The Australian Journal of
Agricultural and
Resource Economics

Journal of the Australian Agricultural and Resource Economics Society

The Australian Journal of Agricultural and Resource Economics, 52, pp. 433–452

Economic and ecosystem impacts of illegal, unregulated and unreported (IUU) fishing in Northern Australia*

Sean Pascoe, Tomas A. Okey and Shane Griffiths†

Illegal foreign fishing for sharks in Northern Australia has increased substantially over the last two decades. This has likely resulted in declines of shark species abundance, with potentially far-reaching impacts on the ecosystem. This, in turn, could also have indirectly affected the legal prawn, shark, and other fisheries in the region through changed predation patterns and direct removal of targets. The prawn fishery in Northern Australia is currently one of Australia's most valuable fisheries. Sharks themselves are also a major target species by many Queensland and Northern Territory fishers. In this article, an ecosystem model developed in the Ecopath with Ecosim framework is used to estimate the impacts of illegal shark fishing on the remaining system, and the potential economic impacts on commercial fisheries in the region.

Key words: economic impact, Ecopath, Ecosim, IUU, shark.

1. Introduction

The persistence of illegal, unreported and unregulated (IUU) fishing has been identified as a major factor contributing to the overexploitation of marine resources worldwide (FAO 2001). Illegal fishing includes activities such as unlicensed fishing (including foreign fishing in national waters) and fishing that contravenes government regulations and international conventions. Unreported fishing involves undeclared catches or misleading reporting of catches, such as when exceeded quotas are not reported. Unregulated fishing involves fishing activities that are not managed. At the national level, IUU fishing has evolved as a result of ineffective management and inadequate surveillance and control, while at the international level IUU has developed as a result of inadequate governance arrangements for key

* This work was funded by the Australian Fisheries Management Authority (Project 2006/825). TAO's contributions were supported in part by a Pew Marine Conservation Fellowship, a program of the Pew Institute for Ocean Science. The conclusions are those of the authors and do not necessarily reflect the views of The Pew Institute for Ocean Science or the Pew Fellows Program in Marine Conservation. The authors would like to thank the anonymous referees who also provided valuable comments.
† Sean Pascoe (email: sean.pascoe@csiro.au) and Shane Griffiths, CSIRO Marine and Atmospheric Research, 233 Middle Street, Cleveland, 4163, Australia. Tomas A. Okey, Bamfield Marine Sciences Centre, Bamfield, BC V0R 1B0, Canada and University of Victoria, School of Environmental Studies, PO Box 1700 STN CSC, Victoria BC V8W 2Y2, Canada.

doi: 10.1111/j.1467-8489.2007.00420.x

areas of the high seas, including activities by vessels from nations that are not party to existing international arrangements (FAO 2001).

The incentives to fish illegally are considerable because fines are generally small relative to the value of the illegal catch (Griggs and Lugten 2007). Sumaila *et al.* (2006) estimate that, globally, the benefits of IUU fishing to the perpetrators far exceed the projected costs if caught, and that existing sanctions may need to be increased by a factor of 24 before IUU fishing becomes unattractive.

Although beneficial to the perpetrators, illegal fishing is costly to the countries in which it takes place. These include increased enforcement and monitoring costs aimed at deterring or capturing IUU fishers, losses in terms of reduced production of the domestic (legal) fishing sector, and losses in biodiversity and ecosystem health and services. Domestic productivity losses may be incurred directly through a reduction in the stocks of the species targeted by both legal and illegal fishers, or indirectly through changes in the ecosystem. For instance, the illegally caught organisms may be predators or prey of other commercially valuable species thus influencing those commercial populations. Relatively few attempts have been made to estimate these costs of illegal fishing, and these have been limited to the estimated value of the illegal catch (e.g. MRAG 2005).

Illegal foreign fishing (IFF) is of particular concern in Australia. All fishing activities in the Australian Exclusive Economic Zone (EEZ) are regulated. Some unreported or illegal fishing activities are undertaken by Australian fishers, but IFF activity is considered of substantially greater concern (Department of Agriculture, Fisheries and Forestry 2005).

For this article, we employed a trophodynamic ecosystem model to estimate both the direct and indirect impacts of IFF on the commercial fisheries and biological communities of the Gulf of Carpentaria, Northern Australia The model was developed using the Ecopath with Ecosim (EwE) software (e.g. Christensen and Walters 2004). The EwE software has been well established in ecological analyses,[1] but there are only a few examples that have considered economic impacts (e.g. Sumaila and Vasconcellos 2000; Alasdair *et al.* 2002; Arrequín-Sánchez *et al.* 2004; Okey and Wright 2004).

The remainder of the article is organised as follows. The commercial legal and illegal fishing activities in Northern Australia, and the Gulf of Carpentaria in particular, is described in Section 2. The key features of the EwE model is described in Section 3, while the results of the modelling analysis of the impacts of IFF in the Gulf of Carpentaria are presented in Section 4. The analysis considers the state of the legal commercial fisheries and stocks with and without IFF. Finally, the implications of the results for Australian fisheries and enforcement activities are discussed in Sections 5 and 6.

[1] Details of most models and their associated applications can be found on the ECOPATH webpage <www.ecopath.org>.

2. IFF in Northern Australia

In Northern Australia, a problem exists with regard to foreign fishing vessels illegally targeting sharks for their fins and red snappers. Shark fins are an attractive target for illegal fishing because dried fins attract a high price in Hong Kong and other Asian markets (Fong and Anderson 2002). The fins can be dried on board and the boats do not require considerable storage space. Red snappers are similarly high valued species that are also believed to be targeted in Northern Australian waters by illegal foreign vessels. The market chain for red snapper is less well known that that of shark fins, but presumably the product is sold as fresh (chilled), requiring different fishing strategies to those used to harvest shark fins.

Surveillance and capture of foreign fishing vessels within the Economic Exclusion Zone (EEZ) of Australia's tropical northern marine domains suggests that the occurrence of foreign fishing vessels has increased considerably over the last two decades. The reputedly large catches by foreign fishing vessels in Australian waters has raised concern that shark and red snapper species in the region may be fished at unsustainable levels, potentially jeopardising the quality, value and longevity of some of Australia's most valuable legal fisheries.

The impact of IFF on Australian fisheries is both direct and indirect. Legal commercial fisheries for sharks and red snapper also exist in these areas, and IFF directly impinges on these resources. Many shark species are top predators that regulate the overall community. Depleting or removing sharks through overfishing is thus likely to result in considerable community changes, which in turn can cause changes in abundance of other important commercial species (Stevens *et al.* 2000; Myers *et al.* 2007). This may ultimately result in a reduction of the economic value of domestic fisheries and changes in the ecosystem structure.

2.1 The Gulf of Carpentaria fisheries

The modelling analysis was restricted to the Gulf of Carpentaria, which contains a number of high valued commercial fisheries and is also a known site of IFF activity. The Gulf of Carpentaria is a large (370 200 km^2), shallow (< 70 m) tropical marine embayment of Australia's northern coastline between Cape York Peninsula and the Wessel Island. While fully within the Australian Exclusive Economic Zone, the waters of the Gulf straddle three jurisdictions in terms of fisheries management: Commonwealth (federal) waters beyond 3 nautical miles (about 5.5 km) with Queensland and the Northern Territory responsible for fisheries in the inshore waters adjacent to their respective States.

