Chapter 22

Ecosystem Effects of Fishing

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22.1 Introduction

The marine ecosystems are highly productive and are being used as a source of recreation, food, pharmaceuticals and livelihood. The relative contribution of the different sectors using it is roughly double the value of goods and services provided by terrestrial ecosystems and comparable to the level of Global GDP (FAO, 2003). Impacts of these uses on marine ecosystems have been reviewed by Jennings and Kaiser (1998), Pauly et al. (1998), Hall (1999), Dayton et al. (2002), Garcia et al. (2003), Sinclair and Valdimarsson (2003), Barnes and Thomas (2005) Myers and Worm (2005) and others. Fishing is one of the oldest and most diverse means of making a living known to humankind. Over the years, due to rapid geographical expansion and technological advancements, the catches have substantially increased and this has defiantly shown to put pressure on the ecosystem. A multitude of fishing gear types are currently in use worldwide, many meant to target specific, commercially-valued species and others that are relatively indiscriminate in their catch (Watson et al., 2006a).

22.2 Ecological consequences of fishing

Fishing mostly imposes three types of effects on fish population dynamics: direct effects on population density and on the mean size of individuals; short-term environmental effects on growth and reproduction, mediated by phenotypic plasticity and density-dependent mechanisms; and long-term effects due to the selective pressure imposed by harvesting. While the problems raised by the first type of effects are commonly addressed by fisheries assessment models and management policies, the other two types of effects are seldom considered. This is partly because these effects are difficult to separate and may be contradictory. Further, the effects will be different for diverse species and a unique response to either a short-time or long-time impact cannot be easily inferred (Rochet, 1998; 2000). Some of the important effects of fishing on marine ecosystems are discussed in the following sections:

22.2.1 Serial depletion

One of the important impacts of fishing involves the shift from prized species to relatively less valuable species, as the prized ones decline in abundance (Dayton et al., 2002). When these less valuable species also decline, fishermen move to yet another species lower in the food web and so on. This sequential or serial overfishing of different species is characteristic of overfished ecosystems (Murawski, 2000). It is a contributing factor in the decline of entire assemblages of commercially valuable populations and has been reported from all major fisheries of the world (Fogarty and Murawski, 1998; Orensanz et al., 1998).

22.2.2 Effects of removing top-level predators in marine food webs

Another ecological process among exploited populations is the shift from higher trophic levels to lower ones. After the removal of top-level predators to the point of fishery closure or economic extinction, the fishery turns to the capture of the prey species. This results in the decline in the mean trophic level of the catch. This "fishing down the food web" is a top-down ecological problem, having its greatest documented influence through the removal of predators at the peak trophic levels with concomitant changes among their competitors and prey (Pauly et al., 1998; Christensen et al., 2003; Bhathal, 2004; Vivekanandan et al., 2005). Examples of truncated trophic webs occur worldwide. In addition to trophic shifts, the changes often reveal unexpected linkages among species not normally considered to interact. This sequential overfishing of different species is characteristic of over fished ecosystems (Pauly et al., 2002).

22.2.3 Effects of removing low-trophic-level species on marine food webs

Lower trophic level species such as sardines, herrings and anchovies typically mature rapidly, live relatively short lives and are extremely abundant. As a result, they are among the most heavily exploited species in the world. Single-species models, particularly those based on maximum sustainable yield, suggest that lower trophic-level species have tremendous potential for sustainable exploitation. But these assumptions may not be true in an ecosystem perspective. The heavy exploitation of these species may increase populations of their competitors and declines in populations of their predators as a result of food scarcity and affect ecosystems from intermediate levels up and from intermediate levels down (Mackinson et al., 1997). The ecosystem models suggest that large removals of forage species could work synergistically with heavy nutrient loading to exacerbate problems of eutrophication in enclosed coastal ecosystems.

22.2.4 Cumulative and synergistic impacts

The cumulative or synergistic contributions of top-down and bottom-up effects on ecosystems can be difficult to detect and equally difficult to apportion causes due to individual stress (Micheli, 1999). Myers and Mertz (1998) used meta-analysis of time series data to determine bottom-up and top-down pressures on marine food webs. The inherently complex interactions combined with inputs from anthropogenic sources, make the system very complex and hard to predict. The most important lesson derived from these models is that fishing impacts on ecosystems are diffuse, diverse, and difficult to predict (Mazzola et al., 2000; Naylor et al., 2001).

