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The Science behind the Guidelines:

A Scientific Guide to the FAO Draft International Guidelines (December 2007) for the Management of Deep-Sea Fisheries in the High Seas and Examples of How the Guidelines may be Practically Implemented

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Cover photography

Front cover: Hatton Bank, NE Atlantic. Deep-sea reef formed by *Lophelia pertusa* showing live and dead coral framework and a variety of other organisms including octocorals, echinoderms and fish. Photograph from the SEA7 Project Dti, U.K. C/O Bhavani Narayanaswamy, Scottish Association for Marine Science, Oban, Scotland (http://www.offshoresea.org.uk/consultations/SEA/SEA7_Benthos_SRSL.pdf)

Back cover: Deep-sea starfish: photo courtesy of Deep Atlantic Stepping Stones Science Team/IFE/URI/NOAA

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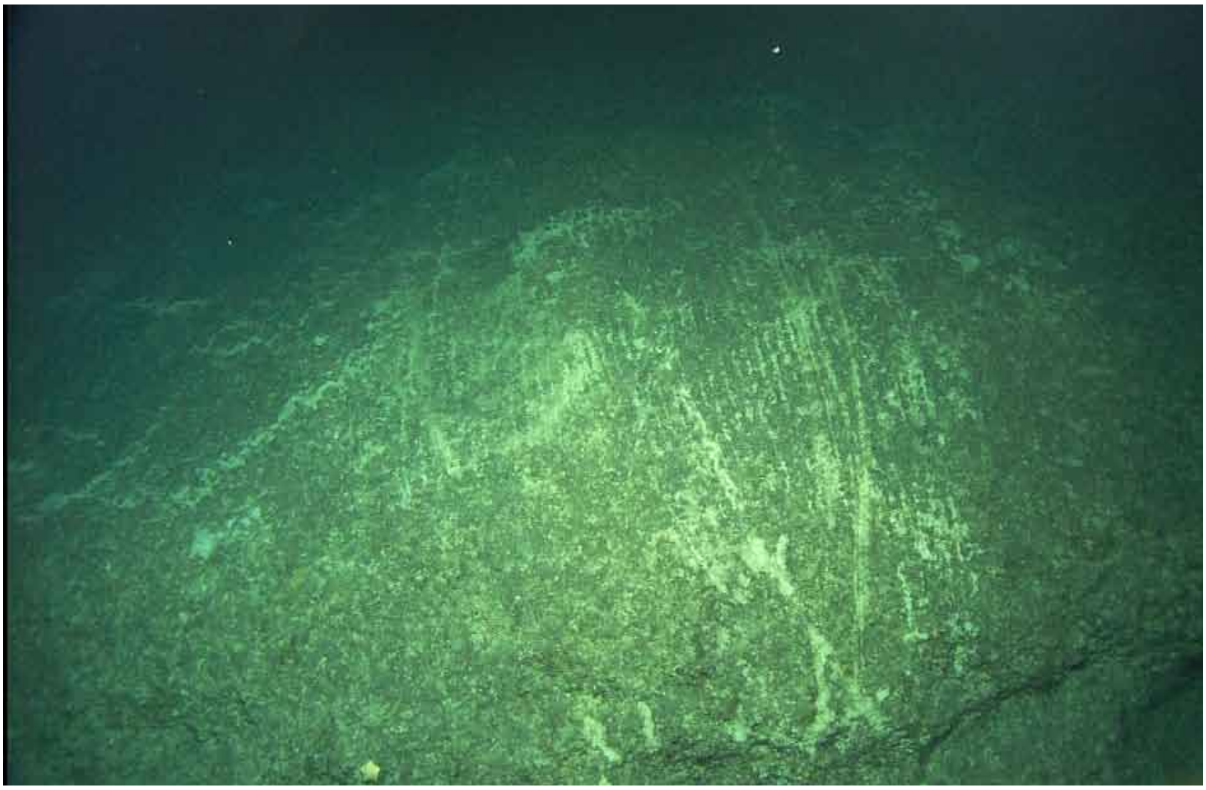
Executive Summary

- The deep-sea fishing industry targets around 20 major fish species globally.
- Many of these species are fished on or in the proximity to deep-sea vulnerable marine ecosystems (VMEs).
- Deep-Sea Fisheries typically exhibit ‘boom and bust’ catches and have been poorly regulated and many are overexploited or depleted.
- Long-term sustainable yields of deep-sea fish species are generally low compared with shelf fisheries.
- Commercial deep-sea fish tend to be long-lived, slow growing, late maturing and form aggregations that make them vulnerable to overexploitation.
- Deep-sea fish stocks have a low capacity for recovery after overexploitation.
- Because of the poor history of Deep-Sea Fisheries precautionary and ecosystem approaches are needed to best manage them, especially where new stocks are exploited.
- Management of Deep-Sea Fisheries can be improved given timely reporting of fine-scale catch and by-catch data.
- Deep-sea coral and sponge habitats are highly species rich VMEs that occur in discrete locations, have a relatively small area and are easily damaged by the mechanical impacts of mobile and static fishing gear.
- Deep-sea corals and sponges are very slow growing and are extremely slow to recover or may never recover from fishing impacts.
- Chemosynthetic ecosystems are classed as VMEs because they host unique communities of species that occur in discrete locations, are rare and are not found elsewhere.
- The vulnerability of deep-sea sedimentary habitats is currently generally unknown.
- VMEs are important ecosystems in the deep sea because of their associated biodiversity, their importance to the surrounding ecosystem and species therein, their fisheries resources and as a source of novel biomolecules for the biotechnology industry.
- Our knowledge of the distribution of deep-sea VMEs continues to be improved through modelling, mapping and analyses of fisheries, research and observer data; methods for identification of where VMEs occur are outlined with examples.
- Satellite tracking through Vessel Monitoring Systems (VMS) requires improvement but offers a cost effective method for the identification of where fishing activities coincide with VMEs and in the design, monitoring and enforcement of spatial management in the deep sea.
- Urgent action is required as climate change and a range of other human activities will affect the deep-sea realm in the coming decades.



Scar marks caused by trawling gear bear evidence of the cause of the destruction to once abundant deep-sea coral communities on the edge of a summit plateau on the Kükenthal Peak. Photo courtesy of Deep Atlantic Stepping Stones Research Group, IFE, URI, NOAA.

1 Introduction

The Draft International Guidelines for the Management of Deep-Sea Fisheries in the High Seas are designed to provide practical guidance to States and Regional Fisheries Management Organizations (RFMOs) for the implementation of the provisions of UN General Assembly (UNGA) resolution 61/105, related to the protection of vulnerable marine ecosystems on the high seas from bottom fishing activities and the long-term sustainability of deep-sea fish stocks (operative paragraphs 80-91).

The UNGA resolution, in particular its provisions in paragraph 83a-d, represents a commitment by States individually, and through RFMOs, to take a number of actions, including the following:

1. States are required to conduct impact assessments of 'individual' high seas bottom fishing activities to determine whether they would involve significant adverse impacts (SAIs) to vulnerable marine ecosystems (VMEs).

2. States are required, based on impact assessments, to ensure that SAIs toVMEs will not occur as a result of high seas bottom fishing activities.

3. States and RFMOs are to identify vulnerable marine ecosystems.

4. States and RFMOs are to close areas where VMEs are known or likely to occur unless or until they can ensure that any bottom fishing in these areas can be managed to prevent SAIs to VMEs.

5. Fishing vessels are required to cease bottom fishing in areas where VMEs are encountered during the course of fishing operations until appropriate measures can be adopted in respect of the relevant site.

6. States are to ensure the long-term sustainability of deep-sea fish stocks.

The purpose of this document is to provide States and other interested parties participating in the UN FAO Technical Consultation on the International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (4-8 February 2008) with more detailed scientific information to better assist and inform the discussion. Specifically, this document provides background information on scientific issues related to the conservation and management of Deep-Sea Fisheries and the protection of vulnerable marine ecosystems and the scientific basis for a number of the provisions of the Draft International Guidelines, including the definitions of vulnerable marine ecosystems, significant adverse impacts and approaches needed to determine the known and likely locations of vulnerable marine ecosystems on the high seas.

The information provided in this document is structured to correspond to the structure and paragraph numbers of the December 2007 Draft International Guidelines (FAO Technical Consultation document TC: DSF/2008/2), but also draws on several of the provisions contained in the September 2007 Draft International Guidelines as adopted by the Expert Consultation in Bangkok (FAO Technical Consultation document TC:DSF/2008/Inf.3), as indicated in the sections below.

2 Background Considerations

Track Record and Impacts of Deep Sea Fisheries

Deep-Sea Fisheries, even within areas of national jurisdiction, have typically not maintained high catch levels over time[1]. There are many examples of 'boom and bust' fisheries, that have developed and declined rapidly, sometimes within a few years or a decade[2,3,4]. A prime example of this, in areas beyond national jurisdiction, is the recent fishery for orange roughy in the Southwest Indian Ocean, which saw catches decrease substantially after only four years in the late 1990s[5]. Orange roughy may be considered an extreme example[4,6,7], but fisheries for other deep-sea species have also shown low resilience to large catches, such as the pelagic armourhead fishery off Hawaii in the 1970s, alfonsino in the North Atlantic, roundnose grenadier on the Mid-Atlantic Ridge, and deep-water notothenids in the Southern Ocean[1]. These fisheries have sometimes maintained catches by moving to new grounds (i.e. serial depletion of seamount populations), or by switching to other species as the target species biomass has declined (e.g. increase in alfonsino catches as pelagic armourhead was overfished on the Hawaiian seamounts). However, even relatively shallow seamount-associated species (e.g. pink mao mao, *Caprodon longimanus*) can be rapidly depleted, evidenced by a short-lived fishery on the Lord Howe Rise where Japanese catch rates in 1976 decreased from 1.7 to 0.2 t/hr over one year with a catch of not much more than 1000 t[8]. Sissenwine & Mace[7] listed 44 deep sea (>200m depth) area-species combinations, and 27 of these included stocks classed as overexploited or depleted. No stocks were identified as recovering.

Vulnerability of Deep-Sea Species

Deep-Sea Fisheries have generally not proven sustainable because of one or a combination of three generic aspects:

1) Biological characteristics

Deep-sea species often exhibit high longevity (e.g. orange roughy, redfish 100 years), late maturation (sometimes >20 years before becoming mature, e.g. orange roughy, oreos), slow growth, low fecundity (e.g. deep-water sharks, orange roughy), intermittent recruitment (occurs with most species, but with long-lived species there could be decades between good year classes), and spawning may not occur every year. These types of fish generally have low rates of natural mortality and low production rates meaning recovery is slow. Their biology is not evolved to cope with high levels of natural predation, and so they are more vulnerable to human exploitation. In the high seas, seamount species are major targets of fishing, and a number of the above characteristics have been demonstrated[9].

2) Habitat/fishery type

In the high seas, many species aggregate on seamounts or ridge peaks because of local conditions that enhance feeding, growth, survivorship and reproduction. Such aggregations are more vulnerable to over-fishing and rapid depletion than where species are more dispersed on shelf or slope habitat. When aggregations are formed for spawning the effects may be greater because of high mortality on the spawning component of the overall population, possible disruption of the spawning process and reduced reproductive success (although the latter has rarely been documented). Target trawling on seamounts is often localized, and the density of tows per seamount area can be high. Heavy bottom trawl gear is used to tow on the rough and hard bottom which is often characteristic of seamounts, and the invertebrate fauna, often dominated by large, slow-growing, sessile (permanently attached) organisms, are especially vulnerable to damage by fishing gear (see below). Static gears (pots, benthic longlines and gill nets) may also damage sessile organisms during deployment and recovery, and impacts to coral and sponge habitats have been observed in the Pacific and Atlantic Oceans[10,11,12]. High seas fishing grounds occur offshore, and so are carried out by large powerful vessels with the ability to work large gear, catch and process large amounts of fish, and stay at sea for long periods.

