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The effects of fisheries for low trophic level species on biodiversity and the prospects and options for mitigating these effects

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Introduction

The Conference of the Parties to the UN Convention on Biological Diversity in COP Decision X/29 (paragraph 53) requested " the Executive Secretary to collaborate with the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), regional fisheries management organizations (RFMOs), as appropriate, and in accordance with international law, including the United Nations Convention on the Law of the Sea, the Fisheries Expert Group (FEG) of the Commission on Ecosystem Management (CEM) of the International Union for the Conservation of Nature (IUCN), and other relevant organizations, processes, and scientific groups, subject to the availability of financial resources, on the ad hoc organization of a joint expert meeting, where possible through existing assessment mechanisms, to review the extent to which biodiversity concerns, including the impacts on marine and coastal biodiversity of pelagic fisheries of lower trophic levels, are addressed in existing assessments and propose options to address biodiversity concerns and report on the progress of such collaboration at a future meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) prior to the eleventh meeting of the Conference of the Parties;"

This paper provides a brief review of the impacts of fisheries for low trophic level pelagic species on marine and coastal biodiversity, a commentary on the ways the impacts have been addressed in assessments and considers options for addressing biodiversity concerns.

Definitions

'Low trophic level' species are here defined as species that feed predominantly on pelagic phytoplankton or zooplankton both before and after sexual maturity.

'Pelagic' species are here defined as species that feed in the water column, but the definition does not exclude species that may use the seabed and to provide habitat, shelter and spawning areas during part of the life cycle.

'Biodiversity' is here defined in the broadest sense as the variety, quantity and distribution of life.

Impacts of fishing

The potential impacts of fishing on biodiversity of low trophic level species can be divided into direct and indirect effects. The former relate to impacts on the fished populations the latter to effects on the food webs of which these populations are part.

Direct effects:

Decreases in abundance
Changes in distribution
Changes in genetic structure

Indirect effects:

Effects on predator species
Effects on prey species
Effects on food web processes

The direct effects on of fishing on population abundance are already considered for assessed low trophic level species for which reference points are defined. Reference points for biomass are already set at levels well above those that are associated with extinction risk. If management is implemented successfully the risk of biodiversity loss for the target species is low. The direct effects of fishing on genetic structure, owing to (a) differences in the mortality rates affecting any population sub-units and (b) any selective effects on populations, are not accounted for in management at present. Populations of low trophic level species can show genetic structure that is not currently accounted for in the definitions of management units (e.g. Hedgecock, 1994) and this knowledge should be considered in discussion about appropriate management units and management methods. High levels of natural variation in the abundance of low trophic level species, even in the absence of fishing impacts (Baumgartner et al 1992, Schwartzlose et al., 1999; Checkley et al., 2009), implies that populations may pass through 'bottlenecks' that can limit the long-term development of genetic variability.

The indirect effects of fishing on low trophic level species (forage fishes) have long been a focus of research (e.g. studies and reviews in Anon, 1997) since it is well recognized that many marine ecosystems exhibit high species diversity in the plankton and among predatory fish, seabirds and marine mammals and yet only few low trophic level species may transfer energy between the plankton and these predators (e.g. Cury et al., 2000). Further, comparisons of fishing and natural mortality, even for populations of small pelagic fishes that form the most productive marine fisheries, show that natural mortality rates owing to predation are characteristically much higher than fishing mortality rates (e.g. Jarre-Teichmann and Christensen, 1998). Changes in the abundance of these low trophic level species can therefore have significant effects on predator populations and on the pathways of energy flow through food webs.

Interplay between environmental and fishing impacts

Most low trophic level species are relatively small (typically less than 30cm), have short life spans and their recruitment and population dynamics are strongly driven by short term variability as well as long term change in the environment. Their abundance tends to be more variable than the abundance of slower growing and longer-lived species where more age classes contribute to the adult population and the variability in abundance from year to year is not so strongly influenced by the success of individual recruitment events.

Fluctuations in abundance in the abundance of low trophic level species in response to the environment are well documented from periods when fishing mortality was much lower than today (Checkley et al., 2009). Baumgartner et al. (1992) provide evidence for fluctuations in northern anchovy and Pacific sardine off California since 200 AD, based on scale deposition rates in anaerobic sediments. Many others records dating back to the14th century or so showing collapse and recovery when fishing mortality rates were low by contemporary standards (Cushing, 1982). The differences between 'high' and 'low' abundance can be two orders of magnitude or more. When both fishing and natural variation interact to influence population abundance populations can fall to 1/1000 of their peak abundance before recovering. Recovery is usually a response to reduced fishing mortality and/ or favourable environmental conditions (Beverton, 1990). Available science suggests that that fluctuations in small pelagic fish species are primarily driven by the environment but that ineffectively managed fisheries can hasten or intensify collapses (Freon et al., 2005).

Many low trophic level species, especially small pelagic fishes, show very strong relationships between distribution and abundance (e.g. MacCall, 1990). Consequently, abundance decreases are linked to range decreases. Thus declining abundance can have the greatest effects on predators and food webs at the margins of the range.

