

ICES WGDEC REPORT 2009

ICES ADVISORY COMMITTEE

ICES CM 2009\ACOM:23

Report of the ICES-NAFO Working Group on Deep-water Ecology (WGDEC)

9–13 March 2009



ICES

International Council for
the Exploration of the Sea

CIEM

Conseil International pour
l'Exploration de la Mer

International Council for the Exploration of the Sea Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2009. Report of the ICES-NAFO Working Group on Deep-water Ecology (WGDEC), 9–13 March 2009, ICES CM 2009\ACOM:23. 94 pp.

For permission to reproduce material from this publication, please apply to the General Secretary.

The document is a report of an Expert Group under the auspices of the International Council for the Exploration of the Sea and does not necessarily represent the views of the Council.

© 2009 International Council for the Exploration of the Sea

Contents

Executive summary	3
1 Introduction.....	6
1.1 Participation	6
1.2 Terms of Reference	6
2 Opening of the meeting and adoption of the Agenda.....	9
3 Recent research into unaccounted mortality.....	10
3.1 Preface	10
4 Reducing unintended effects on the seabed and associated communities	11
5 Do fish farms threaten coral reefs?.....	13
6 Distribution patterns of corals and sponges across the North Atlantic.....	20
7 Term of Reference (e). Consider how the status of biodiversity of deep-water ecosystems could be measured, for example by using diversity indices (in conjunction with WGDEEP).....	25
7.1 Introduction.....	25
7.2 Why is biodiversity important?	25
7.3 How do we measure biodiversity?.....	25
7.4 What are some of the problems of using biodiversity indices?.....	26
7.5 Other biodiversity indices	27
7.6 Can indices be use to assess of biodiversity on deep-water ecosystems?	27
7.7 A short case study-indicators of biodiversity and community structure derived from Scottish survey data.....	28
7.7.1 Size spectra	29
7.7.2 Detrended correspondence analysis (DCA).....	30
8 Sponge grounds in the North Atlantic.....	35
8.1 General introduction to the sponges.....	35
8.2 Structure-forming sponge species in the North Atlantic	36
8.2.1 Habitat-based management vs. single-species management.....	36
8.2.2 Maps of the distribution of sponge grounds in the North Atlantic.....	43
8.3 Association of fish and other organisms with sponge grounds.....	50
8.4 Summary of sensitivity of different sponge species to impact and disturbance	51
8.5 Priorities areas for sponge distribution data.....	53
8.6 Future research.....	53
8.7 References	54

9	Impact of deep-water fisheries on deep-sea habitats.....	56
10	Identification of structure forming habitats in need of protection	57
11	Uses of fine scale VMS analyses.....	66
11.1	VMS data available.....	66
11.2	Deriving a density function of fishing effort.....	67
11.3	Deepwater bottom trawling.....	68
11.4	Deepwater long-lining	68
11.5	Fishing effort in areas likely to contain sensitive deep-water habitats	69
11.5.1	The Wyville Thomson ridge area	69
11.5.2	Rockall bank	70
11.5.3	Rosemary bank.....	71
11.6	Discussion.....	73
12	The issue of scale	74
12.1	Issue: the problem of pattern and scale	74
12.2	Terminology: coarse and fine scale	74
12.3	Data resolution: ecological and surveillance.....	75
12.4	Matching management to relevant ecological scales.....	75
12.5	Matching scientific research and monitoring to relevant management	76
12.6	Predictive habitat modelling	76
12.7	Biogeographic classifications	76
12.8	Estimated confidence	77
13	NEAFC Request for WGDEC regarding vulnerable habitats	83
	Annex 1: List of participants.....	87
	Annex 2: WGDEC Terms of Reference for the next meeting	89
	Annex 3: Recommendations.....	92

Executive summary

The 2009 meeting of the Working Group on Deep-water Ecology (WGDEC) met jointly with the Working Group on the Biology and Assessment of Deep Sea Fisheries Resources (WGDEEP) to address five common terms of reference (ToR). These included updates on unaccounted fishing mortality (ToR a), a review of recent developments in gear technology and fishing operations designed to reduce the impact of fishing on the seabed and associated benthic communities (ToR b), discussion of the best measures for monitoring deep sea biodiversity (ToR e), a review of the impact of deep-water fisheries in areas not previously assessed (ToR g) and lastly a review of the developments of fine scale VMS analyses in relation to assessing habitat interaction (ToR i). For the most part, these ToR are dealt with in the WGDEEP Report. Supporting information to address ToR b can be found in the WGDEC Report where spatial closures are advocated as the principle tool for reducing unintended effects of fishing on the seabed and associated communities (see Section 4). A response to ToR e is found in Section 7 of the WGDEC report, where biodiversity indices widely used in ecology (Shannon-Wiener, Simpson's) are described and assessed for their usefulness when applied to deep-water ecosystems. The Working Group provided a case study of the use of such indicators applied to the fish community on the Atlantic shelf slope to the west of Scotland (ICES Subdivision VIa). Lastly, the review of the development of fine scale VMS analyses in relation to habitats (ToR i) is presented in Section 11 of the WGDEC Report. The availability of VMS data at high temporal resolution together with gear and catch information has been a major advance in confidently developing an index of impact for deep-water ecosystems. For the NEAFC data analysed in ToR G of WGDEC/DEEP 2009 it can be clearly seen how restricted the power of VMS data is if it is: a) not linked to gear information, b) not linked to catch statistics, and c) not provided at temporal resolution that is sufficient to confidently classify periods of fishing activity. Only a small fraction of the data can be used and even this must be treated with the utmost caution. With VMS data of the quality of the Scottish data it is possible to precisely delimit areas that have been heavily trawled and therefore are no longer likely to contain pristine habitats. The data from Rosemary Bank also highlight the issue that all gear types need to be considered because what appears to be lightly impacted with respect to trawling may be heavily impacted with respect to longline fishing activity. The remaining ToRs (c, d, f, h, j, k) were dealt with exclusively by WGDEC.

During the last three years, cases of conflict between human activities and coral reef occurrences have appeared in coastal areas in western Norway. These include conflicts with oil and gas infrastructure, fish farms, soil fertilization, sewage outlets and outtake and infill of sediments, all with the potential of changing the environment in a negative way for corals. The Working Group mapped the location of fish farms and *Lophelia* reefs in Scotland and Norway and identified potential areas where negative impacts on the reefs from the farms could occur (Section 5, ToR c).

The biogeographic patterns of corals and sponges in the North Atlantic were reviewed compiling results from a number of publications (Section 6, ToR d). For sponges, only the species forming sponge grounds were considered. With many data gaps the Working Group felt it was premature to synthesize this information towards identifying hotspots for biodiversity of these taxa.

In addressing ToR f (Section 8) Canadian data on the location of sponges from the Northwest Atlantic was mapped for the first time allowing trans-Atlantic overview of the occurrence of these habitats. The Report also shows detailed maps for some locations. It was noted that the upper limits of some of the sponge grounds in the NW

Atlantic appear to have been heavily modified by past fishing. A call for data on sponge catches from the west coast of Greenland along the southern part of the Davis Strait, the eastern coast of the United States north of 40°N, and the eastern side of the Faroe/Shetland Channel was made to fill in gaps so that investigations on the physical factors which produce sponge grounds can begin. The Working Group provides a list of 25 sponge species which are habitat-forming and can be considered indicators of sponge VMEs in the North Atlantic is presented. The Working Group further examined the types of damage that fishing operations can inflict on sponges and assessed their impact. These impacts were classified as due to mechanical damage, dislodgement and sedimentation. From this Report it is clear that sponges brought on deck and returned to the sea will not survive, nor will sponges dislodged from the seabed. The large sponges take decades to achieve their size and so sponges certainly are at risk of significant adverse impacts due to fishing. WGDEC also recommended that sponge grounds, rather than individual species, be considered as the operational unit for conservation. Most of the sponge species found within fishing depths in the North Atlantic are relatively common and widespread. Over much of their distribution they occur as isolated individuals, however, in some locations, where environmental conditions are favourable, they form dense, multi-species communities and these sponge grounds require protection.

The WGDEC (ToR h, Section 10) provided a list of structural biogenic habitats that are not currently recognized as habitats in need of protection. These included sponge grounds and glass sponge fields, soft bottom gorgonian fields, Xenophyphora fields, sea anemone fields (e.g., *Cerianthus borealis*) and “Serpulid reefs”, specifically reefs formed by the tube-building worm *Filograna implexa*, as structure-forming benthic habitat vulnerable to fishing gear.

WGDEC addressed the important issue of scale when matching biological data sources to those of the activities to be regulated (ToR j, Section 12). The many issues are discussed in detail and six recommendations are put forward.

Lastly, NEAFC requested ICES to provide a list of species that form structural habitat (covered in ToR h, Section 10) for which information is particularly needed from new surveys and to provide updates on new information on the distribution of vulnerable habitats in the NEAFC Convention Area (ToR k, Section 12). In 2007, ICES advised a revision to the current demersal fishing closure on NW Rockall (NEAFC Recommendation IX-2008, EC Regulation No 40/2008), on the basis of new cold-water coral data collected by the Joint Nature Conservation Committee in collaboration with the Scottish Government Fisheries Research Services and the University of Plymouth. This recommended revision to the boundary was reiterated by WGDEC in 2008. However, WGDEC 2008 also stated that, should the north-west boundary be considered for modification on the basis of these coral records then it would also be appropriate to review the most up-to-date fishing activity information (this was not available to WGDEC 2008). New fisheries data have now been made available to WGDEC 2009 for the Rockall Bank area, originating from the Scottish Fisheries Protection Agency. This Scottish VMS data demonstrates all vessels (both Scottish and international) which entered Scottish waters between 2007 and 2008. These data were used to review the proposal to extend the NEAFC/EU closure of NW Rockall Bank (as outlined in WGDEC 2007, reiterated in 2008). WGDEC 2009 notes the contradictory data provided on potential coral distribution and fishing activities in this area to the west of the current Rockall closure over the last four years. Further data on coral distribution is required to refine the boundary of this proposed extension. In the absence of these data, WGDEC recommend that a precautionary approach be taken, and that this area (particularly Sections B and C, which do not appear to have sustained much trawling

activity as yet) be closed to demersal fishing activity. WGDEC considers that there remains sufficient justification for a closure to protect coral reefs on East Rockall, though modifications to the boundary proposed in 2007 would need to be made in light of this new fisheries data. In addition, WGDEC 2009 has been informed that a scientific survey commissioned by the Joint Nature Conservation Committee on the distribution of EC Habitats Directive Annex I reef habitat (bedrock, stony and biogenic reef) is planned over East Rockall (and Anton Dohrn seamount) in summer 2009. WGDEC therefore now recommends that no closure be defined on East Rockall until the results of this habitat survey are available. WGDEC recommends that all available information be examined at either the 2010 or 2011 meeting of the Group.

1 Introduction

1.1 Participation

The following members of the ICES-NAFO Working Group on Deepwater Ecology (WGDEC) participated in producing this report (see Annex 1 for contact info).

Jeff Adron	USA
Annabelle Aish	UK
Maria de Fátima Borges	Portugal
Robert J. Brock, Chair	USA
Brigitte Guillaumont	France
Henk J.L. Heessen	Netherlands
Kerry Howell	UK
Ellen Kenchington, NAFO rep.	Canada
Pål Buhl Mortensen	Norway
Francis Neat	UK
Victoria Sklyar	Russia
Mark Tasker	UK
Ole SecherTendal	Denmark

1.2 Terms of Reference

WGDEC

2008/2/ACOM23 The **ICES-NAFO Working Group on Deepwater Ecology** [WGDEC] (Chair: Robert J. Brock, USA) will meet at ICES Headquarters, 9–13 March 2009 to:

- a) Review and consider recent research into unaccounted mortality in commercial fishery (in conjunction with WGDEEP).
- b) Review ongoing work for reducing unintended effects on the seabed and associated communities of fishing operations and gears, including ghost fishing (in conjunction with WGDEEP).
- c) Consider the nature of threats such as fish farming and eutrophication to coastal coral reef areas, for example those in Norway, Sweden, and Scotland.
- d) Assess broader distribution patterns of species diversity of corals and sponges across the North Atlantic with a view to identifying 'hot spots' and variation in biodiversity and understanding biogeographic affinities.
- e) Consider how the status of biodiversity of deep-water ecosystems could be measured, for example by using diversity indices (in conjunction with WGDEEP).
- f) Define and map sponge associations based on taxonomic information and survey data. Assess the association of sponge fields with fish and other fauna. Provide a summary of sensitivity of different sponge species to im-

pact and disturbance. Assess priorities areas for sponge distribution data and target areas for future surveys.

- g) Consider the impact of deep-water fishery in areas for which information has not been analysed to date, for example the orange roughy fishery on the shelf slope of the Porcupine bank and the roundnose grenadier fishery to the north of Hatton bank by using VMS and historical data. (In conjunction with WGDEEP).
- h) Provide a list of structural habitats for the North Atlantic and assess the status of species such as *Filograna* (a polychaete) that are not currently considered as structural habitat forming organisms.
- i) Review the development of fine scale VMS analysis in relation to habitats and assess vulnerability of deep-water banks, shelf slope and seamounts (in conjunction with WGDEEP).
- j) Address the issue of scale: Advice giving when the scale of records does not match the scale of the feature/the scale of the activities to be regulated.
- k) Provide a list of species that form structural habitats (e.g. hard corals, soft corals and sponges) for which information is particularly needed from new surveys.

WGDEC will report by 16 March to the attention of ACOM.

Supporting Information

Priority:	The current activities of this Group will lead ICES into issues related to the ecosystem affects of fishery, especially with regard to the application of the Precautionary Approach. Consequently, these activities are considered to have a very high priority.
Scientific justification and relation to action plan:	<p>Action Plan No: 1.</p> <p>Term of Reference a)</p> <p>Several countries are conducting or have recently completed significant studies in this area and the subject would benefit from a review of progress and an evaluation of the results obtained. The last review of significant studies occurred in 1996 by the ICES Study Group on Unaccounted Mortalities. A review of more recent work will determine the need for revision and update on planning and methodology for studying this subject.</p> <p>Term of Reference b)</p> <p>All fishing activities have influences that extend beyond removing target species. The approach recommended by FAO is that responsible fisheries technology should achieve management objectives with a minimum of side effects and that they should be subject to ongoing review. WGFTFB members and others are currently undertaking a range of research programmes to provide the means to minimize side effects.</p> <p>Term of reference k) is for PGNEACS</p>
Resource requirements:	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants:	The Group is normally attended by some 10–15 members and guests.
Secretariat facilities:	None.
Financial:	No financial implications.
Linkages to advisory committees:	WGDEC reports to ACOM
Linkages to other committees or groups:	There is a very close working relationship with all the groups of the Fisheries Technology Committee. It is also very relevant to the Working Group on Ecosystem Effects of Fisheries.
Linkages to other organizations:	The work of this group is closely aligned with similar work in FAO and in the Census of Marine Life Programme.

2 Opening of the meeting and adoption of the Agenda

The meeting of the ICES-NAFO Working Group on Deepwater Ecology began at 10.00 am on March 9, 2009. The purpose of the first morning was to reacquaint members with each other, discuss the Terms of Reference and agree on what exactly is being requested, discuss the assignments of each WG member in relation to the Terms of Reference, and agree on the proposed timelines that was put forth. It was very important that Working Group members understood exactly what was being asked and to agree on a Lead person for each Term of Reference where other Working Group members could channel their narratives and discussion. Folders were set up on the ICES SharePoint online portal and Leads managed the information input into each folder.

All in attendance agreed upon the agenda addressing how and when WGDEC would address and complete the Terms of Reference on March 9, 2009.

3 Recent research into unaccounted mortality

Term of Reference (a): Review of recent research into unaccounted mortality in commercial fishery (in conjunction with WGDEEP).

3.1 Preface

This was a joint Term of Reference with WGDEEP and included many discussions between WGDEC and WGDEEP members pertaining to unaccounted mortality in deep-sea fisheries. Information can be found in the WGDEEP report.

4 Reducing unintended effects on the seabed and associated communities

Term of Reference (b): Review of ongoing work for reducing unintended effects on the seabed and associated communities of fishing gears, including ghost fishing (in conjunction with WGDEEP).

This ToR has been dealt with in two parts. Information relating to spatial closures and encounter protocols are covered by WGDEC in this report. Ghost fishing regulations and gear modifications have been dealt with by WGDEEP in their 2009 report.

One of the principle ways to reduce unintended effects of fishing on benthic communities is by introducing spatial closures to restrict the use of fishing gear types (both mobile and static) which come into contact with the seabed. Spatial closures are particularly effective in areas known to support vulnerable marine ecosystems (which may include cold water corals and sponge aggregations) in order avoid incidental physical damage to these structurally sensitive habitats. Spatial closures are part of a suite of measures which can be used to reduce the wider ecosystem effects of fishery as part of an ecosystem based management approach.

Work is ongoing within the Northeast Atlantic to identify areas of vulnerable marine ecosystems which may be at risk from demersal fishing operations. To date, ICES has recommended the closure of several areas supporting vulnerable deep-sea habitats in the NEAFC Regulatory Area and EU waters.

The results of known international deep-sea habitat surveys are reviewed annually by WGDEC to refine advice on the boundaries of these recommended closures. The working group also uses information on deep-sea corals (soft and hard) and sponge distribution collated by OSPAR. In addition, WGDEC takes into account the most up to date available information on past and present demersal fishing operations which give an indication as to where significant fishing-induced damage is likely to have already occurred (and therefore areas which are less suitable for closure).

Despite the increasing availability of deep-sea habitat and demersal fishing activity data and the efficacy of using these different data sources in combination, the delineation of demersal closures inevitably remains partially dependent on expert judgement. Overall, a precautionary approach to the identification of vulnerable marine ecosystems is adopted by ICES when advising on closure placement, particularly where data gaps exist.

In response to the UNGA resolution 61/105, NEAFC and NAFO have recently developed the footprint of demersal trawling activity in their respective areas and have introduced encounter protocols when indicator species of vulnerable marine ecosystems are present in commercial catches above specified threshold levels based on weight (NEAFC recommendation 13/2009, NAFO 2007, NAFO 2008). These areas will then be reviewed by Regional Fisheries Management Organisation (RFMO) scientific bodies and for NEAFC; these areas will be assessed by ICES and appropriate advice provided. Encounters in both existing and new fishing areas should be notified to the RFMO who will then implement a temporary closure of 2 miles radius around the reporting position. Additionally, in new fishing areas observers deployed shall identify sponges, corals and other organisms to the lowest possible taxonomic level. The NAFO measures will be reviewed by the Working Group of Fishery Managers and Scientists (19th and 20th March 2009). The NEAFC measure is also an interim measure which will be reviewed.

References

NAFO, 2007. Scientific Council Meeting-2009, Halifax, Canada. Serial No. N5479. NAFO FC Doc. 07/24.

NAFO, 2008. Report of the Ad Hoc Working Group of Fishery Managers and Scientists on Vulnerable Marine Ecosystems (WGFMS), 8 – 12 September 2008, Montreal, Canada. Serial No. N5564. NAFO SCS Doc. 08/08.

5 Do fish farms threaten coral reefs?

Term of Reference (c): Consider the nature of threats such as fish farming and eutrophication to coastal coral reef areas, for example those in Norway, Sweden, and Scotland.

Background

Lophelia coral reefs mainly occur in oceanic shelf settings in the Northeast Atlantic and elsewhere. In Norway, Sweden and Scotland however, this cold water coral also form reefs in coastal areas at depths generally between 80 and 200 m. In Norway 119 reefs, or about 16% of all documented occurrences are from coastal areas, whereas in Sweden, all reef occurrences are from coastal areas. In Scottish waters, most known reefs are from offshore areas but Roberts *et al.*, 2005 have documented that there also here are locations with live *Lophelia* close to the coastline.

The cold water coral reefs have been recognized as vulnerable and sensitive habitats with a high biodiversity of associated species. Bottom trawling has been demonstrated to have great negative impact on the reef habitats. Additionally, different activities related to the petroleum industry have been identified as potential threats to the reefs.

During the last three years, cases of conflict between human activities and coral reef occurrences have appeared in coastal areas in western Norway (Mortensen and Alvsvåg, 2007). In one case, a reef was detected by an engineering company at a site where an offshore installation was planned to be deployed temporarily in Hardangerfjorden. In the same fjord, another coral reef was detected directly beneath a fish farm that had just been installed. Reports about occurrence of coral reefs in mid-Norway in an area with a planned fish farm were received by the Institute of Marine Research in 2008.

Other human activities such as soil fertilization, sewage outlets and outtake and infill of sediments can have the potential of changing the environment in a negative way for corals.

During a seabed mapping cruise part of the Norwegian research project EPIGRAPH, several well-known and some new coral reefs were inspected. This fjord is known for being nutrient poor, hosting large stocks of sprat and rare deep-sea species. During the survey it became evident that the amount of silt cover on the corals was higher than observed elsewhere on Norwegian coral reefs. This is interpreted as a possible sign of increased particle load in the fjord. Do the fish farms only have local effects on the environment, or do they represent a treat to sensitive animals within a wider range.

Location of fish farms and coral reefs

Scotland

In Scotland there are 454 registered active finfish sites and 332 registered active shellfish sites (Donnelley, 2008; Figure 1). The verified coastal reefs in Scotland were found between the Hebridean Island and the mainland. Because of their exposed location and long distance to nearest fish farm (ca. 13 km) it is unlikely that the reefs should be negatively affected by waste products from the fish farms.

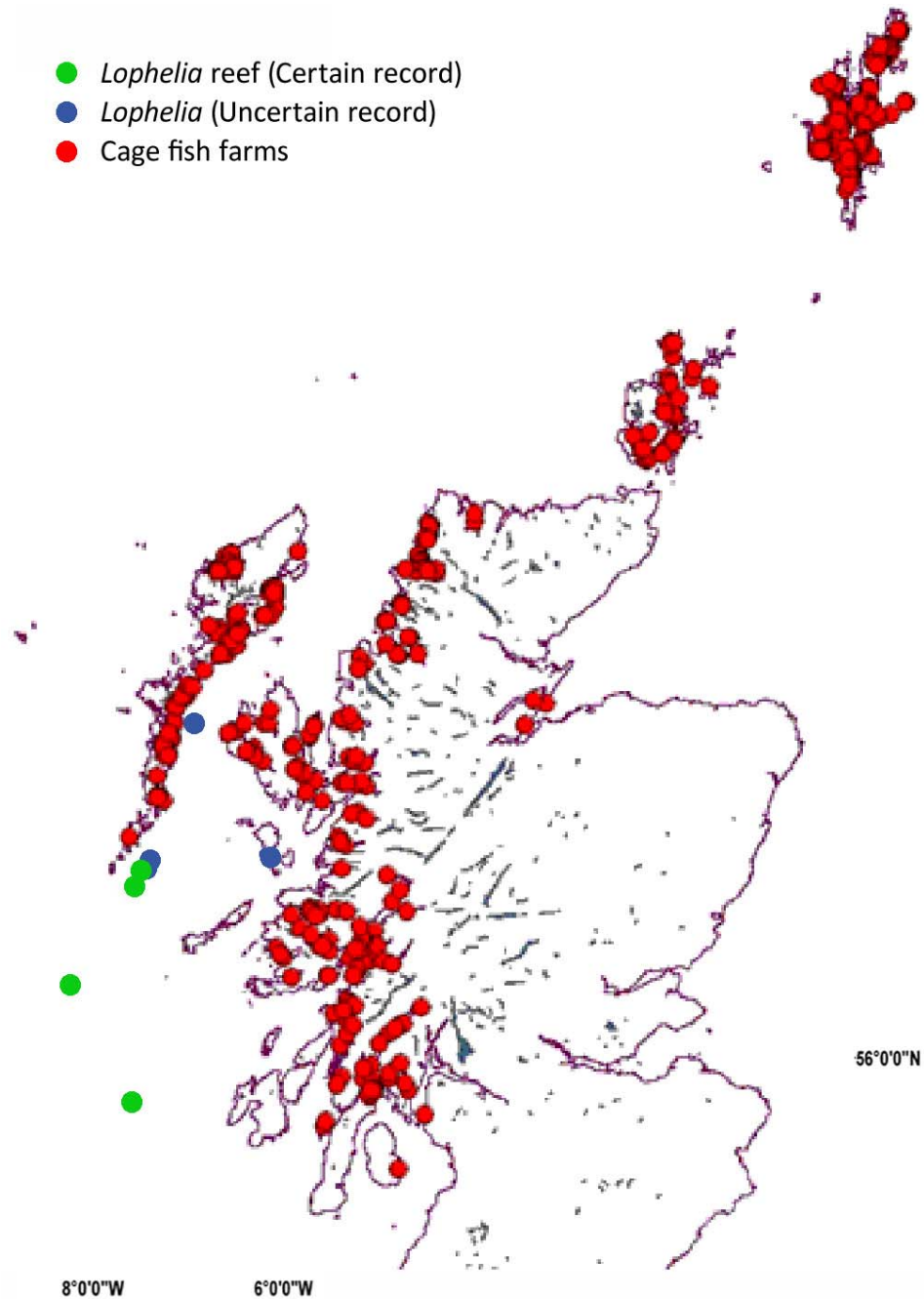


Figure 1. Location of cage fish farms and *Lophelia* coral reefs in Scottish coastal waters.

Sweden

There are few active marine fish farms in Sweden (35 locations of trout farms), and their potential impact for coral reefs is probably very low.

Norway

The highest densities of both fish farms and *Lophelia* reefs are found in Norway, where the geographic overlap is greatest in the county of Hordaland (western Norway). There are 850 commercial licences for salmon and trout farming in Norway. Three hundred of these are located in North Norway. 500 000–600 000 tons of salmon are produced each year in Norway. The outlet of nitrogen and phosphorus per tonne produces fish is 54 and 10 respectively.

In Northern Norway (Figure 2) most fish farms are located more than 10 km from nearest coral reef. The closest location is north of the island Senja where there is one reef 4 km from a fish farm.

