Northwest Atlantic Fisheries Organization

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SCIENTIFIC COUNCIL MEETING – SEPTEMBER 2010

Report of the NAFO Scientific Council Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM)

Instituto de Investigaciones Marinas, Vigo, Spain

1-5 February 2010

Preamble

The Scientific Council Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM), met at the Institute of Marine Research, Vigo, Spain on 1-5 February 2010. A list of participants is provided in Appendix 1. The overall goals for the meeting were:

- To further advance our understanding on how the NAFO ecosystems work, how they are regulated, and how they respond to different types of perturbations.
- Use this knowledge to explore the concept of EAF, and to develop how it could be applied within NAFO.
- To address specific requests from Scientific Council.

The ToRs for WGEAFM were approved by Scientific Council in June 2009 and were intended to guide the future work of WGEAFM in three thematic areas over a medium to long-term horizon. In addition to these general ToRs, and by a specific request of the Scientific Council, one term of reference (ToR 7) was also considered. After the 2009 NAFO September Meeting, the Scientific Council Chair requested WGEAFM to include two additional ToRs (ToRs 8 and 9) to address questions posed by Fisheries Commission to Scientific Council in the FC Requests for Advice No. 8 and 9.

General Context

The NAFO General Council in 2005 discussed various recent Agreements, Conventions and other instruments that outlined the need for RFMOs to strengthen their commitments to an ecosystem approach to fisheries management.

UNGA Res. 61/105 and the FAO Deep-Sea Fisheries Guidelines were published in 2007 and 2008 respectively, calling for, *inter alia*, a reduction in fishing methods that caused significant adverse impacts (SAI) upon vulnerable marine ecosystems (VMEs). These two documents are related to sustainable fisheries and their impacts on the ecosystem and call for regional fisheries management bodies to act accordingly by 31 December 2008.

UNGA Res. 61/222, arising mainly from the WSSD (1992) and CBD (1992), also published in 2007, calls for biodiversity conservation in the marine environment through the establishment of marine protected areas (MPAs). This resolution, *inter alia*, "*Also reaffirms* the need for States to continue their efforts to develop and facilitate the use of diverse approaches and tools for conserving and managing vulnerable marine ecosystems, including the possible establishment of marine protected areas, consistent with international law and based on the best scientific information available, and the development of representative networks of any such marine protected areas by 2012" [Para 97] and "*Calls upon* States and international organizations to urgently take action to address, in accordance with international law, destructive practices that have adverse impacts on marine biodiversity and ecosystems, including seamounts, hydrothermal vents and cold water corals [Para 101].

To date, a response to UNGA Res. 61/105 has received greater attention in NAFO due to the closer link to fisheries and the earlier deadline,

To enable NAFO to commence addressing UNGA res 61/105, the NAFO Scientific Council (SC) WGEAFM in May 2008 identified candidate VME areas, and, in late 2008 and early 2009, areas of high coral and sponge abundance. This information was used as a basis for scientific advice which was subsequently reviewed and translated into management recommendations by the NAFO Fisheries Commission Ad Hoc Working Group of Fishery Managers and Scientists on Vulnerable Marine Ecosystems (WGFMS). This Goup was created in 2008 and its main objective is to make recommendations to Fisheries Commission (FC) on the effective implementation of measures to prevent significant adverse impacts on VMEs. WGFMS recommended closure of 11 locations in the NAFO Regulatory Area (NRA), which FC adopted in September 2009 and implemented on January 1, 2010. These closures are in addition to the five seamount closures in the NRA which are due for review in 2010.

WGFMS has also considered the issue of encounter protocols for corals and sponges in the NRA. Recognizing the lack of satisfactory information, and the difficulties and uncertainties in using tow data from research vessel surveys to scale up to tows in commercial fisheries, WGFMS proposed encounter protocols of 60 kg of live coral and 800 kg of sponge for fisheries in the NRA. This also acknowledges that the areas of highest concentrations of corals and sponges in the NRA had been identified and recommended for protection via closure to fishing.

Future work for SC WGEAFM is likely to include further delineation of VMEs, consideration of fisheries impacts and regime changes on biological diversity and ecosystem productivity, reviews of the current closures, effects on the fishery and ecosystem of gear-specific or partial closures, monitoring of ecosystem health, an increased understanding of bycatch and discards.

The UNGA resolutions 61/105 and 61/222 to some extent relate to two different stakeholders: the former the fisheries sector and the latter the conservation sector. However, both resolutions are related and need to be brought together in a coordinated framework for ecosystem management. The identification and protection of VMEs also requires better information and understanding of ecosystems at a functional level.

Terms of Reference

The concept of managing ecosystems is difficult to operationalise because fisheries management, and the associated scientific advice, currently operate at the single-species level, or occassionally at the level of a group of interacting species. WGEAFM addresses this issue by adopting a framework of themes which are intended to fulfil relevant ToRs agreed by SC, which lead to develop a functional understanding of the ecosystem in the NAFO area. This knowledge can, in turn, provide the way forward for NAFO to develop an ecosystem approach to fisheries management. The themes and related ToRs are as follows:

Theme 1: Take stock of past and planned WGEAFM related work

ToR 1. *Update on identification and mapping of sensitive species and habitats in the NAFO area*.

Theme 2: Status and functioning of NAFO marine ecosystems (empirical evidence)

ToR 2. *Synthesis of current understanding of the dynamics of Large Marine Ecosystems (LMEs) in the NAFO area.*

ToR 3. *Scope of Marine Protected Areas and VMEs in the context of habitat and spatial functioning.*

Theme 3: Practical application (synthesising the evidence and theory)

ToR 4. *Systems level modelling and assessment approaches*.

ToR 5. *Ecosystem indicators and how they can be used in management advice*

ToR 6. *Methods for the long-term monitoring of VME status and functioning.*

In addition to the above long-term ToRs, specific requests for advice by SC are addressed by the following additional ToRs:

ToR 7(based on Scientific Council Request). *Scientific Council noted that no biomass index is available for coral or sponges aggregations within the NAFO Regulatory Area. Therefore, the detection of trends over time and the monitoring schemes to assess impact/recovery that are required by the FAO Deep Sea Fisheries guidelines is* *problematic. Further, it is not possible to analyse the relationship between the occurrence of coral or sponge aggregations and commercial bottom trawl fishing effort.*

ToR 7a- *Scientific Council requests that WGEAFM investigate cost and time effective methods to monitor the health of the VME areas.*

ToR 7b *- Further, and subject to the above and data availability, Scientific Council further requests that the relationship between historical commercial bottom trawl fishing effort and the occurrence of VME indicator species be investigated.*

ToR 8 (Scientific Council Chair Request based on Fisheries Commission Request 8). *Recognizing the initiatives on vulnerable marine ecosystems (VME) through the work of the WGFMS, and with a view to completing fishery impact assessments at the earliest possible date, the Scientific Council is requested to provide the Fisheries Commission at its next annual meeting in 2010:*

ToR 8a *- guidance on the content of fishing plans/initial assessments for the purpose of evaluating significant adverse impacts on VMEs and identify viable risk evaluation methodologies for the standardized assessment of fishery impacts.*

ToR 8 b) *In light of the use of existing encounter protocols in tandem with the closed areas for corals and sponges:*

> ***i.*** *assess new and developing methodologies that may inform the Fisheries Commission on any future review of the thresholds levels*
>
> ***ii.*** *review and report on new commercial bycatch information as it becomes available, and*
>
> ***iii.*** *in light of i.) review the ability of the current encounter threshold values of 60 kg live coral and 800 kg sponge to detect new VME areas as opposed to cumulative catches of isolated individuals.*

ToR 9 (Scientific Council Chair Request based on Fisheries Commission Request 9)*. Recognizing that areas closed to all bottom fishing activities for the protection of vulnerable marine ecosystems as defined in Article 15, including inter alia:*

- *Fogo Seamounts 1*
- *Fogo Seamounts 2*
- *Orphan Knoll*
- *Corner Seamounts*
- *Newfoundland Seamounts*
- *New England Seamounts*

and associated protocols for vessels conducting exploratory fishing in those areas, expire on December 31, 2010.

Mindful of the call for review of the above measures based on advice from the Scientific Council, Fisheries Commission requests that Scientific Council:

ToR 9a *- Review any new scientific information on the Fogo Seamounts 1, Fogo Seamounts 2, Orphan Knoll, Corner Seamounts, Newfoundland Seamounts and New England Seamounts which may support or refute the designation of these areas as vulnerable marine ecosystems.*

ToR 9 b *- Review any exploratory fishing activity on the seamounts in the context of significant adverse impact to vulnerable marine ecosystems and review current exploratory fishing data collection protocols operating in the seamount closure areas as defined in Article 15 for their usefulness in providing scientific information.*

ToR 9c *- Review the potential for significant adverse impact of pelagic, long-line and other fishing gear types other than mobile bottom gear on seamount vulnerable marine ecosystems.*

PART I: Addressing ToRs under long–term themes

Theme 1: Take stock of past and planned WGEAFM related work

***ToR 1**. Update on identification and mapping of sensitive species and habitats in the NAFO area.*

Two different types of activities were reported under this ToR. These types were i) new analysis intended to improve/broaden the scientific basis for identification and mapping of sensitive species/habitats in the NRA and ii) description of ongoing research work expected to become a source of data and analysis on this topic in future years.

i. Analysis to improve/broaden previous work

The density-area method developed by WGEAFM and previously applied to identify locations of high concentrations of sponges was used to identify locations of high concentrations of pennatulaceans.

Delineation of Significant Concentrations of Pennatulaceans using density analysis

Previously, the Working Group on Ecosystem Approach to Fisheries Management (WGEAFM) was asked to delineate significant concentrations of corals and sponge in the NAFO Regulatory Area (NAFO 2008a, b, 2009a). Previously NAFO and ICES had defined the conservation units as sea pen fields, large gorgonians and small gorgonians for the coral, and sponge grounds - which in the NAFO Regulatory Area (NRA) are dominated by *Geodia* sp. (Fuller *et al*. 2008, ICES 2009). These taxa were reviewed against the FAO (2009) criteria for vulnerable marine ecosystems (VME). Initially in the analyses of the coral, plots of the cumulative catch weight distribution from the groundfish trawl surveys were used (NAFO 2008a, b). It was noted that the distribution of cumulative catch weights was highly skewed, with most tows catching small quantities, and only small numbers of tows with larger catches.

The WGEAFM was unable to link any specific catch weight from these distributions to a threshold that would say whether the location was a VME or just a catch of the widespread but isolated occurrence of some of these species. The WGEAFM did feel that the very largest of the catches did constitute a VME based solely on their relative size, and therefore opted to use the upper 97.5 quantile as a standard (2.5% of the catches were above this value) based on standard statistical conventions (NAFO 2008a, b). These were applied to the sea pen and small gorgonian bycatch, while a more precautionary 90% quantile was used for the large gorgonians where it was felt that retention efficiency was lower and the taxa are prone to breakage. Other RFMOs also used properties of the bycatch distribution for decision making, but were equally unable to link any particular value with a biological or ecological property.

Through the consideration of this issue, NAFO developed a spatial approach to identify significant concentrations of sponge, that is, sponge grounds (Kenchington *et al.* 2009, NAFO 2009a). In simple terms, this method considers decreasing threshold values (densities) and calculates the area occupied under each one of these threshold scenarios; then it identifies which is the step between consecutive threshold values that renders the largest increase in occupied area. The threshold associated with this largest area increase is interpreted as the jump from actual grounds/fields to isolated individuals/small aggregations for the species/conservation unit of interest. This spatial method worked well for sponges because they not only had a catch distribution with few medium-sized catches, many small ones and few large ones, but the location of these larger catches were highly aggregated. In principle, this approach could also be applied to the coral conservation units (NAFO 2008a, b). Sea pens or pennatulaceans are known to form dense aggregations known as sea pen fields but are otherwise broadly distributed at low density (Fuller et al. 2008), and so should be good candidates for spatial analysis. WGEAFM applied the spatial analytical approach used on sponges by NAFO (2009a) to the pennatulacean data used previously when applying the cumulative catch weight distribution methodology (NAFO 2008a, b).

The results from this analyis indicate that the largest important increase in area occurs between catches of 0.5 and 0.1 kg (Murillo et al. 2010). This coincides with an area of 8484 km^2 for the 0.5 kg catch threshold and a 3.7 times increase to 33,053 km^2 for the 0.1 kg catch. (Murillo et al. 2010). Consequently the 0.5 kg weight threshold could be considered as a good indicator of the higher pennatulaceans concentrations in the study area. The location of the catches from the NRA (excluding the catches within Canada's EEZ) and their associated weight is provided in Table 1 and illustrated in Figure 1. Compared with the 1.6 kg threshold obtained from the cumulative curve distribution (NAFO 2008a, b), 29 new points have been added (Figure 1) with this methodology in the NRA (Divs. 3LMNO).

These tend to occur within the same geographic area (Figure 1), confirming the robustness of this approach in identifying pennatulacean concentrations (Murillo et al. 2010).

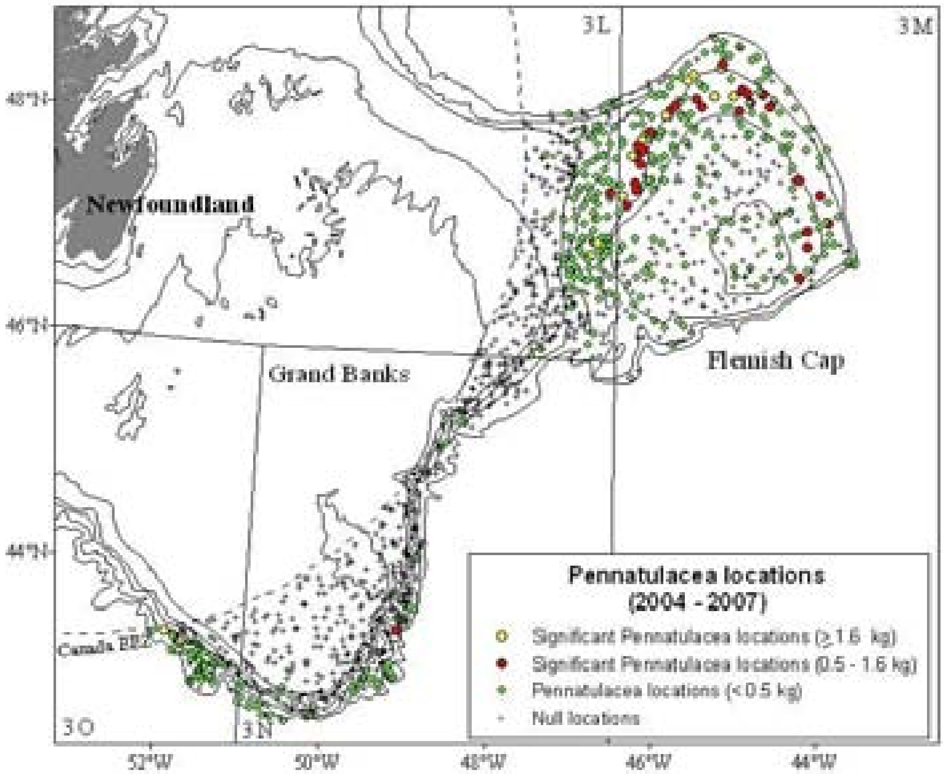

Figure 1. Significant pennatulacean locations (≥ 0.5 kg/trawl) in the NRA (Divs 3LMNO) derived from the spatial density analysis are indicated in red and yellow. Yellow dots represent catches higher than 1.6 kg (threshold obtained from the cumulative curve distribution, NAFO 2008a, b). Green dots represent catches below 0.5 kg. Black crosses represent catches without pennatulacean records.

Table 1. Start and end positions of tows with ≥ 0.5 kg of pennatulaceans derived from the density analysis in the NRA (Divs. 3LMNO) with their corresponding catch weight.

N	Survey	Start position		End position		Weight (kg)
		Latitude	Longitude	Latitude	Longitude	
1	DFO-CAN	47° 58' 12" N	46° 11' 24" W	47° 58' 55" N	46° 10' 55" W	1.615
2	DFO-CAN	43° 19' 55" N	51° 47' 06" W	43° 19' 23" N	51° 46' 23" W	1.578
3	DFO-CAN	48° 15' 18" N	45° 48' 00" W	48° 15' 47" N	45° 47' 24" W	1.2
4	DFO-CAN	43° 18' 36" N	51° 44' 06" W	43° 18' 00" N	51° 43' 19" W	1.024
5	DFO-CAN	47° 23' 42" N	46° 22' 30" W	47° 23' 24" N	46° 23' 24" W	0.501
6	SPAIN-EU	47° 02' 52" N	46° 44' 11" W	47° 01' 28" N	46° 44' 58" W	10.116
7	SPAIN-EU	48° 30' 29" N	45° 34' 46" W	48° 29' 17" N	45° 35' 53" W	5.717
8	SPAIN-EU	43° 23' 15" N	51° 57' 14" W	43° 23' 34" N	51° 59' 12" W	5.517
9	SPAIN-EU	48° 33' 45" N	45° 30' 39" W	48° 34' 59" N	45° 29' 22" W	3.3
10	SPAIN-EU	46° 56' 02" N	46° 50' 04" W	46° 54' 32" N	46° 50' 08" W	2.3
11	SPAIN-EU	47° 50' 37" N	46° 18' 42" W	47° 52' 01" N	46° 17' 47" W	1.994
12	SPAIN-EU	48° 11' 59" N	45° 52' 58" W	48° 13' 10" N	45° 51' 25" W	1.988

13	SPAIN-EU	48° 22' 58" N	44° 57' 49" W	48° 21' 53" N	44° 59' 18" W	1.953
14	SPAIN-EU	47° 28' 39" N	46° 25' 17" W	47° 29' 52" N	46° 23' 55" W	1.941
15	SPAIN-EU	48° 22' 49" N	45° 13' 38" W	48° 22' 01" N	45° 15' 50" W	1.898
16	SPAIN-EU	48° 37' 51" N	45° 08' 32" W	48° 38' 00" N	45° 10' 47" W	1.7
17	SPAIN-EU	47° 28' 50" N	43° 50' 09" W	47° 30' 31" N	43° 50' 28" W	1.599
18	SPAIN-EU	47° 35' 35" N	46° 16' 00" W	47° 36' 55" N	46° 14' 52" W	1.498
19	SPAIN-EU	48° 16' 46" N	44° 28' 37" W	48° 17' 51" N	44° 30' 28" W	1.428
20	SPAIN-EU	47° 55' 23" N	46° 13' 54" W	47° 54' 42" N	46° 11' 52" W	1.3
21	SPAIN-EU	46° 44' 49" N	44° 07' 02" W	46° 46' 14" N	44° 05' 31" W	1.246
22	SPAIN-EU	48° 03' 28" N	46° 04' 17" W	48° 04' 43" N	46° 06' 19" W	1.2
23	SPAIN-EU	48° 17' 31" N	45° 45' 03" W	48° 16' 02" N	45° 46' 08" W	1.051
24	SPAIN-EU	48° 19' 04" N	44° 44' 24" W	48° 20' 01" N	44° 46' 17" W	0.9
25	SPAIN-EU	48° 14' 53" N	44° 52' 55" W	48° 15' 40" N	44° 55' 13" W	0.863
26	SPAIN-EU	47° 49' 38" N	46° 15' 22" W	47° 48' 08" N	46° 15' 23" W	0.85
27	SPAIN-EU	47° 45' 57" N	46° 11' 40" W	47° 44' 34" N	46° 12' 23" W	0.85
28	SPAIN-EU	48° 23' 46" N	44° 34' 49" W	48° 22' 55" N	44° 32' 56" W	0.8
29	SPAIN-EU	47° 37' 13" N	44° 06' 03" W	47° 38' 42" N	44° 07' 23" W	0.8
30	SPAIN-EU	47° 14' 00" N	43° 43' 52" W	47° 12' 22" N	43° 43' 13" W	0.8
31	SPAIN-EU	47° 29' 48" N	46° 35' 49" W	47° 31' 11" N	46° 34' 11" W	0.755
32	SPAIN-EU	48° 21' 20" N	45° 27' 35" W	48° 20' 11" N	45° 29' 29" W	0.712
33	SPAIN-EU	48° 25' 34" N	44° 50' 40" W	48° 26' 14" N	44° 52' 49" W	0.67
34	SPAIN-EU	48° 39' 37" N	45° 06' 55" W	48° 39' 54" N	45° 09' 13" W	0.654
35	SPAIN-EU	48° 16' 28" N	45° 23' 43" W	48° 17' 10" N	45° 21' 40" W	0.65
36	SPAIN-EU	47° 31' 25" N	46° 15' 20" W	47° 32' 34" N	46° 13' 59" W	0.65
37	SPAIN-EU	47° 09' 16" N	43° 59' 38" W	47° 07' 34" N	43° 59' 33" W	0.62
38	SPAIN-EU	48° 24' 20" N	44° 47' 07" W	48° 25' 13" N	44° 49' 10" W	0.56
39	SPAIN-EU	43° 31' 13" N	49° 07' 16" W	43° 32' 25" N	49° 06' 37" W	0.557
40	SPAIN-EU	47° 01' 29" N	43° 59' 52" W	47° 03' 05" N	44° 00' 16" W	0.544
41	SPAIN-EU	47° 53' 36" N	46° 10' 09" W	47° 52' 00" N	46° 10' 05" W	0.502

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ii. Update on ongoing surveys/analyses

Several ongoing research activities are expected to generate data and produce analyses that will contribute towards achieving WGEAFM ToRs in the future. These activities included the ongoing NEREIDA cruises focused on the identification and delineation of VMEs and VME-defining species, the collection and identification of sponges in the 2009 Greenland demersal survey, and the activities being carried-out by the DFO Ecosystem Research Initiative (ERI) in the NL region (NEREUS program).

In 2009, the NEREIDA-related work involved surveys in the Flemish Cap, carried-out by the Spanish RV Miguel de Oliver and Canadian RV Hudson, and in the Scotian Shelf, by the Canadian RV Hudson. These surveys used an assortment of tools (e.g. multibeam acoustics, corers, ROVs) to collect detailed and precise information on the bathymetry, bottom structure, and benthic organisms. There are also plans to continue this work in 2010; detailed information on the planned survey to the Orphan Knoll by the RV Hudson was also presented.

Among ERI-NEREUS activities, preliminary results from the analysis of acoustic data collected during the 2008 2J3KLNO DFO Fall Multispecies Survey were introduced and discussed. These preliminary results were encouraging with respect to the possibility of improving assessment of pelagic species (e.g. capelin) by gathering acoustic data during regular bottom-trawl surveys. A first description of the results from a bottom-grab sampling program carried out during the DFO 3LNO Spring survey was also presented. This work is beginning to provide a large scale picture of benthic communities in the Grand Bank that is expected to serve as baseline for detecting changes over time.

NEREIDA Surveys

The NEREIDA project was designed to study the study of the marine resources within NAFO. The main objective of the project is focused on the improvement of the knowledge of the vulnerable habitats and ecosystems as well as the definition and delimitation of areas candidates to protect.

NEREIDA 2009: RV Miguel Oliver cruises

Between May and August 2009 a series of multidisciplinary research cruises on board R/V Miguel Oliver owned by Secretaría General del Mar (SGM) were carried out. The information obtained during 2009 surveys will be completed during additional cruises which will be carried out during summer 2010. Information derived from these surveys will be very useful in order to have a complete view of the ecosystem allowing a detailed identification of those areas candidate to protect and therefore fulfil the UNGA Resolution 61/105 (paragraph 83) requirements.

Study area

Geographically, the study area covers between the 200 miles of the Canadian EZZ and the 700-2000 m isobaths in High Seas of the Atlantic Northwestern. Total survey area was divided into three parts , each part covered by a different survey (Figure 2):

1st Survey (NEREIDA 0509) covered east of Flemish Cap

2nd Survey (NEREIDA 0609) covered west and north of Flemish Cap

3rd Survey (NEREIDA 0709) covered the Flemish Pass

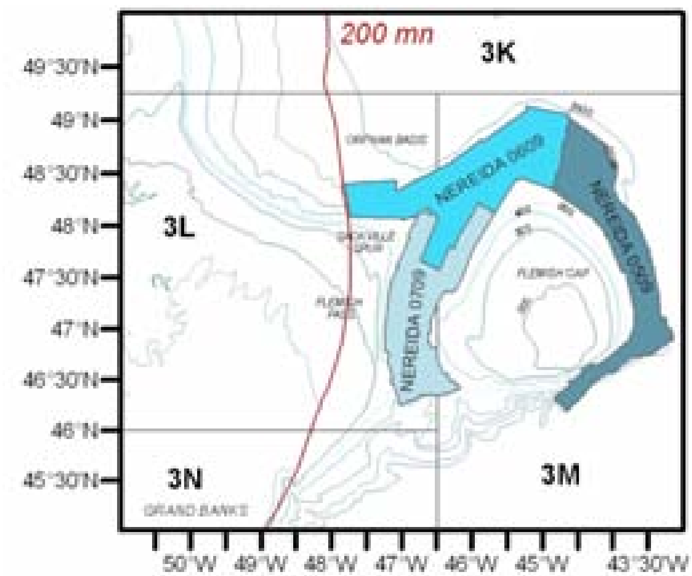

Figure 2. RV Miguel Oliver NEREIDA 2009 survey area.

Material and Methods

Geology

Mapping and seismic: Geophysical and bathymetrical data were acquired from the shelf off Canada during three cruises of the R/V Miguel Oliver in 2009. Navigation data were acquired using differential GPS and the aid of a Seapath inertial system. Two hull-mounted systems were used; a Kongsberg- Simrad EM 302 multi-beam swath-bathymetry system and Topographic Parametric Sonar (TOPAS) PS 18 subbottom profiler.

Multibeam: The EM 302 swath bathymetric system emits up 288 beams/432 soundings per swath, each with a frequency of 30 kHz and a maximum port- and starboard-side angle of 75°. This echosounder could reach a total swath width up 5 times water depth. Swath data were processed through the removal of anomalous pings and gridded at cell sizes of 50 m using Kongsberg-Simrad NEPTUNE software. Then, the processed data were introduced in a Geographic information system ArcGIS.

Seismic: The TOPAS system uses parametric interference between primary waves to produce a secondary acoustic beam of narrow width and a frequency range of 0.5 to 5 kHz. It is used to profile the sub-sea floor at high vertical resolution (i.e. to < 1 m). The locations of the seismic lines were projected over the multi-beam map with the aid of a Geographic information system, and the images of the seismic lines were associated to the projected position lines.

Biological samples

Rock dredge: The rock dredge used in this study consisted of a rectangular metal structure, coupled with a network that is protected by a basis of rubber. When it is dredging the seabed, mouth rectangular metal, can break fragments of rock. They are deposited inside the network and subsequently collected on the surface when the dredge is on the deck. The towing speed is usually low, between 2 and 3 knots.

The use of rock dredges allows sample rocks, semiconsolidated sediment and associated benthos samples. This type of equipment is included in the direct methods to obtain data on the seafloor by means of physical contact with him. The rock dredge is used in areas where it provides for the existence of rock outcrops.

During the first leg of the NEREIDA survey, both rock dredges were lost at sea; as a result a modified scallop dredge was used as a substitute.

Figure 3. Rock dredge (left) and scallop dredge (right)

Mega Box corer: The Mega Box corer (Figure 4a) is a ULSNER iron hot dip with moving parts of stainless steel weighing about 1 ton, with a trigger device on contact. The sample is obtained using a stainless steel box 500x 500x 500 mm and there is a sampling area of 0.25 m^2. The Mega Box corer is activated by collision against the sea bottom at high speed drop. At the impact moment is actuated a lid that blocks the box so that collects sediment that is trapped under the dredge. The sample obtained (Figure 4c) is representative of the environment surrounding the sample point. It is used to take samples of soft and semiconsolidated sediments and associated benthos samples. After an initial processing of sediments aboard, are stored with different techniques. The box corer samples were subsample using a 10 cm diameter PVC tube (push core, Figure 4b). Push cores were pressed into the sample, and a vacuum was maintained to extract the sediment. Push core tubes were sealed and refrigerated to prevent disruption of sediment during store and transport.

Figure 4. Mega Box-Corer (a), Push core(b), Surface and vertical view of the sample (c)

CTD: The CTD consists of equipment which records the conductivity and water temperature and the depth at which the equipment is submerged. We used the SBE 25 SEALOGGER CTD, is a research-quality CTD profiling system for deep-water work (Figure 5). The SBE 25's scan rate of 8 Hz provides good fine-scale measurement Performance. Recorded data are transferred via RS-232 interface to a computer for processing.

These CTD are of stationary manoeuvres (ship stopped). This equipment was released to the water after each rock dredge or Mega-Box corer sample, to make TS diagrams in the water column of all points where the sampling is performed. Its use therefore was conditional on obtaining a sample of rock or dredge box corer valid.

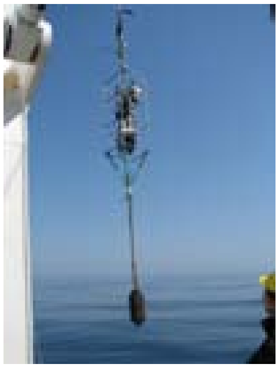

Figure 5. *CTD*

Results

Table 2 shows a summary of all the activities carried out during the NEREIDA 2009 surveys. It also shows the total prospected area in square kilometres.

Table 2. Summary of activities carried out. * indicates 7 scallop gear, and ** indicates 1 scallop gear.

	BC Valid	**BC** Null	**RD** Valid	**RD** Null	**CTD**	**Geology**	Prospected Area (km^2)
1st Survey NEREIDA 0509	43	5	18*	6**	62	**171 lines (112 multibeam + 59 transits)**	**12114**
	48		24				
2nd Survey NEREIDA 0609	57	11	16	4	76	**160 lines (109 multibeam + 51 transits)**	**15227**
	68		20				
3rd Survey NEREIDA 0709	59	5	15	1	78	**179 lines (135 multibeam + 44 transits)**	**10965**
	64		16				
TOTAL	180		60		216	510 lines	38306

Rock dredge/Scallop gear

During NEREIDA 2009 summer surveys, 60 localities were sampled by means of the Rock dredge/Scallop gear. By survey, the number of samplings was as follows:

NEREIDA 0509: 24 (11 valid with rock dredge and 7 with scallop gear)

NEREIDA 0609: 20 (16 valid)

NEREIDA 0709: 16 (15 valid)

Figure 6 shows the location distribution of the sampling carried out during the three surveys. Red dots correspond to NEREIDA 0509, green dots to NEREIDA 0609 and blue dots to NEREIDA 0709.

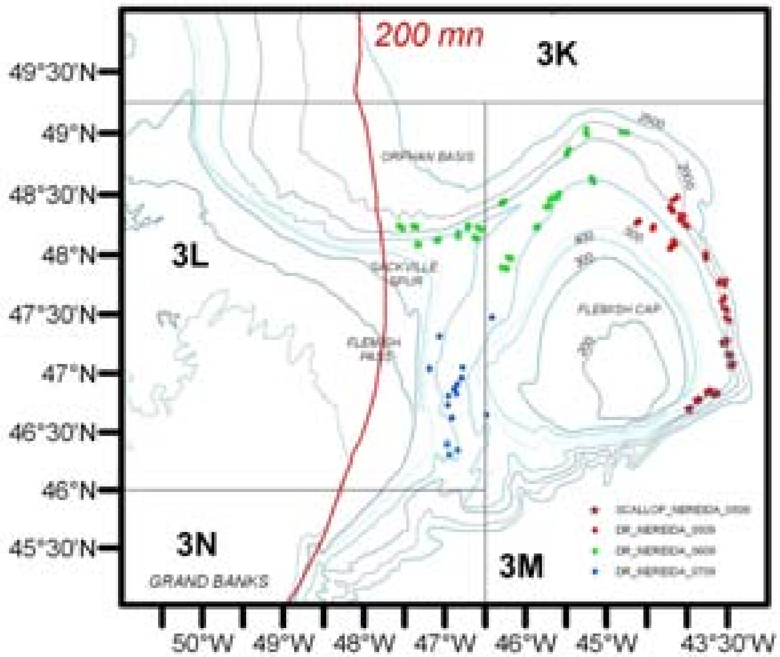

Figure 6. Rock dredge/Scallop gear locations

Total biomass recorded was 295 kg. The phylum Porifera was the main group in the rock dredge as well as scallop gear and took more than the 86 % of the total biomass, followed by the Cnidaria with 8.7 % (Table 3). The others phyla meant less than < 5 % of the total biomass recorded.

Table 3. Biomass (kg) of each phylum recorded in the NEREIDA 2009 survey.

	ROCK_DREDGE		SCALLOP_GEAR		TOTAL	
	BIOMASS (kg)	%	BIOMASS (kg)	%	BIOMASS (kg)	%
PORIFERA	107.5	85.9	148.8	87.6	256.3	86.9
CNIDARIA	11.5	9.2	14.2	8.4	25.7	8.7
ECHINODERMATA	1.6	1.3	3.6	2.1	5.2	1.8
CHORDATA	0.9	0.7	2.4	1.4	3.3	1.1
MOLLUSCA	1.5	1.2	0.4	0.2	1.9	0.6
ANNELIDA	1.6	1.3	0.1	< 0.1	1.7	0.6
ARTHROPODA	0.2	0.2	0.1	0.1	0.3	0.1
BRYOZOA	< 0.1	< 0.1	0.2	0.1	0.2	0.1
SIPUNCULA	< 0.1	0.1	0.1	0.1	0.2	0.1
BRACHIOPODA	0.2	0.1	0	0	0.2	0.1
NEMERTINA	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
CHAETOGNATHA	< 0.1	< 0.1	0	0	< 0.1	< 0.1

Sponges were dominant in the samplings carried out in the deep areas of the Flemish Cap between 1000 and 1500 m, because of the presence of organisms belonging to the family Geodiidae. Other sponges recorded were the genus *Tentorium*, *Stylocordyla*, *Euplectella*, *Asconema* and family Cladorhizidae.

The second phyllum dominant based on biomass was the Cnidaria, mainly for the sea anemones of the family Hormathiidae and the soft corals *Anthomastus* spp. and the family Nephtheidae. Other deep-water corals recorded were the gorgonians *Acanella arbuscula*, *Acanthogorgia armata*, *Keratoisis* sp., *Paragorgia arborea*, *Primnoa resedaeformis*, the sea pens *Virgularia mirabilis*, *Pennatula aculeata*, *Anthoptilum* sp., *Protoptilum* sp., *Halipteris finmarchica*, the black coral *Stauropathes arctica* and the cup corals *Desmophyllum dianthus*, *Flabellum alabastrum* and *Vaughanella* sp.

Echinodermata was the next phyllum dominant based in biomass. The main species recorded were the sea stars *Ceramaster granularis*, *Madiaster bairdi*, *Hippasteria phrygiana*, *Novodinia americana*, *Porania* sp., *Henricia* sp., the brittle stars *Gorgonocephalus lamarckii*, *Ophiomusium limany*, *Ophiacantha* sp., the sea urchin *Brisaster fragilis* and the sea cucumbers of the genus *Psolus* and family Molpadiidae.

Finally, others organisms belonging to the phylla Chordata, Mollusca, Annelida, Arthropoda, Bryozoa, Sipuncula, Brachiopoda, Nemertina y Chaetognatha were recorded and they constituted less than 3 % of the total biomass.

Mega Box-Corer

During NEREIDA 2009 summer surveys, 180 localities were sampled by means of the Mega Box Corer. By survey, the number of samplings was as follows:

NEREIDA 0509: 48 (43 valid)

NEREIDA 0609: 68 (57 valid)

NEREIDA 0709: 64 (59 valid)

Figure 7 shows the location distribution of the sampling carried out during the three surveys. Red dots correspond to NEREIDA 0509, green dots to NEREIDA 0609 and blue dots to NEREIDA 0709.

