

ECOSYSTEM-WIDE IMPACTS OF ALTERNATIVE BYCATCH REDUCTION STRATEGIES: AN ECOLOGICAL-ECONOMIC ASSESSMENT OF THE AUSTRALIAN SOUTHERN AND EASTERN SCALEFISH AND SHARK FISHERY

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ABSTRACT

A concern for the consequences of bycatch and discards in fisheries has led to the implementation of new policies and fisheries management plans aimed at their reduction in many fisheries around the world. Such plans have been developed for the Australian Commonwealth fisheries (the most recent bycatch action plan extends from 2009 to 2011 for this case study). These plans list a wide variety of species, including both commercial fish and non-commercial species, particularly those listed as threatened, endangered or protected. The paper presents an analysis of the potential economic and ecological impacts of alternative approaches to the implementation of these plans, with particular emphasis on the use of economic incentives. The analysis is centered on the Australian Commonwealth Southern and Eastern Scalefish and Shark Fishery, and is based on the Atlantis simulation model developed within CSIRO. Atlantis is a spatially explicit model with sub-components that model the coupled physical transport-biogeochemical processes as elements of the ecosystem, as well as sub-models to include the fisheries, the annual assessments, and the implementation of management regulations and compliance. A feature of the Atlantis model is that it incorporates a fleet dynamics model that allows the main fleets to adjust their fishing behavior in response to incentives. Incentive-based bycatch management scenarios such as the use of deemed values within the existing trade-able quota scheme for over-quota landings, or the imposition of a tax on catches of threatened, endangered and protected species, are considered (as well as tradable bycatch quotas). The consequences of these scenarios are presented in terms of both ecological and economic impacts, with a focus on the ecosystem-wide implications of alternative regulations.

Keywords: ecological-economic modeling, bycatch and discards, fishery management, incentive-based management

INTRODUCTION

Managing multi-stock, multi-fleet fisheries in order to reduce bycatch and 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 their temporal and spatial distribution. This is especially true for trawl gear, although gillnet and longline gear are also non-selective resulting in catches of rare species. Where fisheries are regulated through output controls (i.e. total allowable catches), discrepancies will usually be observed between the catch limitations and what is landed on deck. This leads to what is termed the “catch-quota balancing” problem (Sanchirico *et al.* 2006) in quota regulated fisheries, where individual fishing operators will be confronted with a choice to land or discard fish caught in the process of fishing.

The economic incentive to land or discard any given species is generally well recognized (e.g. Anderson 1994, Arnason 1994, Pascoe 1997). 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 which are higher than the anticipated benefits, is expected to be discarded.

In this study, the potential effectiveness of incentive based bycatch management is examined using the Atlantis ecosystem model of the Australian South East fishery (Fulton *et al.* 2007). Management measures examined include deemed values (to allow over-quota landings and reduce discarding), bycatch quotas, and bycatch taxes.

THE ATLANTIS MODEL OF 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 Australia's Exclusive Economic Zone (Figure 1 – left panel). 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 SESSF lands about 21 934 tonnes of fish which in 2007/08 was worth about AUD\$87 million (Morison *et al.* 2009). The fishery has both trawl and non-trawl sectors (6 principle sectors that overlap in the stocks exploited and areas fished with the main sector being the Commonwealth Trawl Sector). Discarding in the SESSF occurs for a range of reasons, including lack of quota, high-grading, damage to fish, and weak markets for the landings of some species leading to low market prices (Liggins and Knuckey 1999, Ellison *et al.* 2005). The mismatch between actual catches and quota holdings has also contributed to an increase in discarding since the introduction of ITQs in the trawl sector in 1989 (Baelde 2001).

