Final Report

Use of economic incentives to manage fisheries bycatch

An application to key sectors in Australia's Southern and Eastern Scalefish and Shark Fisheries

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Important Disclaimer

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This Report combines and adds to the material and results submitted in previous project research reports:

- **Review of the Use of Incentive Based Management Systems to Limit Bycatch and Discarding.** Sean Pascoe, James Innes, Trevor Hutton, David Galeano, Dan Holland. Report to the Australian Fisheries Management Authority February 2009, and
- **Modelling Bycatch and Discard Incentives**. Trevor Hutton, Sean Pascoe and Beth Fulton. Report to the Australian Fisheries Management Authority February 2009
- **Milestone 1: Modifications to SEF Atlantis model undertaken to allow different incentive structures to be simulated.** Trevor Hutton, Beth Fulton and Sean Pascoe
- **Milestone 2: Use of economic incentives to manage fisheries bycatch: an application to key sectors in Australia's Southern and Eastern Scalefish and Shark Fisheries.** Trevor Hutton, Beth Fulton, Sean Pascoe and Olivier Thebaud

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1 Executive summary

The objectives of the project were to assess the potential for the use of incentive based management measures for the management of bycatch in Australian fisheries. The project consisted of two parts; the first part being mainly review focused to identify a set of potential management measures, and the second being to estimate how these measures may perform for a complex multispecies, multi-fleet fishery.

Review of incentive based measures for bycatch management

The increasing potential of incentive based measures for management of targeted fish species is well recognised, and is attracting increasing attention for the management of bycatch and discarding in fisheries. By creating an appropriate set of incentives, fishers are more likely to behave in a manner consistent with the objectives of management. Incentives can be created through a number of mechanisms, such as creating appropriate user rights in the fishery, financial penalties or rewards, marketing incentives (such as ecolabelling or restrictions on market access), and changing fisher and society's perspectives through social pressures.

In terms of potential management instruments, the use of rights based and financial approaches offer the greatest potential. Marketing approaches have largely been driven by external agencies, while changing social perceptions is a longer term option and falls outside most fisheries agencies potential set of management instruments.

To date, actual examples of incentive based measures are limited in fisheries, with most real-life examples drawn from New Zealand and parts of North America (Alaska in particular). Numerous modelling exercises had been undertaken in different parts of the world to examine the potential efficacy of different management systems.

On the basis of a review, we conclude that deemed values appear to offer benefits in terms of providing incentives to reduce discarding and also incentives to balance catches at the end of the year. A deemed value approach involves charging fishers a proportion of the landed value for any catch of quota species for which they do not hold quota. The system is aimed at reducing discarding of over-quota catch by providing an incentive to land this catch, but ideally no incentive to continue to target it. However, previous reviews have raised the problem that potentially higher catches of quota species may occur under a deemed value system.

For non-quota fish species and other marine species (megafauna and charismatic species), bycatch quotas may offer some benefits in terms of reducing overall bycatch. A potential alternative to bycatch quotas is to directly impose a penalty on the capture of these species, thereby providing an incentive to avoid their capture. Unlike the non-quota fish species, the capture of megafauna (and rare fish species) is likely to be less frequent and readily observable using video surveillance techniques.

Modelling incentive based measures in the SESSF

The potential effectiveness of incentive based bycatch management is examined using the Atlantis ecosystem model of the Australian South East fishery. The management measures considered include deemed values, bycatch quotas, and bycatch taxes. The aim is to ascertain which alternative economic management instruments are more or less appropriate for different types of bycatch issues (e.g. discarding of commercial quota species, catch of non-quota species, and catch of charismatic species).

The results of the modelling analysis illustrate the high degree of complexity which arise from the interaction of ecological changes and fishing fleet dynamics (through effort allocation, quota trading and investment decisions) in response to management intervention. Overall, all the scenarios lead to a more or less transitional reduction in fishing activity (especially in the case of the demersal trawl fleet), catches and landings, and to various impacts with respected to bycatch and discards.

We summarise the main response patterns as such:

For <u>bycatch quotas</u>, when applied to species of conservation concern (e.g. megafauna such as whales, dolphins and seals), the quotas pose a minimal incentive to avoid areas where these species occur since, historically, there has been relative little contact with these animals. For cases where the species were caught by a few fleets only, the initial allocation of catch shares being defined as a proportional reduction in incidental catches as compared to historical levels, the opportunities for trading quota for these species were fairly limited. Hence the quotas impacted the fleets in a similar way as non-tradeable individual quotas would have, constraining fleets at reduced levels of effort and catch. For rare commercial species such as Cardinalfish, the bycatch quota does lead to a positive effect in terms of its function – that is the catch of these fish are reduced. However, the restrictive quotas impose constraints on the operational variability of the fleets.

The introduction of a <u>financial penalty</u> on the catch of species of conservation concern (e.g. the megafauna such as whales, dolphins and seals) also led to initial reductions in the fishing activity of the fleets directly impacted. Given the size of the animals that are of conservation concern (e.g. whales) when contact is made with them the financial burden can be quite substantial, effectively closing down operations for that fishing vessel. In the case of fish species (e.g. Cardinalfish) that have some market value there was a more immediate impact on the decision making, which was graded to some extent with the level of the tax, but perhaps not as much as immediately anticipated by economic theory, because each species makes only a relatively small contribution to the aggregate return in such a multispecies fishery.

For the <u>deemed values</u> there was almost an on-off switch effect. Where quota is constraining (which it is not the case for a number species, except species such as Morwong) then providing even the smallest deemed value for these species is sufficient to induce increases in landings. Overall, both the deemed value scenarios lead to a reduction in fishing activity, catches and landings, and to contrasted impacts with respected to bycatch and discards at a species-by-species level.

A feature of the Atlantis model is that it incorporates a fleet dynamics model that allows the main fleets to adjust their fishing behaviour in response to the incentives. Direct and indirect effects of these measures impact on the fleets (and their catches and discards) via a cascade of complex linkages that are modulated by fleet spatial movement, quota trading and investment decisions. The model also enables ecological effects to be estimated, as changing catch patterns impact the structure of the fishery, with both direct and indirect economic and ecological consequences.

This research represents a first test-case application of an ecosystem model that includes fleet behaviour, to various model simulations of bycatch incentive measures (e.g. deemed values). The results herein have been obtained based on a calibration of the model to historical data for the SESSF, and using simple scenarios concerning the adoption of bycatch management measures. These illustrate the high degree of complexity which results from the interaction of ecological changes and fishing fleet dynamics (through effort allocation, quota trading and investment decisions) in response to management intervention. They should thus be considered tentative, as the detailed sequence of direct and indirect effects that impact on the fleets (and their catches and discards) via a cascade of complex linkages still require a full exploration and some clarification in terms of processes. The research presented is very much a first step, which has resulted in an improvement in the calibration of the model.

2 Introduction

In this study the potential effectiveness of incentive based bycatch management is examined using the Atlantis ecosystem model of the Australian South East fishery. Management measures examined include deemed values, bycatch quotas, and bycatch taxes. A feature of the Atlantis model is that it incorporates a fleet dynamics model that allows the main fleets to adjust their fishing behaviour in response to the incentives. It also enables ecological effects to be estimated, as changing catch patterns impact the structure of the fishery, with both direct and indirect economic and ecological consequences. The model is used to assess the potential impacts of different types of instruments for different types of bycatch issues, such as the discarding of commercial species or the catch of non-commercial species, including charismatic species.

The issue of bycatch is an inevitable consequence of fishing with non-selective or semi-selective gear on a multitude of fish species (Hall 1996), especially in an output-based system with quotas on the main targeted stocks. In a multi-stock multi-fleet context with gear that can not select the exact output mix required by the production unit the resultant consequences are unwanted catch of commercial species (over-quota), unwanted fish (under-size, low value) as well as bycatch of various other marine organisms (e.g. turtles, seals, birds dolphins, sea-snakes) some of which are rare and endangered. If gear is towed along the bottom of ocean, then bycatch can include whatever is removed by the net from the benthic environment, along with the target fish. In many instances, bycatch is discarded back at sea, as its commercial value is low or nil, whereas the costs of retaining and landing this catch, including opportunity costs, can be high. While discarding itself is not economically irrational (Arnason 1994), it is increasingly seen as a wasteful and unstainable practice (Hall *et al.* 2000), to the extent that some fisheries have banned discards in total, as is the case in some Norwegian fisheries.

The economic justification for decisions by fishing operators to land or discard any given species was reviewed by Pascoe (1997). Such decisions reflect the incentives and disincentives associated with either landing or discarding fish caught in the course of fishing operations. Bycatch (strictly, non-targeted catches) which have a positive expected commercial value, taking into account the opportunity costs of retaining and landing this catch (e.g. due to the uptake of holding capacity or processing time on-board fishing vessels) and the anticipated costs and benefits of exceeding individual catch allocations in quota-managed fisheries, will be landed as byproduct. Any non-targeted catch with zero commercial value (such as marine mammals), or the expected retaining and landing costs of which are higher than the expected benefits, is expected to be discarded. In this report the term “catch” refers to what is caught by the gear, whereas “landings” are the portion of the catch that is returned to the port.

Managing multi-stock, multi-fleet fisheries in order to reduce such discards is problematic due to the complex technical interactions which occur between fishing activities, where the selectivity of fishing gears does not match the differential productivity of fish stocks, and its temporal and spatial distribution. This is especially true for trawl gear, although gillnet and longline gear are also relatively non-selective resulting in catches of rare species and marine species such as seabirds. Where such fisheries are regulated mainly through output controls (i.e. setting total allowable catches for each of the fish stocks targeted by the fleets), discrepancies will usually be observed between the structure of catch limitations and the composition of what is landed on deck for any given haul. This leads to what is termed the "catch-quota balancing" problem in multi-species fisheries managed with output controls (see references in Sanchirico *et al.* 2006).

A large majority of management regulations aimed at reducing bycatch and discards have focused on so-called technical solutions, aimed at better adjusting the selectivity of fishing gear to patterns in the abundance and accessibility of targeted catch. There have been many attempts to run bycatch mitigation gear trials which have led to less catch of small fish, or of megafauna such as turtles, or dolphins, via different technical "fixes", for example turtle- or seal- excluder devices (see e.g. Tilzey *et al.* 1996). Physical changes to gear have been successful; however they do not represent the full range of possibilities for avoiding or reducing the capture of bycatch (with consequent discarding). The use of economic incentives to modify behaviour to various degrees is another option (Grafton *et al.* 2005). If it is less economically viable (due to a financial penalty) to fish for a target species with a certain gear, in an area and during a season where catches include a high percentage of unwanted catch, skippers may choose to modify their fishing strategies, despite the costs of doing so, thus reducing bycatch and discards.

The aim of this study is to analyse the potential effectiveness of such an approach to reduce bycatch and discards in mixed fisheries, using the Australian Southern and Eastern Scalefish and Shark Fishery (SESSF) as a case study. The approach is based on the ecosystem simulation model Atlantis which was developed for this fishery (Fulton *et al.* 2007). A set of incentive-based bycatch regulation strategies were implemented in the model, and used to test the potential applicability of a range of incentive-enhancing management options for the fishery, with a focus on the South East trawl and Danish seine fleet, although many of the measures in place impact extensively on the major net and line fleets. The model allows one to predict the discard levels generated under the management and economic conditions that exclude incentive-based bycatch regulations, and to quantify the implications of alternative incentive systems on discards as well as on the profitability of the fleets and the status of both commercial and non-commercial marine species. In order to elicit feedback within the scientific community an attempt has been made to present the material in journals and at scientific conferences (Appendix A).

The report is structured as such: following an Introduction, Section 2 reviews existing approaches to incentive-based bycatch reduction strategies leading to the identification of scenarios for model analysis. We undertake a thorough review attempting to cover the full spectrum of options available. Section 3 presents the case study to which the scenarios were applied ('the South East Australian Commonwealth Fisheries'); Section 4 provides a synthetic description of the modelling approach using Atlantis and the scenarios tested. The final chapters of the report present, firstly the results of the simulation runs (Section 5) and then secondly a discussion (Section 6) on the results obtained, the utility of the approach and future work.

3 Economics of bycatch and discarding – a brief overview

The economics of bycatch and discarding has been well established in the literature (Anderson 1994b; Arnason 1994; Boyce 1996; Pascoe 1998). In this section, the main economic incentives affecting discarding will be briefly outlined[1].

3.1 Why do we get bycatch and discarding?

Classical economic models of fisheries assume a single species exploited by a homogeneous fishing technology. In reality, most fisheries are more characterised by joint production. That is, the application of fishing effort results in the catch of a number of species simultaneously. This is a result of less than perfect selectivity of fishing gear, and overlapping populations of marine species. Further, heterogeneity in fishing practices, gear types and skipper skill all contribute to differing catch compositions across the fleet.

Joint production in itself is a necessary, but not sufficient condition for discarding. The decision to land or discard an individual fish will depend on a number of factors. Discarding involves costs in terms of sorting the catch and the labour costs[2] involved in discarding the good itself. These latter costs are likely to be negligible at the margin, but exist nevertheless. Landing a product also results in costs, including the costs of storage on board (which could also involve an opportunity cost if the hold space was limited), labour costs involved in unloading, and the costs associated with getting the product to market (e.g. ice, freight etc). Fishers have an incentive to land the product only if the price received exceeds the costs of landing. Where a species has no commercial value, fishers would incur a net cost in landing the product so would discard it. This is true under any management system. Even under a discard ban, economically rational fishers would only comply with the ban provided the cost of landing the product was less than the expected fine from discarding, taking into account the probability of detection and the size of the fine if detected.[3]

Management creates additional incentives to discard some of the catch of commercial species. For non-commercial species, the decision to discard is effectively independent of the management system as the market provides no incentive to land the product in any case. With minimum landing sizes, the market value of an undersized fish is effectively zero, so incentives exist to comply with the regulation.

[1] This section is an extract from an internal report co-authored by Sean Pascoe, James Innes, Trevor Hutton, Michael Tudman and Dan Holland, as part of the milestone reports presented to AFMA. It has subsequently been accepted for publication in an expanded form, drawing on some additional examples provided by a number of additional contributors. The full reference for the expanded paper is presented in Appendix A.

[2] In most fisheries, crew payments are linked to either the level of revenue or the level of trip profits (revenue less the variable trip costs). As this is not linked to time (e.g. $/hour), it could be argued that labour involved in sorting, discarding and unloading is costless. However, crew labour still has an opportunity cost, namely the activities the crew could be engaged in if not involved in sorting and discarding.

[3] Social incentives can be created to counter this, as will be discussed in subsequent parts of the report.

The greatest incentives to discard commercial species in multispecies fisheries are created under an output control system, primarily as a result of catching species for which quota are not held. In fisheries characterised by perfect joint production, over-quota catch could be effectively eliminated by ensuring that total allowable catches (TACs) of the species were aligned with the catch composition. Quota trading would allow individual fishers to balance their individual holdings with their catches (Sanchirico *et al.* 2006). However, most fisheries are not characterised by pure joint production, but instead may be “mostly” joint. That is, the composition of the output mix may have some discretionary element. This is expected to be the case in most fisheries, where fishers may be able to increase the proportion of one species or another in the catch through varying their targeting behaviour, although the result output is still a combination of several species (Squires 1987; Pascoe *et al.* 2007; Pascoe *et al.* 2008). In such a situation, bycatch and discarding is less a technological problem, but also a function of fisher behaviour (Abbott and Wilen 2009) Under such a scenario, aligning TACs with expected catches become more complex, as managers will need to anticipate fisher behaviour.

The relative abundance of different species varies considerably across a fishery, and is affected by a range of factors many of which are either unknown or poorly understood, and which are impossible to predict given the state of knowledge. Consequently, catch compositions effectively contain a random component. Imperfect information about relative species abundance in any place or time may result in catch compositions diverging from quota holdings. The additional cost of purchasing/leasing additional quota to cover unanticipated catch reduces the benefits of landing this catch.

A further form of discarding associated with output controls is highgrading. Highgrading occurs when fishers discard lower grade catch of commercial species in order to retain quota for use for the higher grade catch of those species (Anderson 1994a). Usually, highgrading is size related as prices (per kg) tend to increase with size for most commercial marine species. A fisher's incentive to highgrade increases the more ex-vessel prices are differentiated by size or quality of individual fish (Squires *et al.* 1998).

Although once seen as a major problem for individual quota management (Copes 1986), highgrading is potentially less of an issue than over-quota catch, and with increasing fuel prices is likely to become even less of an issue. Highgrading is only economically viable as a strategy if the price differential between the grades exceeds the cost involved in replacing the discarded portion of the catch. Empirical studies in Iceland suggest that highgrading in trawl fisheries is generally less than 5 per cent of the catch (Kristofersson and Rickertsen 2005).

3.2 Potential incentive based systems to reduce bycatch and discards

From the above, the level of bycatch and discards are influenced by the set of incentives facing fishers. Consequently, changes in the incentives facing fishers may have a positive impact on both the level of bycatch and discards.

A hierarchy of potential incentive based bycatch management systems is presented in Figure 1. Incentives can be created by influencing the rewards from fishing, or by placing soft constraints on fishing activities. Soft constrains, such as a bycatch quota, differ from hard constraints, such as an area closure, as fishers are able to adjust the level of their individual constraint through quota trading. Financial incentives include the use of taxes, subsidies or bonds. The first two directly affect the returns from different fishing activities, while the latter provides an incentive for fishers to minimise their impacts through either technological measures or behavioural changes. Incentives can be externally imposed through restrictions on access to markets unless a set of environmental standards are achieved. As with bonds, how these outcomes are achieved is generally best left to the fishers (although some market access restrictions impose particular technologies on the fleet).

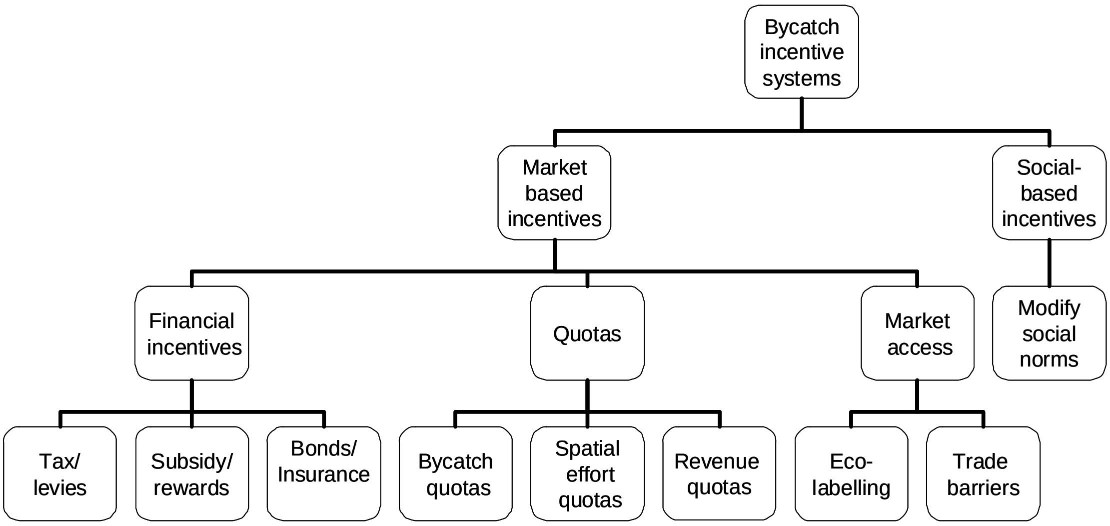

Figure 1 - Hierarchy of incentive based bycatch management systems

Behaviour can also be modified through social based incentives. These involve modifying behaviour through changing attitudes.

These incentive based systems will be presented in more detail in the following sections of the report.

3.3 Financial incentives

Financial incentives aim at changing behaviour through either rewarding or penalising different types of outcomes. Rewards involve subsidies.

3.3.1 Direct subsidies

The use of subsidies to reduce bycatch and discarding is limited in fisheries. Where subsidies exist, these are usually related to reducing the cost of fishing gear to encourage their adoption (Cox and Schmidt 2006).

The use of subsidies in fisheries is generally discouraged, and there is international pressures to reduce subsidies in fisheries (e.g. from FAO and OECD). At a global level, subsidies to the fishing industry are one of the key factors that have led to overcapitalisation and overexploitation in many fisheries. Even “environmentally friendly” subsidies can result in increased exploitation by reducing the cost of fishing (Cox and Schmidt 2006).

Given this, direct subsidies are not considered a desirable method for reducing bycatch. Indirect subsidies, such as research and development of environmentally friendly fishing gears remain an acceptable option. However, these do not provide a direct incentive to fishers so are not considered an incentive based management system.

3.3.2 Tax-based systems

Bycatch is an unpriced input factor in the production process. As such, there is no incentive for fishers to limit bycatch except through the opportunity cost it imposes in terms of time (i.e. to dispose of the bycatch) and the potential effect on harvest (i.e. the consumption of bait and hooks that might otherwise catch fish). Pricing bycatch appropriately provides incentives for fishers to adjust their production and fishing effort allocation accounting for these additional costs, and provides an incentive for fishers to adopt technologies that reduce these costs through reducing bycatch.

Explicit prices for bycatch can be implemented through a bycatch tax system, where fishers pay a fee for each unit of bycatch caught. A tax system in this regard is a fee or levy charged by government for access to the bycatch resource, and is not related to the revenue or profitability of the vessel. Fishers are able to explicitly balance the benefits of fishing in a given area or time period (i.e. the value of the retained catch) against the costs of fishing, including the cost associated with bycatch. An advantage of such a tax system is that, theoretically, different species can attract different tax rates thereby ensuring the greatest protection to the most vulnerable species.

The potential benefits of a bycatch tax in reducing the level of bycatch have been demonstrated by a number of authors (Sanchirico 2003; Diamond 2004; Herrera 2005). These have generally considered bycatch of non-commercial species that are normally discarded, including also bycatch of megafauna (e.g. seals, turtles, seabirds). Fishers have an economic incentive to land byproduct species.

Despite the demonstrated theoretical benefits in terms of reduced bycatch, bycatch taxes are not currently use in any fishery as a management measure (Sanchirico 2003). Where they have been proposed, they have generally been considered as politically unacceptable (Brown 2000). Bycatch taxes are perceived as a means of transferring any economic profits generated through management to the government via the tax revenues, and fishers are no better off financially than under un-regulated conditions (Sanchirico 2003).

Although not considered in any of the theoretical analyses, a bycatch tax system would be very difficult to enforce. Fishers have no current incentive to declare their level of bycatch at present, and imposing a tax on any declared bycatch/discards would provide a greater disincentive to comply. Observer coverage would need to be substantial, and the costs of the observer program may be considerable. Using revenues raised from bycatch taxes to cover the costs of observers may offset these costs. However, the net social gain from the reduced bycatch may be negligible if not negative once these enforcement costs are considered. Further, if fishers change their behaviour in light of the tax system (as it is intended to achieve), then revenues from the tax will decrease while enforcement measures will need to be retained at the same level.

A form of tax has been applied to reduce the level of discards of over-quota bycatch. The New Zealand *deemed value* system is one such approach (see Box). This was initially aimed at reducing over-quota discards rather than the quantity of over-quota bycatch. The deemed value approach allows fishers to land and sell over-quota catch, but pay a fee (NZ$/kg, varying by species and stocks) in order to do so without prosecution. The effective price received for the fish is then the market value less the deemed value. The deemed value charged to the fisher increases as their level of unaccounted for (i.e. over-quota) catch increases (Peacey 2002). The objective of the deemed value fee is to provide sufficient incentive to land the over-quota catch, but not sufficient incentive to target the species (Sanchirico *et al.* 2006). In addition, as the annual level of the deemed value charged to the fisher (i.e. $/kg) increases as their level of over-quota catch increases, incentives are created to seek quota to cover the catch rather than just pay the penalty (Peacey 2002).

A similar system is used in Iceland. Boats are permitted to “carry back” five percent of their next year’s quota allocation to cover over-quota catches. Catches above this five per cent carry-back provision must go to the local auction house, where the proceeds are split between the government (80 percent) and vessel owner (20 percent) (Sanchirico *et al.* 2006). As with the NZ deemed value, the 20 percent that the vessel owner gets is to pay for the variable costs of fishing, and crew wages in particular (Sanchirico *et al.* 2006) as these are related to the value of catch.

Box: The New Zealand QMS

In 1986, the New Zealand quota management system (QMS) was created and included 17 inshore species and the 7 offshore species of the deepwater enterprise allocation system. Today, the QMS includes essentially all the commercially valuable fish stocks taken inside the New Zealand Exclusive Economic Zone (EEZ) as well as a number of stocks with little or no commercial value. The government's goal is to include all "fish" stocks (including invertebrates and some seaweeds but not marine mammals) that are commercially valuable or where sustainability concerns could arise as a result of fishing (Bess 2005).

A direct result of the comprehensive nature of the QMS is that most of the fish stocks in the QMS are part of multispecies complex. Many are taken primarily as incidental catch when targeting other stocks or groups of stocks. Discarding at sea is prohibited for most QMS stocks and has been since the inception of the QMS. If a fisher's catches exceeded his quota holdings (including quota borrowed from the next year) the Fishery Act 1983 provided five "defences" which would allow the fisher to avoid revocation of his permit and continued fishing: (1) surrender the fish to the Crown; (2) obtain additional quota; (3) count the fish against another's quota (CAAQ); (4) use quota of another species as allowed through the bycatch trade-off scheme; or (5) pay deemed value. These last two options are described in more detail below.

The deemed value system is one of the most important mechanisms for dealing with imbalance of catches and quota in New Zealand. Deemed values are monetary payments made to the Crown as a defence for landing catch of QMS species for which the individual holds no catch rights. Deemed values have been used since the inception of the QMS. Fishers are charged an interim deemed value on any catch that is not balanced with ACE by the 15th day of the following month. The interim deemed value is typically half of the annual deemed value. If the fisher later acquires ACE to balance that catch, the interim deemed value is refunded. If not, at the end of the year, the fisher is charged the difference between the interim and annual deemed value. Effectively, the deemed value system creates a dual price-quantity management regime since it is legal to land catches in excess of the TACC as long as the deemed value is paid. Deemed values have been used to provided flexibility for some low knowledge bycatch stocks, defined as fish stocks for which there is relatively little information on their biological status and about which there are no sustainability concerns.

The key advantage of such a tax is that information on total catches of quota species are potentially less distorted by the quota system. However, such a system does not completely eliminate the potential for discarding over-quota catch. Given the costs of landing over-quota catch (including the opportunity cost of the hold space it consumes), if the residual return (i.e. price less the deemed value) is too low, the fishers are still likely to discard the catch. Conversely, if the residual value is too high, incentives can be created to increase the catch. This is not necessarily targeted over-quota catch, but as the returns from the set of all species caught will increase, effort expended in that area will correspondingly increase.

Consequently, a system without a deemed value-type tax may result in less total over-quota catch, but more discarding. Trade-offs need to be made about the value of the additional information obtained, higher incomes to the fishers, and potentially higher bycatch rates. Prohibitions on the sale of bycatch reduces the bycatch level, but they also reduce social welfare (Boyce 1996).

3.3.3 Assurance and insurance

Assurance, or performance, bonds are economic instruments commonly used in environmental management (Shogren *et al.* 1993; Cornwell and Costanza 1994; Ferreira and Suslick 2001; Bagstad *et al.* 2007). In most applications, assurance bonds require the user of the resource to place a sum of money deemed equivalent to the potential damage that the activity can have on the environment. This bond is refundable provided the damage is not incurred, or is repaired by the resource user (e.g. through offsets or habitat restoration work).

In the context of fishing, the instrument would require the industry to place funds into a trust. These funds would be returned provided the industry achieved a pre-determined performance target in terms of bycatch reduction against some base level. Such a system could operate at either the individual level or at the level of the industry, with each industry member having joint and several liability for the actions of industry as a whole. This latter option creates incentives for self-regulation and fosters collaboration in terms of information sharing (e.g. how to avoid the bycatch). However, it may also create perverse incentives: if the individuals believe the industry target will be exceeded, they have no individual incentive to reduce their own bycatch and incur the additional costs in doing so. As they would have already contributed to the fund and believe these to be lost, they have no incentive to incur additional costs by bycatch avoidance. This is effectively the prisoner's dilemma – it is in everyone's interest to collaborate, but if trust regarding the behaviour of others is absent, then it is in each individual's interest not to collaborate. Once the trigger level has been exceeded and the bond is lost, there is no incentive for any further bycatch reduction.

Even if individuals initially believe that others are reducing their bycatch, there may still be incentives for some individuals not to conform. As avoiding bycatch results in increased costs to the fisher, some will choose to free-ride on the behaviour of others and not reduce bycatch. Eventually, this behaviour will create the belief that the bond is lost, with bycatch increasing again. Consequently, although a fishery level assurance bond has the potential to be self regulating, the incentives to the individual not to comply will most likely result in this being ineffective as a bycatch management option.

Fishery level assurance bonds may only be viable in relatively small fisheries, where individuals are aware of each other's activities and are able to influence the set of behaviours. In such fisheries, self regulation may be possible. In larger fisheries, free riding, and expectations of free riding, are likely to result in the bond effectively being a fixed cost of operation.

Assurance bonds could be levied at the individual fisher level. However, as with bycatch taxes, there is no incentive for fishers to accurately report their level of discarding, and widespread surveillance coverage would be necessary. Electronic surveillance systems may be suitable for such a task (e.g. video recording each haul; weighing each haul and determining discards as the difference between total landed and caught weight, etc).

An alternative to an assurance fund would be *insurance*, where fishers would contract to undertake financial liability. The key difference between and assurance and insurance bond is that with the former, the funds need to be provided up-front before fishing can take place, whereas in the latter the industry only need to raise the funds in the event that the performance is not achieved. Both effectively represent a fine for non-performance. A potential benefit of an insurance-based system is that the risk could be potentially sold on the insurance market, with industry members paying a premium to the insurer.

Where the insurance market is used to spread the risk, the premiums paid would reflect the insurer's perception of the probability of liability, which in turn will be influence by the fishers' past performance and adoption of mitigation technologies. Poor performers in terms of bycatch would most likely incur a higher premium, while adoption of mitigation technology may attract a discount. This would provide additional incentives for individuals to modify their behaviour.

Such schemes are most likely to be effective when the chance of bycatch incidence is relatively small, and is highly observable. For example, bycatch of turtles and marine mammals are more readily observable, and potentially more avoidable than general bycatch of non-commercial species.

3.4 Quota systems

Quota systems are often criticised for the incentives they create to discard (Copes 1986). However, the fundamental principles underlying individual transferable quotas (ITQs) and quota trading may be of value to the management of non-commercial bycatch species.

In this section, the potential for quota systems to reduce bycatch and subsequent discards is examined. Three types of quota systems are examined – namely an aggregate bycatch quota system (an output control, either aggregate or individual tradeable bycatch quota), a tradeable effort based quota (an input control), and a revenue based quota system. The first two systems have been applied to both commercial and non-commercial species, while the latter has been proposed to reduce highgrading and "over-quota" catch.

3.4.1 Bycatch quotas

Bycatch quotas may be either at the fleet level (i.e. aggregate bycatch quotas) or the individual vessel level. The incentives created differ depending on which level is implemented.

Aggregate bycatch quotas

To date, examples of bycatch quotas are limited, and these have generally been aggregate quotas rather than individual quotas. Aggregate quotas contain characteristics more akin to command and control management measures, as they are a hard rather than soft constraint to fishing. However, where they have been applied they have generated incentives to reduce bycatch.

Aggregate quotas limit or reduce bycatch by capping the total permissible level of bycatch over a specified period of time. Once the threshold level is reached a fishery may be closed for the remainder of the season. Such bycatch quotas can be applied at either the fishery or vessel level and may be adjusted over time to reflect the state of the bycatch species stock or slowly reduced if the aim is to encourage vessels to become more efficient in this respect. This method of regulation will only propagate improvements in performance if bycatch quotas are set at levels that are likely to be limiting under current conditions (and consequentially result in a loss of revenue once reached). Furthermore, the behaviour of fishers under this type of 'triggered closure' management may provide reasonable insight into how they would react to management using performance bonds.

An advantage of this method of regulation is that in only setting the permissible level of bycatch (whilst conforming to any pre-existing regulation) it leaves open the method/s by which preventing a closure may be achieved. In doing this it overcomes the criticism oft levelled at more 'command and control' orientated management methods, such as the mandatory application of technical measures (e.g. TEDs), that 'one size' does not 'fit all' when local circumstances or regional variations possibly render them ineffective or inappropriate. A further advantage is that in specifying an exact number a clear and easy to understand goal is set and can be worked towards, even the level at which it is set is disputed (Bache 2003).

There are a number of cases where bycatch limits for non-target species are imposed on fisheries, although these have mostly been related to bycatch of megafauna. In the US, a potential biological removal rate (PBR) is defined for several fisheries, being the maximum numbers of marine mammals that may be taken by fisheries. This is calculated annually and is designed to ensure few enough animals are taken so that stocks do not fall below levels considered to be optimally sustainable.[4]

An annual total level of dolphin catch is set under the Agreement on the International Dolphin Conservation Program (AIDCP) for vessels operating in the eastern tropical Pacific (ETP) purse seine fishery. This is divided between the states and then vessels taking part in the fishery but as result of limited entry and other regulations pertaining to this fishery (as previously discussed) the limit is not binding.[5]

New Zealand also uses output controls to manage bycatch of Hooker's sea lions in the squid fishery (Bache 2003; Diamond 2004; Chilvers 2008). The number of sea lions killed is monitored with observers on a proportion of vessels and the fishery is shut down when a certain number have been killed (based on extrapolating from observed vessels). A maximum level of fisheries related mortality (MALFIRM) is also set for marine mammal[6] bycatch in New Zealand and is again centred on maintaining healthy stocks of the species. However, incomplete observer coverage means it is not possible to accurately calculate the actual level of bycatch so the maximum permissible take is combined with the likelihood of catching a sea lion on any given tow (the so called 'strike rate' determined using data from vessels with observers present). This data is combined to determine the maximum number of tows vessels may undertake in the season. This incentivises the vessels taking part in the fishery to reduce their 'strike rate' as much as possible as the higher the strike rate the lower the number of tows for a given bycatch limit. This fishery was closed very early in the year 2000 due to unusually high levels of Hooker's seal bycatch (Bache 2003) consequentially also limiting both the total quantity and period over which squid could be landed. Between 1996 and 2007, the fishery has been closed early six times out of 12 fishing years, with two other years initially closed but overturned by the Court of Appeal (Chilvers 2008).

The MALFIRM method of management has resulted in the industry investing heavily in ways to reduce their rates of sea lion bycatch (Bache 2003). This resulted in the development and application of a sea lion excluder device (SLED), similar in concept to the TED, as well as increased sharing of information amongst vessels to reduce sea lion bycatch (Diamond 2004). The reduced likelihood of seals drowning as a result of coming into contact with this modified gear has led to a discount rate being applied to

[4] The optimal sustainable population level (OSP) being defined as the number of animals which will result in the maximum productivity of the population or species.

[5] A total limit of 5000 dolphins was set for 2006 with actual mortality estimated at 886 for the year (IATTC 2008). During 2007, only 6 per cent of all sets made on tuna associated with dolphins involved mortality or serious injury to the dolphins. The total mortality of dolphins in the fishery has been reduced from about 132,000 in 1986 to less than 900 in 2007 (www.iattc.org/DolphinSafeENG.htm).

[6] Specifically those that are considered threatened or to belong to geographically or genetically discrete stocks.

vessels utilising the technical measure. This allows them a greater overall number of tows per season and therefore a potentially longer season and a higher level of landings.

Aggregate bycatch quotas have also incentivised fishers to create formal systems to share information to reduce bycatch. In the US North Pacific and Alaska trawl fisheries, a number of fleet communication programs have been designed to share real-time information about bycatch hotspots (Gilman *et al.* 2006). These have been found to have been effective at reducing bycatch cost-effectively and thereby avoid pre-mature closures of fisheries in many cases (Gilman *et al.* 2006). In pollock and groundfish fisheries in Alaska, a system known as SeaState was created to share information between vessels on locations with high levels of bycatch of prohibited species (halibut, crab and salmon) (Holland and Ginter 2001). This program has been running since 1994, with 100 per cent fleet participation in recent years. The system relies on observer data which is processed daily and returned to participating vessels in the form of digital charts identifying “hot spots” to avoid.

Although the effectiveness of this system at reducing bycatch is not entirely clear or at least has not been formally evaluated (Holland and Ginter 2001; Gilman *et al.* 2006), the system is clearly effective at distributing information cost-effectively. The fact that bycatch caps are for the overall fleet rather than individual vessels which fish competitively may have undermined incentives to avoid “hot spots.” Gilman et al. (Gilman *et al.* 2006) review an information sharing program in the US Atlantic longline swordfish fishery and report estimated reductions in bycatch rates of marine turtles of around 50 per cent as the result of communication between vessels about bycatch hotspots. They also find evidence of reduction of halibut bycatch and seabird bycatch as a result of a fleet communication program in the US demersal longline fisheries for cod and turbot. They conclude that fleet communications programs for controlling bycatch are unlikely to be an effective unless there are strong economic incentives for individuals or the fleet to reduce bycatch, or if the incidence of bycatch is a common event and occurs all across the fishing grounds. They also note that instituting these types of programs is difficult in fisheries that lack sufficient observer coverage which facilitates collection of information about bycatch rates. Observer coverage can also be critical to ensure compliance with the bycatch caps which create economic incentive to reduce bycatch.

Individual transferable bycatch quotas

Several authors have suggested the use of individual transferable bycatch quotas (ITBQs) as a means of reducing bycatch (Boyce 1996; Edwards 2003; Diamond 2004; Herrera 2005; Hannesson 2006; Ning *et al.* 2009). ITBQs improve efficiency in a fishery by creating a “shadow price” associated with use of the quota reflecting the level of economic rents derived from the use of the quota. This shadow price, while different for each individual, manifests itself in the form of a quota trading price. Fishers’ with a shadow price greater than the trading price are likely to buy quota, while those with lower shadow prices are likely to sell. Given the shadow price reflects the catch compositions of the vessels, this guides quota to those boats that can use it most efficiently.

As noted above, a main problem with bycatch is that it has no value to the fisher, and is subsequently discarded. Value can be created through a taxation system as outlined previously. However, value can also be created through allocation of quotas for the bycatch species. In such a case, the shadow price would reflect the value of the targeted species caught with the bycatch species rather than the bycatch species *per se*. By creating a quota market for bycatch, fishers have an incentive to lower their own bycatch and sell their quota to fishers less able to lower bycatch, fostering innovation and adoption of new technologies.

Relatively real life examples of ITBQs can be found. In 1996, Canada instituted an individual vessel bycatch quota (IVBQ) for its trawl fleet, which helped reduce total fleet bycatch from 681 mt in 1995 to 140 mt in 1996 (Diamond 2004). These quotas were non-transferable, and once the vessel reached its bycatch quota for a particular area, would need to either cease fishing or move to an area where it had available bycatch quota. Vessels could opt to be part of the IVBQ program (Option A), which required them to pay for 100% observer coverage, or opt out of the system (Option B), which involved less observer coverage but restrictive landing requirements (Diamond 2004). Despite the high observer cost, more than 90% of the fleet carried observers in 1996 (Diamond 2004).

ITBQs have been suggested for both megafauna (Hannesson 2006; Ning *et al.* 2009) as well as fish species – either commercial (by-products) or non-commercial (Boyce 1996; Diamond 2004). However, the evaluation of these programs have been model based rather than experience based as, to date, such programs have not been implemented. These analyses generally ignore enforcement issues (Boyce 1996), which are likely to be considerable. Unlike commercial species, where there is an incentive to land the product and thereby evidence of its capture is readily observable, there is no incentive to record quantities of fish that are not landed, especially if doing so can reduce future fishing opportunities.

Based on the experiences of aggregate bycatch quota (and also experiences with general ITQ programs) in different fisheries around the world, elements of successful bycatch quota programs include: (1) individual accountability, in the form of individual bycatch quotas or ITBQs, (2) 100 per cent observer coverage (or al least some reliable form of surveillance), (3) relatively small, manageable fleets, (4) limited landing ports that can be readily monitored, particularly if observer coverage is less than 100 per cent, (5) reliable enforcement, (6) penalties that are true disincentives, and (7) some flexibility in the system for fishermen to have alternatives to manage their bycatch (Diamond 2004). While this is an idealised set of requirements, it is most likely impractical to achieve all for every fishery given the costs of observer programs, and most successful ITQ fisheries do not have all of these characteristics.

3.4.2 Effort quotas

Given difficulties in observing quantities of bycatch in a catch-based quota system, an alternative is to regulate activity. Command and control regulations impose hard constraints on activities, but softer constraints can be imposed through allowing some degree of transferability.

To date, examples of effort quotas to control bycatch are relatively limited. The New England groundfish fishery has, since the mid 1990s, been managed primarily with a system that uses a combination of individual days at sea (DAS) allocations, seasonal and year-round closed areas and trip limits to indirectly constrain catch to target levels. In order to avoid overfishing of some weaker stocks, DAS have been progressively reduced over the years; however there are some groundfish stocks for which catches remain well below target levels. In an attempt to allow more catch of these stocks while limiting "bycatch" of weaker stocks, a system called B-days has occasionally been used for directed effort on some species. Individuals are allowed a certain number of additional fishing DAS (B-DAS) which they can use for directed fishing on these stocks, but if they exceed a given rate of catch of other fish stocks they have the option to "flip" the trip and use A-DAS. The rationale is to provide additional fishing opportunities with incentives to limit bycatch of weaker stocks but a means to land inadvertent catches rather than having to discard them.

3.4.3 Individual Habitat quotas

An alternative form of effort control is the individual habitat quota (Holland and Schnier 2006). These are spatial management instruments where different effort penalties are applied to different areas based on the level of damage created by fishing in those areas. These quotas are tradeable, allowing vessels to adjust their fishing activities to minimise their own damage. Fishers consume their quota based on where and when they fish, with the penalty system providing incentives to either operate in areas where less damage will be incurred, or adopt fishing gear that will have a lower impact.

While not designed with bycatch in mind, such a system can be adapted as a bycatch management system. Indeed, the hook decrementation system proposed for the Australian Eastern tuna and billfish fishery is effectively an example of such a system (Pascoe *et al.* 2009). Individual fishers have an individual hook quota. In the proposed management system, the rate at which this quota will be consumed depends on where and when they fish. Areas with high bycatch of species of concern (mainly seabirds, turtles and sharks) will attract a high penalty rate, whereas other areas with little bycatch may attract a much lower rate.

3.4.4 Revenue or value quotas

The concept of a revenue based quota is aimed at reducing discarding of quota species through either highgrading or over-quota catch (Turner 1997). Unlike weight based quota system, quota programs that regulate the value of harvested fish, on theory, never induce discarding (Turner 1997). As lower valued species (or sizes of species) consume less of the available quota, there is no incentive to discard them. For example, four smaller fish weighing in total 4 kg but with a total value of $4.00 consume 4kg worth of weight based quota. By comparison, a 2 kg individual fish of the same species may also have a value of $4.00, but consume only half the quota to land. There are incentives to discard the fish (i.e. high grade) under the weight based system in order to maximise the value of the landed product. However, under a value based system, $4.00 worth of smaller fish has the same value of $4.00 of larger fish, so there is no incentive to highgrade.

A key advantage of such a system is that more reliable information is derived from the landings data. As the incentives to discard are reduced, landed catch should reflect actual catch.

Such a system has a number of recognised drawbacks. Firstly, prices fluctuate over the year. While this does not affect the operation of the quota system, the actual quantity of fish that will be landed is unknown until after the event. Assigning a constant price to a species for the purposes of the quota management system will distort the incentives within the fishery. For example, if the defined price is substantially greater than the market price at the time then incentives to discard re-emerge.

A second drawback of the system is that managers do not have control over the catch composition, and there is no incentive to target or avoid particular species other than their cost of capture (which provides the same incentive under effort controls). The system as devised by Turner (1997) is based on a total revenue quota for each vessel rather than a species specific revenue quota. As a result, the catch composition is relatively unconstrained, and the only benefit of such a system is the efficiency gains it may generate through autonomous adjustment. While a species-based revenue quota may help to reduce highgrading, it would not help in the case of over-quota discarding.

Despite these limitations, simulations of a revenue quota system suggest that economic profits in the fishery are generally greater than under an unconstrained system (i.e. no bycatch management) and also a bycatch trip limit approach. However, they are not as efficient as a price based system (Herrera 2005).

3.5 Market driven incentives to avoid bycatch

Restrictions on access to market are not necessarily a viable approach to fisheries management as the restrictions are generally imposed exogenously. However, such restrictions, or the threat of such restrictions, create incentives for fishers to reduce their environmental impact, including bycatch and discarding.

3.5.1 Market Access

Significantly reducing the environmental externalities (such as bycatch) of a fishing activity cannot be truly effective unless all participating parties aim to meet the same minimum standards simultaneously. At the national level this can be achieved via the enforcement of management plans implemented at the fleet level. However, when multiple nationalities undertake the activity multilateral management plans or agreements are generally required for the aims are to be achieved. In the absence of such agreements any nation(s) wishing to effectively raise standards need to employ other means of incentivising participants to comply. One method is the use of trade measures. These generally take the form of sanctions prohibiting the import of fish or related produce from the fishery in question. However, relevant legislation and instances in which market access has been denied over concerns relating to impacts of the production process and specifically bycatch are very limited.

Several examples of market restrictions exist that have had a direct impact on bycatch reduction. These include the shrimp import restrictions to the US aimed at reducing turtle bycatch, tuna import restrictions (again to the US) aimed at reducing dolphin bycatch, and US bans of fish imports from nations using drift nets in the high seas. Details on these and other trade based restrictions are given in Appendix B. Within Australia, fisheries must pass an environmental audit in order to be permitted to export under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). As with import restrictions, this export restriction creates incentives for the industry to achieve a set of environmental objectives, one of which involves bycatch and discarding.

It appears the only current example of market access being restricted on the grounds of bycatch alone are those facing wild shrimp imports into the US. The apparent unpopularity of attempting to incentivising fisheries to improve bycatch performance through trade measures may result from a combination of factors. Primarily, the World Trade Organisation (WTO), and formerly the General Agreement on Tariffs and Trade (GATT), panels' dislike for measures perceived as barriers to trade and their preference for multilateral agreements (over unilateral) in the pursuit of environmental action. Furthermore in order to unilaterally have significant influence any nation applying such action would need to control a substantial share of the market. Otherwise the fishing nations in question have the option of supplying alternative markets, significantly weakening their incentive to comply. A review of regulatory regimes (Carr and Scheiber 2002) suggests the relationship between the WTO requirements and trade measures to enforce environmental standards continues to be a matter of controversy due to the 'political economy' of fisheries making the adoption, implementation and enforcement of effective conservations standards extremely difficult.

Furthermore, the effectiveness of such measures is far from proven and the associated costs difficult to predict. An obvious potential cost to the nation imposing restrictions could arise in the case where measures ultimately limit supply and consequentially increase prices. Many markets may simply not be willing to bear such costs, especially if others are not being seen to do so. Any additional costs imposed on US consumers as a result of shrimp trade actions are difficult to quantify. The movements of shrimp prices are influenced by a multitude of factors and records for shrimp imports into the US are not broken down into wild and farmed. It is highly likely that shortfalls in wild imports will have been filled by imported farmed shrimp and first inspection of shrimp import quantities and prices does not profess to any obvious distortions. The National Fisheries Institute (a fisheries trade organisation) suggested the cost of the US shrimp embargo, accounting for loss of trade to importing countries and resulting unemployment in US based shrimp processors, would be in the range of $20-$200 million. Furthermore, tuna prices in the US are reported to have actually fallen over the period 1980 to 1999, however the potential influences of innumerable other factors must not be overlooked (Golan *et al.* 2001).

The willingness to comply of any nation facing measures is also likely to be strongly influenced by the relationship between the nations (i.e. if there is strong asymmetry in strength) and the relative importance of trade in the product in question. For example, the low significance of shrimp (representing only 0.6% of export earnings) in relation to petroleum exports to the US from Trinidad and Tobago meant it was not in their interest to dispute the US demands in relation to the use of TEDs for fear of harming more valuable trade relations (Stewart 1998).

Lastly, it is apparent that a sustained political desire to actively check permissions and enforce legislation is essential. If the assertions of environmental groups such as the TIRN are correct, the mere existence of legislation requiring specific standards to be met are alone insufficient incentive to comply. Existing trade and defence issues between the nations in questions can also result in uneven application of measures. For example, Caron (1989) gives the example of how the US reacted when imposing sanctions against; first the USSR exceeded its International Whaling Commission (IWC) quota for minke whales; and then, Japan took sperm whales without IWC quota (Caron 1989)[7]. The apparent context specific application of legislation is perhaps best summed up by Lones (1989) in a review of how the MMPA has been applied by the US *"When the US's economic interests are more directly and obviously involved the US provides little more that paper protection for cetaceans"* (Lones 1989).

A further difficulty with barriers to markets as a bycatch management instrument is that the incentives are created at the fleet level rather than the individual level. For the

[7] The US had two pieces of legislation available under which to impose sanctions; the 1971 Pelly Amendment that gives the US provision to ban imports of fishing products from nations deemed to be diminishing the effectiveness of an international fishery conservation; and, the 1979 Packwood-Magnuson Amendment to the Fisheries Protective act of 1967 that requires the US to reduce a nations fishing allocations in US waters by at least 50% if certified to be diminishing the effectiveness of the IWC (now defunct as there is no longer foreign fishing in the US EEZ). Subsequently, the USSR had their quota for catch in US waters reduced by approximately 18000 tons in 1985 and then to zero in 1986 under the 1979 Packwood-Magnuson Amendment to the Fisheries Protective act of 1967. Whereas, Japan was not even threatened with either pieces of legislation until the US government was forced to do so as a result of legal action by environmental groups (Caron 1989).

individual fisher, changing their behaviour will not necessarily guarantee that the environmental standard is met for the fishery as whole, so any costs incurred may go unrewarded. Conversely, there are incentives to free-ride on the behaviour of others if there is the belief that the environmental standard will be met. As a result, other management instruments may need to be introduced in any case to ensure the standards are met.

3.5.2 Ecolabelling

An alternative to denying market access through the explicit prohibition of imports is product differentiation via labelling schemes. Industry independent labels that provide additional information, relating for example to method of harvest, allow consumers to make informed choices and effectively ‘vote with their feet’ on matters of concern.

Labelling can be specific e.g. ‘dolphin safe’ tuna or more general e.g. ‘Marine Stewardship Council (MSC) certified’. The former giving consumers precisely defined information; i.e. that no dolphins were harassed or harmed in the process of harvesting the product; the latter giving a much wider ranging indication i.e. that *“This product comes from a fishery which has been certified to the Marine Stewardship Council’s environmental standard for a well-managed and sustainable fishery”*. Both however serve to differentiate the fisheries product from possible substitutes.

The only labelling scheme that specifically relates to bycatch is that for ‘dolphin safe’ tuna, and even this label neglects to account for all the other types of bycatch associated with this fishery (i.e. tuna, billfish, other cetaceans or ‘other’ bycatch). The majority of schemes are broader in scope, designed to indicate that a fishery operates ‘sustainably’. Somewhere within this definition of ‘sustainable’ the majority of schemes (e.g. MSC) give some level of consideration to factors such as the impact a fishery has on other fisheries and the marine ecosystem. However, zero bycatch is typically not a requirement meaning the level of bycatch and extent to which it is considered are harder to ascertain

The main incentives for fisheries to attain certification are typically sold as benefits from price premiums and market access.[8] If fisheries perceive such benefits to exist this may make them more inclined to conform to bycatch requirements (or other sustainability issues).

Suggestions that eco-labels may allow fisheries to realise a price premium are based on the assumption that consumers concerned enough to purchase these products would also have a degree of indifference towards paying some form of premium for the privilege. The value of any additional utility derived from reassurance that what they are purchasing is; from a sustainably harvested stock; did not result in the death of dolphins; or, has some similar attribute, equalling or exceeding the increase in cost. It will also be influenced by levels of demand relative to available supply.

[8] The MSC also list secure contracts, good reputation, improved relationships, economic stability, confidence in the future (http://www.msc.org/business-support/the-value-of-msc-certification).

Whilst the MSC claim some of their certified fisheries do command higher prices, citing increasing demand and retailer commitment for products displaying their label, the evidence for this is believed to be primarily anecdotal (pers. comm. James Simpson, MSC, December 2008). In fact, the existence of any price premium for fisheries that have attained MSC certification or some similar status is generally unclear. It varies by fishery and clearly identifying any price increase as having resulted from certification is difficult due to the complexity and number of factors that can influence seafood markets (Roheim and Sutinen 2006).

'Dolphin safe' tuna (see Box) was reported to be achieving an initial price premium of around US$ 400 per ton (Vogel 1995) and was believed to reflect a combination of higher demand and fishing costs. However, when an initial price premium is thought to exist, its sustainability is far from guaranteed. The price of Thames herring was reported to rise 50% immediately after receiving MSC certification in the year 2000 but relatively quickly returned back to nearer its original level (Jaffry *et al.* 2001). Ultimately the effect labelling has on the long term availability of a product will largely influence any relative or absolute movements in price. It is probable that as more fisheries achieve certification their niche market will erode and so with it the initial price premium first movers may attain. In such a situation prices would eventually revert back to a level somewhat equivalent to the pre-certification *status quo*. Any remaining un-certified products or fisheries would ultimately lose value, or in the worst case market access, as a result. The long term incentive for certification may then revert to maintaining access or the current value of the fishery as opposed to obtaining some form of financial reward for compliance.

Box: Dolphin-safe tuna

Within the US dolphin-safe tuna is defined as tuna caught on a trip in which no dolphins were chased, encircled or killed.[9] From March 1994 only tuna labelled as dolphin-safe could be sold in the US, these trade actions were significant as it is the largest market for canned ETP yellowfin tuna. Tuna caught by setting on dolphins may now also be sold in the US but cannot be labelled as dolphin-safe even if no dolphins were killed or seriously harmed in the process of capture. Following a canned tuna boycott in the late 1980's it was seen that American consumers have an overwhelming preference for tuna labelled as dolphin-safe. Following this the three main US canners (then representing ~85% of market share) resolved to only source 'dolphin-friendly tuna' and as a result foreign tuna sellers that did not adjusted their fishing methods were quickly forced out of the market.[10] This is believed to have enforced a virtual ban on US imports of tuna caught by fleets from Mexico and other foreign nations that encircle dolphins with nets to catch the tuna that swim beneath them (INFOFISH Tuna Market Report - US - May 2007). As such this is an effective barrier to market for non-compliance with measures to reduce dolphin bycatch.

The 'dolphin-safe' label has also been found compatible with GATT so product differentiation in the form of such 'eco-labelling' may prove to be one way of overcoming the difficulties encountered when attempting to enforce bycatch reducing and other conservation orientated principals via trade restrictions.

[9] The US government was recently unsuccessfully in attempting to weaken this definition in order to allow Mexican imports.
[10] Primarily Mexico and other South American countries.

The effectiveness of the US prohibiting tuna caught by setting nets on dolphins from being labelled dolphin safe, in terms of reduced dolphin bycatch, is hard to judge. The number of dolphin sets did decrease moderately during the mid 90s but by 2003 were at the highest level ever recorded and the most recent figures indicate this is still the most common method of set (IATTC 2008).

Lastly, this all assumes a like for like comparison of products. In 2002 Birds Eye attempted to partially substitute some of their UK range with products containing Hoki as opposed to Cod. Despite being of a very similar price the slightly fishier taste meant it was unsuccessful and led to Birds Eye not selling any hoki products in the UK by mid 2005 (Porrit and Goodman 2005). This serves to illustrate that even when companies are willing to provide sustainably harvested alternatives, there is still some distance to go with consumers if there is a perceived difference in quality - a problem identified in a number of previous studies (Wessells *et al.* 1999; Jaffry *et al.* 2001; Johnston *et al.* 2001).

Access to markets can also be restricted at points further down the supply chain. The main UK supermarkets now all have some form of policy relating to the sustainability of the fish they supply with many moving towards only supplying fish certified as being sustainably harvested.[11] As supermarkets are by far the largest retailers of fish in the UK accounting for around 89% of fish sales by value in 2006[12] this may prove to be significant for fisheries failing to attain certification. If enforced on a broad enough scale such policy would effectively represent barriers to market. The MSC even state that certification can allow fisheries access to new markets citing the fact that the fish sourcing policies of many retailers now require their certification.

Whilst labelling schemes may not be able to guarantee specific goals are achieved they are a useful second-best solution when more stringent regulations directly prohibiting imports fall foul of the WTO. Once again, the need to ensure specified standards are being adhered to is possibly a major limitation of such schemes. It can also be argued that even when sufficient incentive exists to obtain certification the primary incentive of a fishery may be to attain certification and not necessarily achieve the underlying requirements, resulting in the so called ‘window dressing’ of performance indicators (Jaffry *et al.* 2001). Perhaps though the greatest limitation of labelling schemes is their reliance on the majority of consumers being informed and concerned enough to ensure an objective is met, especially in the face of a price differential. If, for whatever reason, consumer are indifferent to the issues at hand labelling will be of little or no incentive to ensure problems such as bycatch are reduced. It is believed that the number of Asian consumers that discriminate between products on the basis of environmental attributes or impact is still very low and are consequential not targeted by groups such as the MSC, yet Asia consumes over two thirds of the world’s seafood (Jacquet and Pauly

[11] As of 2006 approximately 60% of the fish Unilever sold in Europe came from sustainably managed sources and they are working towards a target of 100% (Roheim and Sutinen 2006). Marks & Spencer (UK) have announced that all of their fish will come from MSC or other independently certified sources by 2012. Furthermore, in February 2006, Wal-Mart announced plans to, within the next three to five years, purchase all of its wild-caught fresh and frozen fish for the North American market from Marine Stewardship Council (MSC)-certified fisheries. The Dutch Association of Food Retail has committed to supplying only MSC certified fish at all of its 4500 retail outlet in the Netherlands from 2011. Increasing corporate demand, from large firms such as Unilever and Wal-Mart, for sustainably harvested fish potentially has very real market access implications for certain fisheries.

[12] See www.just-food.com/store/product.aspx?id=60731

2007). This combined with the possibility that future growth markets are likely to be in Asia, Latin America and Africa, areas where the impact of sustainability labelling is anticipated to be weak, means the their overall effectiveness could be marginalised (Jacquet and Pauly 2007).

3.6 Social incentives

The focus on incentive based measures to reduce bycatch relies on the premise that bycatch is potentially as much a consequence of behaviour as technology (Abbott and Wilen 2009). The emphasis on economic incentives as an alternative to command and control management measures in fisheries reflects a dominant view in the wider literature on fishers that portrays them as economically rational individuals, seeking to maximize profits and/or minimise risks (Cornwell and Costanza 1994). While fishers may behave in ways that conform to these neoclassical economic expectations, economic rationality is not necessarily the only influence on their behaviour (Cornwell and Costanza 1994).

Research in areas of fisheries compliance suggest that social factors play a significant role in influencing behaviour (Raakjær Nielsen and Mathiesen 2003; Hatcher and Gordon 2005). In particular, social norms and beliefs about others’ behaviour affect the decision to comply with a regulation, along with economic incentives to comply (i.e. expected fines given probability of detection).

Relatively little research has been undertaken in examining how social incentives can be used to modify behaviour with regard to bycatch, with the exception of megafauna such as turtles. Changing social norms has also been found to be beneficial in terms of bycatch reduction, and working with communities has proved beneficial in reducing bycatch of sea turtles (Peckham *et al.* 2007). In principle, there is no reason why bycatch of other species could not also benefit from a program to change fisher attitudes.