The Gulf contains a number of (legal) commercial, recreational and indigenous fisheries. In total, around 380 Australian commercial boats operated in the Gulf in 2004–2005. Of these, around 295 operated in State

Table 1 Estimated catch and value of production of the commercial sectors operating in the Gulf of Carpentaria, 1990–2005 (2004–2005 prices)

	1990–2001		2000–2001		2004–2005	
	Catch (*t*)	Value ($m)	Catch (*t*)	Value ($m)	Catch (*t*)	Value ($m)
Northern Prawn						
• Banana	5920	55.9	6286	94.1	2764	30.6
• Tiger	4350	98.9	2992	86.1	2271	33.6
Pots	155	1.3	966	9.9	477	4.9
Nets	2239	9.4	3350	19.1	3788	22.3
Lines	827	2.8	1391	7.2	1562	7.7
Fish Trawl	NA	NA	NA	NA	NA	NA
Total		168.3		216.4		99.2

Source: derived from ABARE (2006 and earlier issues), Queensland DPI&F Coastal Resources Habitat Information System, and Zeroni and Wood (2005). Allocation of catch between net and line fisheries is approximate only. Value of the prawn fisheries includes catch taken in areas outside the Gulf of Carpentaria. NA, not available.

managed fisheries, with the remainder in Commonwealth managed fisheries. These boats use a variety of fishing gear, including trawl, gillnets, lines and pots.

In 2004–2005, the total value of Australian commercial catch in the Gulf was roughly $99 m, although in recent years had been in excess of $200 m (Table 1). The northern prawn fishery (a trawl fishery) is the dominant economic activity in the Gulf, although the value of the fishery has declined substantially over the last decade due to falling catches and prices (Table 1). This fishery operates mostly in the Commonwealth waters, and extends beyond the Gulf to the Western Australian border.

Within the State waters, commercial activity is based on crabs, sharks, snapper, barramundi and Spanish mackerel, as well as a range of other species. For gillnet boats, sharks make up almost half the value of the catch, barramundi about one quarter, and a range of fish species the remainder. For line boats, mackerels are the dominant species by value, while crabs are the main target species of the pot fishers. Fish trawlers target snapper and a range of other fish species. Fishing effort in all State fleets has generally increased between 1990 and 2005, with a corresponding increase in catches (Table 1).

Recreational and charter fisheries also have developed, targeting a similar set of species to those of the inshore commercial fisheries. Around 10 charter boats operate in the Gulf on average per year, catching between 45 and 50 tonnes of fish in total annually. Indigenous fishers also target a similar set of species as well as dugong and turtles, primarily for subsistence and ceremonial purposes. The indigenous catch was estimated to be around 590 tonnes a year, 570 tonnes of which was dugong.

Illegal shark fishing by Indonesian vessels in Australian waters increased during the 1990s in response to a sixfold increase in product value arising from access to the new export market in Hong Kong, and the subsequent depletion of stocks in Indonesian waters (Fox and Sen 2002; Briggs 2003; Vince 2007). While capture in Australian waters may result in confiscation and destruction of the vessel, the low capital value invested in these vessels means that owners can cover this loss with two successful fishing trips, while the cost of any confiscated gear is incurred by the crew, who become indebted to the owners (Fox and Sen 2002). As a result, the risk to the vessel owner is relatively low, while lack of alternative employment opportunities that can offer equivalent wages means that there is a ready supply of crew members (Vince 2007).

In 1990, illegal catches of shark in the Gulf of Carpentaria were believed to be only around 10 per cent of the legal Australian catch. By 2005, illegal catches of shark were believed to be at least equivalent to those caught legally by Australian fishers.

3. The Gulf of Carpentaria model

The Gulf of Carpentaria model was developed as an Ecopath with Ecosim (EwE) model.[2] As with all EWE models, the Gulf of Carpentaria model is based on a number of functional groups (in this case 83). These functional groups covered the full range of animal and plant species in the Gulf, from primary producers (e.g. microalgae and seagrasses) through to higher trophic level species (e.g. sharks, seabirds and dolphins). Marine species were aggregated into these functional groups based on ecological 'guild' similarity criteria such as habitat, feeding type and diet, size, and rates of production and consumption. Energy in the form of biomass wet weight flows from the lower trophic levels to the higher levels though predation, and much of this biomass eventually returns to detritus through natural mortality unassimilated food and waste, and discarded bycatch (Figure 1). Total biomass is generally greatest for the functional groups comprised of primary producers, and decreases as the trophic level increases (Figure 2). Fishing (both legal and illegal) extracts biomass from both higher and lower trophic levels, only some of which is returned to the system.

The Ecopath model requires the assumption that the system is initially in equilibrium. Subsequent changes in the structure of the ecosystem over time is a result of biomass growth (related to the biomass of the species group), mortality (both as a result of fishing and natural mortality such as through predation and) and migration. With the exception of tuna and mackerel, it was assumed that there was no immigration or emigration for any species, so that all mortality and prey consumption occurred within the system.

The predator–prey diet matrix (i.e. the links among the different functional groups) was constructed primarily using wet weight prey data from quantitative

[2] Details of the derivation of model parameters are described in Okey *et al.* (2007). The complete model is available from the authors on request.

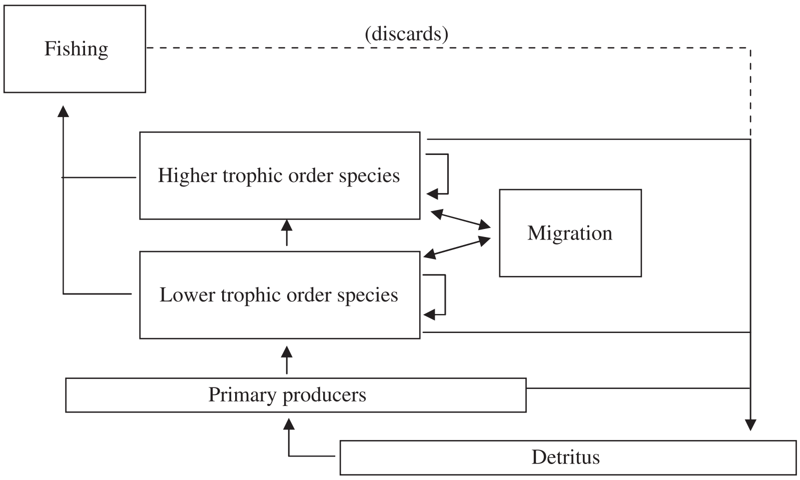

Figure 1 Diagrammatic representation of the EwE model.