3) Management limitations

Deep-Sea Fisheries in the High Seas have in the past generally been unregulated. There have been no controls on catch or levels of effort, leading to overexploitation of the target, and also by-catch, species. Even within EEZs, given the above biological and habitat characteristics, research has been difficult for many deep-sea species, and initial stock assessments based on inadequate data have frequently been too optimistic, and subsequent management responses slow or insufficient[7]. Research is difficult with deep-sea species, and issues of cost and technical difficulties mean that knowledge may be limited and thus precautionary approaches to management are necessary. The biological characteristics also mean that some traditional stock assessment and management concepts (e.g. MSY, fishing down practices) have a high risk, and are definitely not conservative. Economics has a role also, with a number of species (e.g., orange roughy, alfonsino) having relatively high values which provides an incentive to maintain fishing as catch rates decline.

This community of whip corals, sea fans, and bamboo corals on a plateau on the Kükenthal Peak represents one that avoided fish trawling damage that scientists say "effectively denuded" the seamount. Photo courtesy of Deep Atlantic Stepping Stones Research Group, IFE, URI, NOAA.

Impacts of Fisheries

By-catch

A large number and variety of fish and invertebrate species may be caught by deep-sea fishing operations. Fluctuations and shifts in by-catch composition over time with heavy fishing have been shown in a number of major fishing areas, such as Georges Bank and the North Sea, although findings have varied for different fish communities. Typically trawling results in a decline of all associated species, as the method is amongst the least selective of fishing types. This can be potentially serious for species that are less productive than the target fish. By-catch of deep-water sharks and rays is recognized as a major sustainability issue, as these species have a low resilience to fishing as a result of their conservative life histories, although by-catch of sharks can be greater in deep-water long-line fisheries than in seamount trawl fisheries[13].

Although seamount communities can comprise many species, seamount trawl fisheries targeting aggregations in some areas often have a low by-catch of non-target fish species: by-catch by deep-water fleets fishing in New Zealand waters for orange roughy and oreos is about 5-10 %[14]. Similarly, about 5% was recorded in an orange roughy fishery on seamounts south of Tasmania[15], where oreos, rattails and deep-water sharks were the main by-catch. However, by-catch figures in the Northeast Atlantic can be much higher.

Other effects

A reduction in the age composition and size structure of species occurs with fishing. Trawl gear can be size-selective, and larger, older fish are often taken more than smaller younger fish. The result is a reduction in the size and age spectra of exploited populations. Reproductive output can be reduced, with lower fecundity and viability of eggs often associated with reproduction of younger fish, and trophic relationships also change with a shift in community structure, as predator-prey balances change. Species such as pelagic armourhead and orange roughy require production from an area 10 times larger than their home range[16,17]. Reduction of the biomass of such species may affect the ecosystems they live in by increasing the abundance of species they prey on or may have impacts on populations of their predators (i.e. larger fish species or cetaceans).

Recovery Dynamics of Deep-Sea Fisheries

Once overexploited, few Deep-Sea Fisheries have shown signs of recovery. There are situations where fishing success for orange roughy has improved with a reduction in effort levels, and fishers have reported increased catches of alfonsino and pelagic armourhead in some areas when the seamounts or fishing grounds have not been fished for a period. However, this may in part be related to a decrease in disturbance of aggregations with reduced trawling than an increase in stock size[18]. Orange roughy stocks in New Zealand and Australia have generally continued to decline even when catch has been reduced to levels thought by scientists to be sustainable. Irregular recruitment levels may be a key factor with recovery of deep-sea species.

3 Scope and Principles

Scope

The scope of the Draft Guidelines is described in paragraph 13.

13. These Guidelines have been developed for fisheries which occur in areas beyond the limits of national jurisdiction and have two characteristics:

i) The total catch (everything brought up by the gear) includes species that can only sustain low exploitation rates and/or suffer incidental mortality; and
ii) that the fishing gear is likely to contact the seafloor.

Definition of deep sea

The reason the experts did not simply define Deep-Sea Fisheries as those occurring below a certain depth is because the boundaries between shallow and deep-water communities are not clear cut. Some fish and other species undergo extensive vertical migrations from deep to shallow waters on a daily basis and species perceived as living in shallow water may forage or spawn in deep waters. The definition of "deep sea" varies between organizations and countries. FAO uses a criterion of beyond the continental shelf break, typically occurring at about 200 m. The International Council for the Exploration of the Sea (ICES) uses a similar definition. However, this depth-limit means a large number of shallow-water species are included where their depth distribution extends beyond 200 m. Hence the Draft Guidelines have focused on an ecological definition that recognizes fish with low productivity relative to inshore continental shelf species with a high productivity, as stated in Paragraph 13 of the Draft Guidelines.

The Draft Guidelines also focus on fragile marine ecosystems in the deep sea that comprise benthic species that are vulnerable to impacts by fishing gear, and that have a low capacity to recover from disturbance as a result of conservative life histories (i.e. very slow growing, slow to mature, high longevity, low levels of recruitment), and sensitivity to changes in environmental conditions.

Where deep-sea fisheries occur

Deep-water trawl fisheries that occur on the high seas target some 20 or more major species or species groups on both seamounts and along continental slope areas where these extend beyond the EEZs. These include alfonsino (*Beryx splendens*), black cardinalfish (*Epigonus telescopus*), orange roughy (e.g. *Hoplostethus atlanticus*), Greenland halibut (*Reinhardtius hippoglossoides*), northern prawn (*Pandalus borealis*), armourhead and southern boarfish (*Pseudopentaceros spp.*), redfishes (*Sebastes spp.*), macrourid rattails, primarily roundnose grenadier (*Coryphaenoides rupestris*), oreos, including smooth oreo (*Pseudocyttus maculates*) and black oreo (*Allocyttus niger*), deep-sea sharks (e.g squalid sharks), deep-sea crabs (*Chaceon spp.*), Patagonian toothfish (*Dissostichus eleginoides*) and in some areas Antarctic toothfish (*D. mawsoni*), which has a restricted southern distribution[1]. A number of shallower-water species are targeted in bottom fisheries in shelf and upper slope areas extending into the high seas including hakes, squids and skates.

Most of these fisheries use bottom trawl gear, although there is often a mix of bottom contact demersal trawls, and midwater nets towed very close to the bottom. Some species, such as Patagonian toothfish, are caught using benthic long lines; others such as deep-sea sharks and crabs are often targeted in bottom gillnet fisheries and, in the case of crabs, bottom trap or pot fisheries.

Many of these fisheries occur principally on seamount or ridge features (Fig 1), which are the main types of fishery habitat in open ocean high

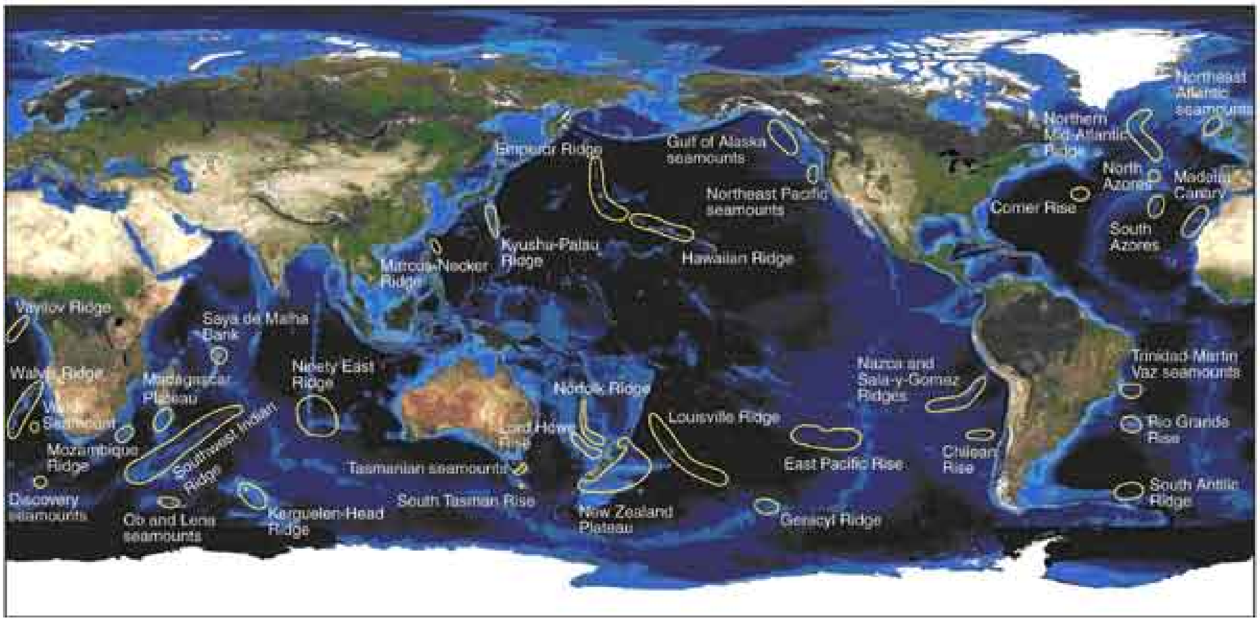


Figure 1. Deep-Sea Fisheries. Global map showing the distribution of major fisheries on seamounts and ridges, including those in the high seas and in national waters[1].

seas areas because they rise to shallower and more accessible depths than the abyssal seafloor.

The areas of the high seas where bottom fisheries occur or have taken place in the past include those on (Atlantic) the Northeast Atlantic seamounts including the high seas portions of the Hatton and Rockall Banks in the Northeast Atlantic, the Northern Mid-Atlantic Ridge, Corner Rise seamounts, Rio Grande Rise, Discovery seamounts, Walvis Ridge, Vavilov Ridge, (Pacific) Nazca and Sala Y Gomez Ridges, East Pacific Rise, Geracyl Ridge, Louisville Ridge, Lord Howe Rise, South Tasman Rise, Norfolk Ridge, Emperor seamount chain, (Indian Ocean) Ninety-East Ridge, Southwest Indian Ridge, Ob and Lena seamounts, Saya de Malha Bank[1] (Fig. 1). The main shelf and slope areas where high seas bottom fisheries take place are the high seas portions of the Patagonian Shelf and continental slope in the Southeast Atlantic and the high seas portions of the shelf and continental slope of the Grand Banks and the Flemish Cap in the Northeast Atlantic.

It is not possible to estimate the percentage of VMEs, or even seamounts, that have been subject to deep-sea fishing because accurate geo-referenced fisheries data is incomplete and knowledge on the distribution of VMEs is poor. Fishing has occurred over extensive areas of the deep sea that are likely to support concentrations of commercially valuable species and are sufficiently shallow to fish (<2,000m depth at the present time). It is estimated that the cumulative catch from seamount trawl fisheries on both the high seas and within areas of national jurisdiction has exceeded 2.25 million tonnes[1]. Given that much of the reported catch of deep-water species does not distinguish between catches taken on the high seas and catch within EEZs, it is not possible to accurately determine how much of the catch has been taken on the high seas.

