Effects of Demersal Fishing on the High Seas

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Abstract

This paper concentrates mainly on the effects of fishing on, or near, the seafloor in the High Seas; i.e., it will say little about the effects of pelagic fishing, the hunting of cetaceans, krill harvesting, etc. Fishing has large effects, direct and indirect, on the fished stocks and on the rest of the ecosystem. Those effects are universally such that, without management or restraint of some kind, fishing is not ecologically sustainable by UN (WCSD) definitions. Most of the evidence for that statement comes from studies within EEZs; some examples will be mentioned from Australian research. There is no reason to suppose that the unsustainability is in any way diminished if the fishing occurs in the High Seas rather than in national EEZs; in fact, in some respects it is worse. This is illustrated by some examples of demersal fishing, which, although within EEZs, has some of the characteristics of High Seas demersal fisheries. The examples do show that actions can be taken to diminish the effects and to make the fishery ecologically sustainable. They will not be done, however, unless there is a will to do them, and this takes considerable effort to develop. In addition, we have to recognize the possibility that in some cases the biology and ecology of the system may be such that there is no way to fish sustainably.

Introduction

It is well known that fishing has profound effects, both direct and indirect, both on target species and on other parts of the ecological system. We do not propose to review these effects systematically; there are many publications on them, such as Hall (1999), Jennings and Kaiser (1998), Jennings *et al.* (2001) and the proceedings of the ICES/SCOR symposium on the ecosystem effects of fishing (Hollingworth 2000). We structure our remarks by habitat-type, and focus attention on demersal fishing (on or near the seafloor). However, a few reminders of the general effects follow.

Direct effects of fishing on target species include a huge mortality rate that is selective with respect to size, age and behaviour. This constitutes a selective pressure that can lead to changes in population size, age and size structure, growth rates, reproductive age or size, and genetic structure of stock. There is a large literature on these effects (Butler *et al.* 2001; Kirkpatrick 1993; Stevens *et al.* 2000; Reid *et al.* 2000; Heino and Godø 2002; Jennings and Kaiser 1998) and we merely note that all of them will apply in High Seas fisheries just as inside EEZs.

The impacts of pelagic fishing have been recently reviewed through the use of historical data. Using catch data from pelagic longlines, the most widespread fishing gear, Myers and Worm (2003) suggest that losses of large predatory fishes have especially influenced marked changes in coastal and shelf ecosystems. As a result of release from predation, species compensation has resulted in noted increases in non-target species (Jackson *et al.* 2001, Myers *et al*. 1997, Pauly *et al.* 2002, Worm and Myers 2003), and ultimately impacts on both ecosystems and biodiversity.

To many people, the term "bycatch" suggests "non-target species of fish", but bycatch also includes marine mammals, turtles, seabirds and benthic invertebrates etc. Bycatch also includes non-commercial sizes of target species – a source of mortality that is often underreported. Bycatch issues for High Seas pelagic and demersal longline fishing include direct mortality through hooking and gear entanglement (Klaer and Polacheck 1997, Croxall and Gales 1998, Gales *et al.* 1998, Kock 2001, Tuck *et al.* 2003) and an indirect effect via alteration of food supply (Crawford and Dyer 1995, Croxall *et al.* 1999, Kitaysky *et al.* 2000, Monaghan *et al.* 1992). For the High Seas demersal trawl fisheries the main bycatch issues are benthic invertebrates and non-target species of fish. The demersal longline is used sparingly on the High Seas but its impacts on marine mammals, turtles and seabirds can be similar to those of pelagic longlines. These effects can be reduced by using mitigation measures, such as gear that sinks rapidly, deploying bird-scaring lines, and avoiding areas/times of known high incidental mortality (Klaer and Polacheck 1998). An advantage of the demersal longline is that it unlikely to have as great a negative impact on the benthos as demersal trawling.