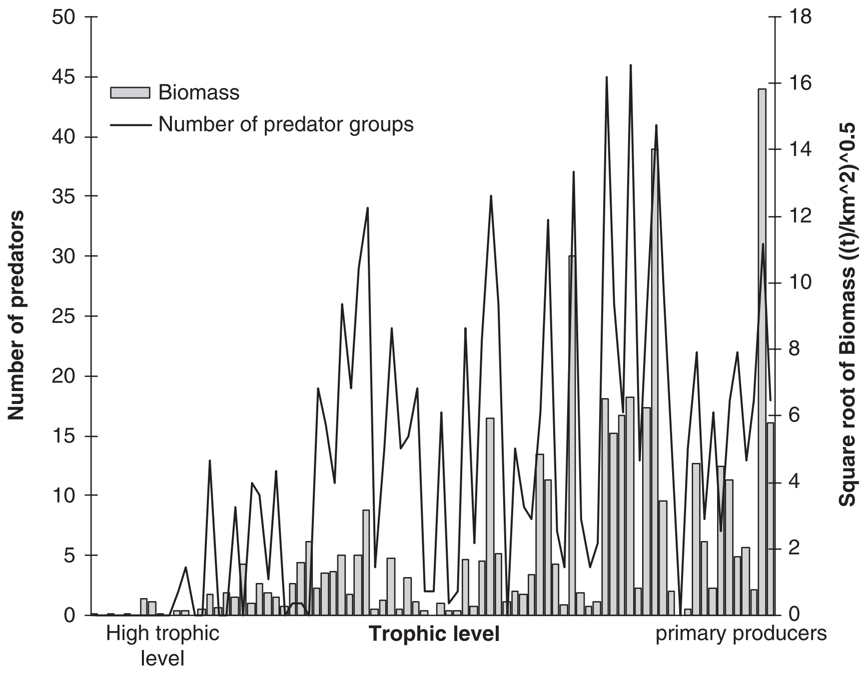

Figure 2 Relationship between trophic level, biomass and predation in the Gulf.

dietary studies undertaken in northern Australia. Extensive dietary data existed for fishes, sharks and various crustaceans in the region. Where data were not available for specific functional groups, values from relevant studies conducted in similar tropical regions were used and cross-referenced with expert opinion (see Okey *et al*. 2007). As would be expected, the number of predator groups related to a prey species was highly correlated with the availability of the prey ($r = 0.7$, Figure 2).

Ten fishing activities were included in the model. The northern prawn fishery was split into two sectors – a banana prawn fishery and a tiger prawn fishery. While exploited by essentially the same set of boats, the two fisheries are separated seasonally, and target different sets of species in each season. The State commercial fisheries were aggregated by gear type into gillnet, line, pots and fish trawl fisheries. Non-commercial fishing activity was represented by charter boat, recreational and indigenous fisheries. Finally, an IFF fleet was included in the model. The fishing activities were modelled separately (i.e. rather than combined), each with differing catch compositions, effort patterns and cost structures.

Economic information in the model included the costs of fishing and the prices received. Cost data were derived from a number of sources for the respective fleet segments, and related to 2004–2005. Full details on fishing costs are presented in Okey *et al*. (2007). Prices included in the model were also from 2004–2005, and were also derived from a number of sources and averaged over species to derive an average for the functional group.[3] For the non-commercial fleets, an assumption was made that the value of species caught by the recreation and charter boat fleets were 10 times those of the commercial fleets, following Okey and Wright (2004).[4] The 'prices' relating to indigenous production were assumed to be the same as those received from commercial fishers. Given that the fish were for consumption, the alternative to catching fish is purchasing fish (or other food sources). Similar approaches have been employed in other studies valuing subsistence production (e.g. Gray *et al*. 2005). For the non-commercial species (i.e. dugong and turtles), the average price for all fish and shellfish was applied on the assumption that the next best alternative food source is other marine species. For the illegal foreign vessels, the price of sharks was derived from the shark fin prices received (scaled up to a live-fish equivalent). These prices were found to be roughly equivalent to the prices received by Australian fishers, so adequately represent the opportunity cost. For other species caught by the illegal vessels, the Australian commercial price was applied.

[3] An unfortunate weakness of the EwE modelling system is that prices are unable to vary over time in the model, and are assumed exogenous (rather than endogenous). Prices do not influence effort levels or targeting behaviour in the model, all of which are imposed exogenously.

[4] This assumption is also supported by two recent Australian studies, where the average value of expenditure on recreational fishing when expressed as a $/kg caught was roughly 10 times the average price received by commercial vessels for the same species (NSW Fisheries 2002; Henry and Lyle 2003). Interpreting 'value' of recreational fishing however, is complex, as expenditure does not equate with value of production, and expenditure may not increase if stocks (and consequently catch) increases. However, as cross-sectoral comparisons (i.e. between commercial and recreational fisheries) are not made in this study, the proxy measure of value was assumed to be appropriate.

4. Simulations and results

A number of simulations were run using the model. First, the ability of the model to replicate known changes in the fishery over time given 'known' fishing patterns was examined. The model was then used to determine the sensitivity of the results to different assumptions about the level and the trajectory of the illegal fishing activities, both of which were uncertain. The model was then used to estimate the impacts of the IFF on the ecosystem and legal fisheries through simulating the system with and without the illegal activity. Finally, the model was used to estimate the potential economic benefits to legal fisheries of stopping (IFF) from 2007.

The base year of the model simulations was 1990. This was chosen as reasonable information on the key biological features of the fishery existed from this time period, which pre-dated the substantial increase in IFF effort for shark. The EwE model requires that the base time period of the simulation period be in equilibrium, though not necessarily at a steady state. While equilibrium may be an unrealistic expectation for a multispecies multi-fleet fishery, it is a convenient starting point and the 15-year period to 2005 was assumed sufficient to ensure that the dynamics of the system were fully operational.

4.1 Validation and sensitivity

The effective fishing effort for each of the State commercial fleets (i.e. gillnet, line, pots and fish trawl) was estimated based on recorded boat days and changes in catch per unit effort over the period 1990–2005 (Figure 3). An assumption was made that changes in catch per unit effort over time reflected

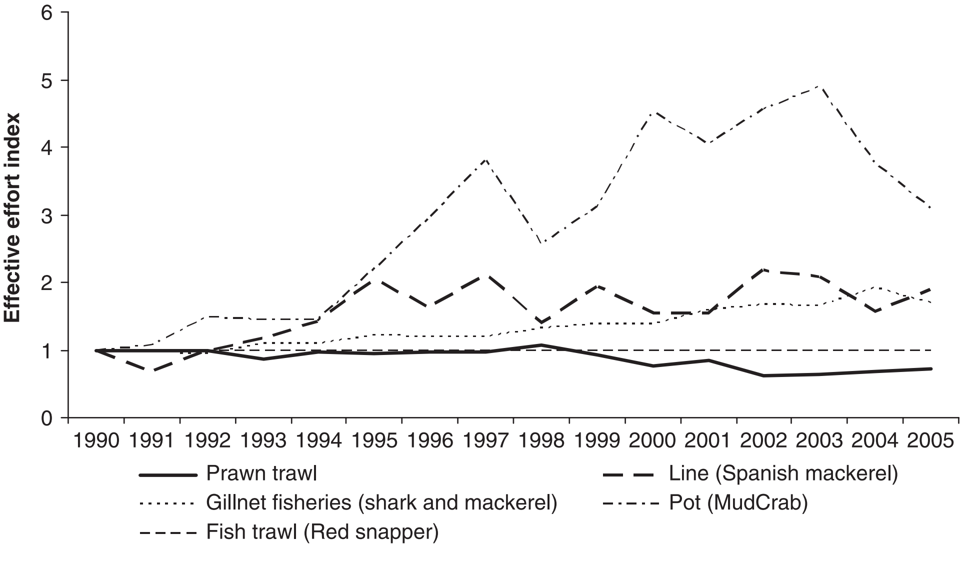

Figure 3 Estimated relative changes in fishing effort by commercial fishing fleets, 1990–2005.