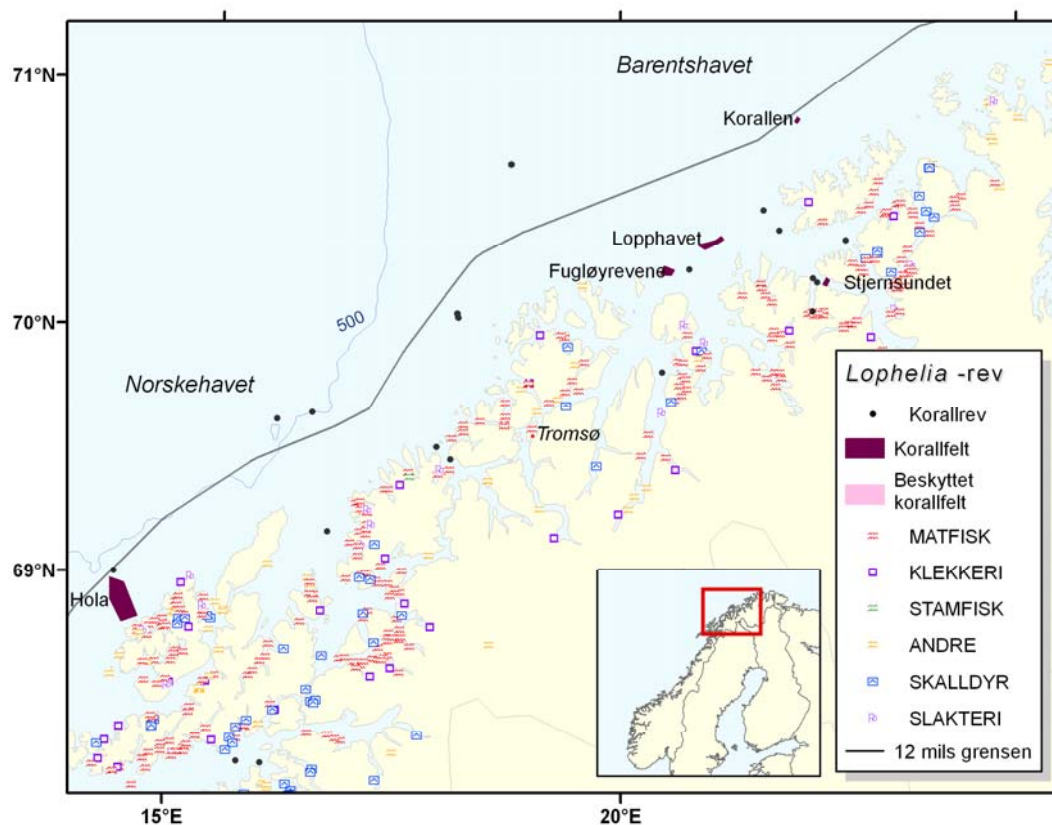


Figure 2. Map showing fish-farm locations (open rectangles) in northern Norway. *Lophelia* reefs are indicated with black dots. Coral reef areas are indicated with a dark brown colour.

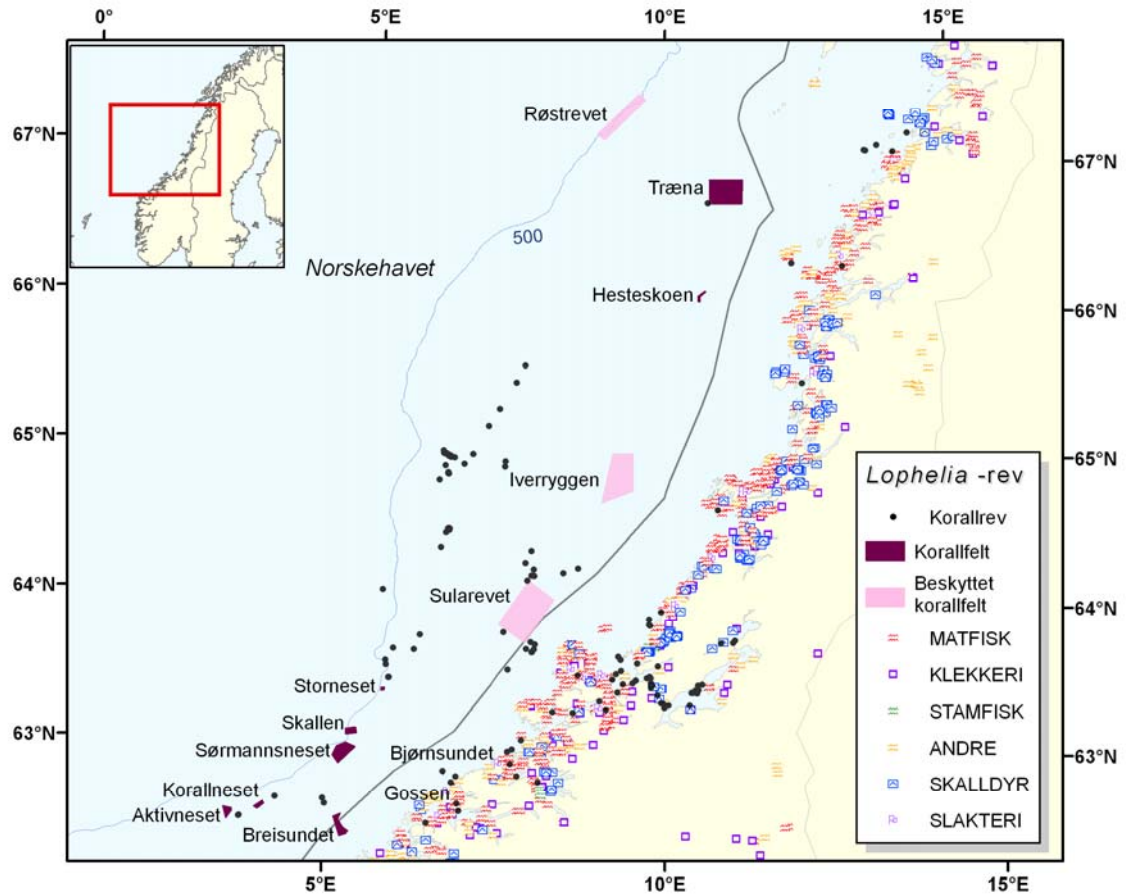


Figure 3. Map showing fish-farm locations (open rectangles) in mid Norway. *Lophelia* reefs are indicated with black dots. Coral reef areas are indicated with a dark brown colour, and protected coral reef area are indicated with a pink colour. Some of the reefs are relatively close (< 2 km) to fish farms.

The closest occurrences of *Lophelia* reefs to fish farms are found in the county of Hordaland in western Norway (Figure 4). Here there, are four fish farms closer than 2 km from coral reefs.

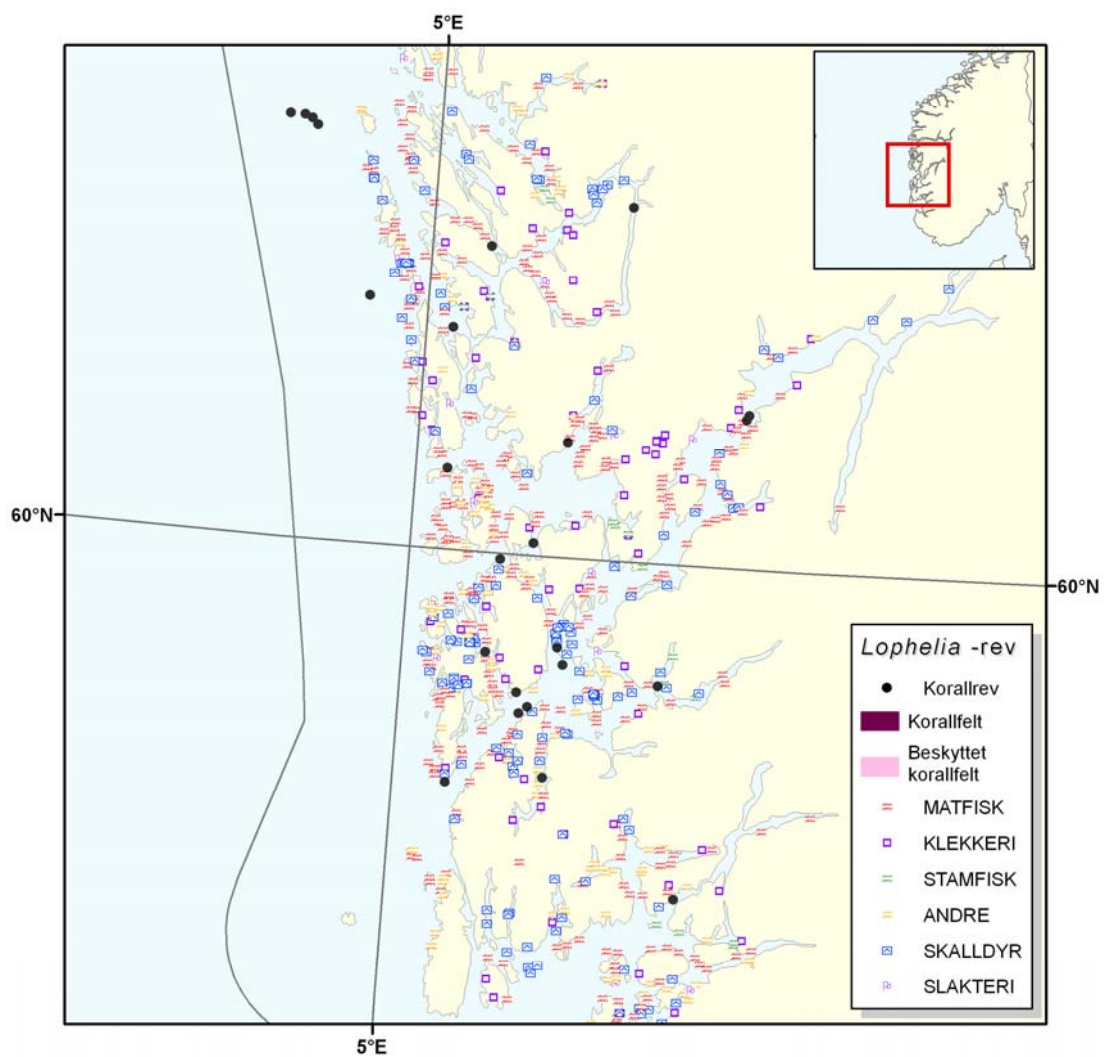


Figure 4. Map showing fish-farm locations (open rectangles) in western Norway. *Lophelia* reefs are indicated with black dots.

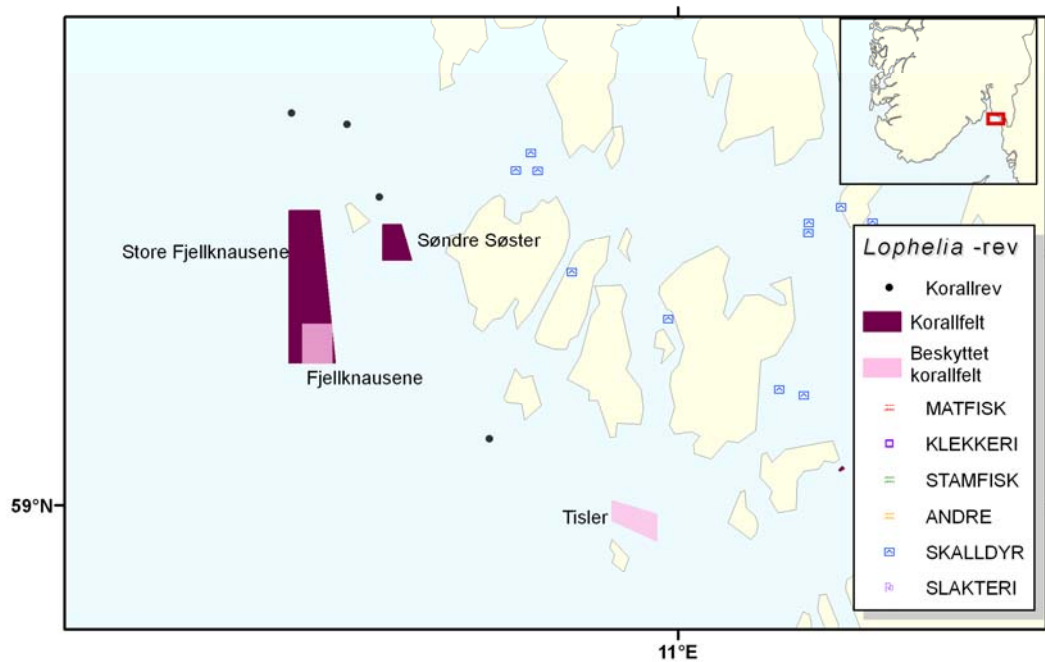


Figure 5. Map showing fish-farm locations (open rectangles) in east Norway. *Lophelia* reefs are indicated with black dots. Coral reef areas are indicated with a dark brown colour, and protected coral reef area are indicated with a pink colour.

Potential impact of eutrophication

Eutrophication is believed to be a general problem in the coastal area of western Sweden and southern Norway. Whether this is also a problem in western Norway has been debated. Increased concentration of particulate organic matter and sedimentation rates surely affect marine life. The effects vary between taxonomic groups. Increased load of organic particles in the water may represent a food source for suspension-feeders. Whether the quality of the organic particles in eutrophicated waters would suite the diet of *Lophelia pertusa* is rather doubtful. One potential negative effect could be outbreak of microbial diseases, or reduced growth because of malnutrition.

For *Lophelia pertusa*, there is very little knowledge that can be used to predict which effects to expect. Monitoring programmes should therefore be established at selected coastal reef locations, preferably with offshore reference locations.

References

- Donnelley, R.R. 2008. Scottish Aquaculture A Fresh Start A Consultation on a Renewed Strategic Framework for Scottish Aquaculture. The Scottish Government St Andrew's House, Edinburgh. 35 pp.
- Mortensen, P.B. and J. Alvsvåg. 2007. Korallrev i fjorder og langs kysten – naturperler med spesielt behov for vern. Side 35-37 i Dahl, E., Hansen, P.K., Haug, T., Karlsen, Ø., (red.) 2007. Kyst og havbruk 2007. Fisken og havet, særnr. 2-2007.
- Roberts, J. M., C.J. Brown, D. Long, and C.R Bates. 2005. Acoustic mapping using a multibeam echosounder reveals cold-water coral reefs and surrounding habitats. *Coral Reefs*, 24, 654–669.

6 Distribution patterns of corals and sponges across the North Atlantic

TOR d: Assess broader distribution patterns of species diversity of corals and sponges across the North Atlantic with a view to identifying 'hot spots' and variation in biodiversity and understanding biogeographic affinities.

Corals and sponges considered by this TOR

In addressing this TOR we have used the definition of corals provided in Cairns, 2007. We have also only taken into consideration sponge aggregations.

Biogeography of the North Atlantic

Dinter, 2001 undertook a thorough review of the biogeography of the OSPAR area based on available published data relating to a number of different taxonomic groups. He concluded that for the deep Northeast Atlantic the most striking factor for the determination of deep-sea species distribution patterns was the temperature difference on either side of the Greenland-Iceland-Faroe-Scotland Rise.

He also concluded that although there was some evidence to suggest separation of western and eastern Atlantic abyssal provinces (Vinogradova, 1979) as well as segregation of biogeographic units related to different trophic situations (Sokolova, 1997), evidence was conflicting and thus no further division was made. Dinter, 2001 commented that at depths below 2000 m (given the division between cold arctic and temperate Atlantic regions) differences between the physical characteristics of the water masses are very small, almost negligible, and hence the most important biogeographical differences at greater depths lie in differences in food supply.

Biogeography of corals

The decisive environmental factors for the distribution of corals (Mortensen *et al.*, 2006) appear to be the composition of bottom substrates, which determines those species that can occur (most deep-water corals depend on hard substrate for attachment but some are able to colonize soft substrate), average salinity, and maximum temperature, high temperatures probably control the upper depth limit of corals, which differ between species. What controls the lower depth limit is not known, but low temperatures and low food transport rates are likely to be important. Relatively strong currents are crucial to a sufficient supply of food; the topography of the seabed has implications for the local current pattern. According to Cairns, 2007 the cause for the high diversity of deep-water scleractinian in some areas is thought to be the result of the availability of large contiguous stable substrate at depths of 200–1000 m (the area effect). Until now, the depth of the aragonite saturation horizon has not been correlated with limitations in coral distribution as it is in the north Pacific.

Many coral species seem to have a northern distribution limit in the North-Atlantic Ocean defined by large ridges such as the Davis Strait, Denmark Strait, the Iceland-Faroe Ridge and the Wyville Thomson Ridge (Mortensen *et al.*, 2006). In Atlantic Canada, 24 species can be encountered: *Scleractinia* (6 species), *Anthipatharia* (1), *Alcyonacea* (5), *Gorgonacea* (12). Most species have a wide geographic distribution (Madsen, 1944), except 5 species, most corals occur on both sides of the Atlantic Ocean. But a general decrease in the number species is observed from west to east.

The number of scleractinian (hard corals) species increases from north to south on both side of the Atlantic north (Cairns, 2007). Seventeen species of scleractinian corals are known from the Gulf of Maine to Cape Hatteras. Only one species occurs in shal-

low water and 71% of the 17 species occur deeper than 1000 m. Forty-seven percent of the scleractinian corals from the cold-temperate US coast are widespread species and 28% occur across the Atlantic, with only a single species, *Vaughanella margaritata*, endemic to the NW Atlantic (Cairns and Chapman, 2001). A hot spot of scleractinian diversity is observed around the western Atlantic Antilles (up to 81 species). In the eastern side, the species number range from 6 species out of Scandinavia to 47 species out of continental Portugal and 52 around Azores (Cairns, 2007). According to Zibrowius, 1980, around the Azores the main increase concerns species living between 300 and 2000 m depth. The Celtic sea and the northern part of Bay of Biscay appear as an important northern limit for almost all of the coastal species (except *Caryophyllia smithii*, a species with a large bathymetric range) and for many bathyal species. *Lep-topsammia britannica* appear endemic to the Shetland-Faroe-Rockall-Hebrides area. Species distributed on both side of the Atlantic Ocean appear at greater depths and higher latitudes on the eastern side than on the western, this has been related to hydrography.

The distribution of *Anthipatharia* (Black corals) has been synthesized by Molodstova in 2006. In the North, *Anthipatharia* are only sporadically collected in higher latitudes of the northern hemisphere and they are especially rare in the pre-Atlantic sector of the arctic. Only 4 species have been recorded occasionally north of 52°N. Northeast Atlantic, black corals do not form dense populations. Current information on species diversity and distribution is not reliable because of the issues concerning the correct identification of taxa reported in the literature. With these limitations, the currently known antipatharian fauna of the northeastern Atlantic can be estimated as 33 species, fifteen species (48%) inhabit simultaneously continental and open-oceanic regions and of these 15 have been reported from both eastern and western continental regions, but not from open-ocean regions. 2 species are known from the western Atlantic and open-oceanic region but not yet reported from continental slope of Europe. 4 species (26.6%) have a transatlantic distribution and inhabit eastern, western and open-oceanic regions of the Atlantic. The antipatharian fauna of open-oceanic regions seems more diverse than the fauna of continental region: 28 have been reported from the slope of islands and oceanic rises and only 13 from the shelves and slope of Europe and northern Africa. An unusually large percentage of endemic antipatharians has been reported from open-oceanic rises: 13 species (39.4% of the total number of species reported from the oceanic rises). In contrast, the antipatharian fauna of the northeastern Atlantic exhibits greater diversity and includes about 25 species. Twelve species are known from Gibraltar to the English Channel and fifteen from the vicinity of Azores. They are characteristic components of seamount faunas.

The distribution of deep-water *Alcyonacea* (Watling and Auster, 2005) also indicates a general increase in the number of species from the northern part (29 species from Davis Strait to Cape Hatteras, 22 from Iceland-Scandinavia to English Channel) to the warm-temperate regions (33 species from Cape Hatteras to Florida straits, 89 from the English Channel to western Africa, including Azores and associated seamounts). The greatest similarity between the northern regions lies in the "stoloniferous" and "massive body form" soft corals, where 7 of the 17 species (41%) recorded could be found on both sides of the Atlantic. For the remaining alcyonaceans, the "Gorgonacea" of old, only 6 of 21 species (28%) were common to both regions. For the warm-temperate region, the picture was vastly different. Only 1 of the 17 species (5%) of soft corals, and 8 of 95 species (8%) of "gorgonaceans" of old, were common to both east and west regions. They attributed this disparity to the very different amount of hard substrate area involved. The southeastern North Atlantic region included the Azores, Madeira, and several seamount groups. These regions increase the total habitat area available. In the southwestern North Atlantic region, the deep slope widens

along the Blake Plateau, but narrows again quickly off Florida, and seamounts are absent. Watling and Auster, 2005 suggest, based on their research on the New England seamount chain that the diversity of “gorgonaceans” in the western Atlantic might be more similar to that of the eastern Atlantic than current data support, but that assessment of this statement will have to await detailed taxonomic work.

Concerning possible differences in the biogeography of coral from bathyal and abyssal depths, Grasshoff, 1985 considered that 75% of the gorgonians, pennatularians, and antipatharians found in the Bay of Biscay at bathyal depths were endemic to the Atlantic, with ~40% confined only to temperate latitudes of the deep NE Atlantic, but that abyssal species of these groups have a wider distribution.

Considering the Atlantic stylasterids, their northern limit (*Stylaster norvegicus*, *S. gemmascens*, *S. erubescens*) roughly coincides with that of the scleractinians, both groups are absent from the Arctic basin (Zibrowius and Cairns, 1992). This is in contrast to the presence of numerous species of both groups in Antarctic waters (Cairns, 1982, 1983a) where conditions favourable to benthic life were not largely disrupted during the Pleistocene. No stylasterids are thus far recorded from between Greenland and North Carolina (but this point needs confirmation as a result of lack of scientific observation). With 21 species in 6 genera, the stylasterid fauna of the northeastern Atlantic is considerably less diversified than the stylasterid fauna of the West Indies, which comprises 42 species in 8 genera (Cairns, 1986). The genera *Lepidotheca* and *Distichopora* are not represented in the northeastern Atlantic (Zibrowius and Cairns, 1992). Only 3 of the 21 stylasterid species (15%) recorded from the northeastern and equatorial eastern Atlantic also occur in the western Atlantic (Cairns, 1986). Among these, *Pliobothrus symmetricus* and *Stylaster erubescens* (with distinct subspecies) range from the West Indies to the eastern margin of the Atlantic and attain high latitudes, whereas *Crypthelia tenuiseptata* is known only from the West Indies and the Azores. Most species have a restricted latitudinal range or occur in a limited area (Zibrowius and Cairns, 1992).

Biogeography of sponges

According to Klitgaard and Tendal, 2004 the distribution of accumulations of larger astrophorid sponges occupies two band-shaped arcs related to the flow paths of the Norwegian Atlantic Current and the Irminger Current and their main branches. These two “ostur” bands are not continuous but represent a series of patches whose presence depends to a great extent on the local topography. Thus, the majority of the areas of “ostur” reported here, are found on the shelf plateau close to the shelf break (the Faroe Islands, the Karmoy area, and the western Barents Sea), on the upper slope (the Faroe Islands, the Karmoy area, and East Greenland), on the slope of the banks (the Faroe Islands, the western Barents Sea, and the Denmark Strait), on ridges (the Reykjanes Ridge), and on the rocky sides of fjords especially off forelands and in narrow straits (the Trondheim Fjord, and the Koster area). In terms of biogeography there are two main types of “ostur” assemblages in the Northeast Atlantic. “Ostur” from the Faroe Islands, Norway, Sweden, parts of the western Barents Sea and south of Iceland have almost the same complement of dominant species, mainly boreal in their distributions and rarely occurring at temperatures lower than about 3°C (*Geodia barretti*, *G. macandrewi*, *G. atlantica*, *Isops phlegraei*, *Stryphnus ponderosus* and *Stellata normani*). In the colder waters north of Spitsbergen, north of Iceland, in most of the Denmark Strait and off East Greenland the dominant genera are the same, but the species are mostly different, (*Geodia mesotriaena*, *Isops phlegraei pyriformis* and *Stellata rhapsidiophora*). A clear difference between the boreal and the cold water “ostur” is in the average size of the dominant geodiid species.

In the North Atlantic off Morocco and the west of Ireland and Scotland large masses of the hexactinellid *Pheronema carpenteri* (Thomson, 1869) have been reported from 740 to 1300 m depth (Carpenter *et al.*, 1870; Rice *et al.*, 1990; Barthel *et al.*, 1996). There are indications that this species may also be common to the west of the Faroe Islands and south of Iceland, at depths from between 800 and 1160 m (Burton, 1928; Copley *et al.*, 1996) and in the Bay of Biscay from 1000 to 2000 m (Le Danois, 1948). In the south of the Bay of Biscay and in north of Spain the structure-forming hexactinellid *Asconema setubalense* is encountered from 800 to 1500 m (Le Danois, 1948).

References

- Barthel, D., Tendal, O. S., and Thiel, H. 1996. A wandering population of the hexactinellid sponge *Pheronema carpenteri* on the continental slope off Morocco, Northwest Africa. *Marine Ecology*, 17, 603–616.
- Burton, M. 1928. Hexactinellida. The Danish Ingolf-Expedition, 6(4), 1–18.
- Cairns, S. D. 1982. Antarctic and Subantarctic Scleractinia. *Antarctic Res. Ser.*, 34 (1): 74p.
- Cairns, 1983. Antarctic and Subantarctic Stylasteridae (*Coelentera: Hydrozoa*). *Antarctic Res. Ser.*, 38 (2): 61–164.
- Cairns, S.D. 1986. A revision of the Northwest Atlantic Stylasteridae (*Coelentera: Hydrozoa*). *Smith. Contr. Zool.*, 418: iv+131p.
- Cairns, S.D. 2007. Deep-water corals: an overview with special reference to diversity and distribution of deep-water scleractinian corals *Bulletin of Marine Science*, 81, 311–322.
- Cairns, S.D., Chapman, R.E., 2001. Biogeographic affinities of the North Atlantic deep-water Scleractinia. In: Willison JHM, Hall J, Gass SE, Kenchington ELR, Butler M, Doherty P (eds) *Proceedings of the First International Symposium on Deep-Sea Corals*. Ecology Action Centre, Halifax, pp 30–57.
- Carpenter, W. B., Jeffreys, J. G., and Thomson, C. W. 1870. Preliminary report on the scientific exploration of the deep sea in H.M. surveying vessel "Porcupine" during the summer of 1869. *Proceedings of the Royal Society of London*, 18, 397–492.
- Copley, J. T. P., Tyler, P. A., Shearer, M., Murton, B. J., and German, C. R. 1996. Megafauna from sublittoral to abyssal depths along the Mid-Atlantic Ridge south of Iceland. *Oceanologica Acta*, 19, 549–559.
- Dinter, W.P. 2001. Biogeography of the OSPAR Maritime area. *Sonstige ver Ffentlichungen*, 168P.
- Grasshoff, M., 1985. Die Gorgonaria, Pennatularia und Antipatharia. In: Laubier, L. and Cl. Monniot, *Peuplements profonds du golfe de Gascogne*. IFREMER, 630 pp.
- Klitgaard, A.B., Tendal, O.S. 2004. Distribution and species composition of mass occurrences of large-sized sponges in the Northeast Atlantic. *Progress in Oceanography*, 61, 57–98.
- Madsen, F.J. 1944. Octocorallia (*Stolonifera-Telestacea-Xeniidea-Alcyonacea-Gorgonacea*). The Danish Ingolf-Expedition V:13, 65pp.
- Molodstova, T.N. 2006. Black corals (Antipatharia: Anthozoa: Cnidaria) of the northeastern Atlantic. In: *Biogeography of the North Atlantic seamounts* (Eds A.N. Mironov, A.V. Gebruk and A.J. Southward), pp. 141–151. Russian Academy of Sciences.
- Mortensen, P.B., Buhl-Mortensen, L. and Gordon, D.C.J. 2006. Distribution of deep-water corals in Atlantic Canada. In: *10th International Reef Symposium, 1832-1848*. pp. 1832–1848.
- Le Danois, E. 1948. *Les profondeurs de la mer, trente ans de recherches sur la faune sous-marine au large des côtes de France*, Payot, Paris.