A remaining, major concern with respect to both pelagic and demersal fishing is the effects of illegal, unreported and unregulated (IUU) fishing (Bray 2000), because of the inherent difficulties in applying responsible fisheries management measures or CCAMLR's conservation measures (Constable *et al.* 2000, Tuck *et al.* 2003).
Although we have made some remarks above about pelagic fishing, this paper concentrates primarily on the effects, direct and indirect, of demersal fishing (i.e., fishing on or near the seafloor) in the High Seas. There is little information from the High Seas, but some inferences can be made from similar environments within EEZs.

<u>Characteristics of Target Species in High Seas demersal fisheries</u>

The deep sea is generally considered an environment in which the food supply (a "rain" from the photic zone) is at low density. Many organisms depend on the hydrological concentrating effect of features such as seamounts to provide a higher food supply than the deep oceanic "average", producing high (local) population densities on seamounts and cinder-cones. Similarly, demersal deep-sea species which are typically widely dispersed – and previously though of as scattered, rare, or of low productivity – have been found to aggregate for breeding events on features such as seamounts.

These aggregations provide a focal point for fishers, and a stock that can be effectively captured, even as the stock reaches very low levels.

Deep-water fisheries are generally based on different orders, and display very different physiology and ecology from those fished on the shelf (Boehlert and Genin 1987). Of the fish families commercially exploited on the continental shelf, only the family Pleuronectidae is also commonly exploited in deep waters (Koslow *et al.* 2000). Although these deepwater fish assemblages are developed from different family groupings in different biogeographic provinces of the world, all aggregating species tend to be deep-bodied, strong swimmers, with similar physiology (Koslow *et al.* 2000). Even though they frequent areas where the characteristically low productivity of the deep sea is locally enhanced, e.g. by the hydrology of seamounts, ridges and shelf-breaks, many of these fish are long-lived, slow growing species, with a delayed maturity (e.g. Berycidae, Gadiformes, orange roughy and Oreosomatidae). They generally exhibit low fecundity and, where estimated, highly variable recruitment (Butler and Smith 1992, Koslow 1996, Koslow *et al.* 2000).

Most importantly (despite the local increase of productivity due to the seamount) these species have characteristically “stress tolerant” (Grime 1979) life-histories – adapted to a limited resource and risky lifestyle – they display long life and low rates of production. Examples of such species include orange roughy, which may live to more than 100 years, and *Sebastes* spp., living to more than 50 years. These slow-growing, low fecundity species will have many reproductive episodes during such a long adult life – most of them of limited success. Such species are known and understood in other environments, and characteristically they *rely* on long life and occasional highly successful recruitment for their ecological stability (Butler and Chesson 1990). They cannot necessarily survive exploitation, which effectively shortens adult lifespan (Butler and Smith 1992, Heino and Godø 2002). Typically, such species are simply *not* adapted for exploitation. This is illustrated by the history of the deep-water fisheries. From the initial 1950’s rapid rise in landings, total landings remained relatively stable (800,000 – 1 M tonnes /yr), but this masks declines in species after species, as new fisheries developed to replace stocks that were fished down. The Redfish fishery consecutively exploited three major *Sebastes* species with CPUE now declined to 10% of the 1980’s levels and landed fish now being of much smaller size (Koslow *et al*. 2000). Northwest Atlantic *Coryphaenoides rupestris* stocks peaked in 1971 and declined quickly, while Northeast Atlantic stocks peaked in 1975 and continued to fluctuate, CPUE falling 50% between 1991 – 1996 (Koslow *et al*. 2000). The orange roughy fishery developed in New Zealand in the early 1980’s and peaked in 1990, but was fished down within several years. Within 10 years, remaining stocks were at 15-30% of initial biomass, and currently exist at only 1-2% of their virgin biomass (Clark 1995). The fishery on the South Tasman Rise (STR), jointly managed by Australia and New Zealand, illustrates this pattern (Figure 1). The stocks in Australian, NZ waters and impinging or straddling the two EEZs are under active management (unlike those of most concern in waters of the High Seas), but the total allowable catches (TAC) imposed are now small, and

Koslow *et al.* (2000) note "stocks too small to be actively managed, or those in international waters, are still at risk of depletion". There are other examples of declines in deepwater fish stocks (Methot *et al.* 1998, Lorance and Dupouy 1998).

