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Report of the

FAO WORKSHOP ON VULNERABLE ECOSYSTEMS AND DESTRUCTIVE FISHING IN DEEP-SEA FISHERIES

Rome, 26–29 June 2007

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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PREPARATION OF THIS DOCUMENT

This report documents the discussions and conclusions of the FAO Workshop that was held to review the subject of vulnerable ecosystems and destructive fishing in deep-sea fisheries. This workshop was held in Rome from 26 to 29 June 2007. It is expected that the outcome will inform future considerations on the management and conservation of deep-sea fisheries and provide guidance to those concerned with developing appropriate management guidelines. Participants attended in their personal capacity.

Ross Shotton organized and convened this workshop and Jean-Jacques Maguire prepared and organized the report. A first draft of the report was put together from text produced during the workshop. Several participants then contributed to an improved second and near final draft. Their contribution, particularly the re-drafting of important sections by Trevor Kenchington, is gratefully acknowledged.

This workshop was organized under the project entitled: “Promotion of sustainable fisheries: support for the Plan of Implementation of the World Summit on Sustainable Development” and was funded by the Government of Japan. The meeting is one of a series of activities designed to inform and assist with the development of the International Guidelines for the Management of Deep-Sea Fisheries in the High Seas.

Distribution:

Participants at the meeting
Directors of Fisheries
FAO Fishery Regional Officers
FAO Fisheries and Aquaculture Department

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ABSTRACT

The FAO Workshop on Vulnerable Ecosystems and Destructive Fishing in Deep-sea Fisheries examined available information on national, institutional and personal experiences in relation to this issue. Relevant ecological aspects were reviewed and suggestions as how to consider these issues in terms of International Guidelines for the Management of Deep-sea Fisheries in the High Seas were discussed and documented.

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OPENING

Ross Shotton, Fisheries Management and Conservation Service, FAO Fisheries and Aquaculture Department, opened the meeting and asked participants to introduce themselves. He then outlined the anticipated order of business (Appendix A) for the following three days. He reminded participants that they were attending the meeting in their personal capacity; and that their comments and views expressed at the meeting would not be considered as necessarily representing the views of their organizations.

John Gordon, Scottish Association for Marine Science, Dunstaffnage Marine Laboratory, Oban, Scotland, was elected Chairman of the workshop.

INTRODUCTION

Deep-sea fisheries have been a source of considerable concerns in recent years because of the nature of the resources they exploit, the vulnerability of the ecosystems where they occur and because fisheries on the high seas are beyond the direct control of any one sovereign State which creates governance problems. Organizations with a variety of mandates have expressed views on the likely, known or feared consequences of deep-sea fishing, both in terms of the habitats in which these fisheries occur, and their effects on the target stocks and associated species, whether the associated species are retained or not. The growing concern has lead to the adoption of resolutions by the United Nations General Assembly (UNGA) and by the FAO Committee on Fisheries (COFI). COFI determined that International Guidelines on the Management of Deep-sea Fisheries in the High Seas should be prepared to assist regional fisheries management organizations and arrangements (RFMO/As) in developing measures required by the General Assembly in time for the deadline of 31 December 2008 set in A/RES/61/105. Those Guidelines are required, *inter alia*, to include standards and criteria for identifying vulnerable high-seas marine ecosystems and the impacts of fishing on such ecosystems. The specific objective of the workshop was to agree definitions of “vulnerable marine ecosystems” and “destructive fishing practices” to be used in drafting the Guidelines, and to place them in an appropriate context in relation to deep-sea fisheries.

Scope of deep-sea fisheries

Small-scale deep-sea fisheries developed prior to the 1900s using hook and line gear. The fishery for black scabbardfish (*Aphanopus carbo*) in the Azores and Madeira began in the 1830s and New England Atlantic halibut (*Hippoglossus hippoglossus*) fishermen were fishing down to 1 000 metres at about the same time. Trawl fisheries for deep-sea species using factory freezer trawlers started in the mid-1950s, primarily based on exploratory fishing conducted by the fishing fleet of the former Union of the Soviet Socialist Republics (former USSR), and their evolution followed trends similar to those of fisheries conducted in shallower waters. With the extension of exclusive economic zones (EEZs) starting in the 1970s some fleets were forced to fish in deeper waters, and new fisheries developed. Since the mid-1990s, there was also some increase in fishing effort because restrictive management measures inside EEZs have pushed vessel owners to look for fishing opportunities outside of EEZs, a process similar to that which occurred in the 1970s when EEZs were declared. While some specific fisheries have emerged in more-recent years, the general expansion of deep-sea bottom fishing seems to have ceased. Future trends are difficult to predict but, unless seafood sale prices rise much faster than energy costs, it seems unlikely that there will be a major expansion of deep-sea fishing into new areas in the coming years. New deep-sea fisheries that emerge in the foreseeable future seem more likely to be small, local, “boutique” fisheries, which may have localized negative effects and may seriously deplete the resources they exploit before sustainable management can be implemented, but are unlikely to cause spatially-extensive ecosystem effects. The greater danger of expanded deep-sea fishing appears to lie in uneconomic development, driven by erroneous expectations, both those of industry promoters and those of funding bodies and development agencies, that promote experimental fishing in areas with little promise of viable and sustained exploitation.