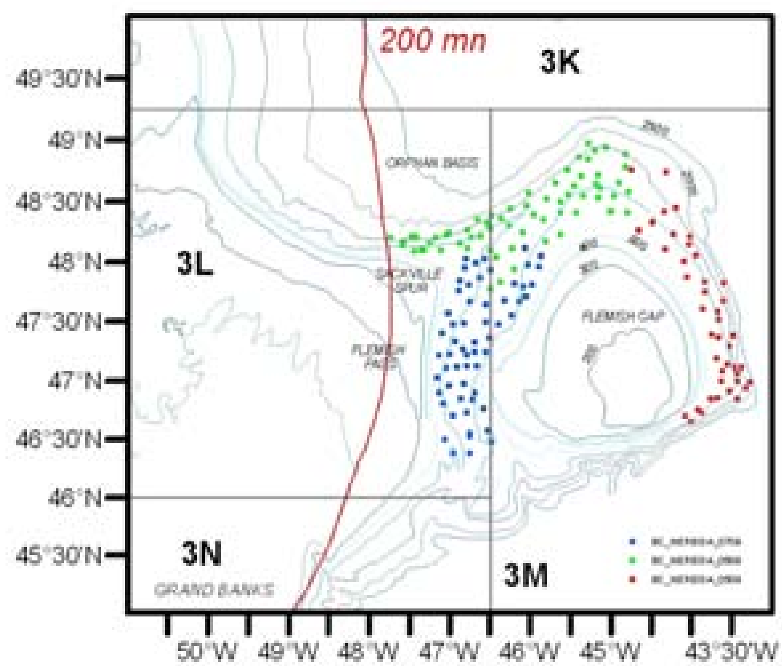

Figure 7. Mega Box-Corer locations

Vulnerable organisms: During the summer NEREIDA 2009 survey several samplings were done inside the candidate Vulnerable Marine Ecosystems areas based on deep-water corals and sponges defined in 2008 (NAFO 2008). In the samplings done in the area known as Sackville Spur and in the southeast of the Flemish Cap, the greatest records of sponges were obtained with rock dredge/scallop gear and in the Box-corer dredges done in this area big sponges appeared in surface too (Figure 8). Small gorgonians and gorgonians fragments were recorded from the southeast of the Flemish Cap and south of the Flemish Pass meanwhile small sea pens were recorded in the northwest of the Flemish Cap and Flemish Pass.

Figure 8. Big sponges found in Mega Box-Corer samples

<u>CTD</u>

216 CTD stations were done during NEREIDA 2009 summer surveys. By survey, the number of stations was as follows:

NEREIDA 0509: 62

NEREIDA 0609: 76

NEREIDA 0709: 78

Figure 9 shows the location distribution of the CTD stations sampled during the three surveys. Red dots correspond to NEREIDA 0509, green dots to NEREIDA 0609 and blue dots to NEREIDA 0709.

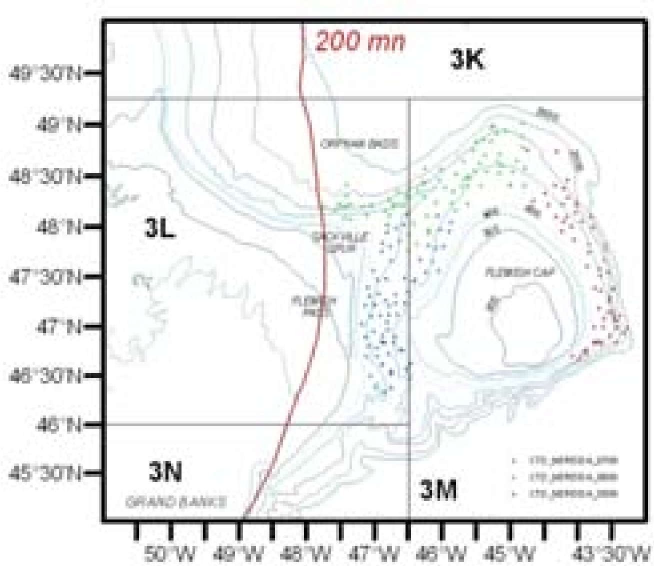

Figure 9.CTD stations.

Multibeam

Multibeam bathymetry provides a rapid means of determining the morphology of the seafloor. During NEREIDA cruises we used the new EM 302 multibeam to make one detailed map covering the eastern, northern and west area of the Flemish Cap from 700 to 2,000 m depth (Figure 9). On doing so we have recordered 356 bathymetric lines covering an area of 38,306 Km^2.

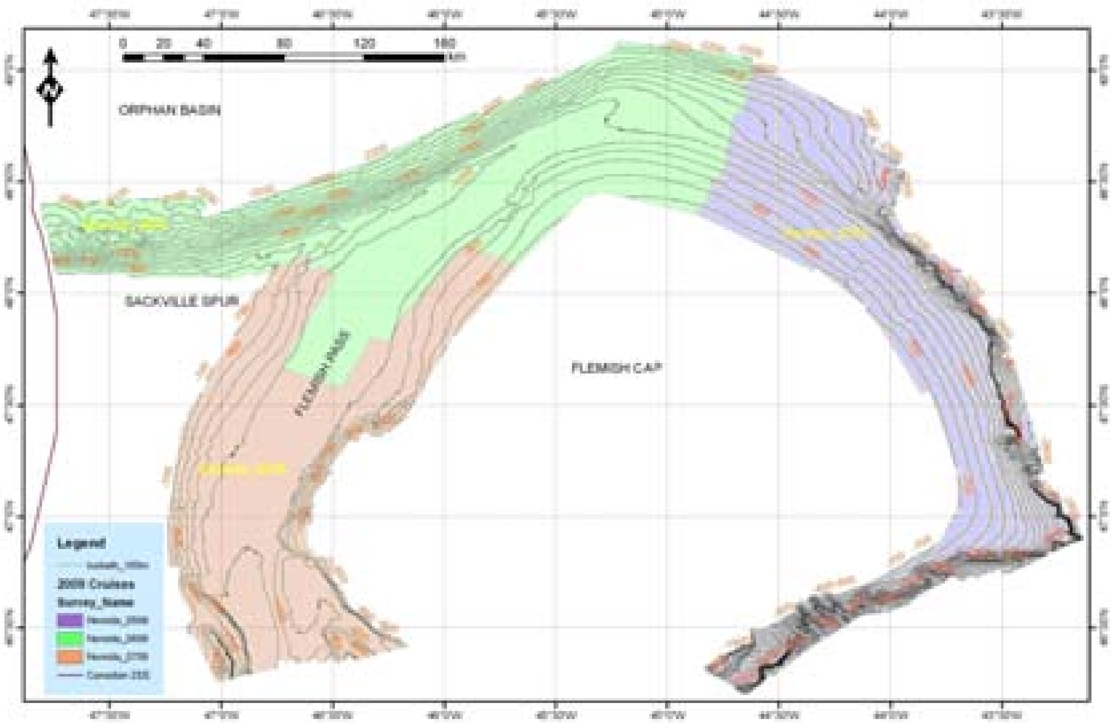

Figure 9. Map showing the area mapped during the NEREIDA cruises. Isobaths every 100 m. The mapping area shows a depth range from 620-2,300 m.

The eastern part of the area is characterized by an escarpment of 350.7 km in length and a depth range from 1300 m in the north to 1500 m in the eastern part. The general orientation is NW-SE in the northeaster part (216.3 km) and W-E in the south part (134.4 km). It shows a relief between 25 and 500 m. This deep escarpment shows some head of landslides.

The north western part is characterized by the presence of important scarps of sediment failures whose heads could be traced during more than 100 km, and their main form are rectilinear. These landslides are oriented to the north. There is other set of scarps of sediment failures whose morphology is mainly semi-circular with mean size of 10 km and their orientation is east and north-east.

The western part is marked by a trough in his central part with an average depth of 1,160 m in the north and 1,220 m in the south part. In its south end is characterized by the presence of a high that divides the main trough into two parts. The eastern branch of this trough has an average depth of 950 m, and the western branch 1,250 m. The high in the middle has its base at a depth of 1,200 m, and its crest at a depth of 590 m.

Approximately 510 seismic lines have been collected during NEREIDA surveys, including the lines logging during the transits between the different sample points. In a processing stage of the seismic data, it will be defined acoustic facies from the available TOPAS data in the Flemish Cap Area.

NEREIDA 2009: CCGS Hudson cruise

The Canadian research vessel *CCGS Hudson* joined the NEREIDA program to conduct benthic video surveys in the cVME areas and in areas closed for the protection of coral and sponge within the fishing footprint. The general cruise track of the 2009 mission (HUD2009-030) is indicated in Figure 10. That mission targeted sponge grounds in the Sackville Spur area and in Flemish Pass, and coral areas on Beothuk Knoll.

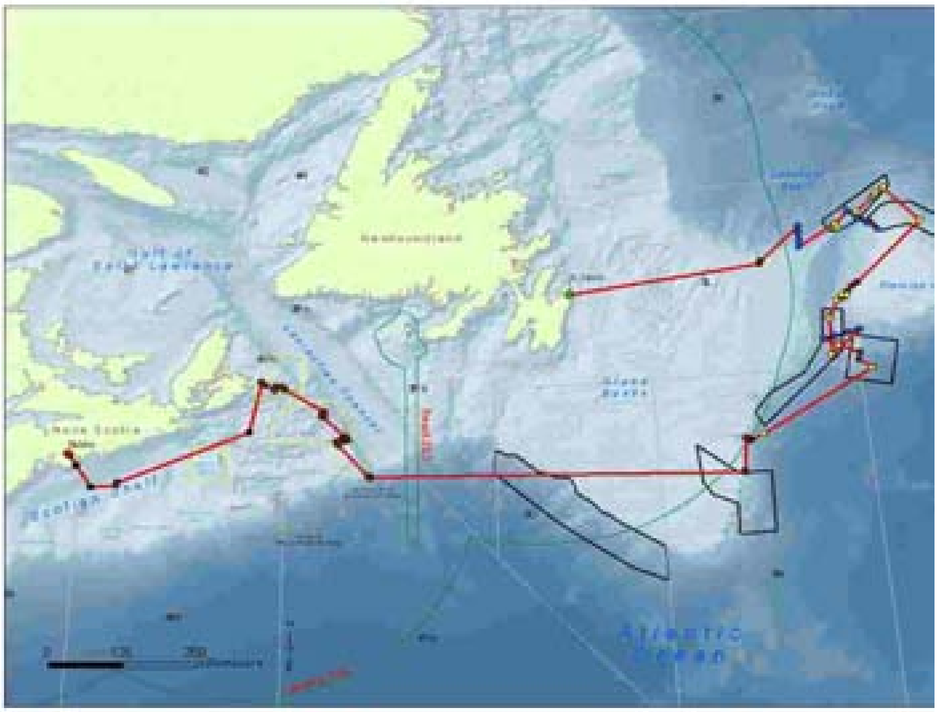

Figure 10. General cruise track of the CCGS Hudson during the 2009 NEREIDA mission.

High resolution video and still images to depths of ~1800 m were collected and 3 CTD lines were run, in addition to CTDs deployed on the video cameras, to collect oceanographic data. Over 200 different organisms were identified in preliminary analyses. All major VME component taxa were encountered but there were few sightings of live large gorgonians as expected from the selection of the survey areas. Evidence of trawl damage was seen on Beothuk Knoll. Two transect lines were run on Sackville Spur extending from the fished area (defined using the NAFO footprint –NAFO 2009a) to the unfished area. Figure 11 shows photos typical of the habitat observed. The upper photo shows the bottom typical of the fished area. The lower photo shows the bottom typical of the unfished area where sponge grounds were found. Sponge density appeared to increase eastward along the Spur. Sediments in some areas were black under the surface area suggesting hypoxia/anoxia. These video transects and photos confirmed the correlation between the research vessel data used to identify areas of significant sponge concentration (NAFO 2009b) and sponge density on the bottom. Two habitat types were found on the top of Beothuk Knoll. These are indicated in Figure 12 where the upper photo indicates the flat featureless bottom which was most prevalent. The lower photo shows rock patches that were scattered throughout. These rocks were colonized by a wide variety of species and the rock habitat appeared to have higher species diversity. In the video there are many images of trawl door marks over the surfaces. Trawl damage was evident as overturned rocks and boulders and as dead gorgonian stalks (Figure 13). In some areas rocks seemed to be piled up together. The NAFO fishing footprint indicates fishing over the top of the knoll (NAFO 2009a). Full analyses of these data will take a couple of years to complete and will await the 2010 field season where CCGS Hudson will again undertake photographic and video surveys of cVME areas in the NRA, this time targeting on the coral locations and Orphan Knoll.

Figure 11. Typical photos of benthic habitat on a portion of Sackville Spur illustrating the shallower fished (upper photo) and deeper unfished (lower photo) areas. *Geodia* sp. is illustrated in the lower photo.

Figure 12. Typical photos of benthic habitat on Beothuk Knoll illustrating the flat featureless bottom which was most prevalent (upper photo) and the rock patches (lower photo) that were scattered throughout.

Figure 13. Some illustrations showing damage to benthos on Beothuk Knoll. The left hand picture illustrates an overturned rock with adjacent trawl gouge. The right hand picture shows a dead bubblegum coral (*Paragorgia arborea*).

References

NAFO. 2009a. Delineation of Existing Bottom Fishing Areas in the NAFO Regulatory Area. Serial No. N5676. NAFO Fisheries Commission Document 09/21, 9pp.

NAFO. 2009b. Report of the NAFO Scientific Council Working Group on Ecosystem Approach to Fisheries Management (WGEAFM) in Response to Fisheries Commission Request 9b and c. Serial No. N5627. NAFO Scientific Council Summary Document 09/6, 25pp.

NEREIDA 2010: CCGS Hudson cruise

In July 2010 a deep-sea research survey will be conducted to survey sites on Flemish Cap, Orphan Knoll and Tobin's Point. Sample collection will focus on surficial geology/corals, benthic biogeography, and fish ecology.

On Flemish Cap, numerous VMEs will be investigated including southern, eastern and northern portions surveyed in 2009 by NEREIDA survey. On Orphan Knoll, several features will be investigated including; Orphan Seamount, Southeast Ridge, Dredged Mounds, and Crater Canyon. On Tobin's Point, continental edge and slope off Northeast Newfoundland Shelf, three sites will be investigated including two shallow water sites and one deep.

An approximate track for this survey is provided in Figure 14.

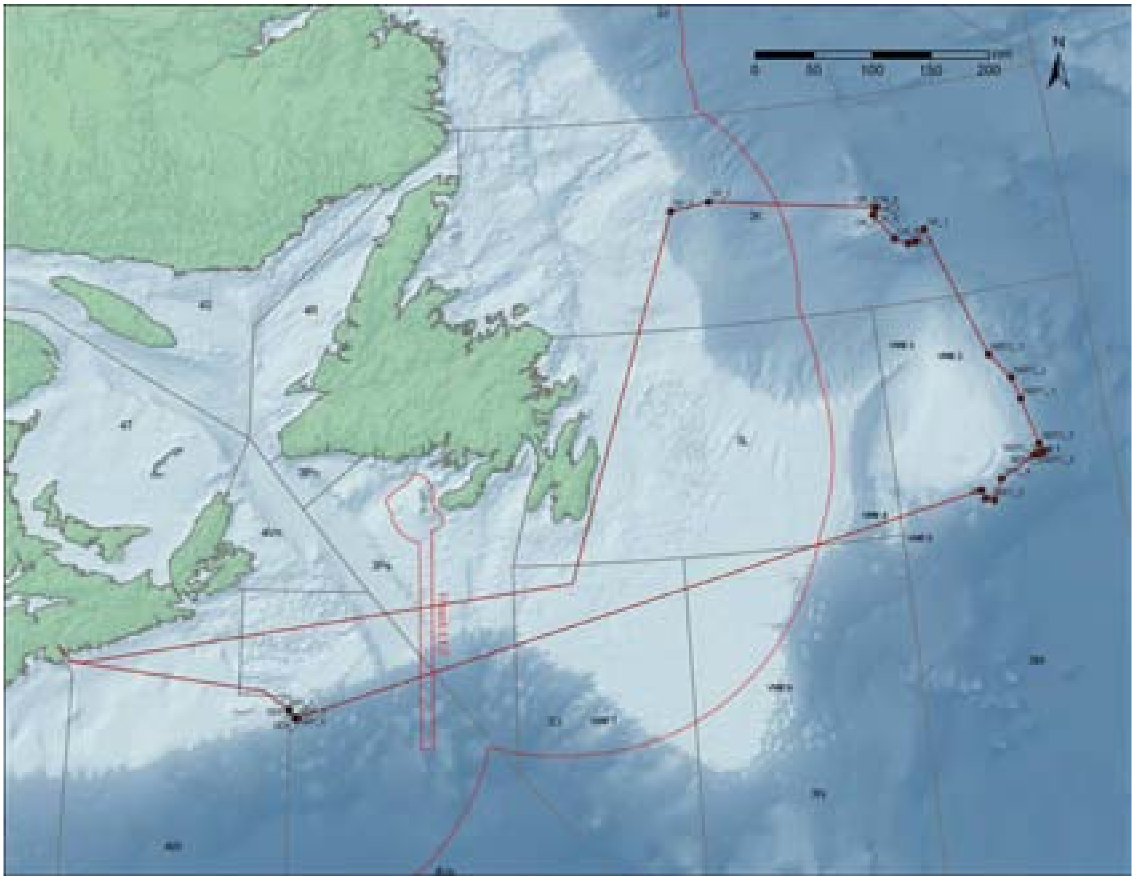

Figure 14. Approximate track for the CCGS Hudson survey in 2010.

Preliminary results on sponges and corals around Greenland

The Joint ICES/NAFO Working Group on Deepwater Ecology presented information on the distribution of sponge grounds in the North Atlantic (ICES 2009) and called for information from two areas where data were sparse: The coasts of Greenland and the Northeast USA. At the June 2009 meeting of the Scientific Council, Dr. Manfred Stein offered to take a benthic taxonomist on the 2009 German survey of Greenlandic cod and redfish stocks with the purpose of identifying benthic invertebrate taxa. Megan Best from the Department of Fisheries and Oceans, Dartmouth, Canada formed part of the scientific crew of the Walther Herwig III (mission WH-327). The survey of took place off the coast of Greenland and along the continental slope, with maximum trawl depths of approximately 400m. A total of 68 tows were completed using a 140-foot trawl net in standard configuration (Polyvalent boards, 1500 kg, 4.5 m^2). Out of these, 64 tows yielded data collected for the purpose of identifying and analysing benthic invertebrate compositions, with an emphasis placed on sponges (Phylum Porifera), and corals (Phylum Cnidaria, Class Anthozoa and Class Hydrozoa, Family Stylasteridae) as particularly vulnerable components of benthic ecosystems. Preliminary analyses of the data show 74 sponge species and 9 coral/hydrocoral taxa. The most commonly encountered sponge was Tetilla cranium (N=38 tows), while the largest biomass was produced by the large ball sponge Geodia barretti. The soft coral Duva florida was the most frequently encountered of the coral/hydrocoral taxa (N=23), while the greatest biomass was collected from another soft coral, Drifa groenlandica. One tow (Station 1144) yielded specimens of the reef-forming coldwater coral Lophelia pertusa. Preliminary results of the coral/hydrocoral and sponge species composition of the catches (Figure 15) indicates differences between the east and west coasts of Greenland. These data will be presented in more detail to the Joint ICES/NAFO Working Group on Deepwater Ecology at their March 2010 meeting.

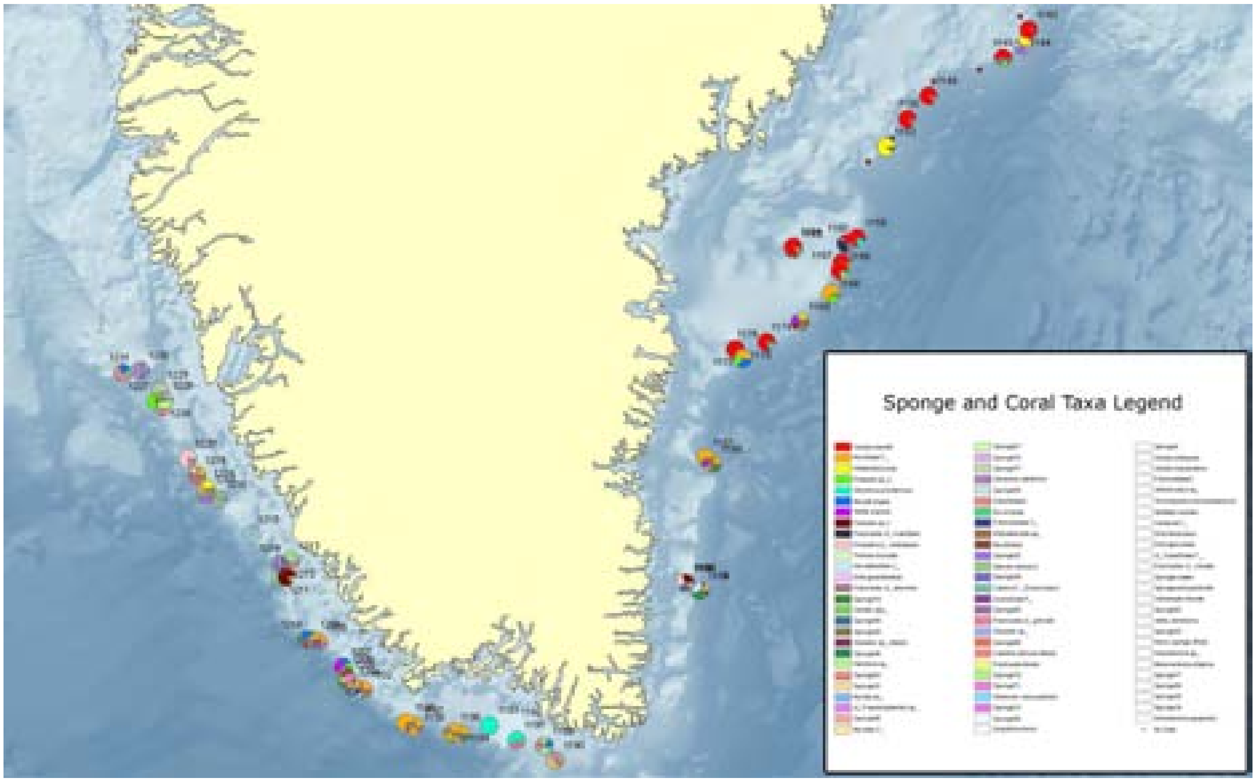

Figure 15. Proportion of sponge and coral taxa per haul (subsample) collected during the 2009 annual German survey of east and west Greenland for Greenlandic cod and redfish.

References

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.

ERI-NEREUS:Program overview

In Canada, the federal department responsible for ensuring the sustainable development and safe use of Canadian waters is Fisheries and Oceans Canada (DFO). DFO's mission is to deliver three strategic outcomes: a) safe and accessible waterways, b) healthy and productive aquatic ecosystems, and c) sustainable fisheries and aquaculture. DFO is committed to achieve these outcomes through the development of integrated management approaches.

In line with this commitment, the provision of scientific support for ecosystem-based management has been identified as high priority for DFO Science Branch. This prompted the development of an ecosystem science framework (DFO 2007, web access at www.dfo-mpo.gc.ca/science/Publications/ecosystem/index-eng.htm), which is being implemented through a 5-yr research plan (DFO 2008, web access at www.dfo-mpo.gc.ca/science/Publications/fiveyear-plan-quinquennal/index-eng.html). This plan provides a rationale for what research is conducted in support of priority areas, especially ecosystem-based management, and how this research will be delivered to ensure federal and departmental priorities are addressed while accounting for regional differences.

Within this plan, identified priority areas are addressed through national Centres of Expertise (CoEs, see www.dfo-mpo.gc.ca/science/coe-cde/index-eng.htm) and the Ecosystem Research Initiative (ERI) (DFO 2008). This initative addresses geographical differences through ecosystem research programs tailored to tackle regional requirements and local priorities. In Newfoundland and Labrador (NL), the regional ERI is the NEREUS program (Newfoundland-Labrador's Expanded Research on Ecosystem-relevant but Under-surveyed Splicers).

NEREUS conceptual underpinning is the recognition that any assessment of the potential impacts of human activities on the Newfoundland and Labrador (NL) ecosystem requires a basic understanding of how the different components of this ecosystem are spliced and how these connections are modulated. Our current understanding of the NL ecosystem is still rudimentary, and our ability to predict how human activities might impact various components of the ecosystem will depend on acquiring a much better understanding of how these components are actually connected. Therefore, **i**mplementing ecosystem approaches to fisheries and integrated management would require an operational understanding of ecosystem functioning.

A starting point towards this understanding is to develop basic quantitative knowledge of what are the main channels and fluxes of energy in the Newfoundland-Labrador ecosystem, how these fluxes are regulated, where the energy is stored, and how environmental conditions affect these processes. Ongoing monitoring activities in the Newfoundland-Labrador ecosystem were not sufficient to address these questions, and hece, NEREUS identified some major themes that needed to be covered to begin addressing them. More concretely, NEREUS has two general goals:

1) enhance the capability of NL surveys for providing information on ecosystem status and main trends by focusing work on forage fishes, non-commercial species, major benthic components and trophic interactions;

2) integrate this (and other) information to identify and track main pathways of energy in the Newfoundland-Labrador shelf ecosystem.

ERI-NEREUS builds onto other regional and national initiatives. It relies on and collaborates with DFO's Atlantic Zone Monitoring Program (AZMP, see www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/index-eng.html) to cover physical and biological oceanography aspects of the ecosystem (physics and lower trophic levels), while it relies on input and collaborations on marine mammals from DFO's Centre of Expertise in Marine Mammals (CEMAM, see http://www.dfo-mpo.gc.ca/science/coe-cde/cemam/index-eng.html). It is also linked to DFO's Centre for Ocean Model Development for Applications (COMDA) through its connection with the Canada-Newfoundland Operational Ocean Forecasting System (C-NOOFS) project, which provides NEREUS with computing infrastructure for numerically intensive modelling. NEREUS is also working together with Universities and other research institutions from Canada and abroad in topics related to acoustic estimation of pelagic fish, modelling top predator-fish interactions, analysis of trends in marine communities, and fish diet studies, among others. In relation to management, results from NEREUS activities and research are intended to contribute towards the provision of science advice both nationally in Canada as well as internationally through participation in organizations like NAFO and ICES. Preliminary results from some of NEREUS components were presented and discuss in this WGEAFM meeting.

References

DFO 2007. A new ecosystem science framework in support of integrated management. Fisheries and Oceans Canada DFO/2007-1296: 1-16.

DFO 2008 Fisheries and Oceans Canada Five-Year Research Plan (2008-2013). Fisheries and Oceans Canada DFO/2008-1525: 1-23.

ERI-NEREUS Acoustic Survey Component: Editing and processing of acoustic data

As part of the DFO Ecosystem Research Initiative (ERI), acoustic data were collected during the 2008 and 2009 fall multi-species bottom trawl surveys conducted in NAFO Divisions 2J3KLNO. The main goal of this project component, carried out in collaboration by Drs. L.G.S. Mello and G.A. Rose (Memorial University, St. John's, NL), and DFO scientists is to improve the knowledge of the distribution and abundance of key species on the Newfoundland and Labrador continental shelf, particularly pelagic forage fish species. Presented is the methodological approach and initial results of the acoustic data collection and editing from the 2008 survey. This survey was conducted between 3 October - 21 December utilizing three vessels (CCGS Teleost, A. Needler, W. Templeman). During the survey 560 random stratified fishing tow stations were occupied and tows conducted using a Campelen bottom trawl. Acoustic data were collected continuously at and between fishing tow stations using a hull-mounted split beam 38 kHz transducer and a Simrad EK500 or EK60 echo-sounder. Approximately 14400 km of track were acoustically surveyed. The acoustic data (echograms) were edited using Echoview (version. 4.3). Seafloor depth was determined for each ping as the depth of the maximum Sv (dB), back-stepped to -48 dB. Manual adjustments to the bottom pick line were conducted when necessary (lost bottom signal). Acoustic backscatter was classified as one of 6 speciated categories (capelin, sandlance, herring, cod, redfish, myctophids), or one of 4 unspeciated categories (shrimp, zooplankton, demersal and pelagic fish), or unclassified. Backscatter was assigned to classes according to echo-traces (shapes, intensity), single fish TS and trawl catch data. Track sections with noisy and attenuated acoustic signal (bubble attenuation, white noise) were identified and classified as bad (unusable) data. The ratio of good to bad data pings was calculated for each 100 m segment of survey track. In the whole dataset, 60% of the 100 m horizontal intervals contained entirely good data and only 9% of intervals contained less than 50% good pings. For a the subset of the data collected during fishing tows on the W. Templeman and A. Needler (data from the Teleost were contaminated by the navigational sounder), 50% of the intervals contained 100% good data, while only 4% contained less than 50% good pings.

Acoustic backscatter was integrated in 100 m long by 10 m deep bins along the survey track producing backscatter area estimates (sa (m2/m2)) for each classification type. These estimates were subsequently summed across the water column. Nearly half of the bins containing backscatter were considered to be 'unspeciated zooplankton', 10-13% were classified either as redfish, myctophids or capelin, with the other classes accounting each for 1-6%. The spatial distribution and intensity of the backscatter indicated that capelin, sandlance, redfish, myctophids and to a lesser extent cod were detected as dense and small aggregations in areas adjacent to the Grand Bank (3LNO). While cod and redfish often overlapped, the distributions of capelin and sandlance were quite distinct. In the northern areas (2J3K), most capelin and cod backscatter tended to be more dispersed through the shelf, with mostly lower values (lower densities), except for cod in the Bonavista Corridor (3K) (found aggregated in a few areas), and capelin in near-shore areas of 2J. Sandlance was practically absent from these northern strata. Redfish and myctophids tended to be found in the deeper water along the shelf slope as relatively dense and continuous layers of fish. Overall a lower degree of overlap among the different classes was observed in 2J3K. As expected, bottom trawl catch data for redfish and cod tended to corroborate the results of the acoustic data, (largest catches in 3NO and in the Bonavista Corridor, respectively). Trawl catches and acoustic backscatter of the other classes were less strongly related, although trawl catch was useful in helping interpret acoustic signal.

Some of the problems encountered during the analysis include (1) signal contamination mainly in northern strata and later in the season (e.g. acoustic backscatter from vessel depth sounder, trawl sensors), turbulence and bubble attenuation in shallow water caused by vessel propellers and bad weather; (2) no useful data (Teleost surveys); (3) missing data (no TS data stream) from some of the A. Needler surveys; and (4) difficulties in interpreting and partitioning the acoustic signal of capelin, sandlance, and zooplankton due to the lack of biological samples in the pelagic domain.

Forthcoming acoustic analysis will focus on (1) producing estimates of abundance (and CI) and distribution of key pelagic (capelin and sandlance), demersal (cod, redfish) and other species (myctophids, euphausiids) in the study area; (2) exploring novel ways to use the data: (i) ID appropriate data use for each file (presence/absence or abundance estimation), (ii) researching and testing of methods for use of acoustic data in conjunction with trawl data to estimate the abundance and distribution of key species or groups of species, (iii) determining indices of vertical availability to trawl of key species, (iv) developing methods of quantifying spatial distribution patterns as they may relate to trawl and acoustic sampling (e.g. changes in autocorrelation and hyper-aggregation of fish schools).

ERI-NEREUS Grab Sampling Program: Initial results

Background and methodology

In 2008, a trial benthic grab sampling program was carried out as a component of the NL region ecosystem research initiative. Primary objectives of a potential long term sampling program are to study patterns of biomass in the benthos in relation to major faunal groups and trophic levels in order to provide indicators of patterns of energy flow, including sinks, through the benthos in the Grand Banks ecosystem. Samples from 2008 have been processed and preliminary data analyses carried out. Samples were collected on board Fisheries & Oceans multispecies survey trawlers (CCGS *Wilfred Templeman* and *Teleost*). Samples were collected with a 0.1 m^2 Van Veen grab. The sampling design consisted of one grab station per DFO survey stratum. These depth stratified areas are for the purpose of selecting trawl set locations during the twice yearly multispecies surveys. Grab sampling was carried out at depths $\leq$ 200 m over a large area of the Grand Banks. At each station, technicians collected a maximum of four successful samples to a maximum of seven attempts. Samples were pre-processed on board in the following manner. Prior to sieving, the proportion of the sample comprising various sediment classes (Wentworth scale) was estimated, while sediment depth was measured for subsequent sample volume determinations. The sample was then washed using seawater through a 1 mm mesh screen. All material (sediment and fauna) retained on the screen was fixed in 10% formalin/seawater solution and sealed in plastic buckets. On-shore, fauna were identified to lowest practical taxonomic level by a private commercial lab. Total faunal weights and numbers were determined for each taxon.

Results and Discussion

A total of 65 grab samples were collected during the spring 2008 survey. Overall, sample volumes were low (<5 L) indicating low penetration into the sediment which is typical on relatively dense sand bottoms on the Grand Banks using this gear type. Average sample biomass was approximately 137 g/m^2 which is similar to biomass recorded by Nesis (1965), the only other comparable study for the Grand Banks in terms of sampling over a large geographic area (Fig. 16). The best estimate of benthic biomass is obtained with the hydraulic grab sampler (DFO- Fishing Impacts). With the hydraulic grab, penetration depths of up to 25 cm are achieved, resulting in collection of deeper burrowing, large bivalves (e.g. the PropellerClam, *Cyrtodaria siliqua*). An average biomass of approximately 1 kg/m^2 was recorded from a sandy bottom on the Northeast Grand Bank. In contrast, mechanical grab samplers such as the Van Veen typically have much shallower penetration depths. A total of 267 taxa were recorded.

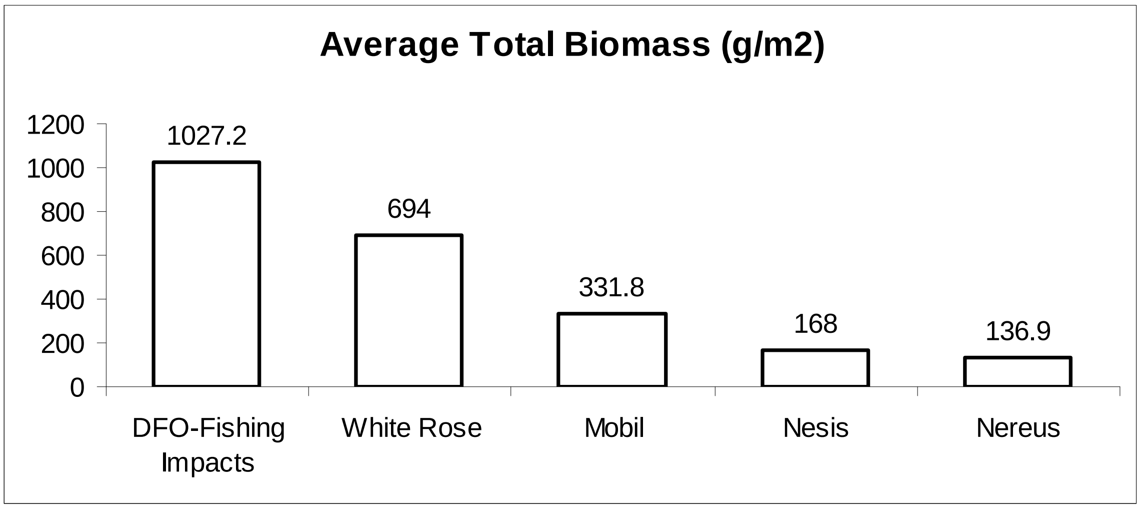

Figure 16. Average benthic invertebrate biomass from locations on the Grand Banks determined from grab samplers. A) DFO fishing impacts (Kenchington et al. 2001). 0.5 m^2 hydraulic video grab, B)White Rose 08- average wet weight biomass g/m2 based on pooling two 0.1 m^2 samples. N=47. Sampler was a 35.6 cm diam corer, C) Mobil (Hutcheson et al 1981). 0.1 m^2 van veen. Average annual standing crop at 4 stations, D) Nesis (1970) average biomass (m^2) at depths 100-200 m. Grab used was a bottom scoop 'Ocean 50' sample area 0.25 m2, and E) ERI-NEREUS- 0.1 m^2 Van Veen grab. Note: all biomass estimates are standardized to 1 m^2

The breakdown of number of taxa by phylum and class are listed in Table 4. Polychaete taxa dominated (43%) followed by amphipods (16%), gastropods (10%) and bivalves (7%). A permuted accumulation curve shows the increasing total number of different species observed (Sobs) as samples are pooled in random order, this being carried out 999 times and the resulting curves averaged, giving a smoothed curve. The shape of the curve indicated that an asymptote had not been reached after processing 65 grab samples (Fig. 17). This not surprising given that samples were taken over a large geographic area and species sampling saturation is unlikely given the sample number.