It is possible to develop rational fishing regimes provided that there is sufficient understanding of the dynamics of the ecological system, and sufficiently tight control over what the vessels do. (Gaining such control in the High Seas is the challenge for this workshop but will not be discussed in this paper). It must be recognized, however, that once an effective, rational system has been established, it might be discovered that a particular species or stock cannot be exploited economically (the UN definition of ecologically sustainable development includes, of course, economic sustainability). For example, Figure 1 shows the decline in an index of abundance for orange roughy on the South Tasman Rise from 1997-2000 (Note that it is not possible to be certain whether the data in Figure 1 represent a decline in abundance or seasonal variation, but there is other evidence to indicate there has been a decline in abundance). Such declines have been noted across many orange roughy fisheries and often the actual catches are below the total allowable catches set by management (Annala *et al.* 2002, Smith and Wayte 2002, Wayte *et al*. 2001). The industry must judge whether it is economic to put to sea for so few fish, but even small numbers of an aggregating species can provide sufficient fish to make it economically worthwhile for the individual fisher. Putting that economic matter aside, for many of these species, highly episodic recruitment and low fecundity are likely to create a further challenge for stock assessment modeling, resulting in a high risk of stock collapse.

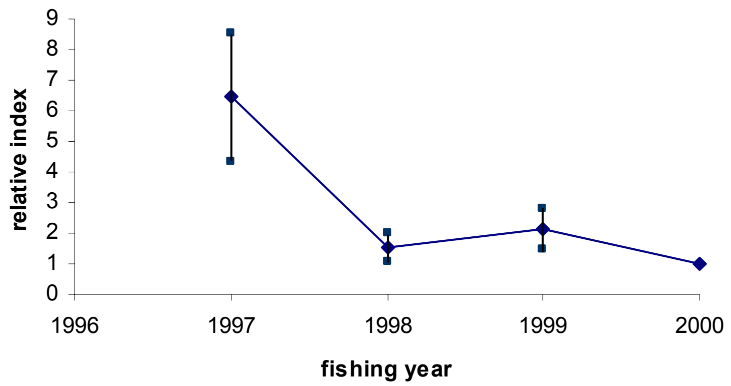

Figure 1. The annual standarised abundance indices for orange roughy (+/- 2 s.e.) on the South Tasman Rise calculated from the catch per shot data using generalized linear modeling (Wayte *et al*. 2001[p11]).

Effects of High Seas demersal fishing on ecosystems

So far we have been considering the effects of fishing on the dynamics of the target species. What of the ecosystem effects? High Seas demersal fisheries may have direct effects on non-target components of the ecosystem, and indirect effects, for example through trophic interactions. The following two sections will discuss the direct and indirect effects of fishing respectively.

Direct effects of High Seas demersal fishing

The general effects of trawling are well known. They include loss of species that form habitat-structure, decrease in biodiversity and a loss of large long-lived organisms (Thrush and Dayton (2002). The direct impacts of High Seas demersal fishing vary depending on the substrata involved. Fauna on stable substrates (such as mud, gravel and coral) are more adversely affected by bottom contact than those on less consolidated coarse sediment (i.e. sand) (Collie *et al*. 2000).