Principles and objectives for Deep Sea Fisheries Management

The Draft Guidelines in paragraphs 16 and 17 are as follows:

16. The main objectives of the management of DSF are to:

i) ensure the long-term sustainability of marine living resources in the deep seas;
ii) prevent significant adverse impacts on VMEs; and
iii) protect biodiversity in the marine environment.

17. In order to achieve these objectives, flag States and RFMO/As should on a case-by case basis

i) adopt and implement measures in accordance with the precautionary approach
and the ecosystem approach,….

The proposed measures for management outlined in the Draft Guidelines are extensive, but reflect the need to operate on a precautionary basis where information is poor or incomplete, most stocks are vulnerable to very rapid overexploitation (stocks have declined in <1 year of fishing)[8], and most species demonstrate poor ability to recover from heavy fishing. Therefore, precautionary approaches to fisheries management are required to improve the chances of a sustainable fishery as stated in Paragraph 17 of the Guidelines. Such approaches should be aimed at ensuring that Deep-Sea Fisheries do not develop more quickly than the information necessary to ensure that they can be conducted in a sustainable manner as consistent with the Law of the Sea Convention (UNCLOS), the UN Fish Stocks Agreement, and Resolutions of the UN General Assembly[19]. In a similar manner, existing fisheries should only continue if measures are in place to ensure that sufficient information is collected to ensure that they are sustainable. These require detailed data collection of catch and effort information to inform stock assessment and fisheries management. Data required for adequate management is described in section 6.A.

The observed rapid destruction of vulnerable seabed communities such as cold-water coral reefs, octocoral gardens and sponge beds by deep-sea fishing operations, and their poor ability to recover from such impacts, if recovery is possible at all (see below), means that the ecosystem approach is a critical part of the management of Deep-Sea Fisheries. Ecosystem approaches are also required because of the likely impacts on foodwebs and critical ecological processes in the deep sea, by the removal of biomass of target and by-catch species, discards and disposal of fish offal and the destruction of habitat and accompanying reduction in the physical complexity of the seabed.

4 Description of Key Concepts

4.A Vulnerable Marine Ecosystems

Paragraphs 19 and 20 of the Draft Guidelines describe the concept of VMEs as follows:

19. Vulnerability is related to the likelihood that a population, community, or habitat will experience substantial alteration from short-term or chronic disturbance, and to the length of time required to recover after a disturbance. The most vulnerable marine ecosystems are ones that are both easily disturbed and are very slow to recover, or may never recover. Vulnerable ecosystem features may be physically or functionally fragile.

20. The vulnerabilities of populations, communities and habitats must be assessed relative to specific threats. Some features, particularly ones that are physically fragile or inherently rare may be vulnerable to most forms of disturbance, but the vulnerability of some populations, communities and habitats may vary greatly depending on the type of fishing gear used or the kind of disturbance experienced.

What are Vulnerable Marine Ecosystems and Where Do They Occur?

The definition of Vulnerable Marine Ecosystems in the Draft Guidelines covers areas that are easily disturbed by human activities, and are slow to recover, or which will never recover. This definition is consistent with that used by other intergovernmental bodies as reflected in reports of the UN Secretary General[20], OSPAR and ICES[21].

In this context ecosystem refers to a defined system comprising organisms that interact with each other and with the chemical and physical factors of the environment[22]. Marine ecosystems may be easily disturbed if: (1) they are characterised by low-levels of natural disturbance and / or low levels of natural mortality; (2) component species are fragile and are easily, killed, damaged or structurally or biologically altered by human impacts, in this case mechanical disturbance by fishing gear; (3) distribution is spatially fragmented with patches of suitable habitat that are small in area and "rare" in comparison to the overall area of seabed; or (4) important ecosystem functions are disrupted or degraded.

Recovery from damage will be extremely slow or will not occur if: (1) ecosystems comprise rare, unique or endangered species or habitats, high levels of endemism (species not found elsewhere), or are functionally unique or rare (e.g. spawning sites); (2) species or populations have life-history or biological characteristics that include slow growth rates, high longevity, a late age of maturity, low or unpredictable recruitment; or (3) populations do not compensate for losses by increasing the numbers of recruits per spawning adult within the population, but instead show a negative relationship between numbers or densities of adults and the number of recruits per spawning adult. This is a particular problem for sedentary animals, such as corals, where specific densities of colonies or individuals are required to ensure successful fertilisation of eggs released into the water (allee effect).

Corals and sponge habitats as VMEs

Vulnerability & fragility

Cold-water coral reefs, octocoral gardens and deep-sea sponge reefs or fields are widely recognised as VMEs[19,20,23]. This is because they are all fragile three-dimensionally complex habitats that are easily damaged by mechanical impacts from fishing gear, especially bottom trawls[8,24] but also gillnets, pots and benthic long lines[10,11,12]. In many cases, mid-water trawls are most effective when fished very close to, or even lightly touching, the bottom (e.g. alfonsino fisheries). Thus, it is likely that the effects of trawling on the benthic fauna, would be similar to that of the bottom trawl fisheries (e.g. for orange roughy).

Resilience and recovery of deep-sea corals and sponges from fishing impacts

Cold-water coral reefs, octocoral gardens and deep-sea sponge reefs or fields all have a low capacity to recover from disturbance or destruction. This is because they comprise structural species that are very slow growing, form habitats over very long periods of time, have low levels of recruitment and live for a long period of time. Growth rates for deep-sea stony corals have been estimated at between 4mm to 25mm per year (linear growth rate)[25,26] with individual colonies of *Lophelia pertusa* being estimated at up to 200-366 years old[27]. Deep-sea octocorals have been estimated as growing at between 0.014 to 0.5 mm per year (radial growth rate)[28,29], with individual colonies aged up to 2,742 +/-15 years (*Gerardia sp* from Hawaii)[29]. The lowest growth rates have been estimated for black corals at <0.01mm per year, with a maximum age of 2,377 +/- 15 years (*Leiopathes glaberrima*)[29]. Coral habitats can grow and remain in place over much longer periods of time. *Lophelia pertusa* reefs in the northern North East Atlantic are estimated to be about 10,000 years old whilst corals from seamounts in more southerly areas of the North Atlantic have resided in some localities continuously for up to 50,000 years[30]. Sponges have been estimated to have higher growth rates (0.76cm to 5.7 cm per year; *Rhabdocalyptus dawsoni*, 40m depth Canada), but colonies are estimated to be up to 220 years old[31]. These growth rates have been estimated from sponges in shallow water (~40m depth) and it is likely that sponges occurring in deeper water grow more slowly and live for longer. Some Canadian sponge reefs have existed at sites for up to 9,000 years.

Most deep-sea corals that have been investigated to date have separate sexes (not hermaphroditic like many shallow-water corals) and are broadcast spawners (shed eggs into the water column)[32]. Fecundity varies from low (*Madrepora oculata*) to relatively high (*Lophelia pertusa*) and whilst coral larvae can disperse over considerable distances, as evidenced by colonisation of oil platforms in the North Sea[33], most recruitment of new individuals to reefs probably comes from larvae produced at the same site[34]. Studies on octocorals have shown that larval dispersal between populations may occur over large distances[35] or can be highly restricted even amongst islands and seamounts within a small region (e.g. Hawaiian Islands and seamounts[36]). As yet there is no clear evidence of recruitment of new coral individuals to sites damaged by trawling[37] indicating that recovery from fishing impacts has not taken place on the scale of tens of years. Current studies in New Zealand indicate that stylasterid corals (hydrocorals) are more frequent on fished seamounts, and may colonise heavily trawled surfaces within 5 years (NIWA, unpublished data) but the original stony corals show no sign of recovery within that time. Full recovery from fishing impacts may take place on scales of hundreds to thousands of years and may not occur at all if the seabed is physically altered or the ecosystem has been changed so that recruitment of new colonies is not possible, or there are no sources of larvae within a suitable distance for colonisation.

At present there are no data on the larval stages or dispersal potential of deep-water habitat-forming sponges. Studies on trawling impacts on deep-sea sponges have indicated that no recovery is evident after a period of one year[38]. Even where sponges are only damaged rather than destroyed entirely, no evidence of repair to tissues was evident after a year and many damaged individuals died following tissue necrotization[38]. Shallow-water sponges (~40m depth) have shown a greater capacity to repair wounds, although a small number also die from necrotization of tissue[31].

Where cold-water coral and sponge habitats are found

Cold-water coral reefs, octocoral gardens and deep-sea sponge reefs or fields are distributed in discrete locations, often with a small geographical area where a narrow range of suitable environmental conditions prevail (e.g. temperature, salinity, nutrient concentrations;[39-42]). These locations typically occur in areas exposed to fast currents that have hard substrata on the seabed (e.g. exposed rock, stones, carbonate crusts) and may be associated with the formation of internal waves or bottom-intensified trapped waves that act to maintain or concentrate the supply of particulate food or plankton on which sponges and corals feed[40,41,43-46]. Such locations occur in areas of steep or irregular topography[41,47-49] and are often associated with the shelf break or upper continental slope[41,47,49], the slopes of oceanic islands and also with banks[47], seamounts[48] and canyons[50] as well as smaller features such as submarine knolls and hills[51,52]. Such areas may also be associated with high productivity in the waters overlying the seabed[41,46,49.] Coral reefs and sponge reefs or fields can occur down to 1,800 - 2,000m depth[53-55] and octocorals and antipatharian fields occur deeper (2,200m +56). Analyses of the depth distribution of corals on seamounts, indicates that species diversity is highest down to 1,000 – 1,500m depth, with peak diversity occurring deeper for octocorals and antipatharians than for scleractinian corals[32]. Depth exerts a strong influence on the species composition of coral and sponge communities in the deep sea so that the species present change moving from shallow to deep water. Such VMEs therefore may occur at all depths at which deep-water fishing is taking place at the present time.

Other VMEs

Chemosynthetic ecosystems

Chemosynthetic communities that are found around hydrothermal vents or hydrocarbon seeps are also easily disturbed. These VMEs are rare and occur in fragmented locations reflecting the distribution of the geological features on which they depend. Hydrothermal vents are located on mid-ocean ridges, on island arcs and on seamounts. Hydrocarbon seeps are associated with continental margins. They have highly endemic faunas because only a few species have evolved the physiological mechanisms to live in such extreme environments. In some cases, endemic species are only known from single hydrothermal vent or hydrocarbon seep, or those from a small geographical area.

Geophysical features including seamounts

Geophysical features including seamounts, banks, knolls, the slopes of oceanic islands, carbonate mounds, canyons, trenches and manganese nodule beds have also been identified as VMEs. This is because they are often associated with biological communities that are easily disturbed and are slow to recover (e.g. cold-water coral reefs, sponge fields, other emergent epifaunal communities).

It is not always the case that such habitats are VMEs. Parts of canyons may, for example, be subject to high levels of natural disturbance and communities can comprise a great abundance of a few resilient species[57]. Some seamounts may not host communities of fragile animals or be associated with high levels of endemism. Thus treatment of such localities on a case-by-case basis is very important as they include a wide range of physical and chemical environments and biological communities. Ocean trenches and manganese nodules occur well below the current depths at which fishing takes place.

