atlantis model (by extracting those spatially allocated time series of landings from the dynamic biomasses in those cells) and predict the resulting state of the entire system as the area underwent 90 years of fishing. A preferred age distribution for the targeted catch (typically weighted towards older heavier fish) was used to distribute the catches across the age classes. If insufficient biomass was available in an age class in the box then the fisheries attempted to take the deficit from the next younger age class, if it is present in the box. This process was repeated through all age classes and if a deficit still remained then it could be collected from adjacent boxes (as historical reporting was sufficiently coarse there was some uncertainty in the spatial allocation of landings). If this also proved insufficient then the deficit was allowed to accumulate and be taken at a future time step in that year (as historical landed catches were often only given in coarse steps, monthly or annual until the logbooks became mandatory). At the end of a calendar year any deficit was eliminated and an undercatch was reported.

Simple rules regarding recreational catches, bycatch and discarding were also used to capture the effects on groups not recorded in fisheries statistics. These rules are summarised in Table 3.3.). The bycatch/byproduct rules determine the biomass of each group caught for each kilogram of landed catch of the target (and reported) species using gear known to have significant amounts of bycatch (e.g. trawl); while discards were implemented as a fixed percentage of the catch (depending on year and dominate gear used at the time). These discard rules were taken from raw discard estimates versus landings (rather than total catch including discards), which are typically higher than the values used in standard stock assessments (which are versus total catch including discards). These rules were necessary for conditioning the whole system's response to historical fishing, extracting landings alone would not have been a faithful reflection of the pressure on the system, nor the potential changes in the system in response to that pressure.

It was not always possible to match the observed time series 100% in every year for every group (almost certainly due to problems with the initial spatial allocation of the landed catches). Nevertheless, it was possible (with the final calibrated parameter sets) to take the observed catch, or very close to it, in the majority of groups in the majority of years. It isn't possible to provide here a yearly catch map and time series per box for every group in the model. Instead overall total catch (landings) time series are given for a representative selection of the fished groups (Figures 3.1 – 3.31) and for the total overall fin-fish and shark catches (Figure 3.32). Catches of baleen whales and invertebrates were omitted from this overall total as they are not the primary target of the focus fisheries for this project and would overwhelm the trends from those fisheries if included in the combined total.

A series of snapshots of the catch distribution for the total overall fin-fish and shark catch is also provided to give a taste of the kind of output given by Atlantis. It is also a useful illustration of the shift in magnitude and location of landings through the period 1910 – 2000. Initially landings were quite small (on the order of 780t) and located off Sydney and central New South Wales. They rose steadily through until the 1940s, exceeding 10,000t in 1941 and 1942, and spreading down along the east coast into Victoria and even as far as Tasmania on occasion. There was then a dip through the remainder of the Second World War before things picked up where they had left off. Landed catches remained at about this level of 10,000t and concentrated along the east coast through the 1950s. It wasn't until the 1960s that landings began to grow again; with notable amounts now coming from South Australia and Tasmania (particularly the island's east coast). The biggest jump in landings was during the mid-late1980s and early 1990s, with peak harvest of 85,000-95,000t during this time. It was also during this time that the deep waters were intensively fished. By 2000 landings had dropped off somewhat and there was a much more even distribution of landings across depths and west-east, though eastern Victoria and the two edges of Bass Strait continued to dominant with regard to the percentage of total landings caught in those locations.

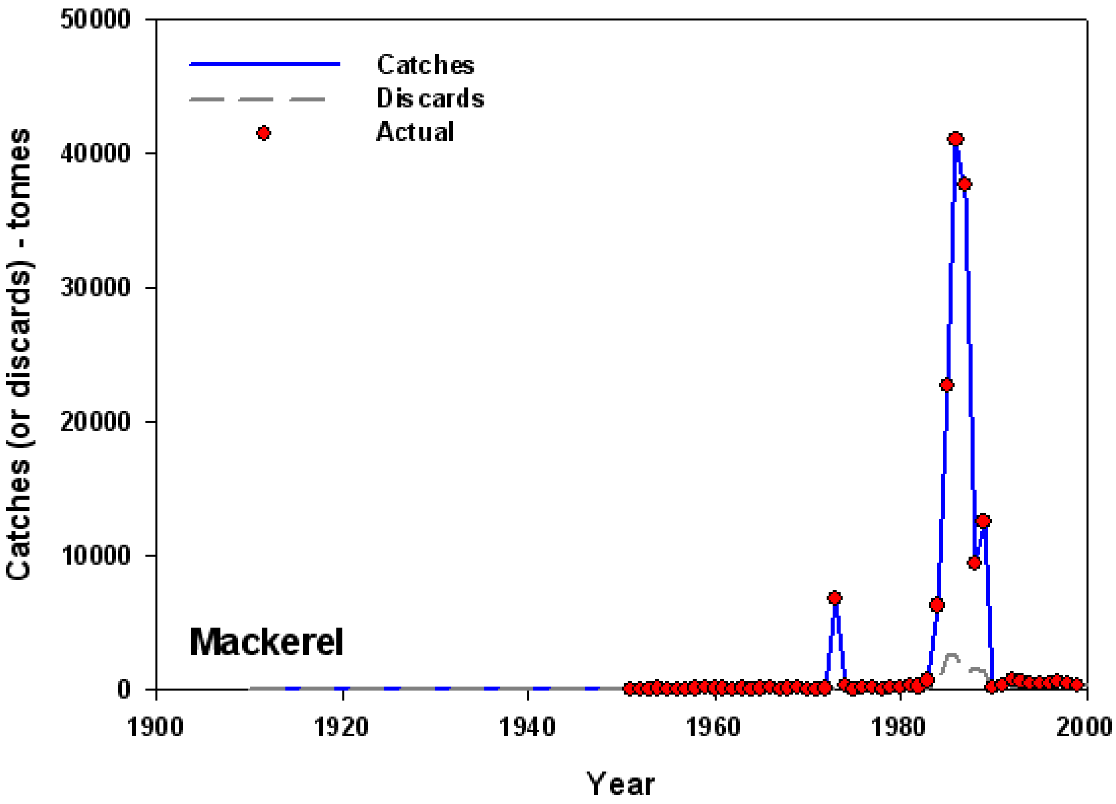


Figure 3-1: Atlantis historical catch (landings) and discards time series for mackerel.

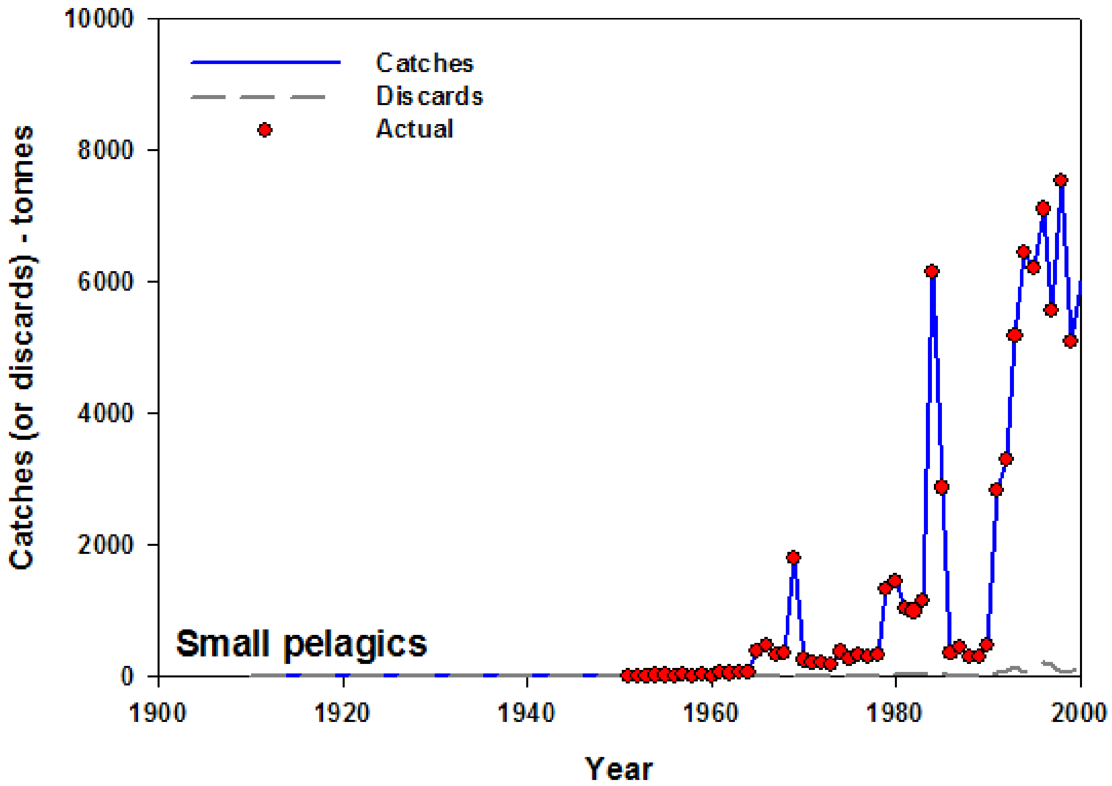


Figure 3-2: Atlantis historical catch (landings) and discards time series for the small pelagics group.

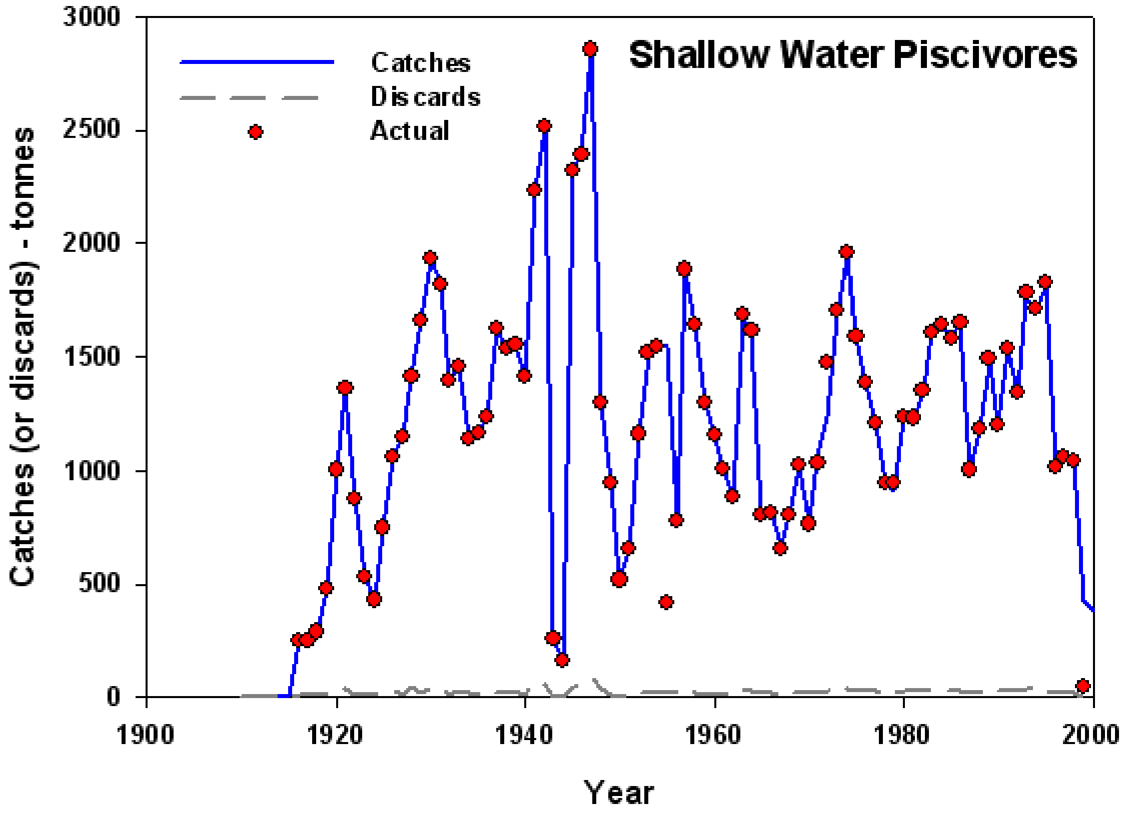


Figure 3-3: Atlantis historical catch (landings) and discards time series for shallow water piscivores

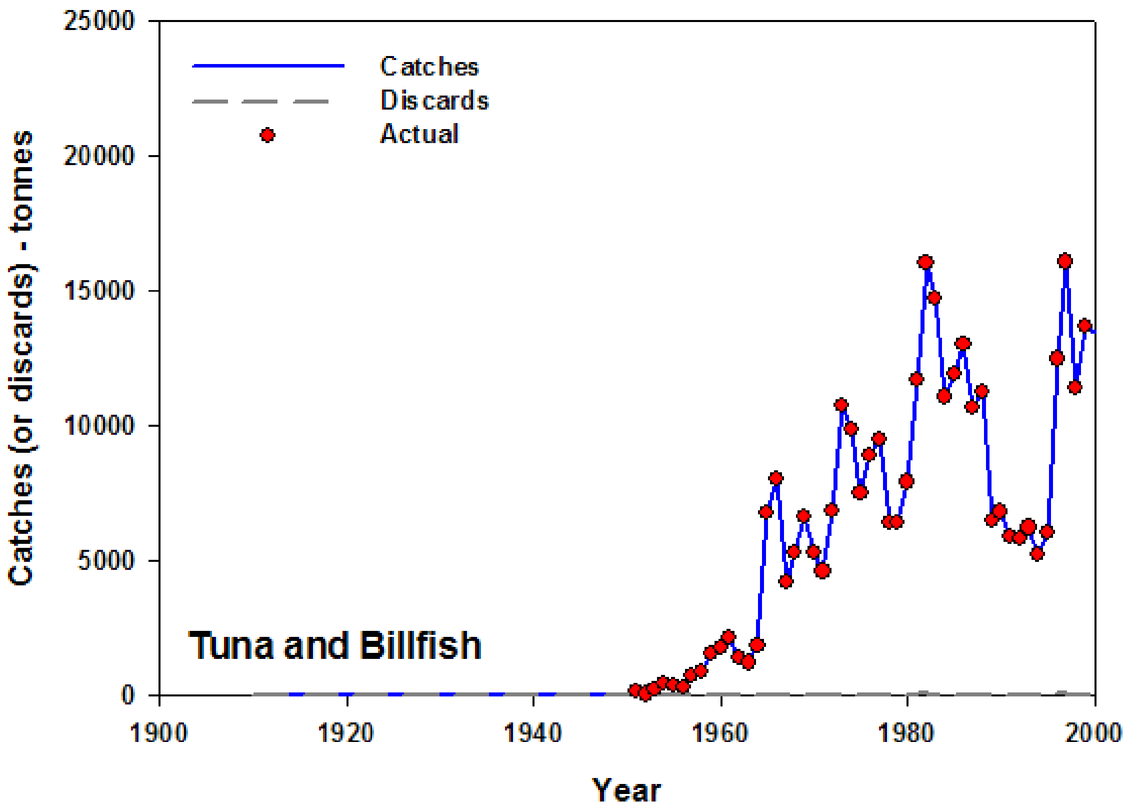


Figure 3-4: Atlantis historical catch (landings) and discards time series for tuna and billfish

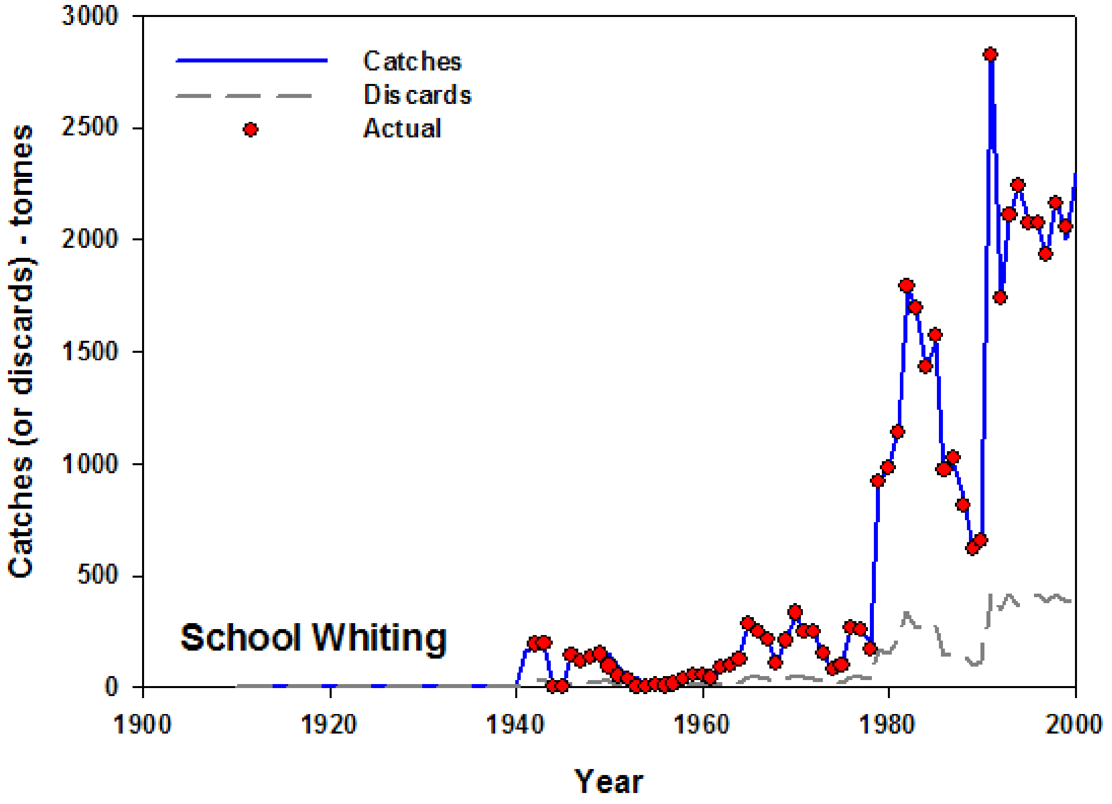


Figure 3-5: Atlantis historical catch (landings) and discards time series for school whiting

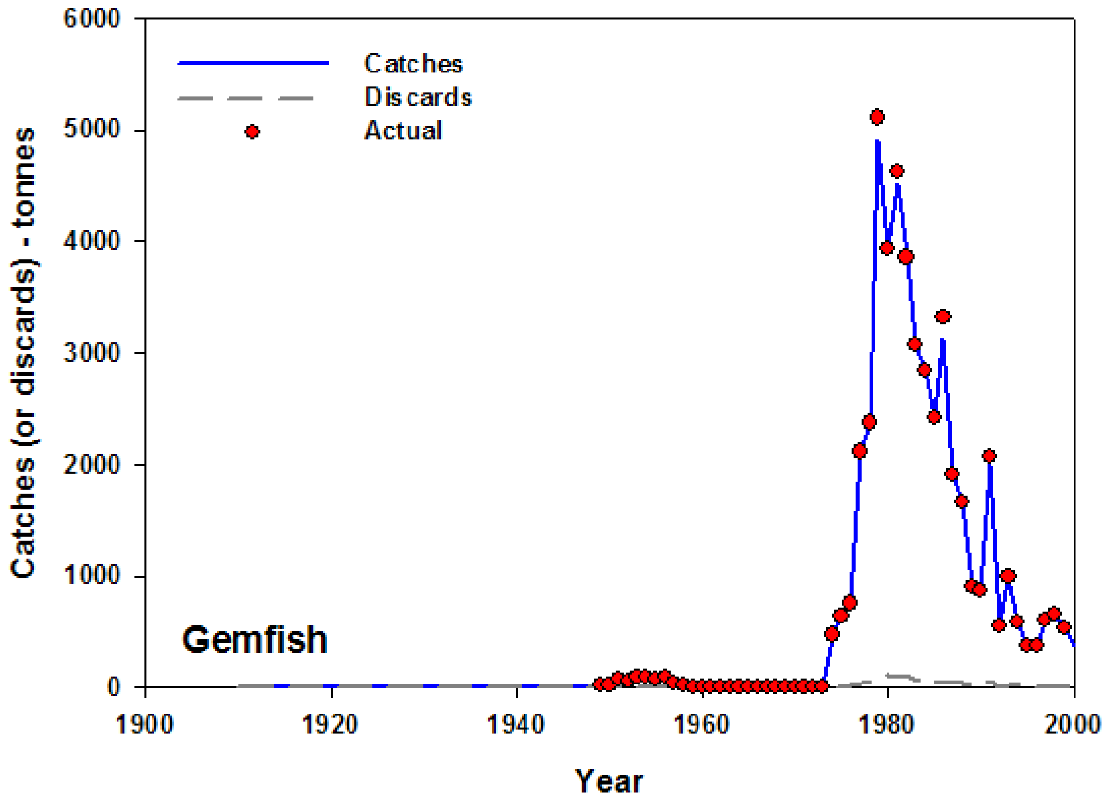


Figure 3-6: Atlantis historical catch (landings) and discards time series for gemfish

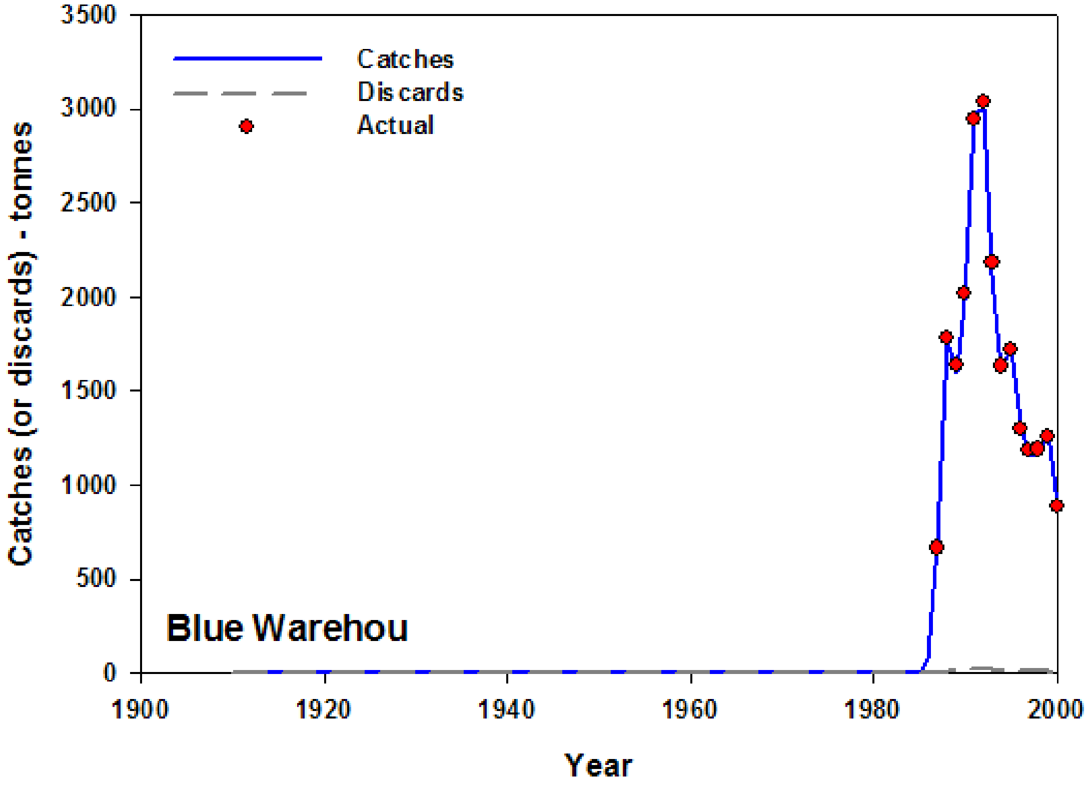


Figure 3-7: Atlantis historical catch (landings) and discards time series for blue warehou

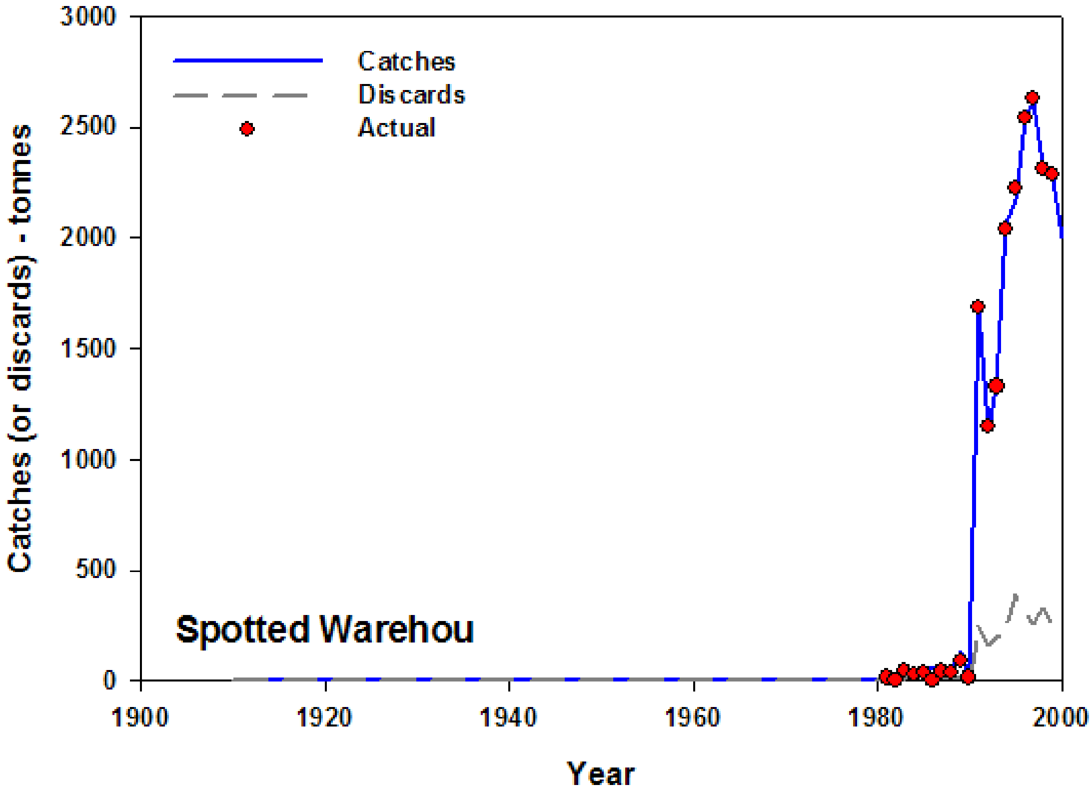


Figure 3-8: Atlantis historical catch (landings) and discards time series for spotted warehou

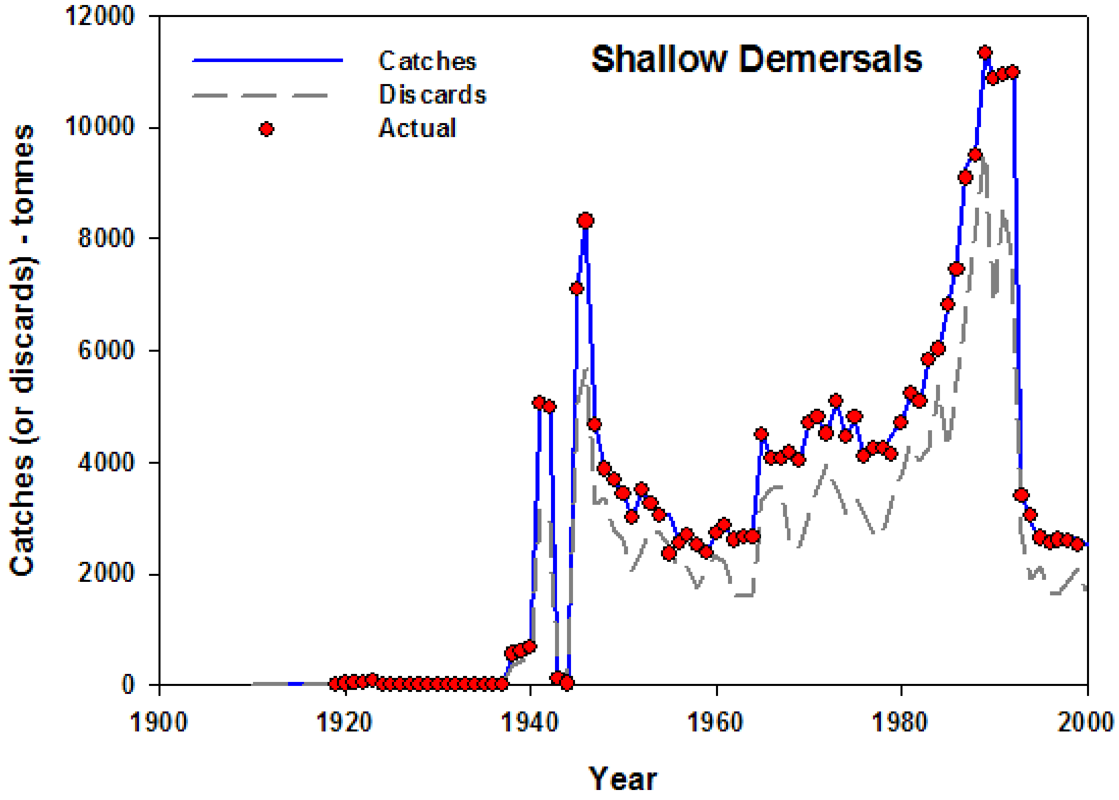


Figure 3-9: Atlantis historical catch (landings) and discards time series for shallow demersal fish

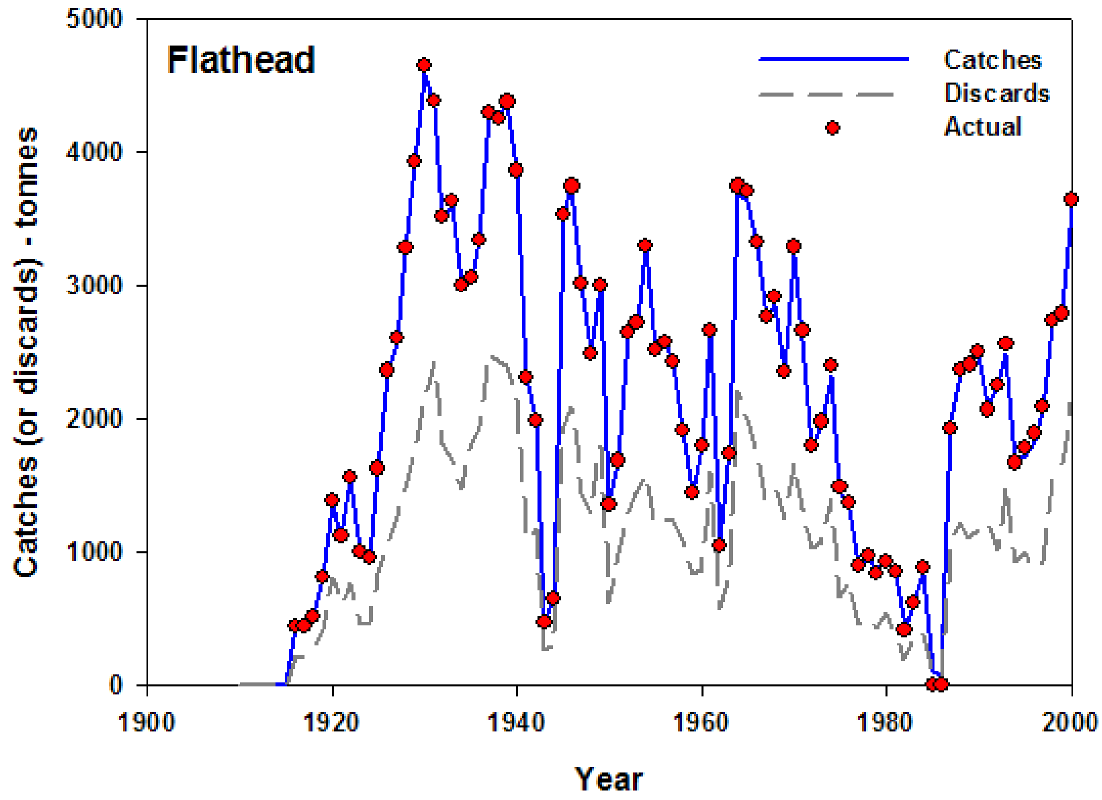


Figure 3-10: Atlantis historical catch (landings) and discards time series for flathead

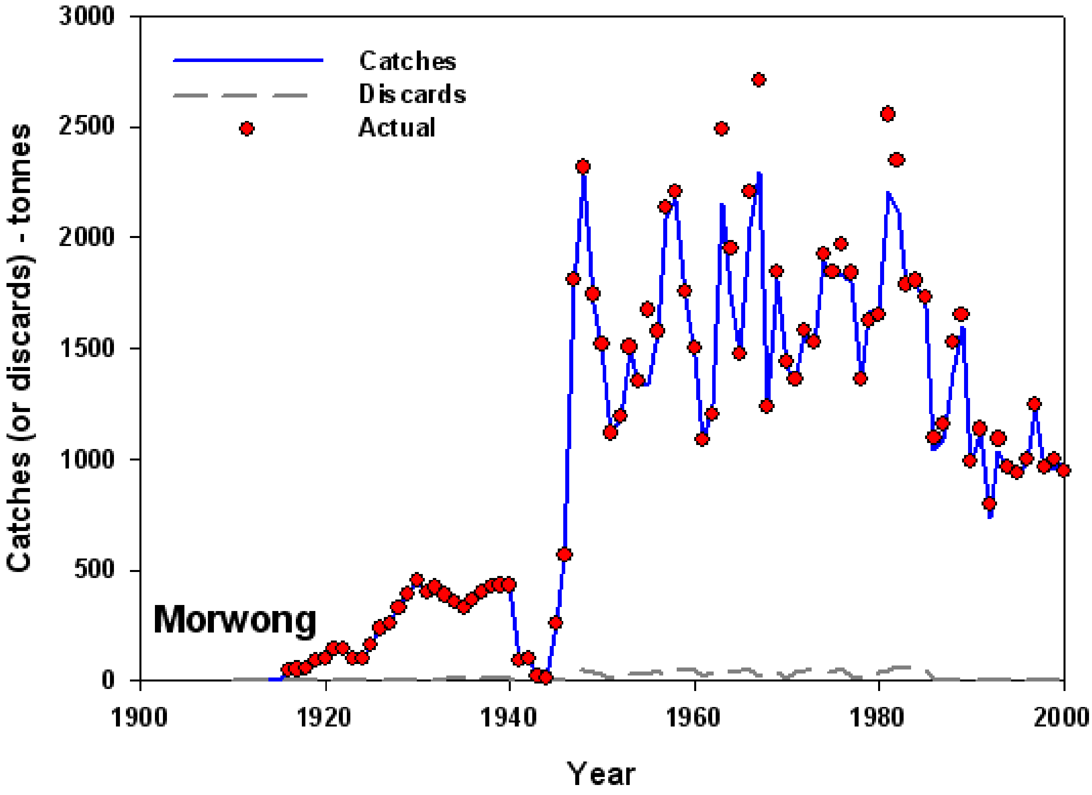


Figure 3-11: Atlantis historical catch (landings) and discards time series for morwong

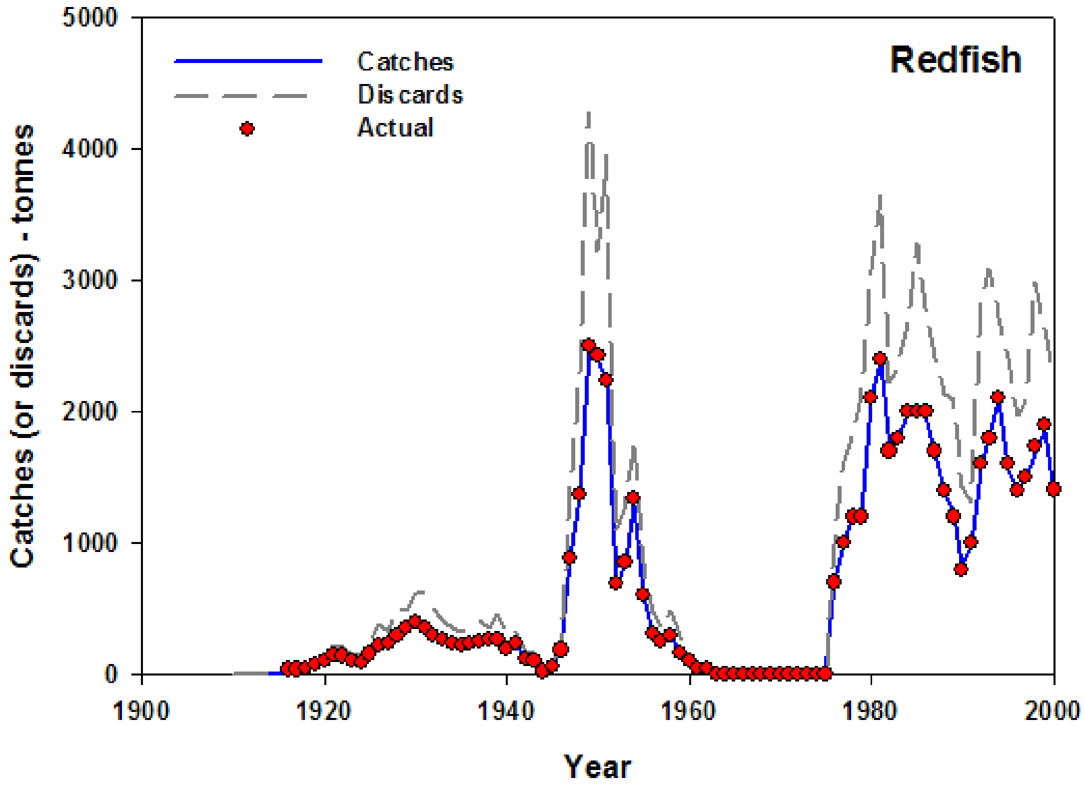


Figure 3-12: Atlantis historical catch (landings) and discards time series for redfish

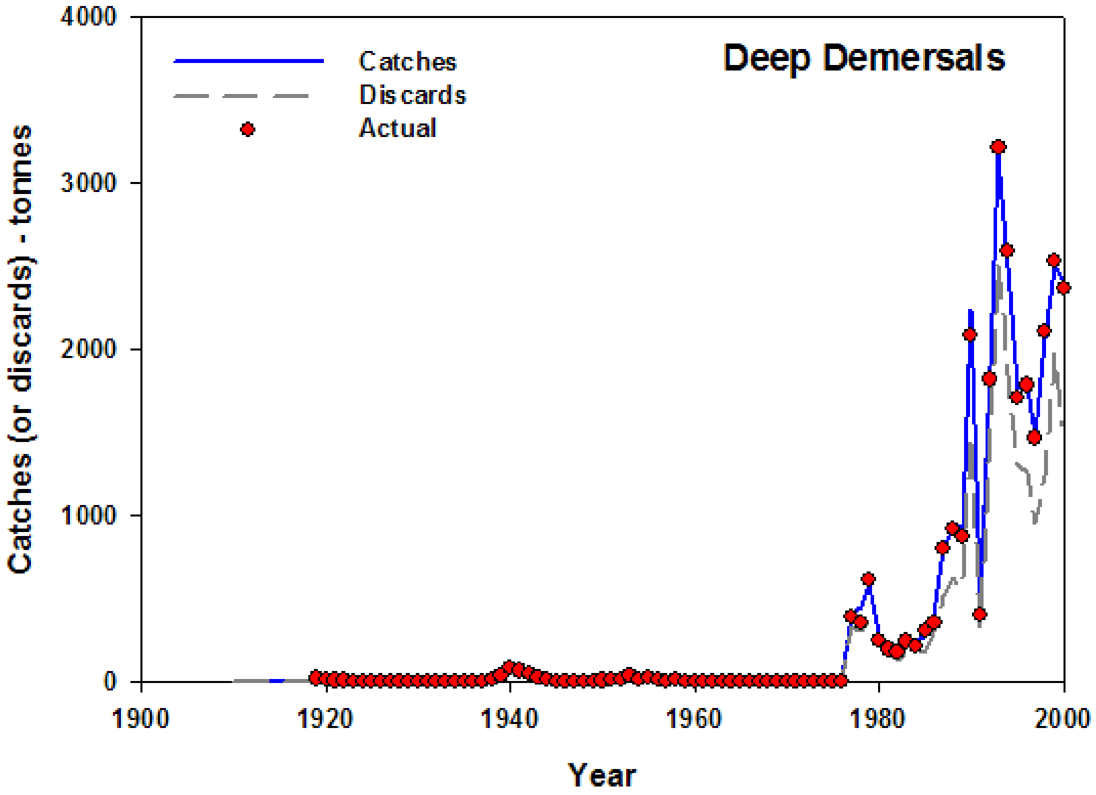


Figure 3-13: Atlantis historical catch (landings) and discards time series for Deep demersal fish

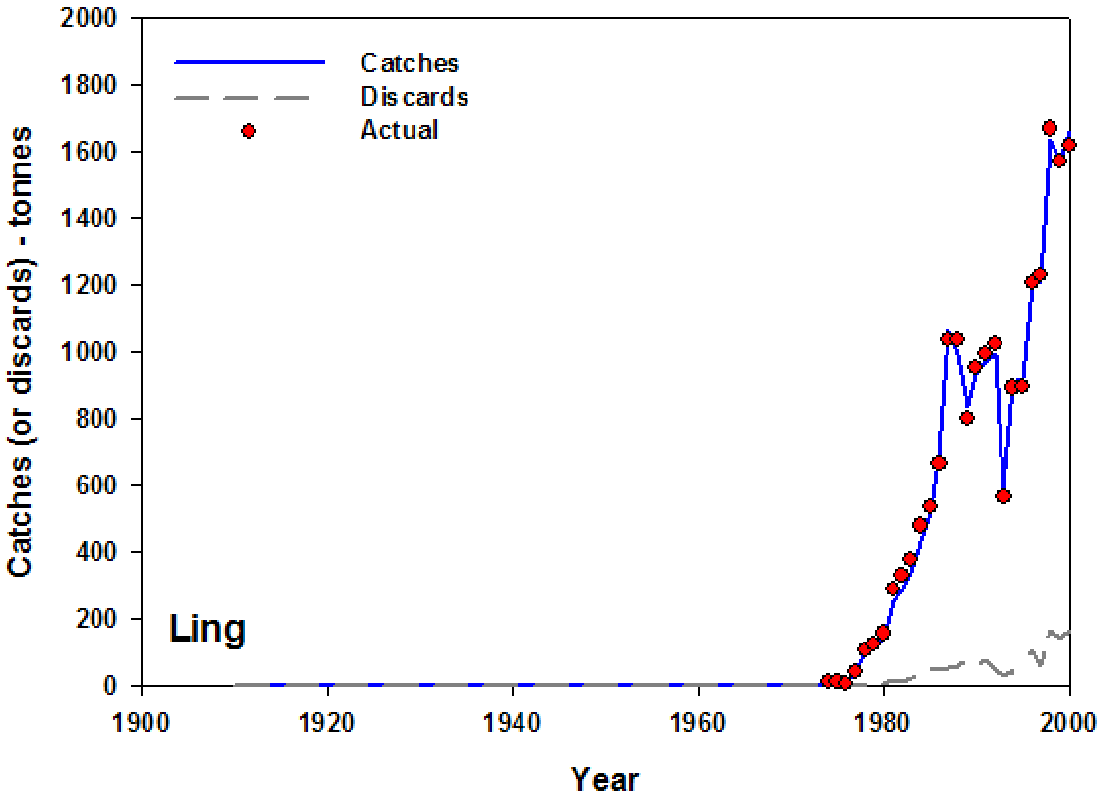


Figure 3-14: Atlantis historical catch (landings) and discards time series for ling

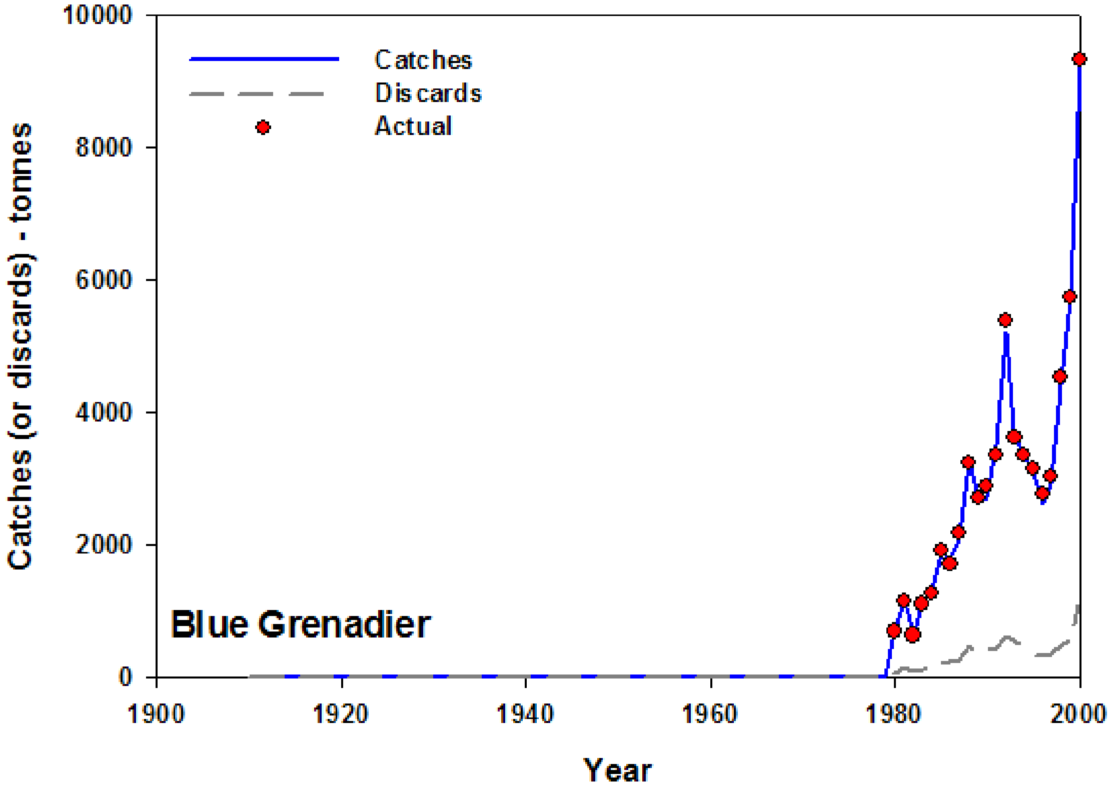


Figure 3-15: Atlantis historical catch (landings) and discards time series for blue grenadier

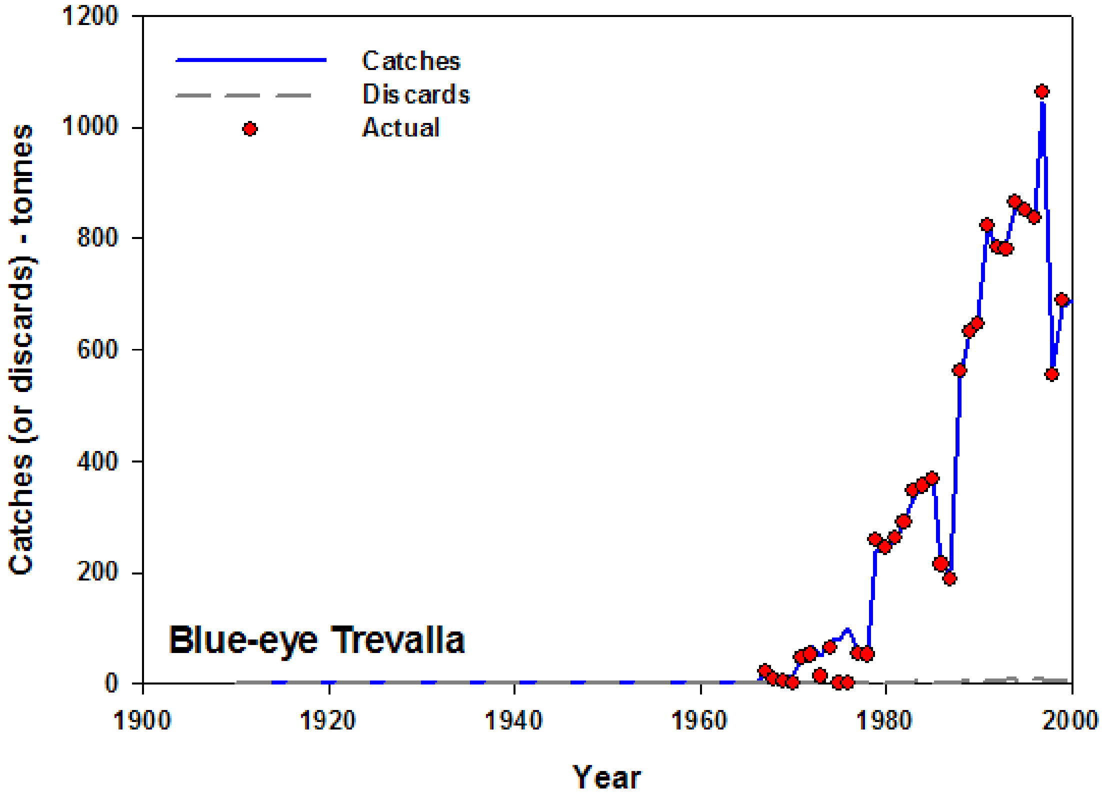


Figure 3-16: Atlantis historical catch (landings) and discards time series for blue-eye trevalla

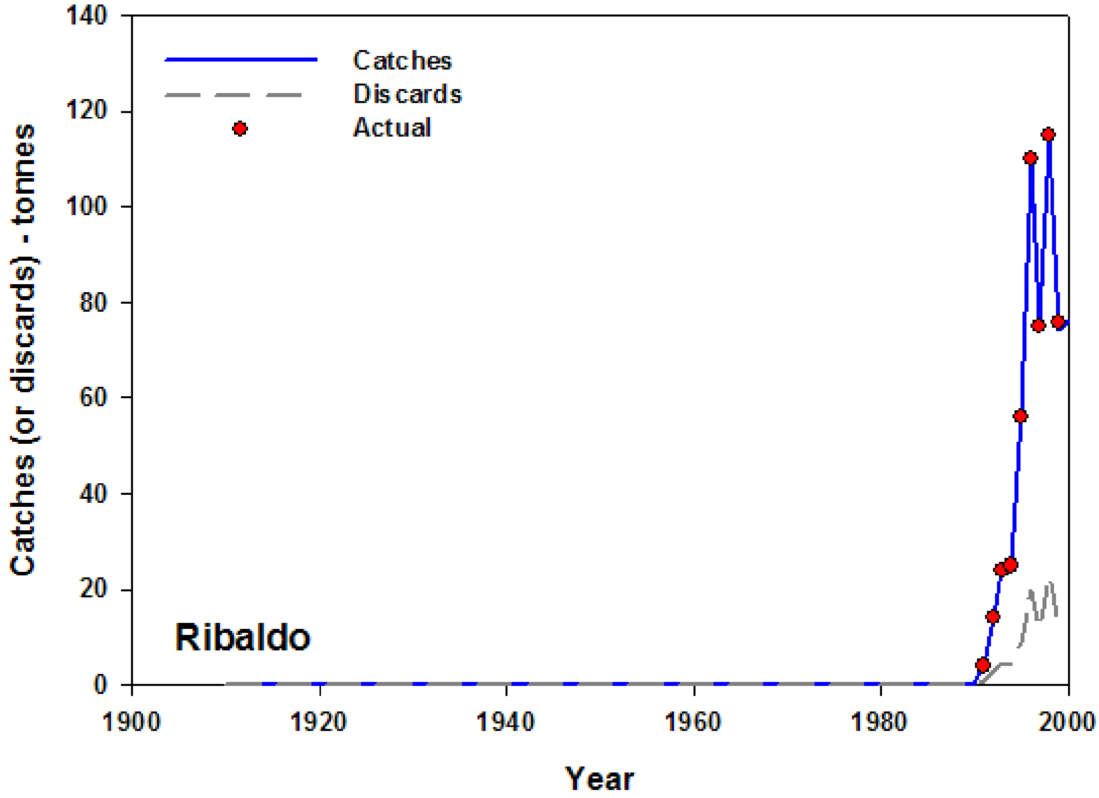


Figure 3-17: Atlantis historical catch (landings) and discards time series for ribaldo

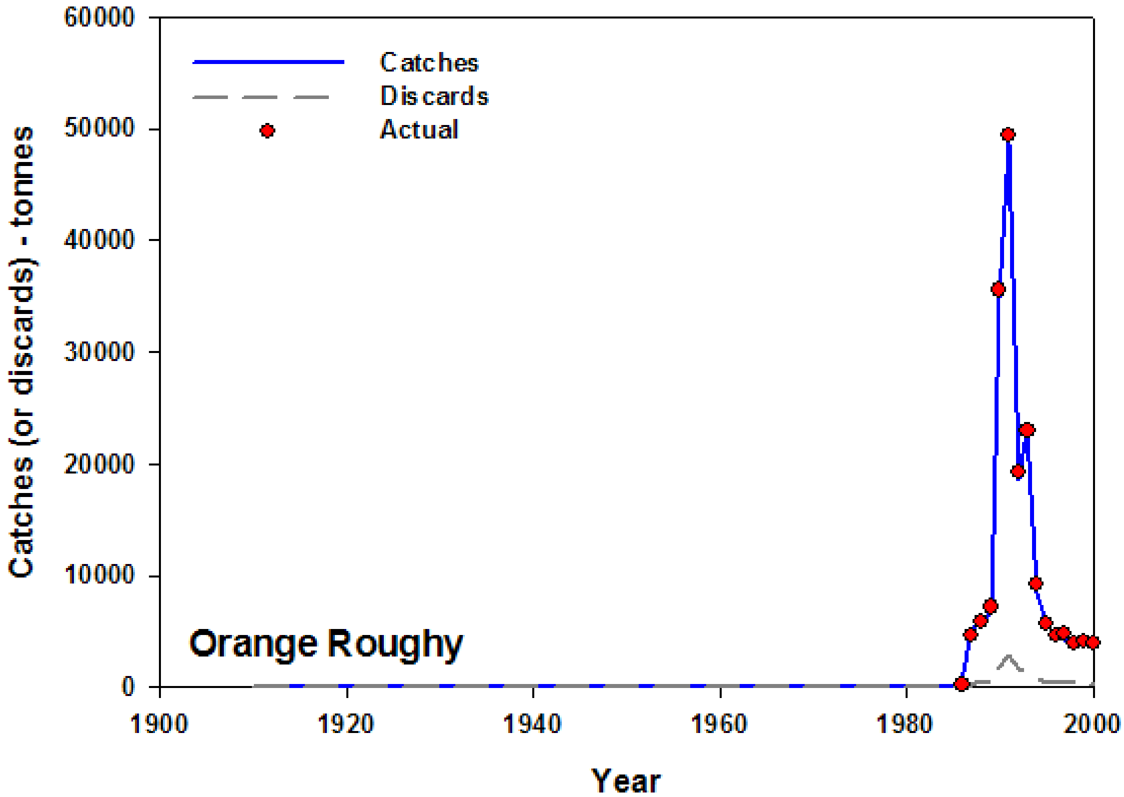


Figure 3-18: Atlantis historical catch (landings) and discards time series for orange roughy

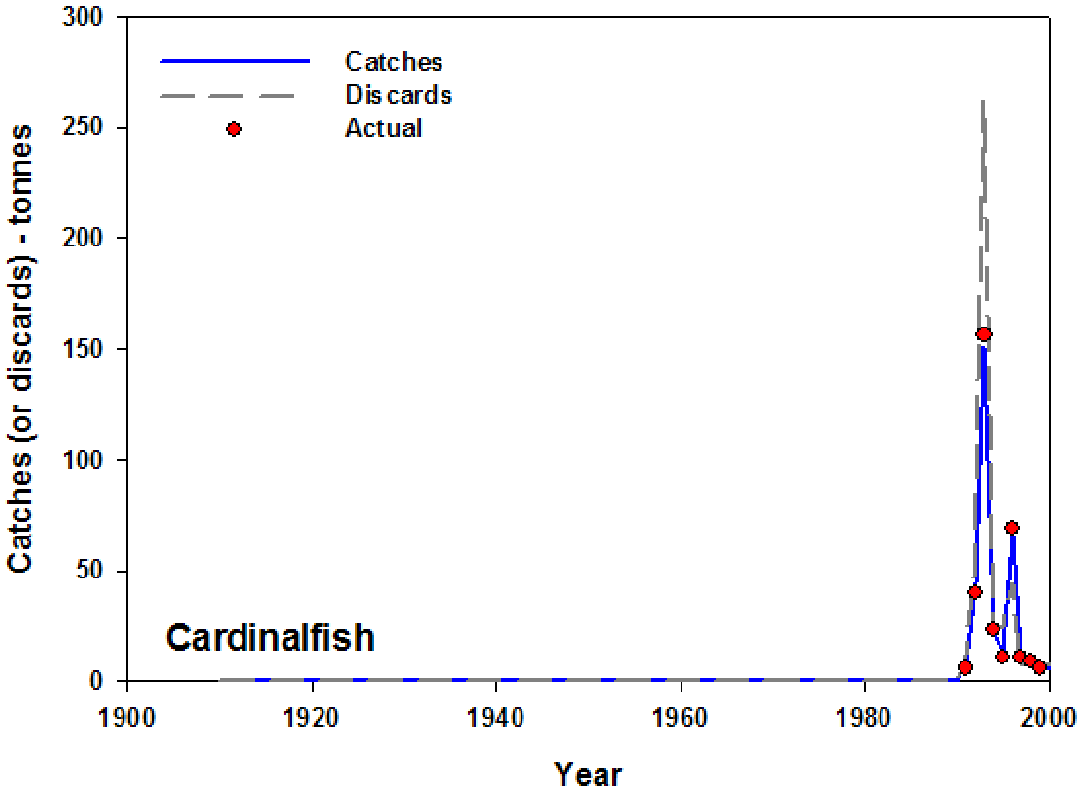


Figure 3-19: Atlantis historical catch (landings) and discards time series for Cardinalfish

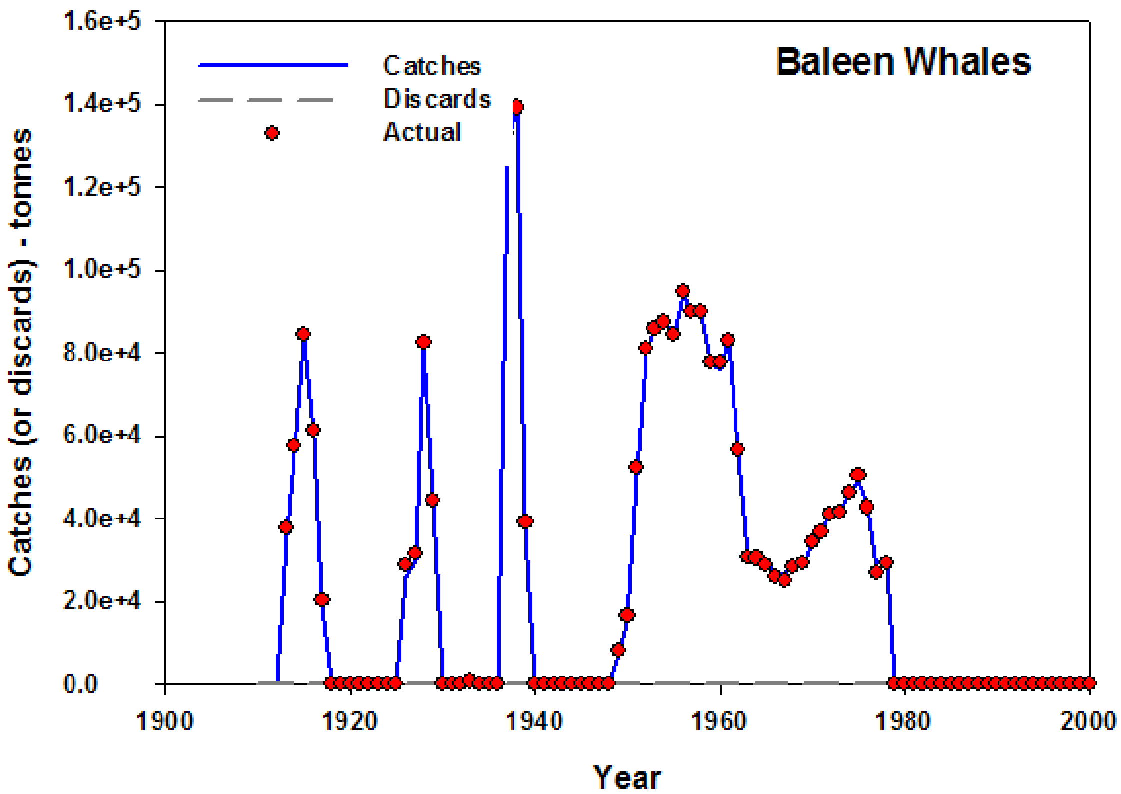


Figure 3-20: Atlantis historical catch (landings) and discards time series for Baleen whales

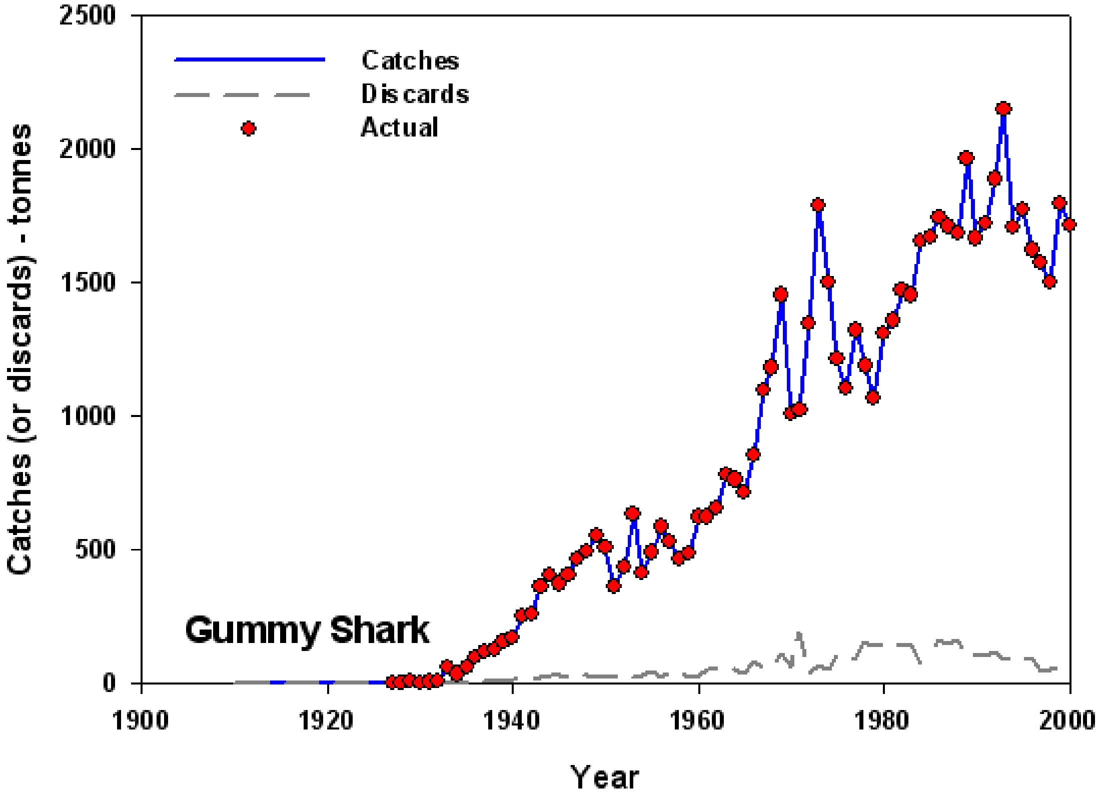


Figure 3-21: Atlantis historical catch (landings) and discards time series for gummy shark

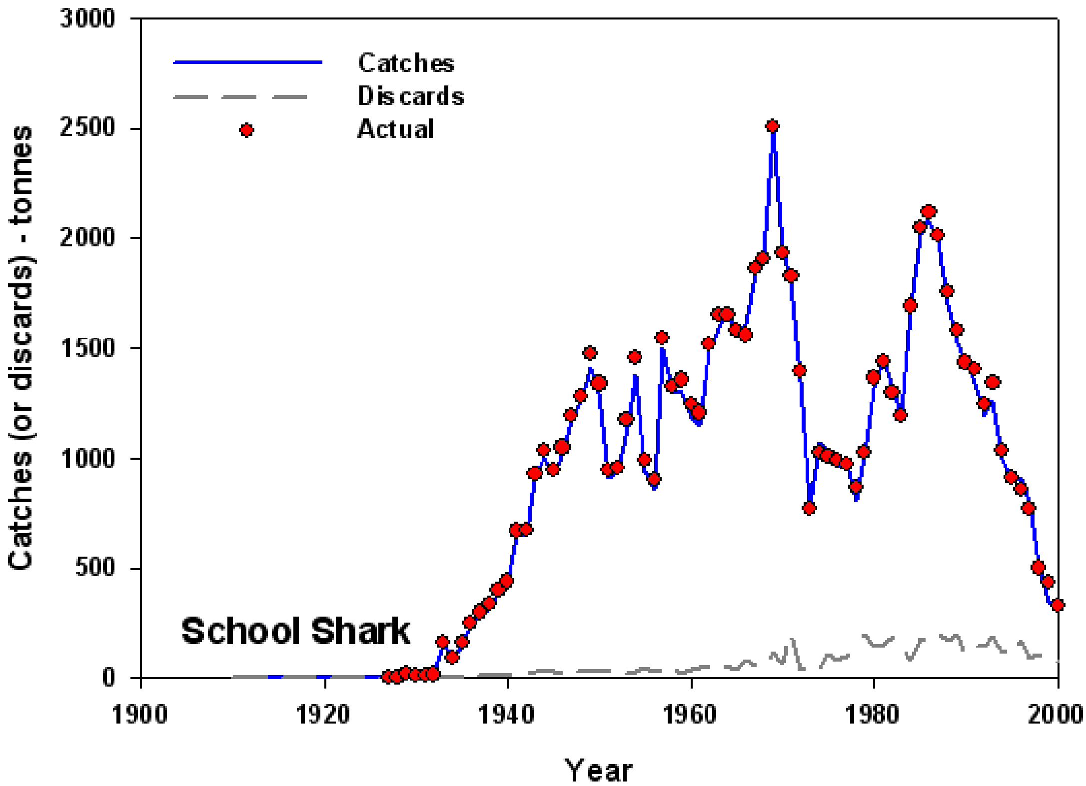


Figure 3-22: Atlantis historical catch (landings) and discards time series for school shark

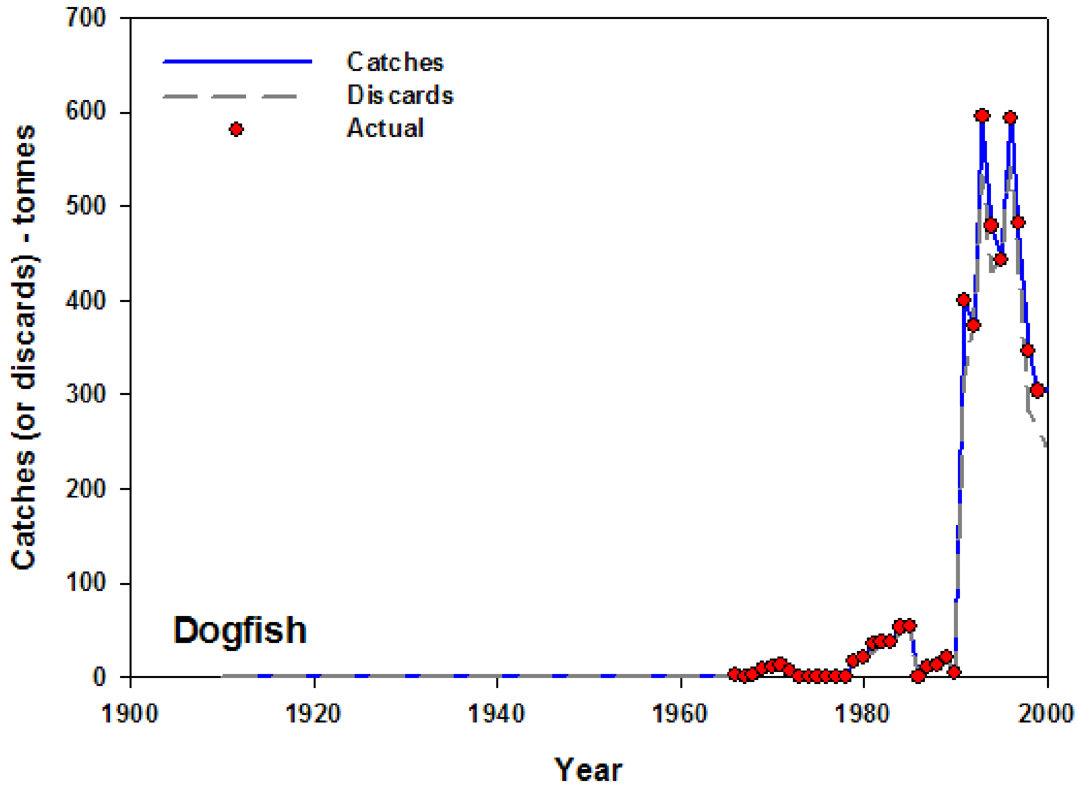


Figure 3-23: Atlantis historical catch (landings) and discards time series for dogfish

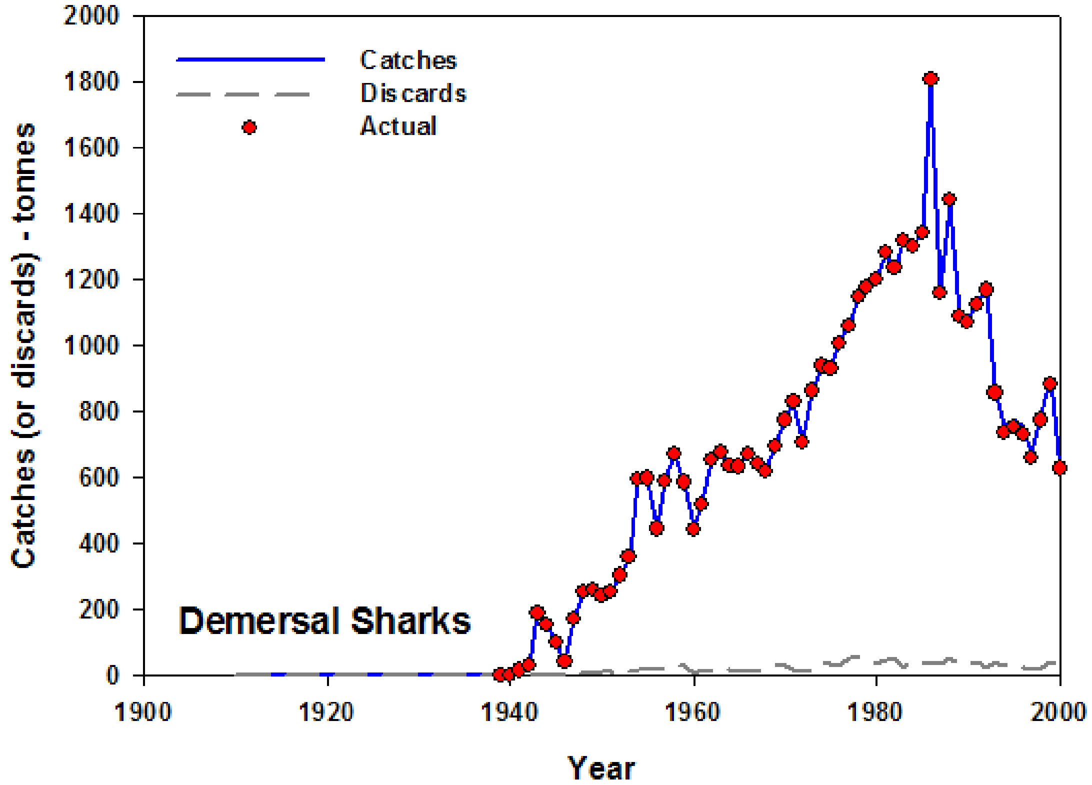


Figure 3-24: Atlantis historical catch (landings) and discards time series for demersal sharks

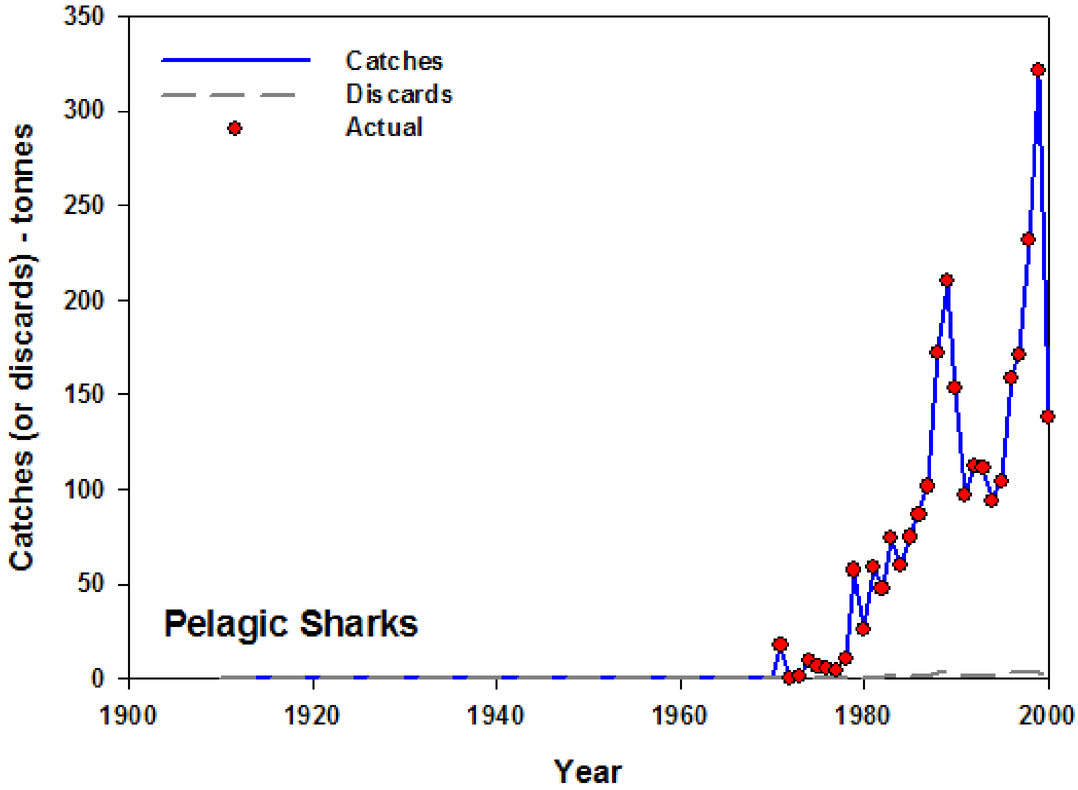


Figure 3-25: Atlantis historical catch (landings) and discards time series for pelagic sharks

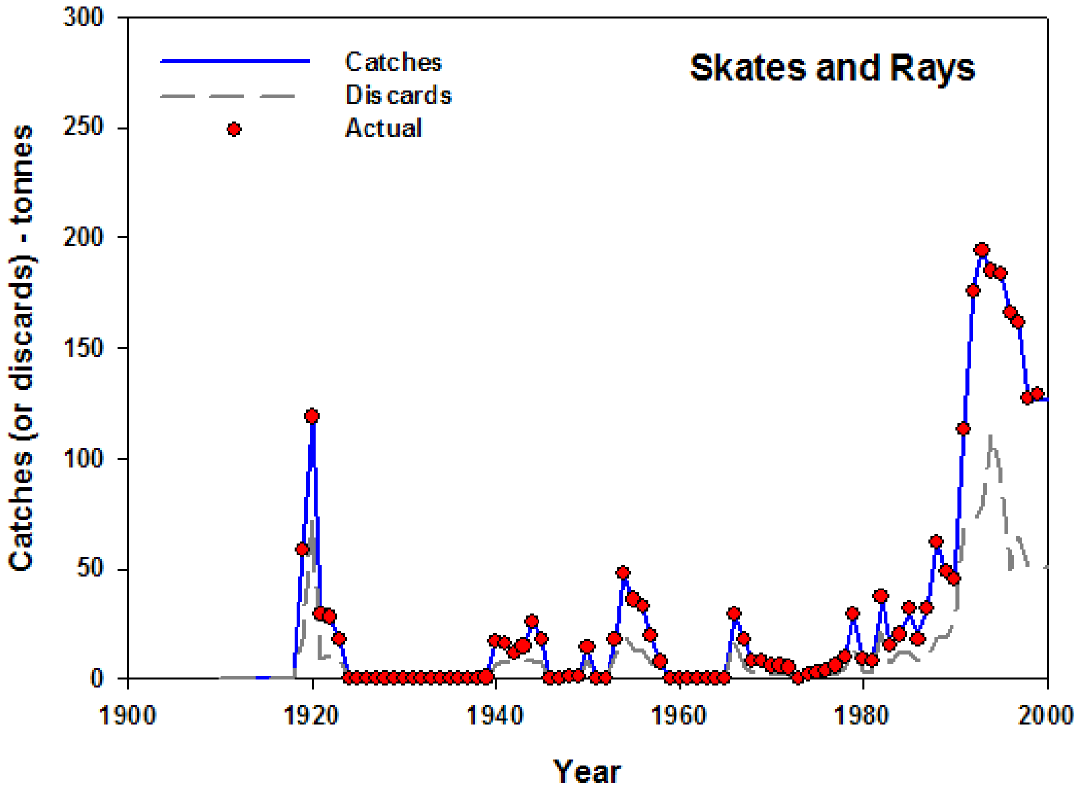


Figure 3-26: Atlantis historical catch (landings) and discards time series for Skates and rays (this level of discards is probably on the low end of the possible range of historical discards, but was the best estimate possible given the quantitative data available).

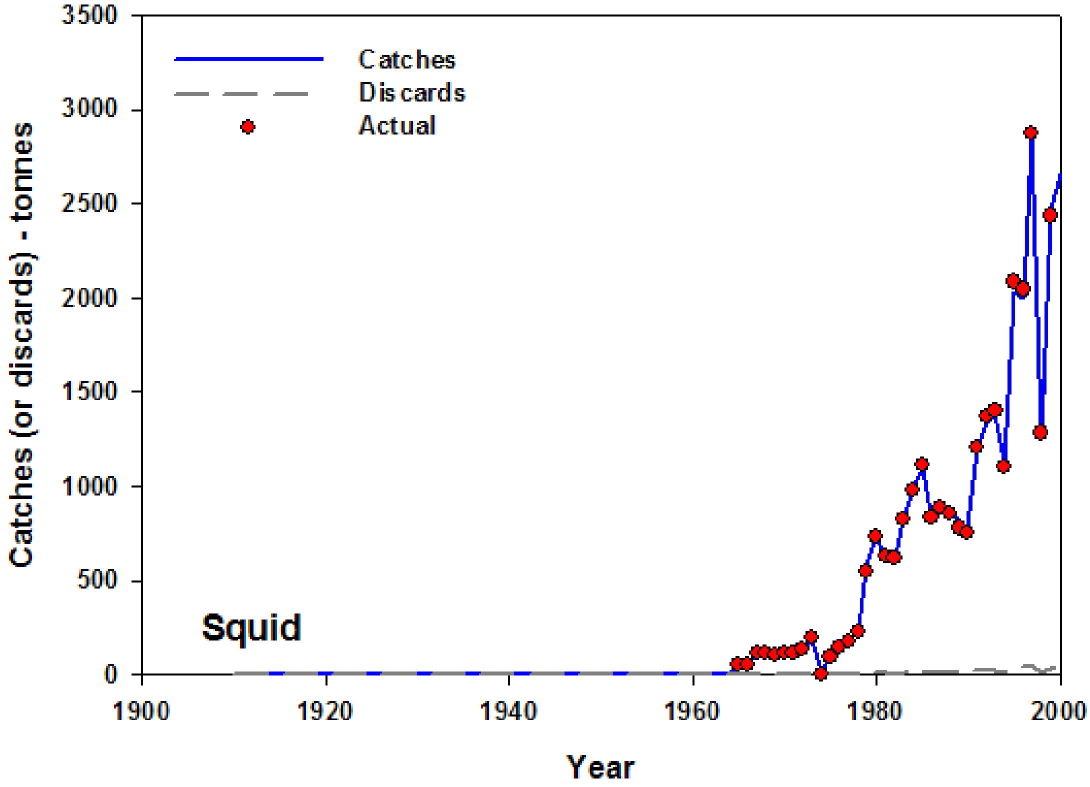


Figure 3-27: Atlantis historical catch (landings) and discards time series for squid

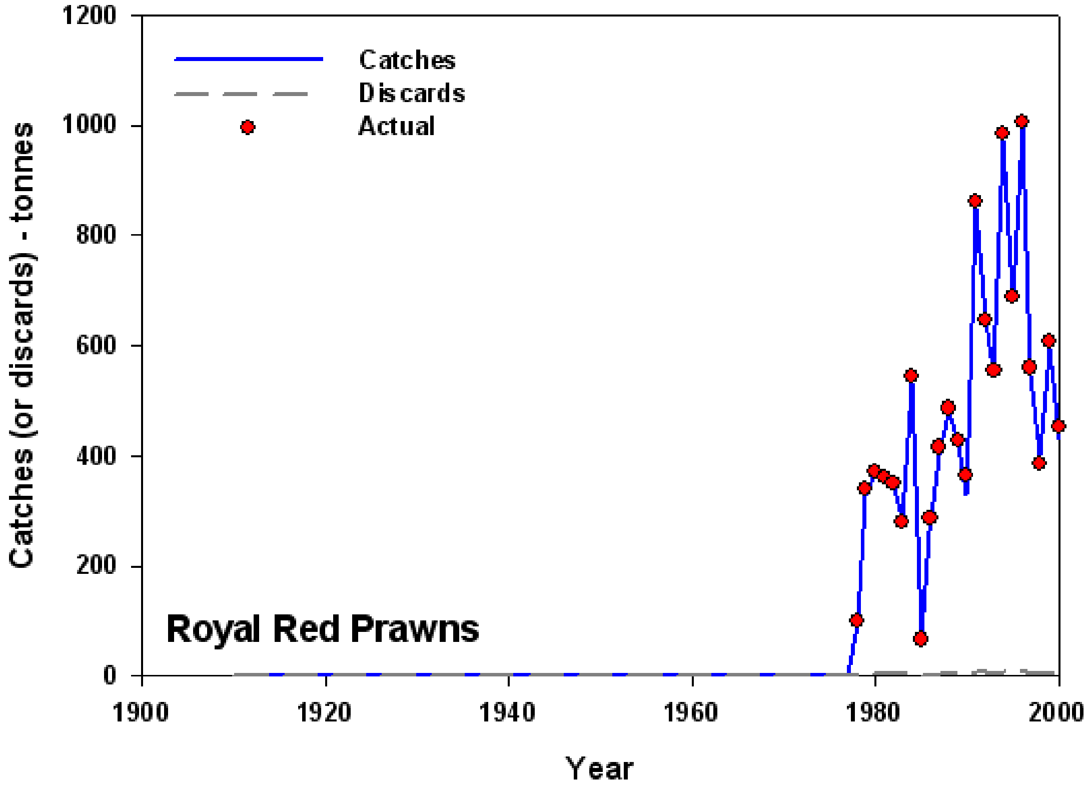


Figure 3-28: Atlantis historical catch (landings) and discards time series for royal red prawns

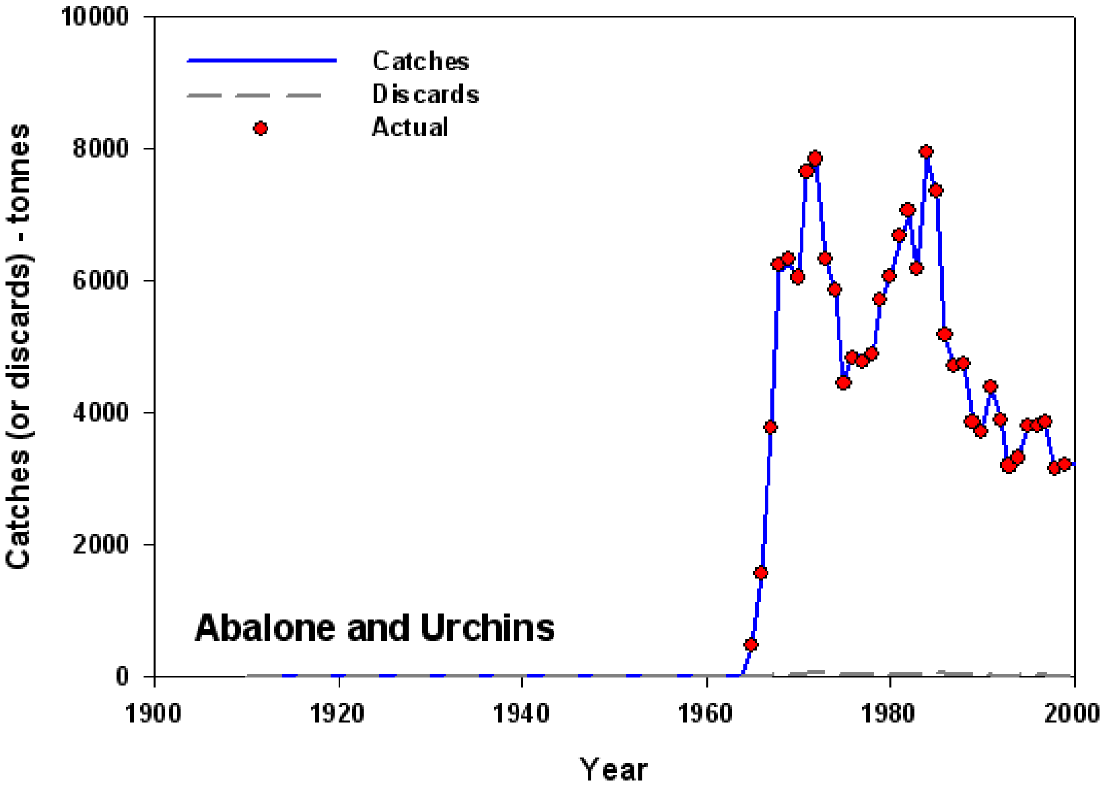


Figure 3-29: Atlantis historical catch (landings) and discards time series for abalone and urchins

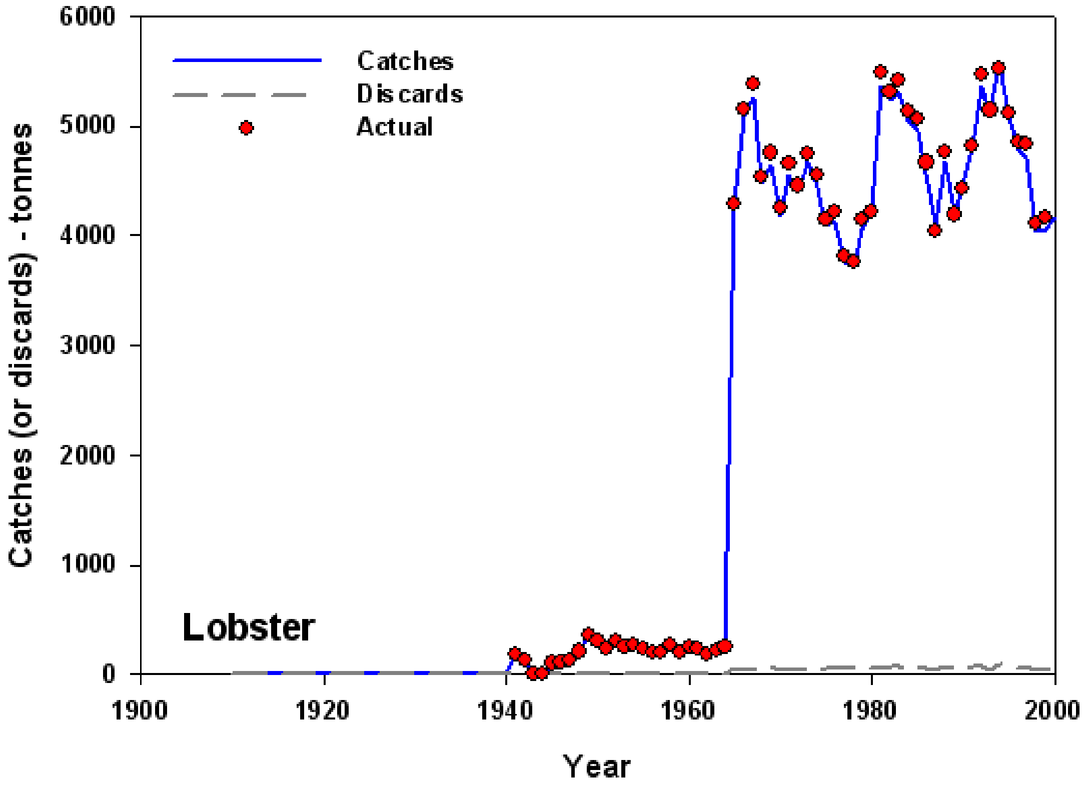


Figure 3-30: Atlantis historical catch (landings) and discards time series for Lobsters. The value through the 1960s may be too low, but these were the catches as listed in publicly available catch statistics.

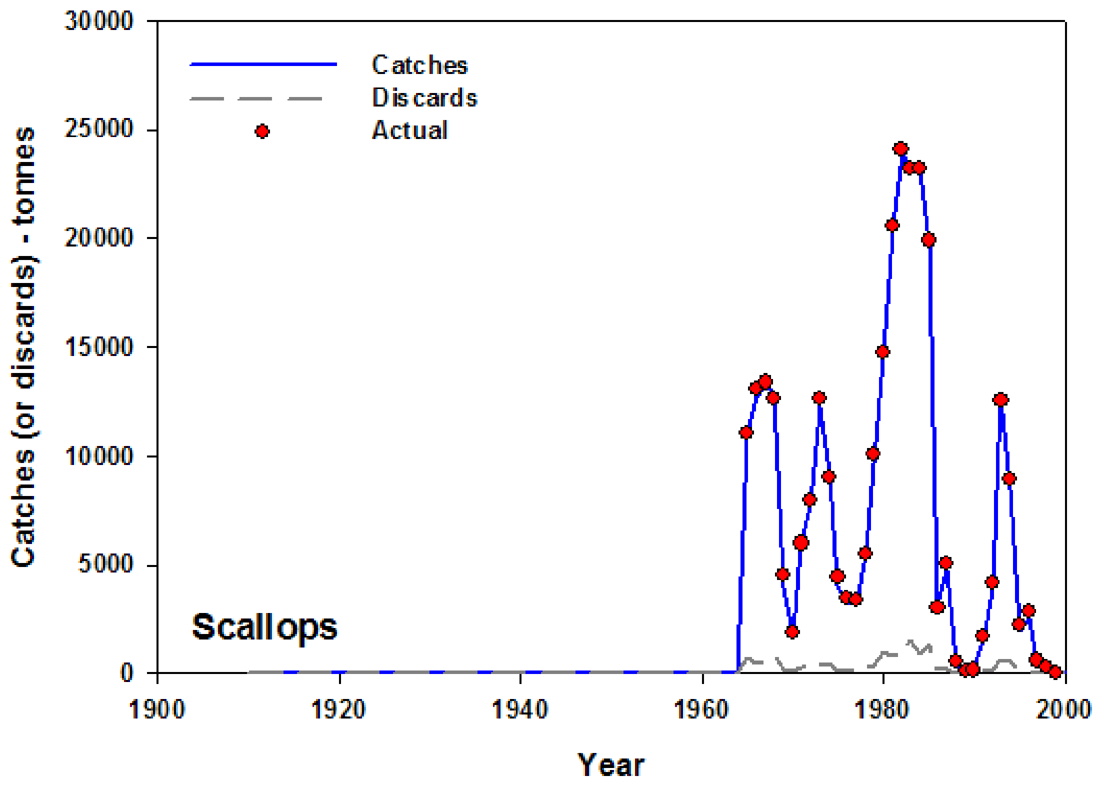


Figure 3-31: Atlantis historical catch (landings) and discards time series for Scallops

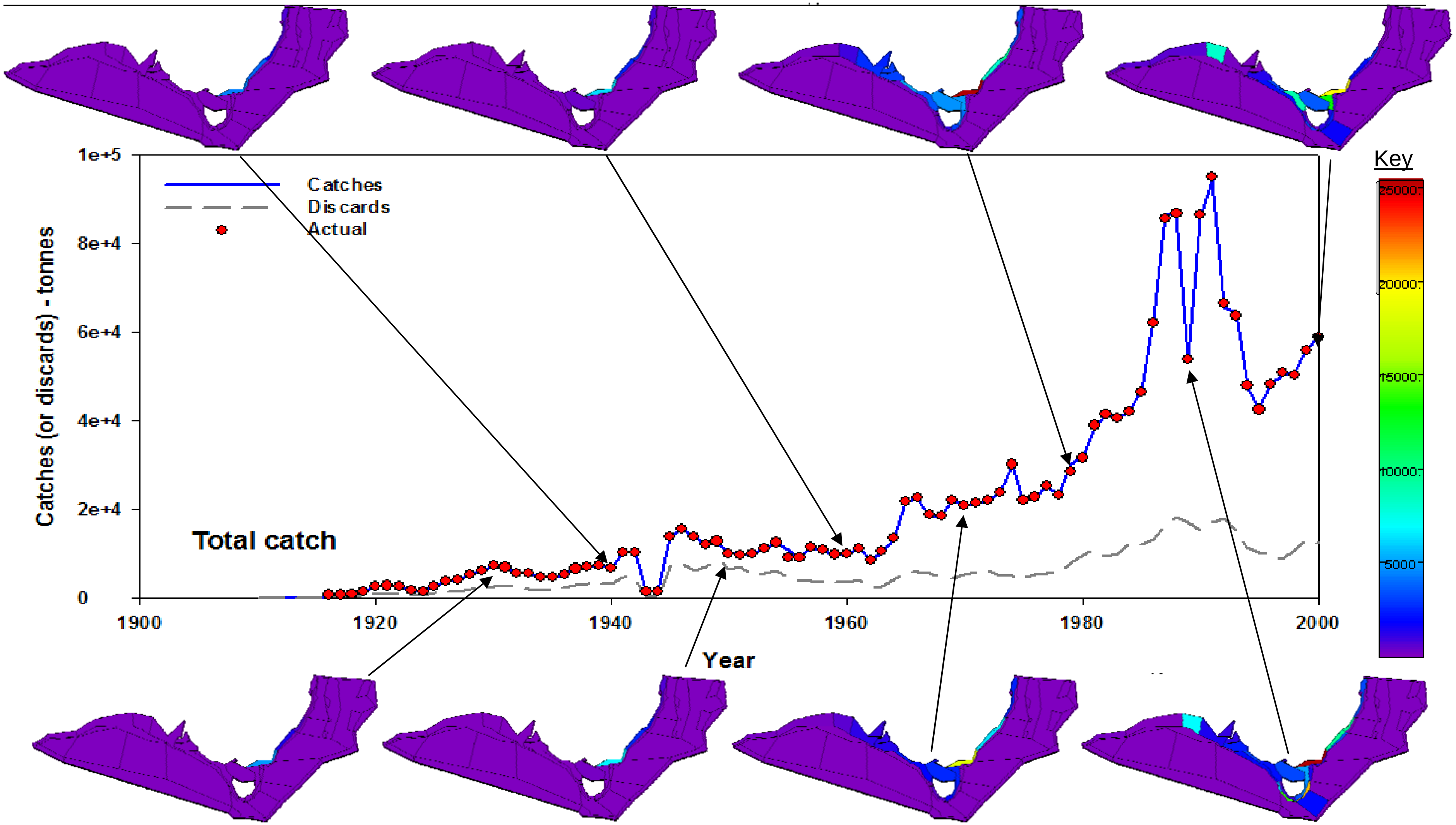


Figure 3-32: Total overall fin-fish and shark catch (landings) and discard time series and distributions (scale bar is in tonnes).

Table 3-3: Rules used to derive bycatch/byproduct and discards when forcing the southeast Atlantis model with historical recorded catches. Note that the range in percentages discarded reflects gear-based, size-based and changing preferences in catch retention (less preferred sizes were more heavily discarded) through out the historical period. This means that some figures may seem high in comparison with current discard rates for dominate gear types, this is because they need to also reflect alternate gears and past targeting preferences. These figures were drawn from NORMAC (1998), AFMA (2001), Klaer (2004), Ward and Curran (2004), Koopman *et al* (2005), Walker *et al* (2005) – since the model was developed the discard estimates based on ISMP have been released by Walker *et al* (2007), where these differ substantially from the rate used the new estimate is provided in parentheses for reference.

Group(s)	Bycatch/Byproduct Rule	Discards as % of total (aggregated) landed catch[A] (new ISMP estimate)
Mackerel	-	62-103%
Small pelagics	0.025 kg / 1 kg of trawl catch	70% of all juveniles and 0.5-3% of adult catch
Red bait	0.025 kg / 1 kg of trawl catch	10-20% (bycatch all discarded)
Mesopelagics	0.025 kg / 1 kg of trawl catch	All discarded
School whiting	-	9.5-120%
Shallow water piscivores	-	0.5-3% (upto 27%)
Blue warehou	-	1-3% (32%)
Spotted warehou	-	1-33%
Tuna and billfish	-	0.3-3.3%
Gemfish	-	1-113%
Shallow demersals	0.025 kg / 1 kg of shallow bottom water catch	0.5-3% (upto 47%)
Flathead	-	42-90% (5-23%)
Redfish	-	120-180% (58%)
Morwong	-	1-10%
Ling	-	5-10%
Blue grenadier	-	1-23%
Blue-eye trevalla	-	0.5-1% (upto 13%)
Ribaldo	-	15-24%
Orange roughy	-	4.5-10%
Dories and oreos	0.025 kg / 1 kg of deep water recorded catch	60-85% (25-42%)
Cardinalfish	-	63-180% (upto 800%)
Gummy shark	0.01 kg / 1 kg of recorded catch	5-23%[B]
School shark	0.01 kg / 1 kg of recorded catch	10-29% (6-9%)
Demersal sharks	0.01 kg / 1 kg of recorded catch	2-11%

Group(s)	Bycatch/Byproduct Rule	Discards as % of total (aggregated) landed catch[A] (new ISMP estimate)
Pelagic sharks	0.01 kg / 1 kg of recorded catch	1-7%
Dogfish	0.01 kg / 1 kg of recorded catch	68-100% (upto 700%)
Gulper sharks	0.01 kg / 1 kg of recorded catch	All discarded until 1991 then used 100-600%
Skates and rays	0.01 kg / 1 kg of recorded catch	30-65% (upto 1000%)
Seabirds	0.001 kg / 1 kg of recorded surface waters or line catch	All discarded
Pinnipeds	0.001 kg / 1 kg of recorded catch	All discarded (model period is all post-sealing)
Whales	0.000001 kg / 1 kg of recorded catch	<0.1% when whaling, otherwise all discarded
Dolphins	0.0001 kg / 1 kg of recorded catch	All discarded
Commercial benthos	0.003 kg / 1 kg of bottom contacting gear catch	0.1-10%
Other benthos (except meiofauna)	0.003 kg / 1 kg of bottom contacting gear catch (Meiobenthos is too small to be collected by the gear)	All discarded
Seagrass	0.003 kg / 1 kg of shallow water bottom contacting gear catch	All discarded
Zooplankton (especially gelatinous)	0.0001 kg / 1 kg of recorded trawl catch	All discarded
Recreational Fisheries (from Henry and Lyle (2003))	$C_{r,i,j} = N_r \cdot p \cdot \frac{s}{d_j} \cdot E \cdot B_{i,j}$ where $C_{r,i,j}$ is recreational (and charter) fisheries catch of group i in box j by people living in port r; N_r is the population in port r and its surrounds; p is the proportion of the population that fishes recreationally (0.2); s is the speed of a recreational boat (2260 $m \cdot hr^{-1}$); d_j is the distance in metres to the recreational fishing grounds (if any exist) in box j; E is the average effort per day of a recreational fisherman (6 hr); and $B_{i,j}$ is the biomass of group i in box j.	All megafauna discarded; 5% of desirable and 50% of catch of undesirable groups discarded

A. These are applied in addition to the recorded catch (so discards of 10% mean that 1.1x the recorded catch was taken as catch from the group with 1.0x kept as catch and 0.1x discarded).

B. This is a good example of a rate that initially seems exceptionally high; gillnets do not discard at rates at the higher end of this range, but trawlers have at points in the past.

3.4 Biomass time series

Time series of relative biomass per group from the run using the final "best fitting" calibrated parameter set and forced by historical catches is given in Figures 3.33 – 3.60; the bounding parameterisations give very similar trajectories). In this case relative biomass (B_{rel}) is calculated as:

$$B_{rel} = \frac{B_t}{B_0} \tag{3.1}$$

with B_0 the biomass of the group at the beginning of the run (1910) and B_t the biomass at time t.

For ease of presentation these biomasses have been grouped base on assemblages (e.g. all zooplankton presented together, all small pelagics plotted together). This also facilitates the identification of general trends within assemblages of groups that have similar roles within the system. By and large regional and stock specific biomass trajectories are not presented (to avoid clutter). In most cases western stocks showed little variation, remaining stable and at about 1.0 relative biomass through out the run and consequently they have been omitted from the plots in favour of the more variable (or impacted) eastern (or total) biomass trajectories. The one exception is for flathead, where the western "stock", which represents deepwater flathead (*Neoplatycephalus conatus*), does see a change in the time series and so has been included in the plots (Figure 3.44).

3.4.1 Pelagic Invertebrates

The relative biomass trajectory for small phytoplankton (Figure 3.33) shows a slight cycle in its interannual variation, due to physical forcing, but it is much weaker than the variation in diatoms. Diatoms show a roughly five year cycle, growing in magnitude until the 1970's, where there were strong blooms in the upwelling areas and elevated productivity in many shelf areas. In contrast, the period after this point shows a very constrained cycle. These dynamics are due to a combination of environmental forcing (currents and upwellings) and trophic interactions, mainly involving the zooplankton and small-bodied fish groups. The presence of this kind of pattern suggests that a nonlinear threshold may occur in the phytoplankton-zooplankton interactions. Further field work and model examination would be required to delve through the mechanisms producing this dynamic and validate its existence in the region in reality. With regard to the final management strategy evaluation, diagnostic trials have shown that while the magnitude of this dynamic can shift overall productivity up and down it has no effect on the ultimate ranking of the performance of the various management strategies.

The zooplankton groups also show quasi-periodic pulses of variation in biomass (Figure 3.34), but these are much smaller than those seen in the diatoms. Mesozooplankton (copepods and chaetognaths) shows the biggest spikes in production (increasing by roughly 25% in the late 1940s and early 1960s). This is again a result of environmental forcing and trophic interactions, though in this case the trophic interactions (with other plankton groups) are the more dominant factor. More important are the dynamics in the final thirty years of the run. Microzooplankton steps up in relative biomass around the beginning of the 1970s; while krill and then gelatinous zooplankton begin a steady increase in relative biomass in these final years (as the effects of fishing really begin to have a significant impact and lead to a restructuring of the fish dominated communities and associated pathway strengths). Squid also show this increasing trend, although it begins much earlier (during the 1950s, with some reversals) in their case (Figure 3.35). The saw-tooth nature of the squid biomass plot is the result of a model artefact due to the crude (two-stage) method of handling ages in the invertebrate biomass pool model. While it is not a particularly attractive feature it has negligible effect on the dynamics of the rest of the model.

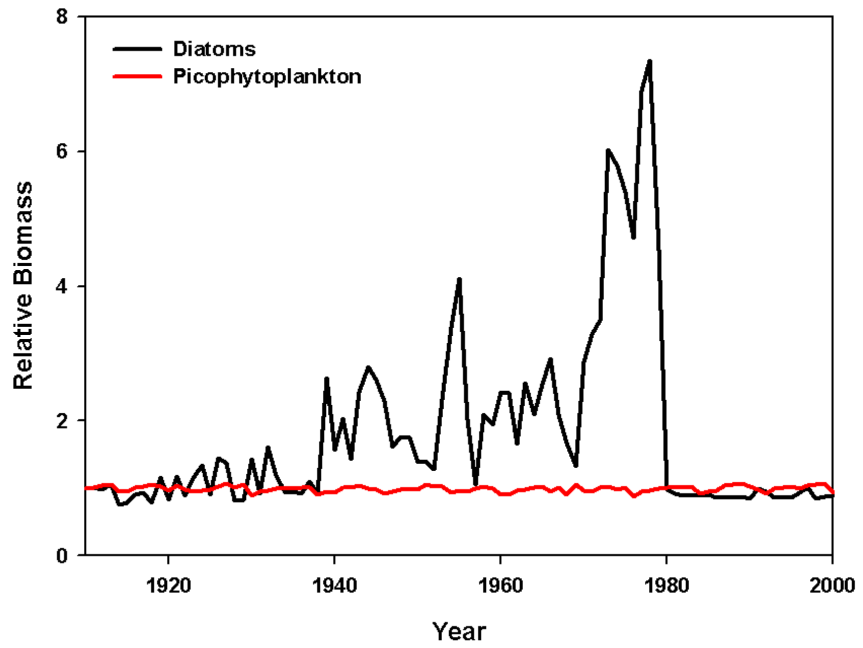


Figure 3-33: Historical time series of relative biomass of phytoplankton predicted by Atlantis SE.

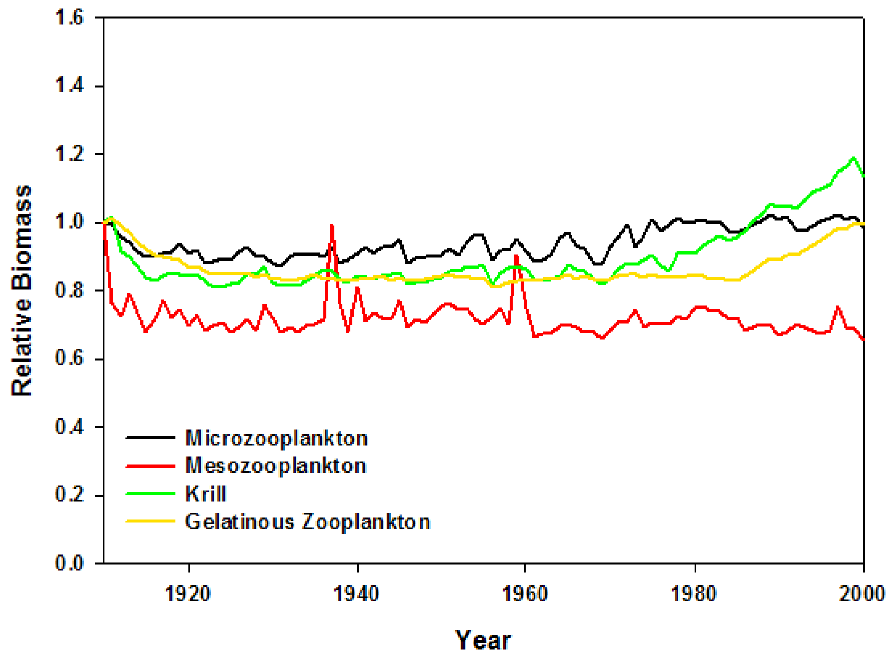


Figure 3-34: Historical time series of relative biomass of zooplankton predicted by Atlantis SE.

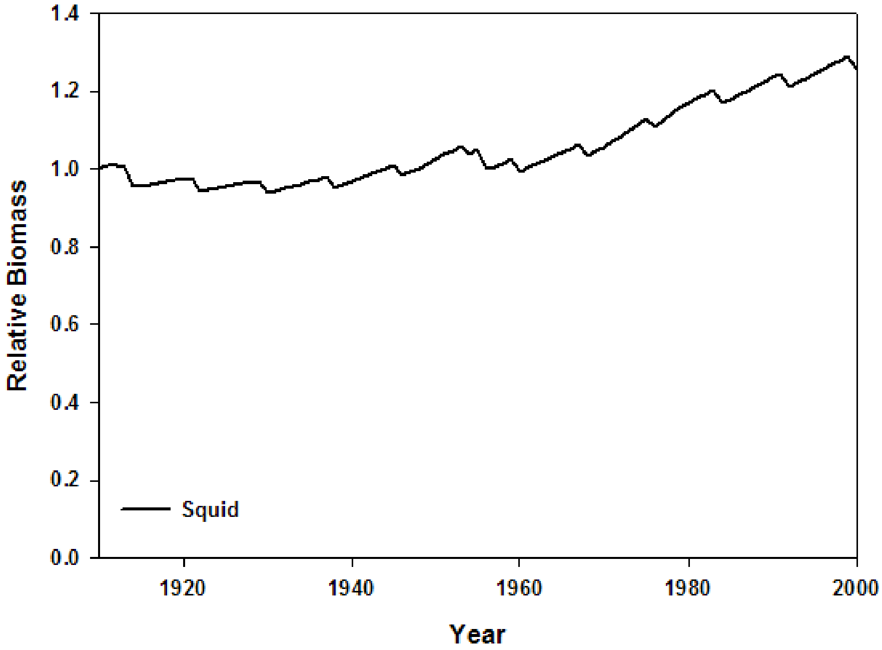


Figure 3-35: Historical time series of relative biomass of squid predicted by Atlantis SE.

3.4.2 Benthic Invertebrates and Macrophytes

The biomass of the benthic groups is the least interesting or trustworthy of the modelled groups. So little is known of these groups that there is little to constrain their overall behaviour, beyond demands put on them by other groups. While they are judged sufficient for proceeding with the model (as they provide sufficient prey resources for the focus fish groups and act as an alternative target for the fisheries), the results for benthos are fairly uncertain and it would be unwise to put heavy weight on them (which we do not). It would take a substantial directed data collection and model refinement effort to improve the benthic dynamics and bring them into line with the standard of the rest of the model.

Nevertheless for reference and context it is worth summarising the overall trajectories of the benthic groups. The filter feeders and megazoobenthos on the regional scale show little response to the effects of fishing, but on local scales the differences can be quite marked, due to direct removals or incidental impacts of gear. Prawns show a very minor increase in biomass due to predation release through until the late 1950s, when the direct losses due to fishing outweigh the indirect benefits arising from fishing impacts on predators and competitors. The lobster trajectory sees a stronger predation release, its change in relative biomass results from changing pathway strengths due to shifting community biomass structures and fishing pressures. The downturn beginning in the 1980s is partly due to fisheries removals, but also due to trophic connections as their prey base is eroded.

Scallops remain fairly stable once the initial relative biomass decay is complete. This is in marked contrast to the oscillating decline observed in reality. This suggests that a significant mechanism (potentially environmental forcing of recruitment) driving scallop population dynamics is not being captured by the simple biomass pool representation used here. It is likely that future modelling of this group may be better served by the use of a stage structured population model or one that includes more fine scale dynamics (such as biomass patchiness and explicit larval supply). While this mismatch is unfortunate it does not derail the general system performance, it should be corrected in future work nevertheless. In contrast to the scallop biomass dynamics, abalone and urchins initially increase by 20% before fluctuating around at that level until the 1980s when they begin a strong decline, dropping to 40% of initial biomasses by the end of the run in 2000. As with the other varying benthic groups, the variation through the middle of the run is primarily due to trophic interactions rather than direct fisheries effects.

The relative biomass of the infauna is the most uncertain of all of the trajectories. The carnivorous infauna show a slight increase through the run, mainly due to the increasing biomass of one of their main prey groups, meiobenthos. The dynamics of meiobenthos and deposit feeders show a community composition swap, with the large detritus feeders being replaced by the smaller detritus feeding meiobenthos. This switch is unlikely to be real, but is a symptom of the problems with the benthic model components mentioned above. In the end the parameterisation of the trophic connections was set such that this switch did not present a detriment to the amount of available prey for the focus demersal fish groups.

The decline in macrophytes biomass from the starting values (Figure 3.36) is due in part to the change in grazer biomass, but more due to habitat degradation as a result of bottom impacting gears and coastal development. The stabilisation after the decline is because the rate of annual growth matches any further degradation due to fishing actions. This balance of growth and impacts may be a real phenomenon in spots, but is almost certainly overstated here, as there has been documented declines much more recently than in the 1970s (Valentine and Johnson 2005).

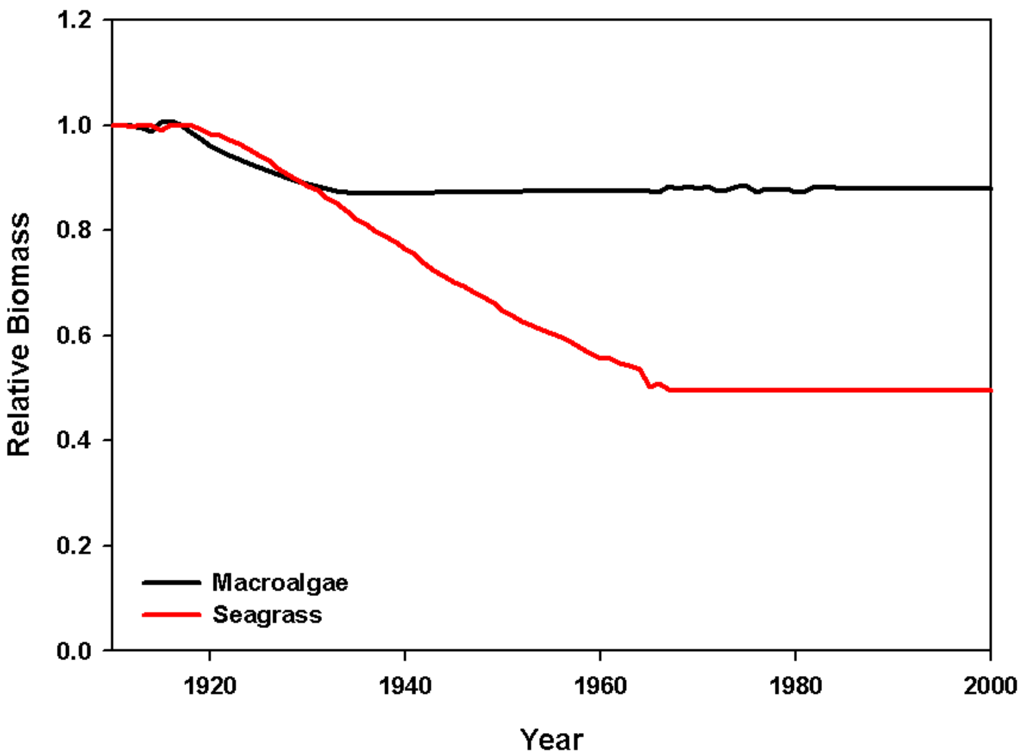


Figure 3-36: Historical time series of relative biomass of macrophytes predicted by Atlantis SE.

3.4.3 Fin-fish

The fin-fish relative biomass trajectories (Figures 3.37-3.43) are a mix of little change, slowly increasing underlying trends due to predation release and large scale declines in the final few decades of the run.

The mackerel show a long-term increase in biomass that peaks around 1984, before dropping sharply under intense fishing pressure in Tasmania waters. That fishery was short lived however and the final years of the historical period also feature strong growth in the Mackerel biomass (Figure 3.37). The other small pelagics (including Red bait) show an increase as fishing impacts the shelf community both directly and indirectly. The specific small pelagic group shows a strongest increase, particularly after 1950. This increase is against shorter term variation (in response to prey variability) and is almost exclusively due to predation release. In the final decade of the run fishing pressure begins to have a strong impact and reverses the trend leading to a 27% decline over that period (though in absolute terms the biomass is still 30% above the initial biomass levels).

Both of the larger pelagic groups (shallow (or small) piscivores and tuna and billfish) show an initial increase. The tuna then remain fairly stable, showing only relatively short term (< 5 year) cycles of variability in biomass levels, until the effects of fishing see the stock begin to decline in the 1970s (Figure 3.38). The biomass variability is only partly due to changes in abundance, there is a strong contribution of changes in the condition of the animals too. In contrast, while the small piscivores also show some increase in biomass initially they show a steady decline from the 1940s, with a quite sudden drop in the 1970s when direct fishing pressure combines with indirect effects of fishing, which acts to restructure the sub-web (and the ratios of predators and prey) the small piscivores sit in.

There is no stronger contrast in biomass dynamics than between the two mesopelagic groups (Figure 3.39). The very short-lived migratory mesopelagics show extreme abundance oscillations, initially due to non-linear responses to transient dynamics in age structure. Once that has settled out the remaining interannual variations in abundance are partly in response to environmental forcing of prey and small juveniles, but is still partly due to non-linear responses of age-structure to the prevailing conditions. The general underlying increase in biomass is due to changes in predation pressure on this group. While the pattern of strong alternating year- to-year variability in biomass of the kind shown periodically by migratory mesopelagics is an indicator of model sensitivity; it is within acceptable bounds after 1940 and introduces an interesting interdecadal pattern in prey supply for other sectors of the model. While such patterns are not recorded as yet in the south Pacific they are found elsewhere in the world, and may make for a more robust evaluation of strategies versus potential system behaviours. At any rate the behaviour is much more dynamic than for the non-migratory mesopelagics, which show almost no variation, beyond a very minor increase, through the period of the run. These contrasting dynamics result from the interaction of life history patterns and trophic interactions. While the overall biomass trajectory of the non-migratory mesopelagics shows little variability, the local supply of both forms of mesopelagics (though particularly the migratory mesopelagics), varies seasonally and interannually as these fish follow eddies onto the shelf. In this way they provide a solid prey base for upper slope and outer shelf groups.

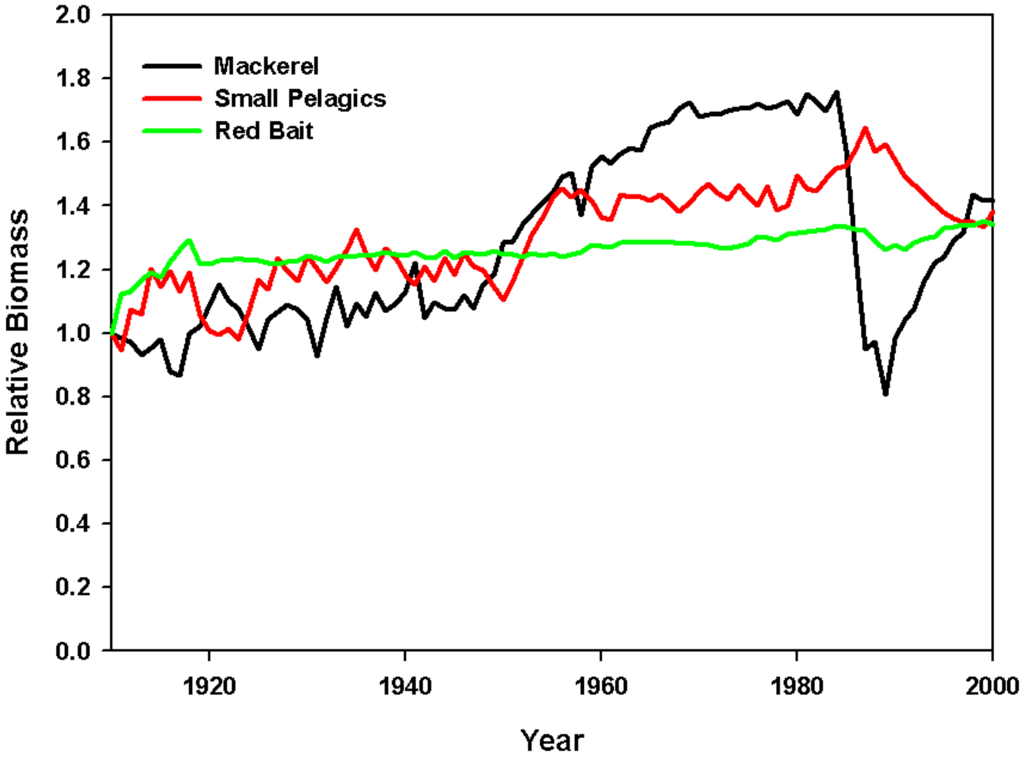


Figure 3-37: Historical time series of relative biomass of small pelagics predicted by Atlantis SE.

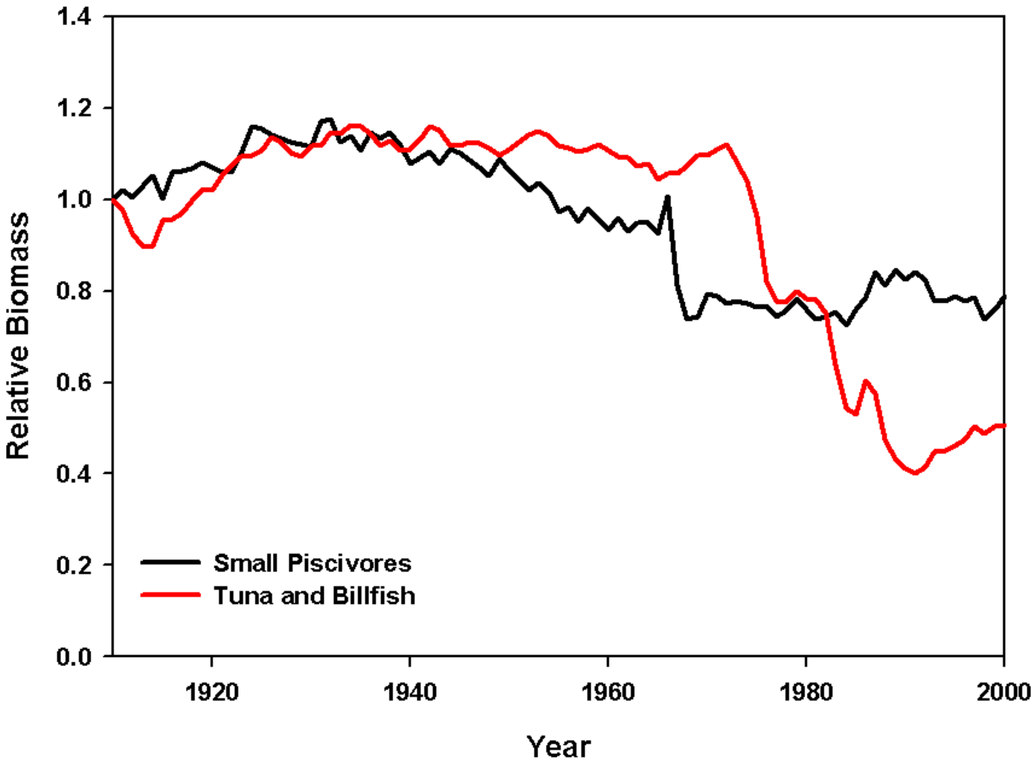


Figure 3-38: Historical time series of relative biomass of small and large piscivorous pelagics predicted by Atlantis SE (small piscivores are also referred to as shallow piscivores).

The two warehou groups also show strongly contrasting biomass trajectories (Figure 3.40). Spotted warehou increase quickly by 40% during the burn-in period of the model (prior to 1920) and then vary about this stable state. The group shows fairly strong variation in response to prey and recruit supply, with a particularly strong drop (of more than 15%) in 1967 and an equally strong spike in 1986. Compared to that spike there was a decline over the final years of the run, but in comparison with the long run average there is no substantive decline in the later years of the run. While the blue warehou group also increased by 40% in the first 30 years of the run this was not simply due to transient dynamics, but resulted from multispecies interactions that primarily impacted juvenile survival. The biomass then stabilized at this higher level through until the mid-1980s when fishing caused a strong decline, with the biomass dropping by more than 65% to only 45% of the initial biomass.