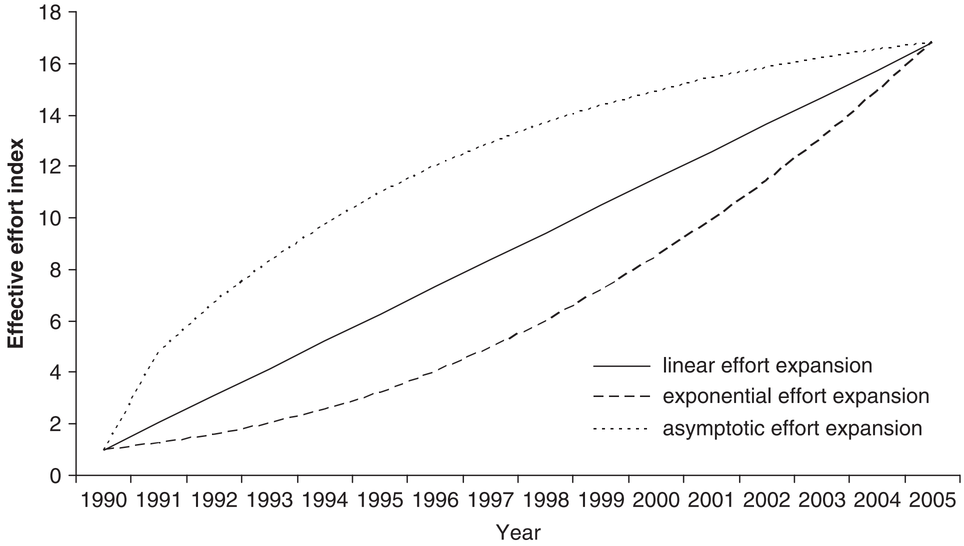

Figure 4 Estimated relative change in fishing effort by foreign fleets, 1990–2005.

changes in fishing power and efficiency rather than improvements in stocks. For the Commonwealth northern prawn trawl fishery, effective effort estimates were derived from Rose and Kompas (2004). For the illegal foreign fleet, fishing effort is believed to have increased 17-fold over the period 1990–2005. The trajectory of this effort increase is unknown, so three assumptions were examined – a linear increase, an exponential increase and an asymptotic increase (Figure 4).

As with any analytical model, relative changes in model variables over the simulation period are more relevant than absolute values. The change in catch was estimated for each assumed IFF effort trajectory, and compared to the change in catch derived from recorded landings between 1900 and 2005 (Figure 5). For most species, the estimated catch followed similar trends to the actual catch, and correlations where generally high (Table 2). The key exceptions to this were the banana prawn catch and the line boats. Banana prawn catches are highly sensitive to environmental conditions, particularly rainfall (Vance *et al.* 2003). The estimated banana prawn catches, by comparison, were relatively constant over the period. In absolute value terms, they were around the long-term average value (not apparent in Figure 5 as the actual catch in 1990 was below the long-term average), and this projection would represent the trophic component of the factors that drive the banana prawn population. Correlation between the estimated and recorded line catch appears to be more highly correlated in the latter half of the simulation period (Figure 5, Table 2). The discrepancies in the earlier years may be an artefact of the equilibrium assumption.

The different assumptions regarding the trajectory of the illegal fishing activity did not appear to result in substantially diverging outcomes. From

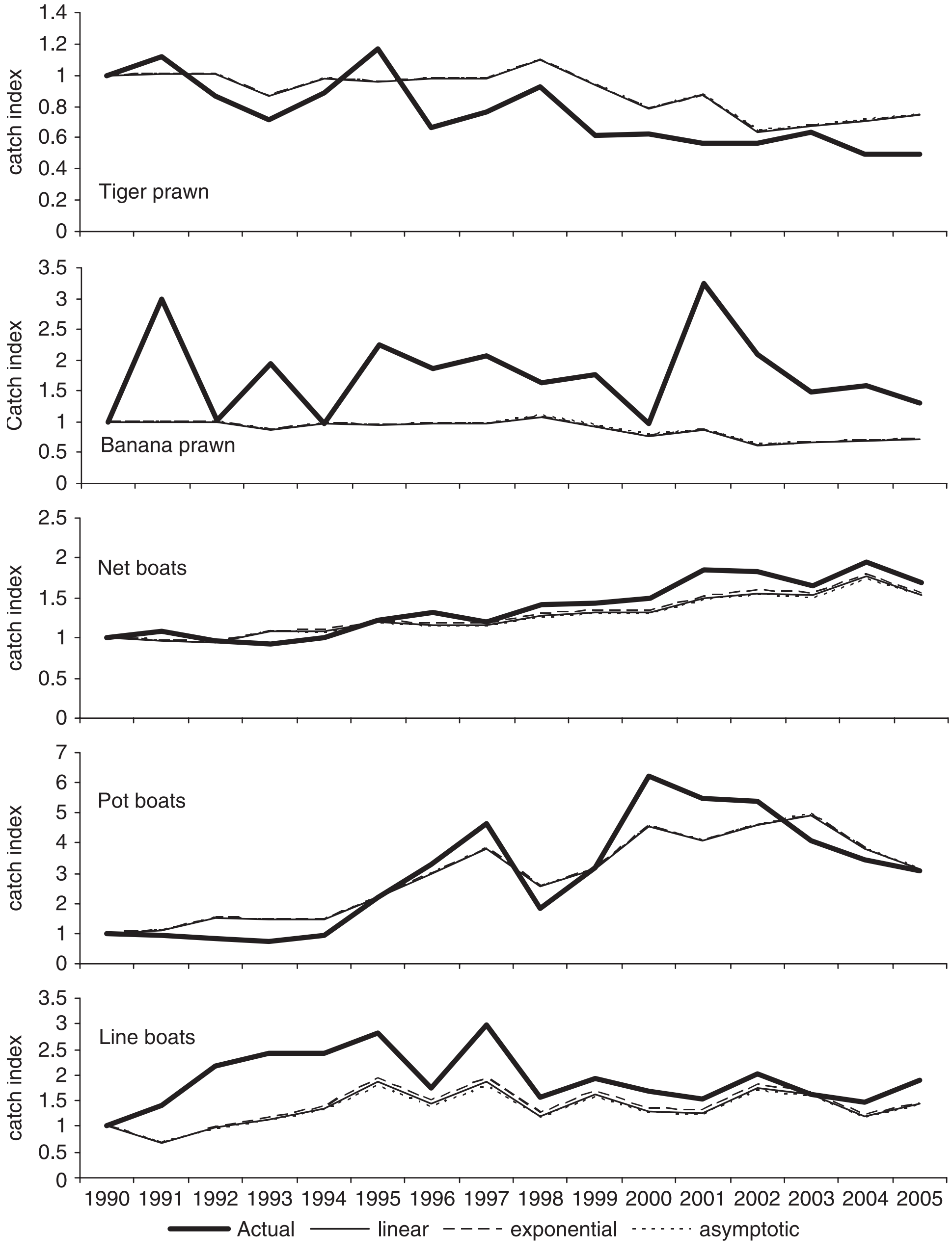

Figure 5 Comparison of model estimates of changes in catch with those derived from landings data, 1990–2005.