Whilst it is widely recognised that some deep-sea communities are vulnerable, our knowledge is insufficient to judge whether this is the case for the majority of deep-sea ecosystems that comprise communities of animals living on or in sediments such as muds. Many types of VMEs are yet to be identified, as exemplified by the recent discovery of bivalve beds in the deep waters of the Azores Islands[58]. It is therefore important to evaluate the potential for deep-sea fishing to impact any biological communities that are contacted by fishing gear or are potentially impacted by fisheries through alterations of ecosystem function, not just those listed above or which are referred to in the Draft Guidelines. In this regard, the commitment by States to conduct environmental impact environmental impact assessments of bottom fishing activities (paragraph 83(a) of UN General Assembly resolution 61/105) is an essential element in the conservation and protection of deep-sea ecosystems on the high seas. The criteria for identifying whether a community represents a VME are those outlined above.

What is the Value of VMEs?

Biodiversity hotspots

Vulnerable marine ecosystems in the deep ocean are biodiversity hotspots and harbour unique communities of species, often with a high diversity or high level of endemism. Corals, sponges and other large emergent epifaunal species add three dimensional structure to the seabed and provide a variety of habitats for other species. These organisms are therefore referred to as ecosystem engineers[47].

For example, the stony coral *Lophelia pertusa* forms complex three-dimensional reef frameworks, with a variety of habitats including the live coral branches, dead coral framework, at various stages of decomposition, and sediment produced by the breakdown of coral skeletons and by the trapping of particles within the coral reef matrix. Different suites of species inhabit these different habitats and overall more than 1,300 species of animals have been found associated with *Lophelia pertusa* reefs in the Northeast Atlantic[59]. Other deep-water coral reefs have also been found to harbour a high abundance and diversity of species including those formed by *Oculina varicosa* off Florida and those formed by *Solenosmilia variabilis* in the southwestern Pacific[60,61]. Octocorals also host a rich associated fauna although they are less well studied than deep-sea reef-forming corals. Analyses of just 25 colonies of octocorals from the Atlantic coast of Canada identified 114 species of associated animals[62]. Many of the species associated with corals do occur in other habitats although a proportion of the community are obligate associates of corals (out of 983 species surveyed, 114 were mutually dependent on deep-sea corals[63]).

Sponge habitats also have a high diversity of associated species with more than 242 associated species identified from sponges in “ostur” (dense sponge beds) regions off the Faroe Islands[64-66]. In addition, when sponges die they leave dense accumulations of spicules that form mats. These can be associated with an increased abundance of animals compared to localities without spicules[67]. It must be emphasised here that the state of knowledge on the diversity associated with coral and sponge habitats is still very poor and species richness is certainly underestimated for most of these communities.

Chemosynthetic communities are characterised by low levels of species diversity but high levels of endemism (species are not found anywhere else). This is because chemosynthetic habitats are associated with stressful environmental conditions (e.g. high temperature, low oxygen, high levels of toxic chemicals, low pH) to which relatively few species of animals have adapted. These ecosystems and the species they contain (including microorganisms) have changed the view of how life has evolved on Earth and what is required for communities of organisms to survive. They remain important in scientific terms in understanding evolution and in the identification of valuable biomolecules (see below).

Seamounts have also been identified as biodiversity hotspots and may harbour abundant populations of epifaunal suspension feeders including reef-forming corals, octocorals and sponges which in turn provide habitat for smaller mobile animals with molluscs, crustaceans and echinoderms being particularly diverse[68]. In some cases, many of these species may be new to science e.g. the Norfolk Ridge and Lord Howe Rise where 730 species have been described from seamounts of which 411 were new to science[61,68]. Levels of endemism amongst seamount communities appear to vary widely depending on location from very low levels (<2%)[69] to very high levels (>50% on a regional basis)[61,70] and generalisations are not possible. Estimating levels of endemism is very difficult partially because the lack of data on the communities found at these localities but also on the difficulty of making comparisons with the surrounding deep-sea ecosystems which are also poorly studied in many parts of the world[68]. In some geographic regions (e.g. the SW Pacific), seamounts harbour relict or fossil species that are scarce or are not found elsewhere. Examples of these include species of glypheid crustaceans, sponges, crinoids and brachiopods with affinities to fossil species from the Jurassic and Cretaceous periods[68]. It is likely that seamounts may act as refugia from the effects of climatic changes and resultant changes in biota that have occurred in the past.

Importance to fisheries and the wider ecosystem

VMEs include important habitats for commercially fished species. A recent analysis of catches from seamounts identified 13 fish species that could be regarded as primary seamount species, those in which a high proportion catches are on seamounts or which are exclusively caught on seamounts[71]. These included finfish, such as pelagic armourhead (*Pseudopentaceros richardsoni*; 100% caught on seamounts), cardinal fish (*Epigonus telescopus* 76%), oreos (*Allocytus niger, Pseudocyttus maculates* 76%), orange roughy (*Hoplostethus atlanticus* 54%), Patagonian toothfish (*Dissostichus eleginoides* 23%) and alfonsino (*Beryx splendens* 19%). These also include two species of crustaceans, the same-spine stone crab (*Lithodes aequispina* 15%) and the Tristan da Cunha lobster (*Jasus tristani* 15%). In addition, at least 29 species of commercially valuable fish may be considered as secondary seamount species[71]. These are species that are not exclusively or primarily found on seamounts, including pelagic species for which catches are enhanced in proximity of seamounts. These include a variety of demersal fish such as mirror dory (*Zenopsis nebulosus*), roudi escolar (*Promethichthys prometheus*), shortspine thornyhead (*Sebastolobus alascanus*) and yellowtail amberjack (*Seriola lalandi*) as well as high-value pelagic species such as yellowfin, bigeye, albacore and skipjack tuna. A number of octocoral species are also harvested for the jewellery industry on seamounts, especially in the North Pacific. In localised areas, small-scale artisanal fisheries on seamounts can be important as well as operate for many years (decades to centuries). These fisheries tend to occur exclusively within national waters and include the black scabbardfish fishery off Madeira and mixed line fisheries off the Azores, Hawaiian Islands and the Seychelles[72].

Analyses of the distribution of catches of large ocean predators, such as tunas, sharks, billfishes and turtles, in the Atlantic and Pacific Oceans have shown that their diversity and abundance may be concentrated around seamounts[73-78]. Observations and surveys have also indicated that marine mammals, including whales, dolphins and pinnipeds may also be associated with seamounts. These include some species with highly restricted ranges, whose distribution centres on offshore and oceanic islands with high seamount densities, such as the Hawaiian monk seal, Galapagos fur seal and a sub-species of the Commerson dolphin[79]. Generally, the reasons for the high abundances of predators around seamounts are poorly understood because of data limitations on these ecosystems[80]. It is thought that at seamounts, the flux of zooplankton, small fish and other swimmers and detritus is enhanced compared to the surrounding ocean or such food sources are trapped or concentrated by the complex current regimes at these sites or that they provide greater access to mesopelagic food sources for large predators[76,80,81]. It has been suggested that, in some cases, seamounts increase primary productivity through causing local upwelling, although there is very little evidence for this and it may only occur on relatively few seamounts. Enhanced fluxes of detritus and plankton also lead to the development of complex benthic epifaunal communities, such as coral reefs, that may lead to the development of complex detritivore-based food-webs which in turn lead to the presence of scavengers and predators on seamounts[81]. Such complex benthic ecosystems may also enhance foraging opportunities for many fish and other predators on seamounts and may even act as a food source for some species. Seamounts may attract large predators for other reasons. There is some evidence that seamounts may act as important navigational waypoints in the oceans[76]. Seamounts are also known to be important as spawning sites for some species such as orange roughy[48].

Studies investigating whether the abundance and biomass of fish are enhanced by the presence of epifaunal coral and sponge communities on seamounts or in other deep-sea ecosystems are sparse. Studies to date have indicated that catches of commercially valuable species may be higher in and around cold-water corals reefs[82]. Observations from research submersibles, ROVs or other scientific methods have identified significantly higher abundances of fish and crustaceans in coral and sponge versus non-coral and sponge habitats[10,83-90], although not in all cases[91]. In Alaska, 97% of juvenile rockfish and 96% of juvenile golden king crab were associated with emergent epifaunal invertebrates such as corals and sponges[10]. In the northeastern Atlantic, visual surveys of areas of the continental margin indicated that 80% of individual fish and 92% of fish species were observed on *Lophelia pertusa* reefs in comparison to non-reef habitat[87]. Identifying why such associations occur is difficult. In many cases fish may use coral in a similar way to other complex topography such as rocks and boulders on the seabed for shelter and for foraging. Other studies have proposed that, in a similar way to seamounts, coral-associated food-webs provide important sources of food for fish[92,93]. Most fish are also found in other habitats although some species appear to be found exclusively or mainly associated with corals[90,94]. Other large predators may also use coral habitat as foraging areas. The endangered Hawaiian monk seal has been observed as foraging preferentially for fish amongst beds of octocorals and black corals off Hawaii[95]. However, spawning aggregations of orange roughy continue to occur on heavily fished seamounts where coral has been removed[8], suggesting that there is no direct link (at least in the short-term of a decade or so) between the benthos and fish concentrations for this species.

Whilst knowledge is still in its infancy, there is a strong possibility that destruction of habitat formed by deep-sea corals, sponges and other emergent epifauna, by fishing, can have knock-on effects on food webs associated with seamounts and other localities where these occur. Such effects may impact on commercially valuable species, either through simply reducing the complexity of seabed habitat and decreasing areas for shelter and foraging by such species, or by directly impacting availability of food and other ecological requirements (e.g. spawning sites). Such impacts may extend through food-webs associated with such VMEs. Likewise, the removal of large quantities of biomass of target species by fisheries as well as discards of unwanted by-catch and offal from fishing may have as yet unobserved consequences for VMEs and their associated foodwebs[8].

Biotechnology

The deep sea is increasingly becoming a source of commercially valuable biomolecules. Chemosynthetic ecosystems, especially hydrothermal vents are proving to be a rich source of thermostable enzymes with novel properties that are useful in molecular biological research, industrial processes and for cosmetic and medical uses. Commercial production of DNA polymerases from deep-sea hydrothermal vent bacteria, for use in molecular biology, has taken place over a number of years[96]. Patents also exist for microbially derived UV-protectants and for enzymes that reduce viscosity in industrial processes, from deep-sea hydrothermal vent ecosystems[96]. Deep-sea sponges have also proved to be a rich source of novel biomolecules, including the potent anti-tumour agent discodermolide discovered in deep-sea sponges by the Harbor Branch Oceanographic Institution (HBOI), subsequently licensed by Novartis and now undergoing drug trials. HBOI have also isolated other anticancer agents from deep-sea sponges including lasonolides from *Forcepia* sp. which shows promise in the treatment of pancreatic cancer[96]. Bamboo corals (family *Isididae*) are being investigated for their medical potential as bone grafts and for the properties of their collagen-like gorgonin[97].

Patents also exist for a variety of biomolecules from deep-sea organisms that have not yet been developed to full industrial application. These include potential antibiotics, anti-tumour, antiviral, anti-inflammatory, anti-allergy and anticoagulant compounds, potential drug carrying compounds, UV-protectants and insecticides[96].

4.B Significant Adverse Impacts

Paragraphs 21 and 22 of the Draft Guidelines describe the concept of Significant Adverse Impacts (SAIs) as follows:

21. Adverse impacts caused by fishing gear or other anthropogenic disturbances are impacts on populations, communities, or habitats that are more than minimal and not temporary in nature. The impact will be adverse if its consequences are spread in space or through ecosystem interactions and are not temporary, even if the ecosystem feature that is directly impacted shows rapid recovery.