Economic incentives are most effective if there is a belief that the desired outcomes are benefit to the community. Getting community buy-in to bycatch reduction may be more important than the availability of the fishing gear and other regulations (Santora 2003). Both on their own are necessary, but not sufficient conditions for bycatch reduction. Without community buy-in, there is an increased likelihood that the gears will not be properly used so will be less effective in reducing bycatch. Community buy-in includes involving fishers in the design of any regulation as fisher knowledge can result in better targeted actions that are more effective in terms of reducing bycatch with a lower impact on the profitability of the vessel (Santora 2003).

Modifying fisher attitudes and beliefs involves considerably more interaction with the industry than introducing an economic incentive system. Changing attitudes also takes time. However, a program to change fisher attitudes coupled with a program that rewards fishers for changing their behaviour is most likely to be more effective than either program independently.

3.7 Synthesis

From the review of the alternative management systems, it is likely that different incentive based systems have different impacts for different types of species (Table 1).

Table 1 - Summary of potential of the incentive based management systems to reduce bycatch and discarding

	Quota species	Non-quota species	Marine megafauna and charismatic species
Financial instruments			
• Subsidies	*X*	*X*	*X*
• Taxes	↔	↔	√
• Deemed values	√ *(discarding, some over-quota)*	*X*	*X*
• Bonds	*X*	↔	√
Market based instruments			
• Bycatch quotas	*X*	√	√
• Habitat quotas	*X*	√	√
• Revenue quotas	√ *(discarding only)*	*X*	*X*
Market Access	*X*	↔	√
Social incentives	↔	↔	√

Key: √ positive impact on bycatch reduction, ↔ could contribute to bycatch reduction in some cases, *X* unlikely to be a useful bycatch reduction instrument.

For quota species, the most effective way of reducing over-quota catch is through the quota system itself, ensuring that total allowable catches are not incompatible, and that an efficient quota trading system exists (Pascoe 1998). However, fishing activities are heterogeneous; and catch compositions are subject to random influences that will result in some imbalance between catches and quota holdings even it total allowable catches are compatible. Further, quota markets are not imperfect, and quota trading involves transactions costs over and above the lease price. Consequently, it is unlikely that the problem of discarding due to over-quota catch will disappear even if total quotas are set in an optimal manner. Further, incentives may still exist for price related discarding (high-grading) even in a well functioning quota system.

Revenue quotas are likely to have the greatest impact on reducing discarding of quota species due to highgrading and (what is currently considered) over-quota catch. However, loss of control over the quantities of individual species that may be caught may not make this option desirable, particularly if rebuilding of stocks of particular species is important. The revenue quota system can be modified by imposing particular prices on certain species to encourage targeting towards or away from them. However, this will re-introduce incentives to discard.

Deemed values appear to offer some benefits in terms of providing incentives to reduce discarding of over-quota catch and also incentives to balance catches at the end of the year. However, incentives to discard are not totally removed. Further, incentives to avoid the catch are also reduced. Potentially, higher catches of quota species may occur under a deemed value system than under a system where over-quota catch is all discarded. The value of the additional information obtained on catches using a deemed value system needs to be assessed against the risk of higher overall catches.

For non-commercial fish species, bycatch quotas and “habitat” quotas may offer some benefits in terms of reducing overall bycatch. A difficulty with bycatch quotas is at-sea surveillance and enforcement. There is currently no incentive to record the catches of these species, and by imposing effectively a cost on their capture if recorded then incentives are created not to record them. Either observer coverage or video surveillance would need to be relatively widespread. Habitat quotas are easier to monitor given current vessel monitoring systems (VMS). Developing an appropriate spatial and temporal effort penalty system to achieve bycatch reductions may be complex, but is not impossible. The main drawback, as in any effort control, is that there is no direct link between the level of effort and the level of bycatch produced.

A wider range of options exist for megafauna and charismatic species. In addition to bycatch quotas and “habitat” quotas, taxes may be a viable option. These directly impose a penalty on the capture of these species, thereby providing an incentive to avoid their capture. Unlike the non-commercial fish species, their capture is likely to be less frequent and readily observable using video surveillance techniques. Compliance with the system can also potentially be enhanced through working with the industry (i.e. develop social incentives).

Based on the review, it is likely that different instruments, and potentially different combinations of instruments, will be required to provide the most benefits given the type of bycatch that managers aim to reduce. Following on from this review an attempt is made to evaluate; using an ecosystem model of a suite of fisheries (a specific case study), the impacts of a set of incentive management measures for reducing bycatch and discarding of marine species.

4 Application to the South East Australian Commonwealth Fisheries

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a complex multi-gear, multispecies fishery that covers a large proportion of Australian's Exclusive Economic Zone (EEZ) (AFMA 2008b; Figure 2). It is Australia's largest scalefish fishery and provides most of the fresh fish to domestic markets, the two largest being in Sydney and Melbourne. The fishery has both trawl and non-trawl sectors. The Commonwealth Trawl sector of the SESSF currently has 59 permits and lands about 16000 tonnes of fish which in 2006/07 was worth about AUD$55 million.

The SESSF now consists of 6 principle sectors that overlap in the stocks exploited and areas fished. The principle sectors include (1) the Commonwealth Trawl Sector (CTS), (2) the East Coast Deepwater Trawl Sector (ECDWTS), (3) the Scalefish Hook Sector, (4) the Shark Hook Sector, (5) the Gillnet Sector; and (5) Great Australian Bight Trawl Sector (GABTS). The fisheries/sectors were previously managed separately, but are now all managed via the *Southern and Eastern Scalefish and Shark Fishery Management Plan 2003 (The SESSF Plan)* in addition to general regulations under the *Fisheries Management Act 1991.*

The complexity of the Commonwealth trawl fishery is described in Smith and Smith (2001) along with other articles that consider this fishery in the same journal volume. An operational management booklet is available which outlines the full extent of the regulations and management controls in this fishery (AFMA 2008a). The status of the stocks over the last few years has been regularly reviewed as assessment is an annual process (see annual reviews: Smith and Wayte (2004, 2005), Tuck (2005; 2006a and 2006b). The most recent TAC recommendations are listed in AFMA (2009).

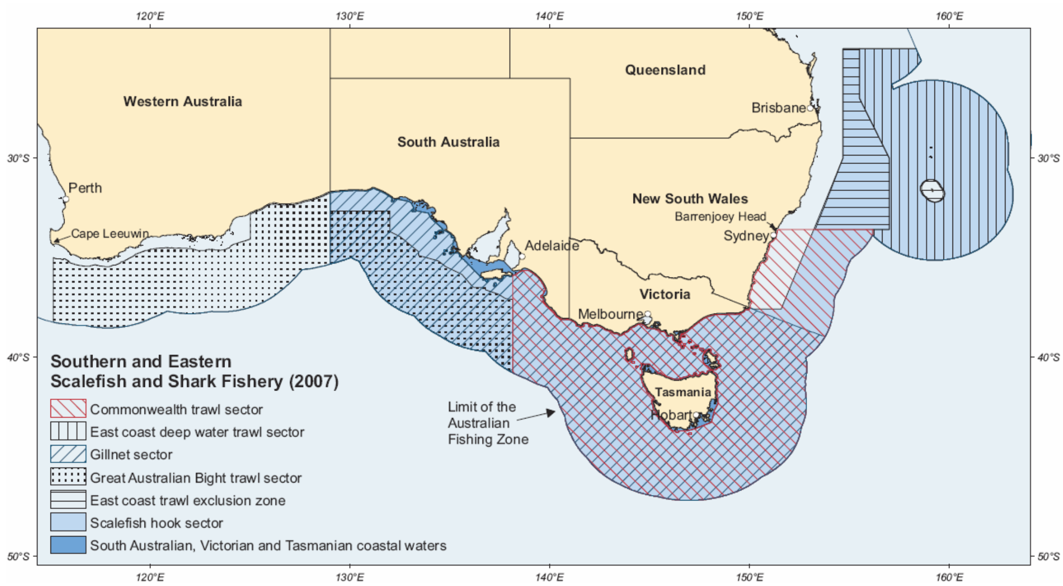

Figure 2 - The area of the Southern and Eastern Scalefish and Shark Fishery showing the different sectors (source AFMA Fishery Status Reports 2007, AFMA (2007c))

There have been some major changes in the operating environment of the SESSF since 2007 as a result of the Ministerial Direction released by the Minister for Fisheries, Forestry and Conservation in December 2005. This Direction required AFMA to take immediate action in all Commonwealth fisheries to:

a) Recover overfished stocks to levels that will ensure long-term sustainability and productivity and to cease overfishing;
b) Avoid further species from becoming over fished in the short and long term; and
c) Manage the broader environmental impacts of fishing, including impacts on threatened species or those otherwise protected under the *Environment Protection and Biodiversity Conservation Act 1999 (EBPC Act 1999).*

The last paragraph alludes to practices such as discarding and the bycatch of rare species. In this study we focus on the Commonwealth Trawl Sector and the Danish seine fleet, although many of the measures we test impact extensively on the major net and line fleets. In the trawl sector, most of the trawl vessels are 'wet boats' (fishing vessels that store fresh fish on ice/brine) that use demersal trawl methods. There are also a few factory vessels that operate in the blue grenadier fishery off western Tasmania using midwater trawls during winter. The trawl sector consists of series of sub-fisheries each of which differs in its spatial location and seasonality of effort on particular stocks, representing a diversity of strategies (Klaer and Tilzey 1994).

4.1 Discarding and bycatch issues

In a review of the Commonwealth Trawl sector *circa* 2000, Baelde (2001) stated that the mismatch between actual catches and quota holding led to an increase in discarding with the introduction of ITQs. While regulators and the industry are attempting to decrease discards, it is seen as an unavoidable aspect of multispecies management. Estimates from the Integrated Scientific Monitoring Program (Table 2) provide an indication of the magnitude of overall discarding in this fishery in 2004 (see also Talman *et al.* 2004). Here we refer to this less recent date as it confers with the initial year of first model run. Readers should refer to the most recent published ISMP reports on discard estimates in this fishery (Koopman *et al.* 2006, 2008).

Discarding in the SESSF occurs for a range of reasons, including lack of quota, high-grading, damage to fish, and weak markets for landings leading to low market prices (Liggins and Knuckey 1999). In a more recent analysis of ISMP data and market information, Ellison *et al.* (2005) concluded that discarding was market related. Differences in price between small and large fish did account for the differences in rates of discarding observed. Furthermore, discarding of non-commercial species occurs in this fishery, as landing rare and endangered species (such as seals and seabirds) is not condoned, and contradicts industry Codes of Practice.

Table 2 - The percentage of total catch retained or discarded (quota and non-quota).

		Percentage of total catch
Quota retained	21,322t	50%
Quota discarded	2,859t	7%
Non quota retained	5,562t	13%
Non quota discarded	12,863t	30%
Total	**42,606t**	**100%**

Estimates are based on data from all observed shots (source ISMP 2004, referenced in South East Trawl MAC 92 agenda item 3.4).

The topic of bycatch has been on the national agenda for at least a decade following the seminal: "*National policy on fisheries bycatch" (1999) Ministerial Council on Forestry, Fisheries and Aquaculture*. Led by global policy initiatives calling for sustainable fisheries management with an onus on ecosystem effects of fisheries and ecosystem management, the magnitude of discarding and bycatch in the Australian fisheries became evident after the publication of Ecological Risk Assessment (ERA) reports on the ecological impact of fisheries (see Hobday *et al*. 2007). Bycatch and discards regulations are to be considered under both the *Fisheries Management Act* of *1991* and the *Environmental protection and Biodiversity Act of 1999*. Industry Codes of Practice also promote the minimisation of discarding of rare marine species. A first step in this domain was taken in 2000 with the identification of how and when Bycatch Action Plans (BAPs) were to be established (AFMA 2000).

In 2005, the Minister for Fisheries, Forestry and Conservation announced a policy initiative "*Securing Our Fishing Future"*. As a response AFMA formulated a set of proposed measures to be implemented (outlined in "*Future Operating Environmental for Commonwealth Fisheries*") in which a goal was established to reduce bycatch by 50% by 2008 and to prohibit the discarding of species that are subject to TACs or quota management.

On the basis of these wide-ranging goals to reduce discarding, AFMA established a bycatch and discarding program in early 2007 to provide additional resources and direction for meeting legislative objectives and policy directives in relation to bycatch and discarding (AFMA 2008b). The program was funded during 2009 after which individual fisheries will assume direct responsibility for program outputs. The bycatch and discarding program is aimed at assisting fisheries tackle bycatch and discarding issues in a cost-effective way. Under directions from AFMA, each fishery (the managers and stakeholders) has been tasked to develop and institute a Bycatch Action Plan (BAP). These are a set of plans to establish strategies for monitoring and minimising bycatch and discarding and maintaining ecological risk assessments of Threatened, Endangered and Protected (TEP) species.

A critical element in the most recent published program for addressing discarding (AFMA 2008a) is the statement that all catch (including discards) be "*covered with the relevant quantity of statutory fishing rights*". This is a major divergence from normal discarding practices as outlined in Sanchirio *et al.* (2006) where discarding of quota stocks has not historically counted against quota. Stocks that are non-targeted catch (strictly “bycatch); which have a commercial value and are not illegal to land will be landed as byproduct. Whereas non-target stocks landed that have no value or are illegal to land (such as seals) will be discarded.

The Southern and Eastern Scalefish and Shark Fishery (SESSF) Bycatch Action Plan was developed by the Australian Fisheries Management Authority (AFMA) in consultation with the South East Trawl, Gillnet Hook and Trap and Great Australian Bight Trawl Management Advisory Committees (SETMAC, GHATMAC and GABMAC)(AFMA 2007a, b). While the term bycatch could potentially refer to all non-targeted catch including byproduct and discards the SESSF BAP is concerned with bycatch that is not currently subject to commercial management provisions, that is that part of the catch which is returned to the sea either because it has no commercial value or because regulations preclude it being retained. As a secondary effect the BAP also relates to the impact of the gear before landings are made (including impacts on benthic communities).

Due to specificity of the bycatch and discard issues in each sector of the SESSF a specific *Bycatch and Discarding Workplan* valid for three years (2009-2011)(AFMA2009) has been established that relates directly only to the Board Trawl and Danish Seine sub-sectors. As a result of risk assessments (not finalised) 10 or so species are rated as high risk (these include a species of skate, a dogfish, a hagfish, 3 species of Gulper sharks, a platypus shark and three species of Cardinal fish). Four species of seabirds are also listed, as well as Australian fur seals (with fur seals being the subject of specific studies in this fishery, see Hammer and Goldsworthy 2006, Knuckey and Stewardson, 2008).

For this study we consider a suite of management measures based on either the institution of physical output restrictions or on financial payments on the basis of the synthesis and options presented in Table 1. As illustrated in Figure 3, we propose to separate management approaches with respect to the ecosystem component impacted by fishing (i.e. target species, bycatch species and habitat) and to the regulatory tools that can be considered (i.e. based on tradeable allocations of physical output from fishing, or on the institution of financial payments).

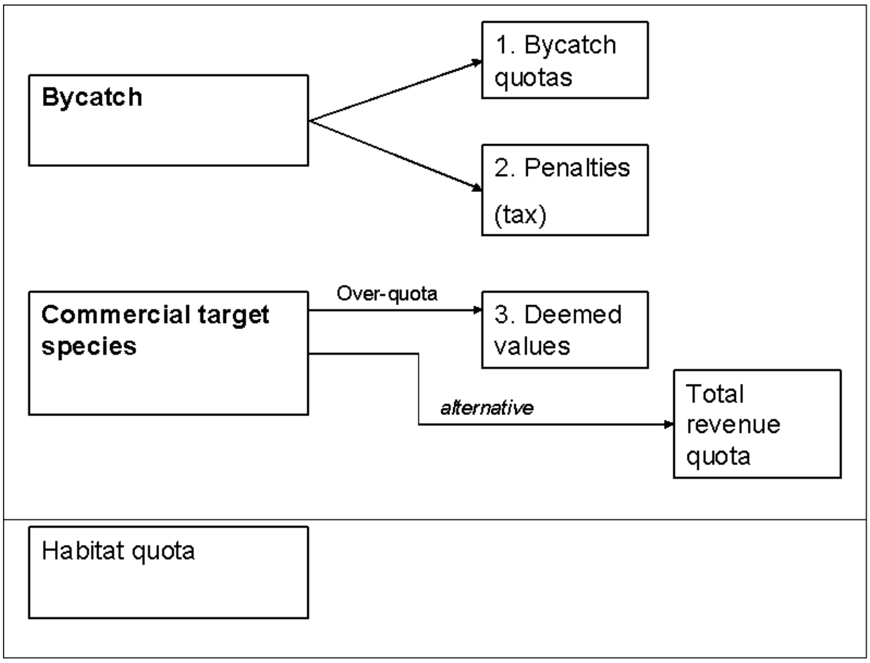

Figure 3 - A typology of incentive-based bycatch & discards reduction strategies.

For bycatch species, the key instruments considered are: (1) Bycatch quota restrictions and (2) Taxes/penalties on Bycatch. For commercial target species, we examine the implications of adopting deemed values (Figure 3). Alternative instruments such as total revenue quota; and habitat quotas could also be considered, but have not been examined as part of this study.

5 Modelling approach

5.1 The Atlantis modelling framework

Atlantis is a spatially explicit ecosystem model which includes representation of ecological processes, fisheries, annual assessments and the implementation of management regulations and compliance (Fulton *et al.* 2007). Atlantis is set up to perform management strategy evaluations at an ecosystem level (Smith *et al.* 2007). Fulton *et al.* (2004) provide a full description of the model while Fulton *et al.* (2005) report on one of the first applications of this model to a series of evaluations of ecological indicators.

In the Atlantis model, the physical environment is represented explicitly via a set of polygons matched to the major geographical and bioregional features of the simulated marine system. In the case of the Southeast Australian Commonwealth fisheries, the geography of the region is represented by 71 polygonal boxes (Figure 4) based on the physical and ecological properties and distributions captured in separate demersal bioregionalisation studies and an independent analysis of the distribution of pelagic marine species (see Fulton *et al.* 2007 for references). In Atlantis, within each box (polygon) there are up to five layers ("slab-like layers"), depending on the total depth of the box, shallower boxes having fewer layers.

Ocean currents and their horizontal and vertical advection-diffusion between these boxes and layers are explicitly modelled based on velocity fields from readily available ocean forecasting models (again see Fulton *et al.* 2007 for references). The same ocean forecasting models are used to provide time series of temperature and salinity in every cell of the model. Sediment types are classified and the proportion of ground in each spatial unit that is rough, flat or soft is listed and inputted in the model. The model tracks the nutrient (usually nitrogen and silica) flows through the main biological groups defined in the model. The biological groups included in Atlantis SE were made up of functional groups (that is, aggregate groups of species with similar size, predators, diet, habitat preferences, life histories and migratory patterns) and the dominant target species in the Southeast Australian Commonwealth fisheries (Fulton *et al.* 2007). Table 3 contains a list of vertebrate groups in the South East fishery Atlantis model (here the vertebrate groups are represented by the main dominant target or bycatch species depending on fishery).

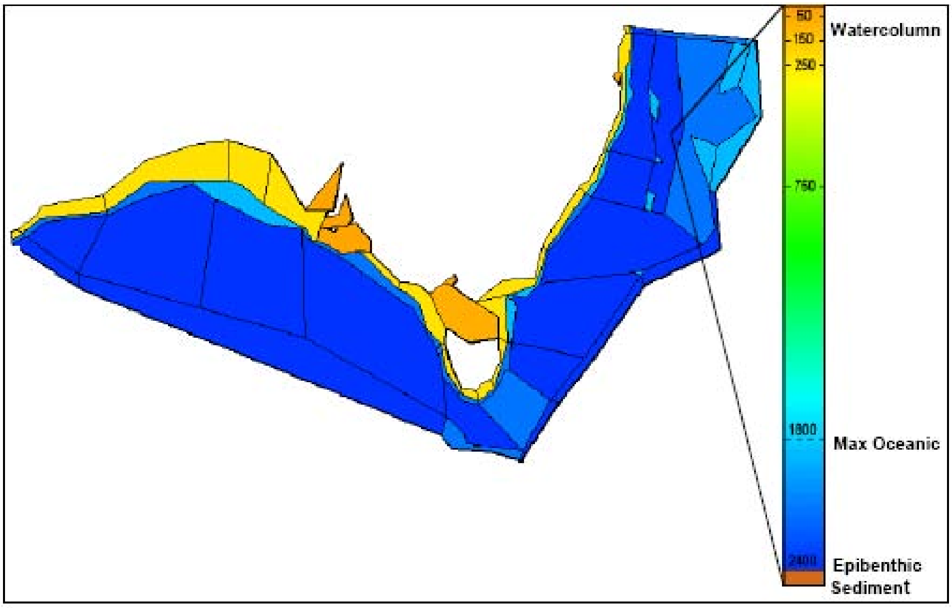

Figure 4 - Map of model domain for south east Australian Atlantis model (source Fulton *et al.* 2007). The separate spatial units are shown as a set of polygons. The depth key shows depth in metres.

The invertebrate groups are represented using biomass pools, while the cephalopods, prawns and vertebrates are presented as age structured stocks (with the possibility for multiple stocks; although this is not used for every vertebrate group). In addition to the living biological groups, pools of ammonia, nitrate, silica, carrion, labile and refractory detritus are also represented dynamically (Fulton *et al.* 2007). The potential trophic connections between groups are defined on the basis of maturity and specified as a set of maximum potential proportion(s) of the prey population that a predator can access at any one time (Fulton *et al.* 2007).

The primary ecological processes considered in the model are consumption, production, waste production and cycling, migration, predation, recruitment, habitat dependency, and mortality (Fulton *et al.* 2007). In terms of being spatially explicit, the biological components are replicated in each layer of each of the polygons. Movement between the polygons is by advective transfer or directed movements (depending on the variable in question).

A key aspect of Atlantis is that it allows for the inclusion and parameterisation of multiple fishing fleets, each with its own characteristics (regarding gear selectivity, habitat association, targeting, effort allocation and management structures). At its most complex it includes explicit handling of economic drivers, compliance decisions, exploratory fishing and other complicated processes such as quota trading (Fulton et al. 2007).

The model is focused in this study on the detailed dynamics of fishing fleets - their exploitation of the fish stocks (fishing mortality) and the technical interactions these fleets have with the marine environment (bycatch and discarding, impact on benthos). Being able to model the impact of fishing fleets on the stocks and the ecosystem components provides the opportunity for evaluating the ecosystem-wide impacts of alternative bycatch and discards management regulations.

Table 3 - Vertebrate groups in the model and species/species-group codes used in the model.

Model Component	Code	Group Composition
Fin-fish		
Small pelagics	FPS	*Engraulis*, *Sardinops*, sprat
Red bait	FBP	Emmelichthyidae (*Emmelichthys nitidus*)
Mackerel	FPL	*Trachurus declivis*, *Scomber australisicus*
Migratory mesopelagics	FMM	Myctophids
Non-migratory mesopelagics	FMN	Sternophychids, cyclothene (lightfish)
School whiting	FVO	*Sillago*
Shallow water piscivores	FVS	*Arripis*, *Thyrsites atu*, *Seriola*, leatherjackets
Blue warehou	SP	*Seriolella brama*
Spotted warehou	FVB	*Seriolella punctata*
Tuna and billfish	FVT	*Thunnus*, *Makaira*, *Tetrapturus*, *Xiphias*
Gemfish	FVV	*Rexea solandri*
Shallow water demersal fish	FDS	Flounder, *Pagrus auratus*, Labridae, *Chelidonichthys kumu*, *Pterygotrigla*, *Sillaginoides punctata*, *Zeus faber*
Flathead	FDB	*Neoplatycephalus richardsoni*, *Platycephalus*
Redfish	FDM	*Centroberyx*
Morwong	FPO	*Nemadactylus*
Ling	FDC	*Genypterus blacodes*
Blue grenadier	FDE	*Macruronus novaezelandiae*
Blue-eye trevalla	FDF	*Hyperoglyphe Antarctica*
Ribaldo	FDP	*Mora moro*
Orange roughy	FDO	*Hoplostethus atlanticus*
Dories and oreos	FDD	Oreosomatidae, Macrouridae, *Zenopsis*
Cardinalfish	FVD	Cardinalfish
Sharks		
Gummy shark	SHB	*Mustelus antarcticus*
School shark	SHR	*Galeorhinus galeus*
Demersal sharks	SHD	*Heterodontus portusjacksoni*, Scyliorhinidae, Orectolobidae
Pelagic sharks	SHP	Prionace *glauca*, *Isurus oxyrunchus*, *Carcharodon carcharias*, *Carcharhinus*
Dogfish	SHC	Squalidae
Gulper sharks	REP	*Centrophorus*
Skates and rays	SSK	Rajidae, Dasyatidae
Top predators		
Seabirds	SB	Albatross, shearwater, gulls, terns, gannets, penguins
Seals	PIN	*Arctocephalus pusillus doriferus*, *Arctocephalus forsteri*
Sea lion	WDG	*Neophoca cinerea*
Dolphins	WHS	Delphinidae
Orcas	WHT	*Orcinus orca*
Baleen whales	WHB	*Megaptera novaeangliae*, *Balaenoptera*, *Eubalaena australis*

Based on targeting and gear use, all fisheries (including State fisheries) were grouped into fleets and further divided into "fleet components" (depending on catch profiles, that is, main target species). The main fleet components, for which a dynamic effort response was developed in SESSF Atlantis, are described in Table 4.

Table 4 – Main characteristics of the fleets explicitly included in the model

Fleet	Fleet code	Sub-fleet	No. of vessels	Average Crew Size	Average Trip Length	Average Boat Size	Average Capital Costs
Demersal line for demersal fish	dlineFD	0	7	3	10	20	575
Demersal line for shallow water demersals	dlineFDE	0	4	3	4	20	900
Demersal line for sharks	dlineSH	0	4	3	4	20	575
Danish seine	dseineFDB	0	25	3	2	20	508
Danish seine	dseineFDB	1	2	4	3	35	650
Demersal celphalopod trawl	dtrawlCEP	0	4	3	3	20	940
Demersal trawl for benthopelagics	dtrawlFBP	0	2	3	4	20	740
Demersal fish trawl	dtrawlFD	0	70	3	3	20	1150
Demersal fish trawl	dtrawlFD	1	10	4	7	35	1190
Demersal fish trawl	dtrawlFD	2	4	5	20	45	3005
Demersal fish trawl	dtrawlFD	3	4	7	40	60	10535
Demersal flathead trawl	dtrawlFDB	0	29	3	2	20	940
Demersal flathead trawl	dtrawlFDB	1	3	4	5	35	1190
Demersal flathead trawl	dtrawlFDB	2	3	5	15	45	2260
Demersal orange roughy trawl	dtrawlFDO	0	7	3	3	20	1150
Demersal orange roughy trawl	dtrawlFDO	1	12	4	10	35	1190
Demersal orange roughy trawl	dtrawlFDO	2	3	5	20	45	3305
Midwater cephalopod trawl	midwcCEP	0	2	3	3	20	640
Midwater fish trawl	midwcFD	0	4	3	2	20	940
Demersal fish gillnet	netFD	0	2	3	2	20	1050
Shark gillnet	netSH	0	52	3	2	20	940
Shark gillnet	netSH	1	2	4	7	35	1190
Shark gillnet	netSH	2	3	5	14	45	2256
Prawn trawl	ptrawlPWN	0	8	3	2	20	740

The management of these fleets was also modelled, that is all the restrictions applying to their fishing activity were specified in a component of the model. These include: (1) output controls (quota); (2) gear restrictions; (3) size limits; (4) bycatch mitigation; (5) discarding restrictions and spatial closures, amongst others, depending on the exact derivation of the model. The inclusion of all of these factors in a single model provides an opportunity for it to be used to evaluate the impacts of alternative bycatch and/or discards management strategies.

Although the possibility exists to add/remove species groups, enough detail exists in the current version of Atlantis SESSF to adequately cover all the bycatch/discard technical interactions. The complexity of the model is evident from the inferred extensive set of relationships between fleet and target and bycatch stocks presented in Table 5. It is acknowledged that the model does not explicitly include the complexity of fleet/species interactions reflected in the Ecological Risk Assessments[13]. However it is suitably detailed to capture the main issues included in the Bycatch Action Plans (BAP).

Note that only the main fleets are presented in Table 5, in this case the fleets with dynamic formulations in terms of effort allocation. The current version of the SESSF Atlantis model includes 16 fleets in addition to those listed in Table 5[14]. For each sector listed above, the magnitude and spatial and temporal extent of bycatch problems are explicitly modelled, along with the impacts of fishing on target stocks (Table 4).

In order to illuminate the main bycatch issues for each Atlantis sub-fleet, the species of concern are underlined in Table 3. Species such as seabirds, seals and whales are shown in italics (see Table 3). This illustrates the level of detail at which the model is able to represent the impacts of alternative bycatch and discard management instruments. In this study, we focus on a selection of bycatch issues which were considered to be the most critical and/or illustrative for the SESSF. The alternative incentive-based management strategies outlined in the previous section of this report have been applied to these specific bycatch issues, and formulated as a series of alternative simulation scenarios.

[13] The detailed ERAs include data on each species recorded as landed. For example, the Commonwealth Trawl sector has 21 target species, 360 bycatch/byproduct species and 17 TEP species which are listed as interacting directly or indirectly with the fishery (Wayte *et al.* 2004).

[14] The fleets are: Cephalopod jig, Midwater planktivore trawl, Scallop dredge, Pelagic line for piscivores, Purse seine for piscivores, Purse seine for planktivores, Lobster pots, Demersal fish traps, Demersal crustacean trawl, Demersal line for piscivores, Dive, Purse seine for shallow water piscivores, Mammal harvesting, Midwater krill trawl, Trap for shallow water demersals, Gillnets for shallow water demersals, Midwater prawn trawl, Kelp mowing, Recreational

Table 5 - Main fleets with dynamic formulations in terms of effort allocation in the SESSF Atlantis model and their main target stocks and bycatch stocks. The species codes – which contribute to the definition of a fleet are listed in Table 2.

Fleet	Target stocks	Bycatch stocks[15]
Demersal fish trawl (dtrawlFD)	Ling, Morwong, Cardinalfish, <u>Gemfish</u>, Whiting, dory/oreo/whiptail, Grenadier, Redfish, Ribaldo, Tiger flathead, Orange Roughy, Trevalla, <u>School shark</u>, Skates and rays, Blue warehou, <u>Gulper shark</u>	Mackerel, Redbait, Gummy shark, demersal sharks, dogfish, *seals*, *baleen whales*, squid
Demersal flathead trawl (dtrawlFDB)	Morwong, Grenadier, Redfish,Tiger flathead,	Mackerel, Whiting, Trevalla, Gummy shark, demersal sharks, dogfish, <u>School Shark</u>, Skates and rays, <u>Gulper shark</u>, *seals*
Demersal celphalopod trawl (dtrawlCEP)	Squid	Cardinalfish, <u>Gemfish</u>, Whiting, Redbait, dory/oreo/whiptail, Tiger flathead, Ling, Trevalla, Gummy shark, Skates and rays, squid, *seals*, *baleen whales*
Demersal orange roughy trawl (dtrawlFDO)	Orange roughy, Ribaldo, Cardinalfish, Trevalla, <u>School shark</u>	Whiting, Redbait, dory/oreo/whiptail, Redfish, Tiger flathead, Ling, Gummy shark, demersal shark, Dogfish, Skates and rays, Blue warehou, squid
Prawn trawl (ptrawlPWN)	Prawns	Morwong, Cardinalfish, Gemfish, Whiting, Redbait, dory/oreo/whiptail, Grenadier, Tiger flathead, Ling, Orange roughy, Trevalla, Gummy shark demersal shark, pelagic shark, Squid, Skates and rays, <u>Gulper shark</u>, *seals, sea-lions, orca*
Danish seine (dseineFDB)	Tiger flathead, Morwong	Mackerel, Grenadier, Gummy shark, Skates and rays
Midwater cephalopod trawl (midwcCEP)	Squid, Ribaldo	Morwong, Mackerel, Whiting, Redbait, Grenadier, Tiger flathead, <u>School shark</u>, Blue warehou
Midwater fish trawl (midwcFD)	Cardinalfish, dory/oreo/whiptail, Ribaldo	Morwong, Mackerel, Whiting, Redbait, Tiger flathead, <u>School shark</u>, Blue warehou, Squid
Demersal trawl for benthopelagics (dtrawlFBP)	Morwong, Mackerel, Whiting, Grenadier	Tiger flathead, Ling, Gummy shark, demersal shark, Dogfish, Pelagic sharks, <u>School sharks</u>, Skates and rays, *seabirds, seals, baleen whales*
Demersal line for demersal fish (dlineFD)	Ling, dory/oreo/whiptail, Trevalla, Pelagic shark	<u>Gulper shark</u>, Whiting, Gummy shark, demersal sharks, Dogfish, Skates and rays, *seabirds*, *baleen whales*
Demersal line for sharks (dlineSH)	Gummy shark, demersal sharks, Dogfish, Pelagic shark	<u>School sharks, Gulper sharks</u>, *seabirds*
Demersal line for shallow water demersals (dlineFDE)	Morwong, Grenadier, Redfish, Tiger flathead, Trevalla, Dogfish	Cardinalfish, dory/oreo/whiptail, Gummy shark, demersal shark, Skates and rays, <u>Gulper shark</u>, *seabirds*
Demersal fish gillnet (netFD)	Ling, dory/oreo/whiptail, Trevalla	Cardinalfish, Spotted warehou, Whiting, Redbait, Orange roughy, Gummy shark, demersal shark, Skates and rays, <u>Gulper shark</u>, *seabirds, sea-lions, seals, baleen whales, dolphins, orca*
Shark gillnet (netSH)	Gummy shark, demersal sharks, Spotted warehou	Pelagic sharks, School sharks, Skates and rays, Blue warehou, <u>Gulper shark</u>, *sea-lions*, *baleen whales, dolphins, orca*

All stocks are explicitly modelled in Atlantis. The species which have been listed as specifically sensitive to bycatch and discards are underlined. Species such as seabirds, seals and whales are shown in italics.

5.2 Economic incentive scenarios

The definition of management scenarios was based on an extensive review of potential alternative incentive-based management systems (see section 3 for a summary of this

[15] Bycatch by trawl fleets can include benthos

review). These included financial instruments (subsidies, taxes, deemed values, bonds), market based instruments (bycatch, habitat and revenue quotas), and controls on market access and other social incentives, not all of which can be modelled explicitly.

Based on this review, three main incentive measures were considered: (1) Bycatch quotas, (2) Deemed values for quota species and (3) Taxes. Additions were made to the Atlantis model to allow explicit representation of the impacts of these regulatory measures[16]. An outline is provided below of the functions for revenue, profit, fleet, effort allocation, quota trading (and quota trading price) that have been modified in order to accommodate the explicit inclusion of the management options. All of the relevant functional relationships that define price, revenues, costs, profit, effort allocation and quota trading processes on the original Atlantis model are presented for reference in Appendix C.

5.2.1 Bycatch quotas

These are quotas applied to bycatch species (including megafauna and rare species or any other group designated as a "species of concern") and then used in much the same way as the quota for target species as follows:

i. Seeking to lease or purchase in new quota

The quota trading equations specified in Fulton *et al* (2007)(Appendix C) are used with modifications such that a subfleet is only interested in looking to trade quota if its cumulative catch to date is greater than a trigger proportion of the quota (target and/or bycatch) in hand. Similarly a subfleet is only willing to trade out if it has a large excess that it does not expect to fill either as catch or bycatch (that is if it needs less than a small trigger level of quota).

If a subfleet is willing to be in a trade, the difference between total take (cumulative catch and bycatch to date plus that expected for the rest of the year) for a species and the quota in hand is used to assess need (if take > quota) or if there is excess available for sale/lease (quota > take). From this point on the quota trading algorithms and formulations in Fulton *et al*. (2007) are applied without further modification.

The initial value of the unit price put on the bycatch quota (${}^{quota}p_{s,i,j,m,y}$) is set using a demand curve:

$${}^{quota}p_{s,i,j,m,y} = P^{m}_{s,i,j,m,y}\left(1.0 + \frac{1.0}{\psi}\right)$$

where $P^{m}_{s,i,j,m,y}$ is the marginal profit for the subfleet based on species *s*; and ψ is the interest rate. Alternatively the initial bycatch unit price can be set by the model user and then updated through time using the empirical quota price model developed in New Zealand by Newell *et al.* (2005) and implemented in this version of the Atlantis model.

[16] See Fulton *et al.* (2007), pages 364-377, for the specification of the equations relating to the socioeconomic model.

ii. Modify scheduled effort

The expected spatial distribution of discards can also be taken into account when scheduling effort. If this option is selected effort is allocated in locations that minimise expected exposure to bycatch and improve expected value per unit effort (thereby reducing the relative attractiveness of areas where there are potentially high catches of low value groups, which are more likely to be discarded due to high grading). This is implemented as an additional multiplier when computing effort distribution (which is a combination of re-distributed effort and current effort)(see effort re-distribution functional relationships in Fulton *et al*. 2007). Economic incentives were also directly included in the effort allocation equations (see below), when considering the potential costs and returns of fishing in specific locations. Moreover, when quota was exceeded and a deemed value or tax was imposed this forced a review of planned effort schedules in the effected fleets, even if they would not normally have reviewed their schedule at that time. Lastly, high grading rules were modified to allow for fleets to check on relative prices of different types of fish while at sea rather than basing decisions on the prices at the time they left port.

5.2.2 Taxes

Taxes can be applied to the take of species of concern (including bycatch for megafauna or rare species or over-quota catch in target species). Any taxes taken (i) reduce profit (acting as an additional cost term in the computation of total costs (see Fulton *et al*. 2007) and (ii) go to government tax revenue.

In addition, during effort scheduling an incentive to minimise bycatch is introduced by including a cost term conditioned on expected exposure to bycatch:

$$R_{e,m,y,j} = \left(\sum_i \left(\sum_s p_{s,j,m} \frac{H_{e,s,i,j,m}}{E_{h,i,j,m}} - p_{tax,s,j,m} \frac{H_{bycatch,e,s,i,j,m}}{E_{h,i,j,m}} \right) - C_{E,i,j,m,y-1} \right)$$

where $R_{e,j,m,y}$ is the expected return for subfleet *j* in month *m* of year *y*; $p_{s,j,m}$ is the sale price of species group *s* for that subfleet in that month; $E_{h,i,j,m}$ is the historical effort expended in that month in box *i* by the subfleet; $H_{e,s,i,j,m}$ is the is the expected harvest of the group in box *i* in that month by that subfleet (based on updating past catches per month); $p_{tax,s,j,m}$ is the bycatch tax for species group *s* for the subfleet in that month; $H_{bycatch,e,s,i,j,m}$ is the expected harvest of bycatch of the species group in that box in that month by that subfleet; and $C_{E,i,j,m,y-1}$ is the cost for that subfleet of fishing in box *i* in that month - calculated as total costs less fixed and capital costs (initially calculated per day and then taken to final costs by multiplying by the scheduled number of days at sea forthe month).

5.2.3 Deemed values for quota species

The calculation of the deemed values is based on a modified form of the market sale price ($p_{s,m}$) for fish being landed over and above the quota holding of a fleet for that species (compare with market sale price model in Fulton *et al.* (2007)):

$$\hat{p}_{deem,s,i,m} = \begin{cases} p_{s,m} & H_{s,i} < Q_{s,i} \\ p_{s,m}.\kappa_{deem,i} & H_{s,i} > Q_{s,i} \quad \text{simple deemed values} \\ p_{s,m}.(1-\kappa_{crew}-\kappa_{deem,i})-C_{marketing,s,j} & H_{s,i} > Q_{s,i} \quad \text{complex deemed values} \end{cases}$$

where $H_{s,i}$ is the landed catch of species *s* by sub-fleet *i* and $Q_{s,i}$ is the corresponding quota. κ_{crew} is the crew's share and κ_{deem} is the proportion of the price the government has set as the deemed value. The final deemed values go to the government as revenue (which is tracked explicitly). The effective market price (i.e. what the fisher gets) is the standard market price minus the deemed value for any landed catch $H_{s,I} > Q_{s,i}$.

The deemed value can be set to equal the current market price, in which case any fish landed over-quota fetches a zero price, and no incentives exist to land in this case. The penalty associated with the deemed value can be varied to determine different levels of impact on the catch, discarding and fleet behaviour. For example, scenarios can be run where the deemed value is less than the price, allowing for a small (but significant) price differential for over-quota landings. For efficient operators this low but significant price may cover the costs of landing over-quota fish. This creates an incentive for fish to be landed rather than discarded. The over-quota quantities landed by particular individuals can then be included in the assessment as an additional mortality rather than excluded (as mortality occurs and is not included in assessments when discarding is not monitored and recorded).

5.3 Scenarios

In order to limit the complexity of the case studies examined, the model runs were developed to test its response to simple bycatch management scenarios, based on only one of the three alternative incentive-based management instruments above: bycatch quotas, taxes and deemed values. Potential analysis could include combinations of management instruments although these are not considered here as multiplicative effects could occur that could mask our interpretation of any results. As part of the process of identifying potential model scenarios we mapped certain types of bycatch (that is, over-quota, rare/TEP species, and megafauna) against specific management options/incentives tools (bycatch quotas, taxes, and deemed values) that have been included in the Atlantis model (Table 6).

Table 6 – Example scenarios of incentive management tools versus stock/species groups caught (quota species, non-quota rare and or Threatened, Endangered and Protected (TEP) species, and megafauna).

	Stocks/Species caught (targeted, byproduct, bycatch and/or unintentional)		
Incentive tools	**Quota species**	**Rare or TEP species**	**Mega fauna**
1. Bycatch quotas	N/A	*e.g.* Cardinalfish (FVD)	*e.g.* Whales (WHB) Dolphins (WHS) Seals (PIN)
2. Taxes	N/A	*e.g.* Cardinalfish (FVD)	*e.g.* Whales (WHB) Dolphins (WHS) Seals (PIN)
3. Deemed values	*e.g.* Tiger flathead (FDB) Ling (FDC) Morwong (FPO) Blue grenadier (FDE) Spotted Warehou (FVB) Blue Warehou (SP) Blue-eye Trevalla (FDF) School whiting (FVO)	N/A	N/A

Bycatch quotas are output controls analogous to ITQs for commercial species, and in this case we have chosen species listed in the Bycatch and Discard Workplan (AFMA 2009) as high risk (Cardinalfish, and seals). Whales and dolphins are also included to consider the impact on a non-trawl fleet (in this case the shark net and purse seine sub-fleets). Taxes can be set and used to manage bycatch of rare/TEP species and megafauna, and apply to the capture of all of these species. For taxes we chose species listed in the Bycatch and Discards Workplan (AFMA 2009) as at high risk (Cardinalfish and seals) as well as whales and dolphins. Thus for consistency, the scenarios for bycatch quotas and taxes in this study can be compared in terms of their outputs – across a set of species that are considered for both incentive management tools.

The deemed values apply only to commercial species, and to over-quota catches of these commercial species. Deemed values have been considered to be the only potential option for management of over-quota catches in this study. As an example, deemed values can be set for species such as Tiger Flathead, Ling, Morwong, Blue Grenadier, Spotted Warehou, Blue Warehou, Blue-eye Trevalla and School Whiting (Table 7), essentially key species for which the TAC is restrictive and limits effort in these fisheries targeting many stocks. These companion stocks are grouped and listed in Fulton *et al.* (2007); and we essentially repeat then as such within this analysis.

Application of these scenarios assumes either that means are available to ensure compliance with the quantitative limits that define quotas, and that which also underlies the calculation of tax or deemed value payments, or that in the absence of such means, default reference bycatch and discard levels can be assumed as a basis for the implementation of such instruments.

A wide range of scenarios were tested in each of these three broad scenario classes, based on different values of the key parameters of the incentive-based management instruments (quota allocations in the Bycatch Quota scenarios, tax rate in the Tax scenarios, and deemed value ratio in the Deemed Value scenarios). Here, we present a selection of scenario runs that illustrate the main responses observed in the model, the parameter values of which are listed in Table 7.

Table 7 - The scenarios run in the analysis of incentives to reduce bycatch and discarding

Scenario No.	**Scenario name**	**Assumption**	**Base run values**	**Values set**
1	Bycatch quota (megafauna)	Whales, dolphins and seals	No restriction	Approximately 0.5 of previous incidental catch, that is Whales (WHB): 7 tonnes limit on shark net fisheries. Dolphins (WHS) 750kg limit on seine fleet and 250kg limit on shark net fleet. Seals reduction in incidental catch restriction by 0.5 for all fleets that incidentally capture seals.
2	Bycatch quota (rare species)	Quota on Cardinalfish	No restriction	Approximately 0.5 of previous catch that is 6 tonne Cardinalfish quota on Orange Roughy trawl fleet (dtrawlFDO)
3	Tax (megafauna)	Tax on whales, dolphins and seals	$0/kg	Whales ($1/kg; Dolphins $5/kg an seals $1/kg)
4	Tax (rare species)	Tax on Cardinalfish	$0/kg	$5/kg
5	Deemed value (3 companion stocks)	Deemed values on Tiger flathead, Morwong and School whiting	$0/kg	0.5*price per kg/stock
6	Deemed value (8 companion stocks)	Deemed values on Tiger flathead, Ling, Morwong, Blue grenadier, Spotted Warehou, Blue Warehou, Blue-eye Trevalla, School whiting	$0/kg	0.5*price per kg/stock

The following scenarios were analysed as part of the analysis (Table 7):

Two scenarios using bycatch quotas (1 and 2): A bycatch quota on Whales, Dolphins and Seals and an alternative scenario with a bycatch quota on Cardinalfish. Cardinalfish is considered due to its listing on the most recent Bycatch and Discarding Workplan (AFMA 2009).

Two scenarios using taxes (3 and 4): A set of taxes on Whales, Dolphins and Seals and an alternative scenario that is a tax on Cardinalfish.

Two scenarios using deemed values (5 and 6): Deemed values were applied across the range of quota species listed in Table 7, as a proportion set to 50% of the landed species specific prices. For the first run where deemed values were applied it is applied to a set of three (3) companion species (i.e. species that are caught together by certain gears e.g. trawl or seine); and in this case Tiger Flathead, Morwong and School whiting. In the 2nd scenario for deemed values a set of 8 companion species have deemed values implemented when quota is exceeded (see Table 6 for the list)

These scenarios represent *example* scenarios (with a starting time of year 2000) of a wide range of possibilities that could be explored. The broad aim is to evaluate the ecological consequences (biomass trends, changes in ecosystem) and impacts on the economic viability of fleets (profit over time) of alternative management scenarios, resulting from the predicted response of fleets to the incentive measures. Given the complexity of the interactions accounted for in the model, our analysis of these consequences focuses on system response to simple management interventions and assessment of the overall impacts on the ecosystem and on the fishing fleets. Further research would be required to identify the relative role of key drivers of such responses, and to examine the potential impacts of combining various management instruments.

As is apparent from the results presented in this report (see Section 5), the dynamic response of the fishery to management measures involves complex feedback interactions involving fleet behaviour, ecological processes and rules regarding the adaptation of management strategies to the status of the fishery, which are all included in the model. Various degrees of fleet sensitivity to changes can be simulated. The results presented here are based on cases in which this response, particularly as regards effort allocation across species and areas, is less dynamic, i.e. it involves a significant degree of inertia although fleets eventually will modify their activity patterns if modifications in the economic conditions change the relative attractiveness of different alternatives. Simulations were also carried out assuming much quicker adaptive responses by fishing fleets. These lead to similar qualitative changes in the fishery, yet these are more marked, and to some extent more complex to interpret.

6 Results

6.1 Reference description of the fishery

The current version of the Atlantis South East Australian fisheries model has been updated since its application for the Alternative Management Strategy evaluation (Fulton *et al.* 2007). In the initial AMS model the year 2000 was the reference year and the analyses were performed over 1910-2004 with projections running from 2000-2020 (and beyond in some cases). In this version of the model, data for fleets size and estimates of biomass have been updated for a more recent time period (2000-2004) where possible. Year 2000 is still the reference year with historical fitting. From 2001, the model runs dynamically without historical values applied to any of the variables in terms of the fleets.

Table 8 - Evolution of fleet sizes in base run scenario

Fleet	Subfleet	0	1	2	3	4	5	6	7	8	9	10	11	12
dlineFD	**0**	7	7	5	4	3	3	3	3	3	3	3	3	3
dlineFDE	**0**	4	4	3	2	2	2	2	2	2	2	2	2	2
dlineSH	**0**	4	4	2	2	2	2	2	2	2	2	2	2	2
dseineFDB	**0**	25	25	23	22	21	20	20	18	17	16	15	15	14
	1	2	2	1	1	1	1	1	1	1	1	1	1	1
dtrawlCEP	**0**	4	4	2	2	2	2	2	2	2	2	2	2	2
dtrawlFBP	**0**	2	2	2	1	1	1	1	1	1	1	1	1	1
dtrawlFD	**0**	70	70	69	68	67	66	65	64	63	62	61	60	60
	1	10	10	9	7	7	5	5	3	3	3	3	3	3
	2	4	4	2	2	2	2	2	2	2	2	2	2	2
	3	4	4	2	2	2	2	2	2	2	2	2	2	2
dtrawlFDB	**0**	29	29	29	28	27	26	25	24	23	22	21	20	20
	1	3	3	2	1	1	1	1	1	1	1	1	1	1
	2	3	3	1	1	1	1	1	1	1	1	1	1	1
dtrawlFDO	**0**	7	7	6	5	5	3	3	3	3	3	3	3	3
	1	12	12	11	10	9	8	7	6	5	4	4	4	4
	2	3	3	1	1	1	1	1	1	1	1	1	1	1
midwcCEP	**0**	2	2	2	2	2	1	1	1	1	1	1	1	1
midwcFD	**0**	4	4	2	2	2	2	2	2	2	2	2	2	2
netFD	**0**	2	2	1	1	1	1	1	1	1	1	1	1	1
netSH	**0**	52	52	50	49	48	47	46	45	44	43	42	41	41
	1	2	2	1	1	1	1	1	1	1	1	1	1	1
	2	3	3	2	1	1	1	1	1	1	1	1	1	1
trawlPWN	**0**	8	8	8	8	8	8	8	7	6	5	5	3	3

The model base-case run considers *status quo* in the fishery as of 2000, with application of none of the economic incentive measures listed above and without the fleet restructuring that occurred in the SESSF in 2006 imposed *a priori*. The evolution of fleets for this base run is summarized in Table 8. Clearly, the initial situation of the fishery is not stable, and adjustments take place without the introduction of new management measures. The base-case run shows a long-term decreasing trend in fleet sizes across all fleets, mainly due to assumptions in the model regarding the evolution of input costs and technical progress which impact on (dis)/investment decisions. These are modelled explicitly: if vessels are not profitable they eventually exit the fleet.

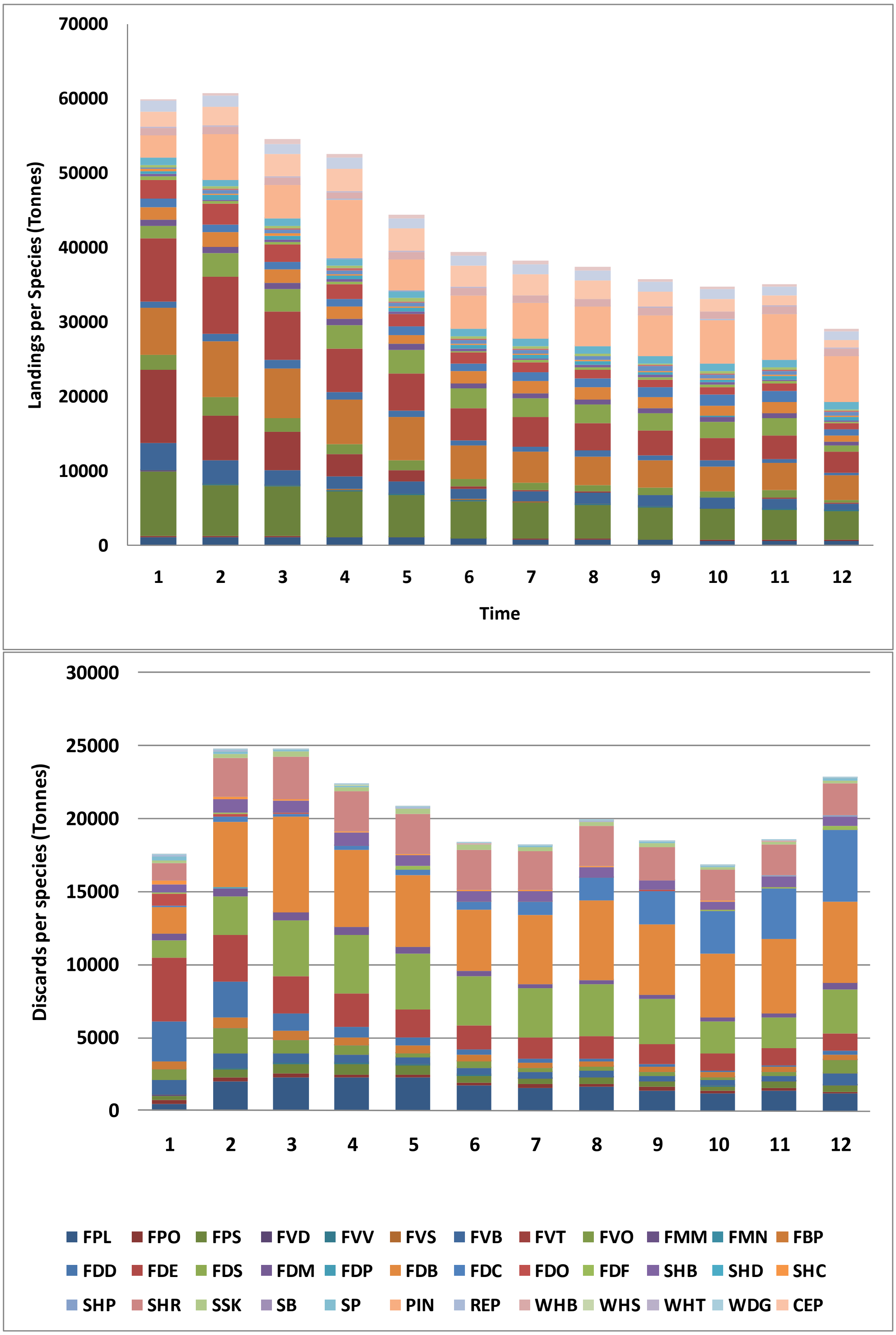

Figure 5 – Base run trends in landings (top panel) and discards (lower panel) per species (Tonnes)

Figure 5 illustrates the base run trends in landings and discards associated to the underlying assumptions made with respect to future technological, economic and ecological conditions under which the fishery operates. These assumptions lead to a contraction of total landings and associated discards in the fishery, across all species.

Results from simulation scenarios are compared against this base run, hence must be interpreted in terms of changes in the trends that would occur following the implementation of incentive-based bycatch management measures. In particular, changes in bycatch and discards which would be expected from any of the three instruments under study, or combination of these instruments, are analysed hereafter in terms of the differences which the scenarios entail as compared to the reference scenario.

In Figure 6, we compare model predicted catch versus observed catch (model versus observed in late 1990s). The similarity between observed and modelled values for many of the stocks is good/reasonable. In a complex ecosystem model, a systematically exact match of these variables is not expected at the individual stock level; rather ecosystem-wide patterns must be considered, along with relative changes in key variables between base-case runs and the alternative scenarios. Overall model distribution of catches across a range of stocks relates well to the observed distribution and most importantly captures the relative differential retention across species, correct spatial distributions of catch, effort and discards and other non-linear systems components. It is these factors (rather than exact matches to observations) that make ecosystem models such as Atlantis SE good testing grounds for considering alternative management approaches.

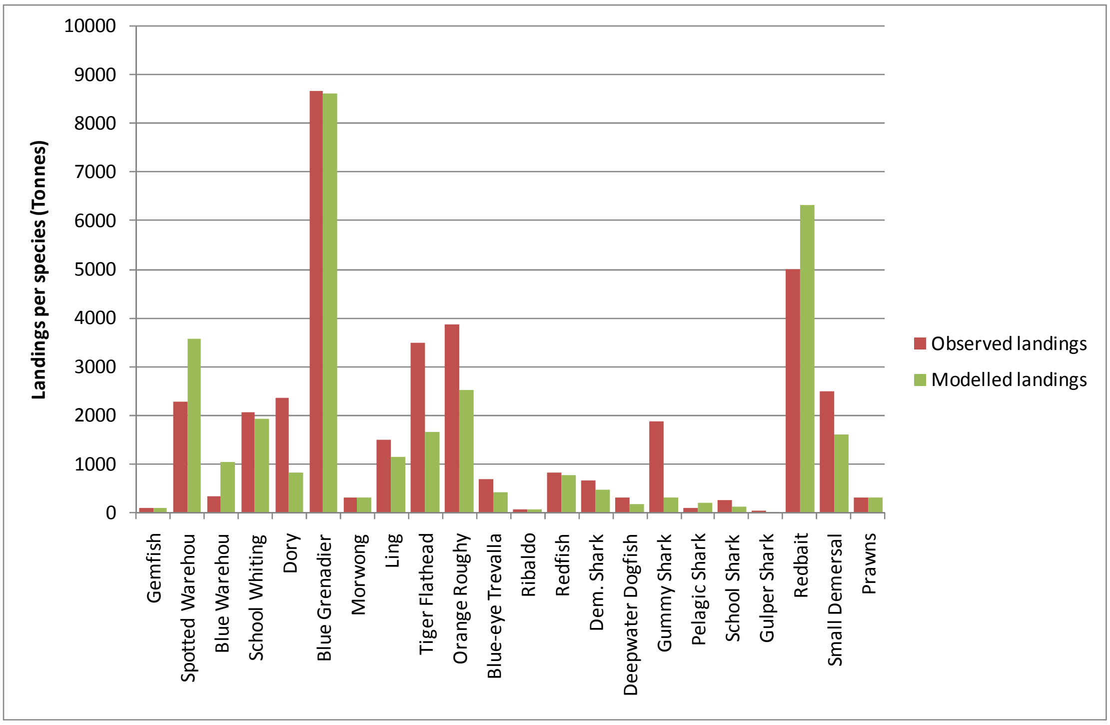

Figure 6 - The model predicted landings versus the observed landings for a range of species groups in the model

Figure 7 illustrates the distribution of catches and discards per fishery and across species, measured as an annual average over the 12 simulation years. This allows one to identify the main fleets with higher absolute catch and discarding levels, which are the main fleets that are considered in the analysis of simulation results hereafter. Although the size and distribution of catch and discards vary from year to year, the overall pattern presented here remains relatively stable. In total tonnage, the largest landings are taken by the main demersal trawl fleet (dtrawlFD) and the major discarding fleets in the model are trawl fleets (dtrawlFD and dtrawlFDO), a Danish seine fleet (dseineFDB), and to a lesser extent a net fleet (netSH) and a line fleet (dlineFDE).