Figure 5 and Table 2, the model estimates were relatively insensitive to the assumptions about the development of the illegal foreign fishery.

The absolute level, as well as trajectory, of IFF is uncertain. The sensitivity of the results to the magnitude of the IFF was examined by varying the level of effort by plus and minus 50 per cent, and comparing the estimated catches

Table 2 Correlation between model estimated and actual catch of each fleet, 1990–2005, under each assumption of IFF effort trajectory

	Linear	Exponential	Asymptotic
Tiger prawn fishery	0.720	0.722	0.717
Banana prawn fishery	0.072	0.072	0.072
Net boats	0.963	0.965	0.962
Pot boats	0.932	0.932	0.933
Line boats (1990–2005)	0.591	0.587	0.575
Line boats (1996–2005)	0.803	0.8073	0.783

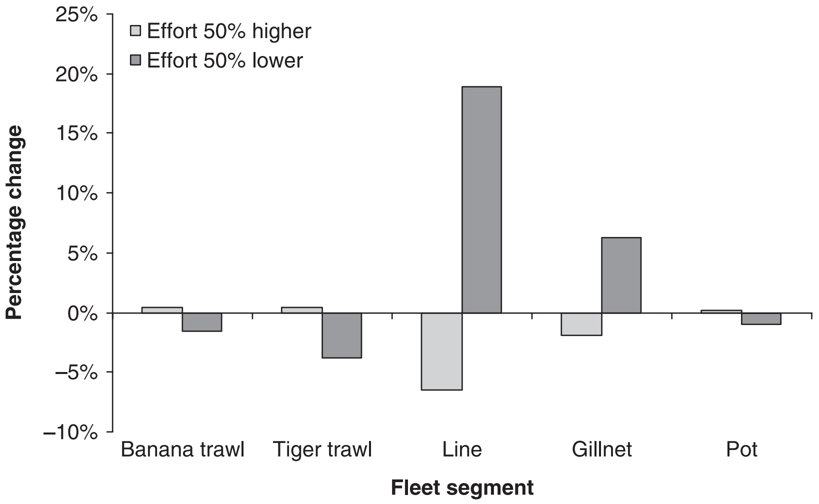

Figure 6 Change in estimated total catches in 2005 under differing assumptions about the level of illegal foreign fishing effort.

in 2005, ceteris paribus. Higher levels of illegal fishing had relatively little impact on the estimated catches, with the exception of the line fleet. Lower levels of effort had an impact on all fleet segments, with line and gillnet boats having a higher estimated catch (Figure 6).

Estimated economic profit as a proportion of revenue was also relatively comparable with that derived from the survey data (Figure 7). The major exception to this was the line fishery, which was estimated to be earning negative economic profits in the simulation (assuming linear foreign fishing effort growth). The economic profits from the gillnet fishery were also underestimated in the simulation. These shortfalls are largely a consequence of lower levels of revenue in the simulation results compared with the survey data, particularly for the line fleet.

The divergence in the model and survey estimates of revenue and profitability for the line fleet may be a consequence of the assumption of equilibrium in 1990. Between 1974 and 1986, Spanish mackerel – the main species caught by the line fishery – was heavily exploited by Taiwanese fishing vessels fishing in

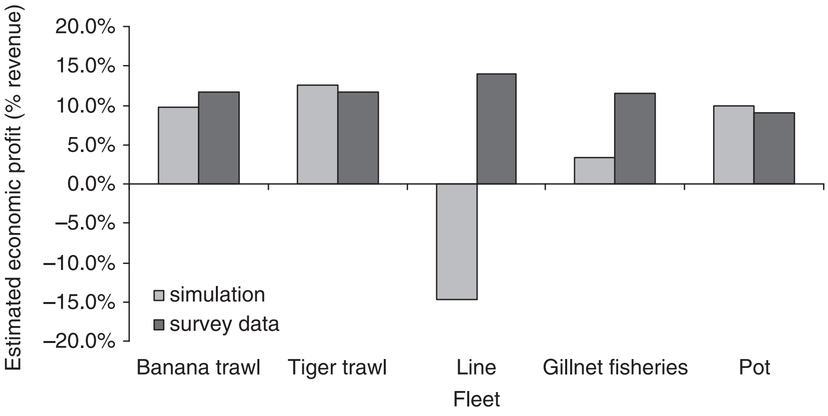

Figure 7 Model and survey-based estimates of economic profit as a proportion of revenue, 2004–2005.

Australian waters (Zeroni 2006). The fishery was believed to have stabilised by the mid-1990s (Zeroni 2006). Part of the increase in survey-based estimates of revenue and catch, and the apparent high rate of efficiency change in the fishery between 1990 and 2005, may be due to stock recovery during the 1990s. In contrast, Spanish mackerel stocks were estimated to decline in the model over this same period.

4.2 The effect of IFF

The model was run over the period 1990–2005 removing all IFF, and the results compared to the model runs with IFF. For the simulations involving IFF, a linear increase in IFF effort was assumed for the purposes of comparison.

As would be expected, the most significant impact of the IFF is on those fisheries that target shark (Table 3). From the model, revenues from the gill net fleet may have been reduced by around 6 per cent between 1990–2005 as a result of IFF, and fleet profits reduced by as much as 66 per cent. Given the relatively small profit margins in the fishery, a small change in revenue has a greater than proportional impact on profitability. Similarly, the profitability of the line fishery may have decreased by more than 100 per cent as a result of IFF (i.e. the estimated profits without IFF were positive, and with IFF were negative). Conversely, IFF appears to have increased the revenue and profitability of the tiger prawn, crab and fish trawl fisheries. These indirect impacts arise through changes in the ecosystem structure resulting from the increased pressure on, and subsequent decline of, the shark stocks. Extrapolating current effort levels[5] forward until 2020, both the positive and negative

[5] Effort levels for all fleets except the northern prawn fishery were held constant at the 2005 level. Implicitly, this assumes that current controls on existing vessels are effective in containing fishing effort, while enforcement prevents the further expansion of IFF effort. For the NPF vessels, a buyback in 2006 reduced the fleet size and subsequently the level of fishing effort.