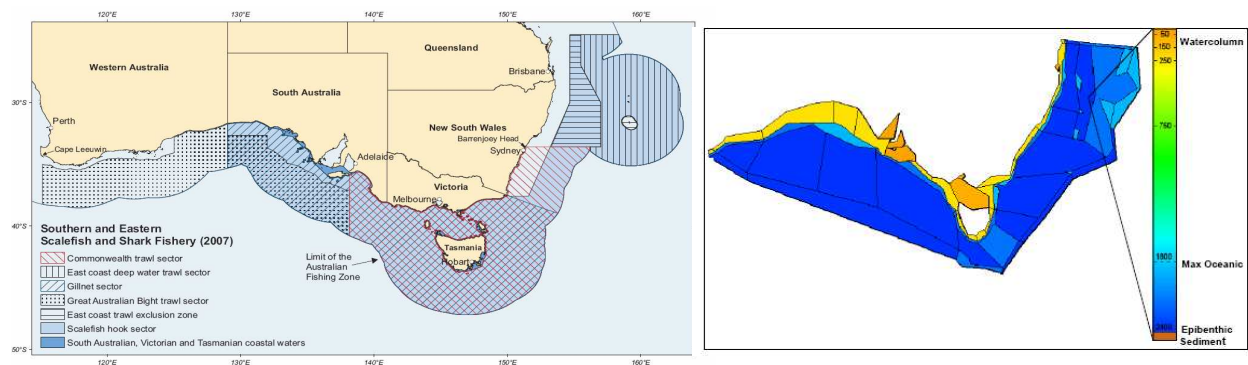


Figure 1 - The area of the Southern and Eastern Scalefish and Shark Fishery (source AFMA Fishery Status Reports 2007, AFMA (2007))(left panel) and map of model domain covering same area (right panel)(source Fulton *et al.* 2007).

Atlantis is a spatially explicit ecosystem model that includes representation of ecological processes, fisheries, annual assessments and the implementation of management regulations (Fulton *et al.* 2004, 2005, 2007). 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 study the geography of the region is represented by 71 polygonal boxes (Figure 1 – right panel). The biological groups included are functional groups (that is, 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).

The primary ecological processes in the model are consumption, production, waste production and cycling, migration, predation, recruitment, habitat dependency, and mortality (Fulton *et al.* 2007). The model includes 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). Based on targeting and gear use, all fisheries (including State fisheries) were grouped into fleets (depending on gear and catch profiles, that is, main target species).

The main fleet components, for which a dynamic effort response was developed in SESSF Atlantis and the target and bycatch species included in the model are given in Table 1.¹ The commercial species of most concern are underlined, while iconic species such as seabirds, seals and whales are shown in *italics*.

Table 1 - Main fleets in the model and their main target stocks and bycatch stocks (the species codes used in figures are listed, in parentheses).

Fleet	Target stocks	Bycatch stocks
Demersal fish trawl (dtrawlFD)	Ling (FDC), Morwong (FPO), Cardinalfish (FVD), <u>Gemfish (FVV)</u> , Whiting (FVO), dory/oreo/whiptail (FDD), Grenadier (FDE), Redfish (FDM), Ribaldo (FDP), Tiger flathead (FDB), Orange Roughy (FDO), Trevalla (FDF), <u>School shark (SHR)</u> , Skates and rays (SSK), Blue warehou (SP), <u>Gulper shark (REP)</u>	Mackerel (FPL), Redbait (FBP), Gummy shark (SHB), demersal sharks (SHD), dogfish (SHC), <i>seals (PIN)</i> , <i>baleen whales (WHB)</i> , squid (CEP)
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> , <i>seals</i>
Demersal cephalopod trawl (dtrawlCEP)	Squid	Cardinalfish, <u>Gemfish</u> , Whiting, Redbait, dory/oreo/whiptail, Tiger flathead, Ling, Trevalla, Gummy shark, Skates and rays, squid, <i>seals</i> , <i>baleen whales</i>
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> , <i>seals</i> , <i>sea-lions</i> , <i>orca</i>
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, <i>seabirds</i> , <i>seals</i> , <i>baleen whales</i>
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, <i>seabirds</i> , <i>baleen whales</i>
Demersal line for sharks (dlineSH)	Gummy shark, demersal sharks, Dogfish, Pelagic shark	<u>School sharks</u> , <u>Gulper sharks</u> , <i>seabirds</i>
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> , <i>seabirds</i>
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> , <i>seabirds</i> , <i>sea-lions</i> , <i>seals</i> , <i>baleen whales</i> , <i>dolphins</i> , <i>orca</i>
Shark gillnet (netSH)	Gummy shark, demersal sharks, Spotted warehou (FVB)	Pelagic sharks, School sharks, Skates and rays, Blue warehou, <u>Gulper shark</u> , <i>sea-lions</i> , <i>baleen whales</i> , <i>dolphins</i> , <i>orca</i>

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 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.