- Rice, A. L., Thurston, M. H., and New, A. L. (1990). Dense aggregations of a hexactinellid sponge, *Pheronema carpenteri*, in the Porcupine Seabight (Northeast Atlantic Ocean), and possible causes. *Progress in Oceanography*, 24, 179–196.
- Sokolova, M.N. (1997). Trophic structure of abyssal macrobenthos. *Advances in Marine Biology*, 32, 427–525.
- Vinogradova, N.G. 1979. The geographical distribution of the abyssal and hadal (ultraabyssal) fauna in relation of the vertical zonation of the ocean. *Sarsia* 64: 41–50.
- Watling, L. and Auster, P.J. 2005. Distribution of deep-water Alcyonacea off the Northeast Coast of the United States. 279–296.
- Zibrowius, H. 1980. Les scléactiniaires de la Méditerranée et de l'Atlantique nord-oriental. *Memoire de l'institut océanographique* 11, 247pp.
- Zibrowius, H. and Cairns, S.D. 1992. Revision of the Northeast Atlantic and Mediterranean stylasteridae : Cnidaria : Hydrozoa, MNHN, Paris. 136p.

7 Term of Reference (e). Consider how the status of biodiversity of deep-water ecosystems could be measured, for example by using diversity indices (in conjunction with WGDEEP)

7.1 Introduction

Many policy decisions around the world are currently aimed at stopping or reducing losses in biodiversity. In simple terms, *biodiversity* is the number of species measured in a given area. The Convention on Biological Diversity (www.cbd.int) defines biodiversity as the variability among living organisms (e.g. number of different species). The number of species is also referred to as *species richness*.

The value of species richness is, in principle, easy: you list all the species in the habitat and count them. Biological structures and processes exist on different organizational levels, however, and assessing the species richness of a subzone as a measure of biodiversity can be misleading. Subzones with high species richness do not necessarily exhibit a high diversity on other levels. Biodiversity can be much more comprehensive than just the number of species however; it can include genetic variation within species, the variety of species in an area, and the number of habitats within an area.

Species evenness, or how well distributed abundance or biomass proportion are among species within a community, is an important factor in assessing biodiversity as it goes beyond just the number of species present. Evenness is ranged from zero to one. When evenness is close to zero, it indicates that most of the individuals belong to one or a few species/categories. When the evenness is close to one, it indicates that each species/categories consists of the same number of individuals.

In a biological multispecies community, the focus of ecological research is often on *relative abundances* of each species. The relative abundances of species are the number of individuals within species divided by the total number of individuals in the community. It is most usual in diversity studies to rank these relative abundances from most to least abundant and list or table these data.

7.2 Why is biodiversity important?

The manner in which organisms are important in the cycling of nutrients, transfer of energy, affect the physical environment, and interact with other species suggests that biodiversity is essential to the functioning and/or sustainability of an ecosystem. Many studies have demonstrated that complexities do indeed exist between species richness and ecosystem services and that certain species may drive ecosystem functioning (and the ecosystem services they provide). It is assumed that biologically complex communities (e.g. high biodiversity) are likely more resilient (e.g. able to adapt to changes) to disturbance. Exploitation of marine fisheries has certainly resulted in population declines, habitat degradation, and ecological changes. Much remains unknown about how the richness of species or functional groups affects ecosystem level responses.

7.3 How do we measure biodiversity?

Biodiversity indices are measures of species diversity expressed as ratios between numbers of species and "importance values" (numbers, biomass, productivity etc.) of individuals. The term may also refer to genetic diversity and diversity of habitats or communities. A diversity index is a mathematical measure of species diversity in a community. Diversity indices provide more information about community composi-

tion than simply species richness; they also take the relative abundances of different species into account. Diversity indices provide important information about rarity and commonness of species in a community. The ability to quantify diversity in this way is an important tool for biologists trying to understand community structure.

Beginning with Claude Shannon's 1948 paper measuring diversity, many diversity indices have been developed. As stated earlier, species richness (S) is simply the number of species present in a given area. Species evenness (E) is a diversity index, a measure of biodiversity and quantifies how equal the communities are numerically. If there are 40 sea pens, and 1000 stony corals, the community is not very even. However, if you record 40 sea pens and 42 stony corals, the community is quite even. Of what importance is this?

Simpson's Diversity Index is a measure of diversity, which takes into account both species richness and evenness. A simple example of computing a diversity index is as follows:

SPECIES	SAMPLE 1 (N)	N(N-1)	SAMPLE 2 (N)	N(N-1)
<i>Munida sarsi</i>	12	132	2	2
<i>Phakellia ventilabrum</i>	5	20	8	56
<i>Axinella infundibuliformis</i>	1	0	4	12
<i>Stichopus tremulus</i>	3	6	1	0
<i>Stylocordyla borealis</i>		0	1	0
<i>Hippasteria phrygiana</i>	3	6		0
<i>Ceramaster granularis</i>		0	1	0
Total	24 (n)	164 (N)	17 (n)	70 (N)

n = the total number of organisms of a particular species

N = the total number of organisms of all species

Putting the above data into the formula for Simpson's Index: $D = [n(n-1)/N(N-1)]$

$$\text{Sample 1} = 164/24(23): \quad D = 0.30$$

$$\text{Sample 2} = 70/17(16): \quad D = 0.26$$

Simpson's Index of Diversity (1-D) or Sample 1 = 0.70 and Sample 2 = 0.74.

Shannon's Diversity Index (H), also referred to as the Shannon-Wiener Index, is by far the most widely used today. The Shannon-Wiener index (H) is measuring the order and or disorder in a particular system. This order is characterized by the number of individuals found for each species/category in the sample. A high species diversity may indicate a healthy environment. The advantage of this index is that it takes into account the number of species and the evenness of the species. The index is increased either by having additional unique species, or by having greater species evenness.

7.4 What are some of the problems of using biodiversity indices?

Calculating biodiversity indices is strongly influenced by *sample size* (Magurran, 1988, Colwell *et al.*, 2004). Assessment of the sampling effort that may be required to produce biodiversity index values that adequately characterize the state of the community must be given serious consideration prior to any monitoring of species diversity (Soetaert and Heip, 1990; Boulinier *et al.*, 1998). As previously stated, biodiversity indices are calculated on species abundance data, and such data are the main product of groundfish surveys but not descriptions of habitat.

The *sampling gear* used also biases calculating biodiversity indices. In fisheries, for example, trawl gears are subject to catchability issues: catching different proportions of each species and, within species, catching different proportions of each size class of fish (Harley and Myers, 2001; Fraser *et al.*, 2007). Estimates of species diversity depend heavily on the fishing gear used.

Taxonomic skills have varied throughout the years, resulting in variation in the extent to which rare species were identified, or variation in the taxonomic level to which were identified.

Many of the large bottom-dwelling, or benthic organisms have an irregular distribution and are not adequately sampled by traditional quantitative sampling gears. Many seabed areas are difficult to investigate using traditional sampling methods such as grabs and dredges. Benthic organisms often are long-lived, and sensitive to environmental changes, making them ideal as environmental indicators. Visual surveillance techniques allow temporal monitoring of such organisms. The *observational technology* to sample deep-sea habitats (e.g. ROVs, AUVs, submersibles) has also changed over the years. The quality of these observations that are made available to taxonomists has varied over the years and this may make time-series comparisons difficult. Remote operated vehicles (ROV) and passive tethered observation platforms are often used for environmental surveys of the seabed. However, the methods used and the results obtained have been rather variable, with respect to geographic positioning, taxonomic precision and quantification.

To ensure better comparability, an expert group in Norway has developed a standard for visual surveillance which will be published this year. This standard describes a selection of established methods to ensure precise and reproducible documentation. The main aims of the methods are to record and monitor seabed conditions and organisms on and just above the seabed.

7.5 Other biodiversity indices

There are many more diversity indices in use today as well (e.g. Berger-Parker Index, Renyi Entropy), each offering advantages and disadvantages. A variety of diversity indices have been used in benthic ecology to assess the environmental quality and the effects of disturbances on benthic communities. The Marine Biotic Index is based on the proportion of five ecological groups to which the benthic species are allocated (Borja *et al.*, 2000). The Benthic Quality Index Index assigns tolerance values to indicator species (Rosenberg *et al.*, 2004). These are but a couple of indices that have been developed dealing with benthic communities. Taxonomic diversity indices express the degree of relatedness of communities, generally expressed as the number of steps up a hierarchical taxonomic framework that are needed on average to find a common link between two randomly chosen individuals from a sample. A community comprising a number of species from different families is inherently more diverse than one containing the same number of species belonging to the same genus.

7.6 Can indices be use to assess of biodiversity on deep-water ecosystems?

Information on the habitats, biotopes and biodiversity on the seabed is an important part of ecosystem-based environmental management, and necessary in order to evaluate the consequences of various anthropogenic activities. Many of the indices can be rather simplistic (e.g. number of species, abundance) or perhaps insensitive to sampling effort or gear used or technological improvements. What do we want the index to convey about deep-water ecosystems? We have demonstrated that statistical indices exist that can give one a diversity number. What about using taxonomic

groups based on function or trophic level? Can we use size class groups (e.g. megafauna, meiofauna) as indices for measuring the status of diversity in the deep sea? The answer to all these questions is probably yes.

Summary of: 164 stations N = 192 species

Station	ABUNDANCE				DIVERSITY INDICES			
	Mean	St Dev	Sum	S	E	H	D'	
1	0.14	0.59	26	13	0.94	2.41	0.90	
2	0.11	0.35	22	20	0.99	2.97	0.95	
3	0.06	0.23	11	11	1.00	2.40	0.91	
4	0.09	0.39	17	11	0.97	2.31	0.89	
5	0.04	0.27	8	6	0.93	1.67	0.78	
162	0.46	1.10	89	42	0.95	3.54	0.97	
163	0.45	1.09	87	42	0.94	3.52	0.96	
164	0.19	0.63	37	25	0.94	3.03	0.94	
AVERAGES:	0.32	0.89	61.24	28.70	0.95	3.10	0.94	

S = Richness E = Evenness = $H / \ln(\text{Richness})$

H = Diversity = Shannon's diversity index

D = Simpson's diversity index for infinite population

Computer software programs exist that easily calculate many of the indices discussed (Clarke and Warwick, 2001a). An example of a summary table for calculating many of these indices using the software PC-Ord is demonstrated above.

Using similar sampling techniques at the same geo-referenced locations would allow for comparing diversity values but perhaps more importantly, would lead to developing a *trend analysis*. Trend analysis refers to the need of collecting information from like sampling methods and attempting to spot a pattern, or trend, in the information. This assessment may be more important than concentrating on the numerical values produced in the biodiversity indices. Visual surveillance using geo-referenced positions which allow locations to be revisited allows a documentation of conditions and changes in indicator organisms and would allow us to compute biodiversity indices of the same areas and to compare trends over time.

In conclusion, the status of biodiversity of deep-water ecosystems can be measured using standard visual surveillance methods, diversity indices calculated using existing statistical computer software, and any possible trends graphed and assessed. The causality of any gain or loss of deep-water biodiversity is an entirely separate subject and will not be discussed here.

7.7 A short case study-indicators of biodiversity and community structure derived from Scottish survey data

The fish community on the Atlantic shelf slope to the west of Scotland has been the subject of biological studies for over a century. More recently, this region has been exploited as a deep-water fishery. In ICES Subdivision VIa the commercially valuable species are monkish (*Lophius piscatorius* Linnaeus, 1758), black scabbard fish (*Aphanopus carbo* Lowe, 1839), tusk (*Brosme brosme* (Ascanius, 1772)), argentine (*Argentina* spp.), blue ling (*Molva dipterygia* Pennant, 1784), roundnose grenadier (*Coryphaenoides rupestris* Gunnerus, 1765) and some of the deep-water sharks (mainly *Centroscygnus coelolepis* Bocage and Capello, 1864). Although full analytical assess-

ments have not been possible, exploratory assessments and available abundance indices for the deep-water fish stocks in this area indicate that they have declined and/or are now outside safe biological limits. Concerns have also been expressed that demersal trawling is impacting on deep-water benthic fauna, particularly the reef-forming corals, that there is evidence of the accumulation of anthropogenic pollutants and that deep-sea organisms and communities are particularly sensitive to environmental alteration associated with climate change. Consequently, deep waters are now recognized as a priority marine habitat, a number of areas have protection measures imposed and a number of sites in European waters are being considered for designation as special areas of conservation.

Data is available on the fish community in this region from ten years of standardized surveys carried out by Fisheries Research Services (FRS) using the FRV *Scotia*. Work is being carried out to examine temporal and spatial trends in size structure and biodiversity of the deep-water demersal fish community revealed by this survey. Diversity of the benthic-pelagic and demersal fish assemblage recovered by each haul has been described using the Shannon Diversity Index (H), as well as a descriptor of community relatedness, taxonomic diversity (A^*). Overlap of species between depth strata was assessed using Sørensen's beta diversity index.

Taxonomic diversity indices reveal no trends in community relatedness over time (Figure 1). The only significant factor influencing diversity of the catch was the depth at which a haul was collected (Figures 2–3). There was no evidence of changes in depth distribution of species over time, as revealed by Sørensen's beta diversity index, a measure of the degree of overlap in species between two strata (Figure 4).

From this study, the absence of a trend in the taxonomic diversity data over time suggests that the effects of fishing over this period have not had a negative impact on fish community diversity. It has been suggested that the peak in the depth related trend in taxonomic diversity around 500m relates to the overlap between shelf and slope ichthyofauna communities. Taxonomic diversity then decreases with depth until the abyssal species begins to appear in catches around 1800 m. Shannon diversity index values vary without any real trend with depth. Sørensen's beta diversity index reveals no changes over time, suggesting that the depth distribution of species is remaining stable. If vulnerable species were being removed at fished depths leaving surviving populations in deeper waters one would expect to see changes in this index over time.

An analysis covering the Hebridean Slope for the pre-exploitation period (1973–1987) and first decade of the fisheries (up to 1999) was carried out by Basson *et al.*, 2002 and is summarized below. Deep-water survey data from CEFAS (UK), SAMS (UK), FRS (UK), IFREMER (France) and ISH (Germany) were used. A database of all scientific trawl hauls carried out on the Hebridean continental slope (latitude 54° 30' to 58° 45' N west to 12°; Figure 5) was compiled. 246 trawl stations between 375 and 2150 m sampled from 1973 to 1999 were included in this study. Indices of fish community abundance and biomass, diversity indices and multispecies size spectra were computed, a detrended correspondence analysis (DCA) was carried out on a subset of stations samples with a small scientific trawl (see Basson *et al.*, 2002 for details). Depth, area and gear effects were taken into account in the analyses, where possible.

7.7.1 Size spectra

Size-spectra were calculated and compared for deep-water trawl catches from thirty-five surveys over the period 1973 to 1999. The slopes of the size-spectra were compared against time, using graphical and analysis of covariance methods. There are

some indications of an increase in slope with time, but this result is neither strong nor highly conclusive. The data are very unbalanced and the results depend on the gear grouping used and the way in which the year-effects are incorporated in models.

7.7.2 Detrended correspondence analysis (DCA)

The results from a detrended correspondence analysis of SAMS semi-balloon trawl data, pre and post-exploitation, suggested that there may have been differences in species composition between catches taken in 1985 and 1999. It was emphasized that, until the results are fully analysed in terms of the biology of the species, it would be inappropriate to attribute this to an effect of exploitation.

Comparison of species diversity indices Diversity indices calculated using data from SAMS surveys carried out with a range of fishing gears demonstrate a consistent decline in diversity and taxonomic distinctness with depth, which stabilizes at depths greater than 1375m. Diversity indices calculated using SAMS semi-balloon trawl data, pre and post exploitation, demonstrate a decline in species diversity but little change in taxonomic distinctness. However the number of hauls completed in the surveys using the semi-balloon trawl was small and differences in catch composition and diversity may reflect sampling variance rather than real differences in the composition of fish assemblages.

The set of approaches used in this study seem of interest to further time-series analyses as and when survey data accumulate (e.g. the FRS survey carried out until 2008 could be integrated in similar analyses and the statistical treatment of the envisaged PGNEACS survey could make further use of these approaches).

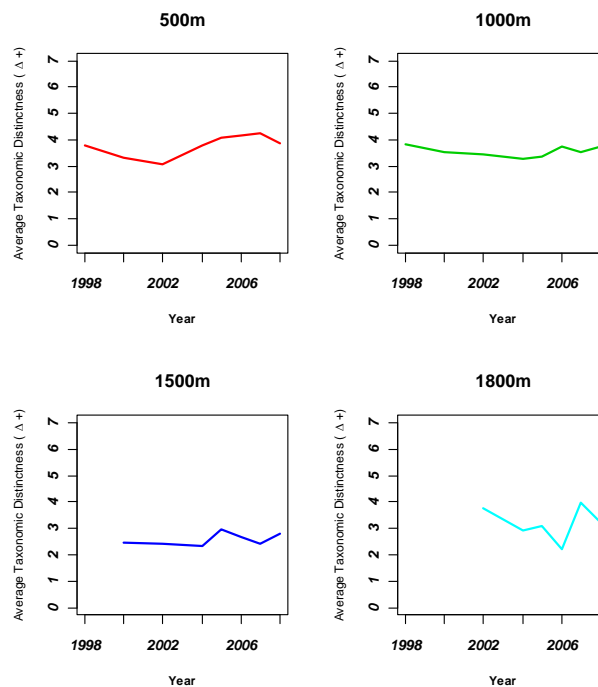


Figure 1. Trends in taxonomic diversity at depth, 1988–2008.

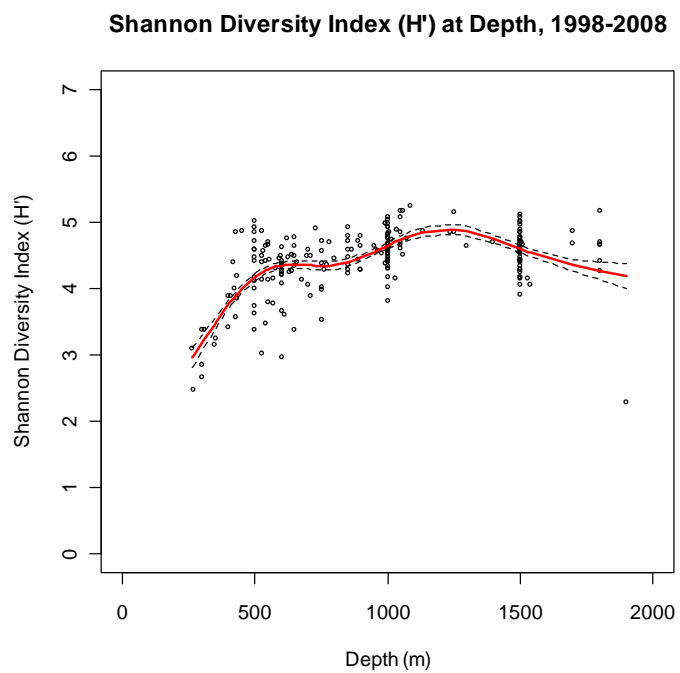


Figure 2. Shannon diversity index values at depth, pooling data across all years.

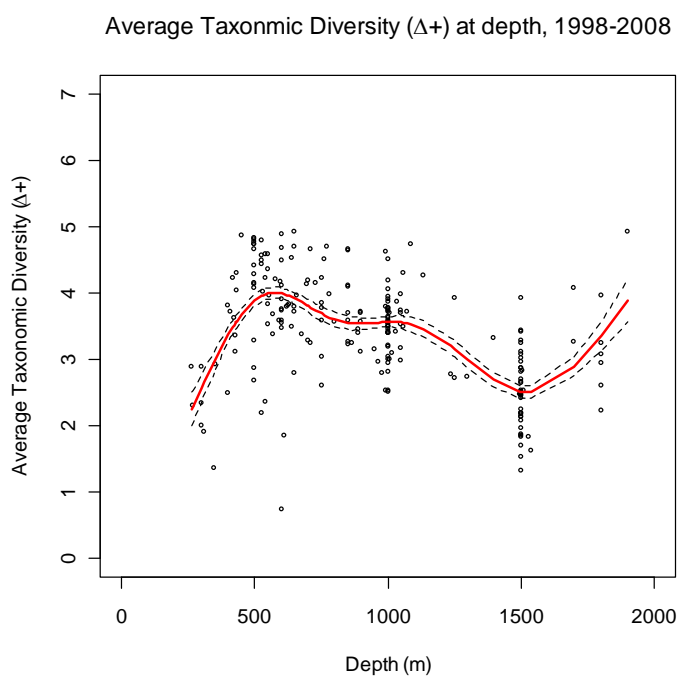


Figure 3. Taxonomic diversity index values at depth, pooling data across all years.

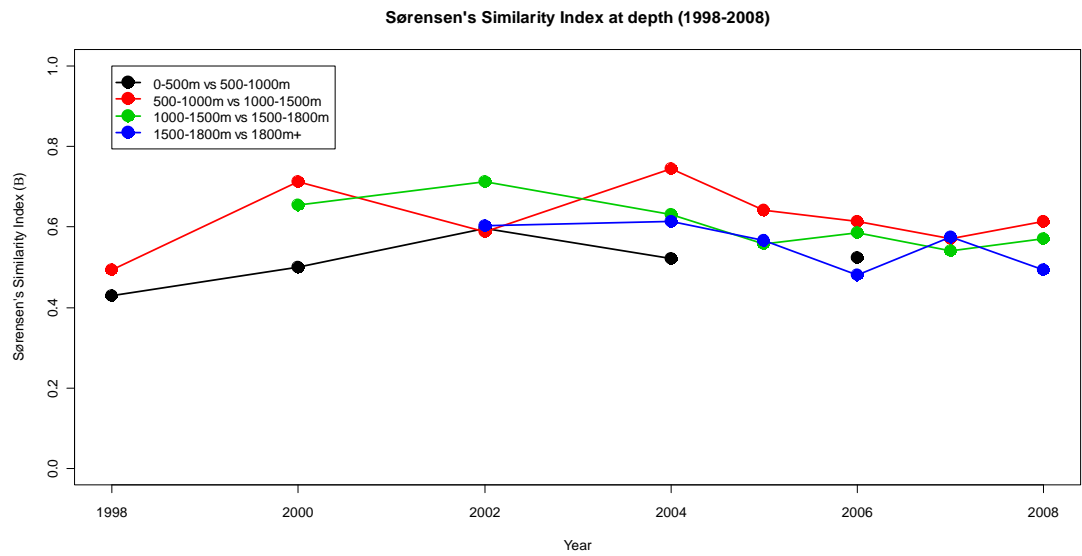


Figure 4. Temporal trends in Sørensen's beta diversity index comparing changes in overlap of species between depth strata.

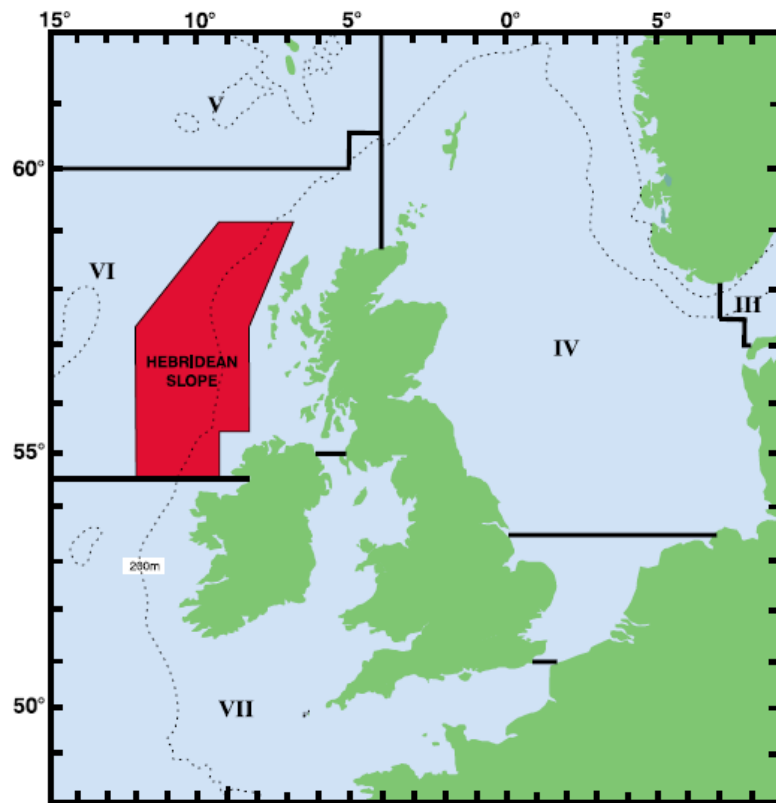


Figure 5. Chart showing the Hebridean continental slope in relation to ICES Subareas (from Basson *et al.*, 2002).

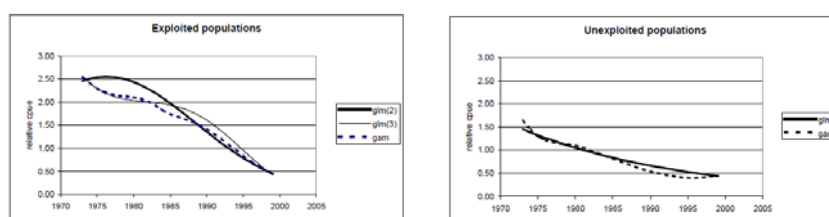


Figure 6. Trends of relative biomass estimated from survey data with different models for: (left) commercial species; (centre) non-commercial species; (right) roundnose grenadier.

References

- Basson, M., Gordon, J.D.M., Large, P.A., Lorange, P., Pope, J.G., Rackham, B., 2002. The effects of fishing on deep-water fish species to the west of Britain. Joint Nature Conservation Committee (JNCC), JNCC Report, Report No. 324, Peterborough (UK), (available at: <http://www.nhbs.com/>), 150pp.
- Borja, A., Franco, J., Pérez, V. 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. *Mar. Pollution Bull.* 40:1100–1114.
- Boulinier T., Nichols J. D., Sauer J. R., Hines J. E., Pollock K. H. 1998. Estimating species richness: the importance of heterogeneity in species detectability. *Ecology* 79:1018–1028.
- Buzas, Marin A. and Lee-Ann C. Hayek. 2005. On richness and evenness within and between communities. *Paleobiology*.
- Clarke, K.R. and R.M. Warwick. 2001a. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E, Plymouth.
- Clarke, K.R. and R.M. Warwick. 2001b. A further biodiversity index applicable to species lists: variation in taxonomic distinctness. *Mar. Ecol. Prog. Ser.* 216, 265–278.
- Colwell R. K., Mao C. X., Chank J. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. 2004. *Ecology* 85:2717–2727.
- Fraser H. M., S.P. Greenstreet and G.J. Piet. 2007. Taking account of catchability in groundfish survey trawls: implications for estimating demersal fish biomass. *ICES J. Mar. Sci.* 64:1800–1819.
- Greenstreet, S.P.R. 2008. Biodiversity of North Sea fish: why do the politicians care but marine scientists appear oblivious to this issue? *ICES J. Mar. Sci.* 65: 1515–1519.
- Gray, J. S. 2000. The measurement of marine species diversity, with an application to the benthic fauna of the Norwegian continental shelf. *Journal of Experimental Marine Biology and Ecology* 250:23–49.
- Harley S. J. and R.A. Meyers. 2001. Hierarchical Bayesian models of length-specific catchability of research trawl surveys. *Can. J. of Fish. Aqua. Sci.* 58:1569–1584.
- Hill, M.O., 1973. Diversity and evenness: a unifying notation and its consequences. *Ecology*, 54, 427–432.
- Magurran A. E. *Ecological Diversity and Its Measurement*. 1988. Chapman and Hall, London. 192.
- Naeem, S., L. J. Thompson, S. P. Lawler, J. H. Lawton, and R. M. Woodfin. 1994. Declining biodiversity can alter the performance of ecosystems. *Nature* 368:734–736.