Direct effects on hard substrata

Specific data on the effects of High Seas demersal fishing are hard to obtain and the interpretation of the results difficult. For some organisms within EEZs, attempts at mortality estimates are now appearing (e.g. Hall 1999) and declines in biodiversity are being demonstrated. The direct and indirect effects on the species-composition of fish communities are starting to be documented for shallow waters. However there are still few data available regarding the long-lived modular organisms in deep water. Thus, our understanding of the effects in High Seas locations comes from some detailed studies in shallow waters combined with some observations in-situ and reasonable inferences concerning life-cycles in deeper water, inside EEZs.
The habitat varies greatly between different hard substrata such as Seamounts, ridges, plateaus, and biogenic structures, but typically the structure-forming organisms in the community include hard and soft corals, sponges and crinoids. A well-known example is the coral *Lophelia pertusa*, which forms biogenic reefs in upper slope waters of the north Atlantic Ocean, that are vulnerable to physical damage by trawling (Rogers 1999). There is a diverse range of species associated with deep-water coral assemblages. Our experience on the seamounts south of Tasmania (Probert 1999, Koslow and Gowlett-Holmes 1998, Koslow *et al.* 2001) shows that there is much still to be discovered about them. The fauna is diverse, with relict groups of great scientific interest, and each cruise discovers new species (Butler *et al.* 2001, Richer de Forges *et al.* 2000).

About 300 species of fish and invertebrates have been distinguished from the Tasmanian Seamounts. Some 24-43 % of these were new to science and 16-33 % of them appear restricted to the seamount habitat. These species of Fish, coral and sponge are long lived (70y, 150y and 500y) as determined by growth ring & radionuclide dating, and often mature late. This means that these species are slow to grow and recover from disturbances and catastrophe. It is also likely that they have a limited dispersal range. Richer de

Forges *et al*. (2000) found few species in common between sites along the Norfolk Ridge (coefficient of community 18%), fewer between Norfolk Ridge and Lord Howe Rise in the latitude of New Caledonia (4%); and none in common between those areas and the Tasmanian seamounts. (Similarities between abyssal plain soft-sediment fauna over similar distances are much higher). This low level of similarities between seamount sites and high endemicity suggests that a destroyed seamount may take a long time to recover if it does at all. We need more data on dispersal rates between sites, and there are current proposals to obtain some relevant genetic information in the region of the Tasman Sea.

It is difficult to demonstrate rigorously the effects of fishing on seamounts due to the lack of base line data. However, Koslow *et al*. (2001) were able to make some comparisons between fished and unfished regions in adjacent depths. They found the biomass per dredge was 83% less and the number of species per sample was 59% less on a fished than on a non-fished site. The surface of heavily fished seamounts in the Tasmanian study consisted of bare rock or coral rubble and sand. Although not a strict comparison between before and after trawling on the same sites (Drabsch 2001, Underwood 1994), this finding is highly suggestive of massive habitat removal by trawling.

The available information about the life-histories of these benthic species, their longevities, localised distributions, and limited dispersal, implies risks of local depletion, even extinction of the species in the benthic communities. But we need better understanding of the ecology and biogeography of these species to predict the details of the effects of fishing and to design management measures, including networks of reserves.

Direct effects on Soft Sediments

Again, there is little information from High Seas areas, but experience from nearshore investigations suggests that the common belief that fishing has little effect on soft bottoms is too simple. Hall (1999) records some mortality estimates, and declines in biodiversity are being demonstrated in soft-substrata, as well as hard substrata and biogenic reefs.

Example - Effects of trawling – Australian North-West Shelf

The study by Sainsbury and colleagues (Sainsbury 1988, Sainsbury *et al*. 1997) on the northwest shelf of Australia is familiar to many at this workshop, but of interest in the present context. We mention it also because a management strategy evaluation model (for a complex ecosystem, under multiple uses) is now being developed for this study area; ecosystem based management is a topic to which we return at the end of this paper.

In brief, there were both trawl and trap fisheries in the area. Over time, changes were observed in the species-composition of the catch; and in parallel, there were changes in structural epibenthos on the seafloor. Fish whose abundance declined in the catches were associated with large epibenthos.

The reasons for these changes were not simple, and the possibilities were specified as four hypotheses, which were stated as models. An experiment was designed to test these models by opening and closing areas to different kinds of fishing. This kind of experimental manipulation is the ideal way to test the effects of fishing, but is rarely achieved, and we know of no such investigations in the High Seas.
We note in passing that the experimental approach is also powerful, but insufficiently used, for examination of the direct effects on target species. An example where it has been attempted occurs not far from the site of our workshop. The Effects of Line Fishing experiment, Great Barrier Reef, involves the opening and closing of reefs in a planned design, with monitoring of the fish populations, to examine direct and indirect effects (Campbell *et al.* 2001).