Table 4. Numbers of taxa, by phylum and class, identified in the 2008 NEREUS program benthic grab samples.

ANNELIDA		
	Polychaeta	116
	Oligochaeta	1
ARTHROPODA		
	Amphipoda	43
	Cumacea	13
	Isopoda	6
	Cirripedia	1
	Mysidacea	1
	Decapoda	1
MOLLUSCA		
	Gastropoda	27
	Bivalvia	18
	Scaphopoda	1
	Polyplacophora	1
ECHINODERMATA		
	Stelleroidea	5
	Echinoidea	3
	Holothuroidea	3
CNIDARIA		
	Anthozoa	11
	Hydrozoa	1
NEMERTEA		4
SIPUNCULIDA		2
PRIAPULIDA		
	Aschelminthes	3
HEMICHORDATA		1
CHORDATA		
	Ascidiacea	5
TOTAL	267	

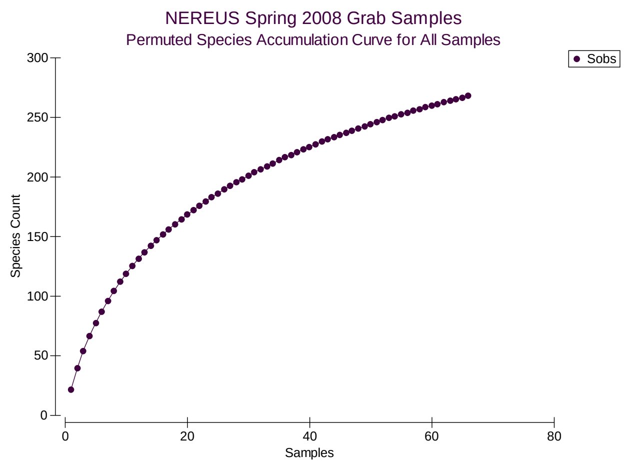

Figure 17. Average species accumulation curve based on 999 permutations for all samples collected in the 2008 spring survey (PRIMER software).

Of the 267 taxa recorded, 252 could be assigned to specific trophic groups based on the literature. Assignment of taxa to trophic groups was achieved by utilizing the species taxonomic database compiled over time by the taxonomy lab at the Bedford Institute of Oceanography. Taxa`collected to date belong to 15 different trophic groups (diets or diet combinations) (Fig. 18). Surface deposit feeders (22%) and carnivores (29%) dominated all species (Fig. 18, Table 5). Highest average sample biomass was dominated by surface deposit feeders and carnivores (e.g. species of gastropods, polychaetes and amphipods) (Fig. 19). Eight trophic groups contributed very marginally to biomass. Of note, these groups represent combinations of diets, unlike the biomass dominant groups.

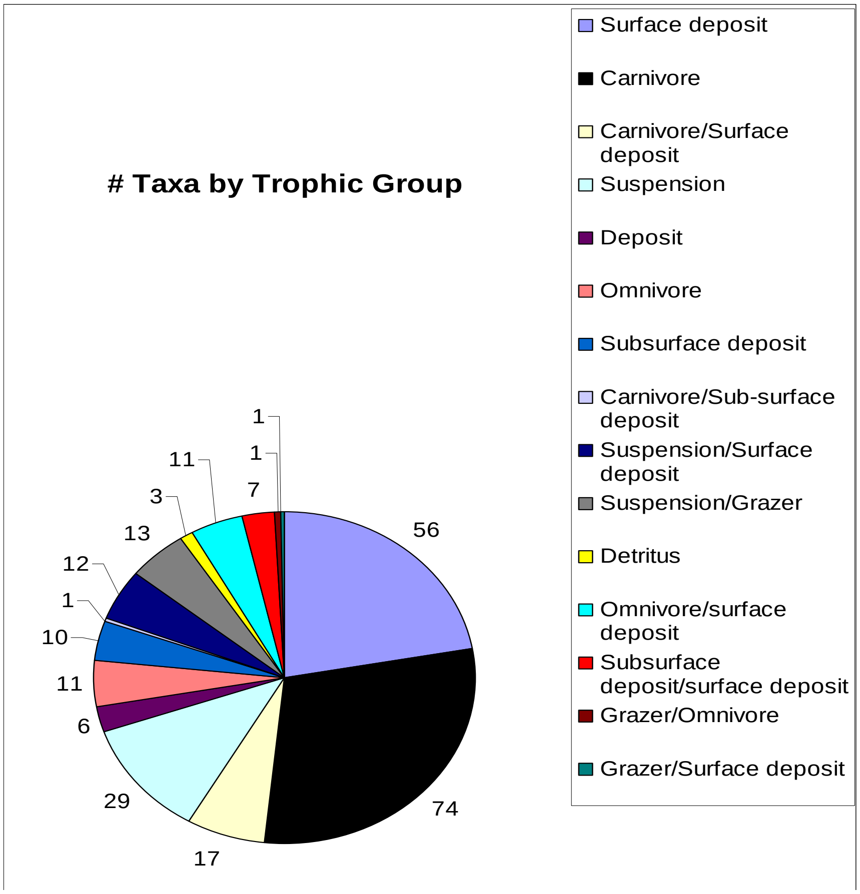

Figure 18. Number of taxa by trophic group recorded from the spring 2008 grab samples.

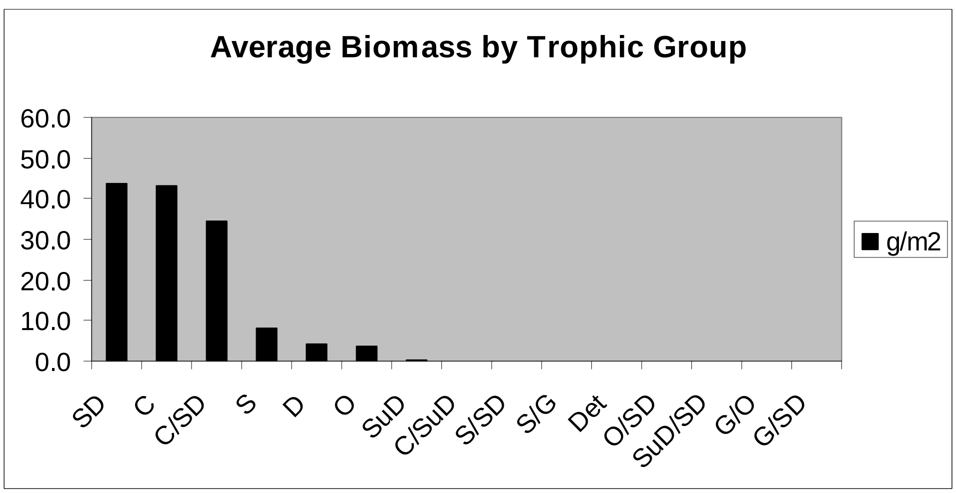

Figure 19. Average biomass of benthos by trophic group.

Trends in community structure based on taxa biomass were explored. Non-metric multidimensional scaling ordination of species biomass showed that grab samples were, in some cases, distinctly clustered by strata which, at this point, should not be attributed to stratum differences without further sampling. (Fig. 20). Points closest together on the 2-D plot are most similar in terms of community structure. As a means of further exploring trends in the data, ordinations of the samples (Fig. 20) were superimposed with depth and % gravel variables in the form of bubble plots indicating magnitude of these variables. It is observed that samples with a high gravel content were grouped separately from samples from predominantly sand (Fig. 21) although this was somewhat confounded with water depth (Fig. 22). Nonetheless, the differences in community composition between areas that are sand bottom vs. high percentage of gravel are expected. Based on the success of the 2008 sampling program, sampling was again carried out in 2009. These samples have now been processed but the data is yet to be analyzed. A distinct outcome of the program to date is that while sampling has yielded a diverse array of species, dominated by small surface-dwelling taxa, it has likely under sampled deeper, larger taxa, particularly bivalves in some cases. The implementation of this grab sampling program has presented numerous challenges, particularly from a logistical standpoint. Foremost among these are the harsh conditions (sea state, wind) encountered in the offshore environment. While grab sampling was attempted during the fall 2008 survey, this was largely unsuccessful due to high winds and sea state and, as a result, the sampling program has been scaled back to the spring survey when conditions are more favourable. A second major challenge has been setting up an on-board processing system on vessels not designed as a scientific sampling platform, for which most available deck space is taken up for trawl gear deployment and storage.

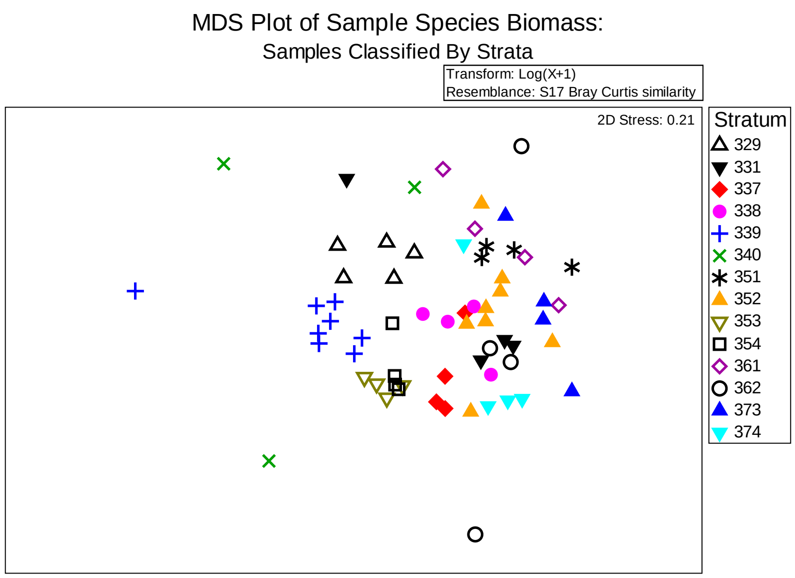

Figure 20. nMDS plots of species biomass by stratum.

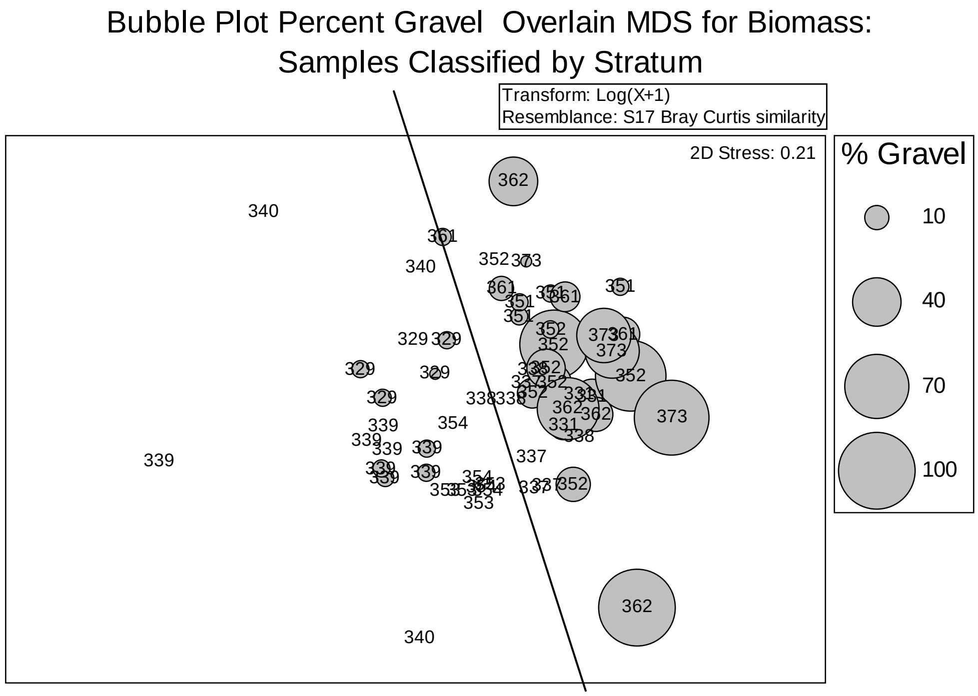

Figure 21. nMDS plots of species biomass. Points represent grab samples and numbers are strata. Bubble plots overlain samples indicate relative proportions of gravel in the samples.

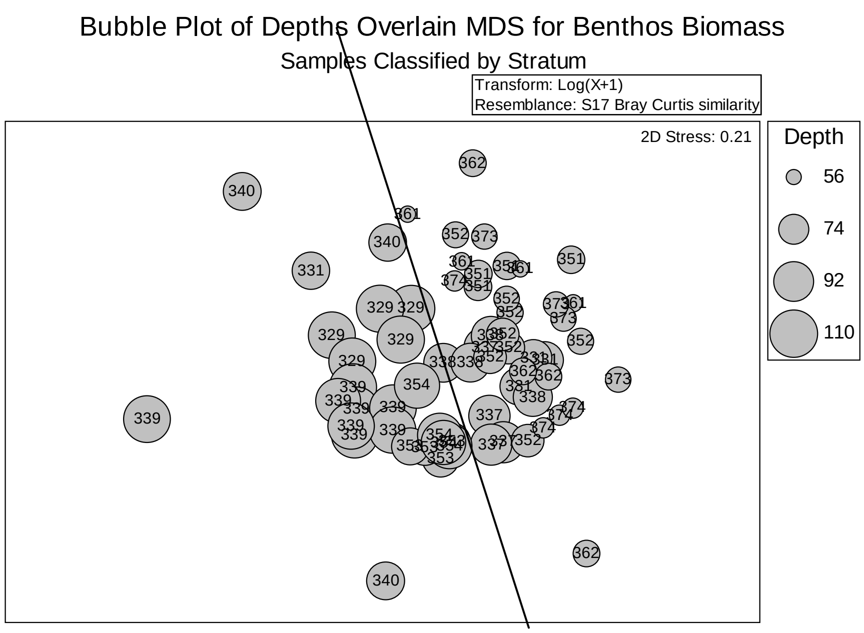

Figure 22. nMDS plots of species biomass. Points represent grab samples and numbers are strata. Bubble plots overlain samples indicate depth intervals from which samples were taken.

Table 5. Species identified in the 2008 grab sampling program by trophic group. D:deposit feeder, C: carnivore, G/SD: grazer and surface deposit feeder, O: omnivore, SD:surface deposit feeder SuD: subsurface deposit feeder, S: suspension feeder, G/O: grazer, omnivore, C/SD: carnivore and surface deposit feeder, SuD/SD- subsurface deposit, surface deposit feeder, and Det: detritivore.

Phylum	Class	Family	Genus	Species	Trophic group
Mollusca	Gastropoda	Buccinidae	*Buccinidae*	*unid*	C
Mollusca	Gastropoda	Buccinidae	*Colus*	*stimpsoni?*	C
Mollusca	Gastropoda	Retusidae	*Cylichna*	*alba*	C
Mollusca	Gastropoda	Naticidae	*Lunatia*	*pallida*	C
Mollusca	Gastropoda	Naticidae	*Natica*	*clausa*	C
Mollusca	Gastropoda	Naticidae	*Naticidae*	*unid*	C
Mollusca	Gastropoda	Turridae	*Oenopota*	*turricula*	C
Mollusca	Gastropoda	Turridae	*Oenopota*	*violacea*	C
Mollusca	Gastropoda	Turridae	*Oenopota*	*sp*	C
Mollusca	Gastropoda	Retusidae	*Retusa*	*obtusa*	C
Mollusca	Gastropoda	Retusidae?	*Retusidae?*	*unid*	C
Annelida	Polychaeta	Ampharetidae	*Aglaophamus*	*circinata*	C
Annelida	Polychaeta	Polynoidae	*Arcteobia*	*anticostiensis*	C
Annelida	Polychaeta	Phyllodocidae	*Eteone*	*longa*	C
Annelida	Polychaeta	Phyllodocidae	*Eumida*	*sanguinea*	C
Annelida	Polychaeta	Phyllodocidae	*Eumida*	*sp*	C
Annelida	Polychaeta	Goniadidae	*Goniada*	*maculata*	C
Annelida	Polychaeta	Polynoidae	*Harmothoe*	*extenuata*	C
Annelida	Polychaeta	Polynoidae	*Harmothoe*	*fragilis*	C
Annelida	Polychaeta	Polynoidae	*Harmothoe*	*imbricata*	C
Annelida	Polychaeta	Lumbrineridae	*Lumbrineris*	*fragilis*	C
Annelida	Polychaeta	Lumbrineridae	*Lumbrineris*	*impatiens*	C
Annelida	Polychaeta	Lumbrineridae	*Lumbrineris*	*tenuis*	C
Annelida	Polychaeta	Lumbrineridae	*Lumbrineris*	*sp*	C
Annelida	Polychaeta	Nephtyidae	*Nephtys*	*caeca*	C
Annelida	Polychaeta	Nephtyidae	*Nephtys*	*ciliata*	C
Annelida	Polychaeta	Nephtyidae	*Nephtys*	*discors?*	C
Annelida	Polychaeta	Nephtyidae	*Nephtys*	*incisa*	C
Annelida	Polychaeta	Nephtyidae	*Nephtys*	*longosetosa*	C
Annelida	Polychaeta	Nephtyidae	*Nephtys*	*sp*	C
Annelida	Polychaeta	Capitellidae	*Notomastus*	*latericeus*	C
Annelida	Polychaeta	Pholoidae	*Pholoe*	*minuta*	C
Annelida	Polychaeta	Phyllodocidae	*Phyllodoce*	*groenlandica*	C
Annelida	Polychaeta	Phyllodocidae	*Phyllodoce*	*mucosa*	C
Annelida	Polychaeta	Phyllodocidae	*Phyllodoce*	*sp*	C
Annelida	Polychaeta	Phyllodocidae	*Phyllodocidae*	*unid*	C
Echinodermata	Stelleroidea	Goniopectinidae	*Ctenodiscus*	*crispatus*	C
Echinodermata	Stelleroidea	Asteriidae	*Leptasterias*	*polaris*	C
Echinodermata	Stelleroidea	Ophiuridae	*Ophiura*	*sarsi*	C
Echinodermata	Stelleroidea	Ophiuridae	*Ophiura*	*sp*	C
Echinodermata	Stelleroidea	Ophiuridae	*Ophiura*	*robusta*	C
Arthropoda	Crustacea	Lysianassidae	*Aceroides*	*latipes*	C

Arthropoda	Crustacea	Uristidae	*Anonyx*	*laticoxae*	C
Arthropoda	Crustacea	Uristidae	*Anonyx*	*lilljeborgi*	C
Arthropoda	Crustacea	Uristidae	*Anonyx*	*nugax*	C
Arthropoda	Crustacea	Uristidae	*Anonyx*	*ochoticus?*	C
Arthropoda	Crustacea	Uristidae	*Anonyx*	*sp*	C
Arthropoda	Crustacea	Lysianassidae	*Hippomedon*	*propinquus*	C
Arthropoda	Crustacea	Lysianassidae	*Orchomenella*	*minuta*	C
Arthropoda	Crustacea	Lysianassidae	*Psammonyx*	*terranovae*	C
Arthropoda	Crustacea	Idoteidae	*Chiridotea*	*caeca*	C
Arthropoda	Crustacea	Munnidae	*Pleurogonium*	*spinossissimum*	C
Arthropoda	Crustacea	Idoteidae	*Synidotea*	*nodulosa*	C
Arthropoda	Crustacea	Idoteidae	*Idoteidae*	*sp A*	C
Arthropoda	Crustacea	Oregoniidae	*Hyas*	*coarctatus*	C
Nemertea	Anopla	Lineidae	*Cerebratulus*	*lacteus*	C
Nemertea	Anopla	Lineidae	*Lineus?*	*sp*	C
Nemertea	Anopla	Lineidae	*Micrura?*	*sp*	C
Nemertea	Nemertea		*Nemertean*	*unid*	C
Platyhelminthes			*Flatworm*	*sp A*	C
Cnidaria	Anthozoa	Nephthyidae	*Gersemia*	*rubiformis*	C
Cnidaria	Anthozoa	Nephthyidae	*Gersemia?*	*sp A*	C
Cnidaria	Anthozoa	Actinidae	*Bunodactis?*	*stella*	C
Cnidaria	Anthozoa	Edwardsiidae	*Edwardsia*	*elegans*	C
Cnidaria	Anthozoa		*Anemone*	*unid juv*	C
Cnidaria	Hydrozoa		*Hydroid*	*polyp A*	C
Cnidaria	Hydrozoa		*Hydroid*	*unid juv*	C
Aschelminthes	Nematoda		*unid*		C
Arthropoda	Crustacea		*Tanaid*	*A*	C
Arthropoda	Crustacea		*Tanaid*	*sp 1*	C
Arthropoda	Crustacea		*Tanaid*	*sp 2*	C
Arthropoda	Crustacea		*Tanaid*	*sp 3*	C
Arthropoda	Crustacea		*Tanaid?*	*unid*	C
Annelida	Polychaeta	Polygordiidae	*Polygordius*	*sp A*	C
Annelida	Polychaeta	Aphroditadae	*Aphrodita*	*hastata*	C/SD
Annelida	Polychaeta	Syllidae	*Exogone*	*dispar*	C/SD
Annelida	Polychaeta	Syllidae	*Exogone*	*hebes*	C/SD
Annelida	Polychaeta	Syllidae	*Exogone*	*verugera*	C/SD
Annelida	Polychaeta	Hesionidae	*Gyptis*	*vittata*	C/SD
Annelida	Polychaeta	Hesionidae	*Hesionidae*	*sp A*	C/SD
Annelida	Polychaeta	Spionidae	*Scolelepis*	*squamatus*	C/SD
Annelida	Polychaeta	Orbiniidae	*Scoloplos*	*acutus*	C/SD
Annelida	Polychaeta	Orbiniidae	*Scoloplos*	*armiger*	C/SD
Annelida	Polychaeta	Orbiniidae	*Scoloplos*	*sp*	C/SD
Annelida	Polychaeta	Spionidae	*Spionidae*	*unid*	C/SD
Annelida	Polychaeta	Syllidae	*Syllidae*	*unid*	C/SD
Echinodermata	Echinoidea	Echinarachnidae	*Echinarachnius*	*parma*	C/SD
Arthropoda	Crustacea		*Ostracoda*	*sp A*	C/SD
Arthropoda	Crustacea		*Ostracoda*	*sp B*	C/SD
Arthropoda	Crustacea		*Ostracoda*	*sp C*	C/SD
Arthropoda	Crustacea		*Ostracoda*	*sp*	C/SD
Annelida	Polychaeta	Glyceridae	*Glycera*	*capitata*	C/SuD

Mollusca	Gastropoda	Aporrhaidae	*Aporrhais*	*occidentalis*	D
Mollusca	Gastropoda	Epitoniidae	*Couthouyella?*	*striatula*	D
Mollusca	Gastropoda	Turritellidae	*Tachyrhynchus*	*reticulatus?*	D
Mollusca	Gastropoda	Turritellidae	*Tachyrhynchus*	*erosus*	D
Sipuncula		Phascolionidae	*Phascolion*	*strombi*	D
Sipuncula			*Sipunculid*	*unid juv*	D
Arthropoda	Crustacea	Calliopiidae	*Apherusa*	*megalops*	Det
Arthropoda	Crustacea	Idoteidae	*Edotea*	*montosa*	Det
Mollusca	Polyplacophora	Ischnochitonidae	*Ischnochiton*	*albus*	G/O
Mollusca	Gastropoda	Lepetidae	*Lepeta*	*caeca*	G/SD
Mollusca	Gastropoda	Trochidae	*Margarites*	*groenlandicus*	O
Mollusca	Gastropoda	Trochidae	*Moellaria*	*costulata*	O
Mollusca	Gastropoda	Trochidae	*Moellaria?*	*sp A*	O
Mollusca	Gastropoda	Trochidae	*Solariella*	*varicosa*	O
Mollusca	Gastropoda	Trochidae	*Solariella?*	*sp*	O
Annelida	Polychaeta	Dorvilleidae	*Dorvilleidae*	*A*	O
Annelida	Polychaeta	Onuphidae	*Nothria*	*conchylega*	O
Annelida	Polychaeta	Dorvilleidae	*Parougia*	*caeca*	O
Annelida	Polychaeta	Dorvilleidae	*Protodorvillea*	*gaspeensis*	O
Echinodermata	Echinoidea	Strongylocentrotidae	*Strongylocentrotus*	*pallidus*	O
Echinodermata	Echinoidea	Strongylocentrotidae	*Strongylocentrotus*	*sp*	O
Arthropoda	Crustacea	Oedicerotidae	*Bathymedon*	*obtusifrons*	O/SD
Arthropoda	Crustacea	Oedicerotidae	*Monoculodes*	*sp A*	O/SD
Arthropoda	Crustacea	Oedicerotidae	*Monoculodes*	*tesselatus*	O/SD
Arthropoda	Crustacea	Oedicerotidae	*Monoculodes*	*latimanus?*	O/SD
Arthropoda	Crustacea	Oedicerotidae	*Monoculopsis*	*longicornis*	O/SD
Arthropoda	Crustacea	Oedicerotidae	*Oedicerotidae*	*sp A*	O/SD
Arthropoda	Crustacea	Oedicerotidae	*Oedicerotidae*	*unid*	O/SD
Arthropoda	Crustacea	Oedicerotidae	*Paroediceros*	*lynceus*	O/SD
Arthropoda	Crustacea	Oedicerotidae	*Periculodes*	*longimana*	O/SD
Arthropoda	Crustacea	Oedicerotidae	*Westwoodilla*	*caecula*	O/SD
Arthropoda	Crustacea	Amphipoda	*Amphipoda*	*unid*	O/SD
Mollusca	Bivalvia	Astartidae	*Astarte*	*borealis*	S
Mollusca	Bivalvia	Astartidae	*Astarte*	*quadrans*	S
Mollusca	Bivalvia	Cardiidae	*Cerastoderma*	*pinnulatum*	S
Mollusca	Bivalvia	Mytilidae	*Crenella*	*decussata*	S
Mollusca	Bivalvia	Mytilidae	*Crenella*	*faba*	S
Mollusca	Bivalvia	Carditidae	*Cyclocardia*	*novaeangliae*	S
Mollusca	Bivalvia	Hiatellidae	*Cyrtodaria*	*siliqua*	S
Mollusca	Bivalvia	Veneridae	*Liocyma*	*fluctuosa*	S
Mollusca	Bivalvia	Mytilidae	*Musculus*	*sp*	S
Mollusca	Bivalvia	Myidae	*Mya*	*truncata*	S
Mollusca	Bivalvia	Tellinidae	*Tellina*	*sp A*	S
Mollusca	Bivalvia	Thyasiridae	*Thyasira*	*flexuosa*	S
Annelida	Polychaeta	Oweniidae	*Owenia*	*fusiformis*	S
Annelida	Polychaeta	Oweniidae	*Owenia*	*sp*	S
Annelida	Polychaeta	Serpulidae	*Spirobis*	*sp*	S
Echinodermata	Holothuroidea	Phyllophoriidae	*Pentamera?*	*calcigera*	S
Echinodermata	Holothuroidea	Cucumariidae	*Stereoderma*	*unisemita juv.*	S
Echinodermata	Holothuroidea	Cucumariidae	*Stereoderma*	*parassimilis*	S

Arthropoda	Crustacea	Haustoriidae	*Acanthohaustorius*	*spinosa*	S
Arthropoda	Crustacea	Pontoporeiidae	*Amphiporeia*	*lawrenciana*	S
Arthropoda	Crustacea	Haustoriidae	*Priscillina*	*armata*	S
Arthropoda	Crustacea	Balanidae	*Balanus*	*crenatus*	S
Arthropoda	Crustacea		*Barnacle*	*unid*	S
Arthropoda	Crustacea	Mysidae	*Mysis*	*sp A*	S
Chordata	Ascidacea	Ascidiidae	*Ascidia*	*callosa*	S
Chordata	Ascidacea		*Ascidacea*	*sp A*	S
Chordata	Ascidacea		*Ascidacea*	*sp B*	S
Chordata	Ascidacea		*Ascidacea*	*sp C*	S
Chordata	Ascidacea		*Ascidacea*	*unid juv*	S
Arthropoda	Crustacea	Diastylidae	*Diastylis*	*cornufer?*	S/G
Arthropoda	Crustacea	Diastylidae	*Diastylis*	*quadrispinosa*	S/G
Arthropoda	Crustacea	Diastylidae	*Diastylis*	*sculpta*	S/G
Arthropoda	Crustacea	Diastylidae	*Diastylis*	*sp G*	S/G
Arthropoda	Crustacea	Diastylidae	*Diastylis*	*sp*	S/G
Arthropoda	Crustacea	Leuconidae	*Eudorella*	*truncatula*	S/G
Arthropoda	Crustacea	Leuconidae	*Eudorella*	*sp*	S/G
Arthropoda	Crustacea	Leuconidae	*Eudorellopsis*	*integra*	S/G
Arthropoda	Crustacea	Diastylidae	*Leptostylis*	*longimana*	S/G
Arthropoda	Crustacea	Diastylidae	*Leptostylis*	*sp A*	S/G
Arthropoda	Crustacea	Diastylidae	*Leptostylis*	*sp*	S/G
Arthropoda	Crustacea	Leuconidae	*Leucon*	*nascicoides*	S/G
Arthropoda	Crustacea	Pseudocumidae	*Petalosarsia*	*declivis*	S/G
Annelida	Polychaeta	Sabellidae	*Euchone*	*elegans*	S/SD
Annelida	Polychaeta	Sabellidae	*Euchone*	*papillosa*	S/SD
Annelida	Polychaeta	Sabellidae	*Euchone*	*incolor*	S/SD
Annelida	Polychaeta	Sabellidae	*Euchone*	*sp*	S/SD
Annelida	Polychaeta	Maldanidae	*Euclymene*	*zonalis*	S/SD
Annelida	Polychaeta	Spionidae	*Polydora*	*quadrilobata*	S/SD
Annelida	Polychaeta	Spionidae	*Polydora*	*socialis*	S/SD
Annelida	Polychaeta	Spionidae	*Polydora*	*sp*	S/SD
Annelida	Polychaeta	Sabellidae	*Sabellidae*	*C*	S/SD
Annelida	Polychaeta	Sabellidae	*Sabellidae*	*unid*	S/SD
Arthropoda	Crustacea	Ampelisicidae	*Ampelisca*	*macrocephala*	S/SD
Arthropoda	Crustacea	Ampelisicidae	*Byblis*	*gaimardi*	S/SD
Mollusca	Gastropoda	Fissurellidae	*Puncturella*	*noachina*	SD
Mollusca	Bivalvia	Arcticidae	*Arctica*	*islandica*	SD
Annelida	Polychaeta	Ampharetidae	*Ampharete*	*finmarchica*	SD
Annelida	Polychaeta	Ampharetidae	*Ampharete*	*acutifrons*	SD
Annelida	Polychaeta	Ampharetidae	*Ampharete*	*lindstroemi*	SD
Annelida	Polychaeta	Ampharetidae	*Ampharete*	*sp*	SD
Annelida	Polychaeta	Ampharetidae	*Ampharetidae*	*unid.*	SD
Annelida	Polychaeta	Ampharetidae	*Anobothrus*	*gracilis*	SD
Annelida	Polychaeta	Ampharetidae	*Asabellides*	*oculata*	SD
Annelida	Polychaeta	Flabelligeridae	*Brada*	*villosa*	SD
Annelida	Polychaeta	Capitellidae	*Capitella*	*sp*	SD
Annelida	Polychaeta	Capitellidae	*Capitellidae?*		SD
Annelida	Polychaeta	Cirratulidae	*Chaetozone*	*setosa*	SD
Annelida	Polychaeta	Cirratulidae	*Cirratulidae*	*unid*	SD

Annelida	Polychaeta	Cirratulidae	*Cirratulidae*	*sp A*	SD
Annelida	Polychaeta	Oweniidae	*Galathowenia*	*oculata*	SD
Annelida	Polychaeta	Spionidae	*Laonice*	*cirrata*	SD
Annelida	Polychaeta	Terebellidae	*Leana*	*ebranchiata*	SD
Annelida	Polychaeta	Ampharetidae	*Lysippe*	*labiata*	SD
Annelida	Polychaeta	Capitellidae	*Mediomastus*	*ambiseta*	SD
Annelida	Polychaeta	Flabelligeridae	*Pherusa*	*plumosa*	SD
Annelida	Polychaeta	Flabelligeridae	*Pherusa*	*sp*	SD
Annelida	Polychaeta	Terebellidae	*Polycirrus*	*eximius*	SD
Annelida	Polychaeta	Terebellidae	*Polycirrus*	*sp*	SD
Annelida	Polychaeta	Spionidae	*Prionospio*	*cirrifera*	SD
Annelida	Polychaeta	Spionidae	*Prionospio*	*steenstrupi*	SD
Annelida	Polychaeta	Spionidae	*Prionospio*	*sp*	SD
Annelida	Polychaeta	Ampharetidae	*Samytha?*	*sexcirrata*	SD
Annelida	Polychaeta	Terebellidae	*Scalibregma*	*inflatum*	SD
Annelida	Polychaeta	Sphaerodoridae	*Sphaerodoropsis*	*minuta*	SD
Annelida	Polychaeta	Spionidae	*Spio*	*filicornis*	SD
Annelida	Polychaeta	Spionidae	*Spiophanes*	*bombyx*	SD
Annelida	Polychaeta	Terebellidae	*Steblosoma?*	*spiralis*	SD
Annelida	Polychaeta	Terebellidae	*Terebellidae*	*unid*	SD
Annelida	Polychaeta	Terebellidae	*Terebellides*	*stroemi*	SD
Annelida	Polychaeta	Cirratulidae	*Tharyx*	*marioni*	SD
Annelida	Polychaeta	Cirratulidae	*Tharyx*	*sp*	SD
Annelida	Polychaeta	Terebellidae	*Thelepus*	*cinncinnatus*	SD
Annelida	Polychaeta	Opheliidae	*Travisia*	*forbesii*	SD
Annelida	Oligochaeta		*Oligochaete*	*unid*	SD
Arthropoda	Crustacea	Podoceridae	*Dulichia*	*porrecta?*	SD
Arthropoda	Crustacea	Ischyroceridae	*Ericthonius*	*rubricornis*	SD
Arthropoda	Crustacea	Phoxocephalidae	*Harpinia*	*plumosa*	SD
Arthropoda	Crustacea	Phoxocephalidae	*Harpinia*	*propinqua?*	SD
Arthropoda	Crustacea	Ischyroceridae	*Ischyrocerus*	*anguipes*	SD
Arthropoda	Crustacea	Ischyroceridae	*Ischyrocerus*	*sp*	SD
Arthropoda	Crustacea	Pleustidae	*Parapleustes*	*sp A*	SD
Arthropoda	Crustacea	Photidae	*Photis*	*reinhardi*	SD
Arthropoda	Crustacea	Phoxocephalidae	*Phoxocephalus*	*holbolli*	SD
Arthropoda	Crustacea	Pleustidae	*Pleustes*	*panopla*	SD
Arthropoda	Crustacea	Pleustidae	*Pleustidae?*	*sp*	SD
Arthropoda	Crustacea	Isaeidae	*Podoceropsis*	*nitida*	SD
Arthropoda	Crustacea	Photidae	*Protomedeia*	*fasciata*	SD
Arthropoda	Crustacea	Synopiidae	*Syrrhoe*	*crenulata*	SD
Arthropoda	Crustacea	Tironidae	*Tiron*	*spiniferum*	SD
Arthropoda	Crustacea	Corophiidae	*Unciola*	*irrorata*	SD
Mollusca	Bivalvia	Tellinidae	*Macoma*	*calcarea*	SuD
Mollusca	Bivalvia	Nuculidae	*Nucula*	*tenuis*	SuD
Mollusca	Bivalvia	Nuculanidae	*Nuculana*	*minuta*	SuD
Annelida	Polychaeta	Maldanidae	*Maldane*	*sarsi*	SuD
Annelida	Polychaeta	Maldanidae	*Maldanidae*	*unid*	SuD
Annelida	Polychaeta	Opheliidae	*Ophelia*	*limacina*	SuD
Annelida	Polychaeta	Opheliidae	*Ophelina*	*acuminata*	SuD
Annelida	Polychaeta	Orbiniidae	*Orbinia*	*swani*	SuD

Annelida	Polychaeta	Pectinariidae	*Pectinaria*	*granulata*	SuD
Annelida	Polychaeta	Pectinariidae	*Pectinaria*	*hyperborea*	SuD
Annelida	Polychaeta	Paraonidae	*Aricidea*	*sp A*	SuD/SD
Annelida	Polychaeta	Paraonidae	*Aricidea*	*sp*	SuD/SD
Annelida	Polychaeta	Paraonidae	*Aricidea*	*catherinae*	SuD/SD
Annelida	Polychaeta	Paraonidae	*Levensinea*	*gracilis*	SuD/SD
Annelida	Polychaeta	Paraonidae	*Paradoneis*	*lyra*	SuD/SD
Annelida	Polychaeta	Paraonidae	*Paradoneis?*	*sp*	SuD/SD
Annelida	Polychaeta	Paraonidae	*Paraonidae*	*unid*	SuD/SD

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Theme 2: Status and functioning of NAFO marine ecosystems (empirical evidence)

ToR 2*. Synthesis of current understanding of the dynamics of Large Marine Ecosystems (LMEs) in the NAFO area.*

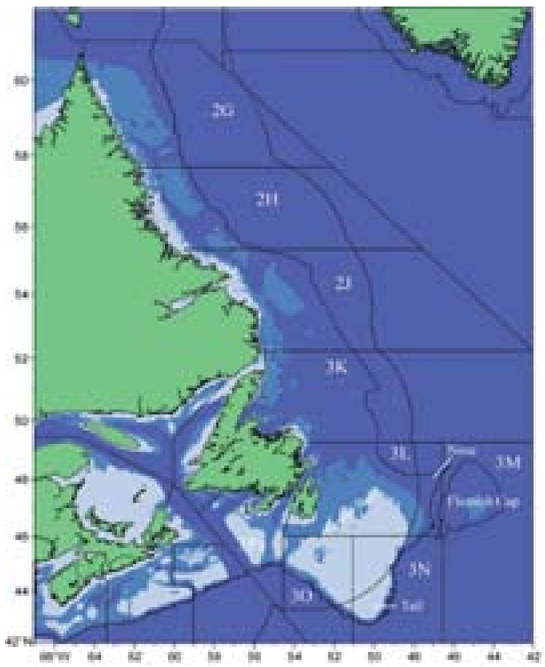
A summary of the current status of commercial stocks managed under NAFO was presented. Similarly, current status of marine mammal species in the NAFO area was described, with notes on a recent aerial survey that is generating the first point estimates of abundance for many cetacean species in the region. Analyses of the changes in the fish communities of the Newfoundland and Labrador (NL) Shelf, and the Flemish Cap ecosystems described and highlighted the major changes observed in these systems. In the case of the NL shelf, a preliminary analysis of common drivers in the trajectories of key fish species suggested that fisheries have been, and continue to be, important drivers in the NL ecosystem, but also indicated that environmental forcing is also important to explain the dynamics of these species. A summary of some results from the recent work done by the ICES Working Group on Holistic Assessment of Marine Ecosystems (WGHAME) was also presented and discussed. Overall, the results and analyses examined by WGEAFM support the concept that the dynamics and status of ecosystems as a whole are significantly affected/driven by large scale environmental processes (i.e. major system-wide trends, regime shifts), but where fishing occurs, it can also have a powerful impact, and severe/rapid changes can occur when both driving forces act in conjunction.