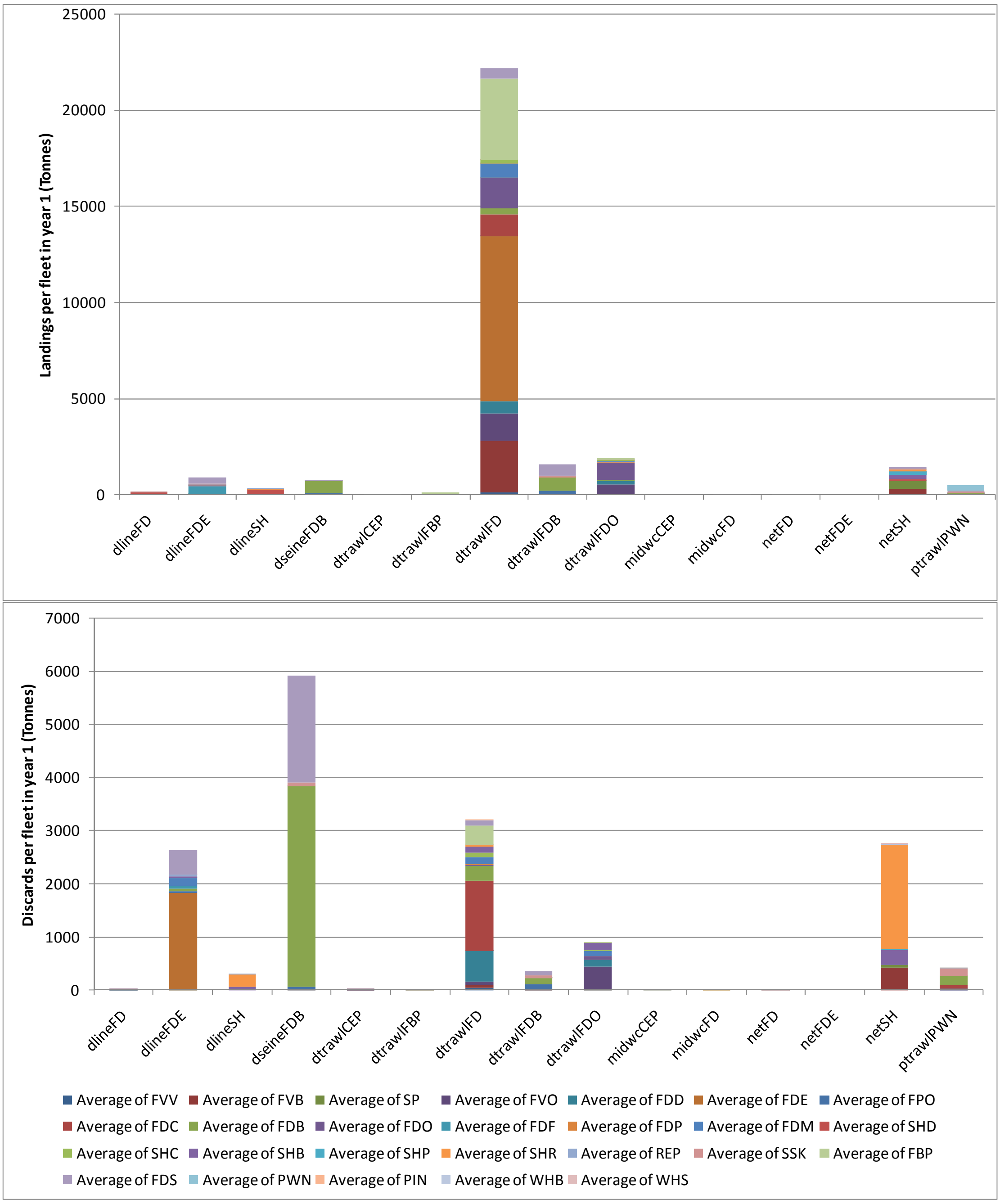

Figure 7 – Landings (top panel) and discards (lower panel) average over the 12 years of the Base Run

The main species landed by the three main trawl fleets (demersal trawl fleet (dtrawlD), demersal Tiger flathead trawl fleet (dtrawlFDB), demersal Orange roughy trawl fleet (dtrawlFDO), Figure 7), land mostly Spotted warehou (FVB), Whiting (FVO), Redbait (FBP), Blue grenadier (FDE), Small demersals (FDS), Tiger flathead (FDB), Ling (FDC) and Orange roughy (FDO). The main species targeted by the Danish seine fleet (dseineFDB) are Tiger flathead (FDB) and Small demersals (FDS). The significant net fleet for sharks (netSH) targets various shark species (School sharks (SHR) and Gummy sharks (SHB)); whereas the line fleet (dlineFDE) targets Blue grenadier (FDE) and Small demersals (FDS). Discards tend to be correlated to the main species targeted by these fleets, due to either market-based discarding (small fish) or in some cases over-quota.

Figure 8 illustrates the dependence of fleets on the main species included in the analysis at the beginning of the base run, measured in terms of the % of fleet gross revenue that landings of each species represent. Large circles illustrate higher levels of dependence of fleets on certain species: tiger flathead (FDB) thus appears as a key species for the seine fleet (dseineFDB), cephalopods are important for the trawlCEP fleet and the midwCEP fleet, demersal sharks are important for the dlineSH and the dlineFD fleets, and small demersals are important for the midwFD and the net FD fleets. In contrast the general trawl fleet is far more cosmopolitan with no one species group dominating in terms of revenue.

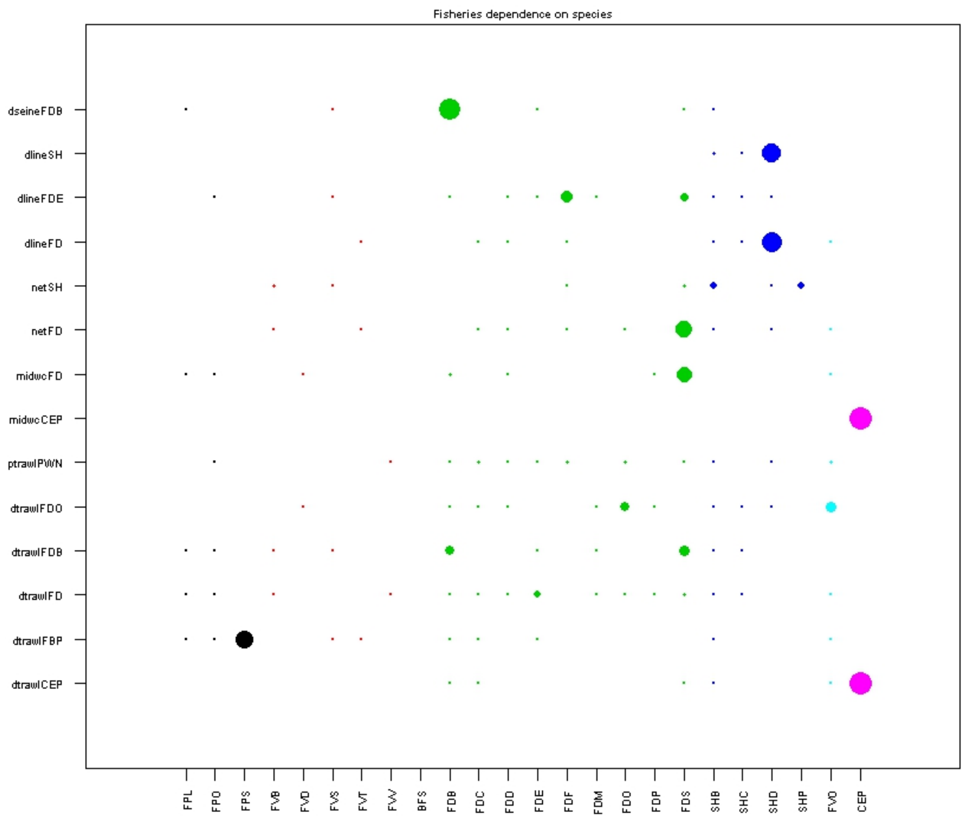

Figure 8 – Fleet dependence on key species, measured as the ratio of revenue generated by the species to the total revenue of the fleet, simulation year 2.

In following sections we review the results for the scenarios. Appendix D provides additional output for each scenario, including the base run in terms of trends in landings, discards, modelled effort per fleet and spawning stock biomass (SSB) for a range of key stocks (and in the case of effort – main fleets in the model).

6.2 Bycatch Quota on megafauna (whales, dolphins, and seals) – Scenario 1

This section presents results for the scenario with bycatch quotas the catch of three marine mammal species: whales (WHB), dolphins (WHS) and Seals (PIN). Figure 9 illustrates the changes which result from the adoption of this measure, in comparison to the base-case run, in the discarding of the three species.

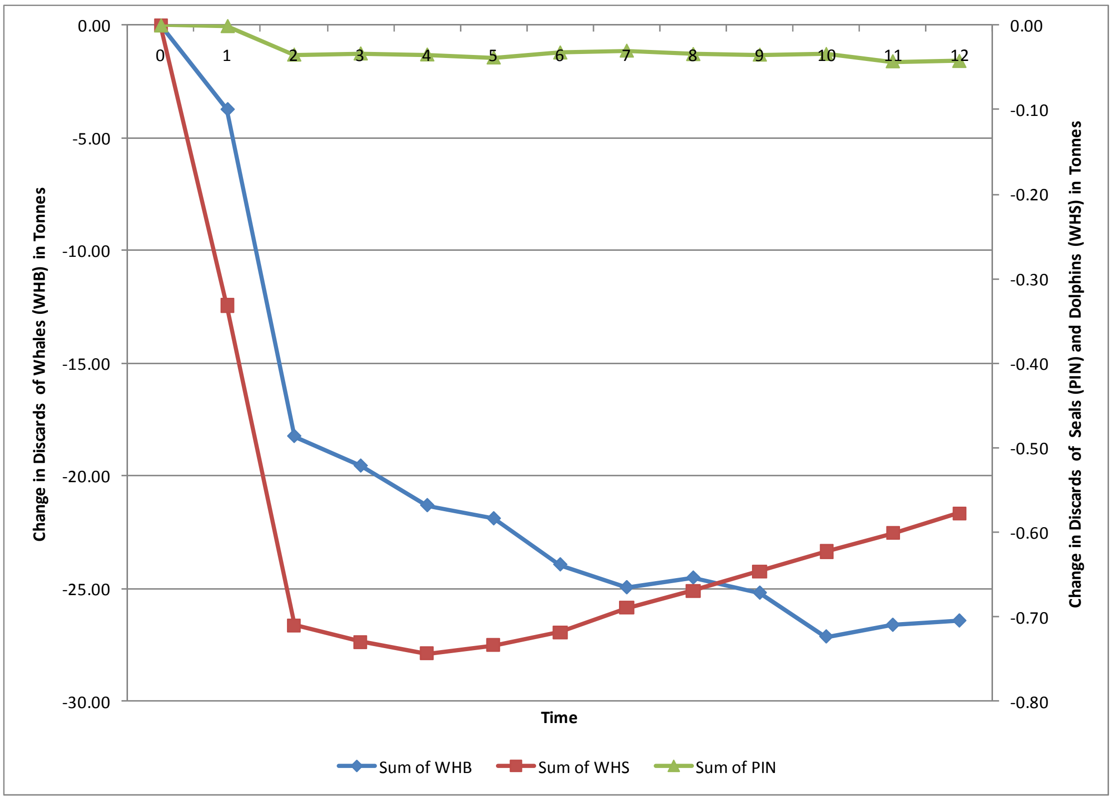

Figure 9 - Changes in discards of whales, seals and dolphins

The introduction of a Bycatch Quota on whales and dolphins entails an immediate decrease of discarding of whales in the order of 27 tonnes, whereas for dolphins it is in the region of 0.7 tonnes (Figure 9). The estimate for seals is lower, with a value of 0.05 tonnes. These reductions correspond to a reduction of the bycatch and discarding by respectively 100%, 29.1% and 88% for whales, dolphins and seals (in year 2 for example).

The implications of this reduction in the catches of whales at a fishery level are significant, and result from the impact which the measure has on the shark net (netSH) fleet, which must meet the strict bycatch quota on whales. This induces the fleet to modify its activity profile (with large decreases in fishing effort), which in turn affects its uptake of quota for various species, and strategy in terms of quota trading. The pathways of the ensuing impacts though the fleets are complex. First, we consider the impacts and then examine the underlying processes.

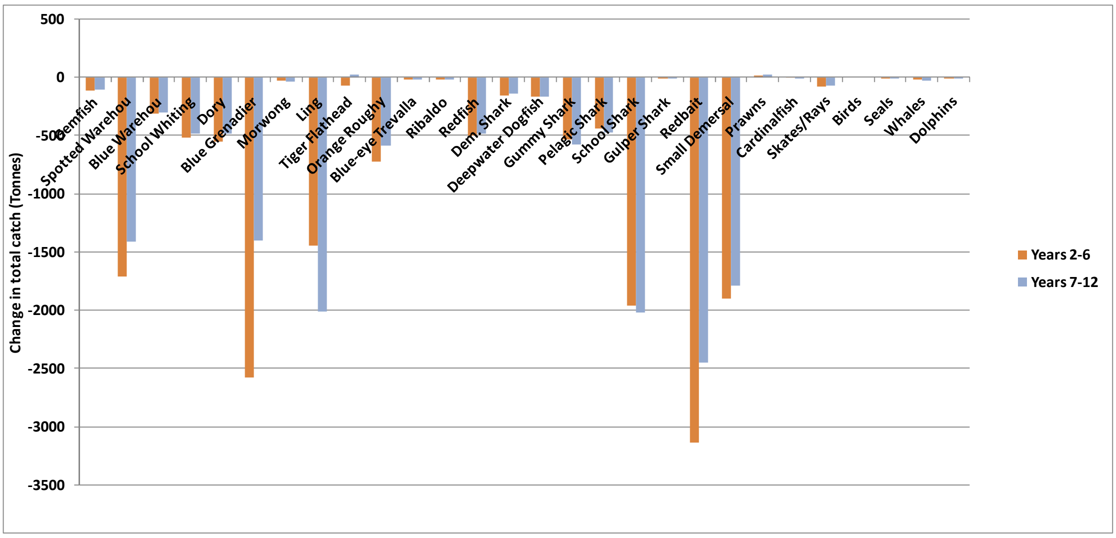

Figure 10 - Change in total catch

Figure 10 shows the differences between the base run catch and the scenario catch for all fleets under bycatch quota scenario 1 (averaged over 5 model years immediately following the introduction of the measure, and a further 5 model years extending into the future). The results clearly demonstrate the magnitude of the impact on the catch of the main commercial species across the fisheries and fleets. The total catch across all fleets of Small demersals, Redbait, various shark species, Orange roughy, Ling, Blue Grenadier, Dory, School whiting and Blue and Spotted Warehou (to name the species/species groups with the largest changes) decrease by large amounts.

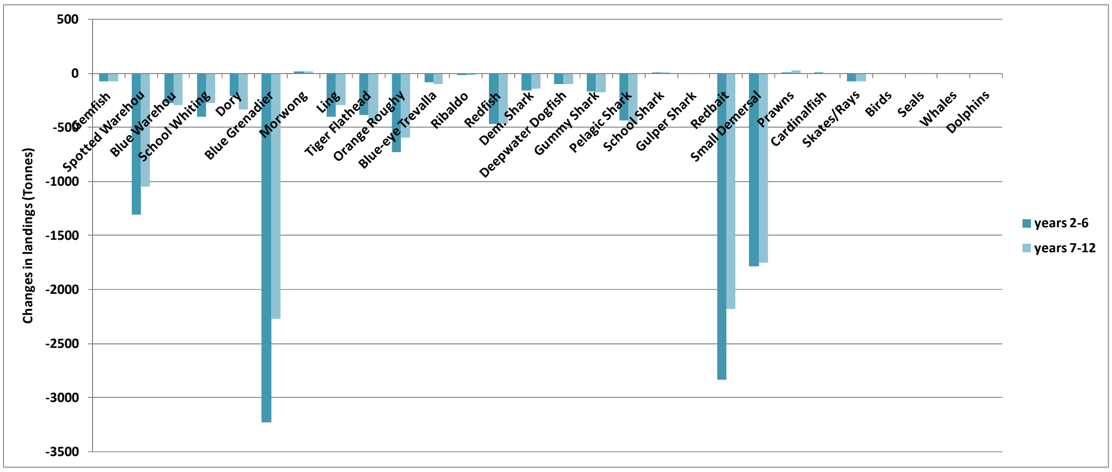

Figure 11 - Change in total landings per species

This reduction in catches is associated with decreases in landings of many species (Figure 11). The key species experiencing lower landings in port are: Small demersals, Redbait, Blue Grenadier, and Spotted Warehou (to name the species/species groups with the largest changes). The mixed nature of the catches and targeting/discarding behaviour of fleets also leads to changes in the proportion of catches landed for a number of species. The changes in discards between the base run and bycatch quota scenario 1 are presented in Figure 12. The scenario leads to an increase in the discards of two stocks as compared to the base run, namely Blue Grenadier and Tiger Flathead, but small increases in discards are also observed for Blue-eye Trevalla. For other species, decreases in discards are observed, notably Spotted Warehou, Ling, Gummy Shark, School shark and Redfish. The decrease in the discarding across the range of these stocks reflects lower effort and thus fishing mortality by the fleets that traditionally target these stocks.

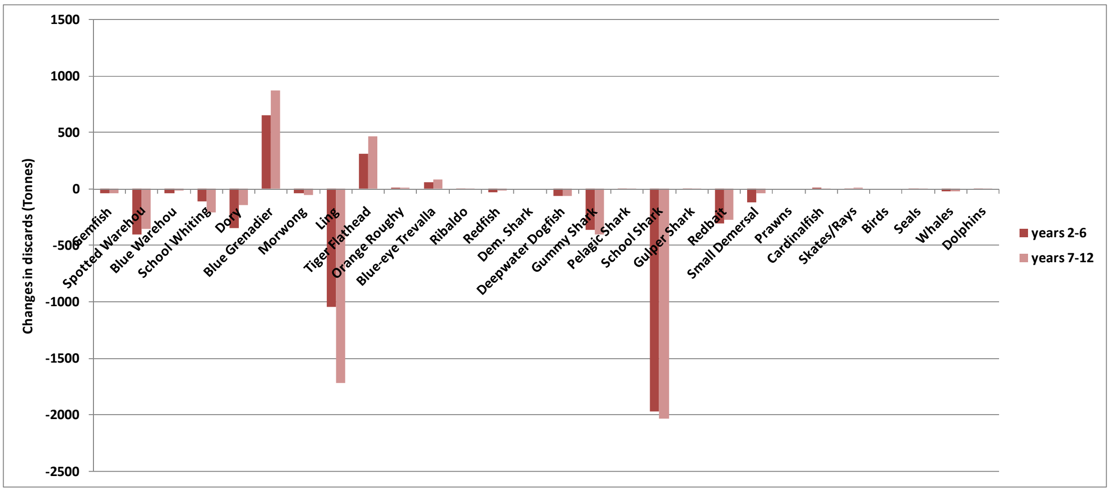

Figure 12 - Change in total discards per species

Figure 13 shows the response of the fleets in term of fishing effort for the main fleets in which impacts have been observed in the simulation for scenario 1. The two main fleets affected are the shark net fleet (netSH) and the demersal; trawl fleet (dtrawlFD), which both reduce their fishing effort as a result of the management measure (Figure 13).

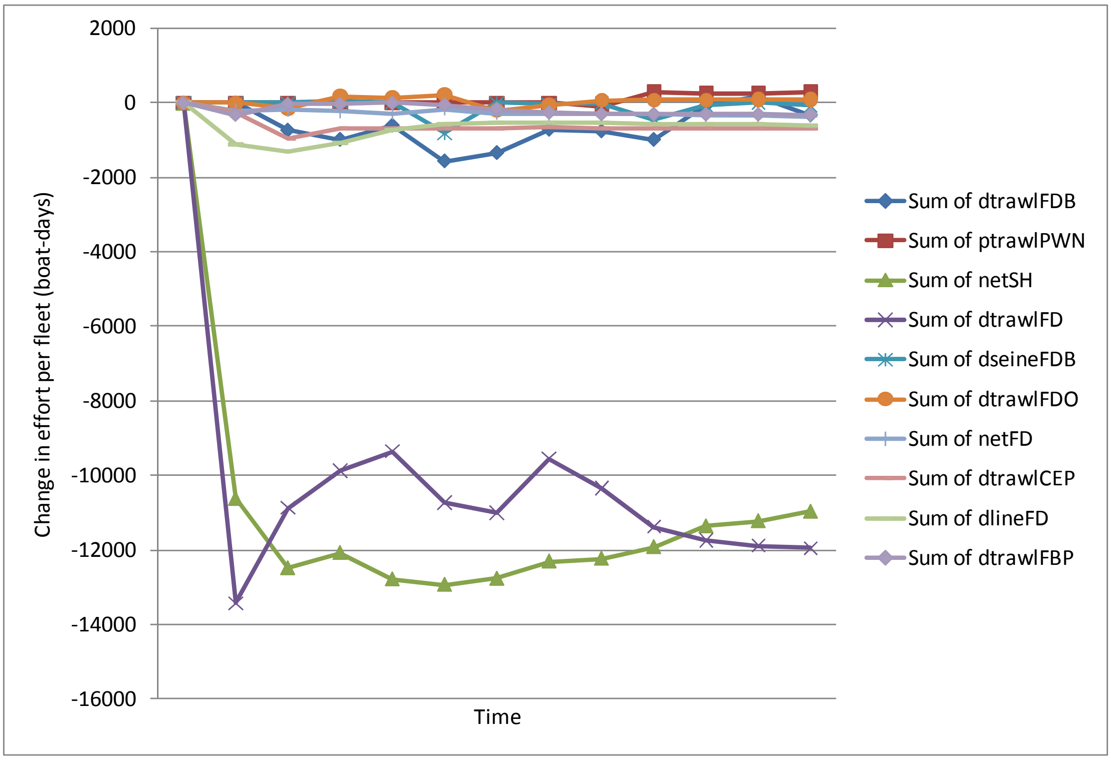

Figure 13 - Change in effort per fleet

Reductions in the effort of other fleets, notably the dtrawlFDB fleet and the dlineFD fleets, are also observed, but they are relatively small changes in comparison to the large effort reductions seen for the shark net fleet and the demersal trawl fleet. This complex suite of consequences of the management in the fishery results from the cumulative effects of fleet responses in terms of quota trading, targeting and resulting effort levels if quota is not made available and boats are effectively excluded from the fishery for the remainder of the year.

For example, the shark net fleet (netSH) which is the main fleet catching whales is constrained by the bycatch quota on marine mammals. This entails a reduction in its discards of other species and in its overall catches of these species, as illustrated in Figure 14. The main species which are caught in lower numbers are obviously the shark species (School shark, Gummy shark and Pelagic shark). Fish species which are also caught in lower numbers are Spotted and Blue Warehou. Given that the fleets that incidentally catch marine mammals are limited in number, and that the initial allocation of bycatch quotas for these species is based on the reference catch levels in the fishery, no trade opportunities exist that would allow the netSH fleet to relax this new constraint on its activity, by leasing in quota from other, less constrained fleets. Hence, the bycatch quota scenario performs in this case similarly to what would occur under an individual non-transferable quota for the catch of marine mammals.

This reduction in activity and catches leads this fleet to increase the proportion of its quota allocations that it leases out to other fleets, thus leading to cascading effects throughout the fleets and changes in their fishing effort on other stocks. The overall impacts are in turn also affected by the changes in relative abundances of the different target stocks (see Appendix D), which modify catch rates and the relative attractiveness of the different species. The many interactions between fleet behaviour and biological responses in the model all contribute to the overall outcomes, which prove much more complex and wide-ranging than could have been initially assumed for a single management measure primarily impacting only a small subset of fleets in the fishery.

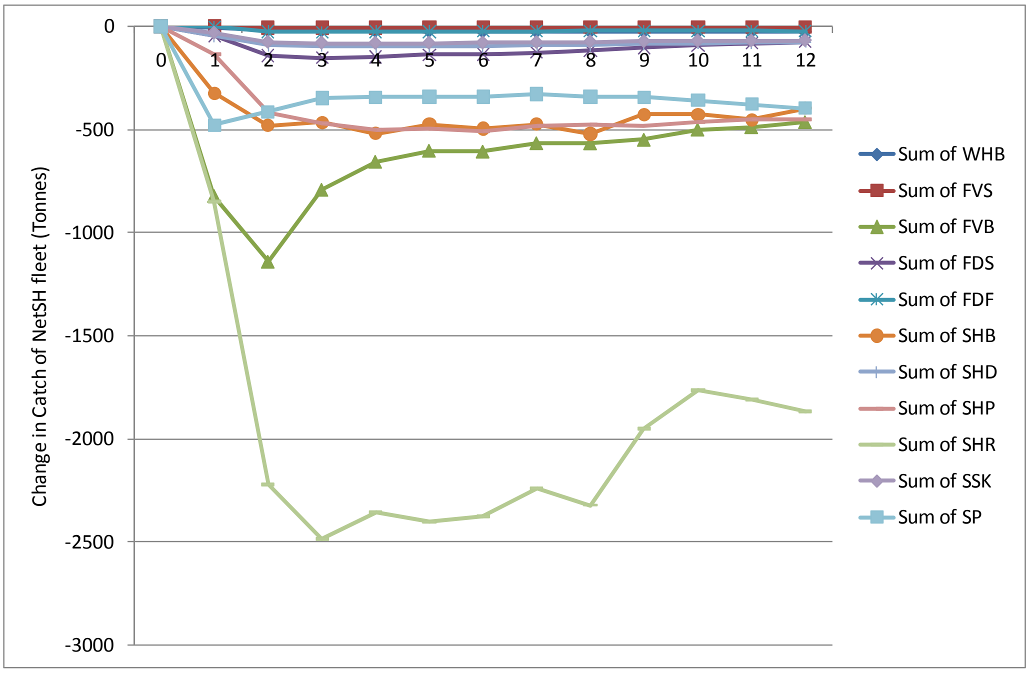

Figure 14 - Change in catch by NetSH fleet

The model allows one to assess the overall consequences of the management measure on the economic performance of the fleets. As illustrated in Figure 15, rent in the trawl fisheries decreases with the adoption of the management measure, as these fleets are negatively impacted from the implementation of the bycatch quota.

The observed reduction in fishing effort in the shark net fleet (netSH) however does not reduce the level of rent in this fleet, rather increases in rent after the adoption of the management measure are observed, possibly as a result of having retained sufficient catch while fishing to cover onshore costs, while not suffering the costs of fishing longer through the year. This outcome is at least in part a reflection of the marginal economic position the shark fleet was in during the late 1990s and 2000, and the fact that non-economic drivers (lifestyle fishing) are also influencing participation in this fleet.

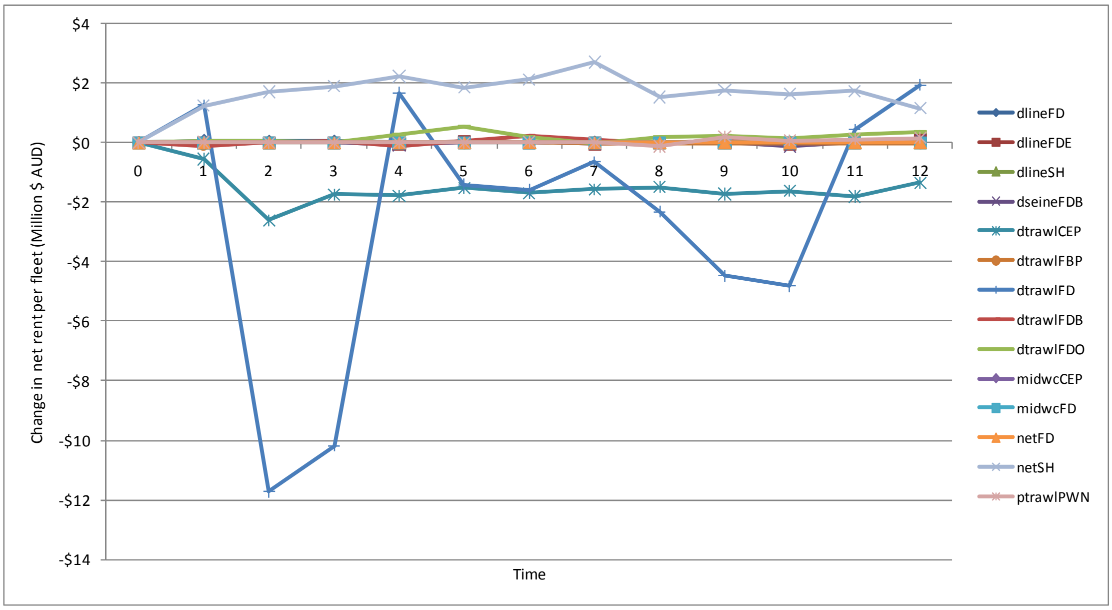

Figure 15 - Change in rent per fishery for the main fleets

6.3 Bycatch Quota on rare species (Cardinalfish) – Scenario 2

In this scenario, we explored the option of introducing a bycatch quota on a rare species, using Cardinalfish as an example, as this group is listed in the bycatch management plans.

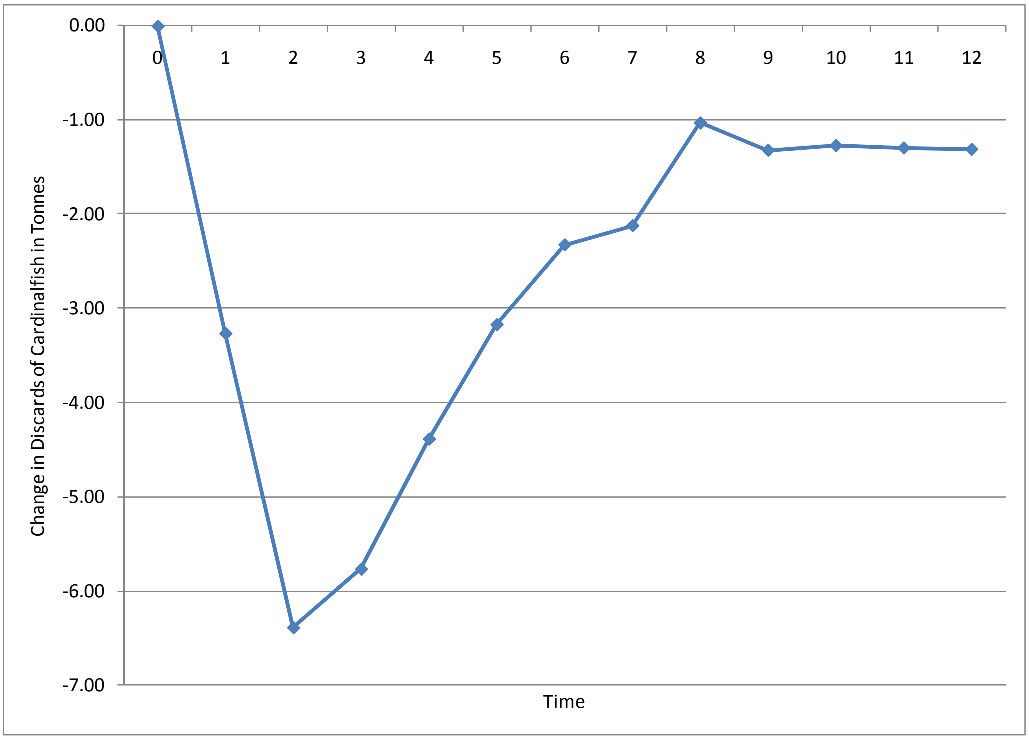

Figure 16 - Changes in discards of Cardinalfish

Figure 16 illustrates the changes in the discarding of Cardinalfish under this scenario. The introduction of a Bycatch Quota on Cardinalfish entails an immediate decrease of discarding of Cardinalfish in the order of 6 tonnes or 98.7% of the reference discard levels (for year 2 of the model), after which this change becomes lower in magnitude, finally reaching a long term reduction in discarding of this species group of about 1.3 tonnes on average.

The implications of the reduction in the catches of Cardinalfish (Figure 17**)** at a fishery level are significant, and result from the impact which the measure has on several fleets, notably the trawl fleets that targets Orange Roughy (dtrawlFDO) and prawns (ptrawlPWN), which must meet the strict bycatch quota on Cardinalfish. This induces the fleet to modify its activity profile (with consequent large decreases in fishing effort), which in turn affects its uptake of quota for various species, and strategy in terms of quota trading.

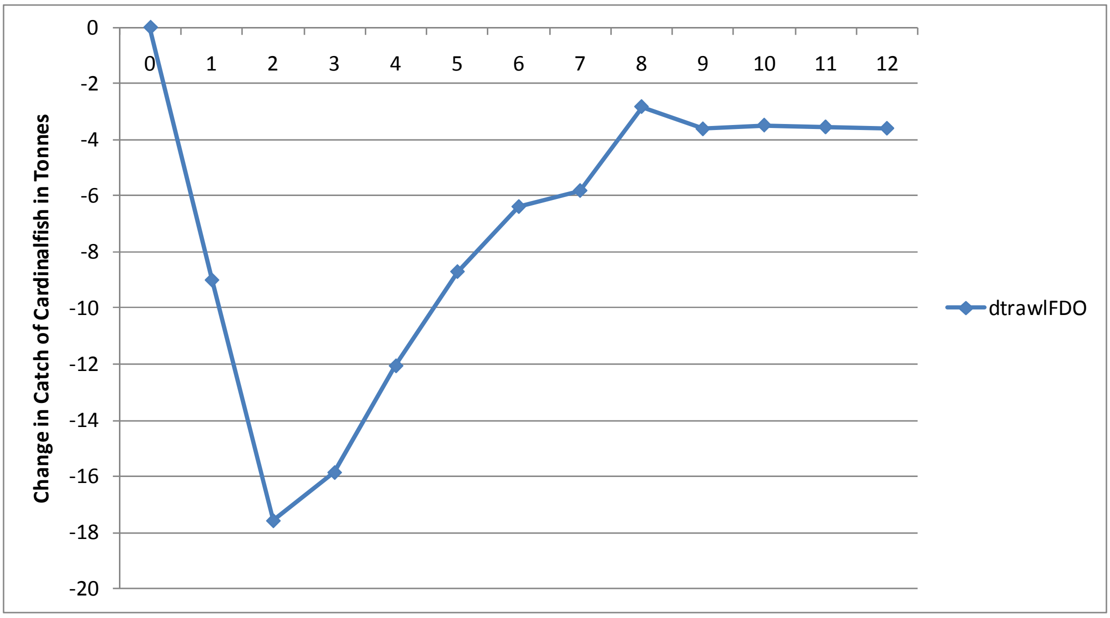

Figure 17 - Changes in catches of Cardinalfish

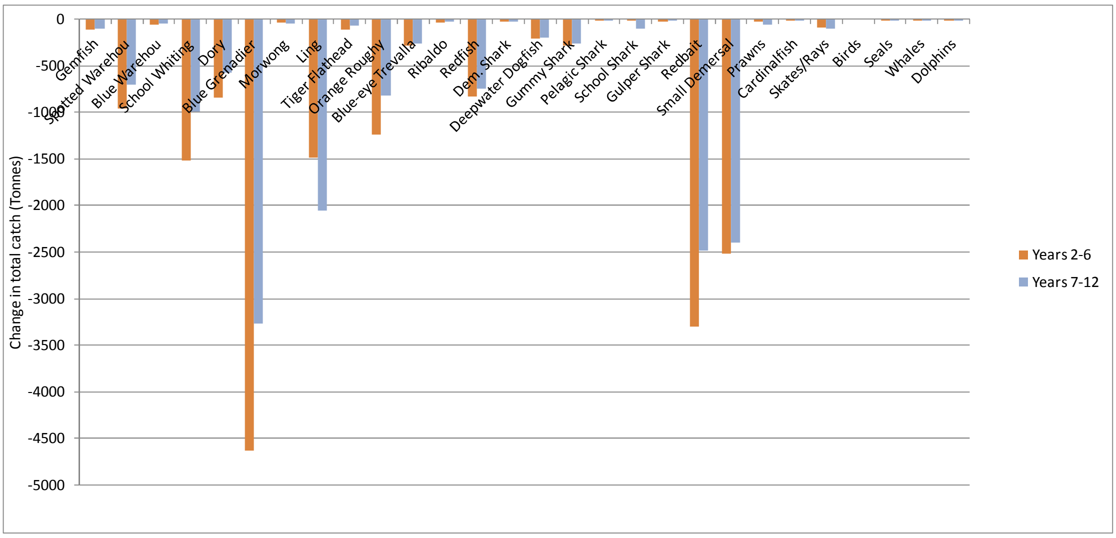

Figure 18 - Change in total catch

Figure 18 shows the differences between the base run catch and the total catch for all fleets for scenario 2 (averaged over 5 model years immediately following the introduction of the measure, and a further 5 model years extending into the future). As in the previous scenario, the impacts of the management measure are wide ranging. The results clearly demonstrate the magnitude of the impact on the catch of the main commercial species across the fisheries and fleets. The total catch across all fleets of Small demersals, Redbait, Redfish, Orange roughy, Ling, Blue Grenadier, Dory, School whiting and Blue and Spotted Warehou (to name the species/species groups with the largest changes) decreases by large amounts.

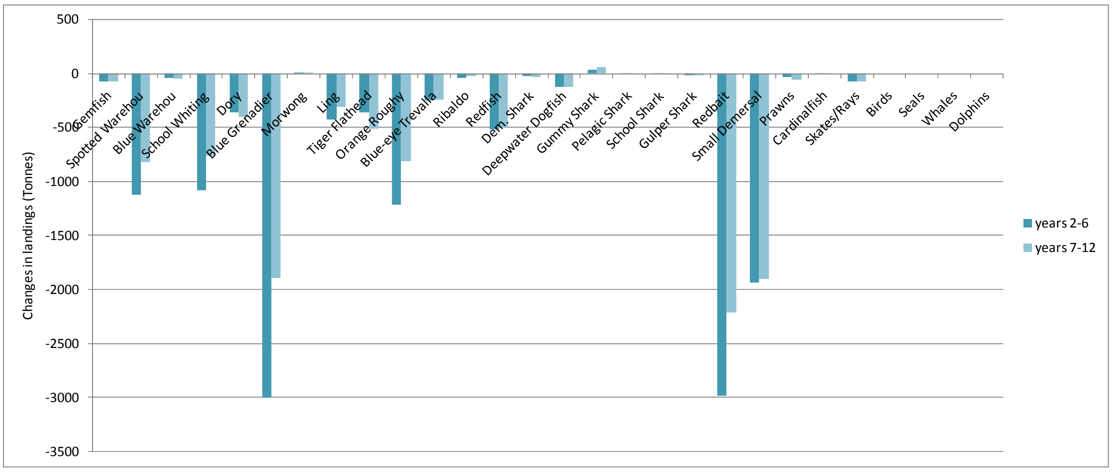

Figure 19 - Change in total landings per species

Mostly in line with the decreases in catches, the landings of many species also decrease (Figure 19). The key species experiencing lower landings in port are: Small demersals, Redbait, Blue Grenadier, Orange roughy, School Whiting and Spotted Warehou (to name the species/species groups with the largest changes). However, the mixed nature of the catches and targeting/discarding behaviour of fleets also lead to changes in the proportion of catches landed for a number of species.

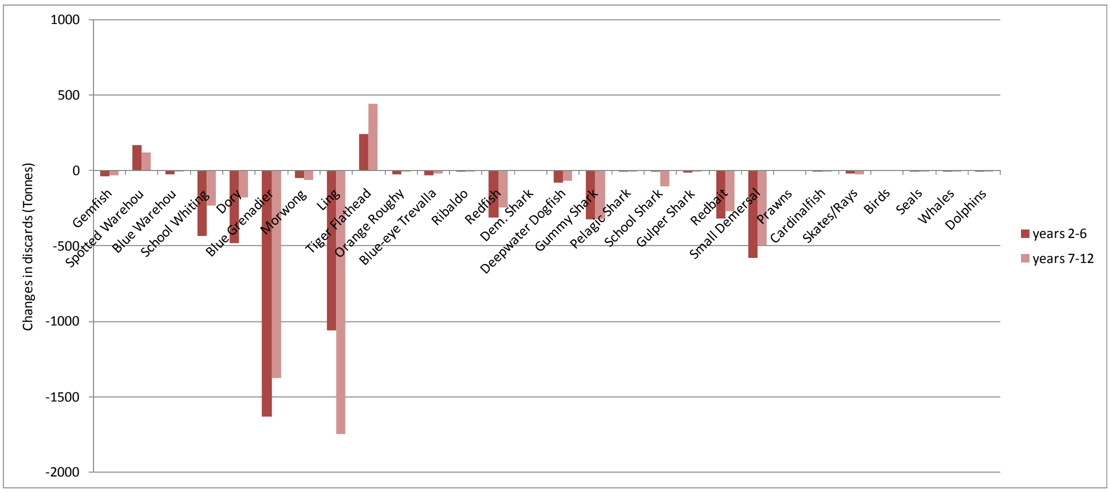

Figure 20 - Change in total discards per species

The changes in discards between the base run and the bycatch scenario 2 are presented in Figure 20. An increase in discards is observed for Spotted Warehou and Tiger Flathead. For other species, decreases in discards are observed, notably School Whiting, Dory, Blue Grenadier, Ling, Redfish, Gummy Shark, Redbait and small demersals. The decrease in the discarding across the range of these stocks reflects lower effort and thus fishing mortality by the fleets that traditionally target these stocks.

Cardinalfish are mostly caught by the trawl fleet targeting Orange roughy. As this fleet is subject to a bycatch quota constraint on the species (and there are limited opportunities to trade with other fleet; only within sub-fleets) the fleet is forced to reduce its fishing activity and thus its total catch of other species declines (Figure 21). The main species which are caught in lower numbers are the main demersal stocks such as School whiting (FVO), the main target species – Orange roughy (FDO) and species such as Dory, Redfish and Redbait. With all the complexities in the model, we can only postulate that these reductions are transitional as fleets switch target species after re-distribution of quota.

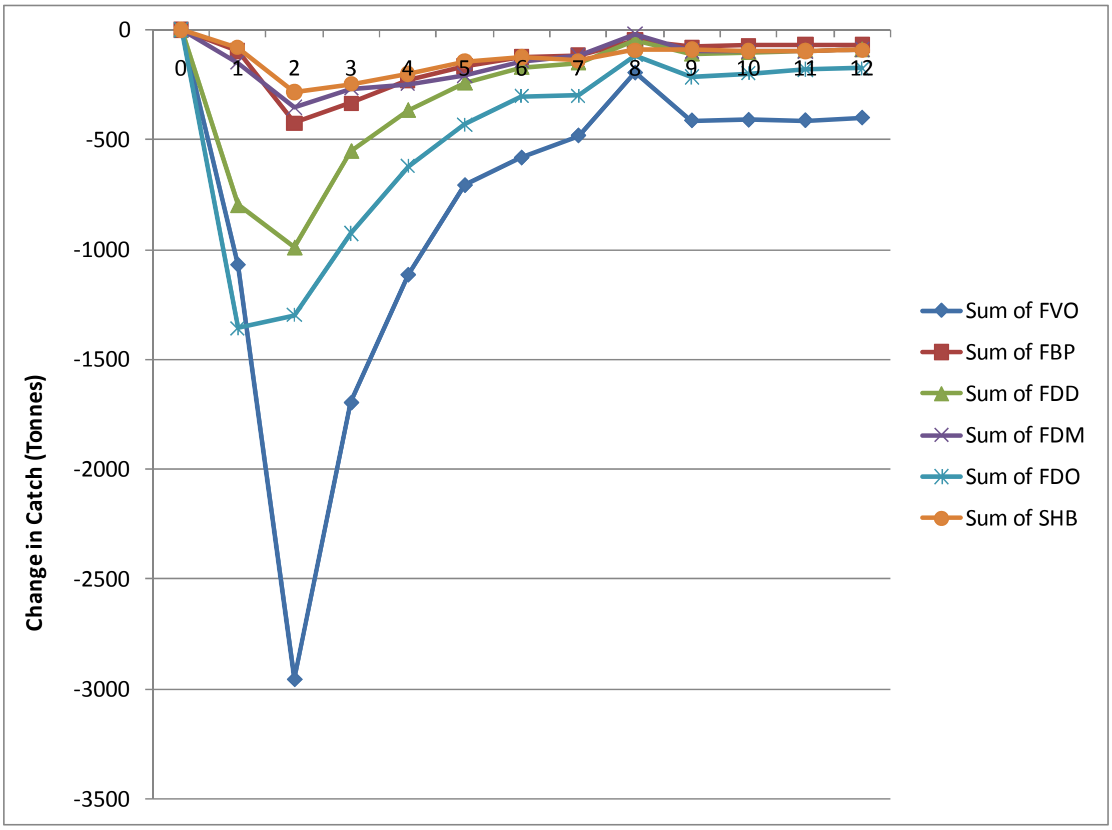

Figure 21 - Change in catch by dtrawlFDO fleet

Figure 22 shows the response of the fleets in term of fishing effort for the main fleets in which impacts have been observed in the simulation for scenario 2. The two main fleets impacted are trawls feets (dtrawlFD and dtrawlFDO). The main demersal trawl fleet (dtrawlFD) is negatively affected to a considerable degree due to the constraints in terms of bycatch quota as it too catches small amounts of Cardinalfish which it cannot avoid and as such the quota becomes restrictive in terms of its operations.

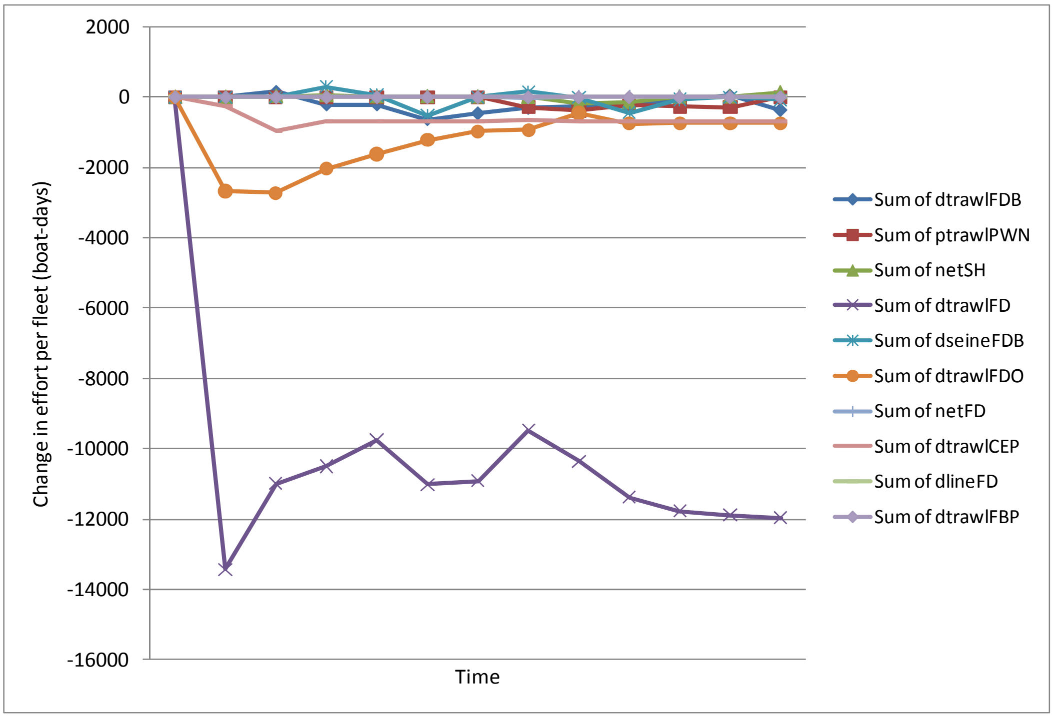

Figure 22 - Change in effort per fleet

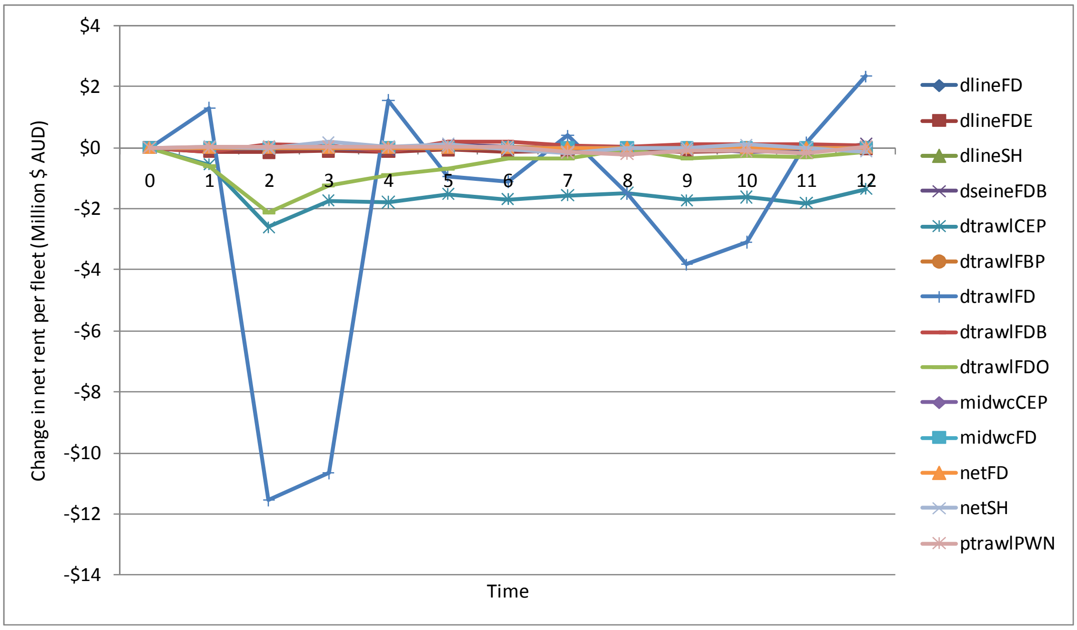

Figure 23 - Change in rent per fishery for the main fleets

As in the previous scenario, model allows one to assess the overall consequences of the management measure on the economic performance of the fleets. As illustrated in Figure 23, rent in the trawl fisheries decreases following adoption of the management measure, as these fleets are the most negatively impacted; the main trawl fleets experiencing decreasing change in profit being the demersal trawl fleet (dtrawlFD), the trawl fleet targeting Orange roughy (dtrawlFDO) and the trawl fleet targeting squid (dtrawlCEP). Note the negative change in rent does not imply absolute rent is negative in any of these fisheries; rather, it means that rent decreases with the management measure as compared to the base-case run.

6.4 Tax on megafauna (whales, dolphins, and seals) – Scenario 3

This section presents results for the scenario with tax on whales (WHB), dolphins (WHS) and Seals (PIN). Figure 24 illustrates the changes in the discarding of marine mammals associated with this scenario.

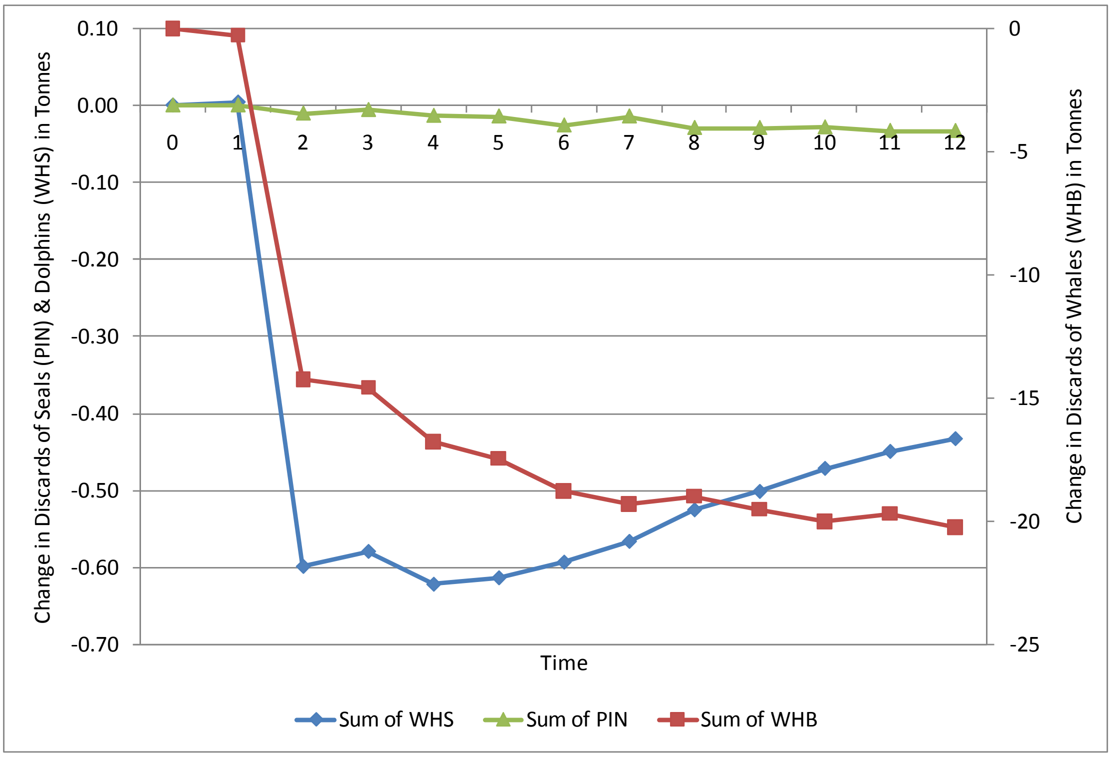

Figure 24 - Changes in discards of whales (WHB), dolphins (WHS) and seals (PIN)

The tax on whales results in an immediate decrease of discarding of whales in the order of 15 tonnes which steadily increases to just over 20 tonnes. For dolphins the impact of the tax is relatively large compared to the base run incidental catch of these animals with discards decreasing by 600kg (with the effect lessening slightly in the longer run). The estimate for seals is lower in absolute terms, with a change in discarding levels of 0.05 tonnes which equate to an average decline in discarding average over years 2-12 of 53.6%. As was the case with bycatch quota, these decreases in discarding reflect actual decreases in incidental catch as fleets avoid the bycatch of these animals.

The implications of this reduction in the catches of marine mammals are significant at a fishery level, and result from the impact which the taxes have on the shark net (netSH) fleet as well as the other fleets that have incidental catch of whales, dolphins and seals. These impacts induce the fleets to modify their activity profiles (and reduce effort), which in turn affects their uptake of quota for various species, and strategy in terms of quota trading. The pathways of the fleet response are complex. First, we consider the overall consequences and then examine some of the underlying processes.

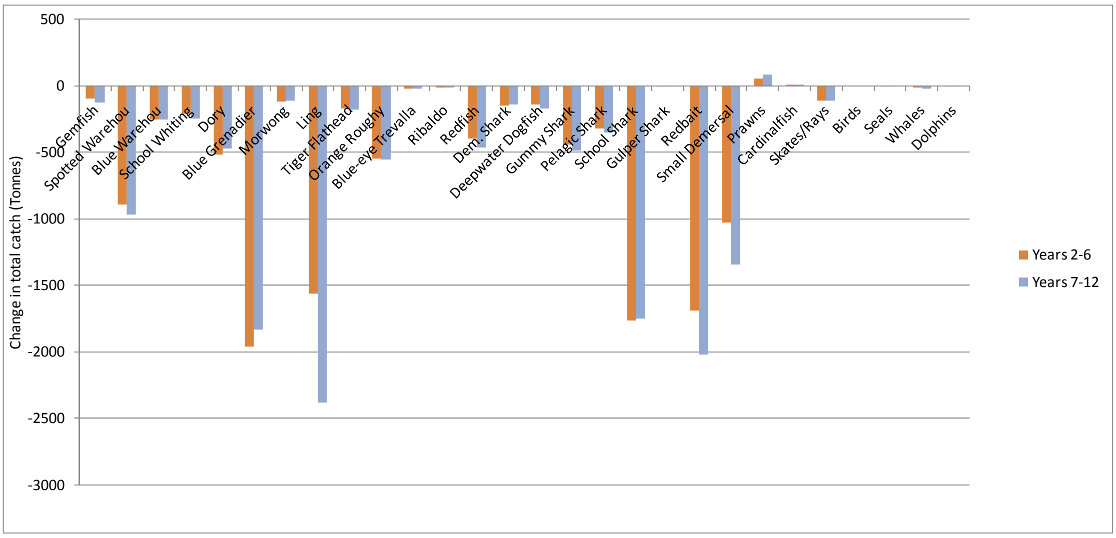

Figure 25 - Change in total catch

Figure 25 shows the differences between the base run catch and the catch for all the fleets for the tax on whales, dolphins and seals, i.e. scenario 3 (averaged over 5 model years immediately following the introduction of the measure, and a further 5 model years extending into the future). The total catch across all fleets of Small demersals, Redbait, various shark species, Redfish, Orange roughy, Tiger flathead, Ling, Blue Grenadier, Dory, School whiting and Blue and Spotted Warehou (to name the species/species groups with the largest changes) decrease by large amounts. The only species group for which catches increase are the prawns (PWN).

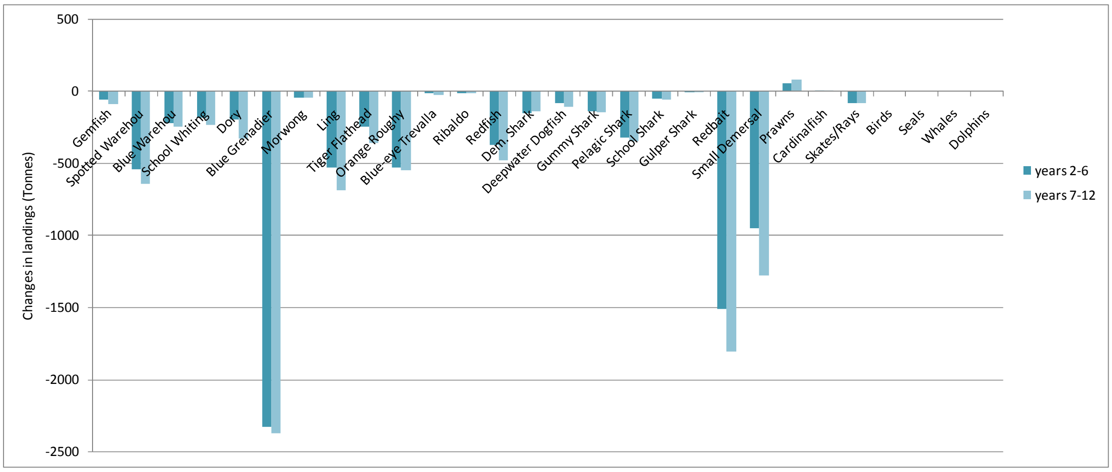

Figure 26 - Change in total landings per species

Mostly in line with the decreases in catches, the landings of many species also decrease (Figure 26). The key species that have lower predicted landings in port are: Small demersals, Redbait, various shark species, Redfish, Orange roughy, Tiger flathead, Ling, Blue Grenadier, School whiting, and Blue and Spotted Warehou. There is an exception to the rule in the sense that landings of prawns (PWN) increase.

The changes in discards between the base run and the bycatch scenario 3 are presented in Figure 27 (averaged over 5 model years immediately following the introduction of the measure, and a further 5 model years extending into the future). Discards increase as compared to the base run for Blue Grenadier and Tiger Flathead. For other species, decreases in discards are observed, the largest decreases being for School shark and Ling (species mostly previously landed by the shark net fleet (netSH)).

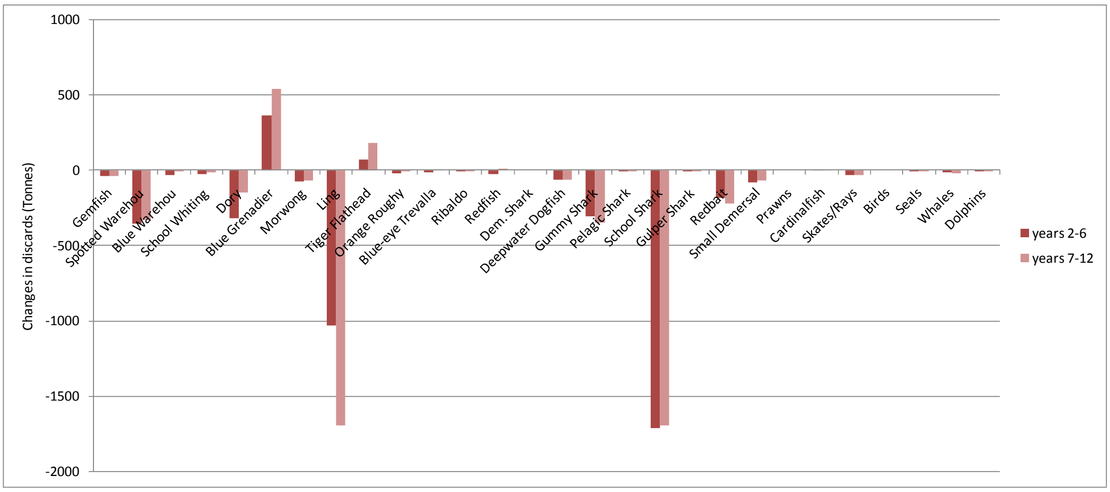

Figure 27 - Change in total discards per species

The shark net fleet (netSH) which is the main fleet that incidentally catches whales (and which in this scenario experiences the largest decrease in incidental catch due to taxes) decreases its effort as a result. This entails a reduction in its catches of other species, as illustrated in Figure 28. The main species that are caught in lower numbers are the main target species of this fleet: the shark species (i.e. School shark, Gummy shark and Pelagic shark), although Spotted Warehou, Blue Warehou and small demersals are also caught in lower numbers.