22. Adverse impacts become significant when the harm is serious or irreversible. Impacts that are likely to take two or more generations of the impacted populations or communities or more than 20 years (whichever is shorter) to reverse are considered irreversible. Impacts that are likely to reduce the productivity of any population impacted by the fishery (whether intentional or accidental); or the productivity, species richness, or resilience of an impacted community or ecosystem; or the structural complexity of a habitat are considered serious. In this context productivity is intended to mean all aspects of a population's capacity to maintain itself. In circumstances of limited information the assumption should be that impacts will be serious or irreversible unless there is evidence to the contrary.

Evidence of significant adverse impacts

Seamounts

The scientific literature of the effects of fishing on seamount habitat is summarised by Clark and Koslow[8]. Their key-findings include:

1. The impacts of trawling on seamounts have been studied most intensively within the EEZs of Australia and New Zealand[51,53];

2. On seamounts off Tasmania (Australia) the fished seamounts had typically fewer species (reduced by about half) and had lower biomass (by about 7 times) of benthic invertebrates;

3. On New Zealand seamounts, the composition of larger benthic invertebrates was different on "fished" seamounts, which had a smaller amount of coral habitat formed by live *Solenosmilia variablis* and *Madrepora oculata* than on "unfished" seamounts. Photographic surveys carried out on several heavily fished versus lightly fished seamounts in the Graveyard seamount complex showed a very strong contrast in the distribution of coral species with photographs often showing 100% coral cover on lightly fished seamounts (Diabolical and Gothic seamounts) compared to never more than 2-3% cover on heavily fished seamounts (Graveyard and Morgue)[51]. Fished seamounts typically had a 7-fold lower biomass of benthic invertebrate species. In addition, trawl marks were observed over six times more frequently on seabed images from "fished" seamounts.

The intensity of trawling on seamounts can be very high. For example, Soviet fishing effort for pelagic armourhead on relatively few seamounts in the Southern Emperor and Northern Hawaiian Ridge system was around 18,000 trawler days during the period 1969–75. Koslow et al.[53] and Clark and O'Driscoll[51] have reported that between hundreds and several thousand trawls have been carried out on small seamount features in the orange roughy fisheries around Australia and New Zealand. Similarly, O'Driscoll and Clark[98] documented that the total length of bottom tows per square kilometre of seamount area off New Zealand averages 130 km of trawled seafloor. Such intense fishing means that the same area of the seafloor can be repeatedly trawled, causing long-term damage to corals and other epifaunal communities, and preventing any recovery or recolonisation[47]. Such damage can occur very rapidly and Deep-Sea Fisheries can be characterised by a high by-catch of species characteristic of VMEs, such as corals, in the initial year of fishing, with a subsequent decline in by-catch as the coral is removed from the seafloor, and as skippers avoid areas of high coral density because of damage to nets[16].

VMEs formed by corals and sponges

Impacts of deep-sea fishing on deep-sea coral and sponge communities have been demonstrated by studies in fished vs. unfished areas using seafloor observations with towed cameras, submersibles or remotely operated vehicles, acoustic imaging of the seafloor, sampling of seabed communities and by documenting by-catch of benthic invertebrates in deep-water fishing gear[8,10-12,15,24,47,51-53,58,99-106]. These studies have shown that fishing destroys long-lived epifaunal animals such as corals and sponges on the seabed, reducing the three dimensional complexity of the bottom and leading to decreased species diversity and faunal biomass[10,38,53,107]. These VMEs may also be susceptible to the direct and indirect effects of increased sediment load in the water overlying the seabed that may smother live colonies or bury hard substrata required for settlement of larvae[47]. Removal of target fish species and the dumping of by-catch or offal from fish processing can also have effects on ecosystems in general, including, potentially, coral and sponge communities and other VMEs, especially if they influence foodwebs within such habitats[8]. Offal from hoki fisheries off New Zealand have been shown to alter oxygen concentrations at 800m depth and change community composition[8].

Observations of significant adverse impacts on deep-water coral and sponge communities have been reported from the northeastern[101,102,108]; and northwestern Atlantic[12,102,103,105], the southeastern Atlantic[11], the northeastern Pacific[10,38,109-111], and southwestern Pacific[16,51-53,99]. At present, there is no evidence of recovery of VMEs in impacted localities that have been studied although observations are few. It is likely that such ecosystems will only recover very slowly as the component species are very slow growing and the VMEs themselves may have taken thousands of years to develop. Recovery from the impacts of fishing may not be possible at all for many VMEs.

Chemosynthetic communities

The small geographic range of species found in chemosynthetic ecosystems means that recovery of the community from significant damage or the destruction of a site is unlikely and may even lead to the extinction of populations or species. Mechanical damage to such sites may also alter the flow of mineral-rich fluids from the seabed, also inhibiting or preventing recovery. At present there are limited data on the impacts of fishing on chemosynthetic communities. A new scientific study from the continental margin of New Zealand has for the first time documented fisheries by-catch of organisms from seeps and has recorded visual evidence of trawling impacts at 5 out of 6 seep sites surveyed[112]. These sites contained several as yet undescribed species of animals so they have been impacted by fishing even before they were located and sampled by scientists.

What can be concluded about significant adverse impacts on VMEs?

Any bottom-contact fishery that is taking place in the same location as a deep-sea VME, comprising emergent epifaunal communities of corals, sponges or other invertebrates, will result in damage to the habitat-forming species that will only recover very slowly, or not recover at all, on the basis of current evidence arising from observations by scientists. Because of the high longevity, slow growth rates and low rates of recruitment within such VMEs, all deep-sea bottom-contact fishing methods result in the cumulative destruction or removal of component organisms and in some cases alteration of the physical structure of the seabed. The difference between the scale of the impact of different fishing methods is the intensity of destruction of seabed communities per deployment of the gear. Mobile gears, such as trawls, show the most intense impact and static gears, such as benthic longlines, gill nets or pots showing a lower intensity of impact. The level of destruction of a VME of this type therefore depends on the nature of the fishing gear used, the fishing effort and the time over which a fishery is prosecuted. These findings are consistent with the application of habitat sensitivity analyses of deep-water coral habitats to different methods of fishing (e.g. *Lophelia pertusa* using the MARLIN framework[116]).

The conclusion must be that any impacts of fishing on deep-water VMEs comprising long-lived emergent epifaunal communities are Significant Adverse Impacts. Fisheries managers must therefore act in accordance with the UN Convention on the Law of the Sea, the UN Fish Stocks Agreement and the Resolutions of the UNGA to preserve such VMEs and the biodiversity they contain. Only when there is sufficient scientific information, for example through a prior environmental impact assessment, allowing managers to determine that VMEs within an area will not be destroyed or left in a non-viable state, over the duration of a fishery (assuming this is finite) would it be possible for such a fishery to commence or continue without Significant Adverse Impacts.

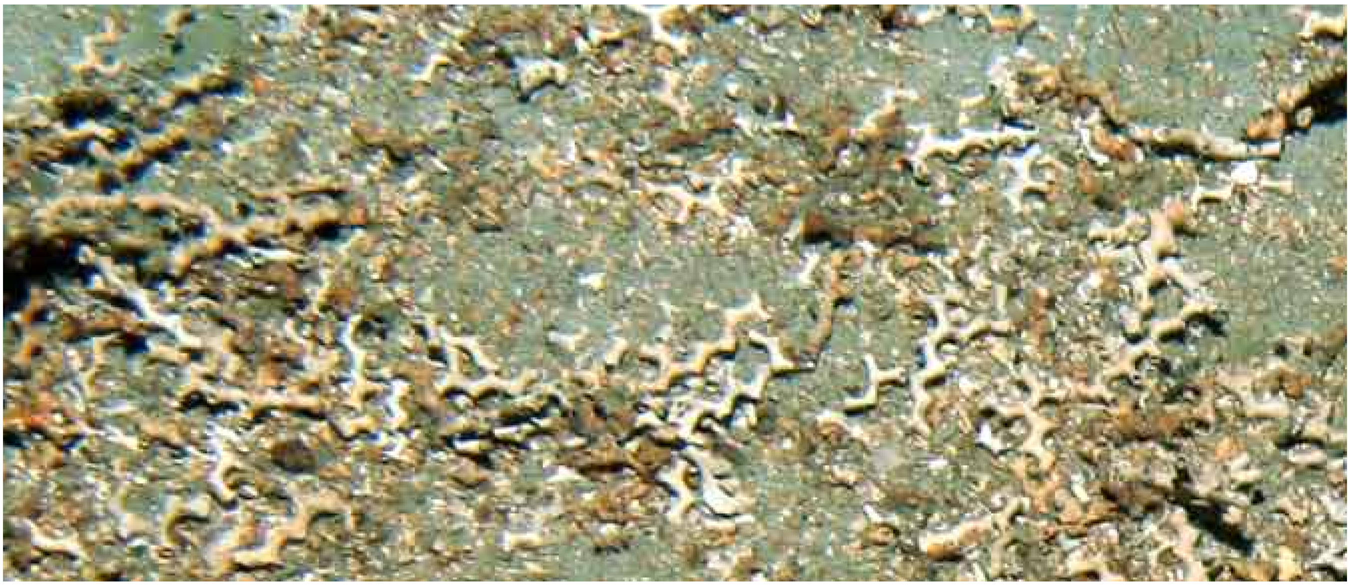
Chemosynthetic ecosystems are classed as VMEs because of their small size, their rarity and the high levels of endemism of component species. Any contact of fishing gear with such VMEs must therefore be viewed as a Significant Adverse Impacts. As with VMEs formed by emergent epifaunal communities, scientific information is required to identify whether fishing poses a low-level of threat to the long-term existence of such ecosystems.

Seamounts and other complex geophysical features comprise a variety of habitats and can host many different types of marine communities[48,114.] The coincidence of fishing in such localities with VMEs formed by long-lived emergent epifauna, chemosynthetic ecosystems or other fragile species with a low capacity to recover from disturbance will result in Significant Adverse Impacts. Given the high likelihood of occurrence of such VMEs on seamounts it should be assumed that there is always the possibility of Significant Adverse Impacts in these localities and management should be precautionary in such circumstances and measures to detect such VMEs taken (see Section 6).

Can significant adverse impacts occur on soft sediment communities?

At present we know that the diversity of small animals that inhabit the biggest habitat in the deep sea, the sediments, is extremely high (millions of species[115]). These communities comprise a high proportion of rare species and a few species that occur in larger numbers[115]. Such patterns of abundance result from the high regional diversity in the deep sea, whereby many species from a wide geographic area can be represented in small local samples, but in low numbers. Thus, such species are not rare in the sense that overall population size is low, or the species is endangered, but are locally "rare" within scientific samples (a similar phenomenon may be observed in other deep-sea ecosystems, including seamounts). The abundance and biomass of the burrowing animals (infauna) decreases with increasing depth as a result of decreasing food supply[116]. The species composition of biological communities also changes with increasing depth and in some geographic areas the diversity of infauna peaks on the slopes of the continental margin[117,118]. Overall diversity in the deep sea is at least partially controlled by the availability of food and therefore by primary productivity at the surface[119].