The great majority of the fishing effort currently being exerted is at shallow depths within EEZs, including on transboundary stocks, while most of the fishing that occurs on the high seas is targeted on straddling stocks or highly migratory fish[1] stocks that are subject to international agreements. Fisheries for deep-sea resources are only a minor part of the world's fishing and most of them operate within EEZs. Deep-sea fisheries in the high seas account for only a fraction of one percent of global catches and only a few fishing vessels from a small number of countries participate in such fisheries. Although limited, deep-sea fishing in the high-seas may have significant localized impacts but only a small fraction of the deep-seafloor is affected. These fisheries capture a wide variety of species including alfonsino (*Beryx splendens*), black cardinalfish (*Epigonus telescopus*), orange roughy (*Hoplostethus atlanticus*), southern boarfish (aka pelagic armorhead *Pseudopentaceros richardsoni*) and others.

The public perception of deep-sea bottom fishing as an industry expanding into "pristine", virgin territory is misleading. Areas where economically viable deep-sea bottom fishing can occur are limited, extending only from perhaps the 200 metres to the 2 000 metres bathymetric contours and exclude the tropical zone, where deep biological productivity seems insufficient to support much fishing. Within that limited range, only select areas offer sufficient catch rates to justify the high costs of fishing in deep seas. Most of those areas had been explored by fishing vessels before 1980, many of them before 1960. Because natural systems are constantly variable in time and space, and often far more so than expected, "pristine" is thus not a static state of being but only an indication that a system has not been impacted by man – perhaps more precisely, not impacted by man using technology developed since some arbitrary date, such as the advent of the Industrial Revolution. It is, however, doubtful whether any marine ecosystems are truly "pristine" in that sense. One of the central truths of marine ecology is that the ocean is a great transporter – of heat, of chemicals but also of migrant animals. All parts of the ocean and its ecosystems are interconnected, albeit to different degrees. Human activities in one part will impact on all. The effects of coastal fishing on deep-sea ecosystems are likely minor but those of oceanic, epipelagic fishing are likely not.

DESTRUCTIVE FISHING

"Destructive fishing" is the use of fishing gear in ways or in places such that one or more key components of an ecosystem are obliterated, devastated or rendered useless.[2] "Destructive fishing" causes indiscriminate harm to marine life, in disproportion to the resulting seafood production or other human benefits, and often results in long-term damage to the physical structure of habitats. The normal consequences of the sustained harvest of fishery resources, including decreases in the abundance or biomass of target populations and associated ecosystem consequences of the decreased abundance, do not constitute "destructive fishing".

Few, if any, fisheries are consistently "destructive". Only a very small number of fishing gears or fishing methods are recognized as inherently "destructive" wherever and however

[1] A "transboundary" fish stock is one whose range includes the EEZs of at least two countries; a "straddling" fish stock is one whose range includes waters within an EEZ as well as in the high seas. A stock can be both transboundary and straddling. Highly migratory fish stocks are those listed in UNCLOS Annex 1.
[2] This definition is consistent with both the UN Atlas of the Oceans and dictionary definitions of "destruction".

they are used, the primary examples being explosives and synthetic toxins. Otherwise, “destructive fishing” is due to “destructive” fishing practices – the use of gears, which themselves have legitimate roles in seafood harvesting, in ways that are destructive, in places where the gear is destructive and/or so intensively used as to be destructive. Examples would include towing of bottom trawls or dredges through areas with rich growths of corals, or dropping numerous heavy fishing pots in those areas.

Except for the explosives, synthetic toxins and muroami fishing mentioned above, “destructive fishing” cannot be defined in the absolute. How severe the harm must be before a fishing practice should be deemed “destructive” is a policy choice related to objectives that have been set. While decision-makers should seek to include all practices that are unreasonably harmful, “destructive fishing” is an extreme designation which will lead to equally extreme responses. It should be used to focus action on the most harmful practices and should not be broadly applied to any and all fishing that has some negative consequences for marine ecosystems.

Overfishing of resource populations and the wastage of undersized or unwanted catch discarded dead are not, in general, considered to be “destructive fishing practices”, except when extreme examples of these practices have been defined as such in policy.

While the use of explosives and synthetic toxins fishing mentioned above can be, and should be, eliminated directly by management action, most other form of destructive fishing practices are beyond effective government control, since they concern the small-scale, short-term choices of individual fishermen. While there is a role for regulatory controls (such as closing vulnerable areas to certain gear types), ultimate solutions require that those directly involved in the fishing are properly trained in best fishing practices and accept stewardship over resources and ecosystems. This requires social, economic and institutional settings that will allow those directly involved in fishing to think of the future, be confident that they and their communities will enjoy access to the resources over the long term, and operate in an environment where present restraint returns future benefits to those who choose to limit themselves.

VULNERABLE MARINE ECOSYSTEMS

Ecosystems may be defined by geographic boundaries (e.g. “Mediterranean Sea ecosystem”) or by characteristic types of organisms and ecological processes (e.g. “tropical coral reef ecosystem”). Vulnerable marine ecosystems (VMEs) will be identified by the vulnerabilities of their components and hence are ecosystems of the second type, defined by those vulnerable components. Geographically-defined ecosystems are each unique but VMEs will usually occur as numerous, replicate patches. The 64 large marine ecosystems (LMEs) are not candidates for listing as VMEs, because they are both geographically defined and much too extensive. LMEs, however, may serve as useful indicators of where in the world ocean certain types of VMEs can occur.