The majority of the demersal fish groups, whether on the shelf (Figure 3.41), slope (Figure 3.42) or in the deep water (Figure 3.43) show fairly steady biomass levels through until the 1990s when they begin to decline, often steeply. There are a few exceptions to this general pattern. Cardinalfish, ribaldo and oreos and dories show only very gentle declines of a few percent, much smaller than the 40-80% decline seen in other groups. The deepwater groups show much less interannual variation than the slope and shelf groups, which are much more heavily impacted by the variability in their predators and prey. However, the deepwater group orange roughy also shows the steepest and strongest decline (of over 80%). Redfish is the slope group that most strongly declines (by 60%), but begins the decline much early than the other groups – beginning in the late 1950s rather than the 1980s. It is not a one way decline, a partial recovery occurred through the 1970s when catches dropped off for a few years. Perhaps the three most interesting demersal groups are morwong, flathead and blue grenadier.

Blue grenadier show quasi-periodic spikes in biomass (Figure 3.42). These are seen in reality, though there is no guarantee that what produces them in reality matches why they are occurring in the model. Within the model they result from post-recruitment mechanisms – temperature effects on metabolism and the productivity of prey groups, as well as predation and prey supply, particularly for young-of-the-year. Predator and prey interactions are also important for the biomass of adults, which contribute to the spikes by being more or less numerous and being fatter or leaner, which all impacts on the amount of spawn produced. The impacts on the smallest juveniles are more important however, as modifications to survivorship at this age have strong roll on impacts for absolute abundance. In reality environmental forcing of recruitment will also contribute to the strength of these cycles in biomass and recruit abundance. As environmental forcing of the recruitment of this group is not included in the model as yet the spikes are not as large as seen in reality.

Flathead begin declining as a result of fishing fairly rapidly, as they are one of the first groups intensively fished (Figure 3.41). The western species doesn't show any significant effect of fishing until they come under intensive pressure in the 1990s, but the eastern tiger flathead sees fishery induced declines by the 1930s. Imposed on the fishery induced biomass variations is a roughly twenty year cycle of productivity, manifested most clearly in an increased survival of newly mature age classes – these groups are typically under the highest mortality rates as they have no size refuges from predation or fishing selectivity.

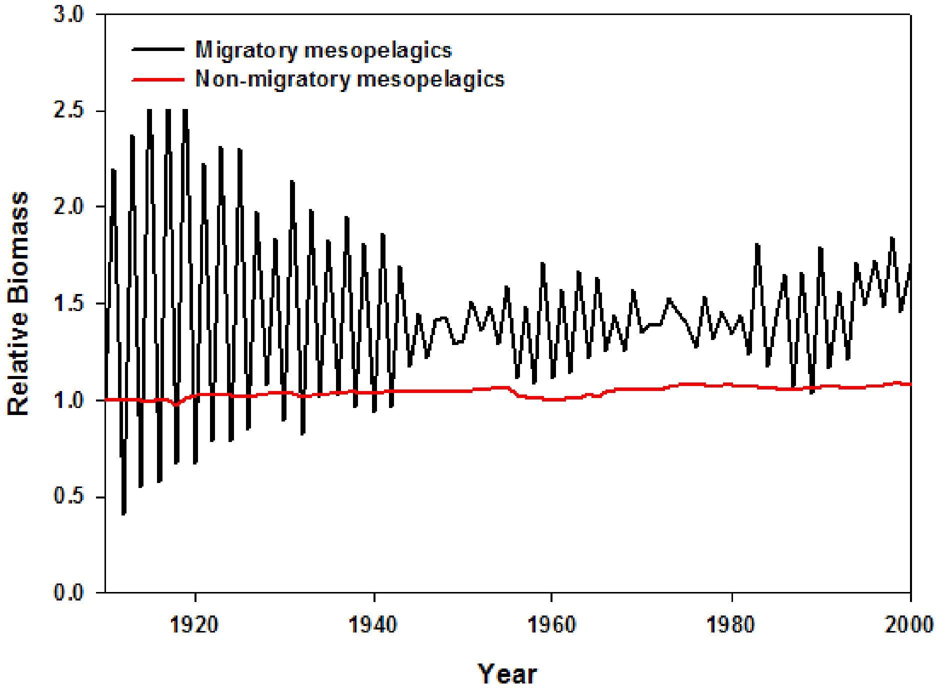


Figure 3-39: Historical time series of relative biomass of mesopelagics predicted by Atlantis SE.

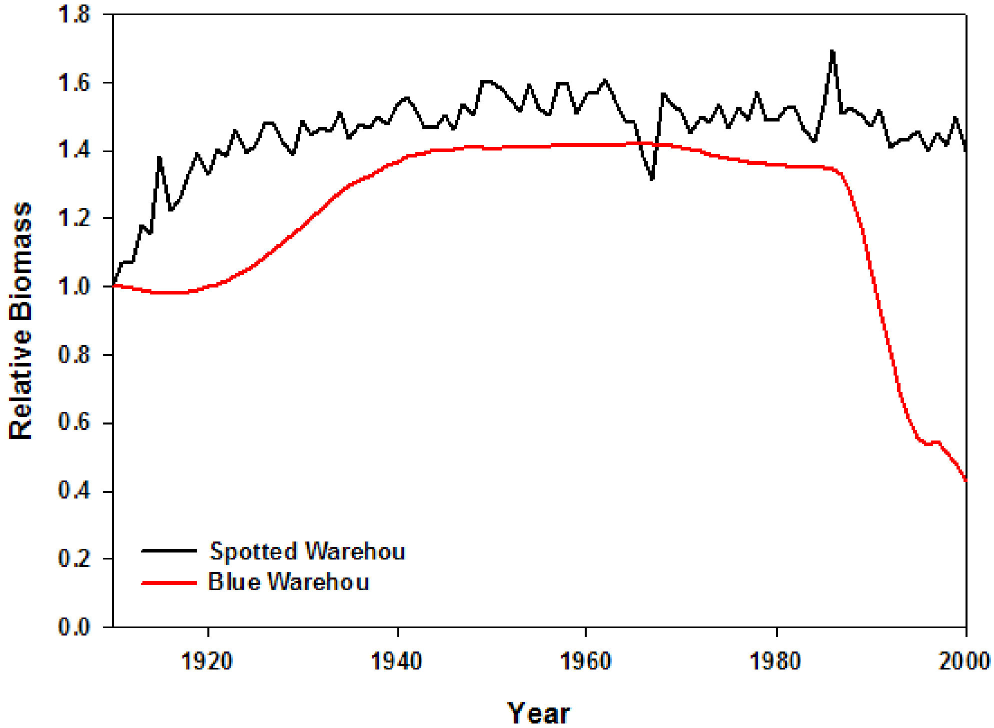


Figure 3-40: Historical time series of relative biomass of warehou predicted by Atlantis SE.

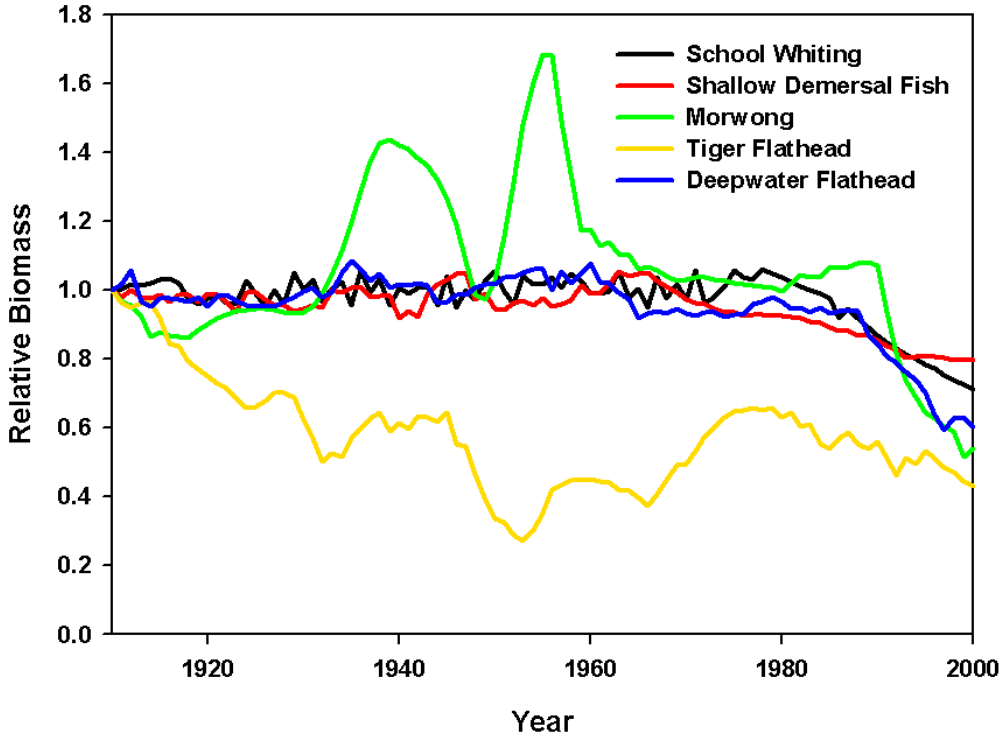


Figure 3-41: Historical time series of relative biomass of shallow demersals predicted by Atlantis SE.

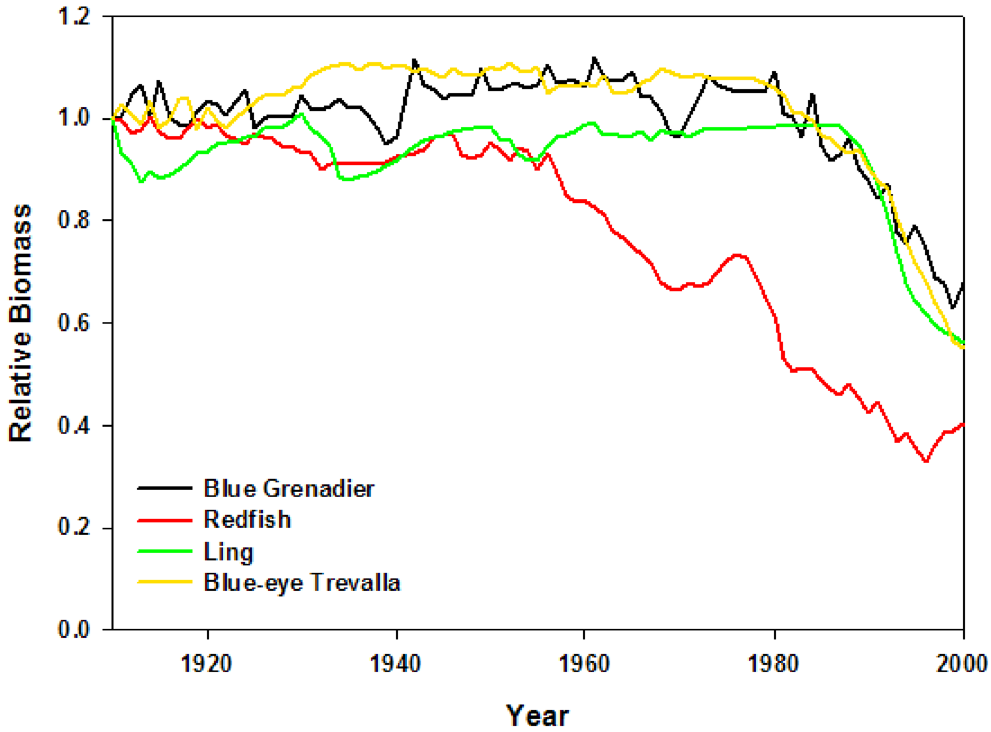


Figure 3-42: Historical time series of relative biomass of slope demersals predicted by Atlantis SE.

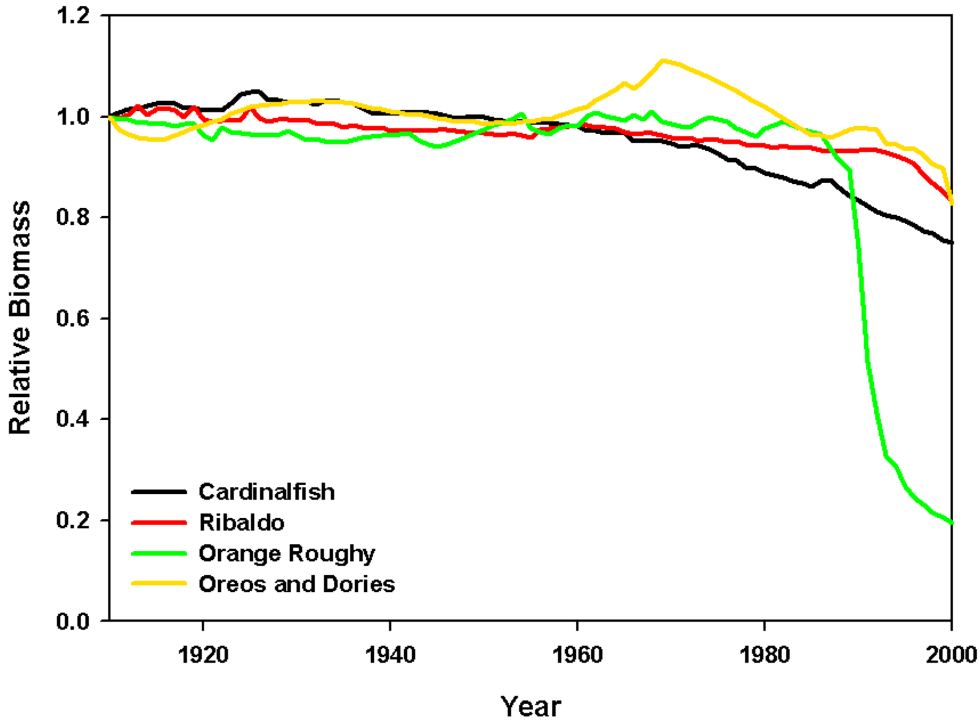


Figure 3-43: Historical time series of relative biomass of deep demersals predicted by Atlantis SE.

Morwong also show strong interannual ups and downs in relative biomass (Figure 3.41). In this case though, they are primarily due to interspecies interactions until the final decade of the run when fishing pressure leads to a 40% decline in the group's biomass. The magnitude of the peaks in productivity may be erroneously high (as they occurred prior to 1960 it is unlikely we will ever know), but the degree of connectedness of this group has been noted in other studies (Dambacher pers. com.). This connectedness makes it a particularly hard group to deal with in a predictive sense, with many factors (which are not always immediately obvious) contributing to the final biomass values. This suggests that assessments for this group may benefit from the inclusion of multispecies impacts and interactions. One facet of morwong biomass dynamics not captured by Atlantis SE is the contribution of recruitment variability. This kind of variability is seen in reality for morwong, and is seen in other model groups like blue grenadier, but did not emerge in the model dynamics in this case. Alternative parameterisations may give rise to such a dynamic, but it is also possible to force recruitment with a variable time series if this feature is desired in future versions of Atlantis SE.

3.4.4 Chondrichthyans

All but the general demersal shark group show a decline in relative biomass by the end of the historical run (Figured 3.44-3.46). The strongest drop amongst any of the Chondrichthyans in the shelf and upper slope waters is that of school shark, which declines quite sharply during the 1960s-1970s, which is when catches peak (Figure 3.45). The other groups and stocks decline by much smaller amounts, including the shallow water dogfish components that represent spikey spurdog (*Squalus megalops*) (Figure 3.44). The declines are much steeper and stronger for deeper dwelling stocks. For instance, the deeper water stocks of demersal sharks decline quite steeply by the end of the period (Figure 3.46), making the contrast with the shallow water stock quite stark (as they do not decline). The deepwater demersal sharks and dogfish decline by more than 70-80%. The trajectory for gulper sharks is quite sensitive to the initial distributions used. If there are stocks in the western end of the GAB and other more lightly fished areas then the drop is steep (50% after only 15 years under fishing pressure), but not as severe as is thought to be the case in reality (as the model predicts stocks that are yet to be impacted). If however, the majority of the stock is in eastern waters initially then the decline can be as much as 90% or more.

Gummy shark holds up under fishing pressure much better than most other shark groups, declining steadily but relatively slowly over the period it is fished. Consideration of the diet and sources of mortality of the species does lend some support to the notion this species has benefited from the reduction of school shark stocks, but it is only limited support as Atlantis SE does not capture some of the behavioural dynamics that sit behind the competitive replacement hypothesis and the gummy-school shark interactions. Consequently, a much more dedicated modelling exercise would be required to explore that issue in detail. These aggregate results also mask the local declines that happen within boxes as areas are exploited; this is seen in school shark for instance, where the aggregate trajectory suggests the greatest declines occurred in the 1960s, but local declines were seen in the eastern boxes before that and in some western boxes after that time (though due to the use of a single stock for school shark these local effects were not as strong as they would have been if multiple smaller stocks has been used).

It is interesting that while many of the shark groups show little interannual variation, particularly those living at depth, the two most heavily commercially fished shark groups (gummy and school shark) show a good degree of interannual variability. School shark in particular display a strong underlying productivity cycle – in the main expressed through changes in condition, rather than abundance. Equally interesting is that the school shark show little sign of recovery despite a reduction in catches of the group in the final years of the run.

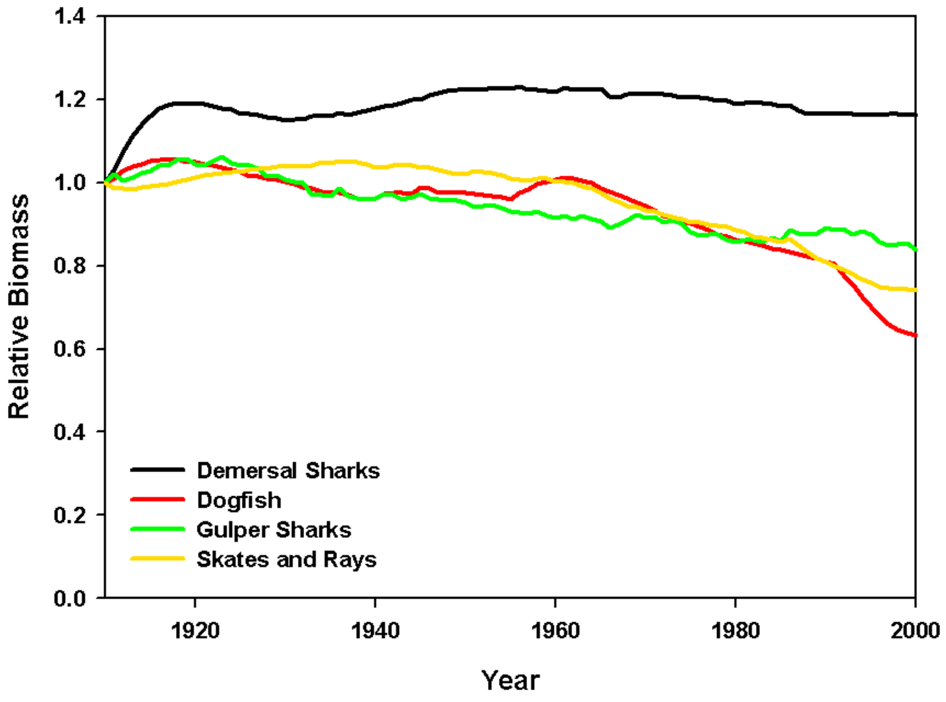


Figure 3-44: Predicted historical time series of relative biomass of shelf and upper slope sharks and rays.

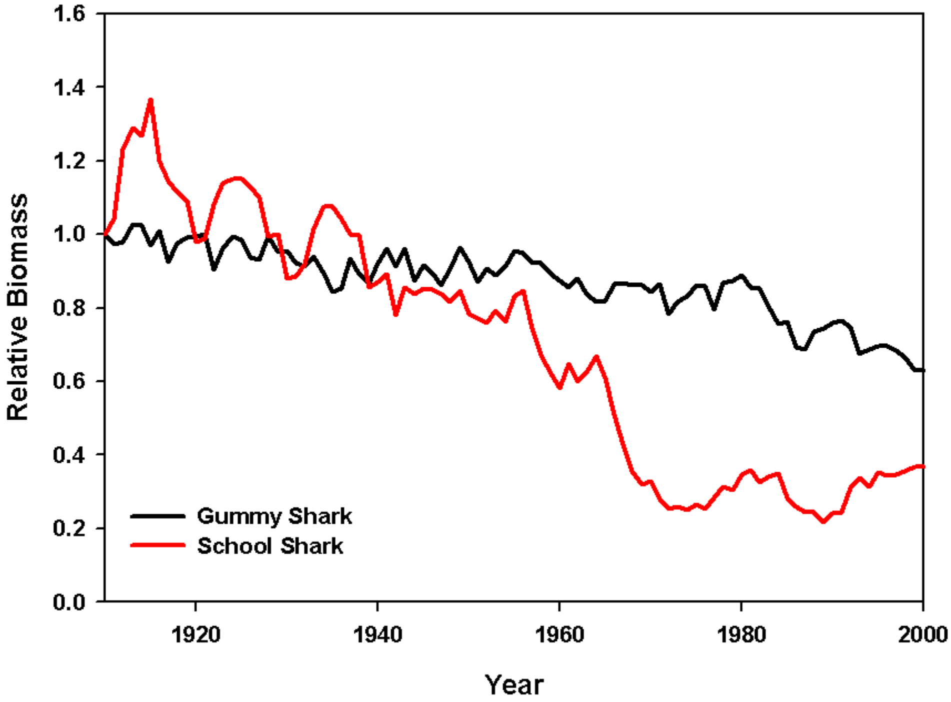


Figure 3-45: Predicted historical time series of relative biomass of commercially targeted sharks.

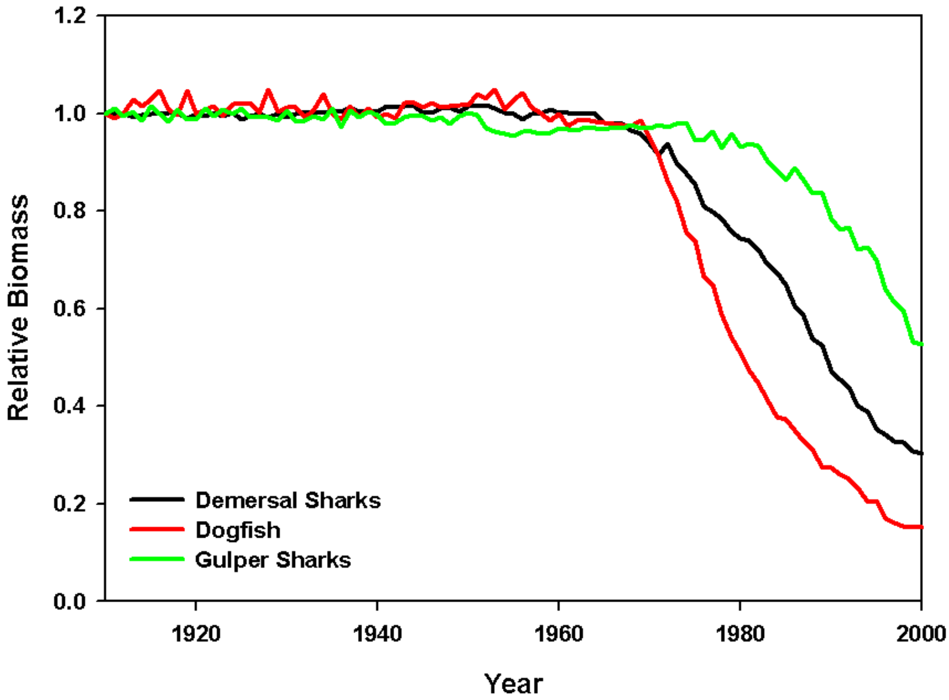


Figure 3-46: Historical time series of relative biomass of deep water sharks predicted by Atlantis SE.

3.4.5 Atlantis vs Single Species Assessments

During the second phase of calibration the model was forced with the observed catch history and tuned to existing biomass or catch rate time series. For ten of the target species groups considered in the Atlantis model recent assessments were available for comparison with Atlantis. While the assessments were not fit to slavishly during this second phase of calibration, parameterisations which lead to trajectories reasonably similar to those in the assessments (in terms of general pattern of dynamics and rough order of magnitude) were preferred to those that lead to diametrically opposed biomass trajectories. In all cases the final parameter sets used did lead to biomass trajectories that reasonably resembled the pattern seen in the assessment biomass predictions (e.g. Figure 3.47-3.55) the fit to standardised CPUE series (if available) for each species was also quite good (except for Blue Grenadier where the very large annual variability could not be matched). For the deeper water groups (blue grenadier, ling, orange roughy, gemfish and blue warehou) there was also a very good match between the Atlantis and assessment predicted biomasses. For all other groups Atlantis predicted higher biomasses than did the single species assessments (Atlantis parameterisations leading to lower biomasses do not survive historical fishing pressure, as they cannot support ecological and fisheries pressure and lead to recruitment levels that avoid stock collapse, making closer matches to assessments impossible). It is important at this point to stress that while this comparison is informative, it is salient to remember that Atlantis is not a predictive stock assessment model and should not be treated as such. It is a very useful tool for exploration of alternative strategies and scenarios, but this is **not** to say stocks are as high as estimated by Atlantis. It is important to remember however, that the mismatch in relative biomasses and assessments means that there is room for an increase in TACs and catches for those species (e.g. the shark and flathead species), as the model is moving toward the target reference point; whereas in reality this shift is not possible as the assessments indicate the stocks are already about the target reference point. This also has implications for the catches and economic returns predicted in the Atlantis model, they are likely to stay higher longer than may be the case in reality. While this has implications for absolute predictions, it should not impact a comparison of relative performances (as all scenarios are evaluated under the same circumstances).

It is also possible to draw some system understanding from the Atlantis-assessment mismatch. In particular, this pattern of results indicates that: (i) trophic interactions are less important than direct fishing pressure for the evolution of the biomass trajectories in the deeper water species, while both are important for shelf groups (thus a higher biomass is needed to satisfy both fishing and predation mortality) and (ii) recreational fishing pressure (which are not always included in stock assessments but are present in Atlantis as a tithe) is a significant factor for shelf groups and single species assessments would probably benefit from their inclusion in some (even crude) form.

Note that this mis-match between the real world assessments and the Atlantis trajectories is not repeated when simulated Atlantis data is used in the assessment. In that case the simulated assessment predicts a trajectory very close to that of the Atlantis trajectory used to create the data used in the assessment. This difference in performance between Atlantis vs single species assessments indicates two things. First it indicates that if the assessment model is applied in a situation congruent with its assumptions it works extremely well (as is the case when it is applied within Atlantis using simulated data drawn from that Atlantis run) – it is apparently free from any pathological bias or artefacts. Second it indicates that (as with all quantitative models) there is some divergence between Atlantis and reality and so the assessment and Atlantis trajectories do not always match. This is an illustration of why Atlantis SE should not be treated as an assessment model itself, though it is still trustworthy for exploration of alternative strategies and scenarios because it does capture the major non-linearities and behaviours of the system.

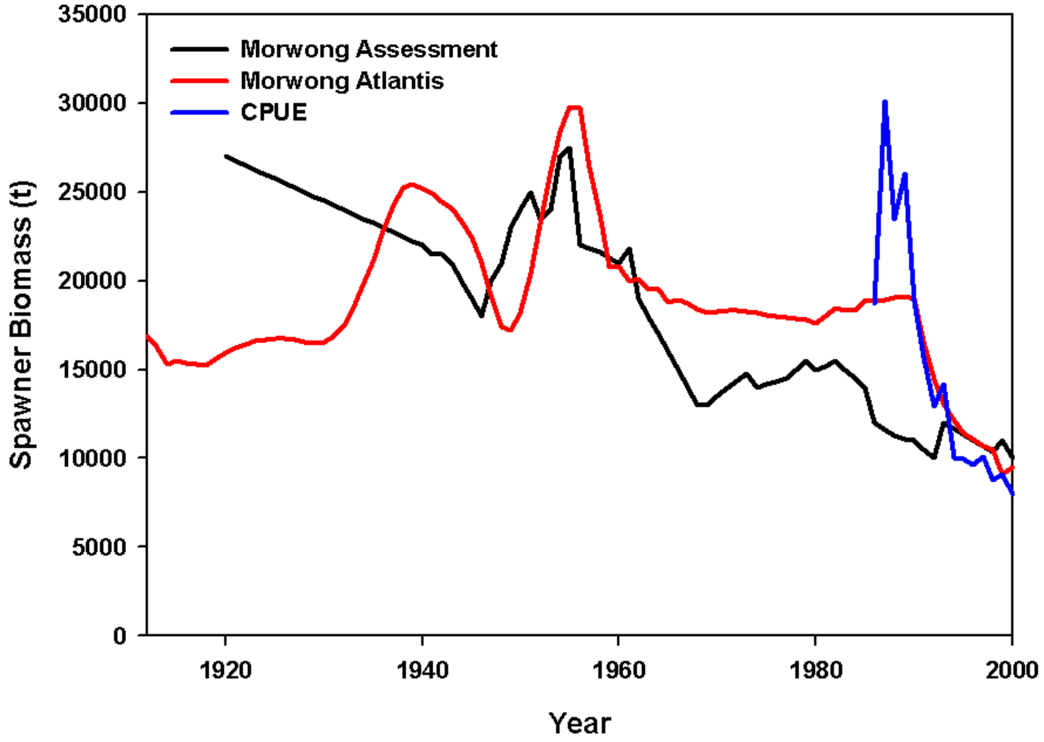


Figure 3-47: Comparison of the historical biomass trajectories of jackass morwong predicted by a single species assessment (Tuck and Smith 2004) and Atlantis.

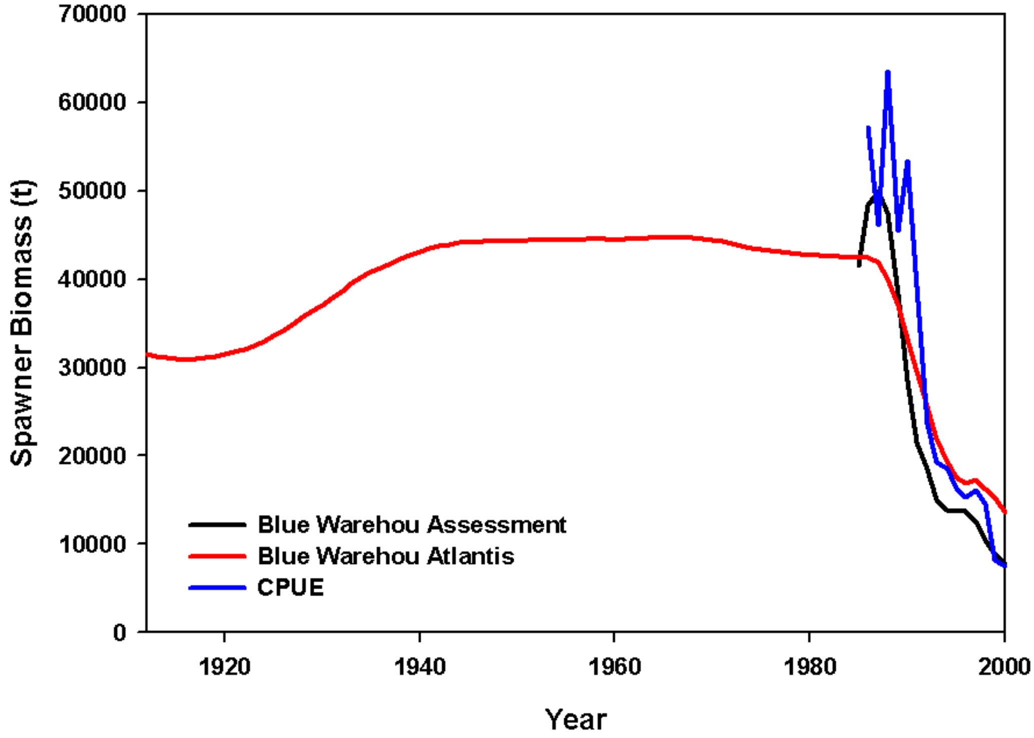


Figure 3-48: Comparison of the historical biomass trajectories of blue warehou predicted by a single species assessment (Tuck and Smith 2004) and Atlantis.

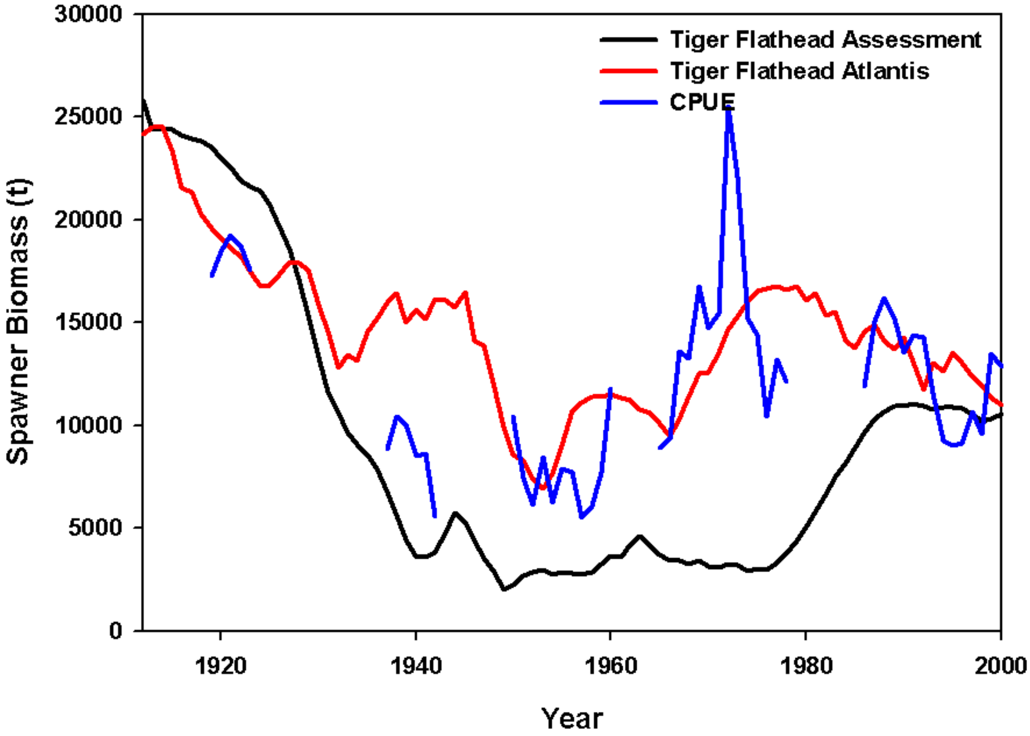


Figure 3-49: Comparison of the historical biomass trajectories of tiger flathead predicted by a single species assessment (Klaer 2006b) and Atlantis with standardised CPUE data given for reference.

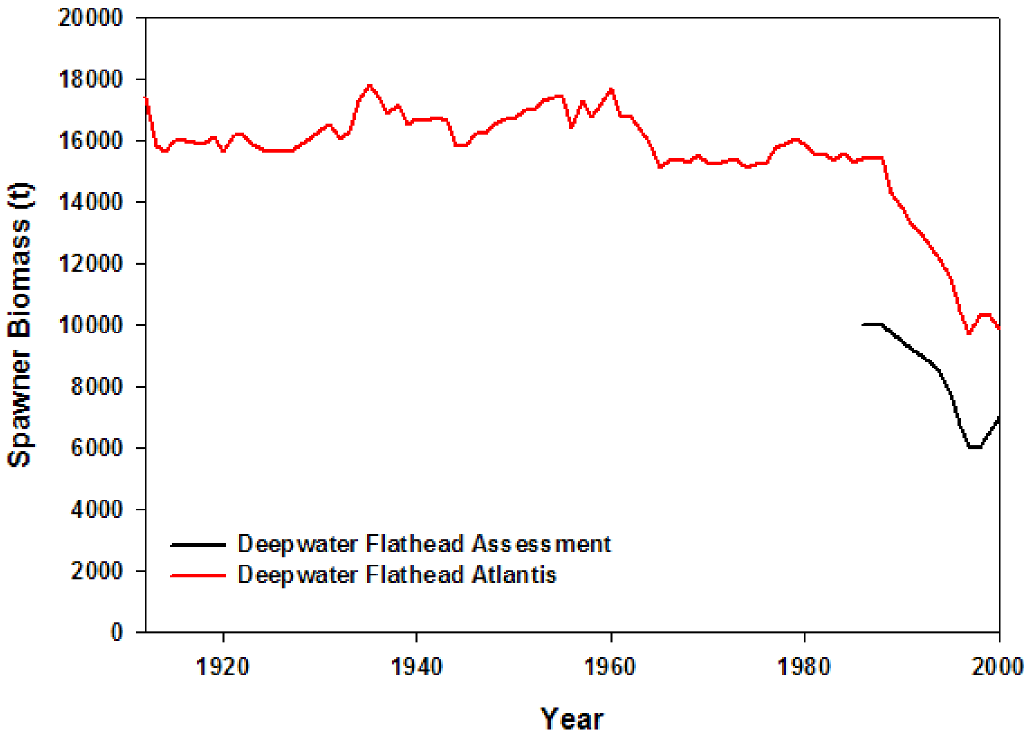


Figure 3-50: Comparison of the historical biomass trajectories of the GAB deepwater flathead stock predicted by a single species assessment (Klaer and Day 2006) and Atlantis.

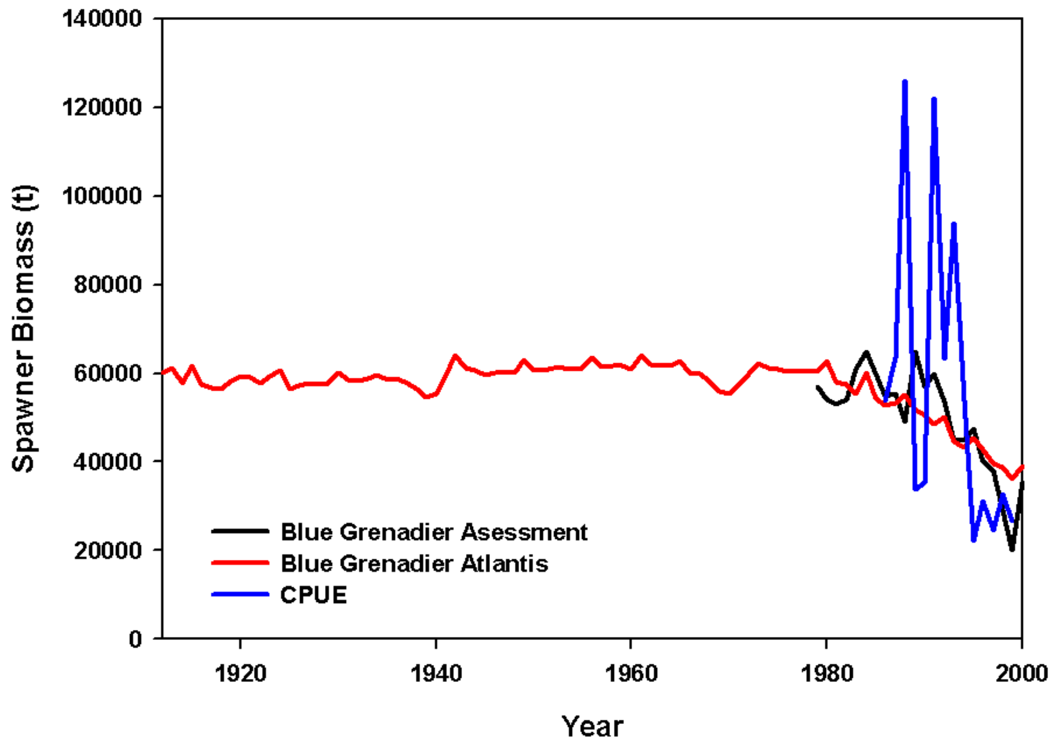


Figure 3-51: Comparison of the historical biomass trajectories of blue grenadier predicted by a single species assessment and Atlantis.

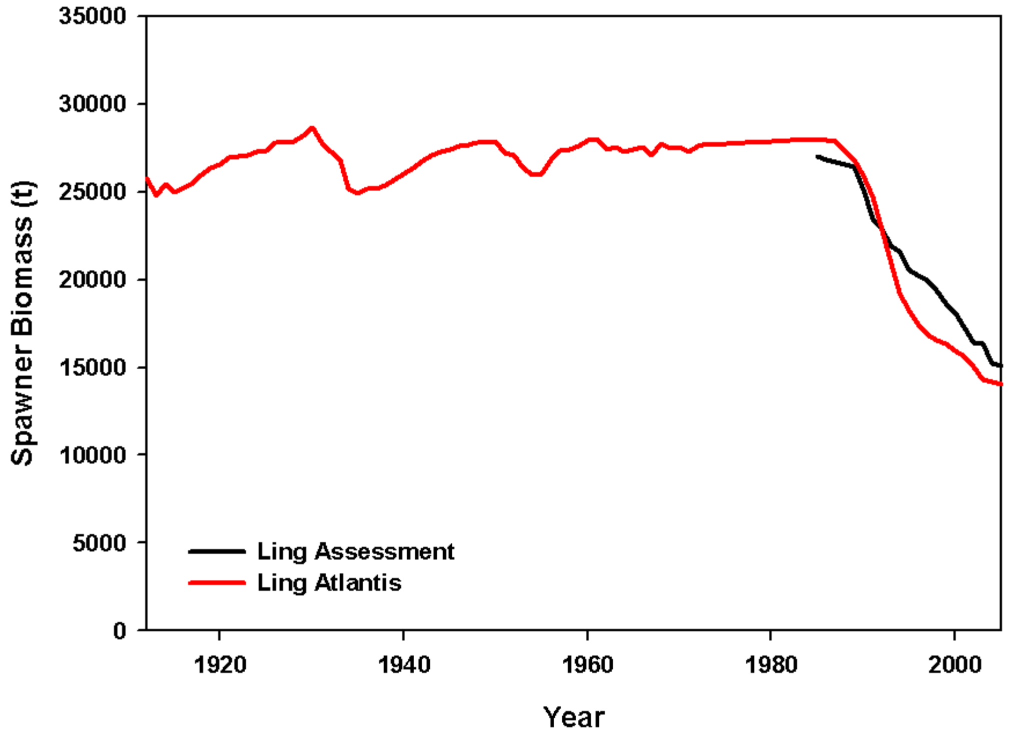


Figure 3-52: Comparison of the historical biomass trajectories of pink ling predicted by a single species assessment and Atlantis.

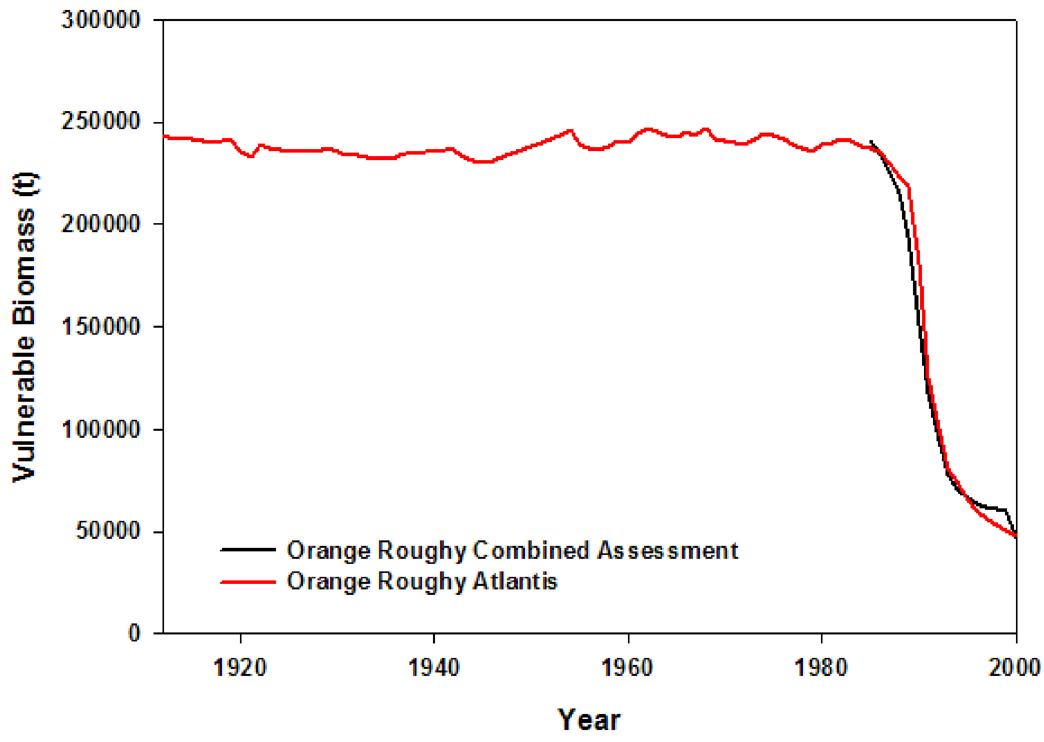


Figure 3-53: Comparison of the historical biomass trajectories of orange roughy predicted by a single species assessment and Atlantis.

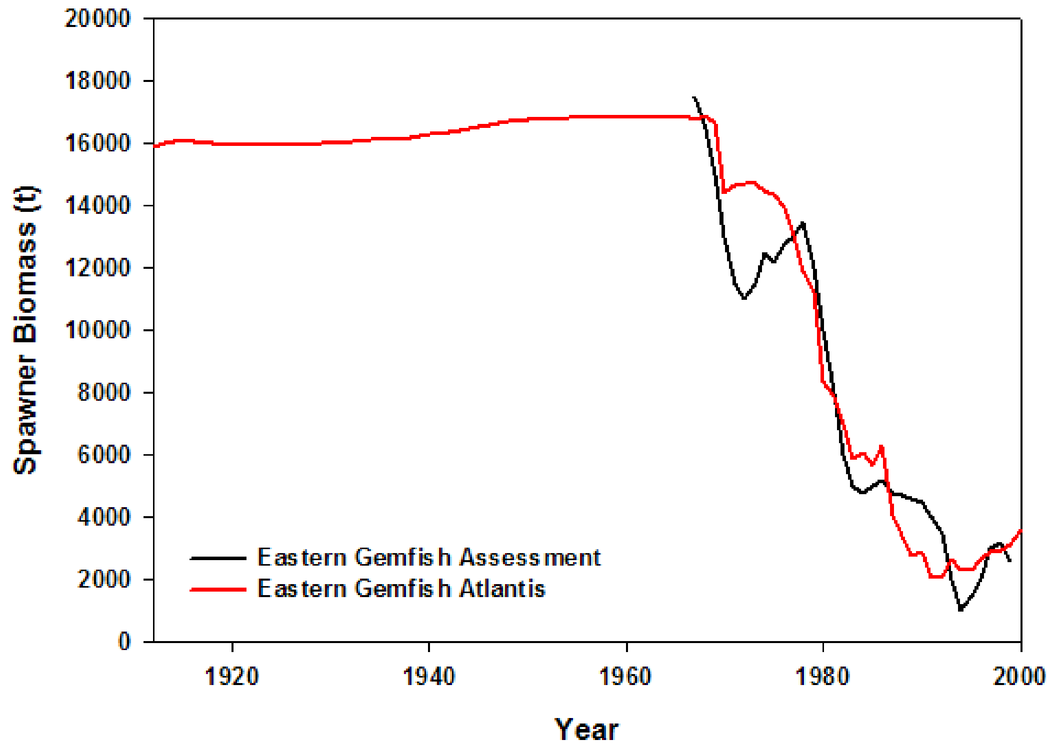


Figure 3-54: Comparison of the historical biomass trajectories of eastern gemfish predicted by a single species assessment and Atlantis.

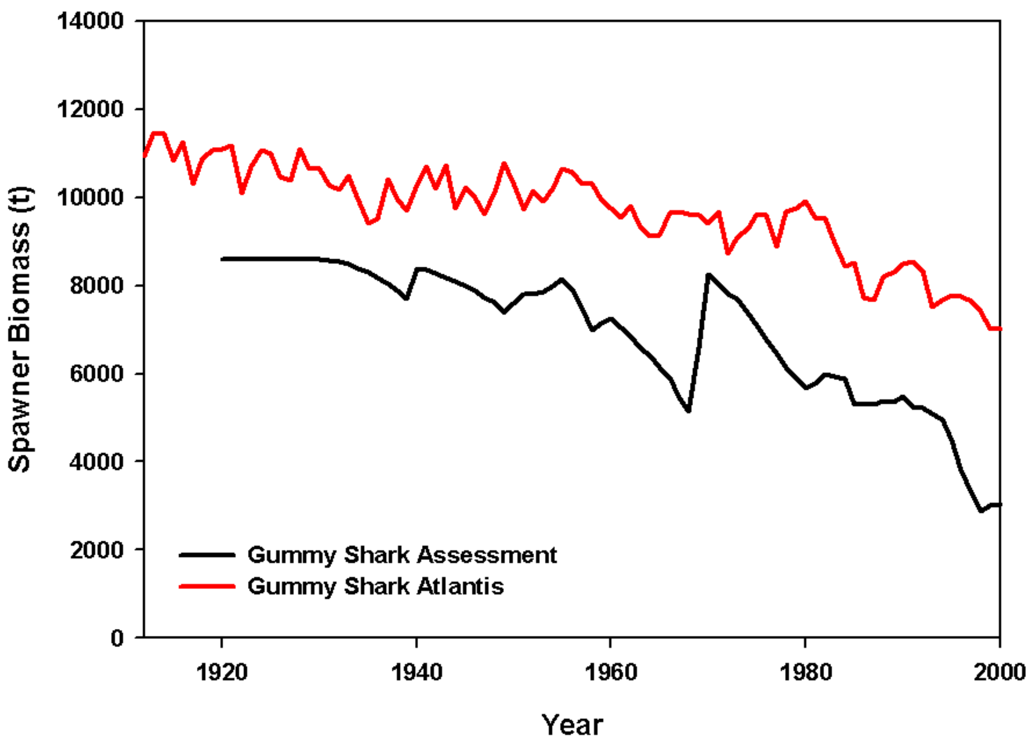


Figure 3-55: Comparison of the historical biomass trajectories of gummy shark predicted by a single species assessment and Atlantis.

3.4.6 Mammals and Seabirds

The top mammalian predators have generally smooth biomass trajectories, except for the toothed whales, which have a high degree of condition dependent biomass variability imposed on an underlying increasing trend in abundance (Figure 3.56). This is driven in part by prey productivity and in part by uncertainty of actual biomass levels that far into the past (more refined biomass estimates may see a flatter initial trajectory, as this was obtained under some alternative parameterisations with higher initial biomasses). Variability of the form expressed by the toothed whales is not seen in the other mammalian groups which smoothly transition through the course of the run (Figure 3.57). The biomass of the baleen whales shows dips with each pulse of catches (which stop during the 1920s and again during the two world wars before ending completely in the late 1970s) but recovers once whaling ends and by 2000 the relative biomass of these large mammals has increased to roughly 70% of the 1910 values. The stock remains depleted despite the strong recovery as the group had been pushed to low levels (< 20%) by the end of whaling. The rate of recovery suggested by Atlantis SE is relatively rapid for a group with such low fecundity, but in comparison to the IWC assessment for southern humpack whales (IWC 2007, available at http://www.iwcoffice.org/conservation/estimate.htm) the 2-9% rate of recovery suggested by Atlantis SE may be too low – IWC (2007) suggests recovery rates may be as high as 7.9-14.4%.

The smaller whales (dolphins) are not directly taken by fisheries, rather they benefit initially from the restructuring of shelf stocks, making use of the increase in prey groups. However, there is a very slight downturn in the dolphin group after heavy fishing pressure begins in the

1970s as the higher calorific prey groups began to decline (i.e. are removed by fishing) and the bycatch rules see an increasing number of dolphins incidentally taken by fishing.

The dynamics of the pinniped groups (Figure 3.57) are also fairly smooth. The seals steadily, if somewhat slowly recover from sealing, with the rate of recovery picking up over the final decades of the run as adult reproductive biomass accumulates, though even these increased rates are lower than observed in some real colonies (Gales *et al* 1992, Goldsworthy *et al* 2003, Pemberton and Gales 2004). The sea lions present a much more complicated trajectory. They initially decline after sealing finishes as the lack of new pups aging through the depauperate age structure combines with senescence of the older age classes to see a continued population decline for a further half century. It is only in the 1960s that the sea lion group shows any recovery, gradually returning to about the level they were in 1910, which is still substantially below those prior to sealing (Gales *et al* 1992, Pemberton and Gales 2004).

The final top predator group is seabirds. This group is not intended as a representation of all seabirds in the region (e.g. the migratory waders are completely omitted). Rather it aims at capturing some measure of the seabird biomass most affected by the fisheries and vulnerable to direct gear impacts or knock-on effects from changes in other parts of the system. As a result their overall biomass trajectory is highly variable, showing strong interannual and interdecadal patterns. These patterns result from prey availability impacting on fledgling success and juvenile and young adult survival. These cycles overstate real levels of variation, but the small size of the absolute biomass of this group in the model means that they do not have an unacceptable net effect on the other model components and they do reflect the general impacts of real system mechanisms that affect these groups. Consequently, they were left as is after the second phase of the calibration. In any future work that is focused more heavily on the upper trophic levels seabirds would need to be dealt with in more detail. More of the total seabird biomass would need to be included, with a greater differentiation of the seabird groups based on their size and functional role (in much the same way that the fish and mammals have been dealt with). In addition, seabird data would need to be better matched during the calibrations so that the cycles are more constrained – as they overwhelm any potential decline due to incidental fishing effects in this case.

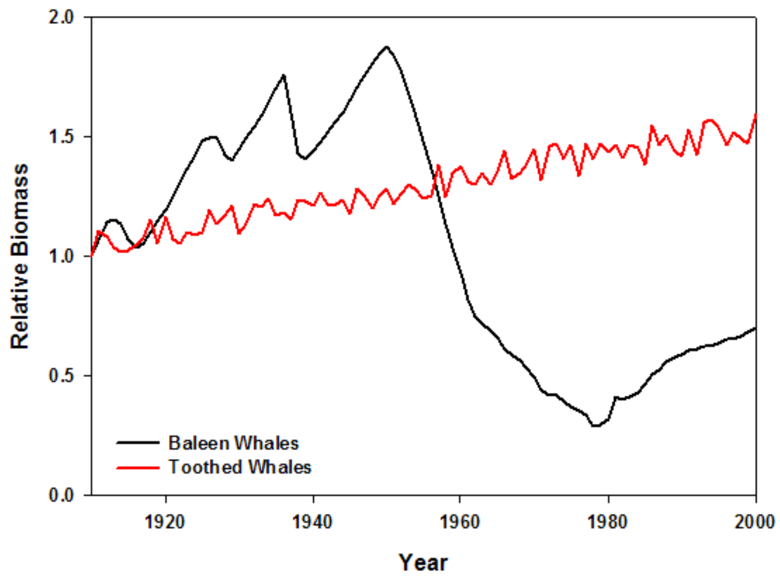


Figure 3-56: Historical time series of relative biomass of large whales predicted by Atlantis SE.

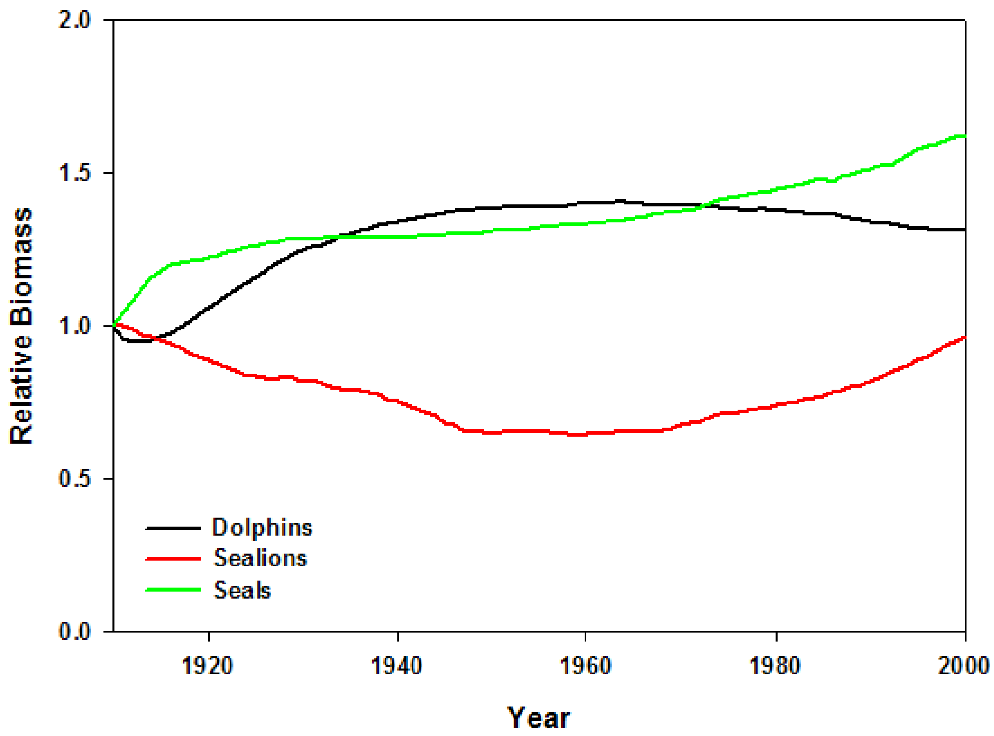


Figure 3-57: Historical time series of relative biomass of dolphins and pinnipeds predicted by Atlantis SE.

3.4.7 Nutrients, Detritus and Bacteria

The dynamics of the inanimate and microfaunal components of the southeast Australian Atlantis model are generally no less interesting than those of the living groups discussed above. The overall nutrients show little change through the run, although there is a slight (<10%) suggestion of an increase at the very end of the run (Figure 3.58). Locally the picture is much more variable seasonally and interannually as upwelling strength and current flows vary, impacting nutrient supplies and primary productivity levels, which cause ripple effects of degrading size as the energy moves further and further through the trophic system.

Perhaps initially surprisingly, gross detritus levels decline through the course of the run, particularly after the 1960s (Figure 3.59 – there is some initial transient oscillation, but this settles very quickly. This decline in detritus is not actually a result of fishing pressure; rather it reflects the immediate impacts of the changing state of the deposit feeding infauna. The sheer magnitude of the detrital pools however, means that neither the breakdown and cycling of nutrients, nor the supply of detritus to other scavenging detritus consuming groups, is adversely affected. This is due in part to the increased availability of carrion from discards as the fisheries progress (Figure 3.60). While the relative increase is quite substantial (>46-fold, which represents an increase from almost zero to 15,000t), the absolute amounts are still fairly small at the regional scale in comparison with the magnitude of the existing detrital pools (which total hundreds of millions of tonnes). This is not to say carrion does not make some contribution to the restructuring of the trophic web with fishing. Locally carrion can have quite a marked, if potentially short term effect, given it is converted to labile detritus within a matter of days. Carrion provides a high quality (relative to the much harder to process detritus pools, even labile detritus can be hard to process) and often spatially concentrated food supply for fast acting scavengers. This potential is not reflected in the overall bacterial levels though (Figure

3.61), which more closely mirror the overall detrital biomass. This is not particularly surprising given their derivation as substrate colonisers, directly related to available detrital surface area, rather than simple consumers (Fulton *et al* 2004).

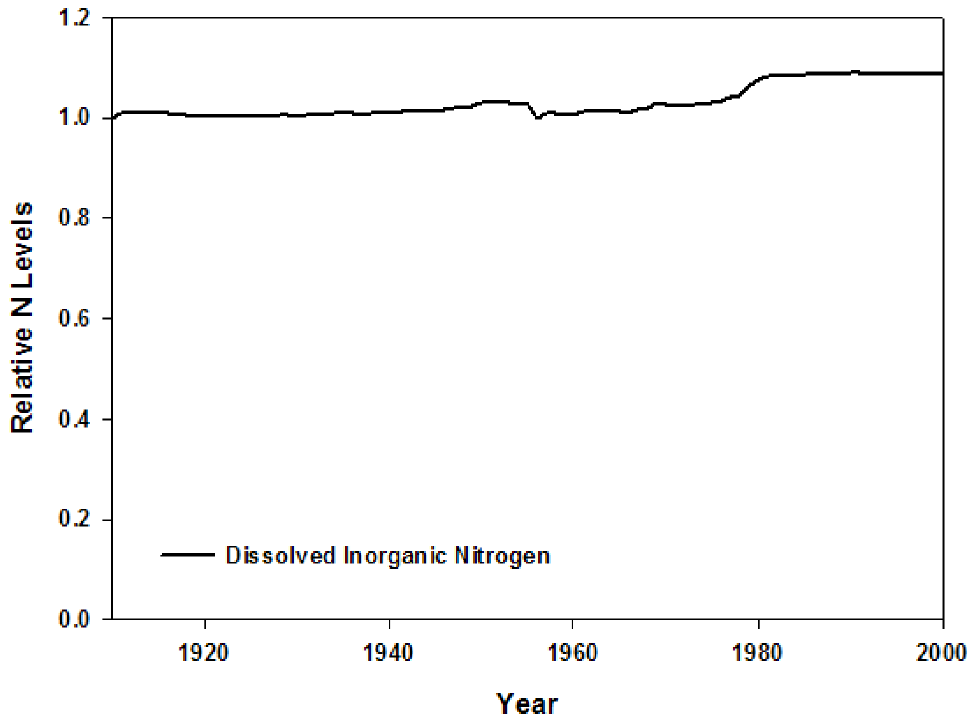


Figure 3-58: Historical time series of relative levels of Dissolved Inorganic Nitrogen predicted by Atlantis SE

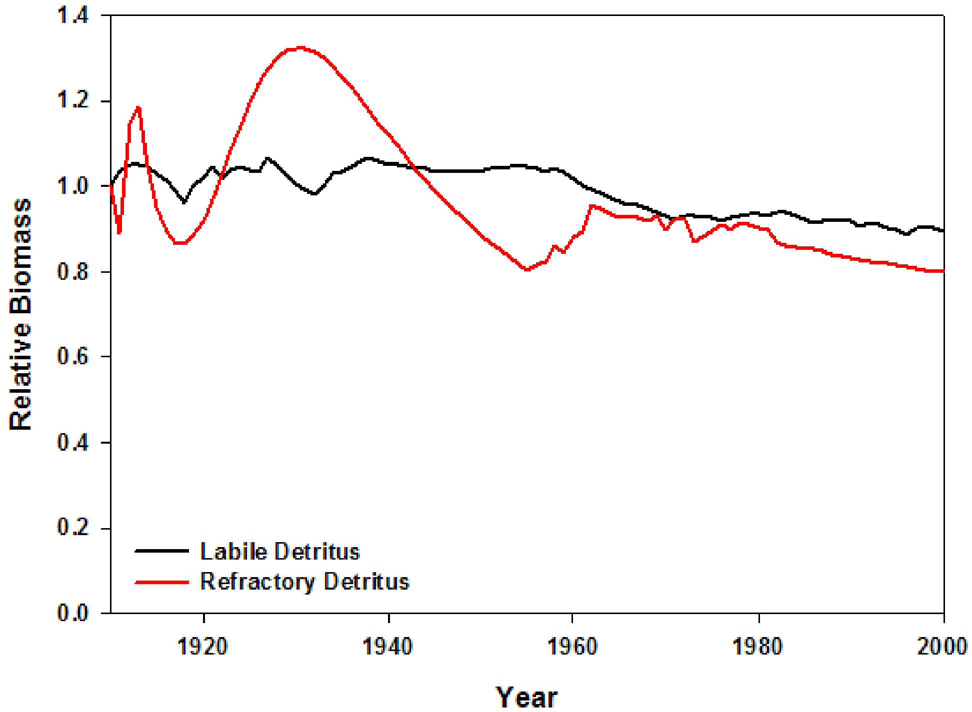


Figure 3-59: Historical time series of relative biomass of detritus predicted by Atlantis SE.

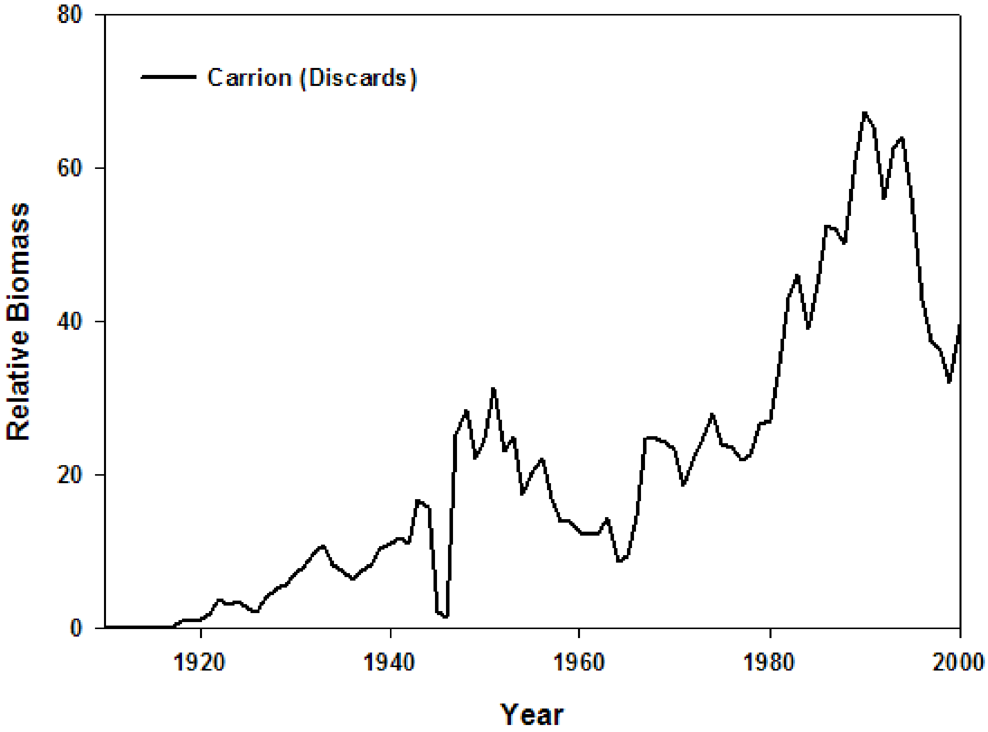


Figure 3-60: Historical time series of relative biomass of carrion from discards predicted by Atlantis SE.

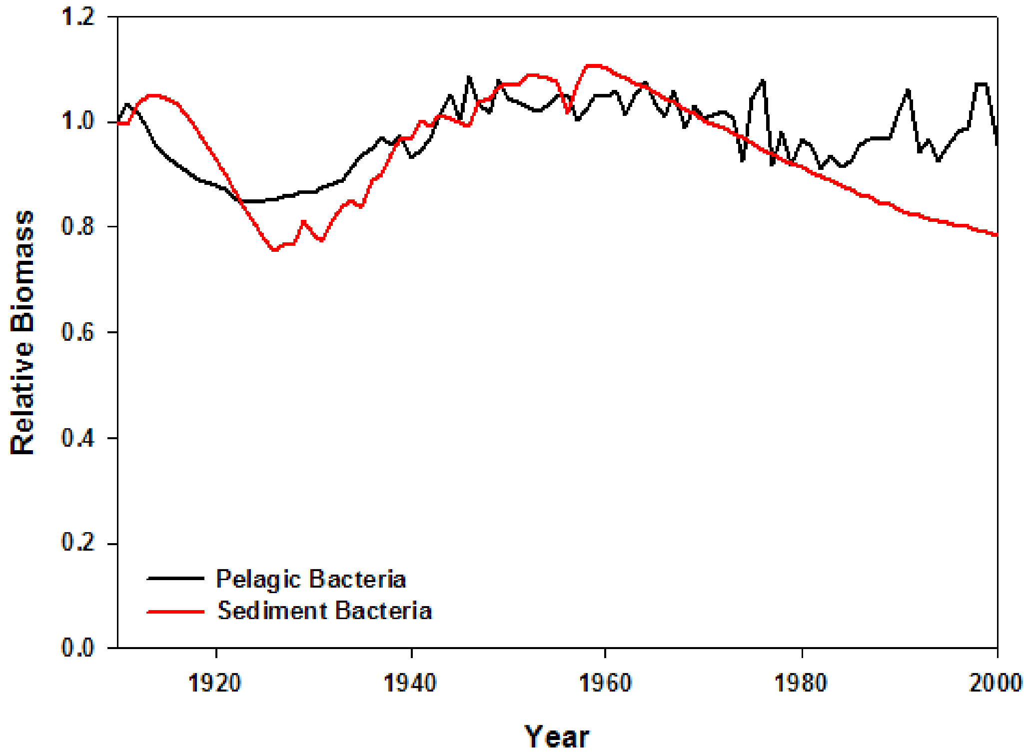


Figure 3-61: Historical time series of relative biomass of bacteria predicted by Atlantis SE.

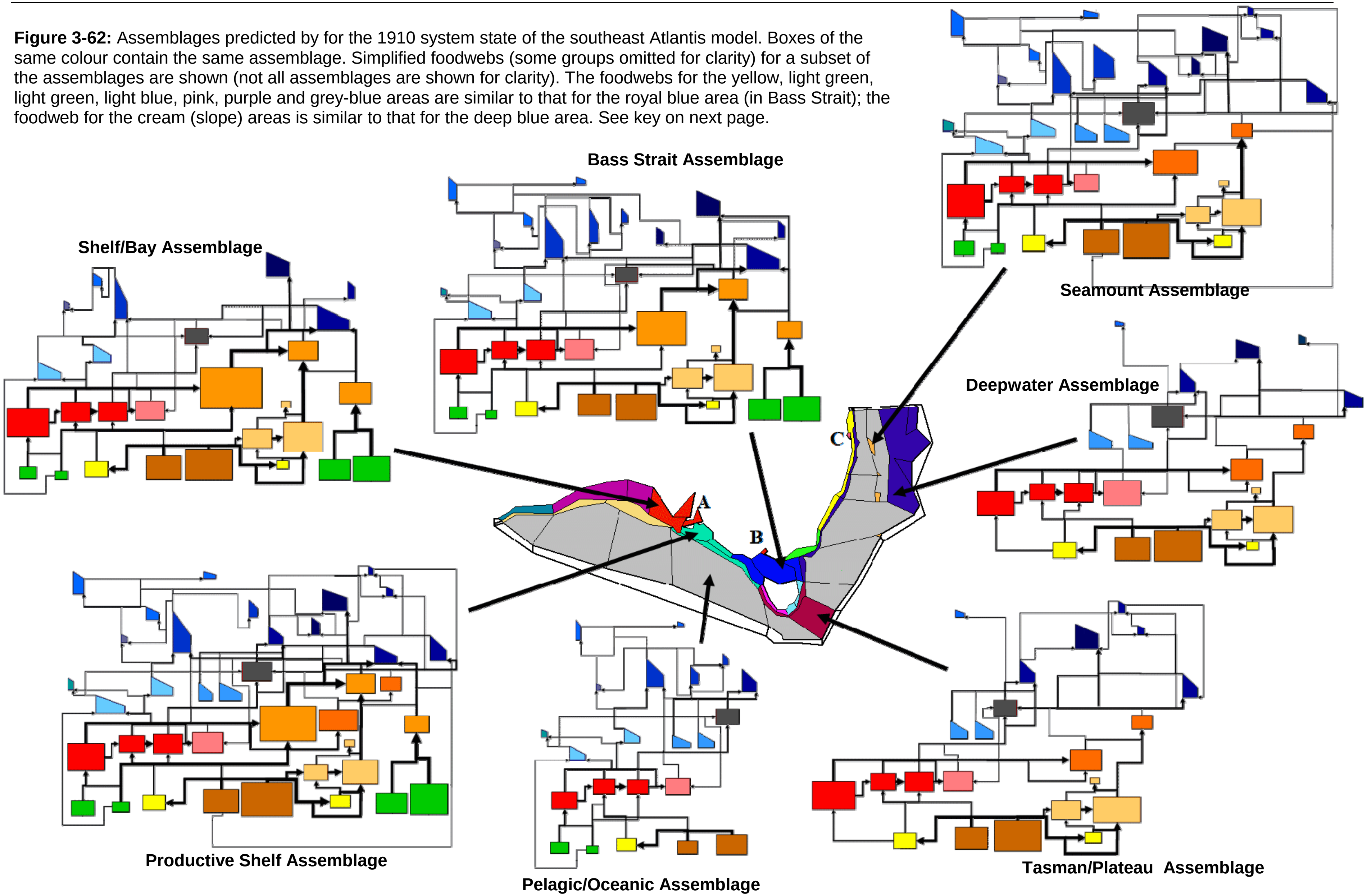
3.5 Changes in community structure

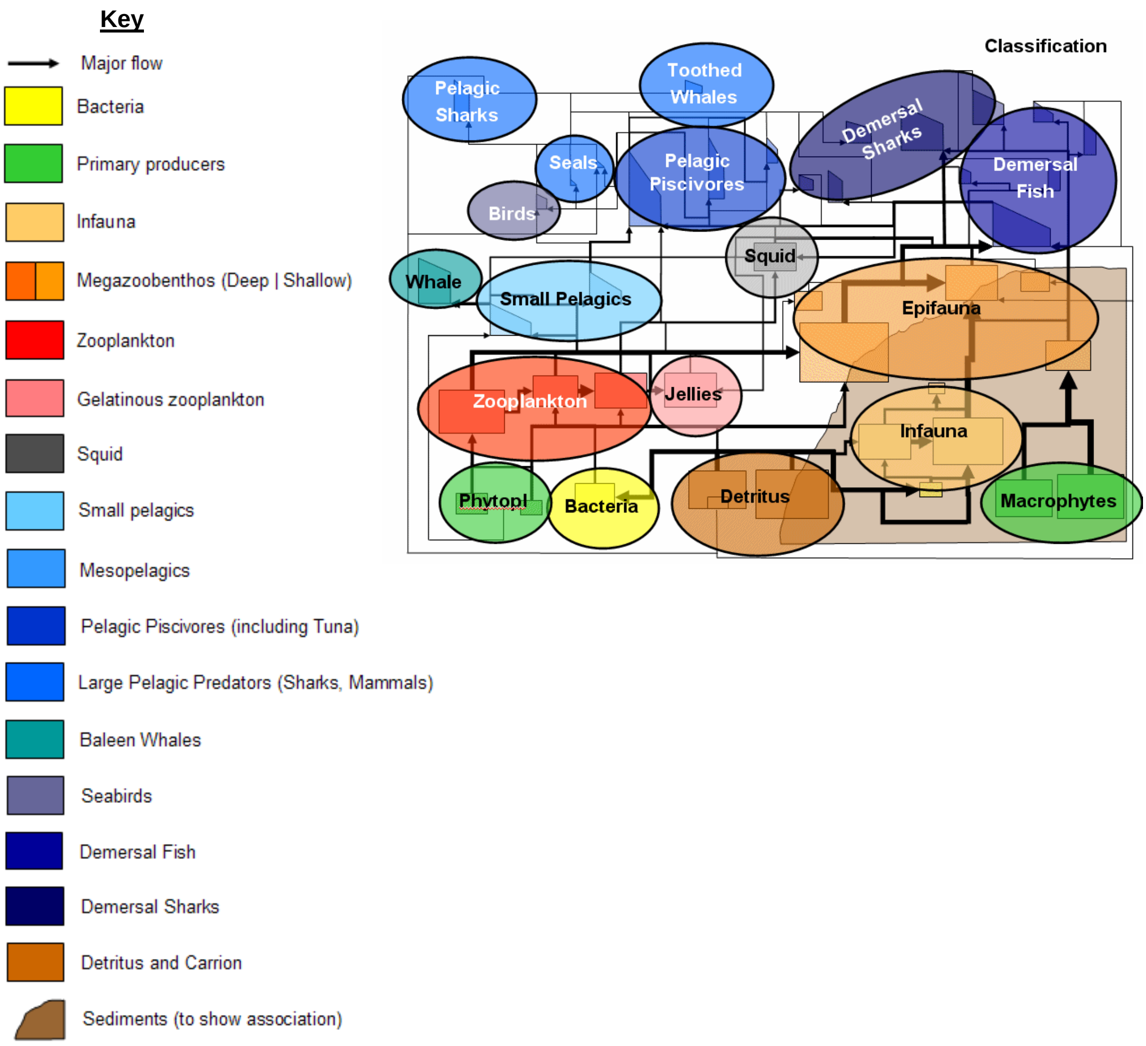
One use for Atlantis is to consider the change in community structure through time as the system state changes. Rather than defining and constraining assemblages within Atlantis, the model predicts assemblages and resource partitioning based on habitat preferences, trophic connections and the results of the physical, ecological and biogeochemical processes included in the model. There is variation through time and from cell-to-cell, but distinct regions that contain similar ratios of groups can be seen through the finer details. While these patterns can be discerned directly from maps of spatial distributions of biomass generated by Atlantis, a more rigorous method is that described in Fulton *et al*. (2004) – where assemblages are determined by (1) considering the fourth root transform of the average biomasses of all groups in each box on a two-dimensional non-metric Multidimensional Scaling (MDS) plot derived from a Bray Curtis similarity matrix; and then (2) examining the average values of the physical variables and the biomass per group (using the SIMPER routine of the Primer software package (Clark and Warwick 1994)) to ascertain which groups determine the clustering seen in the MDS. This analysis identifies areas (groups of boxes) in the model output that share biological and physical characteristics.

In the 1910 state of the system there are five general types of assemblages and 15 individually identifiable assemblages in the modelled area. The different general types are largely related to the depth and nutrient levels (and mixing) found in the boxes:

- Bay assemblages (at A, B and C in Figure 3.62) are shallow water, high nutrient and high light assemblages that are supported mostly by benthic primary producers and detritus and dominated by shallow living fish (or juvenile age stages of groups that live at depth when older)
- Shelf assemblages (the grey-blue, purple, royal blue, light blue, pink, cyan and yellow areas in Figure 3.62) are similar to the bay assemblages, but have a few more groups (or age stages) that are oceanic or live at depth when older; the differences between the shelf assemblages are due to differences in local productivity (areas fed by upwellings, like the aqua zone in Figure 3.62, support more groups at higher biomasses than the less productive shelf areas, like the purple area)
- Slope assemblages (cream, maroon and dark blue areas in Figure 3.62) have no shallow water groups and no photosynthetic producers (though the detritus and zooplankton supporting the webs may be sourced from the photic zone), but are dominated by the deep water groups (e.g. ling and orange roughy); the most productive of these assemblages is the maroon area, which includes the slope and adjoining underwater plateau
- Seamount assemblages (the orange areas in Figure 3.62) are intermediate in content between the shelf and slope assemblages (it does not contain all of the shelf groups, but does have the planktivores, tunas and higher order predators that are attracted to these locations); it contains many more groups than the slope assemblages
- The pelagic (open ocean) assemblage (the grey area in Figure 3.62) contains no demersal or benthic groups and is dominated by the smaller plankton groups, gelatinous zooplankton and vertebrates with planktivorous or piscivorous diets; seasonally there are differences east and west of the maroon area.

Figure 3-62: Assemblages predicted by for the 1910 system state of the southeast Atlantis model. Boxes of the same colour contain the same assemblage. Simplified foodwebs (some groups omitted for clarity) for a subset of the assemblages are shown (not all assemblages are shown for clarity). The foodwebs for the yellow, light green, light green, light blue, pink, purple and grey-blue areas are similar to that for the royal blue area (in Bass Strait); the foodweb for the cream (slope) areas is similar to that for the deep blue area. See key on next page.





Note: The size of the polygons and flow arrows are scaled based on the log(group biomass), a rectangle indicates an invertebrate biomass pool and the irregular polygons represent the age structure of the vertebrate groups (youngest to the left, oldest to the right).

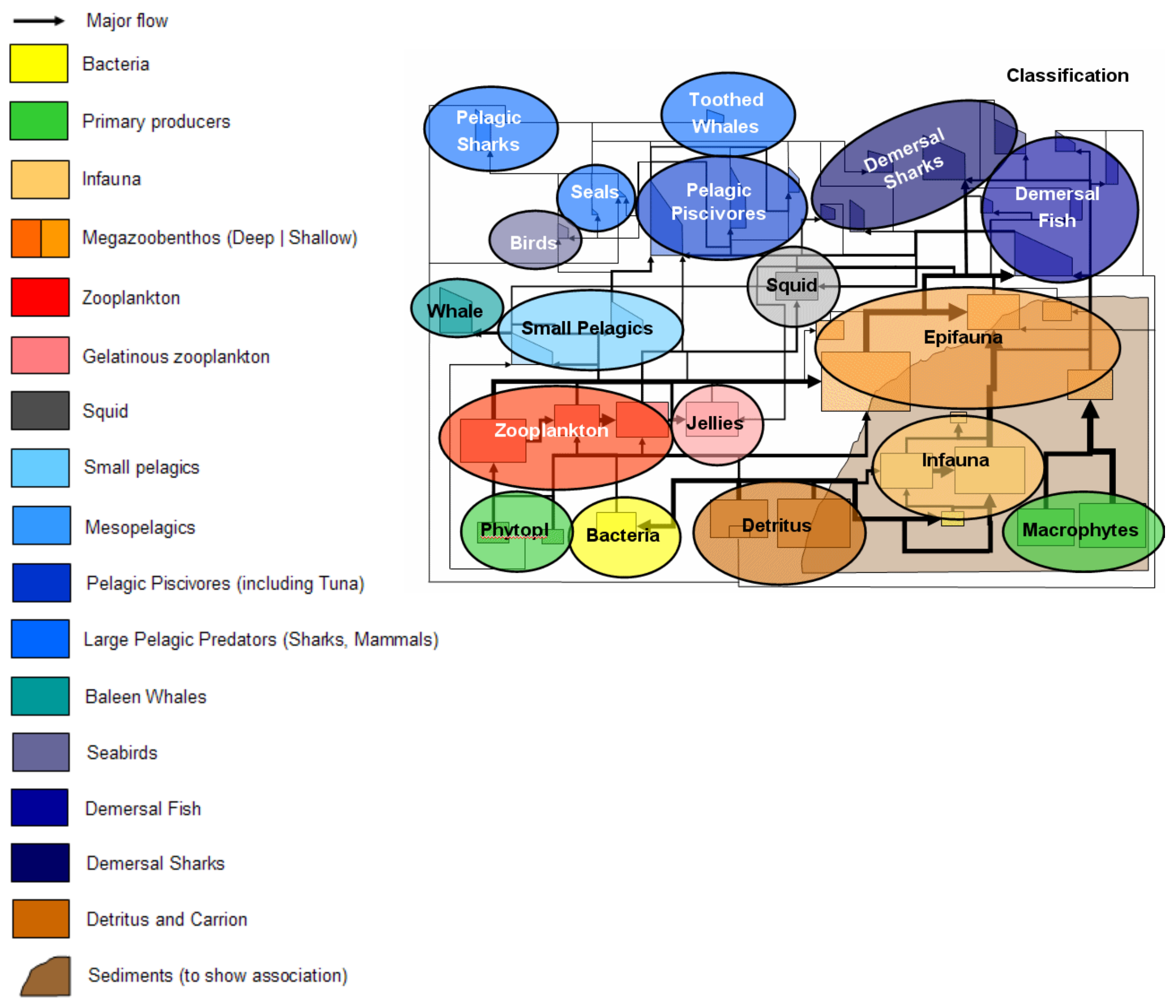
3.5.1 The Perturbed states

Through time, particularly when changing pressures (like fishing or other anthropogenic pressures) are applied to the systems there are shifts in the assemblages. The relative compositions and even membership can change. Different groups can dominate and the differences between regions can decrease (or increase) substantially. As an example of these changes in the assemblages and their foodwebs a series of snapshots from the time series on the shelf and in the canyons off eastern Victoria are shown in Figures 3.63 and 3.64.

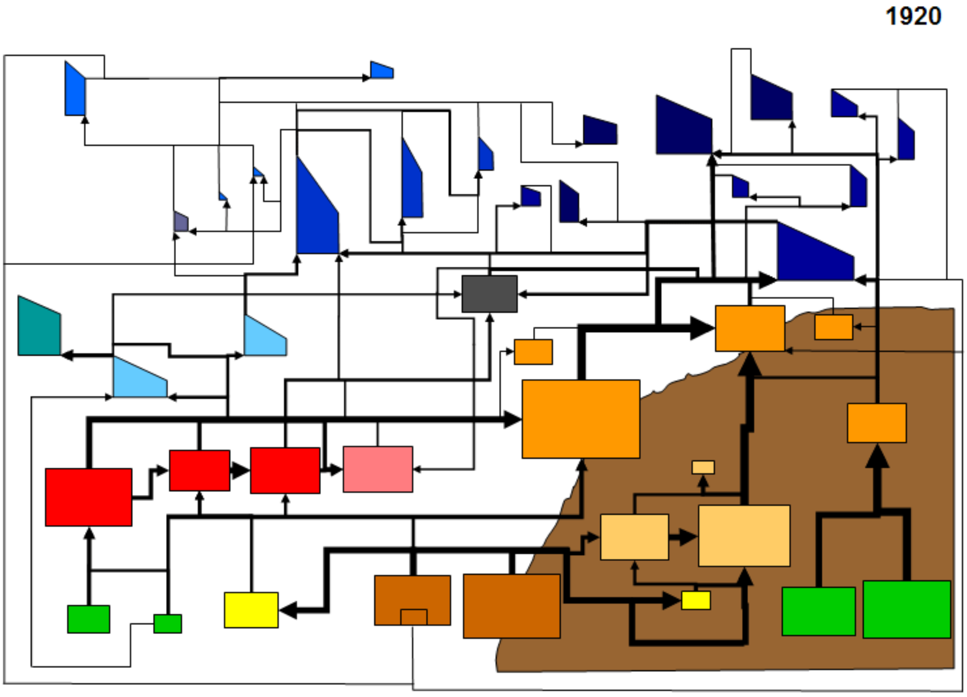
Figure 3.63 shows the evolution in the modelled east Victorian shelf assemblage over 80 years of increasingly intensive exploitation (note that these snapshots are from a single box and so may show steeper changes than indicated in the overall biomass trajectory plots, which integrate over all boxes). While minor changes in biomass (polygon size) do occur prior to 1980, mainly to do with flathead and morwong, it is not until the 1980s that striking changes can be seen. At this point seals have begun to make some recovery and the small pelagics (light blue polygons), zooplankton (in red) and squid (grey boxes) have begun to increase, but the bulk of the rest of the changes are to do with declines: baleen whales have been all but lost; the oldest age phases of many of the exploited fish groups have been depleted (the irregular polygons taking on a much more triangular appearance); and the biomass of some of the chondrichthyans has fallen. By 2000 picture has become more extreme. All of the exploited and bycatch vertebrate groups have triangular polygons, showing the loss of older larger fish in comparison with the unfished state (this truncation of the age/size structure may not be evident if the original structure were unknown, which may be the case in some species in the SESSF with particularly long exploitation histories). Large bodied fish groups have also been severely depleted, seals and now whales have begun a recovery, but squid and small pelagics continue to have elevated biomasses (in comparison to unfished levels). Carrion from discards, jellyfish and some of the small-bodied benthic invertebrates have also increased in abundance at this point. In total this has lead to a restructuring of the pathways in the web too, with the strong demersal flows switching to more pelagic routes.

The patterns that took 60 or more years to develop on the shelf are evident within 10 years at depth (Figure 3.64). By the 1990s the exploited groups have lost the older age phases and seen large biomass reductions, particularly amongst some of the chondrichthyans. The mesopelagics' biomass has increased moderately, as has the biomass of some of the scavenging and smaller bodied invertebrate groups. The trend continues through so that by the time of the 2000 snap shot most of the fish groups have smaller biomasses and modified age structures in comparison with the original populations. Flows have become dominated by pelagic and invertebrate groups.

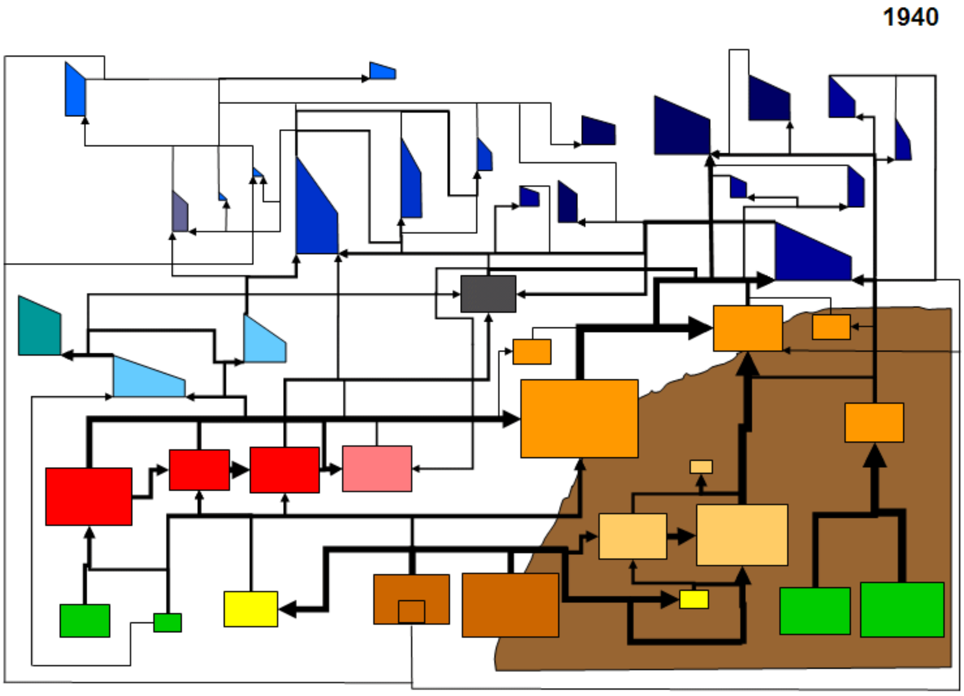
Figure 3-63: Snap shots from the time series of biomasses and food web structure in the box off eastern Victoria on the shelf above the Horseshoe Canyon (this area has been a focus for fishing pressure for over 80 years). The size of the polygons and flow arrows are scaled based on the log(group biomass), a rectangle indicates an invertebrate biomass pool and the irregular polygons represent the age structure of the vertebrate groups (youngest to the left, oldest to the right). Years the snapshots represent are (a) 1920, (b) 1940, (c) 1960, (d) 1980 and (e) 2000. A key and schematic classification of the groups is given as reference after (e).



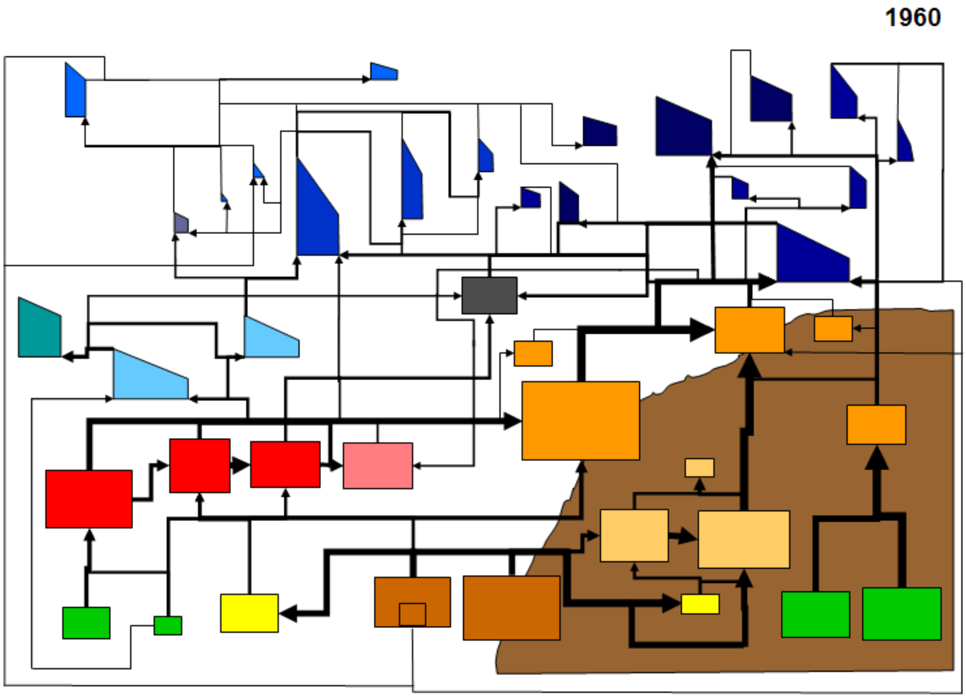
(a)



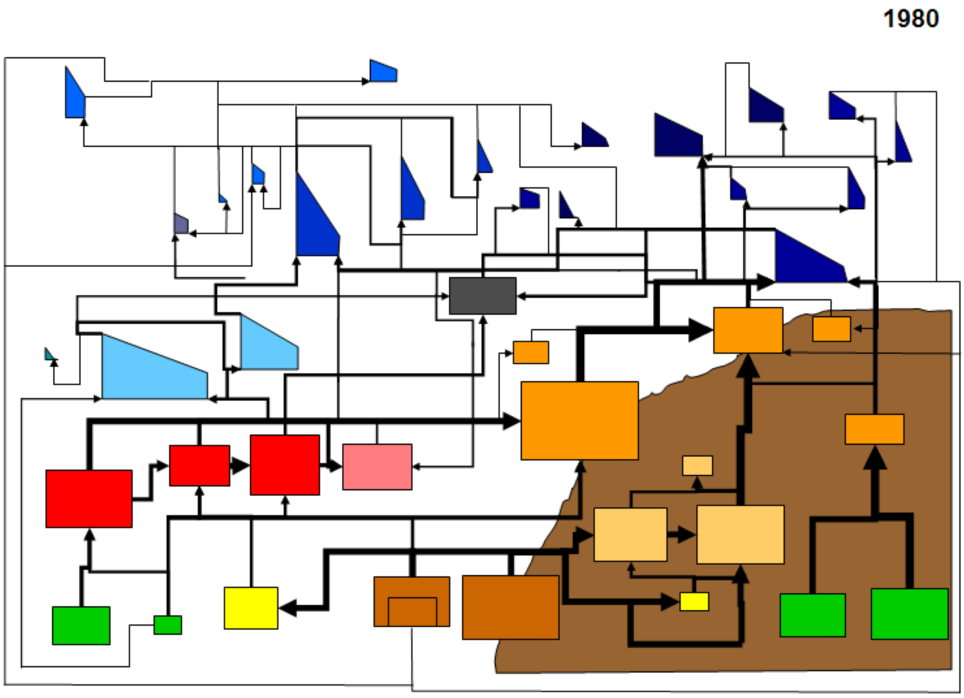
(b)



(c)



(d)



(e)

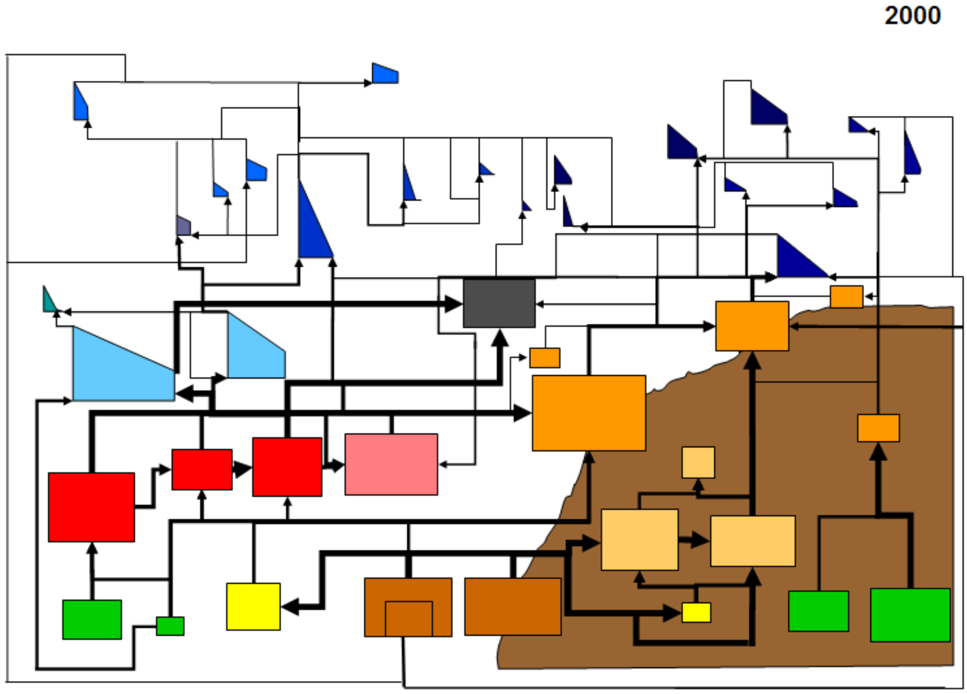
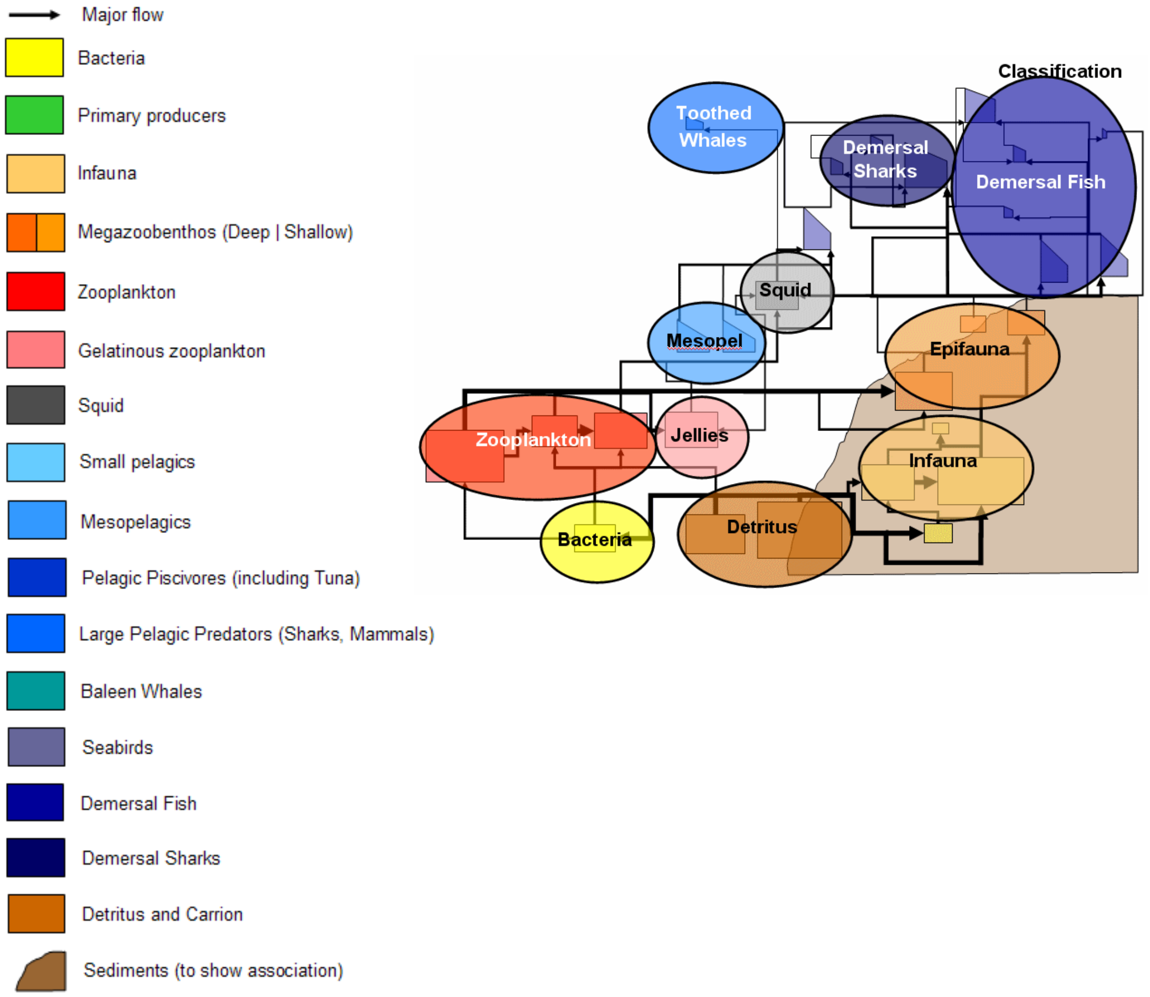
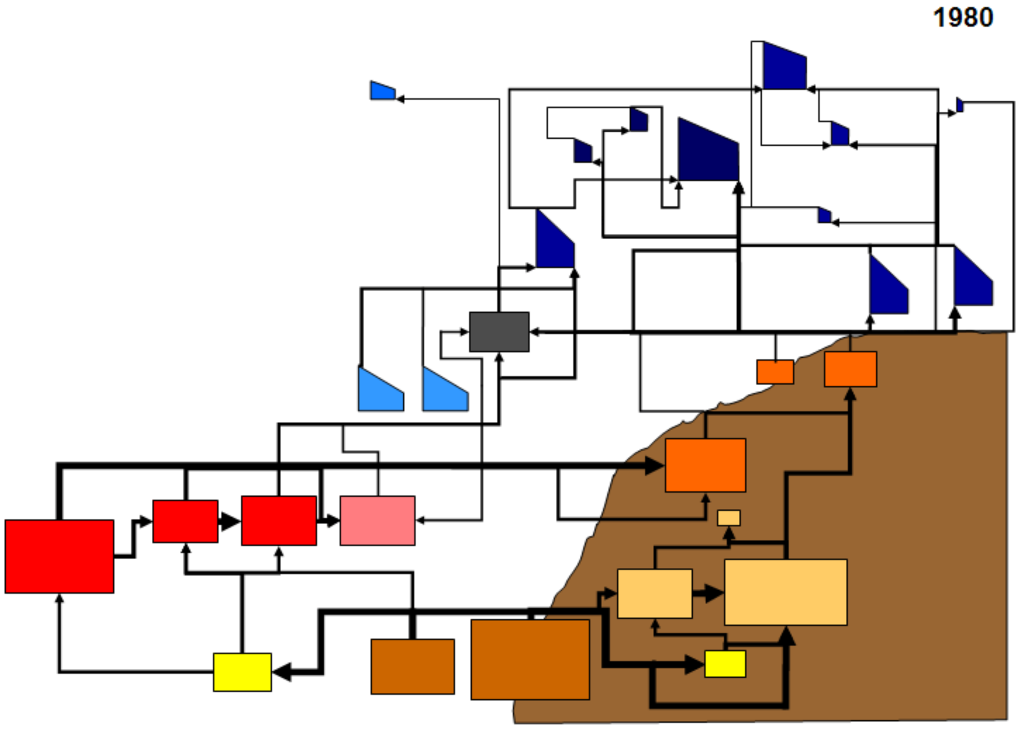


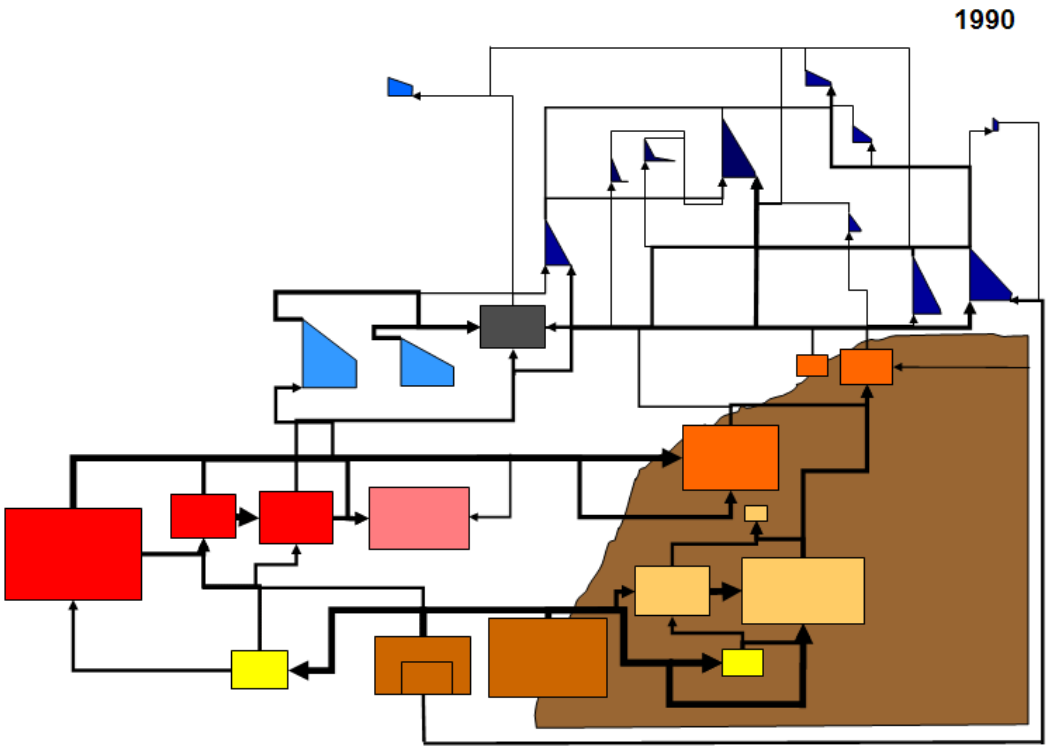
Figure 3-64: Snap shots from the time series of biomasses and food web structure in the slope and canyon box off eastern Tasmania (where fishing was concentrated during the peak periods of the 1980s-2000s). The size of the polygons and flow arrows are scaled based on the log(group biomass), a rectangle indicates an invertebrate biomass pool and the irregular polygons represent the age structure of the vertebrate groups (youngest to the left, oldest to the right). Years the snapshots represent are (a) 1980, (b) 1990, and (c) 2000. The key and a schematic classification of the groups are provided here for reference.



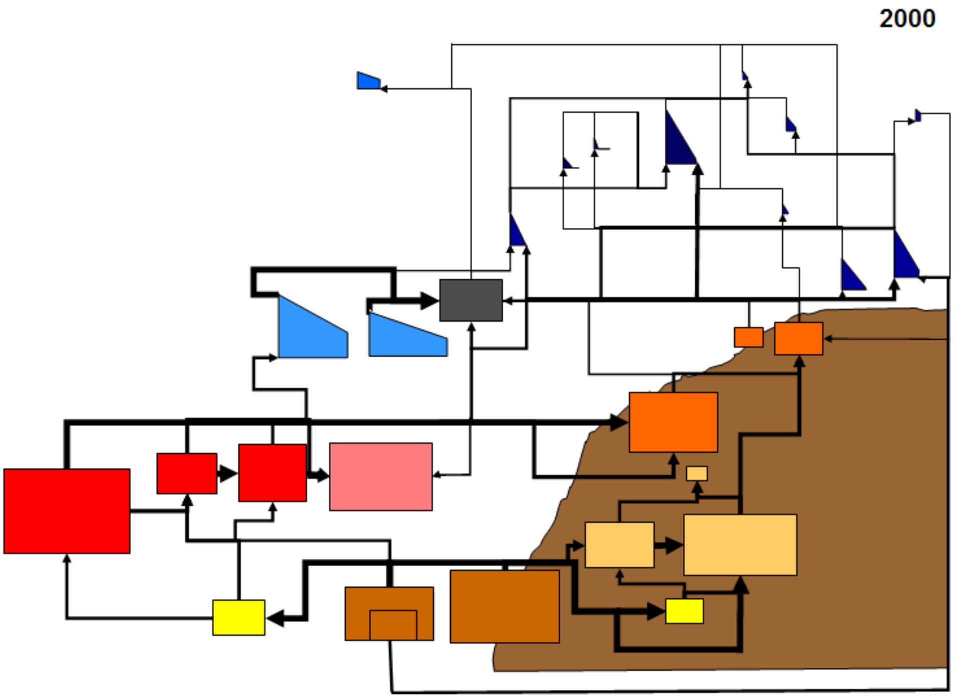
(a)



(b)



(c)



3.6 Dynamic Effort Time Series

To parameterise the fleet dynamics model for those fisheries and fishery components being handled dynamically (i.e. focus fisheries in Commonwealth waters) the model was heuristically fitted to the landed catch and effort time series from the SEF logbook database (the selectivity, catchability and behavioural weights in the effort allocation model were tuned so that the model reproduced historical catch and effort levels). This resulted in a set of catchability, and subfleet-level behavioural weights that produced the fit to 1990s data. Examples of these fits are given in Figures 3.65 – 3.68, for the overall Southeast Trawl (SET), Great Australian Bight Trawl (GABT) and longline fisheries. The later begins dominated by the dropline component but ends dominated by the automatic longline component. Some fisheries, such as the shark gillnet fishery had less certain effort timeseries in terms of days at sea (good net lift time series exist, but Atlantis SE uses days at sea, which proved harder to determine prior to 1997). In those cases alternative time series and parameterisations were trialled and those that gave the best fit to the final years of the data were used (Figure 3.68).

In all cases the model line runs reasonably close to both the training and test data points, though it tends to run along trendlines and underestimate the true size of peaks or troughs that deviate from that trend. The model line also tends to overstate effort levels (by 15-25%) during the earlier years of the time series for the demersal trawl fisheries, but does much better for the shark gillnet. The biggest deviation that should be noted is to do with the spatial resolution of the Atlantis model. In reality the model box adjacent to Kangaroo Island (box 6) should be split roughly evenly between the two fisheries, with effort applied in the western half reported as GABT and effort applied in the eastern half reported in the SET. The resolution of the effort allocation model used in Atlantis means splitting a box in this way isn't possible, only entire boxes can be assigned to a regional fishery component. Based on the historical definition of the southeast fishery area and the identity of the vessels active in it, the data set used to train the effort allocation model had the data from box 6 grouped with the SET rather than the GABT. Trained in this way the model produces effort dynamics of the order of the data, but it would require a substantial reparameterisation of the model to reproduce the GABT component of the demersal trawl fisheries if the data from box 6 was instead grouped with the GABT (see the red dots in Figure 3.66). The grouping of no other box has such a strong effect on the model parameterisation.

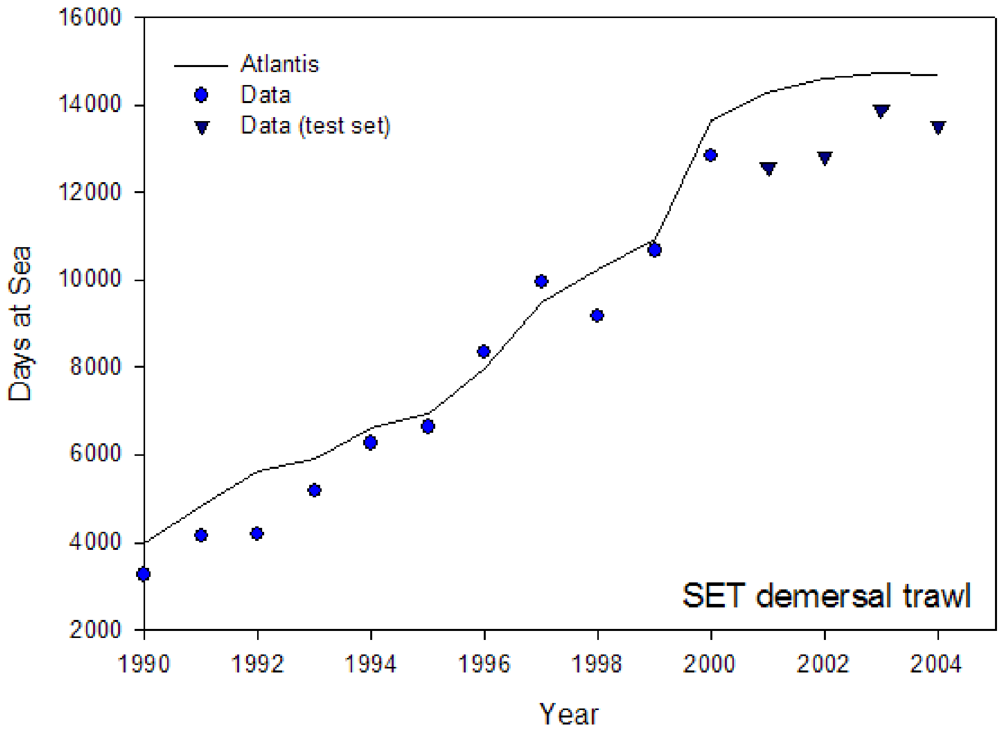


Figure 3-65: Plot of Atlantis model effort time series and the training and testing sets used for the South-east demersal trawl fishery.

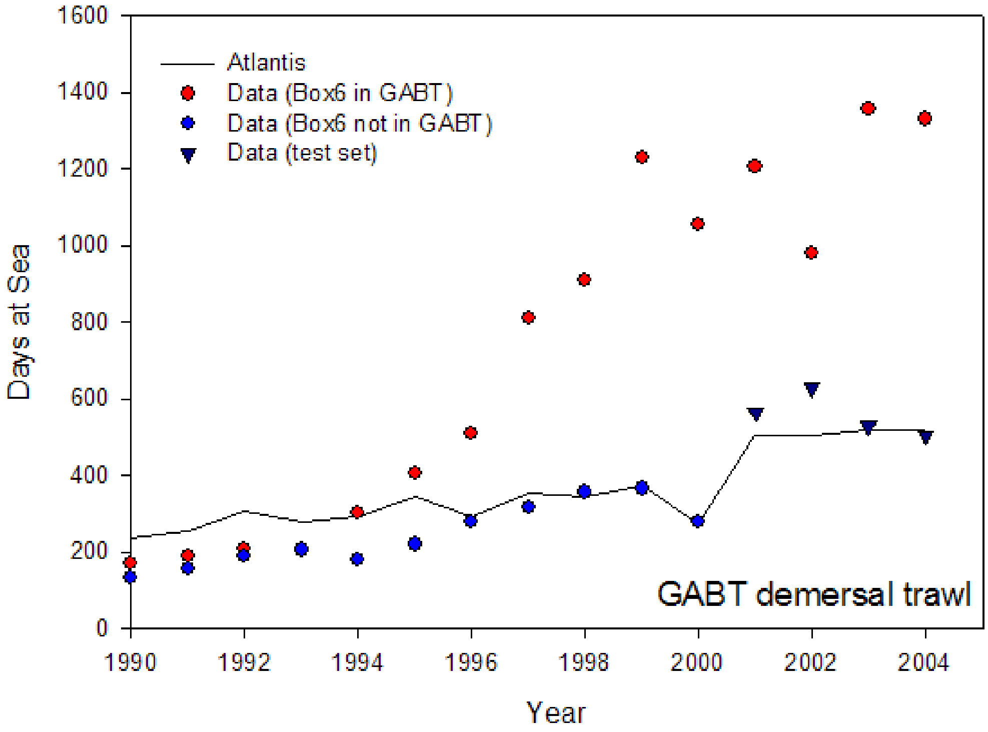


Figure 3-66: Plot of Atlantis model effort times series and the training and testing sets used for the Great Australian Bight demersal trawl fishery.

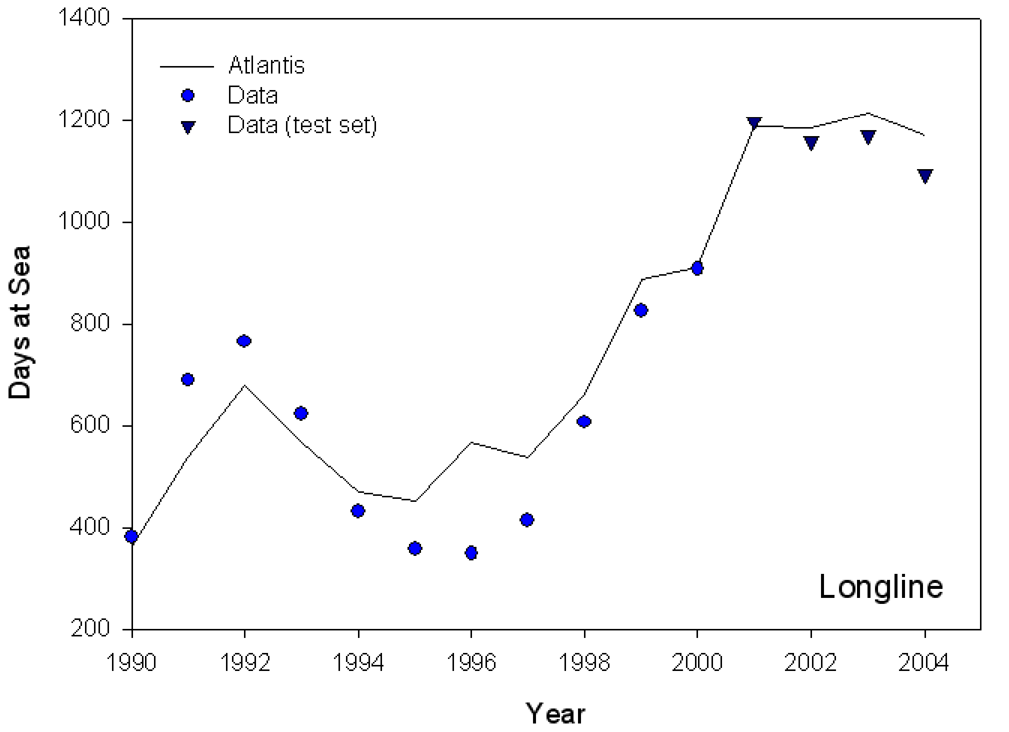


Figure 3-67: Plot of Atlantis model effort time series and the training and testing sets used for the combined drop line and auto longline fishery components.

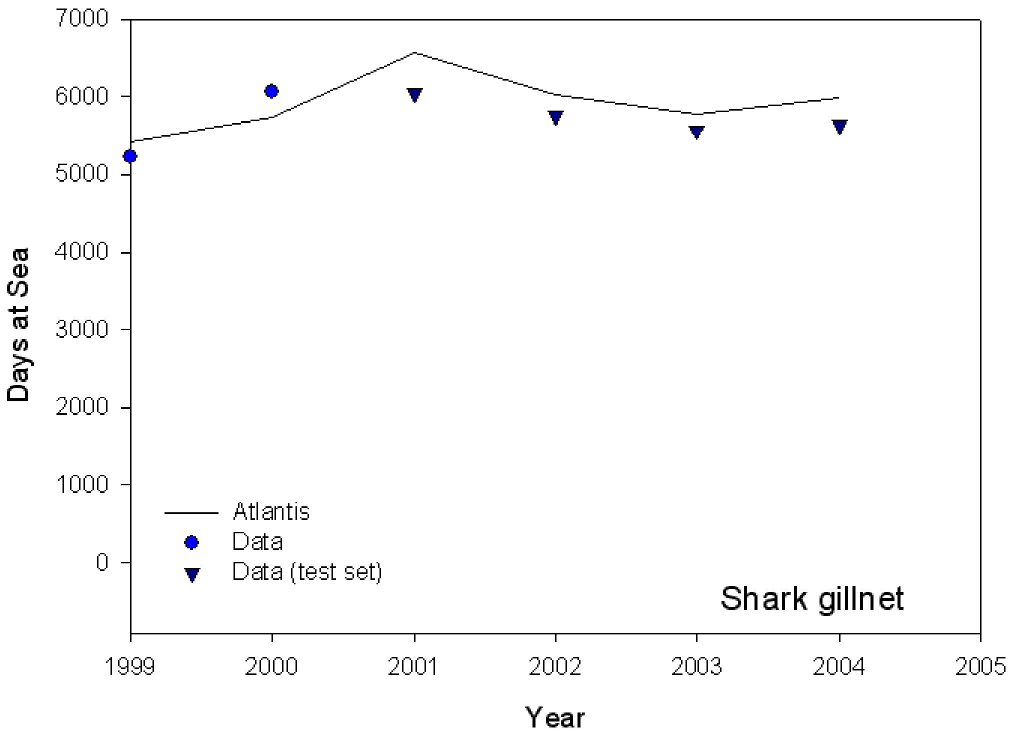


Figure 3-68: Plot of Atlantis model effort time series and the training and testing sets used for the shark gillnet fishery – only the recent historical period (where reliable days at sea time series were available) are shown.

4. SCENARIO SPECIFIC MSE RESULTS

In this section the evolution of each scenario will be summarised descriptively. For the scenario comparisons and further specific detail on each performance measure readers are referred to the next chapter (Chapter 5): landed catch is discussed in section 5.1.1, discards in 5.1.2, effort in 5.1.3, CPUE in 5.1.4, management implications in 5.2, economics in 5.3, social perception in 5.4 and ecology in 5.5. These results will focus on the comparison of the five main scenarios outlined above (Scenarios 1, 3, 4, 9 and 10), though results of the variants of these scenarios will be described if they differ significantly from the results of the basic form of the Scenario. Full details of the variants are given in section 4.6. While alternative parameterisations were used in the full analysis only the "best fit" parameterisation results are presented here. For the majority of the indicators and variables the results were similar across all the bounding parameterisation sets, in the rare case where the results differed substantially from the "best fit" results the differences are noted explicitly here.

4.1 Scenario 1

Scenario 1 retains the 2003 status quo management arrangements throughout the simulated period. All species under quota in 2003 remain so, but no new species are added. There is no gear transferability, but existing gear restrictions remain (e.g. 15,000 hooks per set for the auto-longline, 150-165mm for gillnets, 38mm for Danish seine, 90mm for trawl, except prawn trawls which are restricted to 40-65mm). All spatial closures intended for introduction as of 2005 are included as zoning restrictions; and the licensing and observer coverage in place by 2003 are maintained throughout the simulation.

Effort

Overall effort (in terms of days-at-sea, which is the unit of effort in Atlantis) in this Scenario stays at about the level seen in 2000 until the economic realities (i.e. continual net losses for at least some subfleets in all the major fisheries) lead to a 28% reduction in overall real effort (i.e. active effort not including vessels that spend their time tied up in port) after a decade. Sector by sector the effort plays out a little differently. In the SET there is a 50% reduction in days at sea, despite the fleet pushing further and further into more marginal grounds north-south, and with depth. The GABT sector also pushes out more widely, pushing across to the west. For the first five years this is associated with fairly steady effort levels, but as costs at the vessel level bite effort begins to drop by 2-4% per year. Interestingly, once the SET's effort (and the landed catch of a number of species) has dropped (around 2010) the reduction in market competition has sufficient direct flow on benefits for the GABT that fishers there do not leave the fishery and instead increase their effort by 5-10% per year through the rest of the projection period (leading to about a 42% increase in GABT effort by 2020).

The patterns in the other sectors are quite different from the GABT and more similar to that of the overall effort. Effort levels in the Danish seine fleet fluctuate about 2000 levels until they drop by a third between 2009 and 2015; this drop is triggered by poor returns due to increasingly poor stock status (their cost structure remains amongst the cheapest of all the dynamic fleets). The overall GHAT effort also remains fairly constant until around 2009 and then slowly drops off as costs rise and returns drop, plateauing 32% lower more than 5 years later. This decline in GHAT effort hides differential effects across the gillnet and auto-longline sectors, however. While shark gillnetting effort drops by nearly 50% in the five years after 2010, longlining effort declines by less than 20%. The reduction in longlining effort results from the rapid exit of vessels (which takes less than 2 years) beginning in 2012.

In all cases the changes in effort are associated with increasingly long trips, with the exception of deepwater trawlers, where there is a decline in trip length as they shift targeting onto the shelf (this can be seen in their footprint too, where an initial expansion to try and find new ground is followed by a contraction as they shift to seasonal shelf targeting instead). This shift onto the shelf is accentuated seasonally, but does occur to some degree through the entire year. Danish seine shows only a small increase (about 10%) in kilometres travelled per trip, but increases are much larger for other sectors (such as the GABT where trip length rises by almost 50%). So even when overall effort per year drops off it is usually due to fewer longer trips per year rather than a reduction in both the number and duration of the trips. Moreover as the vessels are largely travelling through the same grounds, fishing as they go, there are high levels of gear conflict, particularly to either side of Bass Strait and off the east coast of Tasmania (right down into some of the deepest waters, where trawlers conflict with the deepest fishing longliners).