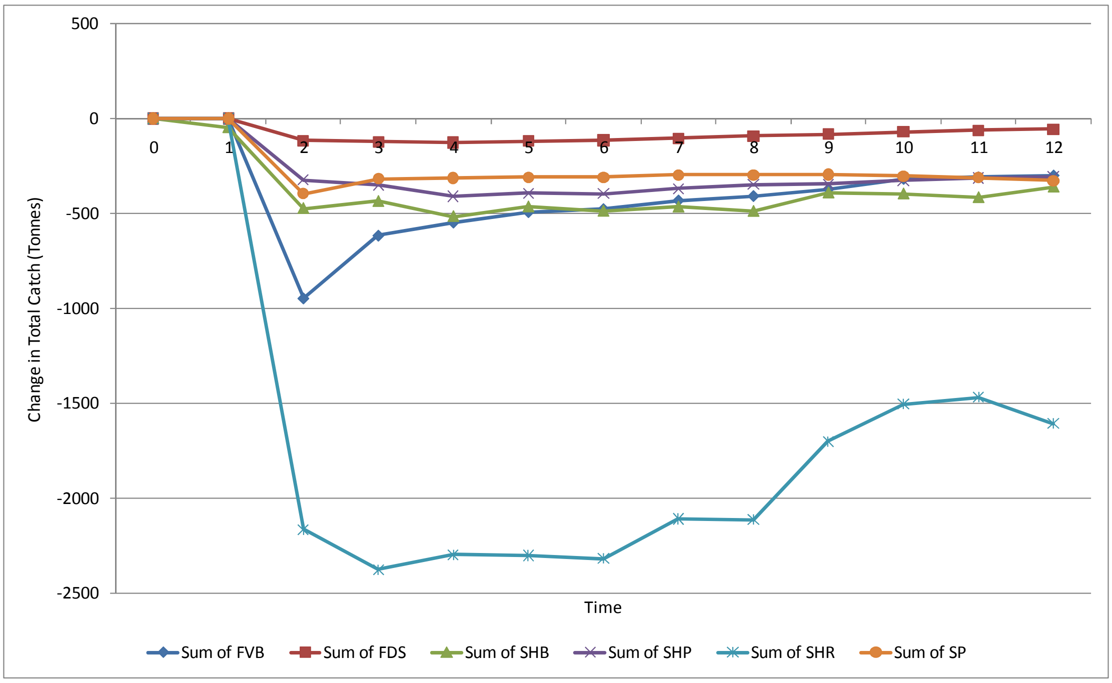

Figure 28 - Change in catch by NetSH fleet

Figure 29 shows the response of the fleets in term of fishing effort for the main fleets in which impacts have been observed in the simulation. The shark net fleet reduces its fishing effort as a result of the tax on catches of marine mammals. For this scenario the impacts on specific fleets can be observed. The main fleets that are affected are the netSH, the demersal fish trawl (dtrawlFD) and the dtrawlFDB fleets (Figure 29). Again, the main demersal trawl fleet (dtrawlFD) is negatively affected to a considerable degree due to the constraints in terms of tax as it too catches marine mammals which it cannot avoid and as such the tax becomes restrictive in terms of its operations. All of the fleets show in Figure 29 which are negatively impacted incidentally catch marine mammals. Note the demersal trawl fleet for Orange roughy displays indirect effects as in the model it is assumed it does not interact with marine mammals.

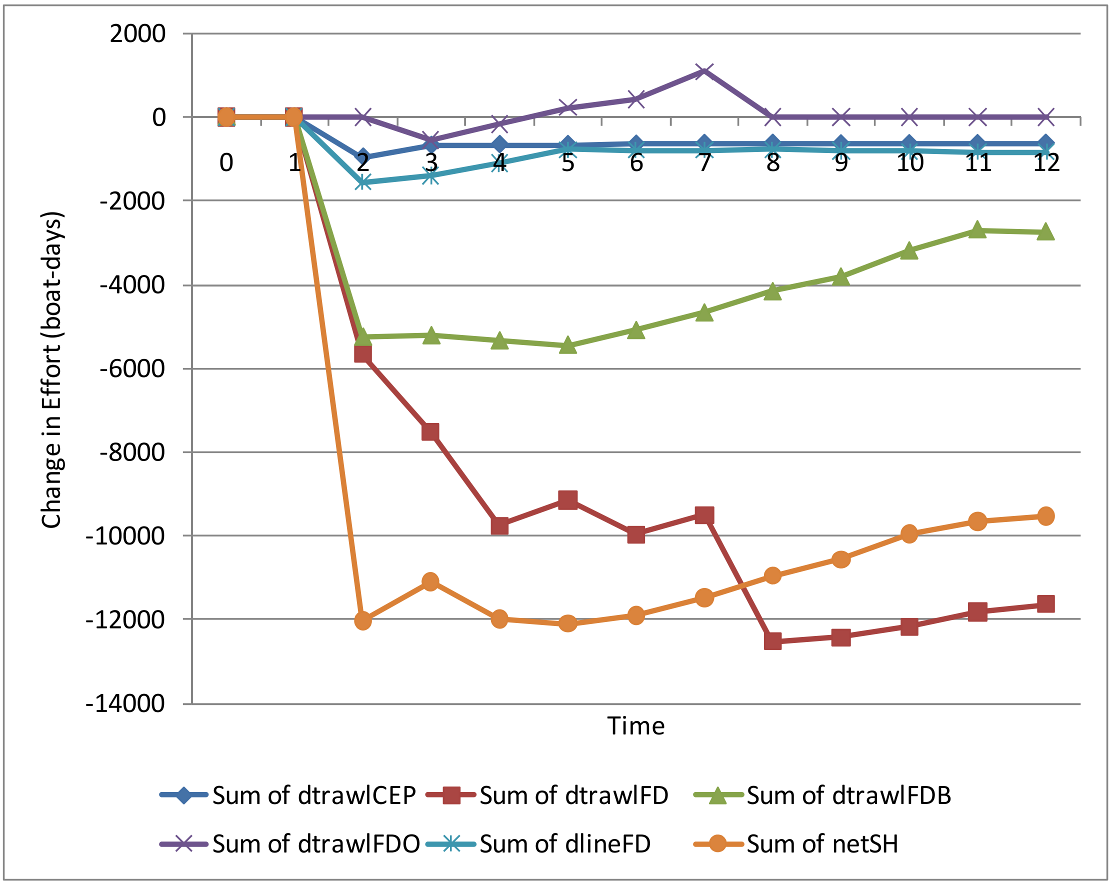

Figure 29 - Change in effort per fleet

The model allows one to assess the overall consequences of the management measure on the economic performance of the fleets. As illustrated in Figure 30, rent in some of the trawl fisheries decreases following adoption of the management measure, as these fleets are initially negatively impacted from the implementation of the tax. However, the impact on rent of the main affected fleet fluctuates over the time period of the model run, as the dynamic adjustments in fishing tactics take place. This leads to years in which some positive changes in rent are also observed for the general demersal trawl fleet (dtrawlFD). For two of the trawl fleets (dtrawlFDO and dtrawlFDB) indirect effects of the manegemtn measure lead to positive, but limited rent increases. As in the bycatch quota scenario the reduction in effort of the shark net fleet (netSH) leads to improved economic performance and increases in rent compared to the base run.

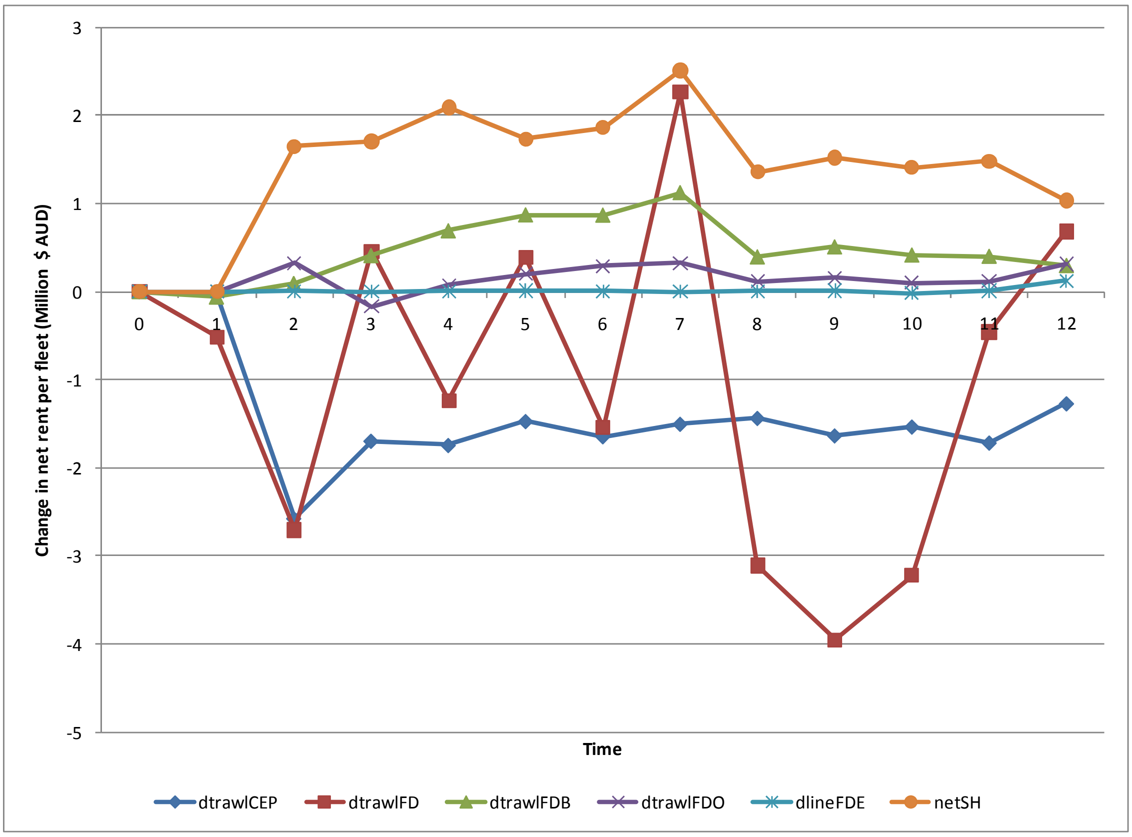

Figure 30 - Change in rent per fishery for the main fleets

6.5 Tax on rare species (Cardinalfish) - Scenario 4

In this scenario, we explored the option of introducing a tax (per kg. landed) on a rare species, using Cardinalfish as an example, as this group is listed in the bycatch management plans.

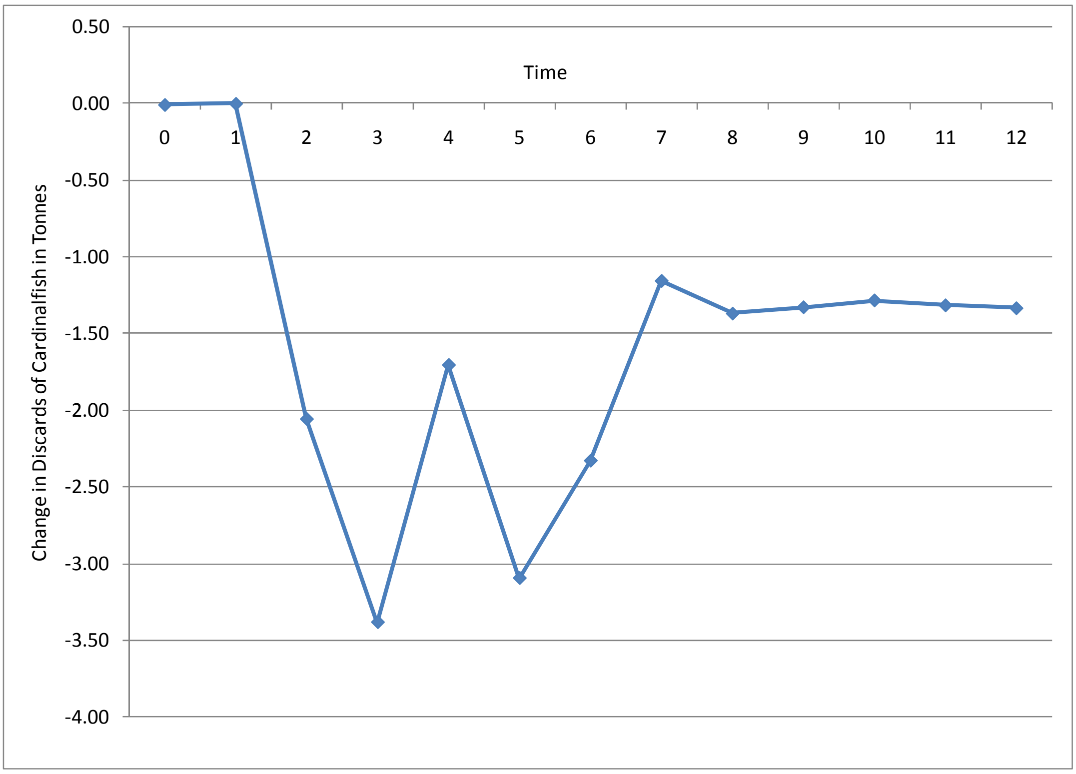

Figure 31 - Changes in discards of Cardinalfish

Figure 31 illustrates the changes in the discarding of Cardinalfish within this scenario. The introduction of a tax (per kg. landed) on Cardinalfish entails an immediate decrease of discarding of Cardinalfish of about 3.5 tonnes or 68%; the longer term reduction in discarding is lower in magnitude, reaching a level of about 1.25 tonnes.

The lower discards result from lower catches due to avoidance behaviour on behalf of the fleets. The implications of this reduction in the catches of Cardinalfish (Figure 32) at a fishery level are significant (that is an average of approximately 8 tonnes initially), and result initially from the impact which the tax has on the demersal trawl fleet that targets Orange Roughy (dtrawlFDO), with cascading effects as in the other scenarios

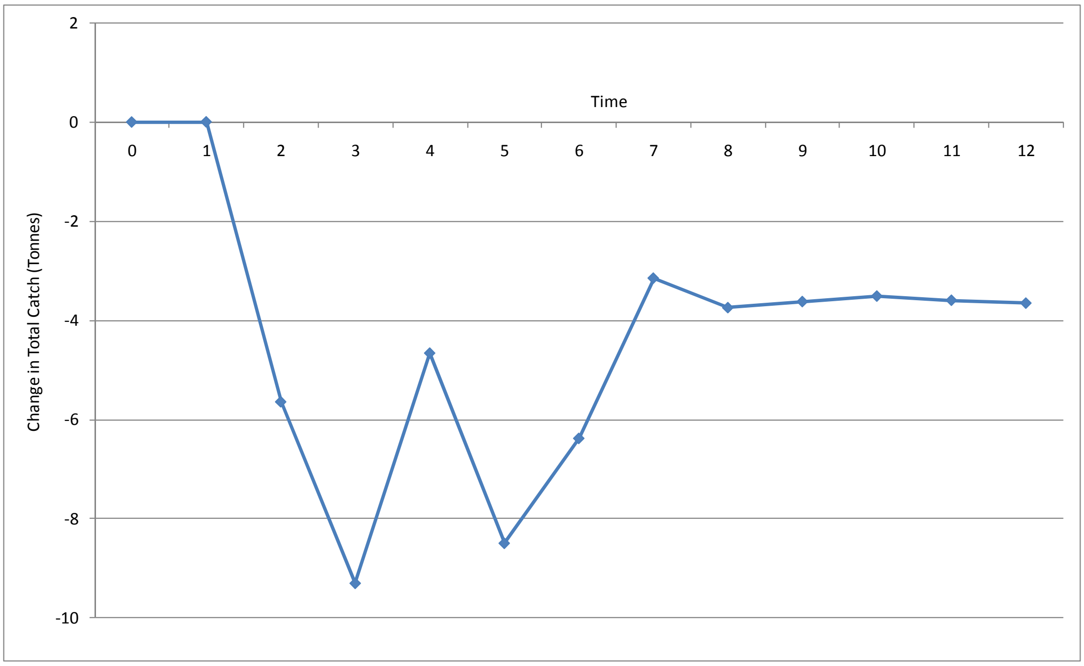

Figure 32 - Changes in catches of Cardinalfish

Figure 33 shows the differences between the base run catch and the tax scenario on Cardinalfish, i.e. scenario 4 (averaged over 5 model years immediately following the introduction of the measure, and a further 5 model years extending into the future).

The total catch across all fleets of Skates/rays, Prawns, Small demersals, Redbait, redfish, Orange roughy, Ling, Blue Grenadier, Dory, School whiting and Spotted Warehou (to name the species/species groups with the largest changes) decrease by large amounts. The only group showing any positive effect (very small increase) are the Schools sharks in the first five years of a model run.

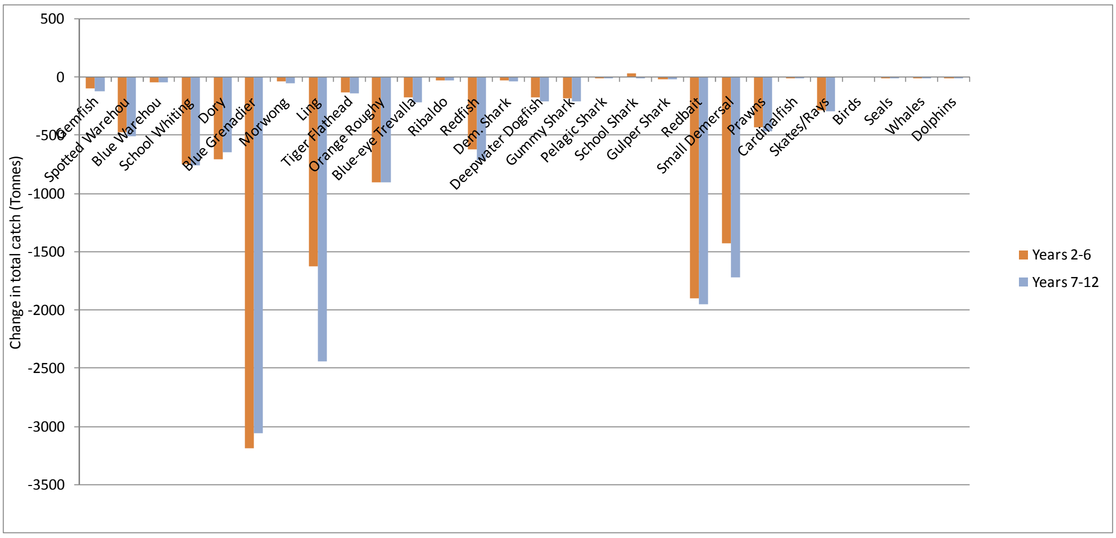

Figure 33 - Change in total catch

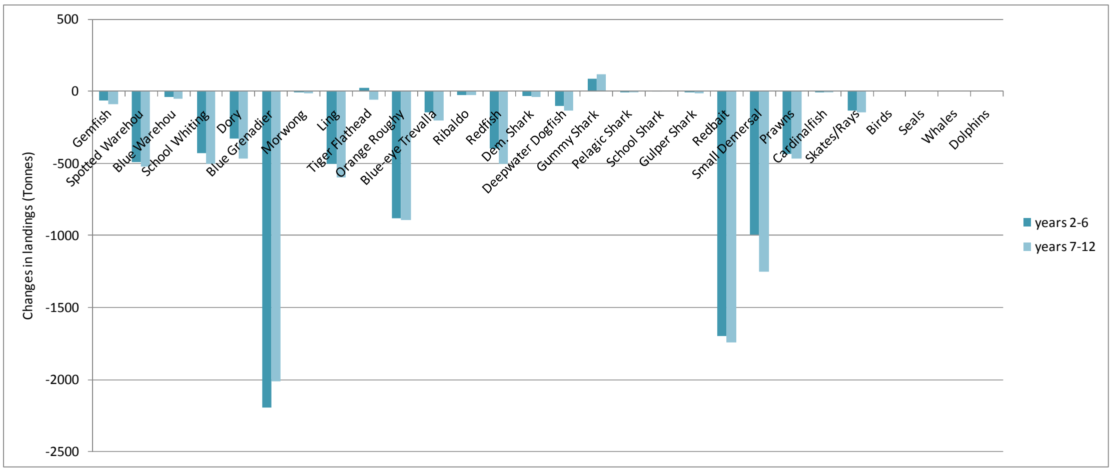

Figure 34 - Change in total landings per species

Again, mostly in line with the decreases in catches, the landings of many species also decrease (Figure 34). The key species experiencing lower landings in port are: Small demersals, Redbait, Blue Grenadier, and Orange roughy (to name the species/species groups with the largest changes). There is a noticeable increase in landings of Gummy shark which is not comparable with any other scenario results.

The changes in discards between the base run and the bycatch scenario 4 are presented in Figure 35. Decreases in discards are observed for many stocks, notably Ling, School Whiting, Dory, Blue Grenadier, Redfish, Gummy Shark, Redbait, Small demersals and Skates and rays.

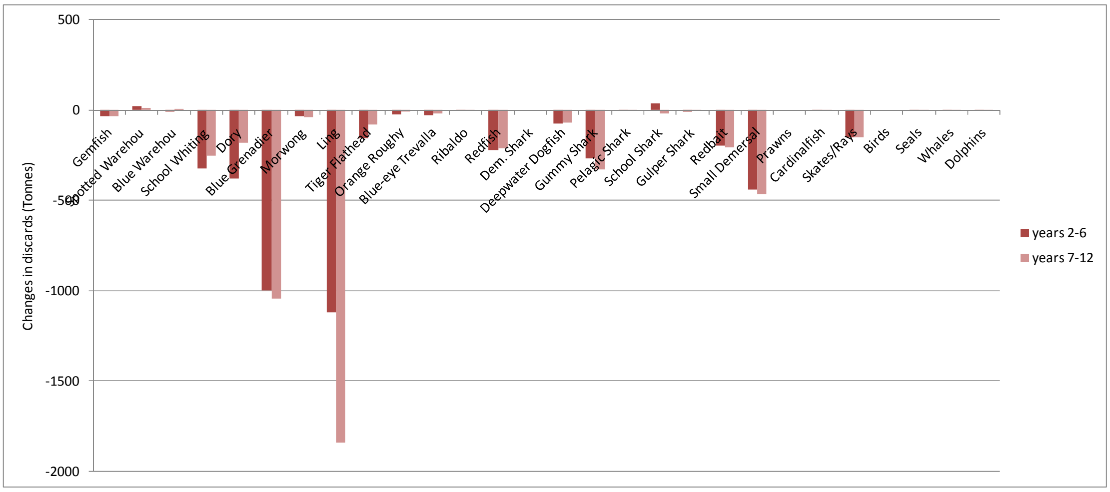

Figure 35 - Change in total discards per species

The main fleets affected in this scenario are the two demersal trawl fleets (demersal trawl, drtrawlFD and demersal trawl targeting Orange roughy, dtrawlFDO) and the prawn trawl fleet. The model allows the tracking of changes in catches for each fleet. For the dtrawlFDO fleet (demersal trawl targeting Orange roughy) the largest declines in catch are for School whiting, Orange roughy and Dory (Figure 36). For the dtrawlFD (demersal trawl) fleet the largest declines in catches are for Blue Grenadier and Redbait, Ling and small demersals (Figure 37).

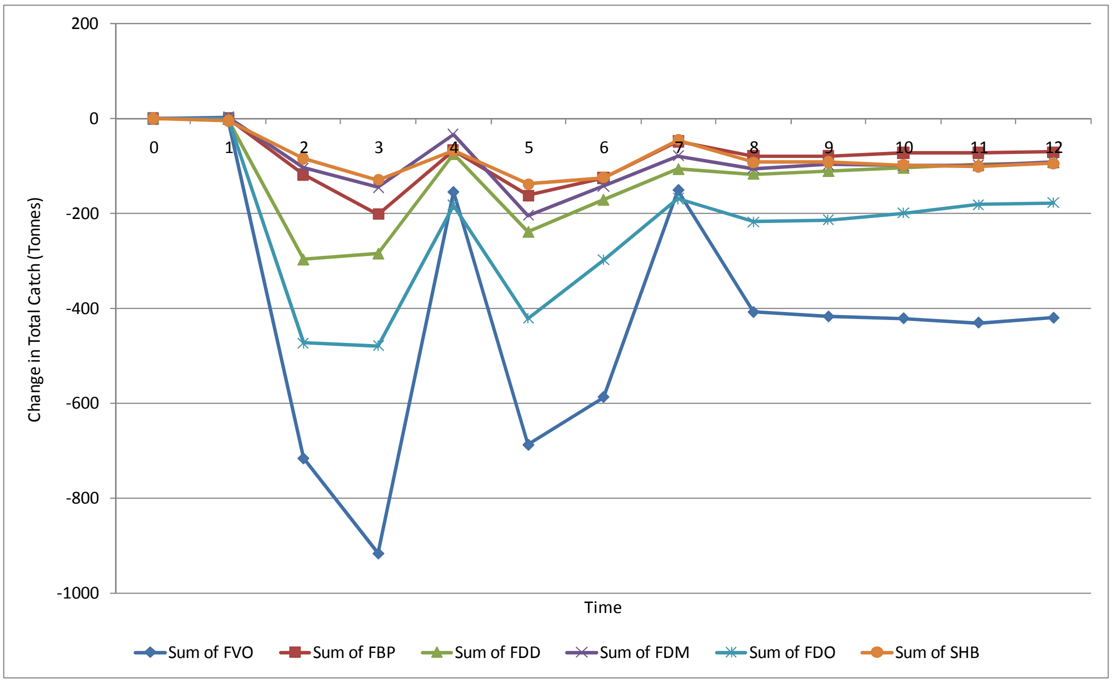

Figure 36 - Change in catch by dtrawlFDO fleet

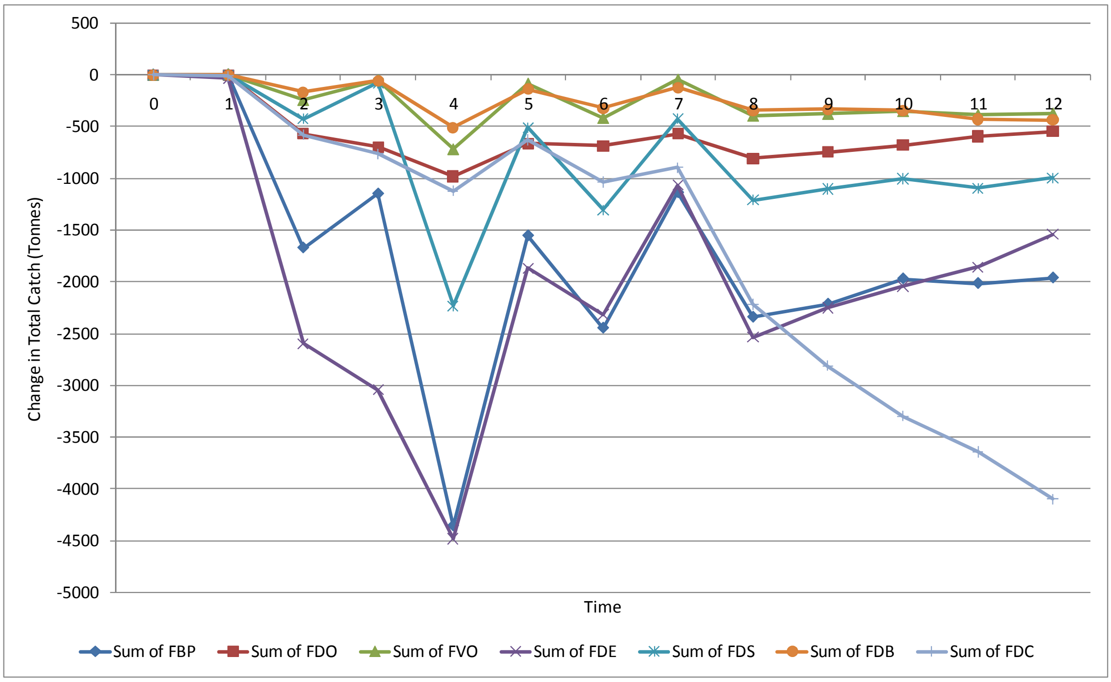

Figure 37 - Change in catch by dtrawlFD fleet

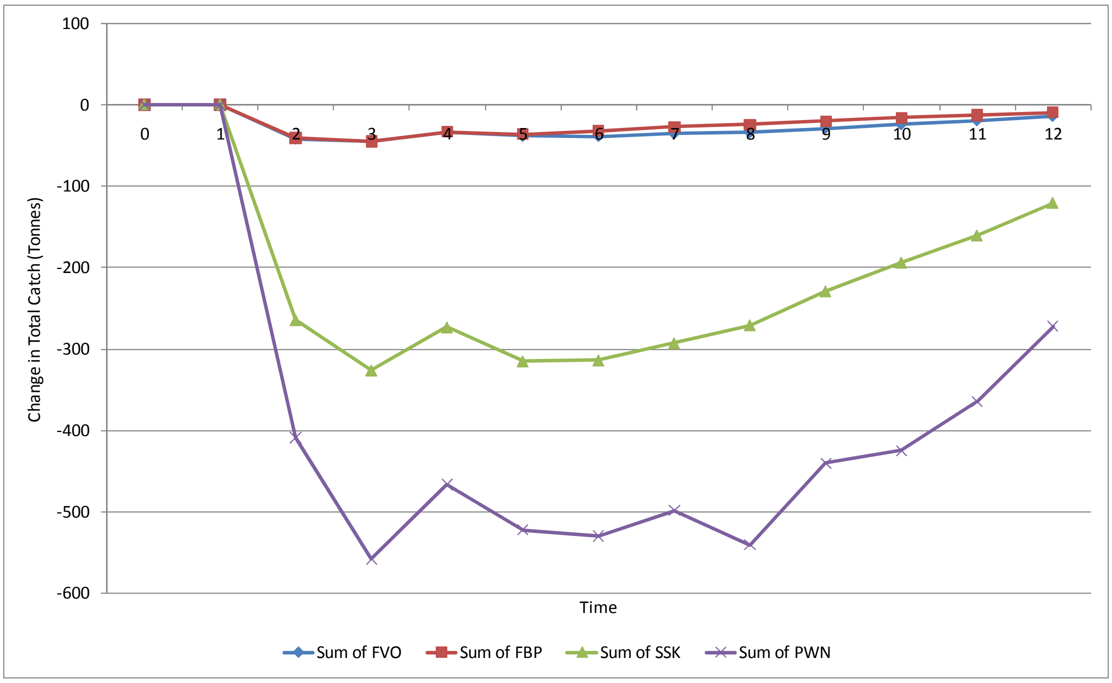

Figure 38 - Change in catch by ptrawlPWN fleet

For the ptrawlPWN fleet (trawl targeting prawns) the largest declines in catch are for the main target stock (Prawns), Skates and rays, Redbait and School whiting (Figure 38).

Figure 39 shows the response of the fleets in term of fishing effort for the main fleets in which impacts have been observed in the simulation. The largest impact is on the demersal trawl fleet, followed by the prawn trawl fleet and the trawl fleet targeting Orange Roughy (Figure 39).

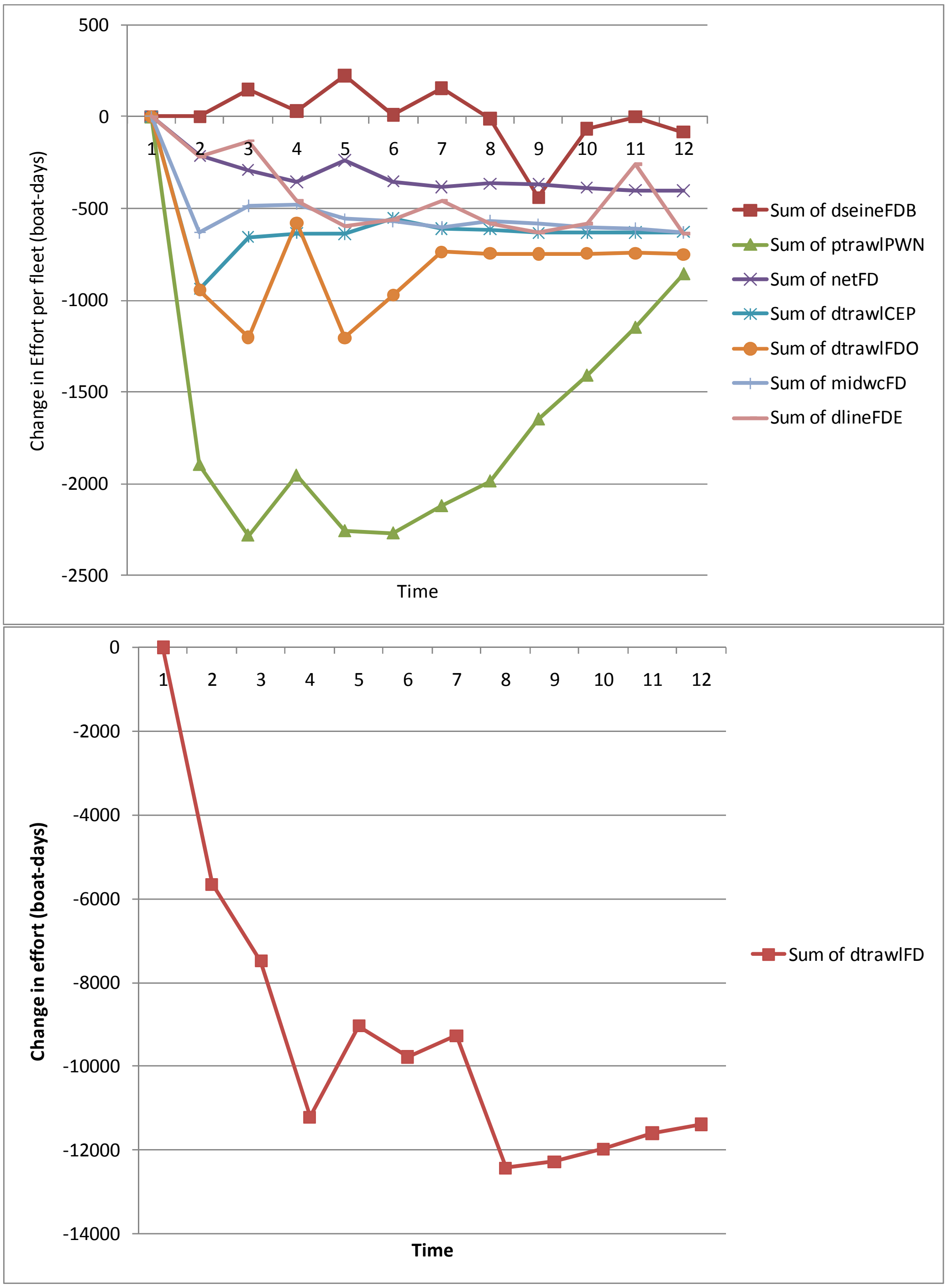

Figure 39 - Change in effort per fleet (top panel and bottom panel). Shown separately due to scale differences

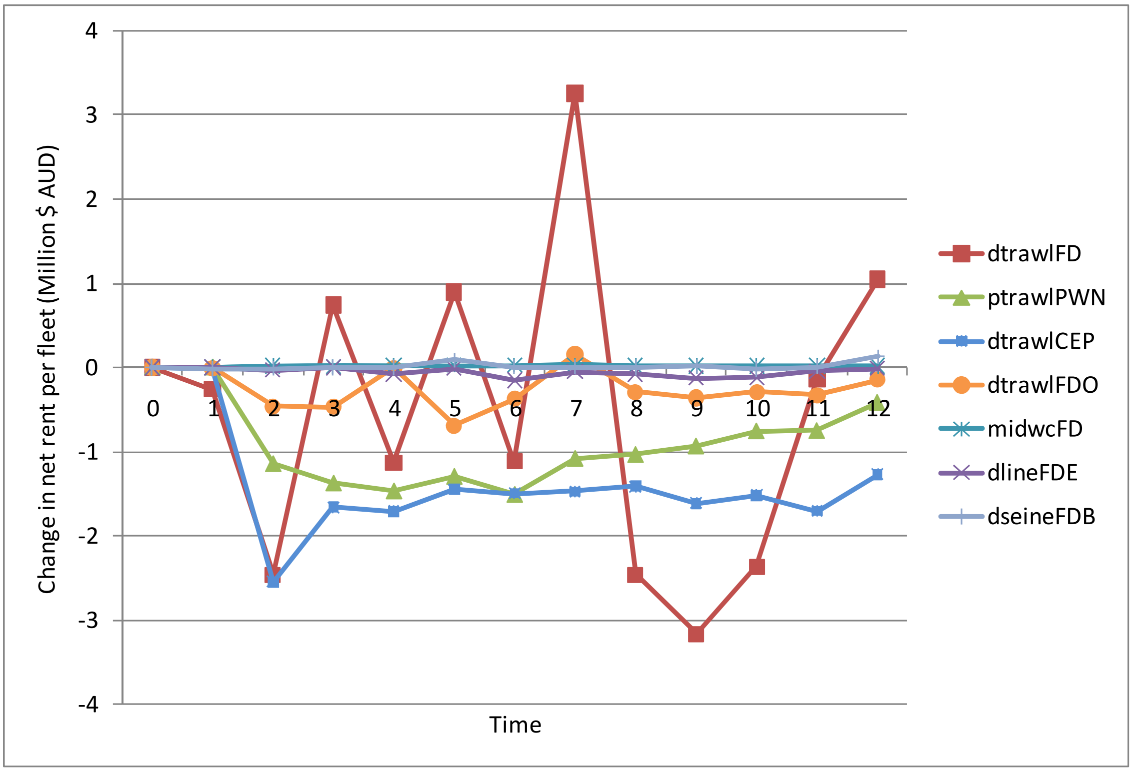

Figure 40 - Change in rent per fishery for the main fleets

The model allows one to assess the overall consequences of the management measure on the economic performance of the fleets. As illustrated in Figure 40, rent in the trawl fisheries (demersal trawl, trawl targeting Orange roughy, prawn trawl and squid trawl (dtrawlCEP)) decreases following adoption of the management measure, as these fleets are directly negatively impacted from the implementation of the tax on the catch of Cardinalfish. The change in rent does tend to fluctuate over the time period of the model run for dtrawlFD, as in the previous scenario, showing a very dynamic response of this fleet to the modified regulatory and economic environment in which it is operating.

6.6 Deemed value (3 companion stocks) – Scenario 5

Figure 41 shows the differences between the base run catch and the deemed value scenario (averaged over 5 model years immediately following the introduction of the measure). As was the case with the previous scenario, what is very clear is the magnitude of the impact on the stocks across the fisheries and fleets. The total catch of Small demersals, and Blue Grenadier decreases whereas there are increases in the catch of School shark and Tiger flathead (in part of the time period over which the simulation was run).

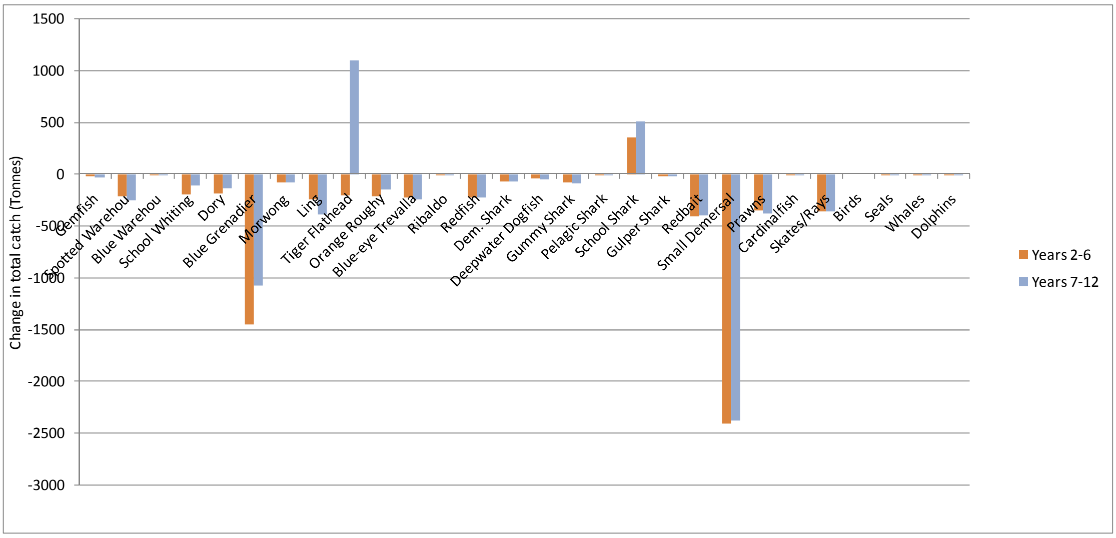

Figure 41 - Change in total catch

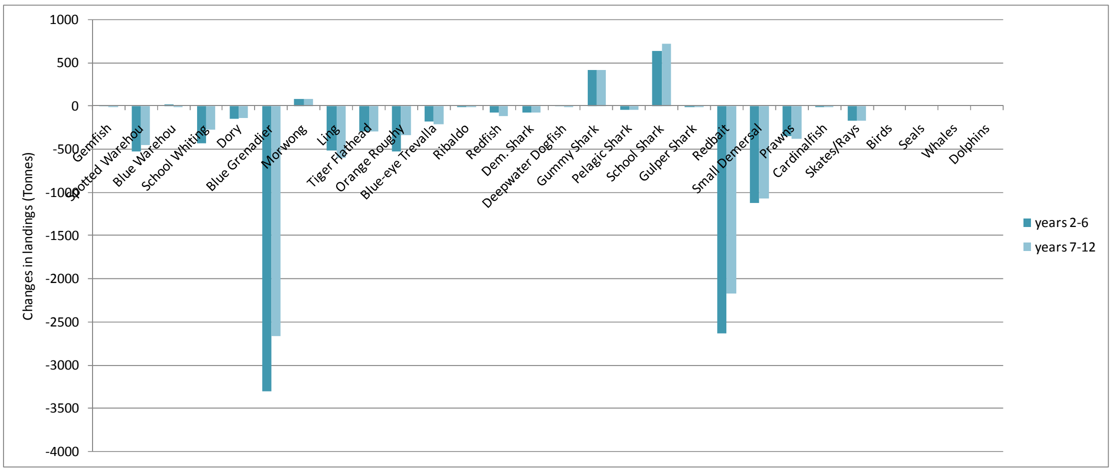

Figure 42 - Change in total landings per species

Similarly, mostly in line with the decreases in catches; the landings of many species also decrease (averaged over 5 model years immediately following the introduction of the measure)(Figure 42). The key species experiencing smaller landings in port are: Blue Grenadier, Small demersals and Redbait. Landings increase for School shark, Gummy shark and Morwong.

However, like in the previous scenario, not all what is caught, is landed. The change in discards between the base run and the deemed value scenario are presented in Figure 43. For this scenario there are considerable increase in discarding, the most being for Redbait, Blue Grenadier and Tiger Flathead. However, for other species the opposite occurs in that discarding decreases, this being the case for Small demersals, Gummy shark and Skates and rays.

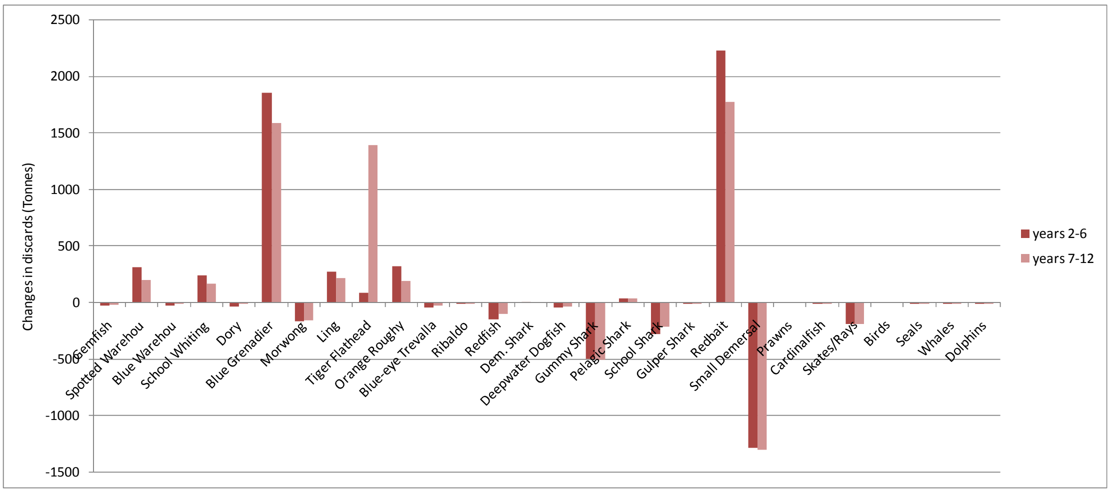

Figure 43 - Change in total discards per species

Ascertaining the exact direction of change for each of the main stocks, that is what combination of change in discarding (a decrease or increase) and a change in landings (a decrease or increase) it experiences can be interpolated from (Figure 44). Where quota really is constraining (which it is not the case for a number species, except for species such as Morwong) then providing even the smallest deemed value for these species is sufficient to induce increases in landings. For instance, the direction Morwong is moving in is what is expected from the introduction of a deemed value, in that more fish of this species are landed and fewer are discarded.

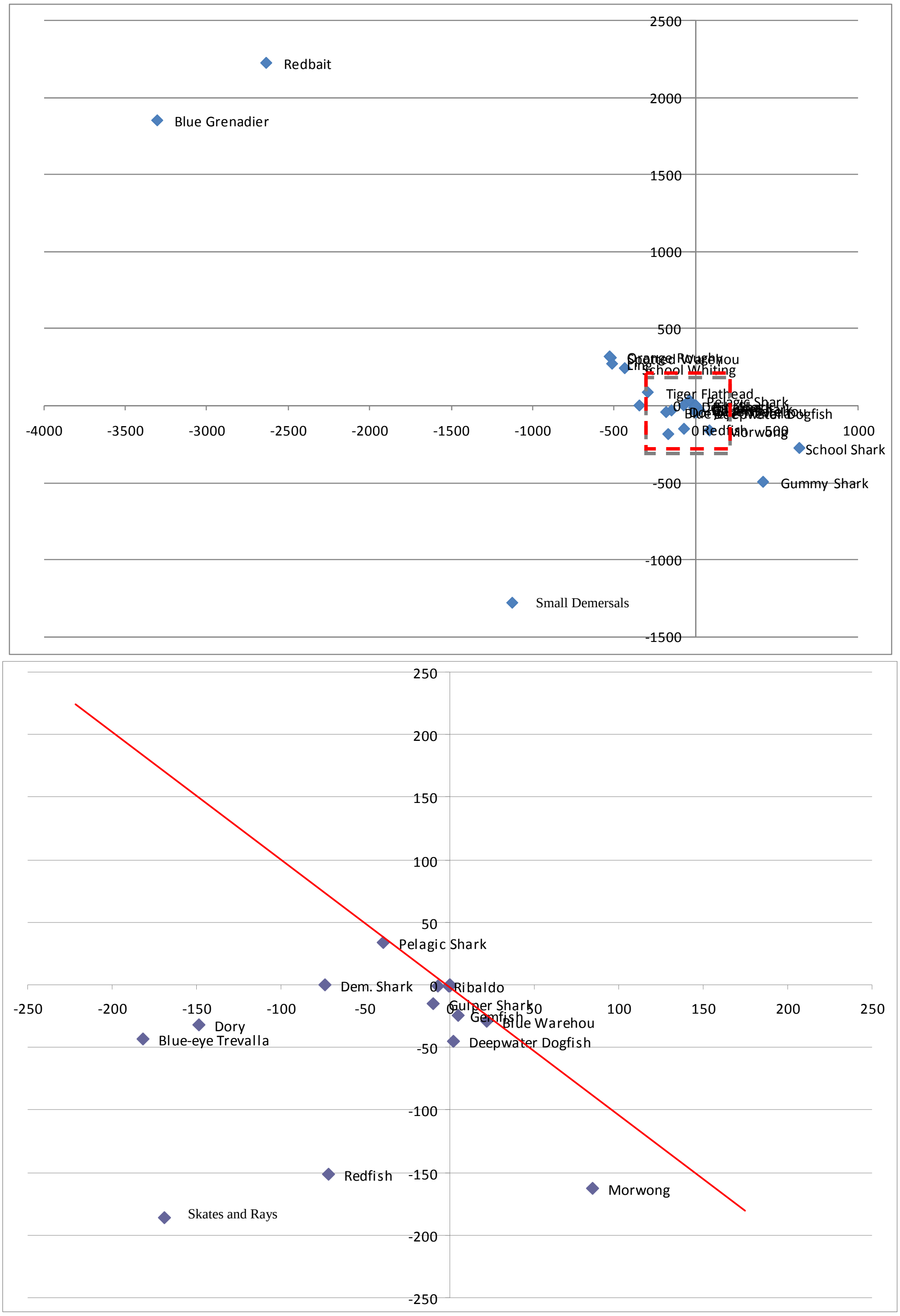

Figure 44 - Changes in landings and discards (both in tonnes). Note that the bottom panel shows the area within the red square in the top panel in more detail.

For illustration, species appearing above the red diagonal line in the bottom panel of Figure 44 experience an increase in F (depending on changes in biomass) whereas species below the redline experience a decrease in F. The large decreases in discarding of Redbait and Blue Grenadier are also associated with corresponding decreases in landings, possibly due to a reduction in targeting of these stocks as fleets shift fishing practices in response to the introduction of deemed values..

There is a change in the magnitudes of catch and discards of most of the main commercial fisheries, and at a sub-fleet level, important changes in the composition of catches and discards are observed. Here we explore further the specific fleet impacts that are evident in Figure 42 and Figure 43. Figure 45 shows the change in landings for the main stocks affected for a set of specific fleets (the three main trawl fleets – demersal, Orange roughy, and Tiger flathead and the Danish Seine fleet, Shark net fleet and demersal line fleet targeting Blue grenadier) over certain model time periods. That is first year of model run, second year, and final year of model run (representing long-term effects).

The species which shows the largest effect is Blue grenadier that is mainly targeted by the dtrawlFD fleet and to some extent by the line fleet (dlineFDE). A significant decrease in landings occurs for this species in the trawl fleet, beginning small (-150 tonnes), and then increases to 6000 tonnes and finally reaching 8000 tonnes a year in the final year of the model run. Ling, Tiger Flathead and Spotted Warehou are also landed less by the dtrawl fleet reflecting this fleets decline in its activity.

Figure 46 shows the change in discards for the main stocks affected for a set of specific fleets (the three main trawl fleets – demersal, Orange roughy, and Tiger flathead and the Danish Seine fleet, Shark net fleet and demersal line fleet targeting Blue grenadier) over certain model time periods. That is first year of model run, second year, and final year of model run (representing long-term effects).

The species which shows the largest effect is Blue grenadier which is mainly targeted by the general demersal trawl (dtrawlFD) fleet and to some extent by the line fleet (dlineFDE). A significant decrease in discarding occurs for this species in the trawl fleet that tends to be small at first (-150 tonnes) and then increases to 5000 tonnes before declining to 2000 tonnes a year, in the final year of the model run. Spotted Warehou are also discarded less by the dtrawlFD fleet reflecting this fleets decline in its activity.

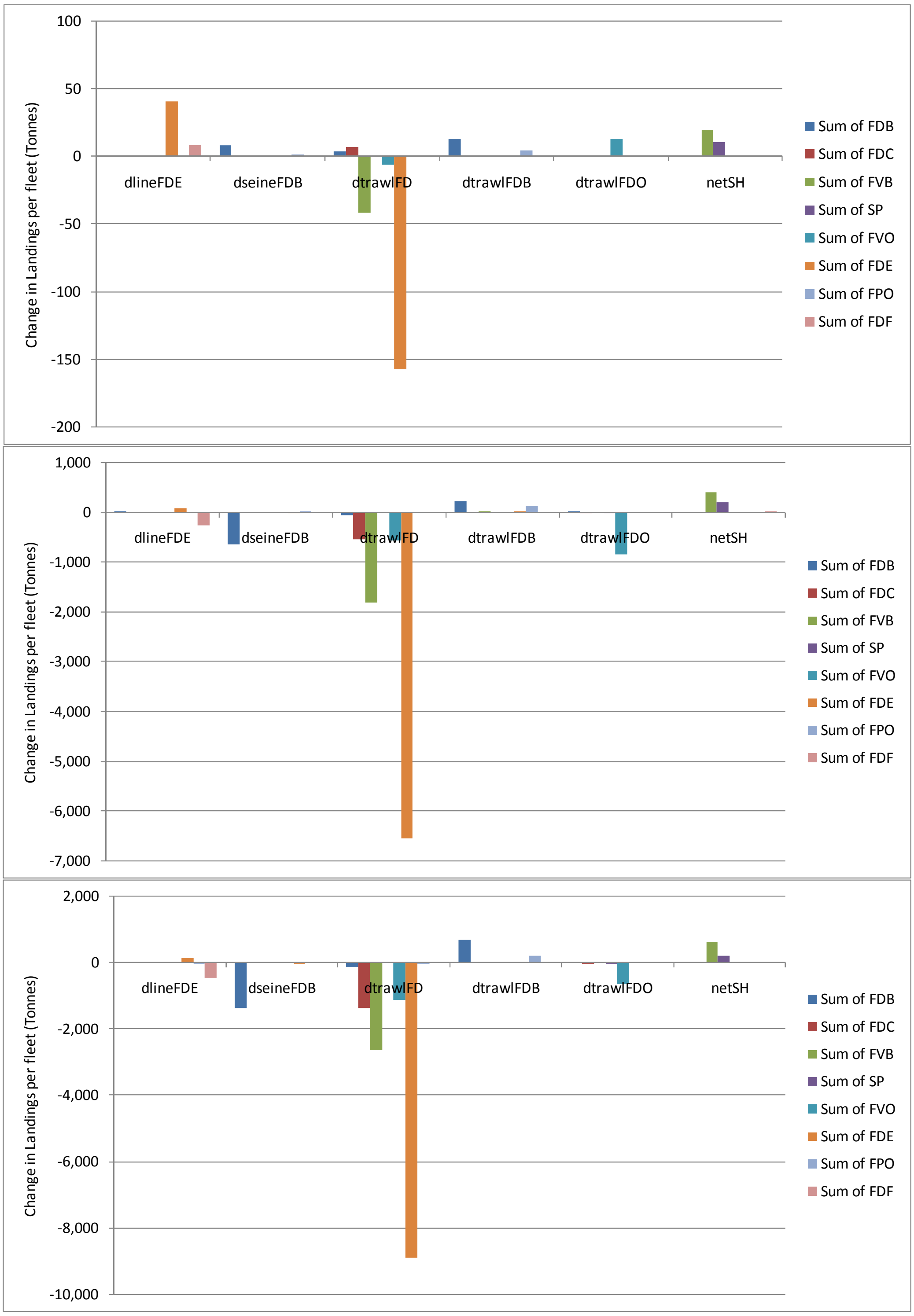

Figure 45 – Change in landings per fleet (top = year 1, middle = year 2, bottom = year 11)

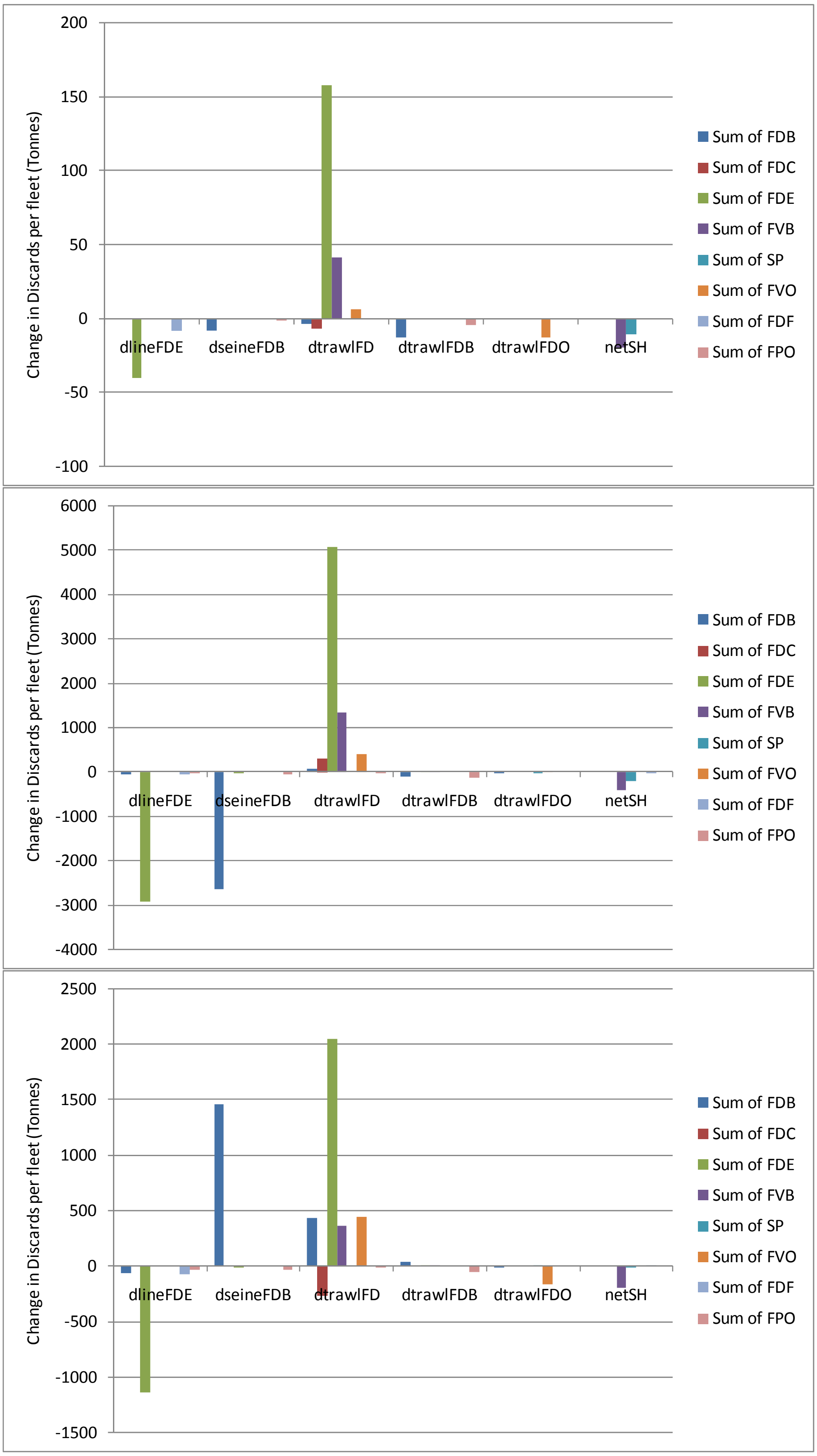

Figure 46 – Change in discards per fleet (top = year 1, middle = year 2, bottom = year 11)

Overall, the effect on effort is such that for most effort declines, especially in the case of the Danish Seine fleet, the demersal trawlers and the prawn trawlers. The reasons for the large decline in Danish Seine is probably related to avoidance behaviour and the availability of alternative target species and areas for this fleet; as we will see later they do not land over-quota (nor pay deem values) and their rent is mostly unaffected. For the demersal trawlers targeting Tiger Flathead (dtrawlFDB) effort fluctuates within the region of zero change, as for the shark net fleet (netSH)(Figure 47). The year to year variability in effort grows for some sectors (in particular the general demersal trawl fleet, dtrawlFD).