All ecosystems are hierarchical, with each lower level containing smaller and less heterogeneous units within it, yet none of the units is either truly homogeneous or without external linkages to other units. Within such hierarchies, the examples of VMEs selected by the UNGA (A/RES/61/105) approximate, in technical terms, to ecotopes – the finest scale units used in mapping ecosystems. Such VMEs may be expected to occur as numerous, small patches, scattered amongst larger areas of larger ecosystems. There is no absolute standard for how finely these hierarchies of systems should be divided and RFMOs must choose appropriate spatial and ecological scales. Too fine a division would impose severe management costs in mapping ecosystems and in enforcing any spatially-specific management measures. However, too coarse a division would risk applying management measures broadly, including not applying them in areas where they are required, or applying them in areas where they are not required. It would also risk lowering the perceived vulnerability of ecosystems by averaging across small patches with highly-vulnerable components and larger areas with only low vulnerability, perhaps eliminating VME status where it is merited while failing to focus attention where it is most needed.

The hierarchical patchiness of marine ecosystems requires further judgements by RFMOs. There seems little doubt that a large reef of dense cold-water coral growths merits VME status because of the very high vulnerability of such corals to most kinds of bottom fishing. However, a lone surviving coral colony would be unlikely to justify that status for an extensive area of seabed surrounding its location, even if the “tree” could be detected and mapped. How dense scattered “trees” must be, or how large a single aggregation of them must be, before VME status is appropriate are policy choices for RFMOs to make. Similar decisions will be needed for most other forms of highly-vulnerable ecosystem components. Once VMEs have been identified, additional decisions will be required about the extent of areas to which spatially-specific conservation measures will apply. Such areas may be considerably more extensive than the VMEs themselves, in order to provide for buffer zones and enforceable boundaries. In making those decisions, RFMOs should clearly distinguish between the ecologically-defined VMEs and the management areas designed for protection of vulnerable components of the VMEs.

A “Vulnerable Marine Ecosystem”, is any deep-sea ecosystem, as defined above that has very high vulnerability to one or more kinds of fishing activity. Designating an area as containing a VME does not automatically imply a closure to any or all kinds of fishing. It is a vulnerable area or a group of vulnerable areas, sharing the same type of features. There is a range of possible management responses to the VME status, the appropriate action depending on the nature of the vulnerable ecosystem component or components, the fishery or fisheries to which they are vulnerable, and the mechanisms that create the vulnerability. In the cases of “tree” corals and vase sponges, with their extreme vulnerability to physical impacts, closure of all or most of the area containing them to all bottom-contacting fishing gears (aside perhaps from vertical longlines operated in such a way as to have very low probability of touching the bottom) may be the most effective management option. However, where the nature of the vulnerability is one of depletion of a target species, conventional management measures limiting fishing mortality rates may be an appropriate response. In some cases, it may be appropriate to close certain areas to fishing pending evidence that they are not vulnerable, whereas elsewhere it may be practical to monitor a fishery and close areas swiftly if vulnerability is detected.

Greater complexities will be encountered. For example, some fisheries will operate on low-vulnerability seabeds while exploiting a key predator species and hence decreasing its abundance, such that the ecosystem being fished designated a VME. Within the general area, and hence within the VME, there may be patches of high-vulnerability benthos, such as coral “trees”. In such a case, an RFMO would need small closures to protect the patches of vulnerable benthos and other measures to limit depletion of the predator. It would not, however, be necessary to close the whole, extensive area to fishing, simply because certain parts of it are highly vulnerable to trawling.

Very high vulnerability of ecosystem components is linked to their slow recovery from impacts. It follows that damage done to such components in the late 20th Century will have shown little recovery to date, raising the question of whether it is acceptable to continue fishing in an area if that continuation is not further altering the ecosystem from its current state. That is a value judgment that must be left to the decision-makers within each RFMO. The early removal of highly-vulnerable ecotopes, such as coral “forests”, has increased the scarcity value of such patches as remain, while the very slow recovery times reduce the present value of patches which might eventually recover in closed areas to almost zero.

Conservation of deep-sea VMEs in the opening decades of the twenty-first century should, in some and perhaps many cases be focused on recovery from past mistakes, not on protection of supposed “pristine” areas from a fishery expansion that is unlikely. Rebuilding depleted target and bycatch species is at least as important, and perhaps more important, to ecosystem conservation than is protection of rare seabed features, such as coral “forests” or hydrothermal-vent communities. Any expansion of fishing into new areas should be consistent with the precautionary and ecosystem approaches and in accordance with the International Guidelines on the Management of Deep-sea Fisheries in the High Seas currently being prepared by FAO.

BACKGROUND

Species caught in deep-sea fisheries have a wide range of life history traits. Some are characterized by low productivity, low fecundity, high age at first maturity and high longevity. These species will be more sensitive to exploitation than typical shallow-water species, and they will only be able sustain low exploitation rates. Species react in very different ways to increased mortality and life history patterns give important clues about the vulnerability of a fish species to substantial fishing. Large-sized and slow growing fish with low reproduction rates are more vulnerable than smaller, fast growing and highly reproductive species. Likewise, it will take longer for sedentary organisms to be replaced than for mobile ones. Finally, endemic species could become extinct as a result of the destruction of one single ecotope.

Other characteristics of deep-sea fisheries that cause concern are listed below.

- There is limited knowledge to support decision-making and difficulties in gathering the necessary information.
- Deep-sea fisheries often develop faster than the ability to manage which increases the risks of unsustainable exploitation and negative impacts on the ecosystem.
- Deep-sea species that aggregate at predictable locations and in high densities are highly susceptible to overexploitation and depletion. Deep-sea fisheries are perceived to occur in habitats that are susceptible to damage by the impact of fishing.