- Purvis A. and A. Hector. 2000. Getting the measure of biodiversity. *Nature* 405:212–219.
- Rosenberg, R., M. Blomquist, H.C. Nilsson, H. Cederwall, and A. Dimming. 2004. Marine quality assessment by use of benthic species-abundance distributions: a proposed new protocol within the European Union Water Framework Directive. *Mar. Pollution Bull.* 49:728–739.
- Shannon, E. and Weaver, W., 1949. *The mathematical theory of communication*. Univ. of Illinois Press, Urbana, 125p.
- Soetaert K., Heip C. Sample-size dependence of diversity indices and the determination of sufficient sample size in a high-diversity deep-sea environment. 1990. *Mar. Ecol. Prog. Ser.* 59:305–307.
- Warwick, R.M. and K.R. Clarke. 1995. New 'biodiversity' measures reveal a decrease in taxonomic distinctness with increasing stress. *Mar Ecol Prog Ser* 129, 301–305.
- Wilsey, Brian J. and Catherine Potvin, 2000. Biodiversity and ecosystem functioning: importance of species evenness in an old field. *Ecology*.

8 Sponge grounds in the North Atlantic

Term of Reference (f): Define and map sponge associations based on taxonomic information and survey data. Assess the association of sponge grounds with fish and other fauna. Provide a summary of sensitivity of different sponge species to impact and disturbance. Assess priorities areas for sponge distribution data and target areas for future surveys.

8.1 General introduction to the sponges

The sponges (*Porifera*) are one of the most ancient animal groups on the planet with a fossil record reaching back to the Cambrium. There are three main groups: *Calcarea*, (calcareous sponges), *Hexactinellida* (glass sponges) and *Demospongiae* (silicious sponges), all well established in the Ordovician 480 MY ago. Despite their multicellular body-plan and lack of tissues, and being little more advanced than certain protozoan colonies, they are highly diverse; comprising about 8000 described extant species and an estimated number of 7000 undescribed species.

Apart from 150 species living in freshwater, sponges are marine and found in all the oceans and at all depths, even in the deep-sea trenches at more than 8000 m depth. The number of species is highest in tropical shelf areas, decreasing toward the polar regions and on the continental slope with increasing depth.

Most species live on hard substrates such as rock, gravel and corals. A small number are soft bottom dwellers, and they have special arrangements of long spicules to keep them from sinking into the mud, e.g. a stalk, a basal tuft, or a fringe along the lower edge of the body.

Sponges are highly effective filter-feeders, both as to the size spectrum of particles they catch and the volume of water filtered per time unit, thus playing a clear role in benthic-pelagic coupling. The filtering device is a complicated interior aquiferous canal system, the unique hallmark of the group. Sponge filter feeding differs from that of the deep-water corals which are carnivores in that the aquiferous system of sponges cannot close as the coral polyps can. Therefore, sponges can be “smothered” if too much debris is taken into the central body. The aquiferous system has evolved into a series of modifications characteristic of different subgroups, the most amazing one being a reduction of the filtering capacity in favour of a carnivorous mode of life. Small crustaceans are caught by hook-shaped spicules protruding from the outer surface of the sponge, and overpowered and digested by a swarm of amoebocytes.

Between the cell layers of the outer surface and of the aquiferous canal system sponges have a collagenous matrix containing a number of specialized kinds of cells. In most sponges some of these cells secrete a mineral skeleton in the form of spicules (‘needles’) of either CaCO_2 or SiO_2 . The spicules are of many forms and sizes and they are important taxonomic characteristics.

Reproduction varies in detail from one sponge group to another, and even between species of some subgroups. Both sexual and asexual reproduction occurs. Most species are hermaphroditic and viviparous, releasing lecithotrophic larvae with a short pelagic life. Some are oviparous and the development takes place outside the sponge, but details are poorly known. Asexual reproduction varies from mere fragmentation through different kinds of budding; the most advanced being functional small sponges falling off the mother-sponge.

Where numerous large sponges are present in the same local area they tend to form a biotope or structural habitat of their own, exerting clear ecological effects on other local fauna. Through their form as thick encrustations, lumps, and branched, funnel- or fan-like bodies they influence near-bottom current and sedimentation patterns. They provide substrate for other species, and, displaying holes, crevices and spaces among branches, they offer sheltering places for associated fauna. Although some of the silicious spicules dissolve rather fast there is a certain accumulation of shed spicules and spicules from dead sponges between and under the living ones. These spicules can form a thick sediment-stabilizing mat, which constitute a special bottom type and houses a rich fauna of smaller species.

8.2 Structure-forming sponge species in the North Atlantic

WGDEC provided some details on large-habitat-forming sponges in their 2007 report (ICES, 2007) and included information on their distribution and sensitivity to human activities. Fuller *et al.*, 2008 also discuss sponge aggregations in the NW Atlantic. Here we consolidate and build on that information to provide a list of species that managers should be concerned with, and update distribution maps to include new information, most importantly data from the NW Atlantic. The species and habitats we discuss generally occur at water depths from 200 to 1500 m.

8.2.1 Habitat-based management vs. single-species management

Most of the sponge species found within fishing depths in the North Atlantic are relatively common and widespread. Over much of their distribution they occur as isolated individuals, however, in some locations, where environmental conditions are favourable, they form dense, multispecies communities. The foundation for these sponge reefs or grounds are often the large, erect sponges, which when caught in trawl gear in such habitats, can fill the nets (Figure 8.2.1.1). Based on expert opinion within the Working Group we have produced a list of 25 sponge species which can be considered as structure-forming in certain environments (Table 8.2.1.2.1). Using these species as indicators, we endorse a habitat-based approach to management, shifting conservation to the sponge grounds as opposed to individual species. The OSPAR Commission in 2005 has followed this approach through the recognition of “sponge aggregations” as habitats on their list of threatened and declining species and habitats.



Figure 8.2.1.1. A large catch of *Geodia* sponges “ostur” from the continental slope off Norway at about 350 m depth. Photo courtesy of H.T. Rapp.

8.2.1.1 Sponge-dominated biotopes-terminology and definitions

There is no unambiguous term for sponge-dominated biotopes; they are variously called sponge beds, sponge fields, sponge grounds, sponge accumulations, ostur, sponge associations, and sponge reefs. Only the last three terms have some degree of delimitation. For the wider conception we prefer the term ‘sponge ground’.

Any definition of ‘sponge ground’ is by nature of the phenomenon vague, because the sites of high abundance are just minor parts of the single species’ geographical distribution area. Moreover, at different sites the species do not necessarily occur in the same proportion in relation to each other. For sites with high abundance of sponges the idea of ‘sponge ground’ is easy to grasp, as sponges pile up in a stack when the trawl is emptied on deck (Figure 8.2.1.1), or fill the frames of the *in situ* photographs (Figure 8.2.1.1.1). Klitgaard and Tendal, 2004 defined a sponge ground as an area where the dominating taxon of a given catch is sponges, estimated on deck to comprise at least 90% of the wet weight biomass, excluding fish. Besides, a considerable part of the catch is often sponge skeletons, spicule balls, spicule mat or loose spicule masses.

In practice, this definition works well for most scientific benthos investigations based on Agassiz-trawl, Sigsbee trawl, beam trawl or various kinds of dredge samples because the gear runs on the bottom for a rather short period of time (ten’s of minutes), covers a relatively small area, and often other samples which can be used to compare the results are taken nearby. The trawl catches taken by fishery research vessels, not to mention commercial trawlers, are quite another matter. The gear is much larger than the above-mentioned and fishing can take place for hours. Catches are the result of running over large areas of bottom, often obviously covering several different biotopes. Catch volume and weight of the sponges are here so large that they are difficult if not impossible to handle unless some overall consideration is accepted and/or

subsamples are taken. Examples from different geographic areas are: The Faroes 1–3 tons, places along the Norwegian shelf up to 12 tons or more, south of Iceland up to 50 tons, off Nova Scotia up to 8 tons.

Underwater *in situ* photography is now a commonly used non-damaging investigation technique, but more studies of simultaneously taken photographic series and dredge/trawl catches are needed in order to intercalibrate the two methods. The few existing North Atlantic studies (Rice *et al.*, 1990; Barthel *et al.*, 1996; Klitgaard *et al.*, 1997) report on average densities of large sponges of 1 specimen per 1–30 m² on sponge grounds. It should be emphasized that photographs from sponge grounds often demonstrate groups of sponges, sometimes growing very close to each other, with more or less empty areas between groups (Figure 8.2.1.1.1).

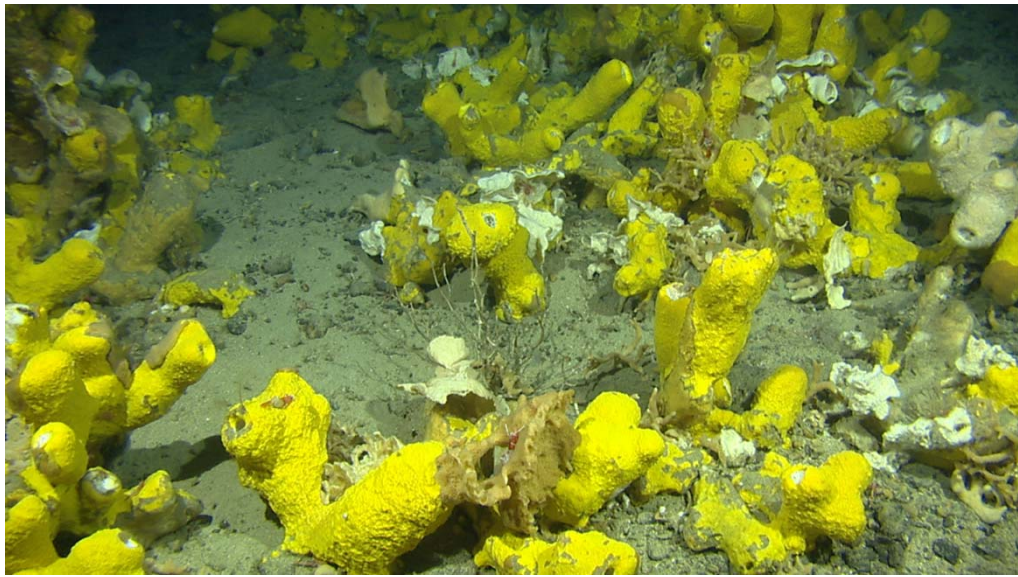


Figure 8.2.1.1.1. Sponge grounds off Norway at about 400 m depth. This photo illustrates the small-scale patchiness of the sponges within the grounds. The yellow sponge (*Aplysella sulphurea*) is growing over another species, *Stryphnus* sp. (Photo courtesy of J.H. Fossaa).

Sponge grounds have been found in other parts of the world ocean. Most widely known are the enormous masses of hexactinellid sponges and spicules around Antarctica and the hexactinellid reefs off the coast of British Columbia, Canada. Other grounds are known in the Arctic Sea, in the North Pacific, off New Caledonia, and in New Zealand, but most are not investigated from an integrated point of view. There must be many sponge grounds as yet undiscovered.

8.2.1.2 Structure-forming sponges: description and justification for inclusion

The 25 sponge species listed in Table 8.2.1.2.1 can be considered as structure-forming in certain environments, and indicators of sponge grounds. Some dominate the grounds to the exclusion of other species, e.g. *Pheronema carpenteri*, *Vazella pourtalesi* (Figure 8.2.1.2.1), *Geodia* spp. (Table 8.2.1.2.1, Figure 8.2.1.2.2), but most either co-occur with other dominating species or are found in abundance with other species but do not dominate the biomass (Table 8.2.1.2.1). Even if some sponge grounds are dominated by only one species, there are always a few more species to be found. For *Pheronema* for instance, 3 other hexactinellids, among them a species of the stalked genus *Hyalonema*, are sometimes associated. The richest sponge grounds so far analysed are in Faroese waters where *Geodia* species and *Stryphnus* dominate. There,

some of the other species mentioned in the table occur, and a swarm of 25–30 smaller species are found as well, some of them forming encrustations only 1–2 mm thick.

Hexactinellids are deep- and cold-water species. *Pheronema* and *Vazella* form beds of their own, dominating their respective areas. The biology of *Vazella* is so far poorly known, except for it being a shelf species off eastern Canada. *Pheronema* is an upper slope species distributed from Iceland to off West Africa, including the eastern Mediterranean, and around the Azores. Mass occurrences are known from off West Scotland, in Porcupine Seabight, and off Morocco. It is characteristic for these grounds that the sponges sit in mud with a basal spicule tuft, on the top of thinner or thicker (a few cm) spicule mats, formed by the skeletons of dead sponges, and providing shelter for a number of small invertebrates. *Asconema* and *Schaudinnia* occur on the outer shelf-upper slope, especially off East Greenland and on the deep parts of the Reykjanes Ridge together with other large sponges, mainly species of *Geodia* and *Thenea*.



Figure 8.2.1.2.1. *Vazella pourtalesi* on the Scotian Shelf south of Halifax, Nova Scotia in about 150 m depth. Photo courtesy of the Canadian Department of Fisheries and Oceans (DFO).

Demospongiae comprise the major number of ‘silicious’ sponge species. The *Geodia* and *Stryphnus* species are all large and massive, occupying gravelly bottoms on the outer shelf and upper slope (Figure 8.2.1.2.2). Although *G. mesotriaena* is an Arctic/cold-water species the other three species are living in boreal waters. In many of the grounds they occur in enormous amounts, the relative abundance of the species varying from place to place. The distribution of *Stryphnus* is unclear, because it has recently been demonstrated that *S. ponderosus* and *S. fortis* which for many years have been considered synonyms, are in fact two different species, the first one mainly living in temperate, the second in Arctic waters. Because of the changing and complex hydrographical conditions in some parts of the NE Atlantic old descriptions and museum collections must be revised before a clear picture on the distribution of these species can emerge.

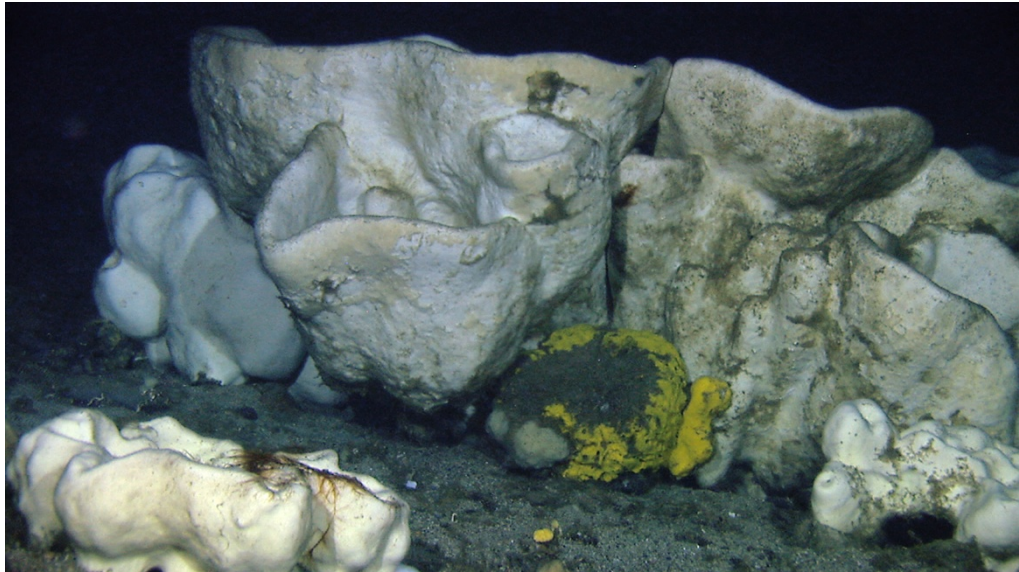


Figure 8.2.1.2.2. *Geodia* sp. dominating sponge grounds off the coast of Sørøysund, Finnmark, Northern Norway (photo courtesy of MAREANO/Institute of Marine Research). The yellow sponge in the foreground (*Aplysella sulphurea*) is growing over another species, *Stryphnus* sp.

Stelletta, *Thenea*, *Tetilla* and *Polymastia* species are all massive, lumpy sponges from outer shelf and slope depths. They represent species-rich genera, and although there are taxonomic problems of various kinds in all of them, they can be divided into shelf-slope and deep-water species, as well as into warm- and cold-water species. Those in the table are shelf-slope species, and both warm- and cold-water species are represented. Except for *Thenea muricata* they do not dominate grounds, but are instead associated with the larger sponge species, sometimes even using them as substrate. In places *T. muricata* can completely dominate, the individuals growing together forming a kind of carpet over many m².

The three *Phakellia* species (Figure 8.2.1.2.3) and *Antho dichotoma* (Figure 8.2.1.2.4) are common all over the boreal NE Atlantic, on the shelf and sometimes down to upper slope depths. They are upright foliate or branched sponges with a very strong skeleton composed of silicious spicules in combination with large amounts of spongin ('horny stuff') and are fixed to stones or rock with strong 'horny roots'. The aquiferous system of the *Phakellia* species is somewhat reduced and they rely to a high degree on exterior currents to keep up a water current through their body.

Mycale lingua belongs to a genus with about 100 species of which about 10 are found in the NE Atlantic. The sponge is soft and often damaged in the catch, but both from the catches and from photographs it is clear that the species is very abundant nearly all over its distribution area, although it never seems to form its own sponge grounds.

Petrosia crassa is a massive, hard sponge, varying much in shape. It rarely grows very large, and it may be that the irregular form leads to parts breaking off and forming independent sponges. It has been found in relatively few places, mostly in the eastern part of the boreal area, but the specimens may in some cases have been taken for small or fragmented *Geodias* and not having been kept cannot be re-examined.



Figure 8.2.1.2.3. *Phakelia robusta* collected from Rockall Plateau at 385 m depth. Photo courtesy of J. Drewery, FRS Marine Lab, Scotland.



Figure 8.2.1.2.4. *Antho dichotoma* collected from Rockall Plateau at 385 m depth. Photo courtesy of J. Drewery, FRS Marine Lab, Scotland.

Table 8.2.1.2.1. Large-sized (> 5 cm maximum dimension) sponge species frequently reported from sponge grounds in the North Atlantic. The nature of occurrence is different from one species to another: D = dominating on the ground; M = one of several dominating species on the ground; A = found on sponge ground in abundance, but not dominating as to biomass.

TAXON	SUBSTRATE	SIZE (RANGE OF ADULT)	ASSOCIATED WITH DENSE GROUNDS	GROWTH FORM
Hexactinellida				
<i>Pheronema carpenteri</i> (Thomson, 1869)	Mud	25 cm	D	Barrel-shaped, thick-walled
<i>Asconema setubalense</i> (Kent, 1870)	Gravel, stones	60 cm	M	Funnel-shaped, thin-walled
<i>Vazella pourtalesi</i> (Schmidt, 1870)	Mud	10 cm	D	Barrel-shaped, thin-walled
<i>Schaudinna rosea</i> (Fristedt, 1887)	Gravel	20 cm	A	Barrel-shaped, thin-walled
Demospongiae				
<i>Geodia barretti</i> (Bowerbank, 1858)	Gravel, stones	50 cm (100 cm)	D, M	Globular, often irregular
<i>Geodia macandrewi</i> (Bowerbank, 1858)	Gravel, stones	45 cm	D, M	Globular, often faintly flattened
<i>Geodia mesotriaena</i> (Hentschel, 1929)	Gravel, stones	15 cm	M	Spherical
<i>Geodia phlegraei</i> (Sollas, 1880)	Gravel, stones	20 cm	M	Globular to funnel-shaped
<i>Stryphnus ponderosus</i> (Bowerbank, 1866)	Gravel, stones	50 cm	D, M	Lumpy, often irregular
<i>Stelletta normani</i> (Sollas, 1880)	Gravel, stones	20 cm	A	Spherical
<i>Stelletta raphidiophora</i> (Hentschel, 1929)	Gravel, stones	15–20 cm	A	Spherical
<i>Thenea muricata</i> (Bowerbank, 1858)	Mud, sand	20 cm	D, A	Spherical
<i>Thenea levis</i> (Von Lendenfeld, 1903)	Mud, sand	15 cm	A	Oblong to crescent
<i>Tetilla infrequens</i> (Carter, 1876)	Gravel, other sponges	5–10 cm	A	Spherical
<i>Tetilla cranium</i> (Müller, 1776)	Gravel, other sponges	10 cm	A	Spherical
<i>Polymastia mammillaris</i> (Müller, 1806)	Gravel, stones	20 cm	A	Encrusting, cushion-shaped
<i>Polymastia uberrima</i> (Schmidt, 1870)	Gravel, stones	10–15 cm	A	Spherical to cushion-shaped

TAXON	SUBSTRATE	SIZE (RANGE OF ADULT)	ASSOCIATED WITH DENSE GROUNDS	GROWTH FORM
<i>Polymastia thielei</i> (Koltun, 1964)	Gravel, stones	5–10 cm	A	Lumpy to spherical
<i>Phakellia robusta</i> (Bowerbank, 1864)	Stones	10–15 cm	A	Upright, foliate
<i>Phakellia rugosa</i> (Bowerbank, 1866)	Stones	20 cm	A	Upright, branched
<i>Phakellia ventilabrum</i> (Linnaeus, 1767)	Stones	45cm (60 cm)	A	Foliate, funnel-shaped
<i>Mycale lingua</i> (Bowerbank, 1866)	Sand, gravel	25–30 cm	A	Lumpy
<i>Antho dichotoma</i> (Esper, 1794)	Gravel stones	30–40 cm	A	Upright, branches
<i>Petrosia crassa</i> (Carter, 1876)	Gravel, stones	15cm (25 cm)	A	Lumpy
<i>Oceanapia robusta</i> (Bowerbank, 1866)	Sand	20cm (40 cm)	A	Partly buried

Oceanapia robusta belongs to a special group of sponges living partly or wholly buried in muddy sand or sand. The sponge body itself is more or less spherical, at least in small specimens, and on the top it has a number of long papillae for incurrent and excurrent water. In photographs sometimes only the papillae are seen, in other cases also the upper surface of the sponge. It is easily fragmented during catch as the inner parts are very soft with only little skeleton, and therefore most samples in museum collections contain only the upper part with the papillae.

8.2.2 Maps of the distribution of sponge grounds in the North Atlantic

The general distribution of sponge grounds dominated by *Geodia*-type sponges or “ostur” in the NE Atlantic was presented by WGDEC in their 2007 report (ICES, 2007) and summarized in Figure 8.2.2.1. Here we present new distributional data for ostur and the glass sponge *Vazella pourtalesi* (“Russian Hats”) from the NW Atlantic. These data were primarily taken from standardized stratified random trawl surveys conducted by the Canadian Department of Fisheries and Oceans (DFO) and provided by T. Siferd (Central and Arctic Region) and B. Brodie (Newfoundland Region). Observer data from DFO Maritimes Region was also included (1977–2001) and provided by S. Fuller and K. MacIsaac (Maritimes Region).

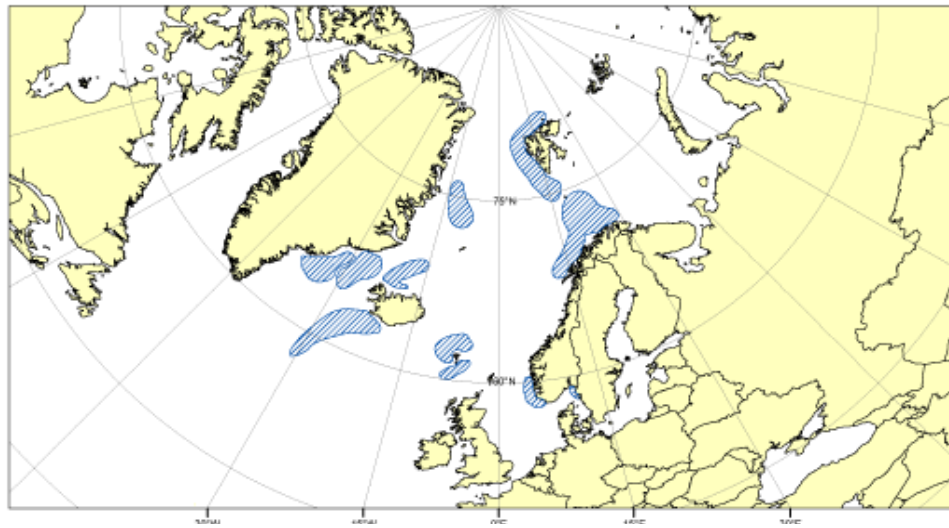


Figure 8.2.2.1. General distribution of habitat-forming sponges “ostur” in the NE Atlantic and Nordic Seas. Concentration of sponges vary considerably within these areas.

Data from the Canadian Arctic (2005–2008) and Newfoundland regions (1995–2008) were not assessed at the species level although the large catches have all been verified as *ostur*. For Maritimes region, catches have been identified by S. Fuller and therefore the presence of the large glass sponge ground is authoritative. Full identification of the other samples is expected in 2009 and may allow for more species-specific assessments and evaluation of sponge biodiversity in each of the major grounds.

Depending upon the survey, different types of trawls were used, including shrimp trawls and bottom trawls with and without rock-hopper gear. Sponge catch biomass data (kg) from Newfoundland surveys (N=1824) has been collected from standardized 15 min tows using a Campelen otter trawl. In Central and Arctic region data were provided from two sources: 1) The Northern Shrimp Research Foundation (NSRF) and DFO joint industry/government surveys in NAFO areas 2G and 0B (N=301), and 2) Central and Arctic Region (DFO) multispecies surveys (2006 and 2008) conducted in the southern portion of NAFO area 0A (south of 73.5N) and in 2007 in eastern Hudson Strait and Ungava Bay (100–1000 m; N=211). These data were normalized to a standard tow which has an area of 23391.04 m². Sets from the DFO multispecies surveys were taken with a standard Campelen 1800 trawl in 2005–2007 for all study areas but in 2008 in the Resolution Island Study area (-63 to -66W, 60.5 to 63N) a modified Campelen was used and modifications were made to the footgear.