Sumary of current state of NAFO Stocks

Bill Brodie provided a brief overview to WGEAFM of the stocks managed by NAFO, as well as the assessment work on these stocks conducted by Scientific Council. Fisheries Commission requests advice on 18 stocks which occur all or partly in the NAFO Regulatory Area (NRA) (Fig. 23). As well SC also provides advice on stocks which are referred to SC by Coastal States in the NAFO area. Shrimp stocks in the NAFO area are assessed together with some ICES shrimp stocks in a joint NAFO-ICES WG (NIPAG) which meets each October.

Of the eighteen stocks in the NRA assessed by SC, six are currently under moratorium. Two stocks (3LN redfish and 3M cod) have recently been opened for fishing, based on advice from SC. A summary of SC's stock classification scheme was presented, showing how the SC-assessed stocks are categorized according to abundance and fishing mortality (Table 6).

A slide showing trends in environmental conditions in the NAFO area, as presented at the STACFEN meeting in June 2009, was discussed (Fig. 24). It was noted that conditions in the last several years had been warmer than average, with 2006 having the highest composite index value in the 59-year time series.



- cod 3NO, 3M;
- American plaice 3LNO, 3M;
- witch 2J3KL, 3NO;
- redfish 3LN, 3O, 3M;
- roughhead grenadier 2+3;
- Greenland halibut 2+3KLMNO;
- yellowtail 3LNO;
- skate 3LNO;
- white hake 3NO;
- squid 3+4;
- shrimp 3LNO, 3M;
- capelin 3NO.

Figure 23. Stocks managed by NAFO.

Table 6. Current classification for the NAFO stocks.

Stock Size	**Fishing Mortality**			
(inc structure)	**None–Low**	**Moderate**	**High**	**Unknown**
Virgin–Large		3LNO Yellowtail flounder		
Intermediate	3M Redfish 3LN Redfish	3LNO Northern shrimp SA0+1 Northern shrimp DS Northern shrimp		
Small	3M Cod SA3+4 Northern shortfin squid 3M Northern shrimp		SA2+3KLMNO Greenland halibut	3NOPs White hake 3LNOPs Thorny skate
Depleted	3M American plaice 3LNO American plaice 2J3KL Witch flounder		3NO Cod	SA1 Redfish SA0+1 Roundnose grenadier 3NO Witch flounder
Unknown	SA2+3 Roughhead grenadier 3NO Capelin	0&1A Offsh. & 1B–1F Greenland halibut		1A Insh. Greenland halibut 3O Redfish SA2+3 Roundnose grenadier

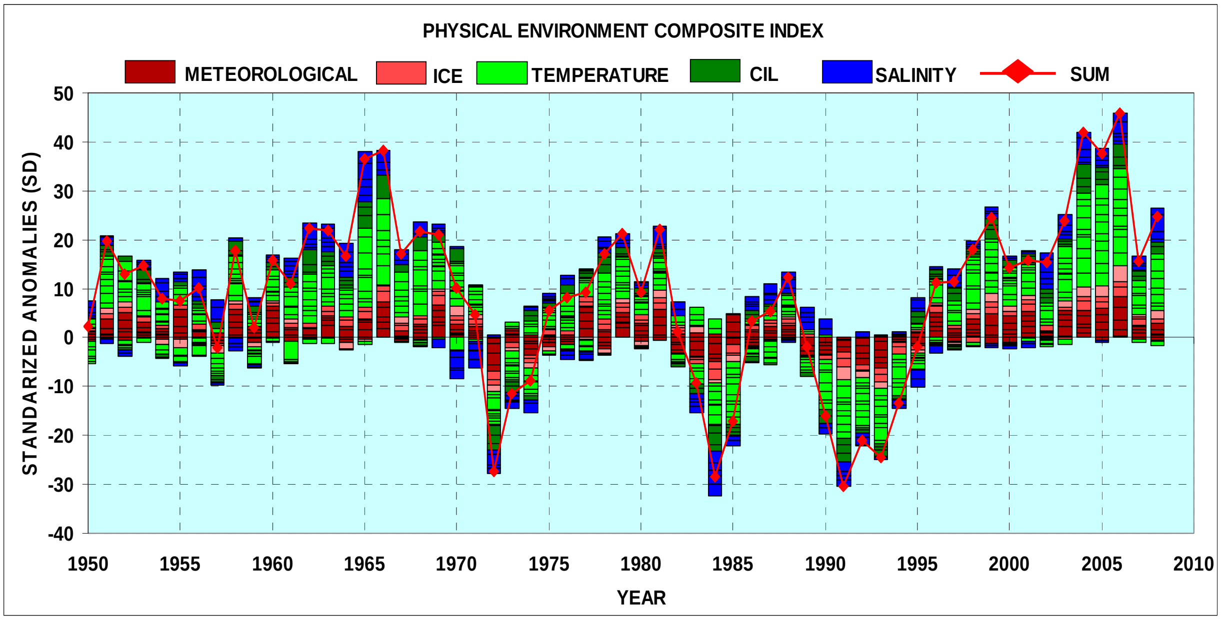


Figure 24. Composite Environmental Index presented at the 2009 STACFEN June Meeting. This index combines standardized anomalies from multiple physical and environmental variables.

Trends in the Newfoundland-Labrador (NL) fish community

The southern Labrador-northeast Newfoundland shelf, and Grand Bank ecosystem (NAFO Divs. 2J3KLNO), or Newfoundland-Labrador (NL) shelf ecosystem for short, has suffered major changes in the last 30 years. Although the collapse of Northern cod (2J3KL cod stock) is probably the best known example, many other components in this fish community also changed dramatically between the early 1980s and today. Together with Northern cod, other important commercial species also declined in the late 1980s and early 1990s, and fishing has been considered a major driver of many of these declines. Concurrently with high fishing pressure, environmental conditions in the Northwest Atlantic were also severe (Drinkwater 1996), and environmental conditions have often been suggested as additional drivers for the changes observed in fish stocks (Drinkwater 2002). In this context, the objectives of this analysis are a) summarize the history of commercial catches in the NL shelf, b) Describe the changes observed in the fish community in the period 1980-2009, and c) Explore the potential role of environment and fishing as ecological drivers for some key species in this marine community.

Fishing Catches

Information on fisheries catches from 1960 to 2008 was obtained from NAFO STATLANT 21A database available online (www.nafo.int/fisheries/frames/fishery.html).

The fishery in the Northwest Atlantic was historically dominated by groundfishes, cod being the most important species among them (Fig 25). Among pelagic fishes, capelin has been the main target species, with important catches in the 1970s and the late 1980s. Invertebrates have dominated the catches since the collapse of groundfish stocks in the early 1990s, with northern shrimp being the dominant species, followed by snow (or queen) crab (Fig. 25).

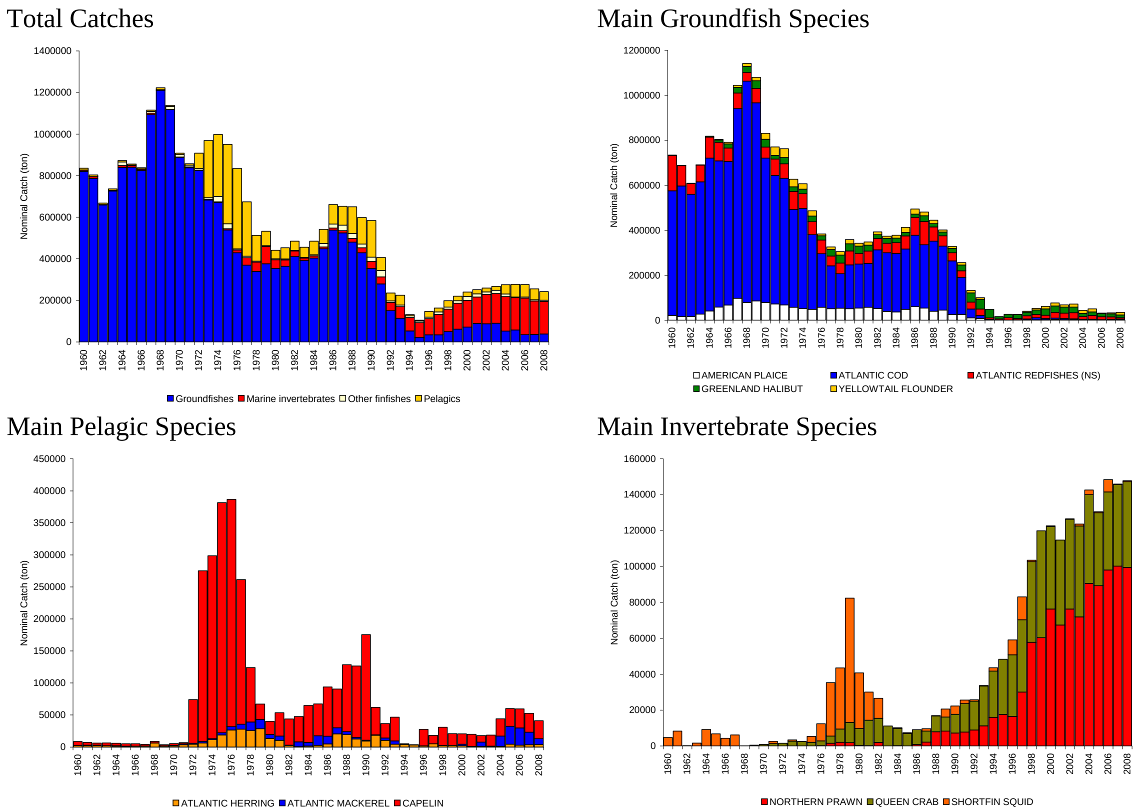


Figure 25. Nominal fishery catches in the southern Labrador-northeast Newfoundland shelf and Grand Bank ecosystem (NAFO Div. 2J3KLNO) from NAFO STATLANT 21A database.

Changes in the fish community

The NL shelf ecosystem can be schematically described as two more-or-less self-contained functional sub-units, the southern Labrador and northeast Newfoundland shelf (NAFO Divs. 2J3KL), and the Grand Bank proper (NAFO Divs. 3LNO), where the northern part of the Grand Bank (NAFO Div. 3L) is a mixing/overlap area between them (Fig. 26a).

For these two functional sub-units of the NL ecosystem, indices of biomass, abundance and biomass/abundance (BA) ratio were used to describe the changes in the fish community. These indices were calculated with data from the spring and fall Canadian multispecies bottom trawl surveys. Indices for the southern region (NAFO Divs. 3LNO) were based on the spring survey and calculated for the period 1985-2009, while the northern region (NAFO Divs. 2J3KL) indices were calculated for 1981-2008 from fall survey data. Since survey coverage varied over time due to the addition of inshore and offshore strata at different points in time, as well as operational constraints (e.g. weather, vessel break-downs, etc), indices for this analysis were calculated from data collected in core strata only. Core strata (Fig. 26b) were selected based on the consistency of their coverage in the surveys.

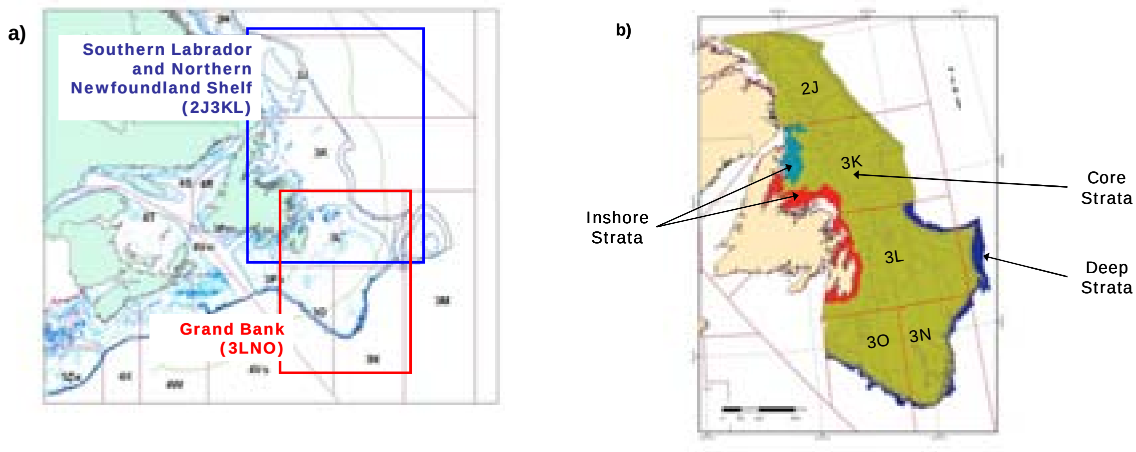


Figure 26. a) NL schematic ecosystem sub-units in the analysis (NAFO Divs. 2J3KL and 3LNO); b) Strata for the DFO multispecies bottom-trawl surveys with indication of core, inshore and deep strata. Core strata, in green, were considered for this analysis.

The standard gear used by these surveys was the Engels trawl; in 1995 and 1996 this gear was replaced by the Campelen trawl in the fall and spring surveys respectively. Although comparative fishing trials were performed, these only targeted a small set of commercially important species. There are no conversion factors for the vast majority of species. In addition, data collection on invertebrates was unreliable during the Engels period; information on commercially important invertebrate species like northern shrimp and snow crab became standard with the migration to the Campelen trawl. These changes and differences prevent us from producing single time series for each region. Instead, analyses are done considering an Engels and a Campelen series for each region.

Trends in the fish community were analyzed considering six fish functional groups (Table 7). Furthermore, since the goal is to explore changes in the fish community as a whole, the geographical regions considered here do not always respect the boundaries of management stocks.

Table 7. Description of functional groups used to analyze changes in the fish community.

Functional group	# spp in the group	Size range	Examples
Small benthivores	45	< 45cm	Alligator fish, sculpins
Medium benthivores	34	45cm< maximum size <80cm	Yellowtail, lumpfish
Large benthivores	29	maximum size > 80cm	American plaice
Piscivores	31	All	Atlantic cod, turbot
Plankton-Piscivores	8	All	Redfish, Arctic cod
Planktivores	14	All	Capelin, herring, butterfish

During the late 1980s and early 1990s the fish community in the NL marine ecosystem collapsed (Figs. 27, 28). This collapse was more dramatic in the northern regions (Fig. 27) but was observed throughout the system. It involved commercial and non-commercial species alike. Most fish functional groups showed significant declines in their BA ratios, and these were generally caused by a loss of large fish.

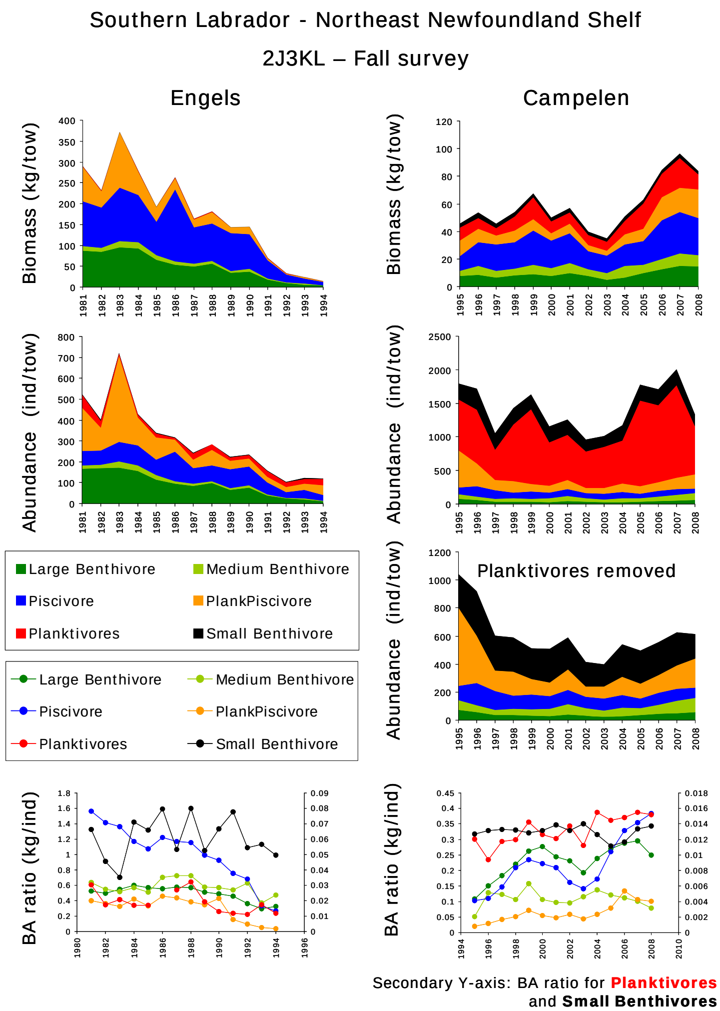


Figure 27. Trends in biomass, abundance and biomass/abundance (BA) ratio for the Southern Labrador-Northeast Newfoundland Shelf (NAFO Divs. 2J3KL) in the period 1981-2008. The abundance estimates for the Campelen series are shown with and without planktivores to allow for a better reading of the trend in the other fish functional groups.

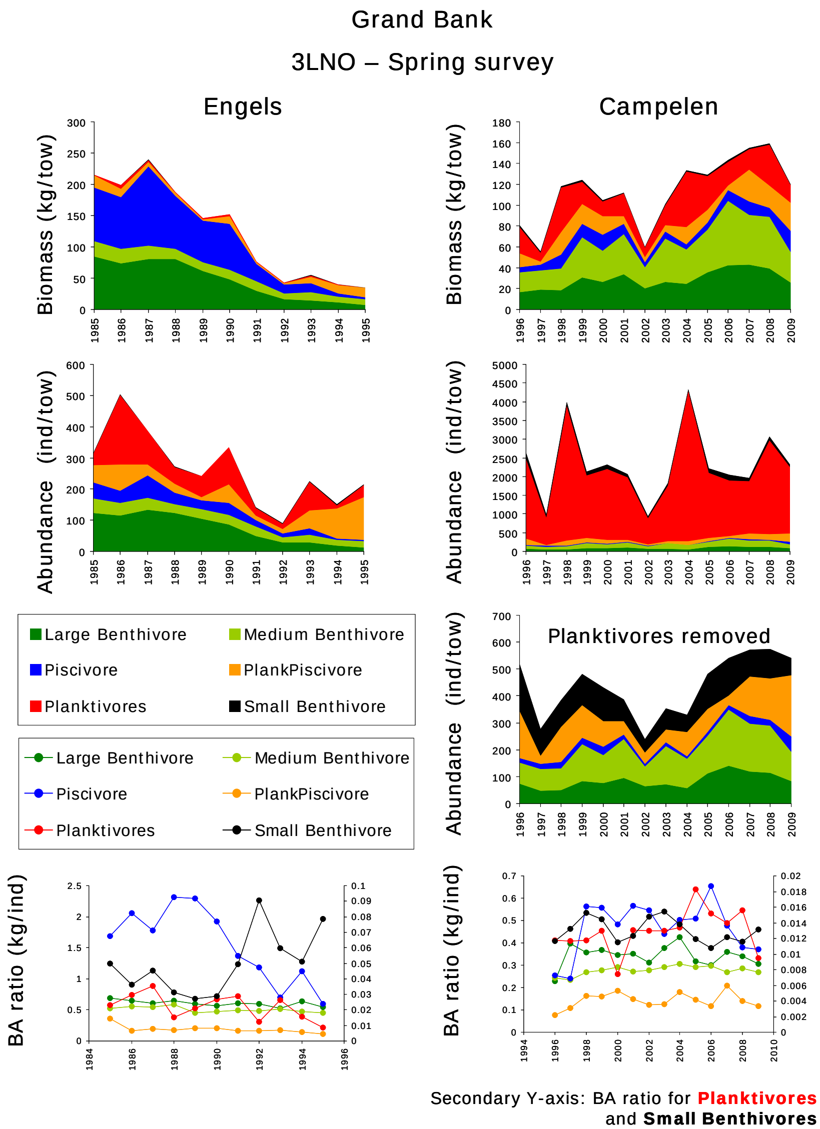


Figure 28. Trends in biomass, abundance and biomass/abundance (BA) ratio for the Grand Bank (NAFO Divs. 2J3KL) in the period 1981-2008. The abundance estimates for the Campelen series are shown with and without planktivores to allow for a better reading of the trend in the other fish functional groups.

Other important changes in the marine community during this period included the increasing trend of harp seals (see below), and the build-up of shrimp (Fig. 29).

Southern Labrador-Northeast Newfoundland Shelf **Grand Bank**

2J3KL **3LNO**

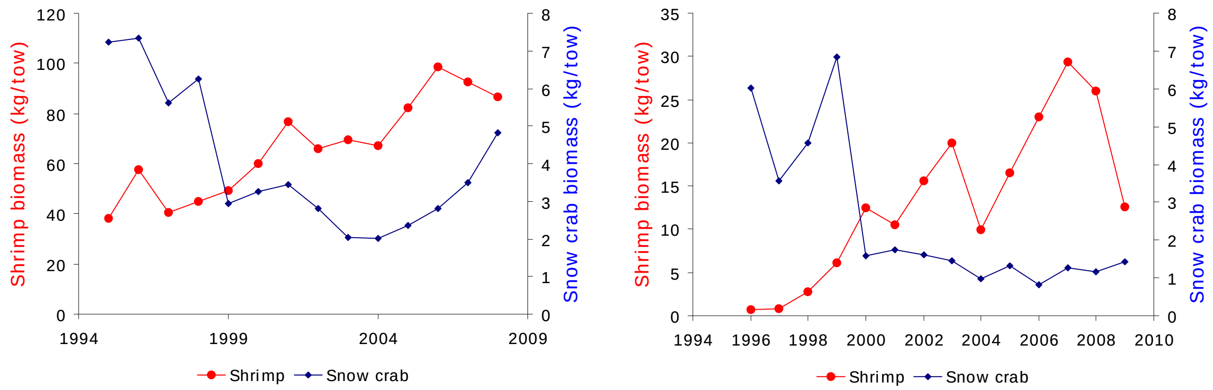


Figure 29. Biomass trends in northern shrimp and snow crab in the Southern Labrador-Northeast Newfoundland Shelf (NAFO Divs. 2J3KL - fall survey), and Grand Bank (NAFO Divs. 3LNO – spring survey) during the Campelen period.

Capelin, a major forage fish in this system, showed a dramatic decline in the early 1990s (Fig. 30) which was accompanied by significant changes in its biology (Carscadden and Nakashima. 1997).

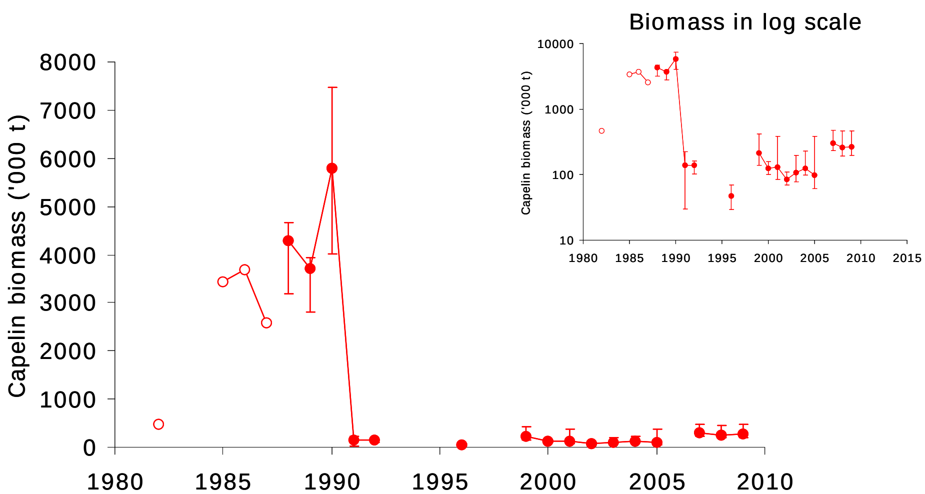


Figure 30. Spring acoustic biomass for capelin in NAFO division 3L from DFO acoustic surveys. The log-scale version of the main graph (upper-left corner) allows a clear view of the increased biomass level in recent years.

In recent years there has been an increasing trend in fish biomass in the Newfoundland and Labrador shelf (Figs. 27, 28). Although a positive signal, biomass levels are still well below pre-collapse levels. This positive trend in biomass is clearer in the northern regions (2J3KL), where an increase in snow crab has also been observed. However, an important decline in shrimp was observed in the southern region. The BA ratio also shows increasing trends in some 2J3KL functional groups. The BA ratio does not show such clear pattern in the Grand Bank (Figs. 27, 28).

In comparison with the levels observed in the 1990s, capelin has showed an increased biomass level in 2007-2009 (Fig. 30). Nonetheless, the current biomass level is still orders of magnitude below the numbers estimated in the late 1980s.

Analysis of common trends and drivers in key species of the NL ecosystem

The influence of environmental variables and fisheries impacts on the trajectories of 5 key species of the NL marine community was explored using dynamic factor analysis (DFA) (Zuur et al. 2003, 2007). This analysis allows assessing common trends among several time series, as well as evaluating the impact of explanatory drivers on those dynamics (Zuur et al 2007).

The species considered for this analysis were cod, turbot, American plaice, redfish and yellowtail flounder. Four sets of time series were assembled by considering these species in each geographical area and survey (2J3KL-fall and 3LNO-spring) and for each research gear (Engels and Campelen). The dependent variable considered for this analysis was the survey biomass index (kg/tow). The candidate drivers for the biomass of these fishes (i.e. explanatory variables) were two environmental variables and fishing impacts. The environmental variables were the North Atlantic Oscillation (NAO) and sea surface temperature at Station 27 (ST27-SST), a long-term oceanographic station located near St. John’s. The fishing impact was incorporated by calculating a“Fishery Index” (FI). This index was intended to measure the overall impact of fishing on the marine community and it was calculated as the ratio between the sum of all nominal catches in a given area (2J3KL or 3LNO) and the total fish biomass estimated for that area from DFO multispecies surveys (fall survey for 2J3KL and spring survey for 3LNO). As before, estimations of survey biomass were calculated considering core strata only. For the Campelen years, the estimation of total survey biomass also included shrimp and crab.

For each dataset (area, gear and time period), several DFA models were built, including those to capture all possible combinations of the explanatory drivers (Table 8). Models were selected using the Akaike Information Criterion (AIC). All variables were normalized for the analysis (Fig. 31).

Table 8. Result from DFA analysis. The best model in each case is denoted in red and bold fonts, and in a grey background; other models still worthy of further consideration are denoted in red.

Dataset	Model				# parameters in the model	Loglikelihood	AIC	Delta AIC
	# common trends	Explanatory variable Included						
		NAO	ST27-SST	Fishery Index				
2J3KL Fall 1981-1994	1				25	-40.0	130.0	25.5
	2				29	-37.2	132.3	27.8
	3				32	-37.4	138.8	34.3
	1		X		30	-35.3	130.6	26.1
	1	X			30	-37.6	135.2	30.7
	1			**X**	**30**	**-22.3**	**104.5**	**0.0**
	2			X	34	-22.3	112.6	8.0
	1	X		X	35	-20.4	110.7	6.2
	1		X	X	35	-18.7	107.4	2.8
	1	X	X		35	-33.3	136.6	32.0
	1	X	X	X	40	-17.0	114.1	9.6
2J3KL Fall 1995-2008	1				25	-58.7	167.4	11.2
	2				29	-53.5	164.9	8.8
	3				32	-53.5	170.9	14.8
	1		X		30	-54.0	168.0	11.8
	1	X			30	-57.4	174.7	18.6
	1			X	30	-48.1	156.1	0.0
	2			X	34	-45.3	158.7	2.5
	1	X		X	35	-46.9	163.9	7.7
	1		X	X	35	-44.9	159.8	3.6
	1	X	X		35	-52.6	175.2	19.1
	1	X	X	X	40	-43.7	167.4	11.3
3LNO Spring 1985-1995	1				25	-36.973	123.9	21.5
	2				29	-35.945	129.889	27.4
	1		X		30	-30.754	121.508	19.1
	1	X			30	-35.607	131.213	28.8
	1			X	30	-23.624	107.249	4.8
	2			X	34	-23.587	115.174	12.7
	1	X		X	35	-21.482	112.965	10.5
	1		**X**	**X**	**35**	**-16.224**	**102.449**	**0.0**
	1	X	X		35	-29.596	129.193	26.7
	1	X	X	X	40	-13.997	107.994	5.5
3LNO Spring 1996-2008	1				25	-56.6	163.2	25.6
	2				29	-56.0	170.0	32.4
	1		X		30	-51.0	162.0	24.5
	1	X			30	-51.8	163.7	26.1
	1			X	30	-46.5	153.1	15.5
	2			X	34	-45.3	158.6	21.0
	1		X	X	35	-37.9	145.8	8.3
	1	X		X	35	-41.7	153.4	15.8
	1	X	X		35	-46.3	162.5	25.0
	1	**X**	**X**	**X**	**40**	**-28.8**	**137.6**	**0.0**
	2	X	X	X	44	-28.8	145.6	8.0

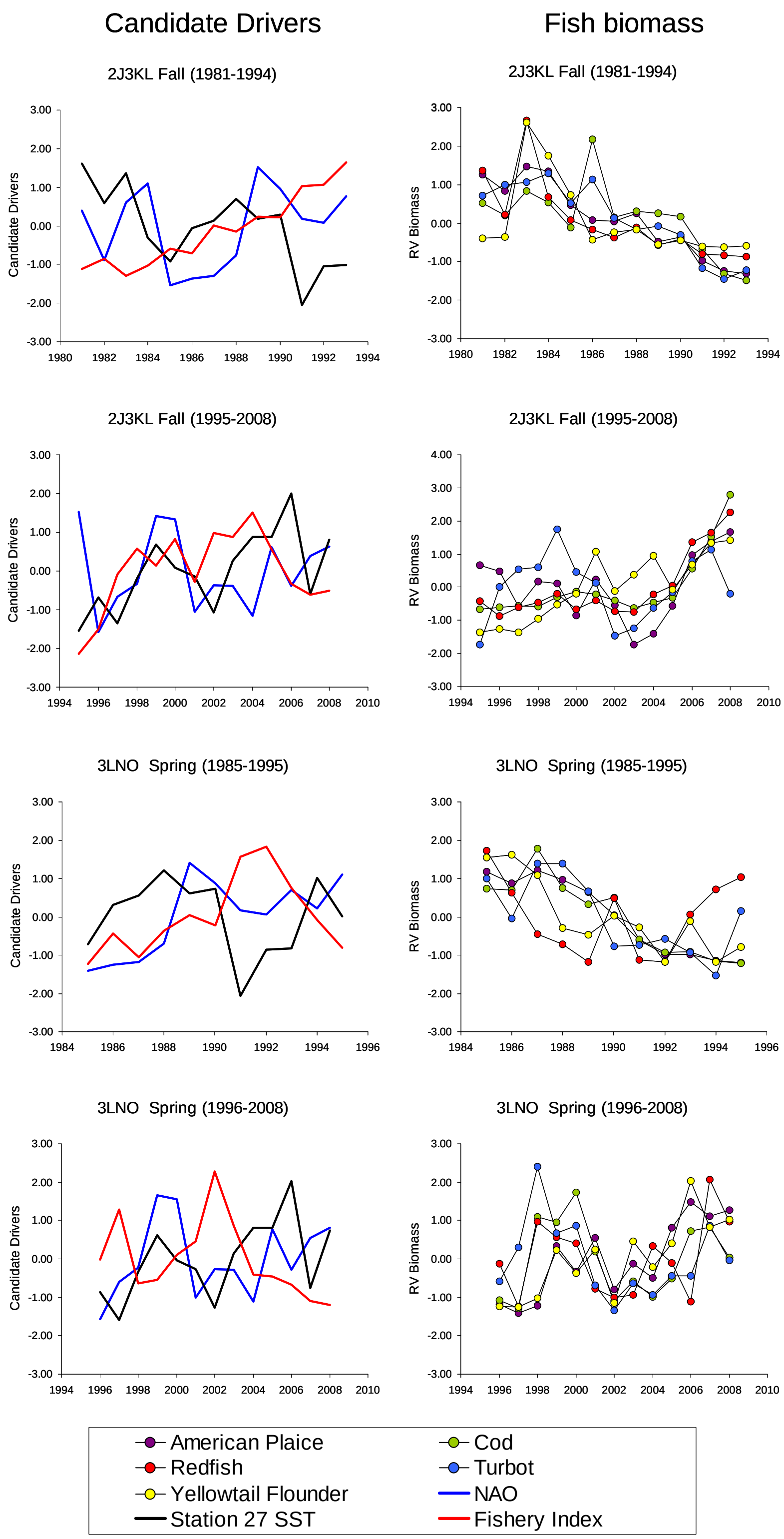


Figure 31. Normalized drivers and survey biomasses considered for DFA.

The results indicated that there were common trends in the biomass trajectories of the 5 fish species (cod, turbot, American plaice, redfish and yellowtail flounder) in all areas and time periods (Table 8). Fishing appears as a consistent and significant driver in the earlier period, but interestingly enough, still remains as an important driver in the more recent one (Table 8), where fisheries have been targeting mainly shrimp and crab. NAO and ST27-SST also appear as significant drivers, but their effect is less consistent than the one observed for fishing (Table 8). Among the two, SST appears somehow relevant for both northern and southern areas, while NAO appears more relevant in the Grand Bank region (Table 8).