Marine ecosystems

Deep-sea ecosystems

While no marine ecosystem is fully independent of others, each contains its own major energy sources. Except for those associated with hydrothermal vents, which provide the energy at depth, all deep-sea ecosystems are powered by primary production in the overlying, sunlit photic zone. Most deep-sea ecosystems therefore include the whole water column from seabed to surface. Because of the mobility of the overlying waters, in many cases, a small patch of deep seabed will be connected to a very much larger area of the near-surface layers, making benthic organisms potentially vulnerable to extensive human activities in the surface layers. On the other hand, the mobility of the overlying waters could buffer benthic organisms from the consequences of intense, local activity near the surface.

It may be noted that the examples of VMEs named by the UNGA, seamounts, hydrothermal vents and cold-water corals, are not ecosystems. Seamounts are bathymetric features, hydrothermal vents are geological features and corals are organisms. Those examples can be seen as convenient labels for the ecosystems characteristic of seamounts and the areas around vents, plus those ecosystems characterized by cold-water corals. However, misunderstandings can easily arise. Hydrothermal vents are rare features, surrounded by small, distinctive ecosystems supported by an energy source unknown elsewhere in the biosphere. Seamounts, however, are both numerous and highly variable, ranging from isolated submarine volcanic peaks to small knolls on mid-ocean ridges. The larger ones can support multiple, different ecosystems, such as a relatively-shallow, flat and muddy plateau on their peaks, flanked by steep, rocky slopes bearing very different benthic communities. Moreover, the physical structure of a seamount is not vulnerable to any current or foreseeable human activity and the vulnerability of a seamount VME results from the vulnerabilities of some of its constituent species – notably cold-water corals. Hence, seamount VMEs may only be a subset of coral VMEs. Meanwhile, although gorgonian corals are extremely vulnerable to some types of fishing (notably bottom trawling), other kinds of cold-water corals, such as some cup-corals, appear to have only average to low vulnerabilities. To avoid major management mistakes, it will be very important for RFMOs to consider the vulnerabilities of real ecosystems and not to be misled by simple labels.

Deep-sea habitats

Some continental shelves have broad sandy areas, while much of the vast abyssal plains that floor the deep oceans are covered in fine mud. Other parts of the seabed, however, including most or all of it at the depths of present interest (200 to about 2 000 metres), are naturally patchy – a mosaic of patches of different habitat types. Yet each patch is not itself homogeneous. Rather it is itself a mosaic of smaller patches, which contain yet smaller patches, the patchiness often extending down to the scale of individual animals, which are typically clumped, as well as upwards to the scale of whole ocean basins. In many areas, some very small patches are quite different from surrounding areas. High-vulnerability seabeds, such as coral “forests”, tend to occur as such patches within broader areas that lack the special characteristics which make development of a rich epibenthos possible. The high-vulnerability species are typically absent from wide areas, thinly scattered elsewhere and densely developed in rare, small areas – “small” meaning perhaps square metres or square kilometres, though a few larger patches of cold-water corals are known.

The depths of present concern lie between the extensive continental shelves and the far more extensive floor of the deep ocean. Only about 8.8 percent of the World Ocean has seabed depths of 200 to 2 000 metres (Merrett and Haedrich, 1997). Much of that seabed comprises (usually steep) continental slopes and the walls of the submarine canyons that cut those slopes. There are also the long mid-ocean ridges, which have very complex topography, including seamounts, lesser “hills” and a few islands that extend above the water surface, as well as flat areas elevated above the deep ocean basins. There are isolated seamounts scattered across the deep ocean, only some of which have the classic form of volcanic cones while many have other morphology, and some isolated oceanic islands. Finally, some continental shelves have deep troughs with depths greater than 200 metres. All of those environments support mosaics of ecosystems, some of which may merit VME status.

A few of those ecosystems are of particular interest here because of the potential vulnerability of some of their components to physical impacts by fishing gear. Hydrothermal vents, for example, support unique communities, powered by chemosynthesis rather than by the energy of the Sun captured through photosynthesis. There are no studies of the impacts of fishing on vent ecosystems and it is not known whether any have ever been contacted by fishing gear but the potential remains. Vent communities include large epibenthic species, such as tubeworms, that would be expected to be particularly vulnerable to gear impacts.

Cold-water corals are better known. There are many kinds that vary considerably in taxonomy, morphology and their ecological role. Some, such as some of the soft-bottom cup corals, do not appear to have any unusual vulnerability to gear impacts but the gorgonian coral "trees" and the mound-forming scleractinian *Lophelia pertusa* are exceptionally vulnerable. Krieger (2001) observed the track of one trawl net through a "forest" of gorgonians and found very extensive damage, albeit not total elimination of the corals. Cold-water coral colonies can also be very long-lived. Estimates vary but single gorgonian "trees" can apparently survive for several centuries, while re-establishment of a "forest", following its elimination by gear impacts, may require much longer than the lifetime of a single colony. Some of the larger "vase" sponges have similar characteristics. Most sponge species produce only small and often encrusting growths which should be little affected by fishing. However, other species can grow to considerable size, with an erect form that exposes them to physical impacts. Estimates of removal rates for such sponges range from about 15 percent (Burridge *et al.*, 2003) to nearly 90 percent (Sainsbury *et al.,* 1997) per pass of a trawl, while there can be serious non-lethal damage to surviving growths which, in a deep-sea environment show very slow recovery (Freese *et al.,* 1999; Freese, 2003).