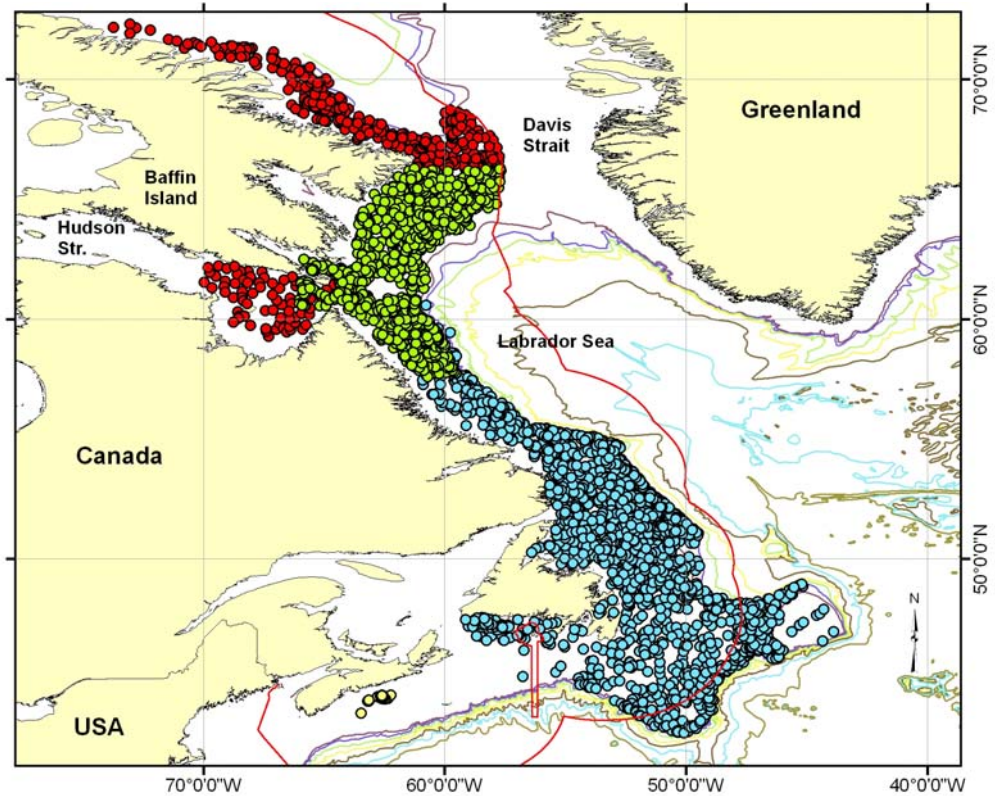


Figure 8.2.2.2. Map of the areas covered in surveys by the DFO Newfoundland Region (blue), the DFO Central and Arctic Region (red) and by the NSRF/DFO joint survey (green), and used in this report to assess sponge distribution. Similar data were not available for mapping from DFO Maritimes Region but the locations of the Russian Hats are indicated in yellow. The red line indicates the Canadian EEZ. Depth contours beginning at 1000 m and at 500 m intervals to 4000 m are displayed.

Overall, survey coverage within the Canadian EEZ is very comprehensive (Figure 8.2.2.2) and reaches depths of about 1450 m off Newfoundland and in the eastern Arctic. No attempt was made to harmonize the survey datasets as previous experience (NAFO, 2008) has revealed that because of the aggregated nature of these species the relationship between tow lengths and/or gear type and weight of coral/sponge is not linear. Given the present application, that is, general localization of the sponge grounds, this was not seen as a serious issue, particularly as the data were internally consistent across broad geographic areas and all from trawls as opposed to smaller benthic sampling tools (see Section 8.2.1.1 above).

In the NW Atlantic, ostur grounds are found along the continental margins from about 67N to 45N (Figure 8.2.2.3), confirming previous speculation by WGDEC that ostur is widely distributed over large parts of the Arctic Ocean (ICES, 2007).

North of about 60N the largest grounds are primarily located at depths of between 550 and 850 m, although data below 1000 m was sparse. Seven aggregations of sponges (nearby tows with high catch weights) have been localized (Figures 8.2.2.4 and 8.2.2.5) with five of these at the mouth of Hudson Strait between 60 and 63N (Figure 8.2.2.5). Overall, the sponge catches ranged from 0.03 to 1578.7 kg in this region and were recorded from depths of 105 to 1465 m.

Along the continental shelf off Newfoundland and Labrador large aggregations appear to form along the bathymetric contours between 800 m and at least to 1500 m,

the maximum depths sampled (Figure 8.2.2.6). This linear distribution pattern has similarities to that of the UK continental slope north of the Wyville-Thompson Ridge, where a continuous narrowband of ostur is found associated with the 500 m contour (ICES, 2007). The upper limit of the depth distribution in the NW Atlantic in this area may be influenced by decades of trawling in the shallower water. Sponge catches in this area ranged from 0.03 to 602.7 kg per standardized tow.

The ostur grounds in the NAFO Regulatory Area (NRA; Figure 8.2.2.7) also occur in deeper water, generally between 1000 and 1500 m (the latter being the limit of the survey depth range). Sponge catches in this area ranged from 0.01 to 5000 kg per standardized tow. The NRA area is intensively fished for Greenland halibut, redfish, shrimp and other species and it is reasonable to assume that the present day distribution of ostur in this area has been heavily shaped by fishing activity in the shallower water. Dense aggregations of ostur are reported from Sackville Spur along the 1500 m contour, in Flemish Pass at depths of 1000 m, and along the eastern Grand Bank slope at 1000 to 1500 m. Ostur grounds were also documented on the eastern slopes of Beothuk Knoll between depths of 1000 and 1500 m. Russian data also notes sponge aggregations in the NRA along the eastern Grand Bank slope and SW Flemish Cap (Vinnichenko and Sklyar, 2008). Records of large sponge bycatch from Spanish/EU groundfish surveys data sources (2005–2007) in NAFO Area (Divs. 3LMNO) were mapped by Murillo *et al.*, 2008 and support these locations of sponge grounds in the NRA. They map locations of catches greater than 50 kg (maximum observed 5000 kg) but do not distinguish among catch weights in their figures. There may be catches of over 100 kg of ostur on the eastern slope of Flemish Cap which are not covered by the Canadian surveys. Certainly catches of over 50 kg are found along the slope in this area (Murillo *et al.*, 2008).

The only confirmed glass sponge ground in the NW Atlantic is found in Emerald Basin on the Scotian Shelf south of Halifax, Nova Scotia (Figure 8.2.2.8; Fuller *et al.*, 2008). This area holds dense, mono-specific growths of *Vazella pourtalesi*, also known as Russian hats for their barrel-shaped morphology. These grounds are located at depths between 100 and 200 m and likely occur in 3 separate areas (Figure 8.2.2.8). Catches ranged from 5 to 1,578.7 kg per standardized tow.

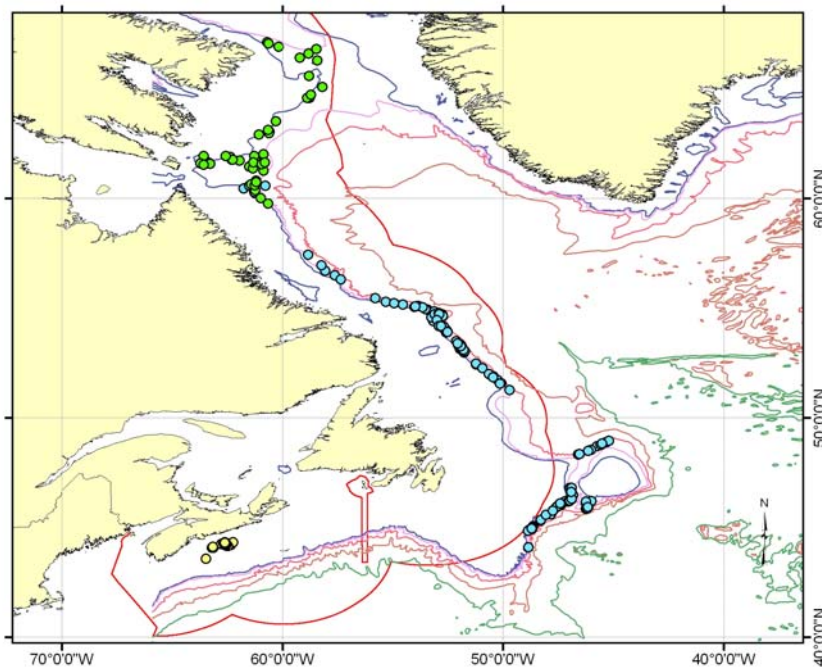


Figure 8.2.2.3. Distribution of large concentrations of *Geodia* spp. and related taxa (blue, green) and *Vazella pourtalesi* (yellow) as collected during Canadian trawl surveys and from observer records (*Vazella* only). Catches of over 100 kg per standard tow are indicated. Tows standardized to 15 min (blue) and 23391.04 m² (green). The red line indicates the Canadian EEZ. 500 m, 1000 m, 2000 m, 4000 m, 6000 m and 8000 m depth contours are indicated.

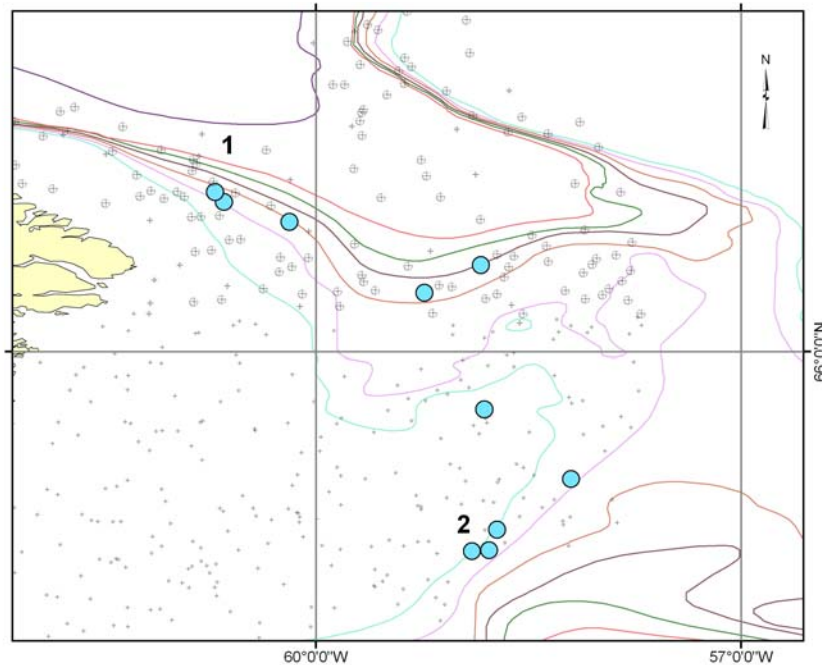


Figure 8.2.2.4. Distribution of *Geodia*-like sponges ("ostur") relative to bathymetry in the NW Atlantic above 63N. Catches per standard tow of over 100 kg are indicated in blue. Catches less than 100 kg are indicated by grey circles whereas null catches are represented by a cross. Where catches were relatively close to each other they were assigned a number for discussion purposes indicative of presence of a sponge grounds. Contours begin at 500 m and increase by 100 m to 1000 m, followed by 1500 m and 2000 m.

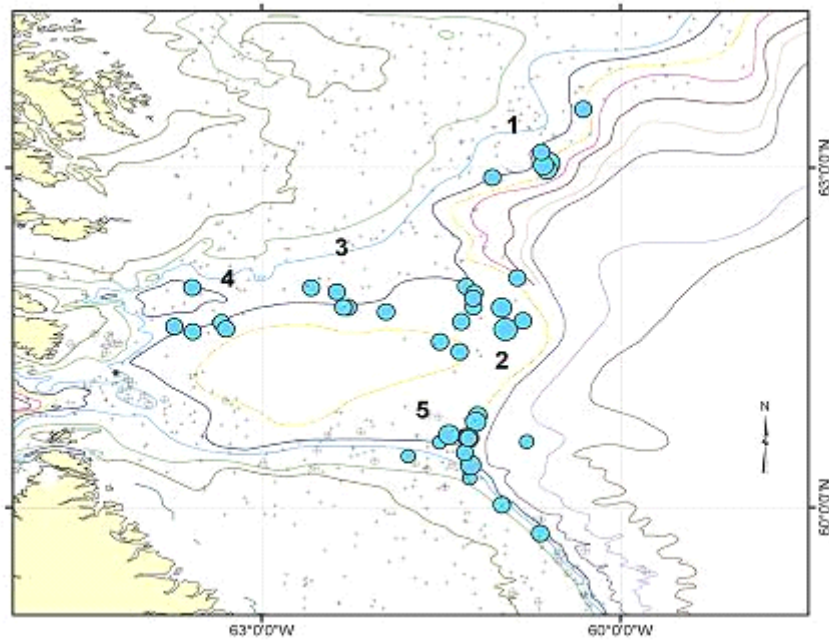


Figure 8.2.2.5. Distribution of *Geodia*-like sponges (“ostur”) relative to bathymetry in the NW Atlantic in the vicinity of 60 to 63N. Catches per standard tow of over 100 kg are indicated in blue. Catches less than 100 kg are indicated by grey circles whereas null catches are represented by a cross. Where catches were relatively close to each other they were numbered and presented as 5 sponge grounds. Depth contours begin at 100 m and advance at 100 m intervals to 1000 m, thereafter 1500 m and 2000 m contours are illustrated.

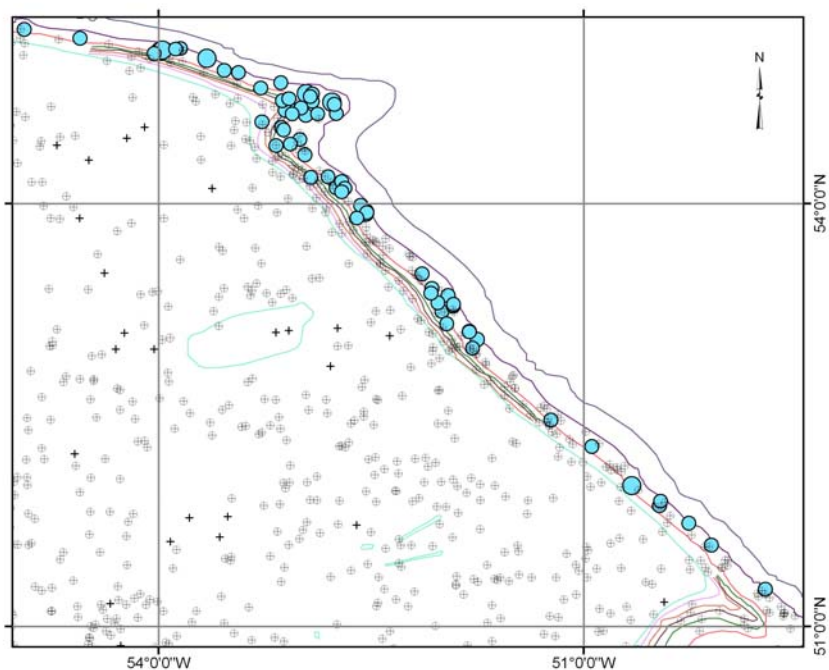


Figure 8.2.2.6. Distribution of *Geodia*-like sponges (“ostur”) relative to bathymetry in the NW Atlantic along the Newfoundland shelf. Catches per standard tow of over 100 kg are indicated in blue. Catches less than 100 kg are indicated by grey circles whereas null catches are indicated by a cross. Contours begin at 500 m and increase by 100 m to 1000 m, followed by 1500 m and 2000 m.

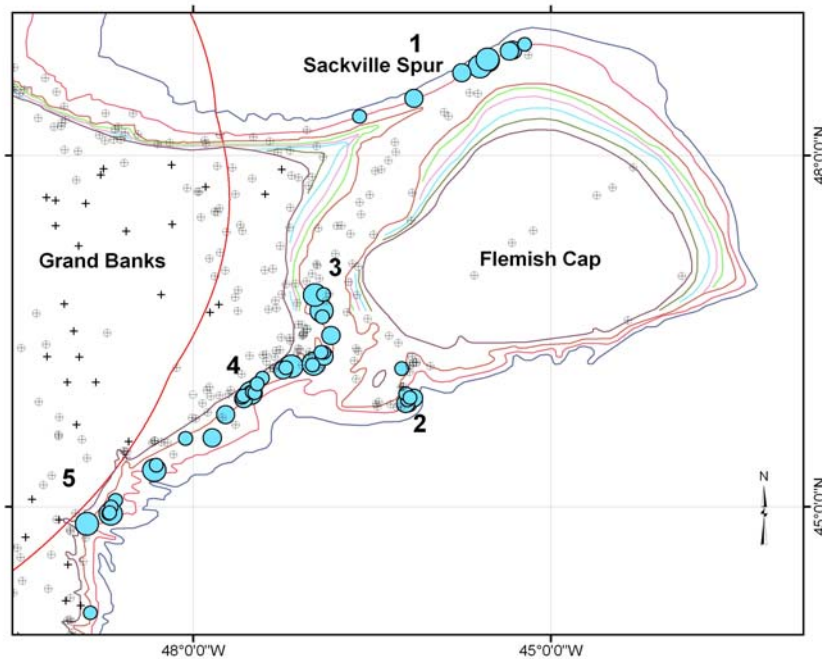


Figure 8.2.2.7. Distribution of *Geodia*-like sponges (“ostur”) relative to bathymetry in the NW Atlantic in the NAFO Regulatory area. Catches per standard tow of over 100 kg are indicated in blue. Catches less than 100 kg are indicated by grey circles whereas null catches are indicated by a cross. Where catches were relatively close to each other they were numbered and presented as 5 sponge grounds. Area 1: Sackville Spur, Area 2: Beothuk Knoll; Area 3: Flemish Pass; Areas 4 and 5: E Grand Banks. The red line indicates the Canadian EEZ. Contours begin at 500 m and increase by 100 m to 1000 m, followed by 1500 m and 2000 m.

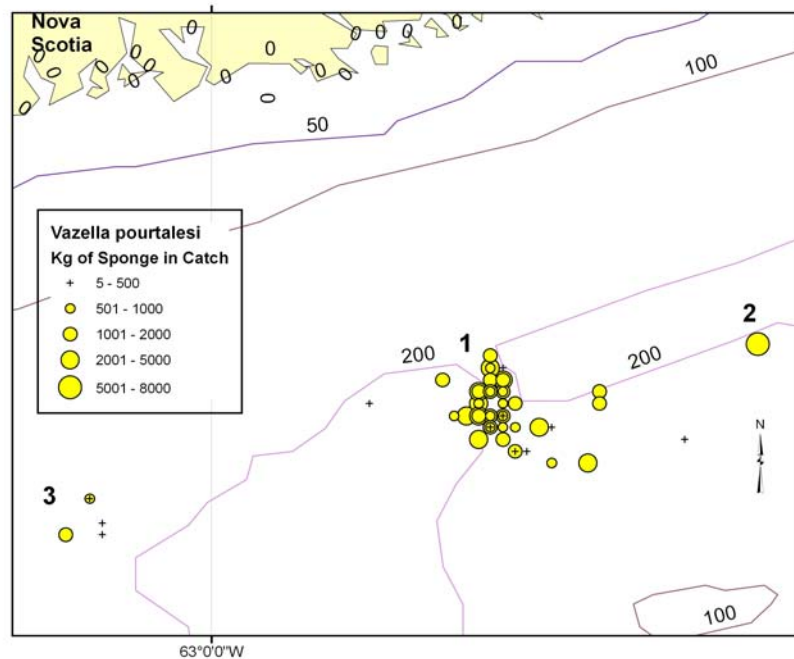


Figure 8.2.2.8. Distribution of *Vazella pourtalesi* (“Russian Hat”) glass sponges off the coast of Nova Scotia, Canada. Catches of over 500 kg are indicated in yellow. Catches less than 500 kg are indicated by grey crosses. Where catches were relatively close to each other they were numbered and presented as 3 sponge grounds. The 50 m, 100 m and 200 m contours are drawn on the map.

8.3 Association of fish and other organisms with sponge grounds

Sponge grounds can increase the physical heterogeneity of habitat and the number of available microhabitats in deep marine ecosystems through their morphology by adding structure and complexity to the physical habitat. This creates additional space for fish and invertebrates to utilize for shelter and other needs. An enhanced level of structure and complexity has been demonstrated to be of particular importance during times of reproduction, and for juvenile life-stages (Auster, 2005), or at night for daytime-active species (Brodeur, 2001).

The fauna associated with the sponge grounds is rich and has a higher diversity compared with surrounding bottoms. The associated fauna are dominated by epifaunal groups such as encrusting sponges, hydroids, zoantharians, bryozoans, and ascidians that use the sponges as a substratum (Klitgaard, 1995; Klitgaard and Tendal, 2004). The spicule mats associated with the sponge communities' support increased biomass of macrofaunal species (Bett and Rice, 1992).

The nature of the relationships between sponges and associates varies considerably, for example, some organisms spend their entire life associated with sponges, whereas others may only utilize sponges as juveniles (e.g. Turon *et al.*, 2000). The majority of species associated with sponge communities are facultative rather than obligate associates, although many may be specific to certain sponge species.

Silicious hexactinellid sponges can form reefs because their glass spicules fuse together such that when the sponge dies the skeleton remains. This provides settlement surfaces for other sponges, which in turn form a network that is subsequently filled with sediment, eventually creating mounds over 18 m high (Leys *et al.*, 2004). These reefs support diverse deep-sea communities that appear to be particularly vulnerable to deep-sea fishing activities, particularly trawling.

Rockfish, especially *Sebastes* species, live in openings and in between sponges. Young rockfish (*Sebastes* spp.), are regularly observed on sponge grounds sometimes seeking shelter inside the cavities of large sponges. In samples taken using fishing gear there are often several species of groundfish represented, such as cod and ling, along with the sponges in the catch. The general co-occurrence of structure-forming invertebrates with groundfish has been described by Hixon *et al.*, 1991 for three deep rocky banks off the coast of Oregon. In this study species distribution and abundance varied by location based on differences in habitat availability between locations; for example, juvenile rockfish (*Sebastes* spp.) were most abundant in rock ridge and boulder habitat where sponges and the basket stars (*Gorgonocephalus eucnemis*) were the most common megafaunal invertebrates.

Associations between sponges and crustaceans have also been documented. Klitgaard, 1991 working in the North Atlantic observed the isopod, *Gnathia abyssorum*, living in a hollowed-out crevice in sponges, where it creates a territorial harem. Off Kamchatka, Russia, young-of-the-year red king crabs *Paralithodes camtschaticus* were associated with sponges, bryozoans, and hydroids (Tsalkina, 1969). In the laboratory, recently molted red king crab glaucothoes preferred to settle on complex substrate (hydroids, bryozoans, algae, and plastic mesh) rather than sand (Stevens and Kittaka, 1998; Stevens, 2003).

Sponge grounds add a three-dimensional structure to the seabed that can provide a surface to live on, a hunting ground and conversely a refuge from predators and strong currents. Protecting habitat is an important goal of resource management and may be critical to maintaining biodiversity and sustaining fisheries. Identifying areas with high concentrations of living substrate may provide managers with needed in-

formation so that fishing practices can be modified so as to minimize impacts to those habitats.

8.4 Summary of sensitivity of different sponge species to impact and disturbance

As a consequence of their upright structure, the sponges listed in Table 8.2.1.2.1 are especially vulnerable to the impacts of bottom tending gear (Freese *et al.*, 1999). The degree of damage is crucial to evaluating the impact of this type of disturbance. Sponges have a certain ability to regenerate tissue, which depends upon the size of the wound and the size of the sponge, with larger sponges demonstrating an increased ability for regeneration (Henry and Hart, 2005). Smaller sponges tend to be younger and age is complexed with size in determining recoverability. Juvenile sponges may not be able to regenerate tissue (Simpson, 1984; Henry and Hart, 2005). Gross morphology also seems to influence regeneration ability and sponges with decreased morphological complexity are expected to regenerate less well than more complex forms. However, recoverability depends on the size of the wound relative to the amount of uninjured tissue and if this ratio is small, other factors may not be important. The key aspect of the wound in determining recovery rate is the wound perimeter, which positively correlate. The depth of the wound does not appear to be a major determinant (Henry and Hart, 2005).

Sponges are also vulnerable to smothering as they are unable to alter current inflow. Clearing accumulated sediments is energetically demanding and in extreme cases may disrupt the aquiferous system. Sponges which have been subject to smothering are also less able to regenerate wounded tissue (Henry and Hart, 2005).

Table 8.4.1 classifies the type of damage that may occur to an individual sponge through fishing disturbance and subjectively evaluates recovery potential. However, it should be recognized that habitat recovery is very different from the ability of an individual to regenerate tissue. Trawling can impose very extensive damage to cold-water sponge grounds which may take decades or even centuries to recover. Klitgaard and Tendal, 2004 suggest that the dominant ostur species are slow growing and take at least several decades to reach the sizes commonly encountered. In general, they are found in relatively constant environmental conditions, suggesting that they are dependent on a certain stability with respect to water mass characteristics, kinds and amount of particles in the water, and on low physical disturbance.

Experimental trawling on sponge communities in the Gulf of Alaska demonstrated that damage is significant (30 to 60% of the remaining sponges of the principle species were damaged). No damaged sponges in the trawl paths demonstrated signs of repair or regrowth after 1 year and damage to some had been so severe that necrosis, probably as a result of bacterial or fungal agents, had led to subsequent death (Freese, 2001). No sign of recovery of the community a year after trawling was observed.

Table 8.4.1. Summary of the prognosis for recovery of structure-forming cold water sponge species according to various disturbance types associated with fishing activities. Recovery assessment is individual-based as opposed to community-based.

DISTURBANCE TYPE	COMMENTS	PROGNOSIS FOR RECOVERY
Mechanical damage		
Minor tearing of body wall	Sponges demonstrating tissue repair have been collected; increased risk of infection; distal wounds appear to heal faster than wounds on lateral surfaces	Excellent
Large wounds relative to body size	Incomplete regeneration; increased risk of infection; impaired reproduction and growth	Moderate
Breakage at base	No signs of recovery after 1 year during experimental trawling in Alaska	Very Poor or No Recovery
Dislodgement		
Minor change to orientation, position relative to currents not strongly affected	Sponges can lay new growth down to adapt to minor change in current direction	Unaffected
Significant change to orientation, position relative to currents strongly affected	Sponges likely to die if food availability is restricted as a result of dislodgement	Poor
Sponge dislodged on bottom, free-floating		No Recovery
Sponge brought up on deck and returned	When the aquiferous system is drained very few sponges can fill it up again; air in the chambers cause the sponges to float	No Recovery
Crushing	Turning over of substrate commonly seen in trawl tracks	No Recovery
Sedimentation		
Light accumulation of sediments in incurrent aquiferous system, no serious damage to aquiferous system	Ability to clear sediment; sediment accumulation can be viewed in cross sections with concentrations near ostiole	Very Good
Repeated accumulation of sediments in incurrent aquiferous system	Sponge death or impairment	No Recovery

8.5 Priorities areas for sponge distribution data

Recording of information on the distribution of the species listed in Table 8.2.1.2.1 and their abundance/biomass remains a high priority. With so few people investigating such habitats, fishers can provide invaluable data. The challenge is to get this type of data and to make the best use of it. Efforts toward improving the quality and quantity of information on sponges should be encouraged.

In terms of spatial coverage, the west coast of Greenland along the southern part of the Davis Strait is perhaps the most undersampled and in need of attention. This will require directed surveys as samples do not currently exist. Another data deficient area is the east coast of the United States north of 40N. In this case data may exist in trawl survey bycatch records. Lastly, WGDEC considers the eastern side of the Faroe/Shetland Channel as an area requiring further investigation. This is an important geographic zone as it represents the convergence of two water masses. Evaluation of the sponge fauna there will assist in the determination of the environmental factors influencing species distribution.

8.6 Future research

With the conclusion of this report the distribution of the major sponge grounds in the North Atlantic has been assembled. WGDEC feels that Section 8.1.3 (assessment of the association of sponge grounds with fish and other fauna) could be further developed. Using the information on the location of the sponge grounds it should be possible to evaluate the association of fish within these areas through analyses of the trawl survey data. Specifically, comparisons of fish catch and diversity inside and outside sponge grounds at similar depths and areas could be statistically analysed. In order to validate the generality of the high biodiversity associated with sponge grounds, detailed data on the associated fauna from the NW Atlantic is required. Some comparable data are available from the NE Atlantic (e.g. Klitgaard, 1995).