Example - Effects of trawling – soft sediment – Great Barrier Reef

Another example of experimental studies of the effects of trawling on soft sediments, albeit in shallow water, also occurs close to here. It concerns prawn trawling between reefs in the Great Barrier Reef area (Pitcher *et al.* 1997, Poiner *et al*. 1998, Pitcher *et al*. 2000, Burridge *et al*. 2003).

The study compared the biological communities of a closed ("Green") zone with the adjacent areas open to trawling. There were some difficulties in interpretation, which we will not discuss here, but there were very few differences in the abundance of benthic animals between closed and open areas. An important component of the explanation was that trawling is not evenly distributed. About 70% of trawled grounds are trawled less than one pass per year; some limited areas are much more frequently trawled. A large repeat-trawling experiment, to simulate this aspect of commercial trawling activities, showed that with each pass of the trawl, 5-20% of the initial megabenthic fauna was removed; after 13 passes, 70-90% of the initial benthos had been removed. Thus, there is a substantial cumulative effect of trawling but limited effect of a single pass in this case. Different species suffer different levels of impact, e.g. large sponges and flowerpot corals are particularly susceptible, whereas sea-whips and gorgonians are more resistant. These differences mean that trawling causes changes in the composition of seabed communities in the heavily trawled areas, but much of the system suffers no detectable impact.

A Before-After-Control-Impact experiment was then conducted, in which twelve 2.7 x 1.2 km treatment plots were trawled entirely, once-over, and compared with control plots. From one to seven tonnes of benthic material was removed from each treatment plot, but despite this obvious impact, there were few significant differences between the benthic communities in trawled plots and control plots. This is not an artifact due to the low power of the experiment – rather, it is a real result; it tells us that the effect of single-pass trawling is small relative to natural variation.

Direct effects – various habitat types

To generalise from the kinds of findings obtained on the seamounts, the NWS, the GBR and in other studies around the world, the extent of trawl impact is dependent on the:

- type of fishing gear; some gears are far more destructive than others.
- location of fishing activities; habitat types (even within one of our loose categories used above, "hard" and "soft" substrata) vary from stable and highly diverse, with delicate epibenthic species, to highly unstable, frequently disturbed; the impact of fishing gear depends on the disturbance it causes relative to the natural disturbance regime.
- spatial and temporal pattern of fishing even within one habitat type; if it is highly repetitive but only in a few locations, there may be large local effects but minimal broad-scale effects.

Management can make use of information on the spatial and temporal distribution of trawling, the natural disturbance regime, the vulnerabilities and recovery rates of different kinds of biota to evaluate risk and manage for ecological sustainability; such information is becoming available from studies such as those of the effects of trawling in Australia, but is largely unavailable for deep waters of the High Seas.

Most studies of the effects of fishing (direct or indirect) begin with little information on what the habitat looked like before fishing began, and so might obtain misleading estimates of effects. This is the "sliding baseline" problem – a general one receiving much discussion lately (Dayton *et al.* 1998, Jackson *et al.* 2001). However, some studies, like the work on Tasmanian seamounts, are likely to have come fairly close to seeing the pre-fishing community, whilst experimental studies, like the GBR work, do at least have a direct comparison of before and after the experimental treatments.

Indirect effects of deep-sea demersal fishing

Indirect effects of trawl fishing on hard substrata

One of the more visible impacts of trawling is the capture of bycatch, as a result of the gear's low selectivity. Bycatch species are generally discarded at sea, but their survival, although species specific, is unlikely. Prawn trawl-fisheries are estimated to account for over one third of the total global fisheries discards (Pascoe 1997) and primarily consist of teleost and elasmobranch species. Sustainability of teleost bycatch species in this fishery is variable (Stobutzki *et al.* 2001a), although less than 10% may survive (Stobutzki *et al*. 2001b), and gear modifications are being made to reduce the degree of bycatch. Of greater concern are the similarly low rates of survival reported for elasmobranchs, particularly as a result of by-product uses (Daley *et al*. 2002, Stobutzki *et al*. 2001b), and further exacerbated by aspects of elasmobranch life-history (low fecundity, late maturity, etc). It is clear that management strategies will need to be fishery- and species-specific.