Both coral "trees" and vase sponges can provide substantial three-dimensional structure on the seabed where they occur. The role of that structure in marine ecosystems is not fully understood. Few species are obligate associates of either coral or sponges but many are more abundant around the structure provided by the large epibenthos, making patches of coral "trees" and/or large vase sponges into "islands of biodiversity" amidst an otherwise relatively barren seabed. That includes higher biomass densities of some commercial fish species and perhaps particularly of the juveniles of some species (notably the North Atlantic redfishes, *Sebastes* spp.), which may obtain shelter from predators by living amongst the structure. It is less clear that any resource population draws much overall benefit from coral "forests" since they are so limited in size that it seems unlikely that they support more than a small minority of the members of any one population. To date, there is no evidence that the presence of coral "forests" on the seabed influences the productivity of the overlying water column. The same could be said of the sponges.

Seamounts, as large bathymetric features, clearly influence the productivity of the waters above them. The overlying waters can even become focal points for surface-dwelling species and seabirds, though the mechanisms by which the features affect water flows and thus generate the enhanced productivity remain unclear. Some seamounts have been shown to be centres of high "biodiversity" and it has been suggested that they also show high endemism. However, seamounts themselves are large masses of rock and their basic bathymetry is not vulnerable to any fishing impacts. Seamount ecosystems may nevertheless be highly vulnerable because of the coral "forests" and large sponges which can be abundant on the flanks of the bathymetric features. Thus, the vulnerability of seamount ecosystems is largely the same as the vulnerability of other coral and sponge ecosystems, while the ecological roles of corals and sponges on seamounts is little different to their roles in other areas, though the value of seamount ecosystems may be higher because of the "biodiversity" and endemism.

Vulnerability of deep-sea ecosystems

Ecosystems are not directly affected by human activities; it is the many constituent species and ecological processes that comprise an ecosystem that are. Hence, the "vulnerability" of an ecosystem is the vulnerability of its constituent parts. Most ecosystems are diverse and likely contain one or more species that are highly vulnerable to some human activity. The vulnerability of the ecosystem itself, however, is that of its key constituents, excluding those whose depletion or elimination would not compromise ecosystem functions. In many cases, the vulnerability of the whole system will be approximately equal to that of its single most vulnerable key component, though some ecosystems may be deemed more vulnerable than any one of their constituent parts. “Vulnerability” should not be seen in terms of lost fishery-resource production or other ecosystem services alone but rather with regard to the potential loss of all ecosystem functions. Vulnerability to fishing activities should encompass all impacts of fishing on all components of deep-sea ecosystems and not simply the physical impacts of fishing gears on the seabed and benthic organisms.

There is no absolute measure of “vulnerability”. It can best be visualized as the amount of change from pre-existing conditions caused by some human activity, the change being integrated over a very long period of time. Ecosystems components subject to severe changes from which there is rapid recovery or to smaller changes from which recovery is prolonged are therefore moderately vulnerable, whereas those subject to major change followed by little if any recovery are highly vulnerable to whatever human activity caused the initial change. In practice, it is not possible to quantify such vulnerabilities but the concept can be applied broadly to rank ecosystems from the least to the most vulnerable, based on expert opinion.

It is difficult to quantify vulnerability to any one human activity because an ecosystem will generally be simultaneously impacted both by natural change and by other human activities. Vulnerability is a property of an ecosystem (or of one of its components) to a specific human activity, such as a particular form of fishing with a certain gear design and mode of operation. It may, however, be possible to rank relative vulnerabilities of ecosystems to broader classes of fishing activities (e.g. bottom trawling vs hook and line vs gillnets), provided that it is understood that an ecosystem may have a very different vulnerability to some specific activities within a given class than to others. Fishing activities differ not only qualitatively but also in the intensity of the fishing. Particular ecosystems are likely to show increasing vulnerability when fishing intensity increases, though the relationship may not be linear and proportional but rather a stepped relationship with abrupt changes once thresholds are crossed.

Vulnerability is a continuous measure, with few ecosystems being entirely invulnerable and none being totally vulnerable to any form of fishing. Within the continuum, the UNGA selected as examples of VMEs only very highly vulnerable features of ecosystems. In that spirit, we suggest that a “vulnerable” ecosystem or component part is one that has a very high vulnerability to some specified fishing activity. “Vulnerability” should be seen as a potential: hydrothermal vent ecosystems may be vulnerable to bottom trawling even though no trawl has been used in such areas and is unlikely to be in the foreseeable future. Otherwise, ecosystems could not be protected as VMEs until after damaging activities had commenced.

Impacts of fishing

The impacts of fishing on deep-sea ecosystems are variable and depend on the physical structure, biological components and ecological interactions of specific deep-sea ecotopes as well as on the fishing method, fishing practices and fishing intensity. It is the impact of fishing on the habitat (physical and biological structure) of an ecosystem that has attracted most of the attention at the UNGA and at COFI.

Soft and especially sandy sediments have been observed to recover relatively quickly from the physical effects of bottom gear (e.g. smoothing and re-suspension of sediments along with nutrients, contaminants). This is particularly true if a system is adapted to strong natural disturbance, e.g. currents. Hard bottoms are much more vulnerable, especially those including fragile structures that can be severely affected by even moderate exposure to bottom trawling (e.g. hard corals such as gorgonians and some scleractinians [*Lophelia pertusa*], sea pens, some large sponges). The slow growth of such taxa prevents their quick recovery and the affected habitats will be unable to repair the damage within a reasonable time frame, i.e. recovery time is at least in the order of decades or more. Such habitat loss will significantly and, practically speaking, "irreversibly" changes the ecology, productivity and species composition within an affected area.