Further information on the sponge species constituting the sponge grounds on the NW Atlantic will allow for biogeographical assessment and provide greater insight into the environmental factors responsible for creating sponge habitat and community composition.

WGDEC feels that there is now sufficient data to produce a summary of the sponge species inhabiting depths below 1500 m in the North Atlantic and that such a summary would be useful, in particular to researchers working at such depths.

8.7 References

- Auster, P.J. 2005. Are deep-water corals important habitats for fishes? In: A. Freiwald and J.M. Roberts (eds.) *Cold-water Corals and Ecosystems*, Springer-Verlag, Berlin Heidelberg. 747–760.
- Barthel, D., Tendal, O.S., Thiel, H. 1996. A wandering population of the hexactinellid sponge *Pheronema carpenteri* on the continental slope off Morocco, Northwest Africa. *Marine Ecology* 17: 603–616.
- Bett, B.J., Rice, A.L. 1992. The influence of hexactinellid sponge (*Pheronema carpenteri*) spicules on the patchy distribution of macrobenthos in the Porcupine Seabight (bathyal NE Atlantic). *Ophelia* 36: 217–226.
- Brodeur R.D. 2001. Habitat-specific distribution of Pacific ocean perch (*Sebastes alutus*) in Pribilof Canyon, Bering Sea. *Continental Shelf Research* 21: 207–224.
- Freese, J.L. 2001. Trawl-induced damage to sponges observed from a research submersible. *Marine Fisheries Review* 63: 7–13.
- Freese, L., Auster, P.J., Heifetz, J., Wing, B.L. 1999. Effects of trawling on seabed habitat and associated invertebrate taxa in the Gulf of Alaska. *Marine Ecology Progress Series* 182: 119–126.
- Fuller, S.D., Murillo Perez, F.J., Wareham, V., Kenchington, E. 2008. Vulnerable Marine Ecosystems Dominated by Deep-Water Corals and Sponges in the NAFO Convention Area. Serial No. N5524. NAFO SCR Doc. 08/22.
- Henry, L.-A., Hart, M. 2005. Regeneration from injury and resource allocation in sponges and corals—A review. *International Review of Hydrobiology* 90: 125–158.
- Hixon, M.A., B.N. Tissot, Percy, W.G. 1991. Fish assemblages of rocky banks of the Pacific Northwest (Heceta, Coquille, and Daisy Banks). US Minerals Management Service, OCS Study 91-0052, Camarillo, California.
- ICES, 2007. Report of the Working Group on Deepwater Ecology (WGDEC). ICES CM 2007/ACE:01.
- Klitgaard, A.B. 1991. *Gnathia abyssorum* (G.O. Sars, 1872; Crustacea, Isopoda) associated with sponges. *Sarsia* 73: 33–39.
- Klitgaard, A.B. 1995. The fauna associated with outer shelf and upper slope sponges (*Porifera*, *Demospongiae*) at the Faroe Islands, northeastern Atlantic. *Sarsia* 80: 1–20.
- Klitgaard, A.B., Tendal, O.S. 2004. Distribution and species composition of mass occurrences of large-sized sponges in the Northeast Atlantic. *Progress in Oceanography* 61: 57–98.
- Klitgaard, A.B., Tendal, O.S., Westerberg, H. 1997. Mass occurrence of large sponges (*Porifera*) in Faroe Island (NE Atlantic) shelf and slope areas: characteristics, distribution and possible causes. Pp. 129–142 in: Hawkins, L.E. and Hutchins, S. (Eds.). *The responses of marine organisms to their environments*. Southampton Oceanographic Centre, University of Southampton, Southampton.
- Leys, S.P., Wilson, K., Holeton, C., Reiswig, H.M., Austin, W.C., Tunnicliffe, V. 2004. Patterns of glass sponge (*Porifera*, *Hexactinellida*) distribution in coastal waters of British Columbia, Canada. *Marine Ecology Progress Series* 283: 133–149.
- Murillo, F.J., Duran Munoz, P., Sacau, M., Gonzalez-Troncoso, D., Seranno, A. 2008. Preliminary data on cold-water corals and large sponges bycatch from Spanish/EU bottom trawl groundfish surveys in NAFO Regulatory Area (Divs. 3LMNO) and Canadian EEZ (Div. 3L) 2005–2007 period. NAFO SCR Doc 08/10.

- NAFO, 2008. Scientific Council Meeting, 22-30 October 2008, Copenhagen, Denmark. Serial No. N5594. NAFO SCS Doc. 08/26.
- OSPAR Commission. 2005. Case reports for the initial list of threatened and/or declining species and habitats in the OSPAR maritime area. Deep sea sponge aggregations. pp. 105–108.
- Rice, A.L., Thurston, M.H., New, A.L. 1990. Dense aggregations of a hexactinellid sponge, *Pheronema carpenleri* in the Porcupine Seabight (Northeast Atlantic Ocean), and possible causes. *Progress in Oceanography* 24: 179–196.
- Simpson, T. L. 1984. *The Cell Biology of Sponges*. Springer-Verlag, New York.
- Stevens, B.G. 2003. Settlement, substratum preference, and survival of red king crab *Paralithodes camtschaticus* (Tilesius, 1815) glaucothoe on natural substrate in the laboratory. *Journal of Experimental Marine Biology and Ecology* 283: 63–78.
- Stevens, B. G., Kittaka, B. 1998. Postlarval settling behavior, substrate preference, and time to metamorphosis for red king crab *Paralithodes camtschaticus*. *Marine Ecology Progress Series* 167:197–206.
- Tsalkina, A. V. 1969. Characteristics of the epifauna of the West Kamchatka shelf (from “Problems of Commercial Hydrobiology”). *Proceedings of the All-Union Research Institute of Marine Fisheries Oceanography*. (VNJRO) Trudy 65:248–257. (Fisheries Research Board of Canada Translation Series 1568, 1970).
- Turon, X., Codina, M., Tarjuelo, I., Uriz, M.J., Becerro, M.A. 2000. Mass recruitment of *Ophiothrix fragilis* (Ophiuroidea) on sponges: settlement patterns and post settlement dynamics. *Marine Ecology Progress Series* 200: 201–212.
- Vinnichenko, V.I., Sklyar, V.V. 2008. On the issue of area closure to protect vulnerable marine habitats in the NAFO regulatory areas. Serial No. N5612. NAFO SCR 08/79.

9 Impact of deep-water fisheries on deep-sea habitats

ToR G. Consider the impact of deep-water fishery in areas for which information has not been analysed to date, for example the orange roughy fishery on the shelf slope of the Porcupine bank and the roundnose grenadier fishery to the north of Hatton bank by using VMS and historical data. (In conjunction with WGDEEP).

This ToR was addressed in conjunction with WGDEEP and it was decided that WGDEEP's Report was the most appropriate place for its presentation. This Section is therefore found in the WGDEEP Report 2009.

10 Identification of structure forming habitats in need of protection

Term of Reference (h): Provide a list of structural habitats for the North Atlantic and assess the status of species such as *Filograna* (a polychaete) that are not currently considered as structural habitat forming organisms.

Almost all larger epibenthic species may serve as substrate for other species or modify the physical structure of the habitat in a way that makes it attractive for other species. Many species or taxonomic groups are already listed as habitat-forming or key structural components of habitats by Eunis and Ospar (Table 1). However, there are still some species or taxonomic groups that are important structuring organisms but not yet recognized by Ospar and Eunis.

The definition of structural habitat forming species is not straight forward because size and density of individuals/colonies and number of associated species varies between species. There are no general thresholds for these attributes that can be used for defining structural habitat-forming species. Some species may create structures extending tens of meters or more, whereas other species occur scattered but are still important for assemblages of associated species.

For many of the taxonomic groups of sessile invertebrates that are recognized as potentially important structure forming species there is a great lack of data for occurrence of accompanying species. This is demonstrated for most species of sea pens, gorgonians and sponges. Sea pens contain species constituting the habitat called Sea pens and burrowing megafauna which are listed as a threatened and/or declining habitat. If all species with records of associated species should be included as habitat-forming species the list would be “endless”. Therefore in this initial review, only species which form relatively large structures or has been regarded as important for communities of associated species in previous studies have been included. For this reason many groups of potential structuring habitat-forming species such as stalked cirripeds, scattered tube-building polychaetes have not been included. This overview is also limited by the restricted time allocated to the research for answering this ToR.

The influence of habitat structure on invertebrates associated with cold water corals and sponges has been the topic for several studies (Frith 1976; Jensen and Frederiksen, 1992; Klitgaard, 1995; Beaulieu, 2001; Klitgaard and Tendal, 2004; Buhl-Mortensen and Mortensen, 2005; Costello *et al.*, 2005; Mortensen and Fosså, 2006).

Deep sea sponge aggregations, coral reefs, coral gardens, and biogenic reefs have been used as terms for groups of certain epibenthic species forming structural habitats. Below, some additional habitats are described, with a brief assessment of their status.

Sponge grounds

Deep sea sponge aggregations are mainly composed of species from the classes: *Hexactinellida* and *Demospongia*. Their distribution and status is covered by TOR c and f.

Soft bottom gorgonian fields

Coral gardens are a heterogeneous type of deep-seabed habitat that could be divided into two or more habitats.

Bamboo coral fields are one candidate with stands of *Keratoisis ornata* or other *Isidae* corals on soft/sandy deep bottoms. Off Canada *Acanella arbuscula* seems to be a key habitat structuring species (Mortensen *et al.*, 2006). In the Norwegian fjords Andfjor-

den and Hardangerfjorden *Isidella lofotensis* have been observed in restricted areas in relatively high densities and with several associated species between the braches. Coral gardens also partly overlap with another threatened habitat, Sea pens and burrowing megafauna, which should be kept separate from this habitat to avoid confusing comparisons.

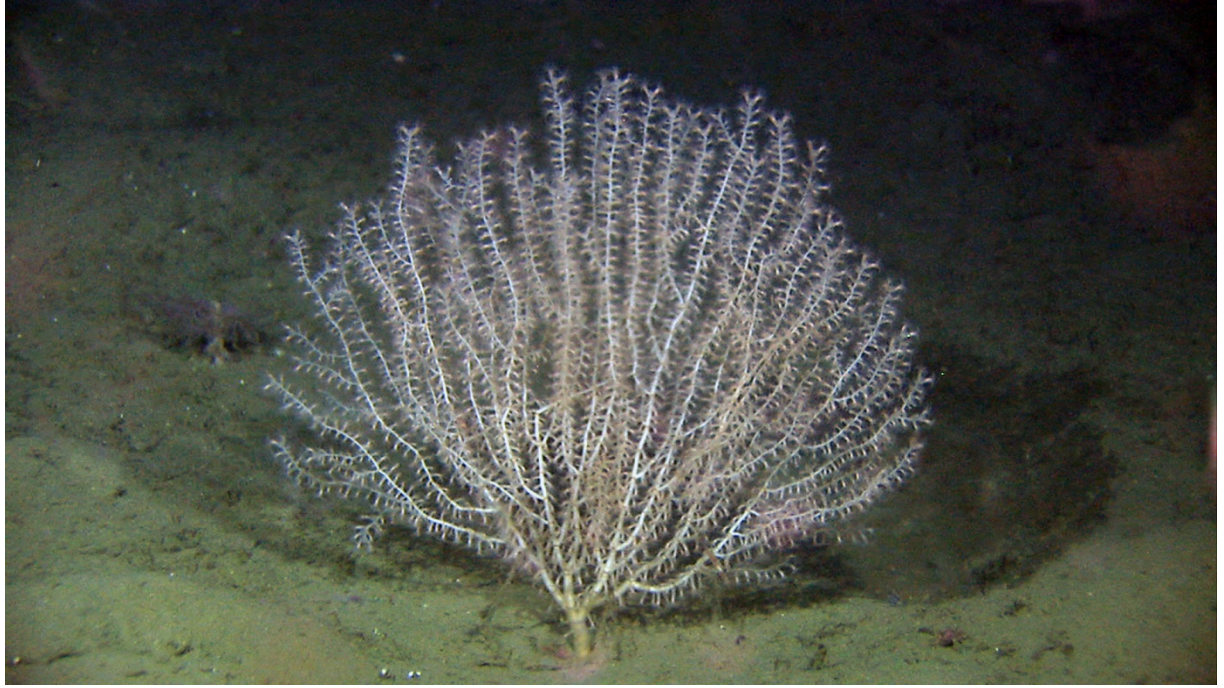


Figure 10.1. One colony of the bamboo coral *Isidella lofotensis* from about 200 m depth in Andfjorden. Photo courtesy of MAREANO/Institute of Marine Research.

Xenophyophora fields

Xenophyophores are marine protozoans, giant single-celled organisms found throughout the world's oceans, but in their greatest numbers on the abyssal plains of the deep ocean. Xenophyophores are delicate organisms with a variable appearance. Most xenophyophora are epifaunal and it buries itself up to 6 cm deep into the sediment. Xenophyophores may be an important part of the benthic ecosystem by their bioturbation of the sediments and by providing a habitat for other organisms.

Actinaria fields

Late juvenile redfish *Sebastes fasciatus*, (11–20 cm total length) have been reported being associated with dense patches of cerianthid anemones *Cerianthus borealis* in the Gulf of Maine (Fuller *et al.*, 2008). The small fish may use the cerianthid habitats on an encounter basis or they may *serve* as a protective corridor for moving between boulder sites (Auster *et al.*, 2003). Similar associations have been observed at greater depths during the MAREANO habitat mapping programme in 2008. The image below (Figure 10.2) shows a sea tadpole (Cf. *Careproctus reinhardti*) close to a cerianthid anemone at 1400 m depth. Similar examples were observed at other deep locations off northern Norway.



Figure 10.2. Sea tadpole (Cf. *Careproctus reinhardti*) close to a cerianthid anemone at 1400 m depth. Photo courtesy of MAREANO/Institute of Marine Research.

Glass sponge fields

Hexactinellida occur mainly in deep water in an environment which is different from where most gregarious demospongia occur. It would therefore be reasonable to keep this group separate from Deep-sea sponge aggregations and Sponge communities on deep circalittoral rock (Table 1).



Figure 10.2. The glass sponge *Caulophacus arcticus* at 1900 m depth in the northern part of the Norwegian Sea. According to Ole S. Tendal, this species may form aggregations of their stalks on the seabed in cold water. Photo courtesy by MAREANO/Institute of Marine Research.

Filograna reefs

Reef-like structures of the serpulide polychaet *Filograna implexa* have been observed off northern Norway and on the Georges Bank in the outer part of the Gulf of Maine.



Figure 10.4. Reef like structures of the serpulid polychaet *Filograna implexa* observed on the shelf off Nordkapp, northern Norway. Photo courtesy of HERMES/Institute of Marine Research.

Table 1. Initial list of species known to for complex habitat structures supporting associated faunas in deep waters (>200 m) in the North Atlantic. Typical size of colonies and habitats are provided in cases where such information was available. Eunis classification after Davies *et al.*, 2004.

HABITAT NAME	GEOGRAPHIC REGION	BATHYMETRIC ZONE	STRUCTURAL SPECIES	CLASS	TYPICAL SIZE OF COLONIES	TYPICAL SIZE OF HABITAT	EUNIS CLASSIFICATION
Xenophyophora fields							No specific Eunis code or Ospar unit
	North Atlantic						
		Slope/Abyssal					
			<i>Syringammina fragilissima</i>		10–20cm	?	
Sponge grounds							
	Northeast Atlantic						
		Shelf/upper slope					
			<i>Geodia spp., Stryphnus ponderosus, Isops phegraei, Aplysilla sulphurea</i>	Demospongia	10–100cm	1–100m	A5.1:A5.2, A6.62 Deep-sea sponge aggregations
			<i>Phakelia ventilabrum, Axinella infundibuliformis, Axinella dissimilis, Stelligera stuposa</i>		10–30cm	?	A4.12 Sponge communities on deep circalittoral rock
HABITAT NAME	GEOGRAPHIC REGION	BATHYMETRIC ZONE	STRUCTURAL SPECIES	CLASS	TYPICAL SIZE OF COLONIES	TYPICAL SIZE OF HABITAT	EUNIS CLASSIFICATION
			<i>Hyalonema spp., Stylocordyla spp.</i>	Hexactinellida	10–20cm	?	
		Slope					
			<i>Caulophacus arcticus</i>	Hexactinellida	10–20cm	?	A6.62 Deep-sea sponge aggregations
			<i>Hyalonema spp.</i>	----"----	10–20cm	?	A6.62 Deep-sea sponge aggregations

HABITAT NAME	GEOGRAPHIC REGION	BATHYMETRIC ZONE	STRUCTURAL SPECIES	CLASS	TYPICAL SIZE OF COLONIES	TYPICAL SIZE OF HABITAT	EUNIS CLASSIFICATION
			<i>Pheronema carpenteri</i>	-----	10–20cm	?	A6.621 Facies with [<i>Pheronema grayi</i>]
	Northwest Atlantic, off Nova Scotia						
	Shelf						
			<i>Geodia spp.</i>	Demospongia	10–100cm	1–100m	
			<i>Vazella pourtalesi</i>	Hexactinellida	10–100cm	1–100m	
Coral reef							A5.6 Sublittoral biogenic reefs, A5.63 Circalittoral coral reefs, A6.61 Communities of deep-sea corals
	non-polar						
	Shelf/upper slope						
			<i>Lophelia pertusa</i>	Scleractinia	50–300cm	10–1500m	A5.631 Circalittoral [<i>Lophelia pertusa</i>] reefs, A6.611 Deep-sea [<i>Lophelia pertusa</i>] reefs
HABITAT NAME	GEOGRAPHIC REGION	BATHYMETRIC ZONE	STRUCTURAL SPECIES	CLASS	TYPICAL SIZE OF COLONIES	TYPICAL SIZE OF HABITAT	EUNIS CLASSIFICATION
Coral patches							
	Shelf break/upper slope						
			<i>Dendrophyllia cornigera</i>	Scleractinia	10–50cm	?	
			<i>Solenosmilia variabilis</i>	-----	10–50cm	?	
Sea pen meadow							A5.361 and A5.362, Seapens and burrowing megafauna communities
	Northeast atlantic						
	Shelf						
			<i>Halipterus finmarchica</i>	-----	10–100cm	?	

HABITAT NAME	GEOGRAPHIC REGION	BATHYMETRIC ZONE	STRUCTURAL SPECIES	CLASS	TYPICAL SIZE OF COLONIES	TYPICAL SIZE OF HABITAT	EUNIS CLASSIFICATION
			<i>Funiculina quadrangularis</i>	----"----	10–100cm	?	
			<i>Kophobelemnion stelliferum</i>	----"----	10–30cm	?	
			<i>Virgularia mirabilis</i>	Pennatulacea	10–50cm	?	
			<i>Pennatula phosphorea</i>	----"----	10–20cm	?	
	Northwest Atlantic						
	Shelf						
			<i>Halipterus finmarchia</i>	Pennatulacea	10–50cm	?	
	Slope						
			<i>Umbellula encrinus</i>	Pennatulacea	50–200cm	?	
HABITAT NAME	GEOGRAPHIC REGION	BATHYMETRIC ZONE	STRUCTURAL SPECIES	CLASS	TYPICAL SIZE OF COLONIES	TYPICAL SIZE OF HABITAT	EUNIS CLASSIFICATION
							No specific Eunis code, but included in Ospars list
Coral garden							
	non-polar						
	Shelf/upper slope						
			<i>Paragorgia arborea</i>	Gorgonacea	30–300cm	?	
			<i>Primnoa resedaeformis</i>	----"----	20–60cm	?	
			<i>Isidella lofotensis</i>	----"----	10–30cm	?	
			<i>Acanella arbuscula,</i>	----"----	10–30cm	?	
	Slope						
			<i>Callogorgia verticillata</i>	Gorgonacea	10–100cm	?	
			<i>Bathypathes patula</i>	Antipatharia	10–100cm	?	
			<i>Antipathes spp.</i>	----"----	10–100cm	?	

HABITAT NAME	GEOGRAPHIC REGION	BATHYMETRIC ZONE	STRUCTURAL SPECIES	CLASS	TYPICAL SIZE OF COLONIES	TYPICAL SIZE OF HABITAT	EUNIS CLASSIFICATION
			<i>Stauropathes arctica</i>	----	10–100cm	?	
Actiniarian fields			No specific Eunis code or Ospar unit				
Nort west Atlantic							
Shelf/slope							
			<i>Cerianthus borealis</i>	Actiniaria	10–30cm	?	
Serpulid reef			A5.6 Sublittoral biogenic reefs				
North Atlantic							
Shelf							
			<i>Filigrana implexa</i>	Polychaeta	10–50cm	?	

References

- Auster, P.J., J. Lindholm, and P.C. Valentine. 2003. Variation in habitat use by juvenile Acadian redfish, *Sebastes fasciatus*. *Environmental Biology of Fishes*, 68: 380–389.
- Beaulieu, S. 2001. Life on glass houses: sponge stalk communities in the deep sea. *Marine Biology*, 138: 803–817.
- Bett, B.J., and Rice, A.L. 1992. The influence of hexactinellid sponge (*Pheronema carpenneri*) spicules on the patchy distribution of macrobenthos in the Porcupine Seabight (bathyal NE Atlantic). *Ophelia* 36 (3): 217–226.
- Buhl-Mortensen L. and Mortensen, P.B. 2005. Distribution and diversity of species associated with deep-sea gorgonian corals off Atlantic Canada. In: Freiwald A and Roberts JM (eds) *Cold-water Corals and Ecosystems*. Springer-Verlag, Heidelberg, p 849–879.
- Cinar, M.E., and Z. Ergen. 1998. Polychaetes associated with the sponge *Sarcotragus muscarum* Schmidt, 1864 from the Turkish Aegean coast. *Ophelia*, 48(3): 167–183.
- Costello, M.J, M. McCrear, A. Freiwald, T. Lundalv, L. Jonsson, B.J. Bett, T.V. Weering, H. de Haas, J.M. Roberts, and D. Allen. 2005. Functional role of deep-sea cold-water *Lophelia* coral reefs as fish habitat in the 22 northeastern Atlantic. Pages 771–805 in Freiwald A, Roberts JM (eds.), *Cold-water corals and ecosystems*. Springer-Verlag Berlin Heidelberg.
- Davies C.E., Moss, D. and Hill, M.O. 2004. *EUNIS Habitat Classification Revised 2004*. Report to the European Topic Centre on Nature Protection and Biodiversity, European Environment Agency. 307pp. (available online at <http://eunis.eea.eu.int/eunis/habitats.jsp>).
- Frith, D.W. 1976. Animals associated with sponges at North Hayling, Hampshire. *Zoological Journal of the Linnean Society*, 58:353–362.
- Fuller, S. D., F.J. Murillo Perez, V. Wareham and E. Kenchington. 2008. Vulnerable Marine Ecosystems Dominated by Deep-Water Corals and Sponges in the NAFO Convention Area. NAFO SCR Doc. 08/22 Serial No. N5524.
- Jensen A., and R. Frederiksen. 1992. The fauna associated with the bank-forming deep-water coral *Lophelia pertusa* (Scleractinia) on the Faroe shelf. *Sarsia*, 77: 53–69.
- Klitgaard, A.B. 1995. The fauna associated with outer shelf and upper slope sponges (*Porifera*, *Demospongiae*) at the Faroe Islands, northeastern Atlantic. *Sarsia*, 80: 1–22.
- Klitgaard, A.B., and Tendal, O.S. 2004. Distribution and species composition of mass occurrences of large sized sponges in the Northeast Atlantic. *Progress in Oceanography*, 61: 57–98.
- Mortensen, P. B., Buhl-Mortensen, L. and Gordon, D. C. 2006. Distribution of deep-water corals in Atlantic Canada. *Proceedings of 10th International Coral Reef Symposium*, Okinawa, Japan, 1849–1868.
- Mortensen, P.B. and J.H. Fosså. 2006. Species diversity and spatial distribution of invertebrates on *Lophelia* reefs in Norway. *Proceedings of the 10th International Coral Reef Symposium*. Okinawa, Japan, pp 1849–1868.

11 Uses of fine scale VMS analyses

Term of Reference (i): Review the development of fine scale VMS analysis in relation to habitats and assess vulnerability of deep-water banks, shelf slope and seamounts (in conjunction with WGDEEP).

Introduction

A primary aim within WGDEC is addressing the issue of threatened and declining habitats in the deep-water marine environment. The criteria for such habitats include ecological importance, sensitivity and recoverability of the habitat, rate and extent of decline and regional importance. Deep-water habitats are defined as those found at depths greater than 200 m. Deepwater habitats are vulnerable to fishing activity and have been heavily impacted over the past decades mainly as a consequence of bottom trawling, although other fishing activities such as longlines and gillnets can also have lesser impacts. One of the challenges WGDEC face is defining how potentially impacted by fishing an area is or has been. To do this WGDEC needs fine scale spatial and temporal information on fishing activity which is potentially available from fishing vessel monitoring systems (VMS).

A fishing vessel monitoring system (VMS) is a programme of fishery surveillance, in which equipment that is installed on fishing vessels provides information about the vessels' position and activity. WGDEC has in the past used VMS data at fine scales to look at potential impact in areas where sensitive deep-water habitats and species are known to occur. Initially this was only possible on a trip by trip basis and there was no means of assigning an overall measure of how impacted an area might be. Where gear and catch information is available with VMS data there is much greater confidence in deriving an index of fishing effort or potential impact. Furthermore by understanding the particular nature of the fishery, i.e. target species one can build a better evaluation of the economic consequences of conservation measures. The Scottish VMS data has complete information in this respect and can therefore be used in this context.

11.1 VMS data available

The Scottish VMS dataset includes all vessels (Scottish and other nations) that entered Scottish waters. The gear used by these vessels is also known, but logbook information on catch composition is only known for those vessels that landed their catch into a Scottish port. The data available at present is for the years 2007 and 2008. The data were filtered by gear type to obtain only those records associated with bottom trawling or 'otterboard'. The speed profile of bottom trawlers has a characteristic peak of about 3.5 knots (Figure 11.1.1), markedly different from the speed profiles of vessels that operate longlines for example (Figure 11.1.1). This dataset was further filtered by speed (between 2 and 4 knots) and depth (deeper than 300 m and less than 1500 m) to reveal VMS positions that correspond to actual deep-water trawling activity as opposed to steaming or dodging in poor weather. A similar selection was made of all vessels recorded as using longline gear.