Overall, fishing emerges from this analysis as a powerful driver for these key species, even in recent times, when the decline in catches and their shift towards invertebrates may have led us to believe that its impact on key fish species could have been reduced. At the same time, environmental drivers also have detectable effects on the dynamics of these fish species. These effects appear to be more closely linked to local conditions as measured by SST rather than be emerging from system-wide changes in ocean climate, as could be expected if NAO had a stronger impact. Nonetheless, in the Grand Bank, both NAO and SST had important effects. The stronger NAO effect on the southern region could be related to the fact that this area (Grand Bank) is closer to the boundary with the North Atlantic Current, and hence, it may be comparatively more susceptible to the large scale ocean climate variations often linked to NAO.

Regardless the specific reasons, this analysis is showing clearly that environmental variables do have a detectable effect on the trajectories of fish populations, but fishing also appears as a more pervasive driver even with the much lower catches we observe today.

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Zuur, A.F., E.N. Ieno, and G.M. Smith. 2007. Analysing ecological data. Statistics for Biology and Health Series, Springer, New York.

Trends in the Flemish Cap fish community

- The Flemish Cap is an isolated bank, separated from the Grand Bank by the Flemish Pass channel (Figure 32), characterized by depths in excess of 1000. This bank is located north of the front formed by the Labrador and the North Atlantic Current (LC and NAC respectively) and presents a quasi-steady water circulation with anticyclonic motion over the central part (Kuldo and Boitsov 1979). Greenberg and Petrie (1988) postulated that the dynamics of the frontal system associated with the confluence of warm and cold waters was the driving mechanism that determines circulation dynamics in the region (Fig. 32). Waters over Flemish Cap are often referred to as mixed waters of LC and NAC, modified by retention within the anticyclonic circulation (Anderson 1984;Hayes, et al 1977). Both, the potential limitation in the migration of adult individuals by the Flemish Pass (Templeman 1976; De Cardenas-Gonzalez 1996) and retention of eggs and larvae by the action of the anticyclonic gyre make Flemish Cap a fairly isolated system for the shallower demersal fish populations like Flemish Cap cod. Variations in the LC and NAC could produce changes on the anticyclonic gyre over the cap affecting the primary production and recruitment of fish populations (Stein 1995). Cod and American plaice recruitment have been found to be more variable in Flemish Cap than in any comparable population (Lilly 1986; Myers and Pepin 1994) . Isolation, along with variations in oceanographic conditions like temperature and intensity of the anticyclonic gyre, have been suggested as the main causes for such a high variability (Stein 1995).

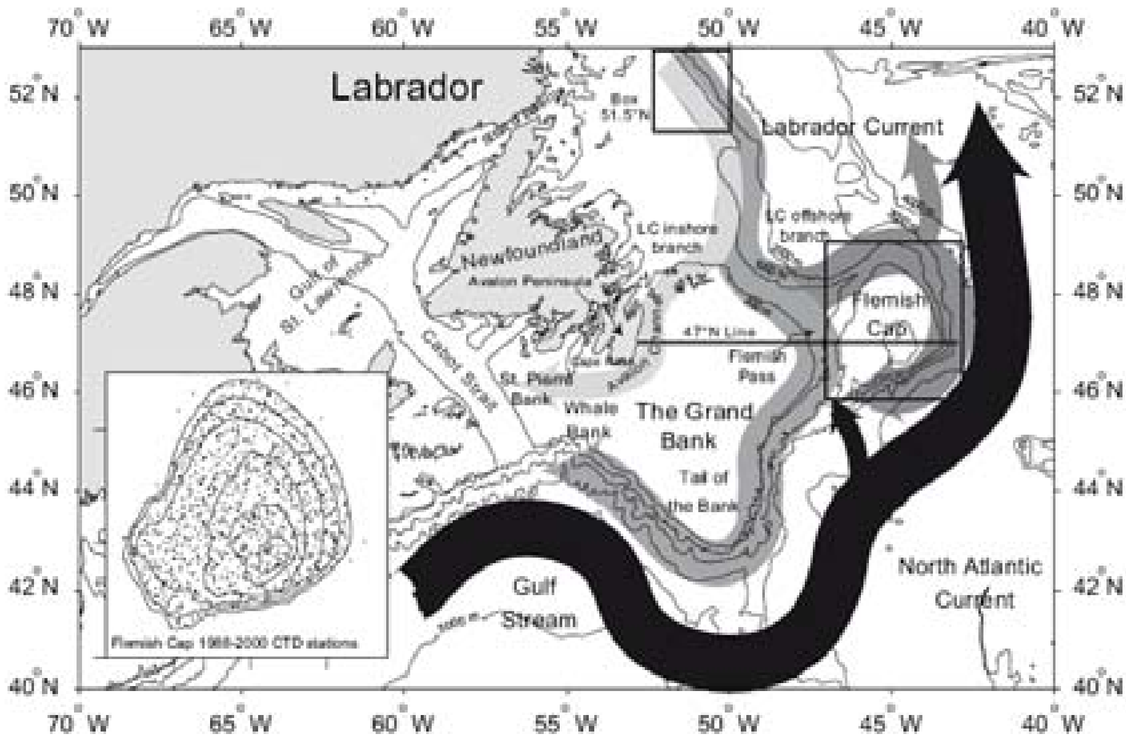

Figure 32. Schematic representation of the main currents which define the ocean circulation around the Flemish Cap (from Gil, et al 2004).

Declared catches of demersal species have shown a fairly variable pattern. Main fished species have varied since early 1980s, with cod and redfish as the main target species until the beginning of the 90s. Catches during the mid 1990s were composed by a variety of species, while shrimp was the almost exclusive fished species in the last part of the 90s and early 21th century (Figure 33).

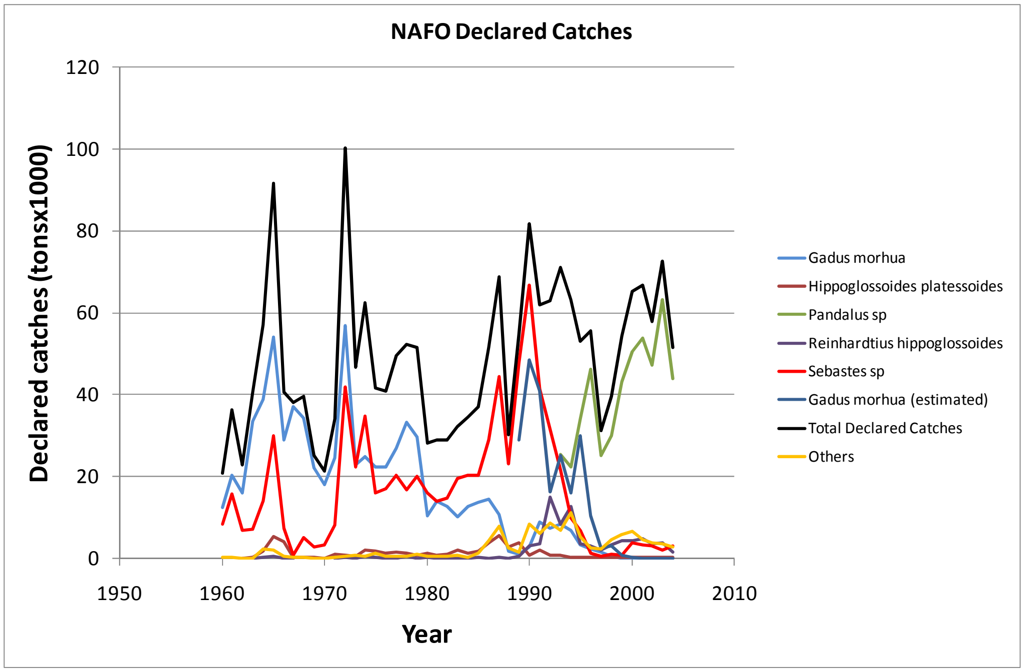

Figure 33. Nominal [declared] catches in the Flemish Cap (catches in tons x1000).

Since 1988, annual randomly stratified bottom trawl surveys have been conducted during the summer (July). Data from these surveys permit the construction of biomass and abundance indices for many fish species. Other biological characteristics studied from these data include size and age structure for the main fish populations, reproductive parameters and diet composition (since 1993). The change of vessel in 2003 from the RV Cornide de Saavedra to RV Vizconde de Eza made necessary a calibration process to ensure the coherence of the time series.

During the study period deep changes in the biomass of the main species in Flemish Cap have been observed. The cod stock experienced a collapse in the middle of the 1990s. A series of years with bad recruitment and with an extremely high fishing mortality concentrated on a stock mostly composed by a single cohort is the more plausible explanation for such a collapse. A good recruitment period for genus *Anarhichas* lead to an increase in the biomass of this genus in the middle of the 1990s. At the end of this decade, shrimp biomass increased considerably, with the maximum peaks in biomass observed in 1998 and 2002, and decreasing afterwards. After 2003, a series of good recruitments led the genus *Sebastes* (*S. fasciatus* and *S. marinus*) to experience the highest increase in biomass ever recorded since the beginning of this time series. In 2006 more than a 95% of the survey biomass belonged these species (Fig. 34).

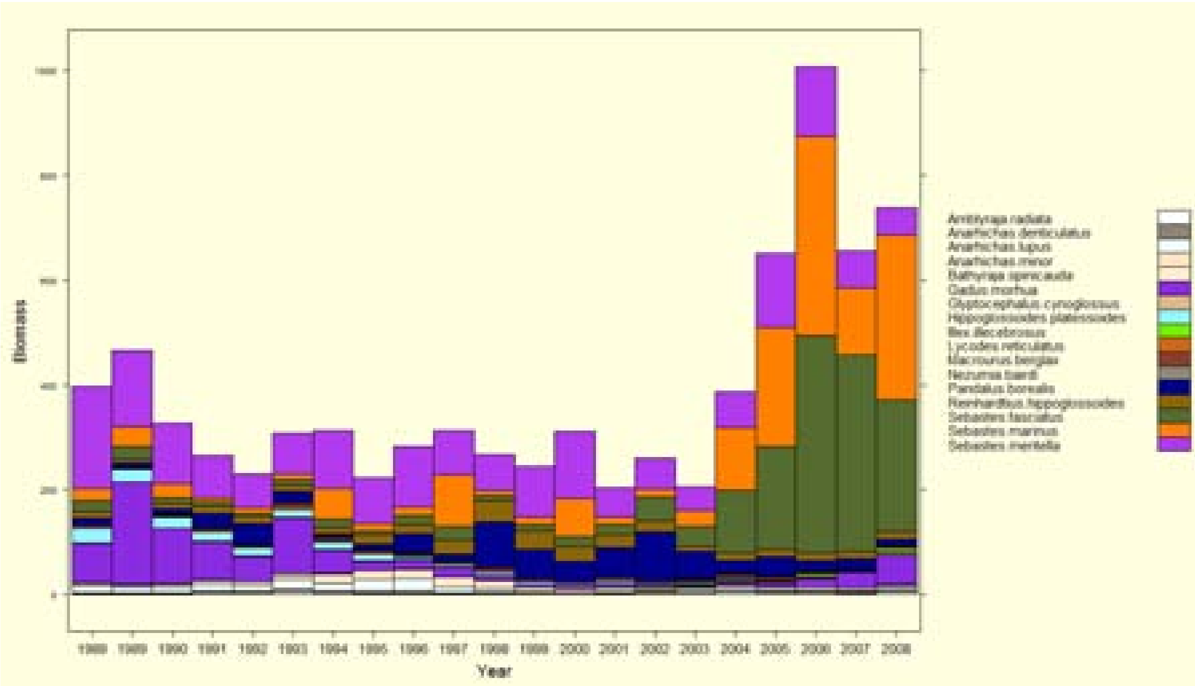

Figure 34. Survey Biomass Index for some key species of the Flemish Cap ecosystem.

The biomass/abundance (BA) ratio showed a decreasing trajectory for some species until 2003, indicating a decrease in the mean size of individuals. From 2003 it seems a reversal of this trend occurred (Fig 35). For cod, redfish and American plaice, this pattern is quite different and the highest value for the BA ratio appeared around 2000.

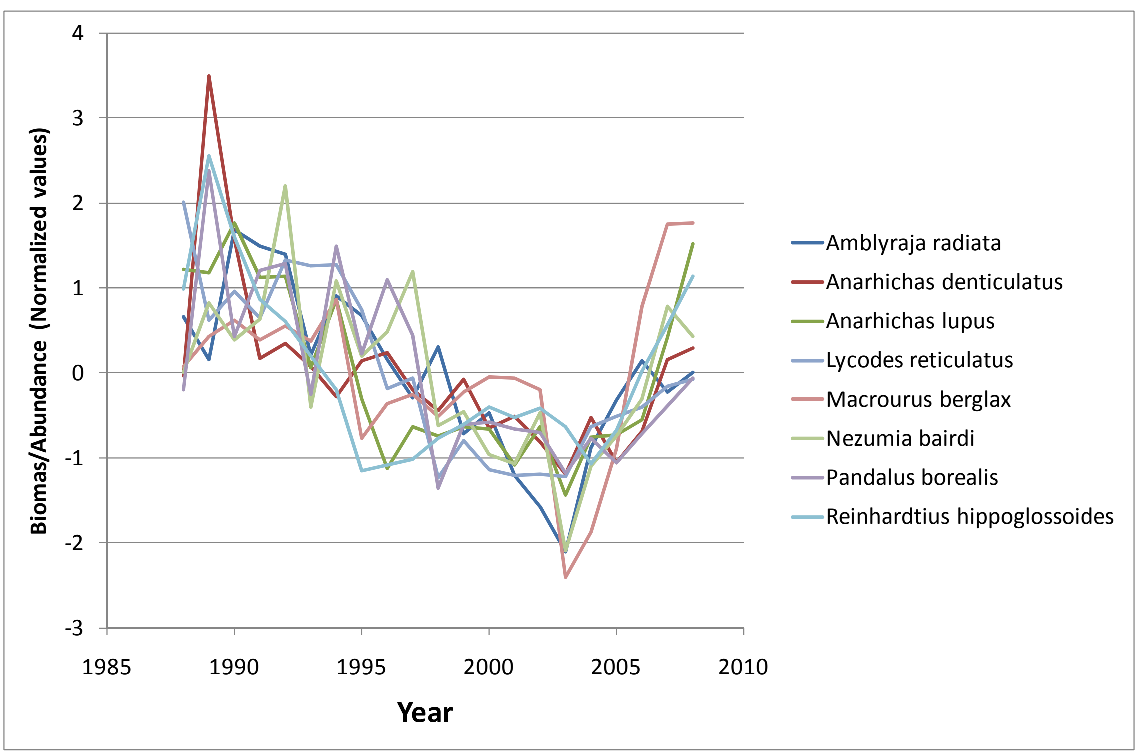

Figure 35. Biomass/Abundance ratio for some species of the Flemish Cap ecosystem.

Analysis of percentage of volume of each prey species in the diet showed that at the same time that changes in biomass and biomas/abundance ratio occurred, changes occurred in the feeding habits of the main demersal fish species on Flemish Cap (Fig. 36). Among these changes there are clear trends in the importance in the diet of *Sebastes* and shrimp. These trends appear to be related with the relative abundance of these species in the Flemish Cap system. A decrease in hiperids and ophiurans consumption, and oscillations of copepod volumes, were also detected in the diet of some species.

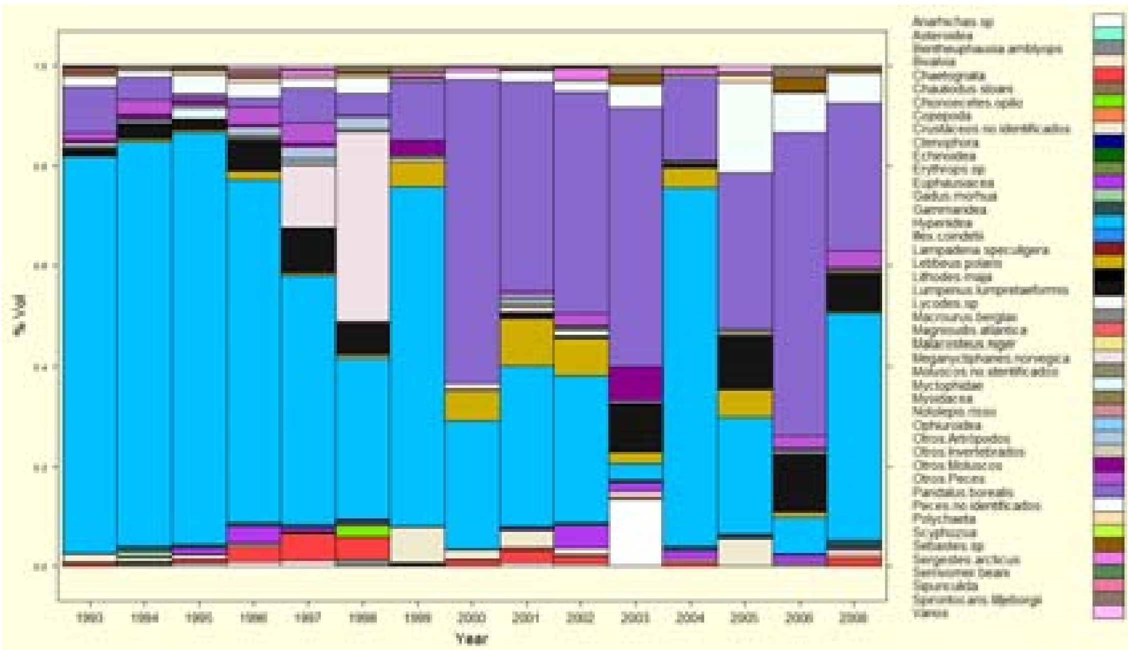

Figure 36. Diet of cod (expressed as percent volume) between 1993 and 2008 as an example of the type of changes observed in diet composition among many species during this period.

A non-metric multidimensional scaling (MDS) analysis was used to study the diet composition (percentage of volume of prey) for each predator species and year. This analysis indicates that the main demersal species on the Flemish Cap have more similar feeding habits nowadays that in early 1990's (Fig. 37). A more similar diet today than in the past could mean higher competitive effects.

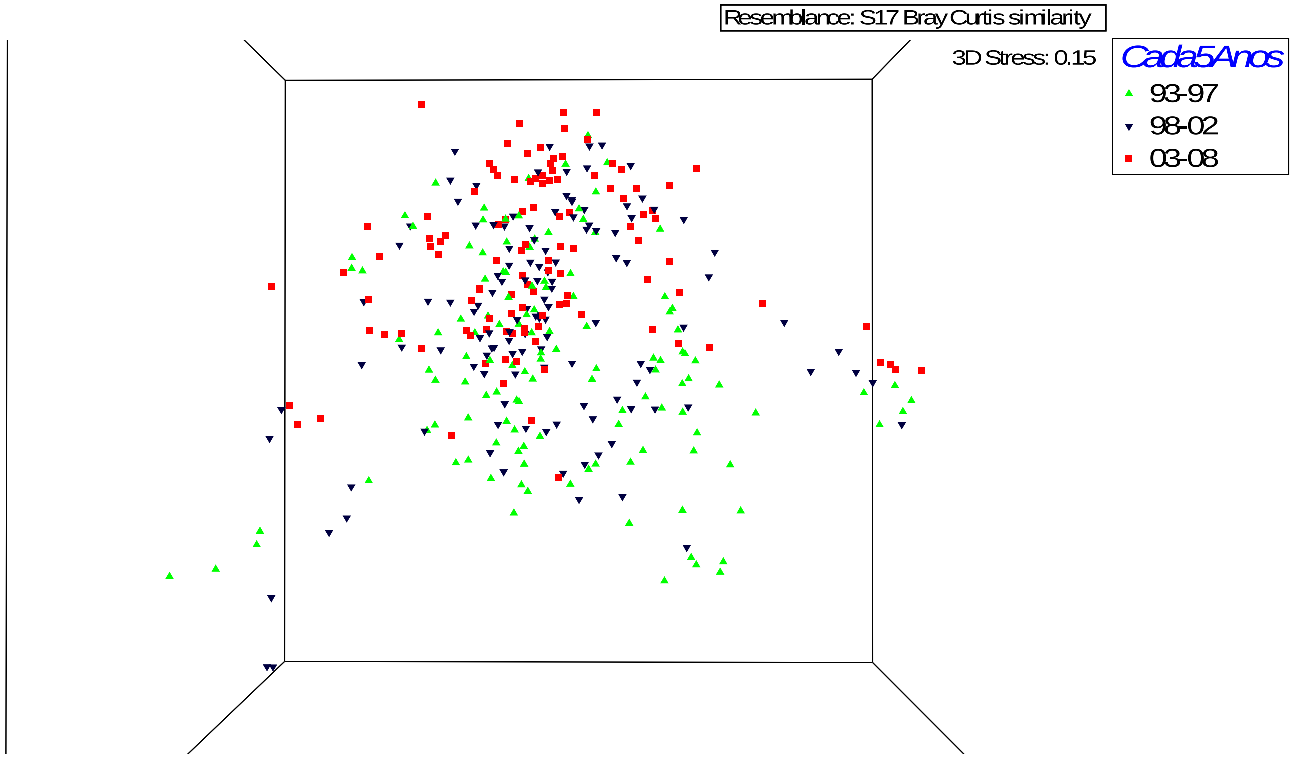

Figure 37. MDS plot based on diet composition. Each point corresponds to a species in a given year. Points are colored to by year groups (“93-97”, “98-02” and “03-08”) to highlight the reduction in dispersion (i.e. more similar diet) in the most recent period.

Mean size at age of Flemish Cap cod has changed during the studied period. These changes could be related with variations in intraspecific competition as cod abundance diminished as well as with increases in shrimp and juvenile *Sebastes* abundance (i.e. higher availability of food). In the same period that cod growth rate increased, a decrease in age and length at maturation was observed (Fig. 38). Such changes in the reproductive parameters could be due to both phenotypic plasticity and/or genetic variations (Dieckmann and Heino 2007; Rijnsdorp 1993b; Taylor and Stefánsson 1999; Law 2000). Such changes in reproductive parameters could lead to variations in the reproductive output of the population (Trippel 1995; Marshall and Frank 1999).

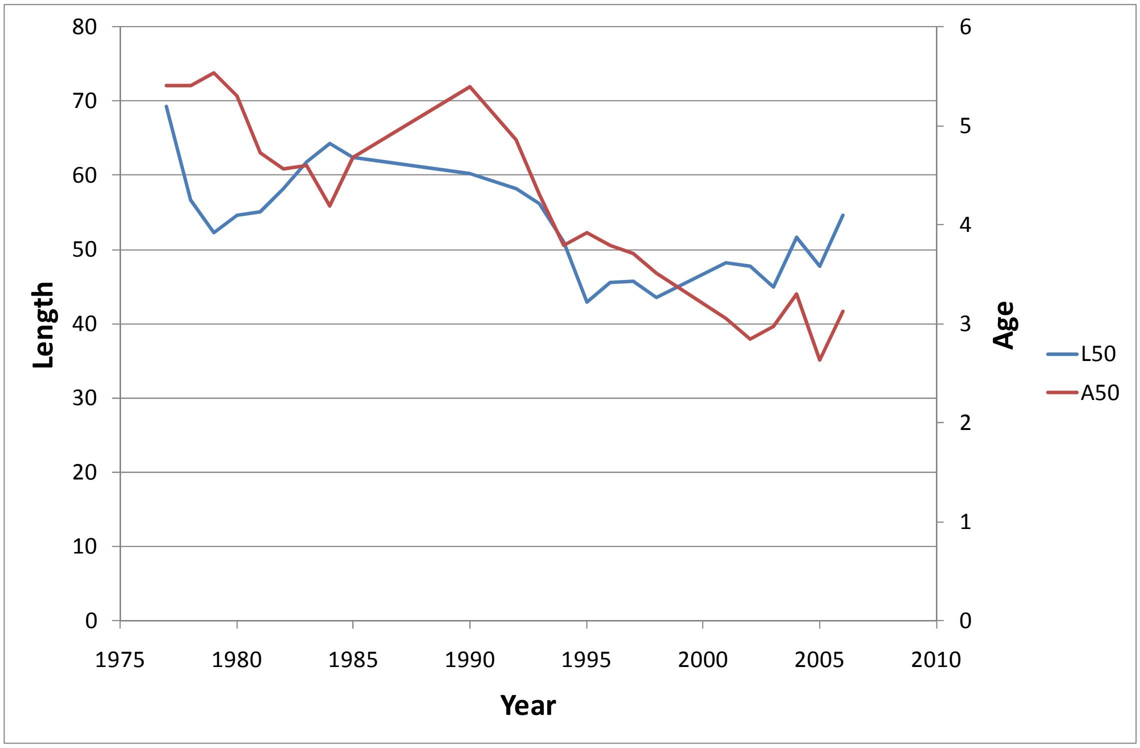

Figure 38. Length (in cm, left axis) and Age (in years, right axis) of maturation (L50 and A50 respectively) for cod in the Flemish Cap ecosystem.

Based on the available information, a working hypothesis on how fish populations in the Flemish Cap are regulated can be described as follows: Variations in the intensity and position of oceanic currents could lead to shifts in the intensity of the anticyclonic gyre, influencing the recruitment of demersal fish species on Flemish Cap. Such changes on recruitment with variations in fishing and natural mortality could led to the observed changes in abundance of species that would lead to feeding opportunity variations for such demersal species. These changes in fishing pressure, diet composition and availability of prey could lead to changes in reproductive parameters and condition that would imply variations in reproductive output, closing the circle with their influence on subsequent recruitment processes (Fig. 39).

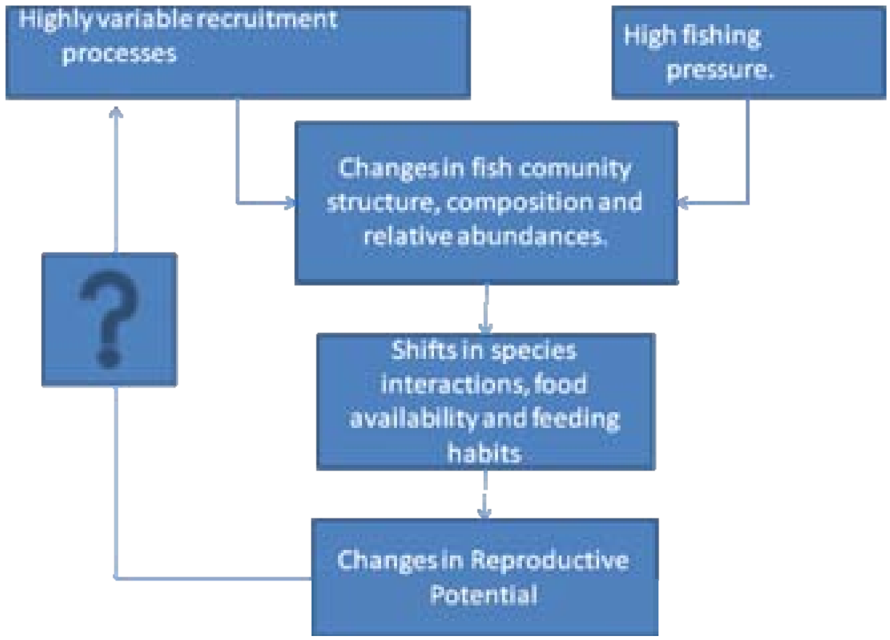

Figure 39. Conceptual flow diagram summarizing some of the potential key processes/interactions affecting the structure of the fish community on the Flemish Cap that emerges from the preliminary analyses presented here.

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Synopsis on the status of marine mammals species in the Northwest Atlantic

A large number of marine mammals inhabit the northwest Atlantic. Because of their wide ranging, pelagic, distribution little is known about many species although considerable research has been carried out on a few, particularly species that have been hunted extensively.

Northwest Atlantic marine mammals are carnivores that consume secondary production over a range of trophic levels. The potential impact of marine mammals on important commercial fish stocks is an issue that has been debated for decades in the belief that predators have seriously impacted important commercial species either directly through predation or indirectly through competition (e.g. see Malouf 1986, Stenson 2007). However, because of their large body size and the abundance of some species, they are also thought to have important top-down influences on the structure and function of the communities they occupy (e.g. see Bowen 1997). With a large number of links to other members of their ecosystems, many marine mammals are considered to be key components that provide a stablizing influence on marine food webs (e.g. Libralto et al 2006, Koen-Alonso and Stenson 2006).

In addition to the polar bear, thirty-two species of seals and whales have been recorded in the northwest Atlantic (Table 9). Because of the influence of the Labrador Current, the southern Labrador shelf area is an area where Arctic and temperate species overlap. Arctic species such as ringed and bearded seals, beluga, and narwhal are found primarily further north and along the Labrador and Greenland coasts, but are occasionally sighted as far south as northeast Newfoundland. Historically, walrus and bowhead whales were also common along the Labrador coast and further south, but due to heavy hunting, they are now considered rare and only seen occasionally. Temperate seals such as grey seals are seasonal summer migrants from their primary range in the southern Gulf of St. Lawrence and Scotian Shelf, northward around Newfoundland and along the Labrador coast. Like grey seals, harbour seals are a nearshore species that are occasionally found as far north as the Hudson Strait. Harp and hooded seals are also seasonal migrants, summering in the Arctic (northern Labrador, Baffin Bay and/or Greenland) and migrating to more temperate areas (southern Labrador shelf, Grand Banks and Gulf of St. Lawrence) during the winter.

With the exception of the Arctic species (beluga, narwhal and bowhead whales) and some individuals that are present during the winter (primarily minke, blue whales and white-beaked dolphins), the majority of cetaceans are summer migrants in the northwest Atlantic. Most species winter in more temperate or tropical waters but move into the highly productive subarctic and Arctic areas to feed, often continuing northward into Baffin Bay and other Arctic areas. The majority of sightings occur on the continental shelf although this is highly influence by the greater observer effort in many of these areas. However, the large number of sightings in areas such as the southeast shoals. Southwestern edge of the Grand Banks and along the Sackville Spur in comparison to sighting effort suggest that these areas are important for cetaceans.

Table 9. Marine mammal species in the Northwest Atlatic

Species	Scientific name
Pinnipeds	
Atlantic Walrus	*Odobenus rosmarus*
Bearded Seal	*Erignathus barbatus*
Gray Seal	*Halichoerus grypus*
Harbour Seal	*Phoca vitulina*
Harp Seal	*Pagophilus groenlandicus*
Hooded Seal	*Cystophora cristata*
Ringed Seal	*Phoca hispida*
Cetaceans	
Atlantic White-sided Dolphin	*Lagenorhynchus acutus*
Beluga whale	*Delphinapterus leucas*
Blue Whale	*Balaenoptera musculus*
Bottle-Nosed Dolphin	*Tursiops truncatus*
Bowhead Whale	*Balaena mysticetus*
Cuvier's Beaked Whale	*Ziphius cavirostris*
Fin Whale	*Balaenoptera physalus*
Harbour Porpoise	*Phocoena phocoena*
Humpback Whale	*Megaptera novaeangliae*
Killer Whale	*Orcinus orca*
Long-finned Pilot Whale	*Globicephala melas*
Minke Whale	*Balaenoptera acutorostrata*
Narwhal	*Monodon monoceros*
North Atlantic Right Whale	*Eubalaena glacialis*
Northern Bottlenose Whale	*Hyperoodon ampullatus*
Sei Whale	*Balaenoptera borealis*
Short-Beaked Common Dolphin	*Delphinus delphis*
Sowerby's Beaked Whale	*Mesoplodon bidens*
Sperm Whale	*Physeter macrocephalus*
White-Beaked Dolphin	*Lagenorhynchus albirostris*
Occasional visitors	
Blainville's Beaked Whale	*Mesoplodon densirostris*
Pygmy sperm whale	*Kogia Breviceps*
Risso's Dolphin	*Grampus griseus*
Striped Dolphin	*Stenella coeruleoalba*
True's Beaked Whale	*Mesoplodon mirus*

The first comprehensive survey of cetaceans along the Canadian continental shelf was carried out in 2007 (Lawson and Gosselin 2009, Fig. 40). They estimated the total number of cetaceans in the area from the northern tip of Labrador down to the southern Scotian Shelf and Gulf of St. Lawrence as part of a trans-Atlantic study of cetacean abundance and distribution. Some offshore areas such as the tail of the Grand Banks were not surveyed due to the limited range of the aircraft. Preliminary estimates indicate that over 300,000 cetaceans were present in the study area although this is considered to be an under-estimate of the total abundance. The most abundant species were dolphins, harbour porpoise, pilot whales and minke whales. The majority of sightings occurred in southern areas, likely due to the timing of migrations into the study area. Based upon these estimates, Lawson (unpublished data) estimated that cetaceans may consume up to 2 million metric tonnes of prey each year in Atlantic Canada which is approximately half of that estimated for seals (Hammill and Stenson 2000). Unfortunately, there are no recent data on diet composition in the northwest Atlantic, but based upon older data and diets in other areas, capelin, squid and copepods were considered to be the most important prey.

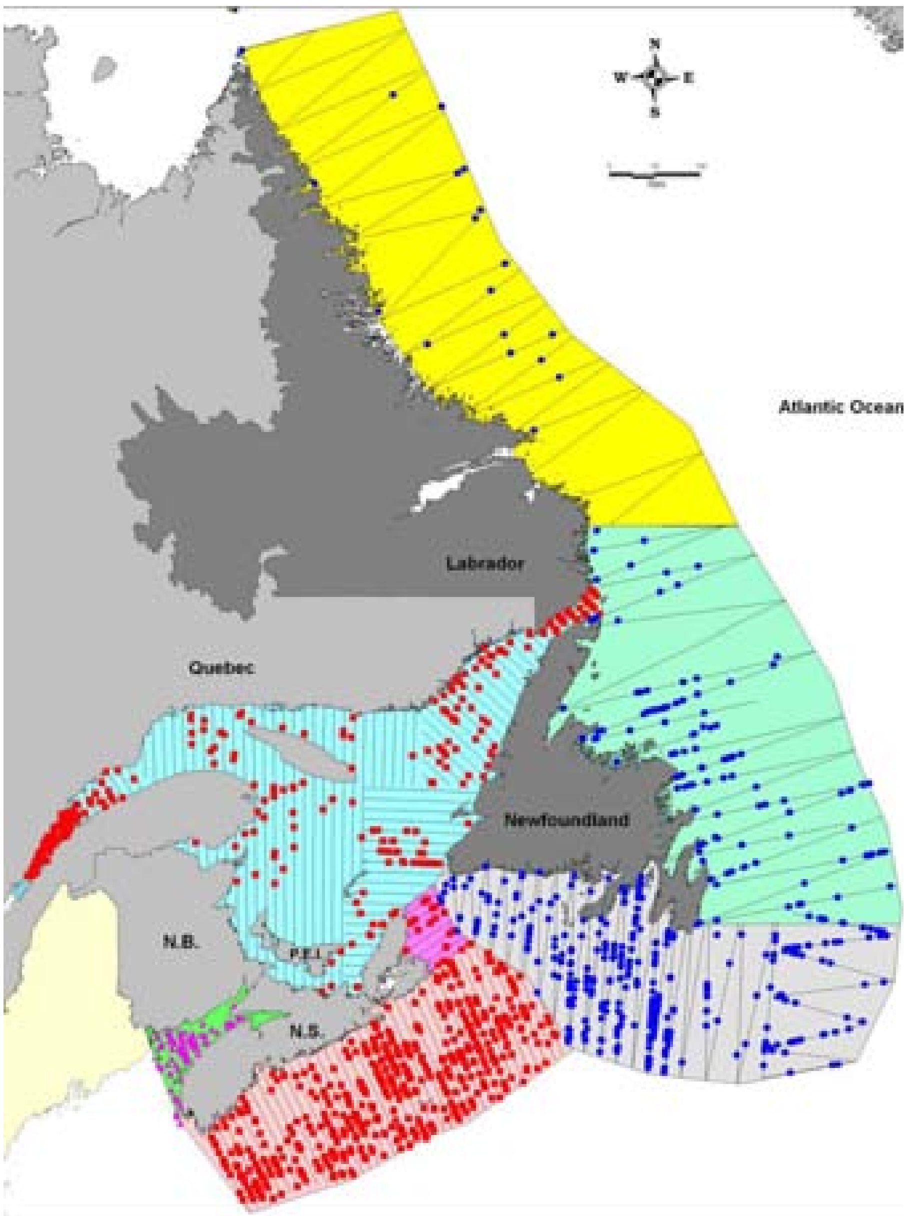

Figure 40. Survey effort (lines) and sightings of cetaceans during the Canadian marine megafauna surveys carried out in 2007. Sightings in the Bay of Fundy were obtained during a NOAA survey. From Lawson and Gosselin, 2009.