Table 3 Estimated impact of IFF fishing on revenues and profits in 2005 and 2020

	2005		2020	
Fishery	Value of output (% change)	Profits (% change)	Value of output (% change)	Profits (% change)
Commercial				
• Banana	0.9	9.6	3.0	23.7
• Tiger	1.2	10.0	3.9	22.3
• Lines	–15.1	–579.6	–17.2	–574.2
• Nets	–6.2	–66.3	–10.2	–103.9
• Pots	0.7	7.7	1.6	17.0
• Fish trawl	0.2	1.7	0.8	6.8
• All fisheries	–1.1	–11.0	–1.3	–9.4
Non-commercial				
• Aboriginal	–3.3	NA	–5.2	NA
• Recreational	–0.6	NA	–0.4	NA
• Charter fishery	0.1	NA	–0.4	NA

NA, Not applicable.

Table 4 Estimated impact of stopping IFF in 2007 on revenues and profits in 2020

Fishery	Value of output (% change)	Profits (% change)
Commercial		
• Banana	–1.4	–9.0
• Tiger	–1.1	–5.2
• Lines	17.2	> 100%
• Nets	6.1	> 100%
• Pots	–0.4	–3.9
• Fish trawl	–0.1	–1.1
• All fisheries	1.7	13.4
Non-commercial		
• Aboriginal	3.2	NA
• Recreational	1.0	NA
• Charter fishery	0.8	NA

NA, not applicable.

impacts are estimated to increase as a result of the change in ecosystem structure (Table 3).

The combined profits from the different commercial fisheries were estimated to be around 10 per cent lower as a result of illegal foreign fisheries. The estimated increase in profits in the northern prawn fishery was estimated to offset to a large extent the declines in profits in the other fishing activities. For the non-commercial fishing activities,[6] the 'value' of aboriginal landings is estimated to have been slightly reduced as a result of IFF, while landings by charter vessels and recreational fishers may have increased marginally.

[6] Charter boats are considered non-commercial for the sake of simplicity. While they are profit making businesses, they are less reliant on the catch directly for their income.

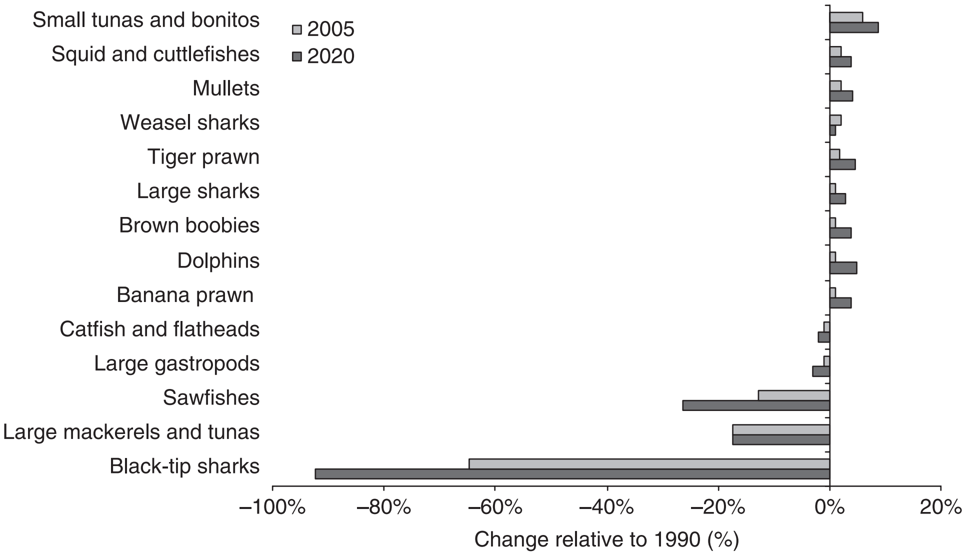

Figure 8 Estimated impact of IFF on stock biomass, 2005 and 2020.

The ecosystem impacts of IFF are illustrated in Figure 8. Only those species groups where biomass was estimated to change by 2 per cent or greater are depicted. The greatest negative impact is on blacktip sharks, the stock size of which is estimated to be over 90 per cent lower as a result of IFF by 2020. A number of non-commercial species benefits from the IFF, namely dolphins and some seabird species, presumably through greater availability of food (i.e. less competition with sharks). Cephalopod (i.e. squid and cuttlefish) and tuna stocks are projected to increase also, most likely as a result of reduced predation (Figure 8).

4.3 Benefits of stopping IFF

The potential benefits of stopping IFF were estimated by setting illegal foreign effort to zero from 2007 onwards, and comparing the final revenue and profit estimates to those from the simulation where IFF was assumed to continue at the current level.

As would be expected, the greatest benefits were estimated to accrue to those fishing activities that target sharks. The profitability of both the netting and line fleet was estimated to more than double by 2020 if IFF ceased in 2007 (Table 3) – moving from a situation of negative to positive economic profits. Conversely, those fleets that were estimated to benefit from IFF were estimated to incur a decrease in profitability if IFF ceased. The overall impact of stopping IFF, however, is estimated to be positive. Overall, fishery profits were estimated to be 13 per cent greater in 2020 as a result of ceasing IFF in 2007.

Ceasing IFF is also estimated to result in an increase in the level of aboriginal, recreational and charter catch (Table 3). These increases effectively mirror the decrease in catch estimated to occur as a result of IFF activity (Table 3).

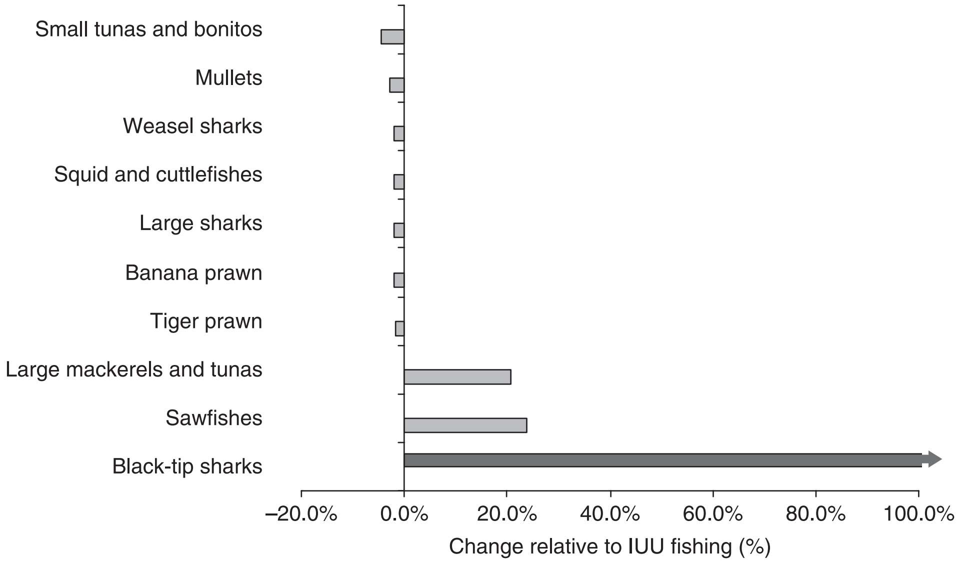

Figure 9 Estimated changes in stock biomass in 2020 from stopping IFF in 2007.