22.2.5 Depensation

It has been reported that the per capita reproduction declines significantly when the population size of a species falls below a critical level and the phenomenon is known as depensation (Dayton et al., 2002). The less mobile species are more vulnerable to depensation (Lillie, 1915; Stokesbury and Himmelman, 1993; Tegner and Dayton, 2000; Stoner and Ray-Culp, 2000). These animals stop reproducing when the density declines below a critical limit. Walters and Kitchell (2001) has given an example of depensation occurring because of a fishery-induced food web shift. The declines in abundance of top-level predators may lead to increased abundance of forage species which in turn may prey upon the juveniles of their predators. This results in decreased juvenile survival, affecting top-level predator populations further. Increased susceptibility to environmental variation in highly variable environments can significantly affect reproductive success.

22.3 Impacts of different fishing systems and mitigation measures

Different fishing systems impact on ecosystems differently, depending on their design features, principles of fish capture and methods of operation. Discards and incidental catches form an important source of uncertainty both in the stock assessment and management and the ecological ramifications of huge quantities of bycatch generation have come to the fore. Annual bycatch in the world fisheries was estimated at 29 million t of which 27 million t was discarded (Alverson, 1994). Shrimp trawling accounted for 35% (9.5 million t) of the total world bycatch (Alverson, 1994). During 1996 average annual global discards was around 20 million t and it came down to 7.3 million t in 2004 (Kelleher, 2005). The actual quantum of discards is difficult to quantify because of the scarcity of statistical information about catch, effort and population features. Also due to its secondary nature from an economic point of view, these species are left aside when planning management regulations. Nevertheless, as in the case of target species, fishing pressure affects the distribution, abundance and population structure of incidentally caught species also (Alverson et al., 1994; Philippart, 1998; Hall et al., 2000) and thus overexploitation risks are high, especially under high fishing effort levels on co-occurring target species (Heessen and Daan, 1996). Problem of sequential depletion hypothesis, which means an overexploitation of target species first and incidental ones later on is also reported (Hall, 1996).

Discards and offal dumped from the fishing vessels can form a temporary source of food for the scavenging birds (Andrew and Pepperell, 1992; Britton and Morton, 1994), but are also found to cause local anoxic zones that effect resident populations (Dayton et al., 1995) and may outweigh the benefits derived from the additional source of food. In addition, these food subsidies can attract novel communities that shift from scavenging bycatch during the highly seasonal fishing season to foraging on resident species when fishing stops.

22.3.1 Trawl and other bottom gear

Fishing operations with trawls and other mobile bottom gear like beam trawl and dredges invariably create changes in the bottom structure and impacts on the fauna and flora associated with these structures (Witbaard and Klein, 1994; Kaiser et al., 1998; Auster, 1998; Hall, 1999; McConnaughey et al., 2000; Jennings et al., 2001; Gaspar et al., 2002; Thomas, 2003; Thomas et al., 2004; Thomas and Kurup, 2004; Kurup et al., 2004; Barnes and Thomas, 2005; Brown et al., 2005; Bijukumar and Deepthi, 2006; Gray et al., 2006; Queiros et al., 2006; Thomas et al., 2006; Meenakumari et al., 2008). This problem becomes more acute where the return intervals are shorter than the time it takes for the ecosystem to recover (Watling and Norse, 1998). Epifaunal organisms provide structure and habitat diversity in what may be a relatively uniform environment, either through their physical presence or by their feeding and excavating activities (Langton and Robinson, 1990; Auster et al., 1996). Habitat complexity has been shown to increase the survival of juveniles of commercial species by reducing predation pressure. Encrusting epifaunal species such as Serpulid worms and sponges, provide complex microhabitats that support specific benthic assemblages with relatively high diversities (Haines and Maurer, 1980; Peattie and Hoare, 1981; Duarte and Nalesso, 1996). The removal of such biogenic structures through physical disturbance caused by towed gear operations, will have repercussions on both the associated assemblage and the fauna that feed and shelter around them.

Ploughing and scraping the bottom up to a depth of 30 cm is found to be common in the clayey areas of trawling grounds (de Groot, 1984). The direct mortality is largely attributed to animals that die in the trawl track, either as a direct result of physical damage inflicted by the passage of the trawl or indirectly owing to disturbance, exposure, and subsequent predation. A single pass of standard trawl is found to reduce the diversity of benthic organisms by 5 to 40 % of the initial levels (Moran and Stephenson, 2000; Bergman and Van Santbrink, 2000; Jagadis et al., 2003; Gilkinson et al., 2005; Kenchington et al., 2006). The study of Sainsbury et al. (1997) have reported benthos mortality up to 89 % after a single pass of an otter trawl in case of sedentary epifaunal species such as anemones, soft corals, sponges, whelk eggs, bryozoans and ascidians. The populations of epifaunal species with certain amount of mobility like crabs, sea stars, whelks etc., tend to re-establish after the fishing pressure is reduced (Smith et al., 2000). Benthic communities play an important role in re-mineralization and release of nutrients in marine ecosystems. Disturbances created by mobile fishing gears temporarily alter the redox state of the system and hence effecting re-mineralization. The rate of sediment infilling of disturbed plots caused by scraping and ploughing is strongly correlated to the recovery rate of the numbers of individuals within disturbed areas. The sediment filling depends on the nature of the habitat and clean sand communities had the most rapid recovery rate following disturbance, whereas communities from muddy sand habitats had the slowest physical and biological recovery rates. Physical and biological recovery rates depends on a combination of physical, chemical and biological factors that differ in their relative importance in different habitats (Dernie et al., 2003).