Landed Catch

The shifts in effort are both driven by, and result in, changes in landed catch. Overall total landed catches, as well as landed catches in the SET, continue the historical decline right through until vessels begin to leave the fisheries in reasonably large numbers. Once that occurs total landed catch jumps before once gain slowly declining to stabilise at just over 40,000t. The SET landed catch also shows a small recovery when effort is reduced, but ultimately continues to decline (though not as steeply as the effort levels do). The landed catch in the GABT is again a reflection of effort levels, with total landed catch growing by 85% (almost twice the rise in effort for the sector). Landed catches decline in the Danish seine sector until the fleet size drops, after which they variably and slowly rise (by 1-10% per annum).

Just as returns (and relative costs) drive higher effort expenditure in the GABT, they are also the reason for the slow decline of landed catches in the GHAT – the gillnet landings dropping smoothly (by 40% in total) after 2012, while the longline landings drop more steeply. The drop in returns is partly (but not totally) driven by indirect impacts on stocks as a result of a loss of key habitat due to the incidental impacts of trawl gear. Direct harvesting at unsustainable rates is a significant factor in the stock decline, but it is exacerbated by the impact of habitat losses on stock productivity and mortality rates. The decline in longline landed catches is more prolonged than in the gillnet sectors and extends throughout the simulation period. This decline means that the proportion of total GHAT landed catches contributed by the auto-longline sector declines into the future for this Scenario.

Patterns of discarding tend to mirror the landed catch trajectories, though the rates of change and overall shifts are often magnified in comparison with the changes in landed catch. For instance, in the SET total landed catch declines by 45% while discards decline by more than 60%. This is due to a reduction in the product discarded (with more of what was once discarded retained, as larger size classes become harder to find – anecdotal accounts by fishers indicate this has occurred in the SESSF, as it has overseas), but also a shift in what is discarded and which species are targeted (i.e. there is a shift to groups where less of the product is discarded regardless, as more of the fish caught are of a suitable size, quality and value to be retained as landings).

The patterns of landed catch and discards (and thus the feedback with effort) are largely driven by shifts in targeting as stocks are sequentially depleted. Flathead landings drop rapidly to 60% of recent historical levels - though this may reflect an improvement in targeting in the recent historical data that is not captured in the model (fishers in reality can maintain higher catches through increased effectiveness, but the formulations and resolution in Atlantis SE cannot capture this unless it is explicitly assigned). Blue grenadier landings steadily decline to about 6000t per year; blue-eye landings fall steadily until the effort drops off in the auto-longline sector, after which point the blue-eye landings show a modest recovery; ling landings show cycles of higher and lower catches (the higher catches seen soon after the major effort reductions but falling off again after an initial recovery); whereas the catch trajectory for orange roughy shows a rapid and on-going decline to a final landed catch level of around 500t. The gummy shark landings remain relatively stable until a shifting fishery focus settles on them as a group with good CPUE rates (at least for a few years). During this time landed catches spike (to 4335t, which is still below the TAC at that point) before dropping away over the final years of the projection as the stock collapses under the pressure.

When fished under Scenario 1, mid-trophic and higher trophic level fin-fish resources prove less and less lucrative and so there is a discernible shift by many sectors to targeting (and sequential depletion) of all of the chondrichthyan stocks, not just gummy shark. These chondrichthyans, initially at least, have much higher CPUE rates than the traditional, but now depleted, target teleost groups. Interestingly, in addition to the increased exploitation of these high trophic level groups, there is also a large jump (by >2x) in interactions with trophic level groups at the other end of the spectrum – namely small pelagics and squid (also driven by CPUE rates). However a substantial proportion of this biomass is often discarded, with only squid landings really rising through the course of the simulation. This growth in interest in the small pelagics and squid begins before the fleet sizes are consolidated, but is most evident after most boats that leave the fishery have exited. Squid landings are not only made by previously dedicated squid vessels, but by many trawlers that use this catch as a means of subsidising other activities. In contrast the landing of small pelagics remains primarily the domain of the dedicated small pelagics sector.

This semi-sequential fish down of (and through) the food web sees the total catch footprint pushed wider spatially, ultimately leading to a modest widening of the overall fishing grounds both east-west and north-south and with depth. Substantial catches are also still taken from traditional grounds. This extension of the footprint is a symptom of the pressure on the fishery, as is the average size of fish landed. At first glance a rise in average size of 20% over the projection period seems counter intuitive, as average size usually falls as “lower grade” fish are retained. While more smaller fish are retained in those sectors where discarding was once high, overall the average size increases mostly as a result of the increasing targeting dependence on large-bodied chondrichthyan species (which lasts through the final 5-10 years of the projection period and for at least a few years beyond that in the small set of longer term runs completed so far). To a much lesser extent the shift in average body size reflects a concerted effort by the different dynamic sectors to try and maximise landed returns by attempting to target (and land) as large a fish as possible. In this way they try to optimise costs, by reducing total catch costs and having to discard only the smallest least valuable fish. In the longer term this is only of limited success, however, as is evident by the discarding shift that also takes place. Despite their best intentions the operators are forced to land smaller than optimal fin-fish, with the chondrichthyan catch leading to the majority of the signature in average size of the catch. This dominance of the landed catch by the new target groups is also evident in the time series of the proportion of the landed catch made up by a single group, which grows to more than 70% on average. The catch composition of individual fisheries reinforces this pattern of specialisation; the importance of current key groups tending to decline with stock size and new (currently less important) groups (e.g. mackerel, squid, small pelagics, shelf demersals, and skates and rays) coming to the fore (or at least increasing in importance). While the total list of groups landed never contracts, there is significant increase in specialisation within the sectors, with the exception of the general trawl sector which never really settles on any particular target group.

CPUE

Maximising returns per vessel usually entails maximising CPUE in models such as the one used in Atlantis SE. And when the effort dynamics are deconstructed relative to CPUE it is apparent that there is some attempt by the sectors to do this here. Unfortunately, CPUE is fairly poor (at or below historical lows) through much of the projection period for many groups. There is an increase in overall CPUE (and economic health of the operators) after fleet size is reduced, as the available catch is taken by a smaller set of operators. This benefit can continue for quite some time (particularly outside the GABT, such as for the Danish seine fleet along the east coast), although ultimately CPUE falls away again into the long term (beyond the 20 year projection period, but before a 50 year horizon); not even the shifting targeting can maintain the rates above low levels in the long-term. The CPUE for all of the main demersal target groups shows some recovery after the fleet sizes are reduced, but the majority fall off again towards the end of the projection period (e.g. tiger flathead CPUE drops by 5-35% per year in the final 5 years). In contrast, the CPUE of all small pelagics (barring Red bait) and the invertebrate target species grow and stabilise at much higher levels (as much as 3x higher).

Economic and Social Implications

Management costs do not change and access to the fishery remains high due to the mostly unconstrained nature of the management. The perception of stability is not as good, however, due to the influence of lobbying, negotiating and compromise on the setting of TACs in this Scenario. This free-for-all atmosphere does not change through the simulation and while this means no sector is denied access the actual perception of operators under these circumstances would be far from secure. A reflection of this can be seen in vessel costs (including management associated costs), which rise with time (because the number of boats to share the cost declines) even as landed catches decline. This bleak economic outlook is reinforced across the economic indicators. Things are particularly tight (with little if any profits) as the large fleets struggle towards the middle of the projection period. Once vessels have exited the remaining boats do better, though these gains tail off again into the long-term. Fairly constant return per tonne and effort supports the expansion of the GABT, but that expansion robs it of many of the gains the other sectors see as the fleet sizes contract. These economic gains are maintained to some degree by the reductions in over all effort (and thus variable costs), but as these gains really only move the sectors from unsustainable to marginal into the long-term. The measure of economic performance that shows the strongest positive signal is return on investment. Ironically this is partly because the operators perceive the system to be not worth investing in, so there is little (if any) new.

This poor economic performance in the very short- and long-term, in combination with the ecological impacts of the various exploiting sectors, leads to declining public perception of the fishery as a whole. Even the longline fishery draws social ire (evident in a low community perception of the fishery) as it is seen to be depleting stocks in habitat that acts as a trawl refuge. There is a brief respite around the time of the effort consolidation (which is seen as a positive management response by the public) but that is relatively short lived as they realise little has actually changed.

Ecological Implications

Without management constraints the impacts on the ecological system can be fairly strong. Habitat interactions are much higher than in any other scenario, at least initially. There is some drop in habitat interactions as the absolute level of effort drops, but a significant component of the drop in habitat interactions is because grounds become cleared of biogenic habitat through time and are given no chance for recovery and re-establishment. By the end of the 20 year projection period the local habitat index has dropped by more than 40% in fishing grounds at all depths (the shelf is slightly more heavily impacted than the slope in terms of the area cleared, but the slower recovery rates of the deeper water groups means the long term impacts are actually stronger with depth).

Every target group declines under this Scenario, the target switching meaning a large number of those groups with any commercial value undergo some significant decline (part of the reason for the falling catches and increasingly dispersed fishery footprint). It is noteworthy that the relative biomass of the lower trophic levels (e.g. squid) remains reasonably high (even continuing to grow in the case of the squid biomass). This is because gains due to further predation release (which increases as top predators are further depressed) outweigh direct pressure from fisheries. This is in part why the forage groups attract further fisheries attention as time goes on – though by the end of the projection period some components of the small pelagics are beginning to show regional to population wide signatures of the direct effects of exploitation. In the case of Red bait the biomass has dropped by 65% (leading to an overall decline in the biomass of small pelagics of 15%).

Nevertheless, the reduction in predation pressure on the forage groups is not the biggest benefit a system component sees under this Scenario. The groups that really benefit from the fisheries activities under Scenario 1 are the scavengers, as the amount of labile and refractory detritus (fed by discards, incidental mortality due to fishing impacts and feedback in the detritus-based foodweb) grows steadily through time, providing a significant food resource for these groups. Even though the discards decline through time under this Scenario their contribution to the dynamics of the detrital foodweb is persistent during the course of the simulation because of the long break down period of some of the detrital components (it can take decades to centuries for the more refractory parts to remineralise). Moreover, incidental mortality (e.g. of fish passing through the gear) does not drop off as much as the discards and so the fishery continues to supply the detrital web throughout the period. Amongst the target groups the strength of these detritus based or associated system components means there does appear to be some benefit conferred on ling (mostly via increased food supply, but also due to some drop in the level of competitors), and to some extent the prawns, but these early benefits are outweighed by increases in direct fisheries pressure. The more general scavenger and detritus dynamics act to exacerbate changes in the system resulting from more direct fisheries interactions (and the system changes already in place due to historical pressure), leading to stronger restructuring of the system – in terms of its size and trophic spectra and the magnitude of alternative energy pathways and pools (e.g. the microbial and detritus webs grow substantially). This restructuring would make it a difficult and exceptionally long term exercise to reverse the changes and attempt to restore a system state closer to an unfished state (or even to a state that would be preferred by the commercial fisheries). This degraded system state also manifests itself as lower diversity (both in terms of richness and evenness).

As there is no real gain in interacting with most of the TEP groups, and encounters are incidental in most cases, TEP interactions are not substantially stronger in Scenario 1 than most other scenarios. Towards the end of the projection period there is some suggestion that the lack of constraint in Scenario 1 does lead to marginally more accidental interactions with TEP groups than in more heavily regulated scenarios, but in the main the TEP interactions are a reflection of the strength of recovery of the large marine mammals from past exploitation. The impact on gulper sharks is much stronger and this group continues to rapidly (and steadily) decline through the projection period.

Summary

To summarise, in Scenario 1 effort remains at around recent historically observed levels, and vessels push into more and more marginal areas as the fishery tries to improve its marginal economic status. Eventually economic pressure proves too much and vessels exit each of the major sectors, except for the GABT. The reduction in fleet size is associated with a temporary recovery in total landed catch, CPUE and profits, though this recovery dissipates fairly quickly. There is also a shift in targeting as traditionally targeted fin-fish resources prove less and less lucrative and the sectors fish through the foodweb (targeting both higher trophic level chondrichthyans and lower trophic level squid and small pelagics). This industry activity leads to a slowly degrading ecological system state (that would take many decades to recover) and poor public perception of the fishery.

4.2 Scenario 3

In this Scenario there is a much greater emphasis on quota management (with 8 individual additional groups added to the quota management scheme and various demersal sharks being added under a basket quota), though some seasonal and spatial closures are also employed (to shape access by gear). Harvest strategies, including regional and weak-link companion TACs, were also used in this Scenario. Discards were taken into account in TAC setting and while fishing without quota is allowed there must be reconciliation before landing. Gear limitations and the ban on gear transferability are as for Scenario 1, except there is a higher use of bycatch reduction devices and more selective targeting (at least in the standard form of the Scenario, these are relaxed in the variants – see section 4.6). While 2003 licensing limits remained throughout, there were higher rates of reporting, observer coverage and the use of fishery independent surveys.

Effort

Overall effort levels are not significantly constrained early on, only declining slightly (by 3%) over the decade before poor economic performance sees fleet sizes contract. At this point effort drops by 24% before stabilising at a new overall level of roughly 28,000 days at sea across all the main sectors in the SESSF. The pattern of effort per sector is slightly different. In the SET there is an initial small decline before effort rises again to match historical highs as fishers push for higher catches to try and cover costs. Ultimately though, low returns mean the fleet size is unsustainable and roughly half the fleet (mainly boats <40m) leave the fishery. As in Scenario 1, the reduction in the SET reduces competitive market pressure in the GABT, which does not contract in size and actually increases total effort levels by 27%.

Danish seine declines more variably and continuously over the first fifteen years of the simulation, rather than in a single step. After roughly two thirds of the smallest boats have slipped out of the fishery, effort finally stabilises at roughly 70% the 2000 level. The decline in overall GHAT effort is also highly variable, although the mean trend is a decline through time until a significant proportion of the fleet has left and then the effort stabilises; this is true of both the longline and gillnet components of the GHAT. Even in the more stable phase the variability (of at least 5% per year) tends to be more dips than peaks suggesting some ongoing economic effort constraints.

The total footprint (in terms of the area fished) through time is as broad under this Scenario as it is in Scenario 1, though the spatial management constraints in place in this Scenario mean that shifting behaviour and associated contractions of some sectors are stronger. The changing behaviour of the deepwater fleets is particularly marked, where the zoning makes it hard to be profitable while fishing deep waters, so the fleet becomes much more seasonal and contracts to fish the most productive grounds around Tasmania.

In the general trawl sector and longline sector, trip lengths increase even as effort drops off, with the operators in these sectors opting to minimise costs and maximise returns by making fewer, longer trips (passing through multiple fishing grounds). This is not the case for operators in the gillnet sector and deep water trawl sectors. The deep water sector actually shifts to shorter trips (especially seasonally) as its targeting by depth shifts – while the original name “deep water trawl” was kept for continuity, the fleet shifts to persecute an altered depth range. In contrast, the gillnet sector effort is reduced both by a reduction in the number of vessels fishing, but also the length of trips, at least for a few years after effort consolidation. As economic pressure increases again in the final years of the simulation the trip length of the gillnet operators grows again (by roughly 5% per year).

Landed catch

Total landed catch declines along the same trajectory seen historically until a significant number of vessels have left the fishery. After that there is an immediate jump in landed catch (mainly as a result of target shifts), which is followed by a long-term decline in total landed catch. The landed catch taken by the trawl sectors follows a slightly different trajectory. Catch drops slightly faster than effort, which is why effort is reduced as the CPUE levels are low enough to trigger conservative management and fisher behaviour. As the fleet sizes drop sharply the catches do too, before growing again once competition for the resource is relaxed (though some of the increase in landed catch is also due to the inclusion of less depleted groups in their target list). The GHAT landed catch is more volatile: longline landings fall until fleet sizes are reduced, after which they recover; while gillnet landings grow slowly for a decade before spiking (by 3x over a 4 year period) and then drop away steeply as the stocks of their fin-fish and shark target species are heavily depleted (some stocks are locally extirpated under some parameterisations).

Across the target groups and sectors, TACs constrain the landed catch of many target groups. As noted above, the need to meet trophic pressure as well as historical fishing pressure sees the parameterisation of Atlantis that results in relative biomasses in the year 2000 that are above those predicted by actual stock assessments (parameterisations leading to lower biomass trajectories do not survive historical fishing pressure, so closer matches to assessments were not possible). This disagreement between real assessments and Atlantis SE estimates of relative stock size allow for TACs (and therefore landed catches) that increase initially for groups such as the flathead species and school shark, but which fall once the stocks become depleted and move below the target reference point of the harvest strategy. For blue grenadier the TACs cause a slow decline in landed catch through time to about 5000t; as do the TACs for orange roughy which stabilises at a little under 450t (the western and southern zones are effectively closed with TACs of less than 5t) after a spike as the fleet tries to maintain catch rates, ultimately "chasing down the last fish". Longline blue-eye catches remain stable, while the catch of deepwater groups (like ribaldo, cardinalfish and dories and oreos) falls away, after peaking during the chase for the last roughy. The TAC for ling is not constraining but the fishery still only manages landed catches of about 750t until a reduction in fleet size and effort allows some recovery, though this is exhausted within about 5 years as pressure shifts back on to this group. Shifts in GHAT effort lead to a peak in shark landed catches in the second half of the projection period. It is a short lived pulse for gummy shark, but lasts longer for school shark – the parameterisation needed for school shark to survive historical pressure means it is more resilient to recent and projected pressure than is generally accepted in assessments. This is because fishing as induced a shift in the southeast system over the last 20-40 years. In species like school shark this has been manifested through the loss of productive substocks. The existence of these substocks was not realised when Atlantis-SE was being constructed and so no allowance for multiple stocks was made (whereas they do exist in stock assessments for the species, Punt 2000 and 2006). Unfortunately, this means that a single parameterisation of Atlantis cannot both allow for the species to survive historical fishing pressure and remain in a depleted state into the projection period. For Atlantis to allow for such a trajectory there would have to be a shift in recruitment parameters in the late 1980s to early 1990s (which is coincident with the predicted extirpation of the eastern stock in the stock assessment). It was decided that fixed parameters should be used throughout to avoid issues with trying to predict when and where other cases of shifting parameters (both for school shark and other groups) should be allowed and so the issue with school shark remains here. Multiple parameterisations or more finely resolved stocks may be more appropriate in future work.

Even with these modelling issues, the results give insight and warn of a potential problem with incentives and the TAC system. As reconciliation occurs on landing not before a vessel leaves port it is possible for the simultaneous activities of multiple vessels chasing the last portions of their individual quotas (and counting on trading to cover any overshoots) to lead to an overshoot of the TAC from 2-18% (or more). Without incentives to avoid this situation the model suggests it can be a persist problem for some species (e.g. dogfish) – this issue is considered in some depth in the discussion chapter of this document.

As in Scenario 1 there is target shifting – to forage fish and invertebrates (especially squid) at one end of the trophic spectrum and some of the chondrichthyans at the other. The shallow demersals group, school whiting and spotted warehou are also increasingly targeted and landed through time. As in Scenario 1, the small pelagics are still mainly landed by the small pelagic fleet, but the squid and other new groups are landed by many of the sectors. This shift in targeting also sees a subtle shift in the sites of highest productivity, though it is still largely associated with the main historical grounds. It also leads to a decline in average size, both because smaller individuals are left in the remnant stock components near the main fishing areas, but also because there is a shift to more smaller bodied groups as fleets find “classical target groups” heavily constrained by companion and regional TACs. As the fishery is put under increasing pressure (as it struggles under its large aggregate size) the fleets diversify, landing as much of everything as possible (though, as described below, this does not ultimately lead to lower discards due to quota restrictions). Once the fleet size has been consolidated the sectors specialise, leading to the strongest dominance of the landed catch (per subfleet) by a single species of all the scenarios (it is not the same group in all cases, but there is strong specialisation in all cases).

Constraining TACs (and strong enforcement of them) leads to high (much higher than historically or in other scenarios) and variable discard rates, as fleets discard target groups once their own quota allocation is exhausted and there is no ability to pick up extra quota from elsewhere. While quota is available, as optimal catches become harder to achieve there is some move to retain more of what was originally discarded. However, the signature of the constraining TACs (and the discards that it leads to) outweighs the shift in discarding behaviour. Instead of the fishery drawing down once quotas are filled they move on to new targets (some of which aren’t under the quota system or are effectively unconstrained by it) and simply discard any take of groups that were once targets and are now bycatch (which means the value of bycatch reduction devices is not as great as it could be, as the groups that are now bycatch were target only months before). When the TAC management system is the only lever in use (i.e. no spatial or other levers are used) this behaviour can lead to the failure of the entire management system as the fishery simply works around the management constraints by subsidising fishing operations using these unconstrained commercial target groups (e.g. squid).

CPUE

Overall and trawl CPUE declines during the early to middle years of the projection, leading to at least some of the decrease in effort, as operators (at least in some sectors) are frustrated and slowly wind down their effort to try and minimise variable costs. After the fleet size has been reduced, the smaller number of boats chasing the TAC leads to recovery in CPUE rates (though it can be a very slim recovery in the trawl fishery), at least temporarily. The longline fishery also follows this pattern, leading (via feedback) to the realised effort trajectory. The peak in landed catches in the shark gillnet fishery as it shifts to a broader set of targets is tied up with a spike in CPUE, though other constraints (mainly costs and expectations based around basket quotas) do not lead to a matching effort spike. The stabilised effort levels do not drop off with the falling CPUE because at that point the fishery judges it better to fish, despite falling CPUE in order to cover costs rather than have large sections tie up and pulse fish (which occurs in some of the variants). The position in the Danish seine is much better, the increase in CPUE lasts much longer, it does eventually fall off, but remains much higher than historically into the medium term. These patterns of overall CPUE and targeting shifts reflect the patterns in species-level CPUE, with the CPUE rates for most demersals falling through time after a brief recovery for roughly 5-7 years following the fleet reductions. The recovery in the ling, blue-eye trevalla and spotted warehou CPUE is quite large and so even with a drop off it still remains much higher than under the larger fleet sizes. Nevertheless the only prolonged improvement in

CPUE in this Scenario is for the small pelagic groups and invertebrates such as squid. The CPUE of skates and rays and pelagic sharks does improve through the projection period but falls steeply into the medium and long-term.

Economic and Social Implications

While this management strategy does eventually lead to semi-stable TACs and improving impressions regarding stability, the cost of research and monitoring associated with the large list of groups under quota management leads to substantially higher management costs. When costs per boat are allocated based on quota holdings the GABT fairs reasonably well with regard to the recovered costs per boat, with no real increases, but all other sectors see their cost per boat burden increase (effectively doubling or trebling or more). This, in combination with the spatial closures, is perceived as restricting access and accelerates changes in fishing behaviour.

The form of the management in this case also means that more resources must be committed to quota trading. Costs of leasing quota also become a significant on-going concern for fishers in this Scenario, especially those already only marginally profitable. This is especially true for the byproduct groups under quota (keeping in mind that what may be the target of one sector can by byproduct in another). Trade of byproduct groups drives much of the market activity – as a lack of byproduct quota can frustrate a fisher’s take of target groups if they are discard averse. This means that supply of quota is an issue and that quota becomes increasingly expensive as it becomes rarer. This is yet another incentive to shift targets to groups that are less constrained by quota (so that there are less costs associated with catching and landing them).

The increases in overall value of the product landed, as well as revenue per tonne or day, seen after the fleet sizes contract, are matched to a large extent by rising costs (particularly in the non-trawl sectors where variable costs grow rapidly). The overall returns are not completely dissipated however and the fleet is much better off economically, once it has reduced in size (reversing the steep and steady decline in economic health the fishery underwent while it tried to push on with large fleet sizes and falling TACs). The initial improvement in profitability matches that seen under similar circumstances in Scenario 1, though it is equally short-lived. Nevertheless, the overall economic state of the fishery is better off once both fleet sizes and TACs have stabilised; although, this new stable state is still much lower than historical highs. Operators within most sectors maintain a fairly pessimistic attitude to the fisheries state (i.e. operator perception is poor) throughout and there is little new investment in the fishery outside of the GHAT. The returns on investment seen in this Scenario matching those seen under Scenario 1 (even with slightly higher rates of investment after the fleet restructure improves the economic state of the fishery).

The improvement in economic sustainability is also not evenly spread across sectors. The trawl shows the greatest improvement, moving from a loss state to a fairly solid potential profit state, while the longline fishery shows a fairly constant (though slow) decline in its profit. The gillnet fishery is the most interesting however. Before the effort reduction it shows a low level of profit, but after the fleet size drops the shift in targeting leads to a peak in returns (driven by the spike in CPUE, total landed catches and GVP), the index jumping by more than four-fold. The decline from this high is fairly rapid however, due to rapidly rising costs and equally rapid declines in quotas, catches and GVP, as new and old target groups are fished down.

The boom years in the GHAT lead to a short lived jump in the public perception of the fishery, but beyond this there is a generally degrading image of the fishery with time, despite all the management efforts invested in the scenario. Port populations also suffer as the boom drops off, contracting by more than 15% in Lakes Entrance, Eden and Bermagui. In contrast the Tasmanian ports see only minor drops in activity levels.

Ecological Implications

When updated discarding preferences, spatial zoning and selective targeting are included in the Scenario, habitat interactions are of moderate intensity (as vessels are either banned from some areas with vulnerable biogenic habitat or tend to avoid ground where they may "hang-up") and decline through time (as many of the grounds they can access that have habitat are cleared early on). If discarding and selective targeting is relaxed and spatial zoning omitted then the habitat interactions are much higher, nearly as high as in unconstrained scenarios. This is because a feedback between catches (subsidised by species which are not constrained to the same degree by TACs), stock depletion and effort levels sees the sectors pushing the grounds as hard as possible (clipping new habitat and preventing the recovery of old grounds). Overall however, even in the "best case" version of this Scenario demersal fishing pressure sees the local habitat index degraded by 21% through the projection period.

The microbial biomass continues to grow throughout the projections for this Scenario, as does the infauna biomass. Although these are poor system state performance measures, at least part of this shift is due to long-term ecosystem processes that are still reacting to changes that occurred (or began) during the historical period. While some ecosystem changes can be very rapid (e.g. regime shifts), most ecosystem-level dynamics can take decades to play out. This is partly the case here, though it is not the entire story. The depletion of larger body sizes (and subsequent skewing of the size spectra) under this Scenario (due to fishing depleting both large fin-fish, but also the large chondrichthyans) enhances the effect and does not mitigate the impacts (or reverse to any extent) of this long-term change. While a well implemented quota system (as used in this Scenario) has some success (at least in some periods) in stock management (e.g. the biomass of blue grenadier grows by more than 20% over the 20 years) it does not necessarily maintain a sound system structure – this is indicated in this case by an increasing ratio of pelagic:demersal biomass (rising by 36%), the slowly weakening ratio of piscivorous: planktivorous fish biomass (which drops by 8.5% over the 20 years) and the steepening size spectra. Shifting targeting can also undermine the efficacy of the management system. Tiger flathead biomass initially grows and deepwater flathead stocks are stable during the first few years, but the biomass of both species falls off again (by as much as 49%) once it becomes a seasonal target group for the "deepwater trawl" sector (a similar pattern is shown by gummy and school shark). This sector is forced to change behaviour by the combination of falling access to areas with significant biomass, declining catches over open areas and the low value of some of the deepwater groups. While the roughy stocks do better under this Scenario than others, due to the spatial management and highly constraining TACs, that extra biomass is not allowed to be taken (as it is within closed areas and because TACs remain low as the overall status of the stocks does not allow for increases in the TACs on those stocks, even if there are local recoveries). There is some push back to upper slope waters when flathead quotas drop, making ling relatively more attractive again, but there are still further shifts as the ling resource also begins to decline under the pressure (its relative biomass dropping by 20% between when the shift back to ling begins in 2009 and when the spike in catches is over in 2015).

The lower trophic levels show a good deal of variability under this Scenario as pressure across their predator groups leads to flow on effects through the web. Squid biomass grows by 15% despite fishing pressure and while there is a drop in the endpoint value of the total small pelagic biomass it is less than 10%. Looking at the individual small pelagic groups Red bait and mackerel are again the source of this decline, as they appear to be the preferred market product groups and still receive reasonable predation pressure from some of the largest predators (i.e. the protected marine mammals). Interestingly the individual condition of these small pelagics is also more attractive for the fishery under this Scenario, as the foodweb flow on effects see a major restructuring of the plankton communities (beyond their usual structuring in response to environmental forcing). Those plankton groups which are higher quality food sources for small pelagics are at higher biomass levels in this Scenario due to the exploitation on the small pelagics themselves (removing some competition and food limitation within the small pelagics) and because of the strength of some of the juvenile components of mid-trophic level finfish (the size of these components could increase even as adult components fell under exploitation due to relaxation of intraspecies cannibalism, competition and interspecies predation) which still feed on plankton to some degree. However, even with all this system restructuring, diversity improves on the state of the system in 2000.

The marine mammal recovery is as strong in this case as any, though the potential for incidental interactions with seal and sea lion stocks in the GAB slows the recovery of these species (but only marginally) toward the end of the projection period. The shift in targeting and the location of fishing sights in this Scenario is sufficiently different from the unconstrained case (which is pushing further a field and so shows less direct overlap with pinniped foraging grounds in the GAB) that the pinniped condition factor is lower in this case leading to a slower recovery in total biomass (and thus suggesting a larger impact). Protection of more of the deeper water areas under the spatial management options included in the base form of this Scenario means that the gulper biomass does not feel as much on-going and direct pressure, but the stock state still continues to decline over the 20 year simulation period – due to low productivity and the (mainly past) impacts of fishing.

Summary

Effort in this Scenario remains about the level observed historically for about a decade before economic pressure forces vessels out of the major sectors, particularly the SET and GHAT. The lower costs in the Danish seine fleet means that effort adjustment in that fleet is much slower and extends over a much longer period of time (as economic pressure at any one time is much lower). The spatial management makes it difficult for deepwater fleets to be profitable, so they change their targeting and shift to shallower grounds. Increasing TACs allow for increasing landed catches in the GABT and GHAT – at least until the target stocks (e.g. tiger flathead and gummy shark) are depleted past the target reference point and TACs are reduced accordingly. The use of TACs as a dominate management lever means problems with overcatch[16] (when total landed catch of a species exceeds the TAC) are a bigger problem in this Scenario. Towards the end of the projection period, when many traditional target groups have constraining TACs and lower CPUE, there is some target shifting to some of the previous un- (or only lightly) exploited chondrichthyans, as well as shallow demersal and forage fish and squid. Ultimately this activity

[16] The topic of overcatch is dealt with explicitly in the discussion chapter and readers are encouraged to read that section to understand the full implications of this model result.

leads to strong economic performance for the trawl sectors in this Scenario, with variable performance in the non-trawl sectors – as they make strong gains once fleet sizes drop, but decline again once their main target stocks are depleted. This boom-bust nature of the non-trawl sectors is reflected in port activity, public perception and the ecological status of the shallower system components. In contrast the status of the system is fairly good for the deeper waters and in terms of diversity.

4.3 Scenario 4

This Scenario was designed to be an integrated combination of management levers. While the basic list of species under quota is the same as for Scenario 1, gulper sharks have been added to the quota management system (as well as being included in demersal shark trip limits). Harvest strategies, companion and regional TACs matching those in Scenario 3 (but only for those groups that are actually under quota in Scenario 4) were also used. The same gear restrictions are in play as for the previous two scenarios. The use of bycatch reduction devices is also required (as in the standard form of Scenario 3), but in contrast to the other scenarios gear transfer is allowed. Spatial zoning is a significant feature of this Scenario, so that conservation and recovery goals may be reached and to give differential access by depth. Licensing is as of the 2003 regulations (with the potential for a buyback of effort in some variants – see section 4.6) with high reporting and observer coverage.

Effort

The management strategies used in this Scenario lead to more constrained effort levels right from the start, putting a greater immediate pressure on the fishery overall and leading to a faster reduction in fleet size – although the absolute fall in days fished per year is not actually as great as when the fishery is allowed to simply run to exhaustion. While there is a reduction in the SET fishery and some market gains to be made from this, the spatial and other management regulations in place in this Scenario mean that the large increases in effort in the GABT sector seen in the other scenarios do not happen here. In fact a single vessel even opts to leave the GABT (though this does not impact effort levels at all).

There is differential effort reduction within the GHAT sectors, with longlining effort dropping by less than 3% despite the fleet halving. This is because under the new restrictions the operators that leave the fishery spend little time on the water in the years running up to their exit decision and those remaining in the fishery expand to meet the market demand. While this expansion initially raises the question as to why the other boats left if this demand existed (and those that left were supplying to that demand) digging into the details shows that the overhead costs of maintaining the vessels and paying the management recovery costs per boat meant individually there could be substantial economic costs that the market demand did not always cover; whereas the same market demand could lead to sustainable returns if spread over a smaller number of boats (as there is much more product sold per boat for only a small to moderate increase in costs). For the gillnet sector however, this dynamic does not play out as favourably however and its effort levels drop by 50% as its fleet size drops by two-thirds.

The contraction of the gillnet fleet also exemplifies the pattern of which vessel sizes leave the fishery. Even with the integrated use of management levers it is still the smallest boats that feel the greatest burden and exit the fishery. This failure of the smaller boats is despite the fact that fishing is concentrated in fairly restricted areas. While the total fishery footprint does span a significant proportion of the shelf and slope waters (and exploratory fishing reaches all but the most distant boxes), and the spatial management imposed means that the fishery is excluded from some historical grounds, the model fishers still find no reason for more than exploratory trawls outside the most productive grounds. This in turn leads to fairly concentrated effort distributions based around hot-spot locations. Longlining, for example, is concentrated in the eastern GAB and around Tasmania and the south-eastern edge of Victoria; while trawling also expands a consider proportion of its effort along the Victorian and Tasmanian coastlines. The potential for increased conflict does not eventuate under these concentrated footprints if zones are carefully planned.

The sectors showing the greatest shift in grounds are those targeting deepwater groups. As significant sections of the resource are closed off historical grounds are closed and effort is displaced leading to a mosaic of closures and intensively fished grounds. While a drop in access and the effort displacement does contribute to the decision to leave the fishery for some operators, others shift their behaviour between a mix of deepwater and more shelf-based activities (as the shelf is more readily accessible year round). This shift in behaviour, as well as the overall concentration in effort over smaller areas also results in shorter trip lengths. Average trip lengths do rise after the fleet size has dropped off, as the influence of the smaller vessels tails off and the larger vessels make good on their flexibility. Nevertheless even then boats still tend to travel directly to and from preferred grounds with very few of the longer trips seen in the previous two scenarios.

Gear switching is too costly to be taken up as viable strategy by any of the sectors in the standard Scenario. If costs are relaxed gear switching becomes fairly common, especially for gillnet and SET slope trawl boats, which switch temporarily into midwater trawling, longlining, Danish seine and shelf trawl. Such high levels are never as profitable as expected as the fishers underestimate the degree of switching and so expected gains of joining the “best perceived fleet” is dissipated over the switching boats. Moreover there are high trading volumes and costs as quota portfolios built for one gear are rarely optimal for another gear. In addition those operators whom switch are those that are not doing so well and they try this option rather than simply exit the fishery. Ultimately though switching only postpones the inevitable and fleet sizes still contract, often by 10-20% more than if switching did not occur (as the continued presence of the vessels means lower returns all round and more vessels suffer economic hardship).

Landed catch

Landings under this Scenario decline initially and then rise (or at least stabilise) for a short period after fleet sizes drop before going into a longer decline after the new fleet sizes stabilise. This is particularly true for the gillnet fishery, where there is an 80% drop in total landed catch; the longline landings do not decline so steeply, only falling by a little over 25% and overall the longline fishery shows the strongest record through time, eventually leading to 75% of the landed catch in the GHAT.

The pattern of landings across the target groups are the result of some quite interesting fleet dynamics. For instance, the landings for flathead, particularly tiger flathead, are significantly below the TAC for all but the final couple of years of the projection period, due to the implications and impacts of the other management levers and the resulting economic decisions. Considering catches of this group at the subfleet level it is clear that the flathead species, but particularly the tiger flathead in the eastern zones of the fishery, see periodic increases in interest as constraints (management and economic) impinge on the returns (and thus targeting and landing) of other target species in some subfleets. While the flathead species are of continual interest to some subfleets in these other subfleets flathead are considered “secondary” species in the effort allocation algorithm, as other species provided potentially higher returns or had more quota remaining. As a result of this the subfleets (via the expected return calculations at the core of the targeting routines in the economic sub-model) consider the flathead and a few other demersal (primarily shelf) fin-fish groups as dependable and “best alternative” replacements. In those subfleets that show primary and continual interest in the flathead the availability of quota for school whiting can be an issue. Along with the varying interest in the flathead there are also varying discard rates, as targeting shifts about and high grading goes in and out of favour (see Appendix B for a description of how high grading is implemented in the model).

Blue grenadier sees much more constant (but constrained) interest, landings and discards; this is a direct result of the widespread use of spatial management in this Scenario. The spatial management and companion TAC system also constrains the ling landings much more than the individual quotas. Trading for blue warehou, spotted warehou and gulper sharks constrains what ling can be taken, as boats are forced to change targeting if they run the risk of exceeding their available quota for bycatch groups – spotted warehou in particular is very constraining, meaning that up to 60-75% of the potential ling catch is passed over as there is no spare spotted warehou quota to be had (the model does not have the ability to adapt targeting to the extent real fishers can, so the magnitude of this effect may be overstated here). In contrast, roughy quota constrains the take of companions rather than vice versa. They remain a key deepwater groups of interest, though more so in the early than the later years. This results in a “chase the last fish” effect that not even the spatial management mitigates. As in all other scenarios, as the depletion of easily accessible stocks of roughy begins to have significant economic implications for their continued harvest (typically just prior to fleet reductions), the deepwater trawl fleet puts significant resources into trying to maintain (as much as possible) CPUE and landings. Ultimately even with the constraints in place in this Scenario the commercially available stocks of roughy are depleted (even if inaccessible components of the resource persist and grow) and all but exhausted. Moreover there is a significant overcatch[17] problem for roughy during the second half of the projection period with landings exceeding the TAC by 10-30%, this overcatch is why discards do not climb with time for this species. Overcatch is also a chronic problem for gummy and school shark (despite very high levels of discarding of gummy shark after 2012 when TACs are particularly constraining), which are treated much like flathead as a “useful backup” if other target species prove less attractive year-to-year. Small pelagics and squid also become an attractive target for many subfleets, though squid is more widely landed than small pelagics, which are the primary target group only for the dedicated small pelagic fishery.

The inability of the model to dynamically improve targeting, and thus avoid unlandable gummy shark catch to any large extent, means that under the very constraining quotas that are predicted in the final years of the simulation the gummy shark discards climb by ten-fold. In contrast, the

[17] Please see the discussion chapter for a more detailed treatment of the overcatch issue.

squid catch is fairly consistently landed, with discard rates remaining fairly stable through time despite the large increases in the size of the catch. The discard rate of small pelagics in the dedicated fishery remains constant and low. In the other fleets however the discard rates rise through time to lead to quite substantial discards for this group.

Spatially the footprint is relatively constrained under this Scenario. While the spatial closures do dislocate the fleets from some historical favourite fishing grounds, the overall distribution of the spatial closures and the economic implications of the other management levers means that the fleets tend to confine their activities to a few locations (based mainly around the most productive historical sites that remained open). There is very little expansion of effort through time under this Scenario – with only occasion exploratory trips (mainly by trawl sectors) in more marginal grounds.

The improvement in the status and management of fish stocks is seen in the index of the average size of fish in the catch, which grows to a steady 20% higher than in 2000. In other scenarios this rise is driven primarily by a switch in target species, but here it is because there is actually an increase in the numbers of larger and older fish, which is reflected in the catch. Admittedly the size of the increase is enhanced by high grading, so as bigger fish in the preferred targets begin to be more common smaller fish are more often discarded. It is worth reinforcing that the increase in average size is still a real phenomenon, reflecting real increases in the numbers of the older (larger) fish (as they age through the population) under this Scenario, rather than simply an artefact of fishing operations and discarding behaviour. The catch composition under this Scenario does contract through time after fleet size reduction. Initially there is a more even landing of species per sector as fleet sizes contract, but, with improving stock status and economic pressure to maximise returns, many of the individual sectors concentrate more heavily on individual species (some of which were historically only of “secondary” importance, such as shelf demersals, small pelagics and squid), with this focus species showing some degree of sector specificity. The only subfleet that does not show this contraction is the general demersal trawl, which lands a fairly even and broad range of species and groups.

CPUE

Finding or maintaining moderate to high CPUE is a significant driver in the dynamics of the fisheries under this Scenario. In the SET the overall CPUE is improved significantly by the reduction in fleet sizes, but for the other major sectors (GABT and GHAT components) the CPUE remains stable or falls off through time. For some of the smaller sectors however, the CPUE remains high, the Danish seine sector for instance has an increasing or stable CPUE rate after the fleet size has dropped. The demersal gears benefit much more than pelagic gears from this management strategy. The CPUE of many of the target groups for the more demersal gears (flathead, blue grenadier, blue-eye trevalla, school whiting, blue warehou, spotted warehou and school shark) rises by as much as 7x between the first 5 years and the final years of the projection period, while the CPUE for Red bait falls off by 30% as pressure on the stock rises (though overall the small pelagic fishery sees a CPUE rise as the rise in mackerel CPUE more than compensates for this).

Economic and Social Implications

The more rapid reduction in the size of the fishery does not see any fewer boats leave the fishery in general, but it does mean those left in the fishery are in a better economic state. It also means that effort levels are steadier for longer and that stability is much higher.

Perhaps the most unfortunate facet of this Scenario is that the highest management costs are coincident with the years of greatest economic stress leading up to the fleet restructures and reductions. These costs are mainly from research needed to verify the usefulness of the spatial closures and other levers chosen for use (see Appendix B for a description of the management cost model). As the fleets drop in size and the system state improves the level of understanding has also had time to increase and associated costs drop. The demand for assessment related research is also lower, as the improved stability of the stocks and more stable TACs mean less immediate demand for further research.

If a buyback is implemented the management costs are not significantly lower, but vessels can opt to leave rather than trying to remain in the fishery until economically unviable. This means the final economic state of the overall fishery is better.

Even without a buyback, the improved economic health of the fishery after the fleet size drops means that while the individual costs per boat rise steeply, at this point the operators are doing well enough to cope with the increased costs. This is true regardless of the sector considered, though it’s a harder proposition in the SET where the jump in management costs per boat is much steeper and higher than any other sector.

Trading costs can also be significant under this Scenario as operators trade away quota for groups they are not encountering (or do not want to land) for quota of byproduct groups they catch regularly with their preferred target species. This behaviour becomes increasingly common in the small fishery sectors as the simulation progresses and can lead to the situation where the entire quota holdings of a bycatch species in a sector are traded away.

These decisions are based on optimising economic return and do lead to a substantial increase in GVP and revenue in most sectors (especially the trawl subfleets) once fleet sizes have been reduced. Only the GHAT shows a decline in GVP, although for gillnet the overall profit per tonne and per day manages to hold relatively steady. All sectors prove potentially profitable under this Scenario, but the differential cost structure (with steeper increases in cost / t in the GABT and longline sectors) means that the realised profit levels differ substantially across the fisheries – it declines slowly through time for longline, holds steady for gillnet (after 2010) and improves for trawl. When gear switching costs are relaxed to the point it becomes an attractive and viable option, this differential cost structure helps drive the decision to switch between gear types. The fact that the fishery is profitable does lead to higher levels of investment, even before the fleet sizes are reduced. More investment occurs as the fleet size is reduced. The operator’s optimism (a higher value for the relative perception) about the fishery is not unfounded and the return on investment grows steadily into the medium and long-term.

The shifts in fleet behaviour, returns and management costs mean that while stability under this Scenario is one of the best, the operators see access as being highly constrained. The public perception however is much better, stabilising quickly once the fleet sizes have been reduced, rising again into the long term. The increased economic health of the fishery is reflected in the port activity and populations. While these contract with the fleet size, they do not do so as sharply or by as much as in other cases.

Ecological Implications

Habitat interactions are relatively low under this Scenario, as spatial management prevents extension into new grounds with significant levels of established biogenic habitat. This means that the local habitat index also sees little extra decline on historical values, though neither does it show any significant recovery on the time scale of the simulations considered here. Even into the medium and long (50 year) term the index only holds steady. It is likely that the slow regional scale recruitment and growth rates shown by these groups lead to recoveries on the scale of a century instead, as seen in similar exercises at other locations (like the Northwest Shelf of Australia, Fulton *et al* 2006). Runs must actually be completed on that temporal scale however, for this to be confirmed.

The TEP interactions rise through time despite the best management efforts under this Scenario. This is because of a rising biomass of the majority of TEP groups, rather than a significant failing in the management regime itself. For instance, from year to year the accidental entanglement of a single baleen whale can lead to considerable variability in the TEP interactions (e.g. compare the biomass killed in 2017 and 2018 in Figure 5.40). In the short term these odd interactions can see the biomass growth slowed (which depresses the size spectra of the entire system), but in the medium to long term the overall TEP biomass fares very well under this Scenario. Large bodied seabirds in particular show significant population growth. Even gulper shark biomass recovers in the long term under this Scenario, but it really does take decades (at least 30 years) to see this turn around. It is not evident by the end of the projection period, although there are indications of a slowing in the rate of decline over that time frame.

The detrital pool made up of fisheries discards is fairly high until the fleets drop in size, after which the carrion pool remains stable, meaning the scavenger groups are guaranteed at least one prey source. The plankton structure also shifts through time, with recovering fish stocks leading to increased predation on the larger zooplankton groups, which flows through to higher diatom and small zooplankton biomass. The state of the target groups also fares reasonably well under this Scenario. Both flathead species show little further decline, stabilising at about the target reference point at the population level, but showing depletion around the most popular fishing grounds. Tiger flathead shows ecologically driven cycles through time, whereas deepwater flathead have a less variable biomass trajectory – declining smoothly to their final stable state.

The other target species that show stable biomasses around the target reference points under this Scenario are: blue grenadier, small pelagics, spotted warehou, blue warehou, cardinalfish, school whiting, shallow piscivores, shallow demersals, gummy shark and demersal sharks. Ling on the other hand (particularly in the east) show a very gentle oscillation before falling steeply away in the final years of the projection period under fairly intense fishing pressure. The biomass of orange roughy also declines through time (falling by an additional 32%), failing to recover from past or on-going fishing pressure during the projection period or in the medium term.

School shark, squid, gemfish, dories and oreos, ribaldo and blue-eye trevalla all increase in biomass between the beginning and end of the projection period. The fin-fish are recovering from past depletion (though for school shark that recovery may be a little fast), but they are also benefiting from the ecological restructuring that is occurring. For instance, the condition of the individual school shark rather than an increase in numbers is the major contributor to this biomass increase. Ecological shifts are also responsible for the increase in squid biomass, with the bulk of the change occurring in locations where the fish communities show the greatest impacts of fishing. These ecological shifts ultimately lead to a reversal in the degradation of the pelagic:demersal fish ratio, though this occurs beyond the end of the projection period. This pattern of recovery in system structure in the medium term is also seen in the stabilisation of the piscivore:planktivore biomass. The diversity indices recover more quickly than the structural indices, showing improvements by the end of the projection period, though (as suggested by the slow rate of structural index recovery) the richness recovers more quickly than the evenness rises (showing that while the management system improves the state of many groups, it still leads to a differential recovery).

Summary

The integrated use of management levers in this Scenario leads to immediate shifts in the system that continues smoothly through much of the simulation. All sectors constrict in size after just a few years, though only a single vessel is lost from the GABT and the longline sector does not see a substantial change in effort levels. The footprint of the SESSF is spatially confined under this Scenario, with fishing concentrated around hot-spots in the eastern GAB and around Tasmania and south-eastern Victoria. Landed catches do stabilise eventually; and for many species this is at a level lower than that taken historically. TACs can be strongly constraining and it is not unusual for the TAC of a target species to go unfilled due to the lack of quota for a byproduct group. Overcatch and high grading remain an issue, but a new issue highlighted by the extensive use of spatial management is whether protected stock components resupply open areas – without sufficient movement between locations it is possible for the available fish to be depleted even when the bulk of the population is doing well. Nevertheless, overall the majority of the performance measures (including average size of the catch, CPUE, profitability, public perception, and the biological status of the majority of groups) are stable or increase through time.

Not all management levers are equally successful, with the costs of switching preventing it actually happening in the standard form of the Scenario. Once the costs are relaxed vessels (particularly gillnet and SET trawl boats) do switch, but it is rarely as profitable as anticipated as the infrastructure associated with fishing (e.g. quota packages) are not optimal when changing from one gear to another.

4.4 Scenario 9

The approach used in this Scenario was specified by the Australian Marine Conservation Society, aiming to emphasise the precautionary principle and recovery while simultaneously minimising habitat and other impacts. It puts aside much of the existing management structure and replaces it with a system of spawning closures and soft and hard bottom ‘paddocks’ outside 3 nm and a ban on fishing by any means on seamounts or deeper than 800m. One feature of the real world management system left in place is the quota management system, which covers the same list of species as in Scenario 1, but also features regional TACs (particularly for deeper water target species). Like most other scenarios gear transferability is not permitted, but in all other respects gear limitations are quite different under this Scenario (there are no limits on longlines, gillnets are allowed to be up to 6km in length and mesh sizes are set to 110mm for trawl, 38mm for Danish seine and 40-60mm for prawn trawl) with mandated use of bycatch reduction devices. Licensing is as of 2003 until a buyback of 25-50% of the effort occurs after 5 simulated years. Monitoring is broad and includes fishery independent surveys (as in Scenario 3) and compliance with the paddocks is good. Effort creep is estimable and accounted for in the decision making process.

One feature present in this Scenario that is not considered in any other is that some attempt is made to consider the direct impacts of changing water temperatures (due to climate change) on fish metabolism, growth and reproductive success. Variants (see section 4.6) were run without this change so that the impacts of the fisheries management regulations could be differentiated from those due to shifting environmental conditions.

Effort

In Scenario 9 the extremely constraining nature of the spatial management methods means that there is high competition on those grounds that remain open and that there is little scope for effort displacement leading inevitably to an effectively immediate readjustment in fleet structure – with the majority of boats tying up for much of the year and living off any existing savings (see Appendix B for a description of how these are calculated). This precarious financial situation means that when the buyback does occur (during the 5th year) there is actually very little, if any, extra drop in effort (as the buyback simply removes those boats who were effectively already non-participants in the fishery). The trawl fishery and especially the deeper water components are particularly hard hit with more than half the fleet leaving (even in the GABT) and amongst the deeper water components the bulk of those remaining in the fishery shift to inshore operations. In total the effort expended in the deepwater drops by more than 80%. The longline sectors are also heavily impacted, the proportion of the GHAT made up by this gear stagnating at 2000 levels (rather than growing as it does in other scenarios). Of the dynamic bottom gears only Danish seine remains relatively unaffected by the new arrangements (its effort declining by only 25% even as its fleet size contracts by 70%). This is for similar reasons to the dynamics seen in Scenario 4 – what is unviable when a low GVP is spread across with a medium to large fleet is sustainable when the same GVP is shared between a smaller number of boats (despite some rises in individual costs). Small fishery sectors, such as midwater trawl for squid, jigging and the small pelagic fishery also fare well in this Scenario, leading to only small (if any) contraction in effort and fleet sizes (the midwater trawl fleet does halve, but that’s a reflection of a small starting fleet size rather than a large exit of vessels).

The spatial management constraints not only lead to overall fleet size reductions but also to substantial effort redistribution (as many traditional grounds become off limits). Effort is squeezed into the outer shelf and upper slope, with the outer shelf seeing more of this fishing pressure. Effort in the eastern sectors is fairly constrained east-west with fewer boats in total making long trips and the majority of effort occurring on the most productive outer shelf locations that are simultaneously closest to the home ports (i.e. mainly off Victoria). This leads to a concomitant drop in average trip length in those sectors. This does not mean the overall extent of the fishery’s footprint drops however (although its intensity surely does), because the loss of the deep waters and the restriction on fishing in the shallowest reaches sees the fleet extend exploratory fishing to even the most distant boxes in search of grounds that are both productive and readily accessible. In other sectors (specifically the GABT) the level of effort vs the distribution of effort is such that the entire area is fished at almost exploratory levels, so that no site is fished particularly intensively but the total spatial extent of the footprint (east-west) is not substantially reduced; meaning that fishing pressure across these western grounds is fairly homogeneous. The low effort levels in the GABT also mean that while the range of trip lengths is broad the average remains low, as the eastern sectors (who make short trips to Victorian and Tasmania waters) are not counteracted by the infrequent GAB spanning trips.

While the spatial management in this Scenario proves to be highly constraining it does still allow the fleets to move with the small southerly shifts in the centre of gravity of some of the main target groups that is caused by the climate change aspect of the basic variant of this Scenario. This is a fairly crude consideration of the impacts of climate change and these results should be treated cautiously.

Landed catch

The highly restrictive nature of the spatial management methods used in this Scenario mean that catches are very low (as a result of very low effort levels). It is still possible to see local depletion - either temporally as fish are yet to flow in from the closed areas, but more commonly among effectively site attached species (i.e. groups showing low rates of adult movement geographically).

The drop in trawl landings is immediate and then almost fixed at that level throughout, as no productive new grounds become available (the searches mentioned above proving unproductive). In contrast, the other sectors show more variability after the initial fall in landings. Longlining is one of the few methods (Danish seine being another) that show more of an increase in catches through time and even then the increase is not large – even dipping slightly during the buyback as some of the vessels that exit had made the occasional trip in the preceding years.

The longline fishery does retain its traditional target groups, but adds more shelf-edge groups to the suite as it increasingly spends more of the effort on the outer shelf rather than on the deeper reaches of the upper slope. The landed catches are also drawn from a wider (in a latitude-longitude sense) spatial distribution. For instance, under this Scenario the traditional NSW grounds that saw early development as much as a century ago return to being of some prominence (though still not the most productive locations) in the fishery.

This pattern of shifting to locations more around the shelf break is fairly characteristic of all the deepwater vessels. The nature of the spatial management system means that these boats soon exhaust the economic viability of targeting many of the offshore stocks and shift to shelf groups, such as the flathead species, the targeting and landing of which increases by more than 90% from the very low levels landed in the first year that the management strategy is in place. The drop in the first year is so steep however (tiger flathead landings drop by 2000t and the catch of deepwater flathead is more than halved) that it is never fully recovered (despite the subsequent shift in targeting and 90% increase in landings). The tendency to shift to chondrichthyan target groups that is noted in other scenarios is not seen in this Scenario. The catches of the various shark groups and the skates and rays falls steeply (along with most other things) from historical levels in the first year. After this point the landings remain stable and there is no significant shift to preferentially target these groups. Not surprisingly (given the lack of spatial constraints on gear that does not interact with the bottom) the biggest increases come in the landings of species and groups taken by midwater trawls, jigs, and purse seines. The squid catch doubles, for example (though this is less variable than the catches seen in other scenarios); and while the landed catch of small pelagics drops away initially it does not fall as sharply as the demersal groups and steadies at about 5500t (making it one of the largest catches by volume at the group level in this Scenario). Red bait makes up the bulk of these landings.

The restrictions in place in this Scenario mean that while the small pelagic landings remain the purview of the dedicated small pelagic fleet the occasional landing and the more typical mass discarding of small fish is not observed in this Scenario. Because the magnitude of catches and are so low and the composition is desirable (with more larger fish), discards are typically fairly low across the board under this Scenario (even though there is no actual ban on discarding, as in Scenario 10).

The large drop in catches under the restrictions imposed in this Scenario leads slowly to increasing numbers of older, larger fish in the populations of the target species; the shorter lived species showing this within 5-10 years, but longer lived species taking proportionately longer. This increase in the prevalence of larger fish plays out in the average size of the individuals landed, which increase by 50% over the projection period. The access to almost an excess of large fish also sees less focus on any one species in the catch of the subfleets. Rather than the dynamic composition dominance seen under the other scenarios the catch composition per sector only increases by 2-5% before stabilising and (potentially) more importantly it is the relative contribution of existing (traditional) key target species that rises rather than new target species as in the other scenarios.

CPUE

Despite the fact that fleets do find it possible to cause local depletion, the stock sizes are such that by moving around (almost rotationally) between the paddocks and using pulse fishing the fleets see relatively high CPUE rates. This sees the overall CPUE for the entire fishery and the individual demersal sectors rise under Scenario 9, reaching higher than most if not all the other scenarios by the end of the projection period. In the GABT the CPUE rates even rise above that seen in the 1990s. The GHAT sectors do not grow as much as the trawls or Danish seine, but they still increase by 20% or more and show none of the decline seen in the other scenarios. Interestingly in this Scenario it is not the likes of the small pelagics and ling that are driving these increases in CPUE, instead it is the more of the traditional SESSF groups, such as: tiger and deepwater flathead, blue grenadier, blue-eye trevalla, ribaldo, school shark, gummy shark and blue warehou (which see 15-350% increases in CPUE). These increases also vary temporally and spatially – leading to the wide use of pulse fishing. The CPUE for squid still rises under this Scenario, but the CPUE for small pelagics declines, as does the CPUE for ling – due partly to fisheries pressure, but more importantly to multispecies trophic interactions and shifts in available food sources.

Economic and Social Implications

Compliance costs see management costs reach high levels for this Scenario and costs per boat can be very high after the fleet sizes have dropped, particularly in the GABT. Trading costs are not much of a concern under this Scenario though as quota is readily available for the small catches taken.

The low catches mean that GVP is never high and in combination with high management costs per boat this means that it is hard (and often impossible in some sectors) for vessels to get sufficient catch to cover costs if fishing frequently – costs per day are high so revenue per day is not great, even though revenue per tonne for trawl increases somewhat. As a result pulse fishing becomes common, putting intense pressure into a few trips per year and then attempting to minimise costs by remaining tied up for long periods in between. The trawl boats show the most steady pressure through the year and even then they take on a more seasonal pattern, preferring to fish in those months when expected market prices are highest. Even with these shifts in behaviour the overall fishery is not profitable. Many sectors fail to fish enough to cover land-based and fixed costs, often being constrained from fishing by stiff costs per day at sea. No sector fares well, but the GABT and longline sectors perform the best against this measure.

This confusing mix of good returns per tonne, but high costs and ultimately low profitability leads to misconceptions about the fishery's future by the individual operators (who are acting on past patterns). The return rate and the stability and access measures see some of the operators invest, this time erroneously, in the fishery. These investments are really never made good on, with the fishery remaining largely unprofitable (or marginal) throughout the projection period. The stability and access measures used to make these poor investment decisions come down to the imprecision of potential provided by the strict spatial management that the fishery is not able to capitalise on.

As spatial management is used so widely those who remain in the fishery see access and stability remain fairly constant; and broader public perception grows through time, stabilising after roughly 15 years. Unfortunately, the lower levels of catch under this Scenario impact the ports fairly rapidly and heavily, with most ports showing significant decreases in activity and population size. Lakes Entrance, Eden and Bermagui are all particularly affected with population sizes dropping by 15-20% or more. These impacts on ports means the public perception of the fishery never fully recovers.

Ecological Implications

There are almost no interactions with biogenic habitat under the paddock system, even when the fisheries look to newer grounds. This gives the margins of the fishing grounds a chance to stabilise and begin the slow process of recovery. The low levels of realised effort and zoning (which helps to direct the fisheries away from areas frequented by many of the TEP groups) also means that the bulk of the TEP biomass and the fisheries do not overlap, leading to a low rate of interaction.

The lower level of catches and discards means that the carrion pool fed by the discards is much lower than historical, which impacts the scavenger groups. While the population biomass of ling, for example, initially improves (by 15%) under the release of fishing pressure, ultimately the condition and then the total biomass of ling falls away (dropping by 45%). This is a direct result of both a degradation in one food source (though carrion is not their primary prey) and an increase in predation and competition as the species that share their habitats recover and strengthen the magnitude of their interactions. Interestingly, even though they are not a scavenging group, a recovery of gemfish is not seen under this Scenario either due to the combined impacts of the fishing pressure (which is actually relatively light) or strong trophic interactions (particularly on the smallest age classes).

The pattern is different for many of the other target groups, showing solid recoveries in many cases – blue grenadier, gummy and school shark (this recovery in the sharks is as much to do with individual condition as numbers), school whiting, dories and oreos, ribaldo, blue-eye trevalla, blue warehou, orange roughy (though the recover is only slight and the population growth rate is very slow) and tiger flathead. Deepwater flathead however ultimately declines after initial gains, due to a combination of fishing and predation pressure. In other groups, such as redfish, the stocks do decline, but not at the rate seen in the other scenarios and often for trophic rather than fishery related reasons (predators and competitor stocks grow while shared prey groups are depressed by the increasing predation pressure). The recovery of the target groups also impacts the prey groups directly and indirectly leading to lower small pelagic and squid biomass and to the restructuring of the plankton groups, with lower biomass of large and mesozooplankton and slightly higher biomasses of the small zooplankton and large phytoplankton.

This restructuring is also evident in the system structure indices, the pelagic:demersal biomass ratio rising with the slowest rate of all scenarios and being to decline again soon after the end of the projection period when the 50 year simulations are considered. The piscivore:planktivore biomass ratio also reflects the more evenly distributed and stable structure generated under this Scenario, remaining fairly steady through the projection period and beyond. The size spectra is also smoother with less bias toward smaller size classes, which is corroborated by higher richness and faster increases in evenness, which include the medium-larger bodied groups that fall out of the more intensely fished scenarios.

Summary

The spatial management implemented in this Scenario is very restrictive; while this leads to a strong recovery in many groups and solid conservation-based performance, it is at a significant industry and human cost. Effort and catches drop immediately with many vessels leaving the fishery from all the major sectors, including the GABT; and all this happens before the buyback is scheduled, so it ultimately has little effect or benefit. Those remaining in the fishery all concentrate on outer shelf and upper slope, but the often shorter trip lengths do not translate into drastically reduced costs and the fisheries in this Scenario are not profitable. This has the knock-on effect of leading to significant downturns in the port economies.

4.5 Scenario 10

Scenario 10 was configured to capture the current state of management (existing and planned) as of November 2006. There were many tactical variants of this Scenario, but the basic form has quota management as it existed in 2006, and fishing without quota is banned, as is discarding of quota species. Harvest strategies and tiered assessments are in place as are gear restrictions. The spatial management included all active management closures as of 2006, as well as those outlined in the Ministerial directive of September 2006 and the entire set of the Department of the Environment and Water Resources spatial management areas. Voluntary seasonal closures are also included. Gear switching is banned and licensing is as of 2006 through out the simulation. Variants of this Scenario included: integrated management which traded additional spatial management against TAC reductions; the addition of specific year round gulper shark closures; companion TACs (both strong and weak link variants).

Effort

The combination of management levers (particularly the inclusion of the ban on discarding) leads to substantial changes in the fisheries dynamics. The eastern and non-trawl sectors are more heavily impacted than the GABT and this is reflected quite strongly in their respective total effort trajectories. The GABT shows an increased and stable level of effort, while the other sectors show a decline that extends for some time (though in extended steps) before stabilising toward the end of the projection period. In many ways Scenario 10 is a pragmatic implementation of the concepts captured in Scenario 4. This is also evident in the response of the fishers to these scenarios, with the realised effort levels often similar for each sector under these scenarios. Outside of the GABT the sector that sees the smallest constraints and grows (at least initially) faster and to a greater degree than under other sectors is the small pelagic fishery. With time this sector does contract again, but initially this sector is more lucrative here than in other scenarios.

Initially fishers are slow to respond to the management changes and the footprint under this Scenario is as wide spatially as it is in the high effort scenarios (Scenarios 1 and 3). However, as the economic and logistic reality of a ban on discards bites the footprint undergoes a significant (and unanticipated) shift. Holds are filled more rapidly when there is a ban on discards, which means the centre of gravity of catches is closer to port and after a smaller number of shots. Across all sectors this means that effort is more evenly distributed along the coast rather than simply at the best hot spots (which may be far from home ports). Looking at specific sectors, the SET essentially contracts to either side of Bass Strait (especially off the eastern side) and around Tasmania, while the GABT shows some contraction eastwards. Other sectors, particularly the longline sector, do explore as widely as ever, but the logistics of actually bringing home all quota caught means that this exploration is not followed up on even if better grounds are found further a field. Ultimately this leads to smaller trips and a smaller overall spatial footprint in all sectors. While the range of trip lengths is as broad as in other scenarios the trips are skewed more toward small straight-out-and-back-in forays, at least in the first half of the projection period. Later on (and especially into the longer term) this pattern is broken down to some degree as the fleets suffer the effects of local depletion and crowding. Even this dissolution however never sees the footprint extend to the levels seen in Scenarios 1 or 3 due to the logistical constraints and effective costs of the ban on discarding of quota species.

Landed catch

Because of the ban on discarding of quota species, the pattern of landed catches is often (but not always) different to that under the other scenarios – in fact the overall landed catches peak (during the early to mid-years of the simulation) just as the total landed catch in the unconstrained scenarios are declining or already at their lowest levels. Economic pressures and the implications of the management strategies lead to composition changes of the catch (to do with both size and composition) not simply to effort shifts. Within the SET these change are not enough to arrest the declining trend in total landed catch for the sector in the final years of the historical period. In the GABT however it leads to much more stable landings. Longline landings fall off through time in this Scenario whereas the landings from gillnets show first an increase before also falling away. In contrast, Danish seine landings become almost cyclic, doubling in one decade to fall back to 2000 levels in the next – with this pattern continuing for some time into the future. This pattern is a result of what they can catch and land vs a higher capacity for absorbing the costs associated with a ban on discards (it is less of a change in costs for this fleet than for any other it seems).

TACs are often constraining in this Scenario because discarding cannot be used as a “release mechanism” by the fishery. This not only confuses the statistics used by fishers and management to judge the state of the fishery (the information content of CPUE shifting sharply) but also has market implications (at least some of which, such as potential market depression or differential product quality within a single haul, Atlantis fails to address adequately). The ban on discarding leads to large landed catches of the most common target groups (e.g. the flathead species, gummy shark) as fishers rely too heavily on historical information and ideas that are now out of date under the new rules. In some cases learning is rapid enough that improved behaviour and adjustment to the conditions happens rapidly – the larger vessels adapting their practices within a couple of years across the entire fleet. The vessels under 40m (many of which ultimately leave the fishery) tend to change their behaviour less (seeing a smaller direct impact on the distribution of good grounds and trip lengths). Overcatch[18] becomes less of a problem as time and learning progresses in the simulation, but is never really eradicated. The fishers do become more adept at accounting for “secondary” species take (vs available quota for those groups) when creating effort allocation plans, but overcatch remains an issue, particularly late in the year, when many boats simultaneously fill the last of their quota and are left looking for extra quota that no longer exists. This is a big problem for deepwater quota species, as illustrated by the nearly 600t overcatch in the year the fishery “chases down the last fish” (in an effort to maintain or increase CPUE, but ultimately commercially depleting available easily accessible stock components). It is also a problem for the shark gillnet fishery, which displays a chronic 100t (or 25-35% of quota) overcatch problem even after the operators have learnt to account for the new “no discard” dynamic in their effort allocation plans (although as already noted real world improvements in targeting may mitigate this effect somewhat).

Shifts in targeting both within subfleets and across the fishery as a whole are fairly evident. With hold capacity now as much a constraint as anything else there is a shift to those groups (even if of moderate value) that are found on grounds closer to port – as no discarding means holds fill rapidly so turn around and trip lengths are shorter. It can, however, take more trips to secure the high value and high quality product that is most sought after. This is why there is an increase in squid and small pelagic catch, with these groups being landed by the dedicated fleet components, but also by subfleets who showed little interest in them in the past. The landings of red bait rise by 1.7x, mackerel by as much as 8x and 2-2.5x for squid.

The move to fish closer to port and more evenly across many targets results in catches that are taken from broader areas. Rather than highly concentrated on a few very productive (or preferred) sites, the catch is more evenly distributed along the coast or contours (especially in the waters off Tasmania, Victoria and New South Wales).

Beyond the shifts in effort and targeting generated by the ban on discards of quota groups there are some ecological impacts that feed to some extent back into the fisheries and catches landed. With the loss of discards as a food source some obligate scavengers (which are trophically linked to target groups) drop off in numbers while other opportunists (like ling) see a drop in condition as they are forced to look to other nutritional sources. Quality of the product (beyond

[18] Please see the discussion chapter for a more detailed consideration of the overcatch issue.

storage impacts) is not an explicit inclusion in the market model in Atlantis SE, but if it were the expectation is that this Scenario would see large penalties (and potentially fishing behaviours that are different again from those discussed here).

The average size of the catch grows (ultimately by 45%) under Scenario 10 for 14 years before it drops off again. This pattern of rise and slight decline is driven as much by the ban on discards and shifts in targeting as changes in population structure. Across all sectors the bycatch that had been discarded in the past is retained, as these species also see some increase in direct targeting the overall average size of the catch increases, to a point. Eventually pressure on the fished locations and stock structure in those areas sees larger proportions of the catch made up of smaller fish, which must be retained due to the ban on discards. The model cannot achieve the levels of selective targeting that real fishers may be capable of and the fishers cannot high grade due to the management regulations, so the smaller fish and species are landed more often. Bycatch reduction devices and improved targeting may lead to very different results, such as an increase in the dominance and catch composition index, rather than the drop that is seen. During the early years there is a small increase in catch dominance by single species as targeting is consolidated under the new management regulations, but with time this dominance actually drops as operators cannot discard the increasing number of quota species they encounter on the fishing grounds. This is particularly the case for the generalist sectors, such as the general demersal trawl.

CPUE

Once the fleet sizes have dropped CPUE improves (for roughly a decade) before beginning to decline again overall and in the major sectors (except the GABT which remains constant through time); although even with the final decline the medium and long-term CPUE rates remain above historical lows. During the increase phase the rises are as steep as in the spatially restrictive Scenario 9. This seems to be because much more of what goes in the net is landed, due to the ban on discards (meaning care should be taken directly comparing CPUE rates between this Scenario and the others).

The increases in the end state vs initial sector-level CPUE rates is due to a combination of old and new target groups – mackerel and other small pelagics, squid, skates and rays, pelagic sharks, shallow demersal fish, spotted warehou, blue warehou school whiting, blue grenadier, blue-eye trevalla, and ribaldo. Not all traditional target groups show an overall increase in CPUE however, even with the ban on discards. Ling, morwong and dories and oreos all show some increase in CPUE but ultimately continue to exhibit falling catch rates. Two of the most prominent target groups, the tiger flathead species and gummy shark show more complex CPUE patterns in this Scenario. The flathead shows large periodic cycles of CPUE that are approximately a decade in length (five years of high CPUE rates followed by 5 years of rates that are 3x lower), which are a combination of variation in fishery focus across multiple sectors and ecological variation. The CPUE for deepwater flathead is more consistent through time and does not exhibit these large cycles. The CPUE for gummy shark has a much simpler form. Initially the rate appears to climb, as behaviour shifts to a higher chondrichthyan focus and biomass once discarded is kept. These high rates fail to be maintained however and they fall away steeply through time, leading to shifts in targeting focus by the gillnet sector to other groups, such as school sharks and the other demersal sharks.

Economic and Social Implications

The constraints in place do lead to a more rapid exit of vessels, leaving the remaining vessels in better shape than if the system was constraint free, but the form of the constraints come with new costs. Costs per boat are initially low, especially for the trawl sectors, but after fleet sizes have dropped costs do rise in some sectors. Management costs are fairly high under this Scenario, though they do decline through time by 25-45% as stabilising management and TACs see a declining demand for a high number of assessments per year (stable TACs and catches lead to a reduction in the frequency of assessments). Compliance and monitoring costs remain fairly high however, which means the costs recovered per boat remain high also.

One of the greatest additional costs under this management scenario is the enormous increase in trading necessitated by the ban on discard of quota species. The level of trading is typically 1.7-350x that seen under any other scenario (but can be more than 7000x that in scenarios with little trading) and comes with a high price tag. It is the secondary and byproduct species quota that is hardest to fill and can lead to significant proportions of the quota of a sector being traded in or out at a species level.

The landing of biomass that would once have been discarded means that GVP can be quite high across the board (in all sectors), though if the market model really caught the quality aspect of those landings that GVP may not be as impressive. Revenue per day and per tonne is more varied across the sectors. The GABT shows a strong improvement immediately following the reduction in fleet sizes in the east, due to benefits flowing from reduced competition in the market place, but it falls off again as things get tougher later in the simulation. Things are more consistent in the SET, where some of the most productive grounds are located. The improvement isn’t as strong in the GHAT sectors, but at least there is no significant decline in their revenue rates through time. Some sectors fare better than others with regard to costs, Danish seine being one of the most well off in this regard. Costs per tonne are more reasonable, meaning it is still possible for the fisheries to be profitable overall, leading some sectors (Danish seine and SE trawl once fleet sizes have been reduced) to have levels of profit that are much greater than in other sectors (the gillnet sector in particular is close to marginal in some years even late in the projection period).

Closures, quotas and other regulations mean that the fishery is not seen as particularly accessible or stable (despite the drop in number of annual TAC adjustments through time). The public perception also shows some (moderate) volatility through time, bouncing from approval of effort reductions to concerns over ongoing deterioration of the biogenic habitat through time – though bans on discards countervail this concern enough to see a strong increase in approval by the end of the projection period. This occurs even in the face of some contraction of port activity through time, which occur despite the catches being landed in them. The overall perception of operators active in the fishery however, is positive enough for them to invest in it, mainly around the time fleet sizes fall. The slim profits made in some years do mean it takes time for there to be significant returns on that investment.

Ecological Implications

The shift in fisheries grounds under Scenario 10 leads to moderately high habitat interactions as the most preferred of the new grounds are cleared (e.g. the Tasmania seamounts that fall outside the closed areas) and their edges pushed as much as possible, technology being used to push closer and closer to the boundary of unfishable habitats. In reality, fear of losing gear (especially gear with net monitors and the like attached) may see a much lower rate of habitat interactions. As it stands, in the Scenario the habitat declines overall as mild recovery in abandoned grounds is counteracted by clearing of habitat on newly preferred grounds.

As with the other scenarios where there was even moderate effort expended the biomass of TEP interactions rises through time as the marine mammal populations recover from past harvesting. As fisheries and marine mammals cannot be completely separated while still allowing for viable economic fisheries this TEP interaction level does not fall even with the contraction in intensively fished grounds.

The ban on discards of quota groups under this Scenario leads to a low carrion pool and so drives the scavenging groups onto alternative prey. In many cases this is insufficient to maintain their biomass and the scavenger populations fall off through time, causing further cascades through the foodweb.

Other cascades cause the shift in plankton structure. Initially a release in predation results in an increase in mesozooplankton during the early and mid years of the projection, as fishing patterns and pressure are restructuring. By the end of the simulation however, the increase in some of the small pelagic stocks and the relative biomass of small planktivorous age classes of other finfish depresses the biomass of the larger plankton groups. This pattern is also captured in the rising pelagic:demersal biomass ratio and the falling piscivore:planktivore biomass ratio. When the longer term simulations are considered these ratios continue to follow these shifts for a further decade before stabilising or beginning to reverse the trend. The size spectra suggests a patchier signal – with the smallest and largest groups present in reasonable levels in the spectra but the mid-sized groups showing some significant impacts. This impression of a patchy system is backed up by a fairly low rise and flat nature of the trajectory in richness; the performance with regard to evenness is slightly better, with a 9% increase, although this is still one of the poorest across the scenarios.

The target species under this Scenario do not show the magnitude of declines seen in Scenario 1, but they do still tend to stabilise below the target reference point. This is in part due to multispecies interactions, but also because of the impacts of the overcatch. Furthermore, there is a differential impact west-east, with the more easily accessible eastern (and southern for orange roughy) stock components more heavily impacted than those in the west.

Summary

Fleets are reduced in size in this Scenario, as in all the others; and this contraction in size happens relatively rapidly (as in Scenario 4). The ban on discards in this Scenario has potentially the biggest impact of any single management action in any of the scenarios. It causes the fishers to shift grounds closer to port, to a more inclusive targeting (anything that has any real value is landed, as there is less scope for “searching”), and to clear habitat from the edges of the most popular grounds rather than moving to sites further away. The ban means there is no “release mechanism” with regard to quota, which can be very constraining and overcatch (especially of byproduct species) is a persistent problem. The ban on discards also means there is a loss of continuity with the historical meaning of measures such as total catches and CPUE, but in absolute terms catches are higher and CPUE stabilises at levels above historical lows (though there is some decline from the highest catch rates seen soon after the fleet sizes contract). The economic performance of this Scenario is good, despite relatively high costs, though in reality the quality of the product may tarnish the returns. Trading associated costs are a significant component of the costs under this Scenario, as trading of quota, especially quota for byproduct groups, is prolific. Both the public perception and the ecological performance measures are patchy, as they respond (each in their own way) to changes in fishing behaviour (some for the good, some for the bad). The public approves of the effort reductions, but disapproves of the increased level of habitat interactions as the grounds shift. Meanwhile these same shifts in behaviour drive cascades through the ecological pathways which lead to a mixed and patchy system.

4.6 Results of the Variant Scenarios

4.6.1 Climate Change

Climate change impacts were not the focus of this study and they receive incomplete attention here. The main changes included in Atlantis SE were metabolic impacts of altered temperature states as well as some limited impacts on reproductive success and distributions. A comparison between Scenario 9 with and without climate change shows little difference in the results beyond slightly lower biomass levels in those groups most heavily impacted by metabolic stress or reduced larval survival. Spatial distributions also shift, though the form of the polygons means these shifts are fairly coarse. The fisheries easily keep up with these shifts, so long as they have a high weighting for knowledge updating. If they are constrained to working close to traditional grounds (as tied to port by short trip lengths) or have high weighting for historical knowledge then their catches fall off and they suffer economically as they cannot shift with their targets.

4.6.2 Lower discard rates

When lower discard rates are used in any of the scenarios (to represent either stricter use of bycatch reduction devices or more selective targeting) there are several changes in the results. Effort is reduced a little but not by substantial amounts, but the main result is not only much lower discards (by half or more) but also more constant catches. For instance, for Scenario 4 tiger flathead catches are far more constant through time, regardless of the size of the fleet pursuing them (Figure 4.1). This is also true of the catches of red bait and gummy shark and ultimately leads to less target switching in this variant of Scenario 4. In combination these changes in fishing practices result in higher relative biomasses for some of the most vulnerable or highly targeted groups. The resulting medium to long term stable population sizes are higher (by as much as 100% or more), but it still does not lead to stock recovery (to target reference points or beyond) for the most heavily depleted groups.

Simulations show that only a complete cessation of fishing (either on the group of interest or in total) can lead to any substantial recovery in the medium term for any of the most heavily exploited or impacted groups. Multispecies interactions mean that avoiding a target group while still fishing other groups does lead to some recovery, but not as great as when fishing is stopped altogether. Overall biomasses do not simply increase across the board when discard rates are lowered (or fishing ceases). Those groups that have benefited from the depletion of predators or competitors, or have found a bountiful additional food source in discards, decline when fishing pressure on the highly exploited groups is reduced (regardless of how it is done). This has strong implications for fisheries on these declining groups, such as the small pelagic fisheries. This highlights a trade-off in the possible sizes of small pelagic and demersal or shark fisheries.

The final change in results with lower discard rates is that with healthier stocks (in particular for the more productive or robust species which all stabilise about their target reference point) associated TACs remain at higher levels. This not only allows for the more constant landings mentioned above but also leads to higher trade in quota for those groups – trading, like catch, remaining fairly constant through the simulation.

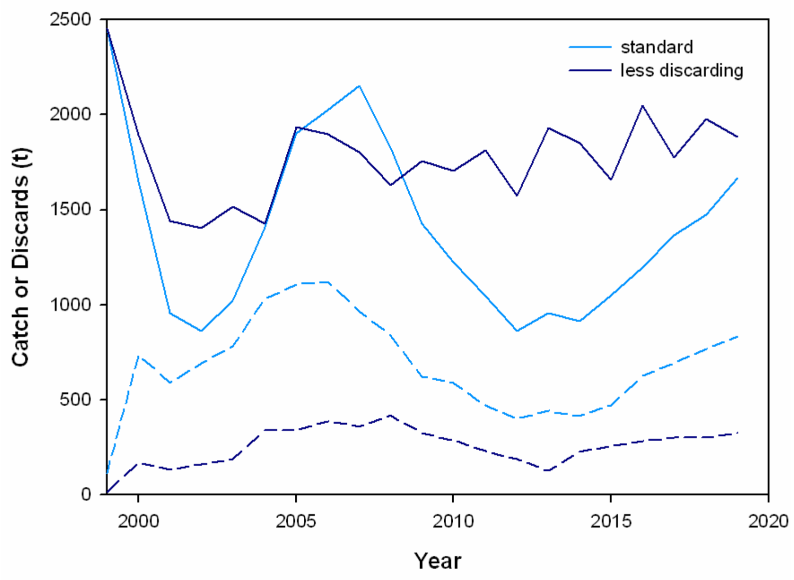


Figure 4-1: Catch and discard of tiger flathead in standard Scenario 4 and with lower discarding rates for trawl fisheries (dashed lines are discards, solid lines are landings).

4.6.3 Cheaper (or negligible) switching costs

The results of these scenarios are discussed at length under gear switching in section 5.3.3.

4.6.4 Buybacks

The introduction of a buyback after 3-5 simulated years in Scenarios 4 and 10 resulted in a healthier fishery than was seen in the scenarios presented above. Without a buyback at least some of the boats in some of the sectors would pulse fish, where boats fish intensively for a few years (or part of the year) and then tie up and don't fish for months (doing this in preference to making a more constant and permanent effort shift). This behaviour was much less common with a buyback, as boats that opted to pulse fish (who often ended up leaving the fishery in the long run) left the fishery more quickly by taking part in the buyback. This resulted in smoother effort profiles after the buyback (and fleet reduction) and lower overall effort levels in total (by 25%). Although, for a small number of sectors (smaller gillnet and longline vessels) effort actually increased marginally (by 5-11%) due to reduced competition between individual boats and subfleets. The buyback also leads to slightly different effort structure, with a few more of the smaller boats remaining while about as many medium sized boats depart. The shift in effort also sees an associated shift in catches – they are lower, but more constant and based on healthier stocks. For instance, when a buyback is introduced into Scenario 10 the tiger flathead landed catch does not climb above 3400 t, nor does it dip and climb through time, but plateaus at about 2600 - 3100t (Figure 4.2).

Looking beyond catch and effort, management stability is also higher after the buyback. Surprisingly, given the slight drop in landed catches, trading was actually slightly higher after a buyback, as the more consistent catches see fishers trying to cover byproduct groups.

The long term persistence of the benefits from a buyback is mixed and is dependent on the state of the system when the buyback is carried out. There appears to be a window of “maximum buyback potential” – if a buyback is presented when the fishery is not in a particularly poor state then there is either not a lot of uptake (so ultimately little different to no-buyback) or little actual impact on an already moderate-good system state (if a buyback is forced). At the other extreme if a buyback is left until the system state is poor (with degraded stock status and substantial losses being sustained by many sectors) also leads to only minor and short-lived differences in system state compared to the case with no-buyback (the damage had already been done, so to speak). There is a period however, when the system state has a number of commercially valuable groups near limit reference points and profit levels are such that there is

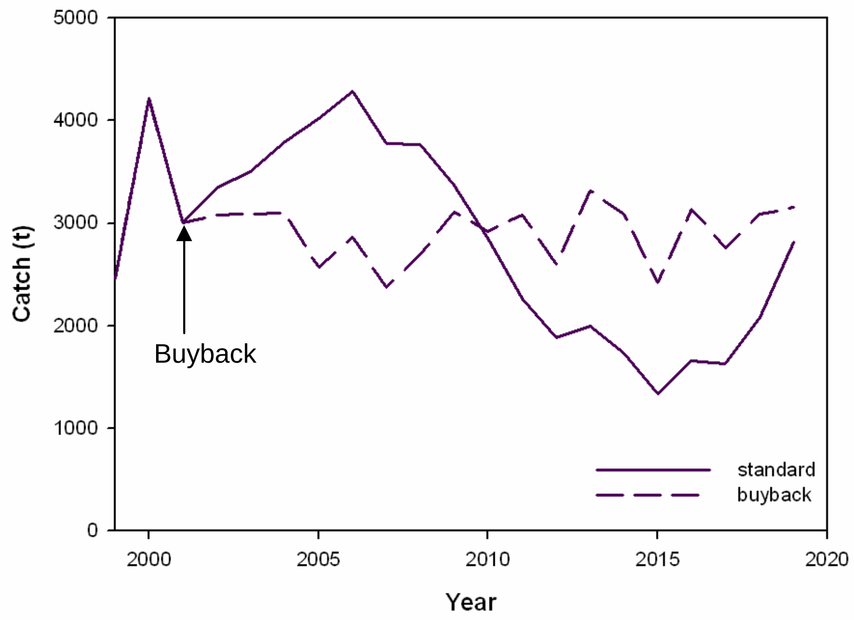


Figure 4-2: Landed catch of tiger flathead in the standard Scenario 10 and when a buyback occurs after 3 years.

pressure on vessels to increase their fishing power and expand their footprint to try and regain CPUE rates that a buyback not only helps ease removal of effort but can lead to a better system state into the medium term. Unfortunately, even when the timing is at its most beneficial it may be hard to detect if trying to measure it from within the system (as would be the case in reality).

If the buyback was mistimed then any benefits dissipated quickly, within just a few years. If the timing fell within the optimal window however, then the magnitude of many of the performance measures differed from the case when there was no buyback. Despite this difference, the pattern of change across the majority of performance measures was still similar to that when vessels left only through economic hardship (putting side the very short term difference generated via different effort reduction profiles). This persistence of the general form of the pattern meant that operators within the system perceived the benefits of the buyback dissipating under new pressures within 5-10 years of the event. Observing from outside the system however (by comparing runs with and without buybacks), showed that some effects were longer lived: effort by the main fleets (but not the small fishery sectors) was lower for longer (mainly due to more smaller boats remaining in the fishery), but did ultimately rise (over a couple of decades) to about the same levels as seen without a buyback; landings for some (but not all) of the target species remained relatively stable for at least 15 years; and economic health and social perception were higher (public perception more so than economic health of the fleets) for about the same period, if a buyback was used to reduce fleet size.

4.6.5 Scenario 3 Without Spatial Management

Scenario 3 is the most sensitive to alternative specifications of strategy components. In addition to the implications of lower discarding rates discussed above, the removal of spatial management also has a big impact on the performance of this Scenario. When spatial management is not in play, and discarding does not change through time, the following changes in dynamics arise:

i) Effort levels can be as high (or higher) than for Scenario 1; longline effort in particular is much higher (by 70%) in this case (as the fleets exert more pressure on the system in an attempt to maximise returns in a continuously degrading system).

ii) Landings and discards (but not CPUE) can be as high as for Scenario 1 for squid and sharks, but are a little lower for demersals, especially deep water species; the fisheries essentially make an end run around the quota management system by expanding into extra groups which are too resilient (or not exploited quite enough) to trigger the “add new species to quota system” lever or have TACs that are unconstraining for the amount of catch the fisheries wish to extract. By fishing these extra groups the fisheries subsidise the fishing of target groups and so pressure on those groups does not fall, extra is simply discarded once quotas are fished, rather than fishing tailing off once quotas are met.

iii) Relative biomass of the most heavily fished groups is pushed as low (or lower for sharks and pelagics) as for Scenario 1, other groups that see less fishing or multispecies pressure do better, ending up intermediate between the biomasses under Scenarios 1 and 4.

iv) There is a higher prevalence of boats pulse fishing (alternating between intensive fishing pressure and months tied up in port), this is associated with a shift of effort through the year too (making effort flatter through the year rather than peaked mid year as it is under standard Scenario 3).

v) While absolute GVP is higher in this variant (as more catch in total is landed), profits are ultimately lower, due to higher costs associated with high levels of effort and catch to be unloaded, packaged and freighted to market (see the description of unloading costs in Appendix B).

vi) Higher levels of catch and effort see higher levels of trading as boats attempt to cover byproduct groups before switching to alternative non-quota groups.

The boats do not preferentially seek the secondary groups, they still prefer the main target groups. Nevertheless they do see the other groups as a subsidy (and less constraining supporting flow) that allows them to keep pressure on their primary targets high and unrelenting. While groups that have any value and are not under a constraining quota exist this tactic remains in the fishery for at least some percentage of the boats. Continual expansion of the list of quota species also leads to steep increases in management costs, but this is not enough of a disincentive to end the practice. The potential prevalence of this behaviour may be over stated here due to the simple form of the socio-economic decision model. Nevertheless exactly this dynamic and problem has been witnessed in fisheries in the northern hemisphere (MAFMC and NEFMC 2001; Hilborn *et al* 2003; Berkes *et al* 2006).

4.6.6 Scenario 4 – Modified Shark Fishery

The biomass of gummy and school shark were more stable under this alternative variant than the standard form of Scenario 4, or in fact any of the Scenarios (Figure 4.3). This is primarily because the predicted catch time series (Figure 4.4) is much flatter and more stable. This was driven primarily by the lower initial TAC, which more quickly became constraining and more closely matched the real (observed) TAC levels. The gillnet contribution to the total catch does still fall away a little (though not as steeply as in the standard variant of the case) with trawl and shark longline picking up the difference. The comparison also shows that the auto longline dynamics in the standard form of the Scenario did contribute to the predicted decline in gummy shark biomass under that form of the Scenario. However, the trawl and shark longline contributions rise in both forms of the Scenario and the level of the TAC is far more important in dictating the final form of the predicted catch and effort time series.

The stable gummy and school shark biomasses and catches also lead to more stable effort levels in the medium term and a smaller contraction in total effort (e.g. gillnet effort in Figure 4.5); there is also a smaller reduction in the number of boats in the fleets targeting gummy shark (the number of boats in these fleets leaving the fishery dropping by half). The indirect effects of these changes do have implications for other groups. For instance, the relative biomass of flathead is also more stable as the sharks remain a viable alternative target. Nevertheless, the general form of the results, the conclusions that can be drawn from those results and the qualitative ranking of the performance of the Scenarios remains unchanged. The specific details regarding the shark fisheries may benefit from more focused attention in future work (building on lessons learnt from this variant), but the general lessons provided by the broader quantitative Scenario comparison presented here are still quite informative.

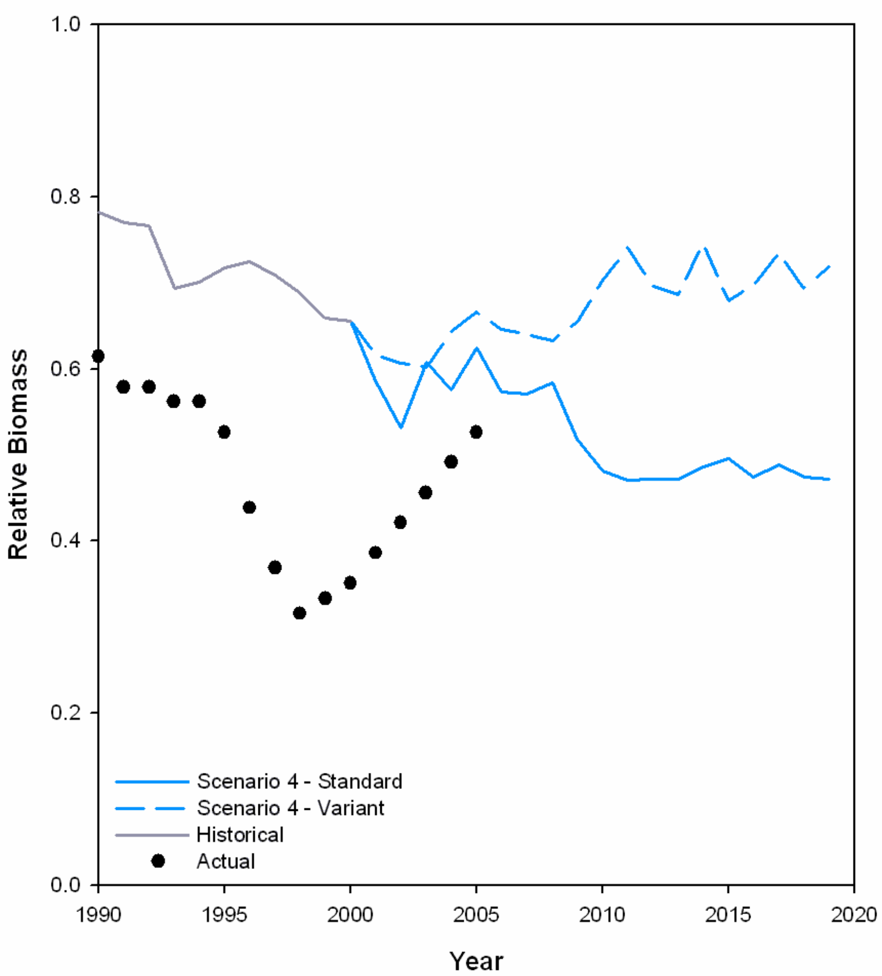


Figure 4-3: Relative biomass of gummy shark under the standard form of Scenario 4 and the variant with a modified shark fishery representation.

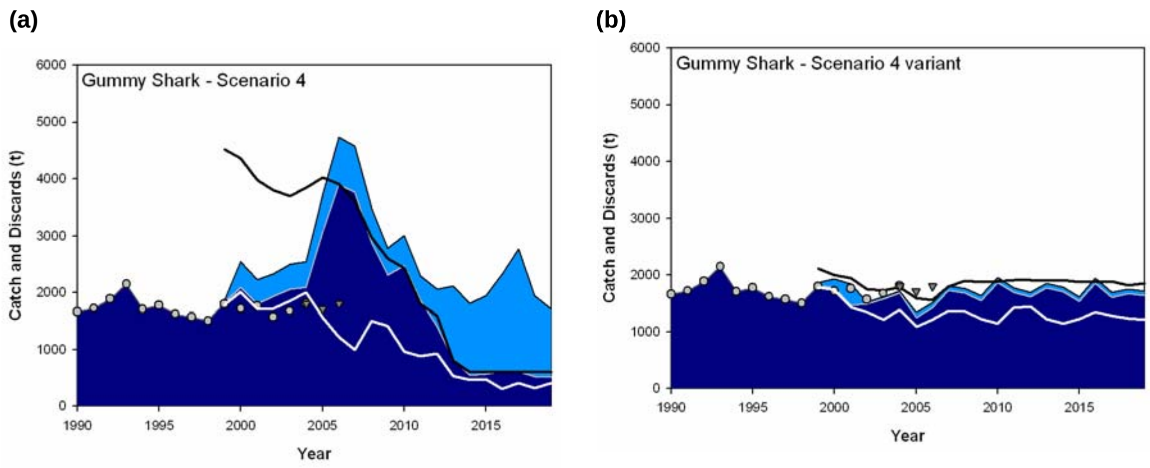


Figure 4-4: Catch, discard and quota time series predicted under (a) the standard form of Scenario 4 and (b) the variant with a modified shark fishery representation.

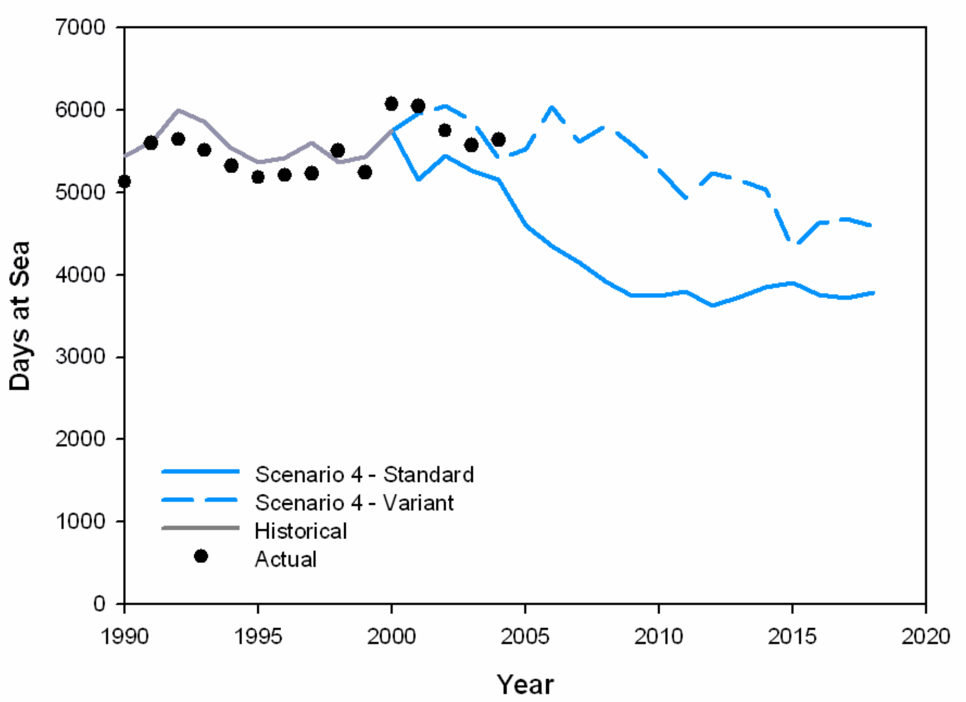


Figure 4-5: Gillnet effort time series predicted under the standard form of Scenario 4 and the variant with a modified shark fishery representation.

4.6.7 Scenario 10 – Integrated Management

With integrated management (where spatial management and TAC reductions are traded off) TACs can stay higher longer. Initially this allows for noticeably higher catches of sharks (e.g. gummy and school sharks), but ends up at lower landed catch levels (by 5-15%) in the long run. For most other groups marginally higher catches are seen in some years, but more than anything the difference is with regard to lower overcatches (when landed catch exceeds the TAC). This marginal change can be seen in the relative biomasses, which are not substantially different except for the relative shark biomasses that are 5-20% lower. Given that TACs do remain higher without significant drops in relative biomass for all but the most vulnerable groups (the sharks) this suggests that the spatial management is compensating to some degree. However, the impact on sharks shows it is not sufficient for all, especially groups that are both mobile but with slow population growth rates.

4.6.8 Scenario 10 – Companion TACs

With strong-link companion TACs in place more effort is seen in the GABT, by as much as 4x (in part due to a relaxation of constraining byproduct or companion TACs). Associated with this are some increases in landed catches, but as effort increases are not across the board the overall increase in total landed catch is not as great as the increase in GABT effort. Landings are higher for the stronger of the groups in the companion TACs (by as much as 30%), but catches for the weaker group slowly decline as the group cannot withstand the extra pressure. Stocks of both weaker and stronger components are pushed lower in this case, by 20% or more, and the weaker group can be effectively locally extirpated. The other notable change under a scenario with strong-link companion TACs is that trading increases, as boats shift around quota for the TAC companions, but also byproduct species taken with them.

When weak-link companion TACs are used as part of the quota management system the success of the approach is often limited. A number of deeper water and upper slope groups (dories and oreos, orange roughy, deepwater dogfish, gemfish and redfish) do not constrain each other's catches even with TACs set based on weaker companions. When landings are constrained overcatch often undermines the impact of the weak link (as the weak-link TAC is exceeded and so it is effectively less constraining). This is sporadically true for ling and spotted warehou too. In cases where the weaker companion is much more constraining catches of the stronger can be reduced substantially – by as much as 50% for some of the more popular targets like tiger flathead. This not only sees a sharp increase in the number of trades per year for the stronger companion species, but also seriously impacts economic viability, with 10% more boats leaving the fishery and profits dropping to marginal levels in many years. Ecologically many species benefit from this, with relative biomass of the stronger companions growing through time (e.g. flathead in Figure 4.6), but as is the case in Scenario 9, the fishery cannot make good on this due to the continually constraining nature of the companion quota system. Interestingly, ling does not show the benefits of a reduction in pressure, dipping 5-10% lower due to multispecies interactions. Similarly, the weaker companions may also drop further (by 10% or more) due to multispecies interactions in combination with being fully exploited. This problem is only exacerbated if the ratio of quotas is not updated through time as the system shifts, but held constant at historical levels. The impacts on groups not directly involved in companion TACs are mixed, but not as strong as those directly involved. These mixed ecological implications of weak companion quotas mean that even into the long term there are economic penalties associated with weak link companion TACs (due to the constraints placed on absolute catches), though the profit margins do improve some what into the long term.

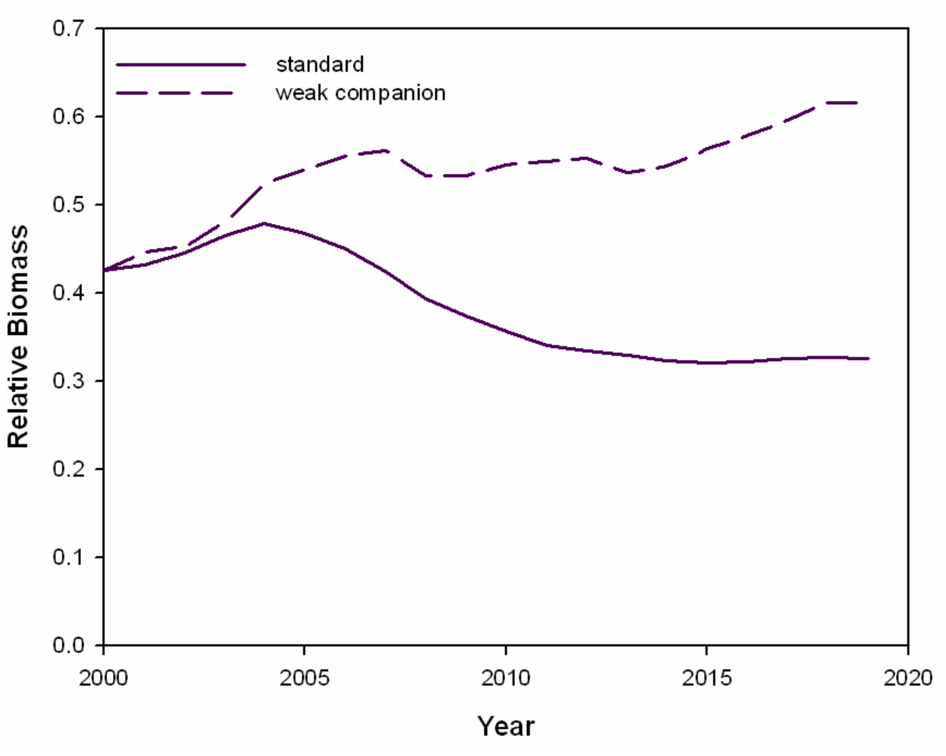


Figure 4-6: Alternative relative biomass levels for tiger flathead under the standard Scenario 10 and the scenario with weak-link companion TACs in place.

4.6.9 Scenario 10 – Gulper shark Closures

The implementation of closures to protect gulper sharks does see a reduction in effort (by as much as 25%) for the longline and deep water trawl sectors. The discards of gulper sharks are reduced by 50-75%. The catch of groups that co-occur with gulper sharks or live in the closed areas – cardinalfish, ribaldo, blue grenadier, dories and oreos and deepwater dogfish – and are normally taken by those sectors that have reduced effort are also reduced by 5-25%. Interestingly the catch of ling does not drop off. The relative biomass of these groups is higher as a result of the reduced pressure, but other species that are linked to them trophically drop by as much as 5% due to multispecies interactions. The altered catch mix caused by displacing at least some of the effort from the closed areas into new locations sees higher trading rates, as the subfleets trade to better match their new species mix.

5. COMPARATIVE MSE RESULTS

These results will focus on the comparison of the five main scenarios outlined above (Scenarios 1, 3, 4, 9 and 10). Detailed results of the variants of these scenarios, and the results under the full range of the bounding parameterisations, will not be presented unless these differ significantly from the results of the basic form of the Scenario using the "best fit" parameterisation. Typically the alternative parameterisations lead to the same overall pattern of relative performance for the various scenarios (see Figure 5.1 for an example). That is, even though trajectories for the strategies under alternative parameterisations may cross (e.g. highest line for days at sea under scenario 3 is greater than the lowest line for scenario 1 in Figure 5.1c) under any one parameterisation the ranking of the trajectories for the different strategies remain the same as presented in the basic results detailed in the following sections. Variant scenarios were more likely to give rise to differing results (a discussion of uncertainty associated with the analysis and its implications for conclusions drawn from this work is given in chapter 6). It is also important to remember throughout this comparison that the alternative management strategies used in each scenario were run from the 1st of January 2000, actual historical action taken after that date was NOT included – this means that all the scenarios have the potential to diverge from each other (and real world events) from the 1st of January 2000.

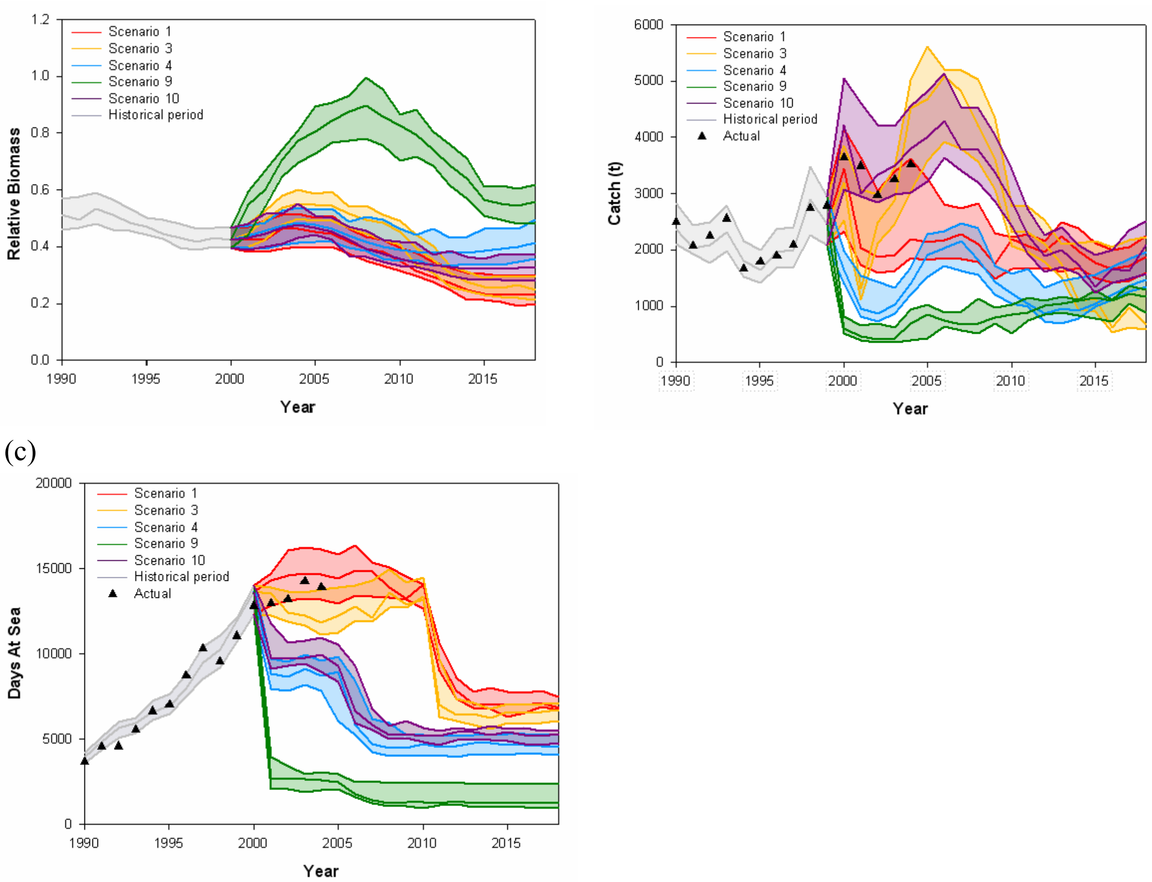


Figure 5-1: Examples of trajectories under alternative parameterisations (a) relative tiger flathead biomass, (b) tiger flathead catch, (c) trawl effort. Lines representing the standard results and upper and lower bounds of the results under alternative parameterisations are given for each scenario, with the area between the bounds shaded.

When using the Management Strategy Evaluation approach, the comparisons of performance measures across scenarios are often performed at the end of the projection (simulated) period. However, in cases where relative performance between scenarios differs over time, consideration of the transient dynamics is also useful. Consequently, the overall aggregate performance measure kite diagrams are shown here at two, ten and twenty-one years into the simulation (Figure 5.2); the year and scenario of the maximum value of each performance measure are also given in Table 5.1. The definition of performance measures used throughout this chapter are detailed in section 2.7. As a reminder, the measures used to calculate the integrated performance measures used in the overall kite diagrams (Figure 5.2) are:

- Industry (non-economic facets of the industry reflecting work load and fishing pressure): Overall discards (inverted[19]), habitat-Impact (inverted), total effort (inverted), CPUE, total landed catch, average size of the catch and catch composition;
- Management (or more correctly, perception of management by fisheries operators): Access, stability and trading;
- Management costs: Overall management costs (inverted), research costs (inverted), compliance costs (inverted), monitoring and assessment costs (inverted);
- Social: Public image, gear conflict (inverted), port activity;
- Economics: Gross Value of landed catch, revenue per tonne, revenue per effort, costs (inverted), profits;
- Ecology: Biomass of bycatch and target species, habitat cover, pelagic:demersal biomass ratio (inverted), piscivore:planktivore biomass ratio, change in BSS-slope (inverted), biomass of TEP groups, microfauna biomass (inverted), shark and skate and ray biomass.

For measures calculated from gear specific information the aggregate values are averaged over all gears. The final values of each of the performance measures are then normalised over all scenarios and all years so that the best performance of a performance measure is assigned a value of 1 and all other values scaled accordingly.

All scenarios have a similar ecological state through the early years (reflecting past impacts) then diverge quickly leading to a diverse range of values for economic, social and management measures. Moreover the differences increase with time (including differences in the ecological state). Scenario 1 appears to be performing reasonably well with regard to management access, stability and costs by 2020. This actually reflects the unconstraining nature of low costs and no action, meaning that the measures as defined return relatively high values for what is in actuality a poor and ineffective management scheme. It is exceptionally difficult to define a performance measure that differentiates between access and stability that is generated by sound management and that resulting from no management (though future work focused on decoupling them would be beneficial). This is a problem faced in many fields where simple measures are used to try and convey the nuances of complex situations. However, rather than moving to more complex analyses and less transparent performance measures, it is probably still better to retain the transparency of simple measures and simply identify when they breakdown, as is the case here. This kind of problem is why the monitoring of complex systems, like ecosystems, is unlikely to ever be fully automated and free of a human interpreter.

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[19] As defined in section 2.7, the use of inverted here means that $^1/_{value}$ of the performance measure is included in the aggregate measure (because it was important that all measures have high values if in a desirable state and low if in a poor state); thus for any performance measure that gave a high value when in a poor state then $^1/_{value}$ was used.

The poor outcomes of Scenario 1 are more clearly seen in the poor performance of the other performance measures (social, economic, ecological and industry) – which are the worst or amongst the worst of any scenario. In particular, the relative performance measure for the industry is less than half of that under any other scenario. This highlights another key feature of performance measures and indicators for complex systems; suites of measures (or indicators) are critical for providing a full picture of the system and avoiding incorrect conclusions due to misleading or contradictory results from one or two overly aggregated measures.

Moving on to consider the other scenarios, Scenario 3 out-performs Scenario 1 ecologically, socially and for the industry performance measures. Economically it has similar outcomes to Scenario 1, as relatively high effort levels (detailed above and in later sections) see costs remain high. More importantly management costs are high for this Scenario with management constantly changing (as TACs change more often in this Scenario than any of the others), leading to poor performance. The management costs and stability are much better under Scenario 9, as is the ecological state and industry's returns per unit effort. However, all this comes at the cost of such low levels of total effort that the industry cannot cover total absolute costs and is all but bankrupted by 2010. Initially the high revenue per tonne and low costs gives a relatively high economic performance result, but by the midpoint of the simulation the almost complete lack of profits is telling. The timing of the snapshots also affects the overall picture of performance. For instance, if the snapshot were taken in the year of a buyback then management costs blow out enormously (as is the case in the variants of Scenarios 4 and 10 which included a buyback, as subsidies were not included in the specification of the buyback).

In contrast, Scenario 4 is fairly even in its performance across all the integrated measures, both initially and throughout the simulation. It does not always return the highest performance against a performance measure, but equally it is never the worst; neither is it particularly lopsided, succeeding in one area at the costs of penalties in another area. Scenario 10 also ends up being fairly balanced in its performance against the various integrated measures, though this is something it only achieves in time – starting off with poor management stability and economic performance, but with good ecological performance and moderate social and management cost performance. This Scenario's slightly weaker economic and industry performance is a result of higher running costs and lower realised value of the landed catch as a result of having to land all target species caught, rather than being able to high grade and thus optimise the landings of these (as in the other scenarios).

To avoid the potential for "false impressions" that overall measures may convey, a more detailed consideration of the individual performance measures is presented in the following sections. Due to the enormous amount of output generated in the analyses the following sections present the overall result as well as the individual results for specific sectors (SEF and GAB trawl and the GHAT) and species groups (tiger and deepwater flathead, blue-eye trevalla, orange roughy, blue grenadier, ling, gummy shark). In addition, any out-lying result (i.e. one that is substantially different to the picture drawn based on the performance of other groups or sectors) is presented.

Scenario **2001** **2009** **2020**

Scenario 1

Scenario 3

Scenario 4

Scenario 9

Scenario 10

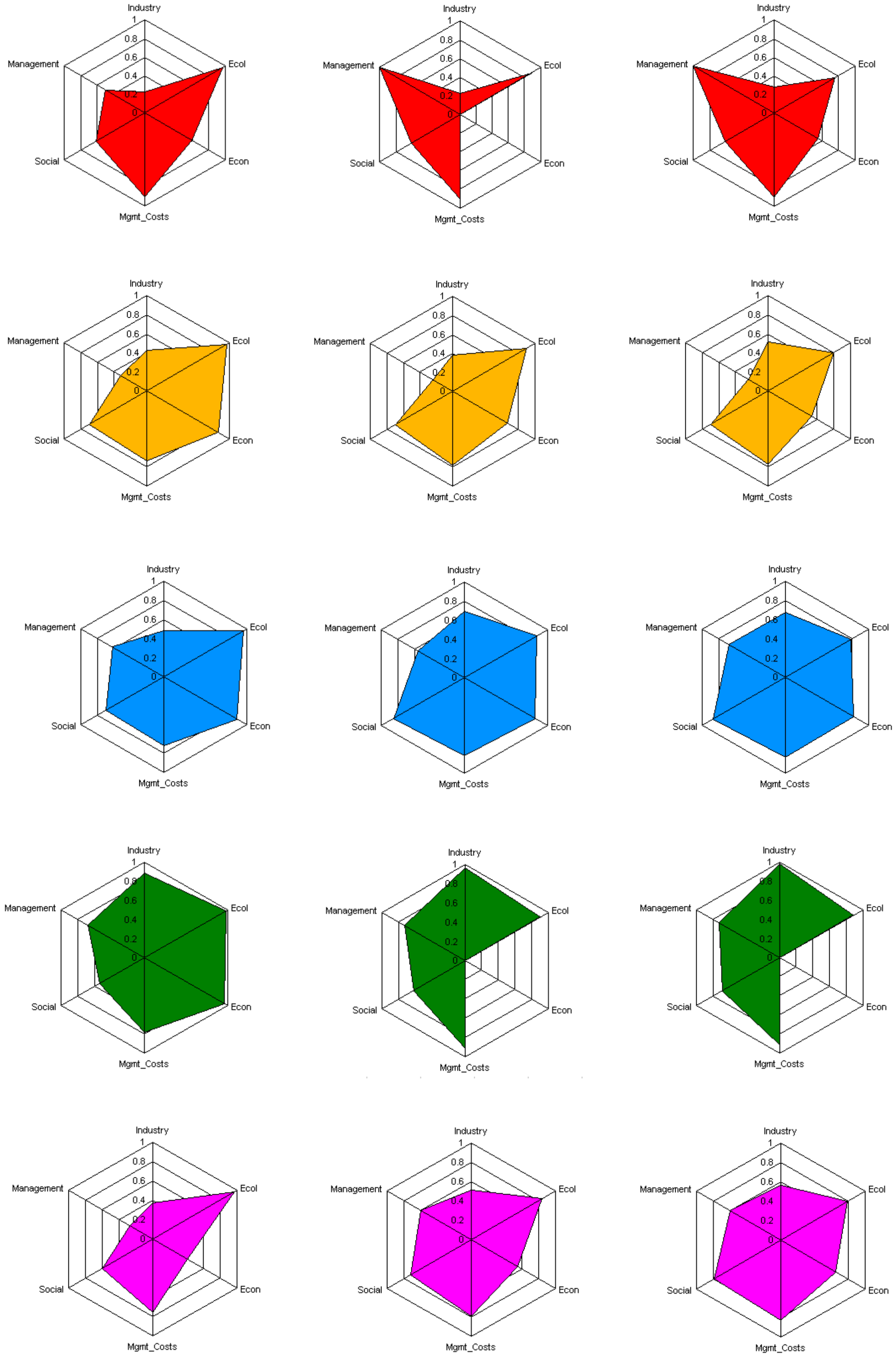


Figure 5-2: The overall performance of the five main scenarios vs the integrated performance measures. Measures have all be converted to relative measures with 1.0 = good and 0.0 = poor performance.

Table 5-1: Peak year and scenario for each of the integrated performance measures.

Performance Measure	Scenario	Year of maximum value
Industry	9	2013
Ecology	9	2000
Economics	3	2000
Management Costs	All	2000+ (all years for scenario 1)
Social	3 and 4	2000
Management	1	2019

5.1 Industry Performance Measures

Considering the kite diagrams that show the industry performance measure out across its constituent topical performance measures (Figure 5.3, Table 5.2), it becomes clear why some scenarios perform better (or worse) than others. For these kites (and all subsequent ones) the definitions used are slightly different to those used for the overall kites above (see section 2.7.1 for details). In this case instead of inverting performance measures whose value rise in undesirable conditions, the proportional value was subtracted from 1. This means a high value (close to 1) still indicates a good performance, but a value of 1 was not obtained by any scenario at any point. This approach gives a clearer indication of individual performance vs the objectives.

The strong performance of Scenario 9 with regard to average size of the catch, catch composition, discard rates and habitat interactions outweighs the moderate to poor results for total landed catch, effort and the variable performance for CPUE. In reality industry members may weight these different aspects differentially and would probably place a larger penalty on the poor performance of the Scenario in the areas of yield and CPUE than is the case here. In contrast, the relatively constant and reasonably good performance of Scenario 1 in catch composition cannot counteract its relatively poor results in all other aspects (which is as poor, or poorer, than any other scenario). The results are more mixed for the other three scenarios, the banning of discards of target species distinguishes the Scenario 10 from Scenario 3, which performs fairly poorly when discards are used as the performance measure. The discard result does not see too much difference between Scenario 10 and Scenario 4, but there is a greater difference between these scenarios when CPUE is considered. Scenario 10 has a higher CPUE than both Scenarios 3 and 4 (as it is based on landed catch and with discards banned landings are naturally much higher), but this comes at the cost of slightly poorer performance with regard to habitat interactions (as restrictions see fishers try areas they had left relatively untouched previously, particularly in the GAB – see the discussion below).

Table 5-2: Peak year and scenario for each of the industry performance measures.

Performance Measure	Scenario	Year of maximum value
Discards	10	2012
Habitat Interactions	9	2013
Total Effort	9	2019
Catch Per Unit Effort	9	2014
Total Landed catch	All	2000
Average Size of the Catch	9	2014
Catch Composition	10	2003

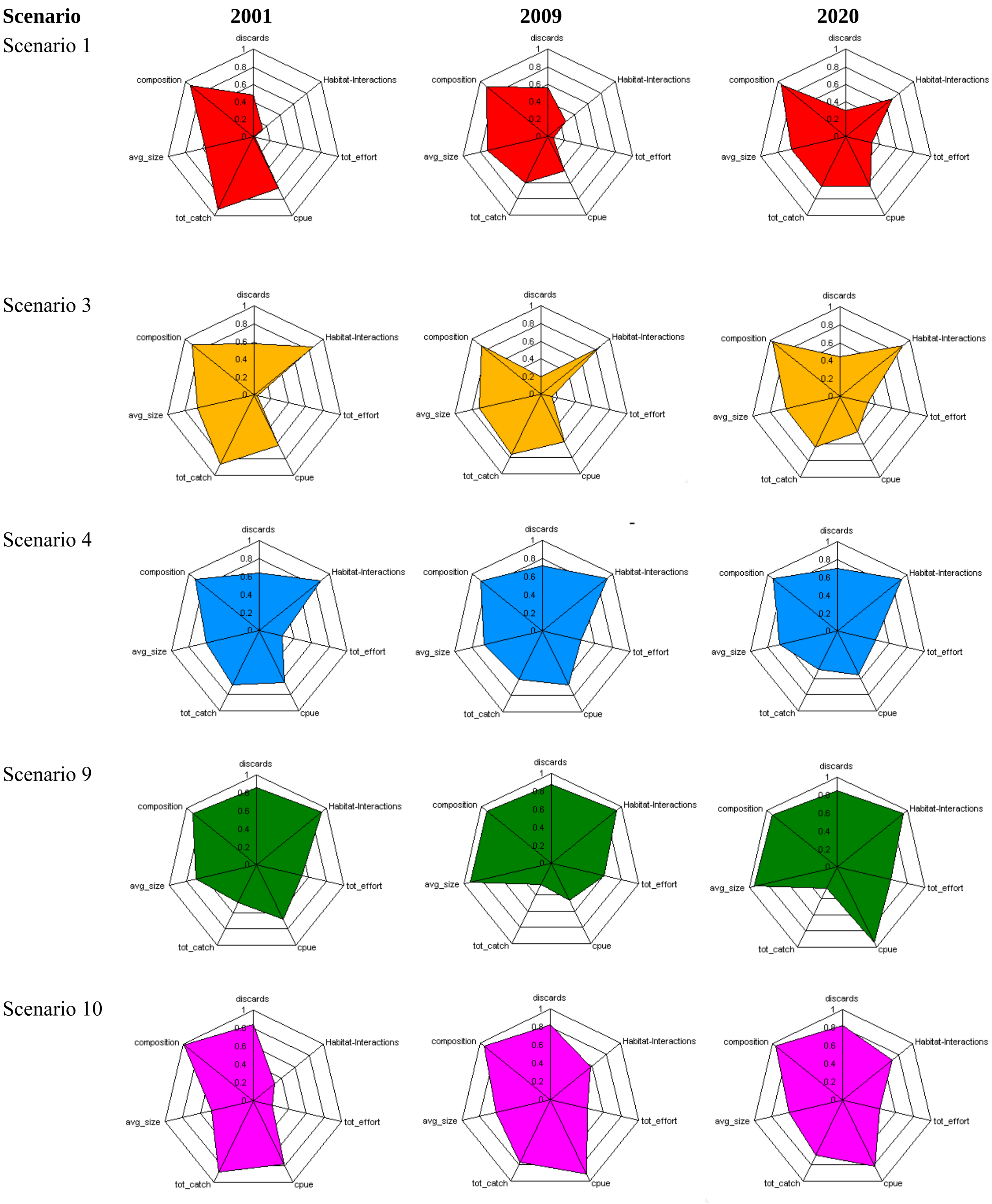


Figure 5-3: The overall performance of the five main scenarios for the integrated industry performance measures. Measures have all be converted to relative measures with 1.0 = good and 0.0 = poor performance.