The species that is projected to gain the most in terms of biomass change is blacktip sharks, which was estimated to have a sevenfold increase in biomass in 2020 if IFF was stopped in 2007 (Figure 9). Mackerel and sawfish stocks are also projected to increase, largely as a result of decreased bycatch. In general, the species that increased (or decreased) biomass from stopping IFF were those identified as incurring the greatest negative (or positive) impact as a result of IFF (Figure 7).

5. Discussion

The model used in this analysis, like all models, includes a large number of assumptions that need to be taken into consideration when interpreting the results. The analysis largely assumes that economic parameters (i.e. prices and input costs) remain constant over time. While the most recent fall in prawn prices has been incorporated into the model, continuing expansion of the aquaculture industry may result in further declines in real prawn prices. Similarly, increasing fuel prices will increase the costs of fishing. These two factors could potentially have a greater impact on profitability in the fishery than the IFF.

The model also assumes effort is constant after 2005 (with the exception of the prawn fleet, which is constant after 2007). In the absence of IFF, the effort patterns may have been different to those observed in the presence of IFF as the operators would have been responding to a different set of incentives. Similarly, it is assumed that effort levels would remain constant at current levels in the future, whereas these would also change with changes in economic incentives. Where fisheries were adversely affected by IFF, it is likely that fishing activity would change, so the impact on profitability may be less than that indicated by the model. Further, changes in fisheries management will also affect future effort distributions in the fishery.

The absolute level of IFF is also not known. The effects of this uncertainty appear asymmetric, with the model results more sensitive to lower levels of illegal fishing effort than higher levels. If the actual level of IFF is lower than assumed in the analysis, then the benefits of removing this effort will also be correspondingly lower.

The model is also deterministic in nature, whereas fisheries are heavily influenced by environmental factors that are not captured in this model (e.g. rainfall, temperature). Prawn fisheries in particular are affected by environmental conditions, with banana prawn stocks varying substantially from year to year. Climate change will also affect the future development of the fishery (both the ecology and the economy).

Despite the limitations of the model, the results are largely consistent with a priori expectations. Shark stocks are projected to decline over time due to current trends in illegal fishing, but they are projected to increase if IFF is stopped. The fishing fleets most dependent on shark are the most affected by the IFF. The estimated changes in output from the main fleets corresponds reasonably well with the known changes in output for the fleets over the period 1990–2005, with the exception of the line fishery that appears to be underestimated in the model.

The analysis suggests that IFF has had a substantial negative impact on the gillnet and line fisheries, but may have had a positive impact on the other fisheries in the Gulf. Overall, IFF may have reduced total revenues by about $1 m in 2004–2005 (i.e. a 1.1 per cent reduction in total revenue), and may have reduced profitability in the fisheries by around 10 per cent.

The impact of the IFF on the prawn fisheries is at odds with a priori expectations. Earlier ecosystem modelling work in the Weipa region on the east coast of the Gulf of Carpentaria suggested that the removal of some shark species might cause the depletion of prawn stocks because of indirect effects that cascade through biological communities (Okey 2006). In this study, the reverse effect was observed, with prawn stocks increasing as a result of the IFF activity, resulting in increases in revenue and profitability of the fishery. Although blacktip sharks are a predator of both tiger and banana prawns, prawn predation accounts for only around 2 per cent of their diet, and the sharks account for only 0.1 per cent of the total prawn predation. Many of the main shark prey species are also not predators of the prawns. For example, over 60 per cent of the blacktip shark diet consists of sardines, tunas and mullets, none of which are predators of prawns. Ponyfish contribute a further 12 per cent to the diet of blacktip sharks, but less than 0.1 per cent of their diet consists of prawn species, and account for only 1 per cent to the total prawn predation.

The impact of IFF on the prawn stocks may, however, be through the discarded species. The trevallies and barramundi species group, and the cobia, grouper and jacks species group account for around 26 per cent of total prawn predation. These groups are both believed to be caught and discarded as bycatch by the illegal foreign fleet. The additional fishing pressure on these groups through the IFF activity may have had beneficial effects on the prawn fishery.

Ceasing IFF in 2007 was estimated to increase annual profits in the Gulf by as much as 13 per cent by 2020 (relative to continuing IFF), assuming Australian fishing effort does not increase to dissipate these potential gains. Ceasing IFF is also projected to result in recovery of the blacktip shark, mackerel and billfish stocks, the latter two of which are caught as bycatch by the illegal foreign fleet. Stocks of other species are largely unaffected. However, recovery of depleted stocks is not always assured in reality. In some cases, the ecosystem may find alternate stable states. Failure of cod stocks to recover in Newfoundland and the North Sea are typical examples where reducing fishing pressure does not guarantee stock recovery (Schrank 2005; Pascoe and Burnett 2007).

Controlling IFF, however, is complex. The potential returns are high to the boat owners, and the cost of capital invested in the fishery is low. The crew have few alternative employment opportunities in their home regions that can match the potential gains of illegal fishing in Australian waters. Even with confiscation of the vessel and gear, the cost of apprehension to the vessel owners is low, and the crew usually incur the cost of any gear lost (Fox and Sen 2002). Often, the only way the crew can re-pay the resulting debt is to continue to fish illegally (Fox and Sen 2002).

In contrast, the cost of preventing IFF is considerable. Roughly \$80 m a year has been allocated to surveillance, apprehension, transportation, processing and accommodation of the several thousand illegal foreign fishermen detained each year over the period 2006–2007 to 2008–2009.[7] While this is for all Australian waters, much of the activity currently occurs in Northern Australia, of which the Gulf is a key area. Although the cost of enforcement of the Australian EEZ appears high relative to the costs imposed on the fishing industry identified in this study, maintaining sovereignty of territorial waters and environmental conservation are additional consideration over and above the fisheries related benefits. Further, IFF could have conceivably been higher in the absence of such enforcement, with subsequently greater costs to the fishing industry.

The surveillance program currently operating in Northern Australia has been successful in apprehending a number of illegal foreign vessels, and there is evidence that the level of IFF effort has declined by as much as 80 per cent since the end of 2005 (Salini *et al.* 2007). Had this program not been in operation,

[7] In May 2006, the Australian Ministers for Fisheries, Forestry and Conservation, Defence, and Justice and Customs announced a budget of \$389 m over the period 2006–2007 to 2008–2009 for combat illegal foreign fishing in Australian waters (Department of Agriculture, Fisheries and Forestry 2006). Of this, around \$150 m was allocated to specific projects, leaving roughly \$240 m for other operational aspects, or \$80 m a year on average.

it is unclear how much greater IFF may have been, and correspondingly, how much lower Australian production may have been.

Longer term measures to reduce IFF in Northern Australia will need to include the development of incentives to undertake activities other than IFF. This may be through regional development projects that provide alternative employment opportunities, and increase the opportunity cost of participating in illegal fishing.

6. Conclusions

IFF in the Gulf of Carpentaria is estimated to have had a significant negative economic impact on several State fisheries, and also to have contributed to the decline in shark populations in the Gulf. While the costs to the fishing industry imposed by the IFF activity appear relatively low, these may have been substantially higher had not the current enforcement measures been in place.