Fishing also removes biomass (catch) from the fished area and may cause encounter mortality of predators that feed on the target species of the fishery. Or the fishery may reduce the food availability, thus increase vulnerability, to predators that feed on organisms affected, but not retained by the gear. A substantial selective removal of a few species will influence the composition of the biological community within an ecotope. This can lead to significant changes in the biocommunity, e.g. in food webs and in predator-prey relationships and by encouraging invaders to take advantage of a niche that has become available. This is especially true if the eliminated species play a "key" role within the ecosystem, a very likely scenario as fisheries tend to target either major predators or principal forage species and seldom rarities. In deep-sea ecosystems "nutrient importers" could be of great importance, i.e. vertically migrating fish that facilitate the downward flux from the productive photic zone to the dark and much less productive seabed (away from the rare alternative energy sources such as hydrocarbon seeps or hydrothermal vents). Depletion of, for example, myctophid fishes could affect the entire ecosystem for that reason. It should be noted that a fishery could have a significant effect on a deep-sea ecosystem without the gear ever being deployed at great depth if it harvests a fish that plays a key role in an ecosystem that extends to much greater depths.

A potential effect of extensive and selective fishing consists in reduction of average size and in the alteration of age and growth patterns within the targeted population. Such changes could alter population genetics which may modify or perpetuate the consequences of the depletion for the whole ecosystem.

Although fishery discards from any fishery can have significant effects in the overall marine ecosystems by attracting scavengers and predators (birds, mammals, etc.) and by influencing nutrient cycles, the local effects of discards on the bottom of the deep sea are unclear. However, substantive amounts of the discard are usually consumed or decomposed in the upper water column and it can be assumed that only remnants actually sink to the bottom depending on the physical conditions of the water column and the amount of surface and mid-water scavenging.

Concerns have been raised regarding other possible impacts from fisheries on deep-sea bottom habitats such as continuous "ghost" fishing by lost gillnets and traps, interruption of animal behaviour by fishing activities, pollution by persistent human waste (e.g. plastic) or chemicals (anti-fouling), etc. The latter may have less effect on deep-sea ecosystems since the discharges are at the surface, far removed from the seabed portion of the ecosystem. However, fishing can disturb spawning schools with indirect effects on reproduction of the species affected, but the effects will be difficult to assess.

The spatial and temporal scales of fishing activities are important factors when determining the impact of fishing on a particular ecotope. For example, a particular fishing technique might have a low impact on structural components but could still cause significant changes through continuous and extensive selective removal of biomass. Replacement of eliminated or killed organisms by re-colonization can be delayed if neighbouring areas are equally affected. Scale considerations are also important for the determination of measures, e.g. protection of areas. A vulnerable ecotope (e.g. seamount) can extend over a relatively small area surrounded by large areas of more resilient soft sediment bottoms. On the other hand, some of the species associated with it have a much larger range and this can influence the decision on the size of protected areas.

Such assessments often rely on (educated) assumptions in the absence of (much needed) research. A precautionary approach should be applied.

Reference points

The use of reference points to measure the impacts of fishing is recommended in the 1995 UN Fish Stocks Agreement (UNFSA) and in the FAO Code of Conduct for Responsible Fisheries. Reference points are benchmarks used to define targets to be achieved, limits to be avoided, and they are linked to specific management responses. Reference points require the prior definition of objectives and the ability to measure progress towards those objectives using indicators. Reference points are most commonly applied to target species, but they are also applicable to defining the boundaries of acceptable impacts for bycatch and habitats. Measurable aspects of habitat extent or condition can be used to define relevant target and limit reference points at which planned management responses are initiated.

Reference points cannot be defined universally and need to be established on a case by case basis. Reference points are intended to be used in harvest control rules: when a reference point is breached or is predicted to be breached, management action is taken. The usefulness, relevance and reliability of reference points need to be taken into account when discussing what management action to take when reference points are met or breached.

Fishing gears and practices used in deep-sea fisheries

The fishing methods used in the deep-sea range from hooks and lines, pots and enmeshing nets operated from small fishing vessels to trawl nets towed on and above the seabed by trawlers.

Hook and line gear

The principle element of the longline gear is the mainline or groundline that can extend up to 50 km in length. Branching off the mainline at regular intervals are leaders or snoods, and hooks. Anchors hold each end of the mainline in place, and surface buoys attached via float lines to the anchors mark the location of the gear. All bottom-set, longline gear is considered fixed and passive because once deployed the gear does not move, and the fish voluntarily takes the hook. The bottom longline has a relatively small footprint on the seabed. Anchors hold the ends of the mainline to the seabed and the mainline lies across the seabed. The mainline can move around while the gear soaks and be dragged across the seabed in the process of hauling the gear. Bycatches of coral trees and other epibenthos including hard and soft corals are known to occur.

Vertical longline gear is usually set from smaller vessels sometimes fishing in association with fish aggregating devices (FADs). The gear consists of multiple hooks and leaders attached to a vertical line suspended from a buoy at the surface with a weight at the bottom used to hold the hooks near the bottom. The FADs are used to attract and concentrate the fish and baited hooks capture the fish. The seabed footprint of this gear is minimal as only the anchor touches the bottom, and therefore seabed impact is minimal.