Fishing by trawling on features such as seamounts and ridges is also considered likely to have indirect effects through trophic webs. The target species are high-order predators – what is the effect on the rest of the system of the removal of enormous populations of these animals? The benthic commuity is the habitat for a range of species lower in the food-web – what is the effect of their reduction on species higher in the food-web (including target species)? As noted by Gislason (2002), Hall (1999) and others, there is little information to begin to answer such questions, either within EEZs or on the High Seas. We need investigations in which the possibilities are rigorously distinguished.

We have done some very preliminary investigation of the indirect (ecosystem) effects of fishing in the system around the Tasmanian seamounts, by modelling the trophic interactions between species (Bulman *et al.* 2002).

Currently the Tasmanian Seamounts Marine Reserve uses a "layered" design; managed fishing for pelagic species is permitted in the top 500 m of the water column; below that is a "no-take" zone. This design assumes limited connection of the water mass and organisms between the upper 500 m and deeper waters. Although there was good evidence for that assumption, there did remain some doubt as to whether there may be some connection via vertical migration and the hydrodynamic trapping of vertically migrating organisms on the seamounts. If significant connection occurs, then fishing in surface waters could potentially influence the benthic communities; the primary objective of the MPA is protection of the benthic biodiversity on the seamounts.
Bulman *et al*. (2002) developed a model to investigate the trophic connections between the surface and the demersal systems and the energy inputs required to sustain the demersal fish community. A trophic model like this represents a hypothetical column of water over the seamounts and may not apply at *population* level to the predators and prey; the model was designed only to answer the question about the possible effects of surface fishing on the demersal portion of the ecosystem.
The food-web, depicted in simplified form here, was modeled using Ecopath with Ecosim (Christensen and Pauly 1992; Christensen *et al.* 2000; Walters *et al.* 1997). The behaviour of this model led to the conclusions that the estimated consumption by orange roughy is now less than 20% of the total consumption of top predators; but that there is no support for the hypothesis that surface fishing will affect the seamount benthos. These conclusions leave some open questions– for example, details of the demersal food-web are insufficiently understood to discuss effect of orange roughy removal on the rest of the system.

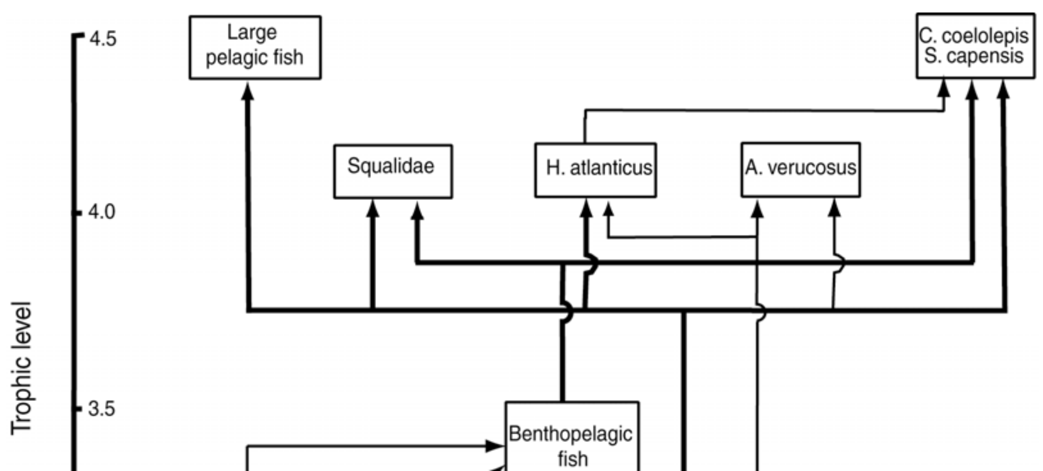

Figure 2. Outline of the food-web modeled for the ecosystem around seamounts in the Tasmanian Seamounts Marine Reserve, on the continental slope south of Tasmania. The model includes benthic and demersal species, and connections to the pelagic system in near-surface waters.