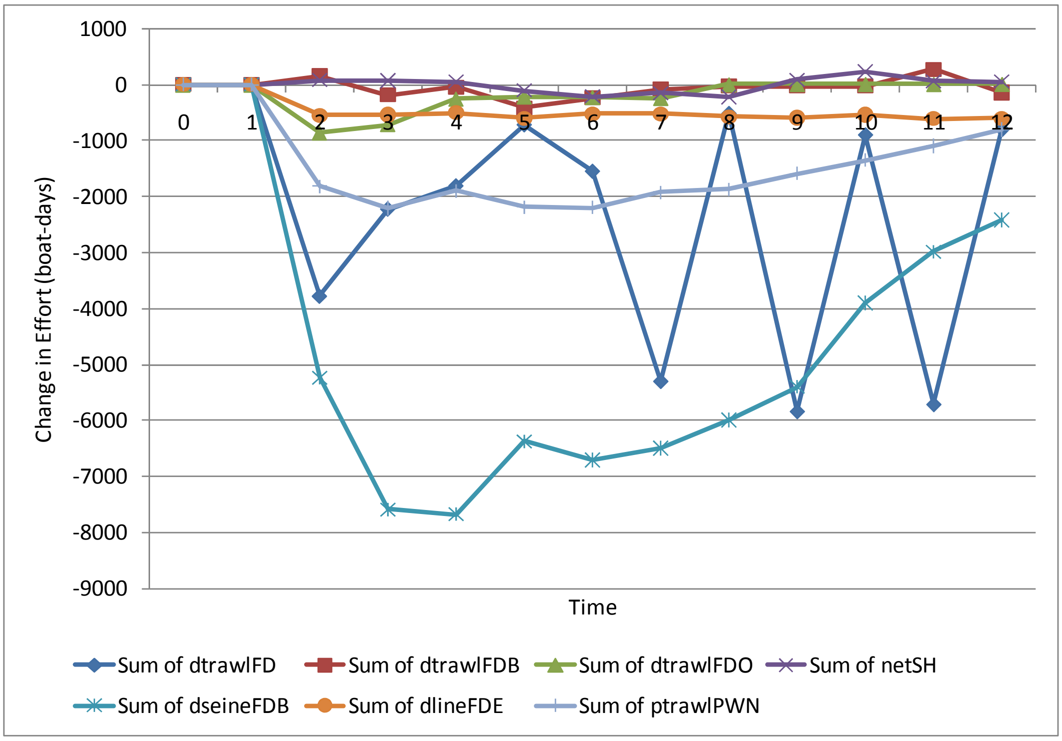

Figure 47 - Change in effort per fleet

The impacts on the economics of the fleets are also an output of the model predictions. Amongst the most affected fleets, the demersal trawl fleet targeting Orange roughy has a slight decrease in rent in the second year (associated with deemed value payments); however this is temporary as the fleet avoids bycatch of the deemed value species after the first year. The demersal trawl fleet's (dtrawlFD) rent decreases sharply after the introduction of deemed values (Figure 48). This is partially due to deemed value payments made, quota trading costs and the indirect effects of these measures on the fleet, and to the fact that the fleet is not able to avoid the deemed value species. The demersal line fleet targeting Blue grenadier (dlineFDE) reduces its fishing effort and it makes deemed value payments. However, this does not affect its rent overall (Figure 48) which implies that their economic performance has improved compared to the base run excluding the effects of deemed value payments.

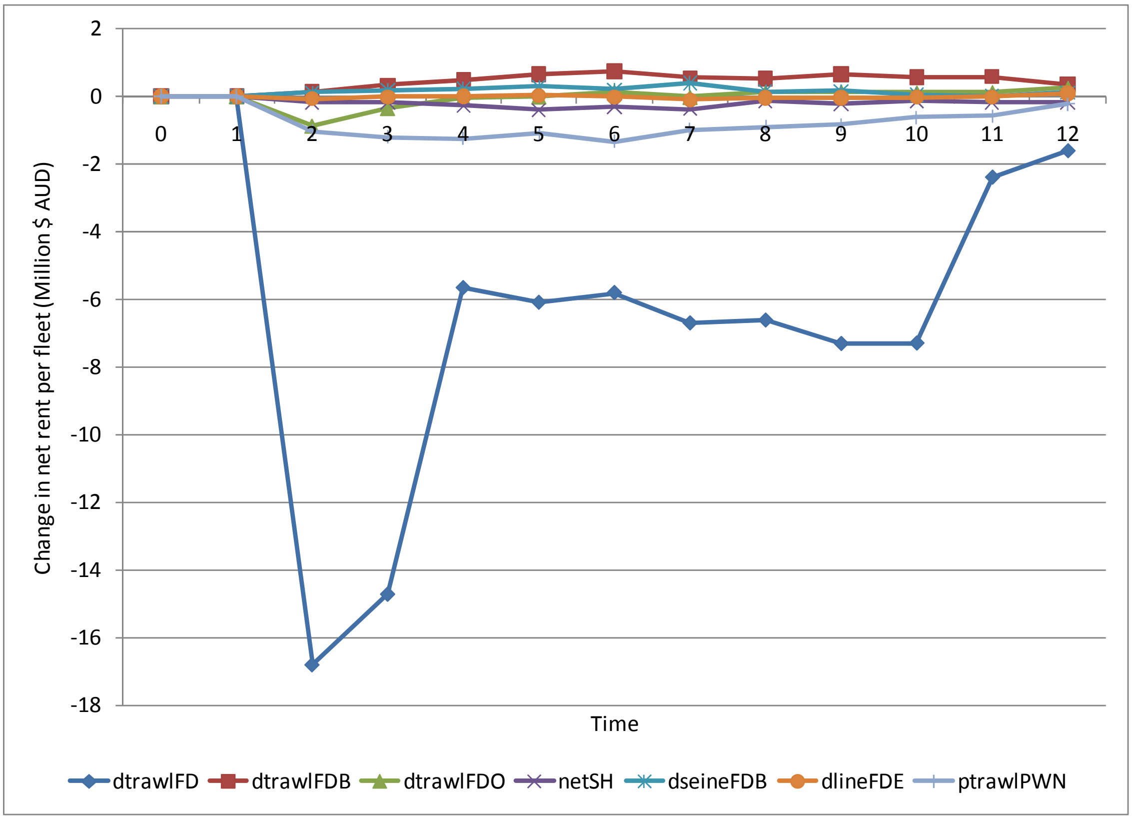

Figure 48 - Change in rent per fishery for the main fleets

6.7 Deemed value (8 companion stocks) – Scenario 6

Figure 49 shows the differences between the base run catch and the deemed value scenario where 8 companion stocks are covered by deemed values. As was the case with the previous scenario, what is very clear is the magnitude of the impact on the stocks across the fisheries and fleets. The total catch of Small demersals, School shark, and Blue Grenadier (to name the species/species groups with the largest changes) decreases. There are essentially declines in catch across most of the stocks except Tiger flathead (in part of the model predicted run).

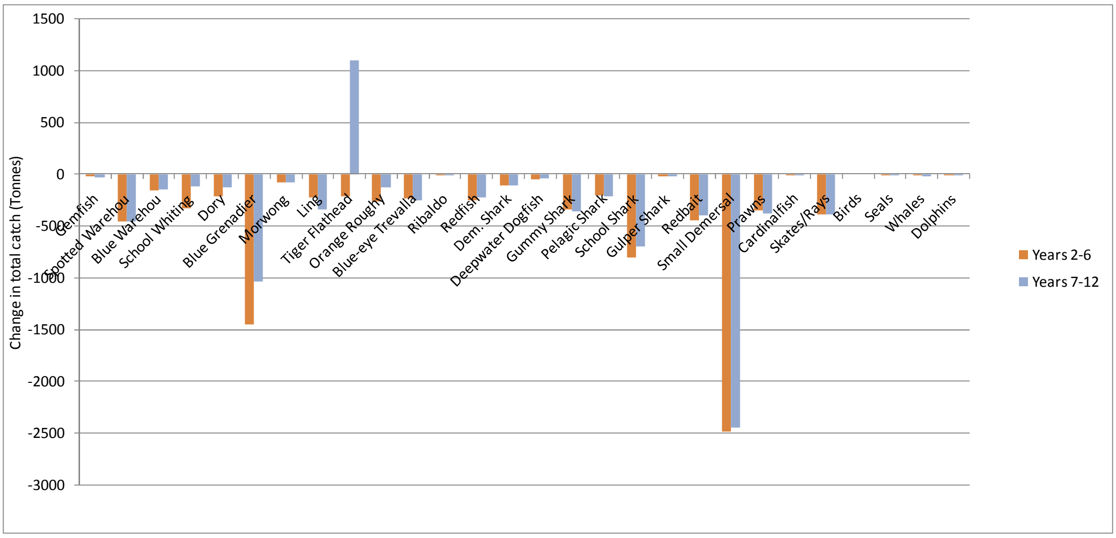

Figure 49 - Change in total catch

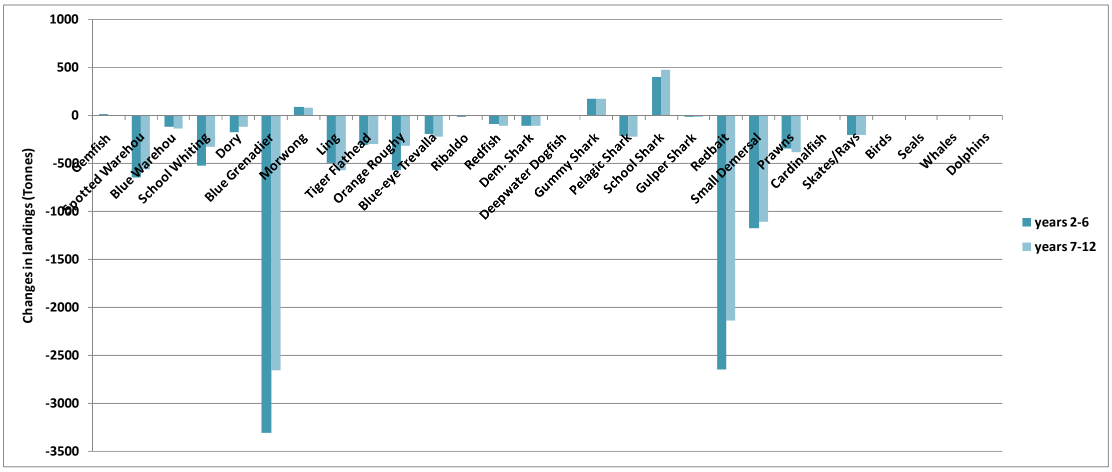

Figure 50 - Change in total landings per species

Similarly, mostly in line with the decreased in catches; the landings of many species also decrease (Figure 50). The key species experiencing lower landings in port are: Small demersals, Redbait and Blue Grenadier. Total landings (across the fleets) increase for School shark, Gummy shark and Blue Grenadier. However, like in the previous scenario, what is caught is not all landed. The change in discards between the base run and the deemed value scenario are presented in Figure 51 (averaged over 5 model years immediately following the introduction of the measure). Here a mix of increases and decreases in discarding occurs across species. For some stocks (e.g. Redbait, Blue Grenadier) an increase in discarding occurs whereas for other (e.g. Small demersals, School shark, and Gummy shark) a decrease in discarding occurs.

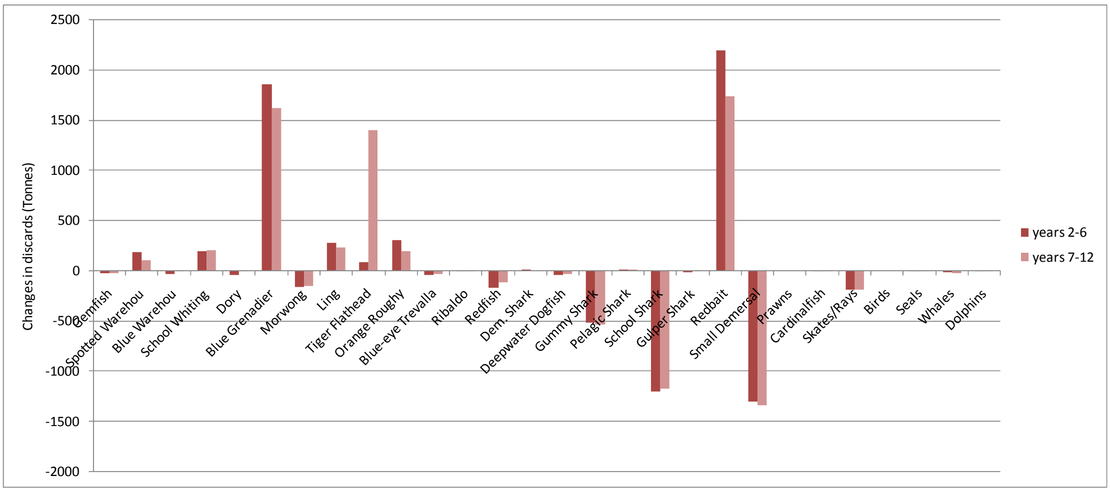

Figure 51 - Change in total discards per species

As in the previous scenario, ascertaining the exact direction of change for each of the main stocks, that is what combination of change in discarding (a decrease or increase) and a change in landings (a decrease or increase) it experiences can be interpolated from Figure 52. Again, for illustration, species appearing above the red diagonal line in the bottom panel of Figure 52 experience an increase in F (depending on changes in biomass) whereas species below the redline experience a decrease in F. As most species are below the line, as a general statement the model predicts low fishing mortality on the stocks after the imposition of the management measure (indirectly due to lower effort levels in the main fishing fleets).

Figure 53 shows the change in landings for the main stocks affected for a set of specific fleets (the three main trawl fleets – demersal, Orange roughy, and Tiger flathead and the Danish Seine fleet, Shark net fleet and demersal line fleet targeting Blue grenadier) over certain model time periods. That is first year of model run, second year, and final year of model run (representing long-term effects). The species which shows the largest effect is Blue grenadier that is mainly targeted by the dtrawlFD fleet and to some extent by the line fleet (dlineFDE). A significant decrease in landings occur for this species in the trawl fleet which begins small at first (-150 tonnes) and then increases to about 6000 tonnes and finally reaches about 8000 tonnes a year in the final year of the model run. Ling, Tiger Flathead and Spotted Warehou are also landed less by the general demersal trawl fleet (dtrawlFD) reflecting this fleets decline in its activity.

Figure 46 shows the change in discards for the main stocks affected for a set of specific fleets (the three main trawl fleets – demersal, Orange roughy, and Tiger flathead and the Danish Seine fleet, Shark net fleet and demersal line fleet targeting Blue grenadier) over certain model time periods. That is first year of model run, second year, and final year of model run (representing long-term effects). The species which shows the largest effect is Blue grenadier that is mainly targeted by the dtrawlFD fleet and to some extent by the line fleet (dlineFDE). A significant decrease in discarding occur for this species in the trawl fleet which tends to be small at first (-150 tonnes) and then increases to about 3500 tonnes and the declines relative to the latter to about 1750 tonnes a year in the final year of the model run. Spotted Warehou are also discarded less by the general demersal trawl fleet (dtrawlFD) fleet reflecting this fleets decline in its activity.

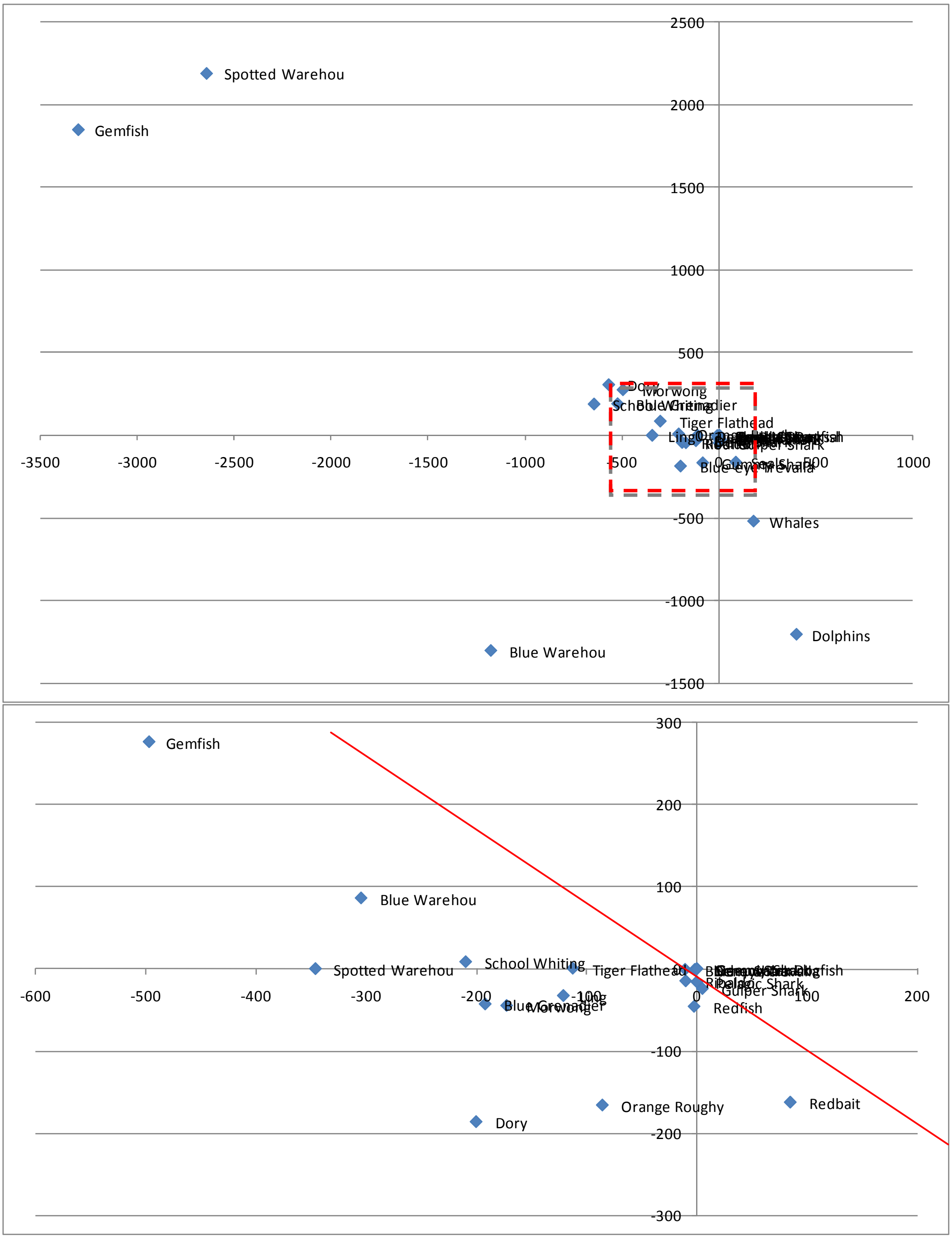

Figure 52 - Changes in landings and discards (both tonnes). Note that the bottom panel presents the region within the red square in the top panel in more detail.

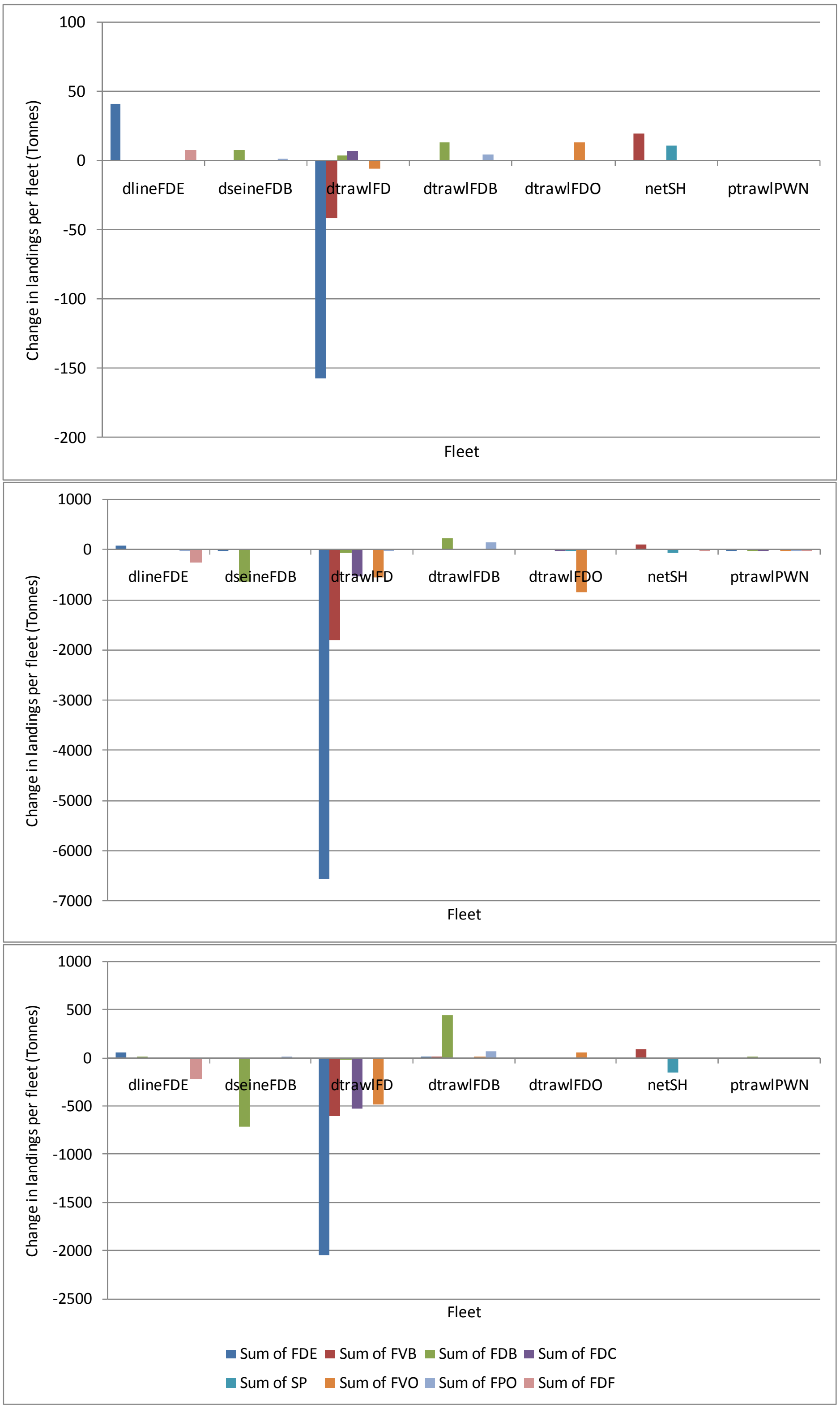

Figure 53 - Changes in landings per fleet and per species (top = year 1, middle = year 2, bottom = year 11)

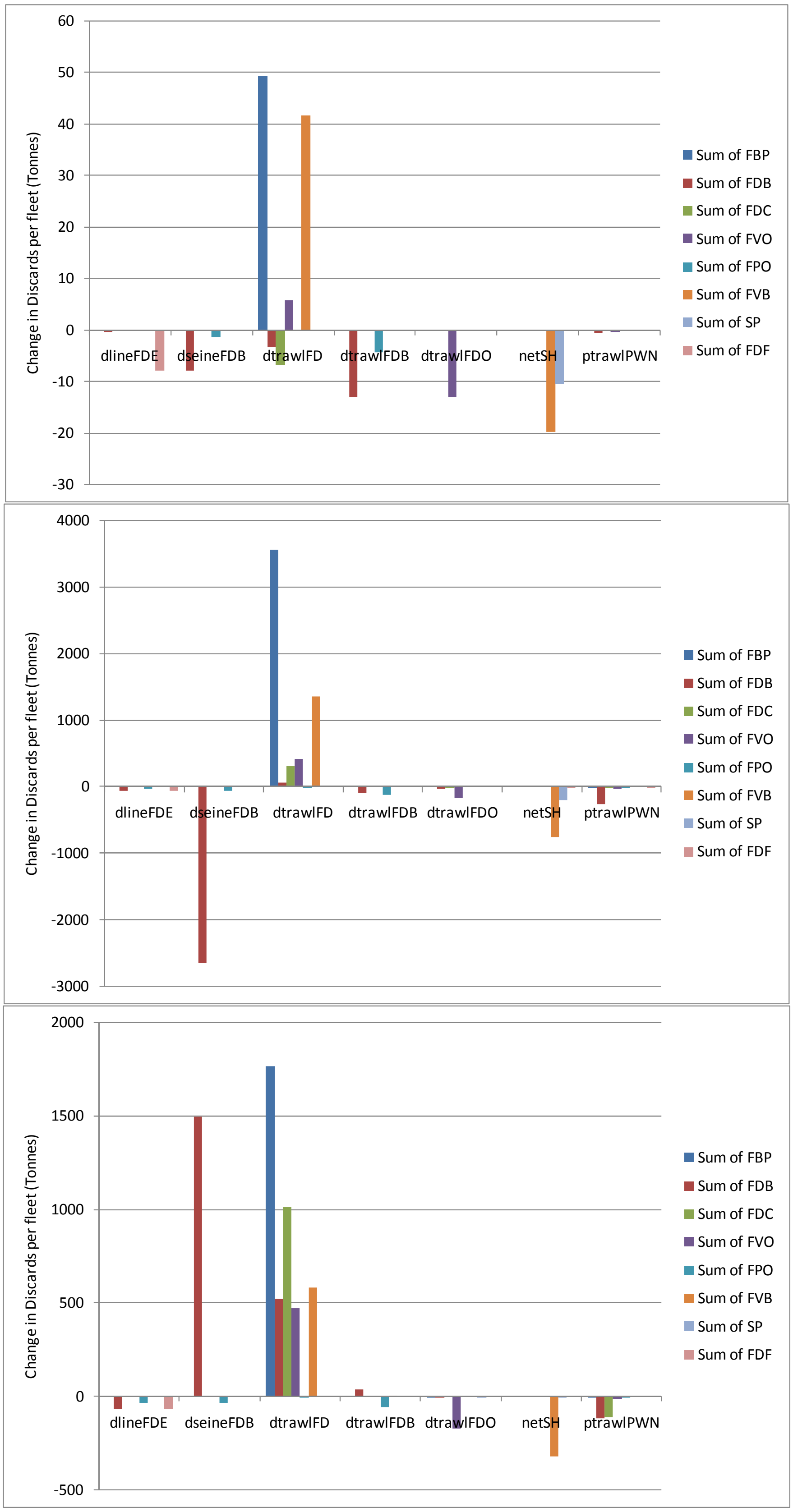

Figure 54 - Changes in discards per fleet and per species (top = year 1, middle = year 2, bottom = year 11)

When tested, increasing the value for the deemed values does not further modify the behaviour (results not presented as effects are equivalent to what is shown). For other sectors only the most minimal of deemed values, entailing only limited decrease in landed value for the additional landed catch, saw the species retained. If higher deemed values were used, then high-grading behaviour occurred, leading to these species being discarded regardless of the removal of the catch quota constraint (e.g. Blue grenadier). This was the case for the demersal seine fishery, particularly when it was assumed that they made discarding decisions based on market information at the start of each trip. If market information was obtained continuously through the trip, there was less discarding observed, but this was not totally eradicated. We consider this to be the result from switching behaviour towards reasonably high value species that these fleets can access, as the deemed values make other species relatively less attractive in the catch portfolio.

Overall, the effect on effort is such that for most effort declines, especially in the case of the Danish Seine fleet, the demersal trawlers, the prawn trawlers and the shark net fleet. For the demersal trawlers targeting Tiger Flathead effort fluctuates within the region of zero change (Figure 55).

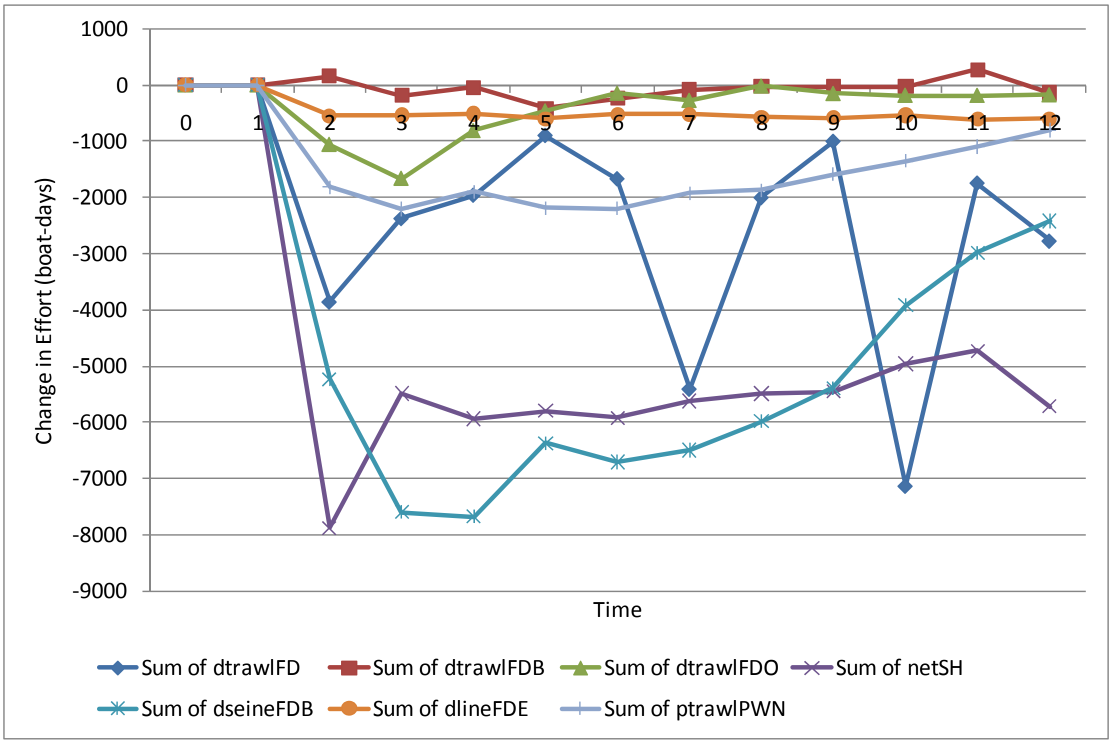

Figure 55 - Change in effort per fleet

The impacts on the rent per fleet are similar to the previous scenario yet larger in magnitude. Amongst the most affected fleets, the demersal trawl fleet targeting Orange roughy has a slight decrease in rent in the first few years, associated with deemed value payments. The demersal trawl fleet's (dtrawlFD) rent decreases sharply after the introduction of deemed values (Figure 56). This is partially due to deemed value payments made, which show an increase over time due to the fact that the fleet is not able to avoid the deemed value species and less so overtime. The demersal line fleet targeting Blue grenadier (dlineFDE) reduces its fishing effort and it makes deemed value payments. However, this does not affect its rent overall (Figure 56) which implies that their economic performance has improved compared to the base run excluding the effects of deemed value payments.

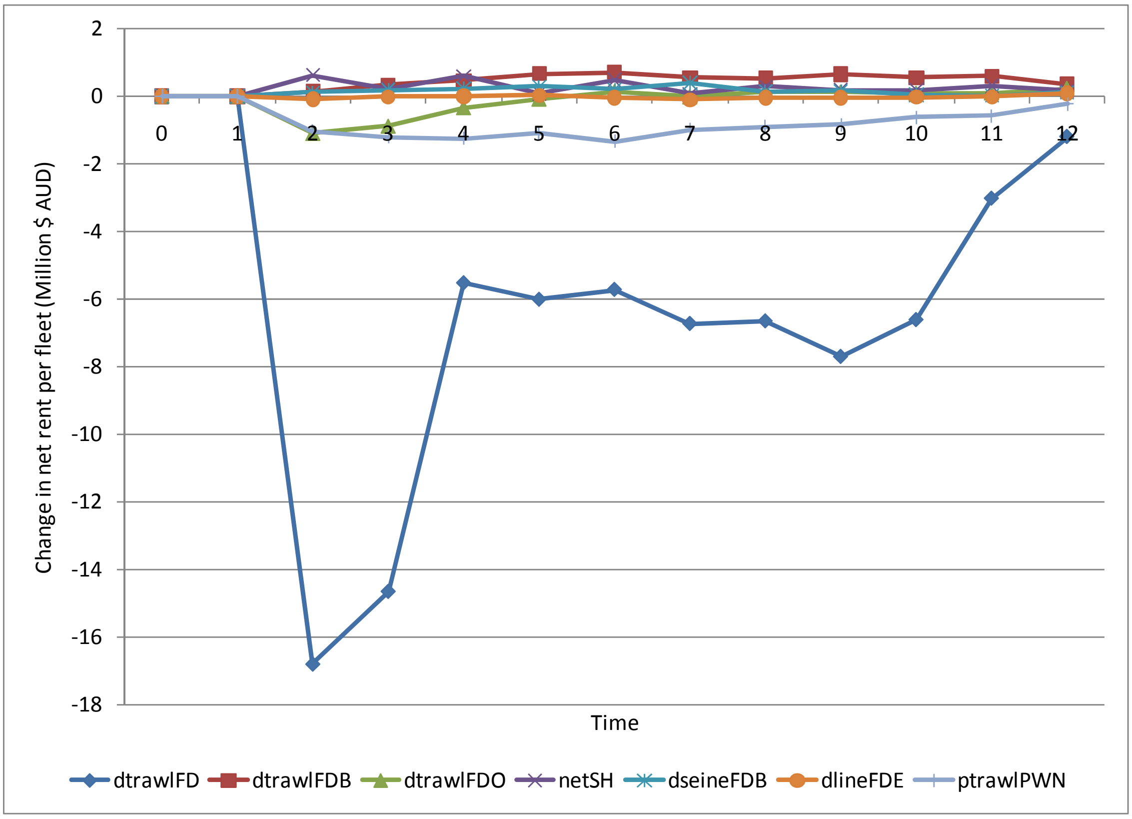

Figure 56 - Change in rent per fishery for the main fleets

7 Discussion

The increasing potential of incentive based measures for management of targeted species is well recognised (Grafton *et al.* 2006), and is attracting increasing attention for the management of bycatch species. To date, actual examples of incentive based measures are limited (here we refer to Section 3), although considerable attention has been given in the theoretical literature.

On the basis of the review, we conclude that deemed values appear to offer benefits in terms of providing incentives to reduce discarding of over-quota catch and also incentives to balance catches at the end of the year. However, potentially higher catches of quota species may occur under a deemed value system than under a system where over-quota catch is all discarded.

For non-commercial fish species, bycatch quotas may offer some benefits in terms of reducing overall bycatch. A difficulty with bycatch quotas is at-sea surveillance and our assumption is either observer coverage or video surveillance would need to be relatively widespread. A wider range of options exist for megafauna and charismatic species. In addition to bycatch quotas, taxes may be a viable option. These directly impose a penalty on the capture of megafauna and charismatic species, thereby providing an incentive to avoid their capture. Unlike the non-commercial fish species, their capture is likely to be less frequent and readily observable using video surveillance techniques.

After careful interpretation of the options that exist and we were discussed as part of the review, it is likely that different instruments, and potentially different combinations of instruments, will be required to provide the most benefits given the type of bycatch that managers aim to reduce. Following on from the review an attempt was made in this study to evaluate; using an ecosystem model of a suite of fisheries (a specific case study), the impacts of a set of incentive management measures for reducing bycatch and discarding of marine species.

This research examined the utility of incentive based bycatch management using the Atlantis ecosystem model of the Australian South East fishery. Management measures examined include bycatch quotas, and bycatch taxes, and deemed values. A feature of the Atlantis model is that it incorporates a fleet dynamics model that allows the main fleets to adjust their fishing behaviour in response to the incentives. The application of Atlantis also enables ecological effects to be estimated, as changing catch patterns impact the structure of the fishery, with both direct and indirect economic and ecological consequences. The model is used to assess the potential impacts of different types of instruments for different types of bycatch issues, such as the discarding of commercial species or the catch of non-commercial species, including charismatic species.

While previous analysis of discarding in this fishery using the Atlantis framework has already been carried out in the past (see Fulton *et al.* 2007), this study is the first considering economic incentives as management instrument to reduce bycatch and discards. Among the scenarios outlined in Fulton *et al.* (2007), one scenario did evaluate the potential impacts of a total ban on discarding. The results were as expected in that the "*ban on discards has the single biggest impact of any single management action*" (Fulton *et al.* 2007). Fulton *et al.* (2007) reported that the discard ban caused fishers to shift grounds closer to port (with habitat implications). Furthermore, less discarding eventually impacted on scavengers, and this impact cascaded through ecological pathways, leading to a mixed and patchy system. In addition, there was an increase in gear conflict and TACs became extremely constraining with overcatch remaining a persistent problem although this was an issue for most of the scenarios (Fulton *et al.* 2007).

The results presented from this version of the SESSF Atlantis have been obtained based on a calibration of the model to historical data for the SESSF, and using simple scenarios that evaluate the adoption of incentive based bycatch management measures. The preliminary results illustrate the high degree of complexity which arise from the interaction of ecological changes and fishing fleet dynamics (through effort allocation, quota trading and investment decisions) in response to management intervention. Overall, all the scenarios lead to a more or less transitional reduction in fishing activity, catches and landings, and to somewhat contrasted impacts with respected to bycatch and discards. The results also demonstrate the great complexity of the effects of any given scenario, as these propagate throughout the fishery via changes in fishing behaviour, interactions between these changes, and the ecological responses. The main response patterns observed for the different scenarios are briefly summarized below.

Bycatch quota

When applied to species of conservation concern (e.g. megafauna such as whales, dolphins and seals), the quotas pose a minimal incentive to avoid areas where these species occur since, historically, there has been relative little contact with these animals. Incidents have occurred, but the chance of individual vessels making contact are so low that fleets see little reason (during their effort allocation decisions) to avoid potentially sensitive areas. Moreover because contact rates are so low, close to zero tolerance with non compliance must be assumed or the bycatch quotas will have minimal effect at all.

It should be noted however that the kind of model used in Atlantis understated the stochastic nature of encounters with very large bodied animals like baleen whales. Modifications to the model are being made to better represent these encounters - where any one event may not lead to an observed death, but rather there is only a chance of an entanglement, but if such an entanglement occurs (even if early in the year) the size of the animal means that it could be sufficient to exceed the quota.

For cases where the species were caught by a few fleets only, the initial allocation of catch shares, which were defined as a proportion of historical incidental catches/encounters, meant the opportunities for trading quota for these species were fairly limited. Hence the quotas impacted the fleets in a similar way as non-tradeable individual quotas would have, constraining fleets at reduced levels of effort and catch. For rare commercial species such as Cardinalfish, the bycatch quota does lead to a positive effect in terms of its function – that is catch of these fish are reduced. However, the restrictive quotas impose constraints on the operational variability of the fleets.

Tax

For similar reasons, the introduction of a tax on the catch of species of conservation concern (e.g. the megafauna such as whales, dolphins and seals) led to initial reductions in the fishing activity of the fleets directly impacted, with only slow adjustments in fishing strategies taking place over longer periods of time. With the rate of contact being low, the anticipated (and potential) tax payments seem to have little impact on original decision making in fleets. However, given the size of the animals that are of conservation concern (e.g. whales) when contact is made with them the financial burden can be quite crippling, effectively closing down operations for that fishing vessel.

In the case of fish species (Cardinalfish) that have some market value there was a more immediate impact on the decision making. This response was graded to some extent with the level of the tax, but perhaps not as much as immediately anticipated by economic theory, because each species makes only a relatively small contribution to the aggregate return in such a multispecies fishery.

Deemed value

For the deemed values the behavioural response amongst the fleets was almost as if the deemed value acted as an on-off switch effect. Where quota really is constraining (which it is not the case for a number species, except for species such as Morwong) then providing even the smallest deemed value for these species is sufficient to induce increases in landings. In these circumstances, increasing the value for the deemed values does not further modify the behaviour. For other sectors only the most minimal of deemed values, entailing only limited decrease in landed value for the additional landed catch, saw the species retained. If higher deemed values were used, then high-grading behaviour occurred, leading to these species being discarded regardless of the removal of the catch quota constraint. This was the case for the demersal seine fishery, particularly when it was assumed that they made discarding decisions based on market information at the start of each trip. If market information was obtained continuously through the trip, there was less discarding observed, but it was still not totally eradicated. We consider this to be the result from switching behaviour towards reasonably high value species that these fleets can access, as the deemed values make other species relatively less attractive in the catch portfolio.

The deemed values scenarios did not entail a shift in the location of fishing effort. This is because the species with deemed values are only a portion of the species caught in the multispecies fishery and so make up only a minority contribution to the spatial effort allocation decision (one that was more than overwhelmed by the increased fuel costs of moving to other locations). Together all of these impacts illustrate the complexity of setting deemed values at appropriate levels in a multispecies fishery to achieve the desired outcome.

Comparing across incentive measures, while deemed values are separate as they only relate to commercial species (essentially to allow over-quota uptake at a cost); in this study the bycatch quotas and taxes are applied to the same species groups in order to allow some limited comparison. We do not wish to draw any strong conclusions on the basis of this comparison as it depends on the magnitude of the tax and how restrictive the bycatch quota is at a specific fleet level per species. As a comparison the bycatch quota is relatively more effective resulting in close to 100% reduction in bycatch of Cardinalfish whereas the equivalent tax only was half as effective. The whales, dolphins and seals again, the bycatch quota was more effective compared to the financial dis-incentive (the tax) again largely due to the fact that there are limited trading opportunities and the quotas are very restrictive in relation to the financial penalties.

Targeting note

When interpreting these results it should be remembered that the complex Atlantis-SESSF framework is still a model and does not include all the processes found in the real world. For instance, there is at least one behaviour, which is not available in Atlantis that could prove to be important with regard to the realised effects of incentive-based controls on bycatch. Atlantis does not allow very fine refinement of targeting practices (e.g. the targeting of very finely resolved temperature profiles or water types, which is possible with net monitors). This could see greater avoidance of bycatch species in reality, but is beyond the capability of the Atlantis model (while the model does contain patch-level dynamics even these are not fine enough to capture this kind of behaviour or level of human learning).

This research represents a first test-case application of an ecosystem model that includes fleet behaviour, to various model simulations of bycatch incentive measures (e.g. deemed values). The preliminary results herein have been obtained based on a calibration of the model to historical data for the SESSF, and using simple scenarios concerning the adoption of bycatch management measures. These illustrate the high degree of complexity which results from the interaction of ecological changes and fishing fleet dynamics (through effort allocation, quota trading and investment decisions) in response to management intervention. They should thus be considered tentative, as the detailed sequence of direct and indirect effects that impact on the fleets (and their catches and discards) via a cascade of complex linkages still require a full exploration and some clarification in terms of processes. The research presented is very much a first step, which has resulted in an improvement in the calibration of the model.

Future work

The current trading model is sensitive to parameterisation. While it does lead to year long trading at realistic levels for many species, for others fishers stock up in the first few months of the year and then hold on to quota after that. In reality there is year long trading for most SESSF quota species. For example, Figure 57 shows the change in quantities of quota leased out to the other fleets by the NetSH fleet over the simulation period, per species (for scenario 1). Overall, there is a decrease in the quantity of quota for Morwong (FPO); that is available to the trawl fleet (dtrawlFD) and an increase in the quota available for Gummy sharks that are traded with the two trawl fleets (dtrawlFD and dtrawlFDB). Lower quota availability of Morwong for the two trawl fleets provides a further constraint on their activity; although the bycatch quota on seals is the predominate effect. This is merely, provided as an illustration of the complex interactions that occur between the fleets in terms of quota trading.

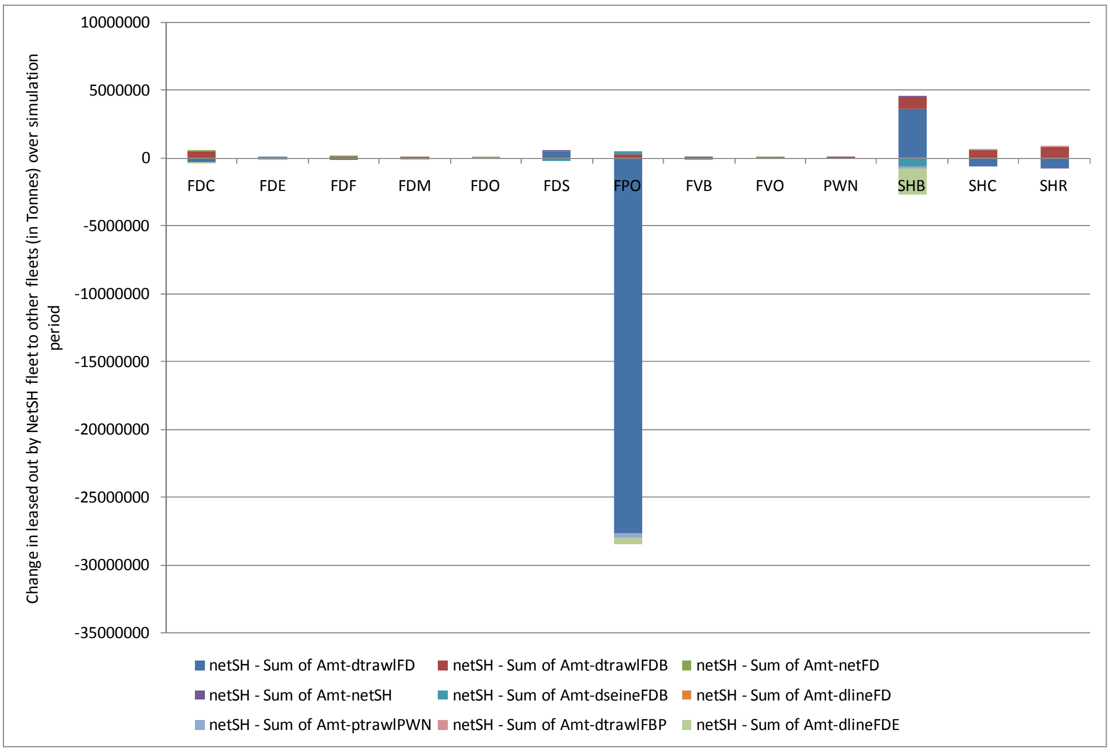

Figure 57 - Change in quantities of quota leased out to the other fleets by NetSH over the simulation period, per species

It is clear from the results of this work that social, economic and psychological drivers play a much larger role than is currently captured in Atlantis. For instance the responses by fleets that did not switch targets (e.g. the trawl fleets) is much more muted than is expected by fisheries scientists with long experience with the fishery given that species like Tiger Flathead are said to be a mainstay of the shelf components of the SESS. In Atlantis this is because those fleets see Flathead as only one of many species that they land (which is consistent with historical logbook data that reports a broad diversity of catches per vessel) and so only see a minority contribution to their decision from that one species.

In reality it appears (based on feedback from fisheries scientists and some fishers) that decisions are more heavily weighted on some species than others. These weightings do not appear to be made on purely economic grounds, but seem to contain some kind of 'psychological component' that increases (at least in their mind) the relative value of these species to the fishers. Future work may benefit from exploring these issues. Similarly, further exploration of the motivations and constraints on trading and information networks could be important for model predictive capacity.

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11 Appendix A: Publications and presentations

Hutton, T., S. Pascoe, O. Thebaud, and B. Fulton 2010. Economic and ecological consequences of incentive based bycatch management. Presented at the Australian Agricultural and Resource Economics Society (AARES) conference in Adelaide (SA), Australia (10th-12th February, 2010).

Hutton T., Fulton B., Pascoe S., Thebaud O. 2010. Ecosystem-wide impacts of alternative bycatch reduction strategies: an ecological-economic assessment of the Australian Southern and Eastern Scalefish and Shark Fishery. To be presented at the International Institute for Fisheries Economics and Trade (IIFET) Conference 2010 - Economics of fish resources and aquatic ecosystems: balancing uses, balancing costs, Montpellier, France, 13-16 July 2010.

Pascoe, Sean, James Innes, Dan Holland, Mark Fina, Olivier Thébaud, Ralph Townsend, James Sanchirico, Ragnar Arnason, Chris Wilcox, Trevor Hutton 2010. Use of incentive based management systems to limit bycatch and discarding. In press: *International Review of Environmental and Resource Economics.*

12 Appendix B: Examples of trade based restrictions

Shrimp Imports into the US

The US embargo on wild shrimp imports from countries that endanger sea turtles through shrimp fishing[17] is perhaps the best example. This action was motivated by both US shrimp fishers and environmental groups; US shrimp trawler fishermen as they were required to use turtle excluder devices (TEDs) in their nets (to prevent turtles from drowning) from the mid 1908s and were concerned this would place them at a competitive disadvantage; and, environmental groups concerned by the level of turtle bycatch in shrimp fisheries. The ban was first implemented in 1989 and initially only applied to countries in the wider Caribbean and Western Atlantic. In 1995 its application was extended to all importing nations and consequentially a case against the ban was brought before the WTO (formally GATT) by India, Malaysia, Pakistan and Thailand in early 1997. However, following an unsuccessful appeal to the WTO appellate body and some subsequent modifications to how the US applied the measures, the ban was ultimately upheld in 2001. A list of countries approved for import into the US is produced by the Department of State in May each year.

It is difficult to determine how effective this policy has been at incentivising fisheries to reduce their turtle bycatch. In general, since 2002 there has been little change to the number of nations certified to import mechanically caught wild shrimp into the US. Costa Rica has been dropped from the list more than once but always gained re-certification the following year. The only country currently certified that was not on the initial list is Madagascar. Thailand, and Trinidad and Tobago, countries that were initially certified in 2002, did not re-gain certification in 2005 and have failed to either apply or do so ever since. Consequentially of the seventeen fisheries certified for import in 2002, fifteen still hold certification with one new fishery gaining approval bringing the total number of currently certified nations to sixteen, one less than in the first instance. If it is assumed this is representative of TED use it would appear that the measure has done little to increase the use of TEDs across nations. However, by prohibiting imports from non-TED using nations any increases in US demand for shrimp can only be satisfied by aquaculture or certified nations[18] increasing wild production (by increasing effort). The potential level of turtle bycatch should therefore be greatly reduced following any such increase in effort. As data relating to shrimp imports into the US are not broken down by method of capture or even into wild or farmed, identifying shifts in supply is currently not possible.

Furthermore, the prohibition of imports is only an incentive to comply so long as the validation process can be depended upon. On the 10th of November, 2008 the environmental group Turtle Island Restoration Network (TIRN) issued a 60 day notice

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[17] On May 1, 1991 it became illegal to import shrimp from a country without certification. Certification requires proof that a country has adopted "a regulatory program comparable to the US program or...that the fishing environment in its waters does not pose a threat to sea turtles." Implementation of TEDs is encouraged; by May, 1994 "the nations affected by this law must require the use of TEDs on all shrimp vessels...or their exports of shrimp to the US will be embargoed."

[18] A number of nations are considered to operate in areas where turtles are so infrequently seen that they do not require certification, for this purpose these nations are considered as certified, i.e. their imports are not prohibited.

of intent to sue for violations of the endangered species act in connection with the state department's certification of shrimp imports to the US (under public law 101-162 609). This action was on the grounds that the state department had not been properly enforcing requirements for shrimp vessels to use TEDs in their nets. Should these accusations be valid the effectiveness of trade measures aimed at reducing turtle bycatch based on this certification is questionable.

Eastern Tropical Pacific (ETP) Yellowfin Tuna

The US Marine Mammal Protection Act (MMPA) of 1972 imposed tight restrictions on domestic vessels and resulted in US vessels leaving or significantly reducing their levels of dolphin bycatch in the ETP yellowfin tuna purse-seine fishery. By the last half of the 1980s the majority of dolphin mortality was being attributed to non-US vessels (~85%) (NOAA, 2000) and the total level of mortality started to rise again. This resulted in the 1988 MMPA amendment requiring foreign fleets to meet US bycatch standards (namely dolphin mortality rates) if they were to still import tuna caught in the fishery into the US[19]. However, the US government did not impose these restrictions until October 1990 when legal action led by the environmental group Earth Island Institute forced them to do so. This resulted in Mexico, Venezuela, Ecuador, Panama, and Vanuatu effectively being excluded from the US market and significant decrease in the level of ETP dolphin mortality was observed at this point in time (Figure A1).

Mexico contested the import restriction in 1991 through GATT (Tuna-Dolphin I) on the grounds the measure was a restriction on free trade and the EU subsequently brought a further case in 1994 (Tuna-Dolphin II) due to concerns over the US taking unilateral action. GATT found in favour of the appellants in both cases, deciding the US had violated free trade agreements and that there should be the pursuit of multi- over unilateral agreements.

After the first case (Mexico vs. US) the multilateral La Jolla Agreement[20] was signed by 10 governments[21] in April 1992 at a special meeting of the Inter-American Tropical Tuna Commission (IATTC). The agreement aimed to; (1) progressively reduce dolphin mortality in the EPT fishery to levels approaching zero by setting annual limits; and (2) seek an ecologically sound means of capturing large yellowfin tunas not in association with dolphins. This was reaffirmed by the Declaration of Panama in October 1995 and signed by 12 governments[22]. Subsequent to this the Agreement on the International Dolphin Conservation Program (IDCP), a legally-binding multilateral agreement was brought into force under IATTC in February 1999. This has now been ratified or ascended to by 13 states[23], and provisionally applied by a further two.[24] An additional provision in this being to avoid, reduce and minimise bycatch and discards of juvenile tunas and non-target species.

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[19] Under the MMPA "The Secretary of the Treasury shall ban the importation of commercial fish or products from fish which have been caught with commercial fishing technology which results in the incidental kill or incidental serious injury of ocean mammals in excess of United States standards."

[20] Also referred to as the 1992 Agreement on the Conservation of Dolphins.

[21] Colombia, Costa Rica, Ecuador, Mexico, Nicaragua, Panama, Spain, the United States of America, Vanuatu and Venezuela.

[22] Belize, Colombia, Costa Rica, Ecuador, France, Honduras, Mexico, Panama, Spain, the United States of America, Vanuatu and Venezuela.

[23] Costa Rica, Ecuador, El Salvador, European Union, Guatemala, Honduras, Mexico, Nicaragua, Panama, Peru, United States, Vanuatu and Venezuela.

[24] Bolivia and Colombia.

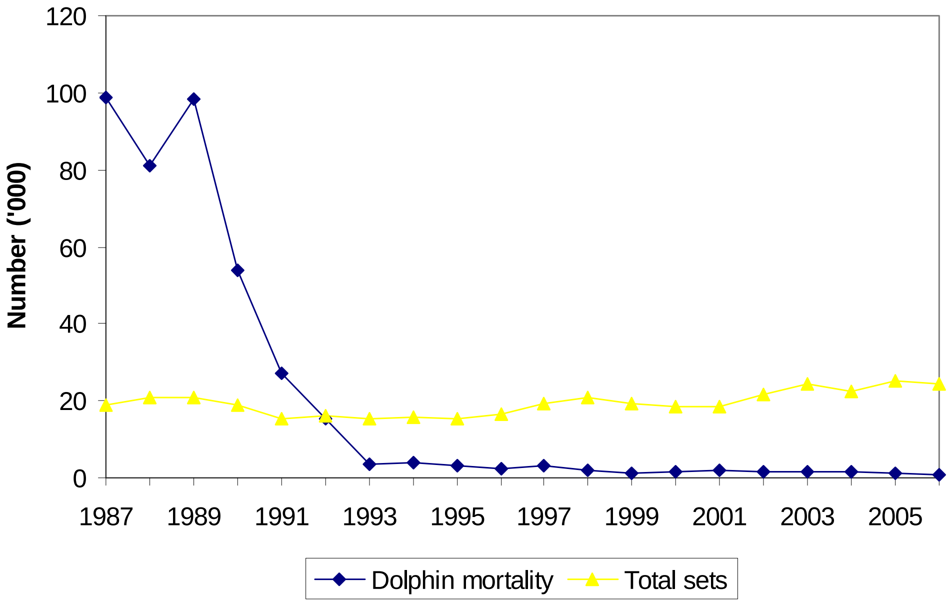

Figure A1. Estimates of total number of sets for purse-seine vessels over 363 tons in the EPO from the IATTC 2002 and 2006 fishery status reports (no. 1 and 5). Dolphin numbers are estimates of incidental mortality in the fishery.

Whether the long term reduction in dolphin bycatch can be directly attributed to the US's initial action is hard to determine. It is possible that without this the latter multilateral agreements would not have come about, however, the independent pressure of environmental groups is likely to have been another significant factor.

Currently, in order to export yellowfin tuna and yellowfin tuna products harvested by purse seine vessels operating in the ETP to the United States countries are required to have an affirmative finding.[25] The affirmative finding process requires that the harvesting nation is meeting its obligations under the IDCP and obligations of membership in the IATTC. The nation must also be a member if IATTC and confirm that the tuna was harvested after the effective date of the IDCPA by vessels which participate in the conservation program. Finally, the nation must show that the total dolphin mortality limits do not exceed the limits under the Conservation Program.

Concerns that pursuing a zero level of dolphin bycatch may imply high levels of other, non-dolphin (i.e. juvenile yellowfin and other non-target species), bycatch and discards have been raised (Enríquez-Andrade and Vaca-Rodríguez 2004). Rates of non-dolphin bycatch are typically much higher for methods of setting purse-seine nets that do not involve encircling dolphins (the method of set associated with highest dolphin bycatch and mortality), particularly when setting on floating objects.[26] However, these concerns are not supported by the IATTC observer estimates of non-dolphin bycatch. Figures indicate that despite increases in all methods of set total non-dolphin bycatch has fallen

[25] This, under the MMPA, applies to a nation harvesting yellowfin tuna in the eastern tropical Pacific Ocean (ETP) with purse seine vessels greater than 400 short tons (362.8 metric tons) carrying capacity. Vessels under 363 tons capacity are not subject to carrying observers nor the requirement to have an affirmative finding in order to import into the US.

[26] These can be both natural e.g. logs, or man-made devices called fish aggregating devices (FADs).

since 1993 with absolute reductions for both dolphin and floating object sets (IATTC 2008).

In absolute terms there has been a general increase in the number of all types of purse-seine sets targeting ETP yellowfin tuna since 1993 (Figure A2) (i.e. sets can be made on tuna associated with either; Dolphins, floating objects, or un-associated) and, for vessels over 363 tons capacity[27], setting nets on dolphins is still the predominant method of operation (IATTC 2008). Yet, proportionally, dolphin sets have become less important (falling from 45% in 1993 to 36% in 2006) with floating object sets more than doubling in significance (13% in 1993 to 29% in 2006). Despite this observer estimates of bycatch indicate that; the volume of yellowfin/other tuna and bonito bycatch; and the numbers of all other bycatch species (this includes billfish, other marine mammals and any other species) have been falling since 1997 (IATTC 2008).

The number of sets on dolphin-associated schools of tuna made by vessels with carrying capacities greater than 363 metric tons decreased by 27 percent, from 12,173 in 2005 to 8,923 in 2006, and this type of set accounted for 36 percent of the total number of sets made by such vessels in 2006, compared to 48 percent in 2005. The average mortality per set was 0.10 dolphins in 2006, compared to 0.09 dolphins in 2005 (IATTC 2008).