Pots

Animals enter the pot gear seeking food, shelter, or both. A device allows the animal to enter the gear but restricts escape. The holding area retains the catch until the gear is retrieved. Bait is placed in a bag or cage within the pot to attract the target species. Culling rings or escape vents are added to the exterior wall of the pot to allow for the release of undersize sub-legal or juvenile animals. Finfish and crustaceans are harvested with pots in deep water. If pots are lost on the seabed, they will ghost fish. Biodegradable panels or other technical means are used in some fisheries to prevent ghost fishing

The use of pots on deep water has been shown to negatively impact some seabed habitat. While individual pots have a small footprint on the seabed, a large number of traps on the seabed has a larger footprint than a longline, and can disturb the seabed in terms of the pots crushing animals or scraping epi-fauna attached to the seabed from its anchored location, additionally when several traps are attached together the mainline will encounter and entangle hard and soft corals on the seabed.

Enmeshing gear

Enmeshing gear includes a group of fishing gear types where animals are captured by a wall of webbing in the water column or on the bottom. The animals are captured by wedging, gilling or tangling. Shellfish and corals are easily entangled in bottom set enmeshing gear; large fish entangle by the jaw; and large marine mammals entangle by wrapping-up in the webbing. Anchored sink gillnets are used to harvest demersal fish. Anchors are used at either ends of the net to hold the gear in a fixed location. Individual nets vary in length from 100 to 200 metres, and in depth from 2–10 metres. Multiple nets are attached together to form a string of nets, up to 2 000 metres in length. The impacts of gillnets and tangle nets on the seabed are a function of the type of seabed and the target fishery resource. On soft substrates the effects will be minimal, while on hard bottoms with attached, emergent fauna, the nets will tangle with corals and other organisms and remove them from the seabed.

Trawlnets

The bottom trawlnet is a funnel-shaped net, with a sweep which tends bottom as the net is towed. The largest trawlers, from 50–100 metres in length, catch, process and freeze their products onboard, and are referred to as factory, catcher, processor trawler but smaller wetfish or freezer trawlers also operate in deep-sea fisheries. In deep-sea fisheries, trawls are generally used in aimed fishing where electronic and navigation equipment allow skippers to minimize seabed impact if wanted.

Bottom trawls have the potential to have a substantial impact on the seabed depending on the type of substrate they are used on. The area impacted is a function of the width of the trawl and the distance it is towed. When used on sandy seabed the impacts are minimal, the otter boards scar the seabed, and the trawl sweep only smooth the seabed removing small bedforms that are regenerated in a relatively short period of time. However when used on hard, gravel, cobble, boulder seabeds, trawls will roll-over the larger rocks, and scrape off attached, emergent, epibenthic organisms including sponges and corals. Numerous studies have documented the negative impacts of trawling on hard bottom on continental shelves.

Off-bottom or mid-water trawl nets are also used in deep-sea fisheries. The nets must be aimed or directed at specific concentrations of fish. Therefore, the fishermen must be able to identify the location of fish both laterally and vertically, and to direct the pelagic trawl to that position. Sonars are used to locate both fish and the fishing gear. When properly used mid-water trawls have no impact on the seabed as the gear is not intended to contact the seabed, however at times these gears do accidentally contact the seabed and when this occurs the impacts on the seabed habitat are similar to the impacts of a bottom trawl.

Interpretation of terms

Acceptable changes, significant changes

All ecosystems are subject to on-going natural change, and most also experience changes due to human activities. Whether change is good or bad is a value judgment. Change that is negative for one species will be positive for another. Change can be neutral or even positive for certain human interests or some species. Whether changes in marine systems provide overall net benefits to human beings depends on the value placed on each of the many other services (including seafood supply) that society could draw from those systems.

How much change is considered "acceptable" is thus relative and depends on policy objectives. Determining what is "acceptable" requires the setting of reference points to evaluate the current situation with respect to the objectives. Ecosystem change might, for example, be considered acceptable if it is reversible within a defined time limit or where the change is confined to a spatial scale that is small in relation to the extent of the ecosystem.

Changes are considered "significant" when the system is taken outside a pre-defined range of acceptability. This may include changes that are irreversible within a set time limit or from which the system or components of the system cannot recover within a set time limit. As indicated above, society has to choose what acceptable change is, and there is not a direct relationship between "significant" and "acceptable". Society can and often does choose to make significant changes, and even irreversible changes to a part of an ecosystem may be considered acceptable, depending on their spatial extent and the objectives that are to be achieved. Significance in this context should not be confused with statistical significance, which is more a matter of measurability and is a function of the variability in the parameter of interest and the sampling intensity.

Deep sea

The deep seas are considered to be the marine environment that extends downwards from the continental shelf break, i.e. waters deeper than 200 metres to its maximum depth. Deep-sea fisheries currently only operate at depths of less than (and usually much less than) about 2 000 metres. However, the deep-sea environment extends to the maximum depths of the ocean and future prospective exploitation that may occur in deeper waters is included in the considerations here.

Equilibrium, resilience and recovery

An equilibrium is a relatively stable state of an ecosystem, its components and its populations. Ecosystems may have multiple stable states or equilibriums. External disturbances, of sufficient strength, can move an ecosystem among its potential equilibrium states, while the ecosystem's regulatory feedback mechanisms may restore it to its original state following lesser disturbances. The ability to recover from any given disturbance is linked to the resilience of the ecosystem.

Resilience of an ecosystem is understood as the magnitude of disturbance that can be absorbed by the system before it shifts to a new equilibrium. Resilience is also related to the speed at which the ecosystem recovers following a disturbance. Recovery is the return of a system to its original state or to its original trajectory, following the disturbance.

The Resilience Alliance (http://www.resalliance.org/1.php) defines resilience as "the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient ecosystem can withstand shocks and rebuild itself when necessary". In this case resilience is measured by the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control its behaviour. This type of resilience has been defined as ecological resilience.