Harp seals are the most abundant marine mammal in the northwest Atlantic. Three populations of harp seals are identified based upon pupping locations: the White Sea/Barents Sea, the Greenland Sea and the Northwest Atlantic. The northwest Atlantic population, which is the largest, summers in the eastern Canadian Arctic and Greenland. In the fall, most of these seals migrate southward to Atlantic Canadian waters where they give birth on the pack ice in the Gulf of St. Lawrence ("Gulf") or off northern Newfoundland ("Front") during late February or March. Following moulting in April and May, harp seals disperse and eventually migrate northward. Small numbers of harp seals may remain in southern waters throughout the summer while others remain in the Arctic throughout the year. Harp seals are found primarily on the continental shelf. Although they are capable of diving to depths greater than 700m, the majority of their dives are 100m or less.

The most recent estimates of abundance are based upon a population model that incorporates data on age specific reproductive rates, human induced mortality (commercial and subsistence catches, bycatch in fishing gear and estimates of the number of seals killed but not landed or recorded) with 10 independent estimates pup production obtained between 1950 and 2008 (DFO 2009, Fig 41). Following declines in the population in the 1950s and 1960s due to overharvesting, harp seals increased from less than 2 million in the early 1970s to approximately 5.5 million in the mid 1990s. Since then, the rate of increase has declined due to lower reproductive rates and renewed hunting in Canada. The population is estimated to be 6.9 million (95% CI=6.0 to 7.7 million) seals in 2009. This estimate is higher than previous population projections due, primarily, to the lower reproductive rates observed in recent years.

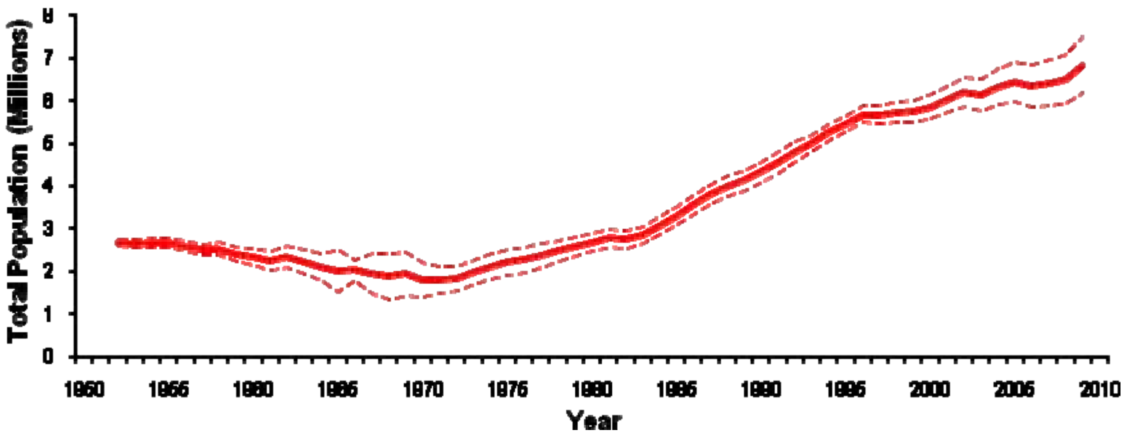

Figure 41. Estimated population (+ 95% CI) of northwest Atlantic harp seals. From DFO 2009.

The diet of harp seals in 2J3KL has been studied since the early 1980s by reconstructing the hard remains found in the stomachs (Stenson et al 2009). Although specific diets vary with season, location and year, forage fish such as capelin, Arctic cod (*Boreogadus saida*), sandlance and herring were the primary prey consumed. Shrimp were also an important prey item in offshore areas while Atlantic cod were present in the diet in the nearhsore. In contrast, diets estimates based on fatty acid signatures showed extremely low levels of Atlantic cod in the nearshore diet and none in offshore diets (Tucker et al 2009). Diets of seals collected in different areas and seasons obtained from fatty acids were more similar than those estimated from reconstructed hard parts, likely as a result of the longer integration period represented by this method. This method also resulted in higher estimates of sandlance, redfish and amphipods, and lower estimates of Arctic cod, capelin and Atlantic herring.

Hooded seals are a large, abundant pinniped that occurs throughout the northwest Atlantic. A sexually dimorphic species, adult female hooded seals reach 200-225 kg while males are 350 – 400 kg. Two putative populations occur in the Atlantic: the Greenland Sea and the Northwest Atlantic. In the northwest Atlantic, hooded seals give birth (whelp) on pack ice off the coast of southern Labrador or northeast Newfoundland (the ‘Front’), in Davis Strait, and in the Gulf of St. Lawrence (the ‘Gulf’). It is not known how much interbreeding there is among hooded seals whelping in these different areas, but seals from all three areas are known to mix during the non-breeding period.

Coltman et al (2007) was not able to differentiate among seals from all of the whelping areas suggesting that hooded seals form a panmictic population in the north Atlantic.

Hooded seals are seasonal migrants, spending most of the year in offshore waters. The northwest Atlantic population summers off south and west Greenland or in the eastern Canadian Arctic. They migrate to the whelping areas during the late autumn or early winter. After weaning their single pup (blueback) in March, females mate and disperse to deep water slope edges to feed. Eventually they migrate to Denmark Strait near southeast Greenland to moult in late June or July. Following the moult, the majority of hooded seals migrate around the coast of Greenland into Davis Strait and Baffin Bay (Andersen et al 2010). In the winter, sexually mature animals return to the whelping areas. Hooded seals are found primarily along the continental shelf edge where they dive to depths of over 1500m (Stenson unpublished data).

Like harp seals, total population of hooded seals is estimated from a population model that incorporates data on reproductive rates, catches and periodic estimates of pup production. Unlike harps, however, fewer studies have been carried out on hooded seals and the only concurrent surveys of pup production in all three northwest Atlantic whelping areas was carried out in 2005. Fitting to pup production estimates from all herds and making assumptions about numbers of hooded seals in the Davis Strait herd for years when this area was not included in the survey program resulted in an estimated population increase from approximately 475,000 in 1960 to 600,000 in 2006 (Hammill and Stenson 2006, Fig. 42). Unfortunately, there is considerable uncertainty associated with these estimates due to our lack of understanding of the relationship between the Davis Strait, Front and Gulf pupping areas, few surveys of all three areas, limited reproductive data and uncertain harvest statistics.

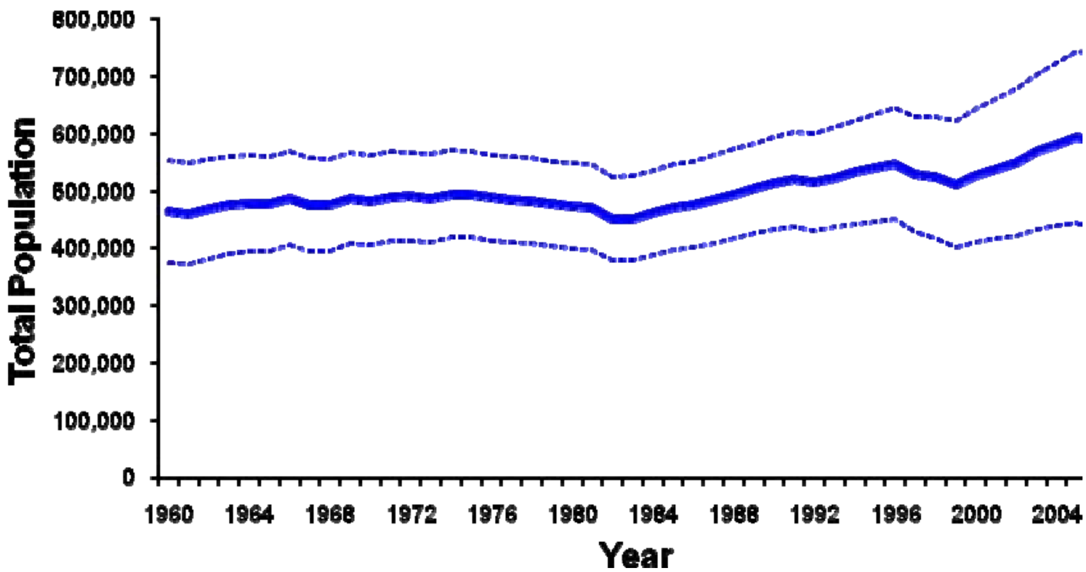

Figure 42. Estimated population (+ 95% CI) of northwest Atlantic hooded seals. From Hammill and Stenson 2006.

The diet of hooded seals reflects their slope edge habitat and deep diving capabilities. Deep water species such as redfish and Greenland halibut are important prey (Hammill and Stenson 2000). Squid, flatfish (mostly American plaice) and Arctic cod also contribute significantly to the diet. Redfish are the most important prey species based upon the fatty acid signatures of both pre and post breeding hooded seals (Tucker et al 2009). However, the method of estimating diet suggests the Atlantic argentine is also an important prey, This species has not been observed in the stomach contents but may represent feeding in offshore areas where samples are difficult to obtain.

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Trajectories of large marine ecosystem change

Despite the complexities of all possible interactions among all components which define a regional ecosystem there is growing evidence that ecosystem change can have some large scale coherence, or definable trajectory of change. Integrated time-series analysis of several large marine ecosystems (North Sea-Kenny *et al.*, 2009; Nova Scotia Shelf-Choi *et al.*, 2004 and Mediterranean, Molinero *et al*., 2008a, 2008b; Mariotti *et al*., 2002) all reveal large scale changes in ecological state or regime shifts (changes in marine system function that are relatively abrupt, persistent, occurring at a large spatial scale and observed at different trophic levels and related to climate forcing, see de Young *et al.* 2004) which affect many trophic levels. These studies also present further insight into how ecosystems change state, for example the rates and magnitudes of change are not the same for the different systems reflecting regional specific differences in the forcing factors. Indeed, such regime shifts may simply be part of multi-annual or multi-decadal oscillations related to climatic shifts occurring at large (hemispherical or global) scales (discussed below). In any one geographical ecosystem the expression of changes resulting from climatic forcing may take on different patterns reflecting the detailed mechanisms and local processes that are influential within the constraints of the larger scale forcing. However, there is growing evidence that although climate forcing appears to be a significant trigger for many regime shifts, those ecosystems subject to high levels of human activity such as fishing appear to be at greater risk to this phenomena (Kenny *et al*., 2009, Kirby *et al*., 2009).

Recent work undertaken by ICES Working Group on Holistic Assessments of Regional Marine Ecosystems (WGHAME) (ICES 2009) examined four atmospheric forcing modes (indicators) selected as most likely being the most influential on the dynamics of North Atlantic ecosystems (Figure 43). What is apparent is that at specific times notable positive and negatively anomalies co-occur such during the early 1970's and again in the late 1980's. The timing of these events coincides with well documented changes in large marine ecosystem state in the North Atlantic, for example Figure 44 shows the relationship between the long-term trends in spawning stock biomass of Norwegian spring-spawning herring and the long term averaged sea surface temperature or AMO.

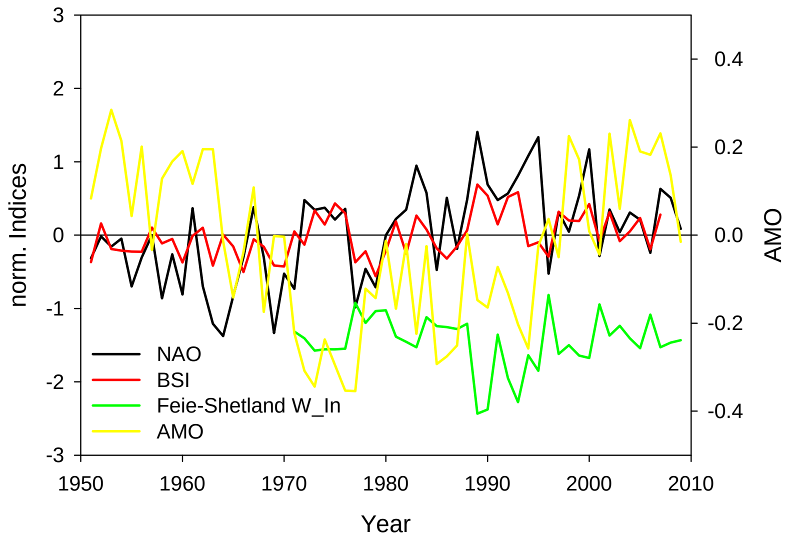

Figure 43. Climatic and hydrographic indices relevant for North-East Atlantic ecosystems: North Atlantic Oscillation (NAO, black), Baltic Sea Index (BSI, red), Influx of seawater into the North Sea (green), and the Atlantic Multidecadal Oscillation (AMO, yellow) from 1950 until 2009.

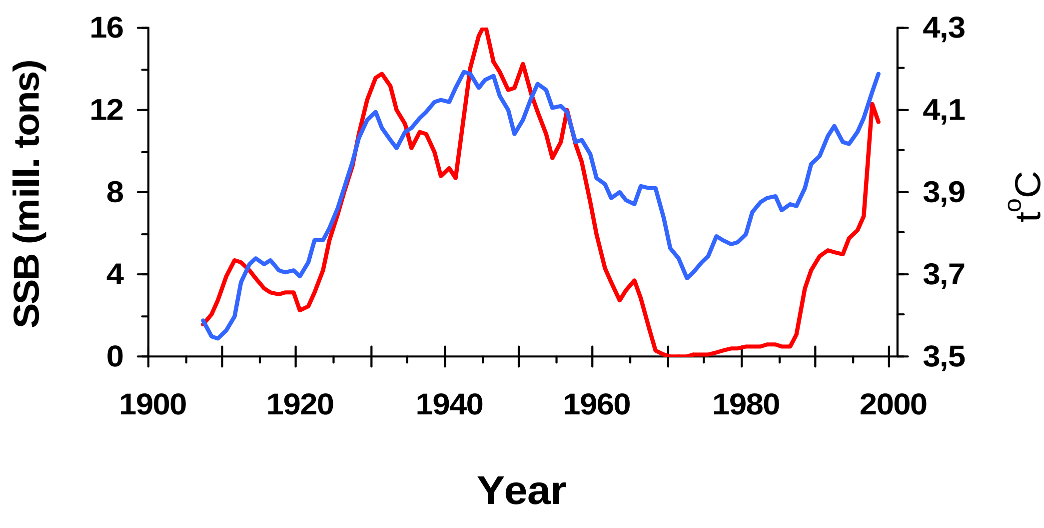

Figure 44. Spawning stock biomass of Norwegian spring-spawning herring and the long-term-averaged sea surface temperature or AMO (Toresen and Østvedt, 2000).

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***ToR 3**. Scope of Marine Protected Areas and VMEs in the context of habitat and spatial functioning.*

Results reported under this ToR included a) a preliminary GIS-based analysis aimed to delineate regional ecosystem sub-units in the Scotian Shelf following a similar method to the one used in the Northeast continental shelf of the US and described in the first WGEAFM report, b) analyses on the efficacy of MPAs as management tools using Georges Bank as study case, and c) some work done by ICES WGHAME on scale and resilience which suggests that ecosystem resilience can be scale-dependent.

Preliminary analysis of biogeographic units for the Scotian Shelf

As pollution pressures on deep sea ecosystems continues to increase through increased human activity, so does the need to identify effective management strategies and tools to sustain its resources. Classification systems are one such tool which have an important role in helping to identify the appropriate spatial units for management. They were first developed and applied to manage shallow shelf sea ecosystems (Allee et al., 2000 and Connor et al., 2004 – see also EUNIS). They divide the marine environment into understandable distinct units that can be quantified and mapped for planning purposes and provide a framework for describing function and sensitivity of habitats. Without such classifications it is very difficult to know which areas and parts of a marine ecosystem require protection.

In 2008 the Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) adopted scientific criteria (Decision IX/20) for identifying ecologically or biologically significant marine areas (EBSAs) in need of protection (their Annex I) and scientific guidance for designing representative networks of marine protected areas (their Annex II). The criteria for identification of EBSAs are based on seven attributes:

1. Uniqueness or rarity
2. Special importance for life history of species
3. Importance for threatened, endangered or declining species and/or habitats
4. Vulnerability, fragility, sensitivity, slow recovery
5. Biological productivity

6. Biological diversity
7. Naturalness,

while the required properties and components for MPA networks are:

1. Ecologically and biologically significant areas
2. Representativity
3. Connectivity
4. Replicated ecological features
5. Adequate and Viable sites.

Delineation of spatial management units is prerequisite to establishment of an effective ecosystem approach to management of human activities in marine ecosystems. Biogeographic classification has been described as "fundamental for marine spatial planning and can serve as a framework for a number of uses from assessment and monitoring to marine protected areas network design" (CBD 2009).

The WGEAFM considered this issue at its first meeting in June of 2008 (NAFO 2008), specifically with its Terms of Reference 1: To identify regional ecosystems in the NAFO Convention Area. They presented the results of a spatially and temporally extensive set of observations of physiographic, oceanographic, and biotic variables to identify regions of biophysical similarity / dissimilarity in the US Northeast Atlantic continental shelf to delineate bioregions. Canada held a workshop in June of 2009 to evaluate various biogeographic classification schemes and to reach consensus on a single scheme to apply within its EEZ (DFO 2009). They delineated 12 biogeographic zones or ecoregions linked to physical oceanographic and geological features underpinned by the control these have on species distributions (DFO 2009, Figure 45).

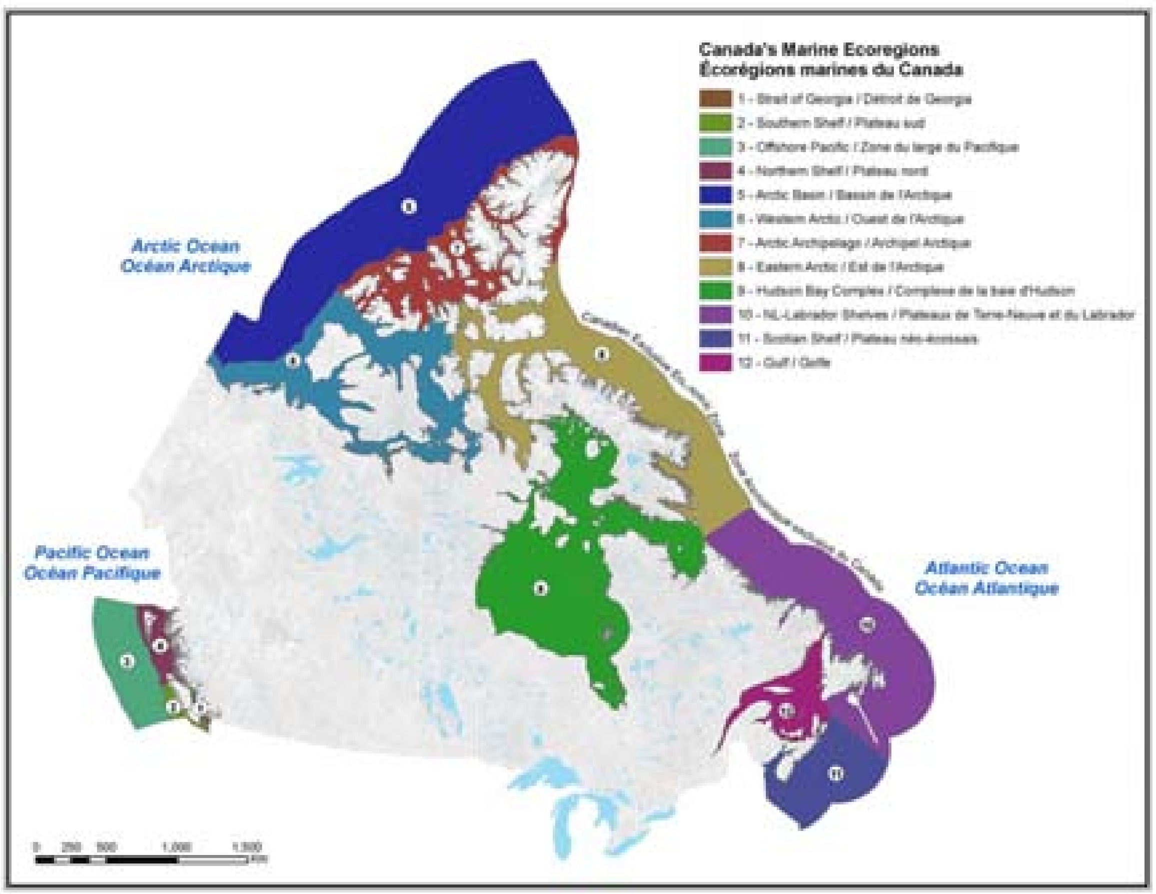

Figure 45. Canadian marine biogeographic zones recommended by the June 2009 National Workshop on Biogeographic Classification (DFO 2009).

Zwanenburg *et al.* (2010), to the extent possible, replicated the analysis presented in the NEFSC white paper on the delineation of regional ecosystem units on the U.S. Northeast Continental Shelf (Fogarty and Keith) for the adjacent large marine biogeographic area, the Scotian Shelf (Region 11, Figure 45). Due to differences in the respective oceanographic and biological sampling programs between these regions exact replications of the methods used by Fogarty and Keith were not possible, but similar data were generally available. Table 10 provides an overview of the data sources used in the two analyses and details of the data layers are found in Zwanenburg *et al*. (2010). The results of the analyses are illustrated in Figure 46. These preliminary analyses provide some direction for a more detailed analysis of biogeographic units for the Scotian Shelf proper and for the broader Northeast Atlantic. The following points are noteworthy. 1) Inclusion of both biotic and abiotic variables in a single PC analysis does not reveal significant structure above what is derived from an analysis of environmental variables alone. 2) The structure of environmental conditions on the Scotian Shelf is directly related to the structure in species composition (Spearman r=0.66 for the three dominant variables, BT, BT range, and mean SST.). 3) Environmental conditions in each of the clustered areas can now be estimated as acceptable conditions for the species composition resident in the areas.

The challenge will be to determine the consistency of boundaries between areas of differing environmental conditions and the consistency of species composition within these areas. These zones show remarkable consistency with the map produce for the U.S. Northeast Continental Shelf with the same regions delineated in areas where the two schemes overlapped. Canada plans to extend this analysis to the Newfoundland and Labrador Shelves in 2011.

Table 10. A comparison of the data used in the Fogarty and Keith (2008) delineation of Regional Ecosystem Units to data used in the Scotian Shelf analysis.
* indicate focal species considered of particular management concern

Data Type/Theme	**US Data (Fogarty and Keith 2008)**			**Canadian Data**
Physiographic	**Data Type**	**Sampling Method**	**Units**	
Bathymetry	Raster	Soundings / hydroacoustics	m	CHS's Atlantic Bathymetric Data (15 arc second resolution), raster, soundings recorded in metres
Surficial sediment	Vector	Benthic grab	Not specified	GSC surficial geology, vector, classified sediment types
Physical Oceanography and Hydrographic				
Sea surface temperature	Raster	Satellite (SeaWIFs)	C	BIO's Hydrographic Data Base 01/01/1900 - 12/17/2001. Raster data, degrees C, 12 minute resolution
Annual SST temperature span	Raster	Satellite (SeaWIFs)	C	BIO's Hydrographic Data Base 01/01/1900 - 12/17/2001. Raster data, degrees C, 12 minute resolution
Water column stratification	Vector	Shipboard hydrographic measurments	Sigma-t units	BIO's Hydrographic Data Base 01/01/1900 - 12/17/2001. Raster data, mixed layer depth (m), 12 minute resolution
Bottom temperature	Not used			BIO's Hydrographic Data Base 01/01/1900 - 12/17/2001. Raster data, degrees C, 12 minute resolution
Annual bottom temperature span				BIO's Hydrographic Data Base 01/01/1900 - 12/17/2001. Raster data, degrees C, 12 minute resolution

Biotic				
Satellite derived estimates of primary production	Raster	Satellite (SeaWIFs)	gC m^{-2} yr^{-1}	Satellite derived estimates of chlorophyll a (from SeaWiFs) [used as a surrogate for primary production]. Vector from Raster.
Shipboard estimates of surface chlorophyll	Raster	Shipboard measurements	dimensionless	Not included.
Zooplankton displacement volume	Vector	ECOMON plankton sampling	Cc 100 m^{-3}	Zooplankton wet weight data from the AZMP program is substituted. Vector.
Benthic biomass	Vector	Benthic grab/sled	g m^{-2}	Not included. No comparable data, no regional benthic survey program exists
Nektonic and epibenthic biomass	Vector	NEFSC groundfish survey	Kg/tow	DFO research vessel summer trawl survey.
Species richness (trawl caught organisms)	Vector	NEFSC groundfish survey	Number/tow	DFO research vessel summer trawl survey.
Presence/absence of marine mammals and sea turtles* (Endangered spp)	Vector	Arial/shipboard sighting program	Presence / absence	MarWhale data obtained from VDC. - **Note: It appears that MarWhale does NOT include observations from Whitehead Lab @ Dal.*
Presence/absence of coral*	Vector	Arial/shipboard sighting program	Presence / absence	ERD coral database, points

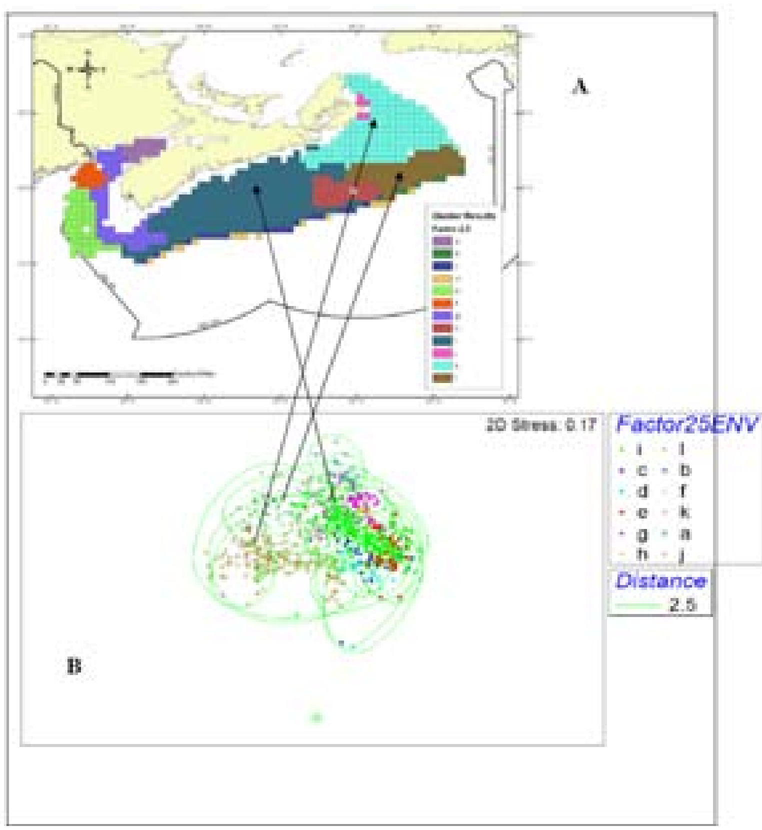

Figure 46. Designation of major ecoregions on the Scotian Shelf of Canada in NAFO Subareas 4VWX. A) Cluster groupings resulting from hierarchical agglomerative clustering of PCA scores for each 10x10 sampling unit using only environmental variables. Note that no minimum unit limit has been imposed on the clustering algorithm. B) Non-metric multi-dimensional scaling of species abundance measures for each 10x10 sampling unit. The arrows

show the correspondence between species multidimensional structure and geographic distribution of clustered z-scores from PC analysis of unit based environmental measures.

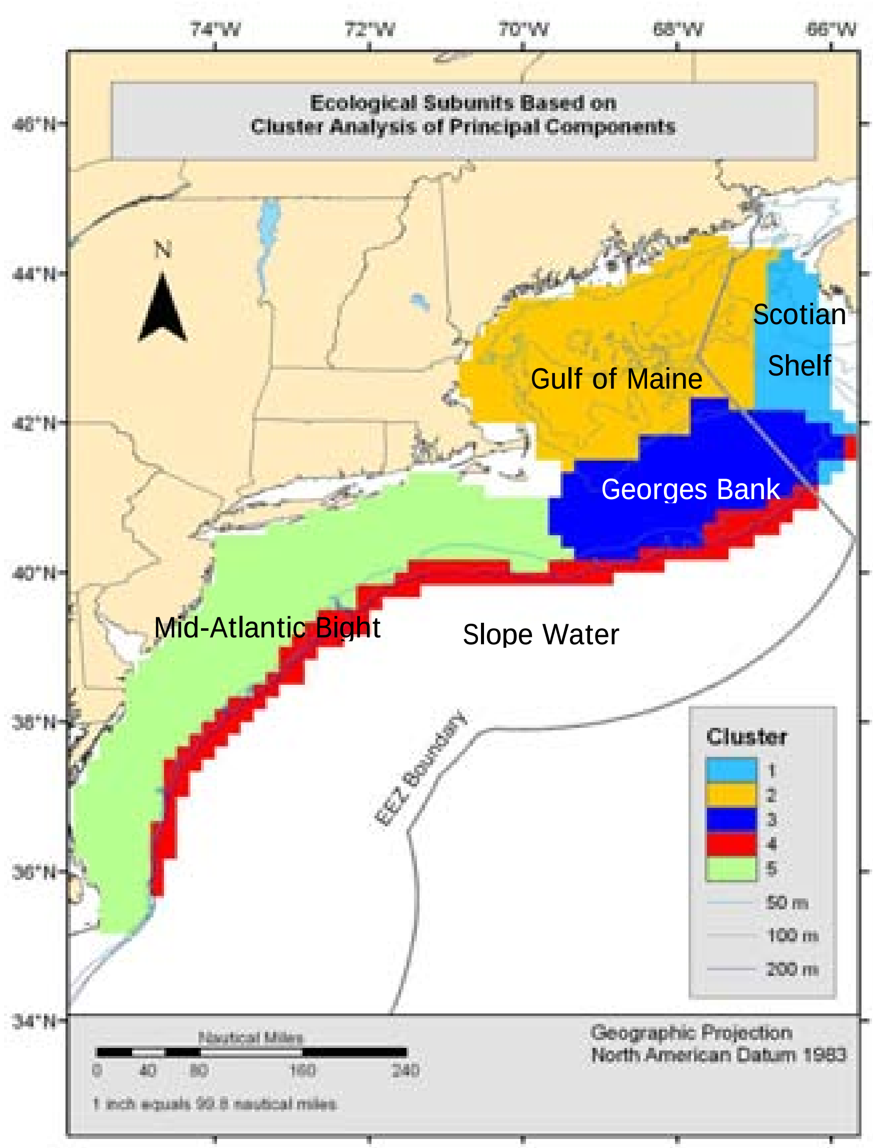

Figure 47. Designation of major ecoregions on the Northeast Continental Shelf of the United States in NAFO Subareas 5 and 6 (From NAFO 2008).

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Efficacy of Marine Protected Areas in a temperate system: A case study of Georges Bank

Seasonal and year-round closures are a major tactical tool used to manage fishery resources on the Northeast Continental Shelf of the United States. Year-round closures were established in three areas on Georges Bank and the nearby continental shelf off Southern New England in 1994 and two additional closure areas were established in the Gulf of Maine during 1996-1998. The total area protected under these closures exceeds 22,000 km^2. On Georges Bank, nearly one-third of the U.S. portion of the bank is protected. These fishery closures prohibit, in general, the use of towed fishing gear, although short-term openings have been allowed to permit scallop dredging for restricted time periods and locations in the two closed areas on Georges Bank. The use of fixed gear (including gill nets, longlines, and traps) is permitted. Although these areas do not represent no-take marine reserves, they have had demonstrable impacts on biomass levels within the closed area and important spill-over effects to the fishery for some groundfish species.

The efficacy of the closed areas as a management tool can be clearly linked to the mobility and movement patterns of the individual species. For sea scallops on Georges Bank, a comparison of biomass levels before and after the closures and inside the closed areas relative to an open reference site has been made using research vessel survey data. Overall, a twenty-fold increase in biomass within the closed areas has been documented. A time-series intervention model fitted to the difference in biomass in the closed and reference sites (on a logarithmic scale) indicates a significant effect of the closures. In contrast, a comparison of recruitment levels inside the closed areas relative to the reference area is non-significant, reflecting the episodic nature of scallop settlement and recruitment and the fact that egg and larval production originating in the closed areas can be shown to provide a subsidy to open areas using a numerical hydrodynamic model. The build-up in biomass can be attributed largely to a dramatic increase in mean weight of scallops in the closed areas.

To assess fishery spill-over effects, we have examined catch rates as a function of distance from a closed area for eight major groundfish stocks. Strong differences in concentration profiles (cumulative catch as a function of distance from a closed area) are evident among these species. Particularly dramatic spill-over effects were observed for haddock with over 70% of the catch taken with 5 km of a closed area. In contrast for the more vagile cod, only about 20% of the catch was taken within 5 km of a closed area. Fishing strategies have evolved that are closely tied to the location of closed areas, particularly the idea of ‘fishing the line’ where vessels congregate at the borders of closed areas (Figure 48).

It should be noted that large-scale displacement of fishing effort can occur with the implementation of closed areas and that these displacements can have unintended consequences. In particular, it is possible that fishing effort can be displaced to areas that may contain fauna that are vulnerable to disturbance. From an ecosystem perspective, these types of effects should be carefully monitored.

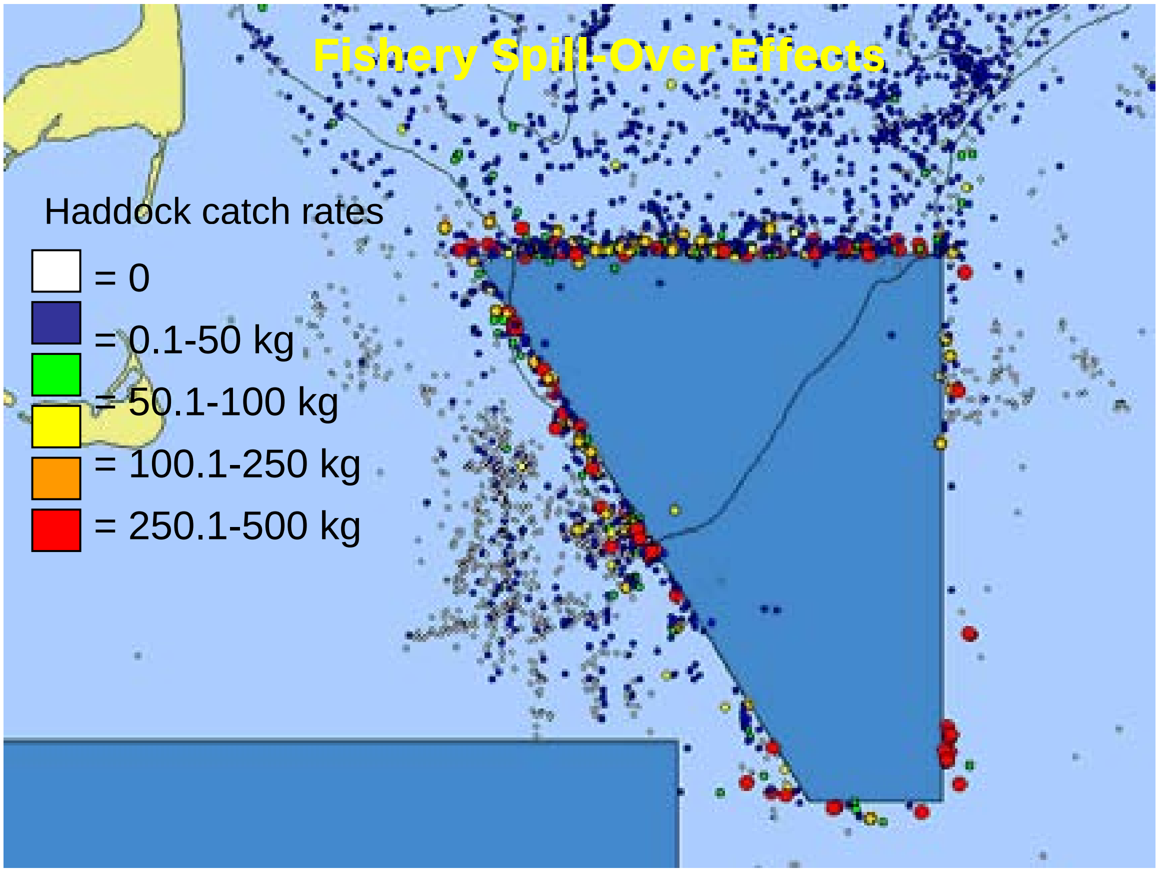

Figure 48. Catch rates of haddock in the vicinity of Fishery Closed Area I on Georges Bank in 2003.