Indirect effects of trawl fishing – soft sediments

As Hall (1999) notes, we are generally hampered by poor data on fishing activities themselves – their rates, spatial and temporal distributions and intensities – and the Great Barrier Reef example above shows that these variables are important. This makes it very difficult to assess even their direct effects on non-target species and habitats, let alone indirect ecosystem effects; this is even more true in the High Seas!

Nevertheless, there are examples of soft-sediment impacts (e.g. Collie *et al*. 1997; Pilskaln *et al*. 1998) and there is evidence to suggest that the ecosystem effects could be substantial. For example, Thrush and Dayton (2002) point out the structural roles of infauna in soft sediments and their vulnerability to habitat disturbance – they argue that functional extinction of certain groups is likely under the influence of trawling. To date, there is limited trawling on soft substrata in deep water but some occurs; for example, trawling on soft substrata is one of the techniques used to catch Patagonian toothfish in the Australian EEZ in subantarctic waters.

Summary

Likely effects of demersal fishing in the High Seas

It is difficult, even with such patchy information, to escape the conclusion that deepwater, hard-substratum, demersal fishing has severe effects. Target species (Berycidae, Gadiformes, orange roughy and Oreosomatidae) of the High Seas demersal fisheries are characterised by being long lived, having slow growth and delayed maturity. These slow-growing, low fecundity species *rely* on a long life for their ecological stability. Exploitation, which effectively shortens adult lifespan, destabilises these populations resulting in local commercial extinctions. In addition to the direct effect on the target species the continual large removal of these predator species will have an indirect effect on the ecosystem through trophic interactions.

Apart from the large-scale removal of target and non-target fish species, there are important effects of trawling on benthic communities. These include loss of large, erect, sessile epifauna; increased dominance by smaller, faster growing species; and general reductions in species-diversity and evenness. However, there are major differences between habitat types. Deepwater, hard-substratum and bioherm habitats are highly vulnerable to bottom-trawl fishing. Even trawling on soft sediments has some of the above effects, at least in some cases, but the effects are likely to vary greatly between different situations, and are unstudied in very deep seas.

Beyond these habitat-specific considerations, there is no reason to expect fishing in the High Seas to be immune from the general ecosystem effects of fishing observed or reasonably postulated in other situations: shifts in species composition and reduction in trophic level of the catch (Christensen 1998, Pauly *et al*. 1998), and changes in community structure (e.g. Hall 1999).

Conclusion

Deep-sea demersal fishing: Ecosystem effects and management

We have noted that it is clear, notwithstanding the limitations of the data, that demersal fishing has effects on target species, effects on non-target species and likely ecosystem effects.

Fishing has expanded to all oceans through increasing the depth fished and fishing new seamounts and ridges. The global impact of this huge catch (the global catch was estimated at some 90 million tonnes; FAO 2000) is not known but it is reasonably argued that it must be substantial.

Ecosystem effects demand ecosystem management, and the challenge for nations, within their EEZs, and for the world community in the High Seas, is to understand the ecosystem effects of fishing and to implement management that considers both direct and indirect effects. Gislason *et al*. (2000) suggest that ecosystem-based management should aim to maintain the objectives of:

- ecosystem diversity,
- species diversity,
- genetic variability within species,
- directly impacted species,
- ecologically dependent species, and
- trophic level balance,

and they propose a series of indicators and reference points to enable management to track its achievement of these objectives.

The implementation of such an approach on the High Seas presents particular challenges, but they must be tackled.

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