Economic incentives measures

A review of potential incentive based bycatch options has been recently undertaken by Pascoe *et al* (2010). Based on this review, three types of economic instruments aimed at reducing discards were identified as having potential applicability to the fishery: implementation of tradable individual bycatch quotas, introduction of taxes on catches of selected species, and application of deemed-value payments on over quota landings of commercial species.

Bycatch quotas

Quotas are applied to bycatch species (megafauna and rare species). In terms of seeking to lease or purchase in new quota, the quota trading equations specified in Fulton *et al* (2007) are used with modifications such that a sub-fleet is only interested in looking to trade quota if its cumulative catch to a given date is greater than a trigger proportion of the quota (target and/or bycatch) in hand. Similarly a sub-fleet is only willing to trade out if it has a large excess that it does not expect to fill either as catch or bycatch. If a sub-fleet 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). In terms of scheduled effort, the expected spatial distribution of discards is also taken into account by the model, in that 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 (see effort re-distribution functional relationships in Fulton *et al*. 2007).

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 sub-fleet j in month m of year y ; $p_{s,j,m}$ is the sale price of species group s for that sub-fleet in that month; $E_{h,i,j,m}$ is the historical effort expended in that month in box i by the sub-fleet; $H_{e,s,i,j,m}$ is the expected harvest of the group in box i in that month by that sub-fleet (based on updating past catches per month); $p_{tax,s,j,m}$ is the bycatch tax for species group s for the sub-fleet 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 sub-fleet; and $C_{E,i,j,m,y-1}$ is the total variable costs for that sub-fleet of fishing in box i in that month.

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:

$$\hat{p}_{deem,s,i,m} = p_{s,m} \cdot \kappa_{deem} \text{ (when } H_{s,i} > Q_{s,i} \text{)}$$

where $H_{s,i}$ is the landed catch of species s by sub-fleet i and $Q_{s,i}$ is the corresponding quota. κ_{deem} is the proportion of the price the government has set as the deemed value. The final deemed value payments made by sub-fleets 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 $H_{s,i} > Q_{s,i}$.

Scenarios

In this paper, we present a sub-set of the simulation results obtained, for a selection of approaches to the use of economic instruments to reduce bycatch and discards. Bycatch quotas and taxes were applied to species such as seals as they are listed in the Bycatch and Discard Workplan (AFMA 2009) as high risk (Table 2). Deemed values were applied to over-quota catches for stocks such as Tiger Flathead, Morwong, and School Whiting (Table 2), essentially key species for which the TAC is restrictive.

Table 2 - 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	Tax (megafauna)	Tax on whales, dolphins and seals	\$0/kg	Whales (\$1/kg; Dolphins \$5/kg an seals \$1/kg)
3	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

RESULTS

Overall model distribution of catches across a range of stocks relates well to the observed distribution and most importantly captures the relative differential retention rates across species (Figure 2). In total tonnage, the largest landings are taken by the main demersal trawl fleets (e.g. dtrawlFD) and include catches of species such as Blue Grenadier. 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).

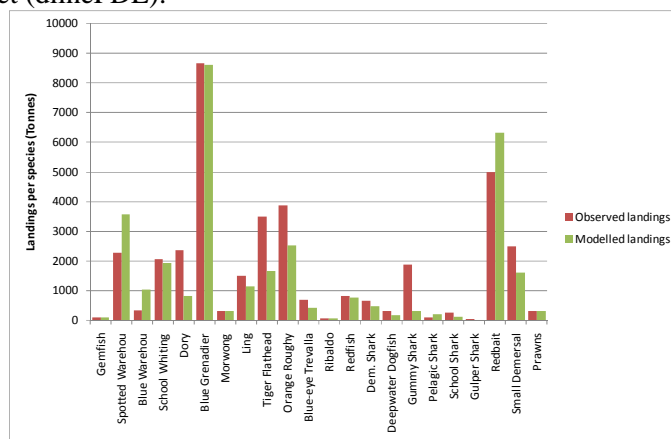


Figure 2 - Model estimated and observed landings for key species groups in the model (base year = 2000)

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

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 3a). 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.