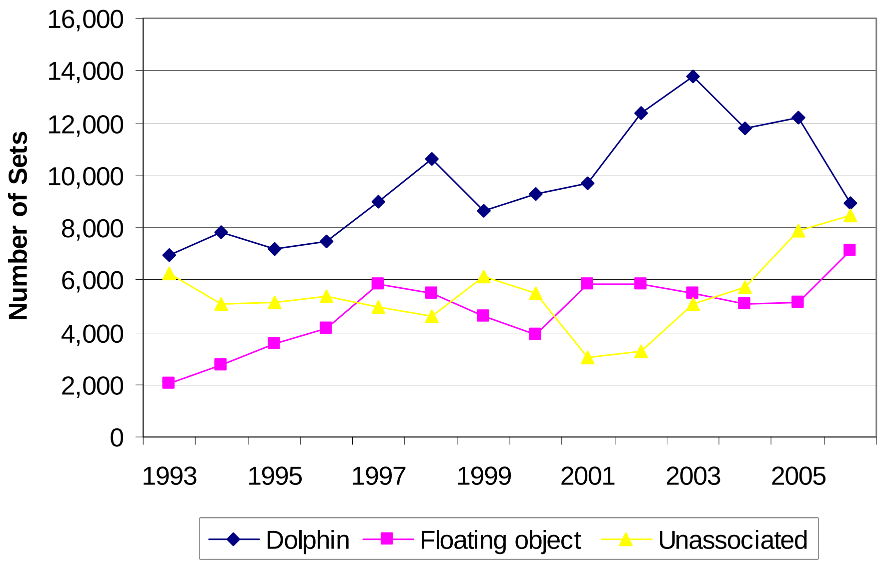

Figure A2. Constructed using data from IATTC (IATTC 2008).

US ban on the Import of Fish and Fish Products from Nations Engaging in High Seas Driftnet Fishing

The level of bycatch associated with primarily Japanese driftnet fleets motivated the UN General Assembly to adopt a number of resolutions (44/225, 45/197 and 46/215) banning driftnetting on the high seas. In particular the 1989 resolution 44/225 that called for the import of fish from nations that defied the UN ban to be prohibited.

The US subsequently banned imports of fish taken with driftnets longer than 2.5 km on the high seas, effective of the 30th of June 1992, under the Driftnet Act Amendments of

[27] The class of vessel to which the measures apply.

1990 (section 107, Public Law 101-627). This was strengthened by the subsequent High Seas Driftnet Fisheries Enforcement Act (US Public Law 102-582). Under these laws the sanctions against nations that do not comply with the high seas drift net bans include:

- port privileges denied to all driftnet or support vessels;
- a ban on the import of sports fishing equipment, fish and fish products from any nation engaging in high seas large-scale driftnet fishing;
- additional economic sanctions: non-compliance continuing six months subsequent to the initial import bans would be followed by a ban on the import of, or raising of tariffs on, any product (e.g. automobiles, electronic equipment, garments, etc.) from the nation/s in question.

Such sanctions would remain in effect until the President certifies to Congress that the offending nation has ceased large-scale driftnet fishing.

It appears the initial threat of these measures was relatively successful at reducing the level of high seas large-scale driftnet fishing. The Japanese government stopped issuing large-scale driftnet fishing licenses after 31 December 1992 and established an enforcement plan. Other nations of concern (primarily Taiwan and the Peoples Republic of Korea) also complied by halting large-scale pelagic driftnet fishing and instigating compensatory buy back/decommissioning schemes and implementing monitoring and enforcement schemes.

Exactly how much of this success can be directly attributed to the specific threat of banning fish imports is hard to determine, will depend on nation specific trade relationships, and may be relatively small. The threat of import bans on other products would in all likelihood be more persuasive, especially when it is considered that the majority of fish taken in these driftnet fisheries by nations such as Japan is believed to have been consumed domestically. Furthermore, a number of European countries were significantly slower to comply and despite the use of drift nets being banned by the EU in 2002 it is estimated that somewhere in excess of 137 of Italian vessels still fish with illegal large-scale drift nets.[28]

Concerns that the US Government was unable to prove swordfish imports met US marine mammal bycatch standards (under the Marine Mammal Protection Act, section 101) resulted in a petition by environmental groups[29] requesting a ban in trade with countries failing to submit proof of the effects of their fishing technology on marine mammals. The petition (dated the 4th of March 2004) states *"the U.S. government continues to illegally import swordfish from more than 40 countries without requiring any proof of its impacts on marine mammals."* It also highlights swordfish caught by Taiwan but imported to the US from Singapore as being of particular concern, describing the Taiwanese longline and drift gillnet fisheries as poorly regulated and known to result in significant bycatch of marine mammals.[30] As seen in the case of shrimp imports, this serves to demonstrate that restricting access to markets can only be an effective measure for reducing bycatch if the means for differentiating products are properly implemented. A recent report to Congress by the Secretary of Commerce

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[28] See www.oceana.org/fileadmin/oceana/uploads/europe/reports/Rederos_Italianos_2007_ING.pdf
[29] The Centre for Biological Diversity and the Turtle Island Restoration Network.
[30] See www.nmfs.noaa.gov/ia/docs/swordfish_petition_l-4.pdf

concedes that the Mediterranean and the North Pacific Ocean are still ‘two major problem areas’ in terms of large-scale drift net fishing.[31]

The Pelly Amendment

The Pelly Amendment of the 1967 US Fisherman’ Protection Act was first passed in 1971 and provided the US with a unilateral method of enforcing international fisheries programmes. Under the initial amendment the US could prohibit imports of nation’s fish products if foreign nationals fishing activities were deemed to diminish the effectiveness of an international fisheries conservation programme. An additional track was included in 1978 enabling sanctions to be imposed on imports of wildlife products if foreign nationals were believed to be “engaging in trade or taking which diminishes the effectiveness of any international program for endangered or threatened species”. The scope for sanction were then broadened in 1988 and 1992 allowing restrictions to be placed on imports of any aquatic species and then of any product, respectively.

The threat of import measures under the Pelly act are believed to have been a relatively effective tactic for the US when encouraging other nations to join or comply with international environmental treaties. Of 18 instances occurring between 1974 and 1993, 50 per cent were deemed successful and 11% partially successful (Charnovitz 1994).

Regional Fisheries Management Organisations (RMFOs)

The dolphin-tuna cases demonstrated that the WTO favours multilateral actions undertaken within the framework of regional organisations over the unilateral imposition of trade sanctions. ICCAT was the first RMFO to authorise restricting access to markets through trade sanctions on the grounds of undermining their conservation and management plans (Carr and Scheiber 2002) and in 1996 recommended members ban the import of blue-fin tuna from then non-ICCAT member countries of Belize, Honduras and Panama. The ban against Panama was lifted in 1999 when it became a contracting party and brought its fishing practice into line with those of ICCAT (Roheim and Sutinen 2006). Equatorial Guinea (an ICCAT member) was also subject to an import ban over the period 1999 to 2004 after exceeding its catch limits (Roheim and Sutinen 2006). Whilst these measures are not bycatch related their apparent ability to influence the practice of Panama may indicate the potential effectiveness of such measures.

The European Union instructs its port authorities to allow vessels from non-EU States to offload fish that were caught on the high seas only if they have been satisfied that the fish have been caught outside the regulatory areas of any competent RFMO of which the European Community is a member, or that the fish have been caught in compliance with conservation and management measures adopted by the RFMO of which the Community is a member. It is uncertain how well this policy is enforced.

Lastly, it has been suggested that trade restrictions could be imposed under CITES (The Convention on International Trade in Endangered Species of Wild Fauna and Flora) as a possible means of reducing marlin and other billfish bycatch in Atlantic bluefin tuna fisheries (Peel *et al.* 2003). These species are severely overexploited due to their international trade as bycatch and from the international trade of Atlantic yellowfin and bigeye tunas.

[31] See www.nmfs.noaa.gov/ia/intlbycatch/docs/CONGO07RPT.pdf

13 Appendix C: Supporting material (socio-economic component)

Equations referred to in Section 3 (including text – from Fulton *et al.* (2007))

Equation B.4 (Profit):

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).

Equation B.6 (Annual effort):

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).

Equation B.16-B.22 (Trading quota- Multispecies):

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:

$$\begin{aligned}\ln\left({}^{quota}p_{s,i,j,m,y}\right) &= \lambda_1 \cdot \ln\left(p_{s,i,j,m,y}\right) + \lambda_2 \cdot \left(\ln\left(p_{s,i,j,m,y}\right)\right)^2 + \lambda_3 \cdot \ln\left(C_{\text{marg},i,j,m,y}\right) \\ &+ \lambda_4 \cdot \frac{H_{s,i,j,y-1}}{Q_{s,i,j,y-1}} + \lambda_5 \cdot \left(\frac{H_{s,i,j,y-1}}{Q_{s,i,j,y-1}}\right)^2 + \lambda_6 \cdot \left(\frac{\sum_{k=1}^{m} H_{s,i,j,k,y}}{Q_{s,i,j,y}} - \frac{\sum_{k=1}^{m} H_{s,i,j,k,y-1}}{Q_{s,i,j,y-1}}\right) \\ &+ \lambda_7 \cdot \left(\frac{\sum_{k=1}^{m} H_{s,i,j,k,y}}{Q_{s,i,j,y}} - \frac{\sum_{k=1}^{m} H_{s,i,j,k,y-1}}{Q_{s,i,j,y-1}}\right)^2 + \lambda_8 \cdot \ln\left(p_{s,i,j,m,y} \cdot \frac{H_{s,i,j,y-1}}{Q_{s,i,j,y-1}}\right) \\ &+ \lambda_9 \cdot \ln\left(T_{m,y}\right) + \lambda_{10} \cdot \ln\left(G_{m,y}\right) + \lambda_{11} \cdot \frac{Q_{s,i,j,y}}{Q_{s,i,j,y-1}} + \alpha_0 + \alpha_{1,i,j} + \alpha_{2,m} + \varepsilon_{i,j,t}\end{aligned} \tag{B.16}$$

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:

$$\tau_{trade} = \begin{cases} 1 & Q_{need,i,j,y} < \left(1.0 - \left(1.0 - \zeta + (1-\zeta) \cdot \dfrac{m-1}{12}\right)\right) \cdot \left(\left(Q_{own,i,j,m,y} - {}^{lease}Q_{out,i,j,m,y}\right) + {}^{lease}Q_{in,i,j,m,y}\right) \\ 0 & otherwise \end{cases} \quad \text{(B.17)}$$

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:

$$\tau_{trade} = \begin{cases} 1 & Q_{need,i,j,y} < \left(1.0 - \varphi + (1-\varphi) \cdot \dfrac{m-1}{12}\right) \cdot \left(\left(Q_{own,i,j,m,y} - {}^{lease}Q_{out,i,j,m,y}\right) + {}^{lease}Q_{in,i,j,m,y}\right) \\ 0 & otherwise \end{cases} \quad \text{(B.18)}$$

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

Equation B.23 and B24 (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:

$$\hat{p}_{t,s} = \beta_{0,s} + \beta_{1,s} \cdot t + \beta_{m,s} \cdot M_t^T + r \cdot e_{t-1,s} \qquad \text{(B.23)}$$

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:

$$e_{t-1,s} = p_{t,s} - \hat{p}_{t,s} \qquad \text{(B.24)}$$

Equation B.25 and B26 (Final effort allocation – step 3 shown)

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.

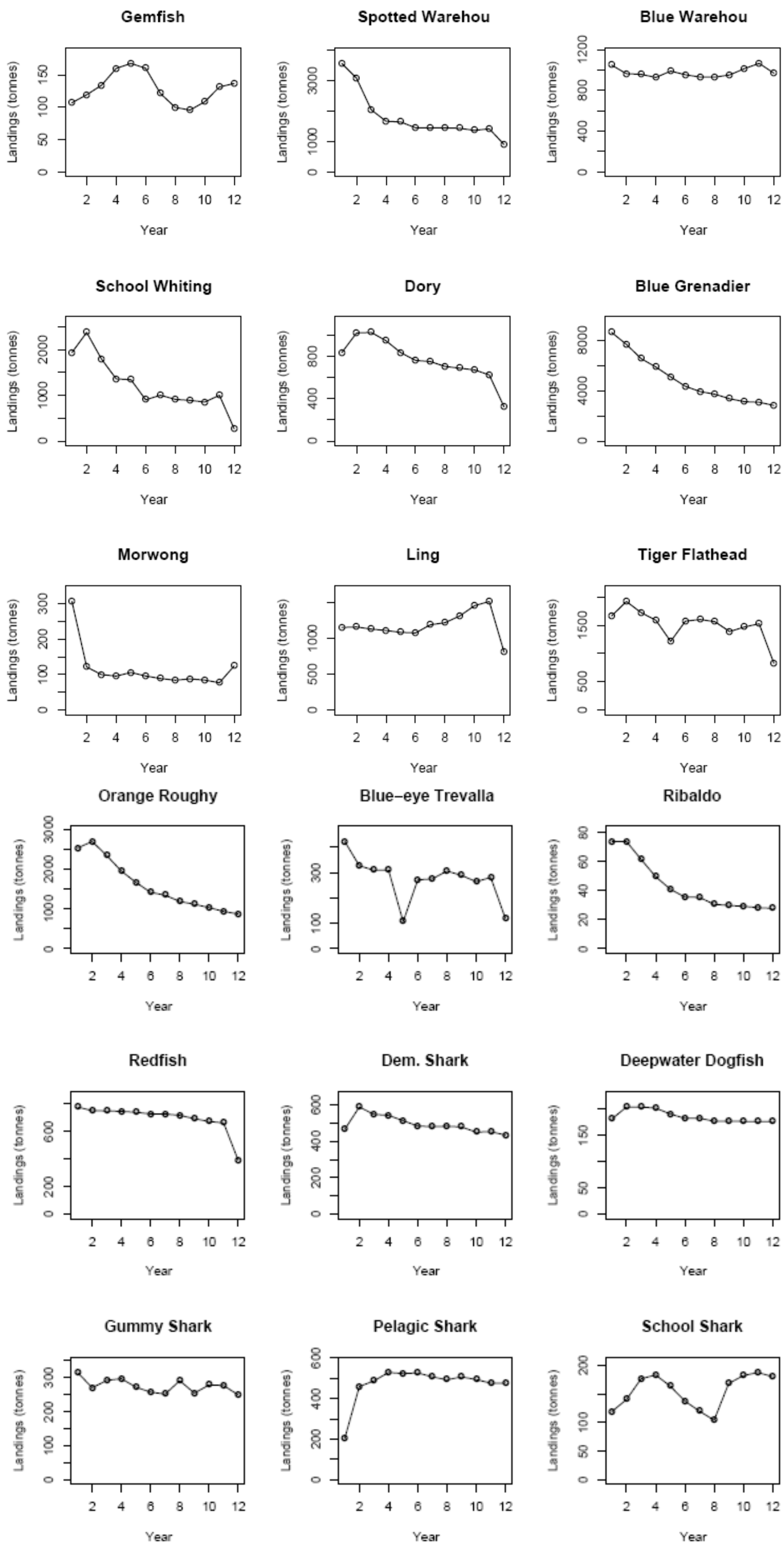
A tentative effort distribution is then calculated by interpolating between the CPUE-based effort distribution and planned (historical knowledge-based) effort locations. This interpolation allows for a shift as information spreads. This spread of information can be constrained by a subfleet specific 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).

$$ {}^{temp}E_{i,j,b} = \gamma_f \cdot \left({}^{CPUE}E_{i,j,m,b,y} - {}^{curr}E_{i,j,b} \right) + {}^{curr}E_{i,j,b} \qquad \text{(B.26)} $$

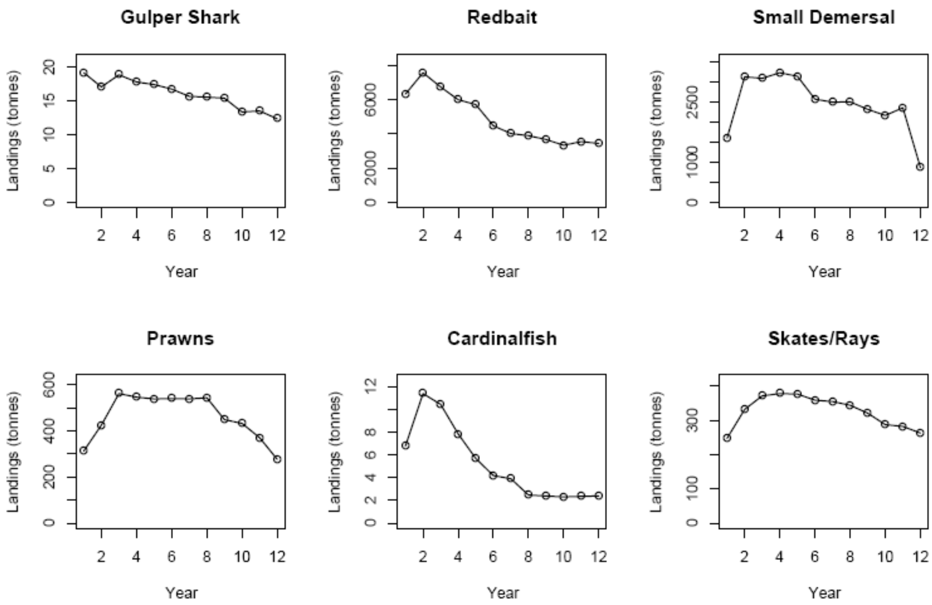
with γ_f is the flexibility index and ${}^{curr}E_{i,j,b}$ is the current effort in box b.

14 Appendix D: Model output per scenario

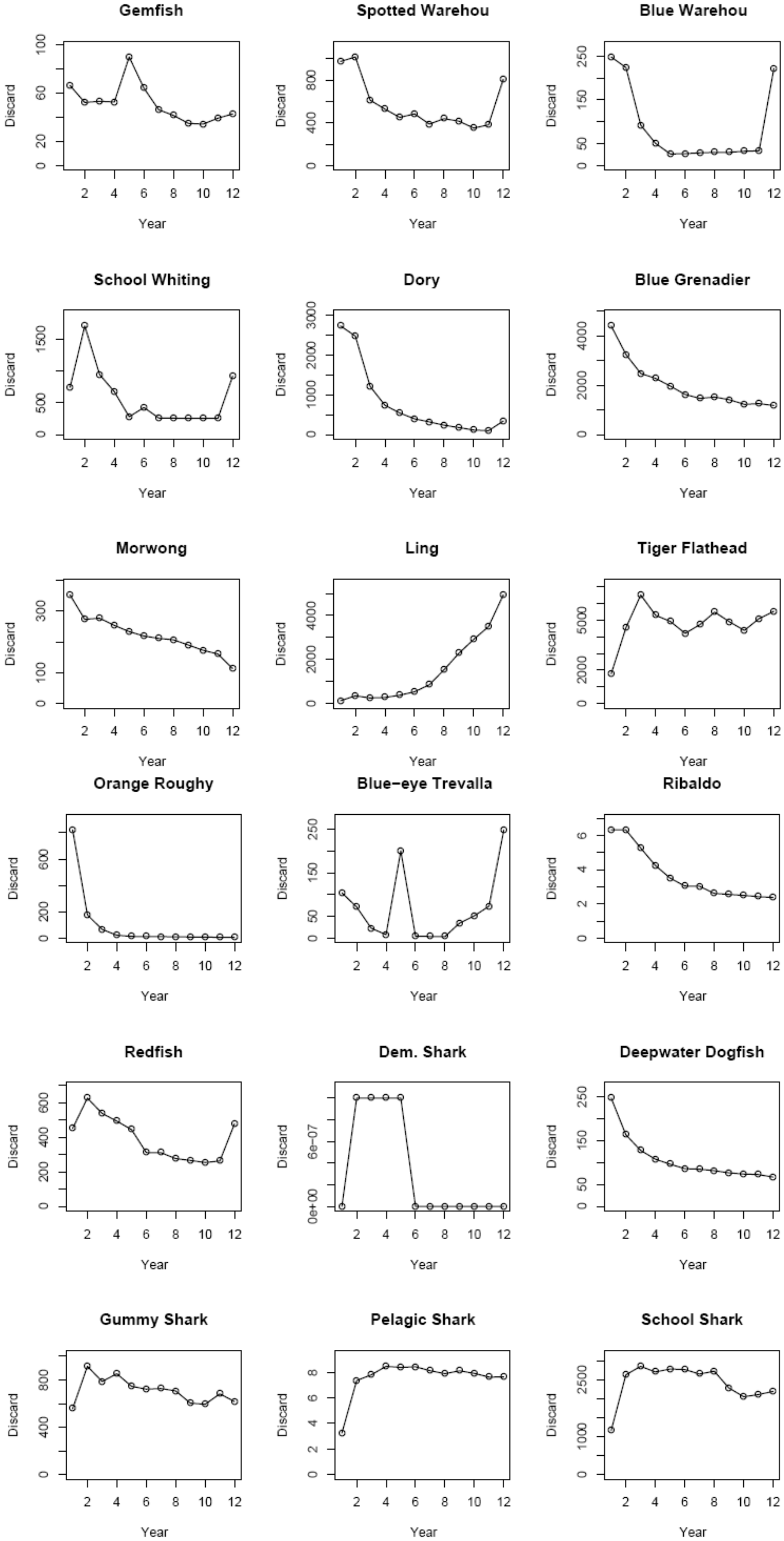
Base case run – Landings per species (tonnes)



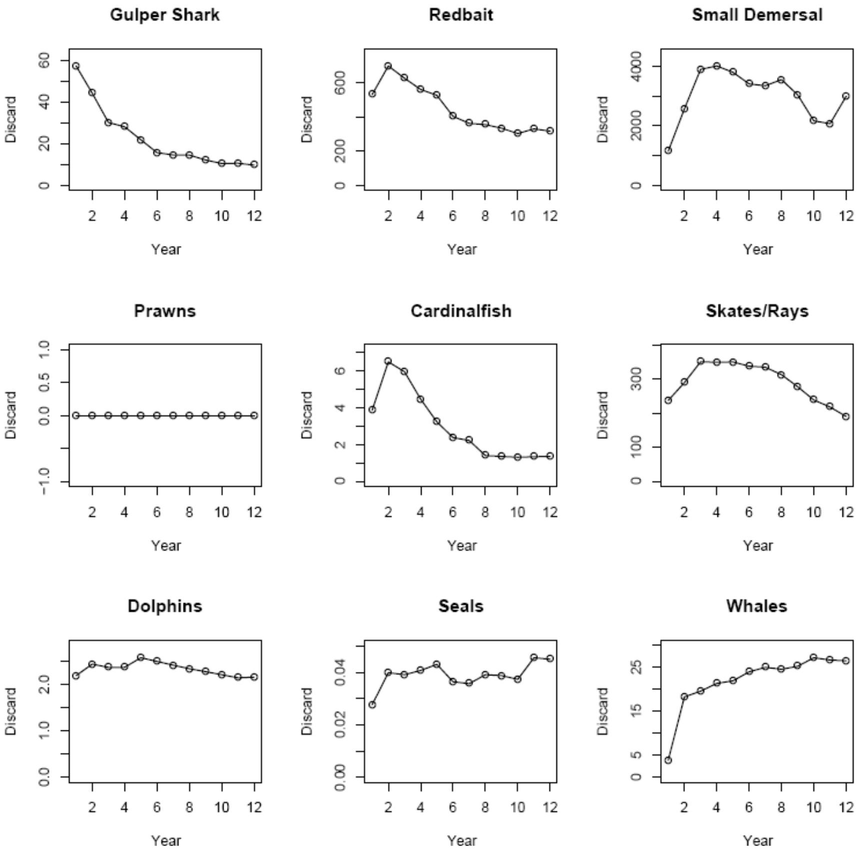
Base case run – Landings per species (continued)



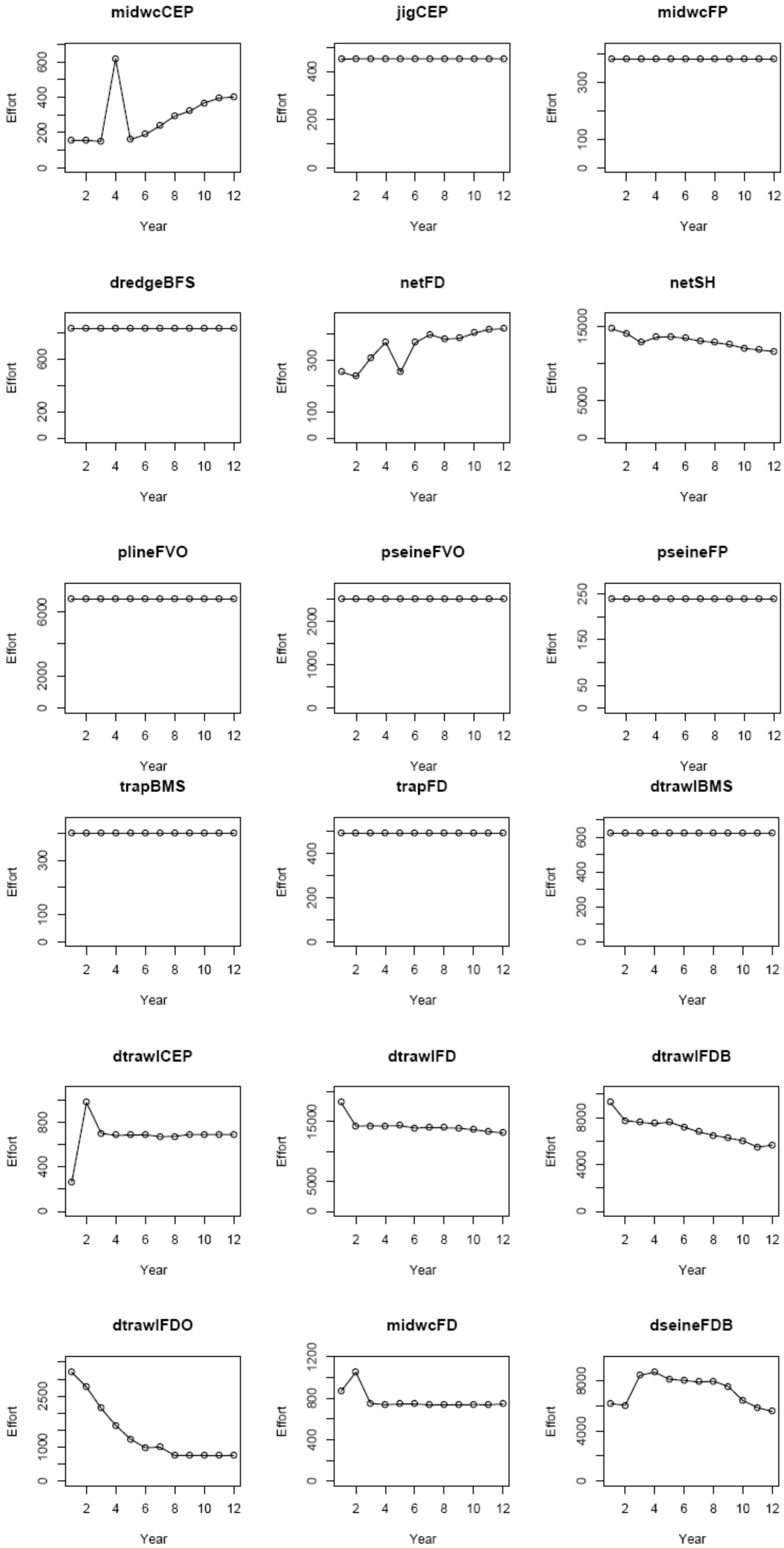
Base case run – Discards per species (tonnes)



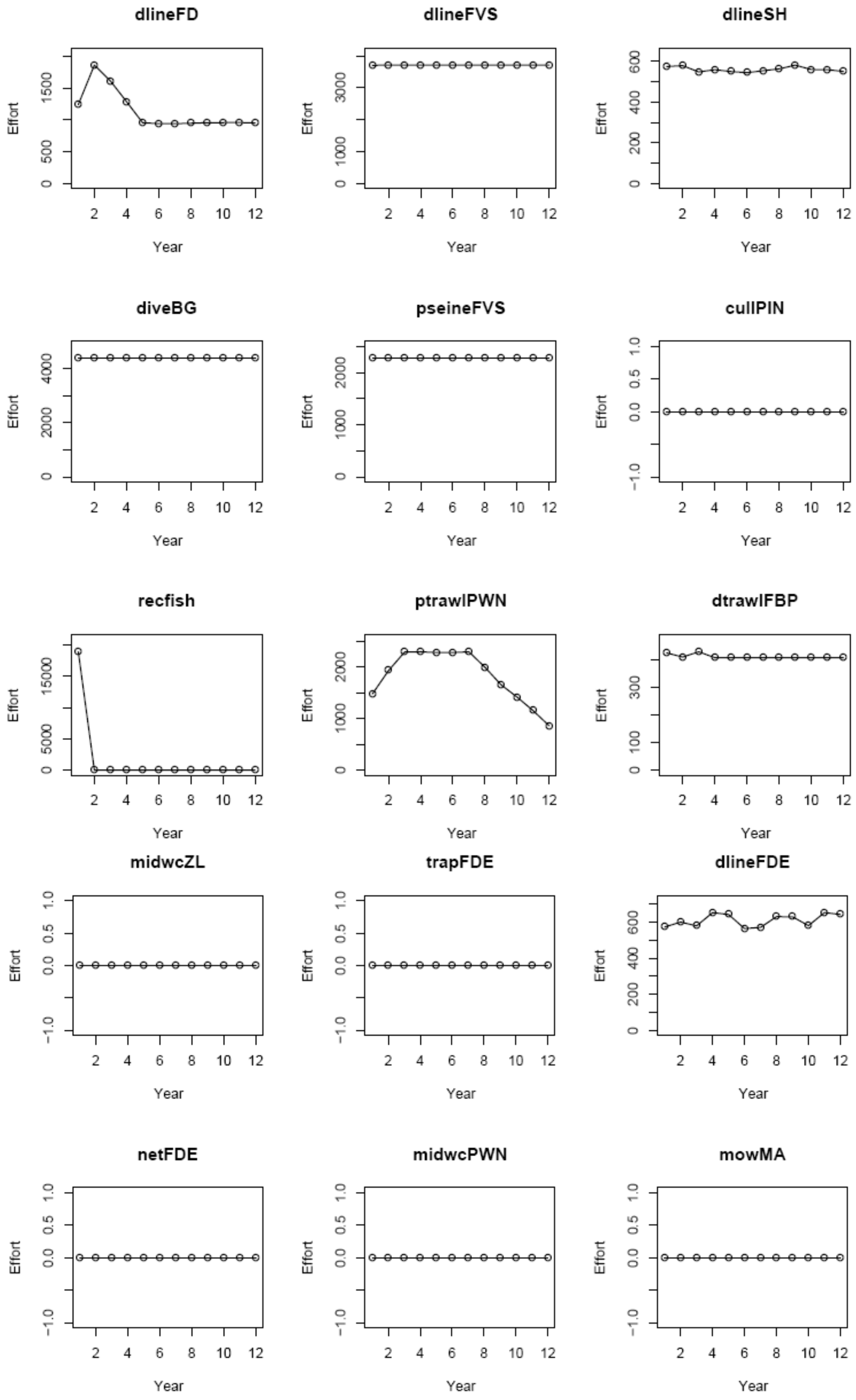
Base case run – Discards per species (tonnes)(continued)



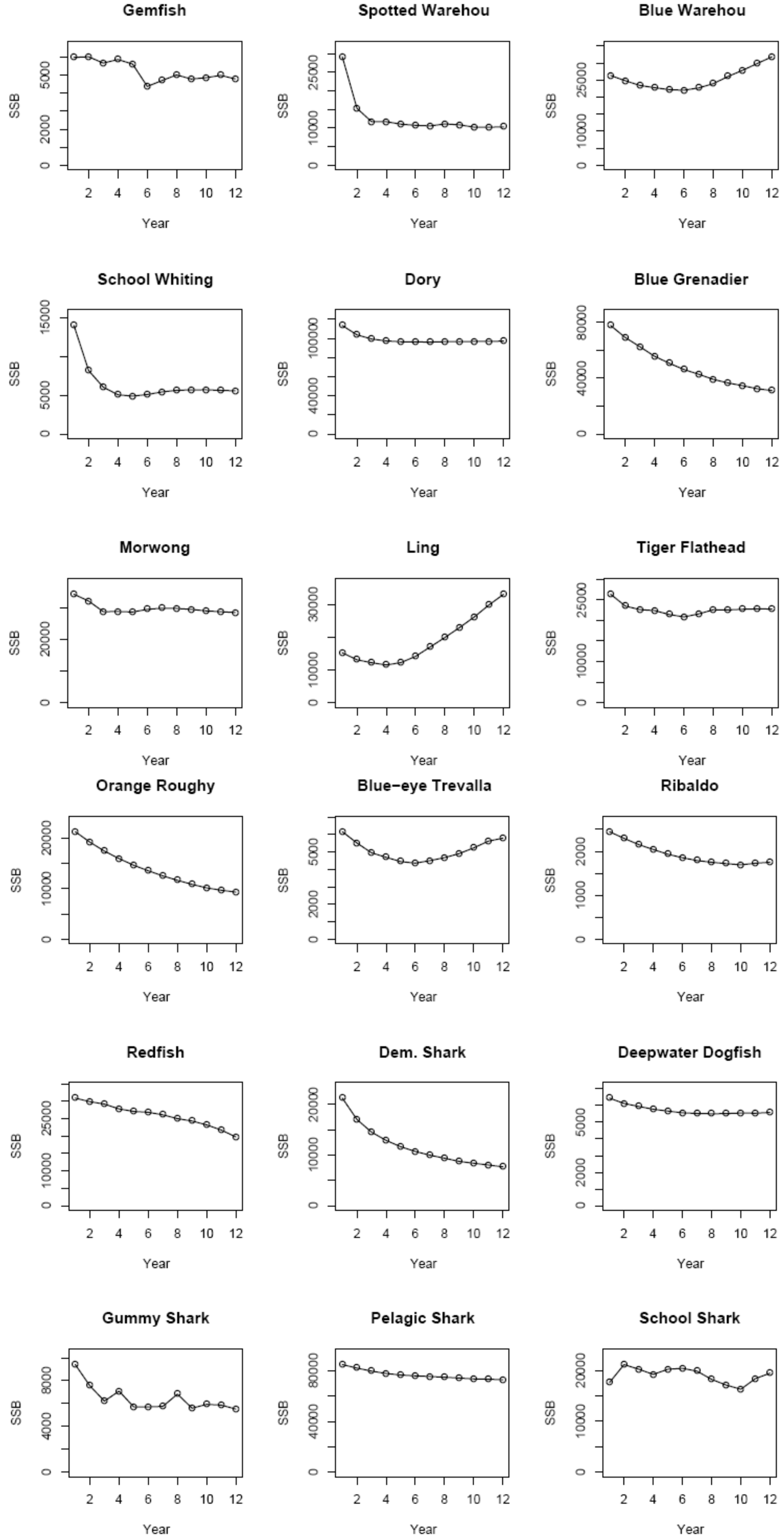
Base run – Effort per fleet (boat days)



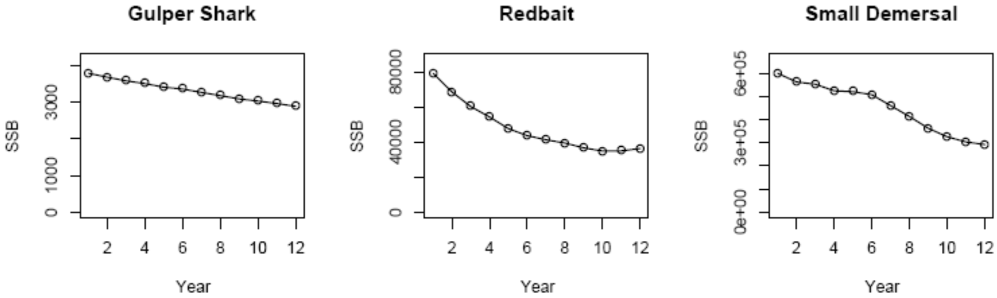
Base run – Effort per fleet (boat days)(continued)



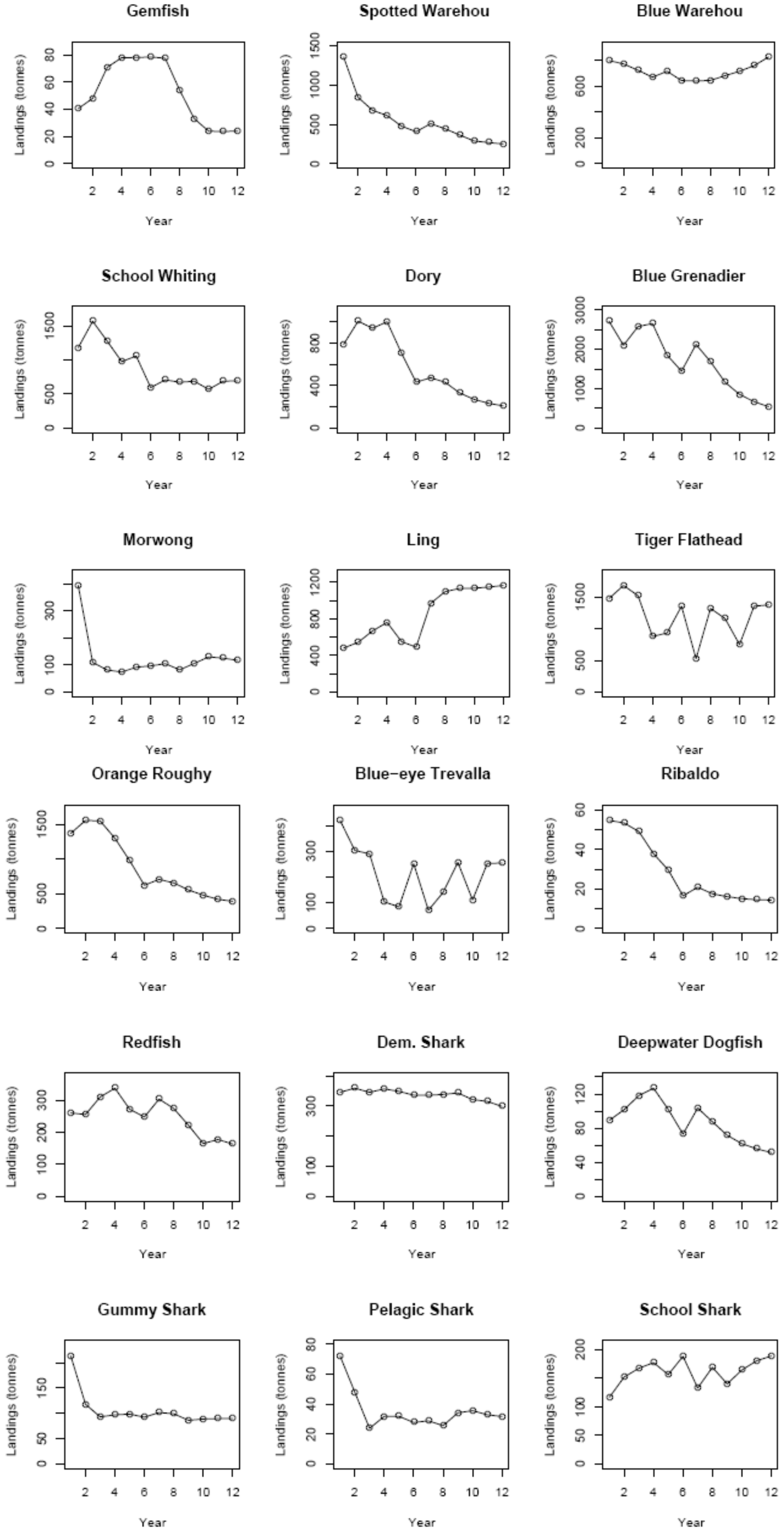
Base run – SSB: predicted spawning stock biomass per species (tonnes)



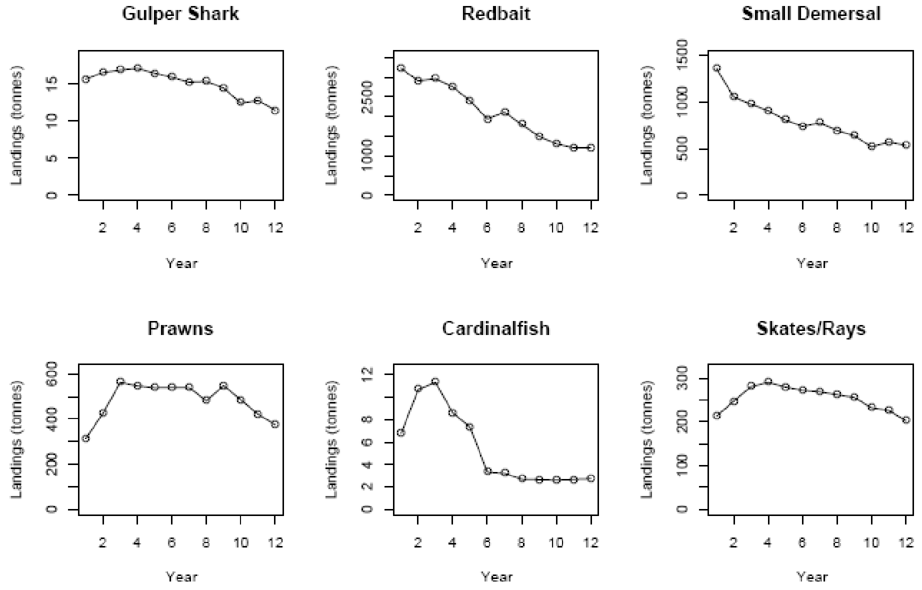
Base run – SSB: predicted spawning stock biomass per species (tonnes)(continued)



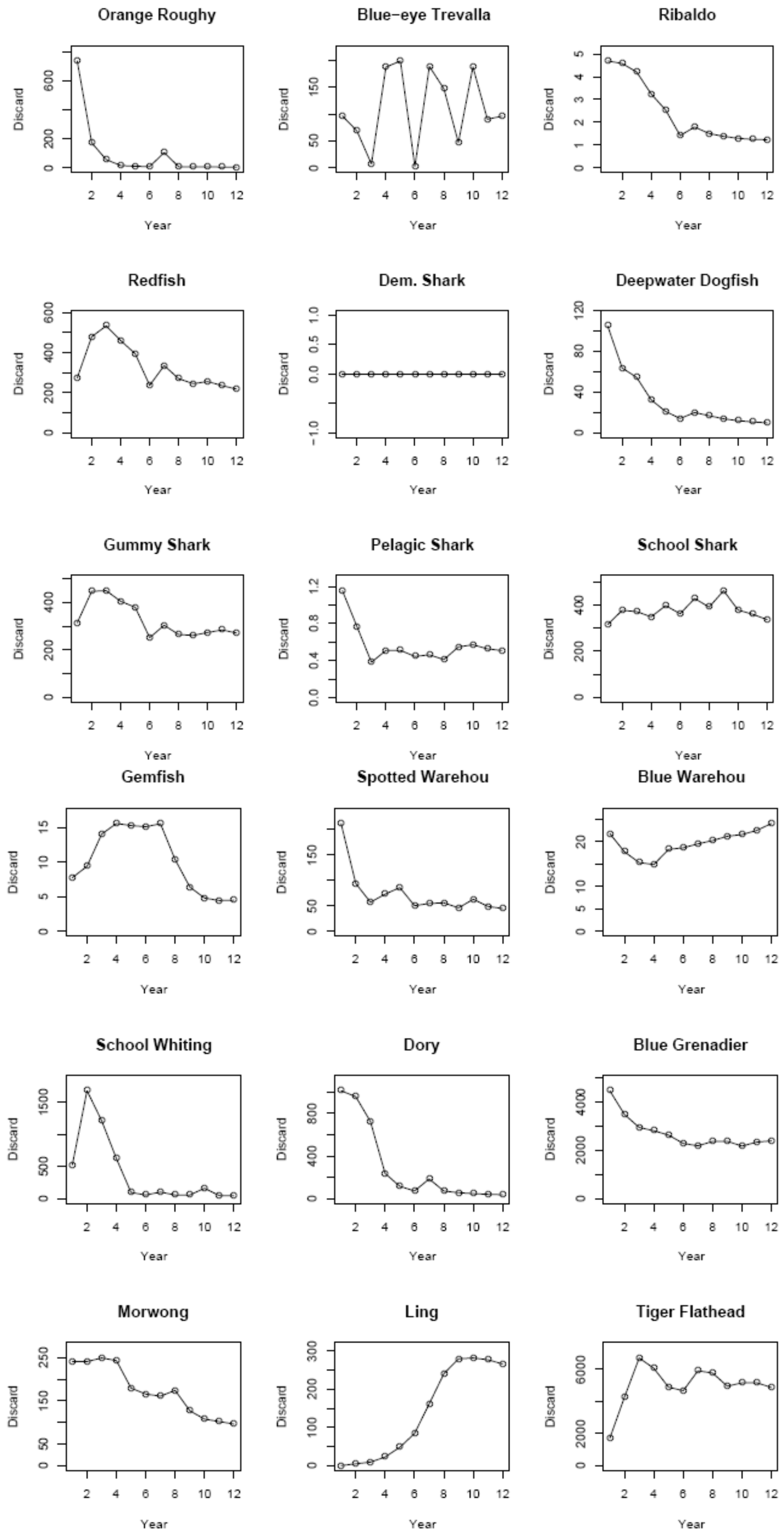
Scenario 1 - Landings per species (tonnes)



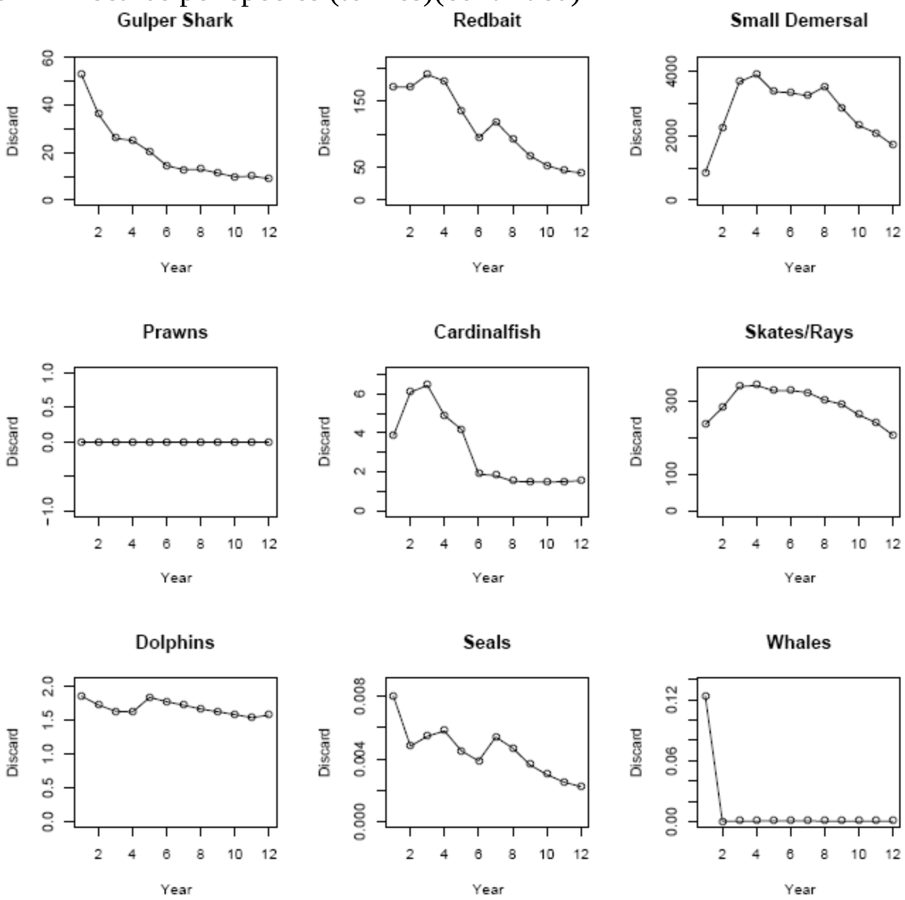
Scenario 1 - Landings per species (tonnes)(continued)



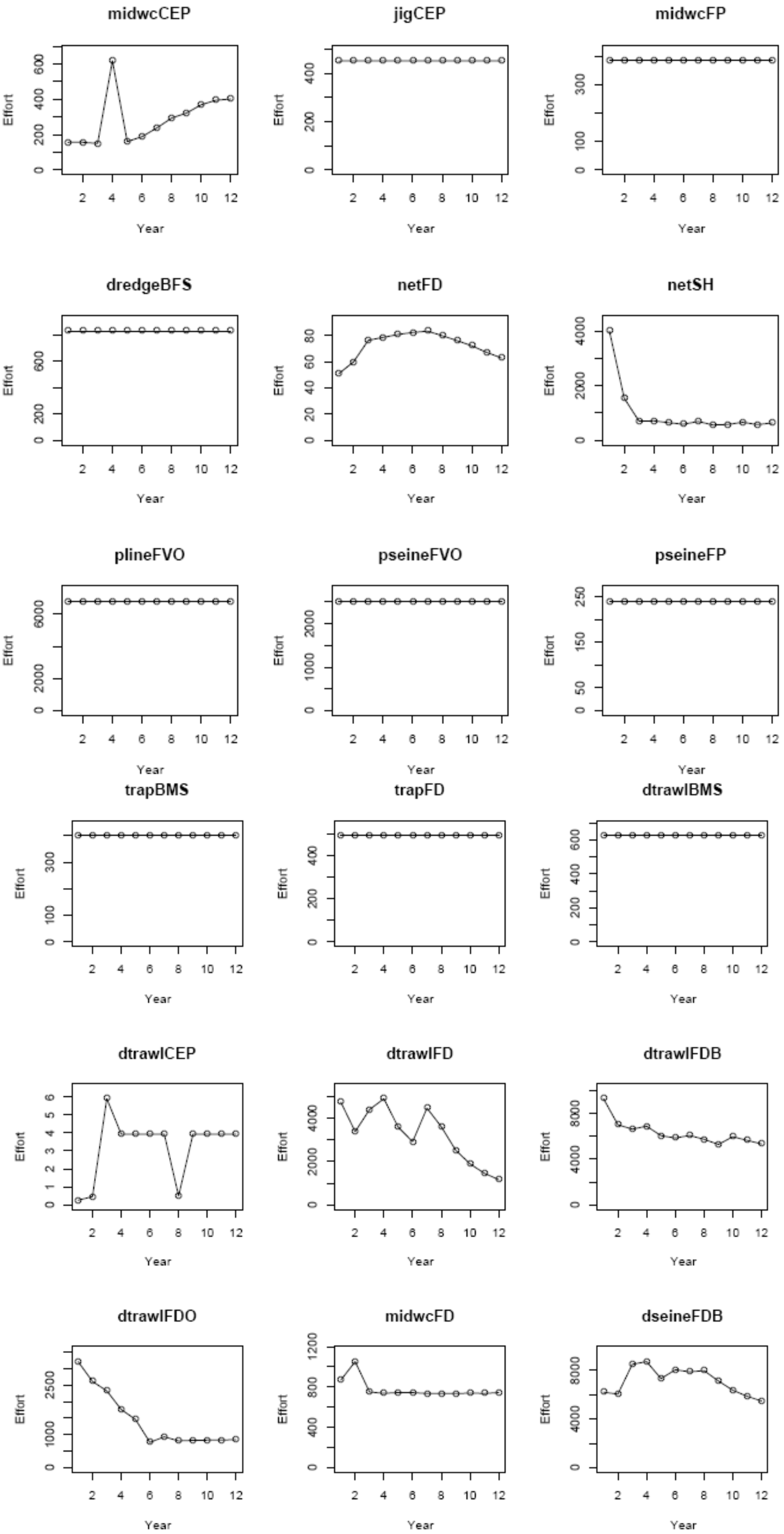
Scenario 1 - Discards per species (tonnes)



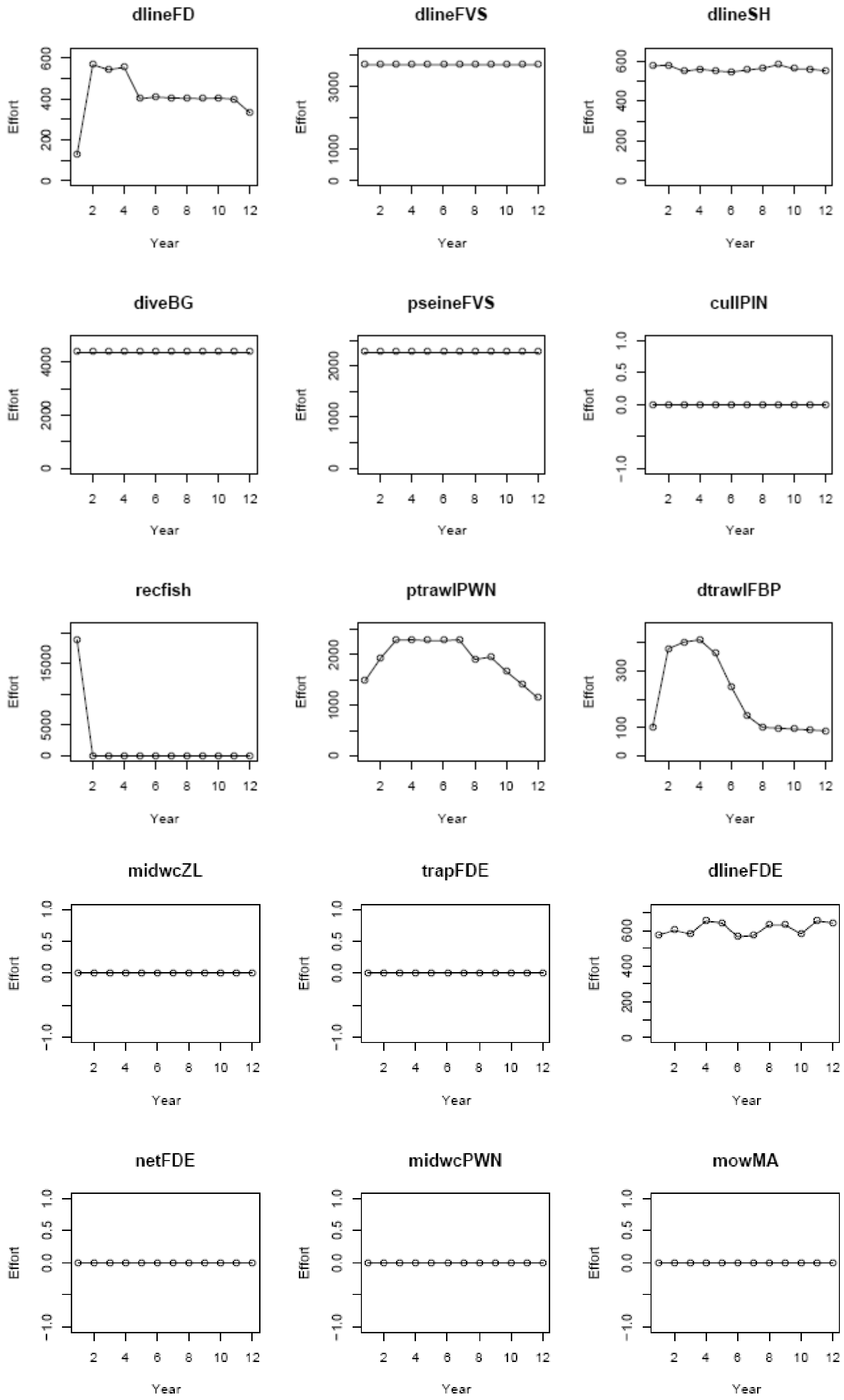
Scenario 1 - Discards per species (tonnes)(continued)



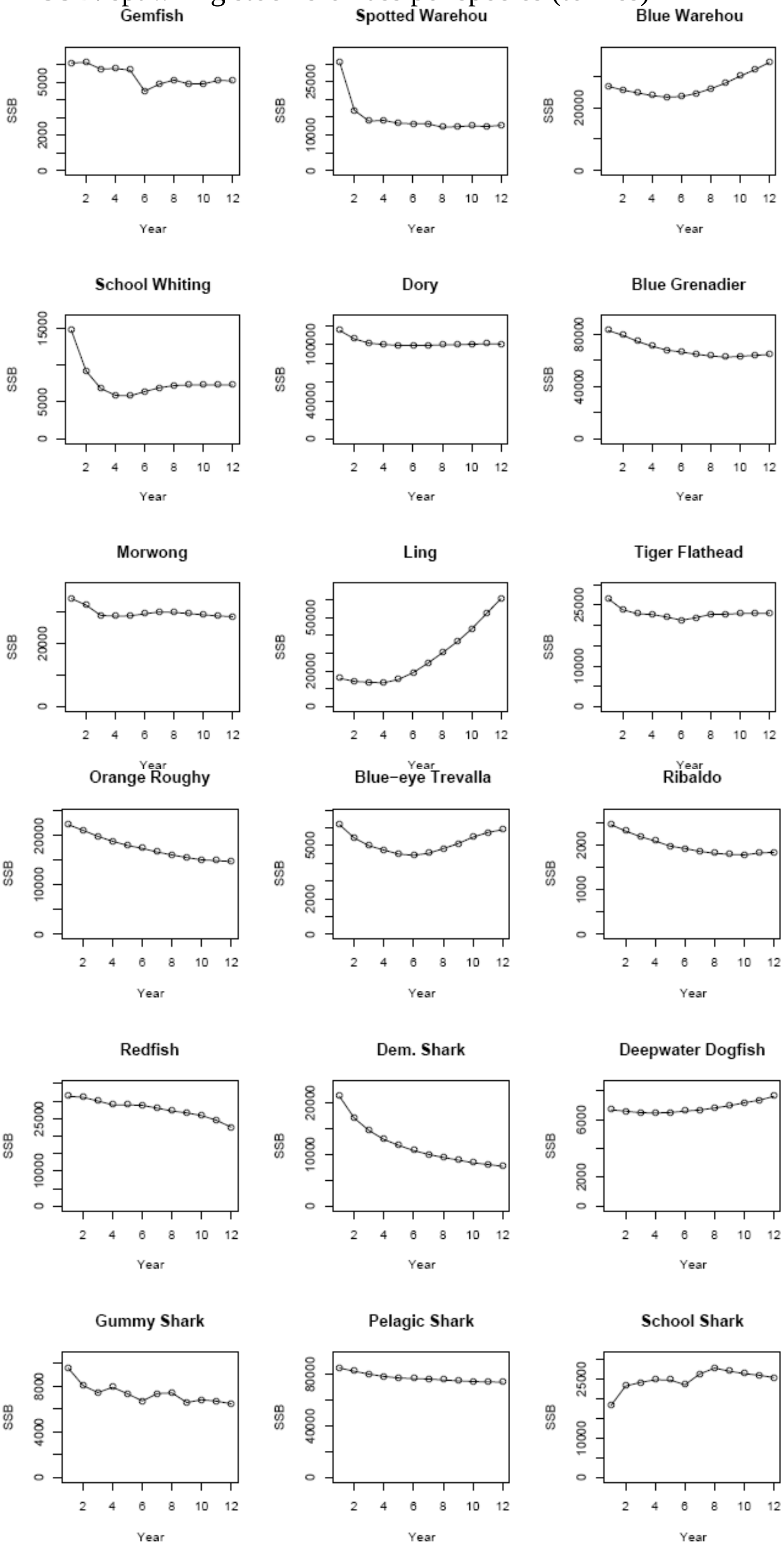
Scenario 1 – Effort per fleet (boat days)