5.1.1 Landed catch

The overall landed catch (Figure 5.4) has been declining for the last fifteen years and continues on that trajectory for a further five years, before jumping back to 2002 levels around 2010 and then slowly declining again to stabilise at just over 40,000 t in Scenario 1 and 43,000 t in Scenario 3. Scenario 4 declines more quickly, but stabilises sooner at just over 30,000t. Scenario 9 also declines steeply and stabilises fairly rapidly, but at only about 16,500 t. Scenario 10 predicts a more mixed trajectory for overall landed catch – declining with Scenarios 1 and 3, the trajectories climbs to a peak of 57,493 t in 2007 before declining again to stabilise at about 45,000 t.

Looking at the breakdown of the total landed catches at the level of the southeast trawl (SET), Great Australian Bight trawl (GABT) and the gillnet, hook and trap (GHAT) sectors during the historical period (1990-2000) gives insight into the model's general performance versus reality in this area (how well it captures the real world dynamics). For the trawl sectors (Figures 5.4 and 5.5) the model shows a clear tendency to underestimate the overall total landed catches (by 5-15%) during the final part of the period, while it tends to overestimate the GHAT sector's landings (Figure 5.7) by about the same margin. Therefore in the projections (2000 onwards) in each scenario the pattern of trajectories is likely to be correct even if the magnitude is slightly in error.

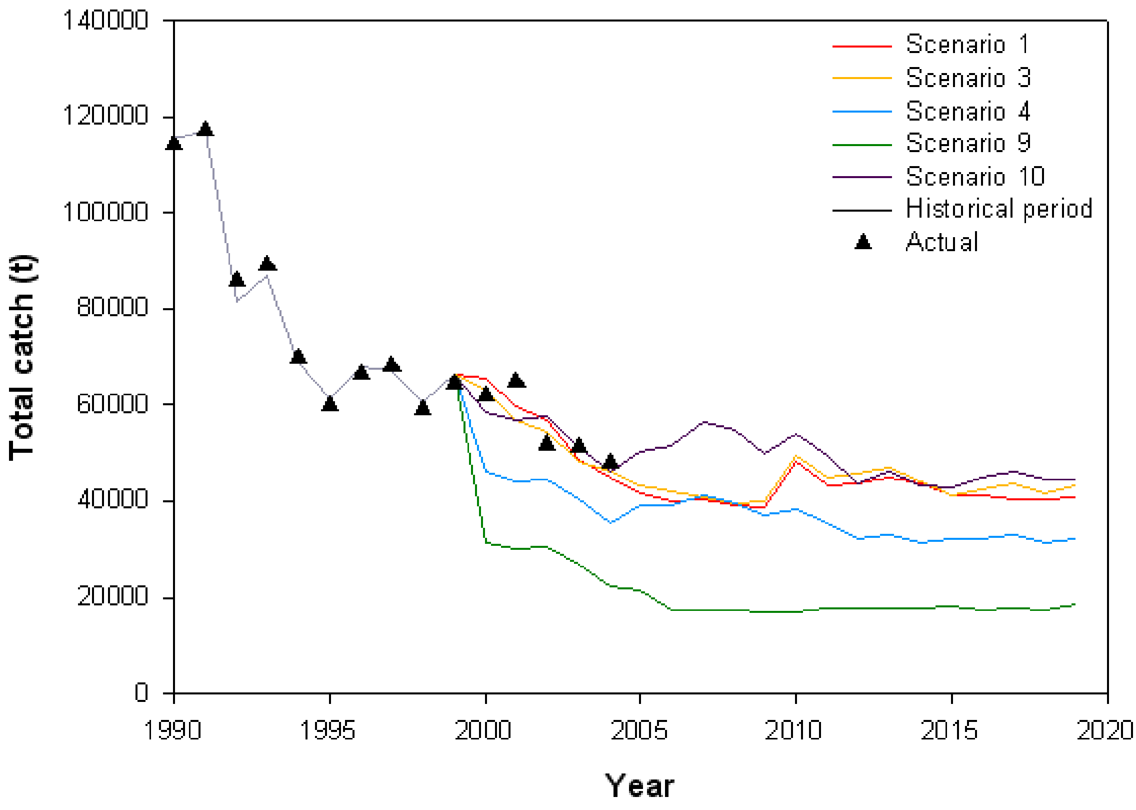


Figure 5-4: Overall landed catch (t) across all fisheries (including static state fisheries) for each management strategy scenario.

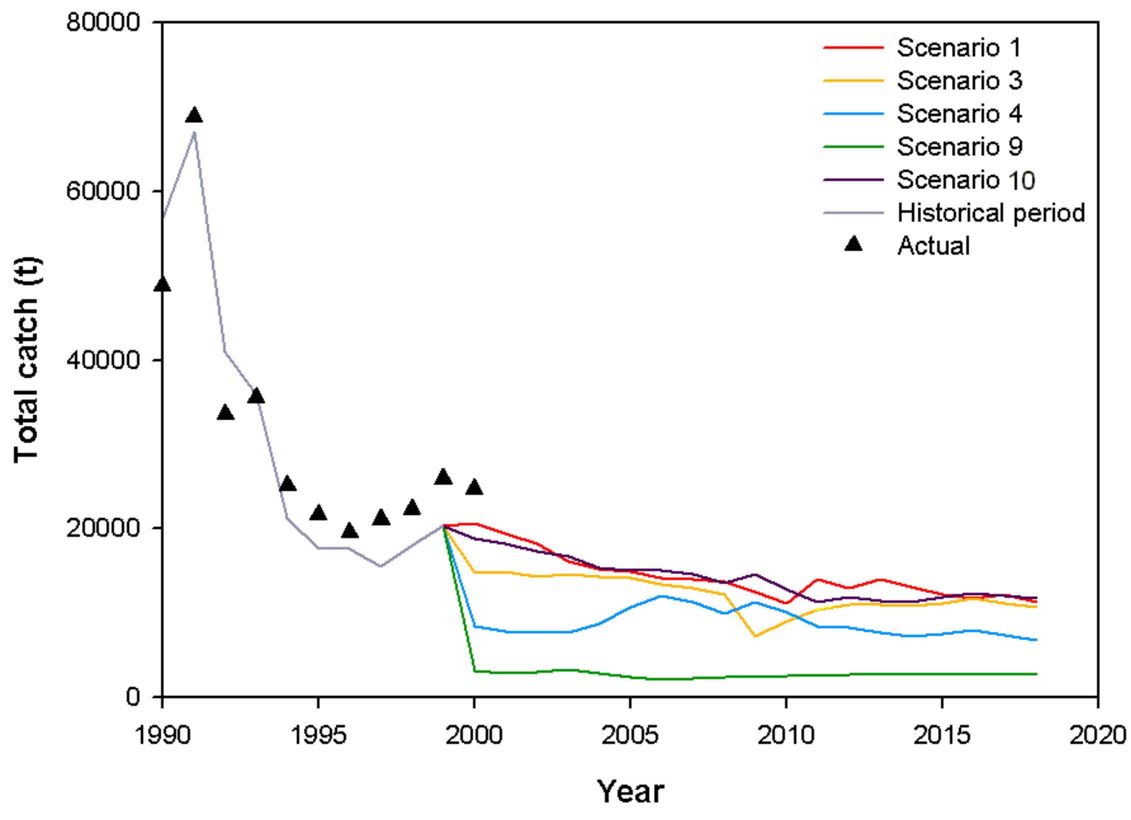


Figure 5-5: Overall landed catch (t) for the Southeast trawl (SET) sector for each management strategy scenario.

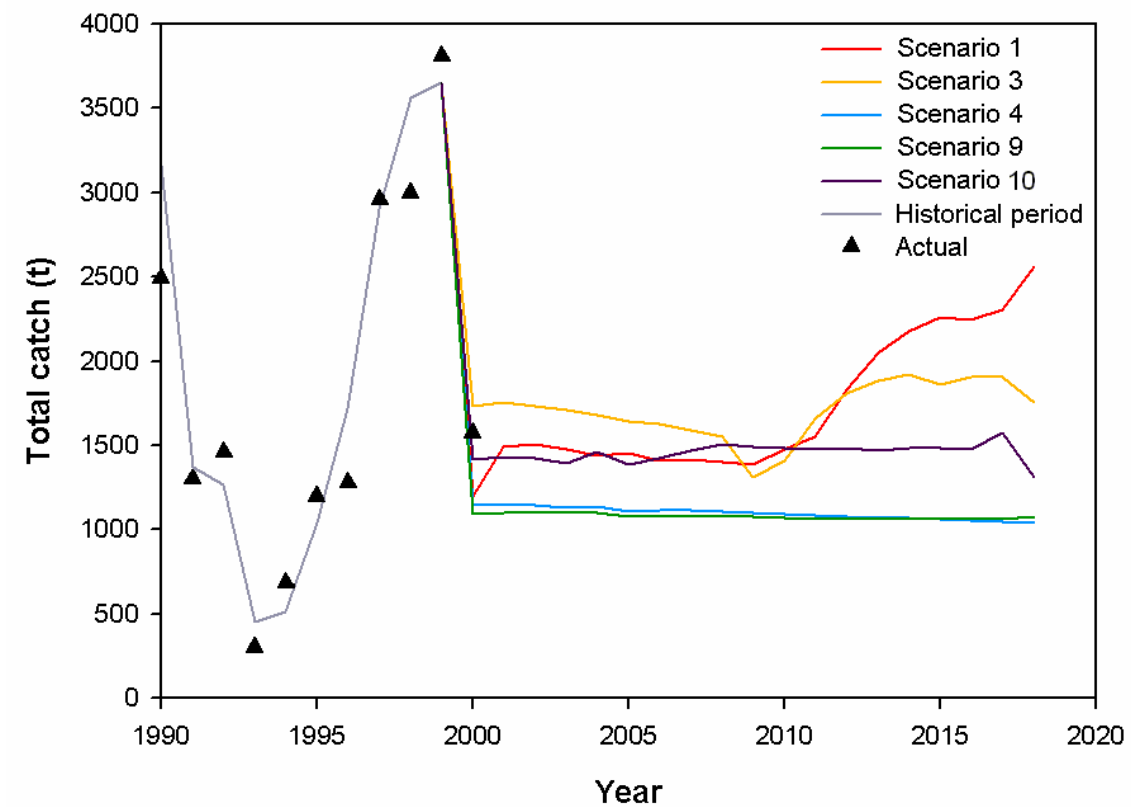
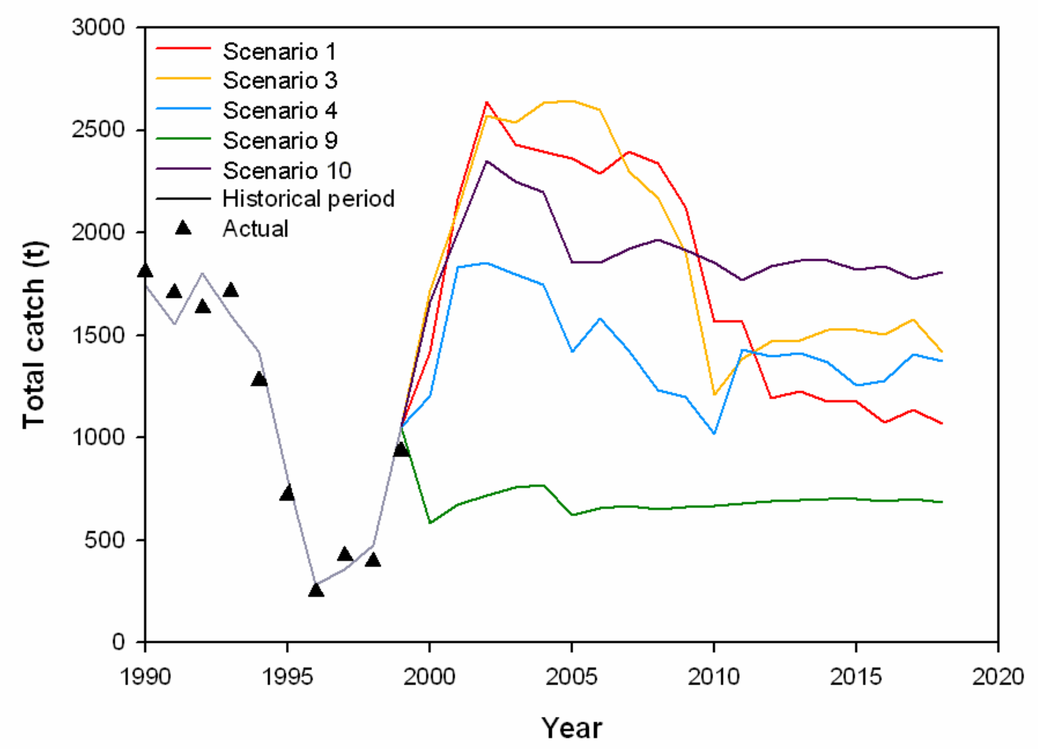


Figure 5-6: Overall landed catch (t) for the Great Australian Bight trawl (GABT) sector for each management strategy scenario.

a)



(b)

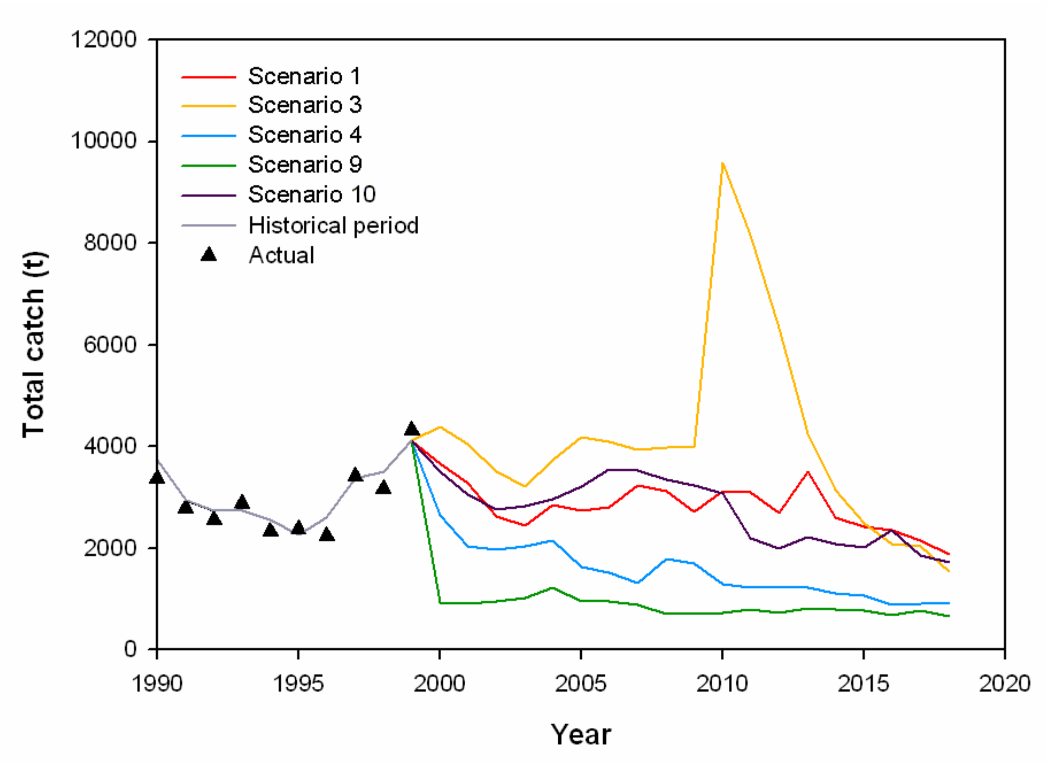


Figure 5-7: Overall landed catch (t) for each management strategy scenario for the main components of the Gillnet, Hook and Trap (GHAT) sector: (a) longline and (b) gillnets.

Overall landed catches in the SET (Figure 5.5) in Scenarios 1, 3 and 10 decline steadily (though Scenario 3 shows more variability, dipping before rising again to its long term endpoint) from the 2000 levels, until they stabilise after 2015 at around 11,000 t. Scenario 4 shows the same general pattern – the catch dropping with the introduction of the new strategy (to roughly half the levels in Scenarios 1, 3, and 10), before climbing slightly as the fleet sizes restructure and then dropping back again, this time the long term landed catch fluctuating between roughly 7000 and 8000 t. Scenario 9 also shows an immediate drop when the management strategy is introduced, but to a much lower level of 3121 t, which it does not rise above during the remainder of the simulation.

In the GABT (Figure 5.6) Scenarios 4 and 9 predict a fairly constant total landed catch of a little over a 1000 t throughout the course of the simulation. This equates to 70% of the landings predicted in the early years for Scenario 3, and 80% of that for the other two Scenarios. While the trajectory of GABT landed catches in Scenario 4 and 9 remain fairly steady, under Scenario 1 there are increasing catches, particularly after 2010, when other sectors have seen a drop in fleet size (which the GABT does not). Scenario 10 also predicts an increase in landed catches after 2005, though it is a modest increase at 10%. Scenario 3 shows a more interesting trajectory in total landed catch. It falls slowly until 2008, when there is a steep dip, before it begins climbing again to end at 1758 t (27t more than it predicted for 2000 and intermediate between the end points for Scenarios 1 and 10).

The total landed catch in the GHAT showed a much wider divergence in the predicted trajectories (Figure 5.7). Scenarios 1 and 10 show a fairly steady decline in gillnet catches to roughly 1800t per annum, while the longline catches increase sharply in the first few years of the projection period before falling away through time to end at around 1800t in Scenario 10 and about 1000t in Scenario 1. The catches under Scenario 1 continue to decline into the long-term, while the catches in Scenario 10 stabilise during the projection period. At the level of the whole of the GHAT, Scenario 4 maintains stable landings at about 2000 levels for 4 years before beginning to decline. This apparent stability hides the fact different component contributions change almost immediately, the contribution by gillnets beginning to drop away almost immediately (eventually stabilising at about 900t), while the longline catches initially grow before also declining to about 1200t per year in 2008 before rising again to stabilise at about 1350t per year. As was the case for the overall and SET total catches, the trajectory of the GHAT gillnet catches under Scenario 9 sees an immediate drop to relatively low levels (compared to historical take) with only small rises above that level at any point in the projection. In contrast, the longline GHAT longline catches drop by less than 50% and remain relatively stable throughout the projection period. Nevertheless, considering the GHAT catches as a whole, the drop in gillnet catches means overall the landings for the GHAT sector shows the same general pattern as the trawl sectors. The most variable total catch trajectory for the GHAT is under Scenario 3. Under this management strategy catches jump almost immediately to around 6000t in total (gillnet and longline combined). Then in 2010 longline catches fall and gillnet catches rise dramatically (to almost 9600t). The longline catches do rise again, to roughly 1500t per year, but this rise is not long lived beginning to slowly drop again by the end of the projection period. The gillnet catches however, do not remain high for very long (dropping back below the level of catch before the spike after only 3 years) and actually continue to decline from the peak, ending the projection period at less than 1500t landed per year. It is likely that this pattern of landings is overstated; it is likely that this increase in catches is much larger than is possible in reality, as Atlantis SE does not include the very fine scale dynamics and potential gillnet gear saturation that appears to constrain catch rates in reality. In turn, it is likely that subsequent declines would also be smaller in magnitude than predicted (as the depletion would not be so great or at least so rapid).

In sectors such as the GHAT, where multiple gear types contribute to the overall landings, it is informative to consider the changing make-up of the gear contributions through time. In Scenarios 3 and 4 the proportion of the landed catches in the GHAT made up by auto-longline activities effectively doubles, in Scenarios 9 and 10 the auto-longlining activity also increases through the course of the run, though only by 20% for scenario 9 and 30% for scenario 10. Only in Scenario 1 does the contributions by the longline sector decrease relative to landings by the other GHAT sectors during the simulated period, declining by 15% from its peak levels to contribute only about a third of the landed catches (in all other scenarios the longline catch makes up half or more of the GHAT landings by the end of the projection period).

Catch of Key Target Species

The group-by-group comparison of landed catches under each management strategy shows that for the vast majority of groups landings drop by 10-50% (or more) once management measures that constrain fleet behaviour in one way or another are introduced. The few exceptions to this revolve around either: (i) the small pelagics and invertebrate groups (the landings of which tend to increase with shifts in targeting); or (ii) the ban on discarding of quota species under Scenario 10 (as fish that would normally have been discarded are landed and so increase landings). While the total landed catches and general evaluation of relative changes in catch are instructive, of more interest (especially from an ecologically sustainable development perspective) are catches for the individual groups. Rather than detail the trajectories for all groups taken by the fishery, the catch vs quota details for the key target species (flathead, blue grenadier, ling, orange roughy, gummy and school shark) are given here. In light of the growing interest in the take of cephalopods and small pelagics, the landed catches for these groups will also be reported here. Note that quotas under Scenario 9 are not mentioned here as they either remain constant at starting values or slowly rise through time as stock status improves and are unconstraining in all cases.

Tiger flathead

The landed catch of tiger flathead in Scenario 1 (Figure 5.8a) drops off quickly from the levels seen toward the end of the historical period (though it does increase at the end of the simulated period), and is only 55-80% of the real world landings 2000-2005. This may suggest that there has been a shift in discarding practices in the real world (that is not being captured in the simulations for this Scenario) as the modelled catch and discards combined is about the level of the real world landed catch (or a little more). The TACs are not constraining in this Scenario (and simply increase periodically through time).

Under Scenario 3 (Figure 5.8b) the landed catch of flathead drops very briefly at the end of the historical period before jumping back to that level again and growing steadily to a peak of over 5000t in 2006, after which it steadily declines to approach a long term annual average of roughly 1100 t. The TACs in this Scenario quite effectively constrain landed catches, though they are markedly different to those TACs set in reality. This is because the stock status predicted by Atlantis is much higher (relative to estimated unfished levels) than in reality and so allows for much higher initial TACs under the harvest control rules. This difference in predicted relative biomass between Atlantis and assessment models is discussed in the ecological performance measure section below, but is primarily due to multispecies interactions.

The TACs set in Scenario 4 (Figure 5.8c) are effectively unconstraining for much of the simulated period, as other management and economic decisions see realised flathead landings much lower than those that were seen in reality and that the Scenario 4 TACs would allow. The TACs become more constraining at the very end of the simulated period. While much lower flathead landings are seen in this Scenario than in Scenario 3, they are much more variable than for Scenario 1 or 9; the later of these having a similar level of landed catches in some years. Interestingly, decomposition of this overall catch by fleet shows that tiger flathead is of periodic interest as constraints or economic considerations that impinge on the returns from other target groups see different sectors turn to tiger flathead and the other demersal fish species to "see them through". This use of tiger flathead as the "best alternative" is also the reason that tiger flathead landings rise from their initially very low levels under Scenario 9. Scenario 9 is quite restrictive spatially and fisheries soon exhaust their ability to economically support targeting of offshore groups, leading to an increasing reliance on shelf and inshore groups, such as tiger flathead.

In Scenario 10 (Figure 5.8e) the requirement to land all the take of target groups sees this Scenario produce the highest landed catches through the bulk of the simulated period. Associated with this is the fact that the catch trajectory (and at least some aspects of the fishery dynamics) ends up resembling those of Scenario 3, though the actual "decision tree path" leading to that endpoint is different in the two cases. Under Scenario 10 (as in Scenario 3) the difference in relative biomass predicted by the assessments and Atlantis lead to a divergence in initial TAC levels, allowing for modelled landings that peak at 120-145% of those recorded in reality in the period 2000-2004 (though this difference would be much smaller if discards from the historical period were added to the landings, which would be a better analogue for the landed catch in Scenario 10). The TACs in this Scenario are quite constraining, though on occasion the landed catch did exceed the quota, despite the fact that fisheries attempted to take remaining quota per species (or group) into account in their effort allocation. The overcatch came about when they fished to fill their quota, unintentionally took more than their remaining quota, could not then discard the difference, and then found that there was no available quota for sale or lease (this was particularly the case toward the end of the year, though individual subfleets could encounter this earlier in the year if they did not shift their targeting to account for "secondary" species take when allocating their effort spatially and temporally[20]).

[20] While flathead is a key target species individual subfleets could consider it a "secondary" species in their allocation algorithms if other species provided potentially higher returns and had more quota remaining (amount of quota remaining is taken into account in the decision process even though no explicit regulatory penalty for overcatch is included in the model).

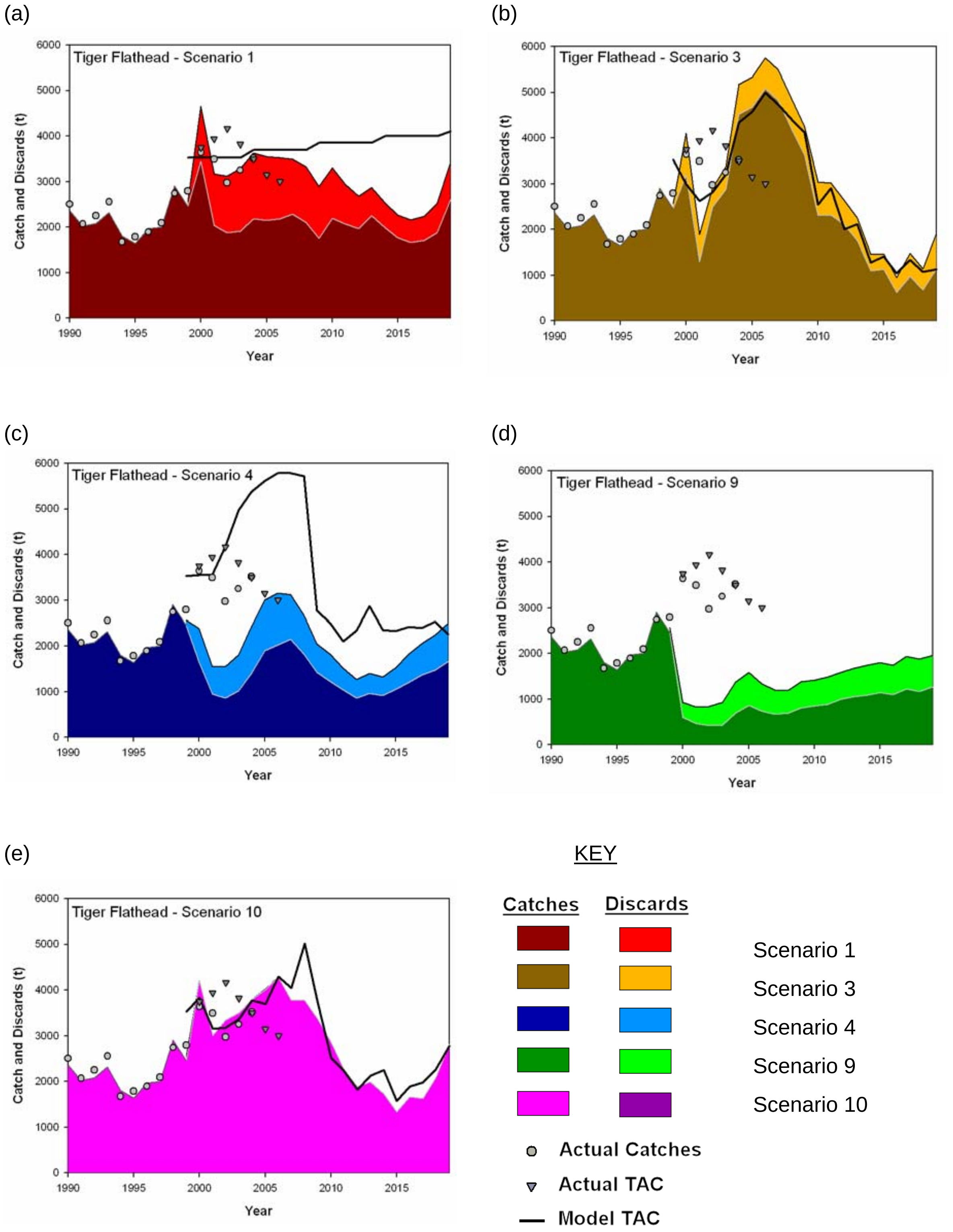


Figure 5-8: Catches, discards and TAC for tiger flathead in the various management scenarios (historical discards omitted; as are the quotas under Scenario 9, which remain constant at 3529t).

Deepwater flathead

The modelled landings of deepwater flathead under Scenario 1 (Figure 5.9a) rise more slowly than actual landed catches, but do still rise to 1403t in 2007, a couple of years before fleet size begins to drop. From this point on landings slowly decline through time, as CPUE rates on the preferred GAB grounds decline, until 2017 when the drop becomes much more rapid ending at 847t. Landings also rise roughly in line with real increases before falling off through time under Scenario 3 to end at 630t, but this is as much to do with constraining TACs as economically-based fleet decisions. Under Scenario 4 landings never rise as high as seen in reality, only reaching 880t at most. The TACs run below the 3000t set in reality and contribute to the high grading decisions that see declining landings and high relative discard rates, with catches and TAC both at about 625t by the end of the projection period. It is spatial zoning, not TACs, that see the low levels (often less than 100t) of deepwater flathead landed catch through much of the projection period under Scenario 9. Shifting targeting, driven by the depletion of other groups and the relative accessibility of the deepwater flathead (which have recovered to the point that they have relatively high CPUE rates), sees the landed catches of deepwater flathead rise to 320t in the end of the projection period under this Scenario. This is in stark contrast to the pattern of landed catches under Scenario 10, where catches rise in a couple of steep steps to 2575t. Landings do not persist at this level long before dropping, with constraining TAC levels, after only a few years. Landings and TACs vary between 1000-1200t over the final decade of the projection period and into the long term.

Blue grenadier

Even with unconstraining quotas (as in Scenario 1, where the simple representation of the negotiated setting of TACs saw the quotas rise through time), the landed catch of blue grenadier does not rise above historical levels, instead slowly declining to just below 6000t (Figure 5.10a). Where real and modelled landings overlap in the projection period catches are a little below actual catches for this Scenario. For Scenario 3 the landed catches are lower stabilising around 5000-5500 t, but in this case the trajectory is dictated by a constraining TAC (though this TAC does not decline to the same extent it has in reality, even its lowest value of 4841t in 2016 is above the actual 2006 quota of 3730t). The TACs in Scenarios 4 and 10 also remain much higher than the actual TACs, though the landed catches taken under these TACs are usually much lower, between 3500 and 4500t in most years. Both of these scenarios also see slight increase in landed catches, after initial quite steep drops in landed catch. The catches taken in Scenario 4 are smaller than those in Scenario 10; this is the case even if landed catches and discards are combined (to allow for a truer comparison, given that no discarding of blue grenadier is allowed under Scenario 10). The landings of 3500t of blue grenadier per annum under Scenario 4 is still more than double that taken in the peak catch years for Scenario 9 (which had a maximum landing for grenadier of 1573t).

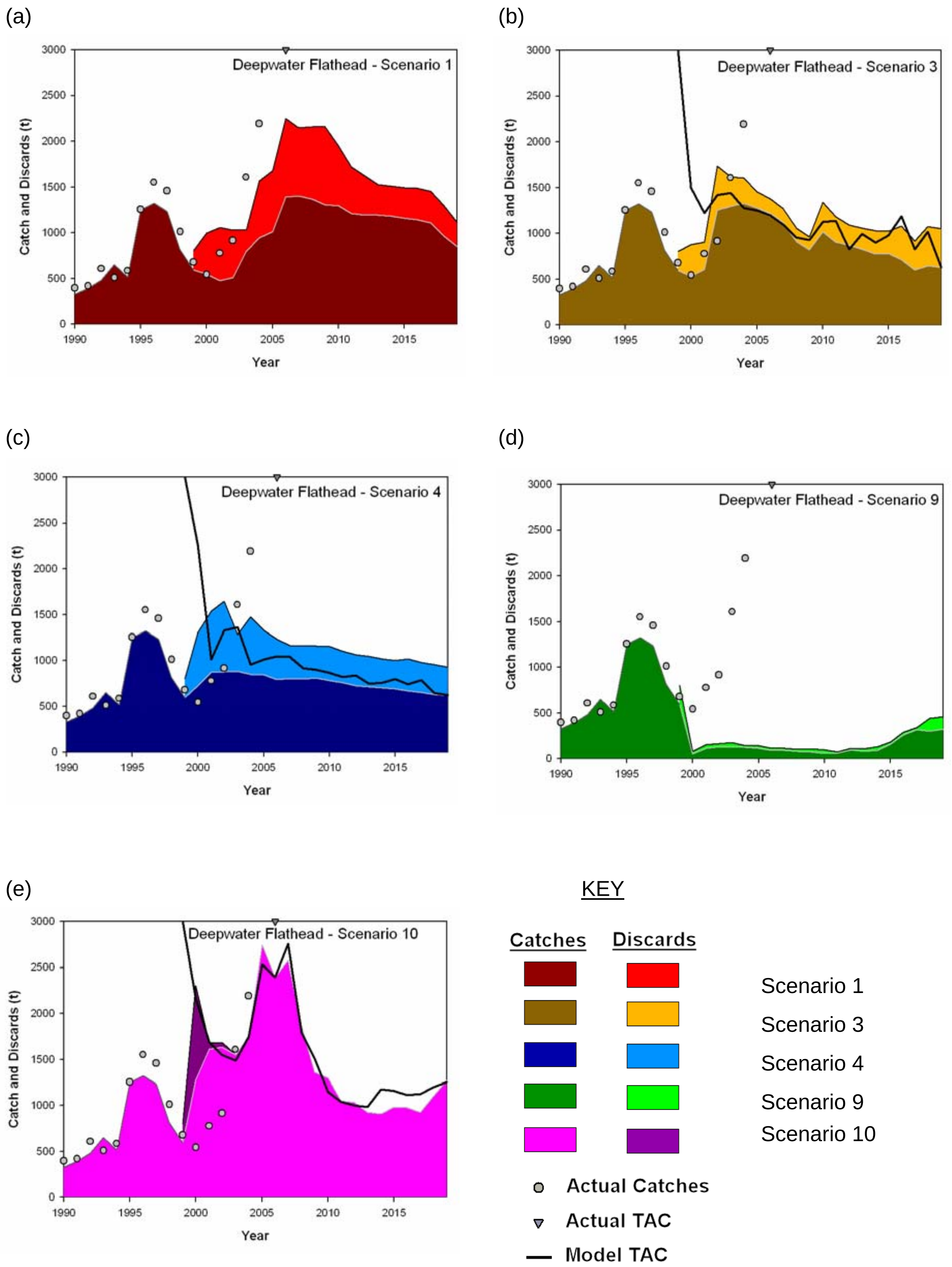


Figure 5-9: Catches, discards and TAC for deepwater flathead in the various management scenarios (historical discards omitted; as are the quotas under Scenario 1, which increase slowly through time, and the quotas under Scenario 9, which remain constant at 3000t). Note that the model TACs begin in 2000 at a value of 3000t and that the TAC line does not continue off to the left above the area shown in the plot.

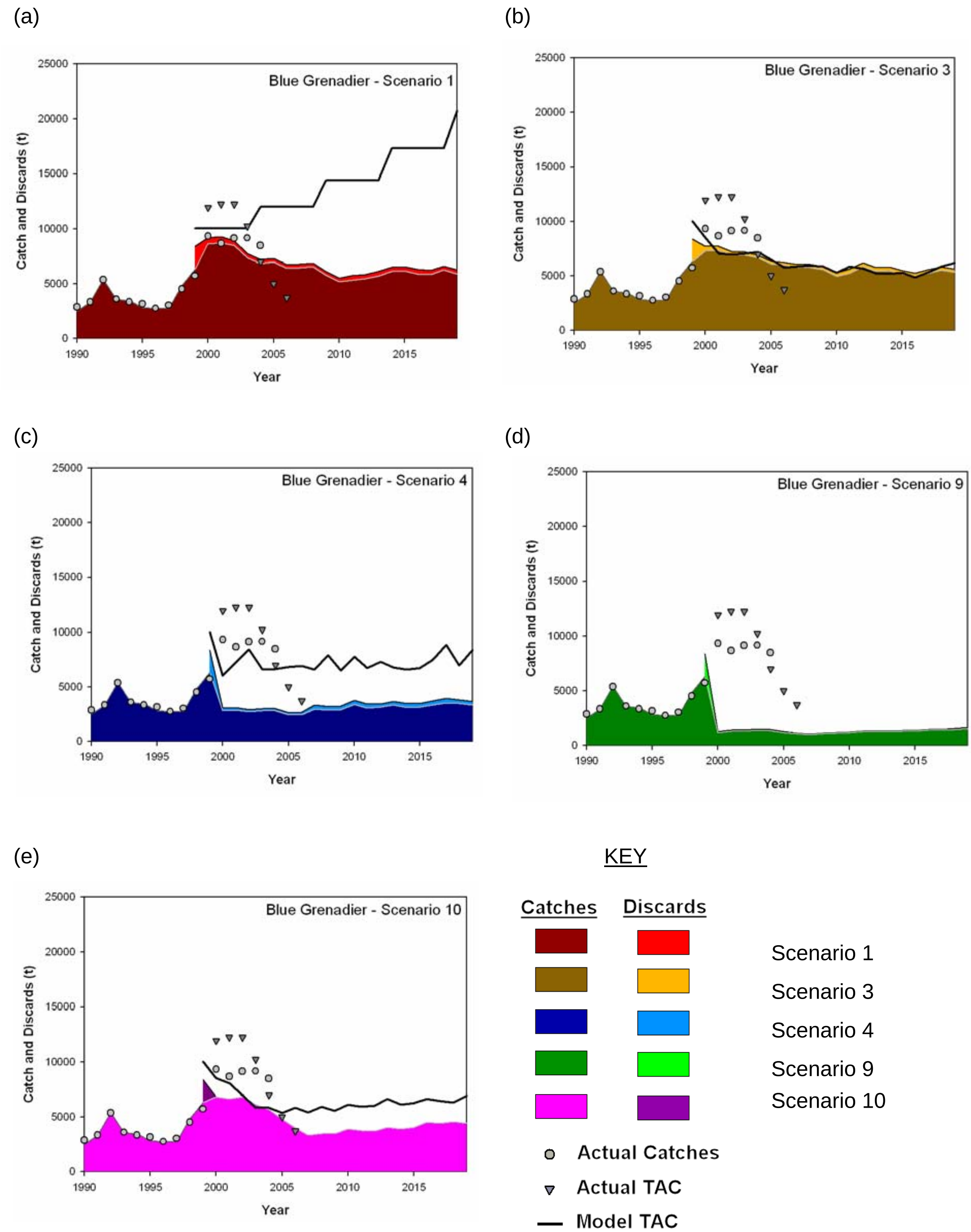


Figure 5-10: Catches, discards and TAC for blue grenadier in the various management scenarios (historical discards omitted; as are the quotas under Scenario 9, which slowly rise through time as the stock status improves).

Pink ling

The TAC for pink ling (Figure 5.11) under Scenario 1 is no more constraining than for any other group, steadily increasing through time (as is the case for the other groups and is a result of the simple representation of the historical form of negotiated setting of TACs (which is asymmetrically influenced by catch rate trends)). Nevertheless, the landed catches first decline, before rising back past historical levels after 2010 and finally stabilising at about 1000t. The TACs in Scenarios 3, 4 and 10 initially drop steeply before fluctuating around (roughly) 2000t for a decade, then rise again in the final years of the projection. The initial drop in Scenarios 10 and 4 is to about the levels that have been set in reality (Scenario 4 drops further to a low of 800 t, while in Scenario 3 the lowest TAC of 1767t remains above the current actual quota of 1200t). The trajectory of the quota setting in Scenario 4 even resembles that seen in reality, because the assessment, in combination with the harvest strategy, indicates that the initial TAC is too high and would lead to overfishing. Sampling error in the estimates and buffers in the TAC setting process keep the TAC bounded through until around 2008 when it begins to rise steadily and incrementally, to values around 2700-2800t, in response to the relative biomasses remaining above the target reference point. In contrast the landed catches stay much lower. Given that the relative biomasses have dropped to the level of the target reference point in the final years of the simulation (with landed catches much less than the quota) downward correction of the TAC in future years would be expected.

For all but Scenario 3 the landed catches stay fairly constant through time, but in Scenario 3 there is a peak and subsequent decline after 2010. Before this peak the Scenario 3 landed catches where about 750t, but after it they are closer to 650t. In Scenario 4 the landed catches stabilise about 400t, which is 50t less than under Scenario 10, but nearly 3x those seen under the heavy spatial constraints in Scenario 9.

Blue-eye trevalla

TACs for blue-eye trevalla are not constraining in any but the earliest years in any scenario (Figure 5.12) – rising steeply in every case, except Scenario 9 where it remained constant. This rise occurs because the increasing relative biomass predicted in each scenario is significantly above the target reference point and so the assessment allows for a higher TAC. Even with these increasing TACs (and increasing overall stock size) landed catches fall off through time in Scenario 1, showing a short lived recovery after fleet sizes are reduced. This is because easily accessible stock components are depleted even when the overall stock is doing well. There is also a shifting of the longline targeting to ling, drawing the focus away from blue-eye in the short term. Ultimately however, ling CPUE is sufficiently low that longliners concentrate increasing effort on blue-eye. Once blue-eye trevalla has become the primary target of the longliners, the landed catches rise into the medium term, rising through 500t at the end of the projection period and varying about 900t into the long term. The landed catches of blue-eye trevalla under Scenario 3 stabilise much earlier (within a couple of years of the simulation's start) and remains at about 650t throughout the projection period.

Landings in Scenario 4 do not stabilise until the medium or long term as shifting targeting away from this species and adjustments to the new spatial and other management measures see blue-eye trevalla landings drop by roughly 500t over the period leading up to the fleet size reduction. After that the landed catches slowly increase again, as the fleets switch back to blue-eye as ling catches decline, and landings are about 250t per year by the end of the projection period.

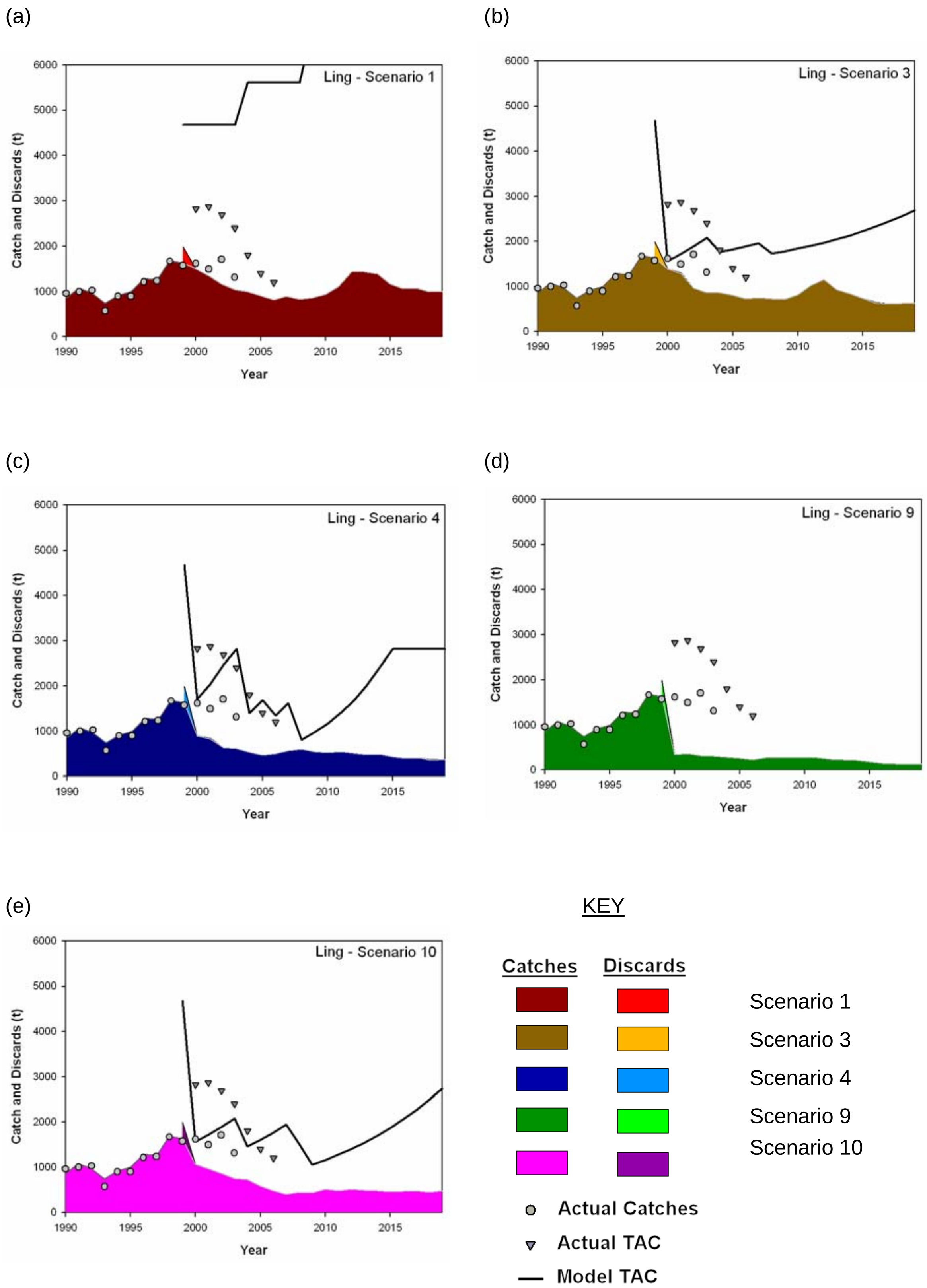


Figure 5-11: Catches, discards and TAC for pink ling in the various management scenarios (historical discards omitted; as are the quotas in later years for Scenario 1, which continue to increase through time, and the quotas under Scenario 9, which remain constant at 4684t).

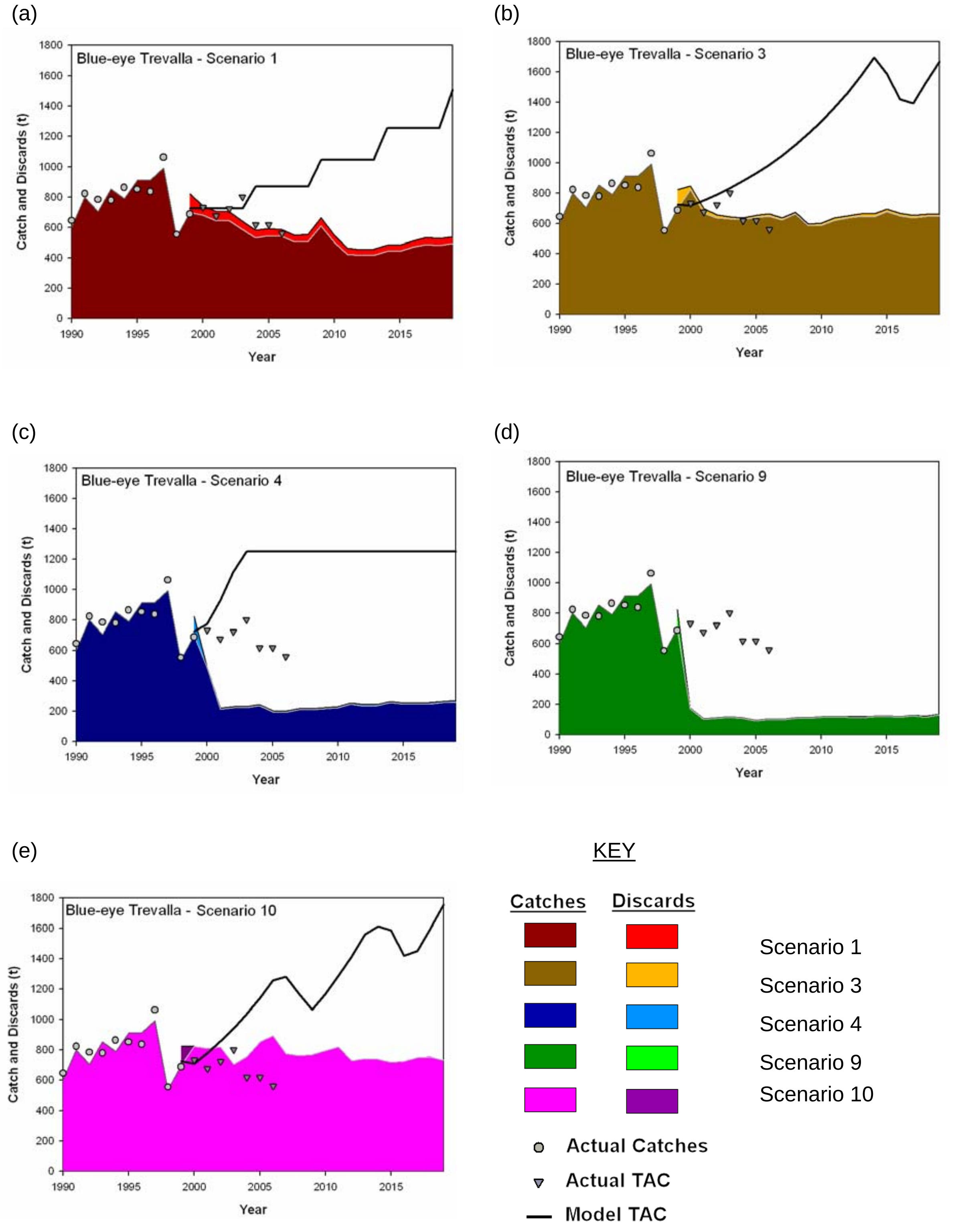


Figure 5-12: Catches, discards and TAC for blue-eye trevalla in the various management scenarios (historical discards omitted; as are the quotas under Scenario 9, which either remain constant at 727t).

After very steep initial drops in Scenario 9, landed catches also increase a little through the course of the run to end at about 120t per year. Compared with these smooth trajectories the landings of blue-eye under Scenario 10 are far more variable; varying from roughly 700-900t.

Orange roughy

The catch trajectories for orange roughy (Figure 5.13) under the various scenarios are fairly similar in pattern (steep declines to low catch levels); though the final catch levels differ between scenarios. The landed catches in the early years of Scenario 1 are close to actual catches during the same period. The landed catches continue to decline until they finally stabilise at about 500t. The drop in landed catches is much steeper in the other runs, particularly Scenario 9 where the landings first drop to just below 700t before stabilising at about 330t. The other three scenarios do not drop this low, with Scenario 3 stabilising at a little under 450t, while Scenarios 4 and 10 end with annual landings of 500 - 600t. The TACs decline more rapidly in these scenarios than they actually did (except for Scenario 1 where they increase through time). The problem of overcatch is also seen in this species; particularly for Scenario 3 where overcatches of 20t or more happen in most years (the problem isn't usually as big in the other scenarios where any overcatch is typically less than 10t). One interesting phenomenon seen in the catch trajectories for orange roughy in all the scenarios is "chasing the last fish". In every case there comes a point (typically just before the fleet reduces in size) where there is a spike in landings (1.2-1.5x the magnitude of landed catch in the preceding year and >2.5x the landed catch in the following year). This occurs as the fleet components targeting roughy attempt to maintain preferred levels of CPUE and ultimately all but exhaust available (and easily locatable) roughy stocks. For those scenarios with a constraining TAC this practice also results in an overcatch and hence the economic pressures and incentives need to be taken into account when setting TACs for highly aggregated populations.

Gummy shark

Gummy sharks are another group that show interesting targeting dynamics through the course of the simulations (Figure 5.14). In all but Scenario 9 landed catches are initially much higher than those that have really been landed since 2000. Landings of this group then tend to increase substantially for a few years spanning the fleet restructuring (so around 2005 for Scenarios 4 and 10, and about 2010 for Scenarios 1 and 3). Landings are about the same in all scenarios (about 2500t), before peaking at some point after 2005. The peak is 4500t in all but Scenario 3 when it is only 3500t. After the peak though there is a strong divergence in the level of landed catches, dropping to 500t in Scenario 4, 1000t under Scenarios 1 and 10, while remaining at 2000-2500t under Scenario 3. The decline in landed catches is at least in part due to constraining TACs under Scenarios 4 and 10, though these TACs are much higher (at least initially) than seen currently because the relative biomasses in Atlantis SE are much higher than predicted by actual stock assessments (see the discussion in section 3.3.5). There is also no such restriction for the other two scenarios (where TACs remain well above landings and discards together; apart from the peak year in Scenario 3 when landed catches just reach the TAC). The fact the TACs are constraining possible landings is obvious from the overcatch (which occurs occasionally under Scenario 4, but is a chronic problem for Scenario 10, where at least 100t is over caught each year). In contrast, landed catches under Scenario 9 remain within a limited range (850-1000t), though they vary year-to-year. This is another example where the simple model representing negotiated TACs predicts a continually increasing TAC.

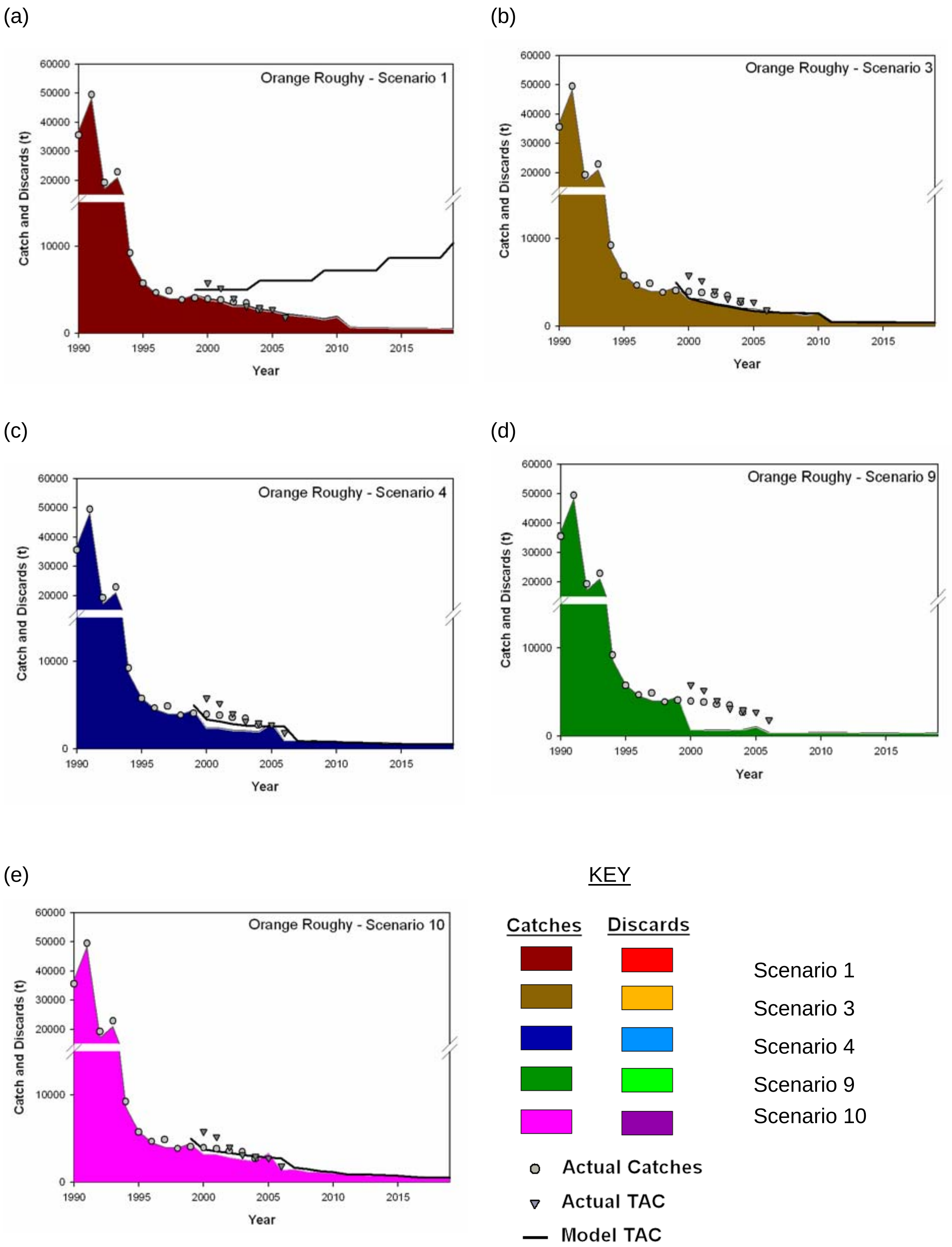


Figure 5-13: Catches, discards and TAC for orange roughy in the various management scenarios (historical discards omitted; as are the quotas under Scenario 9, which either remain constant at 5031t).

As shown by the catch time series predicted in the variant of Scenario 4 (Figure 4.4), the magnitudes and trajectories of the predicted gummy shark landed catches under the standard Scenarios are likely to be too high, making the stock seem less sustainable than it may really be. This is because of three confounding issues with the current version of Atlantis SE and the representation of some of the sectors in the standard form of the Scenarios. First the initial quota settings in the standard form of the Scenarios are too high. They were set high in the standard Scenarios to be unconstraining at the beginning of the projections, given quotas were not introduced until 2001. Unfortunately the quota setting in the model took longer to drop than in reality, meaning the model allowed much higher catches than were actually observed. When a lower initial quota was set for gummy shark in the variant of Scenario 4 the catches were much closer to observed values since the year 2000 (see section 4.6.6 above).

The high catches under the standard form of the Scenarios are also linked to the second issue with the Atlantis SE model, the productivity and mobility of the gummy shark stocks. The parameterisation of the model for this species is what is needed to support historical catches (see section 3.3); they are also within the bounds given in literature regarding pupping rates and mobility. Nevertheless, there is enough uncertainty associated with the literature values that the model may be over estimating the resilience and mobility of gummy sharks in comparison to reality. This allows for landed catches that are higher than actually observed, because it does not capture the fine-scale behaviour that leads to gear saturation and flattish catches.

The third of the model issues is best illustrated by considering the white lines in Figure 5.14 (and Figure 4.4 for the variant of Scenario 4), which indicate the level of gillnet catch in each scenario. The predicted gillnet sector catches are reasonably constant in the first 5-10 years of every scenario. In Scenario 9 the level of gillnet gummy shark catch continues to be flat throughout the entire run, as does the longline catch, which also remains fairly steady throughout the entire projection period for this scenario. The situation is quite different for the other scenarios. Under Scenario 1 gillnet catch drops away after 2013, with the proportion of the catch landed by longliners and trawlers rising sharply before also falling away. The pattern of relative catches between longline, trawlers and gillnet is quite similar to this pattern under scenarios 4 and 10, though the peak in longline catch and associated drop in gillnet catches occurs much earlier, around 2009 and 2006 respectively. The catches under scenario 3 show a different pattern. Overall they are reasonably constant through time (except for a short lived spike in 2009). This relative constancy marks a significant shift in relative catch between gillnet and longline gear. In this case though rather than the gillnet catch simply dropping away as longline catches increase, the gillnet catch spikes to 3414t before dropping to about 1000t for the remainder of the simulation. The rest of the catch is landed by trawlers and longliners; in particular, the relative contribution to the catch of the latter increased by twofold.

The increase in longline catch of gummy shark in the majority of scenarios is due to two things, the already mentioned mobility of the shark within boxes in the model (the resolution of the model and the rates of within box mixing used for gummy shark mean that there is a constant turnover of fish moving into those sections of the box the longliners can access) and the fact that the resolution of the model means the longliners are allowed to access a small to moderate proportion (depending on which scenario is being considered) of the shelf boxes. This access to the shelf boxes is the final of the three issues with the model. Explicit account was made of fisheries closures and restrictions preventing automatic longliners into shallow waters. Nevertheless because of the resolution of the model that access (in combination with the shark movement within boxes) appears to over-state the availability of the gummy shark stock to the longline sector. One solution to this would be to explicitly represent more boxes (for instance

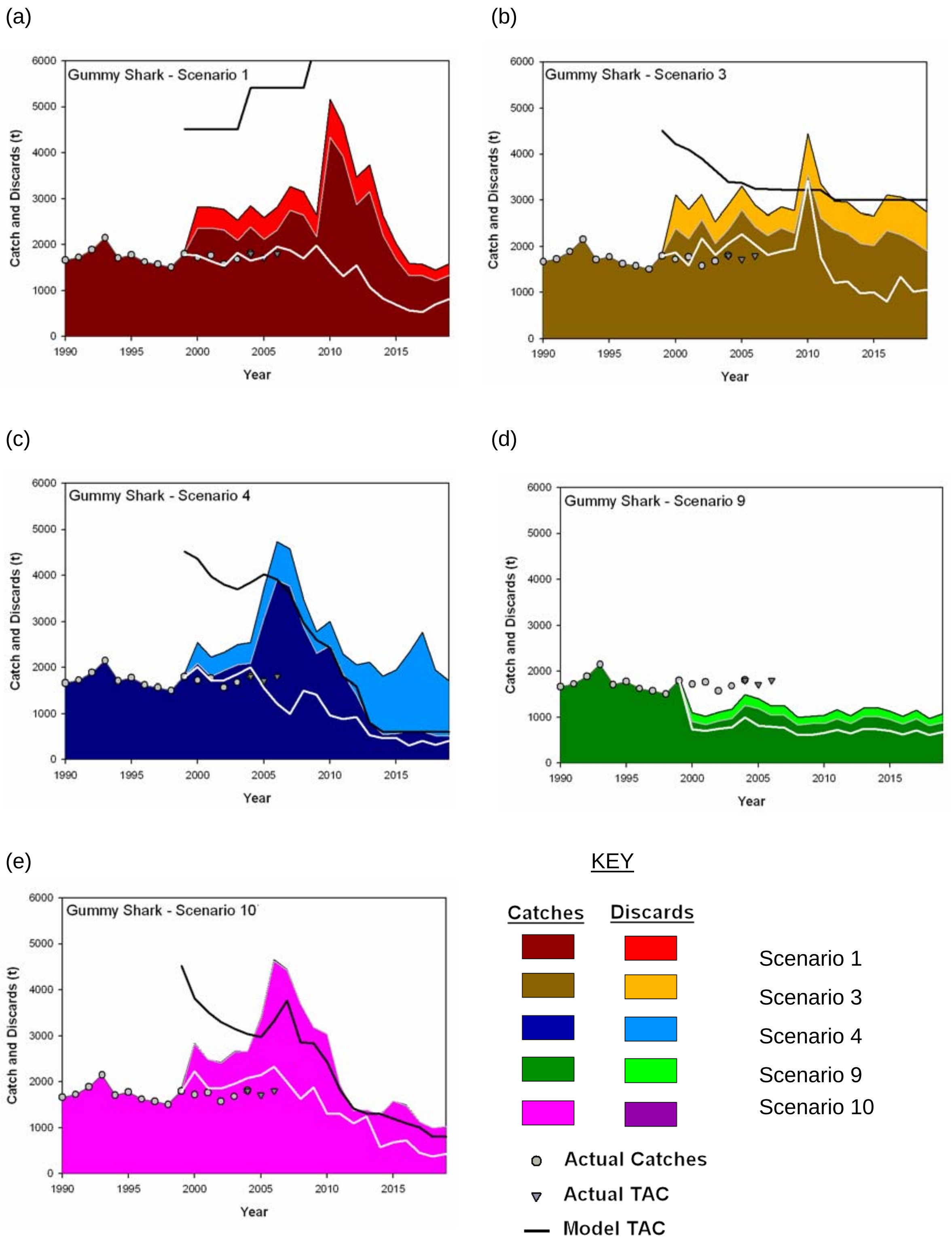


Figure 5-14: Catches, discards and TAC for gummy shark in the various management scenarios (historical discards omitted; as are the quotas in the final years of Scenario 1, which continue to increase through time, and under Scenario 9, which increase as stock status improves). Predicted gillnet catches are shown as a white line.

basing them on depth contours used as jurisdictional boundaries) and to redo the analysis to check for any differences in the realised projections. This approach was not taken here as it would be a reasonably computationally intensive exercise that was beyond the remaining resources of this study. It is however, a potentially very productive avenue for future research. What has been considered using the variant of Scenario 4 is the impact of effectively banning the auto-longline sector from any areas where they could encounter gummy shark. As discussed in section 4.6.6 above this had implications for the stability of overall gummy shark catch (which remain about historical levels rather than falling away) and the contributions made by the various sectors (for instance the gillnet catches do not drop away as substantially).

School shark

The predicted trajectories for the landed catch of school shark (Figure 5.15) vary markedly across the alternative management scenarios. Free of a constraining TAC, the landed catch of school shark grows throughout the course of the projection for Scenario 1, reaching 1750t by the end of the period. The TACs in Scenario 1 also increase through time. The simple negotiated TAC model does not express this behaviour for all quota species, but does so for the main target groups (such as the ones discussed in this section) and it would be good to see, in future research, if more sophisticated implementations of this TAC setting process lead to alternative TAC trajectories (rather than seeing so many cases where it just leads to increases in the TAC through time).

Under Scenario 3 there is an initial increase, a period of fluctuating but relatively high (roughly 1000t) landings, before a subsequent decline and stabilisation about 650t. In Scenarios 4 and 9 and Scenario 10 the landings grow initially before entering a long term run of fairly stable landings. The magnitude of the dip and final landings is very different between these scenarios however. For Scenario 9 the stabilised landings are about 250t while they’re about 600t for Scenario 4 and about 1300t under Scenario 10. In those scenarios with TAC management (except for Scenario 1) the TACs are highly constraining. There is also an overcatch issue, especially for Scenario 10. More selective targeting may mitigate the magnitude of this in reality. In all cases the TACs set in Atlantis are much higher than those seen in reality to date, reflecting the predicted increase in relative biomass and stock status for this group in the model (with the predicted levels being above those thought to be the case in reality). It is likely that the predicted rate of recovery is too high here (Pribac *pers. com.*) and so the resulting TACs (based on the standing biomass (in Figure 5.99) versus reference points) are set too high, leading to the dynamics discussed here.

Under Scenario 3 the school shark is not the only chondrichthyan that was increasingly targeted and landed. The landed catch of skates and rays almost doubles under this Scenario (rising from 115t in 2000 to 248t by the final year of the run). The landing of pelagic sharks also increased (by 1.5-3.5x) in all the scenarios, except Scenario 9 where landed catches fell by 40%.

Small pelagics

Landings of the small pelagics (mackerel, red bait and other small pelagics) increase under Scenario 10 by 150-200% (remaining fairly variable throughout the projection), but decline by 50-60% under all other scenarios (Figure 5.16). The match between model and actual catches in the historical period for the individual species is not as good as implied by the match in aggregate values, where overestimates for one species cancel out underestimates in another. The aggregation of small pelagics also hides the differences in landings between the different

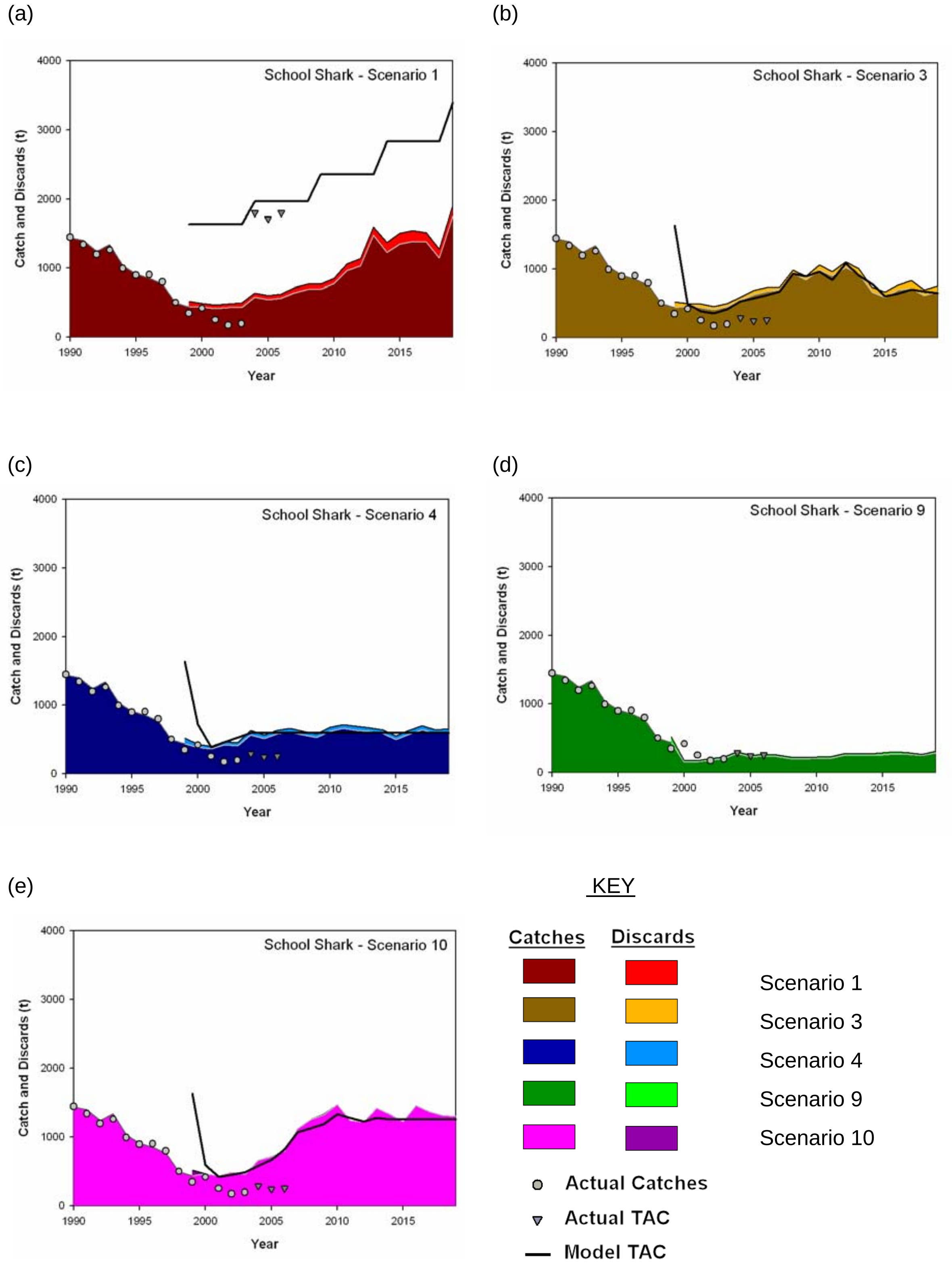


Figure 5-15: Catches, discards and TAC for school shark in the various management scenarios (historical discards omitted; as are the quotas under Scenario 9, which remain constant at increase slowly through time as stock status improves)

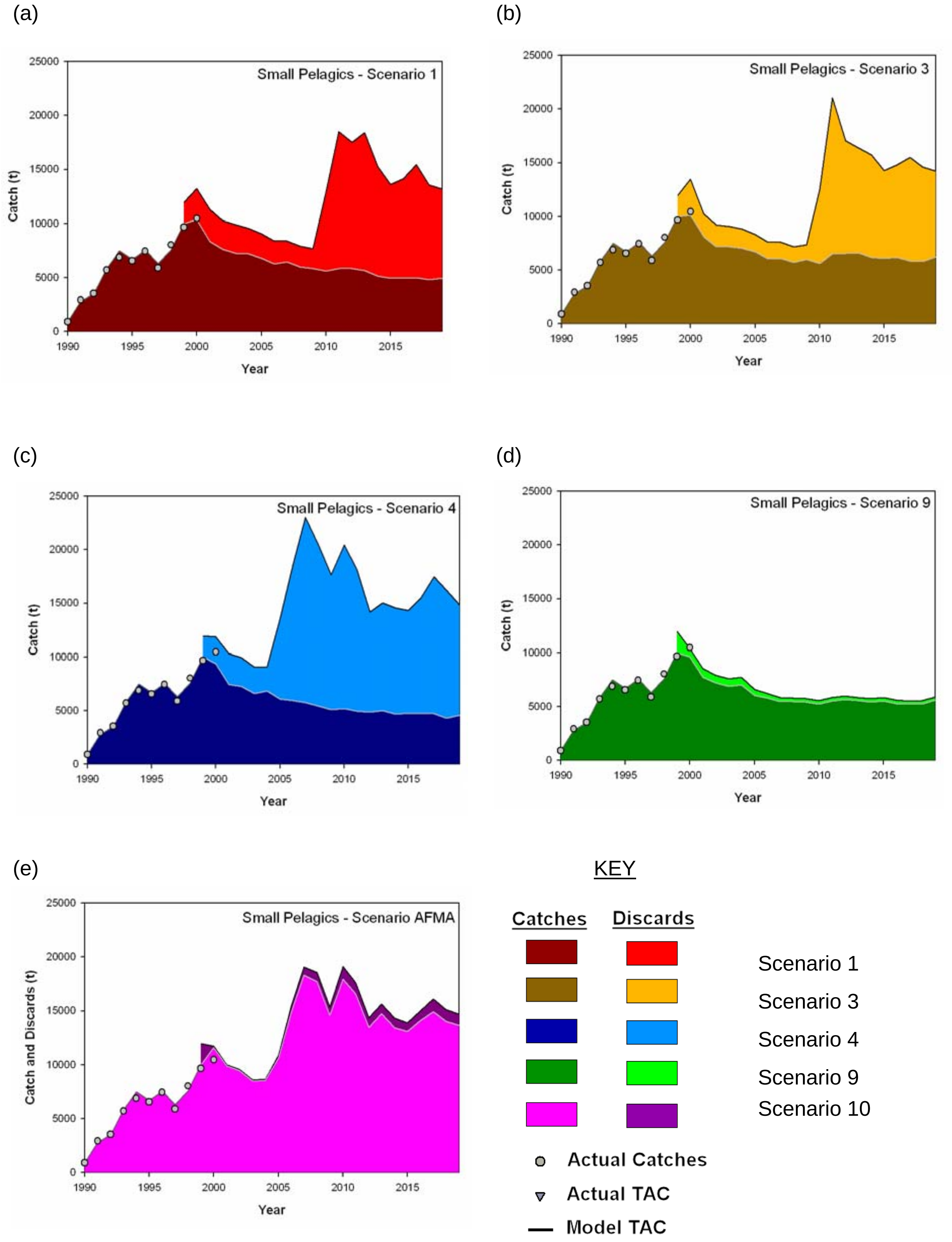


Figure 5-16: Catches, discards of small pelagics (mackerel, red bait and other small pelagics) in the various management scenarios (historical discards omitted, as are quotas under Scenario 3).

scenarios into the future. While the landings of red bait rises by 20% under Scenario 10, it falls by 50% in Scenarios 3 and 9, dropping further to only 25% of starting values in Scenarios 1 and 4. Even under the higher biomasses suggested by recent assessments, which suggest biomasses may be twice that given in Atlantis SE, these drops in catch may still have occurred as they resulted from increasing discard rates rather than simply depletion of biomass.

In contrast to the results for red bait, the landings of mackerel increase by 50% in Scenarios 1, 3 and by 400% in Scenario 10, while they drop by 45% in Scenario 9. The landings of the other small pelagics group remains fairly constant throughout the projection period.

Squid

The catch of squid increases substantially in all scenarios (Figure 5.17); typically rising steeply over the period when the fleet structure changes most rapidly (about 2005 for Scenarios 4 and 9 and Scenario 10, and about 2010 for Scenarios 1 and 3). In Scenario 9 the catch of squid doubles, but under Scenario 1 and Scenario 10 it increases by 2.5x, while for the other two Scenarios the increase is 3.5x (leading to a final landing level of more than 5000t per annum). All this happens free of TAC constraints, but even if they were in place it is unlikely they would change the result substantially as this level of catch was not having a substantial impact on overall squid biomass (though it could lead to local depletion) – see the discussion of relative biomasses below.

Average Size of the Catch

All of the shifts in targeting and landing leads to changes in the average size of individuals in the catch over the course of the projections (Figure 5.18). In Scenarios 1 and 4 there is a steady increase (by 20%) in the average size of fish in the catch (all fisheries combined), but this was for different reasons. In Scenario 4 this increase resulted from a real shift in the average size of the catch, with a greater number of larger bodied individuals present. In contrast, the shift in Scenario 1 is caused by increased discarding of the smallest fish so that in aggregate the average size of the landed catch appeared to rise. While something similar happened initially under Scenario 3, ultimately the smaller fish come to dominate the catches (both with regard to individual size, but also the species mix retained) and so the average size of the catch fell in this Scenario. The 50% increase in the average size of the catch under Scenario 9 reflects the fact that under such tight regulation and low catch sizes the most preferred fish (i.e. large fish) are not only the majority of the retained catch, but also come to represent a significant proportion of the population through rebuilding. There is also an increase in the average size of the catch under Scenario 10 by 45%. There is a hump in this increase however, with the peak occurring in 2014 and declining after that. This pattern is driven almost entirely by a shifting population structure mixed with the requirement to retain a large part of the discards. Across the various fisheries the larger animals of bycatch species that many have been discarded in the past (e.g. sharks caught in finfish trawls etc) were retained, which sees a rise in average size. Eventually however, shifts in population structure see the catches made up by larger proportions of smaller fish that must be retained (due to regulations) and so the average size decreases. An interesting future variant to consider here would be the impacts of improved BRDs on this pattern.

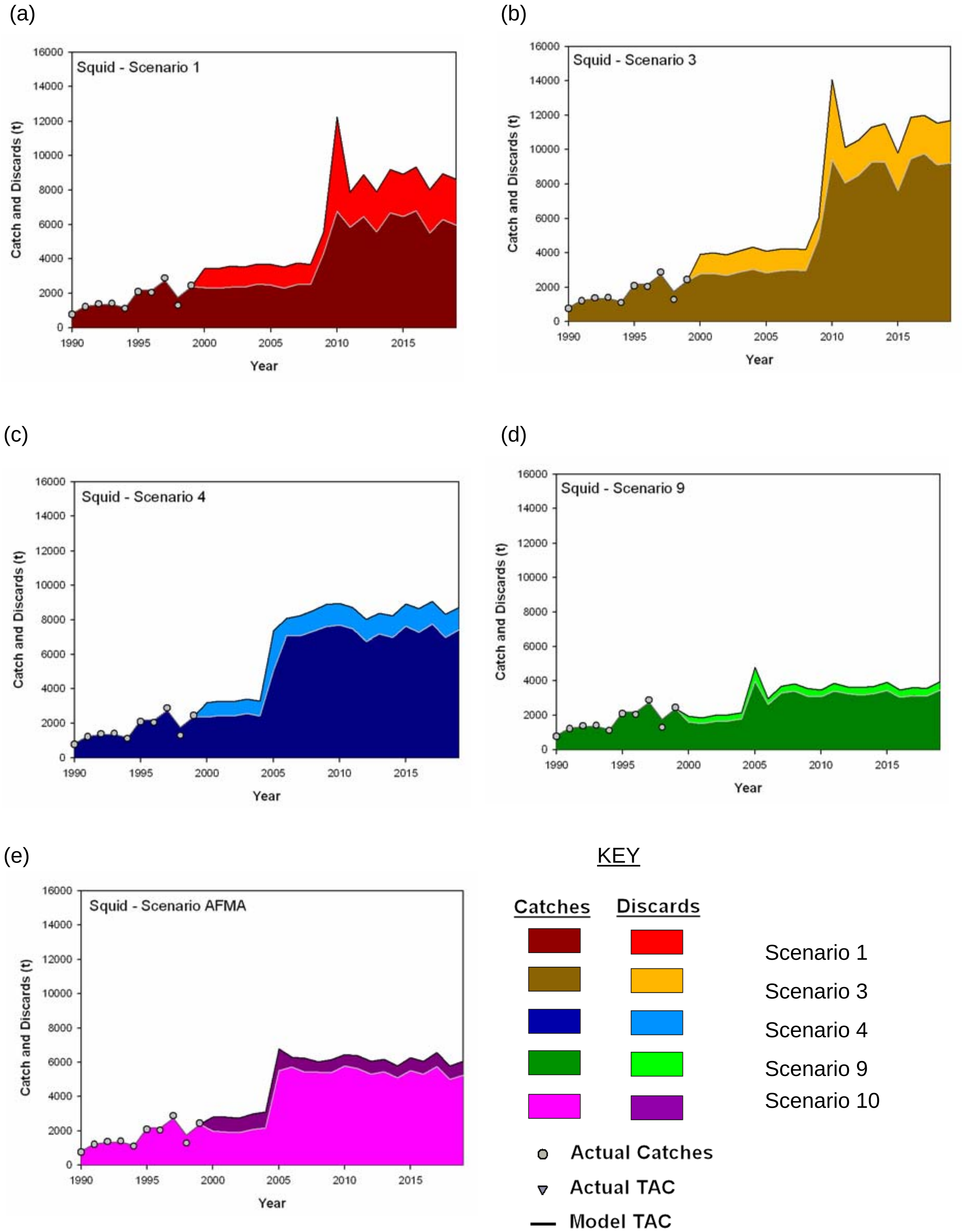


Figure 5-17: Catches, discards of squid in the various management scenarios (historical discards omitted; as are the quotas under Scenario 3).

Catch Composition

The catch composition index is a crude measure of the diversity of the catch and is represented by the largest proportion of the catch made up by a single group (or species). The trajectories of this index (Figure 5.19) were more varied than for the average size of the catch. The ban on discard of quota groups sees the initial values of catch composition much higher than for any other scenario. Beyond that difference, the proportion of the catch dominated by a single species rises by 2-5% in all scenarios in the first few years following a consolidation of targeting as the new management strategies come into effect. In Scenario 9 it then remains about this level for the rest of the projection; for all other scenarios the trajectory is much more dynamic. In Scenario 10 the greatest proportion of the catch made up by a single species drops by nearly 10% as the catches become more varied, with an increasing number of target species taken by fishing operations (which cannot then be discarded). The index continues at this lower level for the remainder of the simulation. The other three scenarios show a slight decrease (by about 5%) after the initial increase. In these Scenarios the proportion of the catch dominated by a single group grows again as the fisheries once again consolidate their list of target groups. In Scenarios 1 and 4 this concentration per fishery on a smaller and smaller set of target occurs slowly and ends with the composition index at 0.72 and 0.7 respectively, with both seeing the proportion of the catch made up by a single group growing by about 0.5% per year. The shift to a skewed catch composition is much steeper in Scenario 3, growing initially by 2% a year, reaching 0.74 (growing by 1% per annum at that point) by the end of the simulations.

The catch composition of the individual fisheries reflects a shift in targeting through time, with current key groups declining in some fishery sectors (though not universally across all fisheries) while other currently less important groups replace them. Ultimately the list of groups taken is as broad as ever across fisheries, but within individual fishery sectors there tends to be increased

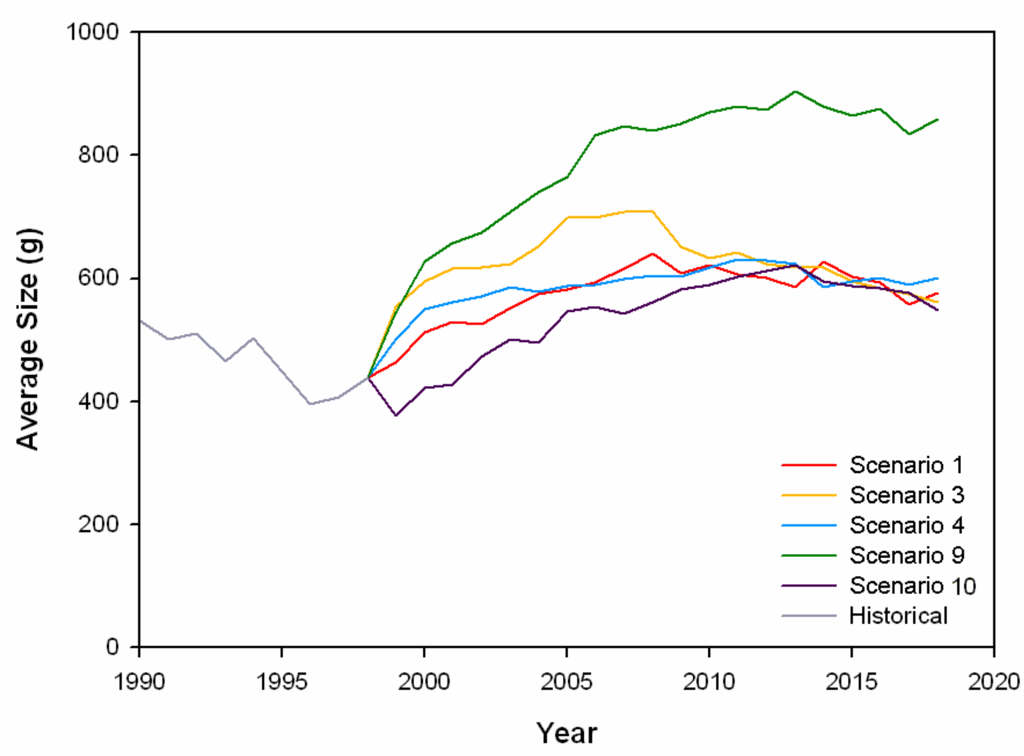


Figure 5-18: Overall average size of the catch in the different management strategy scenarios.

specialisation. The chief exception to this is the general demersal trawl, especially in Scenarios 4 and 10 where its catch is more even and over a wider range of species. There is also a tendency (in all gears) for the role of some historically "secondary groups" – such as shelf demersals, mackerel, small pelagics, squid and other mid trophic groups, and skates and rays – to grow in importance. Of all the scenarios it is Scenario 9 that sees the relative contribution of existing key target species increasing per fishery in a wide number of fisheries. Within the other scenarios the take of grenadier by longline increases though time in all cases, as does the take of gummy shark by the shark longline sector.

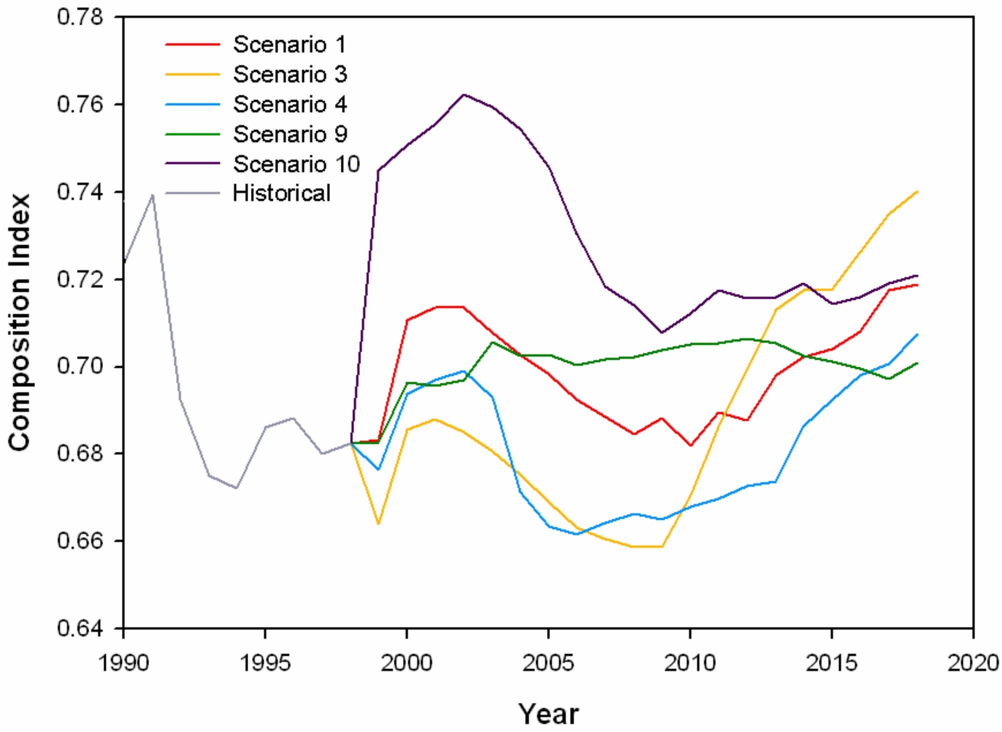
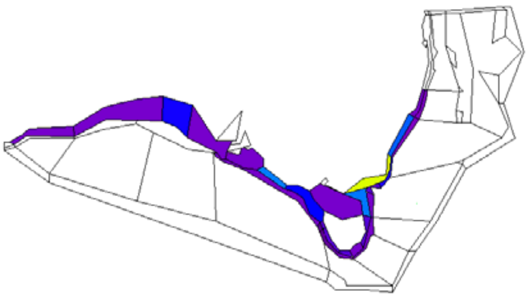


Figure 5-19: Catch composition index (maximum proportion of the catch made up by a single species or group) in the alternative management strategy scenarios.

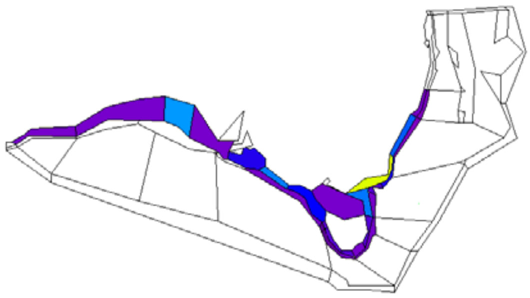
Catch by Box and Depth

Spatially there are many similarities between the distributions of catch across the various scenarios, particularly in the earliest years of the projection period (reflecting the influence of historical knowledge on fisher behaviour) when the distributions match those seen in reality as best as possible given the scale of the polygons. The overall spatial distribution of the combined catch of the two flathead species (Figure 5.20) is fairly typical of the basic trends seen for all key target groups in the region. The distribution under Scenario 1 is quite like that which has been seen historically, with a modest widening of the area fished (pushing at the margins of where the stock is found both east-west but also north-south and with depth). This trend of pushing further a field while still taking quite substantial catches from traditional grounds is also seen under Scenario 3. Under Scenario 4 the expansion is only minor, never really going beyond the occasion exploratory trawl in the more marginal areas. In addition, there are some large scale closures which prevent the fleet accessing some historical grounds. Despite the fact that the fishery is not as tightly constrained spatially under Scenario 10, there is actually a notable redistribution of effort. As holds are filled more quickly under the no-discard rule and catch tends to be taken closer to port (after a smaller number of shots and closer to home) the catch is taken from a more even distribution along the coast than is seen in Scenarios 1, 3, and

(a) Scenario 1

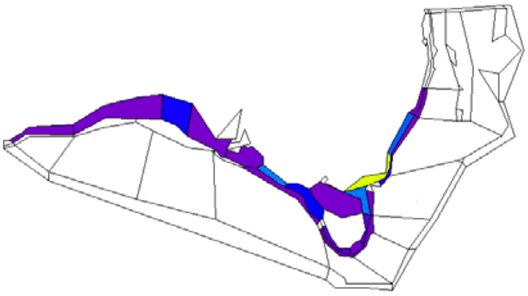


(b) Scenario 3*

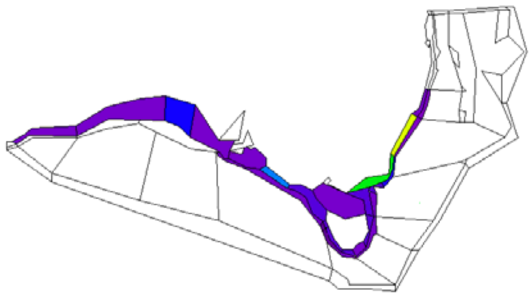


* while not obvious from the scale used here the absolute (though still smallish) levels of catch taken in the more distant (east-west, north-south and deeper) purple boxes is double that seen under Scenario 1

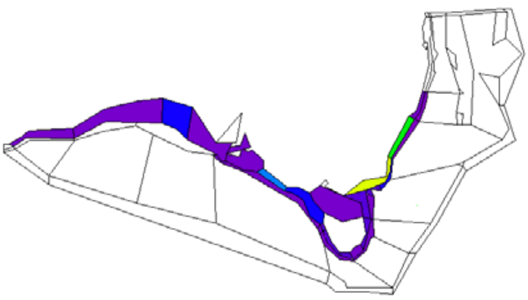
(c) Scenario 4



(d) Scenario 9



(e) Scenario 10



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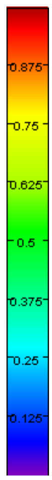


Figure 5-20: Relative overall distribution (summed across years before normalising) of the combined catch of flathead species under the alternative management strategies (the western catches are of deepwater flathead, whereas they represent tiger flathead catches in the east).

4. However, the effect is much smaller in the GAB. The redistribution of effort under Scenario 9 is also notable, though in this case it's a direct result of the displacement of effort by the paddock closure approach.

The biggest impacts of the management strategies are seen in the deepwater groups, where the spatial closures in particular shut down fishery access to significant sections of the resource. There are also notable impacts on the catch of shelf-edge associated groups (like some of the sharks), where at least part of the stock becomes much harder to access under the depth-based spatial management schemes. This leads to pockets of closure amongst patches of displaced effort under Scenario 4. Under Scenario 9 there is essentially simply less catch of these groups across the board as the spatial approach is uniform without preventing large scale displacement (and thus the Scenario has much lower overall effort levels – see below) – an example based on orange roughy is given in Figure 5.21.

When it comes to the distribution of catch of "newer target" groups (like small pelagics and squid) the additional catches tend to be from the currently most successful locations (which continue to be quite lucrative through out the simulation). The climate change aspects of Scenario 9 seem to have little impact on this – there is only the most marginal of southerly shifts in the centre of gravity of the individual spatial distributions of the various target groups. Although this could be because this facet of the Atlantis model may require more refinement (at present it uses only crude temperature forcing) than a reflection on the real implications of climate change for the southeast waters of Australia.

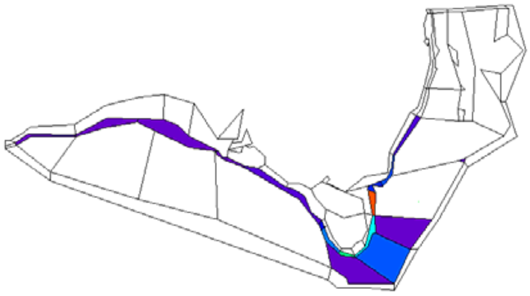
5.1.2 Discards

The discards discussed here (Figures 5.22 – 5.25) are those of vertebrate and invertebrate groups of commercial value (i.e. all non-habitat and non-infauna fisheries interactions). Interactions with habitat groups will be discussed explicitly below (otherwise the informative signals of interest are swamped). The overall discards for Scenario 1 continue at about the level of the historical period before declining to a less than 5000t (Figure 5.21). Scenario 3 also declines overall, but does so with large fluctuations. In the other three scenarios the level of discards that are realised within the first year of the new management strategies are maintained (or close to) throughout the rest of the simulation. The discards for Scenario 10 do show a slight declining trajectory and sit just below the levels realised in Scenario 9, though they are non-zero as only quota species may not be discarded (which still allows for a number of non-quota species of commercial value to be discarded as desired).

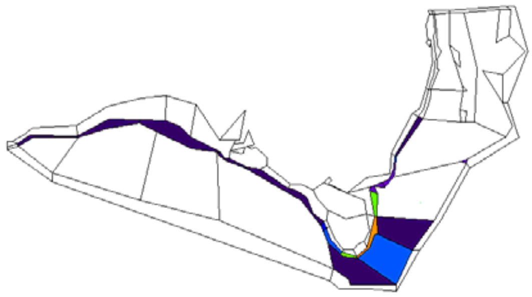
The southeast trawl sector (Figure 5.23) shows the same general patterns of discards as the overall results (Figure 5.22). The relative strength of any fluctuations is larger (by-1.5-15x) than for the overall discards and the trends are stronger too. The discards in Scenario 1 fall below those of Scenario 4 after 2015, but converge again by the end of the projection period. The peak in discards in Scenario 3 after 2010 in the overall discards is also missing for the SET sector.

While the pattern of discards for the GABT are similar to those of the SET and overall results for Scenarios 4, 9 and 10 (falling to low levels with the introduction of the management strategy and only varying to a small degree after that), the discards for Scenarios 1 and 3 are quite different (Figure 5.24). In Scenario 1 the discards also fall sharply initially, but then begin to grow in 2009 as high grading (by size and species) becomes an increasingly common practice (due to the push to maximise return landings and the uncertainty regarding what species will be

(a) Scenario 1

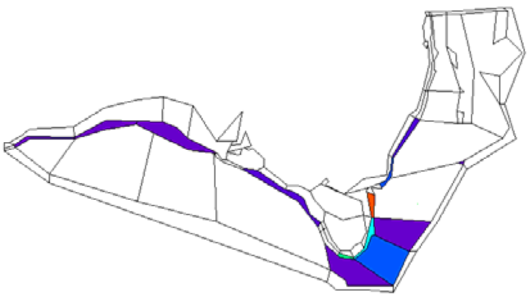


(b) Scenario 3*

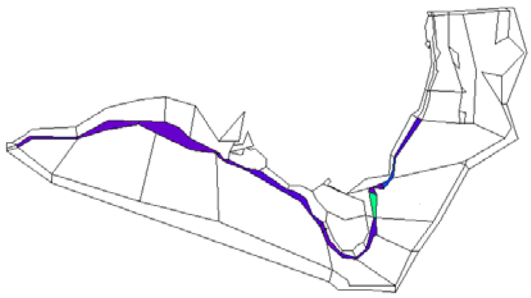


* after an initial expansion into the west, as more marginal areas are strongly depleted, there is a contraction of effort onto the best grounds

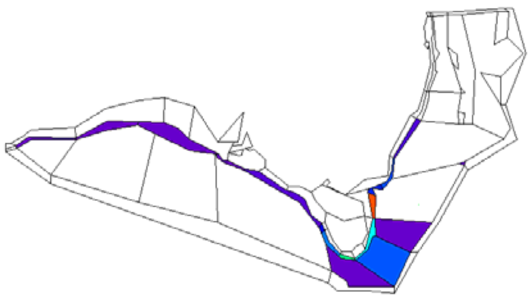
(c) Scenario 4



(d) Scenario 9



(e) Scenario 10



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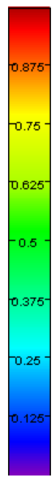


Figure 5-21: Relative overall distribution (summed across years before normalising within a scenario) of the catch of orange roughy under the alternative management strategies. Note that due to the resolution of the Atlantis SE boxes the catches along the edge of the plateau look to extend out into open ocean, this is not the case (as the model explicitly handles sub-grid scale habitats, as discussed under habitat dependencies in chapter 2), unfortunately the resolution of the map does not allow a finer scale representation here.

contacted in numbers in any one trip, fishers hedge their bets by storing smaller or less valuable fish earlier in the trip, but this fish is subsequently discarded if and when more valuable sizes and species are caught). By the end of the projection period they have grown by a factor of 4 and are higher than those of any other scenario by more than double. Scenario 3 shows only a small decline in discards (of less than 9%) in the GABT from beginning to end of the projection period, but with a substantial dip around 2006 and 2012.

The pattern of discards in the GHAT varies from those of the other major sectors (Figure 5.25). The discards by both longline and gillnet under Scenario 10 remain at low levels for the entire simulation; whereas under Scenario 1 both longline and gillnet discards initially rise, but then ultimately a decline, as more species (groups) and sizes are retained. The drop in discarding is of the same magnitude in each case, but is much more sudden and pronounced for the gillnet fleet. Under Scenario 4, the discards by the longliners halve almost immediately and remain at those levels for the remainder of the projection period; in contrast the volume of gillnet discards initially rises by 50% before declining slowly to the very low levels seen under Scenario 10. The discards under Scenario 3 also decline eventually for all fleets in the GHAT, but not until after strong rises (of two to threefold) and further spike around 2010 – when it peaks at more than 2500t for the gillnet (>5x the historical level of discards for this fleet) and nearly 1700t for the longliners (more than twice the estimated historical levels). This spike in discards is the source of the spike seen in the overall results and is driven by magnitude of catch and effort in the gillnet fleet, but is more complicated for the longline fleet, where it results from a combination of a lack of available quota and competition with the gillnet sector.

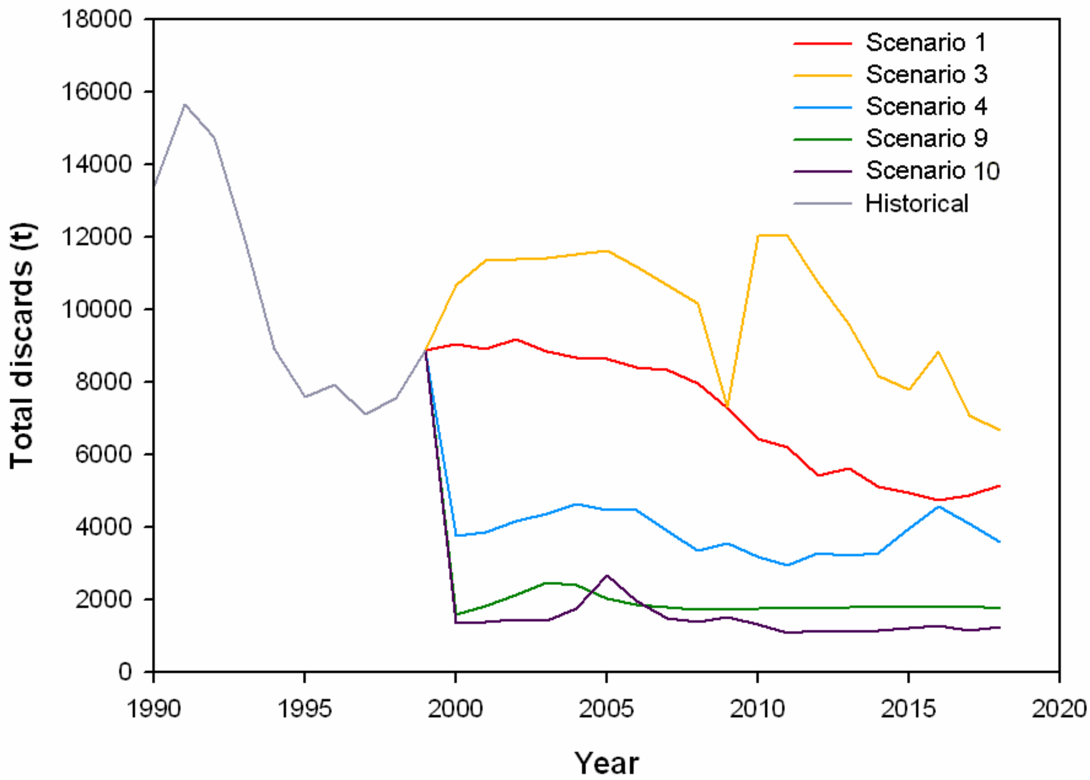


Figure 5-22: Total discards of non-habitat groups under the alternative management strategies.

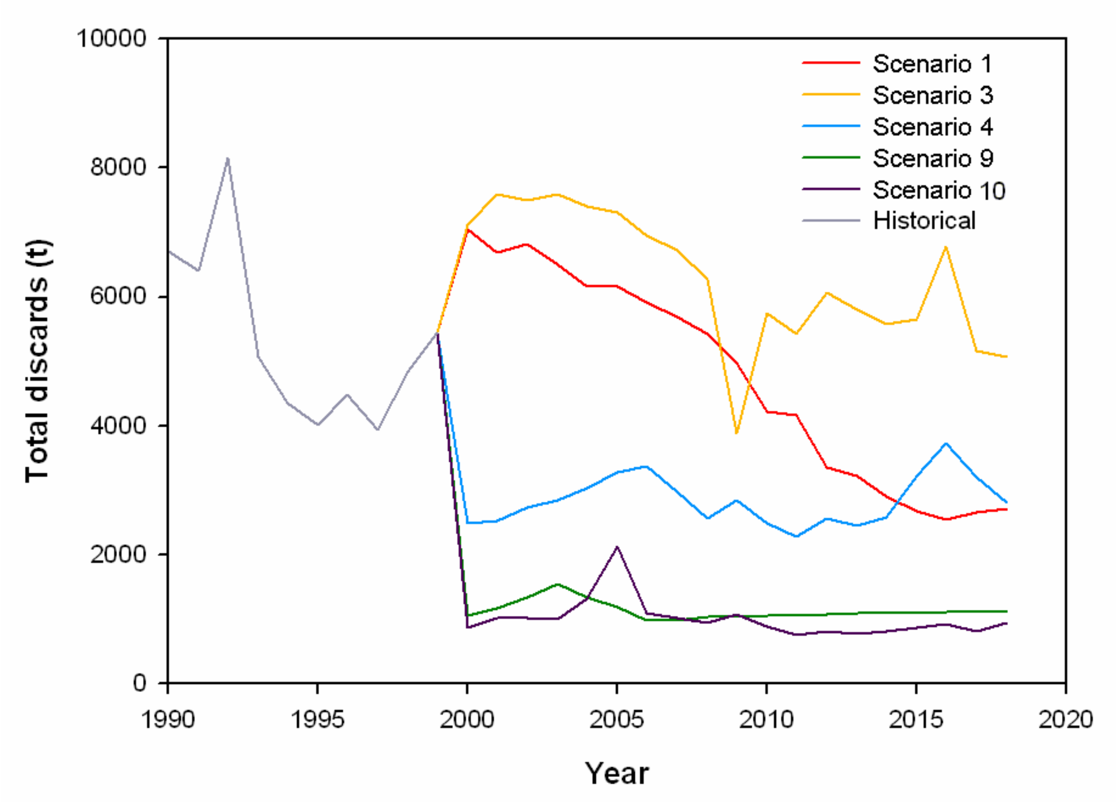


Figure 5-23: Total discards of non-habitat groups in the SET sector under the alternative management strategies.

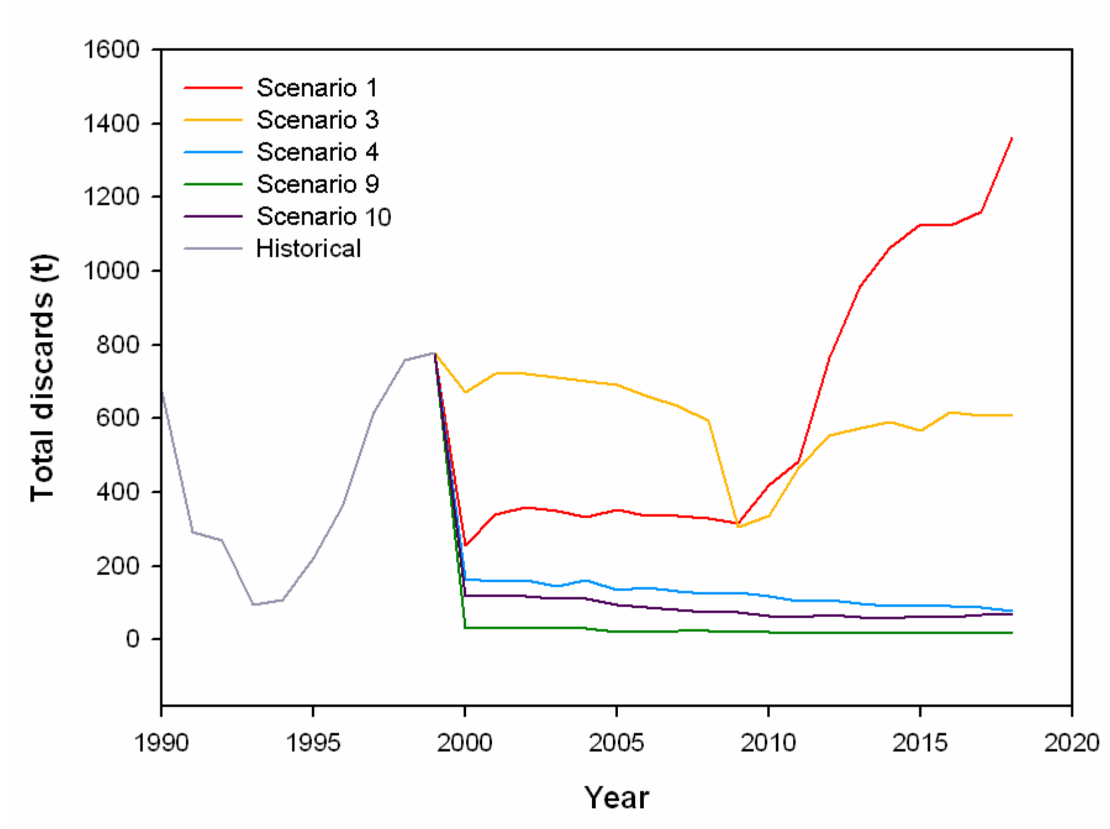
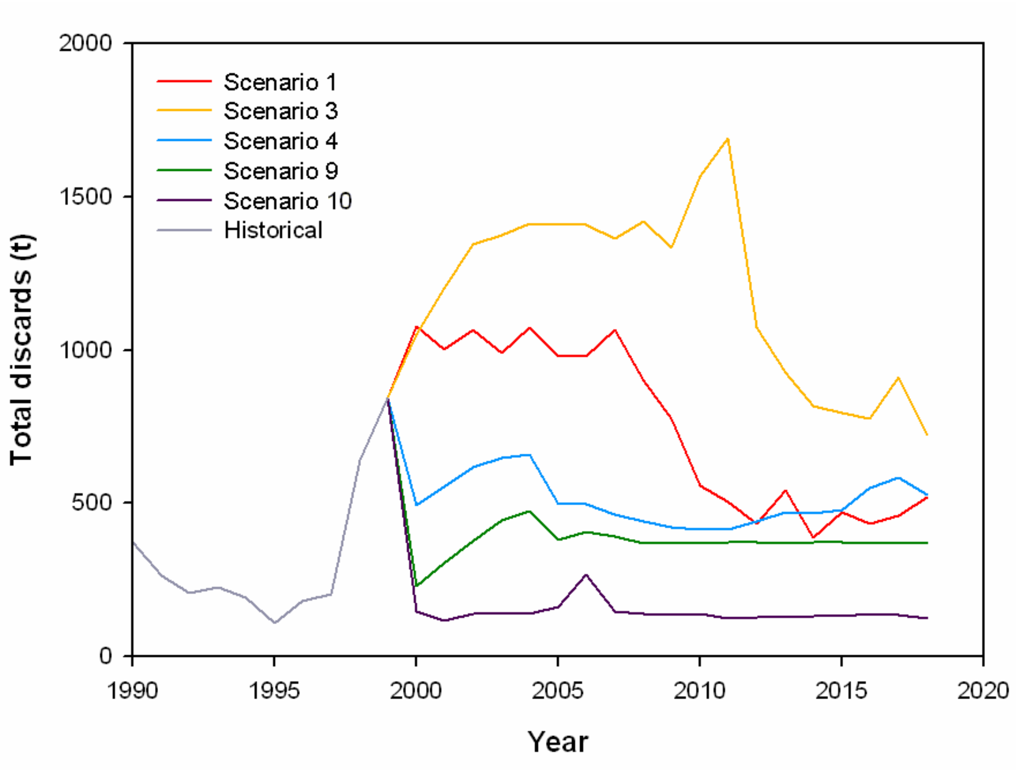


Figure 5-24: Total discards of non-habitat groups in the GABT sector under the alternative management strategies.

(a)



(b)

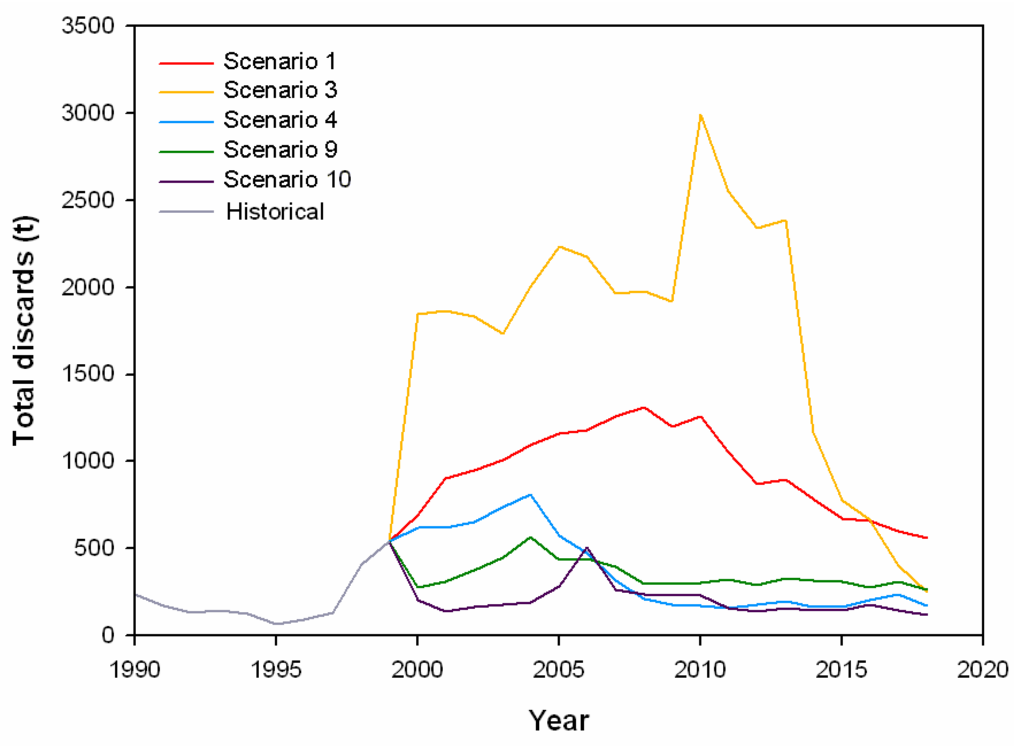


Figure 5-25: Total discards of non-habitat groups in the main components of the GHAT sector under the alternative management strategies: (a) longline and (b) gillnet.

Discards of Key Target Species

Discards of specific groups are shown on the catch plots (Figures 5.8-5.17). The discarding rate for tiger flathead (Figure 5.8) remains fairly constant throughout the simulation under Scenario 9 (and 10 where discarding is outlawed). High grading and target shifting sees a slight increase in the discards periodically under Scenario 4, but leads to a marked increase through the course of the run of Scenario 3 (where the rate doubles from the beginning to the end of the Scenario). The changing fisheries dynamics under Scenario 4 means the rate is actually quite variable, though it never drops to negligible levels. It is actually only under Scenario 1 that the discarding rate consistently declines through time for tiger flathead, as a direct result of changing targeting and discarding practices, smaller fish being considered more and more acceptable for landing as the larger size classes drop out of the population. While this shift in size structure is also seen in the other scenarios with much higher catches, other considerations are also in play so the resultant discard rate patterns differ. The general pattern of deepwater flathead discards (Figure 5.9) is similar to that of tiger flathead across the scenarios; and these patterns have the same drivers for both species. The magnitude can be quite different, however. Under Scenario 10 the ban means the discards are miniscule, but under the other Scenarios the discards could be quite high, ending at a similar level (550-700t) in Scenarios 1, 3, 4 and 9.

Discard rates remain fairly constant in all scenarios for blue grenadier (Figure 5.10), though they decline a little (by 10% or less) in Scenarios 1 and 3. The discards are also fairly constant through out the projections for pink ling (Figure 5.11), although in this case this is because they drop to negligible levels within the first year and remain that way throughout the course of the simulations. This is also the case for blue-eye trevalla (Figure 5.12) and orange roughy (Figure 5.13).

The discards of gummy shark (Figure 5.14) are different between the scenarios. For Scenarios 1 and 9 there is little change through time, but for Scenario 4 there is a substantial increase (by as much as ten-fold) in the later part of the simulation, because the majority of the biomass interacted with by every fleet is discarded (as no remaining quota is available). In reality discard rates maybe a good deal lower than seen here as it is likely that the fishers could become quite adept at selectively targeting to minimise unwanted gummy shark catch (there is flexibility to this end in the model, but not nearly enough compared to reported reductions in real world school shark bycatch, Pribac *pers. com.*). The pattern of discards for Scenario 3 is a little more complicated, dropping by 40% through the mid years of the run as more of the biomass contacted is landed as fishers (especially in the GHAT) attempt to improve economic returns. After the fleet reduction around the midpoint of the simulation the rate of discards begins rising again as the fishers are economically motivated to shift targeting more to gummy shark while also being more selective in what is landed, rising back to historic levels by the end of the simulated period. This pattern of shifting discard rates (declining and then increasing to historical levels) is also seen for school shark in Scenarios 1 and 3; whereas a simple decline (by 30-35%) in the discard rates of school shark is seen under Scenarios 4 and 9 (Figure 5.15).

The discard rate of small pelagics remains fairly stable in Scenarios 9 and 10, whereas it increases markedly (by as much as four-fold) in Scenarios 1, 3 and 4 (Figure 5.16). This increase occurs primarily in the trawl fisheries and at about the same time as the fleet restructuring (which coincides with other large changes in targeting, such as the jump in squid landings or the peaks in catches of some of the fin-fish). It is a reflection of shifting targeting priorities that either see small pelagics targeted directly (with some increase in discarding as a result) or see the fleets (particularly the trawl and squid-based fleets) behave in such a way (spatially and temporally) that they interact more frequently with schools of small pelagics. It is likely that this over states the discarding of small pelagics, as fine scale targeting (which can not be captured in Atlantis) would reduce the frequency of these kind of interactions. A slight decline in the rate of discarding of small pelagics begins in the medium term, but this in no way approaches the original discard rates. The shift in squid discards (Figure 5.17) is much smaller, with little change occurring through the course of the simulations, increasing by 10% in Scenario 4, but dropping by as much in all other cases (including Scenario 10 where discards were unregulated for this group).

5.1.3 Effort

The resolution of Atlantis SE means that reporting of effort must be in terms of days at sea rather than shots, lifts, kilometres of line or net, or numbers of hooks (e.g. Walker *et al* 2003). This means that while patterns should look similar to the more familiar effort plots from assessments and AFMA reports given in terms of shots, the steepness of the plots may differ. This is particularly the case for the trawl fisheries where the effort in terms of days at sea has risen more steeply in the last 15 years than effort in terms of shots (Figure 5.26).

Overall levels of effort (Figure 5.27) under Scenarios 1 and 3 remain at about the levels seen in 2000. The total effort seen in Scenarios 4 and 10 drops more quickly, stabilising at about 65% of the level seen in 1999-2000. The effort levels seen under Scenario 9 are lower still – dropping immediately to about 50% of the historical levels and only declining slightly from this point through the remainder of the simulated period. This suggests total effort in the SESSF may have peaked (or be close to peaking), though there is potentially scope for the fisheries treated here as static forces (i.e. non-dynamic fisheries such as the state fisheries or commonwealth tuna fisheries) could expand there effort levels and impacts on the system.

The match of the model with the dynamic GABT sector is reasonably close, especially through the final years of the historical period (Figure 5.28). In no case was there an increase in the number of boats in this sector, instead the days per boat shifted through time. The effort levels initially realised in this sector under Scenario 1 are of the magnitude actually observed since 2000. After 2009 these effort levels rise steeply and by the end of the simulation they have

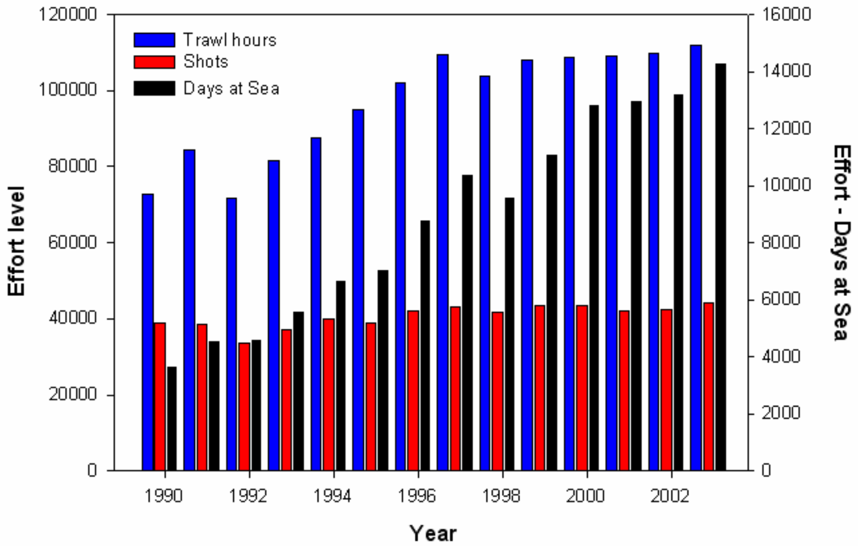


Figure 5-26: Comparison of observed historical effort in the SET in terms of hors trawled, number of shots and days at sea.

reached nearly 800 days at sea (growing by 5% or more per year). The effort levels seen initially under Scenarios 3 and 10 are not quite as high as those under Scenario 1. However, while the trajectory of effort under Scenario 3 is similar to Scenario 1 (ending a little lower at 746 days at sea, but growing almost twice as fast at that point) the Scenario 10 shows no such increase; remaining between 400 and 500 days at sea for the entire period. The trajectories of GABT effort under Scenarios 4 and 9 are also reasonably flat – Scenario 4 showing no increase in effort from the 2000 level, while that under Scenario 9 drops immediately to about 100 days at sea per year and declines slightly (by less than 10%) during the rest of the simulation.

In the southeast trawl sector the match between historical effort levels and those predicted by the model is fairly close, though it misses the detail of the year to year fluctuations, capturing the trends instead (Figure 5.29). The predicted levels of effort under Scenario 1 match those reported in reality, whereas, the effort under Scenario 3 begins a little lower, about 12500 days at sea. Both Scenarios 1 and 3 see a steep decline after 2009 as a large number of boats exit the sector (in just a few years), both Scenarios dropping to end at about 6700 days at sea. The level of effort initially seen under Scenario 10 is 35% lower than under Scenario 1, but sits a bit above that predicted under Scenario 4. The trajectories of Scenarios 4 and 10 are fairly similar though, both declining around 2005 (as a number of vessels leave the fishery within a 4 year period) and ending roughly between 4500 and 5000 days at sea. The effort reduction under Scenario 9 is much more severe, dropping by more than 80% as the strategy begins, and declining still further to end at 1290 days at sea per year (less than 10% of the level in 1999). Looking at components within the SET, the deep water trawl sector is most impacted. In all scenarios their level of effort drops off by as much as 70% through the course of the simulation.

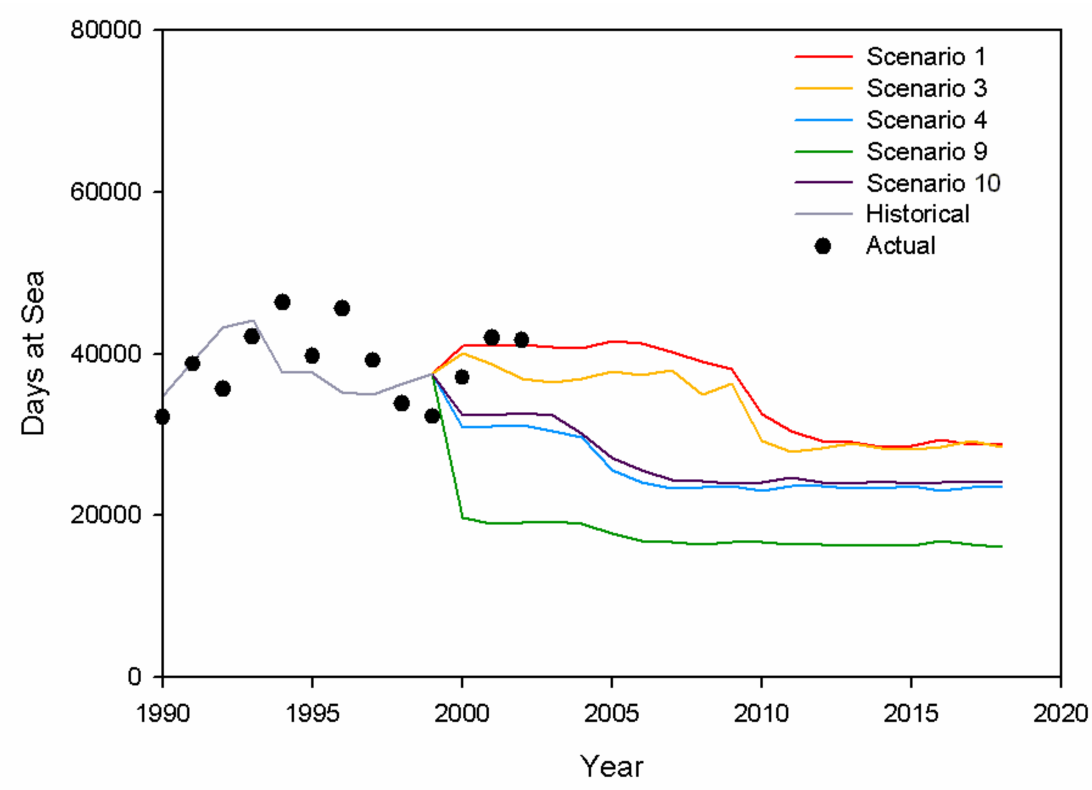


Figure 5-27: Total overall effort (including the static state fisheries) under the alternative management strategies and as seen in actual observations and under historical simulations.