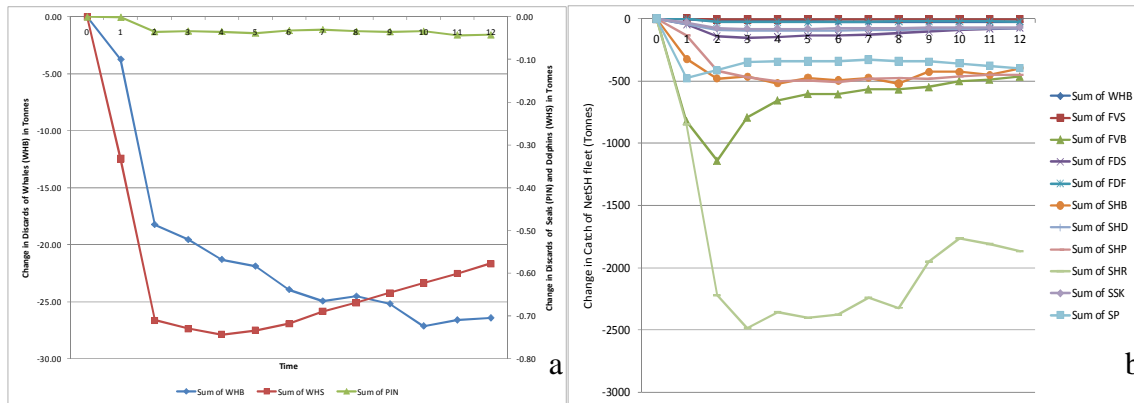


Figure 3 - Changes in a) discards of whales (WHB), dolphins (WHS) and seals (PIN) and b) catch of key species by NetSH fleet

The implications of this reduction in the catch² of whales at a fishery level are significant. 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 3b.

The main species that are caught in lower numbers by netSH are the shark species (School shark, Gummy shark and Pelagic shark). Fish species that 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, notably to changes in their fishing effort, due to the cumulative effects of fleet responses in terms of quota trading, targeting and effort determinants (Figure 4 – left panel). The two main fleets affected are the shark net fleet (netSH) and the demersal trawl fleet (drawlFD), which both reduce their fishing effort as a result of the management measure.

The model allows one to assess the overall consequences of the management measure on the economic performance of the fleets. As illustrated in Figure 4 (right panel), economic profits in the trawl fisheries decreases with the adoption of the management measure, as these fleets are negatively impacted after 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 economic profit in this fleet, rather increases in profitability 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 the period used to parameterize the cost model, and the fact that non-economic drivers (lifestyle fishing) are also influencing participation in this fleet.

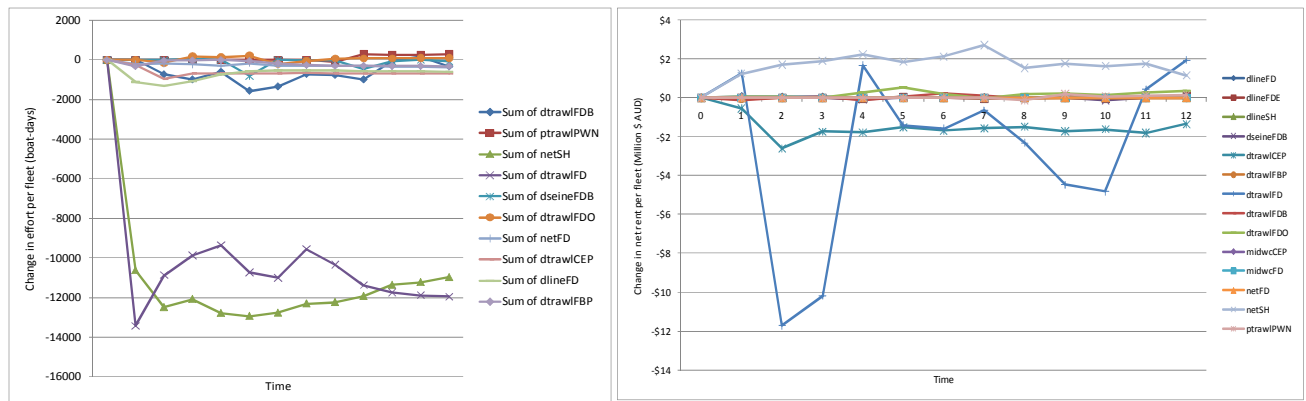


Figure 4 - Change in effort (left panel) and economic profit (right panel) per fleet

Overall, fleet responses lead to wide ranging modifications in their catches and uptake of quota for various species. The reduction in catches is associated with decreases in landings of many species. 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 (Figure 5). For other species, decreases in discards are observed, notably Spotted Warehou, Ling, Gummy Shark, School shark and Redbait (Figure 5). 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.