Since bottom trawling is being carried out along all shelf areas in the world with different habitat structures, the effect of disturbances in all of these may be difficult to discern and quantify with a generic model. Models that can incorporate these variations and the structural patterns in relation to fishing effort can be of immense help (Auster, 1998; Lindholm et al., 2001). Gear modifications are an excellent alternative to reduce the impact of bottom trawling. The use of semi-pelagic trawl, modified clam dredges etc., are reported to have reduced damaging effect on the benthic fauna (Moran and Stephenson, 2000; Gaspar et al., 2003; Valdermarsen and Suuronen, 2003). Bottom trawl and dredge inducted turbidity is also reported to be significant (Palanques, 2001; Pranovi et al., 2004) and can effect the distribution and growth of filter feeders.

22.3.2 Gill nets and seines

Gill netting is widely practiced in small scale coastal fisheries and in the high seas (Watson et al., 2006a). Studies comparing the fishing power of different fishing gears in Danish fisheries show that individual fishing power of gill nets is increasing at a rate of 6% in comparison to an average of 2% in trawler fleets (Marchal et al., 2001). The relative low investment of the gear and low operational costs compared to other active methods, small-scale fishers and the industrial fleets tend to construct larger fleet of gill nets made of non-biodegradable material. Once set, the nets are allowed to drift with the wind and currents, indiscriminately entangling any living creature that swims into them, including marine mammals. Marine mammals, sea turtles and seabirds are entangled during gill net operations. In view of its negative impacts, the General Assembly of the United Nations imposed a global moratorium on all large-scale pelagic drift net fishing on the high seas, including enclosed and semi-enclosed seas from December 1992. Another problem mainly associated with the drift nets are that they often break away from the fleet and the lost nets may continue to fish (ghost fishing). Cetaceans are sometimes caught during purse seining operations.

22.3.3 Long lines

Although overall impact rates from individual long lines are extremely low, the quantum of gear deployed by longline vessels suggests that cumulative effects are substantial. Watson et al. (2006b) suggested that the global catches from the hooks and lines are almost same as that of gill nets. Current estimates suggest that pelagic longline bycatch is high enough to warrant management actions in all fleets that encounter sea turtles and sharks. Studies by Myers and Worm (2003) reveal an alarming reduction of 80% in the population of the apex predators caught by long lines from the early exploitation phase. There is an associated bycatch of non-targeted species like pelagic sharks, sea turtles and sea birds during tuna long lining (John and Neelakandan, 2003; Lewison et al. 2005; Beverly, 2007). The International plan of action for conservation and management of sharks requires that participating states with targeted shark fisheries work towards sustainable fishing and use of shark resources. Methods like deploying deep setting of tuna hooks has been shown to be very effective in reducing the catches of turtles in tuna longliners (Beverly, 2007). Use of modified hooks like the circle hooks instead of the traditional J hooks are found to reduce the mortality of the hooked non-targeted species (Watson et al., 2005) and can be made mandatory for certain fisheries.

22.4 Impact of fishing on marine mammals

Due to their role as the apex predators in the ecosystem, their unique breeding habits and also due to the inadequate knowledge of their ecological roles and interaction with fisheries, the effects of fishing on these organisms demand urgency (Pauly et al., 1998; Northridge, 1991; Bjorke, 2001; Evans and Hindell, 2004; Laidre et al., 2004). The significant decease in the population of cetaceans in the last two decades is mostly ascribed to incidental catches of marine mammals in the long lining and drift netting operations in the high seas (Heide-Jorgensen and Reeves, 1996; Kumaran, 2002). Cetacean bycatch in purse seine is widely reported (Morizur et al., 1999; Kennelly and Broadhurst, 2002). Marine mammal as bycatch during trawling are also reported (Svane, 2005). When caught in fishing gear, small whales, dolphins and porpoises often die because they are not strong enough to break free and come to the surface to breathe. Large whales which break free may continue to tow some of the attached gear for long periods, causing enervating injuries and even slow death. Lines, for example, can coil around an animal's head or lodge in its baleen, interfering with feeding. Perrin et al. (1994) and Read et al. (2006) have reported that a significant number of dolphins and porpoises are killed globally each year in the gill net fisheries. Information on other marine mammals such as seals and sea lions is meager (Moore, 2003; Northridge, 1991). Some management measures that can reduce the problem of mammalian bycatch in the fishing system include:

- Relatively simple and inexpensive alterations (Samaranayaka et al., 1997) in fishing methods and gear are found to be useful in reducing the damaging impacts. Attaching acoustic alarms or pingers to fishing nets or acoustically reflective gillnets to alert cetaceans regarding the presence of fishing gear help them swim away from the nets (Trippel et al., 1999; Carlstrom et al., 2002).