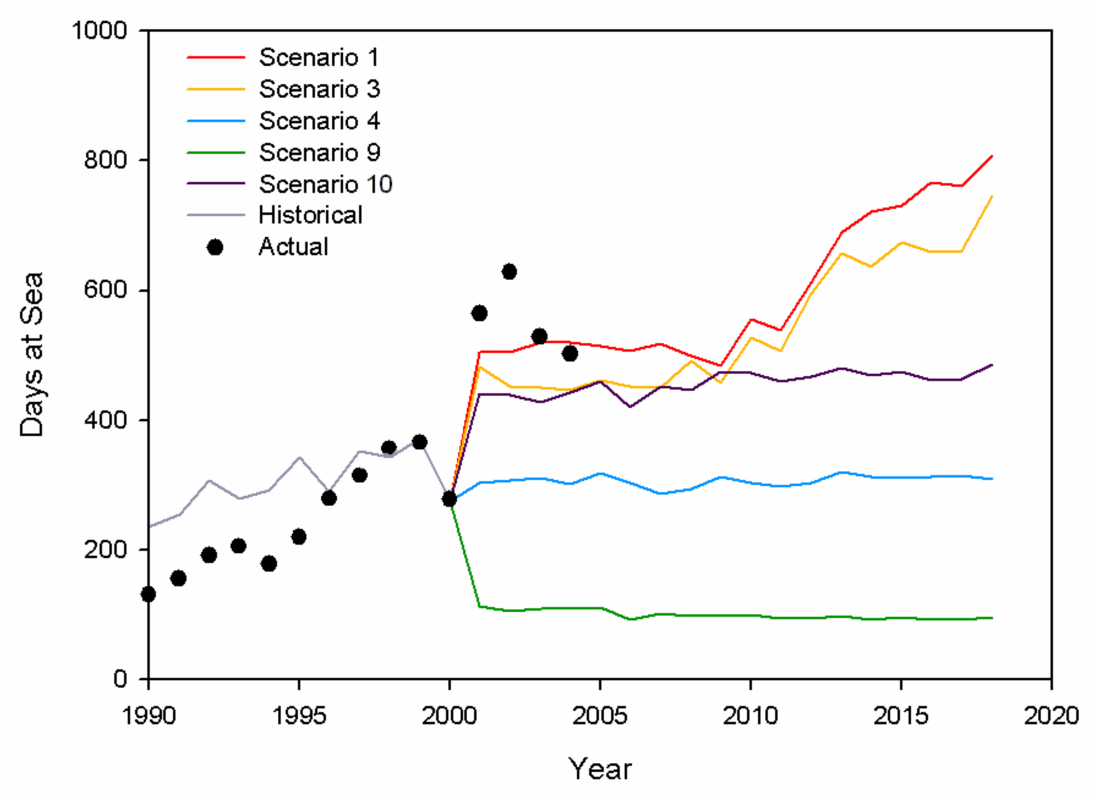


Figure 5-28: Total GABT effort under the alternative management strategies and as seen in actual observations and under historical simulations.

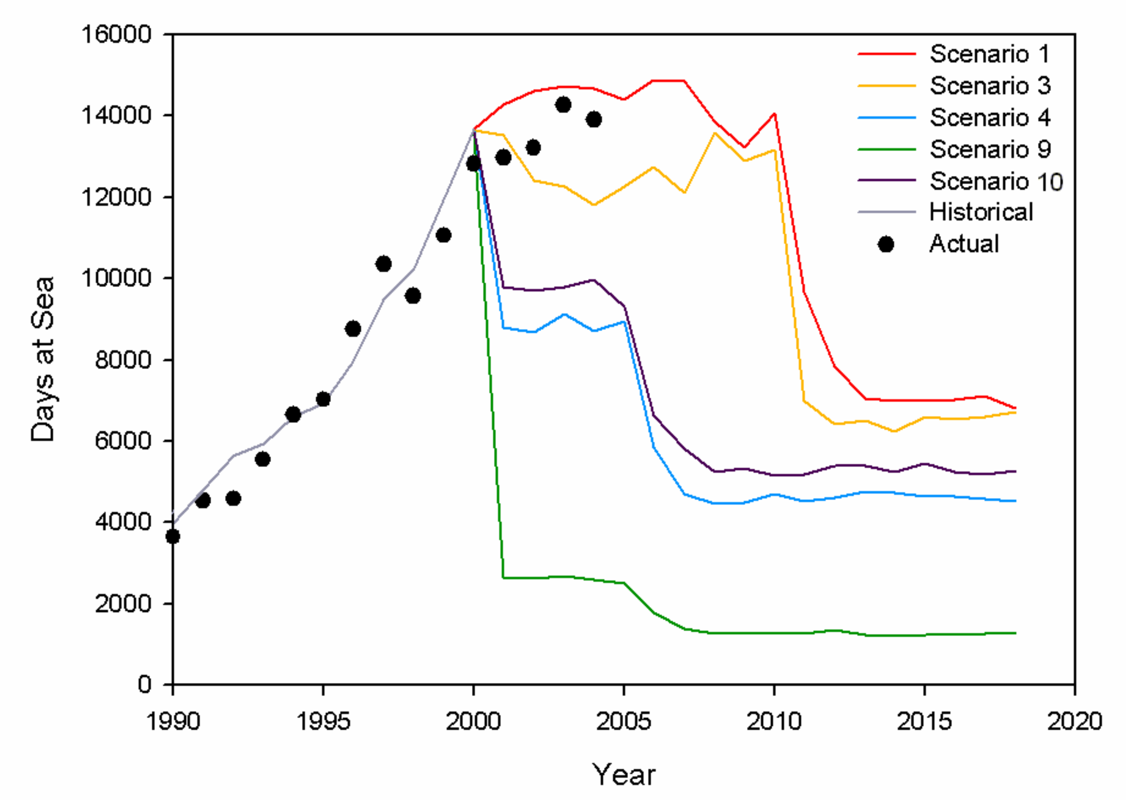
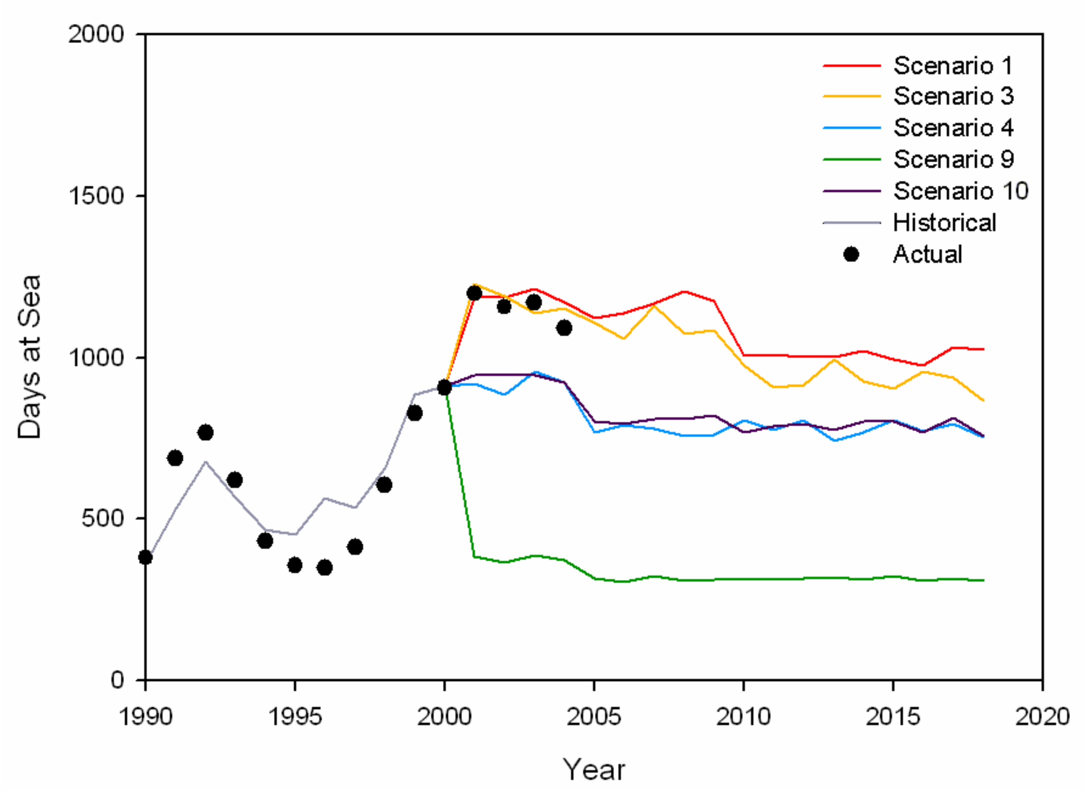


Figure 5-29: Total SET effort under the alternative management strategies and as seen in actual observations and under historical simulations.

The effort trajectories for the GHAT sector (Figure 5.30) are reasonably close to those seen in reality, though they tend to over estimate the level of effort, particularly for longline during the in the mid 1990s. Within the projection period the predicted level of longline effort in Scenario 1 and 3 are close to that observed 2000-2004; similarly, the longline effort observed in Scenarios 1, 3, and 10 bracket the actual gillnet effort reported in 2000-2004. The effort for Scenario 4 is about 10-25% lower for gillnet and 25-30% for longline. From this point these effort trajectories all eventually decline. Effort under Scenario 1 remains high until boats start leaving the fishery; gillnet effort declining by more than 30% to a new level of around 4300 days at sea per year, while longline effort drops by 18% to around 1000 days at sea. The drop off in effort under Scenario 3 is spread over a longer period, and fluctuates more from year to year, for both gillnet and longline fleets. The final level of effort however, ends up about the same as that seen under Scenario 1. For both gillnet and longline, the effort trajectories in Scenarios 4 and 10 are very similar to each other, with both declining as boats exit the fishery after about 5 years; longline effort ends with roughly 750 days at sea per year and gillnet ends with effort at about 3700t. The realised effort levels under Scenario 9 are much lower for both gillnet and longline (and the GHAT overall) – only 3148 days at sea in the first year for gillnet and 384 days for longline, declining still further to around 2300 days at sea for gillnet and 300 days for longline by the end of the simulation. The proportion of the effort in the GHAT made up of auto-longline vessels stagnates at 2000 levels throughout the simulations under Scenario 9, but grows slowly (by 5-20%) in the other scenarios.

Given the aggregate nature of the polygons used to create the 3D space in Atlantis SE there is the potential to be sensitive to splits that would occur midway through a box. This is nowhere as strong as in the match between the predicted effort levels in the GABT and those seen in reality depending on whether the spatial box off Kangaroo Island (box 6) is considered to be in the GABT or the SET (in reality it is partially in both). The model was trained assuming box 6 is within the SET (black dots in Figure 5.31). This means the results are substantially different from those one would expect if the box was instead grouped with the GABT (red dots in Figure 5.32). It is likely (though untested) that if trained with the dataset with this alternative grouping the results would shift to look more like that dataset. This kind of sensitivity is important for the realised magnitude of results, but is unlikely to affect the relative ranking of the results (the most important information to come from this kind of analysis). The sensitivity of this grouping is also much lower in the SET (Figure 5.32).

(a)



(b)

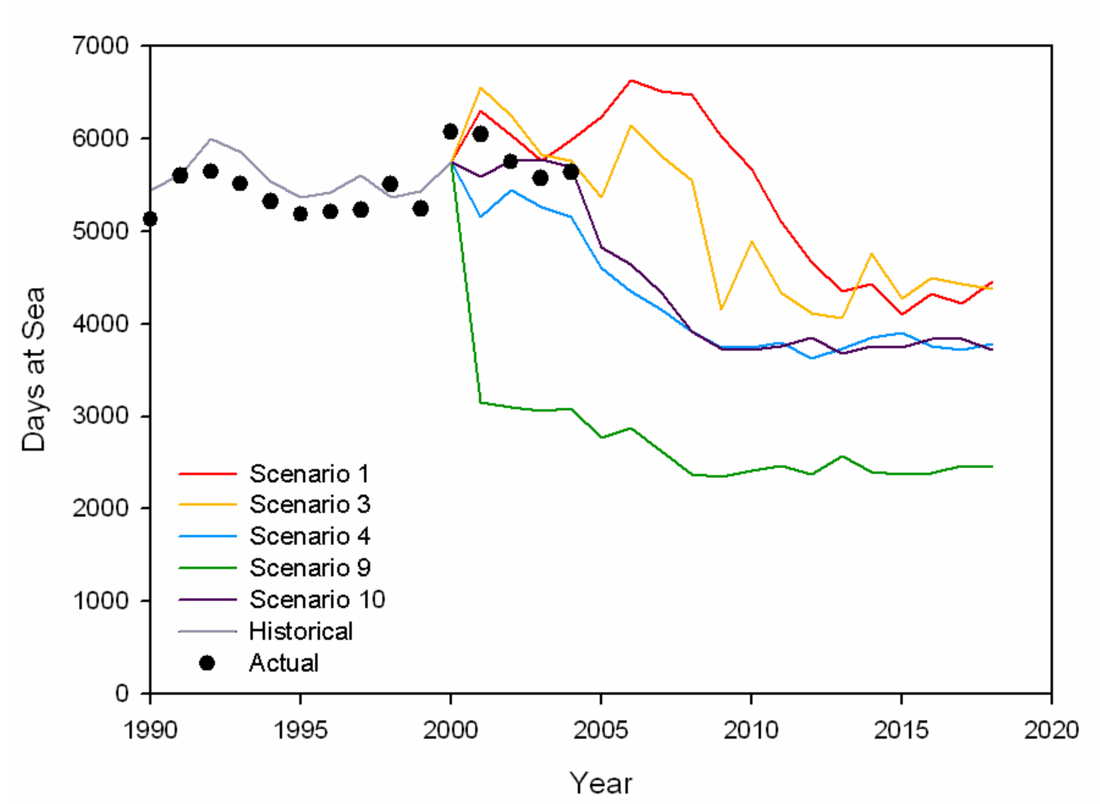


Figure 5-30: Total effort by the major components of the GHAT under the alternative management strategies and as seen in actual observations and under historical simulations: (a) longline and (b) gillnet.

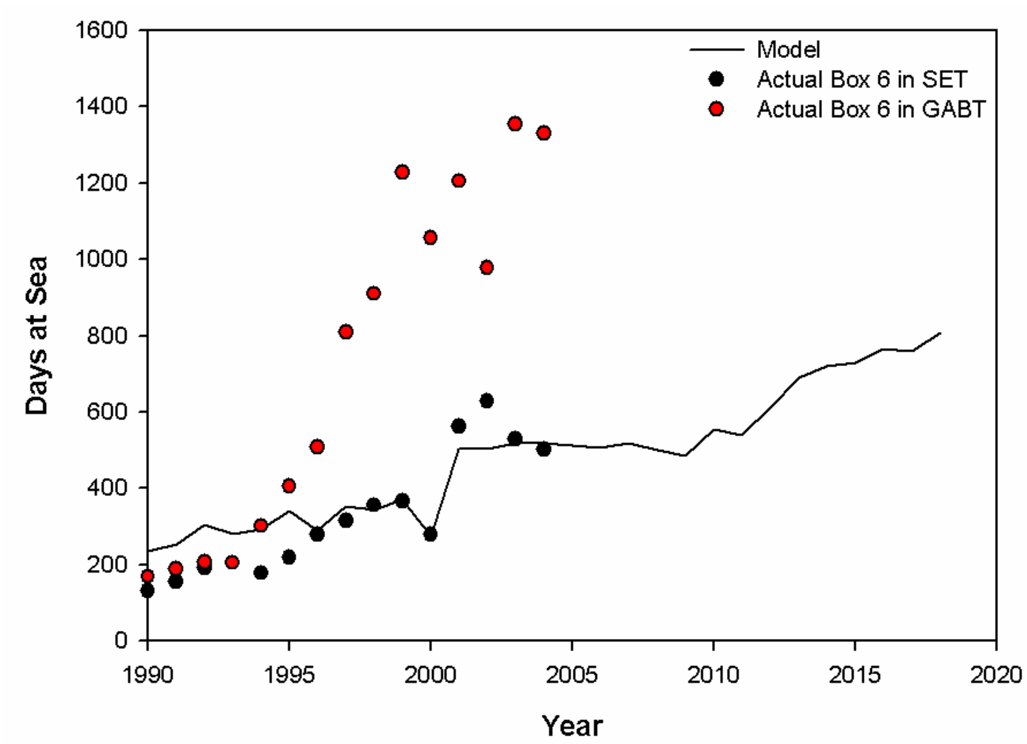


Figure 5-31: Total GABT effort in the model (solid line) and observed when the area off Kangaroo Island (box 6) is grouped with the SET (black dots) or the GABT (red dots).

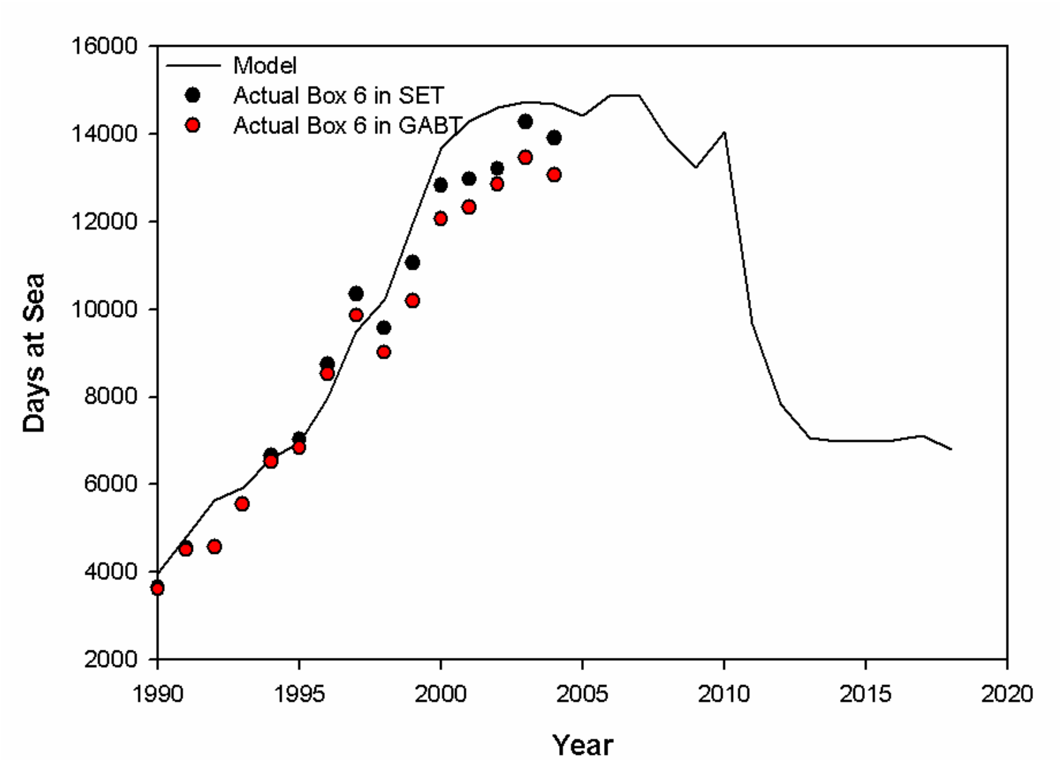


Figure 5-32: Total SET effort in the model (solid line) and observed when the area off Kangaroo Island (box 6) is grouped with the SET (black dots) or the GABT (red dots).

Effort by Box and Depth

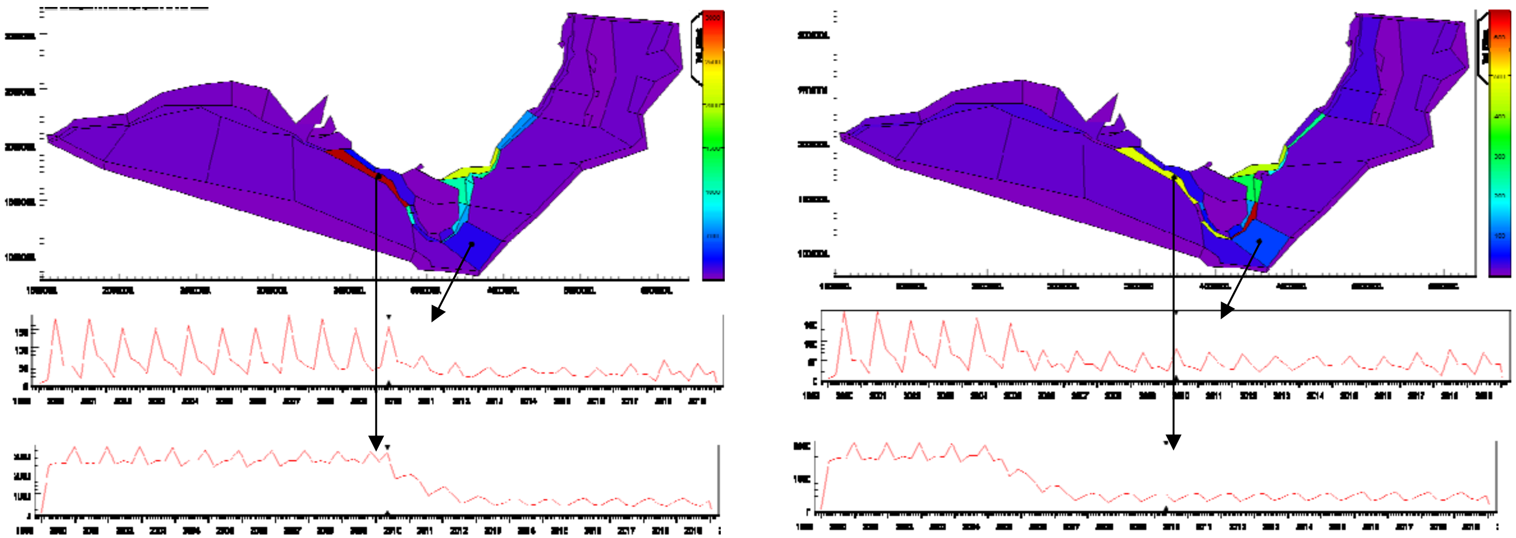
The distributions and patterns of change in the spatial distribution can be quite dynamic (see the time series from the general demersal trawl effort under Scenario 1 that is given in Figure 5.33). The general patterns match those discussed above for the catch taken by that effort. The same expansion (and then subsequent contraction, for the deepwater fleets) are seen under Scenarios 1 and 3 (particularly under Scenario 3 where the deepwater fleets try to establish across the GAB before ultimately pulling back to concentrate most on the waters around Tasmania). Under Scenario 4, effort is displaced by the large scale closures, before it leaves the fishery entirely. While under Scenario 9 any bottom contact effort is highly constrained (and redirected) by the paddock system.

As seen in the catch distributions, the potentially unexpected consequence of the banning of discards is the often shorter distance between harbour and fishing grounds – this is not universally true across all sectors, but it is a fairly common response. In the cases where this does not happen, effort is instead concentrated on the most lucrative grounds (the fishers “first choices”). At a subfleet level this can see the effort distributed quite differently under this Scenario in comparison to any of the other Scenarios (see Figure 5.33). The impact of this redistribution can be local stock depletion, which in turn forces some of the fleet components further a field - damping the magnitude of this pattern into the longer term.

As is the case in reality there can be strong seasonal shifts in effort distribution, particularly around western and southern Tasmania. The size of these shifts (either in their magnitude or the period of time spent in the area in the season) varies through the course of the simulation and is dependent on the gear type. This behaviour is particularly strong amongst the larger trawl vessels and the longline fleet components. The longline in particular shifts its relative distributions quite heavily throughout the year and through time, coming to spend increasing amounts of time off the waters of Tasmania. Longlining is the broadest ranging of the gear types, eventually exploring every box and every depth level with targetable catch. In many instances (particularly in the deepest or most distant boxes) this effort level never rises much above an exploratory level, but it is significantly higher and more widespread a practice than for any other fisheries sector.

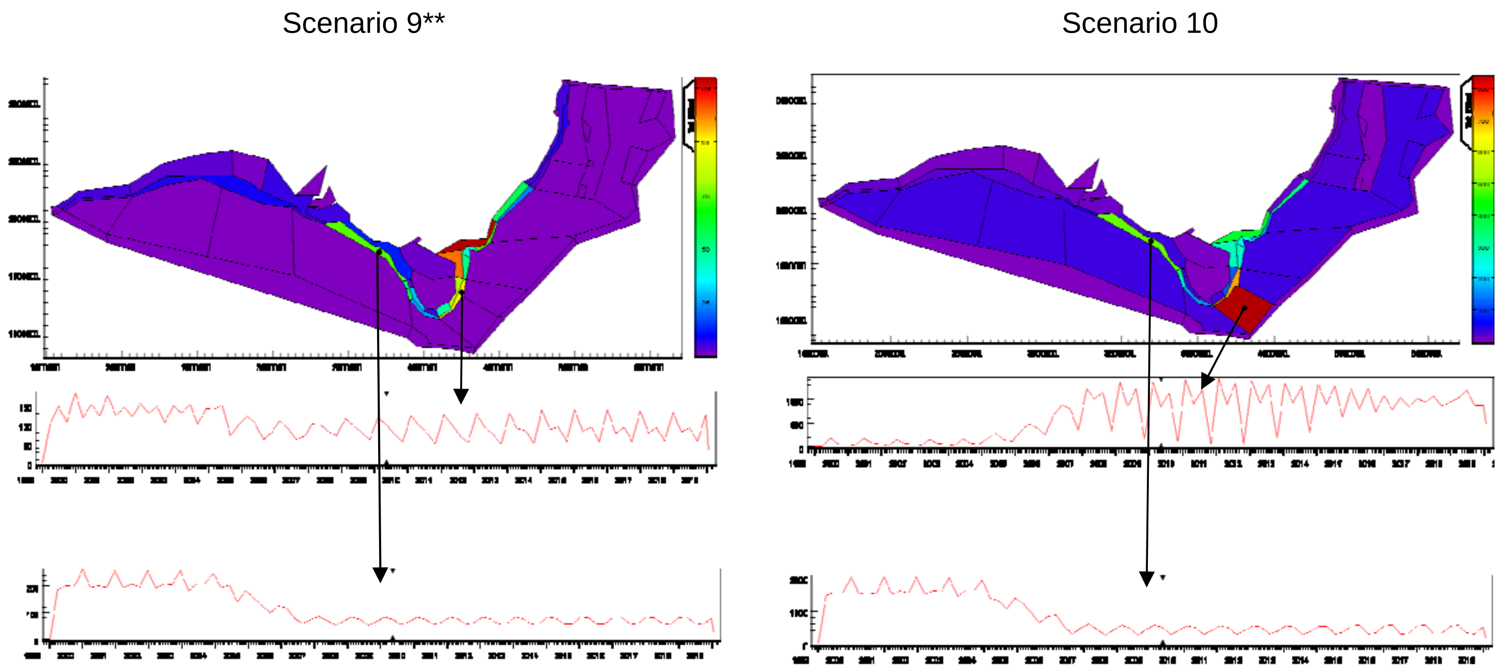
The proportion of effort applied in each effort band was compared with the observed values provided in Walker and Gason (2007). The effort in each depth band varied through time, finally stabilising around the proportions given in Figures 5.34-5.38 (the effort distribution in the final year of the projection period). The distribution by depth of gillnet effort (Figure 5.34) did not change substantially in any run, the biggest shift being in scenario 3, where gillnetting was banned in waters deeper than 200m. The depth distribution of shark longlining (Figure 5.35), as distinct from auto-longlining, was fairly similar in all runs (peaking in the 200-600m depth range); scenarios 1 and 10 remained very similar to the observed distribution, while the other scenarios saw a 5-10% reduction in the proportion of effort in water <200m, which shifted to the 200-600m range. In addition, there was effectively no shark longlining in the deepest depths under scenario 9. There were much stronger differences between the observed and simulated distributions of auto-longlining effort (Figure 5.36). In all cases the strongest peak is in the depth range 200-600m. Due to the issue of model resolution discussed previously, the model also predicts that roughly 8-16% of the auto-longline effort will be in waters < 200m, with the exception of scenario 3 where all effort is in waters >200m. Alternative model geometries that resolve the depth strata more tightly may see more of the scenarios (particularly.

Scenario 1* Scenario 4



* the pattern for Scenario 3 is very similar, just of greater magnitude

Figure 5-33: Maps and time series of effort (days at sea) from the general demersal trawl components under the alternative management strategies. The small black triangles on the time series indicate the point at which the snapshot map was taken. The see-saw pattern in the time series reflects seasonality in combination with the quarterly resolution of the output record.



** A slightly different box is used here as no effort is allowed on the plateau box in this Scenario

Figure 5-32: Continued.

scenarios 4 and 10 where auto-longlining is banned in waters <180m) predict distributions more like that of scenario 3 (Figure 5.36).

Some of the most interesting shifts in the allocation of effort by depth is in the trawl sectors. In the SET the observed effort (Figure 5.37) is 10% higher in waters <200m than in the depth band 200-600m, though both are much higher than the depth allocated to the deepest waters. The model predicted effort allocated to the first two depths (0-200 and 200-600) is about even in all the scenarios and usually much higher than that seen in waters >600m (in many scenarios this is due to restricted access to waters deeper than 700m). Scenario 1 is the only scenario where there is a strong rise in the proportion of effort allocated to deeper water (where it rises by 1.5x due to an expansion of the effort footprint), though there is also a small increase in scenario 10 (where boats on trips to target deep water groups go straight to preferred fishing grounds rather than risk slightly shallower exploratory trawls, given the ban on discarding of quota species). In the other scenarios the proportion of effort in the deeper water drops as effort shifts to shallower waters - particularly to the 200-600m depth band. In the GABT (Figure 5.38) the distribution of effort in Scenarios 1, 4 and 10 show a similar distribution to that observed 2000-2006, but with a greater proportion of the effort allocated to the 200-600m range (particularly at the expense of the effort applied in waters less than 200m). Scenario 3 also shows a distribution roughly like that observed in recent years (with effort tailing off with depth), but there is a much stronger increase in the proportion of effort applied in the intermediate depths, driven by a ban in trawling in waters shallower than 170m. The greatest shift in the distribution of effort in the GABT is under scenario 9, where effort applied in the shallow and intermediate depths are almost equal; this is due to the interaction of regulation (which is particularly strong in waters <150m) with optimal effort distributions based on CPUE and travel costs.

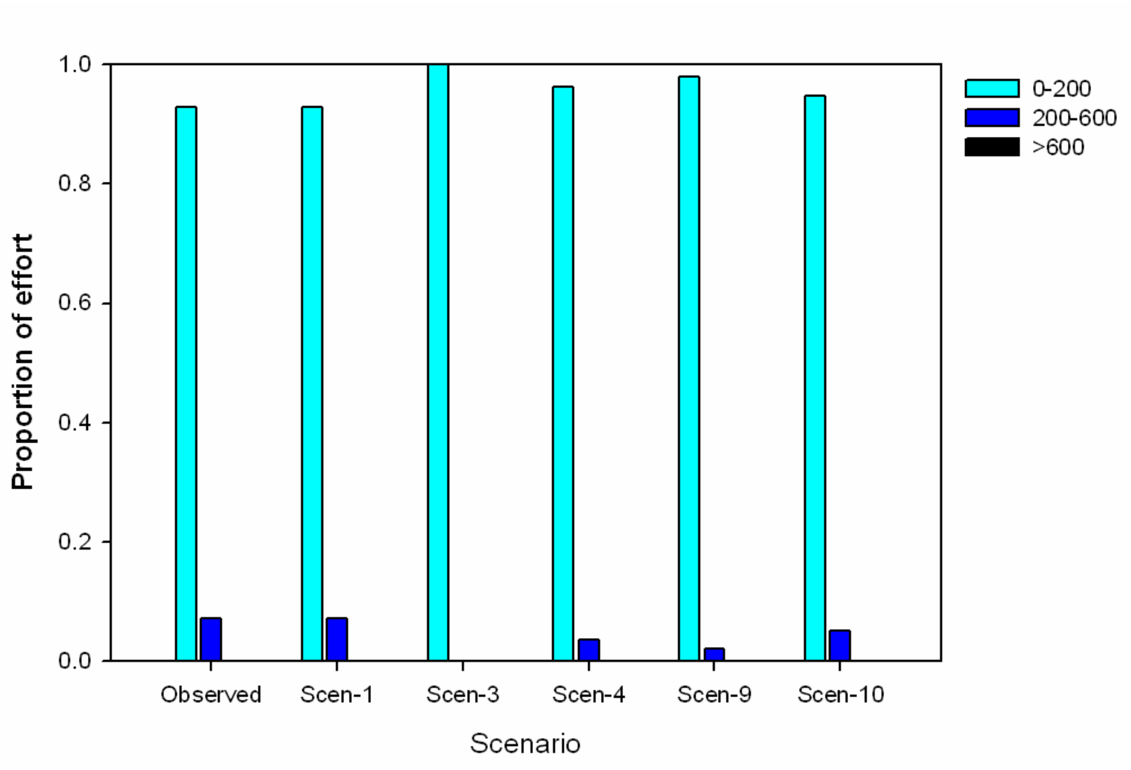


Figure 5-34: Proportional distribution of effort by depth for gillnets.

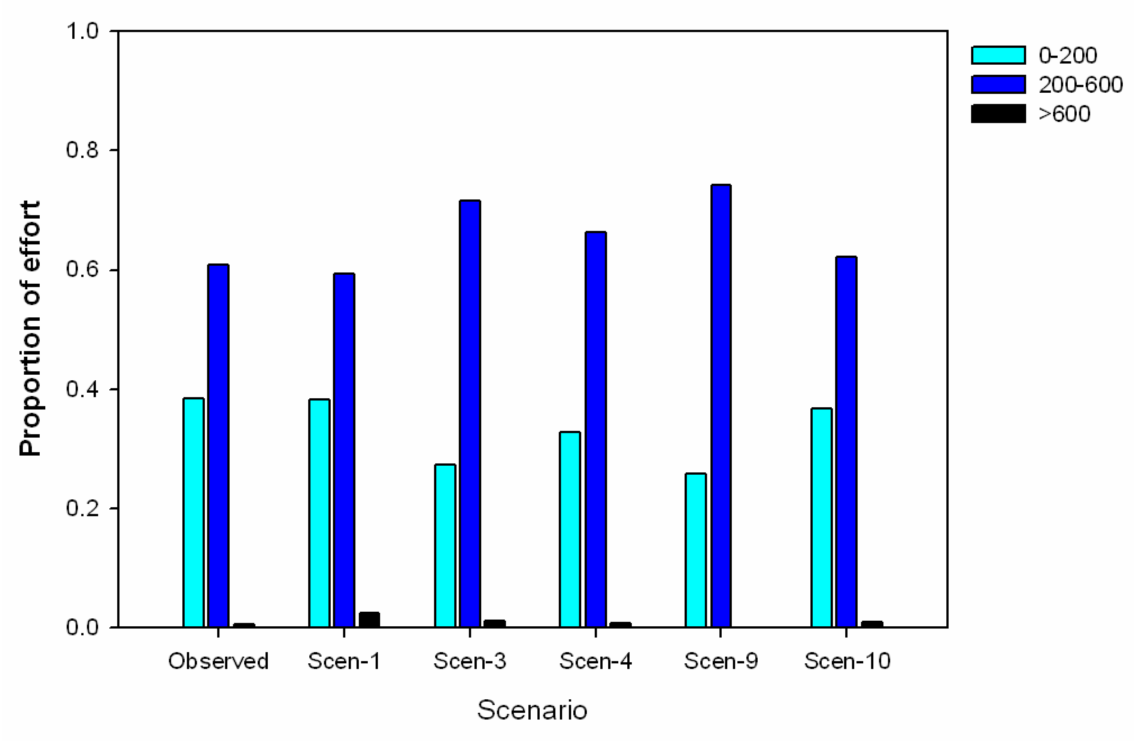


Figure 5-35: Proportional distribution of effort by depth for shark longlines.

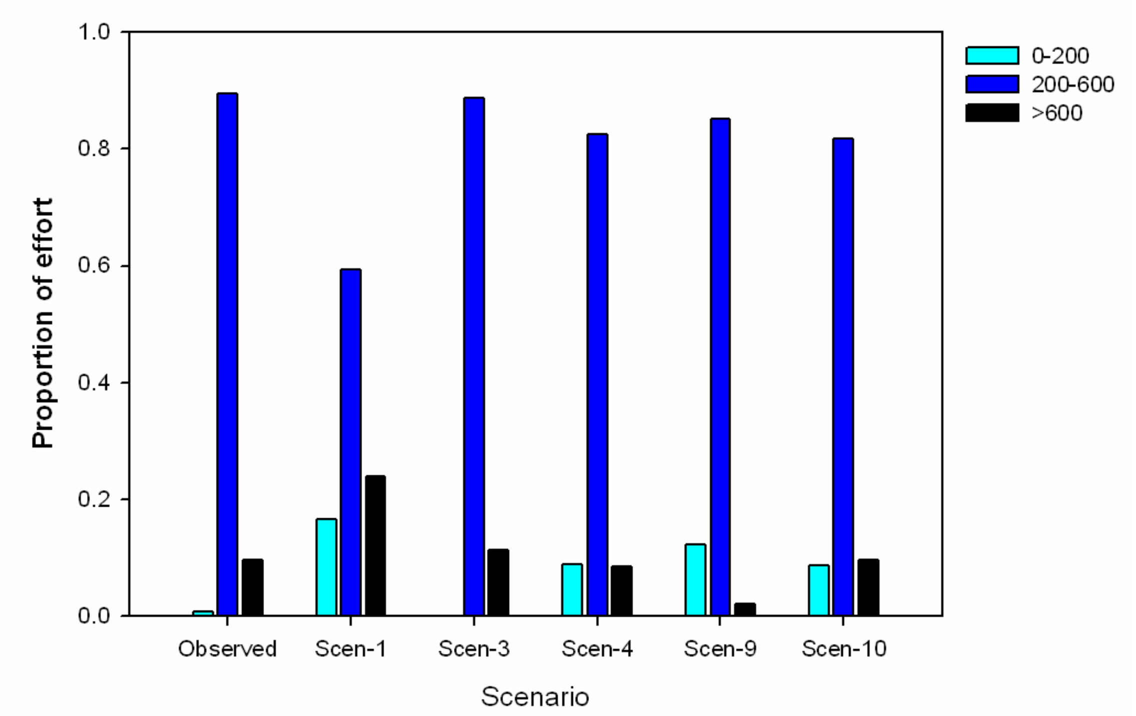


Figure 5-36: Proportional distribution of effort by depth for auto-longlining.

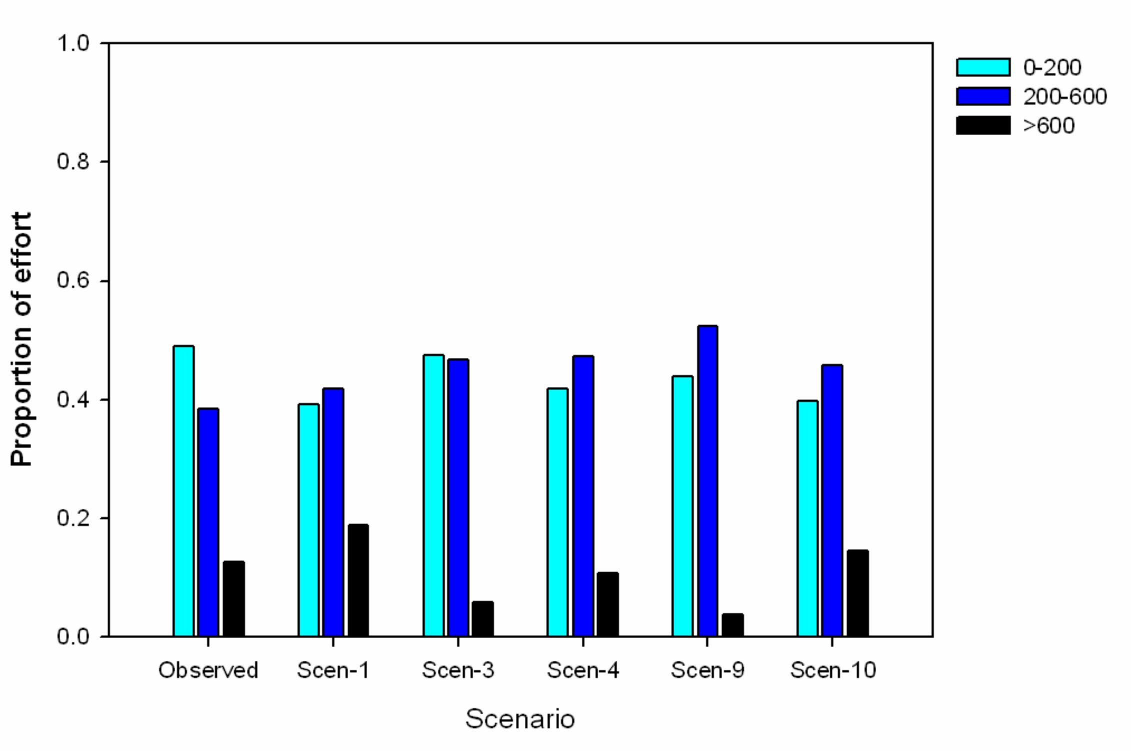


Figure 5-37: Proportional distribution of effort by depth for the SE trawl.

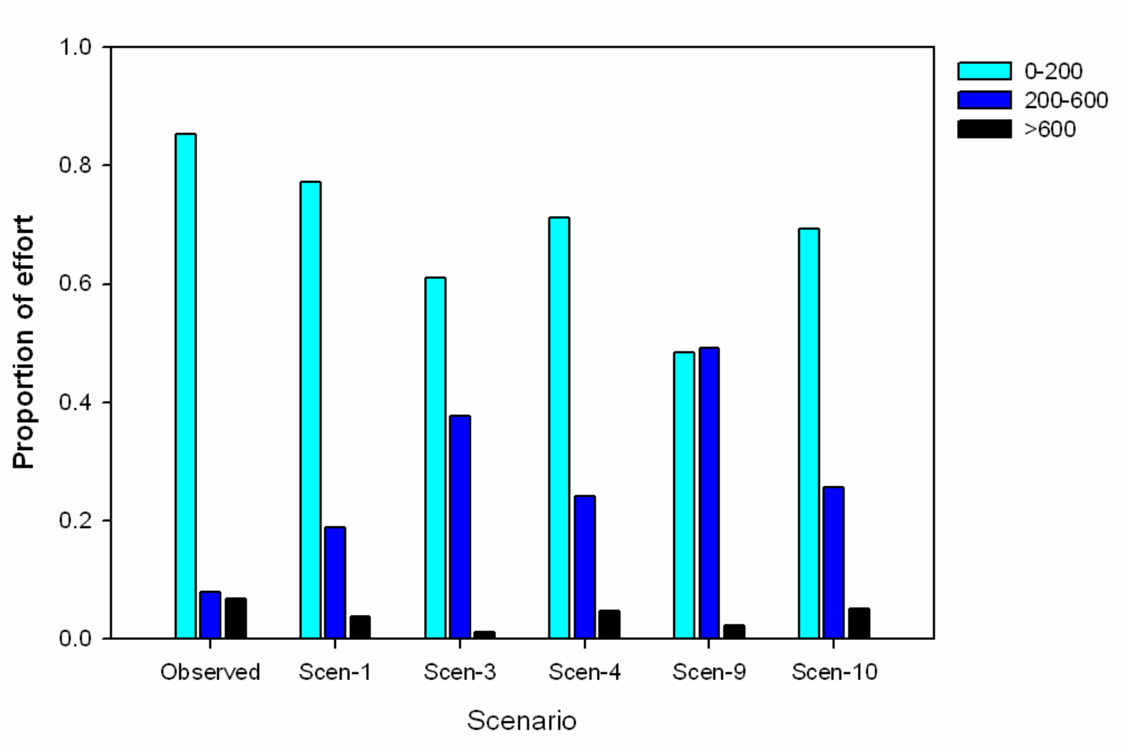


Figure 5-38: Proportional distribution of effort by depth for the GAB trawl.

Fleet Size and Average Size of Boats

The model predicted fairly steep eventual reductions in effort under all scenarios, with many fishery components contracting in size by 50% or more. Some of the smaller components remained untouched, but the bigger sectors, like trawl and gillnets were fairly heavily impacted (dropping to as little as a third of their starting numbers).

In all scenarios the pattern of changing boat size was the same, though the trawl sector under Scenario 9 was more heavily impacted than in the other scenarios. No fleet grew in any Scenario, rather it was a case of some fleets remaining stable while others declined at different rates depending on the constraints placed upon them by the regulations and system state generated under the alternative scenarios. When boats were lost in each case the numbers and timing may have varied somewhat, but the vessels consistently fell out of the same subfleets (the same vessel size classes) across the scenarios (Table 5.3). Smaller fishery sectors were less heavily impacted than large fleets or components with a lot of competing vessels. Interestingly, in all cases it was the smaller vessels that suffered more heavily, as they did not have the same degree of flexibility in modifying their behaviour and acting opportunistically as conditions changed. This was not expected as lower costs were thought to favour the long term survival of the smaller vessels. The trawl fisheries see more vessels exit than the other gears, though some sectors and components are more heavily impacted than others – for instance the GAB sees a (largely) constant fleet size (except under Scenario 9), while the SET declines by two thirds or more. Ultimately these changes in vessel numbers per subfleet mean that for all fleets and components, other than the roughy trawl fleet, the average size of the vessels remaining in the fishery rose. While Danish seine vessels only increased in average size by 5%, the shark gillnet fishery saw average boat size increase by 9% and the trawl fishery components had average boat size increasing by 10-15%. The fishery component that starts out as a roughy oriented trawl fishery (switching targets as this species becomes increasingly hard to access) sees a wider range of vessel sizes dropping out and so the overall average vessel size drops by 5%.

The timing of the fleet reductions also differs between the models. The reductions in fleet size in the standard form of Scenarios 1, 3, 4 and 10 all result from economic decisions. Scenario 9 is the only scenario with a dedicated buyback as standard (after 5 years), though variants of Scenarios 4 and 10 that include a buyback have been run. The management restrictions in Scenarios 4 and 10 see vessels leave the fishery within 4-7 years of the simulation beginning, though as noted elsewhere those that remain are confident enough about the state of the system into the future to invest in new vessels and upgraded gear. In contrast, there is no investment under Scenario 1 and only small levels of investment under Scenario 3, with vessels continuing under increasing economic pain for a decade or more before falling out of the fishery. The management strategies employed in Scenario 3 do mitigate the problems a little, seeing the vessels last a couple of years longer before making the decision to exit the fishery. The variation in the period taken for vessels to leave the fishery reflect the overall fleet size of that component, with the few boats that leave the smaller fleet components doing so quickly, while the larger numbers leaving the larger fleets tailing out over a longer span (a rapid initial drop off ending in a drawn out tail of vessel exits).

Table 5-3: The proportion of dynamically modelled boats remaining in the fishery per gear type, with the starting year and period of time the vessel exits span given for reference. Note this represents real boat losses from the overall fishery rather than gear switching, which is discussed separately elsewhere in the text.

	Fin-fish Longline	Fin-fish Mesh-net	Shark net	Shark Longline	Small pelagic	Midwater trawlers[1]	RRP Trawl	Danish Seine	GAB Trawl	SET Trawl	Roughy Trawl
All sizes handled together	0.45	1	-	0.5	1	0.5	0.375	-	-	-	-
<30m	-	-	0.3	-	-	-	-	0.32	1	0.33	0.43
30 – 40m	-	-	1	-	-	-	-	1	Scen 9 0.4 Scen 4 0.9 Other 1	Scen 9 0.25 Other 0.36	0.33
> 40m	-	-	1	-	-	-	-	-	1	1	0.33
> 50m	-	-	-	-	-	-	-	-	1	1	-
Start Year[A]											
Scen1											
Scen3	11	-	10	12	-	10	11	12	-	10	9
Scen4	12	-	12	13	-	10	11	14	-	13	11
Scen9	6	-	5	5	-	4	6	7	8	6	5
Scen10	5	-	5	5	-	5	5	5	5	5	5
	5	-	5	5	-	6	5	7	-	6	5
Exit Period[B]											
Scen1	2	-	4	1	-	1	3	5	-	4	3
Scen3	2	-	3	1	-	1	3	7	-	5	2
Scen4	2	-	4	2	-	1	3	3	1	4	4
Scen9	1	-	5	1	-	1	3	4	4	8	2
Scen10	3	-	4	1	-	1	3	4	-	3	3

A. The year when the largest number of vessels left the fishery.

B. Number of years over which the vessels left the fishery

Area Fished and Distance Travelled

The footprint of the fisheries shifted through the course of a simulation, with the size of the footprints often dependent on the gear type. The end point footprints (lumped) by gear are given in Figure 5.39. The trawl and longline fisheries had a wider reach than the gillnet fisheries. The trawl fishery did enter the deeper waters, but was actually more restricted to shelf and slope waters, while the longliners were more apt to make repeat visits (though still small in number) to deeper waters. The absolute size (which incorporates effort levels per box) were largest under Scenarios 1 and 3 (the identity of the scenario with the largest footprint swapping back and forth often through the projection period). Average trip length continues about current levels (with some dips when fleet sizes drop), or grows smoothly from that level, for all fishery sectors except longlining where it increased sharply (doubling in 5 years) and continued growing smoothly from there (Figure 5.40).

The magnitude of the footprint under Scenario 10 is 15 – 40% smaller than the magnitude of the two "big signature" scenarios (Scenario 1 and 3). The biggest differences occur in the middle of the projection when effort in Scenario 10 has reduced but it still remains high under Scenarios 1 and 3. By the end of the projection period the magnitude of the footprint is about 80% of that seen in the other two Scenarios. This is due in part to lower overall effort levels, but also to contracted and shifted fishing grounds resulting from the ban on discarding. While the footprint under Scenarios 1 and 3 covered much of the model domain for longline and much of the shelf and slope for the trawl fisheries, under Scenario 10 the bulk of the SET effort contracts to either side of Bass Strait (skewed more to the east than the west) and around Tasmania (this can be seen to some extent in the example effort maps given in Figure 5.33). In contrast, the GABT effort footprint is not that different to what is reported now (and in Scenarios 1 and 3), though there is a small contraction eastward. The longline sectors in Scenario 10 explore as widely as in Scenarios 1 and 3, but they do not follow up and expand much on that exploration, while there is some expansion in the other Scenarios. Altogether this leads to a much smaller footprint and a smaller consolidated set of trip lengths under Scenario 10. It is not that overall steaming times are universally smaller in this Scenario, but they are drawn from a smaller potential set, at least in the short term. In the longer term there is some dissolution of this pattern as the fishers suffer effects of local depletion and crowding and so spread a little further a field (though not nearly as much as in Scenarios 1 and 3). Average trip length (Figure 5.40) is highly variable under this Scenario, dropping initially as the regulations drive shifts in fishing grounds (except for deep water trawl where there is a peak as they chase down the last fish). The average trip length grows again as local depletion sees the fisheries pushed further a field.

The overall footprint in Scenario 4 is substantially lighter (by 25-50%), but only slightly smaller in distribution than for Scenarios 1 and 3. It does not penetrate as far into the more marginal habitats for each fishery, nor does it penetrate quite as deep, but it does still span a significant part of the shelf and slope waters. Exploratory fishing reaches all but the most distant boxes, but it is not developed further. Similarly, longlining touches the entire model domain at some point, but is really only employed to any substantial degree in Scenario 4 in the eastern end of the GAB and in the waters off Tasmania and Victoria. The extent of the sector footprints in Scenario 4 means that while the average trip length time is about 50-75% of that under Scenario 1 and 3 (Figure 5.40), it is closer in magnitude and trajectory to Scenario 10. The maximum of the range of steaming times predicted by the model for this Scenario are as large as those in the other scenarios, however.

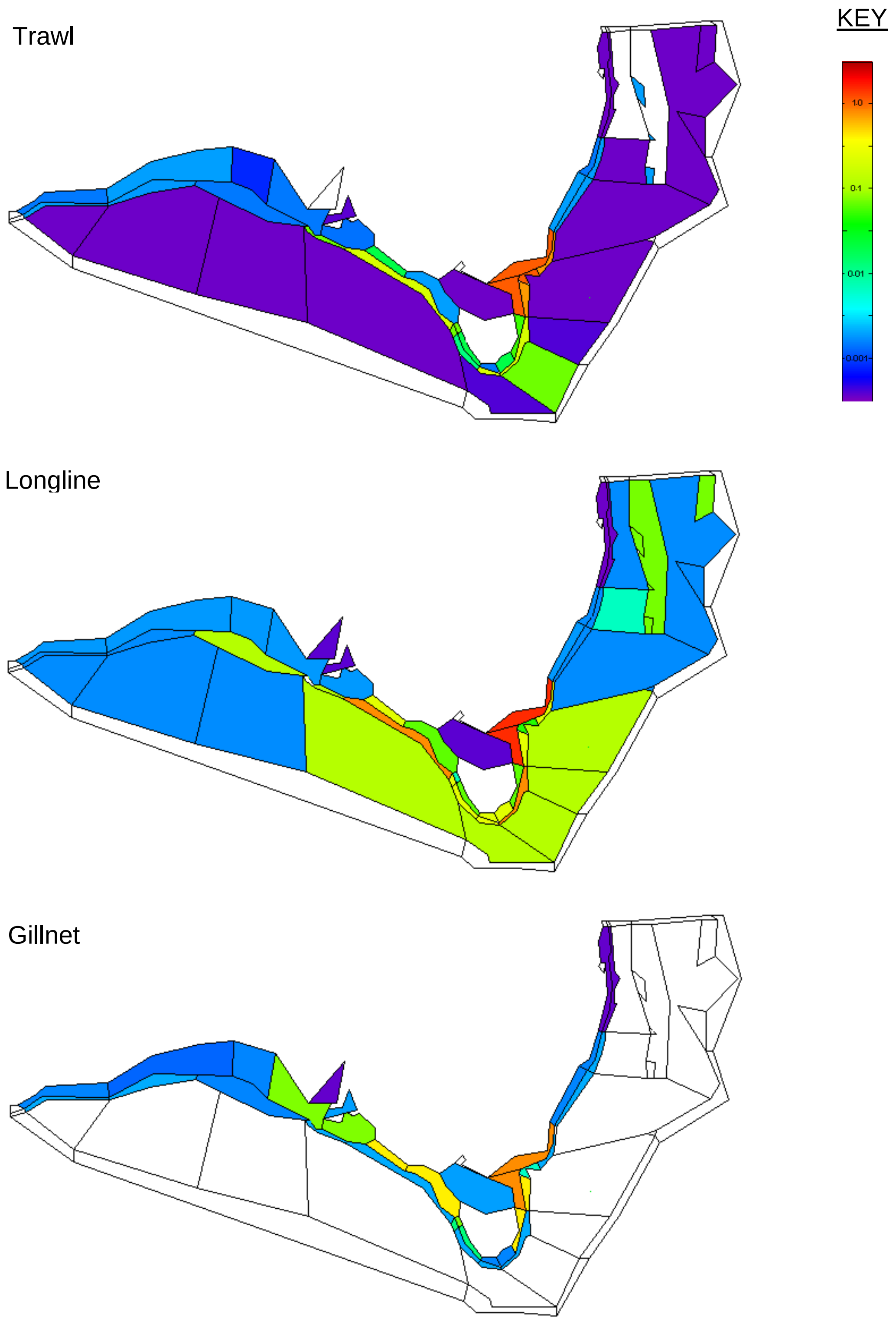


Figure 5-39: Relative fisheries footprints by gear type (this was the same in all Scenarios, but differed once the magnitude of effort per box was included, see text for details). Note that due to the resolution of the Atlantis SE boxes the catches along the edge of the slope, seamounts, Lord Howe rise or southern plateau look to extend out into open ocean, this is not the case (as the model explicitly handles sub-grid scale habitats), unfortunately the resolution of the map does not allow a finer scale representation here.

The average footprint under Scenario 9 is smaller in extent than under the other scenarios, with the dynamic fleets largely staying over the shelf and upper slope. The loss of the deeper waters and the restriction on fishing in the shallower waters means that the fleets still travel to distant boxes in search of grounds they can access. This sees the shelf footprint wider and somewhat more even in extent than in any other scenario. For instance, the entire GAB is fished at levels close to exploratory so there are only small differences in the effort and footprint seen in those boxes. Therefore, while the spatial extent of the fishery is quite homogeneous on the western grounds (there is more concentration of effort in the eastern grounds) the absolute magnitude of this footprint is quite light in comparison with the other scenarios. The concentration of effort in the eastern waters and the light covering of effort in the west mean that trip length is also much lower on average than in the more intensively wide ranging scenarios. Again the range of trip lengths can be just as large (though very long trips are exceedingly rare), but the density of values concentrate at the lower end of the range – as boats steam to the waters off Tasmania and Victoria far more frequently than they cross the GAB (Figure 5.40).

One last observation on trip lengths and footprints is that they both decline in absolute magnitude as effort leaves the fishery. This is not simply a direct effect of less effort, but also less competition between the remaining operators.

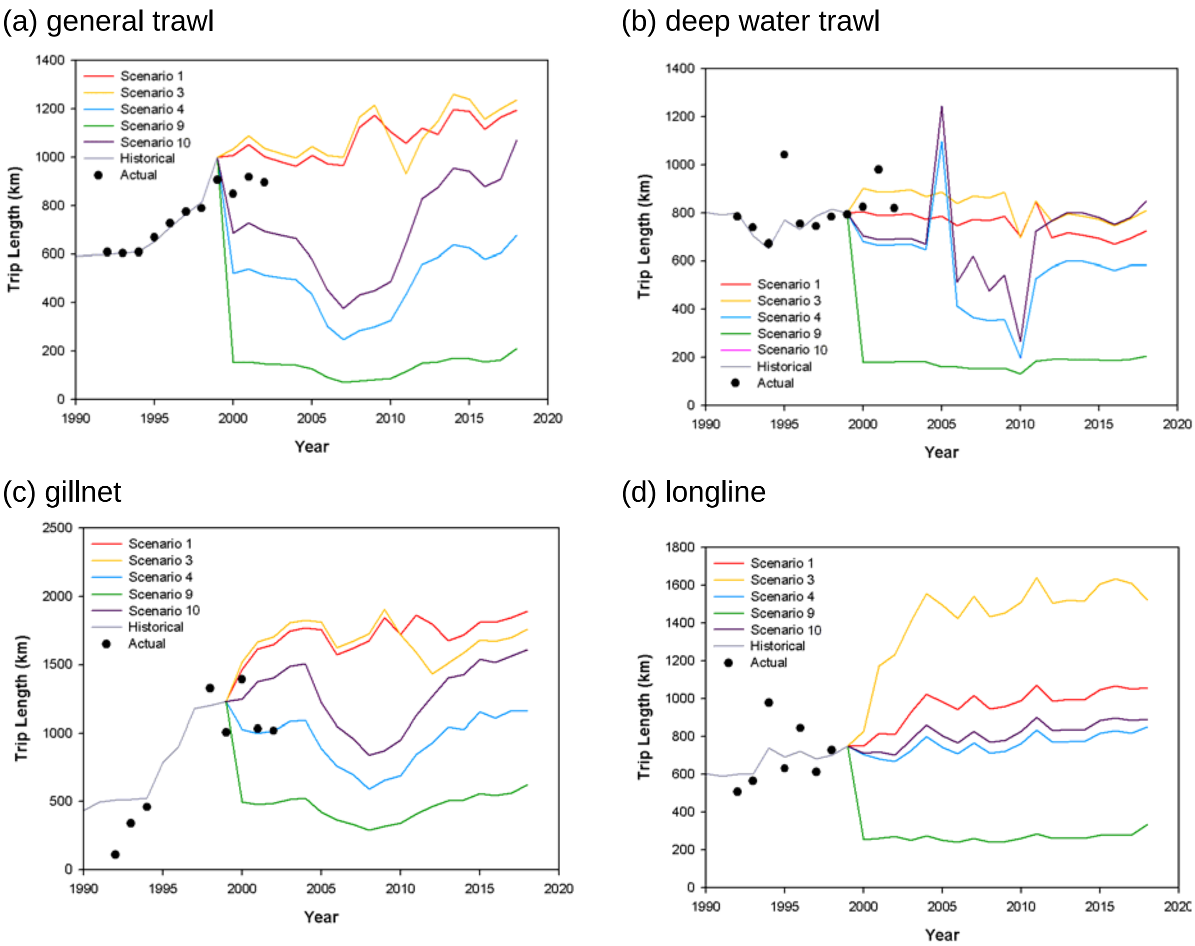


Figure 5-40: Average trip lengths under the alternative management strategies.

5.1.4 CPUE

Just as the use of effort in terms of days at sea saw a steeper rise in effort than is apparent from the more common effort plots in terms of shots (or sector appropriate measure), the resulting CPUE rates can also appear to change more rapidly than the per shot equivalents. Unfortunately, as mentioned above, the resolution of Atlantis SE does not allow for the use of the more common effort and CPUE measures.

The overall rates of Catch Per Unit Effort (CPUE) at no point reached the highs reported from the late 1980s and early 1990s (Figure 5.41), which were largely driven by roughy catches. Scenarios 1, 3 and 4 begin at the historically low levels seen at the end of the 1990s and continue at those low levels until effort leaves the fishery. At that point CPUE does rise (steeply in Scenarios 3 and 4, but only gently under Scenario 1), but ultimately the rates drop off again, though they do not fall back to the levels seen in 2000. Moreover, while the rates under Scenario 1 and 3 continue to fall at the end of the projection period, those of Scenario 4 have apparently stabilised – at 2.3 t/day, 20% higher than the rate in Scenarios 1 and 3. Under the other two scenarios (9 and 10) the rise in CPUEs begins earlier and leads to a higher plateau (around 4t/day in Scenario 9 and 3t/day in Scenario 10). The work presented here has only been run out over relatively short time frames (due to computation constraints), but a few runs were completed on longer time frames (running out for 50 years). On those longer time frames a wider differentiation of the scenarios occurs. Scenarios 1 and 3 decline back to about the levels seen during the historical lows and even a little further (getting as low as 0.9t/day sporadically). In contrast, Scenario 9 remains relatively stable with overall CPUE rates of around 4-4.5 t/day. The rates under Scenario 10 climb a little to approach 4t/day about 30 years into the future. A similar trajectory is followed by Scenario 4, which stabilises on this longer time frame at about 4.35 t /day. A lot less attention has been put on these longer time frames at this point and more runs would be needed before high levels of confidence could be put into these predictions. Nevertheless, they are consistent across the small analyses done thus far.

The overall CPUE rates in the GABT remain fairly stable (rising only a little even in the longer term) for Scenarios 4, 9 and 10 (though the absolute values of the CPUE under Scenario 9 is more than twice that in any other Scenario). Scenarios 4 and 10 converge to a rate of about 3.5t/day by the end of the standard projection period (and only rise by about another 10% by the end of any of the 50 year simulations). Similarly, Scenario 9 shows little variation in its predicted CPUE. While it rises initially, it does begin to decline by the end of the projection period and the long term stabilisation is close to 9.5 t /day (roughly 10% less than it is at the end of the projection period shown in Figure 5.42). The overall total CPUE in the GABT under Scenario 1 and 3 is not as promising. It does not show any recovery; instead continuing to decline slowly for quite some time before reaching a long term average of 1.1 t/day (30% less than its poorest value historically).

The picture in the SET is a little more optimistic and more like those of the overall results. Scenarios 1, 3 and 4 show an initially flat, or slightly declining, CPUE rate that begins to recover with the loss of boats from the various fishing fleets. Scenario 4 shows some fluctuation, rising immediately when the effort is removed, only to dip slightly again (by 20%) by the end of the projection period. If longer time scales are considered this level of fluctuation occurs on a scale a little short of a decadal period, though the mean line of the variations is increasingly higher, leading to an overall increase in average CPUE of 2.5x (so that the average point rises to the level of the high point shown during the projection period plotted in Figure 5.43). In contrast Scenarios 1 and 3 remain relatively steady at around 1.3 t/day for many years before gradually dropping further to 1.0 t/day by the end of the 50 year simulations. The average overall CPUE under Scenarios 9 and 10 fair much better. Under Scenario 9 it remains between 2 and 2.5 t/day into the future. Scenario 10 reaches the lower bound of this same range by the end of the projection period given here, but eventually drops a little to just below 2t/day (meaning it is outstripped by Scenario 4 which rises above this point after 2040).

In the GHAT a very different picture of overall CPUE arises (Figure 5.44). Here Scenario 4, particularly for gillnets, is one of the worst performing during the standard projection period; although in the longer runs done thus far it does rise again and out performs Scenario 3 by 2025 and Scenario 1 after 2035 – by which point it has reached 0.6 t /day for gillnet and 2 t/day for longline. The performance of Scenario 9 is much steadier, fluctuating between 0.25 and 0.45 t/day during the projection period for gillnet (slowly growing to a maximum of 0.55 t/day in the longer runs) and 2.0 to 2.2 for longline (reaching 3.1 t/day in the longer runs). Scenario 10 gillnet CPUE peaks at 0.9 t/day in 2007/2008 but declines again, ending the projection period at 0.45 t/day and stabilising into the long-term at about 0.35 t/day. In contrast, the longline CPUE in Scenario 10 rises quickly to around 2.3 and remains there indefinitely. Potentially the most intriguing results are for the unregulated Scenario (Scenario 1) and the heavily TAC regulated Scenario 3. In both of these there is no apparent stabilisation in overall GHAT, longline or gillnet CPUE. While the fluctuations in the gillnet CPUE rates for Scenario 3 are smaller after 2020 than before (where they drop from a peak of 2.21 t/day to 0.22 t/day in less than a decade) they never settle and there is quasi-cyclic pattern of sharp spikes followed by long tailed declines - the highs around 0.5-0.7 t/day and the tails dropping as low as 0.06 t/day. These lows are lower even than those seen in Scenario 1, which continue to decline from 2012 for two decades, before beginning to fluctuate about 0.27 t/day. These longer term results are only tentative to date, but at least some of this volatility is hinted at even within the standard projection period presented here. The drops for longline CPUE is smaller in magnitude for both Scenarios 1 and 3 – reaching 1.05 for Scenario 1 and 1.3 in Scenario 3.

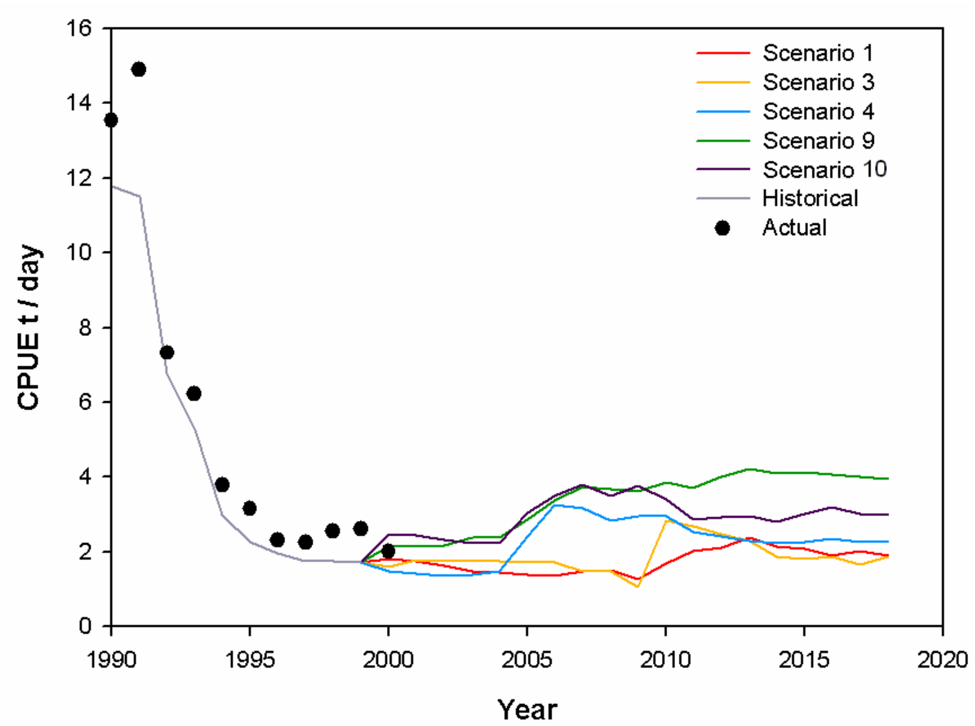


Figure 5-41: Total Catch Per Unit Effort (CPUE) rates (over all species and groups) under the alternative management strategies.

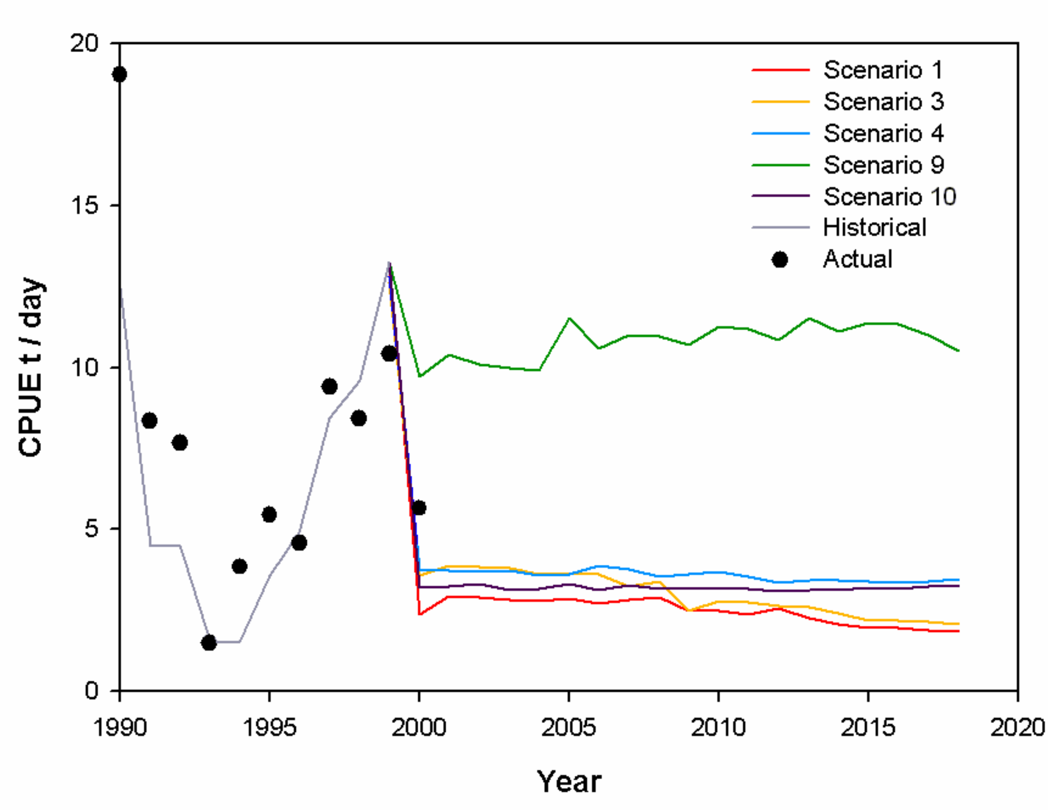


Figure 5-42: Total GABT Catch Per Unit Effort (CPUE) rates (over all species and groups) under the alternative management strategies.

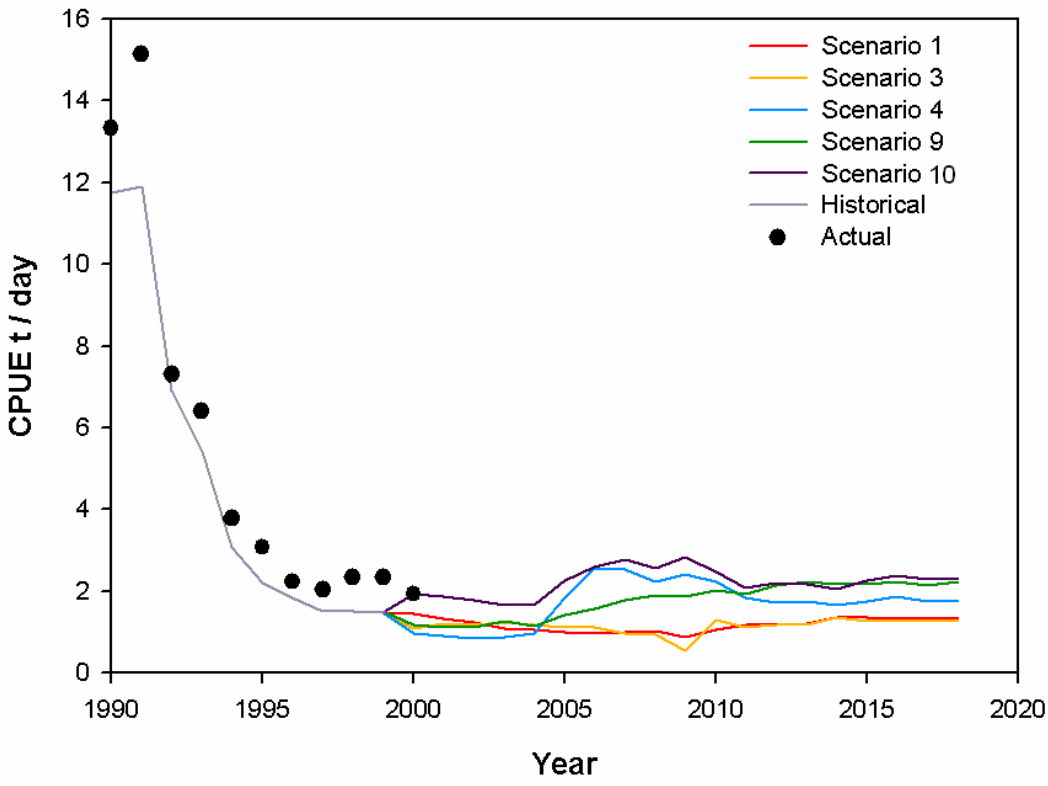
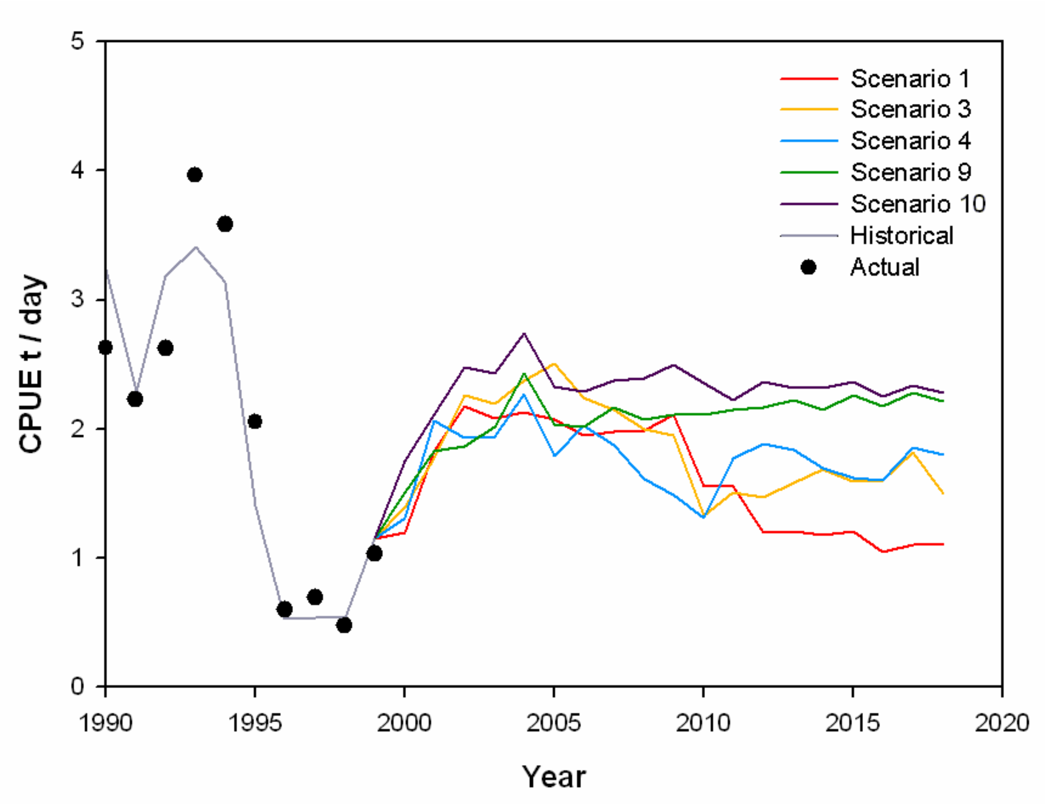


Figure 5-43: Total SET Catch Per Unit Effort (CPUE) rates (over all species and groups) under the alternative management strategies.

(a)



(b)

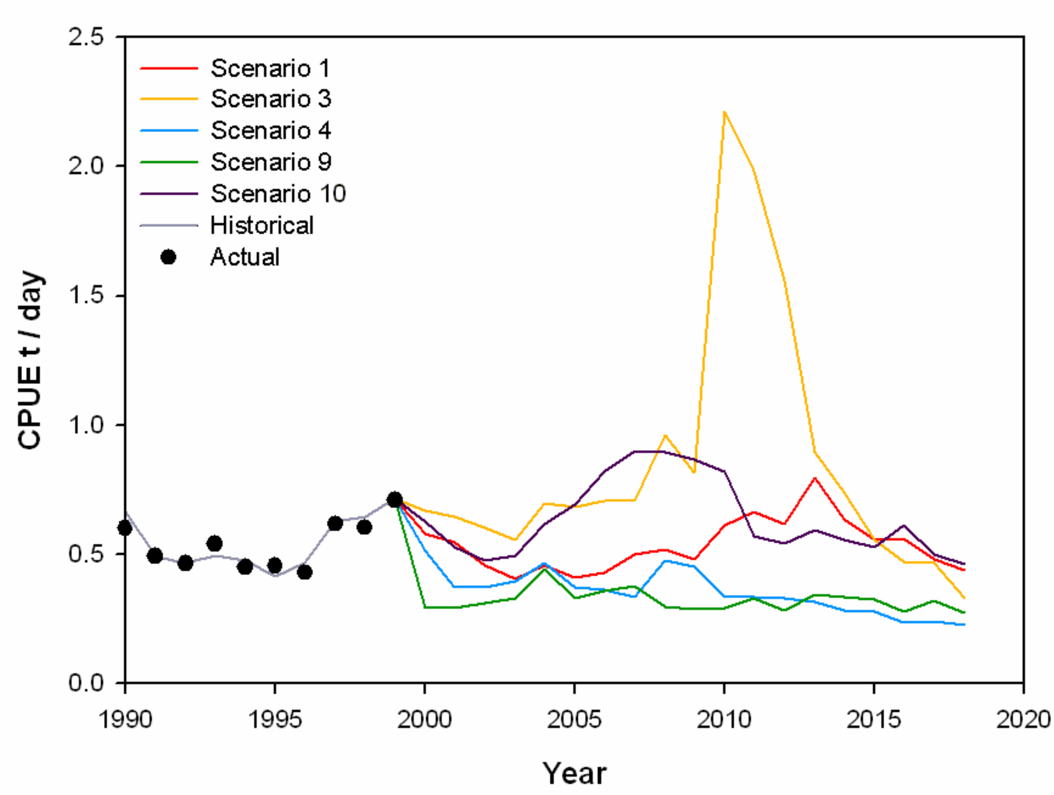


Figure 5-44: Total Catch Per Unit Effort (CPUE) rates (over all species and groups) under the alternative management strategies for each of the dominant GHAT fleets: (a) longline and (b) gillnet.

CPUE of Key Target Species

When the CPUE statistics are broken down to consider the key groups individually some interesting common themes become apparent. First, CPUE rates for red bait fall across the board by up to 30% (due to a drop in biomass of 25-65%), though in all but Scenario 9 this is more than compensated for by rises in the CPUE of other small pelagics (including mackerel) of 1.2-9.8x. In Scenario 9 the CPUE rates consistently drop for all small pelagic groups, partly due to targeting changes and partly due to indirect trophic effects and increased predation pressure (as other predatory target stocks rebuild). Second, amongst the demersal fish and shark groups the catch rates show a broader range, some continuing to decline, some species and gears showing marginal gains, while others show substantial increases (trawl tends to benefit more than longline, for instance). In comparison with Scenario 1, Scenario 3 is often not substantially different in terms of realised CPUE rates per species – typically sitting within 10% of each other. The prime exceptions to this are orange roughy, where CPUE rates under Scenario 3 were 7x higher than under Scenario 1, and gummy shark where the rates could decline sharply (due to local extirpation) under certain parameterisations (and Scenario variants). Under Scenario 4 these demersal groups tended to exhibit higher CPUE rates, though more so on the intermediate and longer term time horizons (where they could be as much as 7x higher than in the first 5 years of the standard projection period). It was not all a simple one way signal however; the CPUE of blue grenadier under Scenario 4 actually falls (due in part to indirect trophic effects). Scenario 9 typically predicts a rise in the CPUE for these larger bodied, mid- to higher trophic level groups, though the increase can be small (on the order of <20%) and patchy temporally and spatially. The quota species discarding ban imposed in Scenario 10 has a mixed impact on individual CPUE rates – predicting some will increase slightly (by <20%) while others are actually negatively impacted (with rates dropping by as much as 30% for some of the largest shark groups due to slightly lower biomasses resulting from an effectively higher fishing mortality rate).

As noted above some changes in CPUE can be quite rapid, though most (particularly for the deepwater groups) can take decades to be realised. This means that while these CPUE patterns are evident to some degree by the end of the projection period, they are not always strong during that time frame for those groups with long response times, particularly those that have already been heavily exploited.

5.1.5 TEP and Habitat interactions

Habitat Interactions

Updating discarding preferences and the spatial limits included in Scenario 3 sees it ending with habitat interaction levels (i.e. degree of contact of gear with habitat) similar to those of Scenarios 4 and 9 (Figure 5.45) – it is slightly higher by about 20%, but is still much closer to those two Scenarios than under Scenario 1, when the levels are more than 4.5x higher. If discarding preferences and spatial management are relaxed the interactions are much higher, only marginally lower than under Scenario 1. The lack of constraint under Scenario 1 sees the fishery expand into new rougher grounds more often than for the other scenarios, though the shifting grounds under Scenario 10 also lead to higher habitat interactions as sea mounts south of Tasmania are cleared of epifauna. The level of habitat interactions seen under variants of Scenario 3 that do not have deepwater spatial zoning is between that of Scenarios 1 and 10. This indicates how sensitive this performance measure can be to constraints on access to new deeper water grounds. These results may also be altered if a penalty (such as lost gear) was imposed for habitat interactions (in reality many fishers are reticent to risk hanging up on rough ground, something that is not captured completely in Atlantis SE).

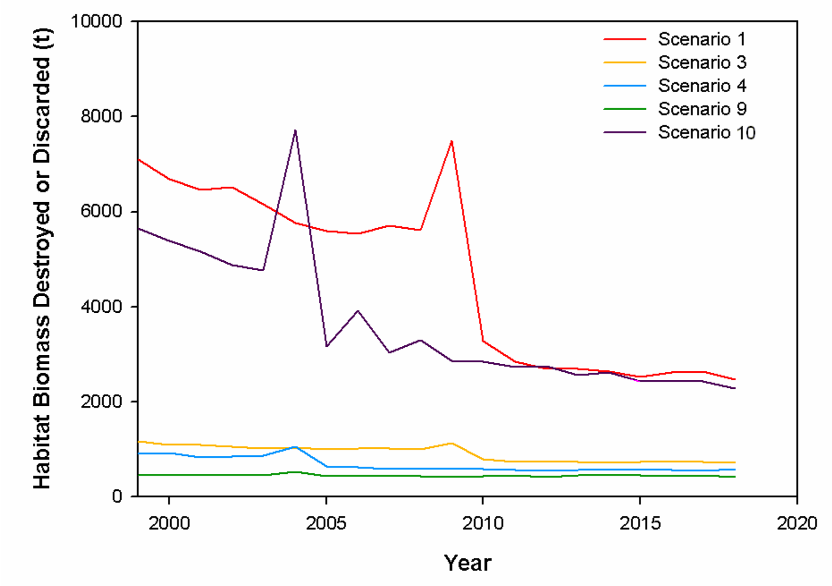


Figure 5-45: Habitat interactions under the alternative management strategies.

TEP Interactions

The low level of efforts and tightly constraining spatial zoning under Scenario 9 mean the fishery is kept away from the bulk of the main TEP groups (e.g. marine mammals) leading to very low levels of TEP interactions (Figure 5.46). In all the other scenarios the TEP interactions increase steeply through time, but this is a direct result of increasing biomasses of the TEP groups. It does not take many accidental interactions with a baleen whale for the biomass of TEP interactions to jump steeply. This is a classic and major problem of using TEP species as bycatch indicators.

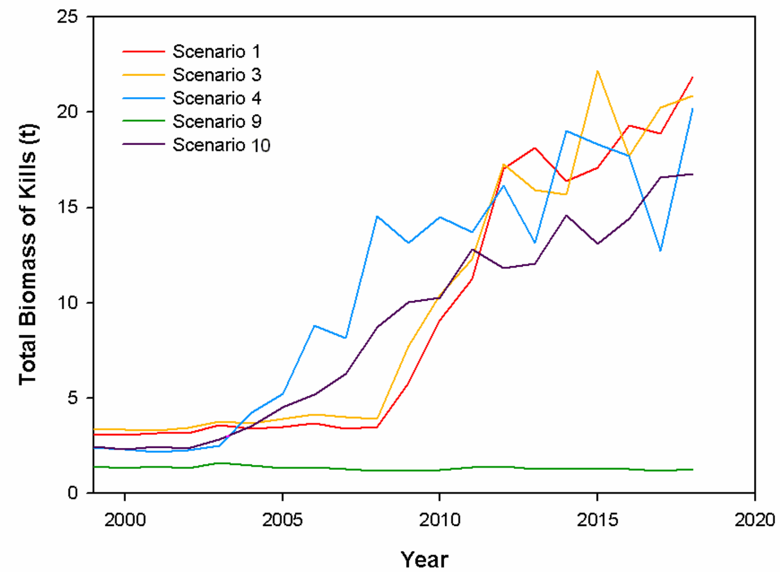


Figure 5-46: TEP interactions under the alternative management strategies.

5.2 Management Performance Measures

There are some clear implications of the various management strategies, which are evident from the peak values (Table 5.4) and kite diagrams that deconstruct the management related performance measures (Figure 5.47). No matter which scenario is considered there are costs, both in terms of access and the dollar costs of management. There are even reasonable costs behind the ineffective management provided under Scenario 1. Access and stability may seem to be higher under those circumstances in an formal sense, but the free-for-all atmosphere associated with such conditions would probably feel far from secure. The danger of scenarios, such as Scenario 9, where single management levers are used, is that the lever must be set to be so constraining that it has high associated costs. In the case of Scenario 9 the kites show that increased formal management stability comes at the cost of higher research and compliance costs, which leads to poorer performances against these measures. In contrast, some of the other Scenarios (3, 4, and 10) manage moderate performances across a number of the axes, rather than simply excelling in a single dimension. It is also interesting to note that the performance of these other scenarios also improves through time; whereas Scenario 9's rigid form sees its performance stagnate.

Table 5-4: Peak year and scenario for each of the management performance measures.

Performance Measure	Scenario	Year of maximum value
Research costs	9	2008+
Compliance costs	All	2000+ (all years in scenario 1)
Assessment costs	4	2015+
Access	1	2015
Stability	4 and 9	All years and periodically in scenarios 1 and 9
Trading	10	2000

5.2.1 Management Costs

Putting aside one off costs of any buyouts (which may attract one-off government subsidies, as happened in reality), overall costs (Figure 5.48) are initially highest for Scenario 4 (at $8.2 million per year). Throughout much of the rest of the simulated period Scenario 3 leads to the highest overall costs (of around $8 million per year). Nevertheless, by the end of the projection period all scenarios are converging on a common cost of $6.5 – 7 million. Moreover, the extra costs of compliance under Scenario 9 push its overall costs to the higher end of the common range.

Looking into the details behind the overall costs, research costs decline through time in all scenarios, except for Scenario 1 where the lack of change in management practices lead to constant costs of $995,000 per year through time (Figure 5.49) – the level of current (2006/2007) observed research costs. Scenario 4 initially has the highest costs (of around $2 million per year), as knowledge of movements is collected to verify the usefulness of the spatial closures being used. Eventually however, stock sizes and TACs stabilise leading to less pressure for research and an overall drop in costs for Scenario 4 that sees it reach the level (if not lower) of the constant value from Scenario 1. In both Scenarios 3 and 10 the drop in research costs is driven primarily by the number of TACs required per year. Initially about half of all species have TACs revised annually, whereas by the end of the projection period only a third of species

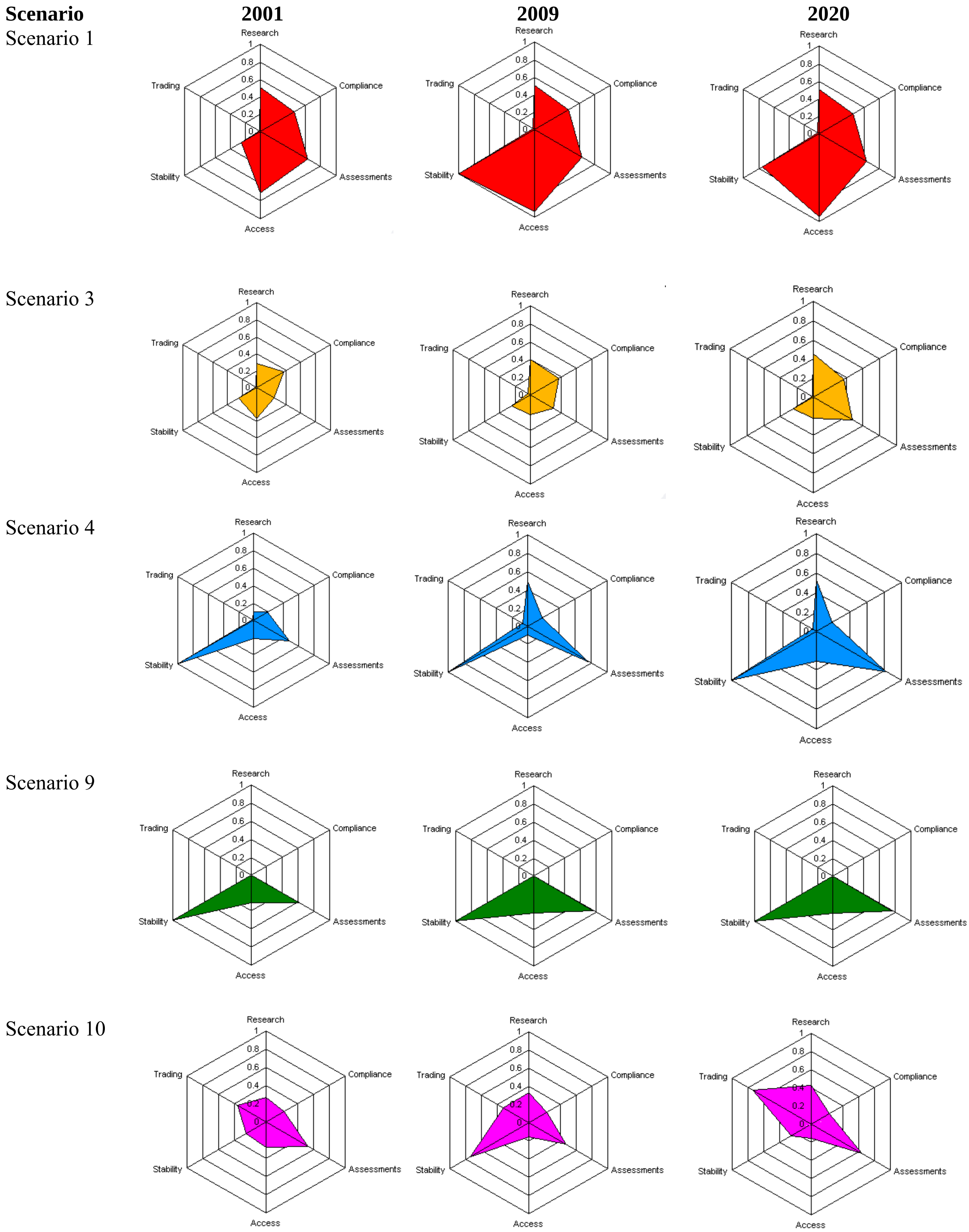


Figure 5-47: The overall performance of the five main scenarios for the integrated management related performance measures. Measures have all be converted to relative measures with 1.0 = good and 0.0 = poor performance. Note for trading good = high is an arbitrary assignment, axes could be inverted. Note that stability and access are crude measures that are used to capture aspects of how management will be perceived by operators: stability is measured in terms of years since the last management lever shift; and access is given by a multiplicative combination of the relative restriction by each management lever.

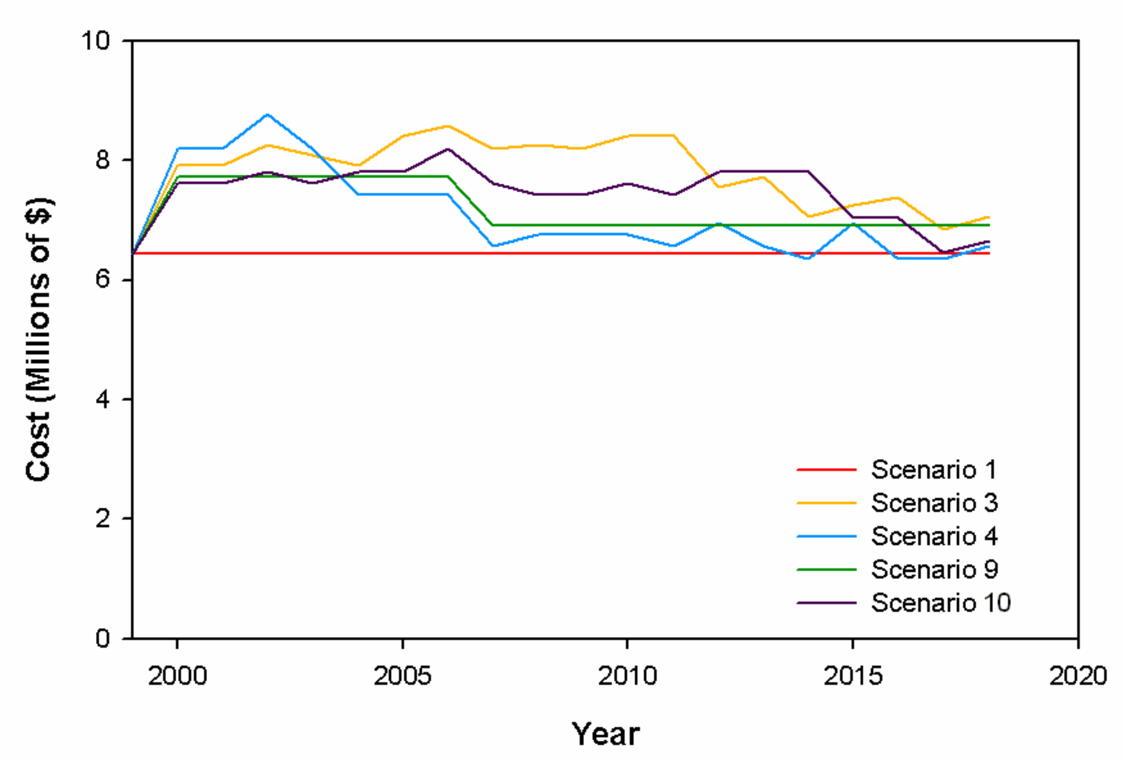


Figure 5-48: Overall management costs for the alternative management strategies.

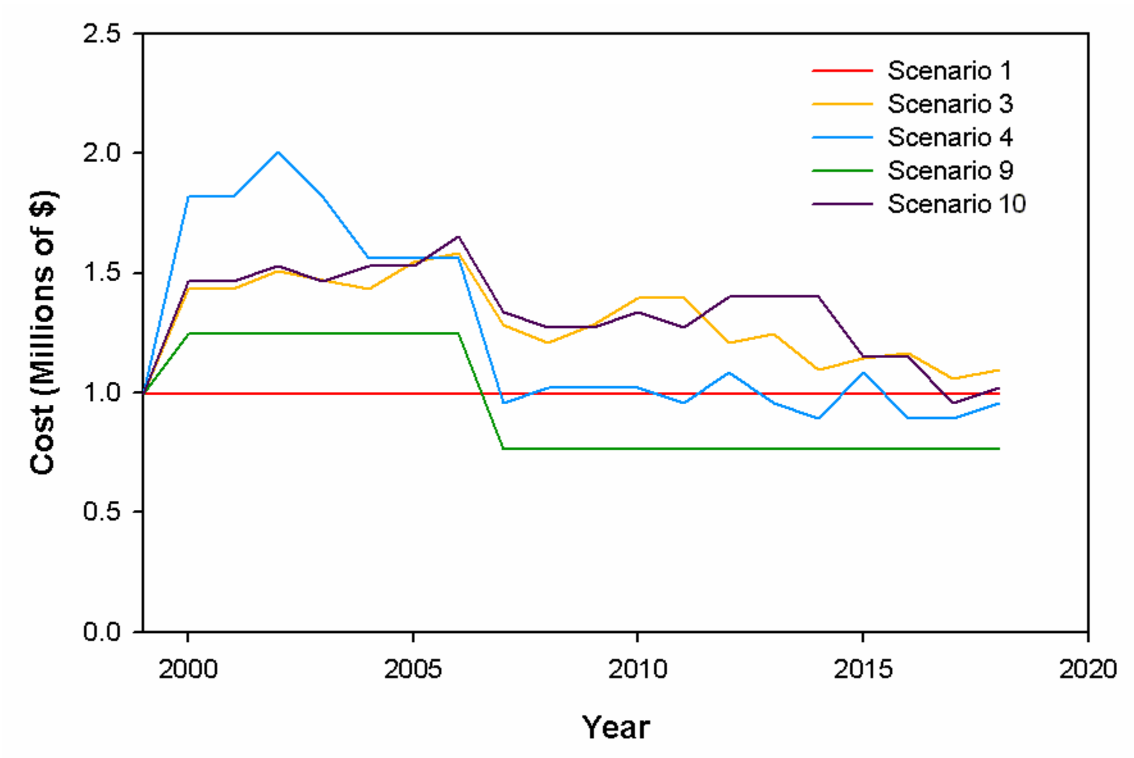


Figure 5-49: Research costs under the alternative management strategies.

are assessed each year. This is due to a stabilisation of at least some stocks (including morwong, spotted warehou, blue warehou, orange roughy, gulper sharks, other demersal sharks and many invertebrates) and associated catch rates and TACs. It is likely that multi-year TACs would also lead to a similar pattern due to the intentional cycling of species on longer time frames.

The large number of quota species that must be assessed (and thus require data for the assessments) mean that monitoring costs are much higher under Scenario 3 than any other scenario (Figure 5.50). Under this Scenario monitoring costs are around $2 million per year until about 2012 when more stable stocks allow for lower monitoring costs. Monitoring costs are also relatively high under Scenario 10 (at around $1.3 million), much higher than under those scenarios where spatial zoning is a core feature of the overall management strategy.

Figure 5-50: Monitoring costs under the alternative management strategies.

Compliance costs proved much harder to model. Relative measures would indicate however that compliance costs will be higher than the $1.258 million of Scenario 1 for all other scenarios. It is highest under Scenario 9 (at $2.29 million), though Scenarios 4 and 10 are also fairly costly at about $1.8 million each. The standard version of Scenario 3 is not much less than this either, though the variants with much less use of spatial zoning come in with much lower compliance costs of $1.45 million, despite the need to monitor landings vs quota holdings.

Costs Per Boat

The costs per boat vary significantly between the different sectors and often rise steeply as fleet sizes are reduced (Figure 5.51 – 5.53). During the earlier parts of the simulation Scenarios 1, 3, 4 and 9 are about equally expensive per boat in the SET, at about $35,000 - $40,000 per boat per year (Figure 5.51). Only Scenario 10 is much cheaper, at roughly $15,000. Ultimately however, Scenario 9 proves the most expensive management strategy per boat in the long term (at roughly $118,000 per boat per year). This is despite the low level of effort seen under this

Scenario. After a brief blip in 2010 (when the costs of a large number of assessments and periodic surveys coincide with the SET landing a large proportion (45%) of the quota), Scenario 10 returns to being the least costly, dropping back to costs of about $26,000. The costs associated with the other three scenarios are intermediate (from $70,000 - $90,000 per boat per year).

The pattern is very different in the GABT (Figure 5.52). Scenario 10 is more costly for boats in the GABT, costing as much as $180,000 per boat per year. The costs per boat under Scenario 9 are also fairly high, $150,000 per boat per year, which is 1.5-3x higher than those under Scenarios 1, 3 and 4. As quota holdings were of little use in Scenario 9 (the quota holdings becoming divorced from activity in this case) allocation of costs was instead based on GVP. While not an ideal solution, this measure still performed better than trying to use the distribution of quota holdings.

Yet another pattern of costs is realised in the GHAT (Figure 5.53). Costs are initially quite low under Scenario 1, rising to $40,000 by the end of the projection period. The costs per boat rise more quickly under Scenarios 4 and 9, but end only 20% higher than under Scenario 1. In contrast, the costs under Scenarios 3 and 10 are much higher, especially once fleet sizes drop. Both of these end with costs per boat over $100,000.

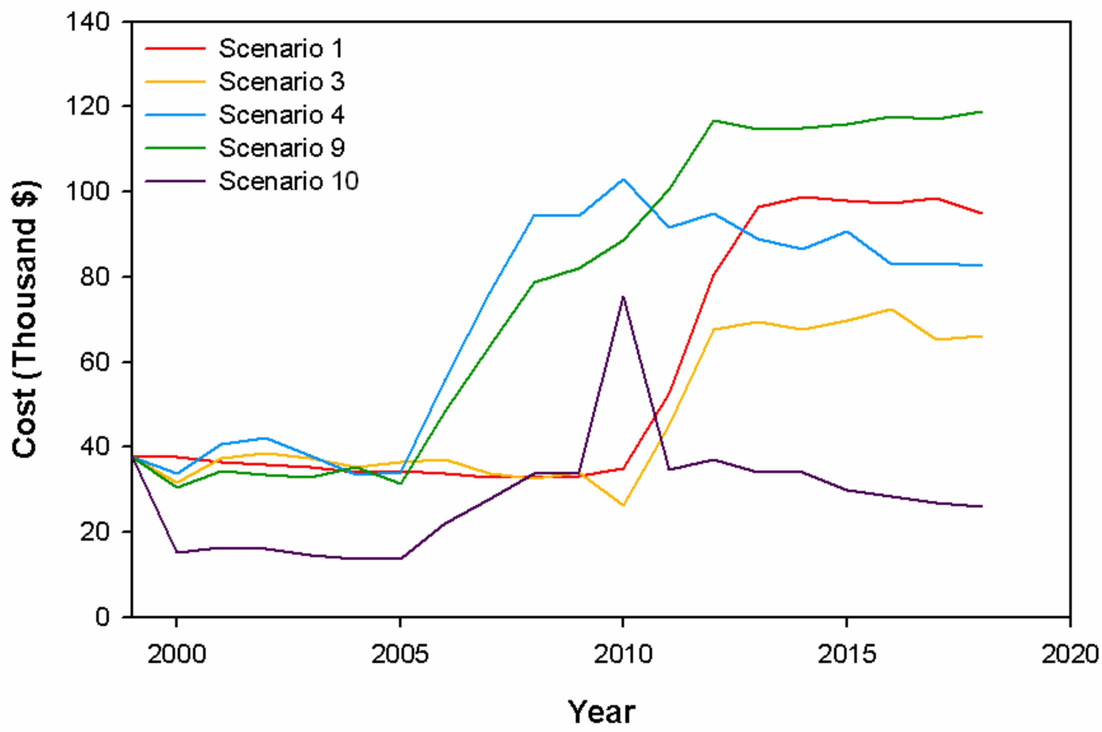


Figure 5-51: Management costs per boat in the SET under the alternative management strategies.

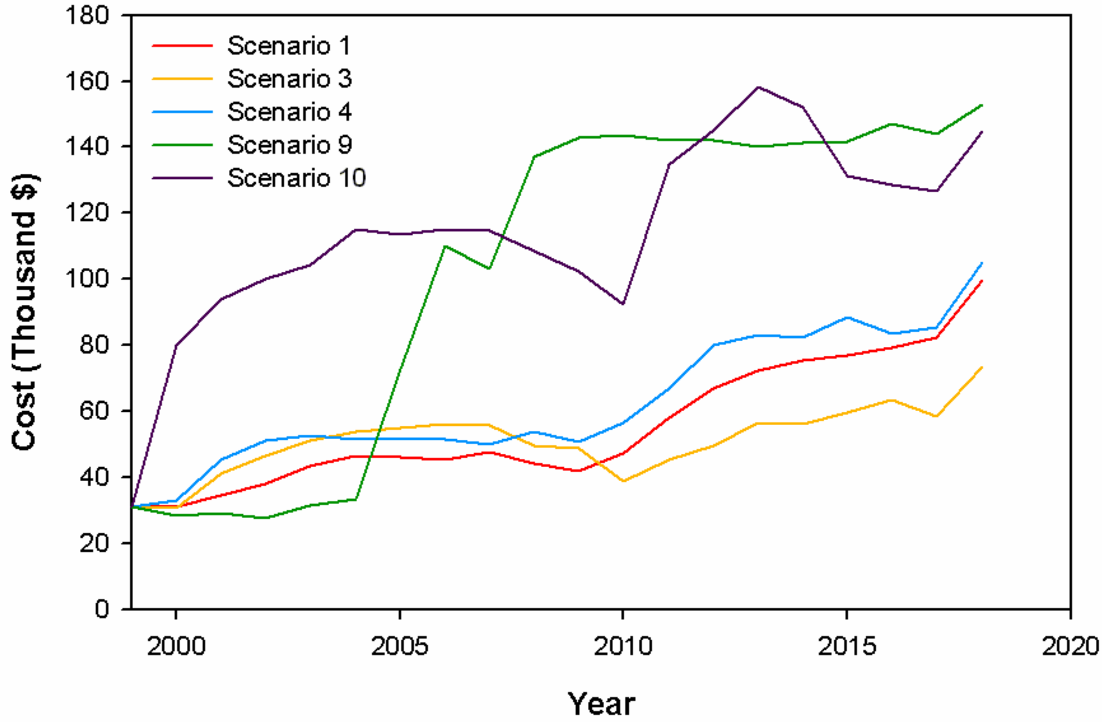


Figure 5-52: Management costs per boat in the GABT under the alternative management strategies.

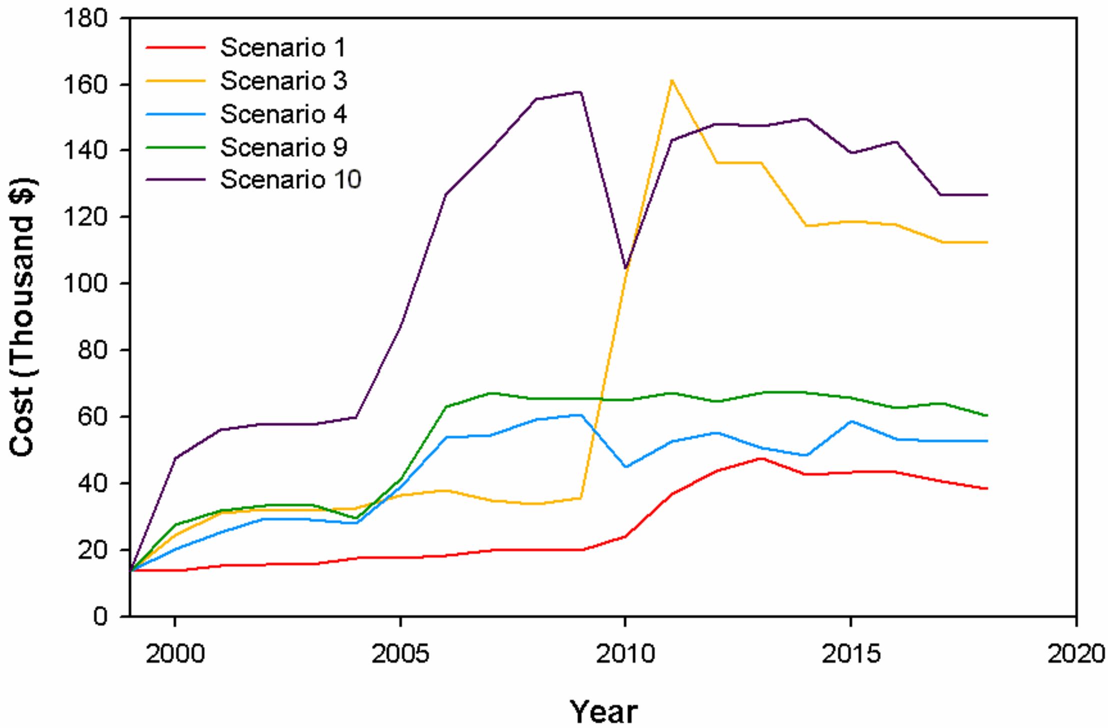


Figure 5-53: Management costs per boat in the GHAT under the alternative management strategies.

5.2.2 Access

The index used to consider access was a multiplicative combination of the relative restrictions due to temporal and spatial zoning, closures around TEP critical habitats (like rookeries) and the degree of restriction of catches by quotas. This is a fairly crude measure but does give the relative ranking of the alternative management strategies. Scenario 1 is effectively unconstrained and no other strategy approaches this level of access, they are all less than half as accessible as Scenario 1. The almost pure dependence on spatial zoning in Scenario 9 means it appears to be more accessible than the other strategies, though looking at the highly constrained signature of the other performance measures for this Scenario, this access result may indicate a weakness in the formulation. The ranking of the other three scenarios (in descending order of accessibility) is Scenario 3, 4 and 10.

5.2.3 Stability

Stability was measured in terms of years since the last management lever shift. Under this criterion Scenario 9 is the most stable, as the spatial zoning is not shifted through time. Scenario 4 is the next most stable, where the combination of stable spatial zoning and a low number of groups requiring assessment per year (about 10% of the total number under quota) lead to higher management stability. The higher number of assessments year to year under Scenarios 3 and 10 see their stability rated poorly. Scenario 10 performs better than the unconstrained and lobby-dominated management of Scenario 1, the use of a range of management levers increasing sustainability and in turn stability. In contrast, the highly formal structure of the level of assessment under Scenario 3 means it is less stable year to year across the suite of quota species than Scenario 1.

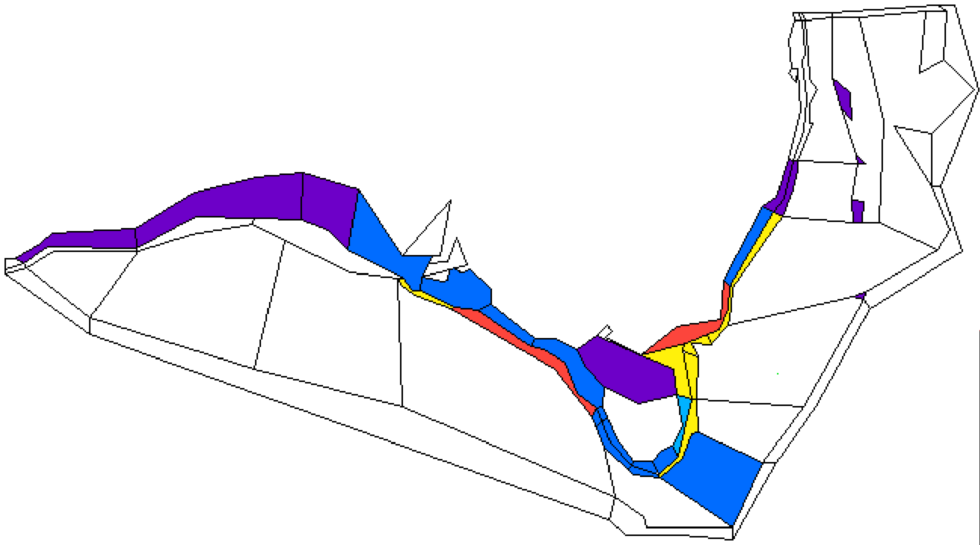
5.2.4 Gear Conflict

Gear conflict was measured as the proportional overlap (per cell) of the effort distributions of conflicting gears. Under Scenario 1 there is some gear conflict (Figure 5.54), particularly between longline and trawl, across all of the main fishing grounds, though it is greatest in all cases around the eastern end of the Great Australian Bight and Victoria, as well as Tasmanian waters (particularly the deeper waters). There is no significant reduction in conflict under Scenario 10, but there is in some locations in the other three scenarios (Figure 5.55). In the more distant boxes conflict falls to negligible levels and there is a reduction of conflict in some of the deeper waters around Tasmania and Victoria. This is reassuring given that this is one of the motivations behind the use of spatial zoning in these areas. There was no reduction in gear conflict in the variant of Scenario 3 that dispensed with spatial zoning; rather it rose in all the major fishing grounds (where conflict was already high).

5.2.5 Trading

Total Trades

As the model deals with subfleets it misses trades that would normally happen within a subfleet and so appears to underestimate the total number of trades – compare the reported trades with the modelled levels in Scenarios 1, 3, 4 and 9 in Figure 5.56. Nevertheless, it is very apparent



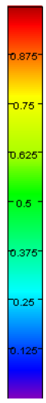


Figure 5-54: Map of relative gear conflict zones in Scenario 1.

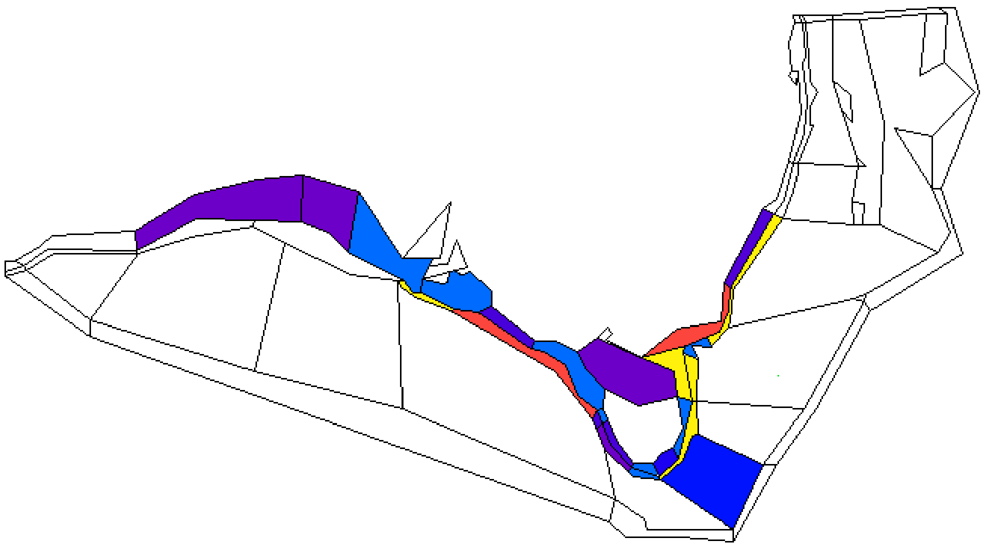


Figure 5-55: Map of relative gear conflict zones in Scenario 4 (the map for Scenario 3 with spatial zoning is similar, as is the map for Scenario 9, though absolute conflict levels are lower in that case).

that under Scenario 10 levels of trading will be markedly higher (by orders of magnitude) than any other scenario – as quota of target and byproduct species are traded to and fro, both to cover catches in the process of being landed, but also in anticipation of catches (that cannot be discarded) that could exceed quota in hand. The one exception to this difference in the magnitude of training between scenarios is during the consolidation of the fleets and orange roughy chase in Scenario 3. The number of species that see high levels of trading is also much higher under Scenario 10 than in any other Scenario. Thirteen of the eighteen main target groups are traded at high levels under Scenario 10, but only half that number sees high levels of trade under the other scenarios. Scenario 9 only has minimal anticipatory trading for byproduct groups and as part of long-term "permanent" leases (rather than actual sales which are much more expensive). In the other scenarios the actual number of species seeing high levels of trade during the last 5 years is 9-10. In all cases it is rarely the target species that is traded through the fleet. Instead byproduct species quota is highly sought after by each subfleet, as these species can constrain target catch quite sharply. Of the main target species only orange roughy, tiger and deepwater flathead and gummy shark see moderate or higher levels of quota trading in all quota-using scenarios – this trading is on the order of a few hundred trades per year, about the level of trades observed for these species in reality between 2000 and 2004. The groups that are traded steadily (at similar rates through time, without sharp fluctuations) under all scenarios are: redfish, orange roughy, shallow demersals, spotted warehou, school whiting, gummy shark and other demersal sharks. The list traded under Scenario 10 includes these as well as: tiger flathead, deepwater flathead, dories and oreos, blue grenadier, blue-eye trevalla, eastern gemfish and school shark. The pattern of trades through the year also changes markedly through time and between species and scenarios, though trade tends to peak around key demand and reconciliation dates.

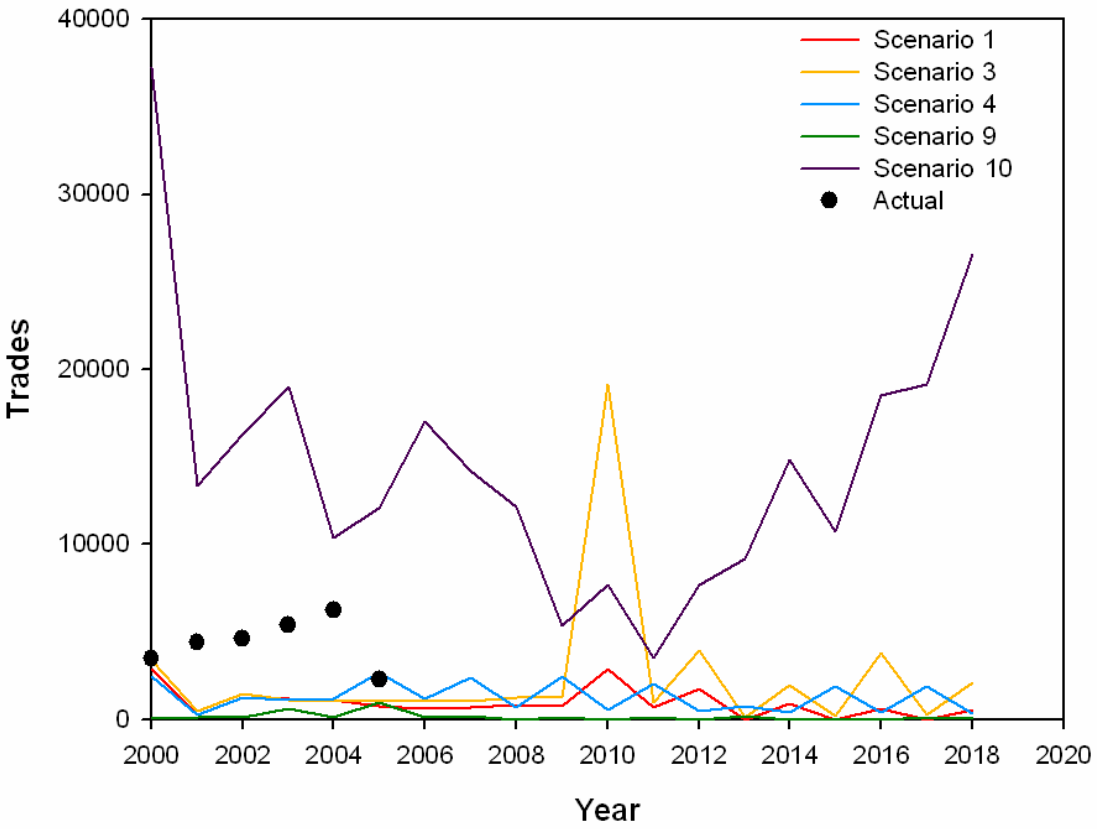


Figure 5-56: Total number of trades (across all species) under the alternative management scenarios.

Proportion of Quota Traded

The average maximum amount of an operator's quota holdings traded at any one time (across all species and fisheries sectors) gives a very different perspective on the trading patterns (Figure 5.57). From this it is clear that under Scenarios 1, 3 and 9 little of an individual's holdings of any one quota species was traded (in the case of Scenario 9 in some years nothing is traded while even in peak years it is less than 0.5-1%). In contrast, the proportion traded under Scenarios 4 and 10 could be quite high (as much as 80% or more of the quota held, for species that individual fishers had little interest in or were avoiding via targeting of other species or fishing in alternative locations). In one extreme year under Scenario 4 all subfleets traded away the entire holdings of at least one quota species (as they fishers shifted their targeting or consolidated, restructuring their quota portfolios according and giving up holdings of the least desirable and avoidable species entirely). When these results are decomposed at the species and group level it becomes clear that once again byproduct groups are dominating these statistics. Operators are trading off all (or nearly all) of their quota holdings in byproduct groups that they do not encounter (or want), but are leasing in significant amounts of the secondary groups that they encounter a lot as byproduct or want to land as byproduct. All of the groups listed above as being traded in all quota-using Scenarios feature in these intense trading exchanges.