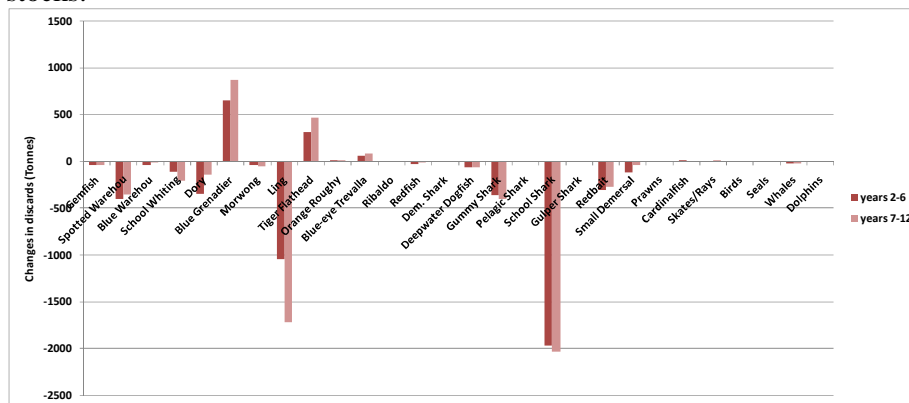


Figure 5 - Change in total discards per species

Scenario 2 - Tax on megafauna (whales, dolphins, and seals)

The changes in the discarding of marine mammals associated with this scenario are illustrated in Figure 6a. The tax on catches of marine mammals results in an immediate decrease of discarding of whales in the order of 15 tonnes which steadily increases to just over 20 tonnes (a 55.5% and 74% decrease, respectively). 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 (a 75.4% decrease)(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 equates 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. As in the previous scenario, the model shows that the implications of this reduction in the catches of marine mammals are significant at a fishery level, and result both directly and indirectly 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. 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 6b. 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

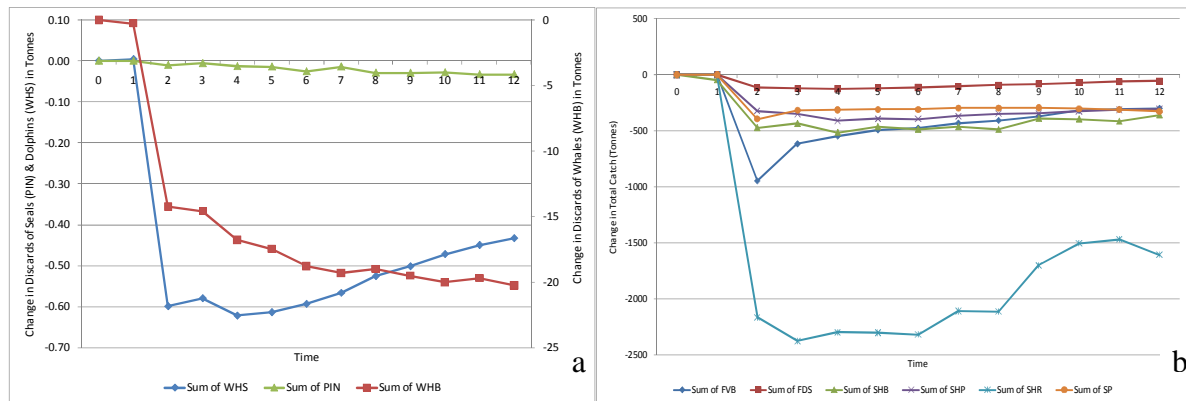


Figure 6 - Changes in a) discards of whales (WHB), dolphins (WHS) and seals (PIN) and b) catch by NetSH fleet