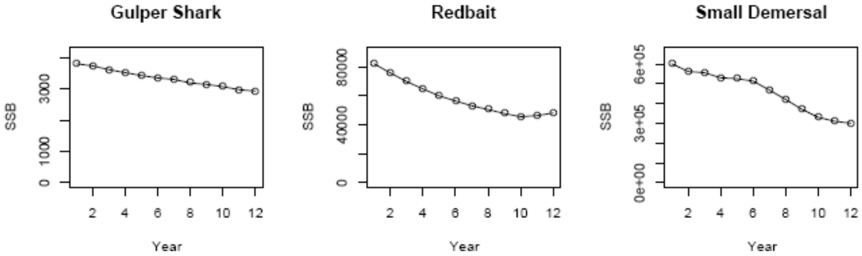
Scenario 1 – Effort per fleet (boat days)(continued)



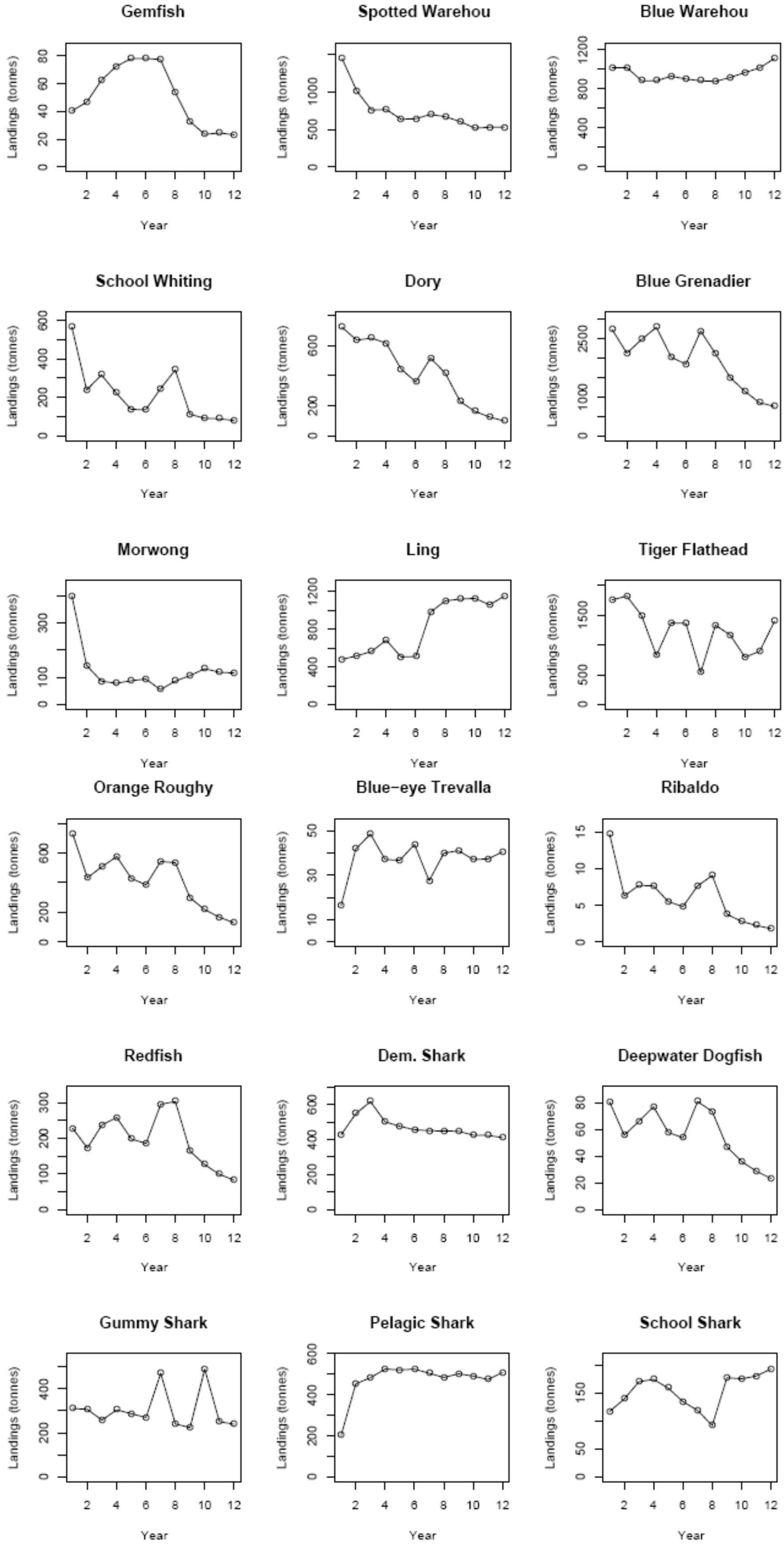
Scenario 1 - – SSB: spawning stock biomass per species (tonnes)



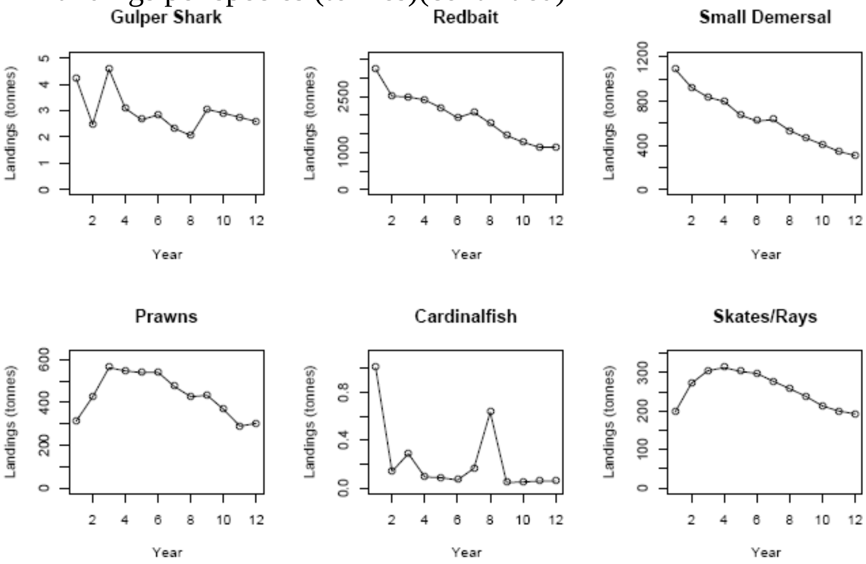
Scenario 1 - – SSB: spawning stock biomass per species (tonnes)(continued)



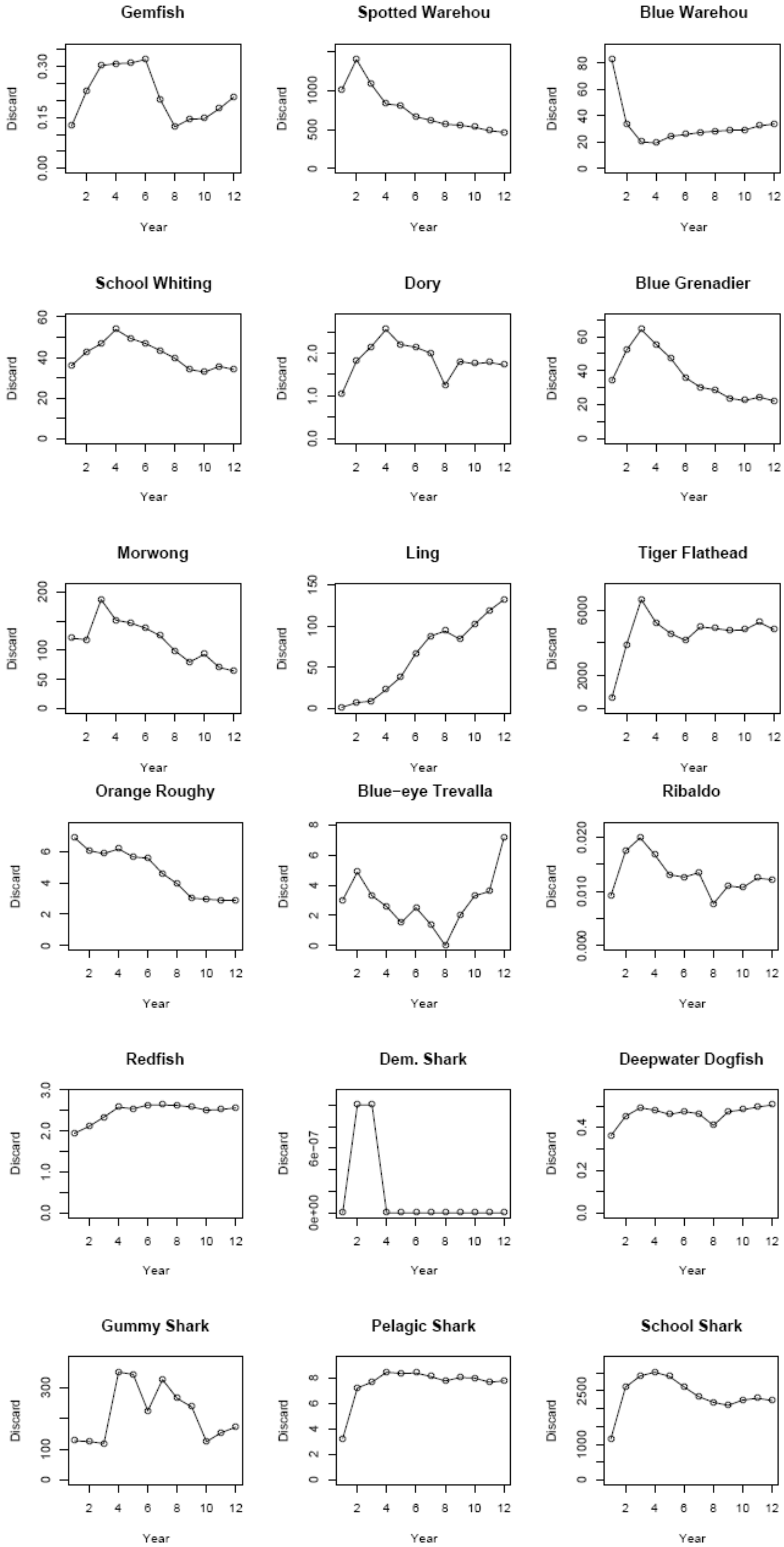
Scenario 2 - Landings per species (tonnes)



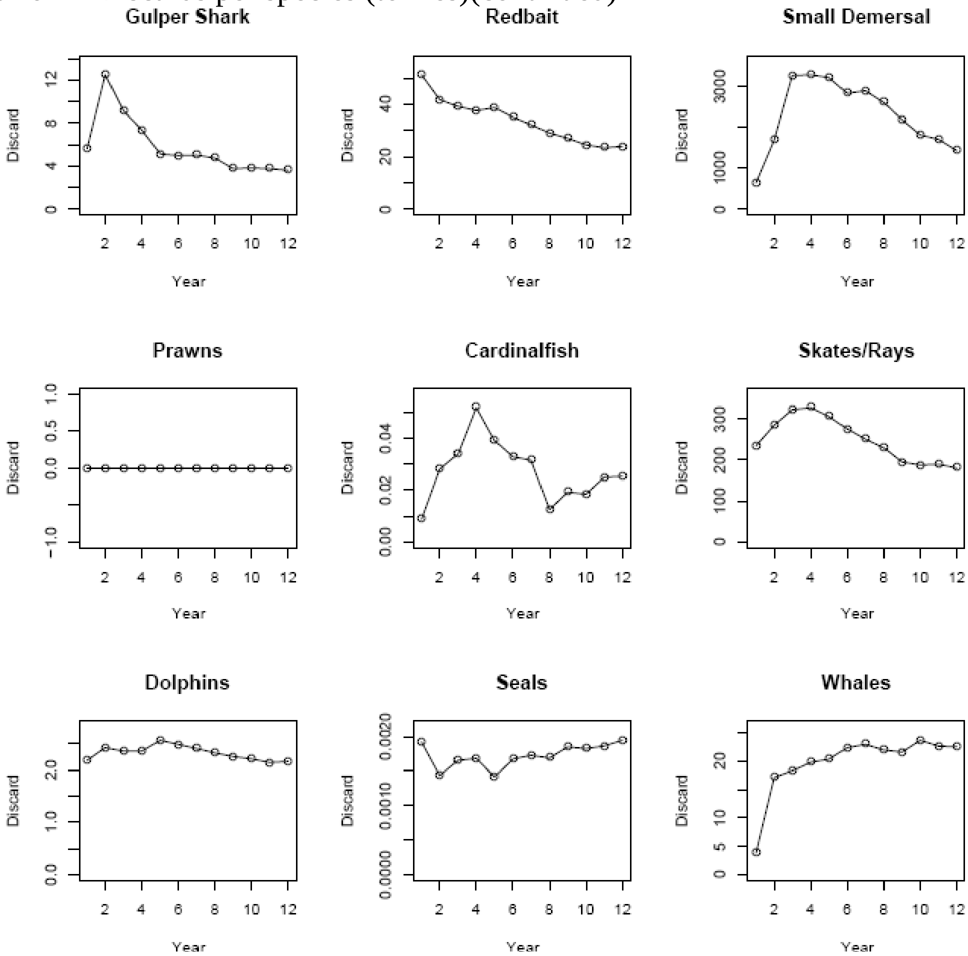
Scenario 2 - Landings per species (tonnes)(continued)



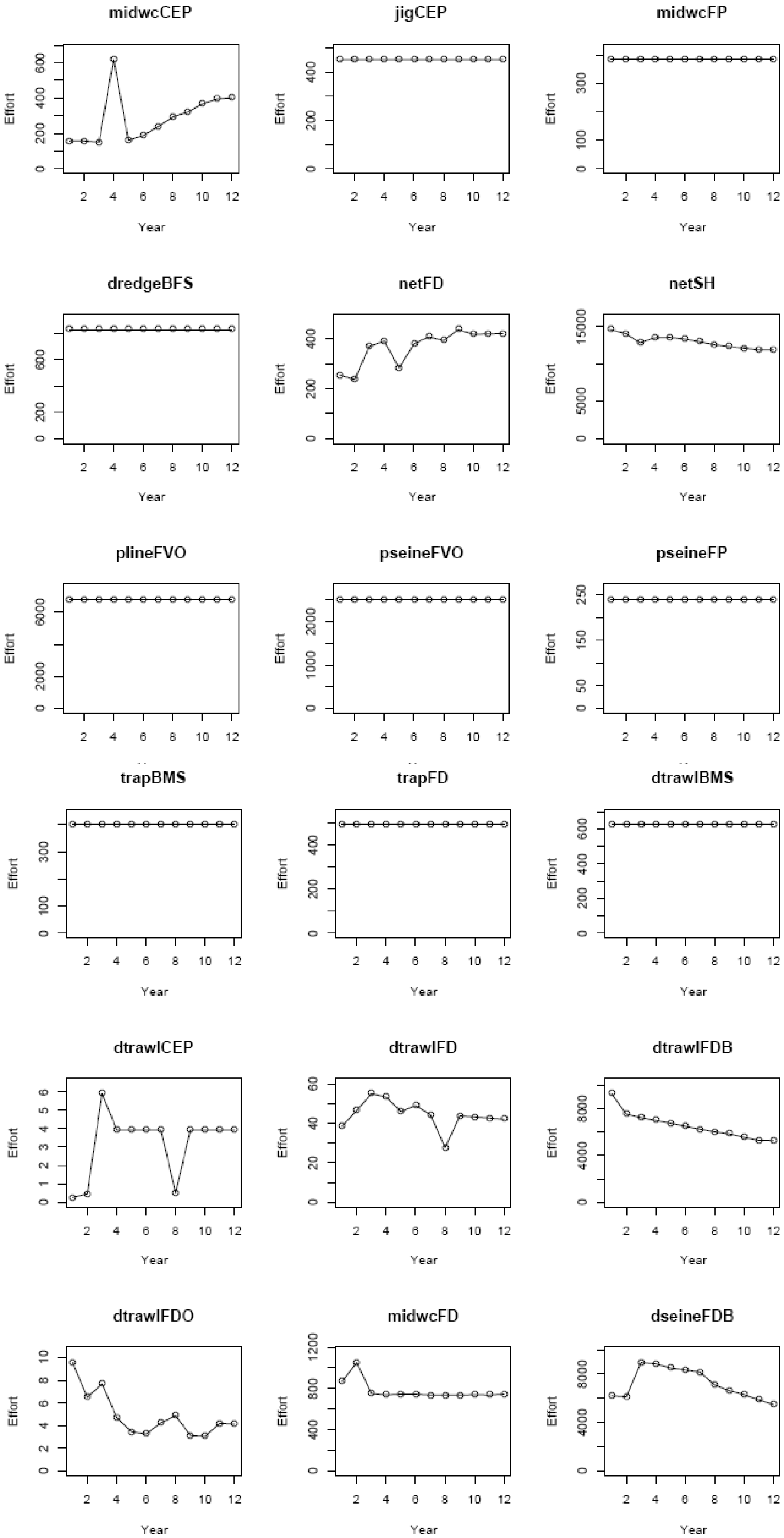
Scenario 2 - Discards per species (tonnes)



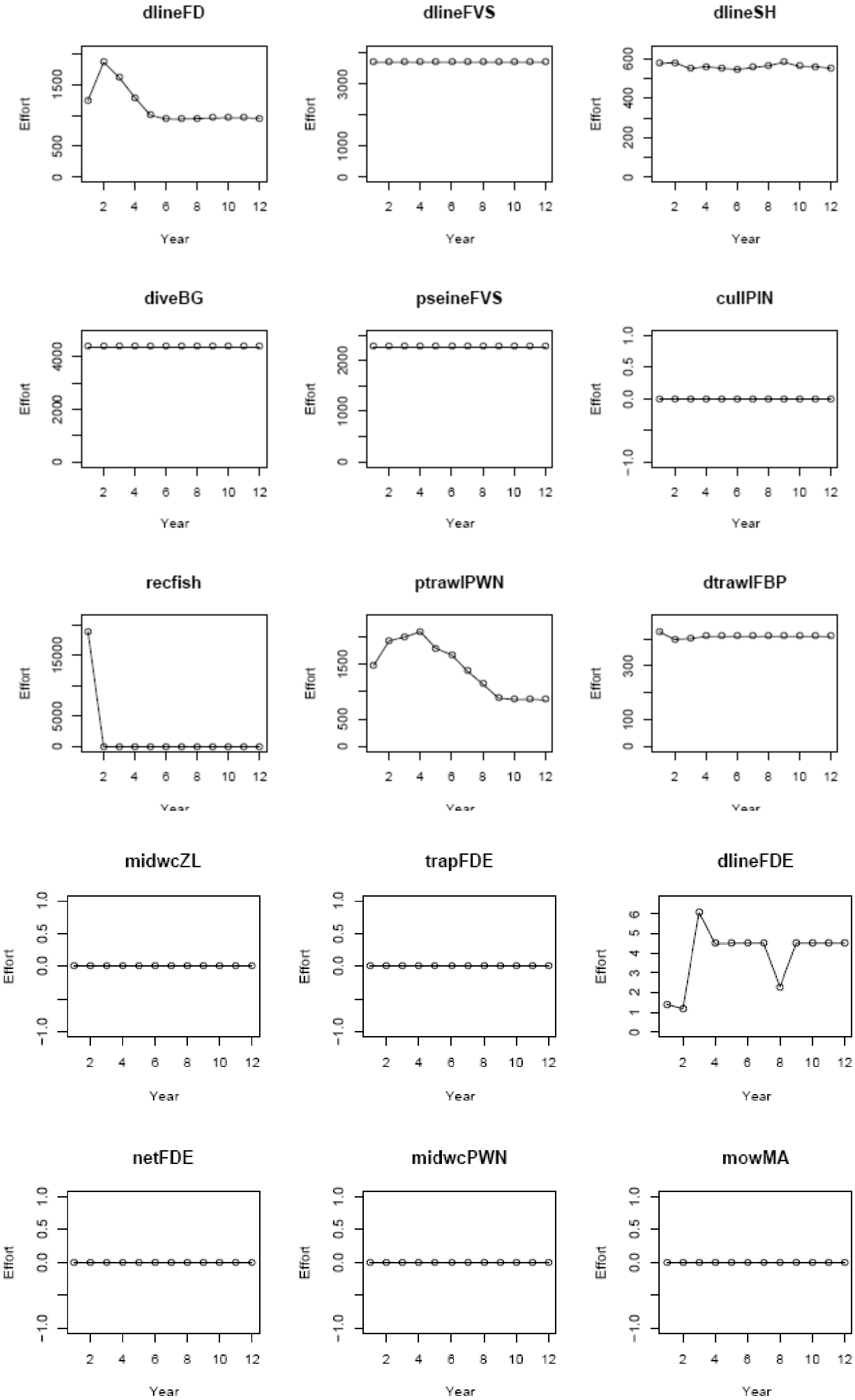
Scenario 2 - Discards per species (tonnes)(continued)



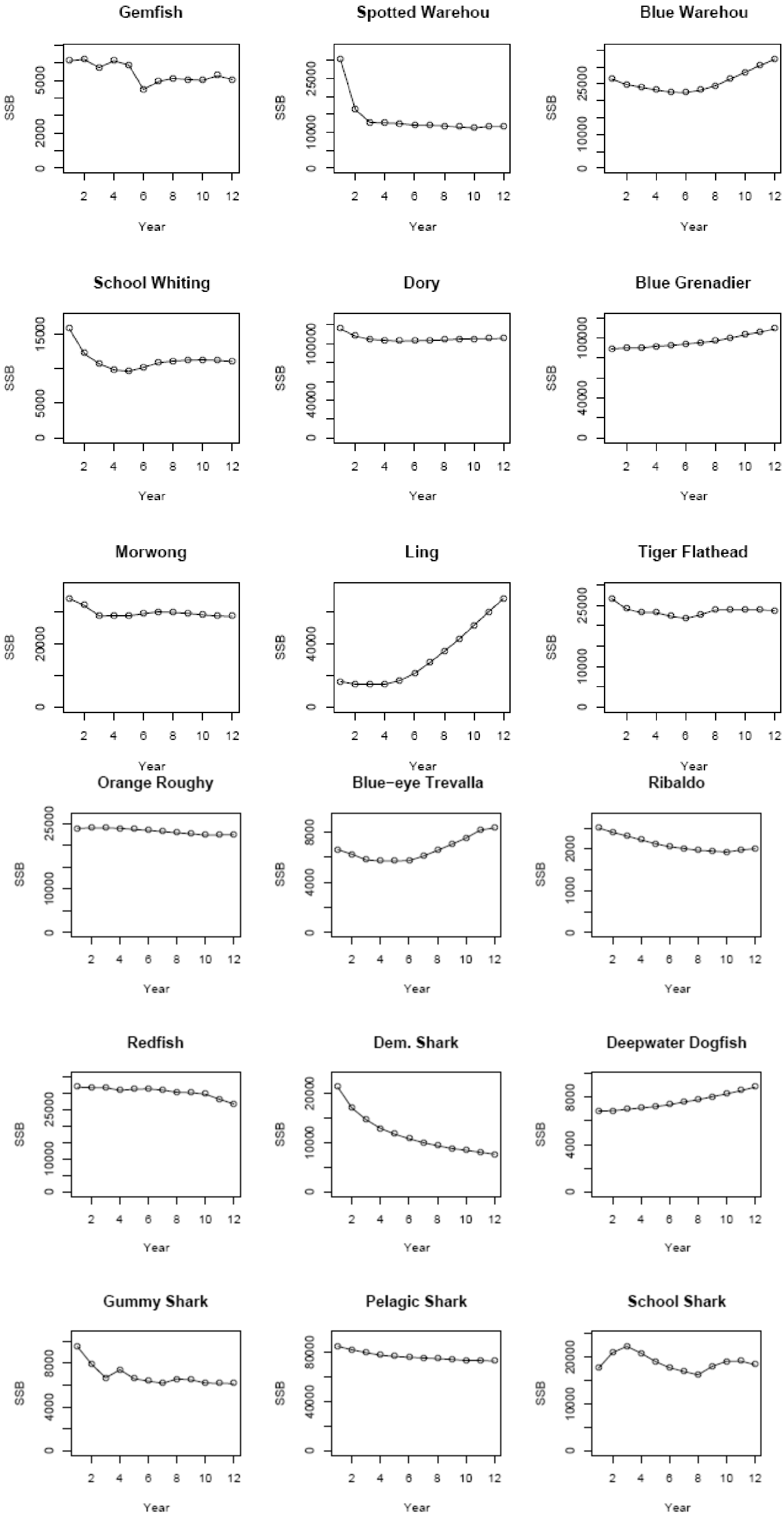
Scenario 2 – Effort per fleet (boat days)



Scenario 2 – Effort per fleet (boat days)(continued)

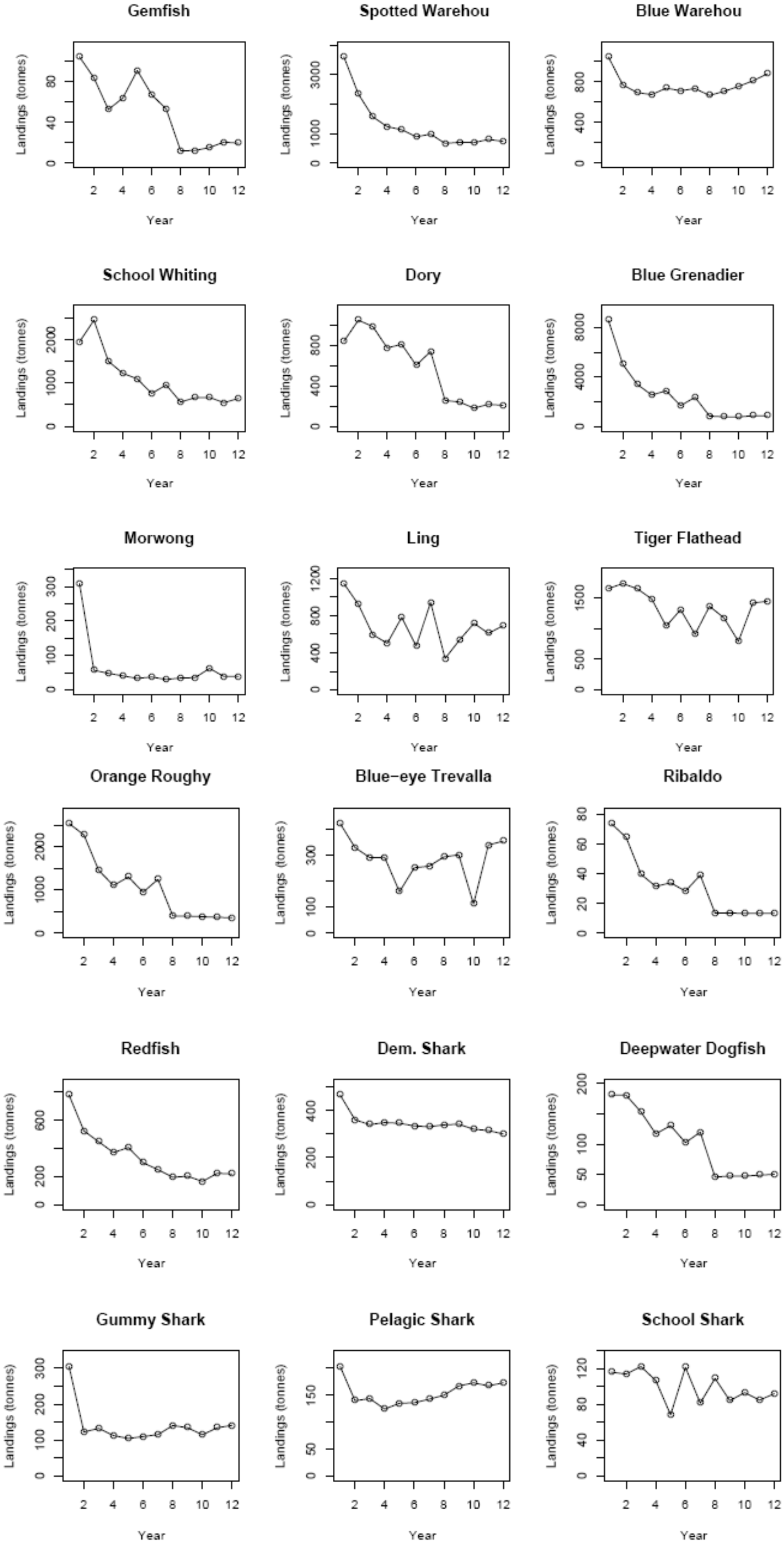


Scenario 2 – SSB: spawning stock biomass per species (tonnes)

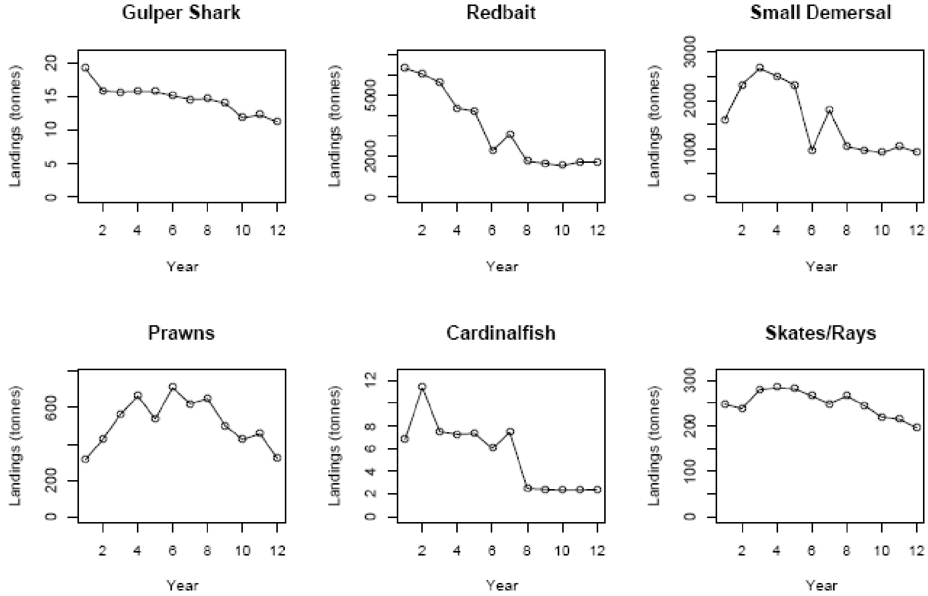


Scenario 2 – SSB: spawning stock biomass per species (tonnes)(continued)

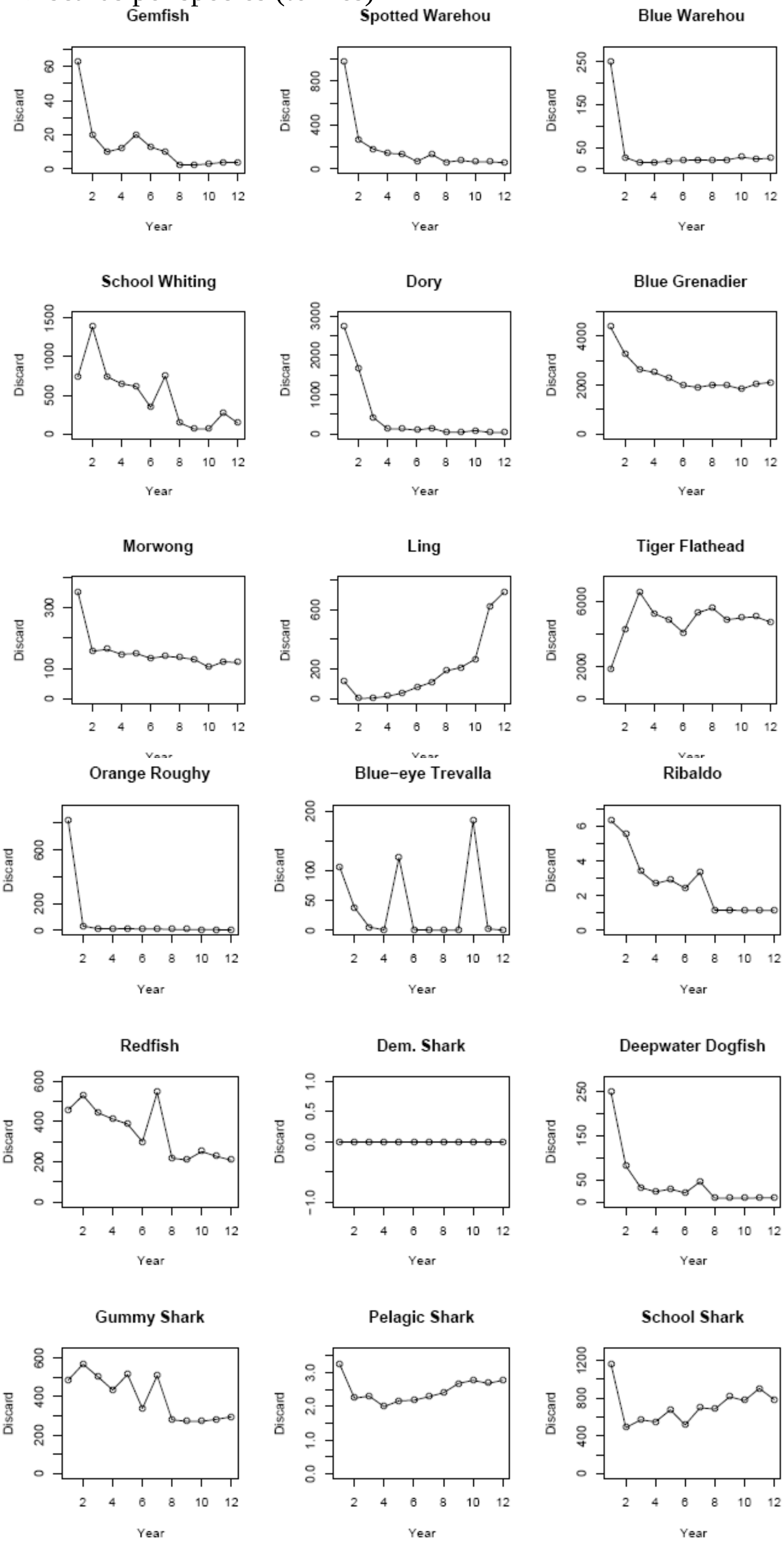
Scenario 3 - Landings per species (tonnes)



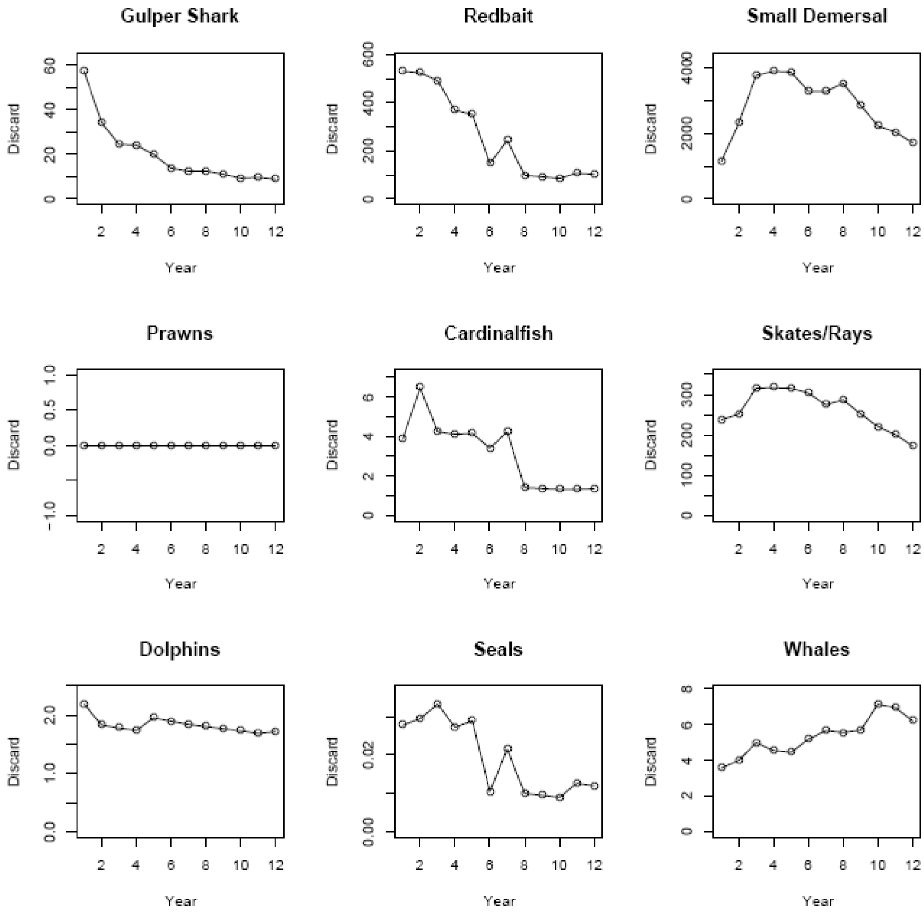
Scenario 3 - Landings per species (tonnes)(continued)



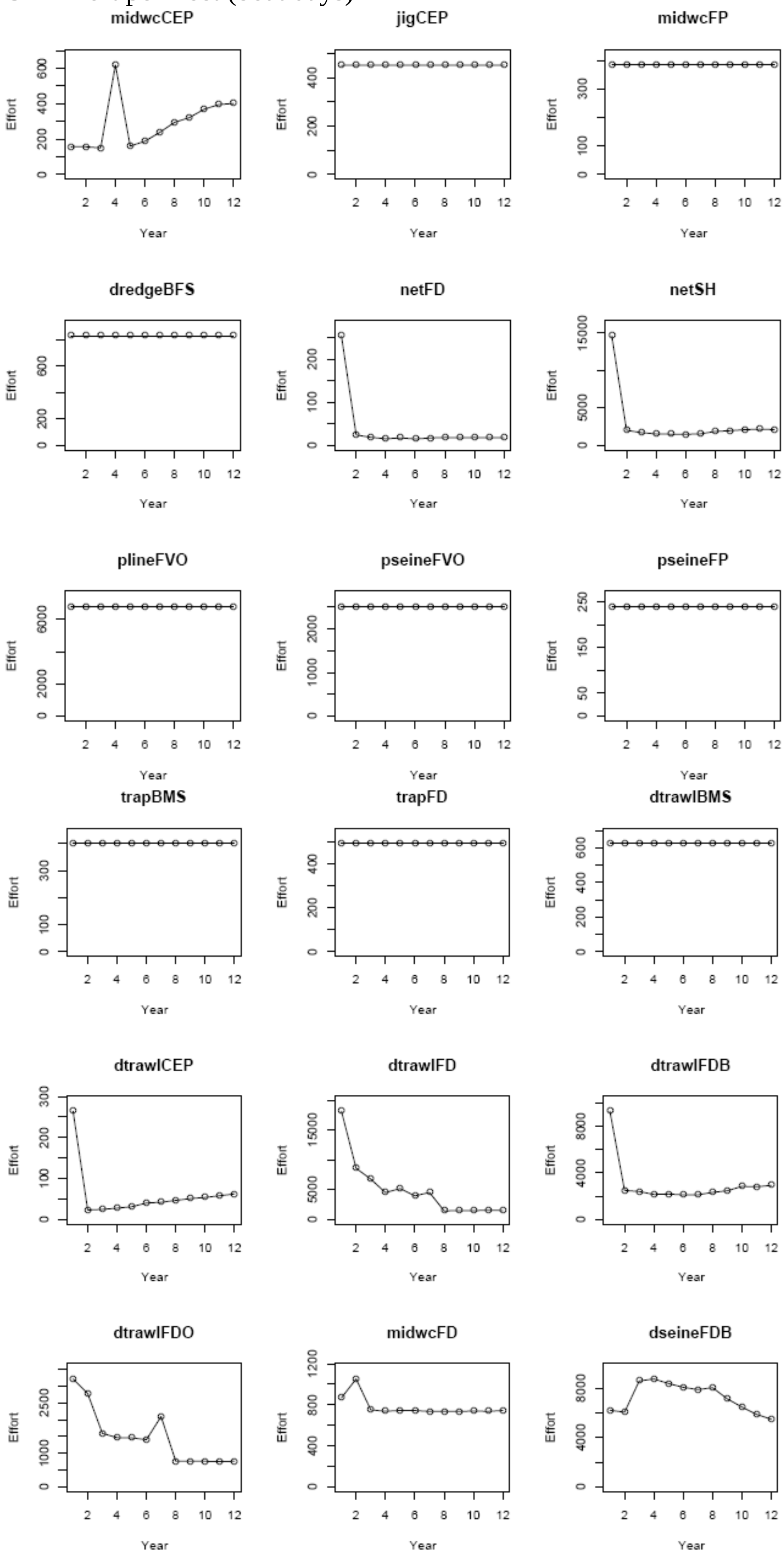
Scenario 3 - Discards per species (tonnes)



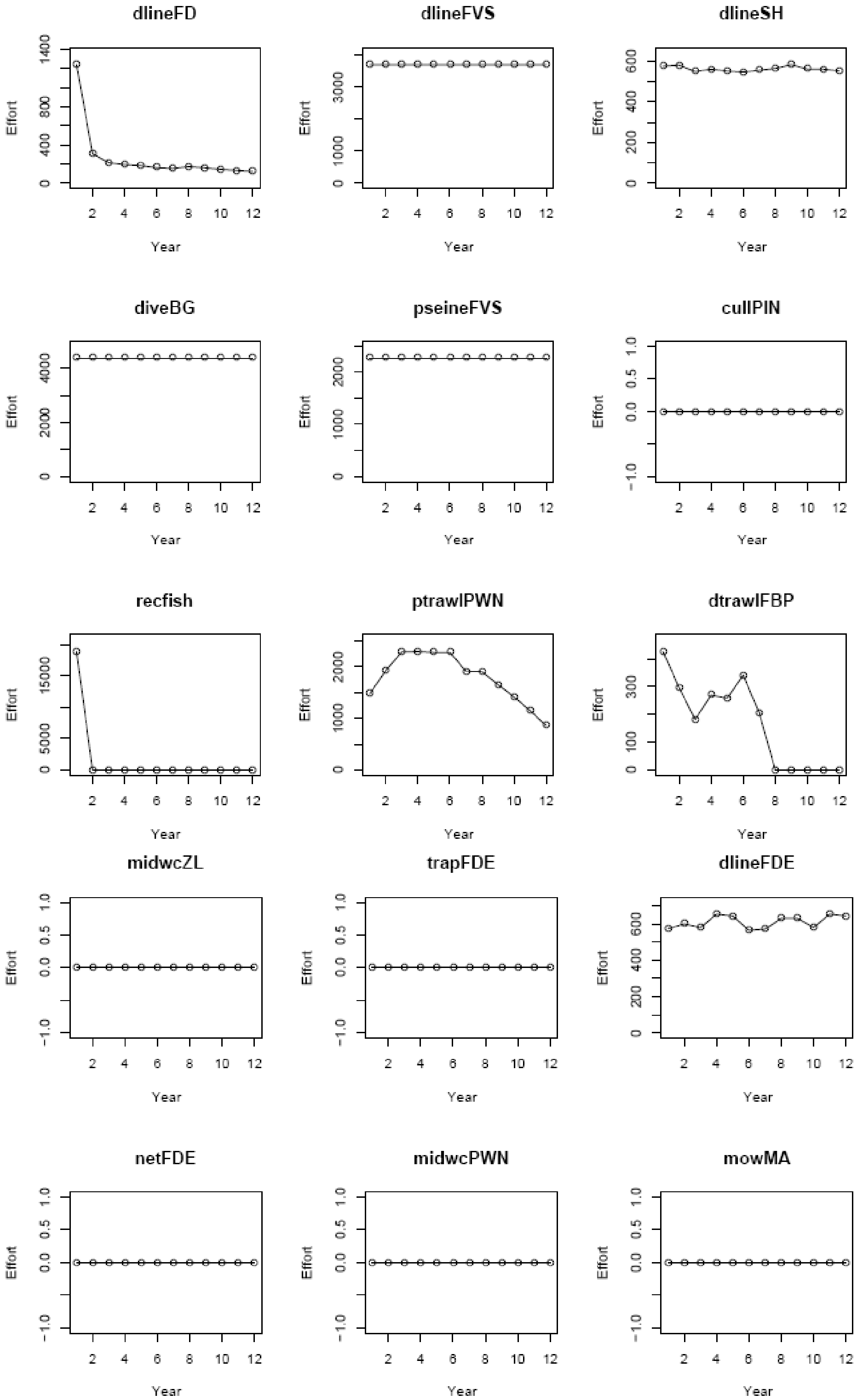
Scenario 3 - Discards per species (tonnes)(continued)



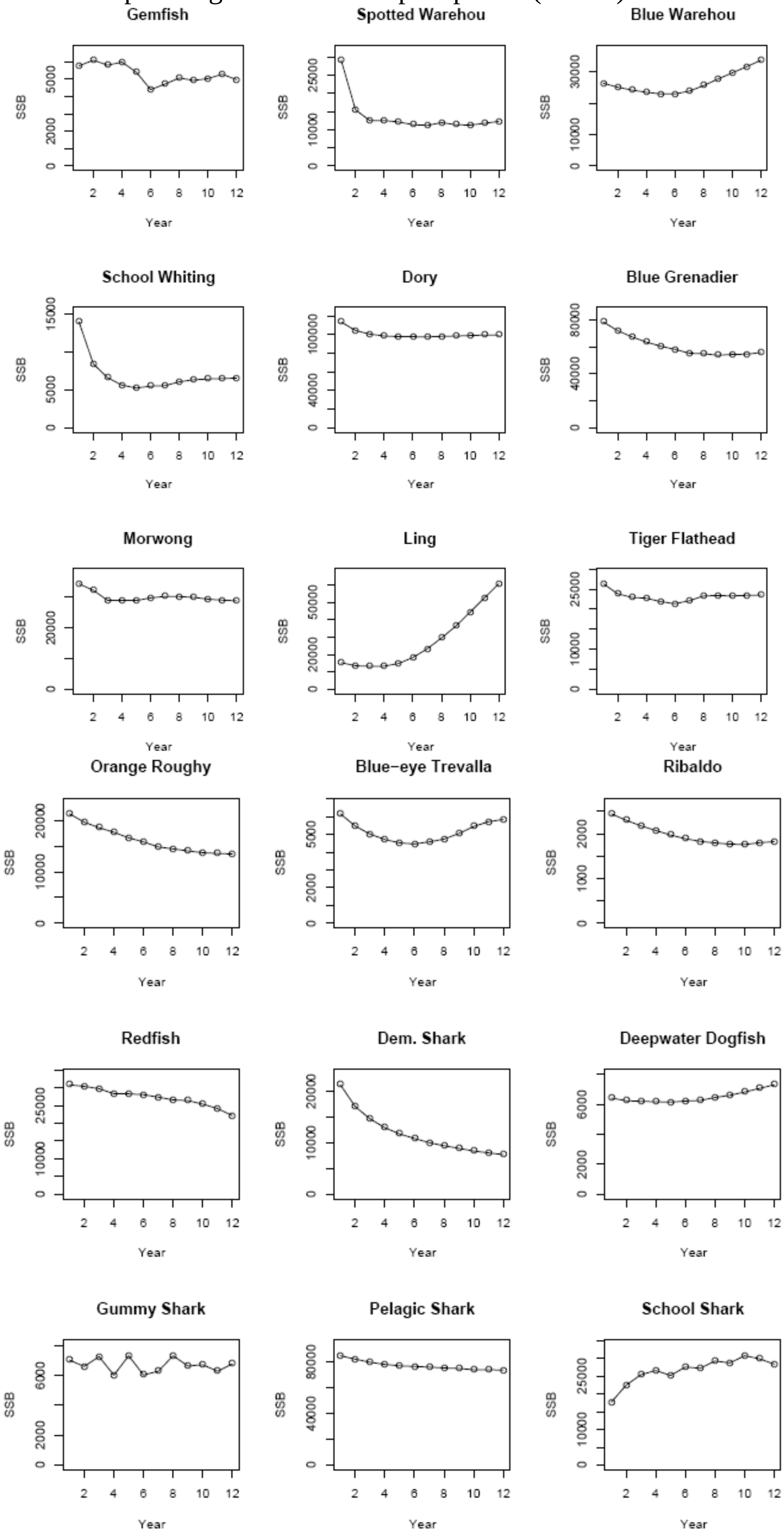
Scenario 3 – Effort per fleet (boat days)



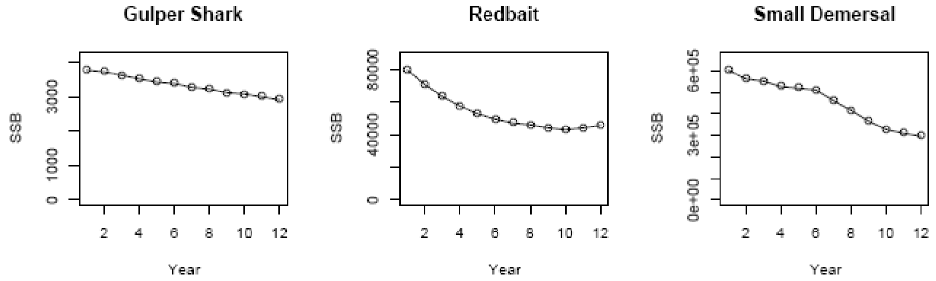
Scenario 3 – Effort per fleet (boat days)(continued)



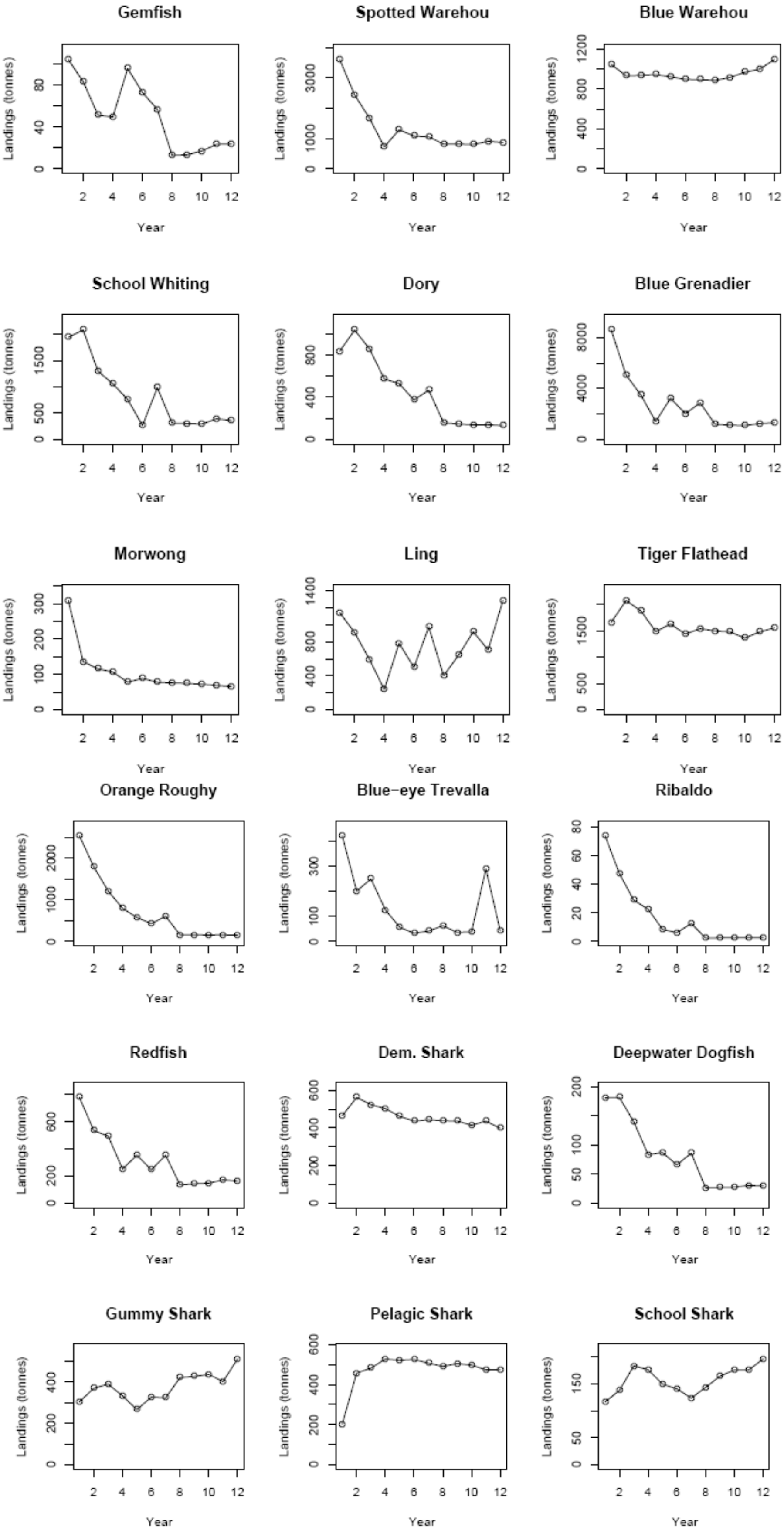
Scenario 3 – SSB: spawning stock biomass per species (tonnes)



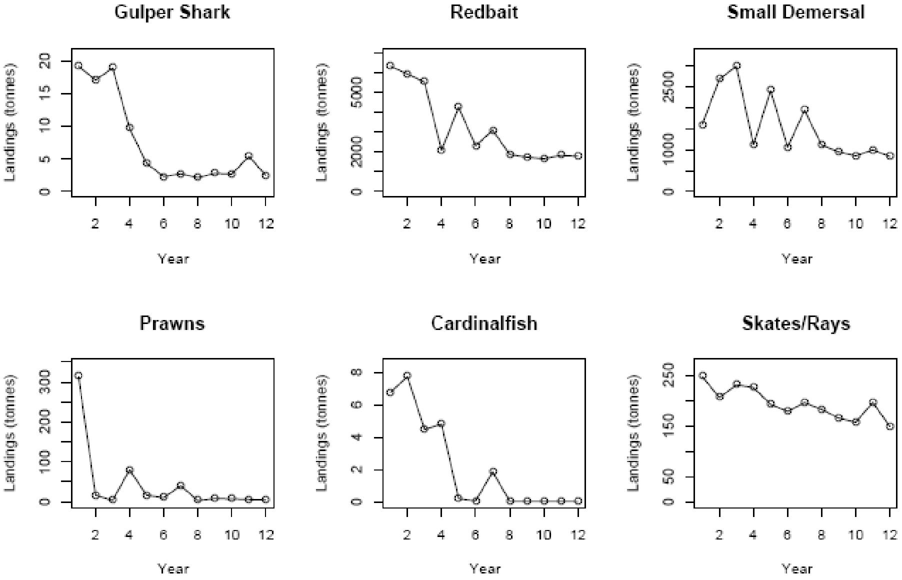
Scenario 3 – SSB: spawning stock biomass per species (tonnes)(continued)



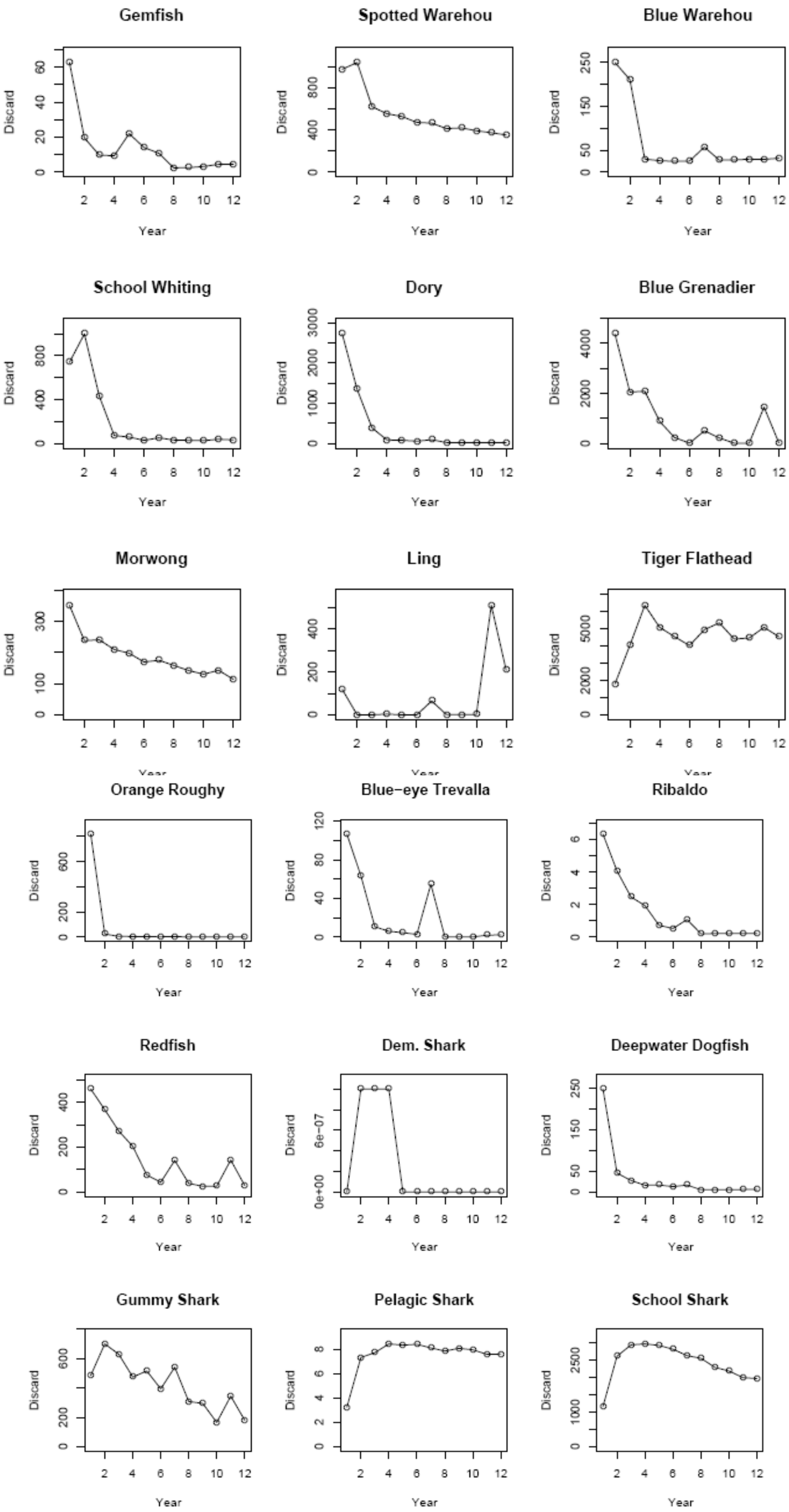
Scenario 4 - Landings per species (tonnes)



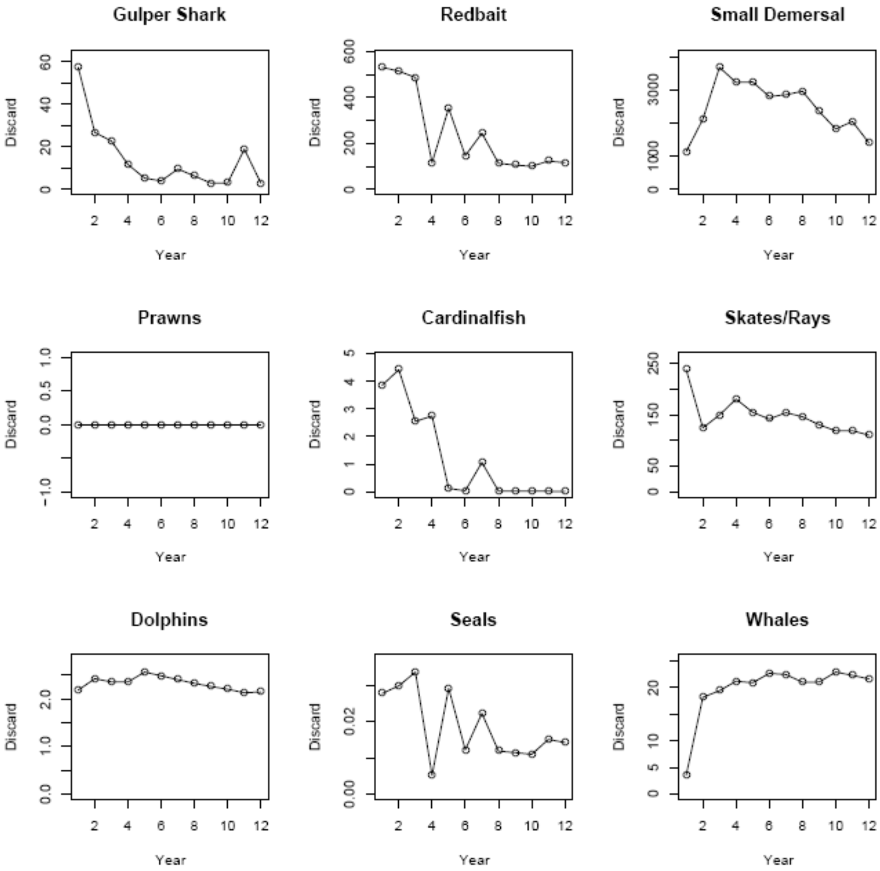
Scenario 4 - Landings per species (tonnes)(continued)