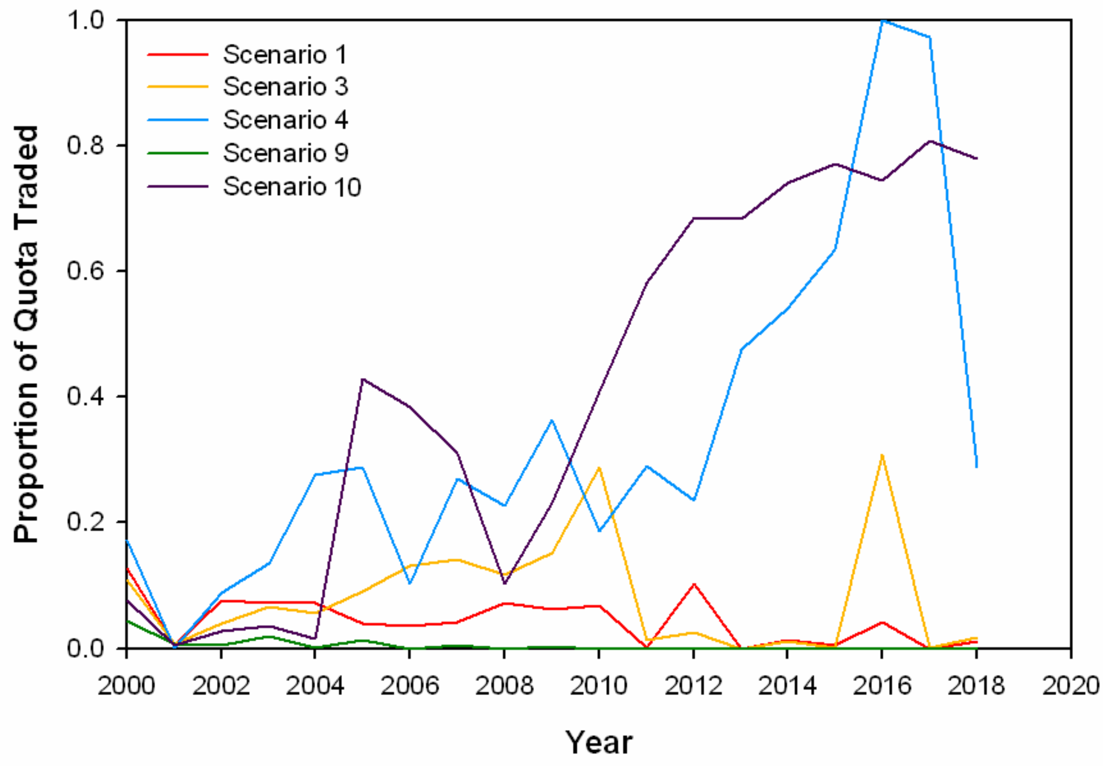


Figure 5-57: Average of the maximum proportion of the quota of any one species (or group) held by a subfleet that is traded away under the alternative management scenarios.

5.3 Economic Performance Measures

The overall economic performance measures for the alternative management strategies continue to highlight the trade-off in properties that comes with complicated system management (Figure 5.58, Table 5.5). The performance of Scenario 1 is fairly bleak, particularly in the years around the period when the fisheries collapse economically and many boats are forced from the industry. The initial profits are better under scenario 3, but the performance through time is not particularly good either, ending in a state not that different from Scenario 1. Transient behaviour is also fairly strong under Scenario 10, where higher costs and sector adjustments see little to no profit in the short term. Only in the longer term when things stabilise and revenue per day and tonne cover investment costs does the performance of this Scenario improve to the point where it outstrips many of the others. The performance of Scenario 4 is more rounded, with moderate to good performance against each measure. Perhaps the most interesting result however is for Scenario 9. While revenue per tonne and day are as high or higher than in many of the other scenarios, the high costs and low absolute value of the product landed (due to the low total amount of product landed) sees the fisheries lose out economically, failing to post positive profits throughout many of the final years of the projection period.

Table 5-5: Peak year and scenario for each of the economic performance measures.

Performance Measure	Scenario	Year of maximum value
Gross Value of Production	10	2007
Profits	3	2000
Revenue per Tonne	4	2019
Revenue per Effort	4	2007
Running Costs	9	2002

5.3.1 Value of Production

Consideration of the historical period shows that the model tends to overestimate gross value of production (GVP) by up to 10% (Figure 5.59). Nevertheless, it does seem to capture the right trajectory.

For Scenario 10 the model predicts the GVP will jump quite steeply initially, as catch that was once discarded is retained and landed (Figure 5.59). The GVP under this scenario continues to growth through time, stabilising at about $135 million into the long-term. The GVP under scenario 4 also stabilises a little below this level in the long-term and it remains more variable than under Scenario 10. The GVP under Scenario 4 also does not rise substantially overall until after the fleet restructuring has begun in earnest (Figure 5.59). In contrast, to this improved GVP under Scenarios 4 and 10, the GVP under Scenarios 1 and 3 declines as things grow tight (Figure 5.59), both immediately preceding the fleet reductions in those scenarios, but also into the long-term. The consistent pattern across all 4 Scenarios however, is that the peak GVP occurs in the few years following a reduction in fleet sizes (Scenarios 4 and 10 peak at around $175 million, while Scenarios 1 and 3 peak between $125-$145 million). After this point the GVP for each of these four Scenarios drops off and stabilises towards the end of the projection period. Scenarios 1 and 3 settle at about $95 million, while Scenario 4 varies about $125 million and Scenario 10 has the highest long-term GVP at $135 million.

The GVP results are much lower for Scenario 9. This Scenario immediately drops to about $30 million (Figure 5.59) and persists at about that level through the entire simulation (with a small and transitory spike as fleet sizes contract).

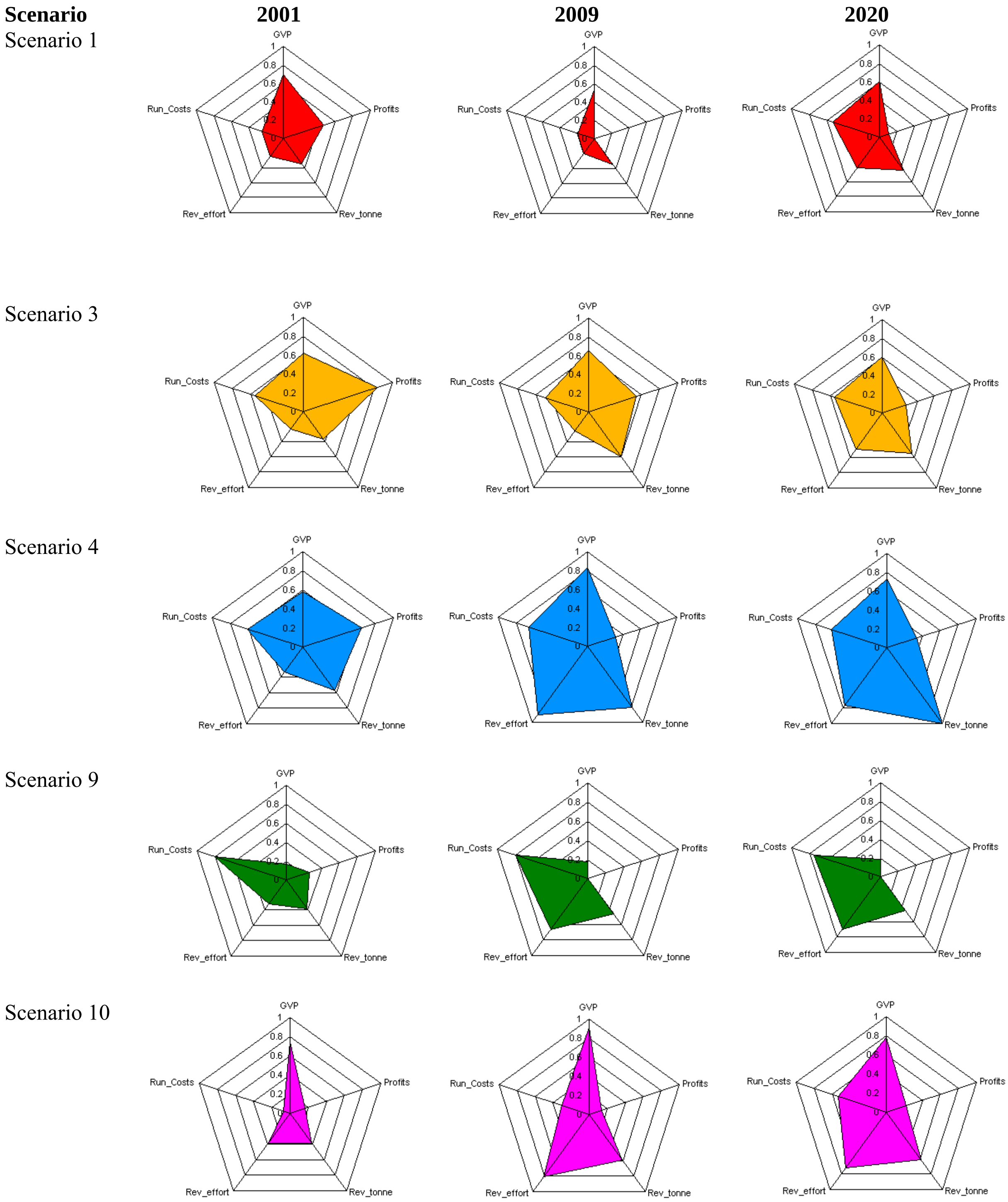


Figure 5-58: The overall performance of the five main scenarios for the integrated economic performance measures. Measures have all be converted to relative measures with 1.0 = good and 0.0 = poor performance.

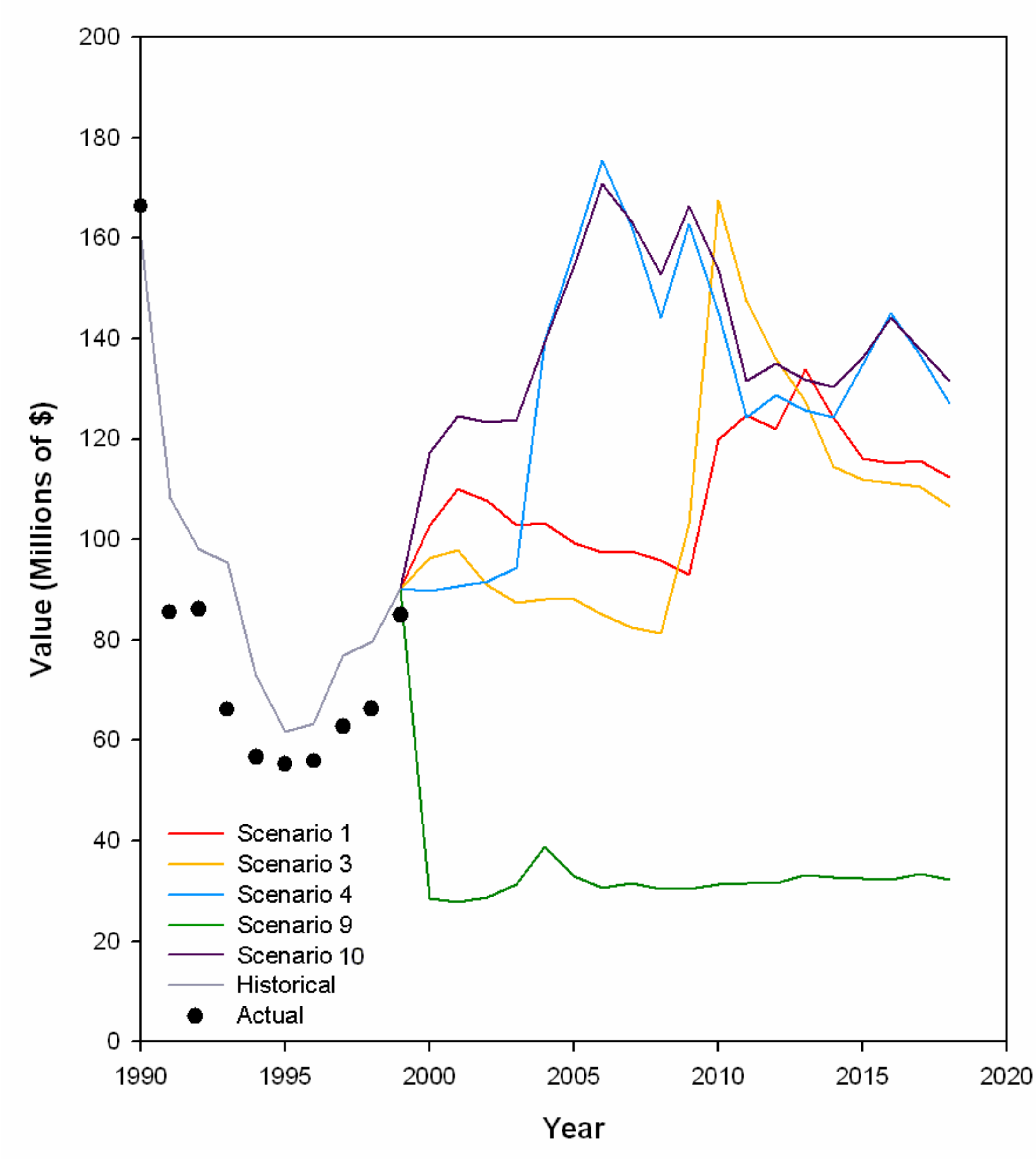


Figure 5-59: Total Gross Value of Production for the dynamic fishery components under the alternative management strategies.

The patterns of GVP in the SET sectors are fairly similar (Figure 5.60) sees Scenario 10 grow in value substantially for 5-8 years, dropping off again after this peak. Scenario 4 follows a similar trajectory but with a delayed beginning, not really starting to grow until after fleet sizes have begun to drop significantly. Into the longer term in the SET, Scenario 10 performs better than Scenario 4, finishing nearly 10% higher than Scenario 4 at just under $115 million per year. Both Scenarios 1 and 3 show a decline in GVP until after fleet sizes are reduced, when there is a recovery in GVP, stabilising at about the levels observed in the late 1990s. As with the overall GVP, the GVP for Scenario 9 in the SET is much lower than in any of the other scenarios, sitting at about $16 million throughout the entire projection period.

In the GABT (Figure 5.61) the pattern of catch leads to a vastly different set of trajectories for GVP. The landing of catch that would once have been discarded means the GVP under Scenario 10 stays flatter through time than many of the other Scenarios for the first decade; it then tails off through the end of the projection period and the long-term level of GVP under this scenario in the GABT is roughly $5 million per year. This is much lower than the GVP under Scenario 4, which rises to around $15 million per year and fluctuates at that level into the long-term. The GVP for Scenario 3 also rises to about this level in the medium term (peaking at around $14 million by the end of the projection period) before dropping off again to stabilise $8 million. This result is much less in the medium term than the values given by Scenarios 1, which slowly rises to around $20 million by 2020 before declining again to stabilise about the same level as Scenario 3 ($8 million) in the long-term. In Scenario 9 the GVP begins at 25% of the other Scenarios' GVP, at $1.6 million, though it does increase to $5.5 million in the later part of the projection period. All of these values have comparative value (for ranking the potential of the different management strategies), but they are likely to be underestimates of the potential GVP in the GABT – the BRS estimate of the GABT GVP in 2004-2005 was $17 million (BRS 2007) vs the predicted value of $8 million in 2006 under Scenario 1 to $15.6 million under Scenario 4.

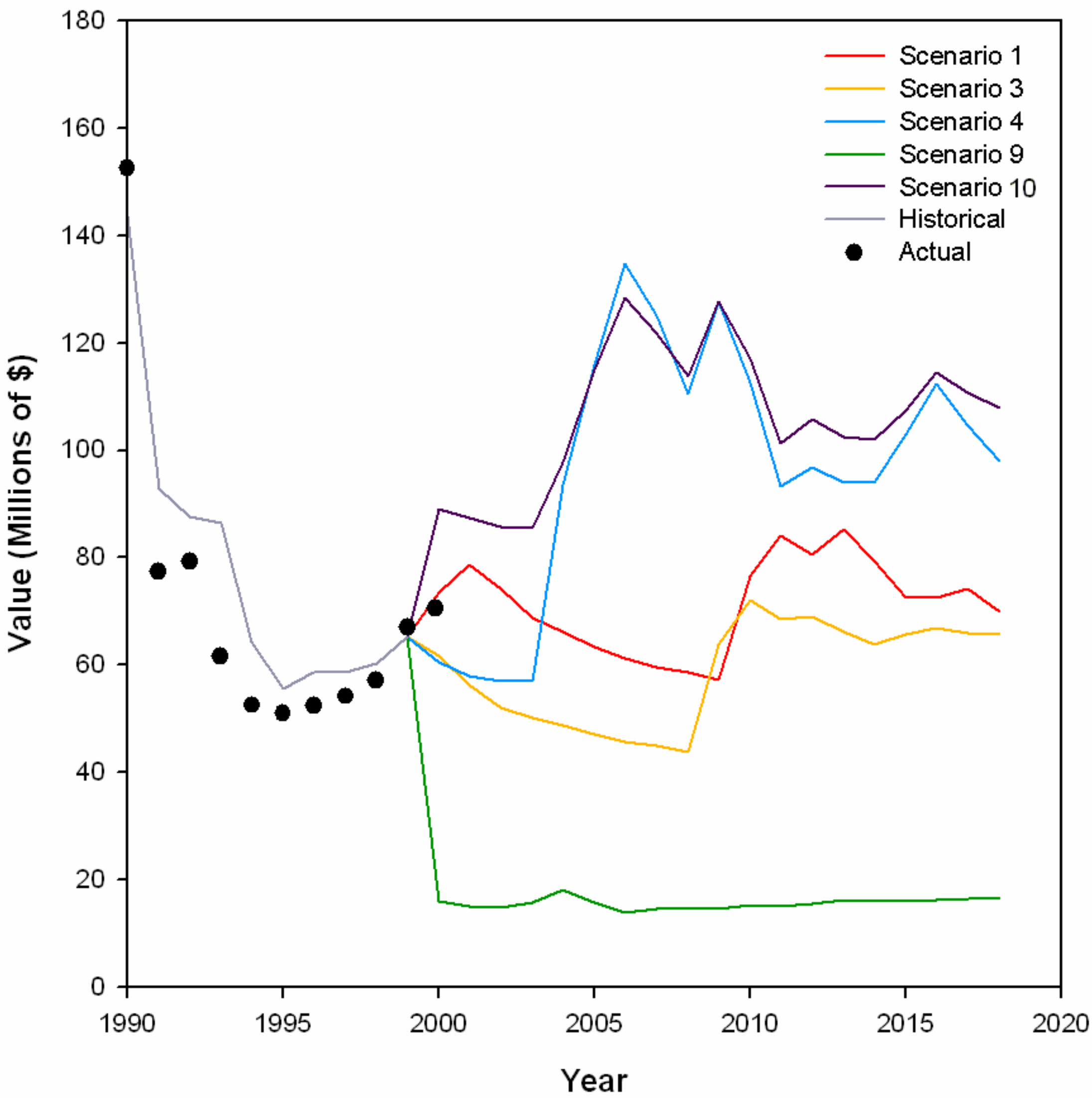


Figure 5-60: Total Gross Value of Production for the SET under the alternative management strategies.

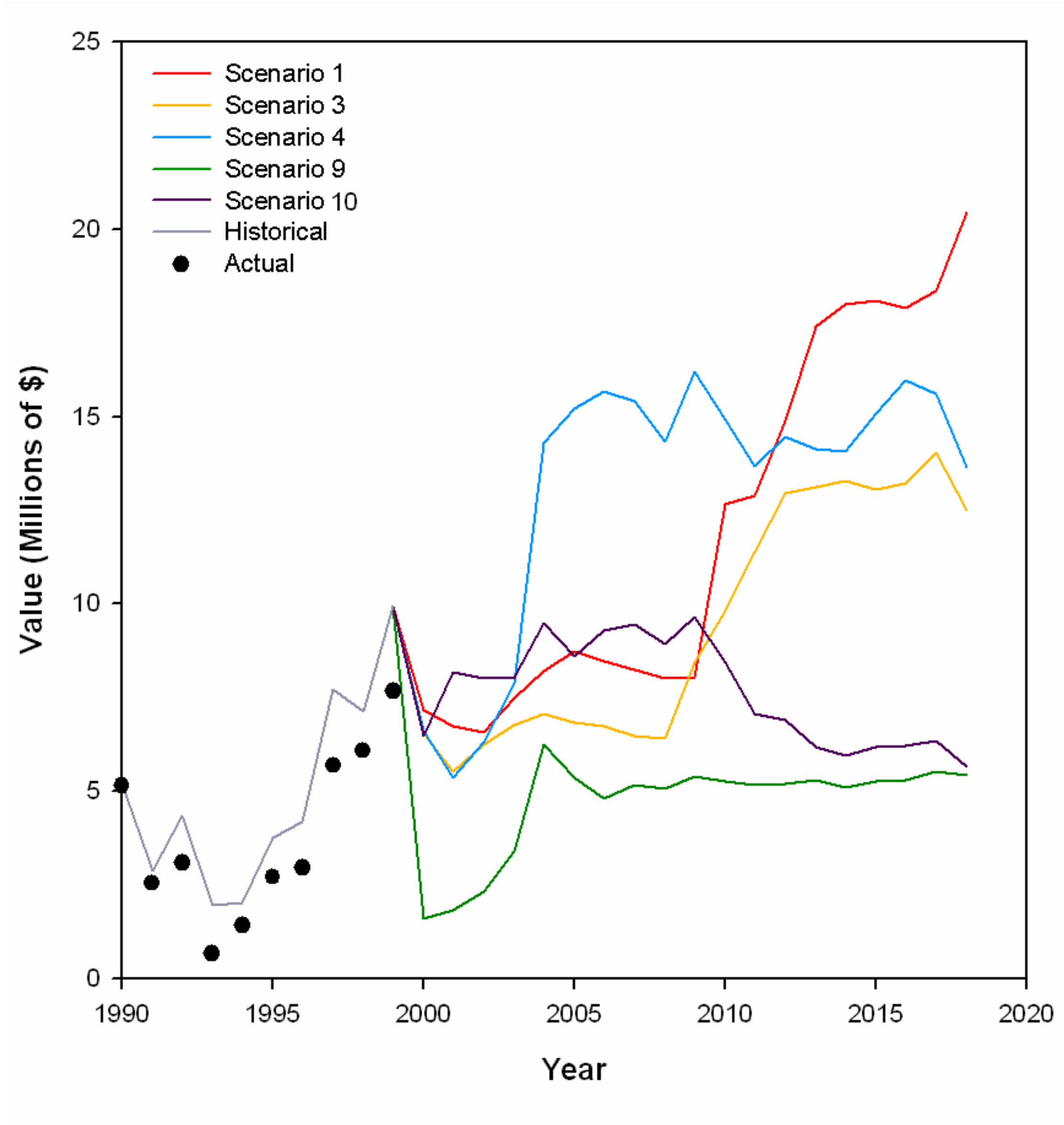


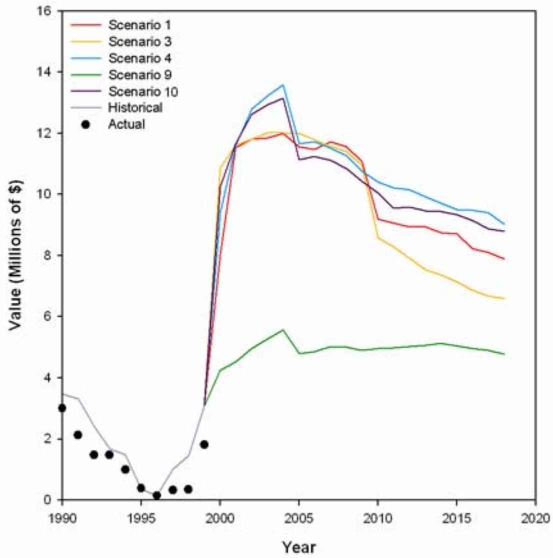
Figure 5-61: Total Gross Value of Production for the GABT under the alternative management strategies.

The GVP for longline is very different to that of the other sectors. The longline GVP for Scenarios 1, 3, 4 and 9 rises steeply in the first few years to roughly $11.5 million, before tailing off in all scenarios. In Scenarios 4 and 10 the GVP eventually stabilises at about $7 million in the long-term. While Scenario 1 ends the projection period above the GVP for Scenario 3 ($7.9 million vs $6.6 million), they both stabilise at around $5.5 million in the long-term. The longline GVP in Scenario 9 is less heavily impacted than in other sectors. It is much less than in any other Scenario for this gear, but it does not drop sharply compared to historical GVP and remains at around $5 million per year through the projection period.

The GVP for the gillnet sector is highly variable. The GVP under Scenario 1 and 10 rise slowly before eventually tailing off. In Scenario 1 the peak is in 2010-2013 at roughly $20 million, while Scenario 10 peaks at $21.8 million in 2007. Both Scenarios eventually stabilise at about $11 million. The peak and fall off is much more rapid in Scenario 4, where it does not rise much beyond historical levels before falling around 2005 and stabilising into the long-term at about

$6-7 million. As in all other sectors the GVP under Scenario 9 remains low (in this case around $6 million) throughout the simulation. The pattern for gillnet GVP is quite different under Scenario 3. The GVP for this sector doubles in the first few years of the projection period and then persists at about that level for nearly a decade. In 2010 there is then a sharp peak in gillnet GVP, peaking at $77.2 million (driven by increases in the catch of demersal sharks, particularly gummy shark) before dropping away again in the next few years. This GVP does not stabilise for some time, but is stable at around $8 million by the end of 50 year runs. A peak of such size may be questionable in reality, it is likely that if landings increased by the magnitude predicted in Scenario 3 then there would be a reduction in market value (due to a feedback on prices in response to the volume of landings vs demand and the quality of the product). Unfortunately, such a reduction is not captured by the simple price model used in Atlantis SE (and so the GVP is likely to be substantially overstated during that period).

(a)



(b)

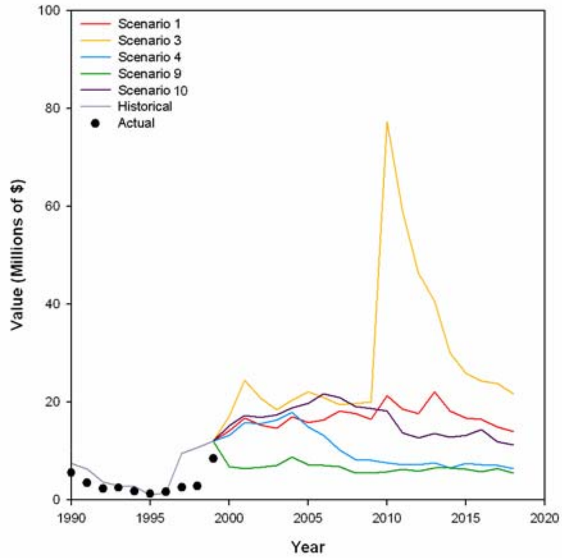


Figure 5-62: Total Gross Value of Production for the GHAT sectors under the alternative management strategies: (a) longline and (b) gillnet.

5.3.2 Costs

For the bulk of the results a single trajectory is sufficient to illustrate the performance of the alternative scenarios. However, in the case of costs (and profits in section 5.3.3) to show the full range of behaviour across all components of the fisheries it was necessary to report a range for the results instead of a single figure. The lower end of the range of costs is the value returned if the majority of each sector is highly efficient and is has costs at rate toward the lower end observed for that sector. The high end of the range of costs marks is the level that would accrue if the majority of the fleet in each sector was of moderate to poor efficiency and faced costs at rates considered to be at the high end of those paid per sector in 2006 (Galeano *et al* 2005, Tom Kompas and Gerry Geen pers. com.). The costs included are not just cash costs, but also management costs, depreciation, quota leases and insurance. Note that maintenance costs do not increase with vessel age in the simple cost model used in Atlantis SE (due to a lack of information on how to parameterise such an increase), this means costs in those Scenarios where investment in new vessels is low (particularly Scenarios 1 and 3) will consequently be lower than would be the case in reality under the same circumstances (this will be corrected in any future implementations).

Costs Per Day

When costs per day are considered, the source of the economic problems with Scenario 9 becomes readily apparent (Figures 5.63 – 5.67); whether considering overall costs per day fished or the breakdown per sector, the costs per day are higher (by 1.5-2.5x) in Scenario 9. The average costs per day across all sectors for Scenario 9 is roughly \$14,000-\$21,000, which is substantially more than the \$9,500-\$16,000 of Scenario 4 and \$6,000-\$14,000 of the other three Scenarios (Figure 5.63).

A similar pattern is seen for costs per day in the GABT (Figure 5.64). The range of costs per scenario in the GABT is much tighter and shows less overlap between the Scenarios than the overall average costs per day. The ranking of costs is similar however, the costs are highest under Scenario 9 (\$34,000-\$39,000), intermediate under Scenario 4 (\$20,000-\$25,000) and lowest under Scenarios 1, 3 (\$10,500-\$16,000) and 10 (\$8,000-\$12,000). The costs under Scenario 10 eventually drop below that of all other Scenarios through time. As much as 85% of the costs are crew, unloading and other variable costs. In comparison with the other sectors the GABT have a much large proportion of their costs (10% or more) as management costs. In particular, under Scenario 9 the recovery of management costs represent 18-25% of the total costs for the sector each year.

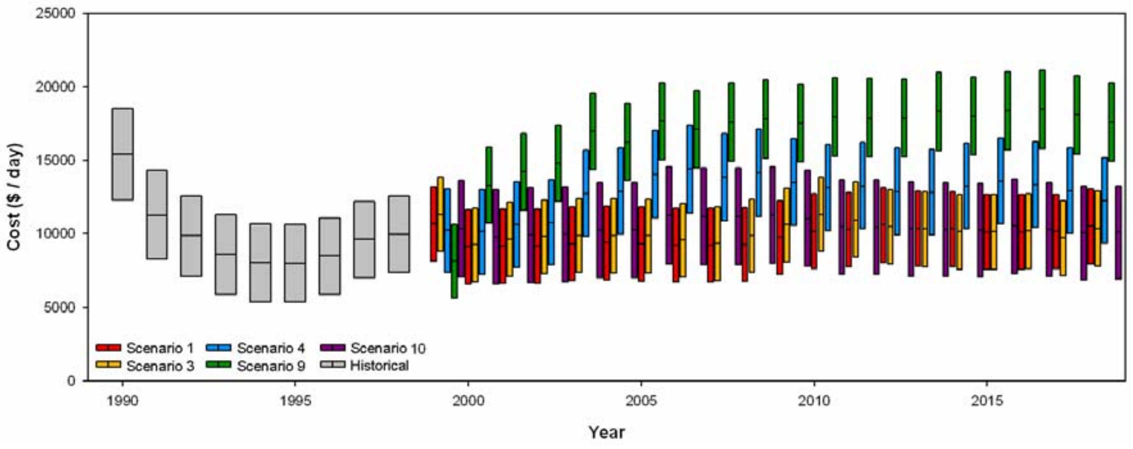


Figure 5-63: Costs per day over all fisheries under the alternative management strategies.

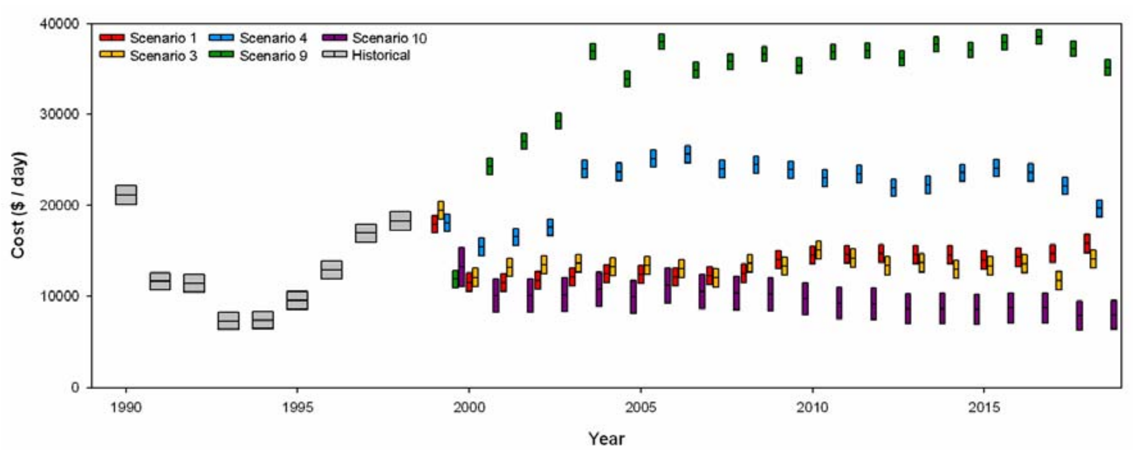


Figure 5-64: Costs per day for the GABT under the alternative management strategies.

A smaller percentage of total costs are made up by management costs in the SET (only 2-7% in all but Scenario 9 where it was as much as 27%). There is also much less differentiation between the costs per day under the different Scenarios for this sector (Figure 6.65). The costs per day in the SET under Scenarios 4, 9 and 10 are all about \$8,000-\$14,000. The costs under Scenarios 1 and 3 are much lower, but increase more steadily through time. While the costs in Scenarios 4, 9 and 10 stabilise after only a few years, those under Scenario 1 and 3 continue rising (first in a large step and then much more slowly) into the long-term reaching \$6,000-\$10,000 by 2020 and potentially doubling again by 2050 – and this is without inflationary increases or other costs such as rising fuel prices (as these factors have been omitted from these results for ease of interpretation).

There is also extensive overlap in potential costs for each of the GHAT sectors under the different management Scenarios (Figures 5.66 and 5.67), where the vast majority of costs are labour and variable costs. For longline, there is very little difference between the costs per day under Scenarios 1 and 3, (\$7,000 - \$22,000) and Scenarios 4 and 10 (\$7,500-\$24,000), but the highest level of costs under Scenario 9 are well above the other Scenarios at \$28,000. The gillnet costs per day appear to be much lower than for the other sectors (though they are also much more uncertain so this difference in magnitude may be spurious). For this sector the costs per day overlap almost completely for the few 8 years, but diverge to some extent after that. The costs per day under Scenario 3 rise steeply, driven by the increased catch seen in the GHAT under that scenario. The maximum costs under Scenario 4 not only drop through time relative to the other scenarios (ending at 85-90% of the cost of the other 4 Scenarios), but the minimum cost is consistently substantially lower than for any other scenario (as much as 50-90% lower).

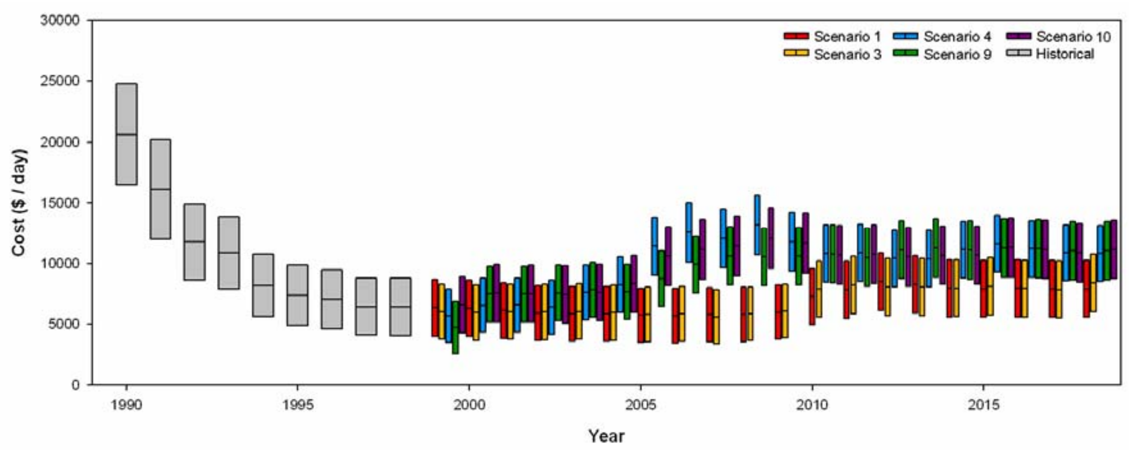


Figure 5-65: Costs per day for the SET under the alternative management strategies.

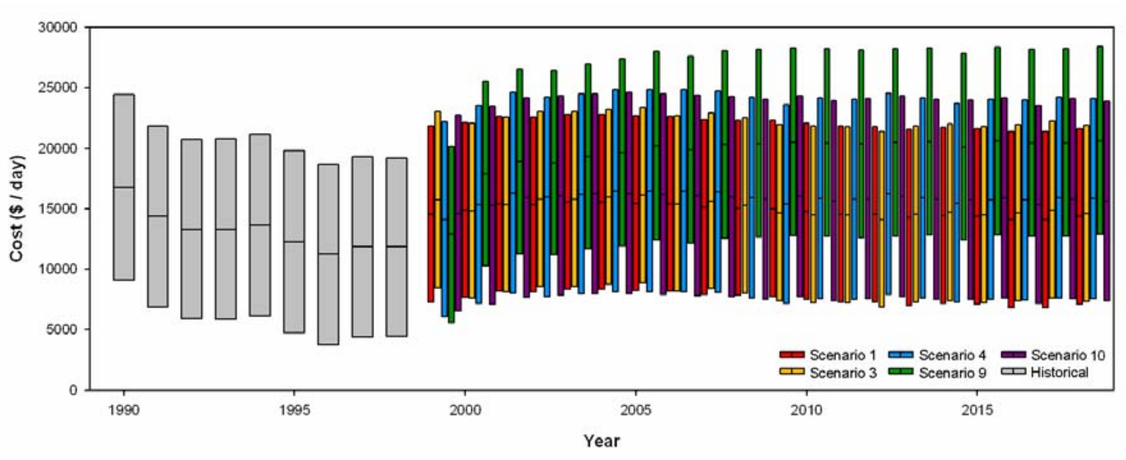


Figure 5-66: Costs per day for longliners under the alternative management strategies.

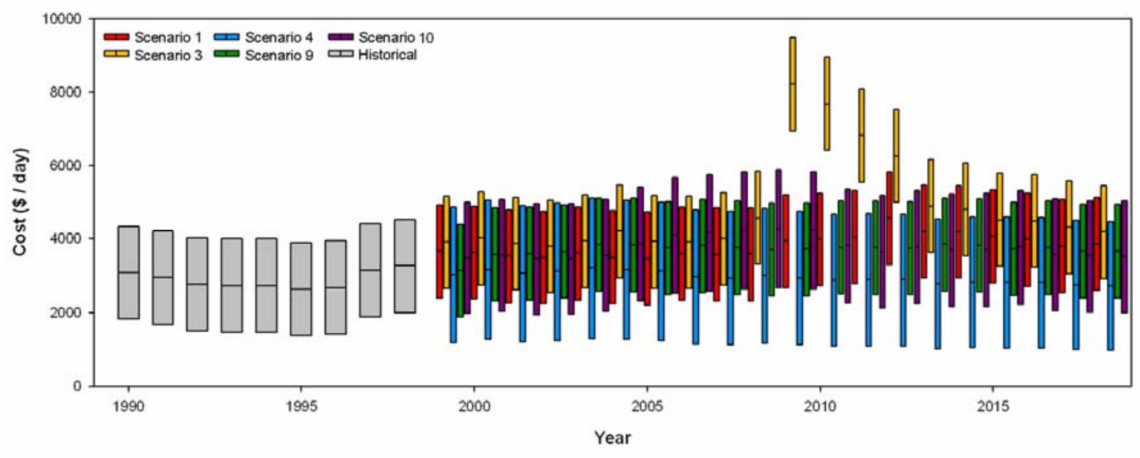


Figure 5-67: Costs per day for gillnet under the alternative management strategies.

Costs Per Tonne

There is a good deal of overlap in the average costs per tonne across the management Scenarios (Figure 5.68). The highest maximum costs per tonne are in Scenarios 4 and 9; while the lowest minimum costs are under Scenario 10. The exceptionally low catches in Scenario 9 in the first year of the projection period means that the costs per tonne in that year for that scenario are exceptionally high, before dropping to stabilise about $5,500-$10,000. The cost per tonne under Scenario 4 stabilises at the slightly wider range of $5,000-$12,000, but the stable catch and lower effort trajectory under Scenario 10 means the cost per tonne stabilises at a lower level ($3,500-$7,500). In contrast, the cost per tonne under Scenarios 1 and 3 grows steadily into the long-term, rising beyond that of even Scenario 4 by 2030.

There is also a good deal of overlap in costs per tonne across Scenarios in the SET sector (Figure 5.69). As with overall average costs per tonne, there is an initial spike in costs per tonne under Scenario 9. After that point costs per tonne decline under Scenario 9 to end the projection period about $4,000-$6,000. For the other four Scenarios costs per tonne are higher until after the fleet sizes are reduced. Only the costs per tonne under Scenario 4 grow rapidly again by 2020 (ending the projection period at $5,500-$8,500 per tonne, noticeably higher than the $3,500-$6,000 of the other Scenarios). The costs per tonne under Scenario 4 stabilise about their

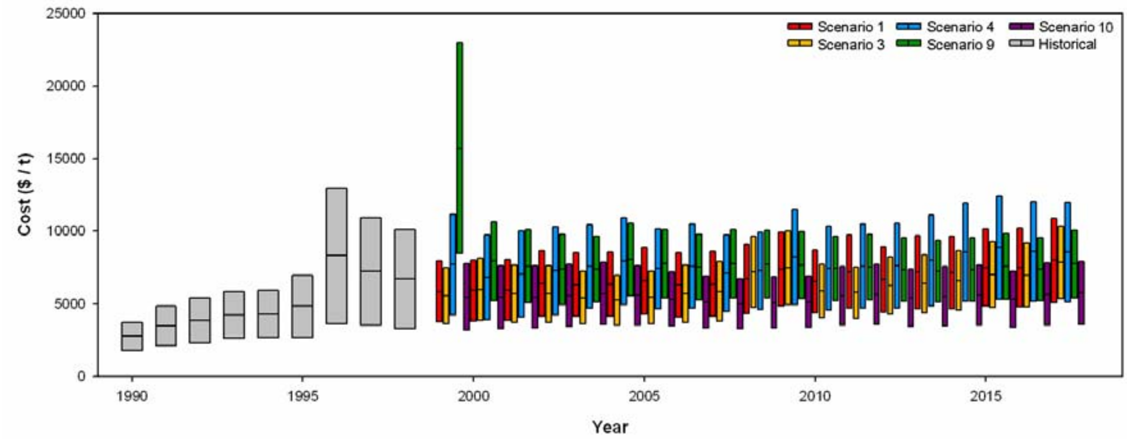


Figure 5-68: Costs per tonne over all fisheries under the alternative management strategies.

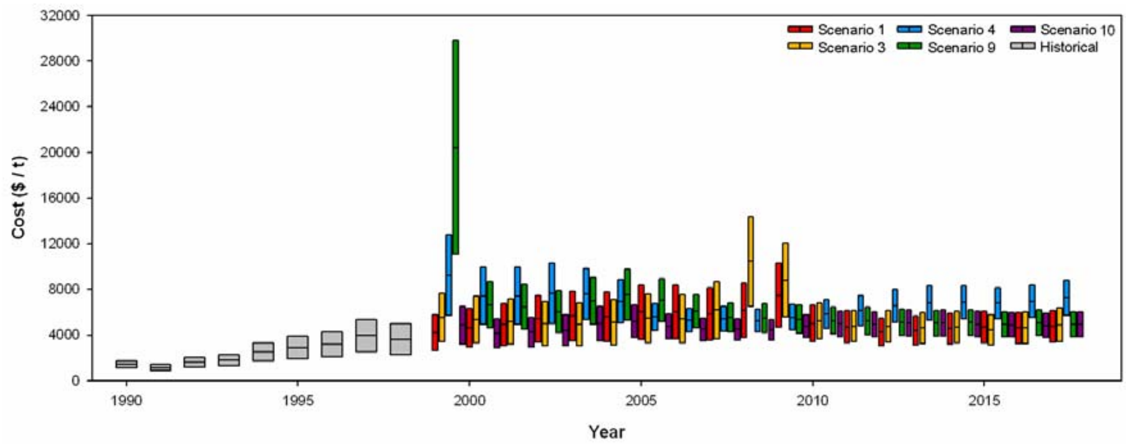


Figure 5-69: Costs per tonne in the SET under the alternative management strategies.

2020 level, but the costs for Scenarios 1 and 3 slowly grow through time to eventually equal (in the case of Scenario 3) or exceed (in the case of Scenario 1) the costs per tonne of Scenario 4 in the long-term.

As with costs per day, the costs per tonne under the different Scenarios are much more constrained and distinct in the GABT (Figure 5.70). The cost per tonne under Scenario 9 is about $3,300, which is lower than the costs under all other Scenarios, except maybe Scenario 10 (which has such a broad range of possible costs that it overlaps the values of many of the other Scenarios). The costs per tonne in the GABT are highest under Scenario 4 (fluctuating around $6,000-$7,000). The cost per tonne under Scenario 1 and 3 are lower than that of Scenario 4. The costs per tonne under Scenario 1 are initially higher than those under Scenario 3, but after fleet sizes are reduced the costs under the two Scenarios are much closer and end the projection period at about $4,500-$5,000. As for overall average costs, and the costs per tonne in the other sectors, the costs per tonne in the GABT for Scenarios 1 and 3 does continue to rise with time, but it is a very slow climb after 2010. In contrast, the costs per tonne under Scenario 10 decline a little through time in magnitude, though their range does not contract. The range of costs per tonne in the GABT under Scenario 10 is twice that seen under the other Scenarios and end the projection period at $2,500-$4,500.

The pattern of cost per tonne in the GHAT sectors is quite different to that in the GABT (Figure 5.71). There is a good deal of overlap between the costs under different Scenarios, but there is a shift in the patterns through time. Initially the maximum costs per tonne for longline under Scenarios 4 and 9 are higher than for Scenarios 1, 3 and 10 (Figure 5.71a). After the first decade however, the cost per tonne under Scenarios 1 and 3 begin to rise, while those for Scenarios 4 and 9 are reduced a little. This means that Scenarios 3, 4 and 9 all end with longline costs per tonne of around $4,500-$13,500. The costs under Scenario 10 stay lower, ending the projection period between $3,300 and $10,000. Only under Scenario 1 does the cost per tonne for longline rise substantially through time, reaching $7,000-$20,000 by 2020 and almost doubling that into the long-term.

The patterns of costs per tonne are more variable across Scenarios and through time for gillnet (Figure 5.71b). Even after the initial spike the costs per tonne under Scenario 9 remain high (the maximum costs under Scenario 9 consistently ranking as high or higher than that of any other Scenario) – ending the projection period at $8,000-$18,000 per tonne. The maximum costs under Scenario 4 can be amongst the highest, but the lowest values for costs per tonne for this Scenario can also be amongst the lowest. Moreover, the costs per tonne for gillnet in Scenario 4 fluctuate quite strongly through time. The range and magnitude of the costs per tonne for gillnet under Scenario 3 also show substantial changes through the projection period – contracting as the fleet sizes are reduced and catch rates recover (being $3,400-$4,800 at their lowest), but expanding again as time progresses (reaching $8,500-$16,000 in 2020). The costs per tonne under Scenarios 1 and 10 also dip as fleet sizes are reduced and rise again through time, though neither do so as strongly as for Scenario 3. In addition, the rate of increase is much lower for Scenario 10 and it stabilises at about $4,500-$10,000 by the end of the projection period (while the costs per tonne under Scenario 1 continue to rise gradually into the long-term).

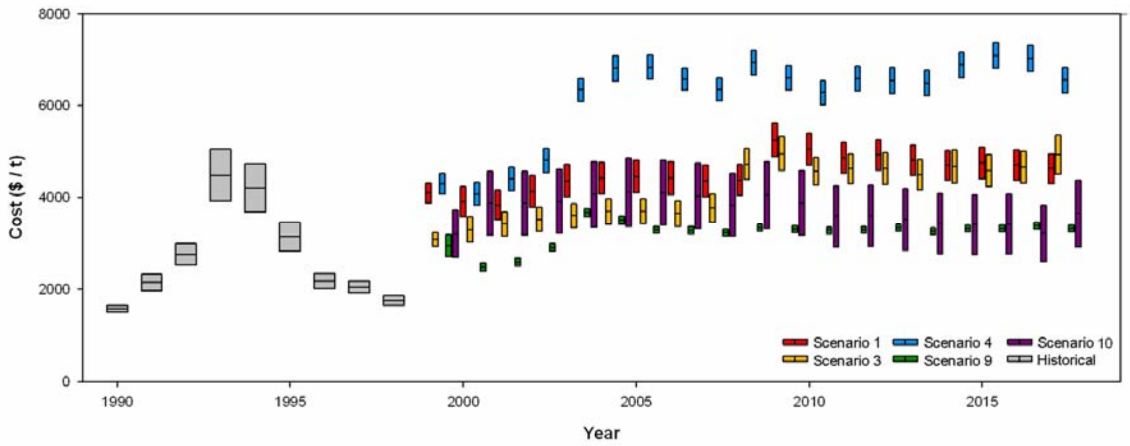
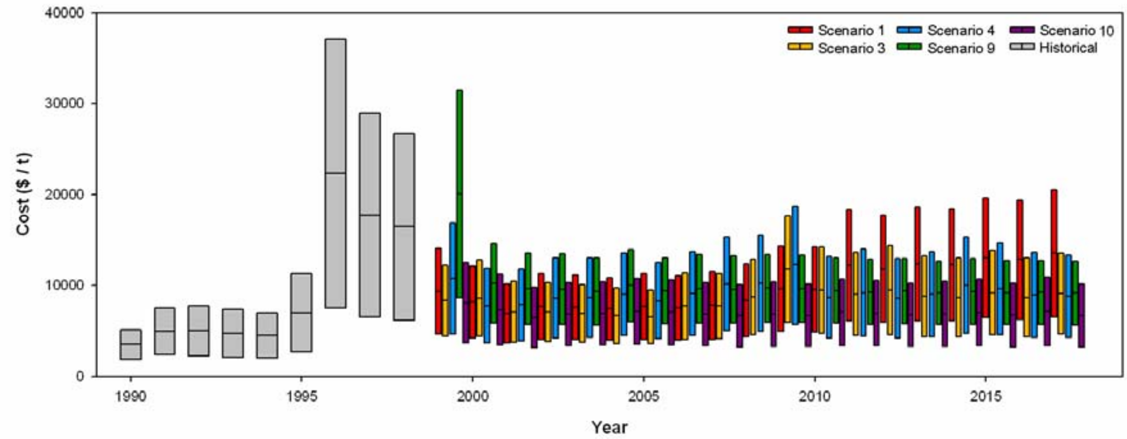


Figure 5-70: Costs per tonne in the GABT under the alternative management strategies.

(a)



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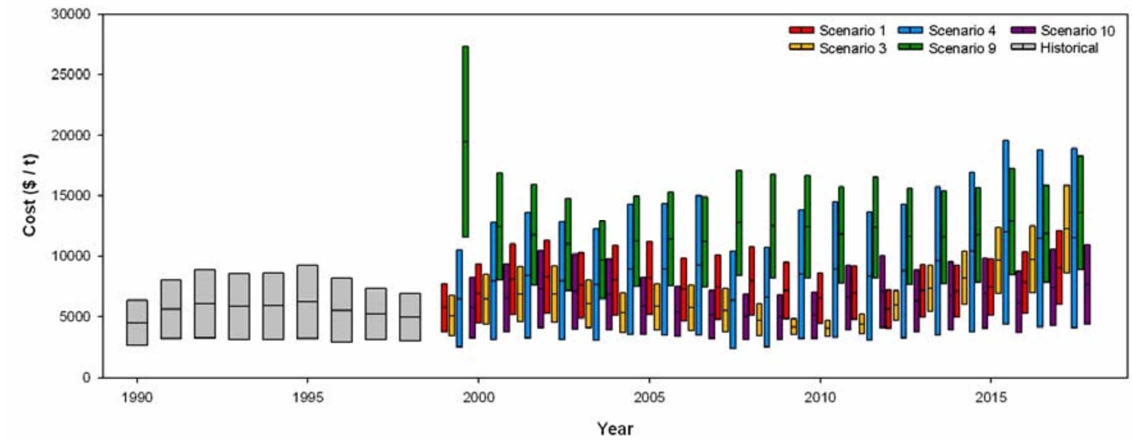


Figure 5-71: Costs per tonne in the GHAT sectors under the alternative management strategies: (a) longline and (b) gillnet.

5.3.3 Profits

As mentioned above, costs are given as a range (from costs associated with a fleet that is highly efficient and is charged at rates toward the lower end of those observed in recent years to costs at the level that would be realised if the fleet was of moderate to poor efficiency and was charged at rates toward the high end of those paid per sector in 2006). Consequently, profits must also be given as a range. These profits are calculated as the difference between gross value of the product and the total costs (including costs such as depreciation, quota leases and management costs).

No publically available data on the observed range of profits is currently available. Average values on boat cash income and profits are available for some sectors (Galeano *et al* 2005), but this does not capture the range that would have been seen across individual operators in the different sectors. As a result, the historical values given in the plots are calculated in the same way as for the projection period, but based on observed catch and effort time series rather than simulated ones. For context, where average information is available reference is made to it in the discussion of the results.

Profits per tonne landed

Despite the potential for relatively high costs per tonne, the highest total profits per tonne are seen under Scenario 4 (as high as $7,000 per tonne), which has profits 2-10x higher than those seen under the other Scenarios. Even at its worst it does not dip as far into a loss as Scenario 9 and it quickly improves with it losses smaller than that of the other Scenarios within a few years. From there (into the medium and long term) it continues to strengthen until profits per tonne under this Scenario are well above break even, even under the highest cost rates and lowest efficiencies (Figure 5.72). The costs and production associated with Scenario 10 mean that early losses (approximately -$2,200 per tonne) are only half of those seen Scenario 4, but its highest potential is also only about a half of that for Scenario 4. The range achieved by Scenario 3 by the end of the projection period (-$760 to $2,700) is about that achieved by Scenario 1 (-$770 to $2,600), which is better than that under Scenario 10 (-$1,800 to $1,400). The range of profits seen under Scenarios 4 and 10 remain steady into the future (those for Scenario 4 even contracting further out of the loss range), but the range for Scenarios 1 and 3 declines by 10% (or more) into the long-term. The economic performance for Scenario 9 is also poor into the medium and long-term. Under average efficiencies and rates the fishery as a whole would be hard pressed to have a positive profit per tonne into the medium and long-term without the large scale changes associated with Scenarios 4 and 10.

As with the overall profits per tonne, the sector level returns in the SET (Figure 5.73) under Scenario 9 are fairly low. The initial year is the worst (at -$6,000 to -$25,000 per tonne), but even as the fishery improves (on the back of high CPUE) the profits do not exceed those under Scenarios 1 or 3 into the longer-term. The improvement in profits under Scenario 9 occurs more quickly than for Scenarios 1 and 3, but ultimately the potential profits under Scenario 9 (-$300 to $2,000 per tonne) are as little as a half of those seen in Scenarios 1 and 3 by 2020 (-$100 to $3,000 per tonne). The performance of the SET under Scenarios 4 and 10 is much stronger and is always positive once fleet sizes have been reduced. The performance in terms of profit per tonne under Scenario 10 is clearly the strongest – at $5,500-$8,600 per tonne by 2020 and growing still further into the long-term – showing that higher relative costs (Figure 5.69) do not always equate to lower profits (Figure 5.73). The performance under Scenario 10 is less variable however and is consistently around $3,000-$5,500 per tonne from 2010 onwards.

Scenario 4 also produces the highest profits per tonne in the GABT (Figure 5.74). The $6,300-$6,900 returned under Scenario 4 is 2-5.5x higher than the profits taken under any other Scenario. The profits per tonne are higher in the medium term under Scenario 1 are higher than any other Scenario (other than Scenario 4). The difference between the profits per tonne under Scenario 1 and 3 contract with time, but are still as much as $1,000 per tonne until at least 2030. In the long-term the performance of these Scenarios does taper off to about $1,500-$2,500 per tonne. The performance under Scenarios 10 is initially stronger than for Scenarios 1 and 3 (and even Scenario 4 in the very early years), reaching $1,600-$3,000, but is eclipsed by them in the medium-term. Fluctuating around $100-$1,500 into the long-term the profits per tonne under Scenario 10 do again rise above those under Scenario 1 and 3 in the long-term. The profit per tonne is also very stable under Scenario 9. After an initially poor level of profit (-$1,750 to -$1,250) the returns per tonne under Scenario 9 stabilise at about $1,600 after 2005.

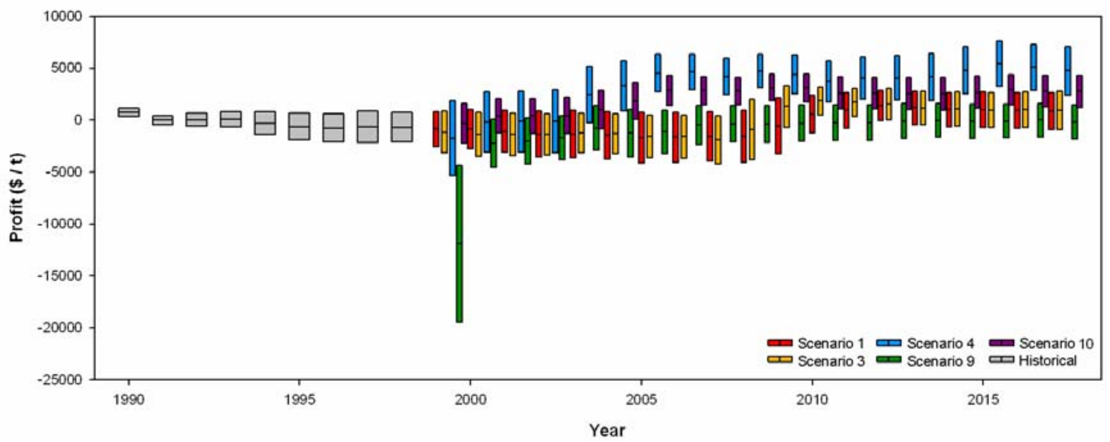


Figure 5-72: Total profit per tonne landed for the dynamic fisheries sectors under the alternative management strategies.

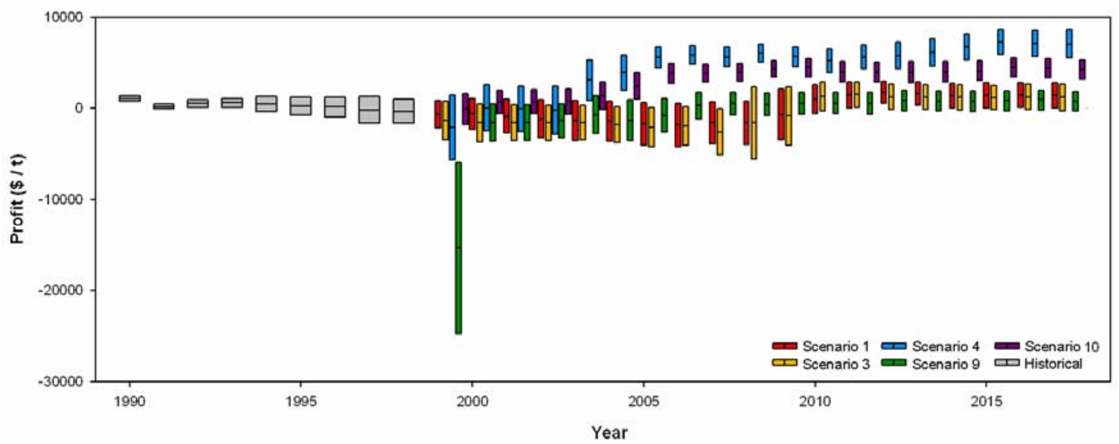


Figure 5-73: Profit per tonne landed for the SET under the alternative management strategies.

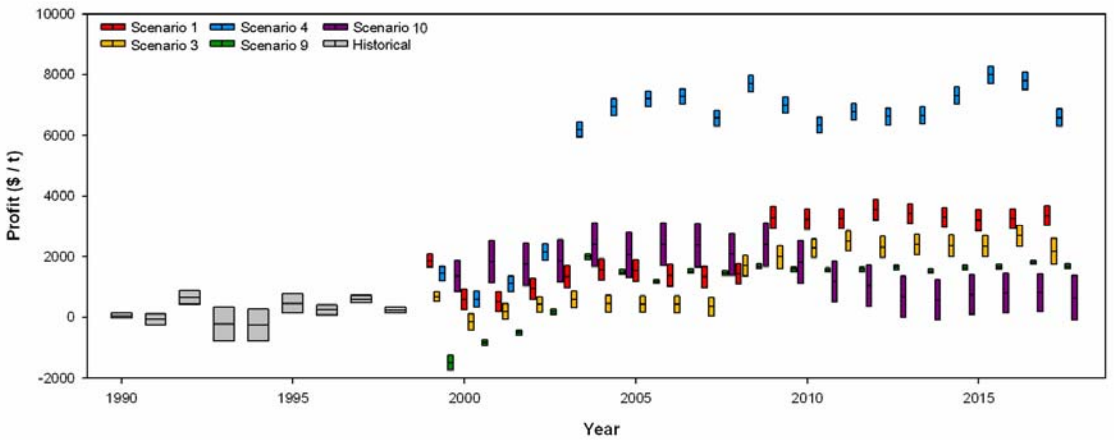


Figure 5-74: Profit per tonne landed for the GABT under the alternative management strategies.

The range of maximum potential profits per tonne for the GHAT sectors are particularly uncertain, as can be seen when the range in potential historical levels of profit are considered for longline (Figure 5.75) – where additional costs (such as bait) make the fishery potentially more costly. While losses were observed through this period (from Galeano *et al* 2005), their average value did not drop as low as the bottom end of the ranges given in Figure 5.75 – the observed average values sitting closer to the upper end of the range given in the plot. This suggests the figures in the plots may tend to be pessimistic, but they do span the average values calculated by independent groups and they remain useful for comparing the performance of the alternative management strategies.

The maximum potential profits per tonne for longline (Figure 5.75a) under Scenario 4 is 2-10x (or more) higher under Scenario 4 (as much as $3,000 per tonne) than Scenarios 1, 3 or 9 (where maximum profits reach $300 to $1,450). The difference between Scenarios 4 and 10 are smaller, but the profits per tonne for longline catch under Scenario 4 are still more than 1.5x those under Scenario 10. The higher costs per tonne under Scenario 4 than Scenarios 9 or 10 means that at the lower end of the range of profits it can have a lower potential profit than those Scenarios (-$6,700 vs -$5,300). Nevertheless, even then the profits losses much lower than those that could occur under Scenarios 1 and 3 (where losses can reach -$9,000 to -$13,000 per tonne).

The potentially high relative costs for the gillnet sector under Scenarios 4 and 9 mean they do not perform as strongly as some of the other Scenarios (Figure 5.75b). The maximum potential profits under Scenario 9 are as little as 5% of those seen under any of the other Scenarios by 2020. While the maximum potential profits under Scenario 4 are on par with those under

(a)

(b)

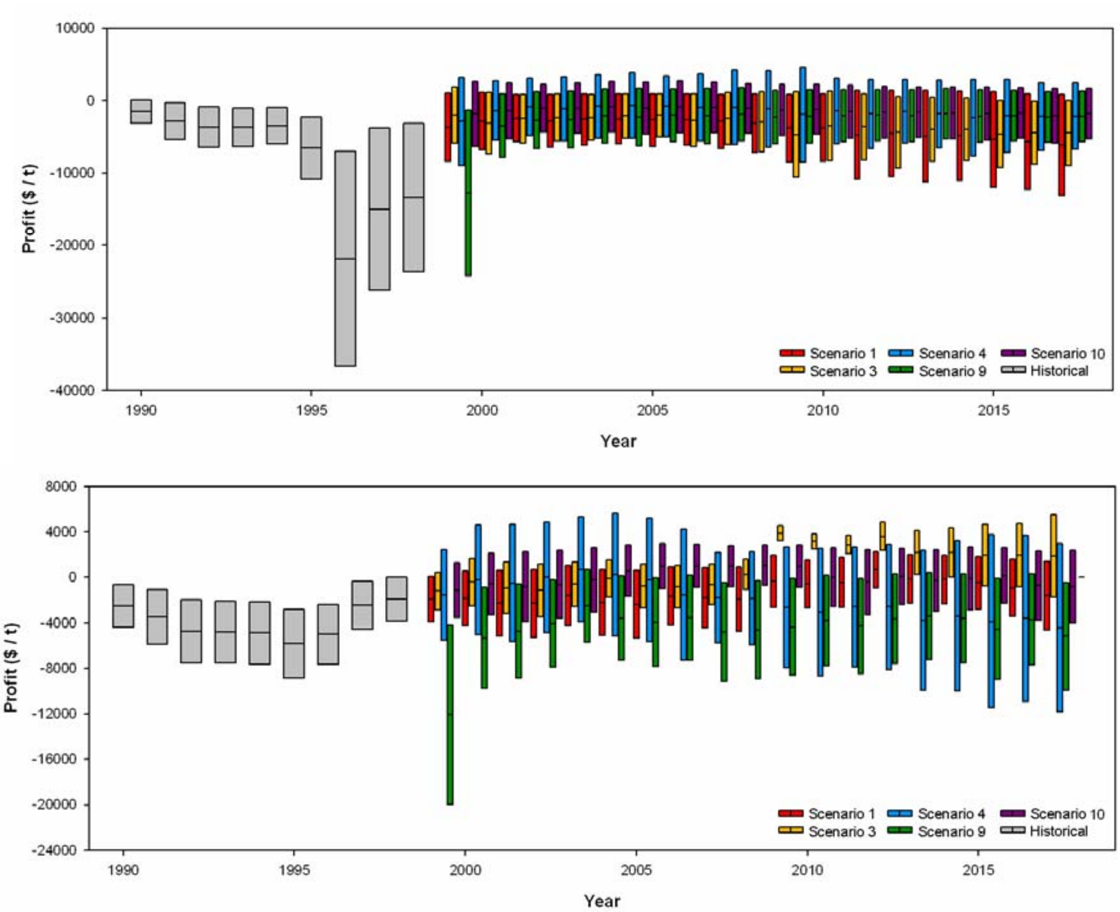


Figure 5-75: Profit per tonne landed for the GHAT sectors under the alternative management strategies: (a) longline and (b) gillnet.

Scenarios 1 and 10, the range of potential profits under Scenario 4 is much broader (reaching -$11,000, more than twice the -$5,000 per tonne reached in Scenarios 1 and 10). This range does contract through time seeing the gillnet profits per tonne under Scenarios 4 and 10 end up quite similar into the long-term. The performance of Scenario 1, but particularly Scenario 3, improves after fleet sizes are reduced. Unfortunately that performance degrades into the long term – with the profits per tonne under Scenario 1 dropping steadily into the long-term and the range in potential profits expanding with time (the maximum potential profit remains at about $5000 per tonne, but the potential loss grows larger, reaching -$8000 by 2040).

Profits per effort

The strong performance of Scenario 4 in terms of total profits per tonne is also mirrored in the total profits per day (Figure 5.76); at $2,500-$10,500 the profits per day under Scenario 4 can reach more than two-fold the level seen in the other Scenarios. The profit per day under Scenario 10 is higher than that under Scenarios 1 and 3, though the difference is much smaller in the medium term (after fleet sizes have been reduced but before stock depletions lead to a long-term decline in the performance of Scenarios 1 and 3). The low absolute catch means that even with low effort levels under Scenario 9 (that keep the variable costs low) into the medium and long-term profits per day are lower in this Scenario than for any other Scenario. Into the longer term Scenarios 1, 3 and 9 all have the potential to return a loss per day fished – with a potential loss of -$2,500 to -$1,000 per day. While constraints on catch keep the profits in Scenario 9 at low levels, for Scenarios 1 and 3 the drop off in catch of higher quality product through time leads to a drop in profits in these Scenarios (even though costs per day stay lower than for Scenarios 4 and 10).

In the SET the costs per day (Figure 5.76) split into two distinct groups of results – by the end of the projection period the values for Scenarios 4 and 10 are about $7,000-$14,000 (with those for Scenario 4 roughly 10% higher than those for Scenario 10) while the profits per day for Scenarios 1, 3 and 9 are -$500 to $4,500. None of these later Scenarios improve into the long-term and the profits under Scenario 9 remain 5-30% lower than those under Scenarios 1 or 3 even as their profit levels decline.

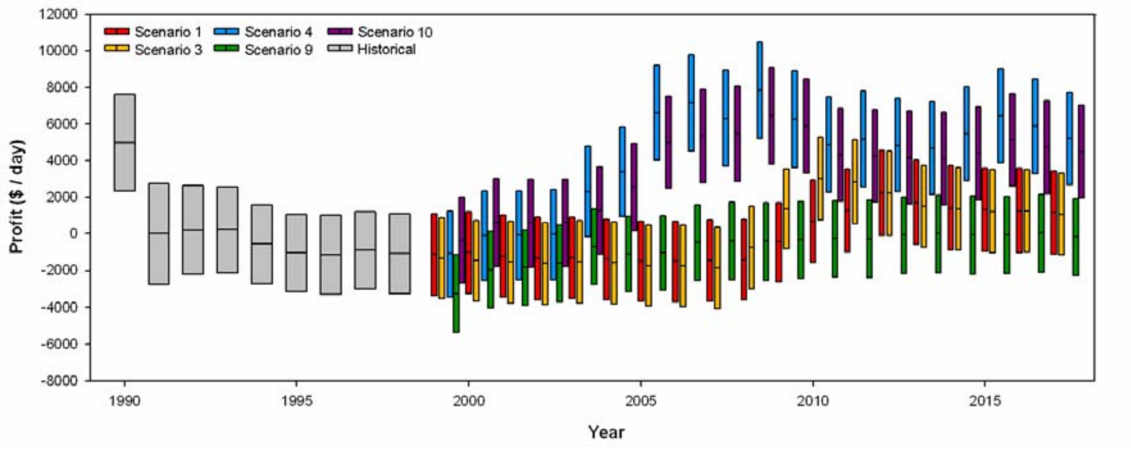


Figure 5-76: Total profit per day for the dynamic fisheries components under the alternative management strategies.

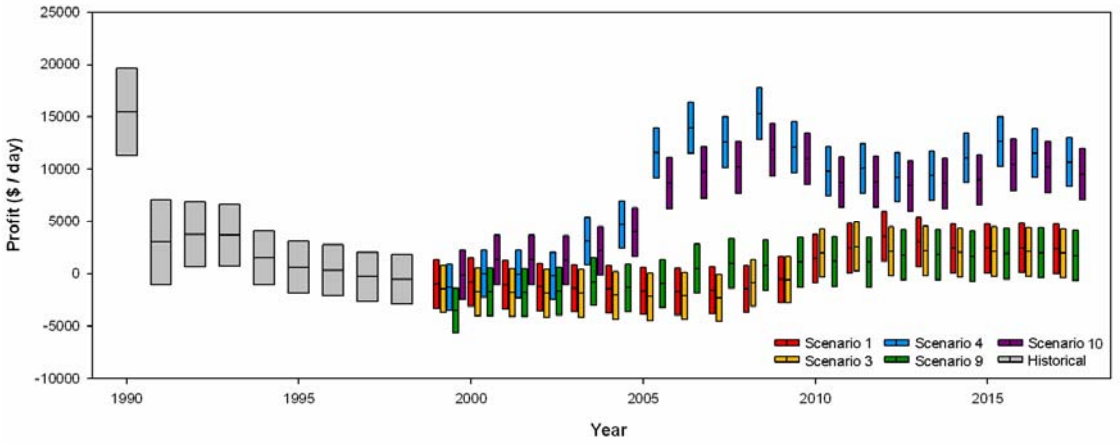


Figure 5-77: Profit per day for the SET under the alternative management strategies.

The profits per day are much higher in the GABT (Figure 5.78) relative to the other Scenarios than in the SET (or overall). Putting aside the initial losses (which could be as much as -$10,000 per day), once the fisheries under Scenario 9 have settled, only the GABT profits under Scenario 4 out perform the returns from this sector under Scenario 9 – the values for Scenario 4 are 1.5x those seen under Scenario 9. Moreover, the profits under Scenario 9 drop a little in the medium term for this sector and stabilise at about $17,000 per day, whereas the values under Scenario 4 stay higher and fluctuate between $21,000 and $29,000 per day. As with profits per tonne, the profits per day under Scenario 10 drops below that for Scenarios 1 and 3 in the medium term; Scenario 10 is at -$500 to $5,000 by 2020, whereas the simulations for the other two Scenarios at this point do not predict potential losses and see profits per day at $4,000-$11,000. However, as with profits per tonne, the profits per day remain steady under Scenario 10 into the long-term whereas the values for Scenarios 1 and 3 ultimately decline and fall back below the level of Scenario 10.

In each of the GHAT sectors (Figure 5.79) there is a good deal of overlap in the potential profits per day across the different scenarios. For the longline sector (Figure 5.79a) the profits per day under Scenarios 4, 9 and 10 are higher than those under 1 and 3 ($4,500 per day vs $1,000) and the potential losses are lower (by 10-15%), but there is still extensive overlap. Potentially the most significant difference in the trajectories is that those for Scenarios 4, 9 and 10 remain steady about the 2020 values into the long-term, while those for Scenarios 1 and 3 continue on a slow decline.

The profits per day for the gillnet sector show less overlap in the years just after 2010, but in other years there is more overlap. Initially and again in the long-term the potential profits are higher under Scenarios 4 and 10 than the other Scenarios, though Scenario 4 also has the potential to produce some of the highest losses for this sector. Scenario 9 has the lowest potential profits (of only $10-$100 per day) and highest potential losses (on the order of -$2,700 per day) for this sector even into the long-term. The low relative GVP for gillnet under Scenario 4 leads to the potential for losses even though costs pre day are often lower than for the other Scenarios. As noted elsewhere, the spike in catch and CPUE that drives the spike in profits per day is likely too be higher than would be observed in reality (as gillnet gear saturation factors have not be captured in Atlantis SE) and that the GVP associated with the peak is overstated (as the current market model does not account for supply and product quality driven reductions in market value). Consequently, it is likely that the degree of difference between the Scenarios after 2010 would be more on the order of that around 2020 at most (though that is still a substantial difference, with low potential losses and potential gillnet profits in 2020 under Scenario 3 2-20x that under the other Scenarios).

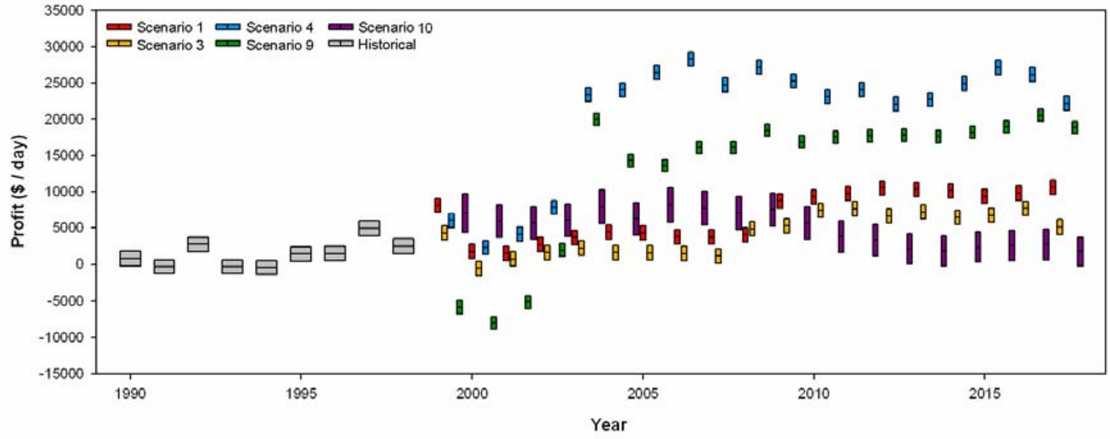
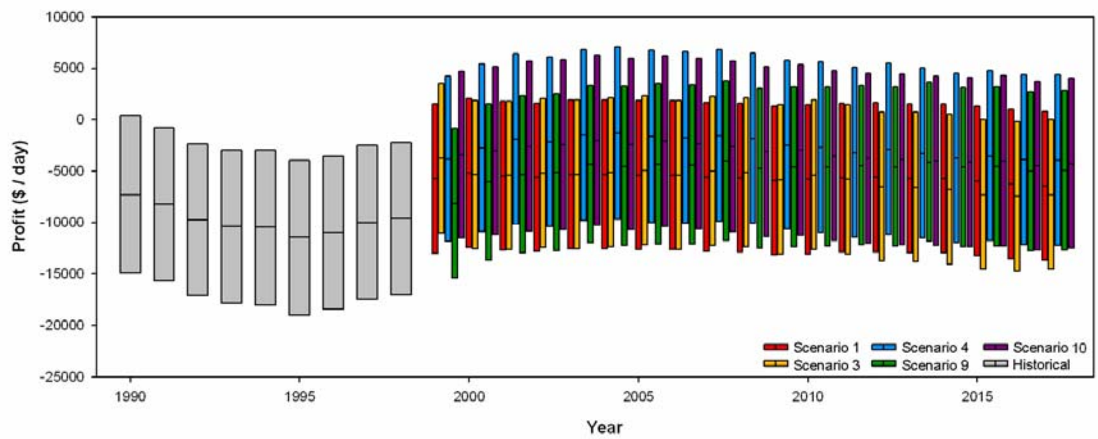


Figure 5-78: Profit per day for the GABT under the alternative management strategies.

(a)



(b)

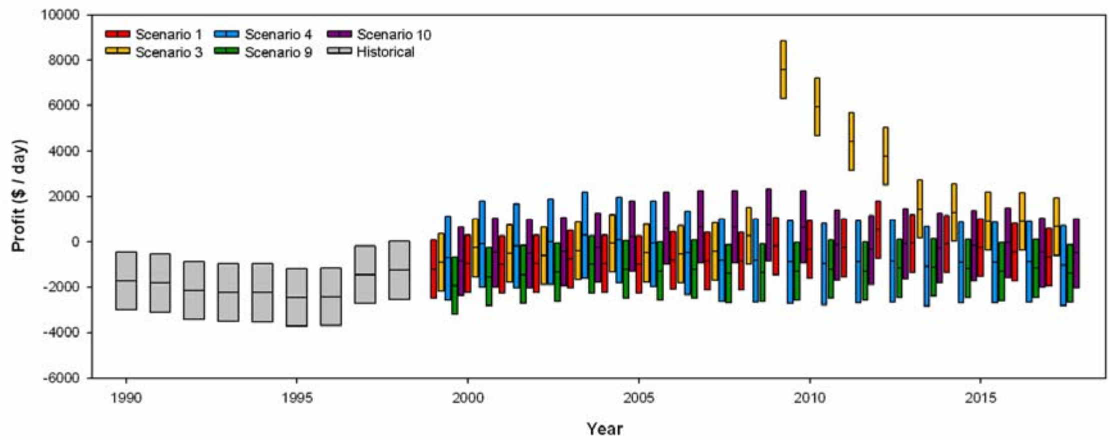


Figure 5-79: Profit per day for the GHAT sectors under the alternative management strategies: (a) longline and (b) net.

Profit per Boat

Looking at the overall profit per boat per year across the fishery (i.e. total profit / total SESSF fleet size) the improved economic performance of the SESSF under Scenarios 4 and 10 is obvious (Figure 5.80). Once fleets have restructured (in the first few years of the Scenario) no boat has a negative potential return for the year under Scenarios 4 and 10; and their potential profit levels are 1.5-8x that seen under the other Scenarios. The overall potential profits per boat under Scenarios 1 and 3 can be substantial (as much as $670,000 per annum) if costs are at the low end of observed rates, but these Scenarios run a significant risk of producing losses (of -$200,000 to -$300,000) in the medium and long term – their performance also declines with time. The potential profits per boat under Scenario 9 are never as high as that under the Scenarios (reaching roughly $160,000 at most) and losses under this Scenario are predicted under even average cost structures.

A very similar pattern of results to that seen for the overall profit per boat in the SESSF is seen within the SET sector (Figure 5.81). The only difference is that there is greater overlap initially, but once fleet restructuring has occurred then the differentiation between the Scenarios is much stronger than for the overall results. The performance of Scenarios 4 and 10 is well above that of any of the other Scenarios (in 2020 these profits per boat for these Scenarios is 2-10x that seen in the other three Scenarios). The maximum potential profits per boat under Scenarios 1 and 3 is well above that seen under Scenario 9 (roughly $800,000 versus $150,000), but all 3 have a similar level of potential loss in the medium to long-term (about -$50,000 to -$70,000 per boat per year). Although, the range in potential profits for Scenarios 1 and 3 remains large throughout the simulation (much larger than for Scenario 9).

The profits per boat in the GABT (Figure 5.82) are quite different to those in the SET. Scenario 4 does again produce the highest profits per boat (at around $800,000 per annum), but instead of being matched by Scenario 10, it is Scenario 1 that also achieves similar medium term results. These results degrade into the long-term (dropping by 30% by 2040). The profits per boat in 2020 under Scenario 3 are not as high as for Scenarios 1 and 4, but they are still respectable at $300,000-$450,000. After initial losses (on the order of -$100,000 per year for the first three years) the profits per boat under Scenario 9 grow to match those under Scenario 3 (the range in potential profits is also far tighter under Scenario 9). The high costs of management and quota trading under Scenario 10 contribute to the low level of profits per boat in the GABT under this Scenario ($30,000 - $225,000), with losses even possible in some years.

While there is some reduction in overall costs through time for the longline sector under many of the Scenarios, there is also drop in GVP and as a result the range in overall profits per boat increase through time (Figure 5.83a). Only in Scenario 9 does the profit per boat hold relatively steady through the projection period – after the initial restructuring of the SESSF fleets is complete the range in profits under Scenario 9 hold steady at about -$500,000 to $145,000. The profits per boat under the other Scenarios completely overlap those for Scenario 9 and have much wider ranges in potential profits. Under Scenarios 4 and 10 the range in potential profits per longline boat is -$1,300,000 to $460,000 in the final decade of the projection period; whereas under Scenarios 1 the range has reached -$1,755,000 to $160,000 by 2020; and the range under Scenario 3 is roughly -$1,600,000 to $60,000. The profits per boat under Scenarios 1 and 3 continue to decline through time into the long-term and by 2025 only losses are predicted under Scenario 3.

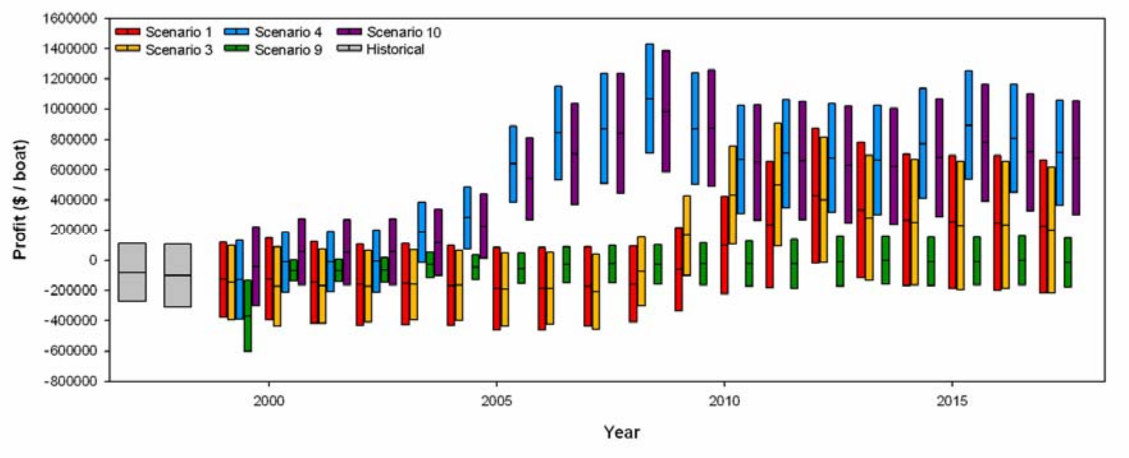


Figure 5-80: Overall profits per boat under each of the management Scenarios.

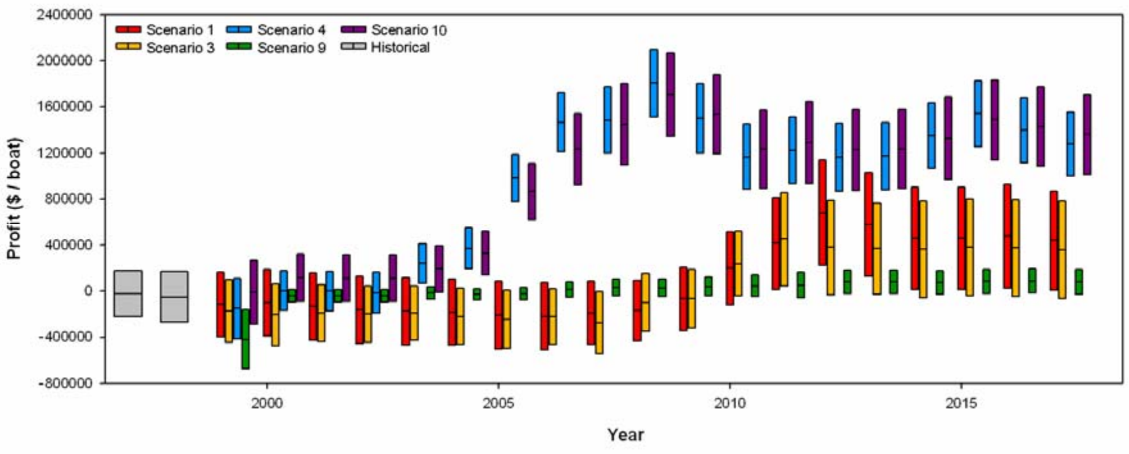


Figure 5-81: Profits per boat in the SET in each scenario.

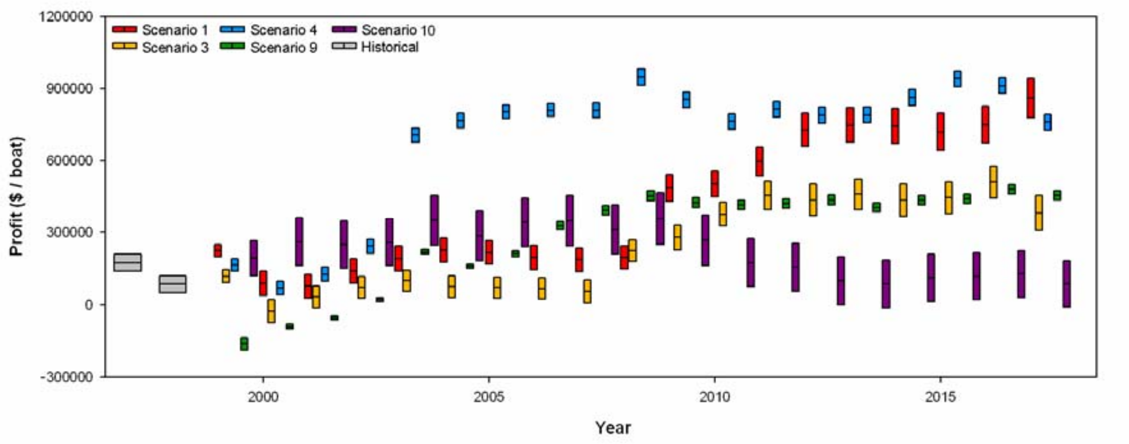
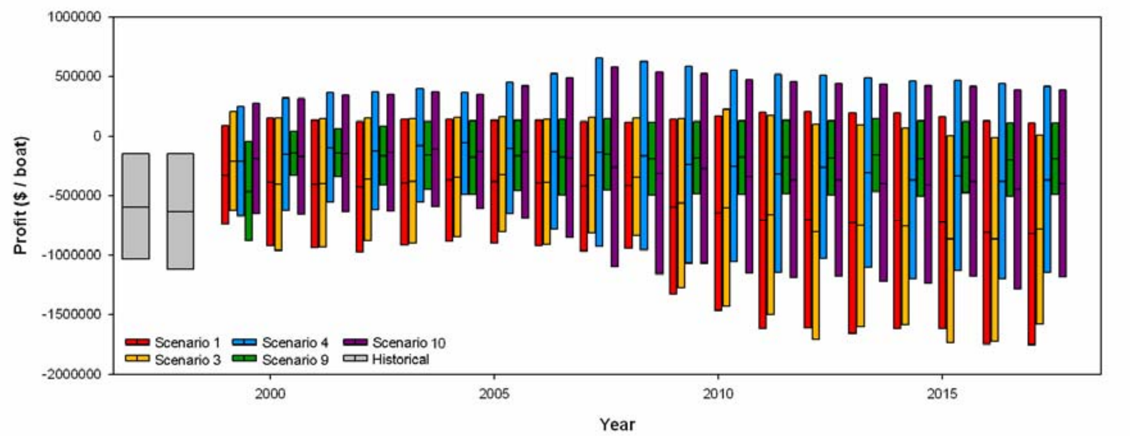


Figure 5-82: Profits per boat in the GABT in each scenario.

There is also an increase in the range of potential profits per boat for the gillnet sector (Figure 5.83b). In contrast to the results for longline, there is a lot less overlap in the profits per boat across the Scenarios. The range of potential profits under Scenario doubles by 2020 (reaching a range of -$500,000 to $20,000), with the maximum potential profit per boat for this Scenario fluctuating about the break even point. The maximum potential profit per boat is well above break even in all other Scenarios into the long-term. The maximum potential profit per boat is of a similar magnitude under Scenarios 1, 4 and 10 (between $260,000 and $450,000), but the level of potential losses under these Scenarios is more variable: roughly -$650,000 under Scenario 1; -$750,000 for Scenario 4; and -$600,000 for Scenario 10. As for the other economic performance measures the values of profit per boat under Scenario 3 are similar to those under the other Scenarios until 2010 when it rises quickly to values substantially above those of the other Scenarios. The profits per boat under Scenario 3 do decline through time and may be overstated (for the reasons discussed above). The overall pattern of profits by boat across the different Scenarios is driven by the same costs and drop in GVP that drive the results for profit per day and profit per tonne.

(a)



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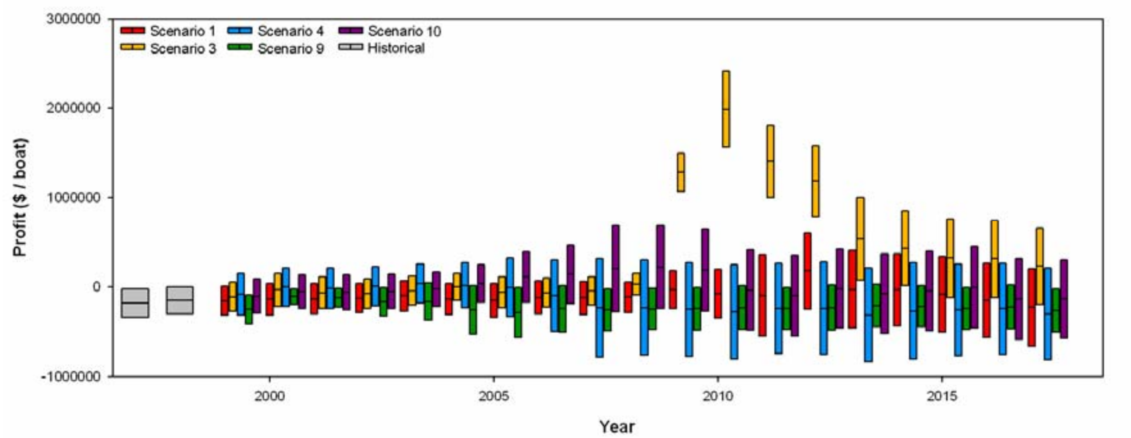


Figure 5-83: Profits per boat in the GHAT sectors in each scenario for: (a) longline vessels and (b) gillnet boats.

Return on Investments

The return on investment is calculated here using the method of Galeano *et al* (2005) - as the return to full equity (which is a measure of profit as a percentage of capital including recovered management costs, quota leases, and spending on new vessels). The return under Scenario 9 is never very great (reaching 2.5% at most). The return under Scenarios 1 and 3 remains low until after the fishery fleets are restructured and then it rises to about 7-10% (about the level actually observed in the GHAT in 2004). The return under the Scenarios 4 and 10 is much higher (about 15% at its highest and above zero in all years after 2004). The levels under these Scenarios are not as strong after 2010, but this is due to increased investment in the fishery under those Scenarios in the later half of the projection period. In Scenarios 1 and 3 investment in new boats is kept to a minimum (due to low confidence in the state of the system), but for Scenarios 4 and 10 there is enough confidence in the future of the fishery that a small percentage of the fishers invest in new boats or gear, especially as they see resources freed by the exit of other vessels. In Scenario 10 there are also high quota costs.

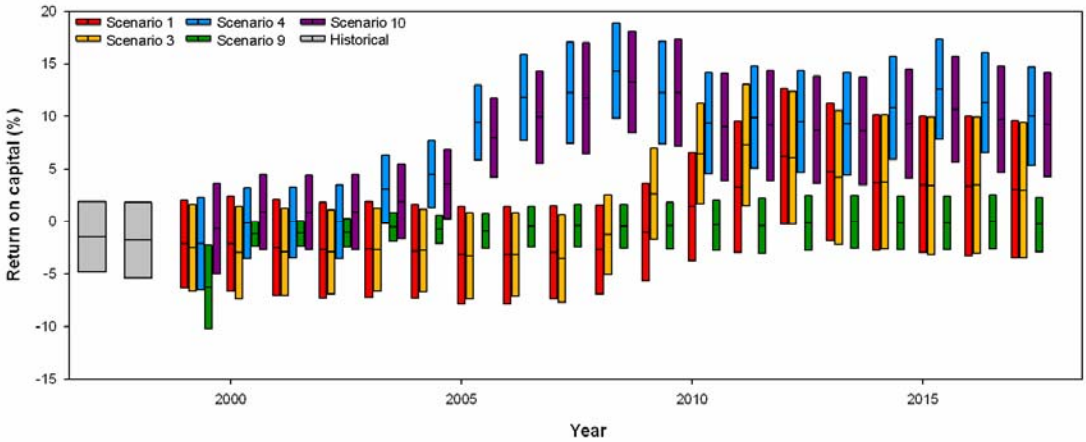


Figure 5-84: Return on investment (profit as a percentage of capital value) under the alternative management strategies.

5.3.4 Gear switching

Under the standard Scenarios no gear switching is seen, as the associated costs are typically too high to make it viable. When these costs were relaxed (in variants of Scenario 4, as discussed in section 2.8.3) quite high rates of switching were observed. A significant percentage of gillnet effort (30 - 40%) and SET slope trawl switch to midwater trawls and longlining, or temporarily into Danish seine and shelf trawl[21]. This leads to a peak in effort per gear as the individual boats switch to the “best perceived fishery” in each season (or month), which can be self defeating in some respects (it’s not as profitable if everyone is doing it typically). Nevertheless, when a benefit is seen it is in terms of improved returns per day or tonne.

One of the major effects of gear switching is that operators do this in preference to leaving the fishery altogether, at least initially. This means the individual boats hold on in the fishery longer by switching, but ultimately this is not a solution and effort still leaves the fishery. The final size of the trawl fleets are actually smaller in this case (vs the case where switching does not occur), by 10-20%; though the gillnet and longline fisheries’ final fleet size is almost identical to the scenarios where switching does not occur.

[21] As noted in the scenario description in chapter 2 some of these gillnet swutches, especially those to trawl, are not feasible in reality. Given the costs of gear switching was a deterrent in most cases the results here are effective as illustrations of potentioal problems with the policy. Nevertheless, if this option is given further consideration in the future the restrictions on which gears are actually transferable in practice should be captured.

Another feature of the scenarios where switching occurs is that there are higher levels of trade, as quota packages optimised for one gear type do not necessarily match that taken using another gear – this is one of the hidden costs of switching gears. The different catch compositions of the different gears also mean that switching has knock on effects for catches, discards and relative biomass. For some species (morwong, tiger and deepwater flathead, ling and squid) catches are higher when gear switching is prevalent, but for others (blue grenadier and cardinalfish) catches are lower. These shifts in catches feed through to associated shifts in relative biomass.

5.4 Social Performance Measures

5.4.1 Community perception

The community perception of the fisheries (as defined in section 2.4.6) does not improve dramatically in the medium to long term under Scenarios 1 and 3 (Figure 5.85), though it does show some improvement after fleet sizes are reduced, but that recovery is short lived and community perception rapidly falls off again. Scenarios 4 declines for a decade, after which community perception stabilises and varies about a moderate level before showing modest rises into the medium and long term. The drop in Scenario 9 is stronger (due to the impacts on the direct community), but does rise through time due to (a) improvement in stock status and conservation ratings and (b) the catches of a few target species (e.g. tiger and deepwater flathead) rising to the point where they are filling a significant portion of market demand. The values for community perception achieved under Scenario 9 by the end of the projection period are where it stabilises into the longer term. Community perception under Scenario 10 is more variable, but does show significant improvements after the benefits of the fleet reductions are seen. The ban on discarding seems to counteract the incident habitat impacts, seeing the improvement in perception outstrip that of any other scenario by the end of the twenty year projection period. This increase does not persist into the long term however, and ultimately shows cycles about 0.55 in the few 50 year runs considered thus far.

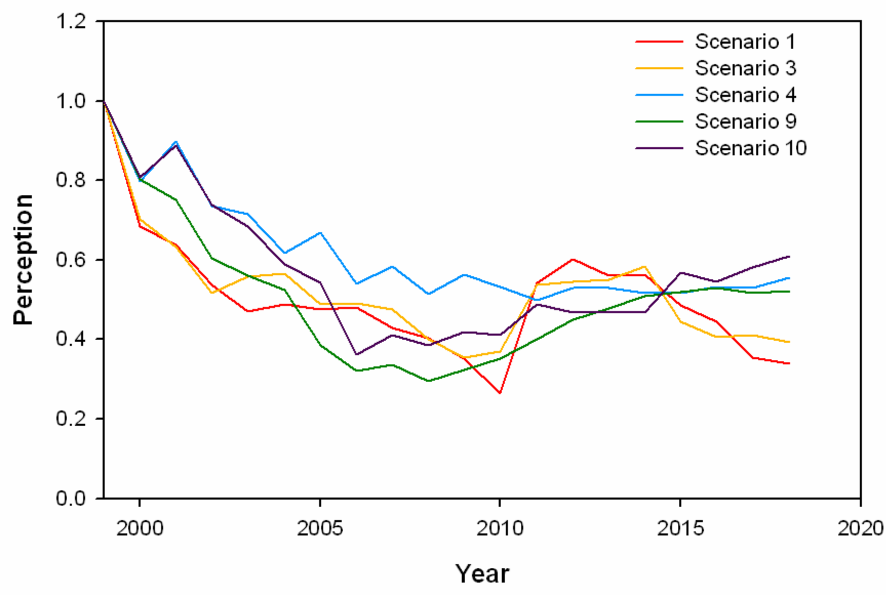


Figure 5-85: Community perception of fisheries under alternative management strategies.

5.4.2 Port status

The port activity index is based on landings flowing through the port. The pattern of this activity is very similar in all scenarios. The Tasmanian ports of Hobart, Strahan and St Helens all see small drops in activity (< 7%); Strahan seeing less of a drop under Scenario 3 than the other scenarios. Albany sees a moderate drop off in activity, but Lakes Entrance, Eden, and Bermagui all see a more substantial drop in activity (by 20% or more). Activity in Portland declines by 7%. Lakes Entrance, Eden, and Bermagui all suffer more heavily under Scenarios 3 and 9 than in the other Scenarios. Scenario 9 impacts activity levels quickly and strongly, whereas a drop-off in activity takes longer and is more gradual for the other Scenarios.

Ports that suffer the heaviest drops in activity also undergo significant declines in population size, as much as 15% in Scenario 3 and even more under Scenario 9. Those ports with only minor drops in activity do not see any significant shift in population size (declining by only 1 or 2% if at all).

5.5 Biological Performance Measures

In the context of stated ESD goals regarding the structural state of ecosystems, and previous work on reference directions and limits associated with perturbation of system structure (Fulton *et al* 2005a, Link 2005), the community and ecosystem level performance measures show a continued shift toward a perturbed system state, in the short to medium term. This on-going shift in measures such as bulk microbial biomass and the ratio of pelagic:demersal groups (Figure 5.86), is unavoidable – it would even occur if all fishing immediately ceased. In the long-term these measures turn around, but it takes decades. This is why the kite diagrams are largely similar for the projection period. This is not unusual; ecosystem dynamics often display long delays in response. Within the standard 20 year projection period comparison of performance under the alternative management strategies is therefore restricted to the more rapidly responsive performance measures (Figure 5.86).

For the more responsive measures – the biomass of target, byproduct, bycatch, shark and TEP groups, habitat cover and the slope of the biomass size spectra (BSS) – Scenario 1 shows the greatest decline through time. Scenario 3 does better, but only patchily, with poorer habitat and BSS results than for Scenarios 4 and 9 and poorer BSS than for Scenario 10. Scenario 9 has the best medium term results for all the responsive measures, except for the biomass of TEP groups. Scenario 10 actually leads to the highest biomass of the groups marked as threatened, endangered or protected (marine mammals and seabirds in the main). The overall performance of Scenario 4 is only marginally different from that of both Scenarios 9 and 10, falling in between them. As was the case for the other types of performance measures (e.g. the integrated overall measures), Scenario 4 tends to capture the most rounded performance.

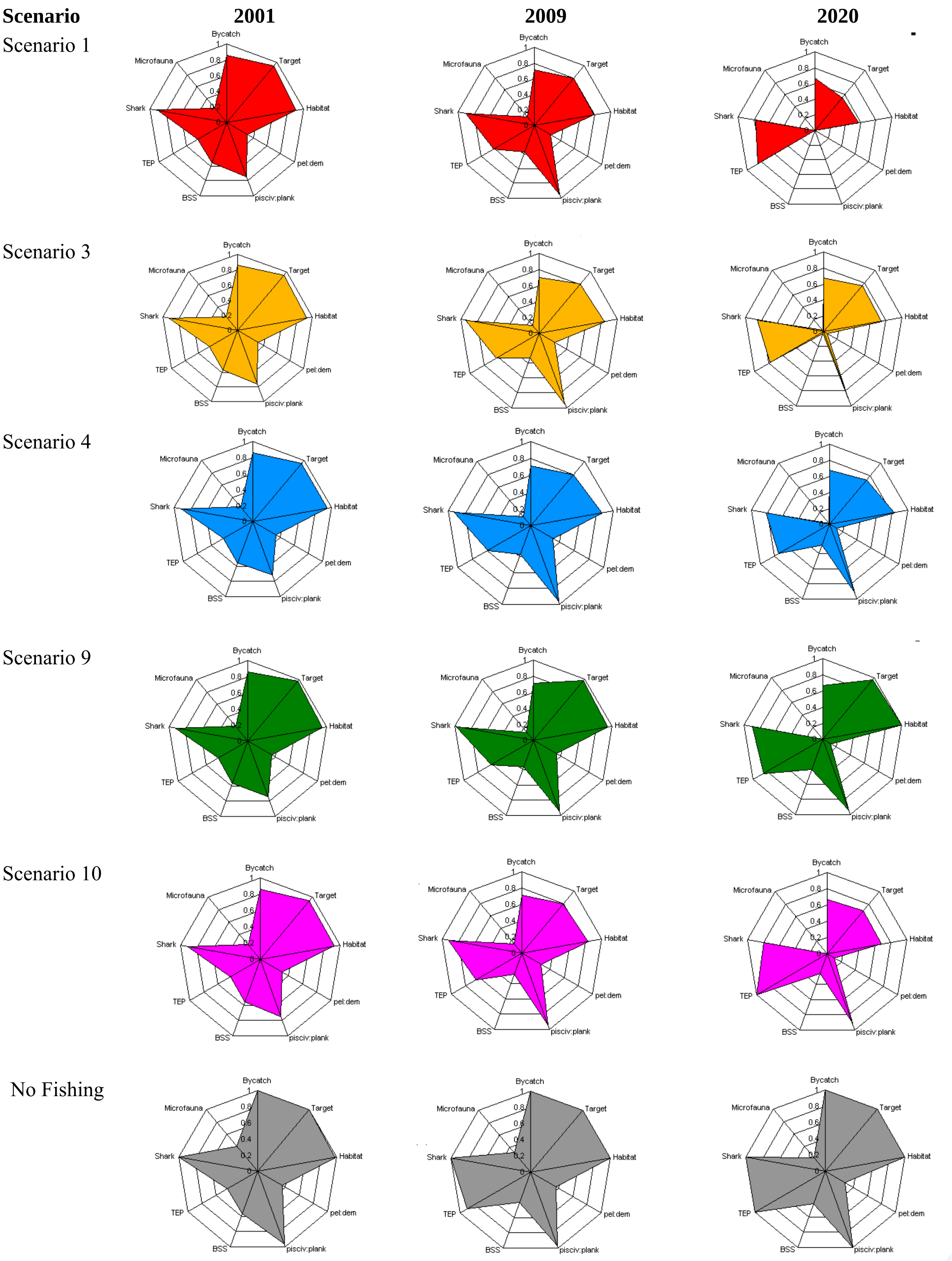


Figure 5-86: The overall performance of the five main scenarios for the integrated ecological performance measures, with the "no fishing" case given for reference. Measures have all be converted to relative measures with 1.0 = good and 0.0 = poor performance – note that the "no fishing" values are calculated against the scenario "best value" rather than resetting the scenario values against the "no fishing" value. Note that Pel:dem is the ratio of pelagic:demersal biomass, while pisciv:planktiv is the ratio of piscivorous:planktivorous fish biomass.

Table 5-6: Peak year and scenario for each of the economic performance measures.

Performance Measure	Scenario	Year of maximum value
Biomass of bycatch groups	4	2019
Biomass of target species	9	2013+
Habitat condition	9	2019
Pelagic:demersal biomass ratio	9	2006
Piscivore:planktivore biomass ratio	3	2006
Biomass size spectra	9	2000
Biomass of TEP groups	10	2019
Biomass of sharks	9	2006
Biomass of microfauna	All	2000

5.5.1 Biomass

In general the relative biomasses (versus unfished biomasses) for target groups (and thus total overall target biomass) are highest under Scenario 9, although even then it does not reach the levels seen in unfished systems (despite a more rapid recovery initially due to the pressures by and on various predators and the younger age classes in the system). The trajectories under Scenario 3 diverge very rapidly from the other scenarios and are much higher in the earlier years of the simulation than in the other scenarios (but only when spatial management and improved discarding and targeting practices are in place). Due to ecological interactions and the differential pressure from predators and competitors means the total relative biomass under Scenario 3 even exceeds that when fishing is halted altogether, at least for the first 5 years of the simulation. After 2005 the order of the trajectories switches, with the total biomass under a total ban on fishing exceeding the biomass under any of the scenarios. It is during these later years of the projection period that the total biomass trajectory under Scenario 3 dropped to converge with those of Scenario 4 and 10. In these later two scenarios the decline in target biomasses continues for around 5 years before stabilising. The poorest performing scenario is Scenario 1, leading to the lowest relative biomasses (Figure 5.87). This pattern tends to be reversed for forage groups and is slightly different again for detritus.

The bulk of the detritus is not impacted, but the labile most biologically accessible parts are contributed to by discards and so under the alternative strategies there are strong changes in this source of carrion. Under Scenario 1 it continues to grow, climbing quickly to twice historical levels and remaining at these high levels through the remainder of the twenty year projection period. The levels are not so high for Scenarios 3, 4 and 9, which have carrion biomasses 30-50% less than under Scenario 1. The banning on discarding of target groups under Scenario 10 means carrion levels are a good deal lower under this Scenario – roughly 15% of that seen in Scenario 1 (the discards of non-quota species means that it is still above where it would be if fishing ceased). This has impacts on scavenging groups, which both diversify their diet to alternative prey, and also decline in overall total biomass. These shifts ripple through the web, with some species benefiting (with their biomasses increasing) and others declining in response.

Plankton composition also differs across the various scenarios. In all scenarios plankton biomass is variable year to year (by as much as a factor of 2). No two scenarios produce identical plankton communities, but there are some general patterns in composition. Mesozooplankton (e.g. copepod) biomass is higher through the middle of the projection period (as fleet structure and fishing practices change) under Scenario 10, though all scenarios converge to within 5-10% of each other by the end of the projection period (only periodically deviating by more than this in the long term). The same is true for large phytoplankton (e.g. diatoms) under Scenario 3. There is less large zooplankton (e.g. krill), by 5%, under Scenario 1, but less large phytoplankton under Scenarios 1 and 10 (by 35-40%). In contrast, the biomass of large phytoplankton is much higher (by two-fold) by the end of the projection period under scenarios 4 and 9. The biomass of small zooplankton and phytoplankton is also higher under these scenarios (by 5-6%). Only part of this increase is due to climate change under Scenario 9, the bulk of it coming from changes induced by perturbations in the foodweb caused by cascades originating with fished groups, as is the case in Scenario 4 (and when fishing stops and the system allowed to move to an unfished state[22]). While the ultimate implications of changes in productivity and plankton community composition are still being deciphered both in models and the real world, it is interesting to note how far reaching the feedbacks associated with fishing spread.

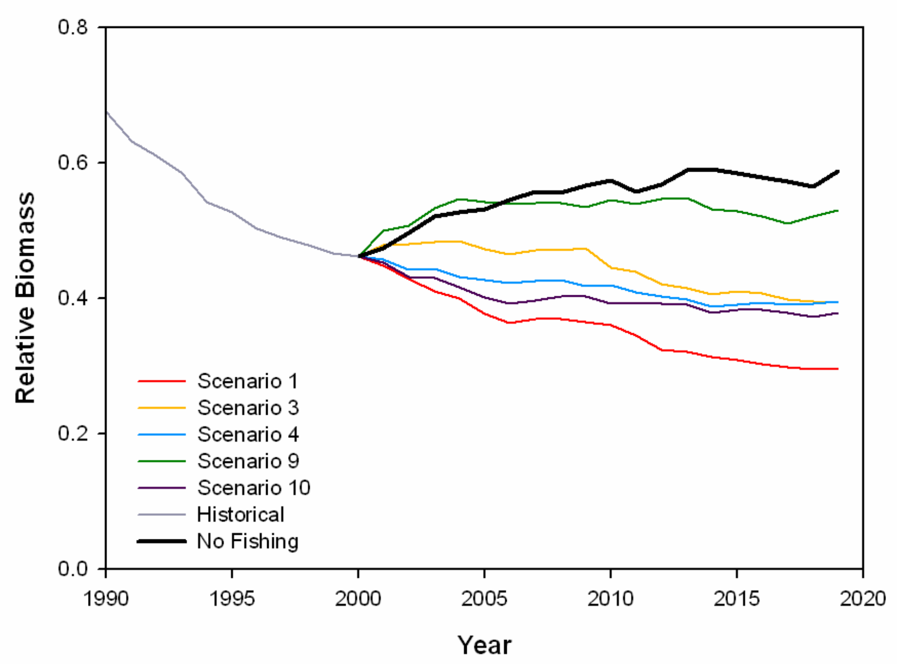


Figure 5-87: Relative total available biomass under the alternative management strategies.

Tiger flathead

The relative biomass trajectories of tiger flathead (Figure 5.88a) under the different scenarios are an interesting mix of initial increases followed by declines in the later part of the projection period, and on-going declines which plateau and even turn around in some cases. It can be seen from the no fishing case that there is the potential for the relative biomass to increase if all fishing was ceased. Under Scenarios 3 and 9 there is initially an increase in the relative biomass of tiger flathead, the biomasses rising faster and quicker under Scenario 9 than even if fishing was stopped completely. Unlike the unfished case though, where stock biomasses continue to grow for nearly three decades (though most growth occurs in the first two), under Scenario 9 the

[22] This state does not match the state in 1910, as the large marine mammals are at higher biomasses, and does not completely settle even in the 50 year simulations.

stock does decline again as fishing pressure on the species increases with shifting fleet behaviour. The rise is not as great in Scenario 3, but the general pattern of rise and fall is similar – the decline through the last 15 years of the simulation seeing it drop as low as under Scenario 1. Scenario 4 shows the smoothest and shortest decline before rising through time, stabilising at roughly two thirds unfished levels (nearly double that under Scenario 1).

The general spatial distribution of the stock is also similar across the scenarios (if different in absolute magnitude); the highest levels of tiger flathead remaining off Tasmania and up the southeast coast (Figure 5.89). At any one location the tiger flathead biomass fluctuates through time, showing both increases and decreases – though increases are more common under Scenario 9 than any other Scenario, with many sites in this Scenario showing a persistent recovery of at least 15-20%. On the most heavily fished locations there are short term local depletions, however. Depletion of these easily accessible stocks is seen in all scenarios to some degrees. The use of spatial management does not lead to a dichotomous state of prolonged increases in protected areas and strong depletions on the open grounds because the parameterisation used sees reasonable rates of movement between locations. This means that depletions are short lived on grounds, so the state is never very poor, but overall biomass does not rise as high as it might as there is a continual drain on recovery (vs the unfished state) due to the loss of fish onto fished grounds.

Deepwater flathead

The relative biomass of deepwater flathead (Figure 5.88b) resembles that of tiger flathead (Figure 5.88a), but with some significant differences. Trophic interactions lead to more complicated trajectories when fishing pressure is removed (leading to some reversals in stock recovery before increases in biomass are complete). In absolute terms the relative biomass of deepwater flathead is not as heavily impacted as the tiger flathead (ending 3-70% above the relative biomasses of the tiger flathead). There is, however, less differentiation between the scenarios for the deepwater flathead. Scenarios 1 and 3 decline pretty much in step, whereas Scenario 10 initially declines more slowly, before dropping steeply under higher pressure and targeting to decline as quickly as in the other two scenarios. Scenario 10 does stabilise more quickly though, reaching its plateau value just before the end of the projection period, whereas the other two decline for some time after that (when the few 50 year runs are considered). The pattern for Scenario 4 is a combination of all these scenarios, it shows the smoothness of Scenarios 1 and 3, but slows and reverses in the final years of the projection period and stabilises by around 2030 in the longer run simulations. Under Scenario 4 the endpoint relative biomass of deepwater flathead is similar to that of tiger flathead (the only Scenario where this is the case). Under Scenario 9 there are significant increases in the biomass of deepwater flathead, at least until shifting fleet behaviour sees significant targeting (and increases catches) of the species towards the end of the projection period. This causes a sharp drop in relative biomass, though this stabilises relatively quickly into the medium and long term (Figure 5.88b).

Spatially, the greatest concentrations of deepwater flathead are found more often at either end of the GAB rather than in its centre (Figure 5.89). On the fishing grounds this species appears more heavily impacted than tiger flathead do on the eastern grounds in the same Scenario(s). In contrast to the fluctuations in status of tiger flathead on the most popular grounds, deepwater flathead simply decline to varying degrees (though only just under Scenario 9). The short term depletion dynamics described above for tiger flathead are also seen for deepwater flathead (which have been parameterised with similar movement rates).

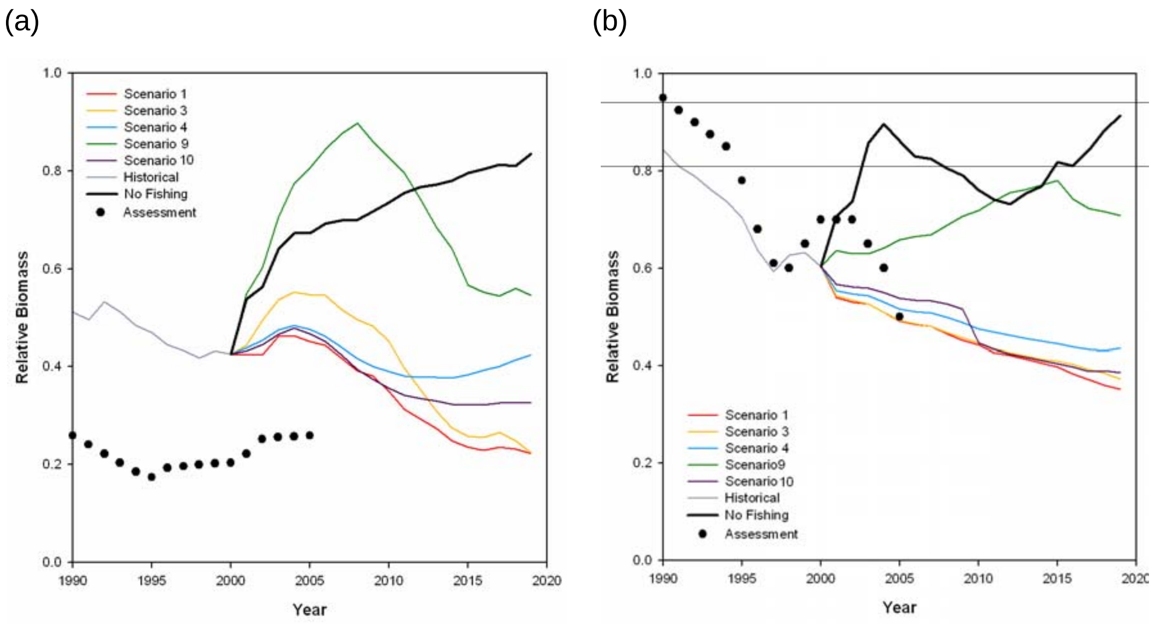


Figure 5-88: Relative biomass of flathead under the alternative management strategies (a) is tiger flathead and (b) is deepwater flathead.

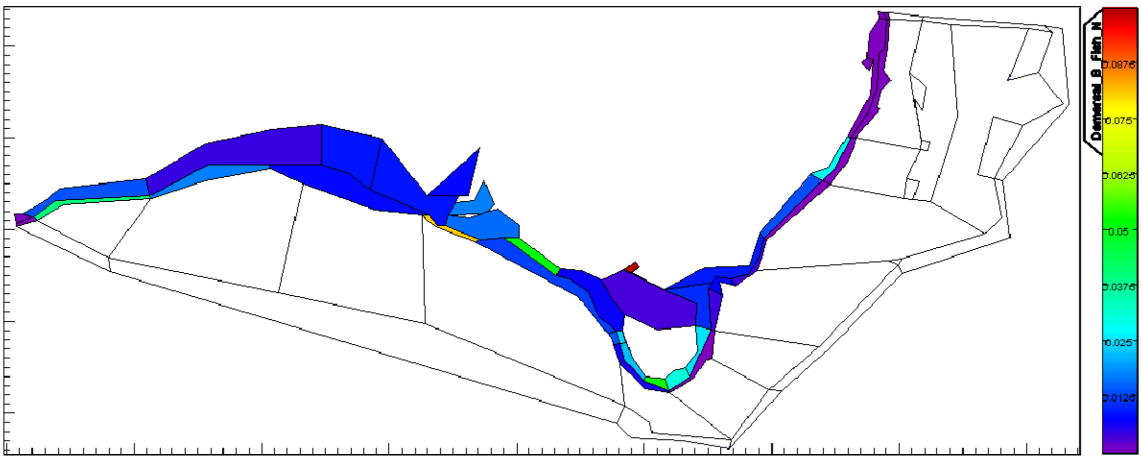


Figure 5-89: Example distribution of combined flathead biomass (from Scenario 1), scale is in t/km^2 (the biomass in the west is deepwater flathead and in the east it is tiger flathead).

Blue grenadier

The most notable feature of the blue grenadier biomass trajectories through the projection period is that the quasi cycle in strong age classes all but disappears (the last occurring in 2002), though there is some suggestion of its re-emergence (at much reduced level) in 2028. This is interesting given the parameter set used in these simulations (as it is the best fit to historical data) is not substantially different to other parameter sets that produce strong cycles throughout the projection period (these parameterisations are not used in the standard runs discussed here as overall they lead to a poorer fit to historical data across all the species together). Moreover, the parameterisation that is used here (where the cycles are damped to disappearance after 2002) predicts the persistence of the cycles if fishing is stopped. This suggests that trophic interactions in the early part of the projection period, which are being impacted by relative biomasses of predators and prey responding to fishing effects, are no longer forcing strong cycles in survivorship of juvenile grenadier in the early years of the simulations. This damping and disappearance of the cycles does not appear to be occurring in reality, which reinforces the previous assertion that while the trophic dynamics uncovered as drivers of the cycles in Atlantis may be part of the cause of the observed cycles in blue grenadier abundance, they are unlikely to be the sole cause.

Beyond this change in cycle strength the relative biomasses differ significantly amongst the alternative strategies (Figure 5.90). Under Scenario 9 there is a strong recovery in blue grenadier biomass, beyond even that seen when fishing is stopped – due to differences in the trajectories of their predators, prey and competitors. There is also a minor recovery (of half the strength of that under Scenario 9) under the standard form of Scenario 3 (this is not the case for the variants which are discussed below). Under Scenarios 4 and 10 there is a small increase in biomass, but more importantly the biomasses stabilise without further decline. In contrast, the biomasses under Scenario 1 continue to fall away before stabilising at about 0.4 of unfished levels (50% less than in Scenario 4). Despite these changes in relative biomass there is no significant change in spatial distributions (Figure 5.91).

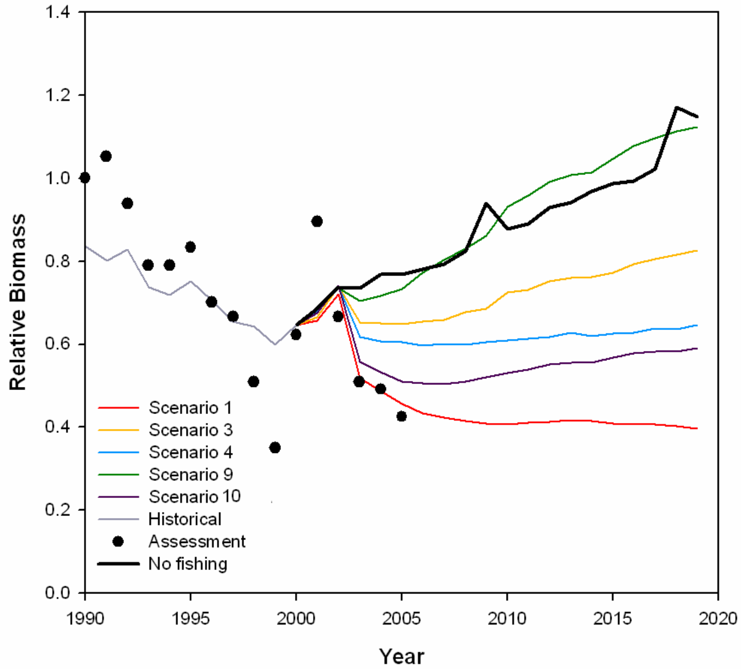


Figure 5-90: Relative biomass of blue grenadier under the alternative management strategies.

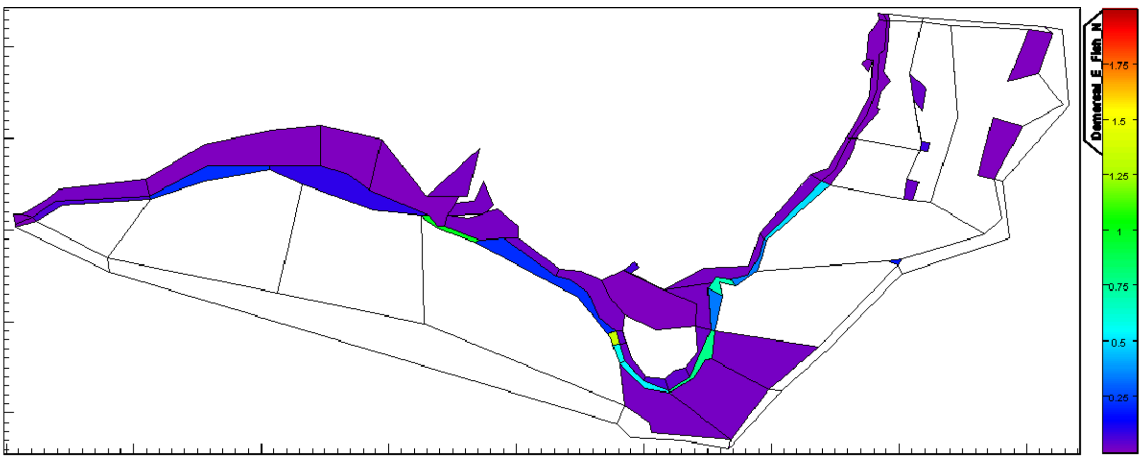


Figure 5-91: Example non-spawning distribution of blue grenadier (from Scenario 1), scale is in t/km^2.