Studies on the impacts of fishing on the biological communities of sediment in shallow waters demonstrate that for habitats that have a low level of natural disturbance, such as stable sediments or areas of sheltered muddy seabed, fishing disturbance reduces the abundance and diversity of the seabed fauna[120,121], and that recovery from such disturbance may take years[122]. The deep sea is regarded as a highly stable environment (though some areas may be affected by benthic storms), and so it would be expected that communities will be vulnerable to mechanical disturbance from trawling or dredging. This is supported by the results of trial studies on the use of dredges to collect manganese nodules in the Pacific Ocean. In this case, trenches left behind from such operations, at depths of 4000m, were still present seven years after the initial disturbance experiment. Differences in the abundance, diversity and community composition of small (meiofauna)



Coral debris at a cold seep site, photographed by NIWA's DTIS (Deep Towed Imaging System) camera on RV Tangaroa. The damage is likely to have been caused by trawling. Image courtesy of NOAA/NIWA.

to large sized (megafauna) animals in and on the sediments still showed differences to non-disturbed sites after 7 years although there were signs of recovery in the soft-sediment fauna[123-126]. The fauna of the manganese nodules did not recover as hard substrata were removed from the dredge paths.

How significant are fishing impacts on soft sediment communities in the deep sea is not known at present because little is understood about the distribution of infaunal species, and the levels of endemism that may be expected within and between geographic regions. We may be better able to evaluate the fragility of such sediment communities as scientific evidence becomes available in the future through programmes such as the Census of Marine Life. At present it is not possible to evaluate whether fishing impacts on the majority of such communities are significant, given the large areas of the seabed they cover (i.e. they are very large ecosystems) and the major problems in establishing the distribution and range of the species therein. Only if specific habitat-forming species occur on soft substrata in well-defined areas can they be classed as VMEs (eg, discrete xenophyophore beds, sponge beds or dense stands of sea pens).

A precautionary approach that fisheries managers may take would be to designate representative areas of the seabed as Preservation Reference Areas (PRAs) in a similar manner to that proposed by the International Seabed Authority (ISA) for deep-sea mining. These would allow scientific comparisons to be made between fished and non-fished areas and could act as sources for recolonisation of impacted areas of the seabed as fishing pressure decreases or stops. Such PRAs would have to be designed to reflect current understanding of the maintenance of populations within protected areas in the ocean.

Finally, for the reasons outlined above, the potential for Serious Adverse Impacts to vulnerable marine ecosystems from bottom contact fishing is high; thus in circumstances of limited information the assumption should be that impacts will be serious or irreversible unless there is evidence to the contrary This is reflected in the concluding sentence in Paragraph 22 of the Draft Guidelines and is an important element of the Draft Guidelines in the implementation of the precautionary approach as outlined in the UNGA resolution 61/105.

5 Governance and Management

In addition to the general management considerations noted in paragraphs 17and 23-25 of the Draft Guidelines, it may be useful to recognize that while the theory of management of high seas fisheries is essentially the same as for national fisheries, there are several differences with the high seas, and with Deep-Sea Fisheries, that require different approaches in practice.

Careful and controlled development of any fishery is central to the management measures proposed in the Draft Guidelines. The inherent difficulties on obtaining sufficient stock assessment or benthic habitat data (compared with near-shore national fisheries) mean that management regimes must operate at a low level of knowledge, and management action must occur in a highly precautionary manner.

Vessels operating in a high seas area may do so in a sporadic and irregular manner. This means that national cooperation is essential to share information and to have centralized data analysis to monitor fishing operations over time, when the vessels and nations involved may vary. This is especially relevant when the high seas habitat may involve numerous VMEs. Hence, sections in the Draft Guidelines relating to MCS and the application of management and conservation tools are detailed. A higher level of "prescription" is necessary to avoid uncertainty and delay in vessels taking appropriate action with fishing operations.

6 Management and Conservation Steps

6.A Data, reporting and assessment

Data Required for Adequate Management

Paragraphs 31-36 provide guidance on data collecting and reporting. It may be useful to consider in this context the type of data required for adequate management and how to overcome its limited availability.

The data required to carry out adequate stock assessments to feed into management of Deep-Sea Fisheries are essentially the same as required for any fishery. However, there are several important aspects of deep-sea high seas fisheries that require emphasis:

Fine spatial scale

Stock structure of deep-sea species is likely to be poorly known, but experience with fisheries for orange roughy around New Zealand, pelagic armourhead off Hawaii, and alfonsino in the North Atlantic show that serial depletion of fish populations on adjacent seamounts can occur rapidly. Hence small-scale data reporting is necessary to relate catch and effort to individual seabed features. Data at the level of the individual tow has been necessary in orange roughy fisheries to enable reliable CPUE analyses, as well as to define the extent of a trawl footprint on individual seamounts. Management at a fine spatial scale may also be necessary to prevent serial depletion.

By-catch recording

The deep-sea fish community will include species which have low productivity and can be vulnerable to the effects of fishing, even if this is targeted at a different species. Deep-water sharks are an example. These by-catch species need to be recorded to ensure that fishing is sustainable for the ecosystem, not just the target fishery. Seamounts and chemosynthetic ecosystems can host endemic species, or species with a very restricted geographical distribution. Recording of rare or unusual species caught as by-catch in Deep-Sea Fisheries is therefore important. The third aspect of by-catch is that geophysical features such as seamounts, ridges, canyons, continental and island slopes can host VME species (such as cold-water corals, hydrothermal vent fauna) and benthic invertebrates must be recorded to ensure that sensitive areas are identified, and appropriate management action taken (see Identifying VMEs below).

Timely reporting of information

New stocks can be found, fished, and depleted rapidly. Similarly, bottom trawl impact on benthic fauna can occur quickly and can completely devastate VMEs located on geophysical features with a small area, such as the summits of seamounts or sites of seeps or vents. This emphasizes the need to ensure that data reporting, monitoring, control and surveillance systems are in place to enable short-term management if catch rates start to change dramatically, or if there are catches of VME species. This is reflected in the UNGA Resolution 61/105, paragraph 83 d, and is why fishing in areas where new VMEs are detected should cease until management measures to protect them are in place[18].

Paucity of data

Management of any high seas fishery is likely to be faced with limited or poor data. Little information will be available from other sources except the actual fishers. For some species, ecological data can be applied from national research results, but data on stock structure and abundance will be problematic. Catch controls would need to be based on limited information, and so need to be combined with effort restriction to ensure overfishing does not occur before sufficient information has been collected.

Options for precautionary fisheries management

In order to reduce the risk of overfishing and serial depletion of aggregations on seamounts, a number of options are available for controlling initial exploitation levels:

1) Effort controls. This might involve limiting the number of vessels able to work in a given area. Namibia restricted their initial exploration for orange roughy stocks in their EEZ to a single vessel before subsequently opening it to others when it appeared a viable fishery existed. However, this does not necessarily limit the amount of catch taken from an area.

2) Catch limits per feature. In two regions off New Zealand, feature limits have been imposed. In one area this involves restricting the catch within a 10 n.mile radius of the fished feature (typically a seamount or ridge peak) to 100 t. Once that limit is reached, the vessel must move on. In another area, a 500 t limit has been imposed within a defined "box" around an area of large catches. An analysis of seamount catch over time indicates that initial orange roughy biomass on a single seamount feature may generally only be a few thousand tonnes[127], so a limit as high as 500 t for a species like orange roughy is unlikely to be precautionary.

3) Sub-region limits. Feature limits can hopefully prevent depletion of aggregations on a single feature, but may not prevent stock depletion if much of the stock is not on seamounts. Hence an overall precautionary catch may be applicable in the region. In New Zealand orange roughy fisheries, the formal quota is often divided in sub-areas to allow spatial control of the overall catch.

4) Catch per unit effort changes. Another aspect of a feature limit has been applied in a New Zealand fishery, whereby unstandardised CPUE is monitored, and if changes occur that reach a threshold, then the area or feature limit is reduced. An example of this is if CPUE drops from 3 t/tow to 1.5 t/tow, then the feature limit is reduced (e.g. to 50 t) and the sub-region limit is reviewed. This approach emphasises the need for tow by tow data reporting.

A major difficulty with a feature/region limit type approach for fish catch (either target or bycatch) is that it can result in an increased spread of fishing effort, with an extension of the area of seafloor impacted by the fishing operation. Hence there needs to be a balance in the management approaches that can ensure the sustainability of the fish stock, yet also conserve benthic habitat and VMEs. A suitable approach might be to apply spatial management, and to close off a number of features to trawling. Features such as large seamounts can be detected by remote sensing techniques and some of their physical characteristics (e.g. summit depth, elevation, size) can be approximated. This would give an initial basis for allocating some areas (e.g. a minimum percentage of 30-40% of the area or number of seamounts) as no-go zones. Precautionary criteria may still apply to management decisions based on fish catch /VME presence, but they are then not in conflict as the extension of effort is controlled. Suitable measures would also need to be applied to fishing on the remainder of the area to prevent significant adverse impacts, as described in section 6.B below.

6.B Identifying Vulnerable Marine Ecosystems and Assessing Significant Adverse Impacts

Paragraphs 37-40 of the Draft Guidelines set out the considerations relevant to identifying vulnerable marine ecosystems (VMEs).

37. In light of the considerations set out in paragraphs 19 and 20, an area should be designated a VME whenever it:

i) contains unique or intrinsically rare species, communities or habitats; or

ii) contains habitats that support endemic species; or

iii) supports the presence of depleted, threatened, or endangered species for all or part of their life histories; or

iv) contains important habitats for populations, for which alternative habitats are not known to exist or are uncommon, whether or not the actual functional relationship between species and habitats are known; or

v) contains populations, communities or habitats that are easily damaged by anthropogenic activities, including fishing, particularly if the features that are damaged have long recovery times or may not recover; or

vi) supports ecological processes that are highly dependent upon complex physical structures created by biotic features (e.g., corals, sponges, bryozoans) or by abiotic features (e.g. boulder fields, clay levees); or

vii) supports species whose characteristics make their recovery slow or unlikely if impacted.

38. These criteria should be adapted and additional criteria should be developed as experience and knowledge accumulates, or to address particular local or regional needs.

39. Flag States and RFMOs/As should assemble and analyse all relevant information on areas where fisheries DSF under their jurisdiction or competence are currently operating or where new or expanded fisheries DSF are contemplated, as a necessary step toward the identification of VMEs.

40. Where site-specific information is lacking, other relevant information that may infer the presence of vulnerable populations, communities and habitats should be used.

Table 2 of the September 2007 Draft International Guidelines as adopted by the Expert Consultation in Bangkok (FAO Technical Consultation document TC:DSF/2008/Inf.3), also provide some concrete examples of the types of ecosystems that would qualify as VMEs, as discussed above.

How to detect VMEs

These provisions are important provisions as they provide clear guidance on science-based criteria for defining VMEs and determining where they occur or are likely to occur. One of the most significant issues raised by the Draft Guidelines is how to identify where VMEs occur and whether fisheries interact with them. In some cases, the location of geophysical features associated with VMEs, such as seamounts, banks or canyons is relatively easy. Such features are readily identified from navigational charts, satellite gravity mapping or from data arising from geophysical surveys by industry, scientists or governmental institutions. Such localities have a high probability of containing VMEs that are vulnerable to impacts from fishing and it is then a question of establishing their presence or lack thereof. Establishing whether VMEs are actually present in such localities or in wider areas of the deep-seabed is more complex but can be achieved through a number of practical approaches.