- Cetacean catches in the purse seines can be abated by facilitating their escape by the use of Medina panels in the gear and 'backing down' procedure during hauling.

- Time-area restrictions can also be used to control the bycatch of non-target species in situations where there is significant co-occurrence between the catch of target and non-target species (Samaranayaka et al., 1997; Goodyear, 1999; Murawski et al., 2000).

- Clear management objectives, involvement of stakeholders, strict implementation and adopting case-specific approaches will help in mitigating much of the problems associated with the fishery related impacts on marine mammals.

22.5 Impact of fishing on seabirds

Most of the interactions of seabirds are a direct consequence of their foraging in the same region as vessels are fishing or an indirect consequence of their attraction to the vessels to scavenge from hooks or offal and also from the discards (Tasker and Reid, 1997; Walter and Becker, 1997; Barrett et al., 2002; Engas and Foster, 2002; Martinez-Abrain et al., 2002). Bycatch of albatrosses, petrels, and shearwaters in longline fisheries is one of the greatest threats to seabirds worldwide (Tasker et al., 2000; Cousins and Cooper, 2000). Methods like improving the sinking rate of the hooks, so that they sink fast and make the food and the hook unavailable and the use of streamer lines from a stern-mounted poles are found to reduce the bycatch of seabirds significantly. Employing the hooks at night was also found as excellent strategy to reduce bird bycatch (Brothers, 1991).

22.6 Impact of fishing on coral reefs

In the coral reefs that are overfished, a decreased presence of large, long-lived carnivore fishes has been reported and the fishery is mostly constituted by small, short life span herbivore fishes (Bellwood et al., 2004). The selective removal of herbivorous fishes that feed on the algal species and increased nutrient availability through domestic runoffs from settlements near the reef structures may facilitate the growth of algal species which are detrimental to the coral wellbeing (McClanahan and Muthiga, 1998; Pet-Soede et al., 2001; Jagadis et al., 2003; Chiappone et al., 2005; Mangi and Roberts, 2006). Several authors have described the prevalence of Malthusian overfishing in the reef ecosystems, which is primarily due to the human interventions (McManus, 1997; McClanahan et al., 1999; McManus et al., 2000; Bellwood et al., 2004).

22.7 Recovery of affected populations

The ability and speed with which a population recovers depends largely on the life history characteristics of the species and the natural history of the community within which the species is embedded. Myers et al. (1995) found that reduced fishing mortality rates would lead to population recovery in cod, plaice, hake and other economically important species. Recovery appears to be the rule rather than exception but depends on the resilience of the population under consideration (Hutchings, 2000). Thus, some species such as herring, sardines, anchovies, and menhaden that mature at relatively young age and feed lower on the food chain, tend to respond more rapidly to reduced fishing pressure than do species that mature late and live longer. Less resilient species include tropical reef fishes such as snappers and groupers and deep-sea fishes worldwide (Koslow et al., 2000). The marbled rock cod (*Notothenia rossi*) fishery of the Indian Ocean and the black-lipped pearl oyster (*Pinctada margaritifera*) fishery in the northwest Hawaiian Islands are examples of such fishery collapses (Dayton et al., 2002).

22.8 Conclusion

The diversity of fishing gears and practices and intensity and efficiency of fishing operations have increased significantly during the recent decades. Fishing has a significant impact on ecosystem which may vary from effects on the sea bottom caused by towed gears such as bottom trawl to impacts on cetacean populations caused due to large scale driftnet operations. Studies by Pauly and Christensen (1995) indicated a much higher ecological footprint for fishing than expected based on the primary production required to sustain a given fishery. Pauly et al. (1998) described the existence of a global "fishing down marine food webs effect" based on the steadily decreasing trend of the average trophic level (TL) values of catches recorded for the period 1950-1994. There is growing consensus on the importance of rebuilding degraded ecosystems, mostly through marine protected areas (MPAs) and using them as a precautionary tool for the systemic management of fisheries (Pitcher and Pauly, 1998; Hastings and Botsford, 1999). These precautionary ecosystem-based measures should be accompanied by general improvements in selectivity of gears and fishing practices, the minimization of the environmental impacts of fishing; removal of excess fishing capacity and illegal, unregulated and unreported (IUU) fishing; awareness building and education of the fishermen in responsible fisheries; and reorienting subsidy schemes towards sustainable fisheries.

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