Pink ling

Under Scenarios 1, 4 and 10 ling show a slow, gently oscillating decline, the biomasses under Scenarios 4 and 10 ending 5% higher than under Scenario 1. The more interesting result is the trajectory of relative biomass under Scenarios 3 and 9. Both of these begin above the other scenarios (in the case of Scenario 9 well above by 20-40%, which is about the level seen in the unfished system) before eventually falling down through the other scenarios to end with the lowest predicted relative biomasses of 0.35-0.4 unfished levels (Figure 5.92). This is in contrast to the continued rise in biomass when fishing is stopped. The spatial distribution also differs amongst the scenarios. Under Scenarios 1, 3, 4 and 10 the eastern stocks are much more heavily impacted than those in the west. The stock status is much more even under Scenario 9 (Figure 5.93).

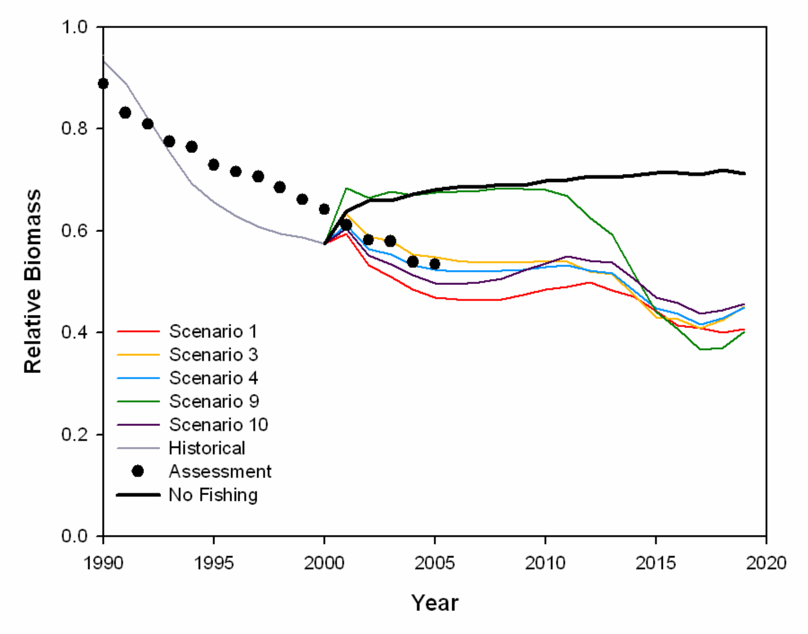


Figure 5-92: Relative biomass of pink ling under the alternative management strategies.

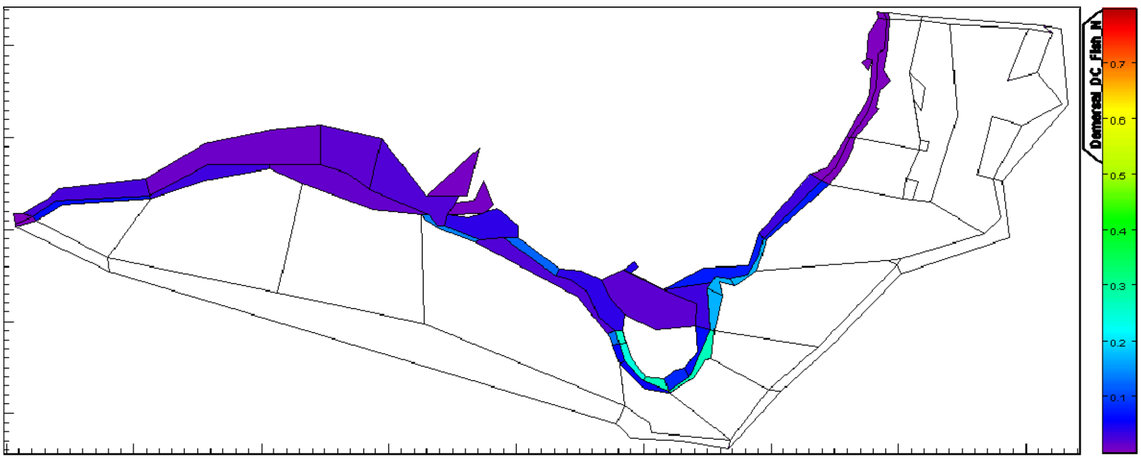


Figure 5-93: Example non-spawning distribution of pink ling (from Scenario 1), scale is in t/km^2.

Blue-eye trevalla

The trajectory for the relative biomass of blue-eye trevalla is almost identical in form in all scenarios, but with varying magnitude, and is only slightly modified even when fishing is stopped completely (Figure 5.94). This trajectory is largely driven by multispecies interactions rather than fishing pressure (which really only sets the level not the shape of the biomass trajectory). By the end of the projection period, the relative biomass under Scenarios 3, 4 and 9 all effectively reach the levels seen in the early years of fishing of this species. The increase is not so strong in Scenario 10 (reaching only 86% of the higher biomass scenarios) and Scenario 1 (which peaks at 0.78 and then falls away into the long term under the combined weight of trophic interactions and fishing pressure). There is no evidence that this strong multispecies forcing of the blue-eye trevalla biomass or the increasing biomass is actually happening in reality. However, further work would be needed to see if this was more than model artefact. Comparative conclusions can be drawn from these results though – even when a species is as robust to fishing pressure as this species appears to be in these simulations it is still possible to significantly impact the stock (as in Scenario 1 here). Spatially there is little change in the stock distribution through time, with the highest biomasses at either end of the GAB and up the east coast (Figure 5.95). When fishing pressure does come to impact the stocks it is manifested as lower biomasses on the most heavily fished grounds.

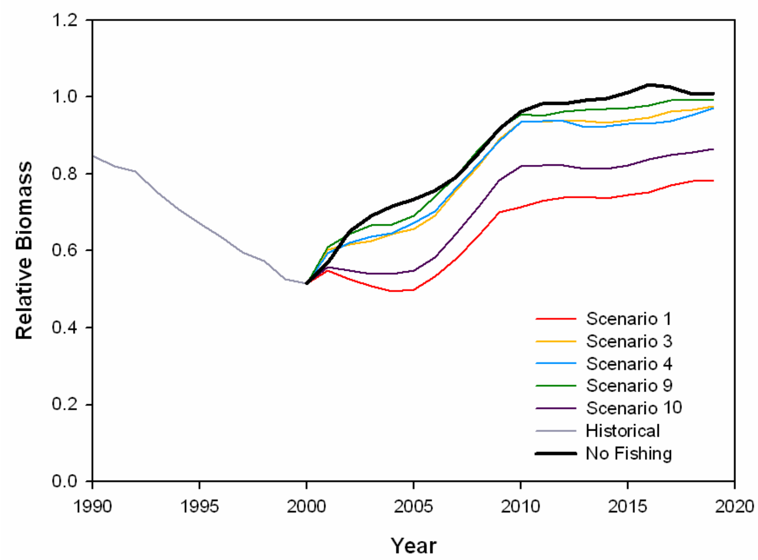


Figure 5-94: Relative biomass of blue-eye trevalla under the alternative management strategies.

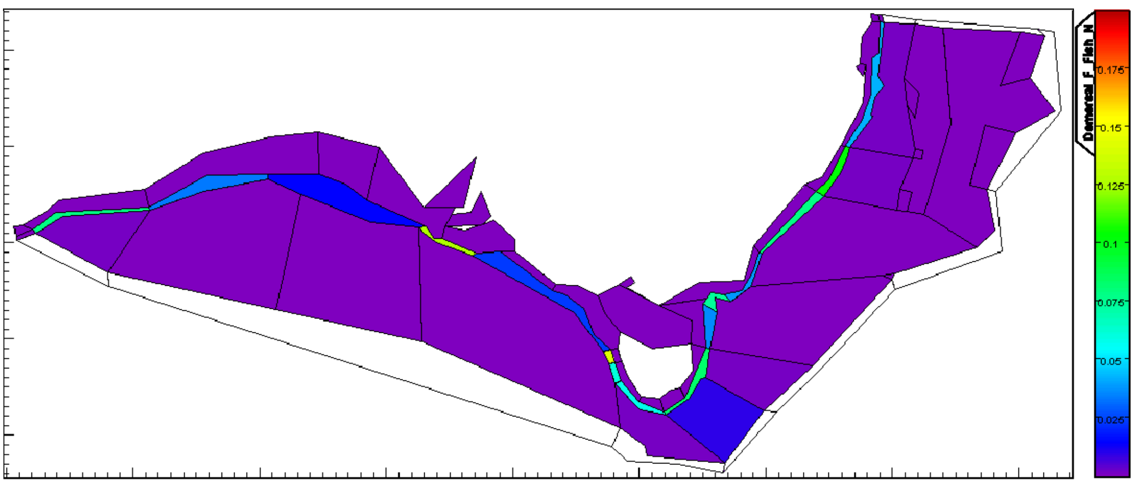


Figure 5-95: Example non-spawning distribution of blue-eye trevalla (from Scenario 1), scale is in t/km^2.

Orange roughy

The change in relative biomass of orange roughy shows a spread over the scenarios. Under Scenario 9 there is a 35% increase in relative biomass by the end of the projection period (Figure 5.96), which is only 0.03 less than when fishing was halted altogether. Under the standard form of Scenario 3 the roughy declines only slightly (by less than 2%), which is a much stronger performance than the declines seen in the other three scenarios. In Scenario 4 the stocks decline 32%, under Scenario 10 the decline is 45% and under Scenario 1 the decline is 54%. The southern and Cascade stocks are most heavily impacted in all cases, though the distributions are again more even under Scenario 9 (Figure 5.97).

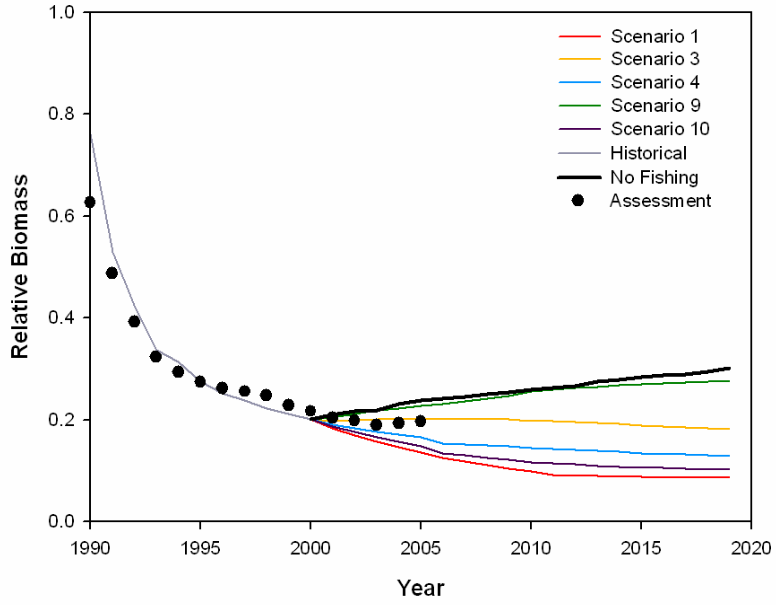


Figure 5-96: Relative biomass of orange roughy under the alternative management strategies.

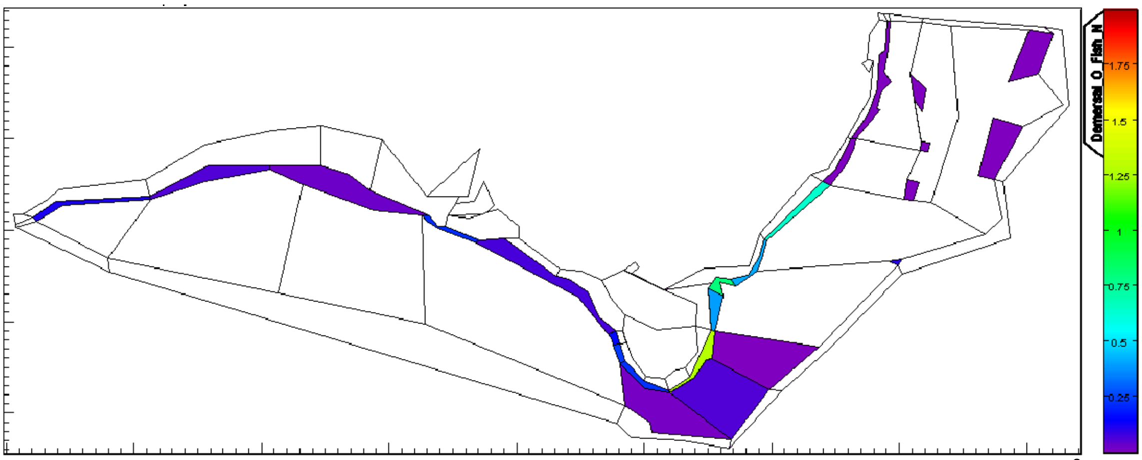


Figure 5-97: Example non-spawning distribution of orange roughy (from Scenario 1), scale is in t/km^2.

Gummy shark

The relative biomass of gummy shark is much more volatile (even when unfished) and mixed across the various scenarios (Figure 5.98). Under Scenario 9 the biomass grows by 30% - as much by increased weight and condition of the individual sharks as by an increase in numbers (this is also much of the reason why the unfished biomass trajectory shows so much variability). In Scenario 3 the increase in condition also takes place, but the biomass eventually falls as the abundance drops off under fishing pressure. Under Scenarios 4 and 10 the trajectories decline to stabilise at 0.45-0.48 of unfished levels. The decline under Scenario 1 is much stronger, to 0.2, as it is driven by drops in condition and abundance.

The spatial distribution of gummy shark does not change substantially in any scenario except for Scenario 3, where the general distribution remains the same, but there are stronger local depletions in the eastern end of its range (Figure 5.99) and even short lived local extirpations under some parameterisations.

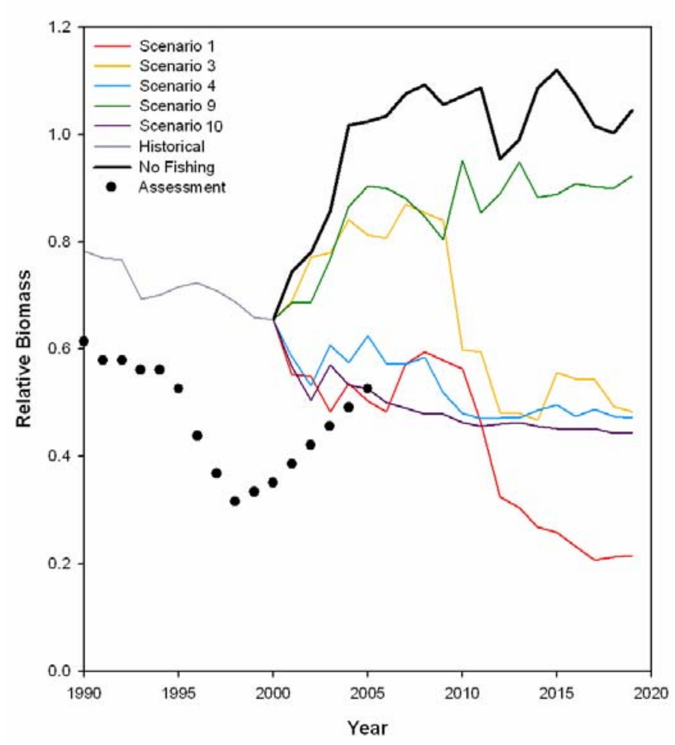


Figure 5-98: Relative biomass of gummy shark under the alternative management strategies.

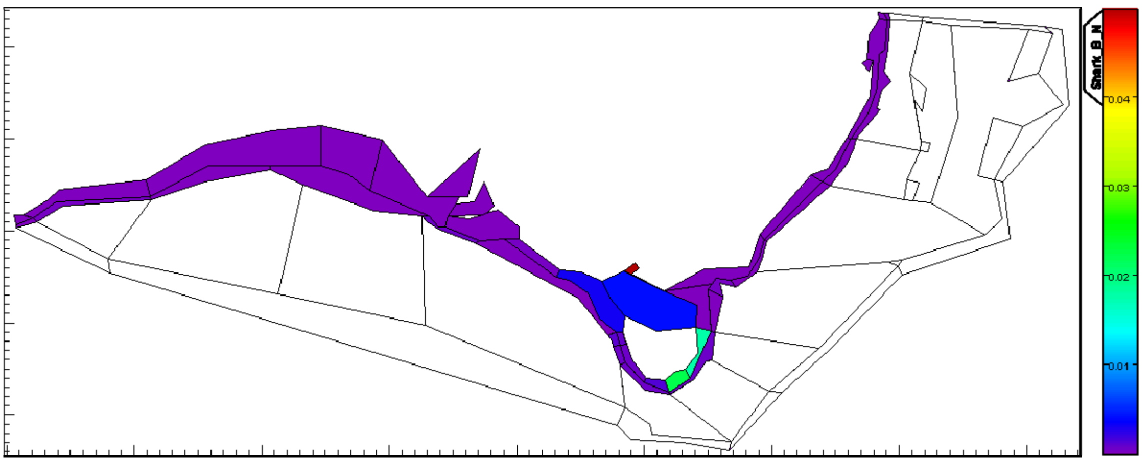


Figure 5-99: Example mid-year distribution of gummy shark (from Scenario 1), scale is in t/km2.

School shark

Under Scenario 1, the gentle recovery evident at the end of the historical period continues at a slow rate (increasing by 30% over the projection period to end at 0.53 of unfished levels). The rate of recovery is much faster (as much as doubling before 2020) under the other strategies (Figure 5.100), with the trajectory of the biomasses under Scenario 9 approaching that produced when fishing ceases. All of these increases in biomass are more a function of improved condition than increased abundance, which grows much more slowly. The distribution is similar to that of gummy shark.

It is worth noting that while the improved condition remains true under other parameterisations of Atlantis-SE the growth in numbers does not. As mentioned previously the parameterisation used in the standard form of Atlantis-SE means the stock is more productive and resilient than assessments and observer data would suggest. This is because a single stock was used to represent the species when it is likely that multiple substocks should have been represented (multiple stocks are used in single species assessments for school shark, one that moves up the east coast and one that moves through South Australian waters[23]). Differential fishing pressure in reality has meant that the (potential) sub-stocks have been depleted to differing degrees historically, something that Atlantis-SE cannot represent using a fixed parameterisation with a single stock. Without explicitly representing multiple stocks a shifting parameterisation would be required to capture such a change in stock structure (and thus overall species properties) through time. Multiple (shifting) parameterisations were not used here as they can present their own problems (such as allowing for further shifts into the future, but with unknown or poorly triggers or drivers this is highly problematic). As a result, the school shark tends to be overly resilient in this form of Atlantis-SE.

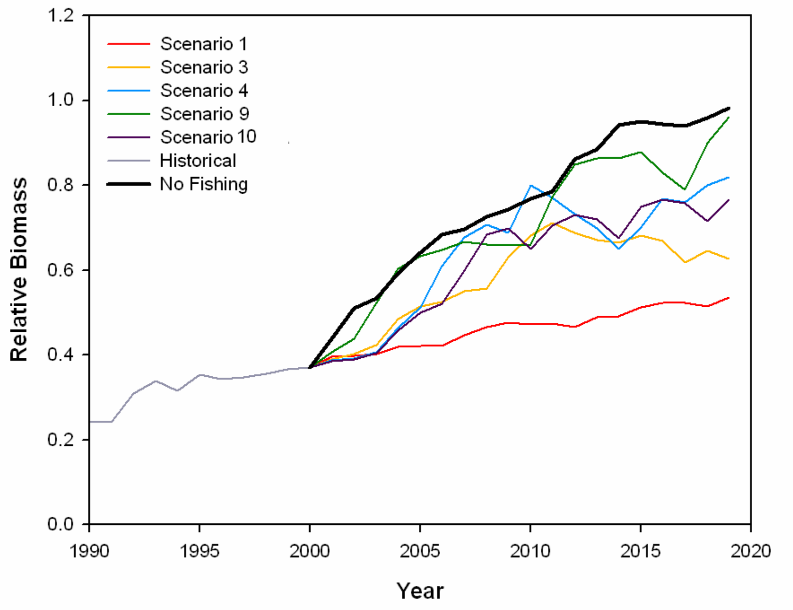


Figure 5-100: Relative biomass of school shark under the alternative management strategies.

Small pelagics

The relative biomass of small pelagics (mackerel, red bait and other small pelagics) declines throughout the projection period under all scenarios. Under Scenario 9 the decline is only 5% (almost identical to when fishing is stopped), whereas it's 15% under Scenarios 1 and 4 (Figure

[23] Another stock structure possibility (confounded with that based on movement east or west) is that there are sub-stocks of School shark with differing reproductive capacity (the difference would only need to be on the order of 1-2 pups extra per litter for it to have an impact) and that they have been differentially depleted, with the more productive stock being more heavily impacted.

5.101). This decline is driven in part by fishing pressure, but more by shifts in trophic pressure, other groups shift prey preference or abundance. The bulk of this decline is by red bait, which individually drops by as much as 65% under Scenario 1 as a result of the combined effects of fisheries and trophic shifts. As mentioned above the biomass of the small pelagics (particularly red bait and Mackerel) in Atlantis SE may underestimate the biomass of those species in the region by as much as 30-50%. This acts to make it more susceptible to the combined effects of predation, competition and fishing pressure and accentuates declines. The trajectories given here for small pelagics may well be flatter if the predicted biomass levels of red bait and mackerel in Atlantis SE matched those given in a recent assessment by TAFI. However, it is important to remember that, given the increase in the biomass of small pelagics under historical patterns of fishing predicted by Atlantis SE (Figure 3.37), these groups have the potential to be significantly impacted by indirects of fishing (as the biomass of groups that prey on small pelagics may change) even if responsible management minimises direct impacts.

The spatial distribution (Figure 5.102) shifts about seasonally and also a little year to year (more than for many other groups), but does not show any real pattern in terms of regional skewed depletions. The shifts are driven by productivity, prey and environmental preferences rather than fisheries induced depletions of one stock or another.

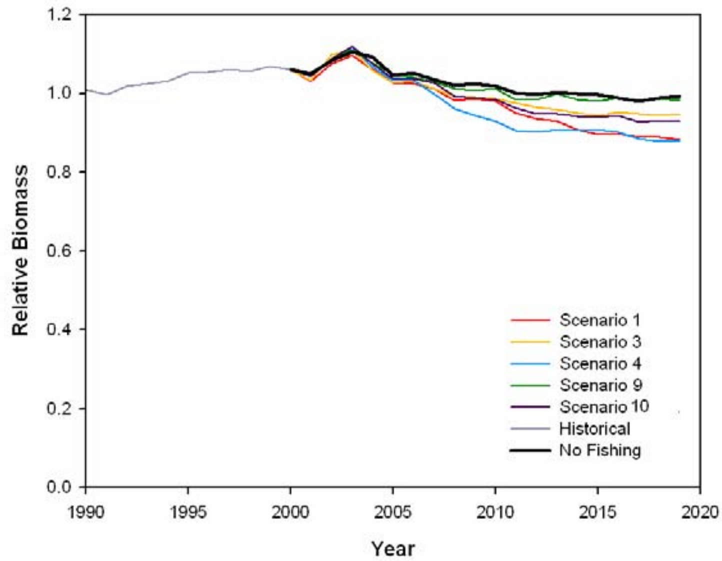


Figure 5-101: Relative biomass of small pelagics under the alternative management strategies.

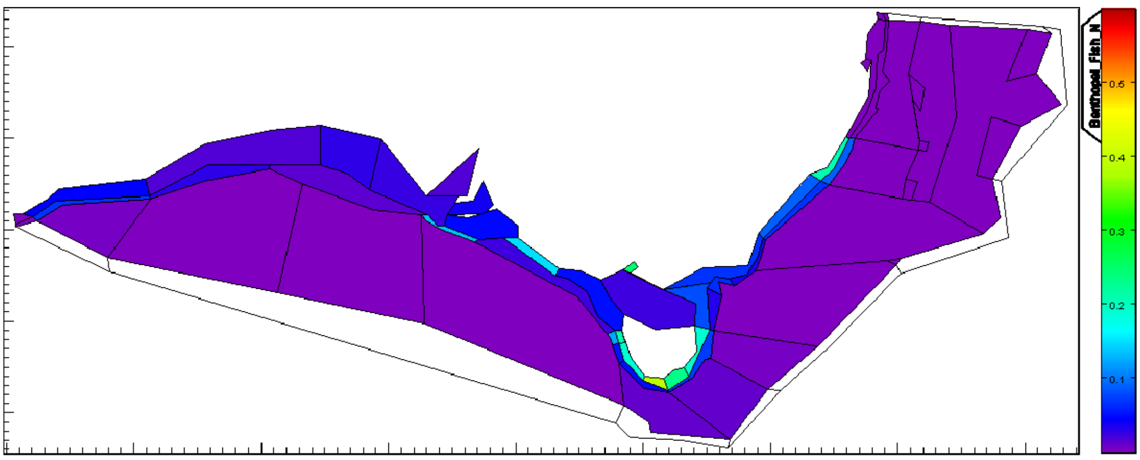


Figure 5-102: Example distribution of red bait (from Scenario 1), scale is in t/km2.

Demersal Fish

To facilitate the interpretation of the biomass ratios (e.g. pelagic:demersal biomass) it is informative to also consider the total available biomass (Figure 5.87) and the combined biomass of demersal fish (Figure 5.103). This combined biomass shares many similarities with that of flathead and ling – in that early stability (or increases) are followed by declines in the medium term (with some potential for a turn around into the long-term). This is true even in the unfished case where it takes as much as 30 years (or more for the slope and deeper waters) for the system structure to stop responding to past overfishing and restructure in response to the cessation of fishing. The target species discussed above may respond more directly and quickly, but the changes are more complicated amongst the major non-target, by-product and bycatch groups.

Under Scenario 9 there is an initial increase in biomass that is of the magnitude seen under a cessation of fishing, though it occurs even more rapidly (due to the combined impact of selective fishing pressure and indirect effects of the remaining fisheries pressure on smaller size classes). Ultimately though all the Scenarios see a decline in overall demersal fish biomass in the medium term (by 20-35%), it is only in the long-term that significant recovery occurs in this aggregate biomass and then only in Scenarios 4, 9 and 10. On that long-term time frame the aggregate demersal fish biomass under Scenario 9 stabilises at about 75% of unfished values, while that of Scenario 4 is around 60% and Scenario 10 is at 55%. The biomass under Scenario 3 is initially at levels close to that under Scenario 4, but it continues to decline when those under Scenario 4 begin to recover. Ultimately the aggregate demersal biomass under Scenario 3 sits around 40% of the unfished biomass, which is still well above the roughly 30% seen under Scenario 1.

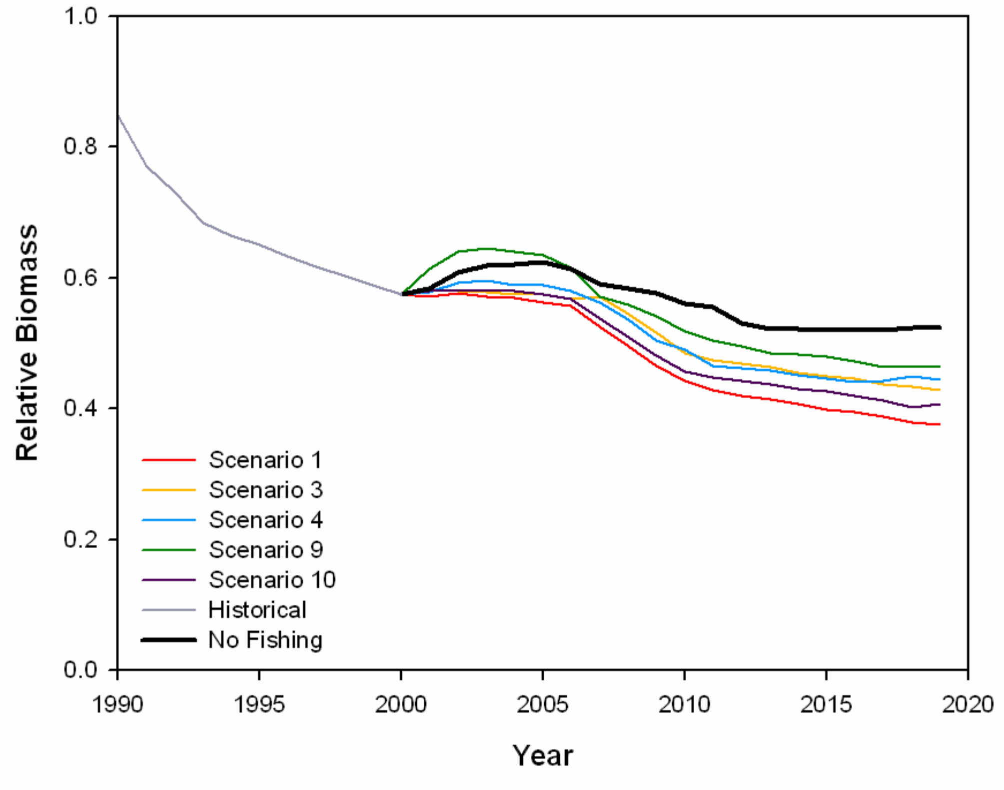


Figure 5-103: Relative biomass of demersal fish (summed across all demersal fish groups in the model) under the alternative management strategies.

Squid

The squid biomass grows slowly through time, increasing by 15% in the 20 years of the projection period unless fishing is stopped altogether where it drops slowly (and with some fluctuations) into the medium to long term instead. This pattern shows little change across the different scenarios, with only 1-2% variation between them. The biomass is fairly evenly distributed, but is higher around sites of higher productivity and off the shelf edge.

TEP Groups

The biomass of the TEP groups grows under all scenarios (Figure 5.104), though never as strongly as it does if fishing is stopped completely. The increases when fishing is in place are primarily as a result of increasing biomass of large marine mammals – both in terms of individual condition and total numbers (the abundance rising slightly faster without fishing, which results in steeper trajectories). There is little to differentiate the Scenarios, except that seabirds do better (by 2x) in the medium term under Scenarios 4 and 9 and pinnipeds have improved condition (and thus 10% higher biomass) under the standard form of Scenario 3. The seabird trajectory is driven by a combination of prey availability and a reduction in incidental capture, while the pinniped dynamics are driven almost entirely by the dynamics of their prey groups.

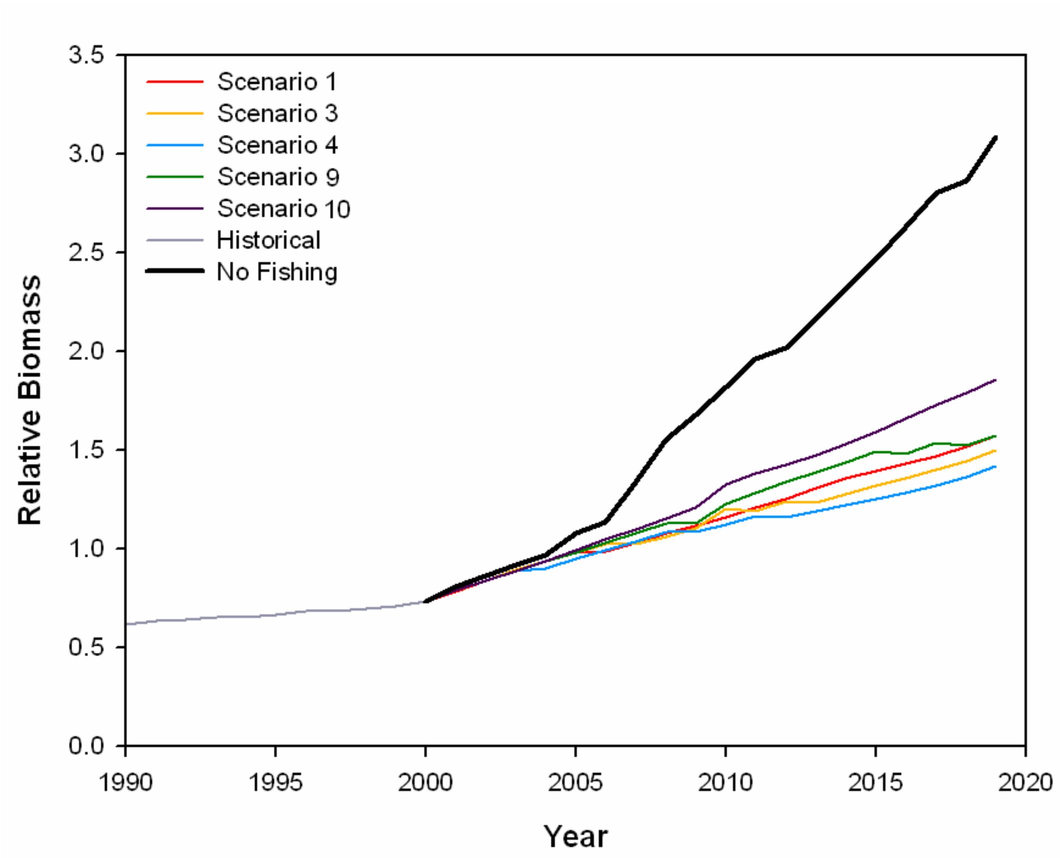


Figure 5-104: Relative biomass of TEP groups under the alternative management strategies

Gulper shark are another group of conservation concern. Their biomass continues to decline in the short to medium term under all scenarios (even if fishing is stopped completely) – this is because the model predicts gaps in the age structure of the exposed population as a result of historical fishing pressure. While the model predicts some components of the stock have yet to be exposed to high levels of fishing effort, they're almost static biomass (as they are close to local carrying capacities) and the lack of large scale movements in this species means that these healthier stock components cannot compensate for the sate of the exposed stocks nor can they aid in their recovery. Instead the holes in the age structure of the depleted stocks take many years (in many cases multiple generations) to be completely rectified and so reproductive potential and overall biomass of the group continues to decline for as much as 50 years. The biomass of this group does recover in the long term if fishing is stopped or under Scenarios 4, 9 and 10 (though for the later it stabilises at a level 10% less than the other two). Scenario 9 leads to higher biomass levels of gulper sharks than the other scenarios where fishing is continued (by 10-20%), while Scenario 1 performs the worst ending at 0.36 unfished levels (Figure 5.105).

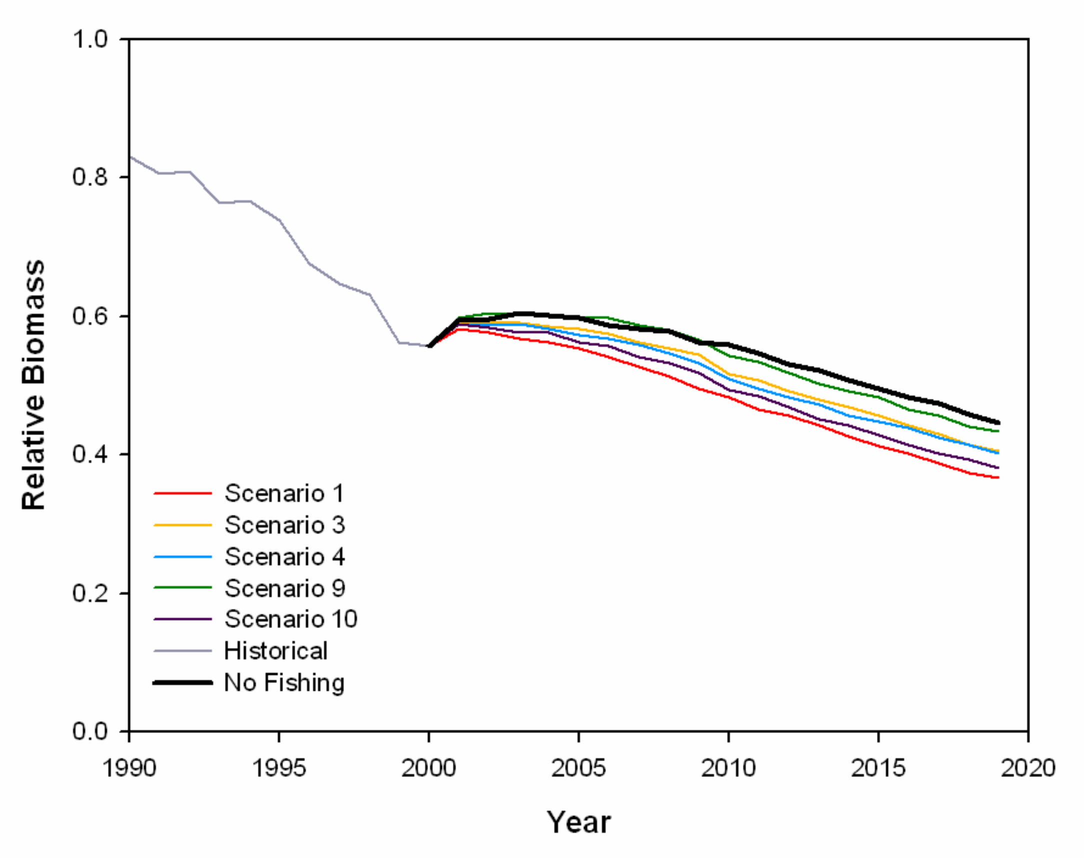


Figure 5-105: Relative biomass of gulper sharks under the alternative management strategies.

5.5.2 Habitat

The overall biomass of biogenic habitat contains little useful information at the regional scale, due to the overwhelming influence of the area of abyssal plan and soft ground on the shelf and slope. A much more useful measure is to consider essential fish habitat on shelf and slope and in particular to look at local habitats around fishing grounds (Figure 5.106). To capture this a local habitat cover index was calculated as the proportion of the area of shelf and slope that is suitable for biogenic habitat growth that has biogenic cover. As this is a simple proxy index it for ranking the performance of the various scenarios it was made relative to the levels seen in 2000.

If fishing is stopped altogether the local habitat slowly recovers through time, and while scenario 9 does rise, no scenario sees such a recovery. The local habitat cover dips marginally (by 3%) initially under Scenario 9 before growing to end at about the same level it begins. The declines under the other scenarios are much stronger. Under the standard forms of Scenarios 3 and 4 the local habitat index stabilises between 75-85% of the level it had in 2000. Under Scenario 1 however, the local habitat index continues to decline, dropping to 0.58 by the end of the projection period. Scenario 10 also shows a strong decline ending at 0.68. This value is a confounded combination of recovery of habitat on old (effectively) abandoned grounds and the clearing of habitat on new grounds. If the vessels in this Scenario did not shift their distribution as radically then the habitat index would be much closer to that of Scenario 4.

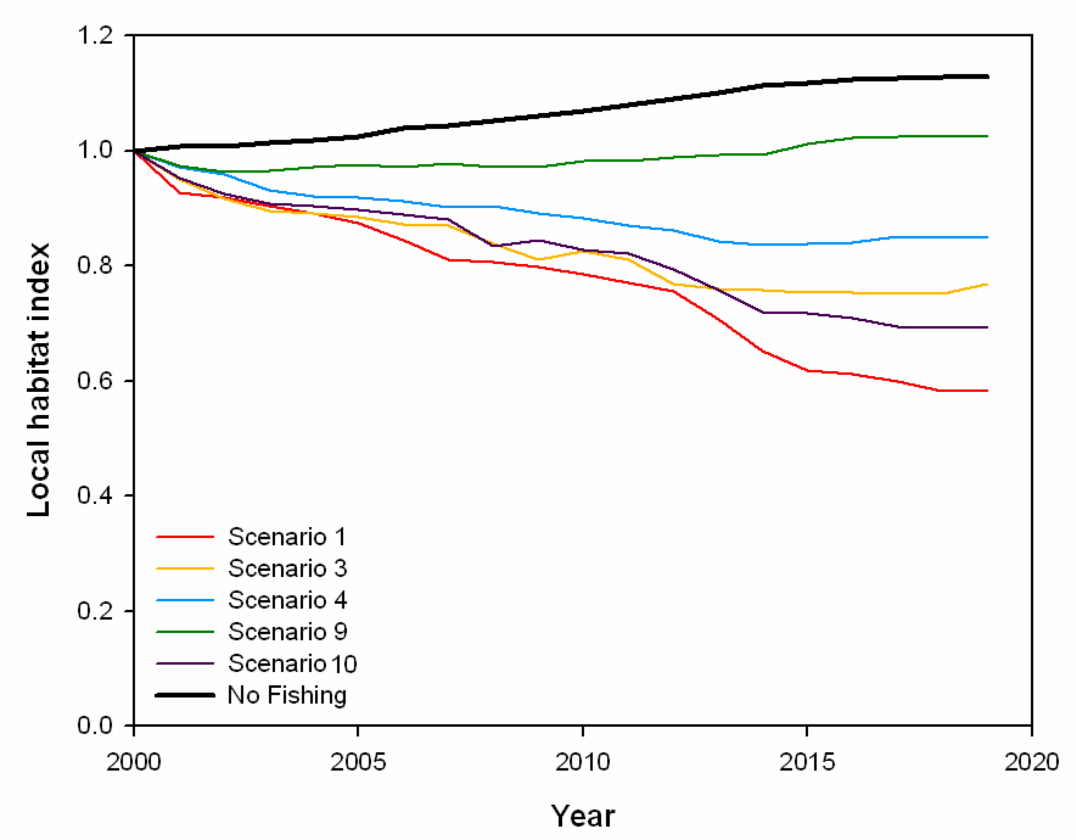


Figure 5-106: Local habitat cover index under the alternative management strategies.

5.5.3 System structure

Biomass Ratios

Biomass ratios can convey information regarding community and ecosystem structure. The ratio of pelagic:demersal fish biomass rises only marginally without fishing and declines into the long term (past then 20 year horizon of the standard runs) as the demersal stocks recovery. In contrast, with fishing the ratio follows roughly the same trajectory during the projection period, increasing through the entire simulation (Figure 5.107). The absolute size is bounded on the lower side by Scenario 9 (at 0.7) and on the upper bound by Scenario 1 (at 0.8). The few long term scenarios run to date indicate that into the longer term there is a suggestion of a greater divergence, with the ratio continuing to increase under Scenarios 1 and 3; rising then declining and then stabilising under Scenarios 4 and 10; and peaking and slowly declining into the long term under Scenario 9.

Similarly, the trajectories for the ratio of piscivorous: planktivorous fish biomass is roughly the same through the projection period under all the fished scenarios, none of which approach the increasing ratio that is seen when fishing is stopped. Scenario 4 is initially most stable, but ultimately all the fished scenarios decline in roughly the same way in the projection period – although they do seem to diverge into the long term (Figure 5.108). Under scenarios 4 and 9 the values at the end of the projection period (at 0.183 and 0.189 respectively) do not change much into the medium and long term. In contrast Scenario 10 drops increasingly slowly for another decade, while the trajectories under Scenarios 1 and 3 continue to drop into the long-term.

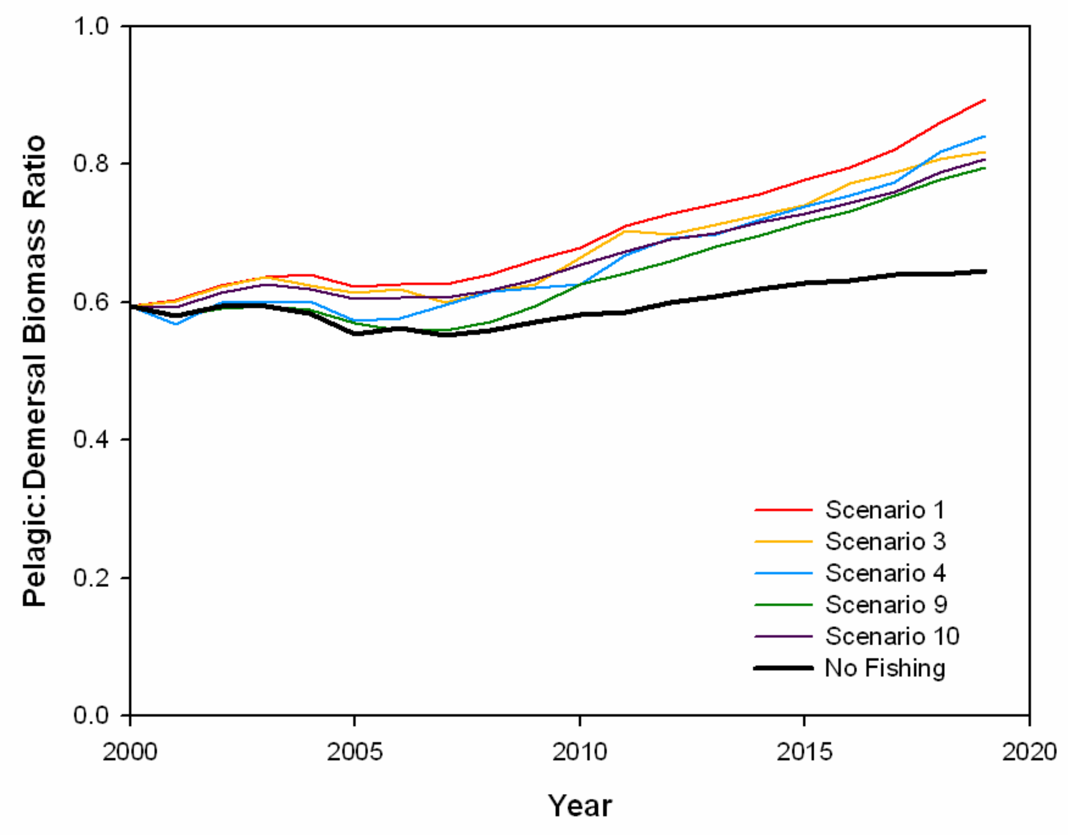


Figure 5-107: Pelagic:demersal fish biomass ratios under the alternative management strategies.

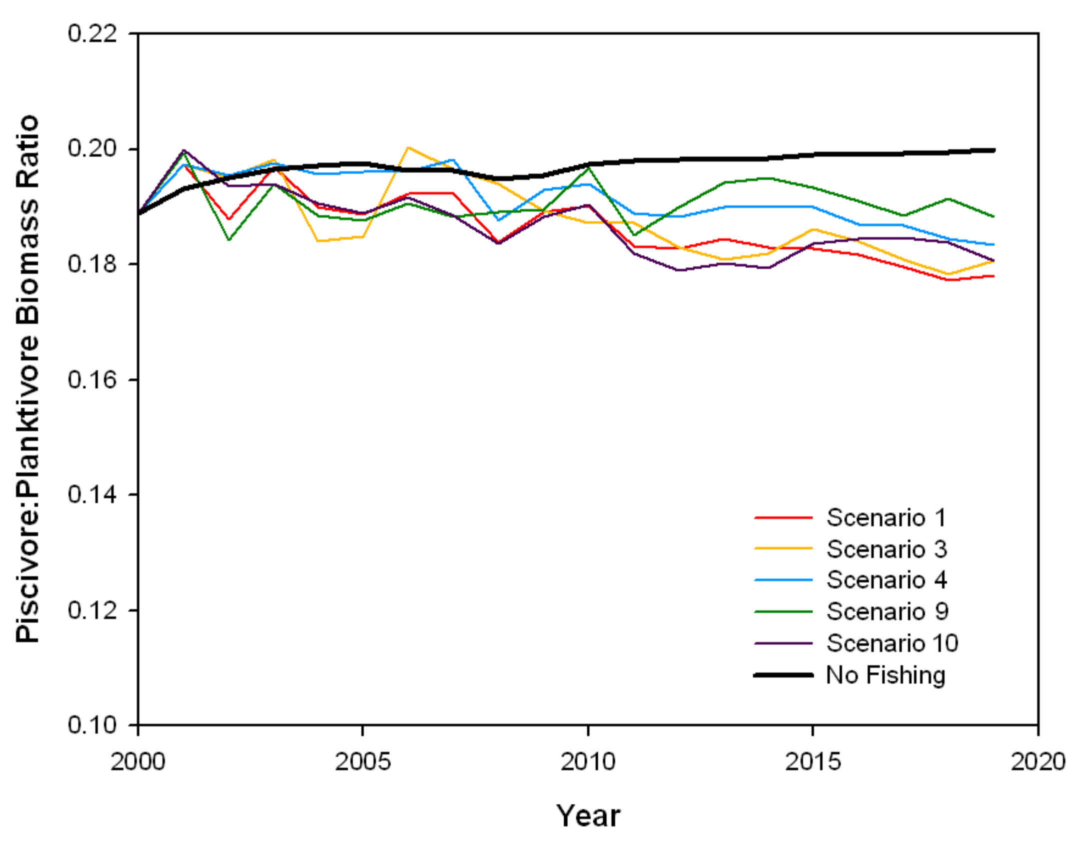


Figure 5-108: Piscivore:planktivore fish biomass ratios under the alternative management strategies.

Biomass Size Spectra

The differences in the vertebrate biomass size spectra under the different scenarios reinforce the system structure results that are suggested above regarding group-level biomasses and biomass ratios. While the impacts of increased mortality through predation and fishing are just becoming apparent amongst the smallest fish in the community by 2020 under Scenario 3, this is absent from Scenario 9 (see bottom right corner of the size spectra in Figure 5.109). The general signal here though is that under all scenarios there is little difference in the size structure of the bulk biomass of fish that are less than 50cm in length. These fish would include the entire life cycle of small bodied species, but also the smaller age classes of species that grow larger than 50cm.

The biggest differences in community size structure comes from the part of the spectra dealing with fish greater than 50cm, and especially that part dealing with vertebrates greater than 1m (Figure 5.110). Under Scenario 1 depressions in the spectra for the largest groups last longer (the long green tail extending across the top of the plot in Figure 5.110(a)) and are not broken up as in the other scenarios. There are also more pronounced and longer peaks for vertebrates in about 2m in length, showing that these predators do benefit from the removal of the largest bodied individuals and species. Similar patterns are found in the other spectra, but are not as long-lived or pronounced. Scenario 9 shows the least impact of fishing, showing only a small short lived dip in the largest size classes and a smoother spectrum overall. Interestingly Scenario 10 does a better job at retaining the community structure amongst the largest bodied animals than Scenario 4 – a direct result of both improved condition amongst the TEP groups and a much lower level of interaction between these groups and the fisheries in this case.

(a)

(b)

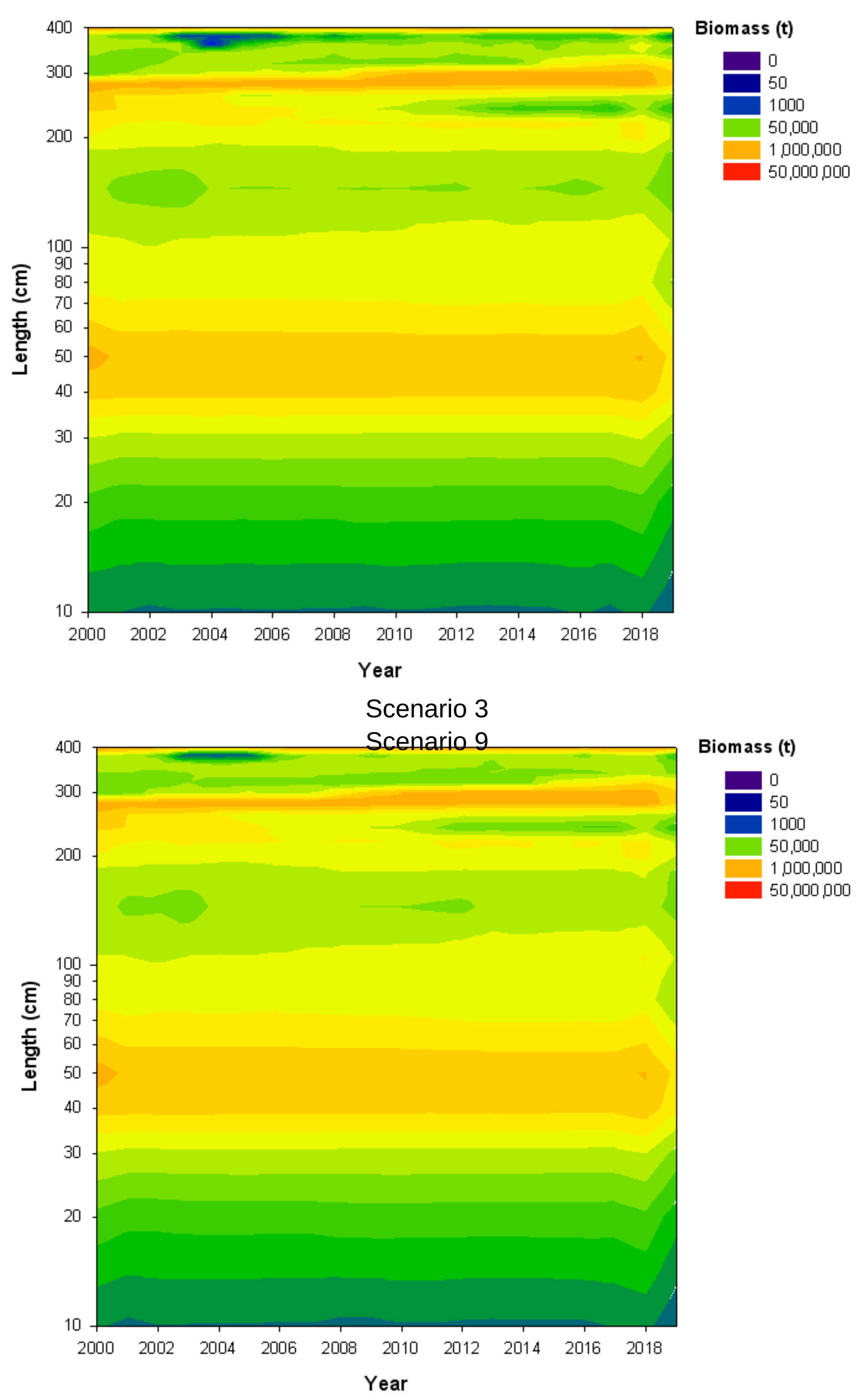
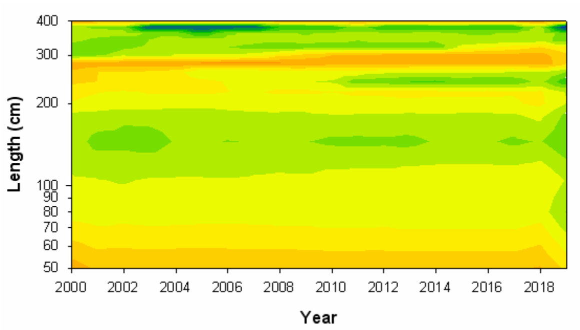
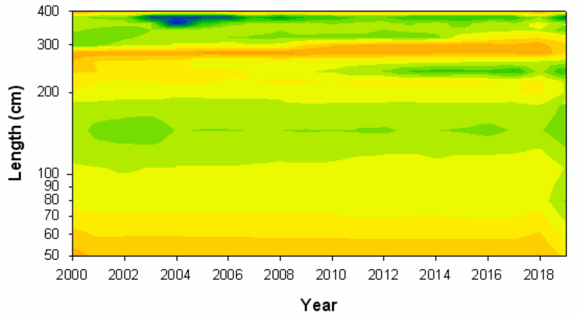


Figure 5-109: Time series of full vertebrate biomass size spectra for (a) Scenario 3 and (b) Scenario 9 – the y-axis gives the log(size) and the log(biomass) is given by the coloured contours. If the system was unchanging the plot would be a set of horizontal bands beginning with deep greens across the bottom, rising to oranges across the middle and then remaining in the oranges-yellows from the middle to the top of the plot. Breaks in the bands as one moves left to right, as well as greens and blues in the upper half of the plot indicate the system has been perturbed (e.g. by fishing). Note that these biomass size spectra were calculated in terms of $\log_2$(length) vs $\log_2$(biomass), as is the standard approach, but the scales are given here in terms of cm and tonnes so that the average reader can more easily interpret the plots.

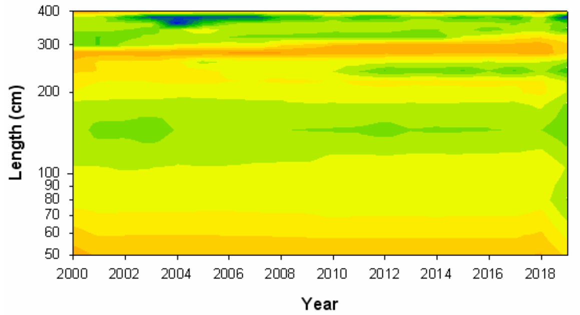
(a) Scenario 1



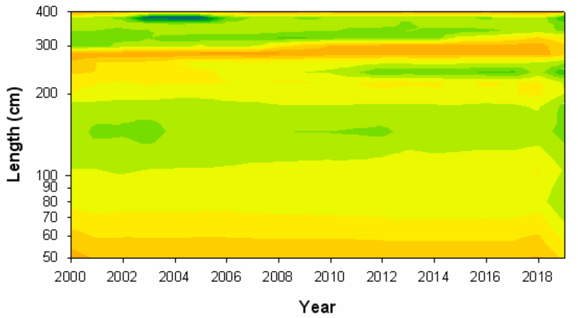
(b) Scenario 3



(c) Scenario 4



(d) Scenario 9



(e) Scenario 10

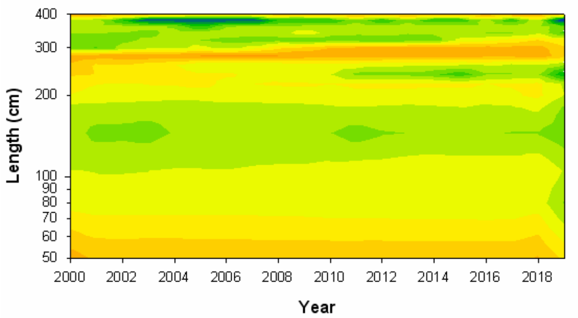


Figure 5-110: Size spectra of larger vertebrates under the alternative management strategies (same scale used in all cases). Note that these biomass size spectra were calculated in terms of $\log_2$(length) vs $\log_2$(biomass), as is the standard approach, but the scales are given here in terms of cm and tonnes so that the average reader can more easily interpret the plots.

5.5.4 Diversity

The Réyni index (Jennings *et al* 2001) uses proportional abundance to rank systems in terms of their diversity. It is one of the most useful indicators for considering diversity (Kindt 2002, Fulton *et al* 2005b), as it not only gives a diversity measure but is also suitable for comparing systems. The index is calculated using:

$$R = \frac{\ln \sum_i \left(\left(\frac{b_i}{\sum_j b_j} \right)^{\alpha} \right)}{1 - \alpha} \qquad (5.1)$$

where b_i is the biomass of group i and a is the order of the index, by varying a it is possible to consider either richness or evenness (to what degree a small number of species dominates the biomass in the system). Both a low order of 0.1 (for richness) and a high order of 10.0 (for evenness) of the index were calculated here.

When considering richness (Figure 5.111) there is a clear ranking of systems, Scenario 9 is the richest (though not as rich as an unfished system), followed by Scenarios 3 and 4 (of equal diversity), then Scenario 10 and finally Scenario 1. Scenario 1 shows no improvement on the current state, while all other scenarios show an increasingly diverse system by the end of the projection period. These general trends appear to continue into the longer term, with periodic increases and plateaus for Scenarios 3, 4, 9 and 10, while Scenario 1 goes through long periods of relative stability punctuated by periods of rapid decline (“system collapse”) into the longer term.

The picture is much less differentiated when considering evenness (Figure 5.112). None of the fished scenarios approach the trajectory of the system where fishing has ended. While Scenario 9 starts off much more diverse in this sense, all the fished scenarios roughly converge by the end of the projection period – although once again Scenario 9 forms the upper bound and Scenario 1 the lower bound on the trajectories. This indicates that the system is evolving toward a more even form in all cases, though under Scenario 9 this evenness is spread across more groups (including the moderate-larger bodied ones that drop out of Scenario 1) and so the absolute value of the index is higher.

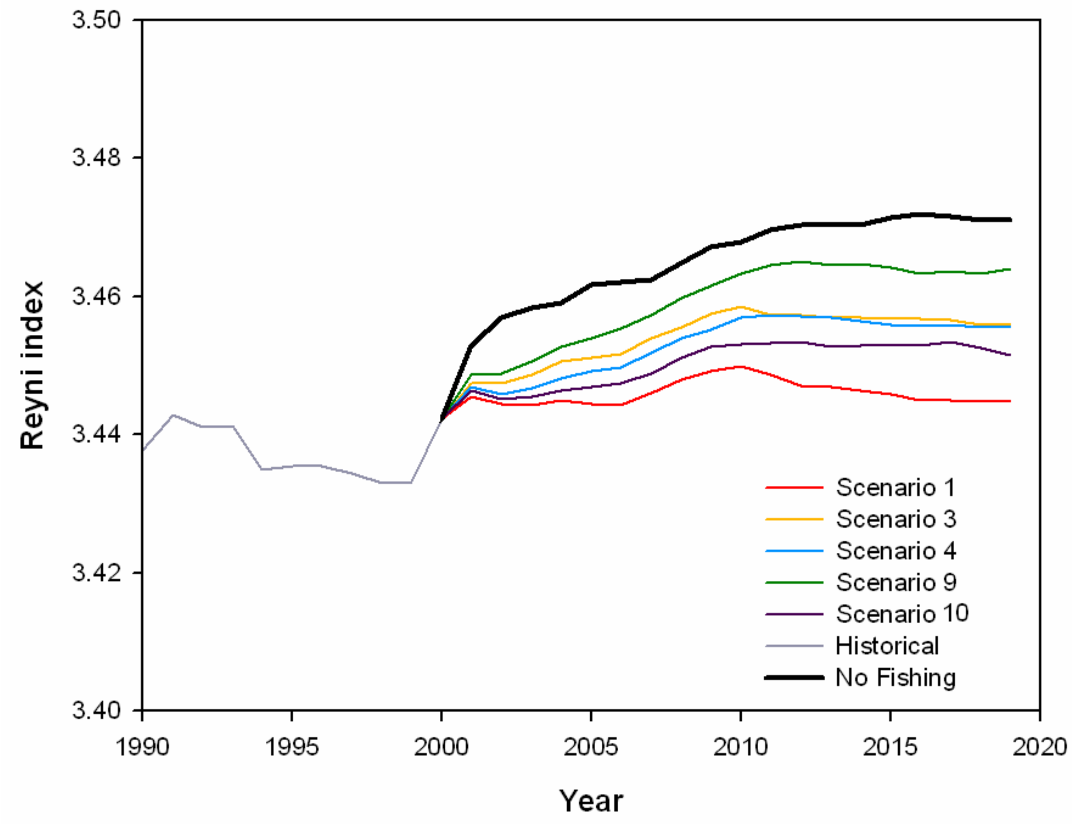


Figure 5-111: Low order (0.1) Réyni index - for richness - under the alternative management scenarios

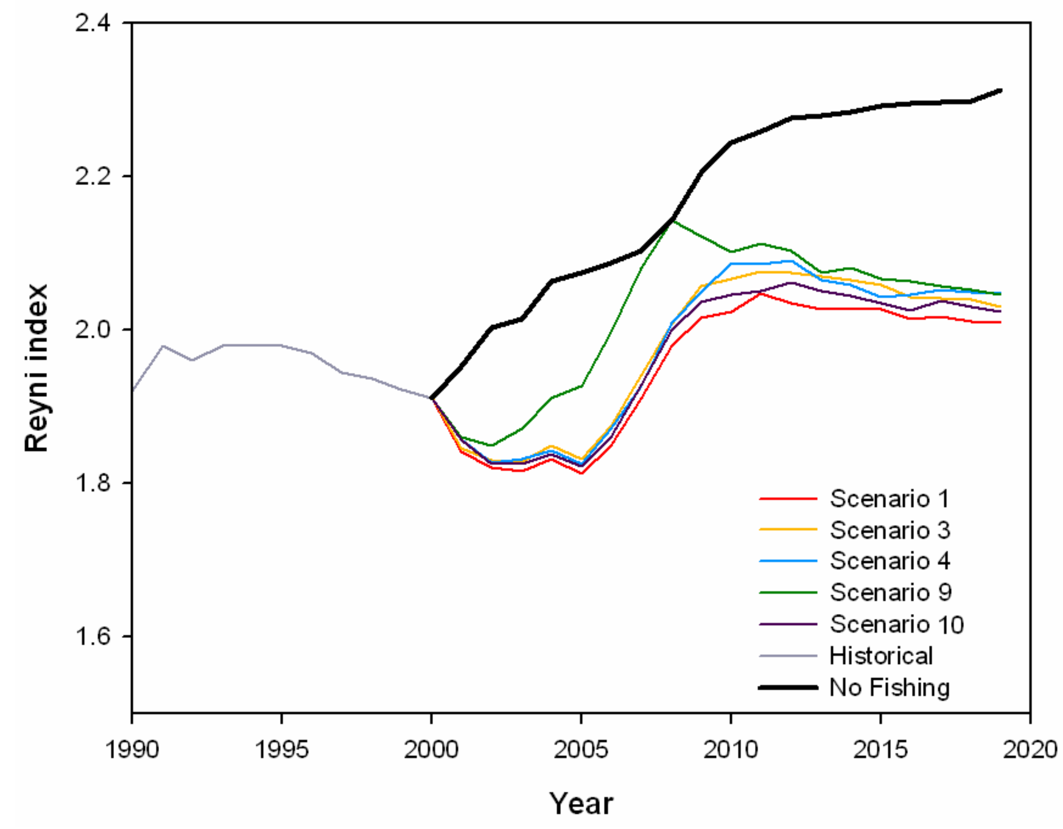


Figure 5-112: High order (10.0) Réyni index - for evenness - under the alternative management scenarios

6. DISCUSSION

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a multi-species, multi-sector fishery that stretches from SE Queensland to SW Western Australia. The area has been fished by a number of trawl and non-trawl sectors historically, which were recently brought under a single management plan. Other managed fisheries in the area include tuna, small pelagic, scallop and squid fisheries, as well as inshore State managed fisheries such as rock lobster and abalone. The new management configuration provides AFMA with the opportunity and platform to improve the fishery's management and shift to an ecosystem-based management foundation, with all sectors managed under common goals and objectives. The alternative management strategies explored here, and in the Stage 1 qualitative phase of the Alternative Management Strategies (AMS) project, aid in the exploration of which combinations of management levers will be most effective in achieving the aims of management.

The focus of the project is to give insight regarding integrated management solutions where a coordinated combination of management tools is in play. This is a major departure from previous approaches, where issues and management responses to them were generally considered on a case by case basis, rather than in an integrated fashion. The AMS project arose from the recognition by all stakeholders that quotas alone were inadequate to manage the fishery, especially with regard to simultaneously meeting ecological and economic goals laid out under AFMA legislation, the Environment Protection Biodiversity Conservation (EPBC) Act 1999 and Australia's National Plan of Action for the Conservation and Management of Sharks.

The performance measures used in this management strategy evaluation (MSE) and the qualitative equivalent were selected as the set that best reflects AFMA's legislative objectives – Ecological Sustainable Development (ESD), maximising economic efficiency, and achieving cost-effective management – as well as industry's goals of profitability, minimal gear conflict, security of access to resources, stable management arrangements and a positive community acceptance. The following discussion summarises the quantitative findings regarding the performance of the alternative management strategies and compares these ratings with those derived from the qualitative stage of the project.

6.1 Uncertainty

As was stated in the Stage 1 reports, these scenarios are not meant to cover all possible strategies nor provide prescriptive formulae for management reform. While "best" and "worst" performances are reported, these are not statements of advocacy. All scenarios have their benefits and flaws and the evaluations presented here should be used in combination with other sources of advice to give insight and to support decisions regarding the relative merits and trade-offs associated with the use of different management levers. In this spirit, the qualitative analysis included multiple forms of some scenario types (specifically the "status quo" Scenarios 1 and 2) in order to try and capture uncertainty regarding the future. Uncertainty was also considered in this quantitative analysis. It is beyond current computing resources and analytical techniques to provide a full sensitivity analysis of models of this form. Computing time and resources also precluded the use of stochastic parameter selection, which would have allowed for the construction of formal probability intervals around the deterministic results. Nevertheless, the issue of uncertainty was tackled by means of variant scenarios, and by bounded exploration of alternative parameterisations – as described in section 3.2, simultaneous fitting of the model to multiple data sets on different scales (via the simultaneous variation of the complete set of the most sensitive and critical parameters) produced bounding parameter sets that covered the range of plausible biomasses and dynamics while also complying with the fitting criteria (e.g. the historical fitting criteria). While only the "best fit" parameterisations were presented here the results under the other bounding parameterisations did not lead to substantially different outcomes regarding the relative performance of the alternative management options (see Figure 5.1). Where alternative parameterisations gave significant deviations from the standard results these exceptions were recorded in the results. This treatment of uncertainty is neither extensive nor exhaustive, but the bounding approach provides a first approximation in dealing with uncertainty in the predictions on which the analyses are based. This approach has been shown to be a useful method in other studies (e.g. Little *et al* 2006), but does depend on the assumption that (untried) parameterisations lying between the bounding sets do not produce dynamic results that lie beyond the model outputs from the bounding parameter sets.

It is still informative and important to consider potential sources of uncertainty. Beginning with the parameterisation and dynamics of the biophysical model, the lower trophic levels are the most uncertain while also having a potential to scale the productivity of the system. This sensitivity is epitomised by the pelagic primary producers, their dynamics and cycles are intriguing and may be a model artefact or due to a threshold dynamic that is overstated compared to real relationships. The dynamics of this group is a significant driver of overall system productivity and helps drive cycles such as the periodic spikes in the blue grenadier biomass. Ultimately however, despite the impacts on biological dynamics it is effectively acts as a scalar on overall system productivity. In terms of the MSE this acts to move up and down the dynamics and can alter the absolute value of the various performance measures, but it does not change the relative ranking of the performance of the various scenarios and it does not lessen any of the highlighted tradeoffs and implementation issues raised.

Structural uncertainty is usually one of the main concerns, and greatest sources of uncertainty, for ecosystem models. No quantitative assessment of this form of uncertainty was undertaken in this study (i.e. alternative biophysical representations were not used in the management strategy evaluation), but during the model development stages a very intensive qualitative and network analysis (based on the methods of Dambacher *et al* 2003) was carried out to address the potential for this form of error and the implications for scenario performance (details of which are given in section 3.2). This degree of conceptual and qualitative consideration of structural sensitivity has been exceptionally rare to date in the broader ecosystem modelling community, but should become an integrated and standard part of all future modelling exercises. It has proven invaluable in avoiding major structural pitfalls from the very beginning of the exercise and does allow for confidence in the final results, as this critical form of sensitivity has been substantially reduced – though it can never be completely eradicated, as there is always the potential to miss rare links or behaviourally moderated links, particularly trophic links or early ontogenetic dependencies, and for new relationships to arise under system-scale perturbations. These remaining uncertainties do have implications for the model predictions, but they do not mean that the results are not still valuable if used appropriately. For instance, for the majority of groups and sectors the model resolution was sufficient to capture population dynamics and fishing pressure, but for the gillnet sector and their major target species it was far more problematic and has added to the uncertainty pertaining to the model results. In particular, Atlantis SE does not capture some of the potential stock structure and fine scale behaviour and targeting of the gummy or school shark; as a result it does not represent gillnet gear saturation all that well and it suggests these species may be more less sustainable than they really are. Moreover the current spatial resolution of the shelf boxes means in the standard form of the Scenarios results in the auto-longline sector having more access (though not complete access) to the outer shelf than is actually the case. Together this means that the explicit predictions of the model regarding catch levels under the standard form of the Scenarios are almost undoubtedly overstated and that further work would be required to refine the model to more effectively represent the more subtle features regarding shark dynamics and the interaction of the gillnet and longline sectors – an example of such work can be seen in the variant form of Scenario 4 discussed in section 4.6.6. Even without these modifications, as all of the standard forms of the different management scenarios were played out in this same setting, there is value in considering the ranked performance of the various management scenarios to look at their relative performance against the indicators. The fact that the results of the variant of Scenario 4 (where there were modifications to the respresentation of those sectors that can target gummy shark) indicate that the overall results do not change significantly shows that the overall results can be treated with some confidence even given their uncertaintites and representational problems. In this way potential improvements due to particular management combinations can be considered even if no one management strategy exactly matches the way reality has played out in the last 5 years of rapid and extensive change in the SESSF. Ideally this is how the model should be used regardless of the uncertainty associated with any particular aspect of its output.

Turning to the greatest sources of uncertainty for the model as a whole, probably the greatest biophysical uncertainty that remains is to do with larval supply. This uncertainty is structural, in the sense that it is an explicit mechanism that is not included in the model. Changes in larval supply under differing system states and oceanographic conditions (particularly under global climate change) are not represented explicitly in Atlantis SE, only post settlement mechanisms are explicitly included. Of all the potential weaknesses in Atlantis SE this is the one with the greatest potential to drastically alter the form of the system into the long-term, which could have a significant impact on the final performance of the management scenarios presented here. It is a possibility that under a more rigorous representation of the impacts of climate change that none of the scenarios presented here can moderate the resulting impacts. Meticulous consideration of this form of uncertainty would require further model refinement and will be a likely subject of future developmental work on the Atlantis framework.

Another focus for future Atlantis development is also the other major source of uncertainty in this analysis. The uncertainty associated with the socioeconomic components of this model is much larger than the biophysical uncertainty. This is for two reasons. The first is that there is a longer history of use of mechanistic biophysical models (many decades in the case of physical and biogeochemical models); despite their complexity they are reasonably well understood. Over a decade of effort means their core dynamics have been evaluated, the impacts of model formulation have been assessed, and critical sensitivities have been identified. While social and some forms of economic model have been in existence for as long as the ecological models, economic models are typically used in a very different way (e.g. for optimisation problems) and under very different assumptions (e.g. rationality) to those used here (where they were used as a mechanistic process driving effort allocation). To the authors' knowledge this is the first time such a comprehensive set of system components have been brought together in a single representation of a fished system. This is also the first time the critical issue of behavioural uncertainty, and the way in which that can see management actions lead to unintended results, has been considered in such detail. This has required the development of a new process-based socioeconomic model (detailed in Appendix B). As this kind of model has not been as widely used, there is much more uncertainty associated with it. This uncertainty is not reduced as much as would be desirable due to the other major reason for socioeconomic uncertainty. Supplying data for an ecosystem model is always a challenge, but in the case of socioeconomic data (particularly data on the behavioural drivers, such as social or cultural pressures that may free or constrain a fisher's ability to respond to immediate returns) the data is incredibly sparse (and this is in a country that has good industry-level economic data collection by global standards). The available data were used to identify alternative plausible parameterisations (and even alternative implementations). It was insufficiently constraining however, and significant uncertainty remains regarding the aspects of the model such as: the finer scale details of effort allocation; the social indicators (such as public perception), more sophisticated investment decisions (especially those involving major capital outlays); the market price models (the current representation completely lacks the potential feedback of recent landing levels and product quality on realised prices); and more sophisticated representation of management costs and their flow-on effects into the industry decision making processes. Future model development, and more importantly data collection or data access (to existing restricted access social and economic databases), would help immensely in this area and result in less uncertain models and more robust analyses. In particular, significant benefits could be had from a more formal and systematic evaluation of the implications of model complexity in these forms of models. In terms of model performance (the dynamics predicted), the logistics of model use, and the data required for model parameterisation, calibration and validation data, consideration of what is gained or lost in the use of models such as individual-based discrete choice random utility models versus aggregate effort allocation algorithms is vital for the future incorporation of socioeconomic components in fisheries models. They are critical components, but they must be held to the same standards of rigour and understanding that the other system components have been subject to over the last decade or more.

This discussion of uncertainty, particularly the socioeconomic uncertainty, should be kept in mind during the following sections dealing with the implications of the MSE. In particular, it should be remembered that because the projections take the time series between 20 and 50 years from the original training data set, there is enormous scope for change in underlying behaviour and motivation. Extra caution should be associated with the social indicators in particular, because they were fitted based on a minimum of data. These indicators were kept in the final analysis however, as social indicators featured in the qualitative analysis; more importantly, social considerations are amongst AFMA's objectives and were identified as critical for sustainable management by Aslin and Byron (2003).

While considerations of the uncertainty are important, it is equally important however, to remember that to the authors' knowledge this is the most comprehensive MSE to date anywhere in the world; and that it is the first (or at the very least one of a very few studies) that has explicitly attempted to explicitly consider the cumulative and integrated behavioural responses of fisheries operators to management actions. This facet of fisheries management is very complex and hard to quantify or represent and has been almost completely ignored previously. This is despite the fact that unforeseen consequences of management actions, which result from behavioural uncertainty, have been a significant factor in many of the fisheries management failures. In part, it is such a troublesome issue because it is not usually considered in full even by experienced scientists and managers. For instance, for those cases where there was a differences in the predicted outcomes of scenarios under the quantitative and qualitative stages of the study (see section 6.2 below) this was because the quantitative analysis predicted a behavioural response by the fishers that the qualitative analysis had not taken into account (e.g. when fishers used non-quota species to subsidise their efforts to pursue species under quota and this effectively circumvent the intent of the extensive use of quota management in scenario 3). Ultimately this meant that in the quantitative analysis there was no outstanding “best” scenario; each had its drawbacks. This is because management does not have complete control of the system and the processes driving it or the industries decisions, so things do not occur as anticipated. So while there are clear shortfalls in the approach used, it represents a much better attempt at considering the most critical issues facing ecosystem based fisheries management and, as such, is a substantial advance on previous efforts in that area. There is room for further substantial development and refinement, but as a pioneering step in the field it has made significant advances in addressing one of the most critical uncertainties facing the successful use of management options.

6.1.1 Future Work to Address Uncertainty

The strength of the management strategy evaluation framework is that comparative evaluation of strategies (or scenarios) can be undertaken even if there is uncertainty regarding the form or magnitude of individual components. Nevertheless it is useful for future expansion of this study to identify areas that would see substantial benefit from further analyses, data collection or validation. Keeping such a list in mind will also add in remembering which are the most uncertain areas of the model when considering the overall results. In this spirit Table 6.1 provides a list of uncertainties associated with Atlantis SE. The table also includes: a qualitative measure of the level of uncertainty; a short description of how the uncertainty has been addressed in this study; and how they may be addressed in future studies.

6.2 Scenario Comparison

6.2.1 Strategic Scenarios

Five of the nine management scenarios evaluated in Stage 1 were identified by the Project Team and Steering Committee for quantitative exploration. Each of these scenarios comprises an alternative mixture of quota management, spatial management, gear controls and effort controls. The scenarios range from what was largely “business as usual” during the late 1990s and 2000 through to what were considered more radical changes during the project’s early stages. There have been rapid changes in the management of the SESSF in the last few years, such that many of the measures identified in the “radical” scenarios are now (or are about to be) implemented. In that light both the qualitative and quantitative evaluations may give some insight into the possible impacts of changes introduced thus far.

Scenarios

Scenario 1 – this Scenario assumes a continuation of quota and other management settings as they stood in 2000 - 2003.

Table 6-1: Sources of uncertainty in Atlantis SE, how important they are (using a qualitative scale, 1= low to 5 = high) and how they have been dealt with or should be tackled in future modelling studies.

Source of uncertainty	Level of uncertainty	How Handled in Atlantis SE	Future Work
Model biophysical resolution (in particular the resolution around the shelf break (150-250m)	1	The split was based on physical properties and ecological distributions rather than properties of the industry (this meant the auto-longline sector could access waters from 150-600m)	The primary division should continue to be based around physical and ecological properties, but should also consider industrial breakpoints (e.g. have an additional break at 180m so auto-longline constrained to the actual management regulated depths)
Long-term environmental variability	3	Based on time-series from the BlueLink II OFAM model (which data assimilates actual physical data); supplemented by trends based on simple indices of upwelling, eddy strength and temperature	Update with new information that it becomes available, including driving the model with output from global climate models.
Larval supply and recruitment variability (and climate impacts)	5	Assumed larval supply is not impeded by physical processes (i.e. currents do not change and stop delivering larvae) and that only fecundity, maternal condition and post settlement processes lead to recruitment variability	Implement the option for the explicit inclusion of larval supply (and potential changes in it, such as shifting currents under climate change) and environmental forcing
Stock structure	3	Multiple stocks (potentially with different parameterisations) included for species if known (as of 2005); this can make a stock look too robust to fishing pressure if it is represented by a single stock when in fact it is made up of stocks that suffer differentially in response to fishing (this may be the case with school shark). For some groups the least important species were omitted as there was too little data and they appear to make negligible contributions to the broader group and system dynamics (this runs the risk of missing “explosive change” in system dynamics and structure under alternative conditions)	Update with information that has become available more recently (e.g. for school sharks); this should allow for species to survive historical fishing pressure (without being extirpated unless they actually were extirpated). But remain depleted under current management actions (as seen in school shark). For some groups (e.g. seabirds) a broader range of species should be included; so that a wider of subtle direct as well as indirect effects can be captured; and the potential for a wider set of sources of “explosive change” have been explicitly included.

Source of uncertainty	Level of uncertainty	How Handled in Atlantis SE	Future Work
Potential dietary connections	4	These are always very uncertain (due to natural variability and data required vs data available), but the structural sensitivity has been intensively considered during the development of Atlantis SE; plus maximum flexibility has been included in the Atlantis handling of trophic connections	Increased data collection and opportunistic monitoring, plus the use of additional methods (like isotope ratios, DNA and fatty acid analyses) will be incredibly useful for validating the structure
Historical biomass	1-5 (depending on specific group of interest)	Used the best available information (as of 2006), this worked reasonably well for the vertebrates, but the invertebrate biomasses are only indicative (and highly uncertain)	Update with information that has become available more recently for vertebrates (particularly for dogfish and red bait), but for invertebrates greater sets of data for validation are required, as are alternative formulations that may better capture life history strategies or population divers (such as environmental forcing)
Historical catches and discard rates	2	Used the best available information (as of 2005)	Update with information that has become available more recently (e.g. Walker and Gason 2007)
Fine-scale targeting	5	This is not currently captured in Atlantis	Sub-grid scale representations of this behaviour should be included, as it can have a substantial impact on realised catches and discard rates.
Gear saturation	3	Only a linear implementation of this currently exists (i.e. effectively no saturation) ; which is apparently problematic for the shark gillnet fishery in the SESSF.	Alternative formulations (including asymptotic or humped forms) should be included to capture a wider range of potential industry dynamics and gear profiles.
Socioeconomic model	4	Best possible prototype socioeconomic process-based model, based on advice from fishers, Galeano *et al* (2005), BRS (2007) and Tom Kompas and Gerry Geen. As there is much less experience in general with these models the impacts of model complexity, structure and parameter uncertainty are not as well known.	Refine the existing models, but also develop alternatives so that the impacts of complexity, type, structure and parameter uncertainty can be considered. This will also require more data (for model development and validation) as well as collaboration with economists and social scientists; particularly with regard to behavioural drivers, information sharing, costs of switching targets to groups such as small pelagics or squid.

Source of uncertainty	Level of uncertainty	How Handled in Atlantis SE	Future Work
Market feedback based on volume and quality of product recently landed	5	Not currently included, as a simple auto-regressive price model is used (as originally advised that they were of minor if any importance in Australian markets, this has turned out not to be completely the case for all groups or all periods of the year).	Include alternative models for setting market prices so that there is the option to include these effects if considered to be a significant feature of the system.
Investment and quota price models	2	Detailed, process-based models from the EU and NZ trawl and line fisheries were adopted (with minor modifications to tailor them to generic or Australian cases); model validation was carried out based on available data, but this was sparse so the model parameterisations are not fully constrained.	Collaboration with social scientists and economists to further validate the model (or re-parameterise it if necessary) would reduce uncertainty about the use of this model; alternatively a dedicated study for constructing Australian models of investment or quota price setting could be undertaken, though it is unlikely that the final structure of such a model would be substantially different to that of the EU and NZ models (as they were based on generic and ubiquitous processes, it was really more a matter of appropriate parameterisation when changing from place-to-place).
Management cost model	1	A simple management cost model based on 2005/2006 management budgets was implemented with advice from RAG and MAC chairs and AFMA managers.	Further of the refinement may be useful, but more importantly this model needs to be more effectively integrated with the rest of the socioeconomic model so that their can be confidence that knock-on effects of cost recovery have been completely considered.
Compliance	1	Level and drivers uncertainty, but impact is easily empirically captured and a wide range of possibilities has been considered (while it does have an impact on the absolute impact of management strategies it does not effect the relative performance of the strategies in comparison with one another).	By its nature the level of compliance is unlikely to ever be known exactly and the current approach is the best possible means of dealing with uncertainty in levels in compliance.
Tiered harvest strategies	2	Uncertainty in the way in which tiers 3 and 4 would be implemented in the management system (in 2005/2006) meant that they were not included in this analysis (all groups managed under tiered harvest strategies were treated as tier 1 or 2)	As tiers 3 and 4 are finalised then they can be trialled in future analyses.

Source of uncertainty	Level of uncertainty	How Handled in Atlantis SE	Future Work
"Negotiated" setting of TACs	2	Current implementation is simple and based on the estimated RBC versus catch rate trends, it does seem to produce a slowly increasing TAC through time (disconnecting with biomass trajectories) in the majority of cases	Refined versions should be developed to allow for more volatile TAC trajectories (and fewer one-way trends).
Assessments	1	Full assessments are prohibitively computationally expensive, but mimics capture the assessment process (and have been verified not to lead to substantially different final results)	Once computing facilities increase to the point full assessments can be run then this issues should disappear.
Public and operator perception	4	Simple indices created based on acknowledged drivers from Aslin and Byron (2003)	Collaboration with researchers from BRS and work with focus groups to refine these indices and our understanding of the drivers
General parameter uncertainty and sensitivity	3	Bounded parameter sets that meet the historical fitting criteria and produce plausible biomass levels were considered (while they could lead to alternative levels of absolute biomass or productivity etc, they did not alter the relative performance of the various management strategies)	New methods for considering model sensitivity in large and complex models are beginning to be developed, as these mature they can be applied in future studies so that all results can more easily be presented with explicit measures of associated uncertainty.
Static model system structure	2	Loop analysis and network analysis was used to check for structural sensitivity and select the simplest system structure that did not lead to abhorrent predictions under perturbation.	Structurally dynamic models will always remain technically and computational prohibitive at the ecosystem level (and they rely on subjective definitions of objective function for each group); but new work considering the differential vulnerability of functional group components to perturbation and the effects of shifting biodiversity on parameters will be incorporated in future versions of the Atlantis framework so that this kind of uncertainty can be minimised (the nature of the complexity of the real world means it will never be completely removed).
Gear switching	2	If allowed in the scenario, then a vessel may switch gears (dependent on expected returns and costs); once a vessel is dual purpose it may switch gears between trips.	Restrictions on which vessels can switch gears should be considered; and inertia representing information lag (including dis-information or uncertainty regarding the profitability of other sectors) should be included.

Scenario 3 – this Scenario includes a major extension of the quota management system (both via expansion of the number of groups under quota, but also through the use of basket quotas) as well as broad spatial controls for the major sectors.

Scenario 4 – this Scenario incorporates changes to all major forms of management: quotas (though not to the same extent as Scenario 3); wider use of spatial management; and modifications to input controls (e.g. removal of restrictions on fishing methods used per sector).

Scenario 9 – this Scenario assumes some quota management, but is heavily reliant on spatial management; the Scenario also makes some attempt to consider some of the potential impacts of climate change on fisheries productivity.

Scenario 10 – the combination of management methods used in this Scenario is structured to try and capture the management arrangements in place in the SESSF in November of 2006.

Performance

Considering the results at the highest level each scenario has strengths and flaws (Table 6.2). Scenarios 1, 3 and 10 provide the best short term economic performance. In the long term however Scenario 1 in particular begins to exhaust the resources. Scenario 3 can also result in ecological (and therefore ultimately economic) deterioration in the system unless quotas are handled carefully as part of a more rounded multi-lever package. Scenario 9 performs well in terms of target species biomasses and overall conservation results, but achieves these at the expense of economic performance. Scenario 4 performs well (or reasonably well) on all fronts; though it is not a universal panacea as it does shift pressure to some of the more productive shelf stocks. The variants of Scenario 10 show an interesting mix of success and potential flaws (Table 6.2) as they grapple with how to pragmatically and tactically implement the ideals captured under Scenario 4.

Generally speaking Scenario 4 is consistently the most rounded scenario in terms of performance against all classes of performance measures. Other scenarios do better for specific indicators, but Scenario 4 is much more consistent – it is rarely “worst” at anything and is often in the middle to high end of the range of projections. Change in this scenario (be it stocks or fleet structure) is smoother; the shift in fleet sizes occurring much earlier (beginning after only a few years), with those remaining in the fishery ending in a better state. Scenario 10 is a close facsimile to Scenario 4, both in the general pattern of change and the timing and general smoothness of many of the trajectories. The differences in the detail of the outcomes of Scenarios 4 and 10 are enough that the performance of Scenario 10 is improved in terms of landings and some biomass levels. This comes with the penalty of higher costs and lower profits, however. Discards also demarcate the two Scenarios. The ban on discards in Scenario 10 appears to be the only means of ensuring a drastic and immediate reduction in discards. The inclusion of discards in TACs in Scenario 4, as an incentive to reduce discards (and thus maximise catch vs discards), saw some reduction in discarding (and shifts in targeting to reduce discards), but this was perhaps less than anticipated, potentially reflecting constraints in how some aspects of fisher behaviour are modelled. This aspect of the modelling would benefit from further focused attention.

Scenarios 9 and 1 tend to be the most extreme, with their values and trajectories often bounding those of the other scenarios. Scenario 9 does well in terms of conservation and maintaining high

Table 6-2: Summary of strengths and weaknesses of each scenario.

Scenario	Strength	Weakness
Scenario 1	Short term economic returns	Extended effort footprint and high absolute level of effort
	High absolute catch	Long-term economic decline
	Fishers know how the management system works (i.e. it doesn't so there will be no new changes)	Fleet collapse
		Poor CPUE
	Low management costs	Low GVP
		Discards remain unconstrained (and potentially high)
		Long-term deterioration of biological system (and poor diversity)
		High TEP and habitat interactions
		Poor social perception
		Little if any investment
Scenario 3	Short term economic returns	Extended effort footprint and high absolute level of effort
	GVP in short to medium term	High costs (including management costs into the long-term)
	Deepwater biomass recovers	CPUE low in some sectors
	Diversity recovers in some areas	Long-term GVP
	High absolute catch	Discards remain high
	Moderate habitat interactions	High number of TEP interactions
	Some reduction in gear conflict	Shelf and upper slope biomass heavily impacted
		Poor social perception
		Sensitivity to the form of non-quota management levers (without them there is poor long-term ecological and economic performance)
Scenario 4	Economic health of all sectors improved	High short-term disruption associated with transition in fleet size and structure and new management arrangements
	Widespread improvement in biological system state	
	Reduced habitat interactions	Pressure on productive shelf stocks
	Reduced gear conflict	Discards remain a potential problem
	Reduced effort footprint and moderate levels of absolute effort	
	Moderate levels of absolute catch	

Scenario	Strength	Weakness
Scenario 4 (cont.)	Higher CPUE GVP and profits True management stability (i.e. management occurring and stable) Moderate management costs Smooth transition in fleet size and structure (no collapse) Improved social perception Investment in the industry and steadily increasing returns on that investment	
Scenario 9	Reduced footprint and absolute level of effort High CPUE Discards reduced substantially Widespread improvement in biological system state Substantially reduced TEP and habitat interactions True management stability (i.e. management occurring and stable) Reduction in gear conflict Improved social perception	Poor economic returns (fishery not economically viable in long-term) Poor return on investment Poor GVP Low catches High short-term disruption associated with new management arrangements High per boat management costs High short term research costs
Scenario 10	Economic health of all sectors improved (though higher costs, lower profits than in Scenario 4) GVP Contracted footprint for intense pressure and Moderate levels of absolute catch and effort Higher CPUE Substantially reduced discarding Widespread improvement in biological system state Moderate management costs Improved social perception Investment in the industry and steadily increasing returns on that investment	Contracted footprint leading to intense pressure on local habitat Habitat interactions remain high High short-term disruption associated with transition in fleet size and structure and new management arrangements Gear conflict remains potentially high

CPUE, but is not economically viable. In the longer term, Scenario 1 is also only marginal economically, reflecting the deteriorating state of many of the target species. These two scenarios also bound the timing of changes for all scenarios. Under Scenario 9 much of the change comes into effect immediately, with the biggest drops in landed catch, effort and economic value happening in the first year that the strategies are in place. Biomass changes more slowly, but for fast turnover species moderate to strong gains in relative biomass are possible even within a few years of the implementation of the Scenario's strategies. In contrast, the rate of change is much slower in Scenario 1. The fishery changes little over the first decade, before the deteriorating economic conditions (which, to a large degree, reflect the ecological status of the system) result in a sudden substantial decline in vessel numbers in most sectors. Those sectors that have lower costs, such as the Danish Seine sector, do not decline so rapidly or so far. The substantial reductions in fleet size and fishing effort in most sectors lead to short term recoveries in some stocks in some areas (and profits), but they do not fundamentally arrest the decline in resources and ecosystem state. In Scenario 1, the overall system persists in a poor economic and ecological state into the long-term.

The performance of Scenario 3 is more mixed, and hard to generalise. Industry and economic indicators perform well (though high effort levels do lead to high costs). Performance on social indicators is poor, while ecologically it does well for deep water target groups and diversity, but poorly against most others. This Scenario is also the most sensitive to the exact form of the management levers used – as shown by the fact that it falls to performances as low as (or even lower than) Scenario 1 if the spatial zoning and improved targeting (reduced discarding) components of the package are removed. The pattern of change through time shares many similarities with that of Scenario 1 – with changes in fleet structure tending to happen suddenly in many sectors, after an extended period when much of the fishery is under a lot of economic pressure. Those sectors that can maintain some economic viability through lower costs (e.g. Danish Seine) still undergo an effort reduction, but it occurs over a much longer period than in any other Scenario.

In terms of industry performance measures, Scenarios 1, 3 and 10 lead to the highest landed catches, with Scenario 4 intermediate and Scenario 9 at almost negligible levels. Effort is highest in Scenarios 1 and 3, with Scenarios 4 and 10 being fairly similar to each other and at a lower level, while Scenario 9 is at a very depressed level. This combination of catches and effort leads to a reversed ranking in terms of CPUE, with Scenario 9 having the highest values and Scenario 1 the lowest. The range of CPUE seen across the scenarios (and even within scenarios for some gears and species) are within the range observed in reality, though the range in the real world may also be associated with changes in availability, presumably driven by environmental factors rather than management strategies alone.

In the long-term GVP tends to be high for Scenarios 3, 4 and 10, while Scenarios 1 and 9 do more poorly, but for different reasons. Scenario 9 simply does not land enough catch to remain viable, especially with the high per boat management costs that need to be recovered, while Scenario 1 suffers from sequential (and in some cases simultaneous) depletion of decreasingly valuable fish stocks. These results can be sector dependent however, with the trawl sector benefiting from the implementation of Scenarios 4 and 10, whereas the GHAT sectors do better economically under Scenario 3 (or even 1). These differences did not lead to substantially different overall fleet structures, however. All Scenarios lead to similar reductions in fleet sizes, simply by different routes and with different economic implications sector by sector (but still not sufficiently different to lead to marked differences in the final form of the fleets). Typically the smaller fishery sectors are least heavily impacted. The smallest boats of the major sectors (especially the SET and gillnet sectors) are most heavily impacted as they appear to lack the flexibility to opportunistically shift targeting and behaviour as rapidly as the larger vessels (which counteracts the benefit of lower costs). The Danish Seine sector, which has lower costs, sees fewer smaller vessels exit; and the GAB trawl sector (which has fewer components and is not yet as heavily exploited or impacted as eastern waters) sees effectively no reduction in fleet size, while the deepwater trawl sector sees a more even loss of boats across the size classes.

The strong conservation performance of Scenario 9 is seen in its low impact on TEP and habitat groups (for the fisheries measures) and the higher biomasses across the majority of groups (for the ecological performance). In contrast the performance of Scenarios 1 and 3 is fairly poor against these criteria. Of note, multispecies trophic and competitive interactions (centred on target species, but with some degree of cascade of the impacts for at least 2 or 3 connections further away through the web) can result in poor performance, even for more balanced scenarios like Scenario 4. For instance, competition for food is a significant contributor to the lower total relative biomass of TEP groups in Scenario 4 in the medium term. Detailed consideration of the ecological performance measures reported above in conjunction with the findings and recommendations of ecosystem indicator reports (e.g. Fulton *et al* 2005a and Link 2005) show that the system is heavily impacted by fishing, particularly in the waters off northeast Victoria, for example on the shelf near the canyon complex, and that there is only marginal to moderate improvement (if any) into the future. The system cannot be fully recovered (to unfished levels) with active, economically viable, fisheries in place. This is due not only to the direct pressure on the groups that are fished, but to trophic and habitat mediated cascades and indirect effects. Compared to the system state in the late 1990s, healthier system states are obtainable, just not fully recovered ones (which would be an unrealistic goal of fisheries management in any case, as an exploited system will always depart from an unfished system to some degree). Ecological system states can be considered in terms of the capacity of the system to deliver services, such as productivity, assimilative capacity, and nutrient cycling.

The decision as to which state should be the "goal state" for the system requires careful thought about what society wants from the system, including production of seafood. One way to consider this is to define “acceptable levels of impact” from fishing (and other human uses). Choices about acceptable levels of impact require broad-based and open discussion, as they have implications for which fishing sectors could remain viable (as well as the viability of other uses and impacts). An example of such considerations is that, with the biomasses used for small pelagics in this study, it is highly unlikely that a medium to large scale small pelagic fishery could be successfully prosecuted simultaneously with a demersal fishery which maintains reasonably healthy demersal stocks. Choices would have to be made about the relative priorities of each fishery (and its products), and these are ultimately social choices. The size and complexity of the SESSF means that there is no combination of management actions that allows for all the components of the system (industry or ecological) to be at an optimum level.

For fisheries management performance measures, two issues of interest are costs of management and resource access. Management costs cannot be avoided, as all management has associated costs at some level. Spatial management tends to be the cheapest to implement and monitor in the longer term, though it has significant upfront research costs as the efficacy of any zoning is verified. Costs are steadier when TACs are used as a prominent management lever, but they can remain high into the longer term as assessments have an on-going data need that can be expensive to meet. Even as stock status stabilises and full quantitative assessments can become less frequent, the cumulative costs of an extensive quota management system (e.g. Scenario 3) are well above (as much as 4x higher than) those with a rounded use of management levers (e.g. Scenario 4). Fleet restructuring under the conditions of cost recovery of management can also be a two edged sword; there are fewer boats competing for the same resource (allowing for potentially higher individual GVP per boat), but costs of management are also concentrated on a smaller base, leading to higher costs per boat (as much as 15% of total costs for boats in the GHAT under Scenarios 3 and 10).

6.2.2 Discards

The results suggest that the use of additional or new management measures can sometimes have unanticipated consequences. For example, in some instances measures to reduce or ban discards could led to the spatial redistribution of fishing effort, leading to increases in gear conflicts and additional habitat interactions. There are also trophic impacts associated with a cessation of discarding that can have significant consequences for scavengers and their alternative prey groups - for example seabirds, some macrozoobenthos and ling can all be impacted directly in this way. This issue has been raised as a serious concern in some overseas studies (Suryan *et al* 2006, Votier *et al* 2007). Some species benefit from a reduction in discarding (like those species which discard reduction devices will save, or prey groups of scavengers), but not all.

Another issue that must be considered when assessing whether a ban on discards is appropriate is whether or not even a small percentage of those discards would normally survive. If fisheries are prevented from discarding small fish when even as little as 5-10% would have survived there can be significant impacts on the realised population structure due to increased juvenile mortality rates. It is therefore possible that banning discarding, as envisaged in Scenario 10, could necessitate compensatory management measures to maintain stocks near target levels. The more precise level of these effects remains to be explored further.

Other implications of the alternative strategies are the impact on ports and management infrastructure. While social perception by the broader community can be improved by fisheries managers being seen to take decisive action, there are consequences for the local port communities if these strategies affect the profitability and behaviour of the fishing fleets (as is so strikingly the case in Scenario 9). New management levers can also result in shifts in fisheries support services, such as quota trading networks. If a ban on discarding of target groups is to be fully effective with minimal over-catch on the one hand and minimal disruption to the smooth running of fishing operations on the other, it is critical to ensure the existence of good landings accounting schemes (with fast updating) and also a well developed and supported quota trading system. This is especially true when volume of trades increases substantially. If such trades cannot be supported, cautious “quota hoarding” behaviour (i.e. when operators refuse to trade quota as they do not want to risk running short of quota later in the year) could lead to a serious dysfunction in the fisheries’ operations (as there would be insufficient flow of quota to support fishing and so overall catches can fall substantially even with healthy available stock biomasses). This has also been seen in other quota trading situations (e.g. tropical fish, Little *et al* in prep) and echoes the kind of behaviour observed when SESSF quota reconciliation periods dropped recently from an annual to bi-monthly cycle.

6.2.3 Tactical Variants

Targeted spatial management, whether as a standalone part of a multi-lever package or integrated with the quota management system, appears to be an indispensable part of any successful management strategy for a multifaceted and complicated fishery such as the SESSF. Without spatial management some objectives cannot be achieved and there is often less of a buffer against behavioural uncertainty. Having said that, spatial zoning itself is not free of unforeseen consequences. For example, areas outside the closures will be subject to higher levels of effort, not all effort will be successfully displaced, and active reduction in effort may need to accompany spatial closures. Moreover, spatial management will have varying impacts on different species and fisheries. For example, the following outcomes are seen in Atlantis SE:

- highly mobile species will see no abundance benefit from closures that do not span a large proportion of their range, but they may still see a biomass benefit because of more abundant (if patchily distributed) food sources within the closed areas
- less mobile species may see enough local increases in abundance for the excess to “spill over”, which is the often claimed benefit of marine protected areas stated in the literature (McClanahan and Mangi 2000; IUCN 2004)
- fisheries on site attached species will see no immediate benefit (in increased catches) though they may see some long term benefit either via rotated opening or via larval supply from healthier stocks within areas that are closed.

This differential impact means the purpose of introducing spatial management needs to be clearly articulated.

The other management levers considered in the variant forms of the scenarios all have their own implications, indicating that their use must be given careful consideration. Use of companion TACs need to consider whether all species are of equal value to society. The current draft Commonwealth harvest strategy policy notes that achieving target (MEY) levels for all species simultaneously in a multispecies fishery is not feasible. This policy indicates that it is acceptable to fish some stocks to lower levels so long as they do not fall below limit reference points (Draft Commonwealth Harvest Strategy Policy, DAFF 2007). There has been some discussion in the fishery science literature (amongst the articles looking for indicators of species vulnerability based on life history characteristics) of the ability of some species to withstand overfishing for long periods of time without collapse, but much work remains to be done in this area. It is also clear that not all species have this capacity and in these cases companion TACs may not be appropriate. There is a policy choice to be made here between strong link and weak link harvest strategies. Strong link strategies focus on efficient exploitation of more productive and usually more valuable stocks, at the expense of those species that cannot withstand higher fishing pressure. Alternatively, weak link harvest strategies attempt to maintain all stocks and species at or above their individual target levels, usually at the expense of efficient exploitation of the more valuable and productive species.

While the economic model used in this study is crude in many ways it does seem to capture some of the coarse behaviour of the fleets in the SESSF. With that in mind it appears that gear switching (as envisaged in Scenario 4) may not be a viable solution to autonomous restructuring, with little uptake unless heavily subsidised; and even then it acts more as a stop gap than a solution to the real problems with the fishery. A buyback on the other hand seems like a much more direct and effective means of addressing the core issue of reducing fleet size and improving economic viability (because if a buyback is well timed so that there is a need for restructuring but it has not been left so late the system is already heavily impacted then there is sufficient engagement with the process that positive benefits flow from the reduction in effort). Interestingly, while banning discarding has some unforseen ecological consequences that must be evaluated against other benefits, some reduction in discard levels does seem to increase economic and target stock viability in the longer term. Whether a complete ban is as beneficial probably deserves further intensive consideration; as does the implications of climate change, which only received a superficial consideration in this study.

6.2.4 Overcatch, Incentives and Multispecies Targeting

Overcatch does occur for many of the target species in one or more years of many of the scenarios. In many cases it is quite small in relation to the quota and is not persistent (i.e. does not continue for extended periods of time), but for some species (e.g. dogfish) it can be a significant and on-going problem (a breakdown of overcatch per species and an explanation of causes is given in Table 6.3).

Overcatch is a result of a number of factors including: lag in learning, which sees mis-matches in actual catches vs expectations in the first year (to few years) that quotas bite; searching and targeting in a multispecies fishery; and to a lesser extent a failure by Atlantis to capture fine-scale targeting. The first two are the primary causes, but the last can tend to overstate the magnitude of the effect. Unfortunately it is not possible, without further development of Atlantis, to completely remove this potential overstatement. Nevertheless it is worth underlining that lag in learning and problems with targeting in multispecies fisheries are very real problems that should not be disregarded completely due to the potential modelling issue. For instance, other multispecies (e.g. the British Columbia groundfishery in Canada) allow for a 10-30% “overage” (at a vessel level) because of the difficulty of targeting in a multispecies fishery. In those fisheries the excess (up to a cap, which is species specific but usually about 10-30% 0f quota) can be carried over from one year and deducted from the next year’s quota. If a vessel exceeds that overage it cannot fish in that fishery (or at least that region if regional management is also in place). As the regions are species specific this can mean a boat may be excluded from the entire coast if it exceeds its quota (and can’t buy in enough to meet the overage) for a species distributed along the coast. In addition the vessel owner is required to relinquish the value of the fish (with the money going to a non-profit society that conducts groundfish research). These are strong incentives in themselves to avoid exceeding their quota, made all the stronger by the fact the reduction in quota in the next year (due to the overage being deducted from that year’s quota) is all the steeper if there is also a TAC reduction. This has meant that in the last decade (since the system came into place for that fishery) it has become very rare for fishers to exceed their quota – the 100% observer coverage in the fishery also means that the incentives are real as discarding is closely regulated and monitored. The operators have learnt and adapted so as to reduce and avoid bycatch; one aspect of this has been a quite clear increase in the cooperation amongst the vessels (who not only lease quota to each other to cover unexpected catches but also share information on areas of high bycatch to avoid the problem in the first place). Atlantis does allow for friendship networks in the model and this kind of information sharing would be an interesting aspect to follow up in future work.

While the effort allocation decision process in Atlantis does take quota remaining into account (via a weighting term) in the scenarios presented here the only incentives to avoid overcatch are: a ban on landing species once quotas have been exceeded; the potential for the fishery to close if enough of the target species had their total quota met (a rare event in any of the simulations). This means it does not contain the regulatory incentives for avoiding overcatch that is seen in a fishery such as the BC groundfishery (e.g. carry over is not included as it is no longer allowed by AFMA for the SESSF) and so the model fishers do not always avoid the risk of overcatch when pursuing the last little bit of quota each year. Inclusion of such incentives may be advisable in future forms of the model, but more importantly the prevalence of overcatch in the results for some species shows this should be taken as a warning that incentives are needed when trying to avoid overcatch in multispecies fisheries. One future scenario shaped to consider this issue directly would be one including a carryover mechanism (or other form of overcatch disincentive). Another set of potential scenarios that would be helpful in this area would be ones that considered the costs and trade-offs associated with increasing levels of observer coverage.

Given the relatively small percentages of the size of the overcatch for many of the species it is fair to question why such attention is being given to the topic here. While it may be expected that such small amounts would lead to little effect on the stock the opposite can be true. For some of the species (e.g. Orange Roughy and Gemfish and Gulper sharks) this additional pressure, though small, is enough to cause a problem for the stock's sustainability. This is because the harvest rules applied used the same settings (B48:B40:B20) for all species. The model dynamics suggest that the ecology of the separate species means these levels are not universally appropriate and may need to be higher for some species (though they could actually be lower for others). This is consistent with the policy, which sets B48 as a proxy that may need to be modified for some species. Significant further work would be needed to be confident of what those levels should be exactly for the various species, but the results here should be considered a warning that such consideration is required.

Table 6-3: Degree of overcatch and causes for that overcatch for each species where quota is exceeded in any scenario.

Species	Overcatch (as % of quota)	Occurrence	Comments and causes
Blue grenadier	2 - 5	Occurs in 6 years total in scenario 3 and 1 year in scenario 10	A small part is due to the inability of Atlantis to fully represent shifts in fine-scale targeting ability, but it is also due to a lack of incentive in the model not to overcatch
Blue warehou	3 - 34	Only during the first year quotas bite under scenario 4, but occurs in 7 years for scenario 3	Due to the issue of multispecies targeting in combination with Atlantis' in ability to capture fine-scale targeting
Blue-eye trevalla	3 - 14	Only in first year TACS bite for scenario 3 and first 2 years of scenario 10	Due to lag in fishers learning to cope with constraining TACs
Gemfish	1 - 20	Occurs in 3 years total in scenarios 4 and 10 and in 6 years in scenario 3 (where they get better through time as they learn to avoid it or stop targeting it	Mostly it is a result of "using by-catch quota to target" and Atlantis not allowing for a very good reflection of changes in fine-scale targeting
Jack mackerel	10	Only in first year that quotas bit (for that species) under scenario 3	Due to lag in fishers learning to cope with constraining TACs
Orange roughy	0.1 - 12	Occurs in 5 years in scenario 10 but happens in 10 for scenario 4 (though typically < 8%) and 12 years for scenario 3 (where typically < 5%)	The causes are mixed, for scenario 3 its usually as a result of vessels hitting a big aggregation with many subfleets getting more than expected all at once; there is some degree of that in scenarios 4 and 10 too, but more often in those scenarios it is down to lack of disincentive, plus the issues of fine-scale and multispecies targeting (other deepwater fish, like dogfish, "dories and oreos", are caught in the same Atlantis areas and in reality – which was the impetus for the proposition of a companion TAC for them)
Red bait	6	Only in the first year quotas really bit (for that species) in scenario 3	Due to lag in fishers learning to cope with constraining TACs
School whiting	1.7	Only in the first year quotas really bit (for that species) in scenario 3	Due to lag in fishers learning to cope with constraining TACs
Tiger flathead	0.1 - 5	Occurs in 7 years in scenario 9 and 9 years in scenario 10	This is again due to a combination of the model's inability to represent fine-scale targeting and to a lack of disincentive to avoid overcatch
Gummy shark	2 - 20	Only 1 year in scenario 3 (when TACS first bite), but 6 years in scenario 4 and 13 years in scenario 10	This is due to lack of disincentive and problems with really being able to selectively target them (this is a real issue) in conjunction with Atlantis' inability to capture fine-scale shifts in targeting (which over states the problem in the projections).
School shark	0.5 - 8	occurs in 7 years for scenarios 4 and 3	This is again a combination of real problems in avoiding them when targeting other shark, but with a degree of overstating the problem (because Atlantis can't capture fine scale targeting)
Dogfish	5 - 35	Occurs in 8 years in scenario 3	It occurs because it is very hard to avoid them when targeting other deeper water fish
Other demersal shark	4 - 6	Occurs in 4 years for scenario 3	Again due to the targeting problems mentioned for gummy and school shark

6.3 Comparison with Qualitative Evaluation

The two stages of the AMS project have addressed the same problems and objectives by using different methods to predict the consequences of alternative management scenarios. Stage 1 used expert knowledge to make those predictions, while Stage 2 (reported here) based its predictions on a quantitative whole-of-ecosystem model. Comparison of the results of the two stages is important for checking and confidence building when the results overlap, but is arguably more importantly in identifying areas where they disagree. These areas will need to be dealt with cautiously and addressed by further data collection and analyses.

General trajectories ("squiggle plots") for the performance measures provided in the Stage 1 report for Scenarios 1, 3 and 4 are compared with trajectories from the quantitative simulations in Figure 6.1. Checks against the description of Scenario 9 were also made, as qualitative trajectories for that scenario were not developed. There were no trajectories or descriptive predictions for scenario 10 so it was omitted from the comparison (though it has been included in Figure 6.1 for reference).

Overall there is a good deal of correspondence between the predicted trajectories in the qualitative and quantitative analyses. For many measures there is a strong match in trends; for others the overall trends match, though the quantitative trajectories contain more detail in the transitory dynamics. These good or solid matches account for roughly 65% of all comparisons. An additional 20% of the comparisons see the qualitative trajectories from only some of the sectors or ecosystem components match the quantitative simulations. These are the cases where there is a bifurcation in the trajectory (one solid, one dashed in Figure 6.1) with the qualitative trajectory falling only along one of the lines or between them. Where the quantitative trajectories split (e.g. for CPUE in Figure 6.1), this was typically as a result of gear or sector specific differences in behaviour or cost structures, or by sectors rebounding (and thus "getting around" the qualitative assumptions) through significant changes in targeting. Some of this may be to indirect effects of trophic and other interactions that the qualitative analysis did not capture, but some of it may also reflect instances when Atlantis SE could not capture dynamics the qualitative analysis easily incorporated (for instance, the modelling issues highlighted previously regarding the structure of the school shark populations and the potential for behaviourally mediated gear saturation).

Most of the remaining 15% of the comparisons predict "no change" or gentle non-linear change either qualitatively or quantitatively while the other method predicts stronger change or non-linear change with opposite inflection. For instance, under Scenario 1 the qualitative analysis predicted a strong increase in gear conflict, while the quantitative evaluation predicts only a minor increase. Although it is difficult to pinpoint the reason for differences in prediction (and there is no way to know which if either prediction is correct), these differences appear to be due to two main causes. When the quantitative model predicted effectively no change, while the qualitative model predicted stronger changes, this seems to be because the quantitative model (typically the socio-economic components) fails to capture some of the nuances of what the experts could capture, missing some key process, mechanism or scale. In those cases where the non-linear inflexions of the two predicted trajectories differ, the differences may be due to issues of detail. In the qualitative scenarios, it was easy to sketch management tools without considering how they would work in detail. The quantitative implementation demanded those details be fleshed out (e.g. an operational specification of how basket quotas would work in practice). When these details played out, the non-linear dynamics that arose did not always match that expected under the qualitative analysis.

Only 1% of the comparisons contain a very clear contradiction between the qualitative and quantitative analyses. These were the expected population biomass trajectories under Scenario 3 and the biomass trajectory for gulper sharks under Scenario 4 (Figure 6.1). The first of these appears to be due to the fact that under Scenario 3 in the quantitative scenarios, fishing pressure remains reasonably high preventing a recovery of common groups within the projection period of 20 years; whereas the qualitative analysis predicted a fairly rapid recovery. While a substantial portion of the pressure on the gulper sharks is lifted under Scenario 4 in both the qualitative and quantitative evaluations, the rate of recovery of the stocks in the quantitative model is much slower than considered qualitatively. In the long term the biomass of gulper sharks does increase in the quantitative analysis, but this is beyond the 20 year time frame of the main comparisons.

The comparisons shown in Figure 6.1 also miss some of the more subtle detail captured in the text of the qualitative reports and the equally subtle behaviours seen in the quantitative work – such as the pulse fishing behaviour. One example of this kind of behaviour is under Scenario 9 in the quantitative simulations, where not all the displaced effort can be redistributed successfully and economically so a portion of the fleet decides to periodically tie up (and so reduce costs) rather than fish. This behaviour (particularly at the levels seen in Scenario 9) is likely to be overstated by the model, though it is seen in some of the seasonal and gauntlet fisheries in the northern hemisphere (e.g. Alaskan fisheries, Finnoff and Tschirhart 2005). There is no suggestion of this behaviour in the descriptive qualitative discussion of this scenario in Smith *et al* (2004).

Such a high degree of congruence between the qualitative and quantitative results does give some confidence in the general findings. This is not to say that either method exactly captures the dynamics of the real world in a precise and predictive sense; no model ever exactly matches reality, each is a simplification of reality. However, the calibration of the quantitative model against historical observations does provide some reassurance that at least the major dynamics and system processes have been captured in the model. Perhaps the adoption of two different methods to address the same problem in this study supports the principle stated by Levins (1966) that "the truth is the intersection of independent lies".

On a side note, the close match between the management inferences that would be drawn based on the results of the qualitative and quantitative analyses gives some confidence that expert information, if suitably inclusive of a wide body of knowledge, can give real insight into system dynamics and may be particularly useful in rapid assessments. However, the key point here is that expert knowledge and fishery understanding must be **extensive** for qualitative methods to be robust. For example, the combined period of engagement of members of the project team in the fishery in the Stage 1 analysis was more than 100 years. It is not sufficient simply to bring together "experts" in a Delphic forum that convenes for a day or so. It is critically important for the success of a qualitative analysis of this form that it draws on significant experience in, and intimate knowledge of the workings of, the actual fishery. And while the qualitative analysis had a reasonably rapid turn around it must also be recognised that it did take a year to complete in full. It was not an insignificant undertaking in its own right.

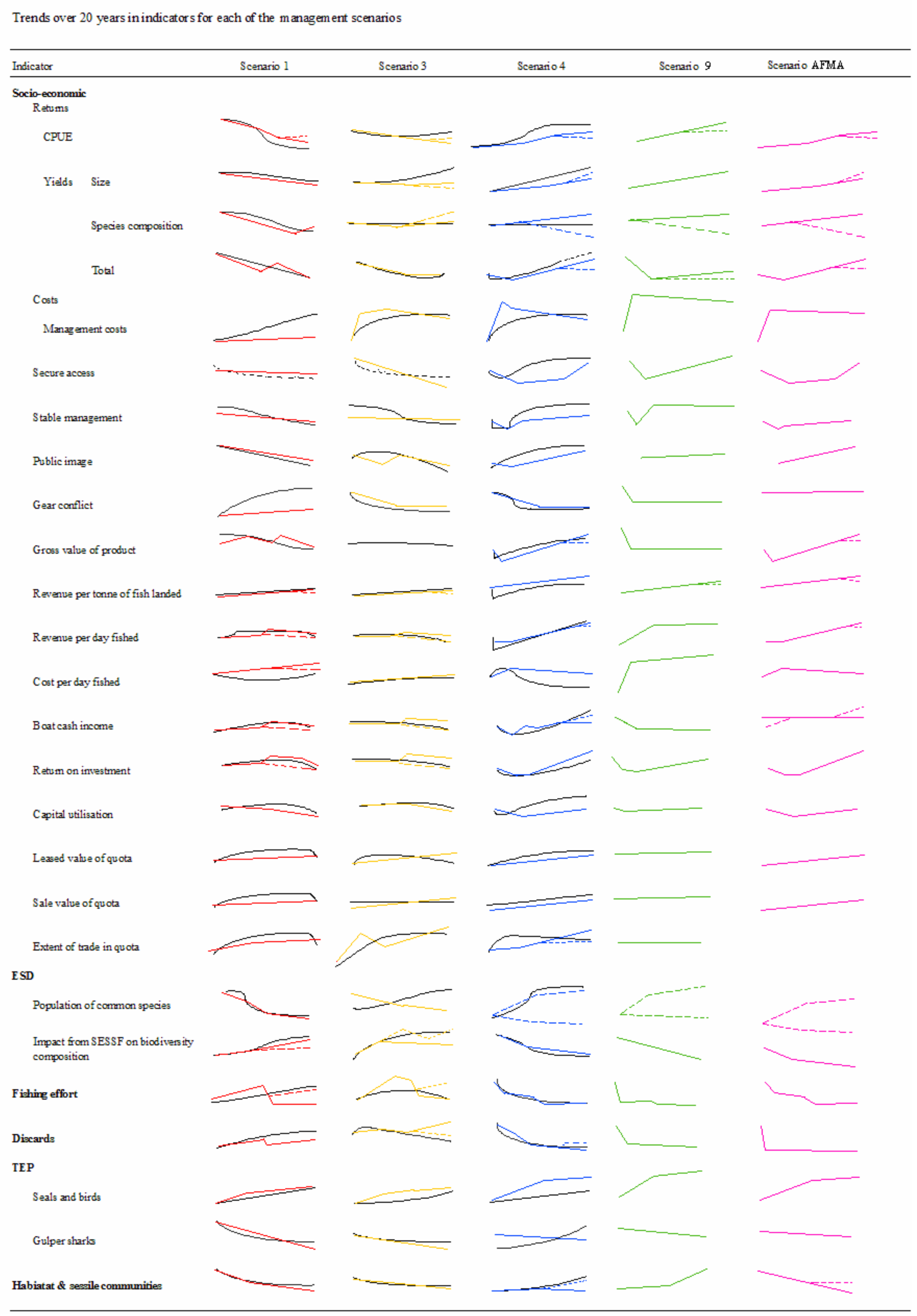


Figure 6-1: Comparison of quantitative and qualitative squiggle plots for each management strategy. Black lines represent qualitative results, and coloured lines are quantitative. Dash lines indicate the range of responses by different gear types or ecosystem components in the quantitative analysis. There are no qualitative trajectories available for Scenarios 9 and 10.

6.4 Comparison with the Real World

During the course of this study real world changes in the SESSF often overtook the model development. It is an interesting exercise then to see how well the model compared to how the world really played out in those years where it overlaps. The parameterisations that best fit the fisheries training data from the 1990s were used in the Scenarios without further training on data from 2000 onwards. Furthermore, the actual evolution of management and fleet dynamics from 2000 to the present were not used to force the simulations before the management strategies in each of the Scenarios were implemented. Instead management strategies in each Scenario began in 2000. The changes in management regulations that have actually occurred since 2000 have no doubt influenced the form of fleet dynamics, but as they were not included in any of the Scenarios run here there is substantial potential for the simulations and the real world to diverge. Nevertheless, to give further insight into the model's potential and the implications of the alternative management strategies it is worth comparing the Scenarios with the evolution of the actual fleet dynamics.

Catch and Effort

The effort of a majority (75%) of the dynamic fisheries (Figures 5.27 – 5.30) and the landed catches (Figures 5.4 – 5.17) of quite a number of the groups (roughly 85%) show a strong agreement between model predictions under Scenario 1 and reported catch and effort data in 2000 – 2004. Moreover, any trajectories that do diverge typically do so by less than a factor of two. As Scenario 1 approximates some of the management approach adopted over this time, such a good match suggests that the behaviour of the model trained on data from the 1990s holds into the projection period, all else being equal.

Fleet Sizes

Looking at fleet sizes, the most notable real world event was the 2006 buyback of effort by the federal government as part of the 2005 "Securing our Fishing Future" package. Even in those scenarios where buybacks were used in the model (primarily Scenario 9 and variants of Scenario 4) the real world buyback data were not used to structure the modelled buyback (as the real world information was not available until after the model runs were completed). Consequently it is an interesting exercise to compare the predicted vs real evolution of fleet size (based on data from Department of Agriculture, Fisheries, and Forestry (DAFF) and the Minister for Fisheries, Forestry and Conservation press release DAFF06/153A, 22nd December 2006). Given that no scenario matched exactly the unique blend of management activities that occurred in the fishery in reality between 2000 and 2007 it is safest to compare Scenarios 1, 4 and 10 with the real world fleet changes. As mentioned in chapter 4, there was actually very little difference amongst the long-term fleet sizes for these three Scenarios, the trajectories leading up to the endpoint differed between these scenarios, but the endpoint was largely the same in all cases (therefore only one average "model" result is listed in Table 6.4).

The real world figures are likely to include the retirement of latent effort as well as real reductions. Latent effort was also included in the Atlantis figures, but as it differed scenario-to-scenario it would be better to compare reduction in real effort in the models and reality. Unfortunately, information on reduction of real effort is not yet available so the comparison is currently restricted to the compound figure.