These impacts induce the fleets to modify their activity profiles (and reduce effort), which in turn affects their uptake of quota for various species, reducing their catch, landings and discards. Figure 7 (left panel) shows the response in terms of fishing effort for the main fleets in which impacts have been observed in the simulation. The main fleets that are affected are the netSH, the demersal fish trawl (dtrawlFD) and the dtrawlFDB fleets (Figure 7 - left panel). Again, the main demersal trawl fleet (dtrawlFD) is negatively affected to a considerable degree 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 7 which are negatively impacted (i.e. decline in activity) incidentally catch marine mammals. Note the demersal trawl fleet for Orange roughly displays positive effects which are indirect (as in the model it is assumed it does not interact with marine mammals).

The model allows one to assess the overall consequences of the management measure on the economic performance of the fleets. As illustrated in Figure 7 (right panel), economic profits 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 economic profit 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 management measure lead to positive, but limited profitability 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 economic profits compared to the base run.

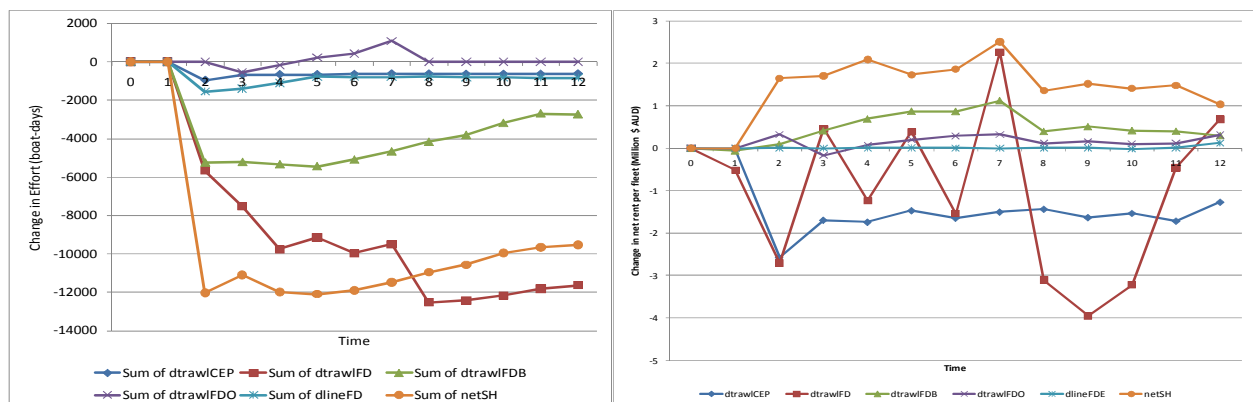


Figure 7 - Change in effort (left panel) and economic profits (right panel) per fleet

In this scenario as in the previous, 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)), these being all an indirect consequence of the adoption of a tax on the bycatch of marine mammals (Figure 8).

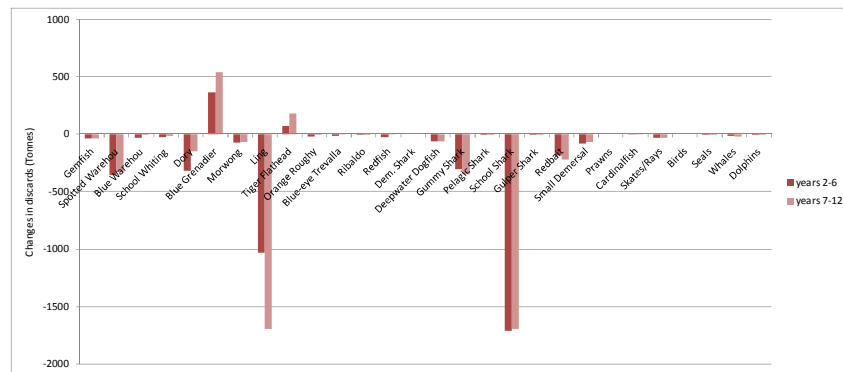


Figure 8 - Change in total discards per species

Scenario 3 - Deemed value (3 companion stocks)

As was the case with the previous scenarios, the simulation illustrates the magnitude of the impact on the stocks across the fisheries and fleets. In this scenario there are large declines in the catch and landings for the main target species; however the impact on the discards are not as clear as before. The change in discards between the base run and the deemed value scenario are presented in Figure 9. For this scenario there are considerable increases 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, Skates and rays, School shark, and Morwong.