Exploring the relationship between ecosystem scale and resilence

The capacity/ability of an ecosystem to 'recover', as well as withstand, pressures and impacts, depends on its resilience. This does not imply a static, ideal state, since change is normal in many marine habitats. There is a growing literature on what determines resilience and what happens when it is weakened (see, for example, the Resilience Alliance –www.resalliance.org). Resilience depends on the ecology of its component species and habitats and the interactions between them operating at different scales. In a more biodiverse habitat there is potentially more 'functional redundancy' whereby one species can take up the ecological role of a lost species. In some cases, comparison of more and less biodiverse systems does indicate a degree of 'ecological insurance' in the former. However, this is not the always the case, for example, if all species performing the same function respond to a pressure in the same way. Also, in low diversity ecosystems, abundance may be as important as diversity for maintaining ecological roles of species.

A recent study carried out in the North Sea investigated the relationship between spatial scale and trends in ecosystem state changes using over 100 variables representing environmental, biological and fisheries data (ICES, 2009). The results appear to show that smaller areas (measured in the order of 10's km) are less resilient than larger areas (assessed at the scale of 100km's) in their ability to respond to fishing pressure (see Figure 49). Clearly this has implications for deciding on the optimal scale for the designation of spatial management unit. For example, if the unit is too small then it may lack the capacity (or resilience) to recover following a given perturbation. By contrast if the area is too large then problems arise in terms of monitoring its condition.

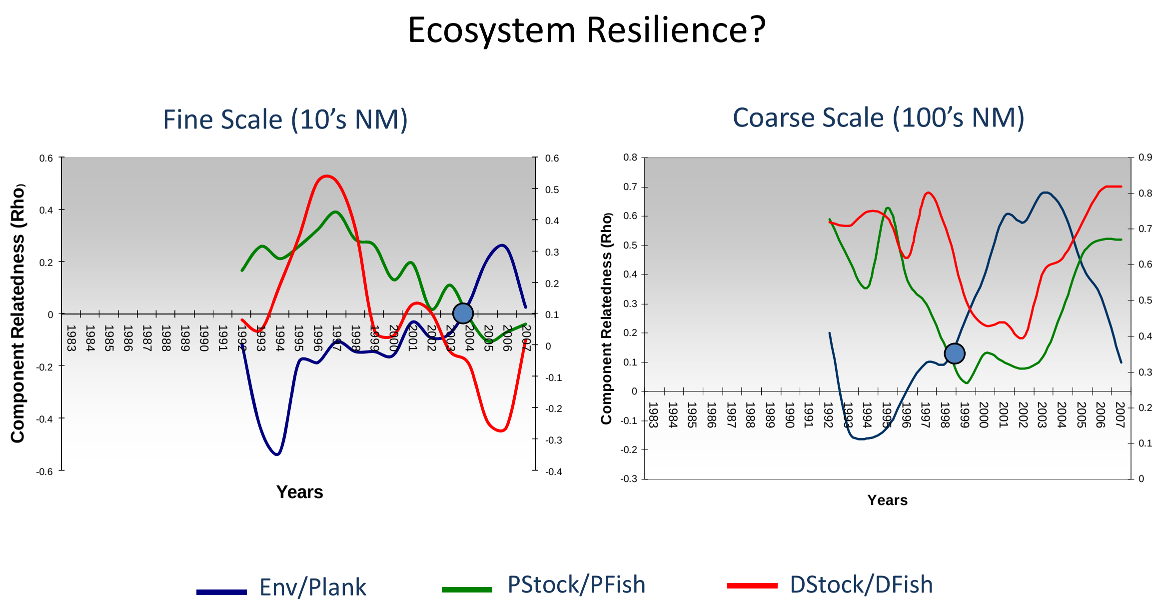

Figure 49. Plots showing trends in ecosystem component relatedness (Rho) for two different spatial scales in the North Sea. Whilst the green and red lines are above the blue line then the system is predominantly under top-down fishery pressure. Note how the sub-regional system for both the pelagic and demersal components become bottom-up driven much later than that shown at the scale of the whole North Sea – this possibly indicates a scale dependant level of stress exhibited by the two systems.

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Theme 3: Practical application (synthesising the evidence and theory)

***ToR 4**. Systems level modelling and assessment approaches.*

Presentations under this ToR included a) a brief description of the modelling work involved in ERI-NEREUS in NL, and b) a summary of ongoing work towards developing Integrated Ecosystem Asssements (IEAs) in the US.

ERI-NEREUS Modelling Component: Bionenergetic-allometric models currently in development for the Newfoundland-Labrador system

Among the diversity of modelling options available (Plaganyi 2007), ongoing work within ERI-NEREUS to address multispecies questions in the Newfoundland-Labrador (NL) ecosystem is currently based on bioenergetic-allometric models (Yodzis and Innes 1992). These models are developed from a basic energy budget equation. Changes in the population biomass can be described as:

$$\frac{dB}{dt} = B(-R + J) - Q - C$$

where *B* is the population biomass, *R* and *J* are mass-specific respiration and ingestion rates respectively, and *Q* represents the losses due to predation and *C* is exploitation.

Although straightforward in concept, implementing these models in practice poses the challenge of defining and estimating a potentially large number of parameters. To address this issue, bioenergetic-allometric models make use of the well-known allometric scaling of several vital rates with individual body mass (Peters 1983, Yodzis and Innes

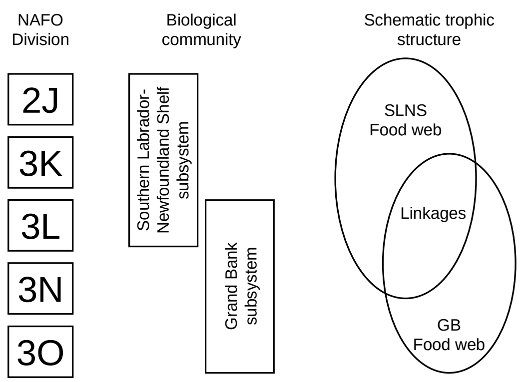
1992, Brown *et al.* 2004). Building upon allometric relationships also allows incorporating in a mechanistic way some of the expected effects of temperature on vital rates (Gillooly *et al.* 2001, Vasseur and McCann 2005). This development opens the door for exploring some potential impacts of climate change on food web dynamics.

In its standard formulation, one of the main caveats of this modelling approach is its inability for capturing the internal dynamics of the interacting populations (e.g. age structure). However, a simple way of representing stage structure and food-dependent growth has recently been developed (De Roos *et al.* 2007). On the other side, one of the advantages of the approach is its capacity for using the same set of equations to represent different model resolutions (from a single predator-prey model up to a whole food web), and different dynamic scales (static, near equilibrium [linearized] dynamics, and far from equilibrium [non-linear] dynamics) (Yodzis 1998, Yodzis 2001, Koen-Alonso and Yodzis 2005).

In the NL two main projects are currently being pursued, one involves the dynamic modeling of core ecosystem components, the other is focused on assessing the impact of harp seals on Northern cod.

The NL multispecies model is aimed to describe the joint dynamics of core components of the system. The large scale structure of this ecosystem can be schematically represented as the connection of two major functional sub-units, one corresponding to the southern Labrador and northern Newfoundland shelf (SLNS subsystem) and the other to the Grand Bank (GB subsystem) (Fig. 50a). The spatial component of this structure is not explicitly represented in the model, but it is implicitly recognized by considering management stocks in the model (Fig. 50b). This model is currently in its implementation stage.

(a)



(b)

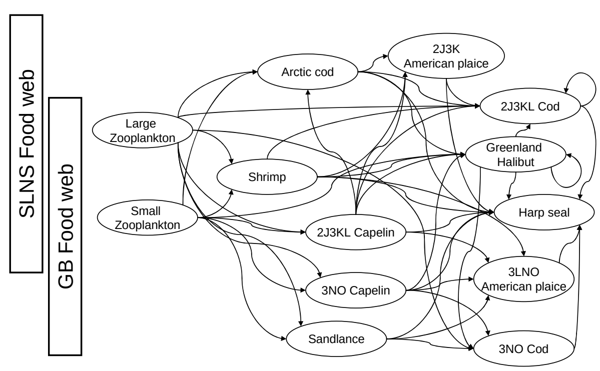


Figure 50. (a) Schematic representation of the large biological and spatial scale of the Newfoundland Shelf ecosystem. (b) food web diagram of the multispecies model in development.

The second project is aimed to assess the potential impact of harp seals on the northern cod stock (2J3KL Atlantic cod stock). Several factors have been hypothesized as main drivers for this population. Conceptually, these factors are availability of food (more specifically capelin), predation by seals, environmental effects (e.g. temperature), and fisheries (Fig. 51). In order to assess if the explicit consideration of these factors significantly improves our description of cod dynamics, a simple bioenergetic-allometric cod population model was developed. In this model, the proposed main drivers are explicitly incorporated as external functions that force cod dynamics.

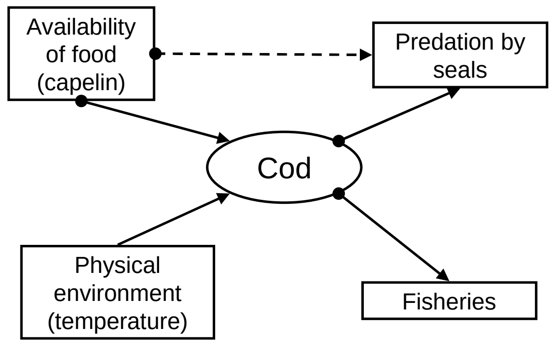


Figure 51. Conceptual representation of the major hypothesized drivers of northern cod dynamics.

The effect of capelin was modeled by making the population growth rate a function of capelin availability (this was derived from capelin acoustic indices). The effect of predation was incorporated through annual removals estimated from an independent seal consumption model (Stenson and Perry 2001, Stenson and Hammill 2006), and including a range of values to incorporate its uncertainty. Temperature effects can be represented in terms of the impact of temperature on vital rates (Vasseur and McCann 2005). Fishing impacts were included by using catch time-series.

At the present time, preliminary results are available for a subset model which only incorporates seal predation, capelin availability, and fisheries catches as external drivers of the Northern cod dynamics. These results indicate that consumption of cod by harp seals does not appear to be a significant driver of Northern cod during the study period (1985-2007). Fisheries and availability of food, on the other hand, appear as significant drivers of the dynamics of this stock. Furthermore, these results indicate that a depressed capelin stock could be a serious impediment for cod rebuilding (Buren *et al.* 2010).

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Options for Ecosystem-Based Fishery Management on the Northeast Continental Shelf of the United States

Mike Fogarty provided the following summary of the onging work within NFSC, NOAA.

In support of the development of Ecosystem-Based Fishery Management strategies for the Northeast United States, we have taken the following steps: (1) defined ecological subunits on the shelf based on analysis of physiographic, oceanographic and ecological variables, implemented a spectrum of different multispecies and full ecosystem models, and evaluated options for specifying ecosystem exploitation rates. These are discussed in turn in greater detail below.

The specification of spatial management units is a critical pre-requisite to the development of ecosystem approaches to management. We analyzed a set of physiographic, oceanographic and biotic variables to provide a basis for identification of ecological subareas on the Northeast Continental Shelf. We first employed a principal components analysis (PCA; e.g. Pielou 1984, Legendre and Legendre 1998) to examine the multivariate structure of the data and as a prelude to classification of ecosystem subunits. We then cluster analysis on the principal component scores to define subareas. The clusters represent major ecological subunits including (1) Eastern Gulf of Maine- Scotian Shelf, (2) Western-Central Gulf of Maine (3) Georges Bank- (4) Continental Slope and (5) Mid-Atlantic Bight. Further analyses are now underway, including the addition of more oceanographic variables, to refine these analyses.

We have undertaken a series of analytical studies employing a range of model types which can be arrayed along a continuum of complexity levels. These can be classified in increasing order of complexity as:

- Fishery Production Potential Models
- Aggregate-Species Surplus Production Models
- Multispecies Production Models (e.g. Lotka-Volterra models)
- Size Spectrum Models
- Ecosystem Network Models (e.g. EcoPath)
- Age/Size Structured Multispecies Models (e.g. Multispecies Virtual Population Analysis)
- Dynamic Ecosystem Models (e.g ATLANTIS)

The models differ not only in complexity but along a continuum from holism to reductionism (with the models classified as embodying higher levels of complexity also incorporating higher levels of structural detail. The choice of appropriate models depends on the specific objectives of the analysis and factors such as the interplay between model complexity and parameter uncertainty. We have particularly used the first two of these approaches to estimate the productive capacity (or carrying capacity) of the system for a given set of environmental/climate conditions. The fishery production potential models trace the flow of energy from primary producers through to the harvested components of the system. We explicitly account for energy pathways through the microbial food web and through the classical grazing food web to generate estimates of the production available for harvest.

For this approach, it is next necessary to specify an ecosystem exploitation rate that will permit sustainable harvest. For this purpose we have considered the results of multispecies models that predict not only the system exploitation rate that results in Multispecies Maximum Sustainable Yield (MMSY) but tracks the number of stocks that collapse as the exploitation rate increases. Using this approach, it can be shown that reducing the exploitation rate that results on MMSY by half results in very little loss in yield but it sharply reduces the number of stocks predicted to collapse at different to exploitation rates.

For the fishery production potential model, it is also necessary to specify an allocation strategy for individual species, we have considered the use of linear programming solutions that incorporate constraints on total removals from the system and individual species exploitation limits to ensure that these species are not driven to levels whci would result in stock collapse.

The aggregate-species surplus production approach was actually first used in NAFO's predecessor institution, ICNAF, to generate estimates of system-wide maximum sustainable yield for the Northeast U.S. Continental Shelf. This early analysis showed that the estimate of system-wide MSY was approximately 30% lower than the result obtained if estimates from individual species stock assessments were simply summed. It was inferred that interactions among species meant that all species could not simultaneously be at biomass levels resulting in MSY (Bmsy). Our updated analyses, which extend the previous modeling work to incorporate environmental/climate factors) confirm this basic result. These models also provide estimates of the level of fishing mortality that results in MSY (Fmsy) and these estimates are also lower for the aggregate species model than for most of the individual species Fmsy levels.

The basic conclusion emerging from these results suggests that there are important constraints on available energy must be considered in setting harvest policies at an ecosystem level. Further consideration of food requirements for threatened species and apex predators under rebuilding strategies highlights the potential constraints on available energy to meet overall ecosystem management objectives. This perspective necessarily involves direct consideration of possible tradeoffs among harvested species if all cannot simultaneously be at Bmsy levels.

Finally, we note that an ecosystem approach to management will use the same basic tools as conventional management but with different objectives and therefore different priorities. The basic tools include:

- Effort Limitation
- Conservation Engineering
- Marine Protected Areas (MPAs)
- Output Controls (TACs)

For example, the design and placement of MPAs intended to control fishing mortality might differ substantially from ones designed to protect vulnerable habitats or threatened and endangered species.

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ToR 5*. Ecosystem indicators and how they can be used in management advice.*

This ToR was only minimally addressed during the meeting.

Comments on indicators for ecosystem management

The abundance of ecosystem indicators under consideration has increased substantially over the last decade (see contributions in Cury and Christensen 2005) and, along with habitat classification schemes, the development of indicators of environmental status are an integral part in delivering an ecosystem approach to management (Rogers and Greenaway, 2005).

In general, an indicator can be defined as a parameter or value derived from a measure which provides information about the state of an environment (OECD, 1993), in this case, specifically identified habitat and biological facies. Indicators have two major functions:

1. They reduce the number of measurements and parameters normally required to give a precise characterisation of the environment – because something is already known about the properties of the habitat being monitored and assessed. However, too few or even a single indicator may be insufficient to provide all the necessary relevant information.
2. They simplify the communication process by which survey results are provided by the user.

Therefore, the selection of indicators has to be undertaken with a great deal of care and attention, particularly in understanding the functional/structural dependencies, since there is a risk that a vital piece of information may be missing from the indicator. To overcome this risk, in part, a more integrated habitat-based approach is being now favoured (Table 11), that is a shift away from the specific conservation of a particular species to one of protecting the habitat which the species depends. Accordingly, 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.

Table 11. Possible indicators of deep sea habitat status based upon determination of overall habitat and biological facies extent and density – such as would apply to “sponge aggregations” as recognised by OSPAR.

Pressure (Impact)	Possible Indicators
Fishing - demersal trawling (habitat structure changes - abrasion; removal of target species)	– Biological facies extent and density (e.g., sponge aggregations, cold water coral reefs, coral gardens, etc.) – Mega (primary) habitat extent and biology (e.g., seamounts, reefs, slopes, etc.) – Evidence of trawl scars and impacts (extent and density)

Whilst these indicators provide an estimate of the status and trends in important & vulnerable benthic habitats, there is also a need to consider the status and trends of many other components of the ecosystem, including the human activities themselves.

From a fisheries perspective, a group was set up in 2005 called ‘IndiSeas’ under the auspices of the EUR-OCEANS European Network of Excellence (www.eur-oceans.eu). It aims were to evaluate the effects of fisheries on marine ecosystems by using a panel of ecological indicators of states and trends, and to facilitate effective communication of these effects, largely by using work already achieved by the SCOR/IOC Working Group 119 on “Quantitative Ecosystem Indicators”, and specifically on the results of Rice and Rochet (2005) who outline some specific practical criteria for the selection of ecosystem indicators which were adopted by the SCOR-IOC Working Group, namely:

- ecological significance (i.e. are the underlying processes essential to the understanding of the functioning and the structure of marine and aquatic ecosystems?)
- measurability: availability of the data required for calculating the indicators
- sensitivity to fishing pressure
- awareness of the general public

The last of these criteria was of particular importance to the aims of the ‘IndiSeas’ WG, that is the awareness of the general public concerning the meaning (what information is communicated) of each indicator. For example, among potential size-based indicators, preference was given mean length rather than the slope of the size spectrum since this would be more difficult to communicate to the general public. In addition to these practical selection criteria, the indicators were selected to address four specific management objectives: Conservation of Biodiversity (CB), ecosystem Stability and Resistance to perturbations (SR), Ecosystem structure and Functioning (EF) and Resource Potential (RP).

Several categories of ***ecological indicators*** were distinguished (Cury and Christensen 2005): namely; **i**. size-based, **ii**. species-based, and **iii**. trophodynamic indicators. The eight indicators outlined in Table 11 (described below) were selected based on the above criteria, and are proposed as a minimum set of indicators for diagnosing the status of an ecosystem in relation to fisheries pressure. Six of the indicators were used to measure the state (S) of the ecosystem and six were used to measure trends (T) over time. Data for the indicators are derived primarily from fisheries independent surveys and commercial fisheries data, with auxiliary information where indicated. In addition to the full indicator name, a shorter "headline label" was attributed to each of the indicators (Table 12) to make them more readily comprehensible. Furthermore, the indicators are all formulated positively so that a low value of an indicator means a high impact of fishing and a high value a low impact of fishing

Total biomass of surveyed species is a conservative property of an ecosystem; as species are fished and their biomass reduced, other species increase in abundance and "replace" these species in the foodweb. With the removal of top predators lower trophic levels can be expected to increase. Thus changes in total biomass can reflect changes in ecosystem productivity. ***1/(landings /biomass)*** measures the inverse level of exploitation or total fishing pressure on the ecosystem. This indicator varies in the same direction as the other indicators in the selected suite, as it decreases when fishing pressure increases. A decrease is considered negative and is a measure of "resource potential". ***Mean length of fish in the community*** is an indicator of the impact of fishing on an ecosystem, that is, the reduction of mean length of fish in the community (Shin et al. 2005). From a single species perspective, the removal of larger fish, which are more fecund and produce more viable eggs than smaller fish (Longhurst 1999), compromises productivity. From an ecosystem perspective, the removal of larger species changes the size structure of the community and potentially ecosystem functioning. "Fish size" is thus a measure of ecosystem structure and functioning and is used to measure state and trend. ***Trophic level of landings*** measures the average trophic level of species exploited by the fishery, and is expected to decrease in response to fishing, since fisheries tend to target higher trophic level species (Pauly et al. 1998). A decrease in trophic level of landings and total catch indicates "fishing down the food web" (Pauly et al. 1998), and a change in the structure of the community and potentially ecosystem functioning. "Trophic level" is a measure of ecosystem structure and functioning and is used to measure state and trend. Trophic level of individual species is either estimated through modelling, or taken from global database such as Fishbase. ***Proportion of predatory fish*** is a measure of the diversity of fish in the community. Predatory fish are all surveyed fish species that are piscivorous, or feeds on invertebrates that are larger than 2 cm. "% predators" is a measure of conservation of biodiversity and is used to measure state and trend. ***Proportion of under and moderately exploited stocks*** represents the success (or not) of fisheries management. Ideally, in a precautionary world, all stocks should be moderately exploited to ensure sustained biodiversity and sustainable ecosystems. "% of sustainable stocks" is a measure of conservation of biodiversity. The FAO classification of stocks as underexploited, moderately exploited, fully exploited etc (*http://www.fao.org/docrep/009/y5852e/Y5852E10.htm#tbl*) was used to define these categories for the stocks in each ecosystem under consideration in the current time period. Thus this indicator is used to compare the state of ecosystems. ***Mean life span*** is a proxy for mean turnover rate of species and communities, and is meant to reflect the buffering capacity of a system. The life span or longevity is a fixed parameter per species, and therefore the mean life span of a community will reflect the relative abundances of species with differential turnover rates. Fishing affects the longevity of a given species (direct effect of fishing and genotype selection), but the purpose here is to track changes in species composition (same principle as for mean TL of catch). "Life span" is thus a measure of ecosystem stability and resistance to perturbations and is used to measure state and trend. ***1/Coefficient of variation of total biomass*** measures the stability of the ecosystem, and is measured as the coefficient of variation (CV) over the last 10 years. As with "fishing pressure", it is expressed as an inverse to make it conform with the directionality of the other indicators. Thus a low 1/CV indicates low "biomass stability", low ecosystem Stability and Resistance to perturbations. Since this indicator is measured over a 10 year time period, it is only used to measure state.

Table 12. List of indicators from the 'IndiSeas' WG for assessing the status of marine ecosystems in relation to fisheries pressure.

Indicators	Headline label	Calculation, Notations, Units	(S)tate, (T)rend	Expected Trend	Management Objectives	Management Direction
Total biomass of surveyed species	biomass	B (tons)	T	D	RP	Reduction of overall fishing effort and quotas
1/(landings /biomass)	inverse fishing pressure	B/Y retained species	T	D	RP	Reduction of overall fishing effort and quotas
Mean length of fish in the community	fish size	$\bar{L} = \frac{\sum_i L_i}{N}$	S,T	D	EF	Reduction of overall fishing effort and fishing effort on large fish species
TL landings	trophic level	$TL_{land} = \frac{\sum_i TL_i Y_i}{Y}$	S,T	D	EF	Decrease fishing effort on predator fish species
Proportion of under and moderately exploited stocks	% sustainable stocks	number (under+moderately exploited species)/total no. of stocks considered	S	D	CB	Decrease fishing effort on overexploited species. Diversify resource composition
Proportion of predatory fish	% predators	prop predatory fish= B predatory fish/B surveyed	S,T	D	CB	Decrease fishing effort on predator fish species
Mean life span	life span	$\frac{\sum_s (age_{max}\ B_s)}{\sum_s B_s}$	S,T	D	SR	Decrease fishing effort on long-living species
1/Coefficient of variation of total biomass	biomass stability	mean(total B for the last 10 years) /sd(total B for the last 10 years)	S	D	SR	

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***ToR 6**. Methods for the long-term monitoring of VME status and functioning.*

This ToR was covered by ToR 7a

PART II. Roadmap for developing an Ecosystem Approach to Fisheries for NAFO

Based on the elements presented during the meeting, other available information and the discussion that took place, WGEAFM developed the following roadmap to guide the work necessary to develop an Ecosystem Approach to Fisheries for NAFO.

1. Introduction

The Ecological Society of America Committee on the Scientific Basis for Ecosystem Management (Christensen et al. 1996) provided one of the first widely used definitions of Ecosystem Management. They defined it as "*management driven by explicit goals, executed by policies, protocols and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem structure and function*".

In its fifth meeting (Nairobi, 2000), the Conference of the Parties to the U.N. Convention on Biological Diversity defined the Ecosystem Approach as "*a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way*" and indicates that is "…*based upon the application of appropriate methodologies focused on levels of biological organization which encompass the essential processes and interactions among organisms including humans and their environment*".

When applied to fisheries, Ecosystem Approaches to Fisheries (EAF) are intended to ensure that the planning, development, and management of fisheries will meet social and economic needs, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems (FAO, 2003). Achieving this purpose requires addressing components of ecosystems within a geographic area in a more holistic manner than is used in classical target resource oriented management approaches. It requires identifying [geographically] exploited ecosystems together with explicit recognition of the many, and often competing, human interests in fisheries and marine ecosystems (FAO, 2003). Therefore, following FAO (2003) "…*an ecosystem approach to fisheries (EAF) strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries*".

Similarly, the U.S. Commission on Ocean Policy noted that *"U.S. ocean and coastal resources should be managed to reflect the relationships among all ecosystem components, including human and nonhuman species and the environments in which they live. Applying this principle will require defining relevant geographic management areas based on ecosystem, rather than political, boundaries.*"

As the recognition for the need of ecosystem approaches grow, political commitments to ecosystem-based fisheries management are increasing worldwide and NAFO is no exception. In line with the spirit of the above definitions, the proposed amendment to the NAFO convention indicates in its new preamble that "*effective conservation and management of these fishery resources should be based on the best available scientific advice and the precautionary approach*" while it commits to "*apply an ecosystem approach to fisheries management in the Northwest Atlantic that includes safeguarding the marine environment, conserving its marine biodiversity, minimizing the risk of long term or irreversible adverse effects of fishing activities, and taking account of the relationship between all components of the ecosystem*".

Overall, these (and many other) definitions of EAF (Garcia et al. 2003) embody the recurring themes of the need to understand and account for interactions among the parts of the system, the recognition that humans are an integral part of the ecosystem and that potential conflict among human activities can exist (and hence, achieving trade-offs is required), and that EAF is fundamentally a place-based management framework.

2. Integrated Ecosystem Assessments

The general implementation of EAF requires ecosystem assessments that are essentially the counterparts of stock assessments currently used in support of conventional single-species management. For this purpose, Integrated Ecosystem Assessments (IEA) have been defined as: "*a synthesis and quantitative analysis of information on relevant physical, chemical, ecological, and human processes in relation to specified ecosystem management objectives*" (Levin et al. 2009). Integrated Ecosystem Assessments are designed to meet multiple objectives and they can be considered as a tool, a product, and a process. They are a tool that uses integrated analysis and ecosystem modeling for synthesis. IEAs are product for managers and stakeholders who rely on scientific support for policy and decision making. Finally, IEAs are a process including the identification of management objectives by managers and stakeholders, the development of quantitative assessments, and the evaluation of alternative management strategies. As a whole, IEAs should not be viewed as a replacement of single-sector and/or single-species management; instead, they should be consider as a necessary supplement that highlights potential conflicts among human activities, as well as potential inconsistencies between human goals and ecosystem states and/or processes.

The steps involved in the development of an IEA are depicted in Figure 52, which begins by scoping and identifying the goals and objectives, but EAF requires managers to take account of how fisheries impact a wide range of marine ecosystem components when setting their ecosystem objectives (Heslenfeld and Enserink, 2008). To achieve such objectives, the mechanistic relationships between the state of these components or attributes and one or more manageable anthropogenic activities needs to be understood (Jennings, 2005). Therefore, for scientists charged with the provision of advice in support of EAF, determining the theoretical, mechanistic links between state and so-called pressure indicators often poses the greatest challenge (Greenstreet, 2008). To implement an EAF successfully, therefore, it is not only necessary to have a suite of indicators that accurately portray the “state” of various ecosystem components, but it is also critical to have indicators that describe changes in the level of different manageable human activities. Only by adequately covering both aspects will the mechanistic links between “cause” and “effect” be well enough understood to provide the advice required (Daan, 2005).

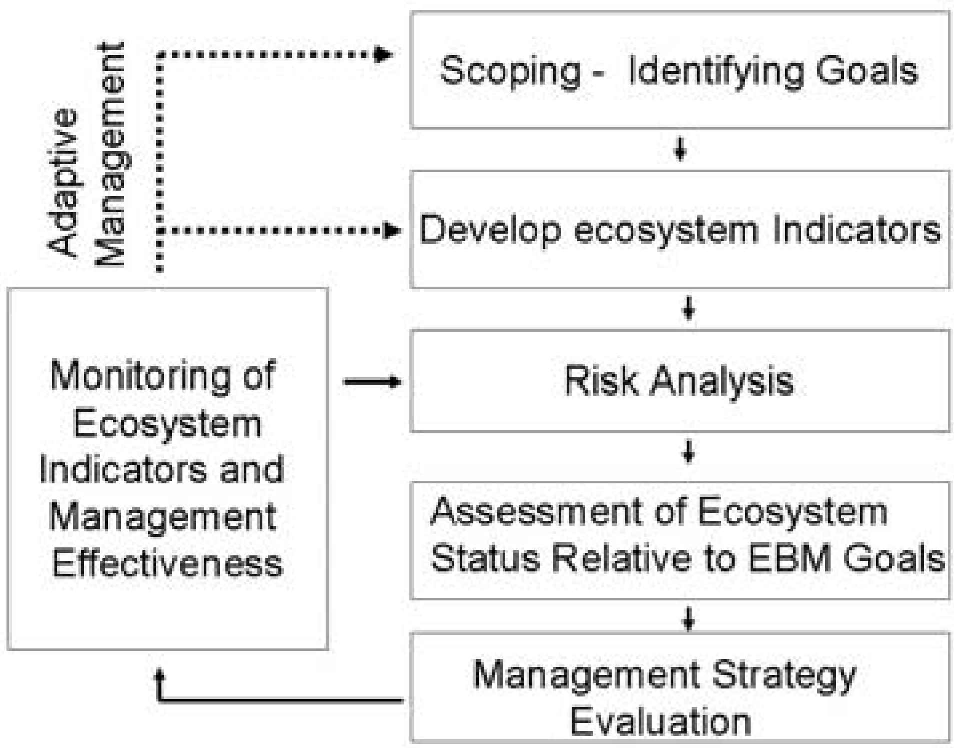

Figure 52. (from Levin et al. 2009). The Five-Step Process of Integrated Ecosystem Assessment. An IEA begins with a scoping process to identify key management objectives and constraints, identifies appropriate indicators and management thresholds, determines the risk that indicators will fall below management targets, and combines risk assessments of individual indicators into a determination of overall ecosystem status. The potential of different management strategies to alter ecosystem status is evaluated, and then management actions are implemented and their effectiveness monitored. The cycle is repeated in an adaptive manner.

3. Practical Implementation

In considering the development of Ecosystem-Based Fishery Management strategies for the Northeast United States, the following pragmatic approach is under development, namely: (1) the identification and definition of ecological subunits on the shelf based on an analysis of physiographic, oceanographic and ecological variables, (2) the implementation of a spectrum of different multispecies and full ecosystem models which can be used to assess ecosystem state and function, particularly of higher order variables such as primary productivity and total biomass, and (3) an evaluation of the management options using existing management tools for specifying ecosystem exploitation rates.

Furthermore, explicit and pragmatic relationship between the application of an IEA and the steps for implementing EBM for any given spatially defined marine ecosystems subject to fisheries management can be identified (Figure 53).

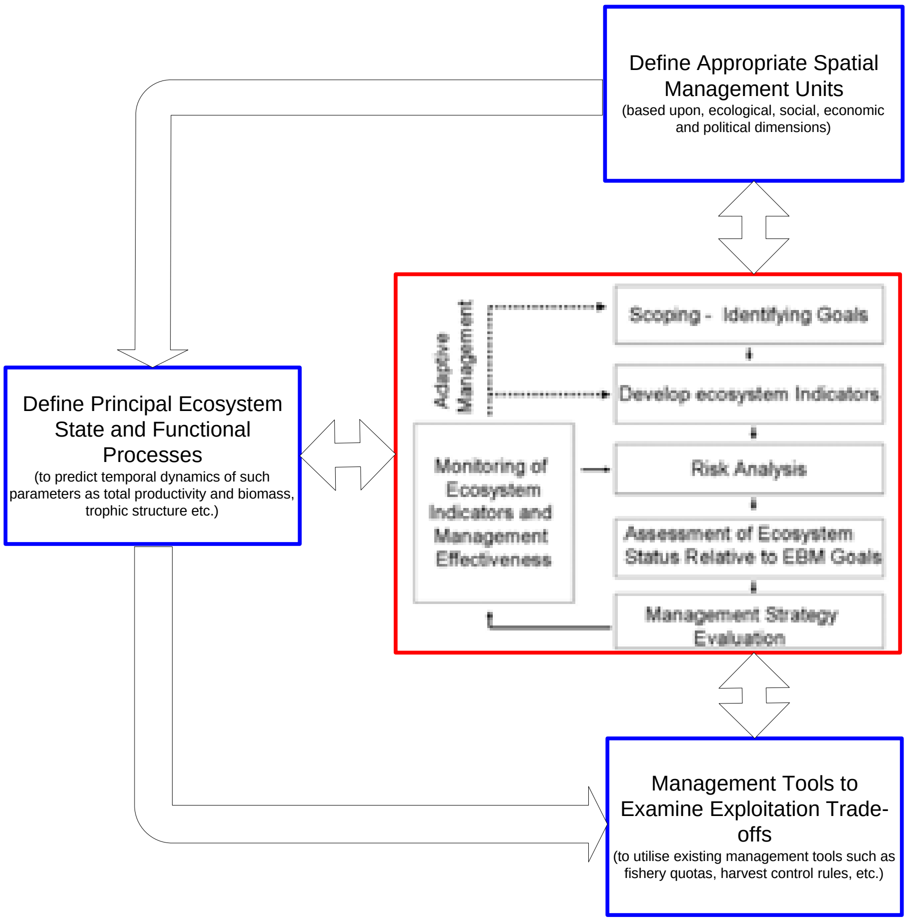

Figure 53. The relationship between the 3 practical steps in moving towards the implementation of an ecosystem approach to fisheries management (blue boxes) and the steps required to deliver effective holistic integrated ecosystem assessments (IEA) shown in the red box.

Given the general similarities and relatedness between marine ecosystems in the Northeast United States with the other ecosystems within the NAFO convention area, the experience already gained in the US towards developing an EAF scheme as depicted by Figure 53 provides a useful and meaningful starting point towards developing an EAF for NAFO.

The following sections briefly describe the rationale and type of activities associated with the 3 practical steps of EAF (highlighted in blue in Figure 53). Together these form the basis for developing a plan for the possible implementation of an EAF in NAFO. If this vision is endorsed by NAFO Scientific Council, WGEAFM will work towards it in future meetings. Accordingly a set of actions linked to each step will be identified and collectively they will form the future workplan of WGEAFM.

3.1. Defining Spatial Management Units

The specification of spatial management units is a critical pre-requisite to the development of ecosystem approaches to management. Therefore, defining meaningful ecosystem management units within the NAFO area is considered the first step in the process towards EAF.