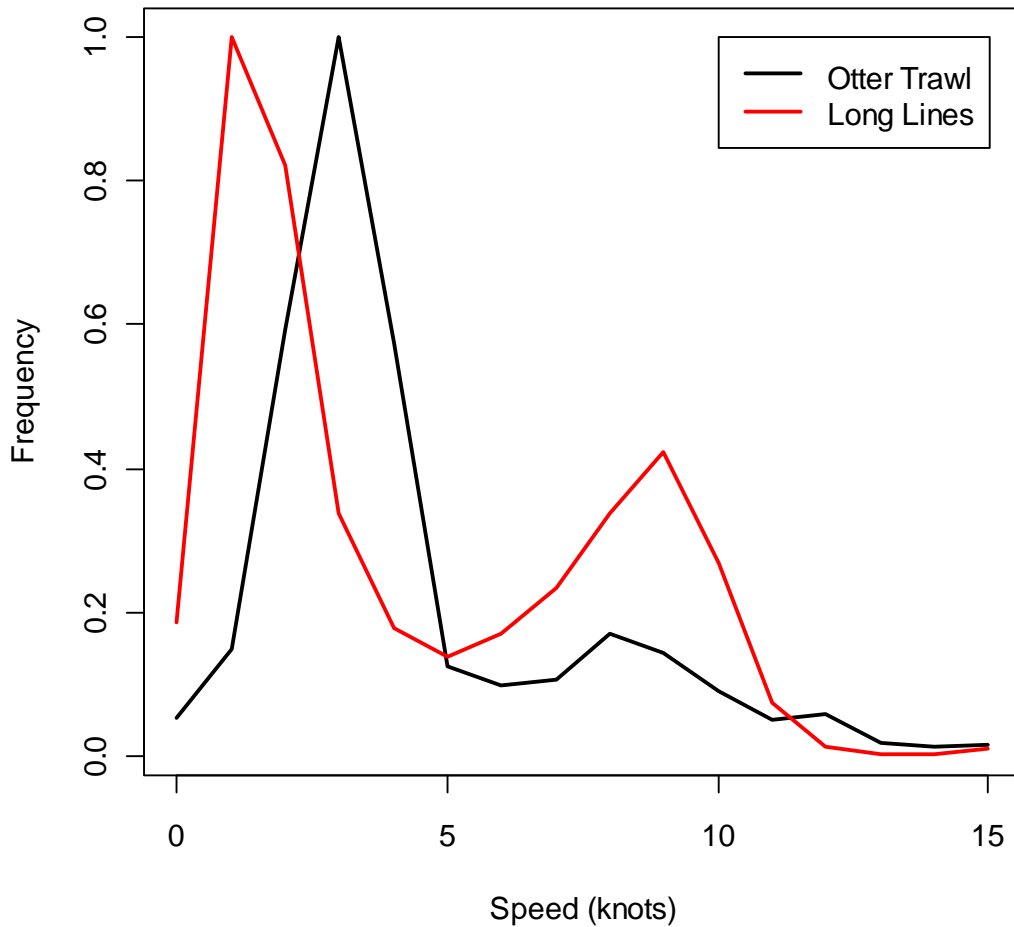


Figure 11.1.1. Speed profiles of vessels are bottom/otter trawling (black line) and long-lining (red line).

11.2 Deriving a density function of fishing effort

A simple density function summing the number of VMS records was generated on a grid at 0.1 of a degree resolution. The matrix of accumulated effort was then incorporated into a GIS database containing WGDEC’s records of sensitive deep-water habitats and species. This can then be cross referenced with areas that have been proposed for closure and with fine scale analysis of VMS records, better assess the degree to which areas have been impacted. This can then be used to inform the advisory process and develop marine spatial planning. It should at this stage be emphasized that these data are only vessels that operated in Scottish waters and therefore gives an incomplete picture for areas outside Scottish waters. In this analysis the frequency of VMS data (time between positions) was assumed to be random, however, the density function should be refined to account for any variation in the frequency of the VMS data. There may also be scope to incorporate the use of algorithms that allow more effective categorization of trawling activity based on combinations of speed and direction.

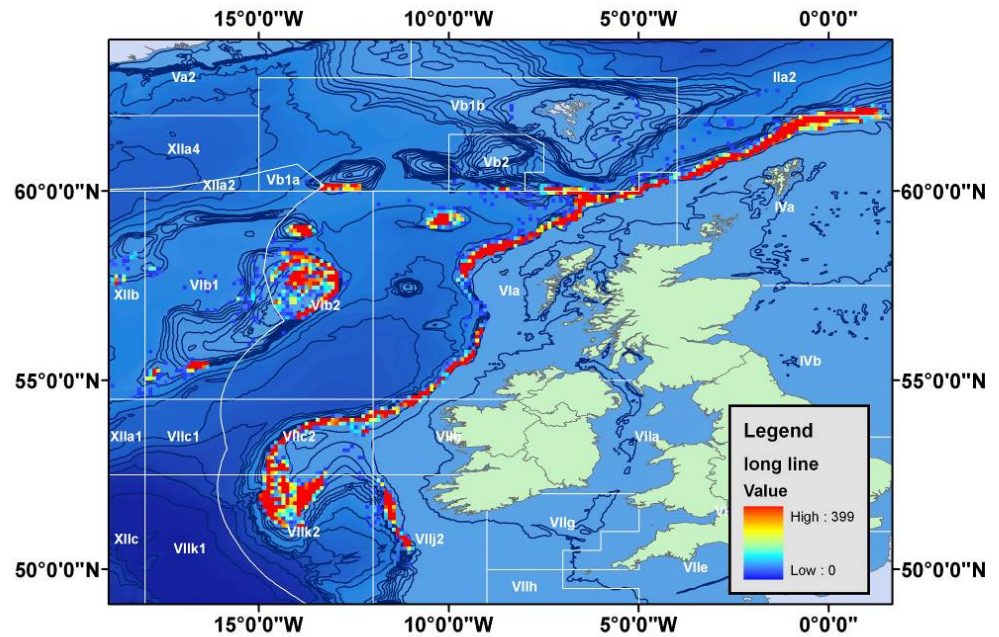


Figure 11.4.1. VMS data from longline vessels between depth of 300–1500 m that entered Scottish waters between 2007 and 2008.

11.5 Fishing effort in areas likely to contain sensitive deep-water habitats

Bottom trawling is the primary cause of damage sensitive marine habitats such as coral reefs, although other fishing gears such as gillnets and longlines may also cause more minor damage. Out of the areas highlighted as impacted by bottom trawling in Figure 1, Rockall bank and the Wyville Thomson ridge are both areas in which conservation measures have been implemented or are being considered for special areas of conservation. We focus in detail on the amount of trawling in these areas and precise location of trawling in relation to records of sensitive marine habitats.

11.5.1 The Wyville Thomson ridge area

This is an area traditionally associated with various deep-water fisheries including blue ling which is thought to congregate to spawn in this area. An emergency closure in the area-the Darwin mounds-was put in place in 2003 to protect the large carbonate mounds and coral reefs discovered in the area. In 2008 an area to the north of the Darwin mounds was proposed as Special Area of Conservation. The sensitive deep-water habitats present in the area include *Lophelia pertusa* reefs and rocky reefs characterised by iceberg ploughmarks and are shown in Figure 11.5.1.1.

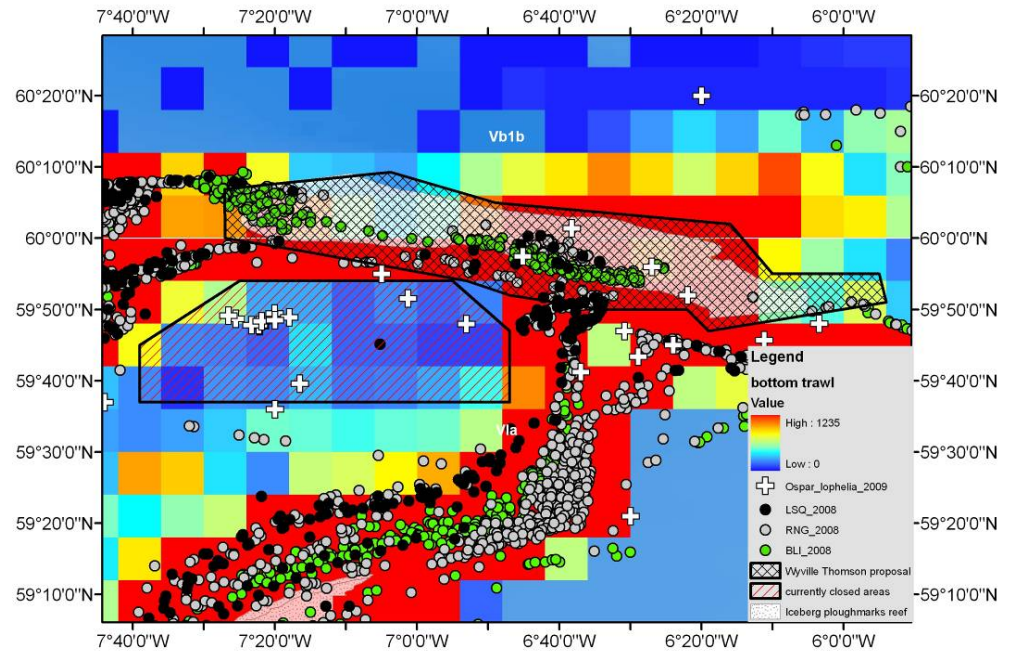


Figure 11.5.1.1 The Wyville Thompson ridge area showing records of *Lophelia pertusa* from the OSPAR database, the Darwin mounds closed area (black box with cross shading) and the SAC proposed by JNCC in 2008 (cross hatched box). Also shown is the index of trawling intensity (VMS effort density) and species-specific VMS information from vessels that landed into Scotland in the years 2007 and 2008 (BLI = blue ling, RNG = roundnose grenadier, LSQ = leafscale gulper shark).

Figure 11.5.1.1 also shows that significant trawling activity occurs in 2007 and 2008 in the proposed area that reported catches of blue ling, roundnose grenadier and deep-water sharks. It is this fishery that will be compromised in the event that the closure goes ahead in its current form.

This is an area with coral records outside the closed areas, some of which appear not to have high trawling effort. In the event of the closure being enforced, the displacement of trawling effort to such areas should be considered.

11.5.2 Rockall bank

Rockall bank is fished intensively for shelf species such as haddock and monkfish as well as deep-water species such as black scabbard fish and roundnose grenadier. A number of closures have been put in place since 2007 partially based on advice from WGDEC. In 2007 proposed an area for closure on the east side of the bank. The closure on east Rockall bank is based on numerous records of *Lophelia pertusa* and information obtained from the fishing industry (Figure 11.5.2.1). Until the Scottish VMS data were made available it was not known to what extent this area was trawled. The VMS data from 2007 and 2008 reveals considerable trawling activity in two bands between 200 and 500 m depth in the NE and SW of the area.

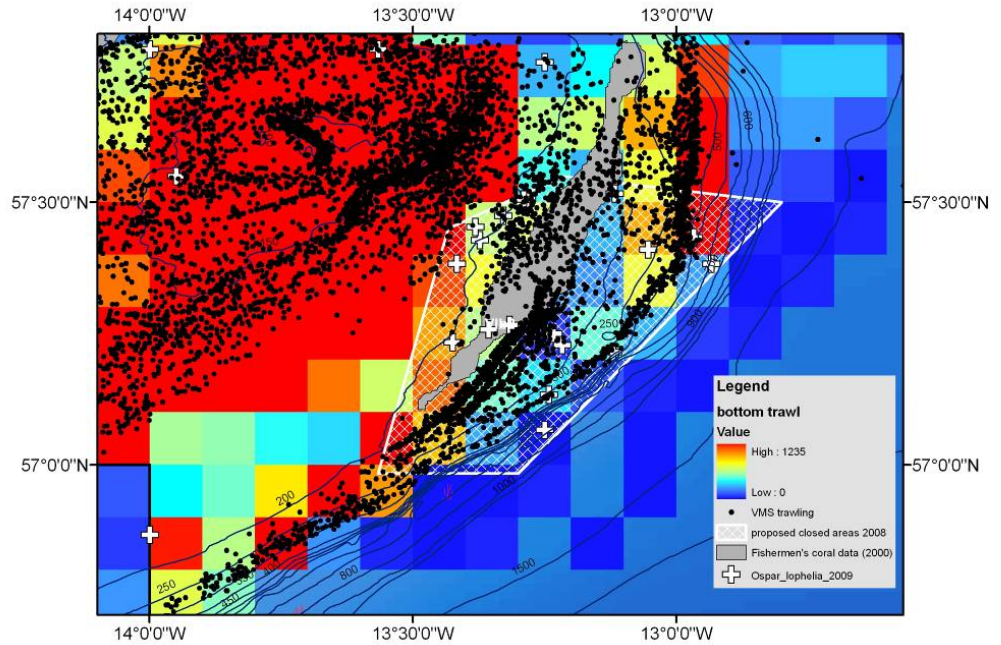


Figure 11.5.2.1. East flank of Rockall bank-OSPAR coral records and proposed closures in relation to the index of trawling intensity (VMS effort density) and individual VMS positions of vessels trawling.

11.5.3 Rosemary bank

Rosemary bank is a seamount situated in the northern end of the Rockall trough. It rises from 2000 m to within 350 m of the surface. There are 3 records of *Lophelia per-tusa* on the southern flank and TV surveys made by FRS Marine Laboratory in 2007 demonstrate the presence of soft corals and rocky reef on the summit areas. Figure 11.5.3.1 shows high bottom-trawl intensity on the northern and eastern flanks of the bank and that at least two of the main species caught on the bank are roundnose grenadier and leaf-scale gulper shark. It is interesting to compare the distribution of trawling activity with that of longline activity (Figure 11.5.3.2). Clearly the longliner vessels target the summit of the bank which is known to be hard and highly topographic. Although long lining has a much lesser impact on sensitive marine habitats than does bottom trawling, this analysis does demonstrate that in cases where bottom trawling is absent one cannot assume that the area is not impacted in some other way by alternative fishing gears.

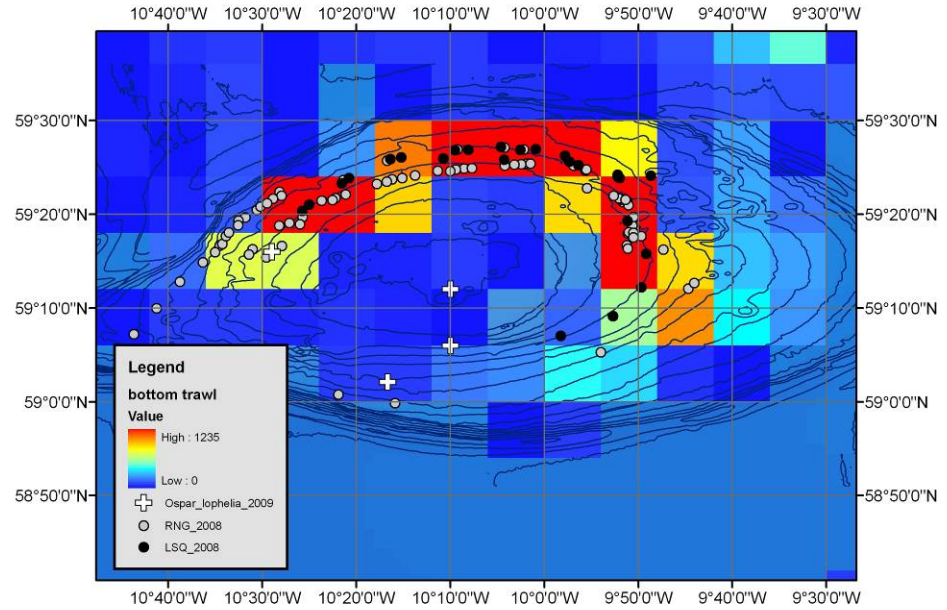


Figure 11.5.3.1. Rosemary bank-OSPAR coral records in relation to the index of trawling intensity (VMS effort density) and individual VMS positions of trawlers that reported catching roundnose grenadier (RNG) and leafscale gulper sharks (LSQ).

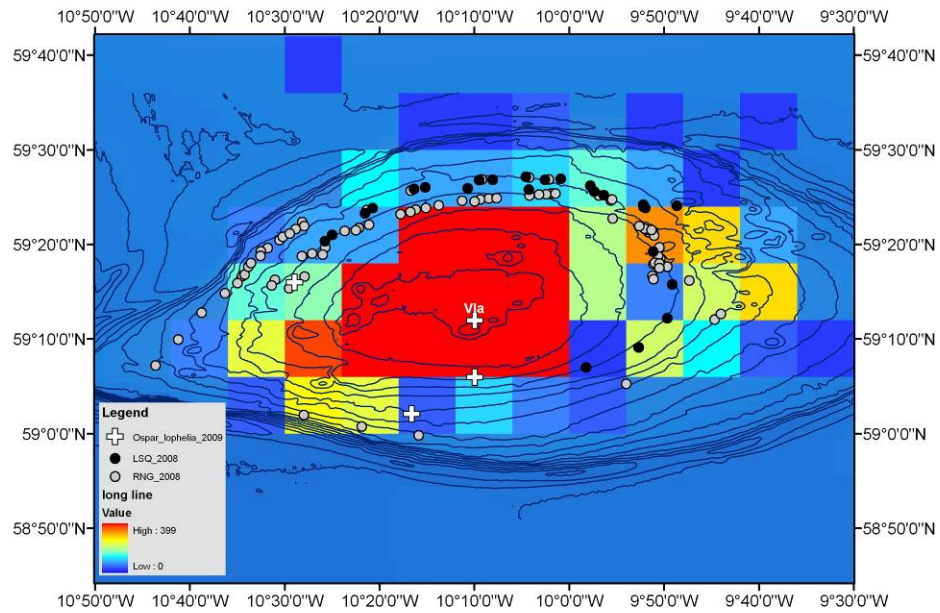


Figure 11.5.3.2. Rosemary bank-OSPAR coral records in relation to the index of longline fishing intensity (VMS effort density) and individual VMS positions of trawlers that reported catching roundnose grenadier (RNG) and leafscale gulper sharks (LSQ).

11.6 Discussion

The availability of VMS data at high temporal resolution together with gear and catch information has been a major advance in confidently developing an index of impact for deep-water ecosystems. For the NEAFC data analysed in ToR G of WGDEC/DEEP 2009 it can be clearly seen how restricted the power of VMS data is if it is: a) not linked to gear information, b) not linked to catch statistics, and c) not provided at temporal resolution that is sufficient to confidently classify periods of fishing activity. Only a small fraction of the data can be used and even this must be treated with the utmost caution. With VMS data of the quality of the Scottish data it is possible to precisely delimit areas that have been heavily trawled and therefore are no longer likely to contain pristine habitats. This has direct bearing on the issue of scale and whether protective measures are in proportion to the data available (ToRs G, J, in this report). It should be possible to give highly spatially resolved conservation options based on such data. The data from Rosemary Bank also highlight the issue that all gear types need to be considered because what appears to be lightly impacted with respect to trawling may be heavily impacted with respect to longline fishing activity.

12 The issue of scale

Term of Reference (j): Address the issue of scale: Advice giving when the scale of records does not match the scale of the feature/the scale of the activities to be regulated.

Background

12.1 Issue: the problem of pattern and scale

Levin, 1992 in his MacArthur Award Lecture argues that the problem of pattern and scale is *the central problem* in ecology. The recognition of the role of scale in ecology rose steadily in the 1990s (Schneider, 2000), and its frequent mention in recent ICES advice certainly speaks to its continued relevance.¹

In the 2008 WGDEC report, for example, “scale” was used in the context of fishing fleets, fishing impacts, seamount features, oceanographic processes, and even ICES advice itself. In that report, it was recognized that there can be mismatches between the coarseness of available data and the management decisions that need to be made. A case in point is the temporal coarseness of most VMS data in the NAFO-NEAFC areas (2 hour frequency) and how this means that protected areas should have at least 6 nautical mile buffer zones around them (WGDEC 2008 Section 16). This issue has re-surfaced again this year regarding how the temporal coarseness of these data impedes the analysis of fishing activities and the protection of Vulnerable Marine Ecosystems (VMS; see this Report ToR-G and -I, as well as B and D).

12.2 Terminology: coarse and fine scale

“Scale” in this advice is interpreted in a broad context, to include temporal, spatial, organizational and functional considerations. Depending on the discipline, scale can have several meanings. However, it generally refers to the observed phenomenon’s/feature’s extent relative to the grain of its measurement (Schneider, 2001). Scale can be roughly summed up as the level of (meaningful) detail available for any given analysis, and is mainly a function of sampling precision, though accuracy, variability and uncertainty play their roles (see section 0, below).

When describing spatial scale, cartographers and ecologists usually use the terms “large” and “small” oppositely; that is, when a cartographer says “small scale” this is usually what an ecologist would call “large-scale,” and vice versa. This confusion arises because cartographers recognize that scale is a mathematical ratio, and that 1:1000 is a larger fraction than 1:3 000 000, say. Ecologists, on the other hand, looking at maps see that a 1:3 000 000 map covers a larger area... To avoid any confusion in terms, **this Advice will use the terms “coarse scale” and “fine scale,”** such that the 1:3 000 000 map would be termed “coarse scale.” (In the literature, “broad scale” is often used interchangeably with “coarse scale.”)

¹ For example, in all past WGDEC reports (2005–2008), a simple word search brings up 96 occurrences of “scale” (including references) versus, say, 27 occurrences of the word “biodiversity.”

Scaling of ecosystems and human activities

12.3 Data resolution: ecological and surveillance

In the context of the above request for advice, data can be broadly divided according to two general uses:

- 1) **ecological data** resulting from the sampling or monitoring of oceanographic, physical, chemical, environmental, and/or biological features, for the purposes of ecological assessments and scientific study / discovery, and;
- 2) **surveillance data** resulting from the tracking and monitoring of human activities for the purpose of the enforcement of rules and regulations.

Both of these types of data should feed into management decisions (and will sometimes overlap). Ecological data should be used to identify features of interest to management, whereas surveillance data should be used to inform the type of management action that can reasonably be expected to succeed. For example, data collected on various scientific surveys have identified VMEs, such as deep-water coral reefs and sponge beds. However, as noted in Section 12.2, above, the current 2 hour resolution of VMS data means that if a closure can be expected to protect such features from demersal trawling, a minimum of a 6 nautical mile buffer around those features should be applied (WGDEC 2008 Section 16).

Recommendation: a management decision should evaluate the scale (resolution) of both ecological data and surveillance data, and that the scale (resolution) of the decision itself should reflect the coarser of the two; i.e. the “weakest link.”

12.4 Matching management to relevant ecological scales

Ecological systems generally demonstrate characteristic variability on a range of spatial, temporal, and organizational scales (Levin, 1992). Even looking at the species level, what is an appropriate scale of study for one life-history stage (e.g. larval) is probably inappropriate to another (e.g. juvenile), and thus an overall life-history study would actually consist of several nested scales within a broader overview. As noted by Thrush *et al.*, 1997, when looking at ecological systems, attempting to answer what is the “right scale” is often futile, and it is more relevant to determine how results can be translated from one scale to another, depending on the linkages between elements in the system. The classic example from terrestrial ecology involves scaling up quadrat-plot results using species-area curves to predict regional species richness (e.g. Stohlgren *et al.*, 1997). However, even here one can quickly get lost in a myriad of arcane considerations (Scheiner *et al.*, 2000). All this taken into account, there remain nonetheless sensible scales of study to address *specific* questions, and these scales are usually fairly self-evident, such as the range of an individual, or the rate of nutrient cycling.

Managing human activities on a scale inappropriate to the ecological characteristics of the resource(s) can lead to unpredictable and sudden changes in biomass or distribution of the resource(s), usually accompanied by economic loss. For example, Wilson *et al.*, 1999 suggest that broad scale fishery management is inappropriate when key life-history stages such as spawning are relatively localized, or when there are several metapopulations within a given management area, which can readily lead to extirpation of the stocks.

Recommendation: when possible, management actions related to a given feature or process should match the ecological scale of that feature or process. Thus, features

that have multiple-scale considerations should have nested management scales as well. For example, in a given fishing area, large bycatch weight allowances for small and slow-reproducing species are unlikely to protect such species in the long term, regardless of how common they may be at the time.

12.5 Matching scientific research and monitoring to relevant management

Increasingly, local and regional scale ecological change is being driven by global environmental processes such as ocean acidification or climate change, and these very broad scale drivers do not match the capacity or scale of existing resource management authorities. Further exacerbating this situation, local scale considerations can be at odds with the global scale goals of international agreements or large environmental NGOs (Agardy, 2005). Addressing these issues, there has been an increase in local participation in resource management, as well as an increase in international cooperation arrangements recognizing the trans-boundary and trans-sectoral scale of environmental issues. The recent memorandum of understanding between OSPAR and NEAFC is one such example.

Recommendation: when possible, science contracted/requested by regulatory authorities should match the scale of available policy instruments. For example, real time scientific monitoring is applicable to policy only if near-real time responses (e.g. 24 hour notice closures) are an option. Otherwise, less expensive monitoring may be adequate when coupled with less nimble management.

Recommendation: if existing policy instruments are too fine to match the broad/coarse scale of relevant ecological processes, trans-jurisdictional and trans-sectoral partnerships should be explored.

Filling data gaps: the use of coarse scale proxies in management

12.6 Predictive habitat modelling

As noted in WGDEC 2008 (Section 16.1), in the absence of good broad scale species survey data, limited fine scale data can be used to calibrate coarse scale predictive habitat modelling. With many very promising techniques emerging (e.g. Bayesian and “entropy” analyses -Maxent: <http://www.cs.princeton.edu/~schapire/maxent/>), such modelling is nonetheless fraught with uncertainties. Driven by usually very coarse scale physical and oceanographic data, the results tend to have many false positives; i.e. more habitat is identified than where the species actually exist (for this reason they are sometimes called “potential habitat” models). Thus, predictive habitat modelling is often too coarse scale to be immediately applicable to moderate scale management decisions, without the addition of other information such as expert knowledge.

Recommendation: in the absence of reliable widespread biological sampling, to approximate species distributions the use of predictive habitat models should be seriously explored. Their coarse scale results should be refined/calibrated to existing finer scale biological data. Management decisions using coarse scale modelled habitat should be augmented with other finer scale information wherever available, including expert knowledge. Such decisions should be open for refinement (adaptive approach) as new data become available.

12.7 Biogeographic classifications

Somewhat related to predictive habitat modelling (above), biogeographic classifications have found increasing usage. In deep-sea areas as broad as the northwest and

Northeast Atlantic, comprehensive surveys are usually not possible. Thus, almost all decisions will be based on limited sampling. In this context, undersampling is sure to be the most pervasive problem, and practitioners often turn to biophysical models by which to subdivide a region into (presumably) ecologically meaningful units. Dinter, 2001, for example, put forward such a system for the Northeast Atlantic which is currently used by the OSPAR Commission. Globally, the "GOODS" (global open oceans and deep sea) biogeographic classification has been presented for use by the Convention on Biological Diversity (UNESCO, 2009).

Despite the usefulness of biogeographic classifications to guide the delineation of planning areas and for checking coarse scale "representativity," they should always be seen as approximations at best, and not replacing actual biological and ecological data when available. Usually built from coarse scale data, a given class may mask many finer scale ecological features, including important biological communities giving the impression of "false homogeneity" (Williams *et al.*, 2009). This shortcoming is, of course, not just limited to biogeographic classifications; rather, it is a general characteristic of coarse scale proxies, interpolations / extrapolations and models, wherein rare and other fine scale features are missed.

When building classification systems, the use of continuous value datasets can be more efficacious than using binned data (Williams *et al.*, 2009).

Given that each biogeographic system has its own unique strengths and weaknesses, OSPAR, 2007 has suggested that when more than one credible classification system is available, all should be used.

Recommendation: in the absence of reliable and widespread ecological data, to design ecologically meaningful management units and to consider questions of representativity, the use of biogeographic classification systems should be considered. Their coarse scale results should be refined/calibrated to existing finer scale biological data. Management decisions using coarse scale modelled habitat should be augmented with other finer scale information wherever available, including expert knowledge. Such decisions should be open for refinement (adaptive approach) as new data become available. When more than one credible classification system is available, all applicable ones should be used.