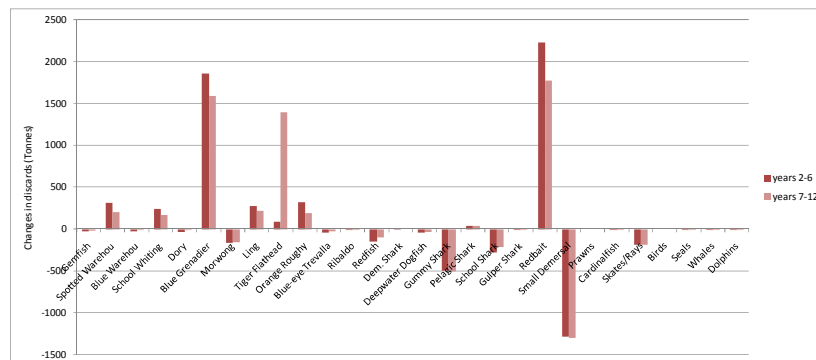


Figure 9 - Change in total discards per species

Ascertaining the exact direction of change for each of the main stocks, that is what combination of change in discarding and landings it experiences, can be interpolated from (Figure 10). The right panel shows the area within the red square in the left panel in more detail. The red line in the right panel represents constant fishing mortality while all points above correspond to an increase in fishing mortality with the scenario, while the opposite is true below the line.

Where quota really is constraining (as is the case 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. The large decreases in landings of Redbait and Blue Grenadier are possibly due to a reduction in targeting of these stocks as fleets shift fishing practices in response to the introduction of deemed values. Overall, the effect on effort is such that effort mostly declines, especially in the case of the Danish Seine fleet, the demersal trawlers and the prawn trawlers (Figure 11 – left panel). The reasons for the large decline in Danish Seine is probably related to avoidance behaviour as they do not land over-quota (nor pay deemed values) and their economic profits are 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 11 – left panel). The year to year variability in effort grows for some sectors (in particular the general demersal trawl fleet, ddrawlFD).

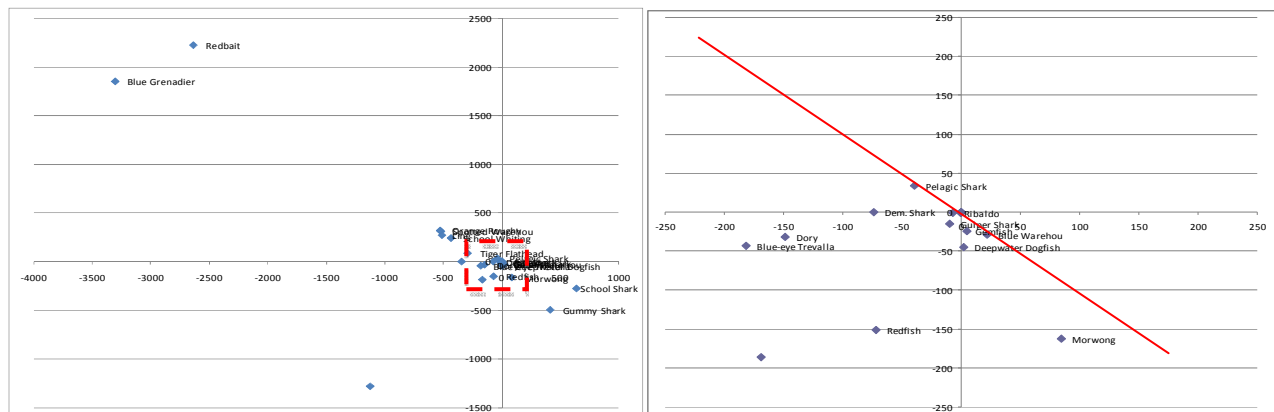


Figure 10 - Changes in landings (x axis, in tonnes) and discards (y axis, in tonnes) (the right panel shows the area within the red square in the left panel in more detail).