The model results for the State line and gillnet fisheries are, reassuringly, similar to what could be predicted without the use of such a complicated model. The key advantages of using such a model is that unexpected results, such as the impact on the prawn fleets, could not be predicted as they are a consequence of a complex set of interactions at the biological level.

The model results suggest that the system may return to its pre-1990s state if IFF ceases (other legal fishing pressures not withstanding). While this suggests that any ecosystem changes that have occurred may be reversible, the model does not allow for hysteretic effects that may exist in real life. As a result, recovery from the current position is not guaranteed, while further deviations from the current position through continuing IFF is likely to increase the probability that the system will not recover to its pre-1990s state.

The solution to the IFF problem, however, is unclear. Enhanced surveillance activity may increase the deterrent, but the low opportunity cost of both capital and labour will most likely still result in incentives to undertake illegal fishing. Shore-based solutions in-country may provide greater benefits through providing alternatives for the fishers, thus increasing their opportunity cost of participating in the illegal fishing activity.

References

ABARE (2006 and earlier issues). Australian Fisheries Statistics 2005, Canberra, July.

Alasdair, B., Sumaila, U.R., Christensen, V. and Pauly, D. (2002). A model for the bioeconomic evaluation of marine protected area size and placement in the North Sea, *Natural Resource Modelling* 15, 413–437.

Arrequín-Sánchez, F., Hernández-Herrera, A., Ramírez-Rodríguez, M. and Pérez-España, H. (2004). Optimal management scenarios for the artisanal fisheries in the ecosystem of La Paz Bay, Baja California Sur, Mexico, *Ecological Modelling* 172, 373–382.

Briggs, M.R.P. (2003). Destructive fishing practices in south Sulawesi Island, east Indonesia and the role of aquaculture as a potential alternative livelihood. A Report to the Collaborative APEC Grouper Research and Development Network (FWG/01/2001).

Christensen, V. and Walters, C. (2004). Ecopath with Ecosim: methods, capabilities and limitations, *Ecological Modelling* 172, 109–139.

Department of Agriculture, Fisheries and Forestry (DAFF) (2005). *Australian National Plan of Action To Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing*. Department of Agriculture, Fisheries and Forestry, Canberra.

Department of Agriculture, Fisheries and Forestry (DAFF) (2006). $388.9m budget boost in fight against illegal foreign fishing in Australian waters Media release DAFF06/035AJ, 9 May 2006. DAFF, Canberra.

FAO (2001). *International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing*. Food and Agriculture Organisation of the United Nations, Rome.

Fox, J. and Sen, S. (2002). *A Study of Socio-economic Issues Facing Traditional Fishers Who Access the MOU Box*. A report for Environment Australia. Research School of Pacific and Asian Studies, Australian National University, Canberra.

Fong, Q.S.W. and Auderson, J.L. (2002). International shark fin markets and shark management: an integrated market preference-cohort analysis of the blacktip shark (Carcharhinus limbatus), *Ecological Economics* 40, 117–130.

Gray, M.C., Altman, J.C. and Halasz, N. (2005). *The Economic Value of Wild Resources to the Indigenous Community of the Wallis Lakes Catchment*. Discussion Paper No. 272/2005. Centre for Aboriginal Economic Policy Research, Australian National University, Canberra.

Griggs, L. and Lugten, G. (2007). Veil over the nets (unravelling corporate liability for IUU fishing offences), *Marine Policy* 31, 159–168.

Henry, G.W. and Lyle, J.M. (eds) (2003). *The National Recreational and Indigenous Fishing Survey*. Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.

MRAG (2005). *Review of Impacts of Illegal, Unreported and Unregulated Fishing on Developing Countries: Synthesis Report*. Marine Resources Assessment Group Ltd, London.

Myers, R.A., Baum, J.K., Shepherd, T.D., Powers, S.P. and Peterson, C.H. (2007). Cascading effects of the loss of apex predatory sharks from a coastal ocean. *Science* 315, 1846–1850.

NSW Fisheries (2002). *Survey of Recreational Fishing in New South Wales*. NSW Department of Primary Industry – Fisheries, Sydney.

Okey, T.A. (ed.) (2006). A trophodynamic model of Albatross Bay, Gulf of Carpentaria: revealing a plausible fishing explanation for prawn catch declines. CSIRO Marine and Atmospheric Research Paper 010, Cleveland, Queensland, Australia.

Okey, T.A. and Wright, B.A. (2004). Toward ecosystem-based extraction policies for Prince William Sound, Alaska: integrating conflicting objectives and rebuilding pinnipeds, *Bulletin of Marine Science* 74, 727–747.

Okey, T.A., Griffiths, S., Pascoe, S., Kenyon, R., Miller, M., Dell, Q., Pillans, R., Buckworth, R., Gribble, N., Bishop, J., Milton, M., Engstrom, N., Salini, J. and Stevens, J. (2007). The effect of IUU fishing on the ecosystem in the Gulf of Carpentaria: management options and downstream effects on other fisheries. Australian Fisheries Management Authority Project 2006/825 Final Report. CSIRO Marine and Atmospheric Research, Cleveland, Australia.

Pascoe, S. and Burnett, A. (2007). Recovering from overexploitation: the European fisheries of the North Sea, *International Journal of Global Environmental Issues* 7, 158–173.

Rose, R. and Kompas, T. (2004). Management Options for the Australian Northern Prawn Fishery: An Economic Assessment, ABARE eReport 04.12 Prepared for the Fisheries Resources Research Fund, Canberra, August.

Salini, J., Edgar, S., Jarrett, R., Lin, X., Pillans, R., Toscas, P. and Wang, Y.-G. (2007). Estimating reliable foreign fishing vessel effort from Coastwatch surveillance and apprehension data. Report prepared for the Australian Fisheries Management Authority (AFMA project 2006/819).

Schrank, W.E. (2005). The Newfoundland fishery: ten years after the moratorium, *Marine Policy* 29, 407–420.

Stevens, J.D., Bonfil, R., Dulvy, N.K. and Walker, P.A. (2000). The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems, *ICES Journal of Marine Science* 57, 476–494.

Sumaila, U.R. and Vasconcellos, M. (2000). Simulation of ecological and economic impacts of distant water fleets on Namibian fisheries, *Ecological Economics* 32, 457–464.

Sumaila, U.R., Alder, J. and Keith, H. (2006). Global scope and economics of illegal fishing, *Marine Policy* 30, 696–703.

Vance, D., Bishop, J., Dichmont, C., Hall, N., McInnes, K. and Taylor, B. (2003). Management of common banana prawn stocks of the Gulf of Carpentaria: separating the effects of fishing from those of the environment. CSIRO Marine Research. AFMA Final Report, Project No: 98/0716.

Vince, J. (2007). Policy responses to IUU fishing in Northern Australian waters, *Ocean and Coastal Management* 50, 683–698.

Zeroni, P. (2006). *Fishery Status Reports 2005*. Fishery Report No. 85 Department of Primary Industry, Fisheries and Mines, Darwin.

Zeroni, P. and Wood, L. (eds) (2005). *Fishery Status Reports 2004*. Fishery Report No. 82 Department of Primary Industry, Fisheries and Mines, Darwin.