1. Mapping of species occurrence

There are a large number of data sources for the sampling locations of species that comprise VMEs. These mainly include scientific records and records of fisheries by-catch but can also include knowledge gained by individual fishers and the fishing industry. Some of these information sources may be regarded as non-scientific, hence the use of the term “information” rather than “scientific information” within the Draft Guidelines (i.e. Paragraph 17 iii). Such records can be plotted to map the likely distribution of VMEs within an area (Fig. 2). The advantages of such an approach are that it is cheap and relatively rapid to achieve. Disadvantages are that historical records can be out of date, especially where fishing has already eliminated VMEs from areas, or data can be inaccurate[70]. For some parts of the world's oceans there are few historical data records because of a lack of scientific research to such regions (e.g. Indian Ocean, western, equatorial and south central Pacific and south Atlantic)[32].

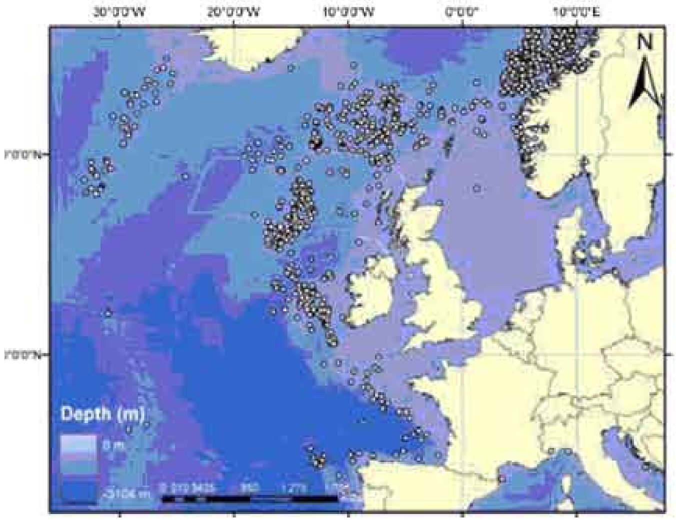


Figure 2 Map of the distribution of cold-water stony corals (Lophelia pertusa, Madrepora oculata and Solenosmilia variabilis) from the NE Atlantic region. Data are from the Joint Nature Conservancy Council of the UK and scientists records128. Coral are immediately identifiable as occurring on the continental margin, banks associated with the continental margin and seamounts associated with the Mid-Atlantic Ridge.

2. Fisheries observer programmes

The by-catch of benthic species during fishing operations can be recorded by fisheries observers. Such by-catch can be recorded through photographic records with voucher specimens or even the entire invertebrate by-catch collected and preserved for subsequent scientific investigation.

The collection of appropriate metadata along with the samples is critical and should include: the vessel name, cruise ID code and details, the fishing gear, the fishing gear deployment number, sample number, observation number, observation date, latitude, longitude of gear deployment and retrieval (and way points during fishing if possible), mean depth at which gear is fished, a species code (coral, sponge or species specific code if known), species number, sample container, sample identification code and sample condition.

It is useful to record the wet weight of by-catch and to record every individual organism within the by-catch even if they are not retained as samples for subsequent studies. Small tissue samples (large organisms) or the entire animal (small organisms) may be preserved in 95% ethanol in 5ml tubes or frozen for subsequent DNA-based identification. Sample containers should be labelled by writing on the outside of the tube with permanent marker and by placing paper labels written in pencil inside the tubes.

Such data may be converted to catch per unit effort of fishing (e.g. trawl time or length, per number of longline hooks etc.) in order to geographically map the relative intensity of by-catch and the likely occurrence of VMEs on the seabed. Such approaches have been successfully used to map areas where VMEs occur on the continental margin[12] and the slopes of oceanic islands[11] where they may be effective even in the absence of any other data.

The advantages of such approaches are that they can be implemented through existing observer programmes and the data can be of very high quality if studies are carefully designed. It is desirable that observer coverage within a deep-sea fishery is 100%, especially in the early stages of development, but coverage can be less than 100% and still produce data that can extrapolated across the fishery as a whole. Training of observers prior to their deployment is critical to insure data quality. The collection of samples in good condition can also promote the involvement of scientists in such programmes and lead to an improvement in the understanding of the deep-sea biodiversity of the region of study in the global context. The disadvantages of such programmes are that fishing gear is highly selective in terms of what is retained by the gear. Organisms that are killed on the seabed may not be retained by gear or may be destroyed and lost from the gear before it is returned to the deck of the vessel, resulting in underestimates of by-catch and ultimately in the interaction of the gear with VMEs. This is a particular problem for large-meshed nets or pots where very little of the by-catch of benthic invertebrates may be retained by the fishing gear by the time it has been returned to the deck of the fishing vessel. For some very delicate organisms by-catch studies may be an unreliable method of recording interactions with fishing as the animals disintegrate on contact with fishing gear. Thus a lack of by-catch of species that comprise VMEs is not definitive evidence that they are not present in an area that is fished.

3. Acoustic survey

Multibeam echosounders not only measure water depth to provide an accurate image of seafloor topography, but also generate a backscatter record giving information on the physical attributes of the seabed[129,130]. VMEs such as deep-sea coral reefs can be detected as mounds or irregular complex structures on the seabed with a low backscatter (appear bright on images) because of poor reflection of acoustic signals by coral framework (Fig. 3). Seafloor maps based on acoustic classes can be produced using by combining information from bathymetry, slope angle and backscatter within Arc- GIS or other software (Fig.3). These maps can identify the presence of coral habitats or the presence of seabed with different geophysical characteristics that may be likely to harbour other types of VMEs (e.g. sponge beds etc)[131]. Acoustic data that are suitable for this type of analyses may be obtained through scientific survey although fisheries companies now also gather these data to help to identify habitat that may be suitable for target fish species and suitable ground for deployment of fishing gear. SIODFOA (Southern Indian Ocean Deep-Sea Fisheries Operators Association) members have established substantial bathymetric databases for the high seas areas of the entire southern Indian Ocean and have used these data to identify potential VMEs and to propose benthic protected areas, including a number of seamounts. The identification of VMEs using acoustic data requires prior understanding of the types of acoustic signature that are generated by these habitats. Ideally, acoustic identification should be accompanied by some form of ground-truthing preferably though the use of underwater photography or video survey, although surface deployed sampling (grabs or box cores) or by-catch of habitat-forming species in the same area can confirm VME presence. Towed and net mounted camera arrays can be deployed for ground-truthing of acoustic data. The advantages of acoustic surveys are that they can cover an enormous geographic area at high resolution for the identification of VMEs. The disadvantage is that they are expensive as they require dedicated seatime and specialised equipment and may be commercially sensitive if gathered by fishing companies or other commercial concerns. Processing of the data and production of habitat maps also requires technical expertise.

4. Scientific survey

Scientific surveys of deep-sea habitat provide the most detailed data on the biological communities present. They may include acoustic surveys, photographic and video surveys using towed cameras, ROVs or submersibles and sampling of animals using surface deployed gear, submersibles or ROVs. The advantage of scientific surveys is that they provide unrivalled detail of the seabed communities present and the species they comprise. As such studies may only encompass a small area of the seabed, they are perhaps most useful in terms of placing other sources of information in context (e.g. ground-truthing acoustic data or assessing actual impacts of fishing on VMEs identified from by-catch studies). There is a high-level of interest amongst the marine science community in deep-sea ecosystems so links between fisheries managers, fishers and scientists can promote relevant and useful research in geographic areas of interest in terms of commercial deep-sea fisheries. Examples of recent relevant studies include the European Atlantic Coral Ecosystems Study (ACES)[132], the HERMES project (Hotspot Ecosystem Research on the Margins of European Seas; http://www.eu-hermes.net/) and various expeditions under the NOAA Ocean Exploration Programme (http://oceanexplorer.noaa.gov/).

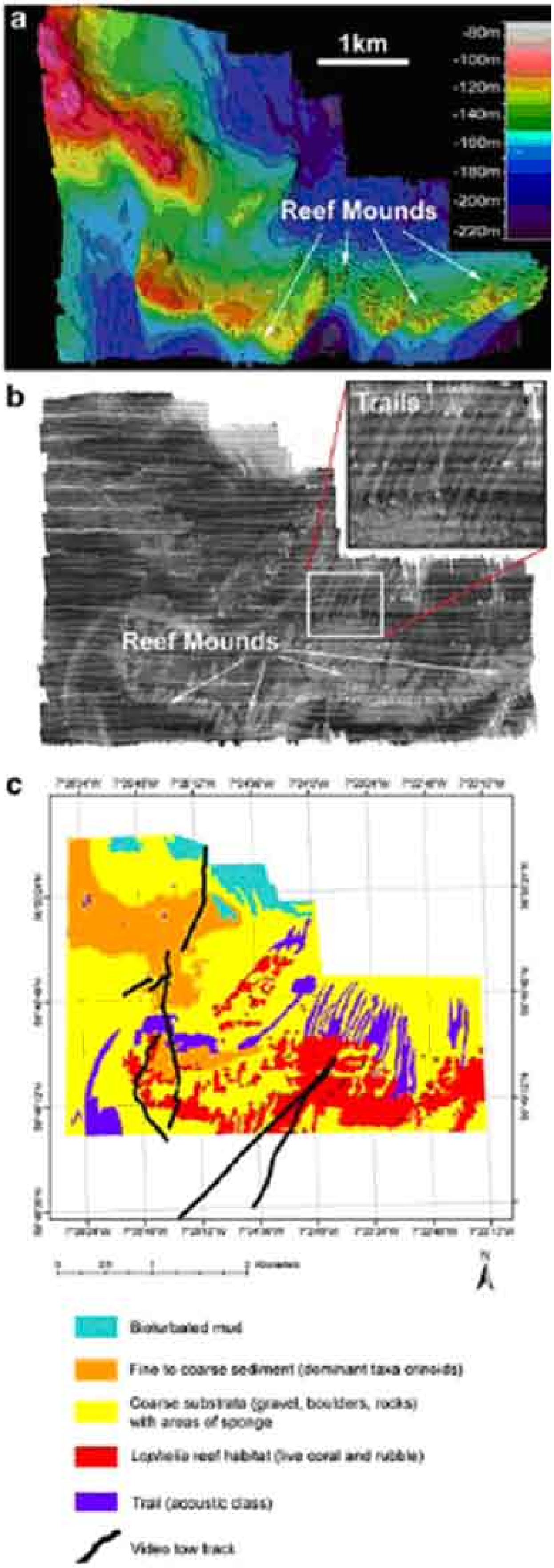


Figure 3 Multibeam survey map of the Mingulay area off the west coast of Scotland showing well-developed mounded topography corresponding to deep-water reef habitat formed by the coral Lophelia pertusa. A - Colour-coded bathymetry of the survey area showing prominent ridge features and seabed mounds. B - Backscatter image of survey area showing signature produced by seabed mounds and the trail features extending from them (features formed on the seabed by interation of the reefs with current). C - Colour-coded habitat classification map generated through GIS. All figures from Roberts et al.[131]. Figure reproduced with kind permission of JM Roberts and Springer Science and Business Media. Springer Science and Business Media retain full copyright of this material.