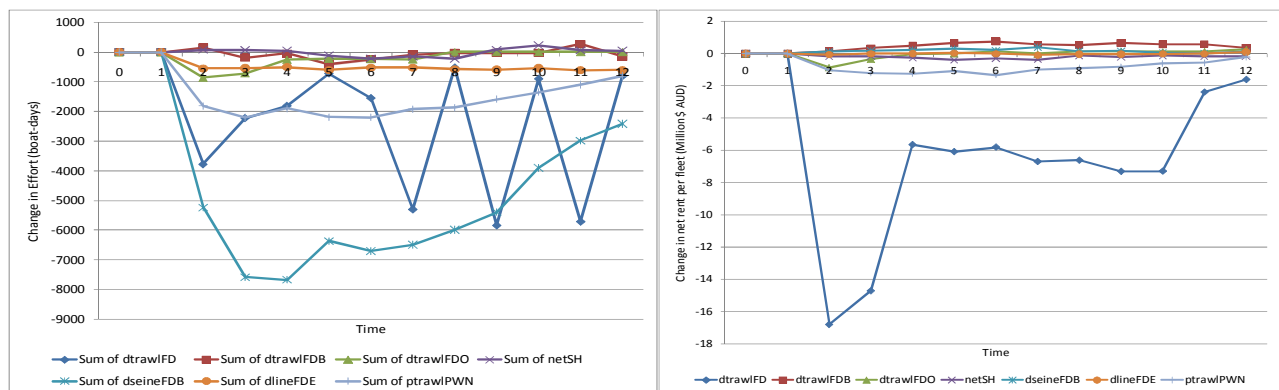


Figure 11 - Change in effort (left panel) and economic profits (right panel) per fleet

The impacts on the economics of the fleets are illustrated in Figure 11 (right panel). Amongst the most affected fleets, the demersal trawl fleet targeting Orange roughy has a slight decrease in economic profits 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 (ddrawlFD) economic profits decreases sharply after the introduction of deemed values (Figure 11 – right panel). This is 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 profitability overall (Figure 11 – right panel) which implies that their economic performance has improved compared to the base run, excluding the effects of deemed value payments.

DISCUSSION

The results presented from this version of the SESSF Atlantis have been based on a calibration of the model to historical data for the fishery, and using simple scenarios that evaluate the adoption of incentive based bycatch management measures. The results illustrate the high degree of complexity which arises from the interaction of ecological changes and fishing fleet dynamics (through effort allocation, quota trading and investment decisions) in response to management intervention in a mixed fishery. Overall, all the scenarios lead to a more or less transitional reduction in fishing activity, catches and landings, and to somewhat contrasted impacts with respect to bycatch and discards.

When *bycatch quotas* are 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. For cases where the species were caught by a few fleets only, the initial allocation of catch shares, which are defined as a proportion of historical incidental catches/encounters, means that the opportunities for trading quota for these species are fairly limited. Hence the quotas impact the fleets in a similar way as non-tradable individual quotas would have, constraining fleets at reduced levels of effort and catch. For similar reasons, the introduction of a *tax* on the catch of on these same species leads 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. For the *deemed values*, which are aimed at commercial species and quota species in particular, the behavioural response amongst the fleets is almost as if the deemed value acted as an on-off switch effect in this version of the model. 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. If higher deemed values were used, then high-grading behaviour occurs, leading to species being discarded regardless of the removal of the quota constraint. This is, for example, the case for the Danish seine fishery, particularly when it is assumed that they base discarding decisions on market information at the start of each trip.

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), the bycatch quotas and taxes are applied to the same species groups in order to allow for a comparison. The bycatch quota is relatively more effective largely due to the fact that there are limited trading opportunities and the quota levels chosen in the scenarios are very restrictive, as compared to the financial penalties of a tax. This, of course, assumes compliance with the regulations. Further simulations should allow the determination of the tax rates that entails impacts equivalent to a given level of quota constraint.

This research represents a first test-case application of an ecosystem model that includes fleet behaviour, to model the potential effects of various incentive based approaches to the reduction of bycatch and discards in a mixed fishery. The results herein should 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. Further work will focus on determining the relative contribution of the different behavioural responses of the fleets (in terms of effort allocation, quota trading, species targeting, etc.) to the overall impacts observed from the implementation of a given measure.

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¹ There are 16 additional non-dynamic fleets in the model apart from those listed in the table (see Fulton *et al.* 2007)

² In this paper, 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.