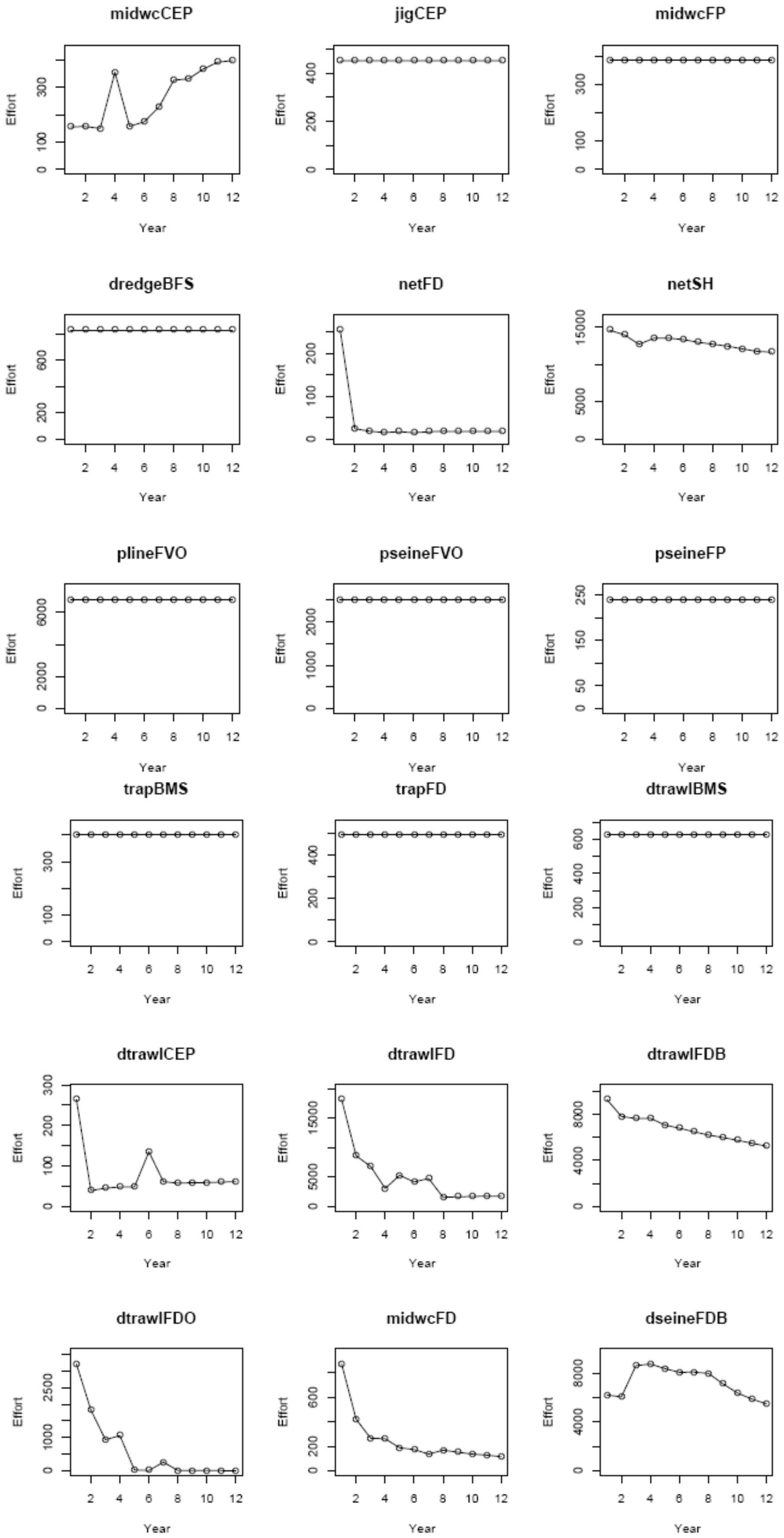
Scenario 4 - Discards per species (tonnes)



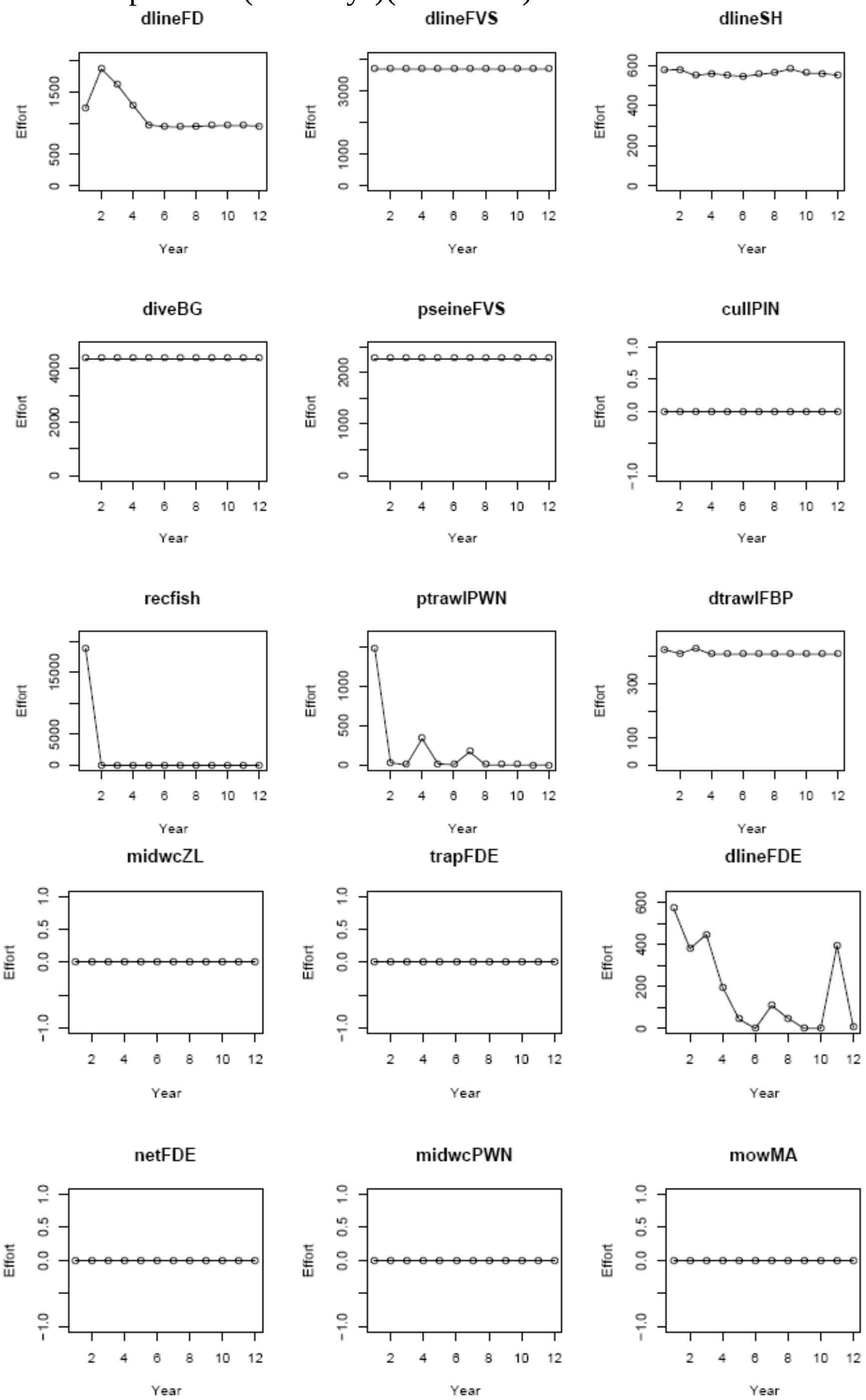
Scenario 4 - Discards per species (tonnes)(continued)



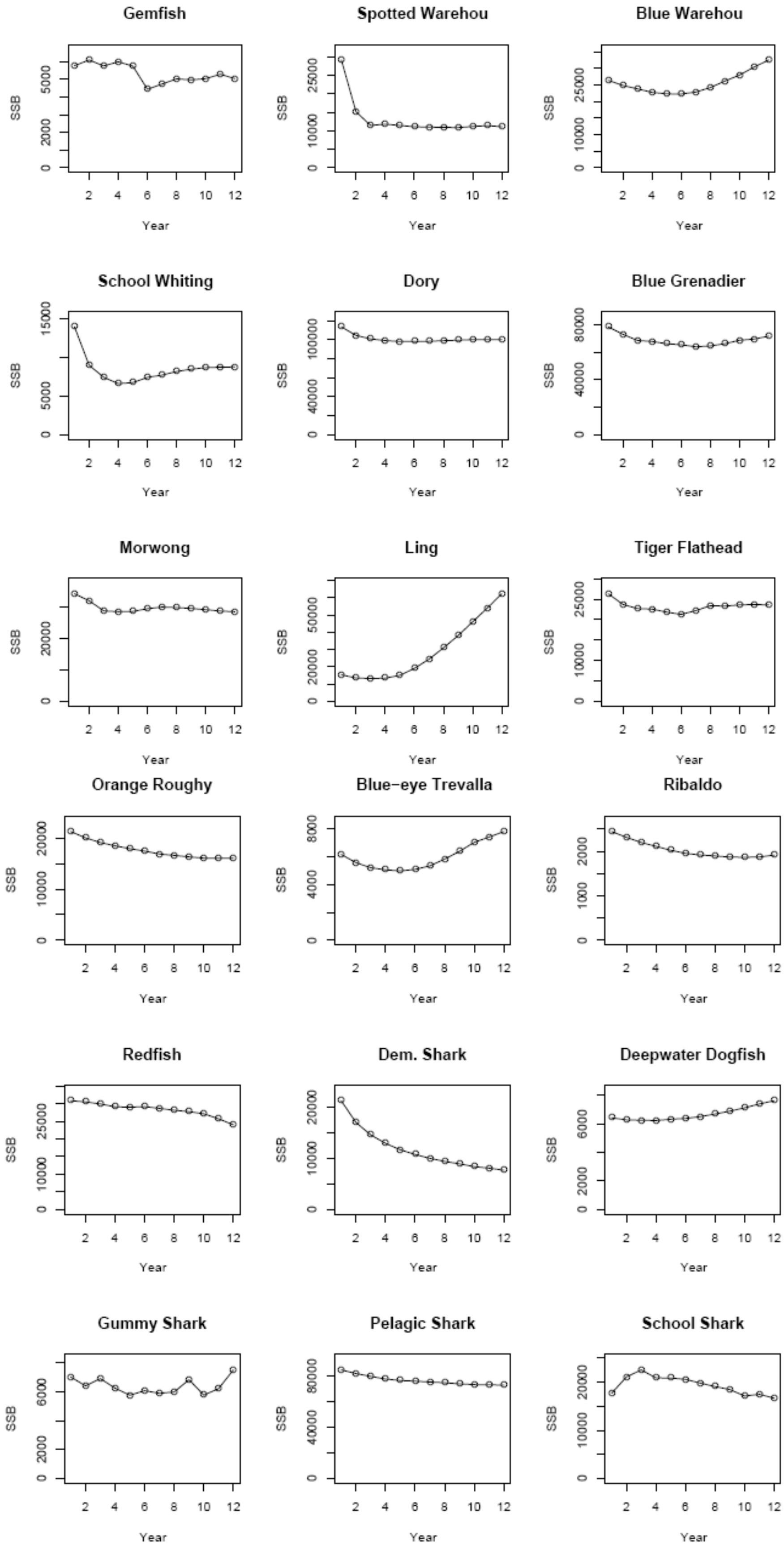
Scenario 4 – Effort per fleet (boat days)



Scenario 4 – Effort per fleet (boat days)(continued)

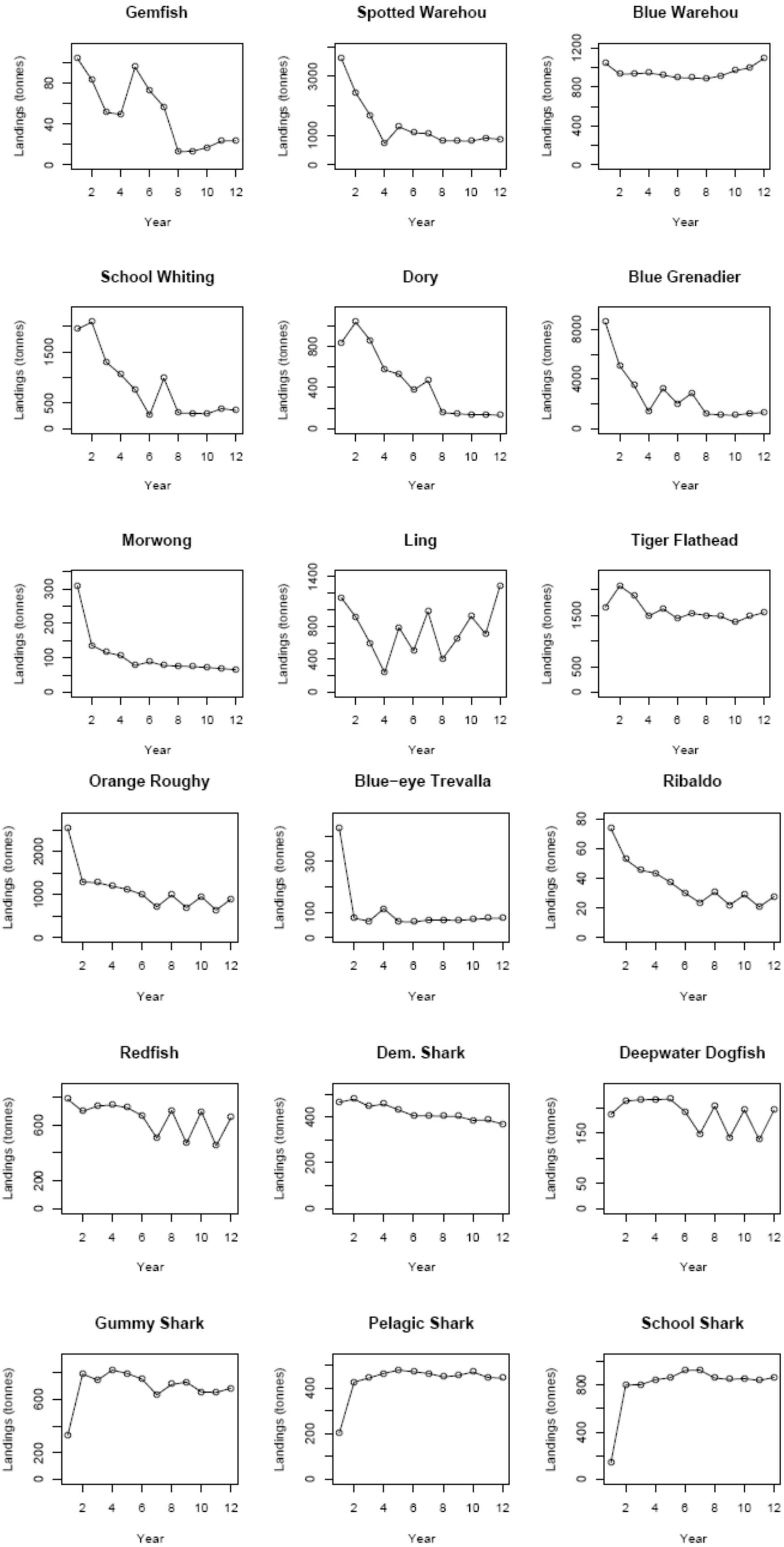


Scenario 4 – SSB: spawning stock biomass per species (tonnes)

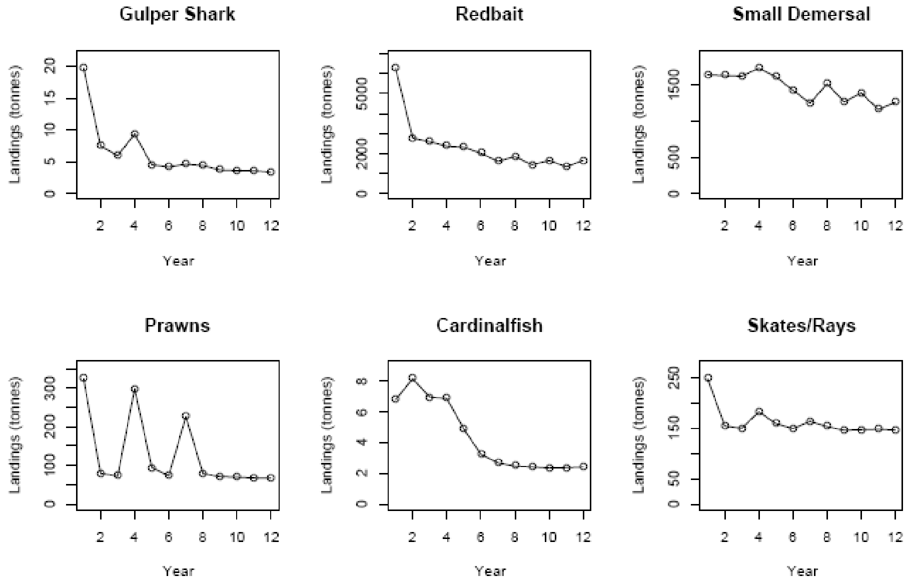


Scenario 4 – SSB: spawning stock biomass per species (tonnes)(continued)

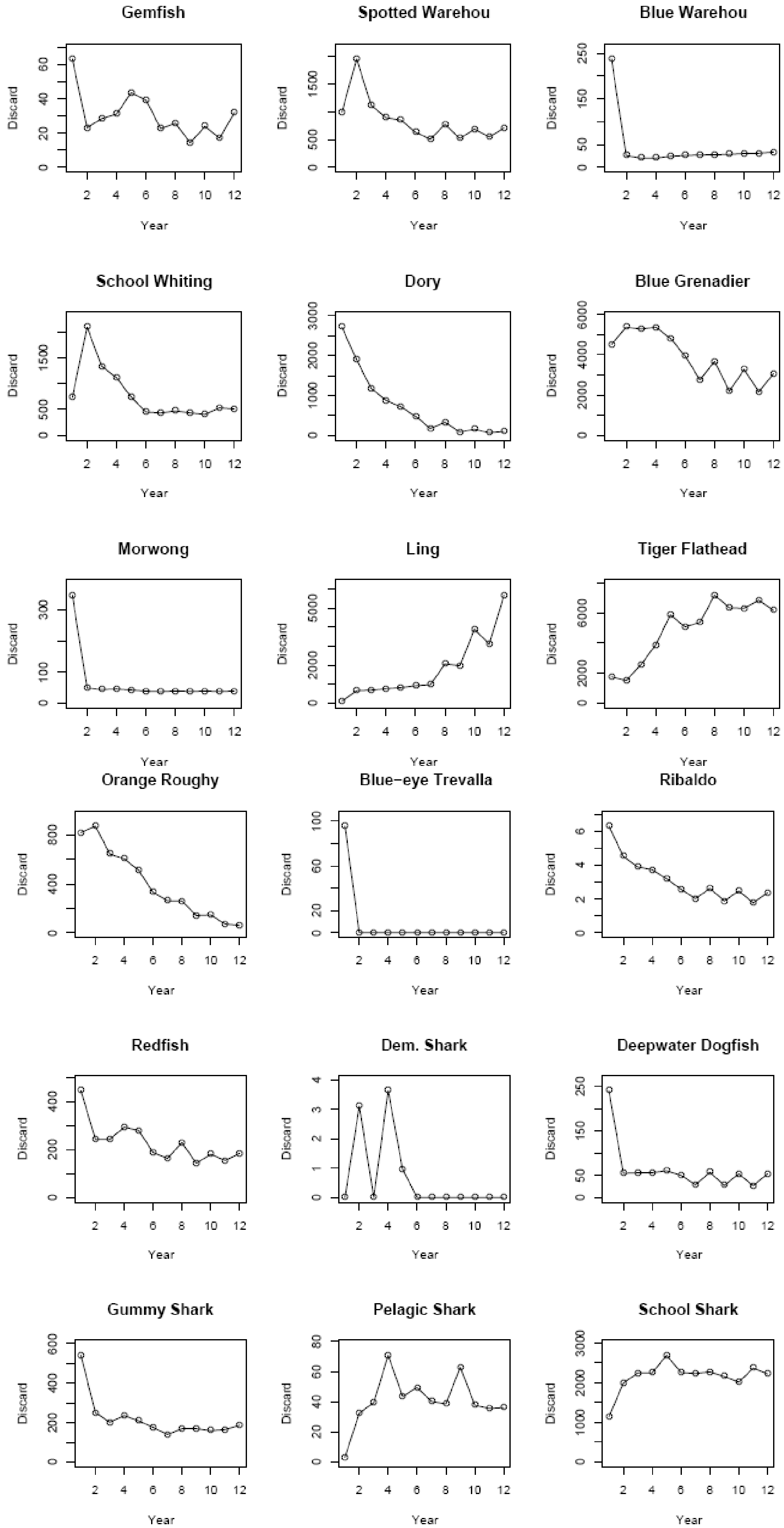
Scenario 5 - Landings per species (tonnes)



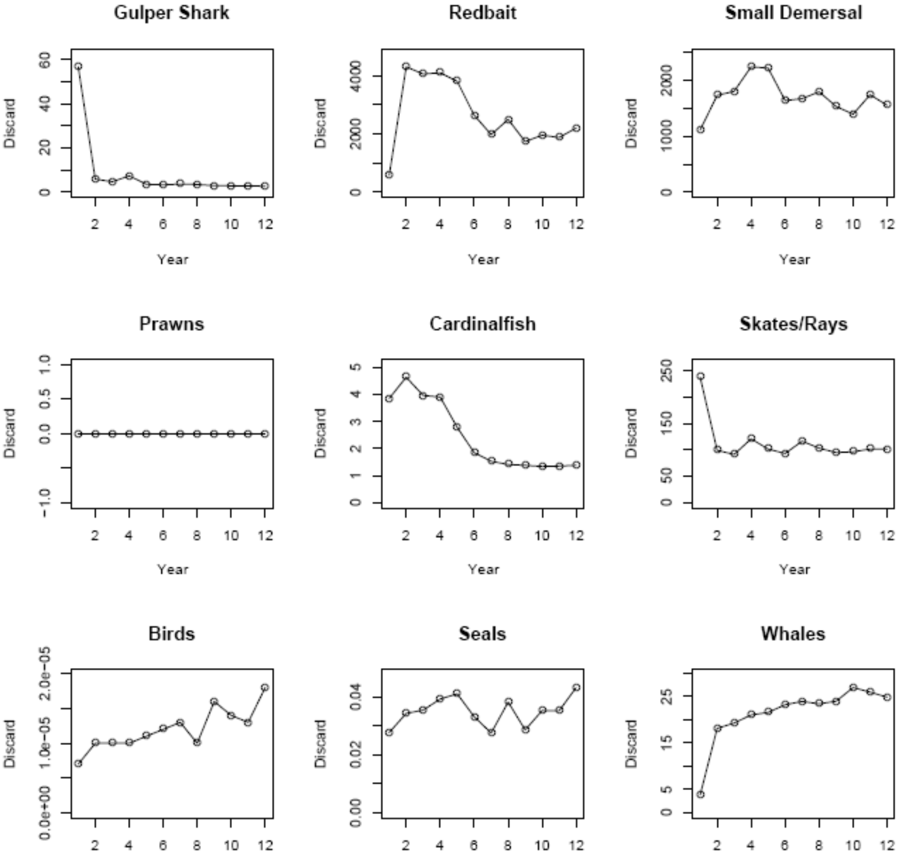
Scenario 5 - Landings per species (tonnes)(continued)



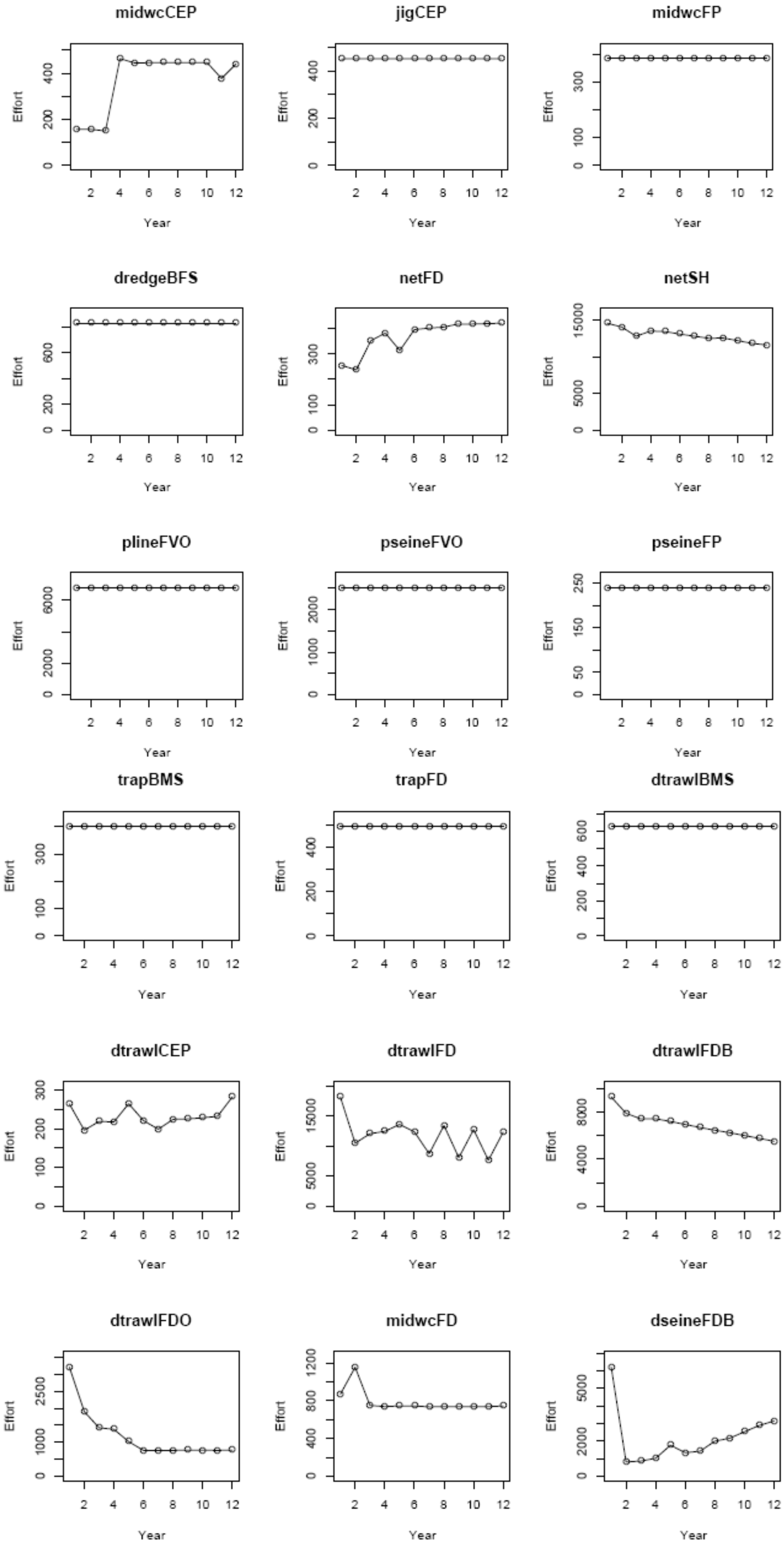
Scenario 5 - Discards per species (tonnes)



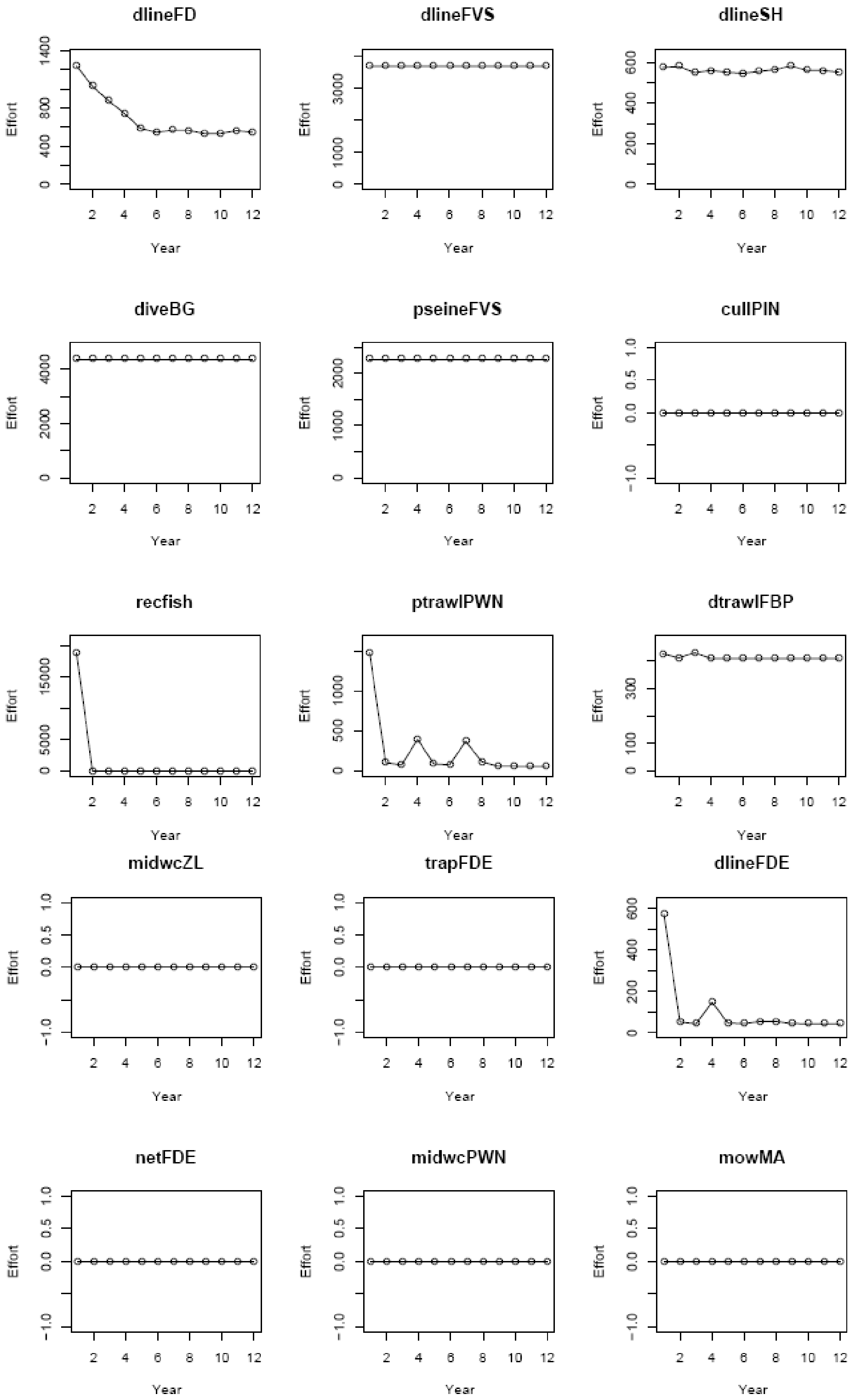
Scenario 5 - Discards per species (tonnes)(continued)



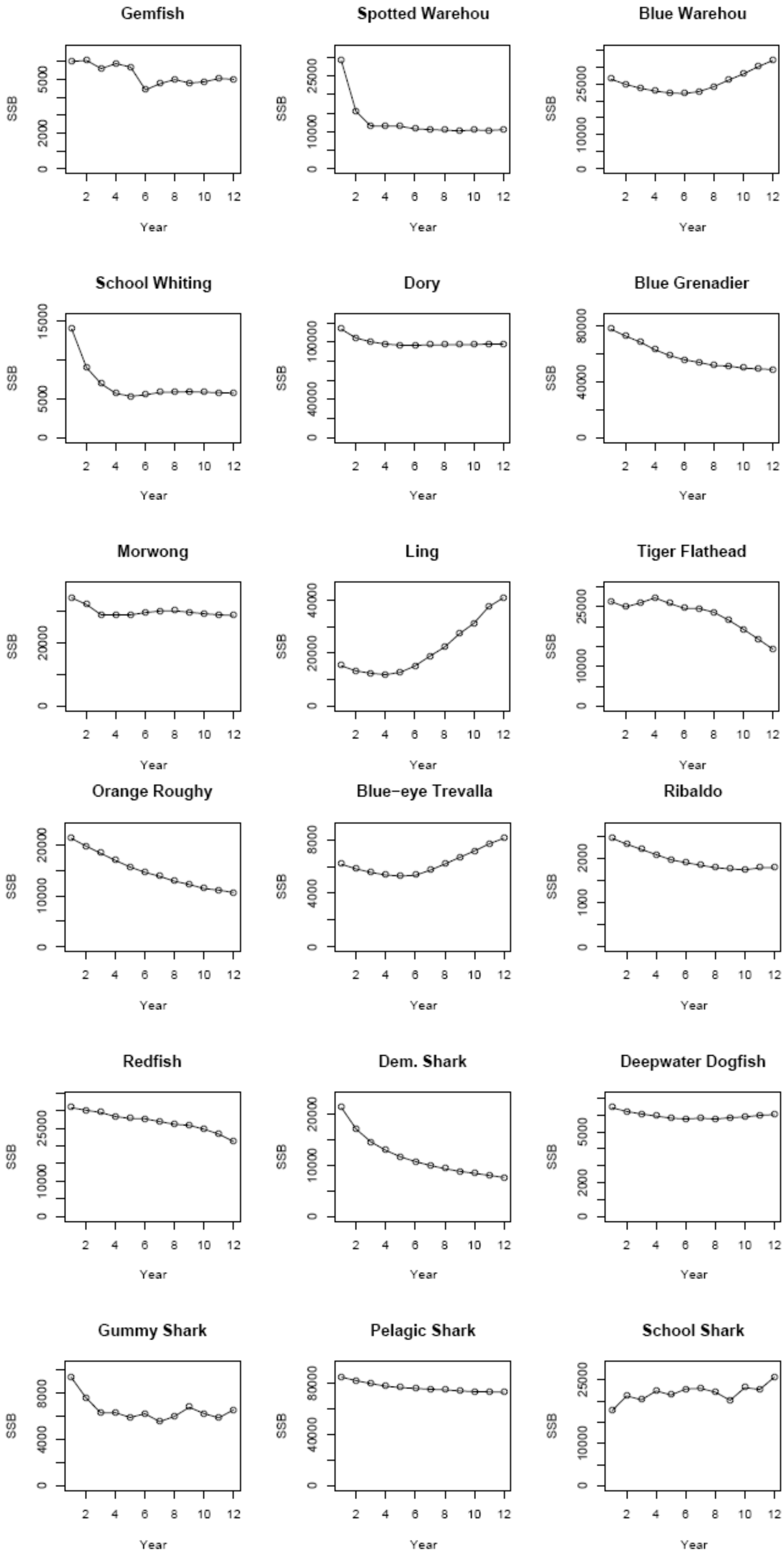
Scenario 5 – Effort per fleet (boat days)



Scenario 5 – Effort per fleet (boat days)(continued)

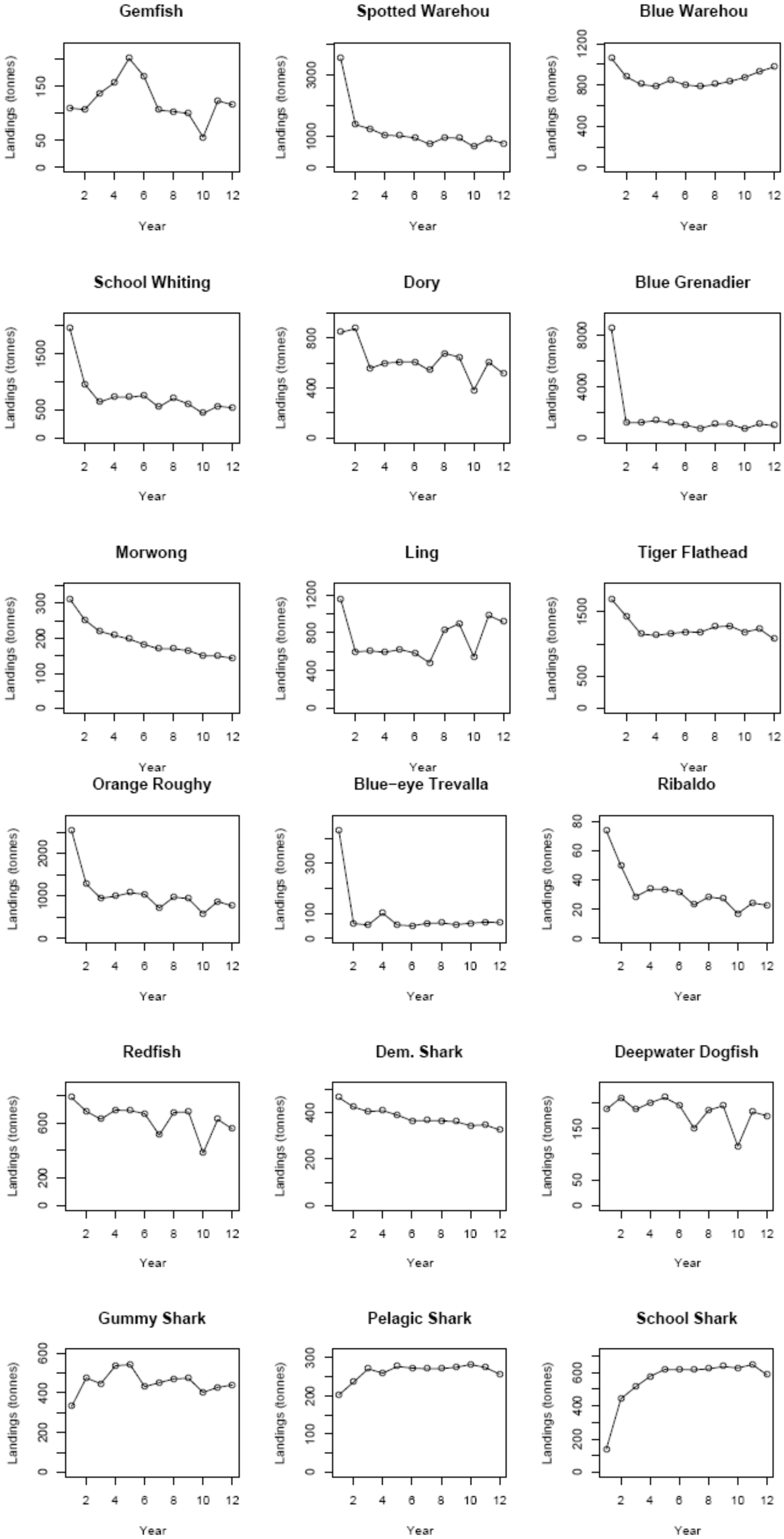


Scenario 5 – SSB: spawning stock biomass per species (tonnes)

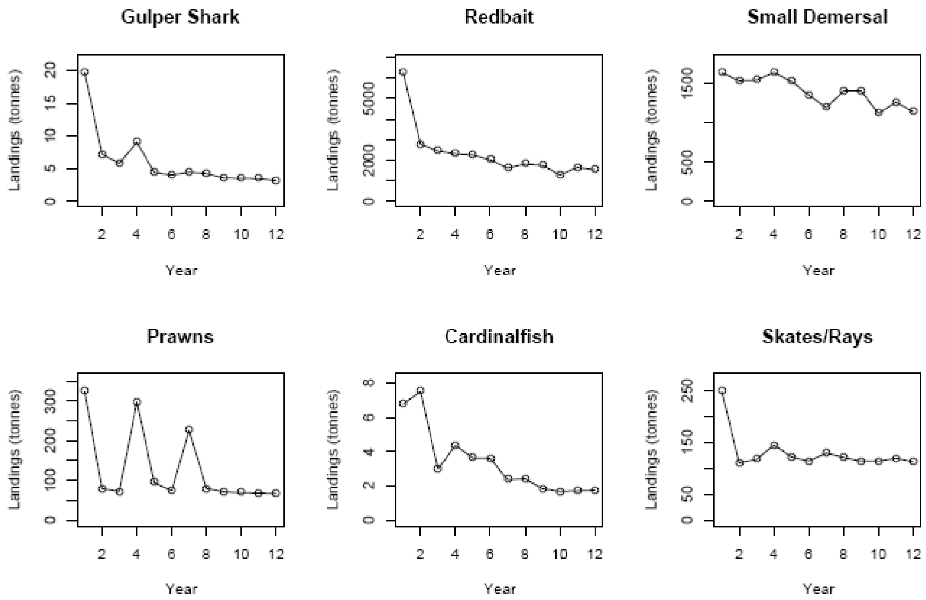


Scenario 5 – SSB: spawning stock biomass per species (tonnes)(continued)

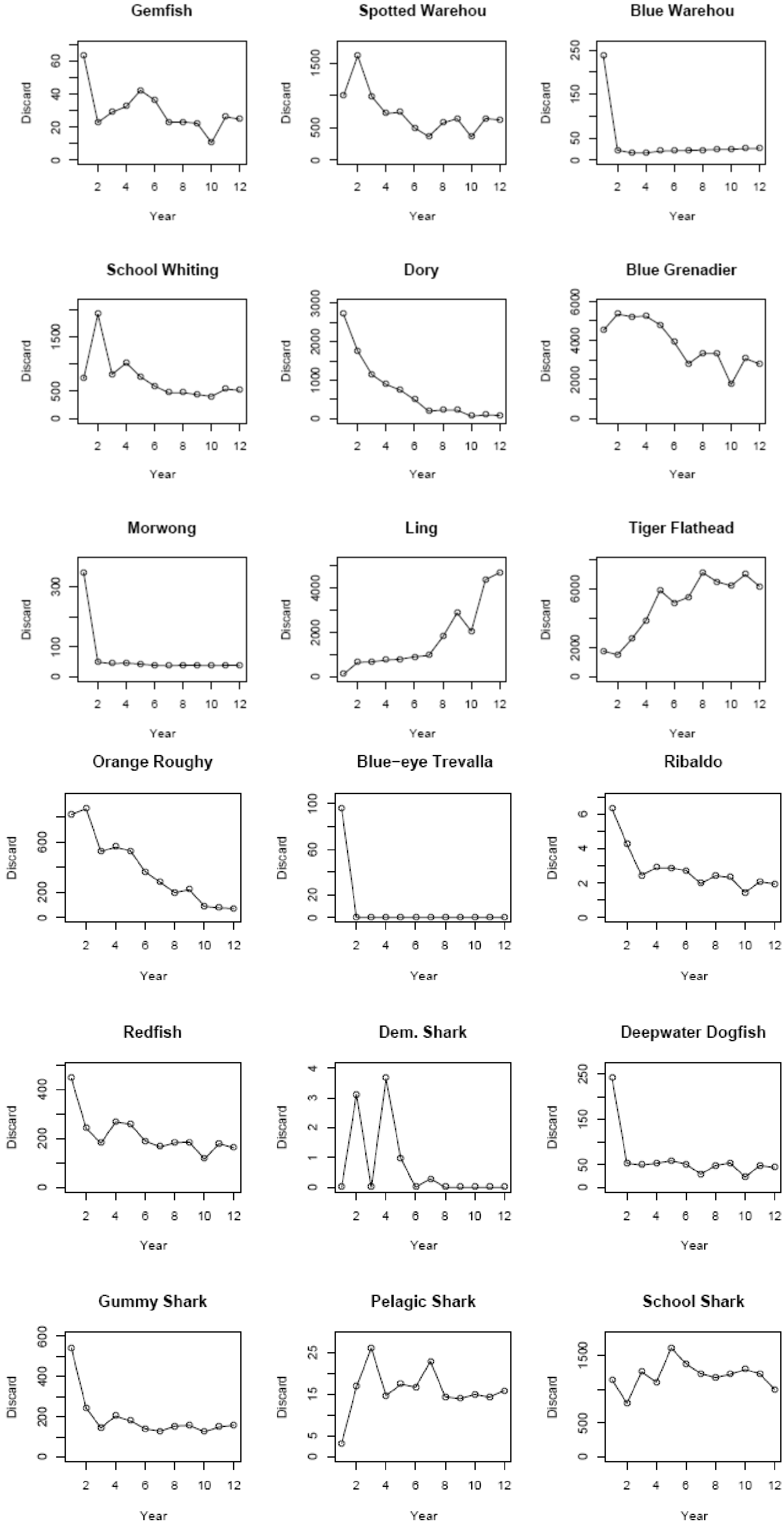
Scenario 6 - Landings per species (tonnes)



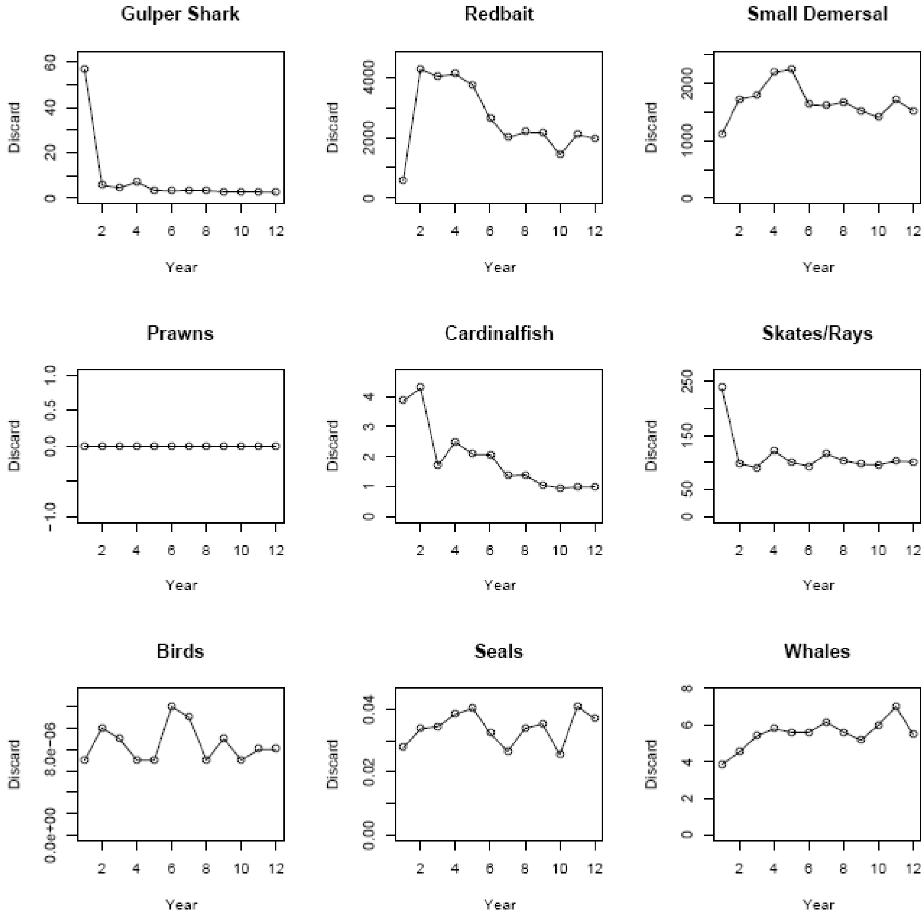
Scenario 6 - Landings per species (tonnes)(continued)



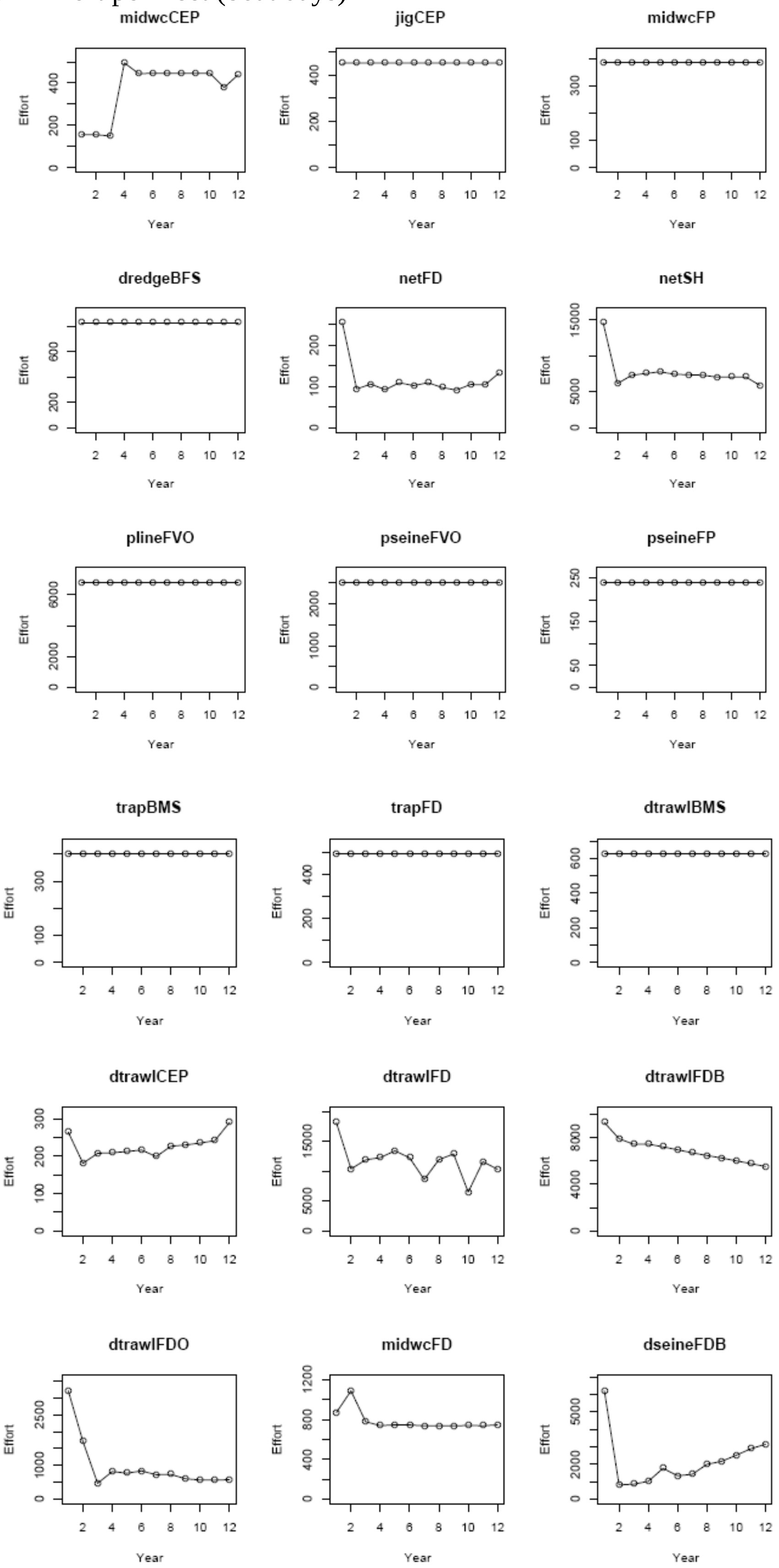
Scenario 6 - Discards per species (tonnes)



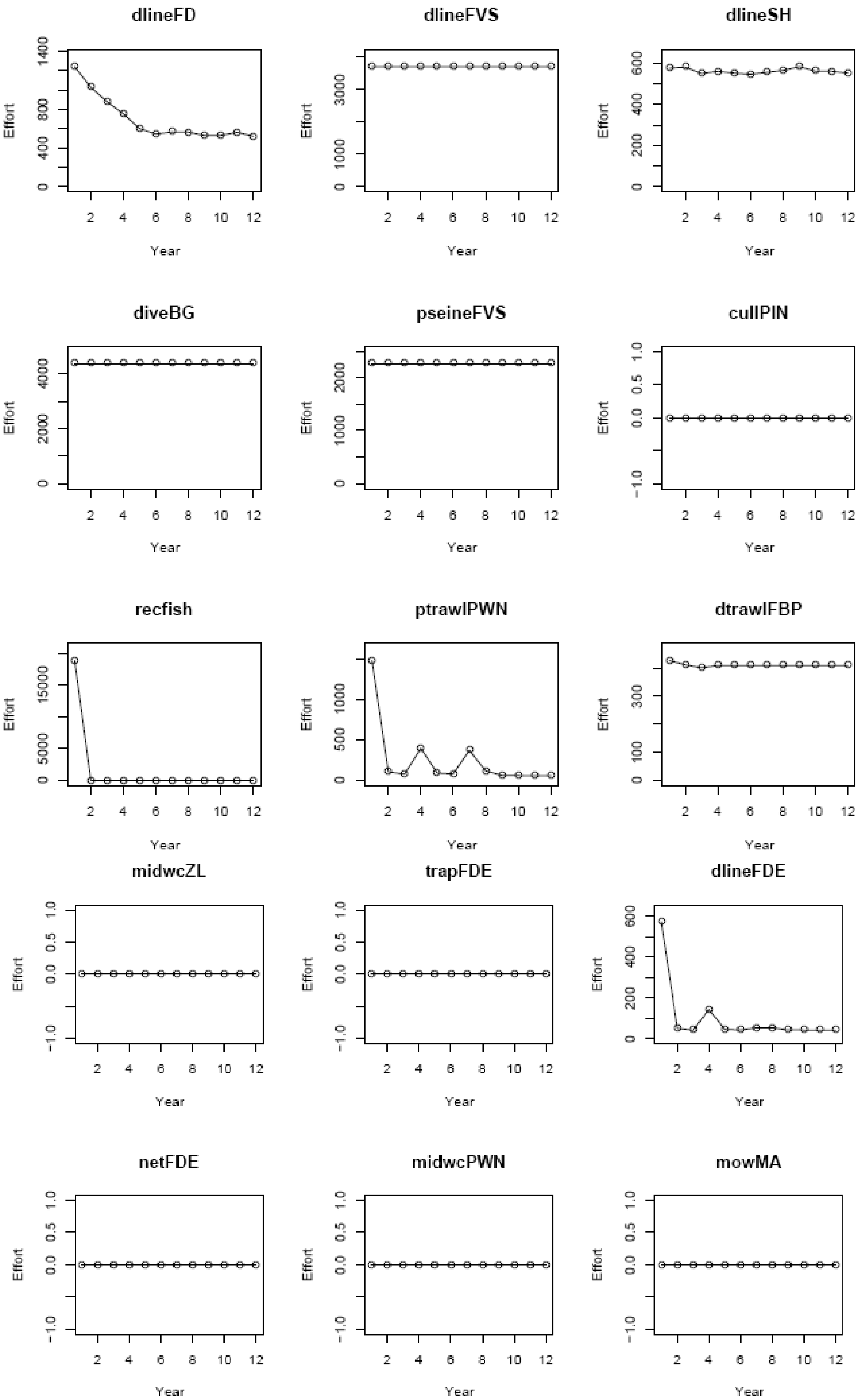
Scenario 6 - Discards per species (tonnes)(continued)



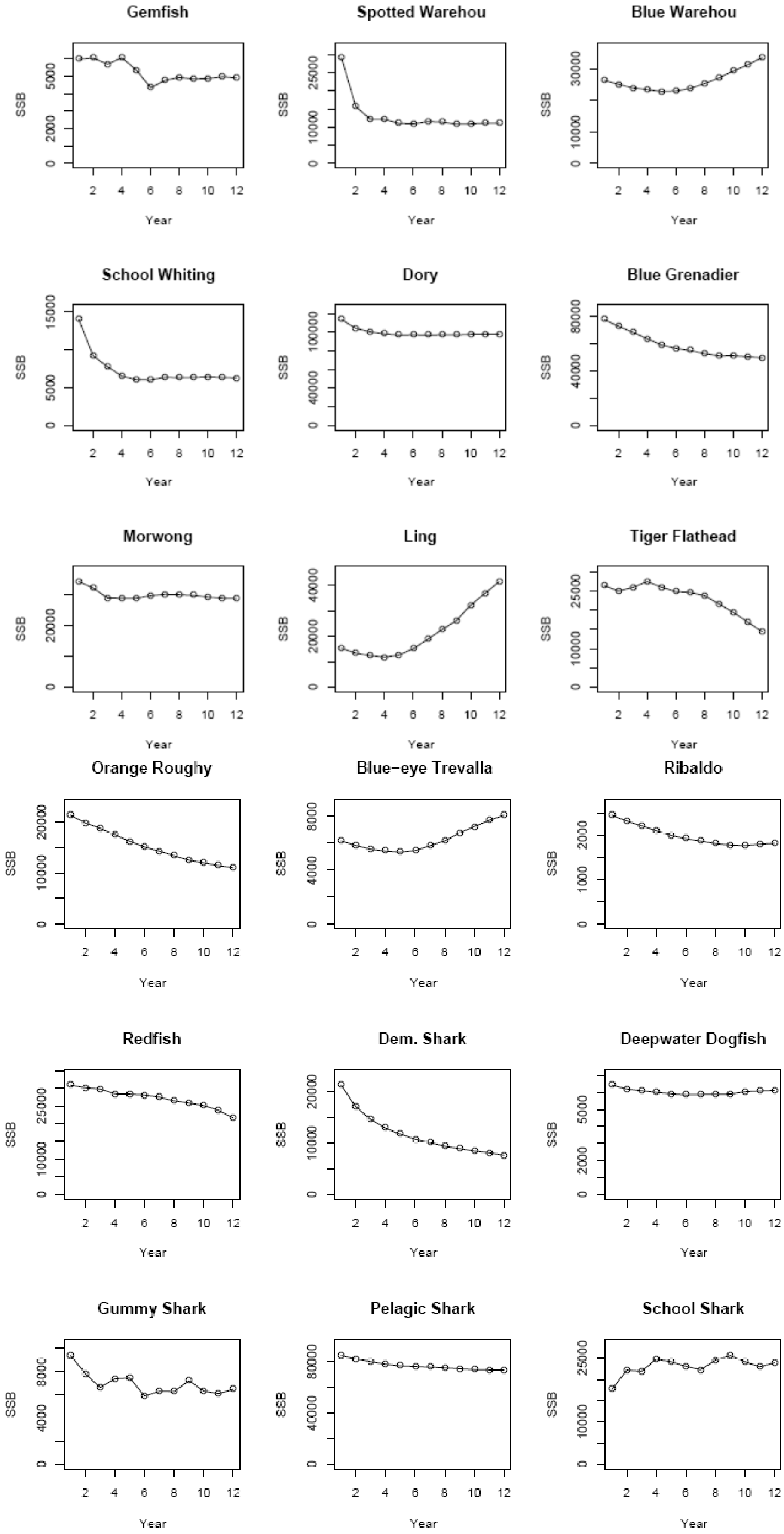
Scenario 6 – Effort per fleet (boat days)



Scenario 6 – Effort per fleet (boat days)(continued)



Scenario 6 – SSB: spawning stock biomass per species (tonnes)



Scenario 6 – SSB: spawning stock biomass per species (tonnes)(continued)