5. Modelling

Predictive modelling techniques can be used to extrapolate from geo-referenced data on the known distribution of VME indicator species (e.g., deep-sea stony corals such as *Lophelia pertusa* and *Solenosmilia variabilis*) to estimate their likely distribution based on physical characteristics of the seafloor habitat and overlying water masses. The distribution of VME indicator species is used to statistically identify the physical characteristics of environments that are favourable for occurrence and then to use this to predict distribution in un-sampled areas. Such approaches have recently been used to model the distribution of octocorals off the coast of Canada and to model the distribution of stony corals on seamounts and other deep-sea habitats globally[41,42,114]. In the absence of any other data for a geographic region such methods may be useful for identifying areas that may potentially harbour VMEs. However, the level of accuracy of such models depends on the quality and quantity of data that has been used to develop them. They are most useful when ground-truthed using survey data.

What constitutes a significant by-catch indicating the presence of a VME?

Many species that comprise some types of VMEs are not solely associated with these features and may occur in other types of ecosystems. For example, the coral *Lophelia pertusa* forms reefs but is also found as isolated colonies or small thickets in non-reef settings on the continental slope. Therefore the occurrence of a single colony in a trawl or on a long-line set may not indicate the presence of a VME in the area. Deciding on what constitutes by-catch that is significant depends on the organisms encountered, the VMEs they are associated with, the quantity of by-catch and the frequency of encounters within an area. The following practical guidelines have been drawn from observations of the quantities of by-catch that may be associated with the existence of VMEs on the seabed from different types of fishing gear[11,12] as well as the authors' own experience of how key species that comprise VMEs are distributed and their size and shape. These guidelines will have to be tailored to regional requirements or through the application of adaptive management strategies, altered in response to new or specific data related to an area. They are included here solely as an indication of the sorts of factors that should be considered when RFMOs or management agencies discuss how to define a significant encounter with a VME in their area of jurisdiction.

Corals

A single haul constituting >5kg of stony coral or coral rubble.

A single haul containing >2kg of black corals or octocorals or more than 2 coral colonies.

Two or more consecutive hauls containing > 2kgs each of live corals on the same trawl track or setting area for fishing gear or where consecutive trawling tracks or sets intersect.

>4 encounters of corals >2kgs within an area (1km^2) within one year.

>4 corals per 1000 hooks in a long line fishery within one year within an area (10km^2).

>15% of hauls of any gear within an area (10-100km^2) containing corals.

Sponges or other habitat-forming epifauna

A single haul constituting >5kg of sponge or other habitat-forming epifauna.

Two or more consecutive hauls containing >5kg sponges or other habitat-forming Epifauna on the same trawl track or setting area for fishing gear or where consecutive trawling tracks or sets intersect.

>10 encounters of >2kg sponges or other habitat-forming epifauna in an area (1km^2) within one year.

>15% of hauls of any gear within an area (10-100km^2) containing sponges or other habitat-forming epifaunal taxa.

Chemosynthetic ecosystems

Any encounter with elemental sulphur, mineral chimneys (usually smelling of hydrogen sulphide) or methane hydrate (brightly coloured ice-like substance).

Any encounter with chemosynthetic organisms (vent or seep mussels or clams, pogonophoran or vestimentiferan tube worms, vent shrimp or other identifiable vent fauna).

Other schemes are currently being assessed in New Zealand that reflect the fact that encounters with VMEs often take two forms; (i) a high abundance but low diversity of species, as could be recorded for a trawl that encounters a section of stony coral reef where the by-catch is mainly coral; (ii) a low abundance but high diversity, where the catch is small but consists of a wide variety of organisms. Such schemes score by-catch on the basis of both abundance and/or diversity categories where a cumulative score above a threshold value triggers actions appropriate for the discovery of a VME.

The important point behind the intent of the Draft Guidelines is that a system is used whereby a VME can be detected based on real time vessel catch, and a set of rules can be in place to determine the appropriate action to be taken by the vessel if a VME is encountered.

Where significant encounters with VMEs occur associated with a specific geophysical feature (e.g. seamount, knoll, hill, seabed mound, other irregular topography) then immediate cessation of fishing on such a feature should take place until further assessment of the likelihood of such a feature hosting a VME is assessed by managers and effective measures have been agreed and are in place to prevent significant adverse impacts from any resumption of fishing in a portion or all of the area.

6.C Enforcement and compliance

Detecting when fishing activities coincide with identified VMEs

It has become increasingly important that measures are developed to effectively manage and enforce those measures that are in place to protect deep-sea VMEs. In coastal areas, spotter planes, patrol vessels and onboard observers are often used to monitor protected areas but these methods may be prohibitively expensive and offer only limited spatial coverage in deep-sea areas. One cost effective method is the emerging use of position data sent by vessels via satellite, offering complete spatial coverage. However, improvements are needed as there can be uncertainty over when and what type of fishing is taking place since this currently requires corroborative evidence such as visual sightings in closed areas[133,134]. In addition, information can be falsified, leading some authorities to investigate the use of remotely sensed imagery to check positions sent by vessels[135].

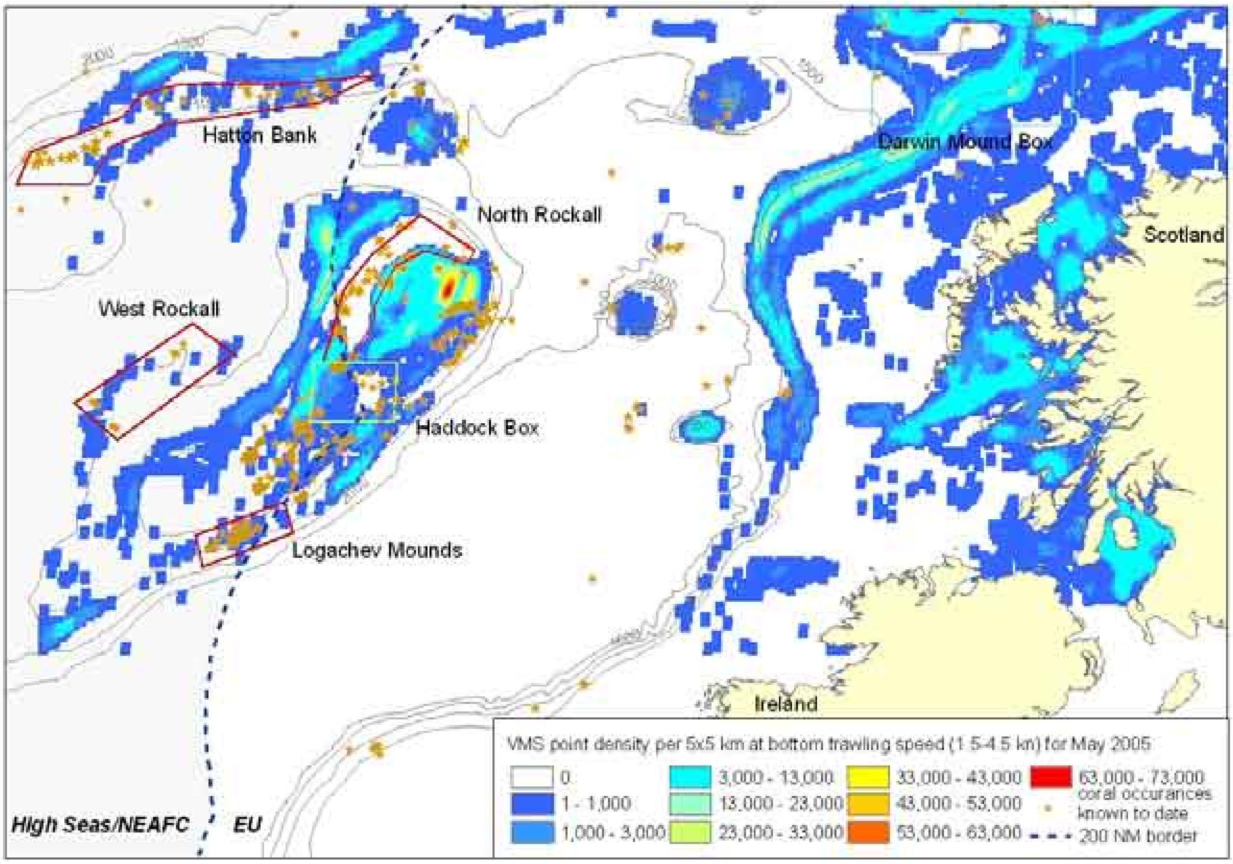


Figure 4. ICES Area VI showing the coral-rich Darwin Mounds (closed to demersal fishing in 2003) and other vulnerable marine ecosystems closed to demersal fishing in 2007. The known distribution of cold-water coral records and VMS fishing intensity for May 2005 (vessels moving 1.5-4.5 knots were assumed to be trawling) are also shown. The most intensively fished areas are the continental slope, banks associated with the continental margin and seamounts.

The potential for satellite tracking as a fisheries management tool in the deep sea can be illustrated using ICES area VI as an example, an area that straddles the High Seas, Irish and UK waters with intensive fishing activity on the deep slopes of offshore banks, seamounts and the shelf-break (Fig. 4). The European Union's offshore fishing fleet is required to submit their vessel positions via GPS. Each member state receives Vessel Monitoring System (VMS) data for vessels that are active within its exclusive economic zone and the global positions of vessels that are registered to that member state. At present these data are seldom used for deep-sea habitat protection but could be used as an additional tool for the design of protected areas and the spatial management of offshore fishing fleets[101,136,137]. Knowledge of the distribution of deep-water corals was recently combined with VMS data to design protected areas on the Rockall Bank in the Northeast Atlantic that avoid displacing fleet activities away from sites that are heavily fished and onto VMEs[134].

VMS is one of the most valuable tools available to monitor and enforce marine protected areas in the deep sea since it can graphically demonstrate breaches of areal closures and could even be used to warn fishermen when they are entering restricted areas[138].

In fisheries where a relatively small number of vessels are involved, the use of Fisheries Observers on every vessel fishing in the region can be a valuable alternative to reliance on indirect VMS information. Observers can monitor every gear deployment, and assess the catch for presence of a VME based on the sorts of criteria in 6.B. Immediate action can then be taken and VME location can be sent through to the central management agency and other vessels informed.

7 Additional Considerations on Implementation

The importance of liaising with other sectors in management of deep-sea fisheries

Other activities in the deep sea may impact VMEs and ecosystem-based management of fishing must account for the distribution and area of impact of such operations. These include oil and gas exploration, extraction of sand and other aggregates, submarine cable and pipeline deployment, deep-sea mining and research[139]. Some of these activities are currently more or less restricted to the continental margin and generally take place within EEZs and therefore do not fall under the remit of the present Draft Guidelines. Other activities do potentially impact the deep-seabed in the High Seas, especially cable laying and research. Mining of hydrothermal deposits on seamounts is likely to take place in the next five years and whilst initial interest has centred on seamounts within EEZs, metal-rich hydrothermal sediments almost certainly lie within High Seas areas as well.

Research may have an impact on VMEs but at least in some areas is regulated through voluntary codes of practice. At least one of the Benthic Protected Areas declared by the SIODFOA on the South West Indian Ocean Ridge (Bridle) is adjacent to recently discovered hydrothermal vents sites that are likely to attract considerable attention by researchers. Another (Atlantis Seamount) has been the site of drilling by the Ocean Drilling Project. In future, industrial activities in the deep-waters of the High Seas are likely to increase and may include extraction of sands and aggregates and the mining of cobalt crusts on seamounts.

The potential impacts of climate change on VMEs such as cold-water coral reefs emphasises the imperative need to protect these habitats from other anthropogenic impacts. It is also likely that patterns of productivity in the oceans may change as a result of climate change and this in turn may alter the productivity associated with deep-sea fisheries and the ecosystems in which they occur.

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