Resilience can also be defined as the “rate at which a system returns to a single steady or cyclic state” following a perturbation, assuming that the behaviour of a system remains within the stable domain that contains this equilibrium state. This definition, which is more traditional, concentrates on stability near an equilibrium steady-state, where resistance to disturbance and speed of return to the equilibrium are used to measure the property. This type of resilience has been defined as engineering resilience.

The first definition focuses on persistence, adaptiveness, variability, and unpredictability while the second focuses on efficiency, control, constancy, and predictability. These two aspects of a system's stability have very different consequences for evaluating, understanding and managing complexity and change. Sustainable relationships between people and nature require an emphasis on ecological resilience, because the interplay between stabilizing and destabilizing properties is at the heart of present issues of development and the environment-global change, biodiversity loss, ecosystem restoration and sustainable development. Emphasis on engineering resilience reinforces the dangerous myth that the variability of natural systems can be effectively controlled, that the consequences are predictable and that stable and sustained production is an attainable and sustainable goal.

Risk and utility

Risk assessment combines the probability of a human activity (e.g. a fishery) causing a negative impact and the consequence of that impact. In a fisheries management context, the risk that is assessed is the risk of not meeting agreed objectives of ecosystem and habitat protection, but it should be clear that without stated objectives, risk cannot be assessed. Risk can be classified as negligible, moderate, high, or very high. Risk will increase with the magnitude and frequency of the human activity considered, and it will also be related to resilience and recovery time. When resilience is low and/or recovery times are long, even low frequency disturbance could imply high risks.

The utility of an ecosystem is a measure of its value (to humans) and may depend on its potential as a source of food, employment, or as a tourist attraction, and thus its existence value.

Species and stocks

A species is a group of living organisms whose members are capable of interbreeding. The concept of a “stock” is not always as unambiguous. A “stock” is a subgroup of a species where individuals in a defined geographical area have similar growth and mortality and do not breed to any significant extent with other groups (stocks) of the same species in neighbouring areas. The application of the concept for management and conservation purposes varies: for salmon, a river may contain several stocks, one for each of the tributaries where spawning occurs, while in other cases, stocks have been defined as containing more than one species (e.g. some redfish [*Sebastes* spp.] stocks in the Northwest Atlantic). Obviously, in this latter case, members of the “stock” cannot all interbreed.

Deep-sea fish stocks have sometimes been called “discrete high-sea stocks” to differentiate them from straddling fish stocks, highly migratory fish stocks, transboundary fish stocks, and stocks entirely within EEZs. “High-seas stocks” is a preferable term to refer to stocks that are purely or entirely in the high seas because the discreteness of such stocks is generally unknown (e.g. fish caught on distinct seamounts hundreds or thousands of kilometres apart may not necessarily belong to discrete/separate biological units). Instead, individual aggregations may be part of a metapopulation with some of them (sinks) dependent on other aggregations (sources) for receiving recruits. In this context, aggregations that are sinks are not self-sustaining, they depend on other aggregations (sources) for their supply of recruits. The vulnerability of the species will be closely linked to the identification and protection of the source aggregations. Deep-sea species do occur inside EEZs as well as on the high seas.

Sustainability

FAO defines sustainable management as "The management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment of continued satisfaction of human needs for present and future generations. Such sustainable development conserves (land), water, plants and (animal) genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable" (FAO, 1989).

From an ecosystems perspective, sustainability of activities depends on the maintenance of ecosystem functions. Thus, as proposed in the Code of Conduct for Responsible Fisheries, fisheries, to be sustainable, should not substantially change the function and integrity of marine ecosystems not only for the fisheries resources but also for the benefit of other uses and users including biodiversity, scientific interest, intrinsic value, trophic structure and other economic uses such as tourism and recreation.

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APPENDIX A

Agenda

1. **Meeting arrangements**
   - Schedule of work
   - Election of a chairperson
   - Other
2. **Output of the meeting**
   - Nature and purpose of report
   - Report structure
3. **Impacts of fisheries on marine ecosystems**
   - Documentation of fishing activities
   - The affects of human society on our ecosystem and the place of fisheries within this context
   - Definition of sustainability, recovery, equilibrium, acceptable adverse impact, risk, utility
4. **Vulnerable marine ecosystems**
   - Definition of VME, ecosystem in an operational management context
5. **What do existing “conventions” say?**
   - LOS
   - UNFSA
   - RFMOs and RFMAs
   - Our comments and evaluations
6. **Destructive fishing**
   - Definition
   - Reversibility and time frames
   - Specific gear considerations:
     - bottom trawls
     - mid-water trawls
     - gillnets
     - line fishing
     - pots and traps
     - other
7. **Can the precautionary approach help?**
   - An objective rational evaluation of the precautionary approach and its implications for deep-sea fisheries
     i. the threats (certain and uncertain – and appropriate reactions)
     ii. the dimension of uncertainty – scientific proof?
     iii. possible actions and
     iv. compliance/obligation/enforcement/regulation – not necessarily in any order.
8. **The ecosystem approach to fisheries management**
9. **Needs of the UNGA, COFI, RFMOs and other IGOs**
10. **Synthesis**

APPENDIX B

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The FAO Workshop on Vulnerable Ecosystems and Destructive Fishing in Deep-sea Fisheries examined available information on national, institutional and personal experiences in relation to this issue. Relevant ecological aspects were reviewed and suggestions as how to consider these issues in terms of International Guidelines for the Management of Deep-sea Fisheries in the High Seas were discussed and documented.

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