The extent to which predators can tolerate or compensate for changes in the abundance of their low trophic level forage species depends on their foraging behavior and prey choice. Some seabirds are tied to breeding colonies at specific times of the year for example, while some marine mammals will travel significant differences to pursue prey if resources are scarce locally (Kuletz et al., 1997; Piatt et al., 1990). For predators that cannot forage over large areas, even small reductions in prey abundance can lead to significant limitations in food availability at local scales. Further, some predators can be dependent on specific life history stages of low trophic level prey and factors such as annual recruitment success of these prey, that may be only weakly related to total population abundance, can have a significant effect on predators (Wright, 1996).

Given the significant natural fluctuations in abundance and distribution of many low trophic level forage species, there will be significant variations in the food available to predators. To some extent the life cycles of predators have evolved to provide resilience to these variations (e.g. the considerable longevity of seabirds that buffers the population against breeding failures) but, typically, taking a multi-annual perspective, populations of predators do fluctuate significantly in response to the availability of their prey (e.g. Anker-Nilssen et al., 1997)

So, while the population abundance of predators can reach high levels during periods when low trophic level prey are abundant and widely distributed, these high levels of predator abundance should not be seen as indicative of targets that could be maintained by managing fisheries for the prey. Further, owing to the differential responses of predators to prey abundance, a consequence of differences in feeding behaviour and mobility, a given fisheries management target for prey abundance would not provide the same feeding opportunities for all predators.

Assessing impacts

There are many assessments of the effects of variations in the abundance of low trophic level species on their predators (e.g. Anon, 1997) but a recent analysis attempted to draw some generalizations. Smith et al. (2011) explored the impacts of fishing low trophic level species on the structure of marine food webs, including the abundance of marine mammals and seabirds and other commercially important species. They assessed these impacts with a range of models. Their metric of 'impact' was based on a comparison between (a) the estimated abundance of predators (in some cases defined as 'ecological groups') when there were no fisheries for low trophic level species and (b) the abundance of predators when the low trophic level species were fished at defined rates.

In five ecosystems that Smith et al. (2011) studied, fishing low trophic level species at rates of fishing mortality that were predicted to lead to single species maximum sustainable yield (MSY) led to large impacts on other parts of the ecosystem. Halving fishing mortality rates led to lower impacts on the ecosystem, while fisheries still yielded 80% of MSY. In general, if reductions in the biomass of low trophic level species owing to fishing were limited to 25% of unfished biomass then this led to relatively low proportion of predators being reduced to >40% of their biomass in the absence of fishing.

While there would be legitimate debate between fishing and conservation concerns about acceptable impacts on predators, the analysis of Smith et al. (2011) does suggest that relatively small reductions in potential yield relative to MSY can disproportionately reduce the indirect effects of fishing.

Management to account for impacts

There are a few examples where management agencies have already established minimum biomass thresholds in their management plans for low trophic level species and/or have used technical measures to reduce competition between fisheries and predators for low trophic level species. These include plans for capelin, anchovy, sardine, sandeel and krill (see Rice *et al*. paper for this meeting). Not all these thresholds have been defined with an explicit focus on providing for dependent species as they do serve to minimize the risk that the abundance of mature individuals in the populations of low trophic level species will fall to levels that would further reduce prospects for population recovery in favourable conditions. The thresholds could be further adjusted to meet some specified management objectives for dependent predators if management objectives for these predators were specified and if suitable models had been developed to make the necessary predictions of the responses of the predators to changes in the thresholds for low trophic level species.

The management plans that I am aware of do not take account of distribution – abundance relationships for the fished species (but see comment on the Commission for the Conservation of Antarctic Marine Living Resources, CCAMLR below) but this is an issue that may also need to be considered if the availability of low trophic level species at a particular site had to be maintained at some specified level and if this specified level was dependent on total population size.

CCAMLR adopt an overall target biomass for krill that is similar to the general value proposed by Smith et al. (2011) but as well as the target biomass for the whole population they impose spatial limits in a series of sub-areas to ensure that prey are available for those krill predators that are restricted in their foraging range (Constable, 2011).

Addressing biodiversity concerns

Based on this brief analysis, I would draw the following tentative conclusions.

1. Fishing low trophic level species at MSY is very unlikely to place those species at risk of extinction as they routinely recover from very low population abundance during natural fluctuations.
2. If fishing mortality rates on low trophic level species are set to meet targets for the abundance of dependent predators they are expected to be lower than those that provide MSY for low trophic level species.
3. Analytical tools to assess how predators respond to changes in the fishing mortality rates on low trophic level species have already been developed for some of the major low trophic level fisheries.
4. Natural fluctuations in populations of low trophic level species are considerable, but harvest control rules that prevent fishing at lower biomass may help to minimize these fluctuations, promote recovery from low abundance and provide more food for dependent predators. However, such approaches could also increase variability in yields for the fishery.
5. Efforts to define acceptable fishing mortality rates for low trophic level species in an ecosystem context need to be informed by a debate on acceptable impacts on predator species and the extent to which society is willing or able to forgo yield from low trophic level species.

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