12.8 Estimated confidence

Traditionally, maps were assumed to be created and used at a single scale. However, it has always been true that positional uncertainty of features has varied from place to place, with some areas better surveyed than others. With the advent of GIS, users seldom adhere to working within a single scale and often zoom in and out depending upon what is of interest, seldom aware of the intended scale. Likewise, the results of modelling (such as predictive habitat or biogeographic classifications, above) are not actually of uniform scale, with some places reflecting better input data and confidence (less uncertainty) than others. When this information is not made explicit, the prudent user must assume these modelled surfaces are only as good as their weakest links, thus sacrificing the strong for the weak. However, the creation of an estimated confidence layer can begin to address some of these shortcomings. Whereas it is very difficult to take all uncertainties into account, it is not so difficult to note some of the more readily available factors such as sampling density, nominal accuracy, and so forth, which can be especially relevant if input layers were stitched together from various disparate datasets. Even if an absolute value cannot be arrived at, it is usually possible to estimate *relative confidence*; i.e. Area A is considered to have more uncertainty than Area B. Simple relative confidence scores (e.g. 1=lower; 2=moderate;

3=higher) for each input layer can go a long way towards producing an overall relative confidence layer that is helpful for planning. Such a layer indicates the varying scale of the information, and thus should be reflected in the varying scale of decision-making from place to place, with some areas having larger buffers (precaution) against uncertainty than others. Thus, areas that may have appeared to have been important but which have associated low confidence will perhaps not appear as attractive to planners as areas with moderate importance. However higher confidence, i.e. when given the opportunity, many managers would prefer to base their decisions on better known factors than uncertain ones. Thus, an estimated confidence layer allows for better informed decisions and is a valuable strategy to deal with maps and data of varying scales. In light of this, it is perhaps surprising that confidence layers are seldom generated and thus the techniques to generate them are still evolving.

Recommendation: for maps, calculations, or models using data of varying scales and qualities, the development of an estimated confidence layer is highly recommended. Decisions being made using proxies such as predictive habitat modelling and biogeographic classifications will be more likely to meet their management objectives when estimated confidence is taken into account.

Theoretical considerations: precision, accuracy, and uncertainty

Discussions of scale inevitably lead to discussions of precision and accuracy. Finer scale sampling is by definition more precise, and so scale and precision are linked. Finer scale data are often considered to be more accurate than coarser sampling, but this is not necessarily so. Accuracy and uncertainty are closely related, and for the purposes of this discussion uncertainty in its broadest sense can be considered the obverse of accuracy; i.e. error rate, whereby a 10% error rate at a given scale (resolution) implies 90% accuracy, ignoring for the moment the uncertainty associated with the measurement of that error rate...

Perhaps counter-intuitively, variability (one aspect of uncertainty) generally increases within a given biome as the sample size decreases; that is, whereas coarse scale sampling in a given biome returns roughly the same signal, replicates across finer scale samples can vary considerably (Stohlgren *et al.*, 1997). The greater the diversity (alpha, beta, or gamma; see ToR-E this report) the greater the fine scale variation...

Observed patterns and trends will further vary depending on the acuity, aggregation, and bounding of the study, and can provide contrasting results (Scheiner *et al.*, 2000). For example, a dataset that at first glance appears chaotic at a coarse scale, may contain trends when stratified (spatially or temporally) into finer scale subdivisions, and these trends may contrast with each other and even with other finer scale trends within each subdivision.

Although it is often a good strategy to reduce data to its finest unit of resolution, this is sometimes not meaningful, as that statistically significant variation on a finer scale does not necessarily affect coarser scale trends and in such cases can be treated as "noise" on that broader scale (Levin, 1992). How to characterize the coupling of fine to coarse scale ecological processes is an ongoing area of research in ecology, and can occasionally lead to intriguing scale-independent results (e.g. Sugihara *et al.*, 1989). However, in the context of this advice, having too much fine data is rarely (if ever!) the problem; rather it is the challenge of interpreting coarse scale and/or incomplete data for management decisions that ideally would have finer data.

Although a full discussion of uncertainty is outside the parameters of this ToR, it should be noted that there are broadly speaking two manifestations of uncertainty relevant to this discussion of scale: content and boundaries.

- 1) **Content:** The confidence that can be placed on the recorded content within any given sample unit largely reflects the identification of features, commonly referred to as “accuracy,” and hinges upon many factors such as instrument design, operator technique, expert knowledge, and so forth. Content uncertainty can be further broken down into what is incorrectly “seen” (false positives –type 1 error) and what is missed (false negatives –type 2 error). For any given feature type, false positives should decrease with increasing precision; i.e. they are “seen” (detected) more clearly. Likewise, false negatives should also decrease with the increasing precision associated with finer scales; i.e. one ought to be able to see more the closer one looks. However, this is only up to a point, until very large features may not be seen very well “up close.”

As the scale of research becomes finer and finer, hitherto unnoticed small features will begin to come into view, and they too will have associated type 1 and type 2 errors... The worlds-within-worlds nature of nature precludes any single ideal scale for measuring ecosystems (Levin, 1992). It all depends on what it is one wishes to see... Seeing one thing clearly means not seeing others very well.

- 2) **Boundaries:** uncertainty regarding the edges of “hard” features and events will generally decrease with the precision of the measurements, until the fractal-like variability of those edges eclipses the precision of the measurements. For “soft” features –those that have variable edges such as migrating fish routes– broader scale studies are adequate, though finer data can be helpful in calibrating predictive models when associated with equally fine habitat data. In any case, management decisions usually rely on hard boundaries regardless of whether the features themselves share this property, and as such a decision on where it is to be placed has to be made, ideally using a probability surface (e.g. inside the 98% percentile). It is worth noting that the use of GIS can often give a false sense of accuracy, particularly with regard to boundaries, and that in marine environments, many boundaries will vary over time.

Although it is generally true that coarse scale data only allow for coarse scale management decisions, sometimes additional expert knowledge can refine boundary placement. Finer scale data may not refine management actions if the feature is highly variable or if detection accuracy is considered to be low. For continuous function variables, boundaries are necessarily artificial but should at least reflect ecologically meaningful delineations, if known. If not known, natural breakpoints in the dataset (as seen by plotting a histogram) should be used as a surrogate. Ecological data rarely follow regular steps and so boundaries that follow regular class breaks should be the exception and not the rule.

Summary

Managing human activities on a scale inappropriate to the ecological characteristics of the resource(s) can lead to unpredictable and sudden changes in biomass or distribution of the resource(s), usually accompanied by economic loss.

Increasingly, local and regional scale ecological change is being driven by global environmental processes such as ocean acidification or climate change, and these very broad scale drivers do not match the capacity or scale of existing resource management authorities, requiring broad scale cross-sectoral cooperation.

Although it is generally true that coarse scale data only allow for coarse scale management decisions, sometimes additional expert knowledge can refine management actions. Finer scale data may not refine management actions if the feature is highly variable or if detection accuracy is considered to be low.

The worlds-within-worlds nature of nature precludes any single ideal scale for measuring ecosystems. It is more relevant to determine how properties are transmitted from one scale to another.

The use of coarse scale proxies, such as predictive habitat modelling and biogeographic classifications, is becoming increasingly frequent. However their use comes with many caveats, and should not be seen to usurp the use of biological or ecological data.

The results of interpolations/extrapolations and modelling (such as predictive habitat or biogeographic classifications) are not of uniform scale, with some places reflecting greater confidence (less uncertainty) than others. When this information is made explicit, better informed decisions can be made.

Recommendations

- 1) A management decision should evaluate the scale (resolution) of both ecological data and surveillance data, and that the scale (resolution) of the decision itself should reflect the coarser of the two; i.e. the “weakest link.”
- 2) When possible, management actions related to a given feature or process should match the ecological scale of that feature or process. Features that have multiple-scale considerations should have nested management scales as well.
- 3) When possible, science contracted/requested by regulatory authorities should match the scale of available policy instruments.
- 4) If existing policy instruments are too fine to match the broad/coarse scale of relevant ecological processes, trans-jurisdictional and trans-sectoral partnerships should be explored.
- 5) In the absence of reliable widespread biological sampling, to approximate species distributions the use of predictive habitat models should be seriously explored. Their coarse scale results should be refined/calibrated to existing finer scale biological data. Management decisions using coarse scale modelled habitat should be augmented with other finer scale information wherever available, including expert knowledge. Such decisions should be open for refinement (adaptive approach) as new data become available.
- 6) In the absence of reliable and widespread ecological data, to design ecologically meaningful management units and to consider questions of representativity, the use of biogeographic classification systems should be considered. Their coarse scale results should be refined/calibrated to existing finer scale biological data. Management decisions using coarse scale modelled habitat should be augmented with other finer scale information wherever available, including expert knowledge. Such decisions should be open for refinement (adaptive approach) as new data become available. When more than one credible classification system is available, all applicable ones should be used.

For maps, calculations, or models using data of varying scales and qualities, the development of an estimated confidence layer is highly recommended. Decisions being made using proxies such as predictive habitat modelling and biogeographic classifications will be more likely to meet their management objectives when estimated confidence is taken into account.

Literature cited

- Agardy, T. 2005. Global marine conservation policy versus site-level implementation: the mismatch of scale and its implications. *Mar Ecol Prog Ser*, 300: 241–296.
- Dinter. 2001. Biogeography of the OSPAR Maritime Area. German Federal Agency for Nature Conservation, Bonn. 167 pp.
- Levin, S.A. 1992. The Problem of Pattern and Scale in Ecology. Adapted from the Robert H. MacArthur Award Lecture, presented August 1989, Toronto, Ontario, Canada. *Ecology*, 73(6): 1943–1967.
- Schneider, D.C. 2001. The Rise of the Concept of Scale in Ecology. *BioScience*, 51(7): 545–553.
- Scheiner, S.M., Cox, S.B., Willig, M., Mittelbach, G., Osenberg, C., Kaspari, M. 2000. Species richness, species–area curves and Simpson’s paradox. *Evolutionary Ecology Research*, 2: 791–802.
- Stohlgren, T.J., Chong, G.W., Kalkhan, M.A., Schell, L.D. 1997. Multiscale sampling of plant diversity: effects of minimum mapping unit size. *Ecological Applications*, 7(3): 1064–1074.
- Sugihara, G., Schoenly, K., Trombola, A. Scale Invariance in Food Web Properties. *Science*, 245 (4913): 48–52.
- Thrush, S.F., Schneider, D.C., Legendre, P., Whitlatch, R.B., Dayton, P.K., Hewitt, J.E., Hines, A.H., Cummings, V.J., Lawrie, S.M., Grant, J., Pridmore, R.D., Turner, S.J. and McArdle, B.H. 1997. Scaling-up from experiments to complex ecological systems: where to next? *Journal of Experimental Marine Biology and Ecology*, 216: 243–254.
- OSPAR. 2007. Background document to support the Assessment of whether the OSPAR Network of Marine Protected Areas is Ecologically Coherent. OSPAR Convention for the Protection of the Marine environment of the Northeast Atlantic. Publication Number: 2007/320. www.ospar.org.
- UNESCO. 2009. Global Open Oceans and Deep Seabed (GOODS) – Biogeographic Classification. Paris, UNESCO-IOC. IOC Technical Series, 84.
- Williams, A., Bax, N. J., Kloser, R. J., Althaus, F., Barker, B., and Keith G. 2009. Australia’s deep-water reserve network: implications of false homogeneity for classifying abiotic surrogates of biodiversity. *ICES Journal of Marine Science*, 66: 000–000.
- Wilson, J., Low, B., Costanza, R., Ostrom, E. 1999. Scale misperceptions and the spatial dynamics of a social–ecological system. *Ecological Economics*, 31: 243–257.

13 NEAFC Request for WGDEC regarding vulnerable habitats

Term of Reference (k): Provide a list of species that form structural habitats (e.g. hard corals, soft corals and sponges) for which information is particularly needed from new surveys.

Vulnerable deep-water habitats in the NEAFC Regulatory Area. NEAFC requests ICES to continue to provide all available new information on distribution of vulnerable habitats in the NEAFC Convention Area and fishery activities in and in the vicinity of such habitats.

Westwards extension to North West Rockall closure

ICES has a standing request from NEAFC to provide all available information on the distribution of vulnerable deep-water habitats and fishery activities in and near such habitats. The EU (DG MARE) has also indicated an interest in the occurrence of habitats that may be harmed by fishing activities. In 2007, ICES advised a revision to the current demersal fishing closure on NW Rockall (NEAFC Recommendation IX-2008, EC Regulation No 40/2008), on the basis of new cold-water coral data collected by the Joint Nature Conservation Committee in collaboration with the Scottish Government Fisheries Research Services and the University of Plymouth. This recommended revision to the boundary was reiterated by WGDEC in 2008. However, WGDEC 2008 also stated that, should the north-west boundary be considered for modification on the basis of these coral records then it would also be appropriate to review the most up-to-date fishing activity information (this was not available to WGDEC 2008).

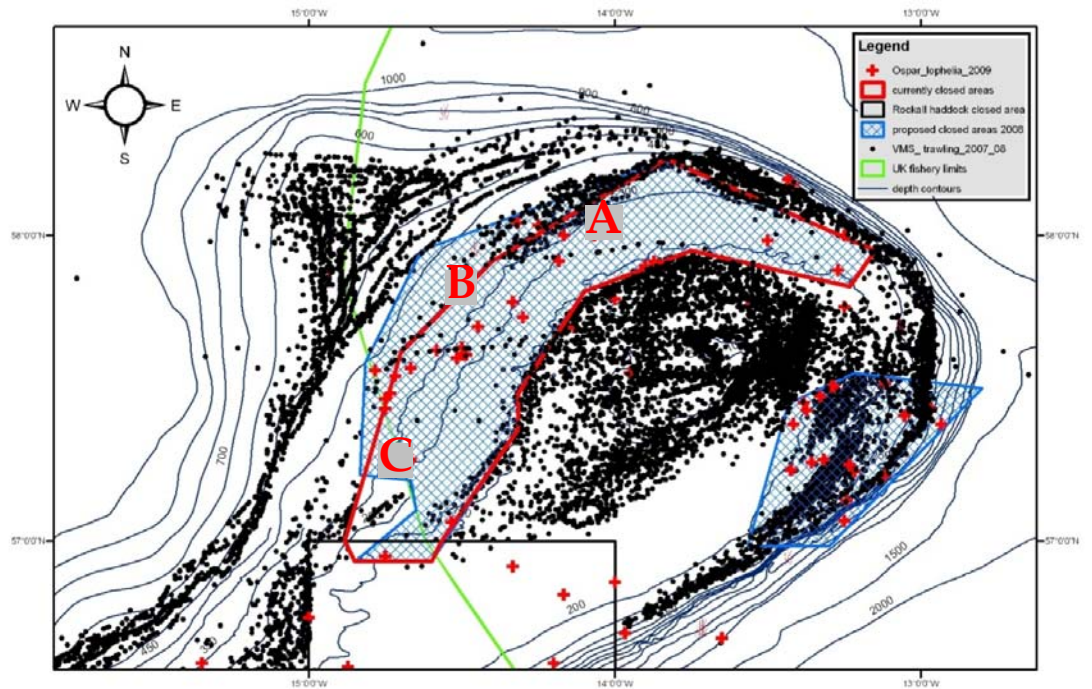


Figure 13.1. Fishing activity over Rockall Bank during 2007 and 2008, for those vessels which landed catch in Scottish ports.

New fisheries data have now been made available to WGDEC 2009 for the Rockall Bank area, originating from the Scottish Fisheries Protection Agency (see Figure 13.1). This Scottish VMS data demonstrates all vessels (both Scottish and international) which entered Scottish waters between 2007 and 2008. The VMS records were filtered by gear (bottom trawling) and speed, so that only vessels travelling between 2–4 knots are displayed (note that this filter may include some vessels travelling slowly in the area, but not fishing). The data do not include vessels that did not enter Scottish waters, and therefore an absence of VMS data in the NEAFC controlled area (beyond 200 miles) does not necessarily mean an absence of trawling activity.

These data were used to review the proposal to extend the NEAFC/EU closure of NW Rockall Bank (as outlined in WGDEC 2007, reiterated in 2008). These areas are shown in blue hatch in Figure 13.1. The existing demersal fishing closure boundary is shown in red. Records of cold water corals collated by OSPAR are also highlighted in Figure 13.1.

The VMS data were used in conjunction with information provided by the Scottish Fishermen's Federation (SFF) on Scottish vessel activity in the area and likely benthic habitat distribution within the proposed extension. No new scientific surveys of VMEs over Rockall Bank have taken place since 2008.

The proposed extension can be broken down into three sections (A, B and C) as indicated on the map.

Section A of proposed extension: UK surveys in 2005/2006 indicated the presence of biogenic reef in this area. Fishermen's records of suspected reef loca-

tions (J. Hall-Spencer, pers. comm. cited in WGDEC, 2005) also appear to support boundary extension here. At WGDEC 2009, Scottish VMS data and prior discussion by WGDEC members with the Scottish fishing industry suggest that this area is now subject to considerable demersal fishing effort. Coral communities are therefore likely to have been damaged in this area.

Section B of proposed extension: Fishermen's records of suspected reef locations (J. Hall-Spencer, pers. comm. cited in WGDEC, 2005) appeared to support some degree of boundary extension in 2007. No additional coral records (negative or positive) from scientific surveys are available. Discussion between WGDEC 2007 and an SFF representative suggested coral presence in this area, which provided an explanation for the absence of VMS records. Subsequent discussion between WGDEC 2009 and SFF in 2009 now suggests substratum in much of this section may be deep mud, not coral. The VMS records that are demonstrated indicate a suitable trawling area running northeast to southwest on the outside edge of the existing closure boundary.

Section C of proposed extension: Historical records (cited in Wilson, 1979) supported the proposed boundary extension at WGDEC 2007. New VMS data from Scotland suggests some demersal trawling in this southern part of the proposed extension.

WGDEC 2009 notes the contradictory data provided on potential coral distribution and fishing activities in this area to the west of the current Rockall closure over the last four years. Further data on coral distribution is required to refine the boundary of this proposed extension. In the absence of these data, WGDEC recommend that a precautionary approach be taken, and that this area (particularly sections B and C, which do not appear to have sustained much trawling activity as yet) be closed to demersal fishing activity.

East Rockall closure

WGDEC 2007 proposed a closure over East Rockall Bank, based on UK Government surveys of the area in 2005/2006 which demonstrated that this area supported patches of intact *Lophelia pertusa* reef along with a mixed substratum of boulders, cobbles and pebbles, and exposed bedrock. VMS records from 2002 had indicated considerable demersal fishing over East Rockall, although in contrast, 2005 records suggested little trawling activity in this area. WGDEC 2007 therefore suggested that "further investigation of the actual fishing activity is required in order to determine the likelihood of damage to reefs in this area". As outlined in this section, new fisheries data have now been made available to WGDEC 2009 for the Rockall Bank area, originating from the Scottish Fisheries Protection Agency (see Figure 13.1). This data indicates active demersal fishing by vessels entering Scottish waters between 2007 and 2008 over significant areas of East Rockall bank. Some sections targeted by trawlers coincide with coral records from 2005/2006 surveys; however, areas towards the eastern and western edges of the boundary appear to support corals that are less likely to have affected by demersal trawling operations. WGDEC considers that there remains sufficient justification for a closure to protect coral reefs on East Rockall, though modifications to the boundary proposed in 2007 would need to be made in light of this new fisheries data. In addition, WGDEC 2009 has been informed that a scientific survey commissioned by the Joint Nature Conservation Committee on the distribution of EC Habitats Directive Annex I reef habitat (bedrock, stony and biogenic reef) is planned over East Rockall (and Anton Dohrn seamount) in summer 2009. WGDEC therefore now recommends that no closure be defined on East Rockall until the re-

sults of this habitat survey are available. WGDEC recommends that all available information be examined at either the 2010 or 2011 meeting of the Group.

Annex 1: List of participants

NAME	ADDRESS	PHONE/FAX	EMAIL
Jeff Ardron	Marine Conservation Biology Institute MCBI Public Policy Office 600 Pennsylvania Avenue SE, Suite 210 Washington DC 20003 United States	Phone +1 202 546 5346/+1 202 460 4960 Fax +1 202 546 5346	jeff.ardron@mcbi.org
Annabelle Aish	Joint Nature Conservation Committee Monkstone House City Road Peterborough Cambs PE1 1JY UK	Tel: +44 (0)1733 866 872 (direct dial) Tel: +44 (0)1733 562 626 (switchboard) Fax: +44 (0)1733 555 948	annabelle.aish@jncc.gov.uk
Maria de Fátima Borges	IPIMAR Avenida de Brasilia PT-1449-006 Lisbon Portugal	Phone +351 21 302 7098 Fax +351 21 301 5948	mfborges@ipimar.pt
Robert J. Brock Chair	NOAA National Marine Fisheries Service 1315 East West Highway Silver Spring MD 20910 United States	Phone +1 301 713 2363 Fax + 1 301 713 1875	Robert.Brock@noaa.gov
Brigitte Guillaumont	IFREMER Centre de Brest PO Box 70 F-29280 Plouzané France		brigitte.guillaumont@ifremer.fr
Kerry Howell	School of Biological Sciences University of Plymouth Drake Circus PL4 8AA Plymouth UK		kerry.howell@plymouth.ac.uk
Ellen L. Kenchington, NAFO representative	Fisheries and Oceans Canada Bedford Institute of Oceanography PO Box 1006 Dartmouth NS B2Y 4A2 Canada	Phone + 1 902 426 2030	kenchingtone@mar.dfo- mpo.gc.ca

NAME	ADDRESS	PHONE/FAX	EMAIL
Pål Buhl Mortensen	Institute of Marine Research PO Box 1870 N-5817 Bergen Norway		paal.buhl.mortensen@imr.no
Francis Neat	Fisheries Research Services PO Box 101 Aberdeen AB11 9DB UK	Phone +44 1224 295516 Fax +44 1224 295511	F.Neat@MARLAB.AC.UK
Mark Tasker	Joint Nature Conservation Committee Dunnet House 7 Thistle Place AB10 1UZ Aberdeen UK	Phone + 44 1 224 655 701 Fax + 44 1 224 621 488	mark@ices.dk
Ole SecherTendal	University of Copenhagen Danish Zoological Museum (SNM) Universitetsparken 15 DK-2100 København Ø Denmark		ostendal@snm.ku.dk
Victoria Sklyar	Knipovich Polar Research Institute of Marine Fisheries and Oceanography 6 Knipovitch Street RU-183763 Murmansk Russian Federation	Phone +7 (8152) 472532 Fax +7 (8152) 450568	sklyar@pinro.ru
Henk J.L. Heessen	IMARES PO Box 68 1970 AB IJmuiden The Netherlands	Phone +31 317487089	henk.heessen@wur.nl

Annex 2: WGDEC Terms of Reference for the next meeting

The ICES/NAFO Joint **Working Group on Deepwater Ecology** [WGDEC] (Chair: Robert J. Brock, USA) will meet either at ICES Headquarters in Copenhagen, Denmark, or I.E.O.- Centre Oceanogràfic de les Balears in Palma de Mallorca, Spain (yet to be determined) in March or April 2010 to:

- a) Continue to update coldwater coral and sponge maps;
- b) Assess the association of fish species with sponge grounds;
- c) Review the science used in assessing vulnerable marine ecosystems and the “Encounter Clause”; and
- d) Address other ToR’s received from ACOM and others this Fall

WGDEC will report by 30 April to the attention of ACOM.

Suggested ToR for WGDEC 2010

Assess the association of fish species with sponge grounds using trawl survey data where available. Summarize the environmental factors influencing sponge distribution in the N Atlantic based on the distribution of sponge taxa. Update maps of sponge grounds using any new data provided. Provide a description of sponge species occurring at depths greater than 1500 m.

Justification

WGDEC has reviewed the literature on the association of sponge grounds with fish and other fauna. With the location of the sponge grounds now mapped it should be possible to evaluate the association of fish within these areas through analyses of the trawl survey data. Specifically, comparisons of fish catch and diversity inside and outside sponge grounds at similar depths and areas could be statistically analysed. It is expected that further information on the sponge species constituting the sponge grounds on the NW Atlantic will be available in 2009. This will allow for biogeographical assessment and examination of the environmental factors responsible for creating sponge habitat and determining community composition. WGDEC feels that there is now sufficient data to produce a summary of the sponge species inhabiting depths below 1500 m in the North Atlantic and that such a summary would be useful, in particular to researchers working at such depths. Data gaps from western Greenland and the NE USA have been identified, and in the event that more information from those areas is provided to the WGDEC, maps on the distribution of sponge grounds in the North Atlantic should be updated. Sponges have been identified as key components of vulnerable marine ecosystems by FAO. It is expected that the work produced under this and previous ToRs will have direct relevance to NAFO, NEAFC, ICES and other organizations concerned with the protection of VME.

Suggested ToR for WGDEC 2010

Using existing scientific knowledge and data, assess the VME (vulnerable marine ecosystem) ‘encounter rules’ for commercial vessels as currently formulated by NAFO and NEAFC, taking into account similar rules in other regions, and offering suggested refinements, as appropriate.

Justification

RFMOs globally have been seeking to implement the requirements of the UN 2006 Resolution 16/105 with regard to protecting vulnerable marine ecosystems from the

effects of bottom fishing. In doing so, scientific advice has routinely been sought (e.g. mapping the distribution of corals and sponges). Section 83 (d) of the resolution calls for fishing activities to cease where, in the course of fishing operations, vulnerable marine ecosystems are encountered. WGDEC proposes to review the scientific advice on what constitutes such an encounter and to suggest approaches that would best fit the situation in the North Atlantic. Currently, NEAFC and NAFO have provisionally stated that in a single trawl tow, up to 100 kg of live corals and 1000 kg of live sponges may be caught as bycatch before fishing operations should cease and move on.

Supporting Information

Priority:	The current activities of this Group will lead ICES into issues related to the ecosystem affects of fishery, especially with regard to the application of the Precautionary Approach. Consequently, these activities are considered to have a very high priority.
Scientific justification and relation to action plan:	<p>Action Plan No: 1. Term of Reference a) Several countries are conducting or have recently completed significant studies in this area and the subject would benefit from a review of progress and an evaluation of the results obtained. The last review of significant studies occurred in 1996 by the ICES Study Group on Unaccounted Mortalities. A review of more recent work will determine the need for revision and update on planning and methodology for studying this subject.</p> <p>Term of Reference b) All fishing activities have influences that extend beyond removing target species. The approach recommended by FAO is that responsible fisheries technology should achieve management objectives with a minimum of side effects and that they should be subject to ongoing review. WGFTFB members and others are currently undertaking a range of research programmes to provide the means to minimize side effects.</p>
Resource requirements:	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants:	The Group is normally attended by some 10–15 members and guests.
Secretariat facilities:	None.
Financial:	No financial implications.
Linkages to advisory committees:	There are no obvious direct linkages with the advisory committees.
Linkages to other committees or groups:	There is a very close working relationship with all the groups of the Fisheries Technology Committee. It is also very relevant to the Working Group on Ecosystem Effects of Fisheries.
Linkages to other organizations:	The work of this group is closely aligned with similar work in FAO and in the Census of Marine Life Programme.

Annex 3: Recommendations

There are no “action items” for the ICES Advisory Committee (ACOM) at this time. However, this report does contain several recommendations or suggestions as they relate to the issue of scale and closed areas as well as identifies several issues that should be more closely reviewed in future meetings of WGDEC.