The model predictions were quite close to the realised levels of fleet reduction, for the majority of sectors. The two sectors where the model was substantially at odds with the real world were the gillnet and royal red prawn sectors (where the predicted reduction of effort in the model is more than twice that seen in reality). The royal red prawn sector may be less of a concern as it is a smaller component of the overall fishery. The gillnet result deserves more attention, as they are an extreme form of a general tendency of the model to be more pessimistic about long-term fleet sizes than has been seen to date in reality. This may reflect a shortfall in the model (which is likely given the issues already highlighted regarding the model resolution, which allows auto-longline effort on to the outer shelf, and representation of gillnet related factors, such as gear saturation), or it may indicate that more pain is to come in the real world fishery.

Given the investment in the long term state and prosperity of the fishery that a buyback represents, there should be considerable interest in the duration over which the benefits of any buyback persist. Analysis of the state of the system (ecological and socioeconomic) in the simulations containing buybacks in this study shows that there is a window of "maximum buyback potential". Within this window a buyback can lead to a better system state into the medium (and even long) term; though longer term benefits would be hard to measure from within the system and so benefits would probably be seen to dissipate relatively quickly (within a decade). This window of maximum potential is characterised by a system where a number of commercially valuable species have been depleted to around their limit reference points and there are declining profit levels that are pushing the fishers to increase fishing power and fish in more distant or marginal grounds.

If a buyback is mistimed and is implemented too early (before there is significant economic decline) or too late (when the system is in a very poor state both ecologically and economically), then any benefits really do dissipate quite rapidly (within 3-5 years, if that). This is because a buyback under those conditions has minimal impact on the future evolution of the system. In comparison, when viewed from outside the system, a well timed buyback can have benefits that last for 15 years or more (in terms of effort levels, catches, economic health and social perception). The cost of a buyback means that the value of these aspects of the system into the medium term should be weighed against the current system state and the upfront costs of the exercise. Buybacks can prove to be beneficial in some circumstances (where real effort is being taken from the fishery rather than simply stripping out latent effort), but they are by no means a cheap or universal solution (Grafton and Nelson 2005, Weninger and McConnell 2000).

Table 6-4: Real world and model predicted effort reductions (under standard form of the Scenarios)

Fishery sector[1]	Real World Effort Reduction (%)	Model Effort Reduction (%)
Gillnets	30	70
Shark hook	57	50
Scalefish hook	52	57
Longline + Trap	40	40
Deep water trawl	44	63
Royal red prawn	21	62
GAB Trawl	0	0-10
SET Trawl	50	65

1. The relevant model fishery components have been mapped to the real world sectors here to facilitate the comparison

TACs

The TACs predicted by the model under Scenario 1 were often quite different to the actual implemented values in the period 2000 to 2005. This may indicate that the representation of the lobbying and negotiating that characterised TAC setting over this period was too simplistic and not completely captured in the model. Nevertheless, for 60% of the quota groups the quotas set within the model do approach actual values in magnitude in at least a few of the scenarios. A higher proportion would match if the relative biomasses predicted on the one hand by Atlantis SE and on the other by the stock assessments conducted by the Resource Assessment Groups (RAGs) did not differ so much for groups like tiger flathead. For this species, Atlantis SE predicts that the relative biomass in 2000 is considerably higher than in the RAG assessments. The assessments and RBCs calculated by Atlantis try to move the stock to the target limit point by increasing landed catch levels whereas in reality the stock is already thought to be close to target levels and so the real TACs have been set accordingly. Even with this qualification in mind, the rough trajectory of predicted TACs parallels that seen in reality indicating that the gross form of the system state and assessment steps are being captured by the assessment and management decision modules in Atlantis SE. This means that a reasonable level of confidence can be invested in the comparison of the strategies even while it warns that models like Atlantis SE cannot be used directly as assessment models in the real world.

It is also worth considering what can be learnt from the divergence of single species assessments and the relative biomasses predicted by Atlantis SE. Under the current management arrangements TACs are dependent on the RBCs given by stock assessments. As the assessment method itself was not under direct consideration in this study a pseudo-assessment was used (which uses Atlantis biomasses observed with error as the data used to feed into the fishing mortality estimator and harvest control rule calculations). It was computationally prohibitive to use a full integrated assessment (e.g. CAB by Cope *et al* 2004) in these simulations, but trials showed little difference in the end results of the MSE simulations when the pseudo-assessment was replaced by an integrated assessment (it simply took ten times longer to run). This means that divergences between real world stock assessments and the Atlantis assessments ultimately derive from differences between assessed biomass (and potentially its drivers) in the real world and that which is predicted by Atlantis SE. For those species where there was an existing assessment that could be compared to the Atlantis biomass trajectories, there was typically a good match in overall pattern of biomass change through time, but for several shelf species there was a mismatch in the magnitude of the relative biomasses. Stock assessments can use recruitment deviations to support the productivity necessary given historical fishing pressure. This approach is not used in Atlantis, instead the state of the system (and the parameterisation leading to that state) must be sufficient to cope with or respond to historical fishing pressure without leading to the extirpation of the stock. Consequently the mismatch in biomasses between Atlantis SE and assessments is because parameterisations of Atlantis SE that lead to lower biomasses (matching the early years of the historical time series predicted by the single species assessments) do not survive the combined impacts of trophic interactions and historical fishing pressure. Those parameterisations that do survive the combined mortality load lead to higher relative biomasses. This mismatch does raise some interesting issues for both single species assessments and Atlantis SE. For the single species assessments it may indicate that attention needs to be given to the impacts of physical or environmental drivers, trophic interactions and recreational fishing pressure. This **does not** mean existing stock assessments are too precautionary or conservative in their biomass estimates, it simply highlights areas that need further consideration. For Atlantis SE it suggests that a single parameterisation may be insufficient for capturing either stock structure that is actually more finely resolved or the large scale system changes that occur over decades as a system is perturbed. Experience is leading to increasing acknowledgement within the ecological modelling field that misrepresentation of stock structure can have a significant impact on the relative robustness predicted for a species. Nevertheless static parameterisations are likely to have problems capturing the long-term facets of dynamic ecosystems even with full stock structure representations. There is new evidence to suggest that large scale change in demographic and other (e.g. productivity) parameters is a real and potentially widespread phenomenon even within species (Pelletier *et al* 2007, Weir and Schluter 2007) let alone across the species that make up functional groups. This facet of the impact of diversity on system structure and dynamics, and model performance, will be a challenge that needs careful thought into the future. Interestingly, the deeper water groups (blue grenadier, ling, orange roughy, gemfish and blue warehou) show a very good match between the Atlantis and assessment predicted biomasses – these are the very groups known to change slowly and to be more heavily impacted by exploitation than trophic interactions, the same groups that would be the most robust to single model parameterisations. This corroborates the need for careful consideration of how different systems and system components are handled in models of any form that purport to span long periods of time with changing levels of fishing or other pressures.

7. CONCLUSIONS

The management scenarios evaluated here each involve an integrated package of management measures. Scenario 4 represents the most balanced combination of management levers, while Scenario 10 is a pragmatic implementation of the basic Scenario 4 approach (costs and other political or regulatory considerations for instance do not allow for an exact implementation of Scenario 4 so AFMA has had to take a pragmatic approach to implementing its key features, which is what is captured in Scenario 10). The other scenarios tend to focus on one particular management lever above the others, often with limited success. Evaluation of the future consequences of each scenario against their achievement of a broad set of management and industry objectives shows that no single management scenario consistently returned the strongest performance across all the performance measures. However, the results do support the proposition that successful management for a fishery such as the SESSF requires a balanced combination of a variety of input, output and technical management levers. As the scenarios considered in the project only represent a limited set of the enormous number of possible combinations of ways the many management levers could be selected in managing the fishery, it should not be concluded that future management of the fishery should exactly match any of the scenarios considered here. Instead the results presented should be used to give insight into the likely outcomes of different combinations of management levers.

As with the qualitative analyses, the quantitative evaluation shows that complex tradeoffs exist when trying to satisfy the various ecological, economic and social objectives. This is clear from the failure of any one scenario to consistently outperform all others across all the performance measures. The trade-offs highlighted by the management strategies not only include the trade-off in short term costs and long term payoffs highlighted in the Stage 1 report, but also unanticipated outcomes of management decisions. For instance:

i) the potential for the fishery to effectively circumvent management strategies that are highly dependent on quotas (if quotas are the dominant management lever then it can be circumvented via using remaining non-quota groups to subsidise pursuit of target species);

ii) the many implications of banning the discarding of target groups on effort distribution, targeting, habitat interactions, trophic cascades (with some species declining while others increase in biomass) and population mortality rates;

iii) the ecological and economic implications of companion TACs;

iv) target shifting from deeper water groups to popular shelf species (like tiger flathead) as fisheries are squeezed by management constraints and rising costs.

Models such as Atlantis SE represent a considerable investment and it is unlikely that such models will be developed for a large number of fisheries. However lessons learnt from case studies such as the SESSF can be carried over to other fisheries and systems. Atlantis SE can help address a number of issues and questions in fishery management more generally, as well as improving understanding of how exploited ecological systems may respond. There is considerable scope for further work on the socioeconomic modules in Atlantis SE; the current implementations represent a fairly rudimentary representation of the processes and pressures. Moreover, there is a lot of scope for testing alternative representations of habitat mediation and other fine scale mechanisms as well as the effects of diversity and shifting community structure through time. This last point could be important, as suggested by conflicting biomass predictions for some species between conventional stock assessments vs Atlantis SE. Models may always be improved in their predictive capabilities; nevertheless Atlantis SE appears to provide a sound basis that can facilitate further consideration of the impacts of alternative management strategies, especially in the longer term. It also provides one of the only quantitative tools to explore topics such as the potential impacts of climate change on the fisheries and stocks in the region.

Finally, this project highlights the great potential that the management strategy evaluation approach presents in all its forms. The general agreement in results of the qualitative and quantitative forms shows the potential of qualitative methods for rapid assessment and the utility of quantitative MSE at the ecosystem level. A very important outcome of this two pronged approach is that it provides not only greater confidence in the overall conclusions, but at the same time helps to identify key processes and assumptions that deserve further detailed study. The analyses reported in this study and in the accompanying Stage 1 report represent one of the very few studies ever undertaken to explore alternative management strategies at a whole of fishery and whole of ecosystem level. The tools developed in this study provide managers, industry and other stakeholders with the first sound basis to evaluate integrated rather than piecemeal solutions to complex fishery management problems. Such evaluations should not be seen as a strict forecast or assessment of the fishery or exploited stocks, but they should be used to give strategic insights into the consequences and potential tradeoffs that are associated with a range of management strategies that could be used to manage the fishery or region. The results of such an evaluation do not provide optimised or prescriptive management advice. They do however provide key information for strategic planning and decision support.

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APPENDIX A: TROPHIC CONNECTION MATRIX

The potential trophic connections between groups are given in Tables A.1-A.4. These trophic connections are broken up based on maturity; represented as a juvenile-juvenile connection matrix, a juvenile-adult matrix, and adult-juvenile and adult-adult matrices. For instance if you consider the first column in each of the tables, then the entry on the third row is for mackerel as the predator: in Table A.1 juvenile mackerel are marked as being able to access 5% (a proportion of 0.05) of the juvenile small pelagic biomass at any one time; similarly in Table A.2 adult mackerel may access 5% of the juvenile small pelagics; while in Table A.3 juvenile mackerel cannot access adult small pelagics at all (cell has a value of 0); and neither can adult mackerel access adult small pelagics in Table A.4 (again there is a cell value of 0). This division of the trophic connections allows for more flexibility with changing behaviours and size through the life history of both predator and prey. For further discussion of the trophic connections used in Atlantis SE see the main text (chapter 2).

Table A-1: Juvenile prey - juvenile predator trophic interactions used in Atlantis SE (see text for derivation of estimates). Rows are predators, columns are prey groups.

Predator/Prey	Small pelagic	Red bait	Mackerel	Migratory mesopelag.	Non-mig. mesopel.	School whiting	Shallow piscivore	Blue warehou	Spotted warehou	Tuna & billfish	Gemfish	Shallow demersal	Flathead	Redfish	Morwong	Ling
Small pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Red bait	0	0	0	0.003	0.25	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0.05	0.09	0	0.001	0.25	0	0	0	0	0	0	0.01	0	0	0	0
Migratory mesopelag.	0.02	0	0.005	0.005	0.25	0	0	0	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0.02	0	0.005	0.009	0.25	0	0	0	0	0	0	0	0	0	0	0
School whiting	0.1	0	0.01	0	0	0.05	0.4	0.15	0.175	0	0	0.45	0.1	0	0	0
Shallow piscivores	0.025	0.2	0.005	0.0007	0.25	0.02	0.15	0.004	0.01	0	0	0.065	0.05	0	0.06	0
Blue warehou	0	0	0	0.01	0.25	0	0	0	0	0	0	0	0	0	0	0
Spotted warehou	0	0	0	0.002	0.25	0	0	0	0	0	0	0	0	0	0	0
Tuna and billfish	0.125	0.2	0.1	0.008	0.25	0.1	0.4	0.02	0.06	0.1	0	0.09	0	0	0.1	0
Gemfish	0.3	0	0	0.01	0.25	0	0	0	0	0	0.3	0	0	0	0.3	0
Shallow demersal fish	0.02	0.55	0.004	0.00005	0.25	0.01	0	0.0035	0.01	0	0	0.05	0.1	0.0005	0.015	0
Flathead	0.05	0	0.2	0.01	0.25	0.2	0.3	0.015	0.35	0	0	0.4	0.05	0	0.2	0.005
Redfish	0	0.2	0	0.06	0.25	0	0	0	0	0	0.2	0.12	0	0.005	0	0.008
Morwong	0.05	0	0.005	0.001	0.25	0	0	0.03	0.06	0	0	0.08	0	0	0	0
Ling	0	0	0	0.011	0.25	0	0	0	0	0	0.2	0.275	0	0	0	0
Blue grenadier	0	0	0	0.005	0.25	0	0	0	0	0	0.15	0	0	0	0	0
Blue-eye trevalla	0	0	0	0.005	0.25	0	0	0	0	0	0	0	0	0	0	0
Ribaldo	0	0	0	0.1	0.25	0	0	0	0	0	0	0	0	0	0	0
Orange roughy	0	0	0	0.03	0.1	0	0	0	0	0	0.15	0	0	0	0	0.001
Dories and oreos	0	0.15	0.01	0.0075	0.25	0.1	0	0	0	0	0.15	0.065	0	0.0015	0	0
Cardinalfish	0.05	0	0	0.005	0.25	0	0	0	0	0	0.1	0	0	0	0.07	0
Gummy shark	0	0	0	0	0	0	0.52	0	0	0	0.25	0.35	0	0	0	0
School shark	0	0	0	0	0	0	0.45	0	0	0	0.2	0	0	0	0	0
Demersal sharks	0.03	0.09	0.01	0.001	0.25	0.02	0	0	0	0	0	0.055	0	0.003	0.06	0.0015
Pelagic sharks	0.075	0	0.05	0.01	0	0.3	0.52	0.02	0.08	0.3	0.3	0.3	0.3	0.05	0.35	0

Predator/Prey	Small pelagic	Red bait	Mackerel	Migratory mesopelag.	Non-mig. mesopel.	School whiting	Shallow piscivore	Blue warehou	Spotted warehou	Tuna & billfish	Gemfish	Shallow demersal	Flathead	Redfish	Morwong	Ling
Dogfish	0	0.09	0	0.03	0.25	0.3	0	0	0	0	0.3	0.3	0	0.05	0	0.01
Gulper sharks	0	0	0	0.7	0.7	0.2	0	0	0	0	0	0	0	0	0	0.01
Skates and rays	0	0	0	0.001	0.25	0.07	0	0	0	0	0	0.05	0.1	0	0	0.002
Seabirds	0.75	0.2	0.3	0	0	0.3	0.5	0.2	0.45	0.1	0	0.55	0.25	0	0.6	0
Seals	0.65	0.5	0.3	0.15	0	0.2	0.6	0.125	0.45	0.2	0.5	0.55	0.4	0.05	0.35	0.1
Sea lion	0.5	0.5	0.3	0.15	0	0.25	0.4	0.2	0.5	0.08	0.5	0.6	0.5	0.07	0.55	0.15
Dolphins	0.35	0.5	0.3	0.04	0.25	0.2	0.7	0.15	0.28	0.3	0.4	0.55	0.4	0	0.35	0.11
Orcas	0.35	0.4	0.3	0.04	0.25	0.2	0.4	0.1	0.07	0.05	0.25	0.45	0.3	0	0.35	0.1
Baleen whales	0.05	0	0.006	0	0	0	0	0	0	0	0	0	0	0	0.1	0
Small zooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesozooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large zooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gelat. zooplankton	0.00003	0.000015	0.0000025	0.0000055	0.00008	0.00001	0.00001	0.000015	0.00002	0	0.00001	0.0001	0.00001	0	0.00001	1.75e-6
Squid	0.001	0.00015	0.0001	0.00006	0.003	0.00001	0.0004	0.00065	0.00015	0.0001	0.0007	0.0005	0.00005	0	0.00075	0.00075
Carnivorous infauna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deposit feeders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deep filter feeders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shallow filter feeders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scallops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Herbivorous grazers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deep megazoobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shallow megazooben.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rock lobster	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawns	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0
Giant crab	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Predator/Prey	Blue grenad.	Blue-eye trevalla	Ribaldo	Orange roughy	Dories & oreos	Cardinal -fish	Gummy shark	School shark	Demersal shark	Pelagic shark	Dogfish	Gulper shark	Skates & rays	Seabird	Seals	Sea lion
Small pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Red bait	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0.11	0	0	0	0	0	0	0	0	0	0	0
Migratory mesopelag.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
School whiting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shallow piscivores	0	0	0	0	0	0	0.01	0.8	0.05	0	0.7	0	0.0007	0	0	0
Blue warehou	0	0	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0
Spotted warehou	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0
Tuna and billfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gemfish	0	0	0	0.001	0.003	0.025	0	0	0	0	0	0	0	0	0	0
Shallow demersal fish	0	0	0	0	0.005	0	0.008	0.7	0.01	0	0.7	0	0.00025	0	0	0
Flathead	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0
Redfish	0.1	0.1	0.3	0.002	0.2	0	0	0	0	0	0	0	0	0	0	0
Morwong	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0
Ling	0.1	0	0.85	0	0.01	0.035	0	0	0	0	0	0	0	0	0	0
Blue grenadier	0.08	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0
Blue-eye trevalla	0.4	0	0.9	0.015	0.2	0	0	0	0	0	0	0	0	0	0	0
Ribaldo	0	0	0	0.075	0.145	0	0	0	0	0	0	0	0	0	0	0
Orange roughy	0	0	0	0.001	0.01	0.02	0	0	0	0	0	0	0	0	0	0
Dories and oreos	0.04	0	0	0.002	0.022	0.01	0	0	0	0	0	0	0	0	0	0
Cardinalfish	0.04	0	0	0.001	0.2	0.005	0	0	0	0	0	0	0	0	0	0
Gummy shark	0	0	0	0	0.25	0.1	0	0	0	0	0	0	0	0	0	0
School shark	0	0	0	0	0	0.015	0	0	0	0	0	0	0	0	0	0
Demersal sharks	0.04	0.1	0.9	0.001	0.045	0.01	0.01	0.7	0.03	0	0.7	0.02	0.001	0	0	0
Pelagic sharks	0.1	0	0.8	0	0.11	0.02	0.025	0.7	0.3	0.003	0.8	0.02	0.02	0.1	0.03	0.05
Dogfish	0	0.1	0.9	0.015	0.4	0.05	0.045	0.9	0.15	0	0.8	0	0.015	0	0	0

Predator/Prey	Blue grenad.	Blue-eye trevalla	Ribaldo	Orange roughy	Dories & oreos	Cardinal -fish	Gummy shark	School shark	Demersal shark	Pelagic shark	Dogfish	Gulper shark	Skates & rays	Seabird	Seals	Sea lion
Gulper sharks	0	0	0	0.4	0.31	0.1	0	0	0	0	0	0	0	0	0	0
Skates and rays	0	0	0	0.001	0.02	0.015	0.008	0.6	0.09	0	0.8	0	0.002	0	0	0
Seabirds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seals	0.7	0	0.8	0	0.2	0.25	0	0	0	0	0	0	0	0	0	0
Sea lion	0.6	0	0.6	0	0.2	0.2	0	0	0	0	0	0	0	0	0	0
Dolphins	0.7	0	0	0	0	0.2	0	0	0	0	0	0	0	0.2	0	0.005
Orcas	0.4	0.3	0.7	0	0	0.2	0.1	0.7	0.35	0.003	0.8	0	0.005	0.2	0.04	0.035
Baleen whales	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small zooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesozooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large zooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gelat. zooplankton	0.0001	0.0002	0.0004	0	0	0.00001	0	0	0	0	0	0	0	0	0	0
Squid	0.0005	0.0015	0.0002	0	0.0015	0.0005	0	0	0	0	0	0	0	0	0	0
Carnivorous infauna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deposit feeders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deep filter feeders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shallow filter feeders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scallops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Herbivorous grazers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deep megazoobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shallow megazooben.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rock lobster	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prawns	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Giant crab	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Predator/Prey	Dolphin	Orca	Baleen whale	Large phytopl.	Small phytopl.	Small zoopl.	Meso zoopl.	Large zoopl.	Gelat. zoopl.	Squid	Infauna	Deposit feeder	Deep filt feed	Shallow filt feed	Scallop	Herbiv. grazer
Small pelagics	0	0	0	0.00000001	0	0	0.08	0.1	0	0.005	0	0	0	0	0	0
Red bait	0	0	0	0	0	0	0.35	0.5	0.15	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0	0	0.35	0.5	0.15	0.01	0.05	0.08	0	0	0	0
Migratory mesopelag.	0	0	0	0	0	0	0.05	0.05	0	0.07	0.005	0.003	0.01	0.005	0.001	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0.05	0.1	0.07	0	0	0	0	0	0
School whiting	0	0	0	0	0	0	0.1	0.1	0.1	0.05	0.1	0.0075	0.01	0.01	0.01	0.003
Shallow piscivores	0	0	0	0	0	0	0.2	0.15	0.1	0.1	0.01	0.0075	0	0.0001	0.0001	0.0003
Blue warehou	0	0	0	0.1	0	0	0.35	0.5	0.15	0.1	0.1	0.06	0	0	0	0
Spotted warehou	0	0	0	0	0	0	0.375	0.25	0.15	0.08	0.01	0.1	0	0	0	0
Tuna and billfish	0	0	0	0	0	0	0.1	0.1	0.1	0.2	0	0	0	0	0	0
Gemfish	0	0	0	0	0	0	0.1	0.2	0	0	0	0	0	0	0	0
Shallow demersal fish	0	0	0	0	0	0	0.01	0.01	0.01	0.1	0.2	0.003	0.1	0.1	0.0005	0.0001
Flathead	0	0	0	0	0	0	0.05	0.05	0.05	0.1	0.2	0.015	0.08	0.08	0.01	0.001
Redfish	0	0	0	0	0	0	0.1	0.1	0.1	0.08	0.01	0.015	0	0	0	0
Morwong	0	0	0	0	0	0	0.01	0.01	0.01	0.1	0.2	0.08	0.5	0	0.05	0.01
Ling	0	0	0	0	0	0	0.15	0.15	0	0	0	0	0	0	0	0
Blue grenadier	0	0	0	0	0	0	0.15	0.15	0.1	0.1	0	0	0	0	0	0
Blue-eye trevalla	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.2	0.015	0.1	0	0	0
Ribaldo	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.2	0.015	0.7	0	0	0
Orange roughy	0	0	0	0	0	0	0	0	0.2	0.1	0	0	0.1	0	0	0
Dories and oreos	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.2	0.009	0.3	0.1	0	0
Cardinalfish	0	0	0	0	0	0	0.1	0.2	0.01	0.2	0.03	0.0054	0.01	0	0.001	0.0003
Gummy shark	0	0	0	0	0	0	0	0	0	0.1	0.1	0.075	0	0.1	0.035	0.008
School shark	0	0	0	0	0	0	0	0	0	0.01	0.1	0.075	0.1	0.1	0.035	0
Demersal sharks	0	0	0	0	0	0	0	0	0	0.2	0.2	0.005	0.7	0.7	0.004	0.0003
Pelagic sharks	0.05	0.05	0.05	0	0	0	0	0.1	0	0.2	0	0	0	0	0	0
Dogfish	0	0	0	0	0	0	0	0	0	0.2	0.2	0.03	0.3	0.3	0.01	0.008
Gulper sharks	0	0	0	0	0	0	0	0	0	0.25	0	0.08	0.6	0	0	0

Predator/Prey	Dolphin	Orca	Baleen whale	Large phytopl.	Small phytopl.	Small zoopl.	Meso zoopl.	Large zoopl.	Gelat. zoopl.	Squid	Infauna	Deposit feeder	Deep filt feed	Shallow filt feed	Scallop	Herbiv. grazer
Skates and rays	0	0	0	0	0	0	0.15	0.15	0	0.2	0.2	0.008	0.7	0.7	0.008	0.0008
Seabirds	0	0	0	0	0	0	0.15	0.1	0.05	0.2	0.05	0	0	0.05	0.05	0
Seals	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0.07	0.008
Sea lion	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0.2	0.1
Dolphins	0	0.00001	0	0	0	0	0	0.1	0.01	0.2	0	0.05	0	0.1	0.1	0.02
Orcas	0.035	0.00005	0.00001	0	0	0	0	0	0	0.2	0	0	0	0	0	0
Baleen whales	0	0	0	0	0	0	0.55	0.55	0	0	0	0	0	0	0	0
Small zooplankton	0	0	0	0.0007	0.0035	0.001	0	0	0	0	0	0	0	0	0	0
Mesozooplankton	0	0	0	0.15	0.00015	0.02	0.05	0.0005	0	0	0	0	0	0	0	0
Large zooplankton	0	0	0	0.07	0	0.0005	0.4	0.1	0	0	0	0	0	0	0	0
Gelat. zooplankton	0	0	0	0	0	0.001	0.05	0.04	0	0	0	0	0	0	0	0
Squid	0	0	0	0	0	0	0.01	0.02	0	0.01	0	0	0	0	0	0
Carnivorous infauna	0	0	0	0.0075	0	0.001	0	0	0	0	0	0	0	0	0	0
Deposit feeders	0	0	0	0	0	0.001	0.001	0	0	0	0	0	0	0	0	0
Deep filter feeders	0	0	0	0.0005	0.000025	0.001	0	0	0	0	0	0	0	0	0	0
Shallow filter feeders	0	0	0	0.0005	0.00025	0.001	0	0	0	0	0	0	0	0	0	0
Scallops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Herbivorous grazers	0	0	0	0	0	0	0	0	0	0	0.01	0.1	0.25	0	0	0.00008
Deep megazoobenthos	0	0	0	0	0	0	0.01	0.03	0	0	0.01	0.108	0	0	0.0005	0.00008
Shallow megazooben.	0	0	0	0	0	0	0.01	0	0	0	0.01	0.1	0	0	0.0003	0.00008
Rock lobster	0	0	0	0.025	0.0001	0	0	0	0	0	0	0	0	0	0	0
Prawns	0	0	0	0	0	0	0	0	0	0	0.01	0.08	0.01	0.25	0.0001	0
Giant crab	0	0	0	0	0	0	0.05	0.1	0	0	0.05	0.05	0.01	0.25	0.0001	0

Predator/Prey	Deep megaben.	Shallow megaben.	Rock lobster	Meioben.	Macro-algae	Seagrass	Prawns	Giant crab	Carrion	Labile detritus	Refractory detritus
Small pelagics	0	0	0	0	0	0	0	0.001	0	0	0
Red bait	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0	0.0001	0.0001	0	0	0	0	0.001	0	0	0
Migratory mesopelag.	0.01	0.001	0.005	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0	0	0	0
School whiting	0.01	0.005	0.001	0.1	0	0	0.001	0.001	0	0.1	0
Shallow piscivores	0.01	0.003	0.01	0	0	0	0	0	0	0	0
Blue warehou	0	0	0	0	0	0	0.001	0.001	0	0	0
Spotted warehou	0.005	0.005	0.005	0	0	0	0.005	0.001	0	0	0
Tuna and billfish	0.01	0.005	0	0	0	0	0.001	0.001	0	0	0
Gemfish	0.01	0.005	0	0	0	0	0.001	0.001	0	0	0
Shallow demersal fish	0.1	0.0009	0.003	0	0.00006	0.00005	0.0001	0.0001	0.8	0.000001	0
Flathead	0	0.004	0.05	0	0	0	0.02	0.01	0	0.001	0
Redfish	0.02	0.01	0.02	0	0	0	0.01	0.01	0.8	0.001	0
Morwong	0	0.05	0.01	0	0.0007	0.0005	0.001	0.001	0.8	0.000001	0
Ling	0.9	0.008	0	0	0	0	0.02	0.01	0.8	0.001	0
Blue grenadier	0	0.01	0.1	0	0	0	0.001	0.001	0	0	0
Blue-eye trevalla	0.1	0	0	0	0	0	0.01	0.01	0.8	0.001	0
Ribaldo	0.5	0	0	0	0	0	0	0	0.8	0.001	0
Orange roughy	0.1	0	0	0	0	0	0	0	0	0.01	0
Dories and oreos	0.5	0.005	0.03	0	0	0	0.002	0.002	0.8	0.001	0
Cardinalfish	0.008	0.003	0.001	0	0	0	0	0	0	0	0
Gummy shark	0	0.01	0.1	0	0	0	0	0	0	0	0
School shark	0.1	0.01	0.1	0	0	0	0.001	0.001	0	0.1	0
Demersal sharks	0.45	0.004	0.01	0	0.00005	0.00008	0.002	0.002	0.8	0	0
Pelagic sharks	0	0.004	0.01	0	0	0	0	0	0.8	0	0
Dogfish	0.3	0.05	0	0	0	0	0	0	0.8	0	0

Predator/Prey	Deep megaben.	Shallow megaben.	Rock lobster	Meioben.	Macro-algae	Seagrass	Prawns	Giant crab	Carrion	Labile detritus	Refractory detritus
Gulper sharks	0.6	0	0	0	0	0	0	0	0	0	0
Skates and rays	0.45	0.005	0.02	0	0	0	0.001	0.001	0.8	0	0
Seabirds	0	0.1	0.01	0.05	0	0	0.01	0.01	0.5	0	0
Seals	0	0.08	0	0	0	0	0	0	0.5	0	0
Sea lion	0	0.3	0	0	0	0	0	0	0.5	0	0
Dolphins	0	0.1	0	0	0	0	0.03	0.03	0.5	0	0
Orcas	0	0	0	0	0	0	0	0	0.5	0	0
Baleen whales	0	0	0	0	0	0	0.01	0.01	0	0	0
Small zooplankton	0	0	0	0	0	0	0	0	0	0	0
Mesozooplankton	0	0	0	0	0	0	0	0	0	0.07	0.05
Large zooplankton	0	0	0	0	0	0	0	0	0	0	0
Squid	0	0	0	0	0	0	0	0	0	0.01	0.01
Carnivorous infauna	0	0	0	0.0001	0	0	0	0	0.001	0	0
Deposit feeders	0	0	0	0.0001	0	0	0	0	0	0.1	0.05
Deep filter feeders	0	0	0	0	0	0	0	0	0	0.2	0
Shallow filter feeders	0	0	0	0	0	0	0	0	0	0.2	0
Scallops	0	0	0	0	0	0	0	0	0	0.2	0
Herbivorous grazers	0	0	0	0	0.000035	0.000035	0	0	0	0.000001	0
Deep megazoobenthos	0.01	0	0	0	0	0	0	0	0.9	0	0
Shallow megazooben.	0	0.0005	0	0	0	0	0	0	0.9	0	0
Rock lobster	0	0.00015	0	0	0	0	0	0	0.9	0.00001	0
Prawns	0	0	0	0.000001	0	0	0	0	0.001	0.025	0.01
Giant crab	0	0.0005	0	0.0001	0.00007	0.000005	0.005	0.005	0.9	0	0

Table A-2: Juvenile prey - adult predator trophic interactions used in the southeast Atlantis model (invertebrate predators other than squid are omitted, as they have no size-age structure and the values given in Table 2.3 always apply).

Predator/Prey	Small pelagic	Red bait	Mackerel	Migratory mesopelag.	Non-mig. mesopel.	School whiting	Shallow piscivore	Blue warehou	Spotted warehou	Tuna & billfish	Gemfish	Shallow demersal	Flathead	Redfish	Morwong	Ling
Small pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Red bait	0	0	0	0.003	0.25	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0.05	0.09	0	0.001	0.25	0	0	0	0	0	0	0.075	0	0	0	0
Migratory mesopelag.	0.02	0	0.005	0.001	0.25	0	0	0	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0.02	0	0.005	0.001	0.25	0	0	0	0	0	0	0	0	0	0	0
School whiting	0.1	0	0.01	0	0	0.05	0.4	0.15	0.25	0	0	0.45	0.1	0	0	0
Shallow piscivores	0.025	0.2	0.005	0.0007	0.25	0.02	0.15	0.004	0.01	0	0	0.065	0.05	0	0.06	0
Blue warehou	0	0	0	0.01	0.25	0	0	0	0	0	0	0	0	0	0	0
Spotted warehou	0	0	0	0.002	0.25	0	0	0	0	0	0	0	0	0	0	0
Tuna and billfish	0.125	0.2	0.1	0.008	0.25	0.1	0.425	0.02	0.06	0.1	0	0.12	0	0	0.1	0
Gemfish	0.3	0	0	0.1	0.25	0	0	0	0	0	0.3	0	0	0	0.3	0
Shallow demersal fish	0.02	0.25	0.004	0.00005	0.25	0.01	0	0.0035	0.01	0	0	0.05	0.1	0.0005	0.015	0
Flathead	0.05	0	0.1	0.01	0.25	0.2	0.35	0.01	0.3	0	0	0.45	0.025	0	0.2	0.005
Redfish	0	0.2	0	0.06	0.25	0	0	0	0	0	0.2	0.12	0	0.005	0	0.008
Morwong	0.05	0	0.05	0.001	0.25	0	0	0.03	0.06	0	0	0.11	0	0	0	0
Ling	0	0	0	0.03	0.25	0	0	0	0	0	0.2	0.275	0	0	0	0
Blue grenadier	0	0	0	0.005	0.25	0	0	0	0	0	0.15	0	0	0	0	0
Blue-eye trevalla	0	0	0	0.005	0.25	0	0	0	0	0	0	0	0	0	0	0
Ribaldo	0	0	0	0.1	0.25	0	0	0	0	0	0	0	0	0	0	0
Orange roughy	0	0	0	0.002	0.08	0	0	0	0	0	0.15	0	0	0	0	0.005
Dories and oreos	0	0.15	0.01	0.0075	0.25	0.1	0	0	0	0	0.15	0.065	0	0.0015	0	0
Cardinalfish	0.05	0	0	0.005	0.25	0	0	0	0	0	0.1	0	0	0	0.075	0
Gummy shark	0	0	0	0	0	0	0.52	0	0	0	0.25	0.35	0	0	0	0
School shark	0	0	0	0	0	0	0.45	0	0	0	0.2	0.125	0	0	0	0
Demersal sharks	0.03	0.09	0.01	0.001	0.25	0.02	0	0	0	0	0	0.055	0	0.003	0.06	0.002

Predator/Prey	Small pelagic	Red bait	Mackerel	Migratory mesopelag.	Non-mig. mesopel.	School whiting	Shallow piscivore	Blue warehou	Spotted warehou	Tuna & billfish	Gemfish	Shallow demersal	Flathead	Redfish	Morwong	Ling
Pelagic sharks	0.075	0	0.05	0.01	0	0.3	0.52	0.02	0.1	0.1	0.3	0.3	0.1	0.05	0.35	0
Dogfish	0	0.09	0	0.03	0.25	0.3	0	0	0	0	0.3	0.3	0	0.05	0	0.03
Gulper sharks	0	0	0	0.7	0.7	0.2	0	0	0	0	0	0	0	0	0	0.03
Skates and rays	0	0	0	0.001	0.25	0.07	0	0	0	0	0	0.07	0.05	0	0	0.005
Seabirds	0.75	0.2	0.3	0	0	0.3	0.5	0.2	0.45	0.1	0	0.55	0.25	0	0.6	0
Seals	0.65	0.5	0.3	0.15	0	0.2	0.6	0.125	0.45	0.2	0.5	0.55	0.15	0.05	0.35	0.1
Sea lion	0.5	0.5	0.3	0.15	0	0.25	0.4	0.2	0.5	0.08	0.4	0.6	0.5	0.08	0.55	0.4
Dolphins	0.35	0.5	0.3	0.04	0.25	0.2	0.35	0.15	0.28	0.3	0.4	0.55	0.15	0	0.35	0.11
Orcas	0.35	0.4	0.3	0.04	0.25	0.2	0.35	0.1	0.07	0.05	0.25	0.45	0.105	0	0.35	0.125
Baleen whales	0.05	0	0.006	0	0	0	0	0	0	0	0	0	0	0	0.1	0
Squid	0.0015	0.005	0.00015	0.00015	0.0025	0.00015	0.001	0.0009	0.0008	0.001	0.002	0.0005	0.00008	0	0.0007	0.00125

Predator/Prey	Blue grenad.	Blue-eye trevalla	Ribaldo	Orange roughy	Dories & oreos	Cardinal-fish	Gummy shark	School shark	Demersal shark	Pelagic shark	Dogfish	Gulper shark	Skates & rays	Seabird	Seals	Sea lion
Small pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Red bait	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0
Migratory mesopelag.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
School whiting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shallow piscivores	0	0	0	0	0	0	0.01	0.8	0.05	0	0.7	0	0.0007	0	0	0
Blue warehou	0	0	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0
Spotted warehou	0	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0
Tuna and billfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gemfish	0	0	0	0.001	0.1	0.025	0	0	0	0	0	0	0	0	0	0
Shallow demersal fish	0	0	0	0	0.005	0	0.008	0.8	0.05	0	0.7	0	0.00025	0	0	0
Flathead	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0

Predator/Prey	Blue grenad.	Blue-eye trevalla	Ribaldo	Orange roughy	Dories & oreos	Cardinal-fish	Gummy shark	School shark	Demersal shark	Pelagic shark	Dogfish	Gulper shark	Skates & rays	Seabird	Seals	Sea lion
Redfish	0.1	0.1	0.3	0.002	0.2	0	0	0	0	0	0	0	0	0	0	0
Morwong	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0	0	0
Ling	0.1	0	0.85	0	0.01	0.035	0	0	0	0	0	0	0	0	0	0
Blue grenadier	0.08	0	0	0	0.06	0	0	0	0	0	0	0	0	0	0	0
Blue-eye trevalla	0.08	0	0.9	0.015	0.2	0	0	0	0	0	0	0	0	0	0	0
Ribaldo	0	0	0	0.075	0.145	0	0	0	0	0	0	0	0	0	0	0
Orange roughy	0	0	0	0.001	0.007	0.02	0	0	0	0	0	0	0	0	0	0
Dories and oreos	0.04	0	0	0.002	0.022	0.01	0	0	0	0	0	0	0	0	0	0
Cardinalfish	0.04	0	0	0.001	0.0375	0.005	0	0	0	0	0	0	0	0	0	0
Gummy shark	0	0	0	0	0.4	0.1	0	0	0	0	0	0	0	0	0	0
School shark	0	0	0	0	0.05	0.015	0	0	0	0	0	0	0	0	0	0
Demersal sharks	0.04	0.1	0.9	0.001	0.025	0.01	0.01	0.6	0.05	0	0.7	0.02	0.001	0	0	0
Pelagic sharks	0.1	0	0.8	0	0.11	0.02	0.025	0.5	0.3	0.0008	0.8	0.02	0.02	0.2	0.04	0.045
Dogfish	0	0.1	0.9	0.015	0.4	0.05	0.02	0.8	0.3	0	0.8	0	0.015	0	0	0
Gulper sharks	0	0	0	0.4	0.31	0.1	0	0	0	0	0	0	0	0	0	0
Skates and rays	0	0	0	0.001	0.07	0.015	0.02	0.6	0.15	0	0.8	0	0.001	0	0	0
Seabirds	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0
Seals	0.7	0	0.8	0	0.2	0.25	0	0	0	0	0	0	0	0	0	0
Sea lion	0.6	0	0.6	0	0.2	0.2	0	0	0	0	0	0	0	0	0	0
Dolphins	0.7	0	0	0	0	0.2	0	0	0	0	0	0	0	0.2	0	0.005
Orcas	0.4	0.3	0.7	0	0	0.2	0.1	0.7	0.35	0.003	0.8	0	0.005	0.2	0.04	0.035
Baleen whales	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Squid	0.0005	0.005	0.0008	0	0.007	0.0008	0	0	0	0	0	0	0	0	0	0

Predator/Prey	Dolphin	Orca	Baleen whale	Large phytopl.	Small phytopl.	Small zoopl.	Meso zoopl.	Large zoopl.	Gelat. zoopl.	Squid	Infauna	Deposit feeder	Deep filt feed	Shallow filt feed	Scallop	Herbiv. grazer
Small pelagics	0	0	0	0.00000005	0	0	0.7	0.7	0	0.01	0	0	0	0	0	0
Red bait	0	0	0	0	0	0	0.35	0.5	0.15	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0	0	0.35	0.5	0.15	0	0	0.08	0	0	0	0
Migratory mesopelag.	0	0	0	0	0	0	0.05	0.05	0	0.07	0.005	0.003	0.005	0.005	0.005	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0.05	0.1	0.07	0	0	0	0	0	0
School whiting	0	0	0	0	0	0	0.01	0.01	0.01	0.05	0.01	0.0075	0.01	0.01	0.01	0.003
Shallow piscivores	0	0	0	0	0	0	0.0001	0.0001	0.0001	0.1	0.001	0.0075	0	0.0001	0.0001	0.0003
Blue warehou	0	0	0	0.1	0	0	0.35	0.5	0.15	0.1	0.1	0.008	0	0	0	0
Spotted warehou	0	0	0	0	0	0	0.375	0.25	0.15	0.08	0.01	0.1	0	0	0	0
Tuna and billfish	0	0	0	0	0	0	0.005	0.005	0.001	0.2	0	0	0	0	0	0
Gemfish	0	0	0	0	0	0	0.001	0.005	0	0	0	0	0	0	0	0
Shallow demersal fish	0	0	0	0	0	0	0.001	0.001	0.001	0.1	0.2	0.003	0.1	0.1	0.0005	0.0001
Flathead	0	0	0	0	0	0	0.001	0.001	0.001	0.1	0.2	0.015	0.08	0.08	0.01	0.001
Redfish	0	0	0	0	0	0	0.1	0.1	0.1	0.08	0.01	0.015	0	0	0	0
Morwong	0	0	0	0	0	0	0.001	0.001	0.001	0.1	0.2	0.08	0.5	0	0.05	0.01
Ling	0	0	0	0	0	0	0.15	0.15	0	0	0	0	0	0	0	0
Blue grenadier	0	0	0	0	0	0	0.15	0.15	0.1	0.08	0	0	0	0	0	0
Blue-eye trevalla	0	0	0	0	0	0	0.001	0.001	0.001	0.1	0.2	0.015	0.1	0	0	0
Ribaldo	0	0	0	0	0	0	0.001	0.001	0.001	0.1	0.2	0.015	0.7	0	0	0
Orange roughy	0	0	0	0	0	0	0	0	0.2	0.1	0	0	0.1	0	0	0
Dories and oreos	0	0	0	0	0	0	0.001	0.001	0.001	0.1	0.2	0.009	0.3	0.01	0	0
Cardinalfish	0	0	0	0	0	0	0.001	0.005	0.002	0.2	0.001	0.0054	0.001	0	0.001	0.0003
Gummy shark	0	0	0	0	0	0	0	0	0	0.1	0.005	0.075	0	0.005	0.005	0.008
School shark	0	0	0	0	0	0	0	0	0	0.1	0.1	0.075	0	0.05	0.05	0
Demersal sharks	0	0	0	0	0	0	0	0	0	0.2	0.2	0.005	0.7	0.7	0.004	0.0003
Pelagic sharks	0.05	0.05	0.05	0	0	0	0	0.1	0	0.2	0	0	0	0	0	0.003
Dogfish	0	0	0	0	0	0	0	0	0	0.2	0.2	0.03	0.3	0.3	0.01	0.008

Predator/Prey	Dolphin	Orca	Baleen whale	Large phytopl.	Small phytopl.	Small zoopl.	Meso zoopl.	Large zoopl.	Gelat. zoopl.	Squid	Infauna	Deposit feeder	Deep filt feed	Shallow filt feed	Scallop	Herbiv. grazer
Gulper sharks	0	0	0	0	0	0	0	0	0	0.25	0	0.08	0.6	0	0	0
Skates and rays	0	0	0	0	0	0	0.15	0.15	0	0.2	0.2	0.008	0.7	0.7	0.001	0.0008
Seabirds	0	0	0	0	0	0	0.15	0.1	0.05	0.2	0	0	0	0	0	0
Seals	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0.07	0.008
Sea lion	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0.2	0.1
Dolphins	0	0.00001	0	0	0	0	0	0.1	0.01	0.2	0	0.05	0	0.1	0.1	0.02
Orcas	0.035	0.00005	0.0005	0	0	0	0	0	0	0.2	0	0	0	0	0	0
Baleen whales	0	0	0	0	0	0	0.55	0.55	0	0	0	0	0	0	0	0
Squid	0	0	0	0	0	0	0.008	0.015	0	0	0	0	0	0	0	0

Predator/Prey	Deep megaben.	Shallow megaben.	Rock lobster	Meioben.	Macro-algae	Seagrass	Prawns	Giant crab	Carrion	Labile detritus	Refractory detritus
Small pelagics	0	0	0	0	0	0	0	0.001	0	0	0
Red bait	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0	0	0	0.001	0	0	0
Migratory mesopelag.	0.005	0.0005	0.005	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0	0	0	0
School whiting	0.01	0.001	0.001	0.05	0	0	0.001	0.001	0	0.01	0
Shallow piscivores	0.001	0.0008	0.001	0	0	0	0	0	0	0	0
Blue warehou	0	0	0	0	0	0	0.001	0.001	0	0	0
Spotted warehou	0.001	0.005	0.001	0	0	0	0.005	0.001	0	0	0
Tuna and billfish	0.01	0.005	0	0	0	0	0.001	0.001	0	0	0
Gemfish	0.01	0.01	0	0	0	0	0.001	0.001	0	0	0
Shallow demersal fish	0.1	0.0001	0.002	0	0.00006	0.00005	0.0001	0.0001	0.8	0.000001	0
Flathead	0	0.004	0.05	0	0	0	0.02	0.01	0	0.001	0
Redfish	0.02	0.01	0.02	0	0	0	0.01	0.01	0.8	0.001	0
Morwong	0	0.005	0.01	0	0.0007	0.0005	0.001	0.001	0.8	0.000001	0

Predator/Prey	Deep megaben.	Shallow megaben.	Rock lobster	Meioben.	Macro-algae	Seagrass	Prawns	Giant crab	Carrion	Labile detritus	Refractory detritus
Ling	0.9	0.008	0	0	0	0	0.02	0.01	0.8	0.001	0
Blue grenadier	0	0.01	0.1	0	0	0	0.001	0.001	0	0	0
Blue-eye trevalla	0.1	0	0	0	0	0	0.01	0.01	0.8	0.001	0
Ribaldo	0.5	0	0	0	0	0	0	0	0.8	0.001	0
Orange roughy	0.1	0	0	0	0	0	0	0	0	0.01	0
Dories and oreos	0.05	0.005	0.02	0	0	0	0.002	0.002	0.8	0.001	0
Cardinalfish	0.005	0.005	0.001	0	0	0	0	0	0	0	0
Gummy shark	0	0.01	0.005	0	0	0	0	0	0	0	0
School shark	0	0.01	0	0	0	0	0	0	0	0	0
Demersal sharks	0.45	0.005	0.01	0	0.00005	0.00008	0.001	0.001	0.8	0	0
Pelagic sharks	0	0.004	0.01	0	0	0	0	0	0.8	0	0
Dogfish	0.3	0.05	0	0	0	0	0	0	0.8	0	0
Gulper sharks	0.6	0	0	0	0	0	0	0	0	0	0
Skates and rays	0.45	0.005	0.02	0	0	0	0.001	0.001	0.8	0	0
Seabirds	0	0.1	0.01	0	0	0	0	0	0.5	0	0
Seals	0	0.05	0	0	0	0	0	0	0.5	0	0
Sea lion	0	0.3	0	0	0	0	0	0	0.5	0	0
Dolphins	0	0.1	0	0	0	0	0.03	0.03	0.5	0	0
Orcas	0	0	0	0	0	0	0	0	0.5	0	0
Baleen whales	0	0	0	0	0	0	0.01	0.01	0	0	0
Squid	0	0	0	0	0	0	0	0	0	0.01	0.01

Table A-3: Adult prey - juvenile predator trophic interactions used in the southeast Atlantis model (invertebrate predators other than squid are omitted, as they have no size-age structure and the values given in Table 2.3 always apply). Rows are predators, columns are prey groups.

Predator/Prey	Small pelagic	Red bait	Mackerel	Migratory mesopelag.	Non-mig. mesopel.	School whiting	Shallow piscivore	Blue warehou	Spotted warehou	Tuna & billfish	Gemfish	Shallow demersal	Flathead	Redfish	Morwong	Ling
Small pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Red bait	0	0	0	0.03	0.3	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0	0.06	0	0.005	0.3	0	0	0	0	0	0	0	0	0	0	0
Migratory mesopelag.	0	0	0	0.005	0.3	0	0	0	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0	0	0	0.005	0.3	0	0	0	0	0	0	0	0	0	0	0
School whiting	0.2	0	0.075	0	0	0	0.4	0.2	0.3	0	0	0	0.1	0	0	0
Shallow piscivores	0.075	0.3	0.002	0.003	0.3	0.0075	0.15	0.0015	0.005	0	0	0.1	0.15	0	0.045	0
Blue warehou	0	0	0	0.05	0.3	0	0	0	0	0	0	0	0	0	0	0
Spotted warehou	0	0	0	0.015	0.3	0	0	0	0	0	0	0	0	0	0	0
Tuna and billfish	0.15	0.3	0.02	0.02	0.3	0.015	0.25	0.015	0.02	0.25	0	0.12	0	0	0.06	0
Gemfish	0.4	0	0	0.0075	0.3	0	0	0	0	0	0.5	0	0	0	0.2	0
Shallow demersal fish	0.15	0.1	0.005	0.001	0.3	0.002	0	0.025	0.01	0	0	0.1	0.1	0.00005	0.01	0
Flathead	0.15	0	0.02	0.04	0.3	0.075	0.5	0.008	0.2	0	0	0.3	0.05	0	0.1	0
Redfish	0	0.55	0	0.05	0.3	0	0	0	0	0	0.5	0.3	0	0.00001	0	0.04
Morwong	0.085	0	0.05	0.008	0.3	0	0	0.04	0.06	0	0	0.2	0	0	0	0
Ling	0	0	0	0.15	0.5	0	0	0	0	0	0.4	0.3	0	0	0	0
Blue grenadier	0	0	0	0.03	0.3	0	0	0	0	0	0.4	0	0	0	0	0
Blue-eye trevalla	0	0	0	0.045	0.3	0	0	0	0	0	0	0	0	0	0	0
Ribaldo	0	0	0	0.05	0.3	0	0	0	0	0	0	0	0	0	0	0
Orange roughy	0	0	0	0.03	0.15	0	0	0	0	0	0.4	0	0	0	0	0.15
Dories and oreos	0	0.2	0.01	0.03	0.3	0.015	0	0	0	0	0.4	0.1	0	0.0005	0	0
Cardinalfish	0.1	0	0	0.006	0.3	0	0	0	0	0	0.5	0	0	0	0.1	0
Gummy shark	0	0	0	0	0	0	0.35	0	0	0	0.4	0.45	0	0	0	0
School shark	0	0	0	0	0	0	0.4	0	0	0	0.3	0	0	0	0	0
Demersal sharks	0.1	0.55	0.0045	0.01	0.3	0.01	0	0	0	0	0	0.05	0	0.0005	0.04	0.004

Predator/Prey	Small pelagic	Red bait	Mackerel	Migratory mesopelag.	Non-mig. mesopel.	School whiting	Shallow piscivore	Blue warehou	Spotted warehou	Tuna & billfish	Gemfish	Shallow demersal	Flathead	Redfish	Morwong	Ling
Pelagic sharks	0.1	0.15	0.04	0.05	0.15	0.2	0.35	0.01	0.08	0.5	0.5	0.35	0.7	0.005	0.2	0
Dogfish	0	0.2	0	0.05	0.3	0.2	0	0	0	0	0.4	0.5	0	0.02	0	0.06
Gulper sharks	0	0	0	0.8	0.7	0.2	0	0	0	0	0	0	0	0	0	0.1
Skates and rays	0	0	0	0.005	0.3	0.01	0	0	0	0	0	0.6	0.2	0	0	0.02
Seabirds	0.8	0.5	0.4	0	0	0.4	0.475	0.4	0.4	0.5	0	0.6	0.6	0	0.3	0
Seals	0.8	0.6	0.4	0.5	0	0.2	0.45	0.1	0.35	0.7	0.7	0.6	0.6	0.005	0.25	0.25
Sea lion	0.8	0.55	0.6	0.5	0	0.3	0.4	0.4	0.4	0.7	0.6	0.6	0.9	0.05	0.3	0.5
Dolphins	0.8	0.6	0.4	0.5	0.3	0.2	0.4	0.2	0.35	0.8	0.5	0.6	0.7	0	0.25	0.25
Orcas	0.8	0.2	0.2	0.2	0.3	0.2	0.4	0.125	0.06	0.4	0.5	0.6	0.7	0	0.25	0.15
Baleen whales	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.15	0
Squid	0.001	0.00015	0.0001	0.00006	0.003	0.00001	0.0004	0.00065	0.00015	0.0001	0.0007	0.0005	0.00005	0	0.00075	0.00075

Predator/Prey	Blue grenad.	Blue-eye trevalla	Ribaldo	Orange roughy	Dories & oreos	Cardinal-fish	Gummy shark	School shark	Demersal shark	Pelagic shark	Dogfish	Gulper shark	Skates & rays	Seabird	Seals	Sea lion
Small pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Red bait	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0
Migratory mesopelag.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
School whiting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shallow piscivores	0	0	0	0	0	0	0.08	0.6	0.02	0	0.3	0	0.000375	0	0	0
Blue warehou	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0
Spotted warehou	0	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0
Tuna and billfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gemfish	0	0	0	0.002	0.004	0.4	0	0	0	0	0	0	0	0	0	0
Shallow demersal fish	0	0	0	0	0.01	0	0.008	0.6	0.02	0	0.4	0	0.005	0	0	0
Flathead	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Predator/Prey	Blue grenad.	Blue-eye trevalla	Ribaldo	Orange roughy	Dories & oreos	Cardinal-fish	Gummy shark	School shark	Demersal shark	Pelagic shark	Dogfish	Gulper shark	Skates & rays	Seabird	Seals	Sea lion
Redfish	0.3	0.3	0.3	0.007	0.1	0	0	0	0	0	0	0	0	0	0	0
Morwong	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0
Ling	0.8	0	0.9	0	0.1	0.5	0	0	0	0	0	0	0	0	0	0
Blue grenadier	0.9	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0
Blue-eye trevalla	0.4	0	0.8	0.008	0.01	0	0	0	0	0	0	0	0	0	0	0
Ribaldo	0	0	0	0.012	0.2	0	0	0	0	0	0	0	0	0	0	0
Orange roughy	0	0	0	0.01	0.03	0.25	0	0	0	0	0	0	0	0	0	0
Dories and oreos	0.3	0	0	0.002	0.001	0.55	0	0	0	0	0	0	0	0	0	0
Cardinalfish	0.3	0	0	0.002	0.05	0.2	0	0	0	0	0	0	0	0	0	0
Gummy shark	0	0	0	0	0.1	0.5	0	0	0	0	0	0	0	0	0	0
School shark	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0
Demersal sharks	0.9	0.3	0.8	0.0006	0.001	0.5	0.08	0.4	0.02	0	0.4	0.02	0.000175	0	0	0
Pelagic sharks	0.5	0	0.9	0	0.08	0.5	0.9	0.9	0.4	0.001	0.9	0.01	0.00015	0.1	0.3	0.01
Dogfish	0	0.3	0.8	0.01	0.04	0.5	0.08	0.7	0.05	0	0.4	0	0.0015	0	0	0
Gulper sharks	0	0	0	0.01	0.29	0.8	0	0	0	0	0	0	0	0	0	0
Skates and rays	0	0	0.3	0.0002	0.02	0.6	0.05	0.5	0.025	0	0.9	0	0.0005	0	0	0
Seabirds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seals	0.9	0	0.9	0	0.19	0.6	0	0	0	0	0	0	0	0	0	0
Sea lion	0.9	0	0.9	0	0.15	0.6	0	0	0	0	0	0	0	0	0	0
Dolphins	0.9	0	0	0	0	0.6	0	0	0	0	0	0	0	0.2	0	0.005
Orcas	0.9	0.3	0.9	0	0	0.6	0.7	0.8	0.55	0.006	0.9	0	0.00015	0.2	0.2	0.005
Baleen whales	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Squid	0.0005	0.0015	0.0002	0	0.0015	0.0005	0	0	0	0	0	0	0	0	0	0

Predator/Prey	Dolphin	Orca	Baleen whale	Large phytopl.	Small phytopl.	Small zoopl.	Meso zoopl.	Large zoopl.	Gelat. zoopl.	Squid	Infauna	Deposit feeder	Deep filt feed	Shallow filt feed	Scallop	Herbiv. grazer
Small pelagics	0	0	0	0.000001	0	0	0.8	0.8	0	0.03	0	0	0	0	0	0
Red bait	0	0	0	0	0	0	0.35	0.5	0.15	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0	0	0.5	0.65	0.25	0	0	0.2	0	0	0	0
Migratory mesopelag.	0	0	0	0	0	0	0.05	0.05	0	0.01	0.005	0.003	0.01	0.005	0.005	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0.015	0.1	0.03	0	0	0	0	0	0
School whiting	0	0	0	0	0	0	0.1	0.1	0.1	0.075	0.1	0.0075	0.01	0.01	0.01	0.003
Shallow piscivores	0	0	0	0	0	0	0.2	0.15	0.1	0.1	0.01	0.0075	0	0.0001	0.0001	0.0003
Blue warehou	0	0	0	0.1	0	0	0.35	0.5	0.15	0.05	0.1	0.03	0	0	0	0
Spotted warehou	0	0	0	0	0	0	0.375	0.25	0.15	0.12	0.01	0.1	0	0	0	0
Tuna and billfish	0	0	0	0	0	0	0.1	0.1	0.1	0.15	0	0	0	0	0	0
Gemfish	0	0	0	0	0	0	0.1	0.2	0	0.1	0	0	0	0	0	0
Shallow demersal fish	0	0	0	0	0	0	0.01	0.01	0.01	0.012	0.2	0.003	0.1	0.1	0.0005	0.0001
Flathead	0	0	0	0	0	0	0.05	0.05	0.05	0.1	0.2	0.015	0.08	0.08	0.01	0.001
Redfish	0	0	0	0	0	0	0.1	0.1	0.1	0.01	0.01	0.015	0	0	0	0
Morwong	0	0	0	0	0	0	0.01	0.01	0.01	0.03	0.2	0.08	0.5	0	0.05	0.01
Ling	0	0	0	0	0	0	0.15	0.15	0	0	0	0	0	0	0	0
Blue grenadier	0	0	0	0	0	0	0.15	0.15	0.1	0.04	0	0	0	0	0	0
Blue-eye trevalla	0	0	0	0	0	0	0.1	0.1	0.1	0.08	0.2	0.015	0.1	0	0	0
Ribaldo	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.2	0.015	0.7	0	0	0
Orange roughy	0	0	0	0	0	0	0	0	0.2	0.025	0	0	0.1	0	0	0
Dories and oreos	0	0	0	0	0	0	0.1	0.1	0.1	0.008	0.2	0.009	0.3	0.1	0	0
Cardinalfish	0	0	0	0	0	0	0.1	0.2	0.002	0.005	0.001	0.0054	0.01	0	0.001	0.0003
Gummy shark	0	0	0	0	0	0	0	0	0	0.1	0.1	0.075	0	0.1	0.05	0.008
School shark	0	0	0	0	0	0	0	0	0	0.05	0.1	0.075	0.1	0.1	0.05	0
Demersal sharks	0	0	0	0	0	0	0	0	0	0.005	0.2	0.005	0.7	0.7	0.004	0.0003
Pelagic sharks	0.05	0.015	0.008	0	0	0	0	0.1	0	0.05	0	0	0	0	0	0

Predator/Prey	Dolphin	Orca	Baleen whale	Large phytopl.	Small phytopl.	Small zoopl.	Meso zoopl.	Large zoopl.	Gelat. zoopl.	Squid	Infauna	Deposit feeder	Deep filt feed	Shallow filt feed	Scallop	Herbiv. grazer
Dogfish	0	0	0	0	0	0	0	0	0	0.05	0.2	0.03	0.3	0.3	0.01	0.008
Gulper sharks	0	0	0	0	0	0	0	0	0	0.3	0	0.08	0.6	0	0	0
Skates and rays	0	0	0	0	0	0	0.15	0.15	0	0.01	0.2	0.008	0.7	0.7	0.005	0.0008
Seabirds	0	0	0	0	0	0	0.15	0.1	0.05	0.2	0.05	0	0	0.05	0.05	0
Seals	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.07	0.008
Sea lion	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0.2	0.1
Dolphins	0	0.00001	0	0	0	0	0	0.1	0.01	0.2	0	0.05	0	0.1	0.1	0.02
Orcas	0.0025	0.000015	0.000008	0	0	0	0	0	0	0.1	0	0	0	0	0	0
Baleen whales	0	0	0	0	0	0	0.6	0.45	0	0	0	0	0	0	0	0
Squid	0	0	0	0	0	0	0.01	0.02	0	0.0001	0	0	0	0	0	0

Predator/Prey	Deep megaben.	Shallow megaben.	Rock lobster	Meioben.	Macro-algae	Seagrass	Prawns	Giant crab	Carrion	Labile detritus	Refractory detritus
Small pelagics	0	0	0	0	0	0	0	0.001	0	0	0
Red bait	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0	0	0	0.001	0	0	0
Migratory mesopelag.	0.01	0.0005	0.005	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0	0	0	0
School whiting	0.01	0.005	0.001	0.1	0	0	0.001	0.001	0	0.1	0
Shallow piscivores	0.01	0.0015	0.01	0	0	0	0	0	0	0	0
Blue warehou	0	0	0	0	0	0	0.001	0.001	0	0	0
Spotted warehou	0.001	0.005	0.001	0	0	0	0.005	0.001	0	0	0
Tuna and billfish	0.01	0.005	0	0	0	0	0.001	0.001	0	0	0
Gemfish	0.01	0.01	0	0	0	0	0.001	0.001	0	0	0
Shallow demersal fish	0.1	0.0001	0.002	0	0.00006	0.00005	0.0001	0.0001	0.8	0.000001	0
Flathead	0	0.004	0.05	0	0	0	0.02	0.01	0	0.001	0

Predator/Prey	Deep megaben.	Shallow megaben.	Rock lobster	Meioben.	Macro-algae	Seagrass	Prawns	Giant crab	Carrion	Labile detritus	Refractory detritus
Redfish	0.02	0.01	0.02	0	0	0	0.01	0.01	0.8	0.001	0
Morwong	0	0.05	0.01	0	0.0007	0.0005	0.001	0.001	0.8	0.000001	0
Ling	0.9	0.008	0	0	0	0	0.02	0.01	0.8	0.001	0
Blue grenadier	0	0.01	0.1	0	0	0	0.001	0.001	0	0	0
Blue-eye trevalla	0.1	0	0	0	0	0	0.01	0.01	0.8	0.001	0
Ribaldo	0.5	0	0	0	0	0	0	0	0.8	0.001	0
Orange roughy	0.1	0	0	0	0	0	0	0	0	0.01	0
Dories and oreos	0.5	0.005	0.03	0	0	0	0.002	0.002	0.8	0.001	0
Cardinalfish	0.1	0.005	0.001	0	0	0	0	0	0	0	0
Gummy shark	0	0.01	0.1	0	0	0	0	0	0	0	0
School shark	0.1	0.01	0.1	0	0	0	0.001	0	0	0.1	0
Demersal sharks	0.45	0.004	0.01	0	0.00005	0.00008	0.002	0.001	0.8	0	0
Pelagic sharks	0	0.004	0.01	0	0	0	0	0	0.8	0	0
Dogfish	0.3	0.05	0	0	0	0	0	0	0.8	0	0
Gulper sharks	0.6	0	0	0	0	0	0	0	0	0	0
Skates and rays	0.45	0.005	0.02	0	0	0	0.001	0.001	0.8	0	0
Seabirds	0	0.1	0.01	0.05	0	0	0.01	0	0.5	0	0
Seals	0	0.08	0	0	0	0	0	0	0.5	0	0
Sea lion	0	0.3	0	0	0	0	0	0	0.5	0	0
Dolphins	0	0.1	0	0	0	0	0.03	0.03	0.5	0	0
Orcas	0	0	0	0	0	0	0	0	0.5	0	0
Baleen whales	0	0	0	0	0	0	0	0.01	0	0	0
Squid	0	0	0	0	0	0	0	0.005	0	0	0

Table A-4: Adult prey - adult predator trophic interactions used in Atlantis SE (invertebrate predators other than squid are omitted, as they have no size-age structure and the values given in Table 2.3 always apply). Rows are predators, columns are prey groups.

Predator/Prey	Small pelagic	Red bait	Mackerel	Migratory mesopelag.	Non-mig. mesopel.	School whiting	Shallow piscivore	Blue warehou	Spotted warehou	Tuna & billfish	Gemfish	Shallow demersal	Flathead	Redfish	Morwong	Ling
Small pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Red bait	0	0	0	0.03	0.3	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0	0.5	0	0.03	0.3	0	0	0	0	0	0	0	0	0	0	0
Migratory mesopelag.	0	0	0	0.0075	0.3	0	0	0	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0	0	0	0.003	0.3	0	0	0	0	0	0	0	0	0	0	0
School whiting	0.2	0	0.075	0	0	0	0.4	0.2	0.4	0	0	0	0.06	0	0	0
Shallow piscivores	0.075	0.3	0.002	0.005	0.3	0.0075	0.15	0.0015	0.015	0	0	0.04	0.09	0	0.055	0
Blue warehou	0	0	0	0.25	0.3	0	0	0	0	0	0	0	0	0	0	0
Spotted warehou	0	0	0	0.015	0.3	0	0	0	0	0	0	0	0	0	0	0
Tuna and billfish	0.15	0.3	0.02	0.025	0.3	0.015	0.3	0.015	0.035	0.5	0	0.1	0	0	0.09	0
Gemfish	0.4	0	0	0.1	0.3	0	0	0	0	0	0.5	0	0	0	0.25	0
Shallow demersal fish	0.15	0.1	0.002	0.001	0.3	0.002	0	0.025	0.009	0	0	0.06	0.1	0.00005	0.02	0
Flathead	0.15	0	0.03	0.04	0.3	0.075	0.3	0.008	0.225	0	0	0.15	0.05	0	0.15	0
Redfish	0	0.55	0	0.065	0.3	0	0	0	0	0	0.5	0.15	0	0.00001	0	0.04
Morwong	0.085	0	0.15	0.025	0.3	0	0	0.04	0.075	0	0	0.17	0	0	0	0
Ling	0	0	0	0.2	0.5	0	0	0	0	0	0.35	0.175	0	0	0	0
Blue grenadier	0	0	0	0.03	0.3	0	0	0	0	0	0.4	0	0	0	0	0
Blue-eye trevalla	0	0	0	0.1	0.3	0	0	0	0	0	0	0	0	0	0	0
Ribaldo	0	0	0	0.08	0.3	0	0	0	0	0	0	0	0	0	0	0
Orange roughy	0	0	0	0.03	0.15	0	0	0	0	0	0.4	0	0	0	0	0.15
Dories and oreos	0	0.2	0.005	0.03	0.3	0.015	0	0	0	0	0.4	0.04	0	0.0005	0	0
Cardinalfish	0.1	0	0	0.006	0.3	0	0	0	0	0	0.5	0	0	0	0.1	0
Gummy shark	0	0	0	0	0	0	0.35	0	0	0	0.4	0.4	0	0	0	0
School shark	0	0	0	0	0	0	0.4	0	0	0	0.3	0.25	0	0	0	0
Demersal sharks	0.1	0.15	0.005	0.025	0.3	0.01	0	0	0	0	0	0.02	0	0.0005	0.055	0.003

Predator/Prey	Small pelagic	Red bait	Mackerel	Migratory mesopelag.	Non-mig. mesopel.	School whiting	Shallow piscivore	Blue warehou	Spotted warehou	Tuna & billfish	Gemfish	Shallow demersal	Flathead	Redfish	Morwong	Ling
Pelagic sharks	0.1	0.15	0.04	0.035	0.15	0.2	0.35	0.01	0.14	0.6	0.5	0.3	0.2	0.005	0.15	0
Dogfish	0	0.2	0	0.25	0.3	0.2	0	0	0	0	0.4	0.3	0	0.02	0	0.06
Gulper sharks	0	0	0	0.8	0.7	0.2	0	0	0	0	0	0	0	0	0	0.1
Skates and rays	0	0	0	0.015	0.3	0.005	0	0	0	0	0	0.2	0.04	0	0	0.018
Seabirds	0.8	0.5	0.5	0	0	0.4	0.475	0.4	0.4	0.5	0	0.6	0.4	0	0.35	0
Seals	0.8	0.6	0.4	0.8	0	0.2	0.475	0.1	0.35	0.7	0.7	0.6	0.2	0.005	0.3	0.25
Sea lion	0.8	0.55	0.6	0.95	0	0.3	0.4	0.4	0.6	0.7	0.6	0.6	0.8	0.05	0.35	0.5
Dolphins	0.8	0.6	0.4	0.95	0.3	0.2	0.475	0.2	0.55	0.8	0.5	0.6	0.2	0	0.3	0.35
Orcas	0.8	0.2	0.2	0.6	0.3	0.2	0.3	0.125	0.1	0.4	0.5	0.6	0.2	0	0.3	0.15
Baleen whales	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.15	0
Squid	0.0015	0.005	0.00015	0.00015	0.0025	0.00015	0.001	0.0009	0.0008	0.001	0.002	0.0005	0.00008	0	0.0007	0.00125

Predator/Prey	Blue grenad.	Blue-eye trevalla	Ribaldo	Orange roughy	Dories & oreos	Cardinal-fish	Gummy shark	School shark	Demersal shark	Pelagic shark	Dogfish	Gulper shark	Skates & rays	Seabird	Seals	Sea lion
Small pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Red bait	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0
Migratory mesopelag.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
School whiting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shallow piscivores	0	0	0	0	0	0	0.08	0.2	0.01	0	0.3	0	0.000375	0	0	0
Blue warehou	0	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0
Spotted warehou	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0
Tuna and billfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gemfish	0	0	0	0.002	0.1	0.7	0	0	0	0	0	0	0	0	0	0
Shallow demersal fish	0	0	0	0	0.01	0	0.008	0.2	0.01	0	0.4	0	0.005	0	0	0
Flathead	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Predator/Prey	Blue grenad.	Blue-eye trevalla	Ribaldo	Orange roughy	Dories & oreos	Cardinal-fish	Gummy shark	School shark	Demersal shark	Pelagic shark	Dogfish	Gulper shark	Skates & rays	Seabird	Seals	Sea lion
Redfish	0.3	0.3	0.3	0.007	0.1	0	0	0	0	0	0	0	0	0	0	0
Morwong	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0
Ling	0.4	0	0.9	0	0.2	0.5	0	0	0	0	0	0	0	0	0	0
Blue grenadier	0.5	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0
Blue-eye trevalla	0.4	0	0.8	0.008	0.1	0	0	0	0	0	0	0	0	0	0	0
Ribaldo	0	0	0	0.012	0.2	0	0	0	0	0	0	0	0	0	0	0
Orange roughy	0	0	0	0.01	0.02	0.25	0	0	0	0	0	0	0	0	0	0
Dories and oreos	0.3	0	0	0.002	0.03	0.55	0	0	0	0	0	0	0	0	0	0
Cardinalfish	0.3	0	0	0.002	0.05	0.2	0	0	0	0	0	0	0	0	0	0
Gummy shark	0	0	0	0	0.1	0.5	0	0	0	0	0	0	0	0	0	0
School shark	0	0	0	0	0.02	0.5	0	0	0	0	0	0	0	0	0	0
Demersal sharks	0.5	0.3	0.9	0.0006	0.01	0.5	0.08	0.2	0.01	0	0.4	0.02	0.000175	0	0	0
Pelagic sharks	0.5	0	0.9	0	0.05	0.5	0.3	0.8	0.3	0.0018	0.9	0.025	0.00015	0.2	0.35	0.01
Dogfish	0	0.3	0.9	0.01	0.3	0.6	0.08	0.5	0.05	0	0.4	0	0.0015	0	0	0
Gulper sharks	0	0	0	0.01	0.29	0.8	0	0	0	0	0	0	0	0	0	0
Skates and rays	0	0	0.5	0.0002	0.02	0.6	0.2	0.8	0.2	0	0.9	0	0.0005	0	0	0
Seabirds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seals	0.9	0	0.9	0	0.19	0.6	0	0	0	0	0	0	0	0	0	0
Sea lion	0.9	0	0.9	0	0.15	0.6	0	0	0	0	0	0	0	0	0	0
Dolphins	0.9	0	0	0	0	0.6	0	0	0	0	0	0	0	0.2	0	0.005
Orcas	0.9	0.3	0.9	0	0	0.6	0.7	0.8	0.45	0.06	0.9	0	0.00015	0.2	0.2	0.005
Baleen whales	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Squid	0.0005	0.005	0.0008	0	0.007	0.0008	0	0	0	0	0	0	0	0	0	0

Predator/Prey	Dolphin	Orca	Baleen whale	Large phytopl.	Small phytopl.	Small zoopl.	Meso zoopl.	Large zoopl.	Gelat. zoopl.	Squid	Infauna	Deposit feeder	Deep filt feed	Shallow filt feed	Scallop	Herbiv. grazer
Small pelagics	0	0	0	0.000001	0	0	0.8	0.8	0	0.03	0	0	0	0	0	0
Red bait	0	0	0	0	0	0	0.35	0.5	0.15	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0	0	0.5	0.65	0.25	0	0	0.2	0	0	0	0
Migratory mesopelag.	0	0	0	0	0	0	0.05	0.05	0	0.01	0.005	0.003	0.005	0.005	0.005	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0.015	0.1	0.03	0	0	0	0	0	0
School whiting	0	0	0	0	0	0	0.01	0.01	0.01	0.075	0.01	0.0075	0.01	0.01	0.01	0.003
Shallow piscivores	0	0	0	0	0	0	0.0001	0.0001	0.0001	0.1	0.001	0.0075	0	0.0001	0.0001	0.0003
Blue warehou	0	0	0	0.1	0	0	0.35	0.5	0.15	0.05	0.1	0.008	0	0	0	0
Spotted warehou	0	0	0	0	0	0	0.375	0.25	0.15	0.12	0.01	0.1	0	0	0	0
Tuna and billfish	0	0	0	0	0	0	0.005	0.005	0.001	0.15	0	0	0	0	0	0
Gemfish	0	0	0	0	0	0	0.001	0.001	0	0.1	0	0	0	0	0	0
Shallow demersal fish	0	0	0	0	0	0	0.001	0.001	0.001	0.012	0.2	0.003	0.1	0.1	0.0005	0.0001
Flathead	0	0	0	0	0	0	0.001	0.001	0.001	0.1	0.2	0.015	0.08	0.08	0.01	0.001
Redfish	0	0	0	0	0	0	0.1	0.1	0.1	0.01	0.01	0.015	0	0	0	0
Morwong	0	0	0	0	0	0	0.001	0.001	0.001	0.03	0.2	0.08	0.5	0	0.05	0.01
Ling	0	0	0	0	0	0	0.15	0.15	0	0	0	0	0	0	0	0
Blue grenadier	0	0	0	0	0	0	0.15	0.15	0.1	0.04	0	0	0	0	0	0
Blue-eye trevalla	0	0	0	0	0	0	0.001	0.001	0.001	0.08	0.2	0.015	0.1	0	0	0
Ribaldo	0	0	0	0	0	0	0.001	0.001	0.001	0.1	0.2	0.015	0.7	0	0	0
Orange roughy	0	0	0	0	0	0	0	0	0.2	0.025	0	0	0.1	0	0	0
Dories and oreos	0	0	0	0	0	0	0.001	0.001	0.001	0.008	0.2	0.009	0.3	0.01	0	0
Cardinalfish	0	0	0	0	0	0	0.001	0.005	0.002	0.005	0.001	0.0054	0.001	0	0.001	0.0003
Gummy shark	0	0	0	0	0	0	0	0	0	0.1	0.005	0.075	0	0.005	0.005	0.008
School shark	0	0	0	0	0	0	0	0	0	0.08	0.1	0.075	0	0.05	0.05	0
Demersal sharks	0	0	0	0	0	0	0	0	0	0.005	0.2	0.005	0.7	0.7	0.004	0.0003
Pelagic sharks	0.055	0.015	0.008	0	0	0	0	0.1	0	0.05	0	0	0	0	0	0.003

Predator/Prey	Dolphin	Orca	Baleen whale	Large phytopl.	Small phytopl.	Small zoopl.	Meso zoopl.	Large zoopl.	Gelat. zoopl.	Squid	Infauna	Deposit feeder	Deep filt feed	Shallow filt feed	Scallop	Herbiv. grazer
Dogfish	0	0	0	0	0	0	0	0	0	0.05	0.2	0.03	0.3	0.3	0.01	0.008
Gulper sharks	0	0	0	0	0	0	0	0	0	0.3	0	0.08	0.6	0	0	0
Skates and rays	0	0	0	0	0	0	0.15	0.15	0	0.01	0.2	0.008	0.7	0.7	0.001	0.0008
Seabirds	0	0	0	0	0	0	0.15	0.1	0.05	0.2	0	0	0	0	0	0
Seals	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.07	0.008
Sea lion	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0.2	0.1
Dolphins	0	0.00001	0	0	0	0	0	0.1	0.01	0.2	0	0.05	0	0.1	0.1	0.02
Orcas	0.0025	0.000015	0.00003	0	0	0	0	0	0	0.1	0	0	0	0	0	0
Baleen whales	0	0	0	0	0	0	0.6	0.45	0	0	0	0	0	0	0	0
Squid	0	0	0	0	0	0	0.008	0.015	0	0.00025	0	0	0	0	0	0

Predator/Prey	Deep megaben.	Shallow megaben.	Rock lobster	Meioben.	Macro-algae	Seagrass	Prawns	Giant crab	Carrion	Labile detritus	Refractory detritus
Small pelagics	0	0	0	0	0	0	0	0.001	0	0	0
Red bait	0	0	0	0	0	0	0	0	0	0	0
Mackerel	0	0	0	0	0	0	0	0.001	0	0	0
Migratory mesopelag.	0.005	0.0005	0.005	0	0	0	0	0	0	0	0
Non-mig. mesopel.	0	0	0	0	0	0	0	0	0	0	0
School whiting	0.01	0.001	0.001	0.05	0	0	0.001	0.001	0	0.01	0
Shallow piscivores	0.001	0.0008	0.001	0	0	0	0	0	0	0	0
Blue warehou	0	0	0	0	0	0	0.001	0.001	0	0	0
Spotted warehou	0.001	0.005	0.001	0	0	0	0.005	0.001	0	0	0
Tuna and billfish	0.01	0.005	0	0	0	0	0.001	0.001	0	0	0
Gemfish	0.01	0.01	0	0	0	0	0.001	0.001	0	0	0
Shallow demersal fish	0.1	0.0001	0.002	0	0.00006	0.00005	0.0001	0.0001	0.8	0.000001	0
Flathead	0	0.004	0.05	0	0	0	0.02	0.01	0	0.001	0
Redfish	0.02	0.01	0.02	0	0	0	0.01	0.01	0.8	0.001	0

Predator/Prey	Deep megaben.	Shallow megaben.	Rock lobster	Meioben.	Macro-algae	Seagrass	Prawns	Giant crab	Carrion	Labile detritus	Refractory detritus
Morwong	0	0.005	0.01	0	0.0007	0.0005	0.001	0.001	0.8	0.000001	0
Ling	0.9	0.008	0	0	0	0	0.02	0.01	0.8	0.001	0
Blue grenadier	0	0.01	0.1	0	0	0	0.001	0.001	0	0	0
Blue-eye trevalla	0.1	0	0	0	0	0	0.01	0.01	0.8	0.001	0
Ribaldo	0.5	0	0	0	0	0	0	0	0.8	0.001	0
Orange roughy	0.1	0	0	0	0	0	0	0	0	0.01	0
Dories and oreos	0.05	0.005	0.02	0	0	0	0.002	0.002	0.8	0.001	0
Cardinalfish	0.005	0.005	0.001	0	0	0	0	0	0	0	0
Gummy shark	0	0.01	0.005	0	0	0	0	0	0	0	0
School shark	0	0.01	0	0	0	0	0	0	0	0	0
Demersal sharks	0.45	0.005	0.01	0	0.00005	0.00008	0.001	0.001	0.8	0	0
Pelagic sharks	0	0.004	0.01	0	0	0	0	0	0.8	0	0
Dogfish	0.3	0.05	0	0	0	0	0	0	0.8	0	0
Gulper sharks	0.6	0	0	0	0	0	0	0	0	0	0
Skates and rays	0.45	0.0025	0.02	0	0	0	0.001	0.001	0.8	0	0
Seabirds	0	0.1	0.01	0	0	0	0	0	0.5	0	0
Seals	0	0.05	0	0	0	0	0	0	0.5	0	0
Sea lion	0	0.3	0	0	0	0	0	0	0.5	0	0
Dolphins	0	0.1	0	0	0	0	0.03	0.03	0.5	0	0
Orcas	0	0	0	0	0	0	0	0	0.5	0	0
Baleen whales	0	0	0	0	0	0	0	0.01	0	0	0
Squid	0	0	0	0	0	0	0	0.005	0	0	0

APPENDIX B: SOCIOECONOMIC MODEL

The following equations are used to implement the socioeconomic model outlined in Section 2.4 of the main document. All parameters used in this section were drawn from market data from the Melbourne and Sydney fish markets, Galeano *et al* 2005, BRS 2007, or data on costs supplied by Tom Kompas and Gerry Geen).

B.1 Economic Statistics

The steps used in the socioeconomic model used to drive effort allocation are described in the following sections. The first of these steps is the calculation and reporting of a few standard economic indicators: costs, gross value of product, profits and the amount of quota in hand. This last value must be known so that total costs can be taken into account when calculating total profits to date. The formulations for these indicators and described briefly below. These values are also used in subsequent steps to help determine realised effort allocations.

B.1.1 Costs

The total costs ($C_{i,j,m,y}$) per subfleet i of fleet j in month m of year y is the sum of fixed (C_{fix}), variable and unloading costs such that:

$$\begin{aligned} C_{i,j,m,y} &= C_{fix,i,j} + C_{quota,i,j} + C_{cap,i,j} + C_{unload,i,j} \cdot H_{i,j,m,y} \\ &\quad + \left(C_{gear,i,j} + \left(a_{fuel} + b_{fuel} \cdot y + d_{m,fuel} + \rho_{fuel} \cdot \varepsilon \right) \cdot \lambda_{fuel,i,j} \right) \cdot E_{i,j,m,y} \end{aligned} \tag{B.1}$$

where $C_{fix,i,j}$ are fixed costs for subfleet i of fleet j including licence and other management costs, as well as insurance and maintenance; $C_{gear,i,j}$ are gear maintenance costs for subfleet i of fleet j (this does not currently increase with the age of the vessel, as no information was available for parameterising such an increase, but any future implementations of the model should include increasing costs for aging vessels); $C_{cap,i,j}$ are monthly capital (primarily depreciation) costs for subfleet i of fleet j; $C_{quota,i,j}$ are quota lease costs for subfleet i of fleet j for quota traded in as of month m of year y (this cost is calculated using the quota price model given in section B.8); $C_{unload,i,j}$ are unloading costs per tonne for subfleet i of fleet j; $H_{i,j,m,y}$ is the total catch landed by subfleet i of fleet j in month m of year y; $E_{i,j,m,y}$ is the effort expended (in days) by subfleet i of fleet j in month m of year y; a_{fuel}, is the intercept of the autoregressive fuel cost model (fitted to RACT data on diesel prices over the last decade), b_{fuel} is the trend coefficient of the autoregressive fuel cost model, $d_{m,fuel}$ is the month coefficient for month m of the autoregressive fuel cost model, ρ_{fuel} is the autoregression parameter, ε is the residual and λ_{fuel} the subfleet specific daily fuel consumption scalar of the autoregressive fuel cost model. For ease of interpretation it was also possible to report costs without inflationary trends (using costs as of 2000), this was done when reporting results in the main body of this report. One potentially import cost ignored here is the cost of disposing unmarketable fish, this could be a particular concern in Scenario 10, where discarding of quota species is banned.

B.1.2 Gross Value of Production

Gross Value of Production (GVP) for subfleet i of fleet j in month m of year y ($V_{GP,i,j,m,y}$) is given by the simple formula (which sums the value of the catch over each species landed):

$$V_{GP,i,j,m,y} = \sum_{s} H_{s,i,j,m,y} \cdot p_s \tag{B.2}$$

with $H_{s,i,j,m,y}$ the landed catch of species (or group) s by subfleet i of fleet j in month m of year y; and p_s is the sale price of species (or group) s in the market chosen by the subfleet (there are two potential markets in Atlantis SE, representing the Melbourne and Sydney markets). The model used to calculate market prices is given in section B.10. Currently the price is assumed to be the same across all fisheries regardless of the gear used, this would not be the case in versions were product quality was taken into account.

B.1.3 Quota In Hand

The quota in hand ($Q_{avail,i,j,m,y}$) for subfleet i of fleet j in month m of year y is given by:

$$Q_{avail,i,j,m,y} = Q_{own,i,j,m,y} \cdot \left(1 - {}^{lease}Q_{out,temp,i,j,m,y} - {}^{lease}Q_{out,perm,i,j,m,y}\right) + {}^{lease}Q_{in,i,j,m,y} \tag{B.3}$$

where $Q_{own,i,j,m,y}$ is the quota owned by subfleet i of fleet j in month m; ${}^{lease}Q_{out,temp,i,j,m,y}$ is the proportion of quota owned by subfleet i of fleet j that, as of month m of year y, has been temporary leased to another subfleet (potentially in another fleet, these temporary leases are reset at the beginning of each year); ${}^{lease}Q_{out,perm,i,j,m,y}$ is the proportion of quota owned by subfleet i of fleet j that, as of month m of year y, has been permanently leased to another subfleet (potentially in another fleet, this quota is still owned by subfleet i in fleet j but at the beginning of each year it is automatically traded with the permanent lease partner); ${}^{lease}Q_{in,i,j,m,y}$ is quota leased in by subfleet i of fleet j from another subfleet (potentially in another fleet) as of month m of year y (this is the cumulative total of temporary and permanent leases, the value of this variable is reset to zero at the start of each year and then immediately updated to account for any permanent leases before beginning normal trading or quota use activities).

B.1.4 Profits

Profits in month m of year y for subfleet i of fleet j ($P_{i,j,m,y}$) represents the cash remaining after various costs (calculated using B.1) are deducted from GVP and revenue generated by leasing quota such that:

$$P_{i,j,m,y} = V_{GP,i,j,m,y} + {}^{quota}V_{i,j,m,y} - C_{i,j,m,y} \tag{B.4}$$

with ${}^{quota}V_{i,j,m,y}$ is the value of quota leased or sold to other subfleets or fleets by month m of year y (calculated using the method given in section B.8). As these statistics are reported annually the costs, GVP and profits are dynamically accumulated through the year (meaning that costs accrued later in the year can reduce accumulated cash reserves from earlier months of the year).

B.2 Allocate Quota

Annually once the economic indicators have been calculated, the model then allocates quota before determining the annual effort plan. When initialising the model the initial quota allocations per fleet and subfleet are calculated based on the average proportion of the catch landed by that subfleet in the preceding five years (for Atlantis SE this was calculated using logbook and other catch records). That proportion is then used as the proportion of the initial quota allocated to the subfleet. Once initialised, in all subsequent years a simple proportional allocation of owned quota is used (any leases, permanent or temporary were dealt with after quota was allocated to the owners), such that:

$$Q_{own,i,j,y} = \frac{Q_{own,i,j,y-1}}{Q_{tot,j,y-1}} \cdot Q_{tot,j,y} \tag{B.5}$$

where $Q_{own,i,j,y}$ is the quota owned by subfleet *i* of fleet *j* in year *y*; and $Q_{tot,j,y}$ is the total quota allocated to fleet *j* in year *y*. Typically the proportion of the overall total quota allocated to fleet *j* was calculated in the same proportional way. Obviously these calculations could be simplified by combining the proportional calculations and cancelling terms to give direct allocation from total quota to subfleet holdings, but the two step calculation (total → fleet → subfleet) was kept as it provided the flexibility needed to represent differential TAC reductions across fleets if that is ever needed.

B.3 Determine Annual Effort Plan

Once the quota allocation has been updated the annual effort plan is calculated. The formulation of the decision model that generates this effort plan (and the hierarchy of effort allocation) is based heavily on direct consultation with skippers and operators in the SESSF. It has been supplemented with work by Guyader (2002) and Little *et al* (in prep).

The annual effort scheduling is done at the level of subfleet *i* of fleet *j* and consists of a number of steps:

STEP 1: For each target group in each month the expected return ($R_{e,s,j,m}$) is calculated using:

$$R_{e,s,i,j,m,y} = p_{s,j,m} \cdot \frac{H_{e,s,i,j,m}}{E_{h,i,j,m}} - \gamma_{s,i,j,m} C_{E,i,j,m,y-1} \tag{B.6}$$

Where $p_{s,,m}$ is the sale price of that group in that month, $H_{e,s,i,j,m}$ is the expected harvest of the group in that month by that subfleet (based on updating records of past catches per month), $E_{h,i,j,m}$ is the historical level of effort expended in that month by the subfleet, $\gamma_{s,i,j,m}$ is the proportional contribution of the catch of group *s* to the total per unit effort costs for the subfleet in the previous year ($C_{Ei,j,m,y\text{-}1}$, which is calculated as total costs less fixed and capital costs divided by the level of effort expended in the previous year).

STEP 2: The total expected return for the subfleet is calculated by summing the per group (or species) expected returns.

STEP 3: The total expected return for the year is normalised so that the values per month can be used as proportional weights or probabilities of effort being allocated to that month (depending on which effort allocation method is used, for the purposes of the alternative management strategy project the deterministic weighted model was used, but the probabilistic model has also been implemented).

STEP 4: Target groups (the groups that the subfleet is specifically targeting and bases effort allocation decisions upon) are updated to match those with the highest expected returns (target groups that are no longer both profitable and desirable are stripped from the list and an effort switching notice is entered in the run log/event file).

STEP 5: Calculate Annual Effort Scheduling at monthly resolution

(i) Weighted method

This method was used in the final MSE simulations of this study. Under this model the by month gross effort allocation ($E_{e,i,j,m}$) is initiated using:

$$E_{e,i,j,m} = E_{h,i,j,m} \cdot \frac{R_{e,tot,i,j,y}}{R_{tot,i,j,y-1}} \cdot \gamma_{effort} \tag{B.7}$$

With $R_{e,tot,i,j,y}$ the total expected revenue for the subfleet in month m, $R_{tot,i,j,y-1}$ the realised revenue in the previous year; $E_{h,i,j,m}$ is the historical effort in this month (from updating records of effort per month – the Black book for the subfleet) and γ_{effort} is a scalar to ensure the level of effort is sensible given available quotas – this is calculated using:

$$\gamma_{effort} = \max\left(1.0, \sum_{s} \frac{Q_{i,j,y}}{H_{e,s,i,j,y}} \cdot \frac{R_{e,s,i,j}}{R_{e,tot,i,j}}\right) \tag{B.8}$$

which scales back the effort to be scheduled if the expected catches under that effort level ($H_{e,s,i,j,y}$) exceed the quota that the subfleet already owns or could conceivably obtain through trading. The ratio of returns is used to weight the rescaling to match the perceived value of that species to the subfleet's take.

(ii) Probabilistic method

This method was trialled initially, but was **not** actually used in the final simulations. In this method the effort allocation to each month is done by drawing from a uniform random distribution (form 0 to 1) and comparing that value vs the cumulative distribution of probabilities over the months. Effort is assigned to a month if $\tau_{m-1} < x < \tau_m$ (where τ_m is the cumulative proportion of catch caught by month m and x is the random number) – the amount of effort allocated is either equivalent to one trip's worth or to the remaining possible effort for that month (it is impossible to allocate more effort than the number of boats in the subfleet by the number of days in the month). Once a month is "full" (no more effort possible) it is withdrawn from the distribution, which is recalculated before continuing the iterative allocation process. This iteration continues until all available quota has been accounted for (i.e. the cumulative sum of the expected catches for the year under this schedule matches the quota) or all possible effort for the year has been allocated.

STEP 6: Spatially allocate the scheduled monthly effort.

This step is common to both allocation methods (deterministic or probabilistic). To reflect different behaviours and tendencies of different skipper types the effort scheduled in step 5 is interpolated with historical effort levels with a subfleet specific behaviour weighting – this allows for differential degrees of flexibility and updating (from those who rigidly return to past fishing sites to those who update their distributions quite rapidly). Flexible fisheries weight heavily for the new scheduled effort while traditionalists have low weights on the new schedule and will tend to have a final effort schedule closer to the pattern stored in their Black book. While the weights were largely set to neutrality for Atlantis SE the value for small boats was set to be slightly less flexible than that for larger boats, to capture the greater constraints on the operators of these smaller vessels, which are often constrained by vessel size to remain closer to port (they may even have other shore-based commitments they must also attend to each week). These largely neutral weighting terms mean there is significant potential for distributions to diverge from historic patterns.

This final schedule is then spatially allocated in proportion to the effort applied by the subfleet to each spatial box in each month, so that the planned effort in a box *b* in month *m* by the subfleet ($E_{plan,i,j,b,m}$) is:

$$E_{plan,i,j,b,m,y} = E_{e,i,j,m,y} \cdot \frac{E_{h,i,j,b,m}}{E_{h,i,j,m}} \tag{B.9}$$

With $E_{e,i,j,m,y}$ the scheduled monthly resolved effort for the subfleet, $E_{h,i,j,m}$ the historical levels of effort for the month and $E_{h,i,j,b,m}$ the level of effort by the subfleet historically seen in box *b* in month *m* (like all other aspects of the subfleets historical knowledge of catch and effort, this distribution updates through time).

B.4 Monthly Economic Update

With a monthly frequency the economic indices listed under the Economics Statistics section (B.1) are calculated and stored. The indicators per fleet and subfleet listed in section 2.4.1 of the main text are also tracked dynamically through the course of the simulation.

B.5 Update Vessels

After the economic indices and current profits have been updated for the month the number of vessels is checked – in case some wish to switch gears or leave the fishery entirely. The equations used here are essentially a direct adaptation of the work in Brittany by Thébaud *et al* (2006). This is the most thoroughly researched and best performing model of vessel investment/disinvestment currently available in the form of a process model rather than an optimisation model. As none of the authors had personal experience with this kind of modelling and preliminary tests indicated that it did capture the kinds of decisions seen in the SESSF it was decided to use the model largely as it was formulated for Brittany.

Under this model there is a two stage process regarding which fleet a vessel will fish in any one year, or month in the case of this study (see Figure B.1)

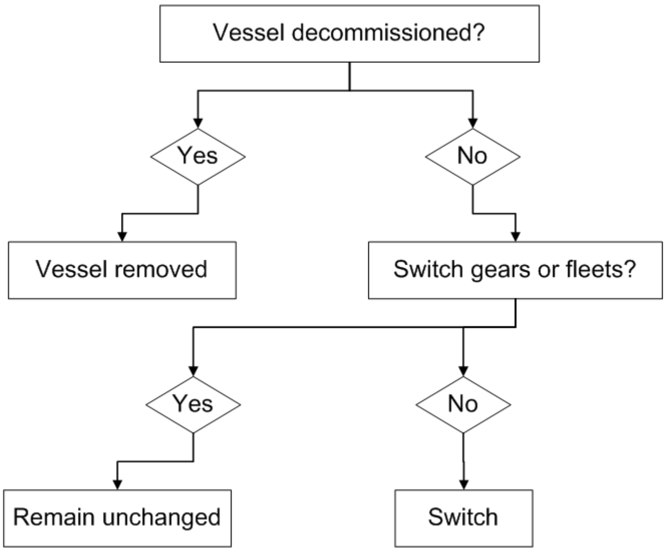

Figure B-1: Schematic of vessel level decision model.

To determine if a vessel will remain in a subfleet the probability of leaving the fishery (τ_d) is calculated using the operator's utility function:

$$\tau_d = \frac{1}{1+e^{-V(R_N)}} \tag{B.10}$$

with the anticipated returns due to the decision is given by the difference in returns from an immediate sale (minus the crew's share) versus the long-term returns that could be gained by keeping the vessel in service, such that:

$$V\left(R_N\right) = \max\left(0, \left(\log\left[\frac{R_d}{L}\right] - C_{crew}\right) - \left(\log\left[\frac{1}{L}\cdot\sum_{t=1}^{n}\frac{V_t}{\left(1+\psi\right)^t}\right] + \frac{R_n}{\left(1+\psi\right)^n} - C_{crew}\right)\right) \tag{B.11}$$

where R_N is the net return of the decision; R_d is the return if the vessel is sold second hand; R_n is the anticipated sale price if the vessel is kept in service another *n* years; *L* is vessel length (m); C_{crew} is the crew costs that must be covered (calculated as log crew share corrected for vessel length); V_t is anticipated net returns of operating the vessel in year *t*; and ψ is the interest rate. This assumes an operator maximises utility by deciding to either decommission their vessel or to remain active in a fishery. Also, as with Thébaud *et al* (2006), logged values corrected for vessel size were used to avoid scaling effects due to vessel size. Note that when a buyback has been included in the management strategy the same calculations are used with R_d set to the buyback vessel value and all vessels deciding to leave the fishery being counted as taking up the buyback. If a forced buyback is included in the scenario and this decision process does not lead to sufficient reduction in fleet size then further vessels are forcibly marked as decommissioned (starting with the most marginal vessels in the fleet).

The probability of switching gear is treated in the same way as (B.11) except that in place of R_d the returns expected under the other gear are used instead (these are calculated based on perfect knowledge of the profitability to date of the other sectors, future implementations of this model should include the potential for lags in information transfer and also the potential for dis-information) and the cost of switching gear is taken into account along with crew costs. Another variant of the switching decision simply compared the expected returns of the alternative gears (with costs and discounting ignored) and shifted vessels to the gear with the most lucrative returns. Both variants were considered and discussed in the main body of the document. Not just any vessel may switch gears. There is an initial (quite large) cost to make a vessel is dual purpose, from that point on it may switch between any permitted gears from trip to trip with a much smaller cost (to do with gear maintenance and labour primarily).

Once the probabilities have been calculated random draws from U(0,1) are used to see if the decision is executed. If the subfleet contains a single vessel then the decision is simply a comparison of the probability and random number and reacting accordingly. In multi-vessel subfleets if the decision to leave the fishery or shift gears is made then the number of vessels actually following through on the decision (N_d) is given by:

$$N_d = \max\left(1.0, x \cdot N\right) \tag{B.12}$$

where $x \sim$ U(0.0,ρ) and ρ is the maximum proportion of the fleet that can shift in any one month. Further to N_d boats may be forced to leave the fishery (by debt) if they have not gone fishing for some time. Note that due to the number of boats in the subfleets and the need to move integer vessels (rather than part vessels) the effect of this draw was effectively a deterministic proportion of the subfleet size.

For a new vessel to enter a fishery there must be an available licence (so if no such licence then an existing vessel must leave) and a random number draw must be less than the following probability for acquiring a new vessel (τ_a):

$$\tau_a = \frac{1}{1+e^{-V(R_A)}} \tag{B.13}$$

with

$$V\left(R_A\right) = \max\left(0, \left(\log\left[\frac{1}{L} \cdot \sum_{t=1}^{n} \frac{V_t}{\left(1+i\right)^t}\right] - C_{acquire}\right)\right) \tag{B.14}$$

where R_A are the expected returns on the new vessel and $C_{acquire}$ is the log of the size corrected cost of purchasing (or building) and equipping a new vessel. The expected returns from the new vessel are based on the current and historical returns of vessels of the same size (provision for technological improvement to scale these returns has not been made in this case, but should be considered in future alternative implementations of the model). This formulation does not see much additional investment unless profits are reasonably high; this may change if a penalty (via increasing maintenance costs) was built in to reflect the costs of maintaining an aging fleet.

Once the final size of the subfleets is settled the Black books are updated to reflect the changes. Even if a subfleet is emptied the effort distribution for a single vessel is left in the Black book in case the subfleet is reactivated into the future (this is done to avoid initialisation issues and is quickly replaced by the updating information of the reactivated fleet).

B.6 Update Ports

Port use and market activity indices are just the sum of the vessels supplying that market or landing their catch in that port. These indices are updated monthly after the number of vessels in the fisheries has been calculated. For the ports the ratio of this activity level to the previous level is used to scale background population growth to produce the port's population status.

B.7 Update Monthly Effort Plan

This component of the effort planning system is again based heavily on direct consultation with skippers and operators in the SESSF.

When updating the annual plan at the monthly level, expected catches and actual catches to this point of the year are compared. If catch is lagging behind, quota is available and more effort is possible then effort is stepped up. Alternatively if catch is beyond expectations the fleet may reduce effort (this reduction is parameterised so that it is possible to represent the case where there is no reduction in effort even if catches exceed expectations). This means the scheduled effort ($E'_{e,i,j,m}$) is recalculated as:

$$E'_{e,i,j,m,y} = \min\left(d_m \cdot N_{i,j,m,y}, E_{e,i,j,m,y} \cdot \max\left(\left(1 - E_{buff}\right), \max_s \left(\frac{H_{e,s,i,j}}{H_{s,i,j,y}} \cdot \frac{1}{\left(1 + l_s\right)^2} \right) \right) \right) \qquad \text{(B.15)}$$

where the first term in the minimum is the maximum possible days fished per month by the subfleet (d_m the days in the month and $N_{i,j,m,y}$ the vessels in the subfleet in that month and year); the (1-E_{buff}) term deals with effort reduction should catches exceed expectations; and the final maximum is picking out the appropriate effort scalar to apply based on which target group produces the biggest scalar. The term l_s is a rank, starting at 0 for the most desirable and profitable target and incrementing as desirability and profitability tapers, so that the most desirable target groups have the strongest influence on the results. Consequently, the most desirable and profitable target group for which current catches diverge differ from expected catches tends to dictate the effort rescaling. The squared power is used so that predicted effort levels better fit observed effort data from the SESSF logbooks.

Expected profits are checked for this effort schedule and compared against what is considered tolerable (losses may even be permissible). If the profits are less than tolerable the effort schedule will actually be reduced to reflect the decision by at least some boats in the subfleet to tie up and not go fishing in this month. If this decision was repeated continuously for a user specified period, a year in this case, then those boats would be forced from the fishery.

B.8 Trade Quota

Two quota trading models have been implemented in Atlantis. One is done on a species-by-species basis and the other is done based on multi-species packages. The later is the model used in the Alternative Management Strategies study for the southeast commonwealth fisheries.

(i) Species-by-species quota trading

This is the quota trading model of Little (2005) and Little *et al* (in prep), interested readers are referred to those papers for further exposition. It was not used here, as it is possible under the multispecies trading method for operators to seek/lease a single species (if that was all that was needed/in excess). Nevertheless, it may be more appropriate in future to use this form of trading when dealing with quota leasing, but use the other form with selling quota (Gerry Geen pers. com.).

(ii) Multispecies trading packages

This was the quota trading model developed for the Atlantis SE model. While supply and demand persists trading occurs following these steps

STEP 1: Each subfleet calculates its personal value for quota for each species.

This calculation uses the fishing quota price model developed in New Zealand by Newell *et al* (2005). This model was used in Atlantis SE, as it captured all the major factors thought to be dictating price setting within the Australian market (Connor and Alden 2001, Tom Kompas and Gerry Geen pers. com.) and preliminary tests showed it did match available information on the price of quota trades. Specifically, the formulation used for quota lease price is:

$$
\begin{aligned}
\ln\left({}^{quota}p_{s,i,j,m,y}\right) = {} & \lambda_1 \cdot \ln\left(p_{s,i,j,m,y}\right) + \lambda_2 \cdot \left(\ln\left(p_{s,i,j,m,y}\right)\right)^2 + \lambda_3 \cdot \ln\left(C_{marg,i,j,m,y}\right) \\
& + \lambda_4 \cdot \frac{H_{s,i,j,y-1}}{Q_{s,i,j,y-1}} + \lambda_5 \cdot \left(\frac{H_{s,i,j,y-1}}{Q_{s,i,j,y-1}}\right)^2 + \lambda_6 \cdot \left(\frac{\sum_{k=1}^{m} H_{s,i,j,k,y}}{Q_{s,i,j,y}} - \frac{\sum_{k=1}^{m} H_{s,i,j,k,y-1}}{Q_{s,i,j,y-1}}\right) \\
& + \lambda_7 \cdot \left(\frac{\sum_{k=1}^{m} H_{s,i,j,k,y}}{Q_{s,i,j,y}} - \frac{\sum_{k=1}^{m} H_{s,i,j,k,y-1}}{Q_{s,i,j,y-1}}\right)^2 + \lambda_8 \cdot \ln\left(p_{s,i,j,m,y} \cdot \frac{H_{s,i,j,y-1}}{Q_{s,i,j,y-1}}\right) \\
& + \lambda_9 \cdot \ln\left(T_{m,y}\right) + \lambda_{10} \cdot \ln\left(G_{m,y}\right) + \lambda_{11} \cdot \frac{Q_{s,i,j,y}}{Q_{s,i,j,y-1}} + \alpha_0 + \alpha_{1,i,j} + \alpha_{2,m} + \varepsilon_{i,j,t}
\end{aligned}
\tag{B.16}
$$

where ${}^{quota}p_{s,i,j,m,y}$ is the average lease price subfleet i of fleet j is willing to pay in month m of year y; $p_{s,i,j,m,y}$ is the market price for group s; $C_{marg,i,j,m,y}$ is the marginal fishing cost for the subfleet; $H_{s,i,j,y}$ is the total catch taken of group s by subfleet i in year y; $H_{s,i,j,k,y}$ is the total catch taken of group s by subfleet i in month k of year y; $Q_{s,i,j,y}$ is the total quota for group s held by subfleet i in year y; T is an environmental index (in this study this term was omitted by setting its coefficient = 0 because no consistent index could be found); $G_{m,y}$ is the GDP growth rate; α_0 is a constant; α_1 are market fixed effects (set to zero in this case as have negligible contribution even in the New Zealand model); α_2 are seasonal fixed effects (also set to zero as have negligible contribution); ε is an error term (set to zero in this case).

STEP 2: Packages are matched between buyers (leasors) and sellers (lenders).

A subfleet is only interested in looking to trade quota if their cumulative catch to date is greater than a trigger proportion of the quota in hand such that:

$$\tau_{trade} = \begin{cases} 1 & Q_{need,i,j,y} < \left(1.0 - \left(1.0 - \zeta + (1-\zeta)\cdot\dfrac{m-1}{12}\right)\right)\cdot\left(\left(Q_{own,i,j,m,y} - {}^{lease}Q_{out,i,j,m,y}\right) + {}^{lease}Q_{in,i,j,m,y}\right) \\ 0 & otherwise \end{cases}$$

(B.17)

where the buyer (leasor) is looking to get in more quota if the expected catch is more than proportion ζ of the quota in hand (set to 0.9 in this case, but with the monthly slide included so that extra quota is not leased needlessly as the year's end approaches).

Similarly a subfleet is only willing to trade if have a large excess they do not expect to fill (that is if the need less than a small trigger level). The calculation used to determine if the seller (lender) is actually willing to sell (lease) is:

$$\tau_{trade} = \begin{cases} 1 & Q_{need,i,j,y} < \left(1.0 - \varphi + (1-\varphi)\cdot\dfrac{m-1}{12}\right)\cdot\left(\left(Q_{own,i,j,m,y} - {}^{lease}Q_{out,i,j,m,y}\right) + {}^{lease}Q_{in,i,j,m,y}\right) \\ 0 & otherwise \end{cases}$$

(B.18)

where the seller (lender) is willing to trade quota if the expected catch is less than proportion φ of the quota in hand (set to 0.2 in this case, but with a monthly increasingly slide built in so that the trigger level rises through the year so a subfleet is not left needlessly holding excess unused quota at the end of the year). This trigger is set low initially so quota that may be needed later in the year is not traded away in the early months of the year.

If willing to be in a trade the difference between total catch (cumulative to date plus expected for the rest of the year) for a species and the quota in hand is used to assess need (if catch > quota; giving Q_x as Q_{need}) or excess available for sale/lease (quota > catch; when Q_x as Q_{avail} (which can also be expressed as a negative Q_{need})):

$$Q_{x,i,j} = \sum_{k=1}^{m} H_{s,i,j,k,y} + \sum_{k=m+1}^{12} H_{e,s,i,j,k,y} - \left(Q_{own,i,j,m,y} - {}^{lease}Q_{out,i,j,m,y}\right) - {}^{lease}Q_{in,i,j,m,y} \quad \text{(B.19)}$$

This representation of quota needed and available for trade means that there is great flexibility in what quota is available on the market. It is possible for quota needed or available to be zero, in which case the traders are only be interested in leasing a single species. Alternatively they may be interested in trading quota for a range of species. The species up for trade are considered to be components of a quota package. Quota owners prefer to trade whole packages rather than subdivide them (though they will do so if a single trade does not exhaust all components of their package on offer). Thus the final need for and availability of quota is compared individually across all willing participants (i..e the need of the leasor is individually compared in turn to the available packages). To find which operators will actually enter into the final trade (i.e. who the buyer (leasor) will trade with) a final "quality of match" index is calculated. This index (${}^{match}Q_{tot,i,j,k,u}$) is a function of species targeting preference (so that the decision is weighted more heavily based on the most desirable as well as the most constraining species), the quota package available across quota species (and how close it is to what's desired) and a friendship measure (between the vessels in subfleet *i* of fleet *j* and the vessels in subfleet *k* of fleet *u*) and has the following form:

$$^{match}Q_{tot,i,j,k,u} = \sum_{s} \frac{\left(Q_{need,s,i,j} - Q_{avail,s,k,u}\right)}{\omega_{i,j,k,u} \cdot \varpi_{tar}} \tag{B.20}$$

where $Q_{need,s,i,j}$ is the demand for species *s* by subfleet *i* in fleet *j*; $Q_{avail,s,k,u}$ is the available quota of species *s* held by subfleet *k* in fleet *u*; ϖ_{tar} is the target preference weighting; and $\omega_{i,j,k,u}$ is the friendship network coefficient from vessels in subfleet *i* in fleet *j* to vessels in subfleet *k* in fleet *u* (various forms of this friendship network were trialled including one where there was no friendship weighting and one that was based on trade data from AFMA, as it has the potential to have a significant impact on model results and there was insufficient data to fully parameterise the network all friendship weightings were set equal for the standard simulations discussed in the main body of this report, work with social scientists would allow further exploration of this facet of the fishery in future studies). The final list of indices across all possible trades is then sorted based on a minimisation – so the package with the least difference between what is desired and available, given weightings due to the friendship network, is finally selected for trade.

Not all quota is leased, some is sold. The decision to sell or lease quota is very similar in principle to the decision to decommission a vessel or continue fishing. Consequently, a modified version of the Thébaud *et al* (2006) model is used to capture this decision making process. The decision whether to buy, permanent lease or simply temporarily lease quota is made based on a uniform random number (~U(0,1)) compared with the following probabilities (which essentially determine whether the returns gained by owning quota make it worth purchasing rather than simply leasing it)[24]:

$$\tau_x = \frac{1}{1+e^{-V(R_x)}} \tag{B.21}$$

with

$$V\left(R_x\right) = \max\left(0, \left(\log\left[\frac{1}{L} \cdot \sum_{t=1}^{n} \frac{V_t}{\left(1+\psi\right)^t}\right] - C_x \cdot {}^{quota}p_{s,i,j,m,y} \cdot Q_{need,s,i,j,y}\right)\right) \tag{B.22}$$

where *x* can be either buy or permanently lease (so there is a probability τ_{buy} of buying quota and a probability of τ_{perm} of permanently leasing quota with associated costs C_{buy} and C_{perm} of making those transactions). If a trade occurs and the random draw is not less than either of these probabilities than a temporary lease of quota is performed. After this trade if remaining demand exceeds zero (i.e. the last trade did not satisfy the entire demand for quota by this operator) then the next operator in the sorted list is traded with until the demand reaches zero, available funds

[24] Note that under the current parameterisation the relative costs of buying quota is so much higher than permanently leasing quota no actual sales occurred during the course of any simulation, only lease agreements were entered into. This makes this model effectively deterministic (in effect).

(including loans, if debt is allowed for, which it is in Atlantis SE) to pay for the transactions are exhausted or the available quota is exhausted.

B.9 Landed Catch

Catch of each group taken in each box is recorded by fleet in the harvest module of Atlantis. To subdivide that amongst subfleets the catch by fleet is simply pro-rated based on the proportion of total fleet effort expended in the box that is due to the particular subfleet. This can be modified by a subfleet specific fishing efficiency scalar, but this feature was not used in the case of the SESSF as there was insufficient data available to parameterise it and it was considered unnecessary given the realised efficiency of the subfleets can vary as is as a result of the differential subfleet vessel characteristics, their different distributions of historical effort, different realised CPUE, marginal returns, quota prices and needs and behavioural weightings. Given so much already varied between the subfleets and that this variation lead to different realised levels of catch and effort (and CPUE) per subfleet an additional explicit fishing efficiency term seemed extraneous in this case (and so was not used).

B.10 Fish Prices

Monthly average fish prices for species (or group) *s* from the Melbourne (1992-2001) and Sydney (1992-2004) markets were fit (separately) using the first order autoregressive model:

$$\hat{p}_{t,s} = \beta_{0,s} + \beta_{1,s} \cdot t + \beta_{m,s} \cdot M_t^T + r \cdot e_{t-1,s} \tag{B.23}$$

where $\beta_{0,s}$ is the intercept term representing the price for group *s* prior to the start of the data in 1992; $\beta_{1,s}$ is the term for the trend in price for group *s*; $\beta_{m,s}$ is a vector representing the seasonal (monthly) pattern in fish price for group *s*; M^T_t is a transpose of a vector of dummy variables weighting the elements of the vector β_m, with the *m* elements (which are 1 if time *t* is in month *m* and 0 otherwise); r_s is the autoregressive coefficient representing the degree of autocorrelation fro group *s*; and e_{t-1} is the first order (lagged) residual:

$$e_{t-1,s} = p_{t,s} - \hat{p}_{t,s} \tag{B.24}$$

This model was fit to the price data for each of the landed groups *s*. The simplex method was used to find the best fit parameterisation that minimises the least sums of squared deviations. The fits were quite good (e.g. Figure B.2), but a useful extension for the dynamical Atlantis model would be the addition of the effects of supply on demand (where large volumes of supply can flood the market and depress prices etc). Another useful extension would be consideration of the quality of product when setting prices.

One price related facet of fishing behaviour that is already represented in Atlantis SE is high grading. That is when quotas are constraining (i.e. enforced quota is in place and the quota of a group has been filled beyond a trigger point, set to 90% in Atlantis SE, or catch in the hold is approaching capacity) then less valuable (typically smaller) size classes and species are discarded in favour of retaining the most profitable (usually larger) size classes and species.

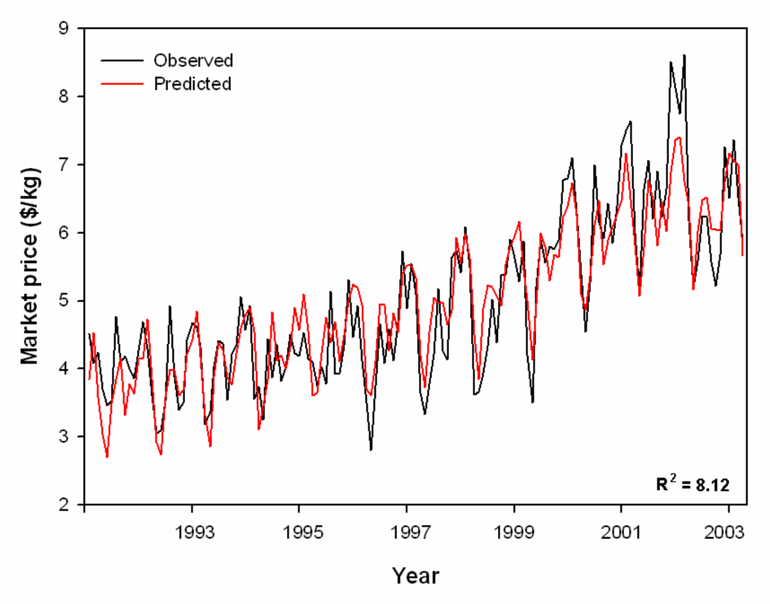

Figure B-2: Market price model for tiger flathead in the Sydney markets.

Note that for ease of interpretation it was also possible to report prices (and thus GVP calculated using those prices) without inflationary trends (using market prices as of 2000), this was done when reporting results in the main body of this report.

B.11 Update Costs and Cash Flow

Once trading and other weekly transactions are complete the costs and cash flow is update at the subfleet level (see section B.1 for cost and profit calculations).

B.12 Final Effort Allocation

This is the final component of the effort planning system used in Atlantis SE and derived based on consultation with skippers and operators in the SESSF. There are two forms of this part of the model, one based on a classic bioeconomic effort allocation model (formulated by Dr Daniel Holland, Gulf of Marine Research Centre), which was not used in this study and one developed specifically as a part of the nested effort allocation model derived based on the behaviour of operators in the SESSF (described here). This later form has a number of steps:

STEP 1: Species with quota remaining are identified (per subfleet). If no quota is available the subfleet cannot target that group and so must try and direct effort away from areas where catch of that group would be likely. Moreover if there is no available quota for any group then they will not fish (species not under quota management are assigned infinite quotas, so it is possible to fish for non-quota species even if quota for species in the quota management system has been exhausted).

STEP 2: A check for scheduled effort in the current month is made, as is a check for whether that scheduled effort has already been exhausted – although if in the last week of the month (or last month of the year) and the total cumulative catch for the year is still less than the allowed quota then the vessel can go beyond what was scheduled. If this check is passed then effort is allocated in the next step.

STEP 3: Effort is allocated by considering: whether there is sufficient expected return to justify going to sea (if not a percentage of the fleet, which is based on the difference between expected and sufficient returns, remains in port) and whether quota remains (or quota management not in use). If these checks are passed then effort is allocated based on expected returns, with the form of the spatial distribution dependent on trip length, costs, catch plans at higher temporal steps and the spatial distribution of the target groups. The optimal map based on CPUE (${}^{CPUE}E_{i,j,m,b,y}$) is constructed across target groups - weighting by target preferences - and then constrained by spatial management zoning. It is still possible for a non-zero value in a cell covered by a spatial closure (due to historical knowledge of the area), but subsequent steps in the harvest execution model (see Fulton *et al* 2005) will see that effort deflected to other accessible cells (unless infringement is allowed, in which case at least some part of the effort will play out as initially mapped). ${}^{CPUE}E_{i,j,m,b,y}$ is given by:

$$ {}^{CPUE}E_{i,j,b} = Z_{m,b} \cdot E'_{e,i,j,m,y} \cdot \frac{E_{i,j,m-1,y}}{H_{i,j,m-1,y}} \cdot \frac{\sum_{s} H_{s,i,j,m-1,b,y}}{E_{i,j,m-1,b,y}} \qquad \text{(B.25)} $$

where $Z_{m,b}$ is the proportion of the box *b* open to fishing to fleet *j*; $E_{i,j,m-1,y}$ is the total effort expended by the subfleet over the last month; $H_{i,j,m-1,y}$ is the total catch landed by the subfleet over the last month; $E_{i,j,m-1,b,y}$ is the total effort expended in box *b* by the subfleet over the last month; $H_{i,j,m-1,b,y}$ is the total catch from box *b* landed by the subfleet over the last month; and $E'_{e,i,j,m,y}$ is the scheduled effort for the month in the current year.

A tentative effort distribution is then calculated by interpolating between the CPUE-based effort distribution and planned (historical knowledge-based) effort locations. This interpolation allows for a shift as information spreads. This spread of information can be constrained by a subfleet specific operator flexibility index (to capture the willingness or ability of fishers to respond to new information, which may be constrained by either personality or fisheries independent considerations to do with supplementary employment or familial commitments).

$$ {}^{temp}E_{i,j,b} = \gamma_f \cdot \left({}^{CPUE}E_{i,j,m,b,y} - {}^{curr}E_{i,j,b} \right) + {}^{curr}E_{i,j,b} \qquad \text{(B.26)} $$

with γ_f is the flexibility index and ${}^{curr}E_{i,j,b}$ is the current effort in box *b*.

The new effort (${}^{new}E_{i,j,b}$) distribution (in terms of days at sea) is then calculated using (B.27), given below, which is an interpolation of this ideal but tentative effort distribution and the current effort map, constrained by costs, operator behaviour, and trip length (with the final effort clipped at the maximum possible time fished per month if that would be exceeded). This prevents vessels fishing more than is physically possible in a single month while simultaneously preventing the vessels "teleporting" around the map in unrealistically short time periods (and so better captures steaming).

The cost weighting of the interpolation is based on the distribution of effort contributions by ports currently used by this subfleet – basically distance from the port to the fishing grounds, we well as social and economic forces (such as variable costs, including fuel costs) dictate whether vessels in subfleet from port *x* will visit box *b*. In this way tension between costs and social behaviours that causes fishers to either stay close to home or go far out to sea (even when not economically efficient to do so) can be captured.

$$\begin{aligned} {}^{new}E_{i,j,b} = \varpi_d \cdot \sum_n \frac{v_{boat}}{C_{i,j,fuel}\sqrt{\left(x_n - x_b\right)^2 + \left(y_n - y_b\right)^2}} \\ \cdot \max\left(1.0, \left(\frac{v_{boat}}{w_{region}}\right)\right) \cdot \left({}^{temp}E_{i,j,b} - {}^{curr}E_{i,j,b}\right) + {}^{curr}E_{i,j,b} \end{aligned} \qquad \text{(B.27)}$$

where ϖ_d is the weighting showing impact of social and economic costs on effort allocation decisions; v_{boat} is the steaming speed of a fishing boat; w_{region} is the width of the region in metres; (x_b,y_b) is the coordinates of the fishing ground (or box midpoint); (x_n,y_n) is the coordinates of port n; and $C_{i,j,fuel}$ are fuel related variable costs (so that boxes that are far from port are penalised due to the higher costs associated with steaming there).

The actual effort applied in box b by the harvest model is determined by taking this new distribution and multiplying by shot length per day (t_{shot}) and the scheduled effort (standardised per month) to get final realised effort per day fished for use in the harvest sub-model (this is only updated once per week at present, with provision for multi-week trips).

$$E_{i,j,b} = t_{shot} \cdot \frac{E'_{e,i,j}}{30.0} \cdot \frac{{}^{new}E_{i,j,b}}{\sum_b {}^{new}E_{i,j,b}} \qquad \text{(B.28)}$$

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