In the Northeast US Continental Shelf, a set of physiographic, oceanographic and biotic variables was analyzed to provide a basis for identification of ecological subareas (NAFO 2008). This approach (Fogarty and Keith, 2005) includes an initial step where principal components analysis is employed to examine the multivariate structure of the data and as a prelude to classification of ecosystem subunits. Then cluster analysis on the principal component scores is used to define subareas. These clusters represent major ecological subunits including a) Eastern Gulf of Maine- Scotian Shelf, b) Western-Central Gulf of Maine, c) Georges Bank, d) Continental Slope and e) Mid-Atlantic Bight. Further analyses are now underway, including the addition of more oceanographic variables, to refine the initial results.

Preliminary analysis using a similar approach are available for the Scotian Shelf area in Canada (Zwanenburg et al. 2010), and are also underway for the Grand Bank of Newfoundland. These results will complement other available classifications for Canadian marine ecosystem units (e.g. Powles et al. 2004, DFO 2009).

Once all these results become available, and the methodological details fully standardized, this approach could be applied to any remaining NAFO area with sufficient amount of data. In this context, priority is expected to be given to the NRA in general and the Flemish Cap system in particular. Also, integrative analyses for the entire Northwest Atlantic region, from the Northeast US to Newfoundland, are expected to provide insights on the large scale structure of these marine ecosystems.

3.2. Defining Ecosystem State and Function Processes

A wide range of analytical methods should be employed (including a range of model types) to define and understand the principal dynamic properties of the spatially defined ecosystem (Plaganyi 2007, DFO 2008). The choice of appropriate models depends on the specific objectives of the analysis and factors such as the interplay between model complexity and parameter uncertainty (Fulton et al. 2003, Plaganyi 2007, DFO 2008, Koen-Alonso 2009).

In the case of the Northeast US ecosystems, the models available can be classified in increasing order of complexity as:

- Fishery Production Potential Models
- Aggregate-Species Surplus Production Models
- Multispecies Production Models (e.g. Lotka-Volterra models)
- Size Spectrum Models
- Ecosystem Network Models (e.g. Ecopath)
- Age/Size Structured Multispecies Models (e.g. Multispecies Virtual Population Analysis)
- Dynamic Ecosystem Models (e.g ATLANTIS)

These modeling approaches differ not only in complexity but along a continuum from holism to reductionism (with the models classified as embodying higher levels of complexity also incorporating higher levels of structural detail). The first two of these modeling approaches have been particularly used to estimate the productive capacity (or carrying capacity) of the system for a given set of environmental/climate conditions. Fishery production potential models trace the flow of energy from primary producers through to the harvested components of the system. In this case, energy pathways through the microbial food web and through the classical grazing food web to generate estimates of the production available for harvest were explicitly accounted for.

For this approach, it is next necessary to specify an ecosystem exploitation rate that will permit sustainable harvest. For this purpose results of multispecies models that predict not only the system exploitation rate that results in Multispecies Maximum Sustainable Yield (MMSY) but tracks the number of stocks that collapse as the exploitation rate increases were considered (Worm et al. 2009). Using this approach, it can be shown that reducing the exploitation rate that results on MMSY by half results in very little loss in yield but it sharply reduces the number of stocks predicted to collapse at different to exploitation rates.

For the fishery production potential model, it is also necessary to specify an allocation strategy for individual species. In the Northeast US case, the use of linear programming solutions that incorporate constraints on total removals from the system and individual species exploitation limits to ensure that these species are not driven to levels which would result in stock collapse was considered.

Interestingly enough, the aggregate-species surplus production approach was actually first used in NAFO's predecessor institution, ICNAF, to generate estimates of system-wide maximum sustainable yield for the Northeast U.S. Continental Shelf. This early analysis showed that the estimate of system-wide MSY was approximately 30% lower than the result obtained if estimates from individual species stock assessments were simply summed. It was inferred that interactions among species meant that all species could not simultaneously be at biomass levels resulting in MSY (B_{msy}). Updated analyses, which extend the previous modeling work to incorporate environmental/climate factors, confirm this basic result. These models also provide estimates of the level of fishing mortality that results in MSY (F_{msy}) and these estimates are also lower for the aggregate species model than for most of the individual species F_{msy} levels (e.g. see ICES 2008).

The basic conclusion emerging from these results suggests that there are important constraints on available energy which must be considered in setting harvest policies at an ecosystem level. Further consideration of food requirements for threatened species and apex predators under rebuilding strategies highlights the potential constraints on available energy to meet overall ecosystem management objectives. This perspective necessarily involves direct consideration of possible tradeoffs among harvested species if all cannot simultaneously be at B_{msy} levels.

Regardless the specific modeling details, the overall framework can be described as a three-tiered, hierarchical one. The first tier defines fishery production potential at the ecosystem level, taking into account environmental conditions and ecosystem state. This allows a first order consideration for the potential influence of large scale climate/ecological forcing on fishery production, as well as explicitly considering the basic limitation imposed by primary production on fisheries production (Kestevan and Holt 1955, Ricker 1969, Ryther 1969, Ware 2000, Ware and Thomson 2005, Chassot et al. 2010). The second tier utilizes multispecies models to allocate fisheries production among a set of commercial species, taking into account species interactions and considerations pertaining the stability and dynamic resilience of the exploited community (e.g. Levin and Lubchenco 2008, Koen-Alonso 2009). This allows considering trade-off among specific fisheries, identifying exploitation rates which are consistent with multispecies sustainability (e.g. ICES 2008), as well as providing a venue for incorporating ecosystem objectives beyond purely exploitative ones (e.g. maintenance of ecosystem resilience through conservation of biodiversity, minimizing impact on threatened species). The third and final tier involves single-species stock assessment, where the exploitation rates derived from tiers 1-2 can be further examined to ensure single-species sustainability. The necessarily more holistic nature of the first two tiers implies that those models do not include detailed representations of the intra-population mechanisms that often characterize single-species population dynamic models. Tier 3 analyses are intended to prevent that the lack of biological detail generate unintended impacts on specific species, while it provides yet another set of models with different structural details and assumptions.

3.3. Utilising Management Tools

Although the conceptual framework encapsulated in EAF is broader than classical single-species management, the goal is to keep it simple and work with current management and assessment tools as much as possible. The move towards EAF should be evolutionary rather than revolutionary. The evolutionary aspect of this process is critical for EAF success. Both people as well as institutions need to adapt to the new EAF perspective.

However, it is important to note that an EAF will use the same basic tools as conventional management but with different objectives and therefore different priorities. The basic tools include a) effort limitation and control, b) conservation engineering, c) use of protected areas, and d) output controls (TACs).

Some new aspects brought about by EAF will include the need for developing suitable types of output to inform managers and stakeholders about likely trade-offs among fisheries, as well as expected changes in the status of specific ecosystem components given anticipated variations in fishing and climate pressures. One important requirement at this level will be the identification and definition of explicit management objectives.

Finally, the very nature of EAF, due to its intrinsic consideration of ecologically meaningful boundaries, would likely require changes in governance structure and/or institutional reforms. A priori, it can be expected that the level of coordination and integration between domestic management practices within the EEZs of coastal states and the NRA will need to broadened and strengthened.

However, and as first step, priority will be put on developing the integrative understanding of ecosystem dynamics, environmental forcers and fisheries, so that the conventional management tools indicated above can be meaningfully applied. Once this goal is reasonably achieved, one of its outcomes will be highlighting the actual level and type of management integration required between NAFO and the coastal states to ensure a successful EAF implementation. At that point, if the results indicate that governance/institutional chances are actually necessary, contracting parties will need to discuss how to move forward on that front.

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PART III. Addressing additional ToRs from specific SC Requests

ToR 7(based on Scientific Council Request). *Scientific Council noted that no biomass index is available for coral or sponges aggregations within the NAFO Regulatory Area. Therefore, the detection of trends over time and the monitoring schemes to assess impact/recovery that are required by the FAO Deep Sea Fisheries guidelines is problematic. Further, it is not possible to analyse the relationship between the occurrence of coral or sponge aggregations and commercial bottom trawl fishing effort.*

ToR 7a*- Scientific Council requests that WGEAFM investigate cost and time effective methods to monitor the health of the VME areas.*

Any monitoring plan should have well developed objectives so that survey designs which will allow the appropriate analyses can be implemented. In NAFO, research vessel surveys for fish have been used to delineate the general sponge and coral areas and cVME areas, but now that these areas are described more detailed surveys are needed to refine the habitat areas and to procure information on, for example, the size structure, age/sex structure (for some species at least), genetic structure, biodiversity, physical environment and health of the habitats. In terms of cost effectiveness, sampling that can be done in association with existing surveys will be the least costly, however, surveys targeting specific components of VMEs will also be required. The working group would like to revisit this ToR in order to reconsider this question when it has more time to consider it. Specifically we would attempt to define appropriate objectives and discuss the research needed to meet them. Here, we provide some general considerations which relate to this topic.

Use of Trawls in Coral and Sponge Habitats

Trawls are the most widely used research tool for carrying out benthic surveys, and compared to commercial fishing, the footprint of research trawls is relatively small. Nonetheless, trawls are not the best gear to survey the coral and sponge concentration areas, given the potential to cause significant adverse impacts in these areas (Kreiger 2001, Fuller et al. 2008). This is of particular concern for the areas closed by NAFO in the NRA to protect vulnerable marine ecosystems, which were assessed as being subject to significant adverse impact (SAI) from bottom tending gear. These areas may still be trawled by research vessels as part of annual stock surveys.

The issue of closing areas to research surveys is an important one to consider further, given the possible disruption of time series of survey results. However, there are areas on the Flemish Cap and Grand Banks that are continuously skipped over because the seafloor is untrawlable (Gilkinson and Edinger 2007).

The WGEAFM suggested that areas which are already excluded from the various fish surveys be mapped so that the research vessel trawl footprint can be compared with the location of the cVMEs and the coral and sponge closures in the NRA. With this information the WGEAFM could better assess the potential impact of research trawling in the closed areas and in the cVMEs and the assessment groups could evaluate whether excluding more area would be detrimental to their analyses. Data in the form of video images from such areas (i.e., areas that have already been excluded because of rough bottom) could fill important information gaps that can not be filled with current survey methods, but such methods would not replace the information on fish species collected by trawl surveys.

Non-intrusive monitoring methods should be utilized, particularly on suspected VMEs or for the purposes of monitoring the health of known VMEs. Examples of such methods include drop-cameras and Remotely Operated Vehicle (ROV) technologies. The later can be costly and cruise planning can be time consuming, however the types of data they can collect, including biological samples is often not achievable by other means. Drop cameras may be a cost effective method for gathering general information on species distributions and associations, once the initial purchase of equipment is made. As well, drop-cameras can also be incorporated into existing trawl survey cruises - with cameras deployed in areas where trawling cannot or should not be conducted (within existing VME closures).

Such techniques have been used successfully in other areas. Several seamounts off New Zealand were surveyed using non-intrusive photographic tools; eight on the Graveyard Hill complex on the Chatham Rise, and one on Ritchie Hill (Clarke and O'Driscoll 2003). The seamounts ranged from unfished (Diabolical and Gothic) to moderately fished to heavily fished (Graveyard and Morgue). Epibenthic sleds were also used. The results indicated evidence of damage to benthic ecosystems and provided data on the type, distribution and degree of impact between fished and unfished areas.

In the Mediterranean video and acoustic surveys were conducted in order to map deep-sea benthic ecosystems (< 650 m) using video mosaics created from successional imagery (Vertino et al. 2009). Successional mosaics can be used to document long-term changes in benthic community structures (Rhoads and Germano 1986), and can provide information on substrates, abundance and occurrence of VME species, as well as disturbances (anthropogenic or natural).

Such non-intrusive methods are currently being used in stratified random benthic surveys operating within the boundaries of the Gully MPA, and the *Lophelia* Coral Conservation Area, on the Scotian Shelf of Canada (Cogswell et al. 2009). In the Gully Monitoring Plan surveys of VME taxa are recommended every 10 years or so given the expectation that changes to these long lived and stationary organisms are not likely to be apparent on shorter time scales. Thus while such surveys may be costly, they may only be required every decade or so. Similar survey designs could be used within the current VME closures in order to monitor VME health and to verify current boundaries. Initial operational costs can be expensive but the long-term payoff would be extremely beneficial.

Standardized collection procedures are necessary to ensure quantitative and qualitative information is collected during exploratory surveys and fisheries. Several identification guides have been developed for VME species (see NAFO ID guide), as well detailed instruction manuals are available. Instruction manuals are useful companion tools to guide the collection of valuable information on deep-sea corals (see Etnoyer et al. 2006).

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***ToR 7b** - Further, and subject to the above and data availability, Scientific Council further requests that the relationship between historical commercial bottom trawl fishing effort and the occurrence of VME indicator species be investigated.*

This request was formulated by the Scientific Council at their June 2009 meeting. Subsequently the WGFMS considered the relationship of significant concentrations of coral and sponge to fishing effort in the NRA (NAFO 2009a) and determined that the sponge and coral closures which were put in place affect less than 1% of fishing effort (from 2003-2007). Nevertheless, the WGEAFM has prepared some information for SC on this issue. In order to answer this request, sponges and some deep water coral groups present in the NRA were used as indicators species of VMEs. The coral groups considered were the small and large gorgonians (sea fans), pennatulaceans (sea pens), and antipatharians (black corals) in addition to sponges. The rationale behind this selection is in Fuller *et al.* (2008).

The relationship between historical commercial bottom fishing effort (1987 to 2007) and the occurrence of these VME indicator species has been investigated by overlapping the fishery effort in the NRA (Divs. 3LMNO) based on VMS, logbook and observer data (NAFO 2009b) with catches of coral and sponge recorded from the Canadian and Spanish/EU R/V multispecies surveys in the NRA (Divs. 3LMNO) from 2004 to 2007 for corals and 2002 to 2008 for sponges (Figures 54, 55, 56, 57, and 58). The thresholds used by the WGEAFM for delineating of significant concentrations of corals and sponges (NAFO 2008, 2009c) have been used in order to separate significant concentrations from other records. Most of the significant catches of VME indicator species were recorded in survey tows carried out in areas within the fishery effort map that have been only lightly fished or not fished at all.

Large gorgonians

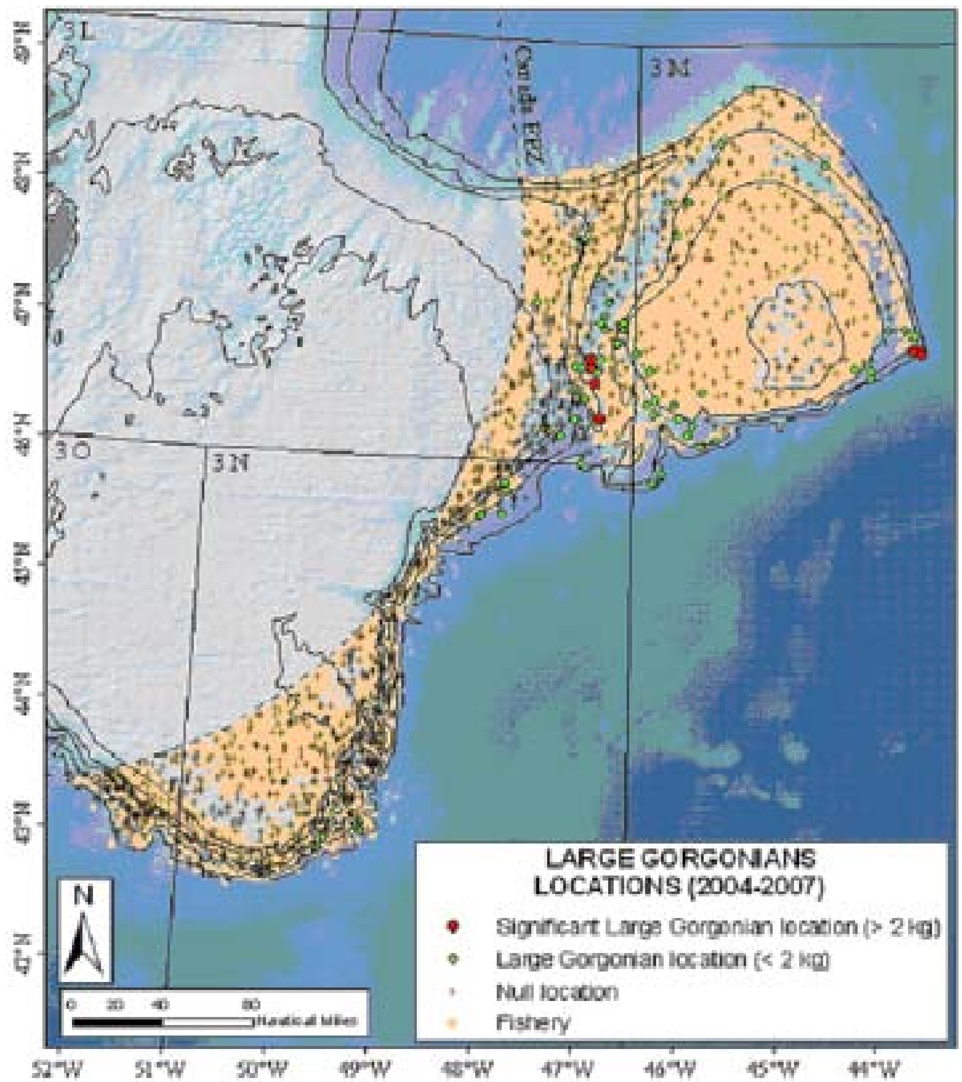

Figure 54. Location of survey tows analysed from the Canadian and Spanish/EU R/V multispecies surveys in the NAFO Regulatory Area (Divs. 3LMNO) from 2004 to 2007. Red dots represent significant locations of large gorgonians above or equal to 2 kg. Green dots represent locations of large gorgonian below 2 kg. Black cross represent locations without large gorgonian records. Orange dots represent fishing effort data.

Small gorgonians

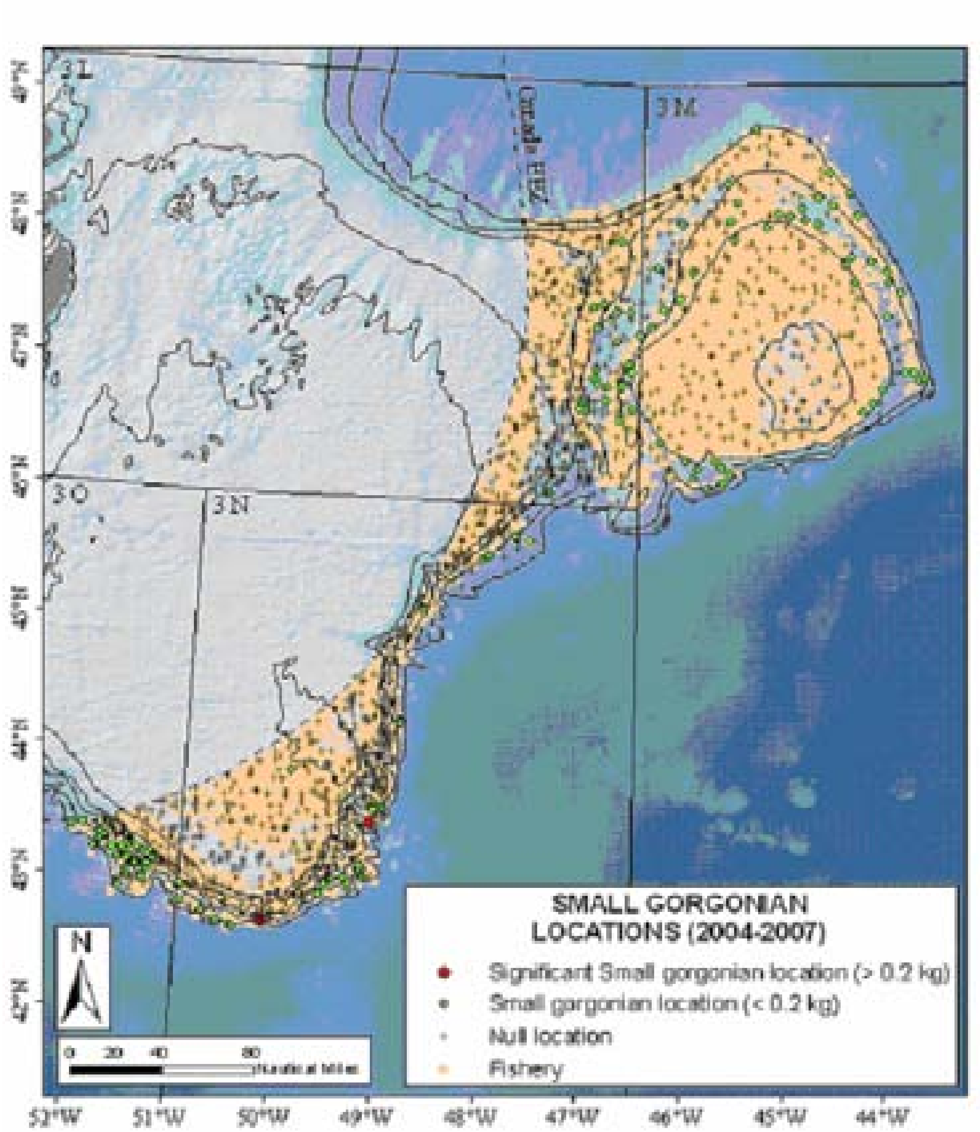

Figure 55. Location of survey tows analysed from the Canadian and Spanish/EU R/V multispecies surveys in the NAFO Regulatory Area (Divs. 3LMNO) from 2004 to 2007. Red dots represent significant locations of small gorgonians above or equal to 0.2 kg. Green dots represent locations of small gorgonian below 0.2 kg. Black cross represent locations without small gorgonian records. Orange dots represent fishing effort data.

Pennatulaceans

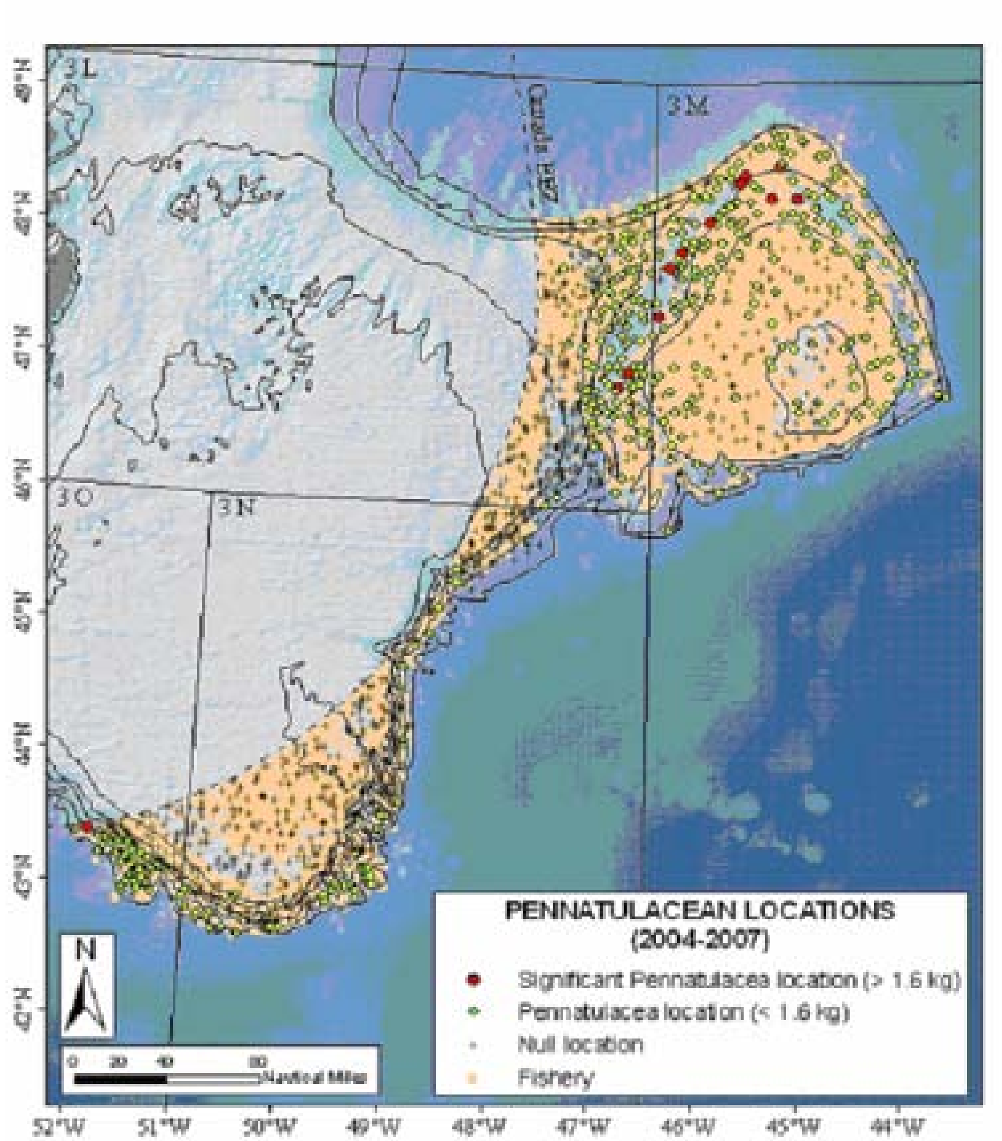

Figure 56. Location of survey tows analysed from the Canadian and Spanish/EU R/V multispecies surveys in the NAFO Regulatory Area (Divs. 3LMNO) from 2004 to 2007. Red dots represent significant locations of pennatulaceans above or equal to 1.6 kg. Green dots represent locations of pennatulaceans below 1.6 kg. Black cross represent locations without pennatulaceans records. Orange dots represent fishing effort data.

Antipatharians

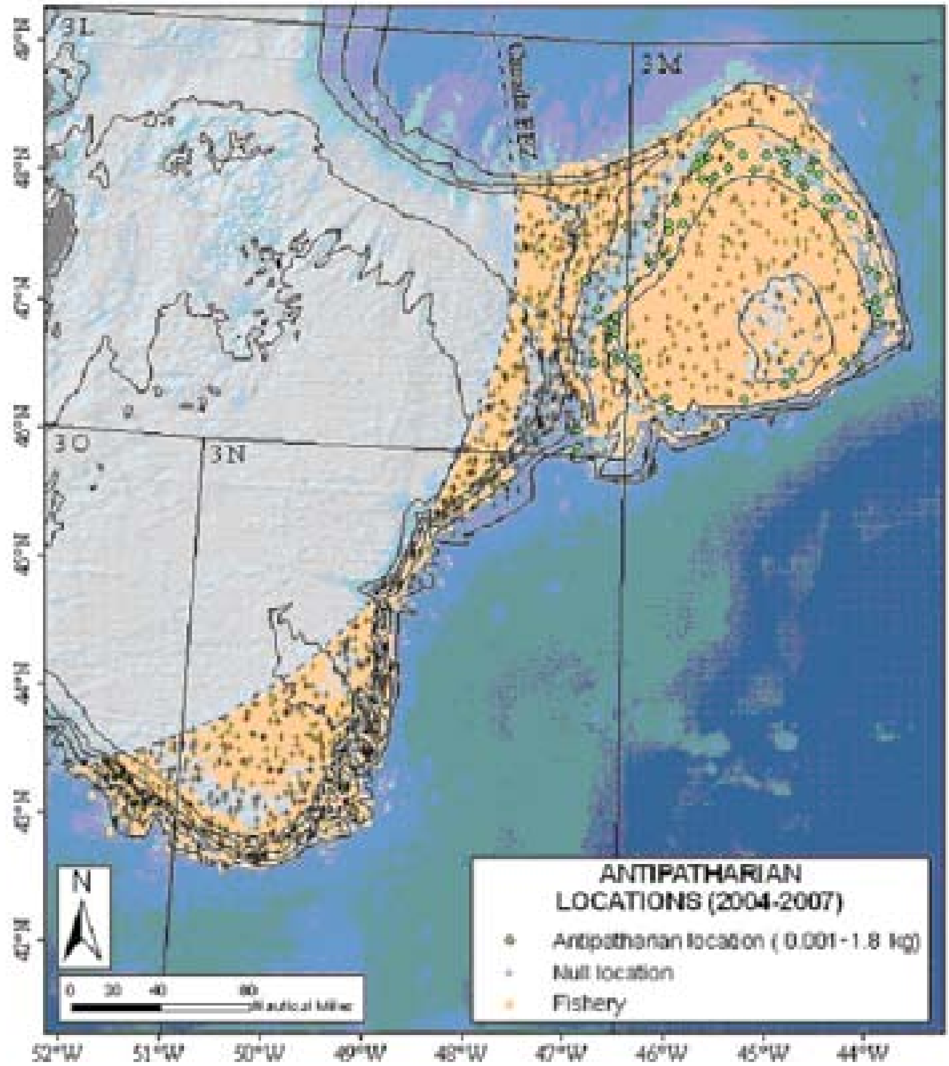

Figure 57. Location of survey tows analysed from the Canadian and Spanish/EU R/V multispecies surveys in the NAFO Regulatory Area (Divs. 3LMNO) from 2004 to 2007. Green dots represent locations of antipatharians (no threshold defined for them). Black cross represent locations without antipatharian records. Orange dots represent fishing effort data.

Sponges

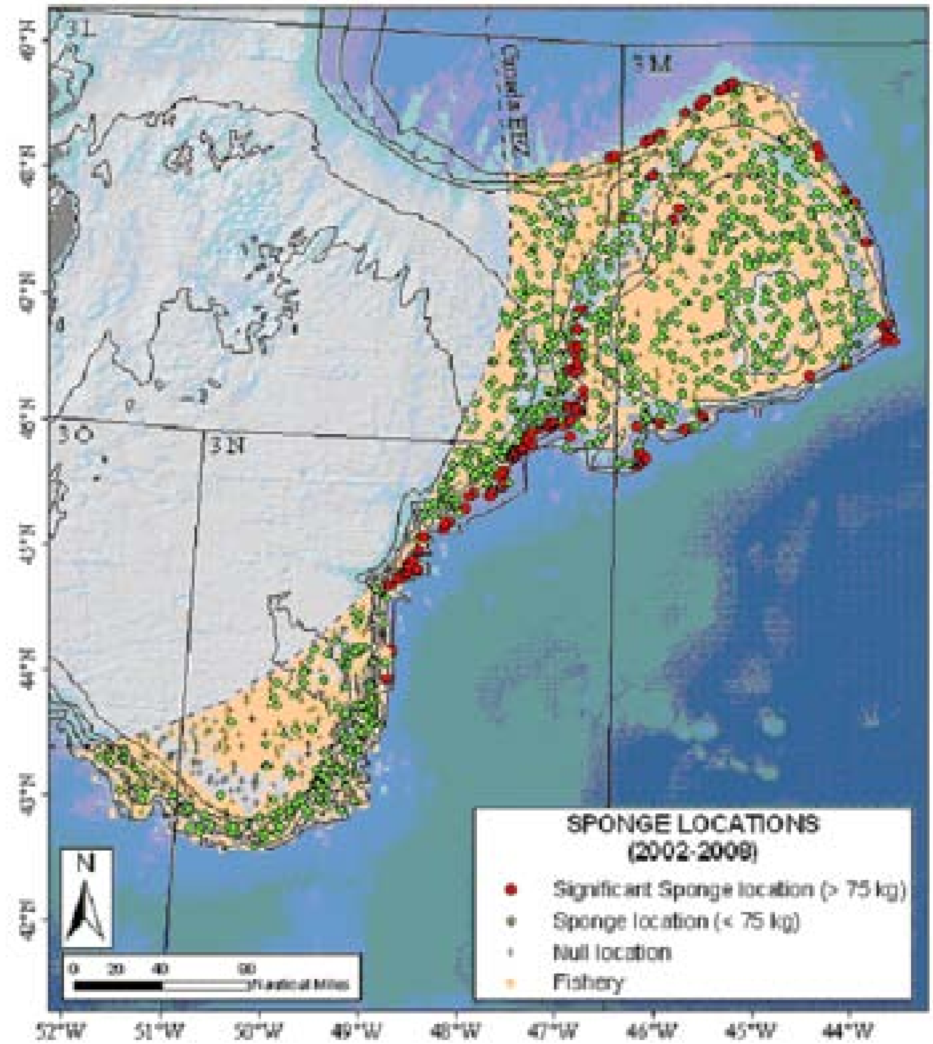

Figure 58. Location of survey tows analysed from the Canadian and Spanish/EU R/V multispecies surveys in the NAFO Regulatory Area (Divs. 3LMNO) from 2002 to 2008. Red dots represent significant locations of sponges above or equal to 75 kg. Green dots represent locations of sponges below 75 kg. Black cross represent locations without sponge records. Orange dots represent fishing effort data.

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NAFO. 2008. Report of the NAFO SC Working Group on Ecosystem Approach to Fisheries Management (WGEAFM) Response to Fisheries Commission Request 9.a. Scientific Council Meeting, 22-30 October 2008, Copenhagen, Denmark. Serial No. N5592. NAFO SCS Doc. 08/24.

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NAFO. 2009b. Delineation of Existing Bottom Fishing Areas in the NAFO Regulatory Area. NAFO SCS Doc. 09/21, Serial No. N5676, 9 p.

NAFO. 2009c. Report of the NAFO SC Working Group on Ecosystem Approach to Fisheries Management (WGEAFM) Response to Fisheries Commission Request 9.b and 9.c. Scientific Council Meeting, 4-18 June 2009, Dartmouth, Canada. Serial No. N5627. NAFO SCS Doc. 09/6.

ToR 8 (Scientific Council Chair Request based on Fisheries Commission Request 8). *Recognizing the initiatives on vulnerable marine ecosystems (VME) through the work of the WGFMS, and with a view to completing fishery impact assessments at the earliest possible date, the Scientific Council is requested to provide the Fisheries Commission at its next annual meeting in 2010:*

ToR 8a *- guidance on the content of fishing plans/initial assessments for the purpose of evaluating significant adverse impacts on VMEs and identify viable risk evaluation methodologies for the standardized assessment of fishery impacts.*

In general terms, fishing plans should include the following information:

1. Harvesting plan detailing type(s) of fishing expected to be conducted, vessels and gear types, fishing areas, target and potential bycatch species, fishing effort levels, dates of fishing, duration of fishing tows, soak time, etc;
2. Best available scientific and technical information on the current state of fishery resources and baseline information on the ecosystems, habitats and communities in the fishing area, including known or potential VMEs;
3. Identification, description and evaluation of the occurrence, scale and duration of likelihood of impacts, including cumulative impacts on VMEs;
4. Proposed mitigation plan including measures to prevent significant adverse impacts on VMEs;
5. Proposed monitoring plan of the effects of the fishing operations that includes recording/reporting that follows agreed NAFO template for exploratory fishery protocol for new fishing areas, or in existing fishing areas includes VME-indicator species in the by-catch reporting.

Although fishing plans should strive to fulfill this general content structure, properly addressing many of these elements requires scientific knowledge currently in development, both in terms of methods and basic data requirements. Practical definitions of what constitutes a significant adverse impact on VMEs, and robust methods to determine cumulative impacts are areas where no widely accepted international standards have been developed yet, although research efforts are ongoing to remedy this situation.

A critical aspect, necessary for properly developing fishing plans and which can certainly be addressed today, is the need for more and better data of commercial fisheries. Enhanced data collection and monitoring plans should be sufficiently detailed to conduct an assessment of the activity, when required, as well as to facilitate the identification of vulnerable marine ecosystems/species in the area fished. These data requirements would be specially considerable in the case of evaluating the impact of new fisheries on VMEs. Implementation of the fishing plan structure described above would likely place a considerable workload on observers on vessels engaged in these fisheries, however this could be mitigated by the development of sub-sampling strategies.

Regarding the Exploratory Fishery Data Collection Form adopted by the NAFO Fisheries Commission (NAFO 2009), the SC strongly recommends that:

a) Catches of the quantities of coral and sponges are requested to be recorded but this should be revised to *live* corals and sponges, in line with existing threshold regulations and broken down to species level as much as possible using the NAFO Coral Guide.

b) Zero catches of VME-indicator species (e.g. coral and sponge) should be recorded.

Further, the distinction between actual and estimated weights needs to be clarified. Estimated weights presumably refer to weights raised from catch sub-samples (as opposed to guesstimates based on visual inspection). Given the threshold approach to monitoring presence/absence of VMEs, actual catch weights should be collected where possible.

Some gear types (e.g., bottom set longlines and gillnets) can take bycatches of corals and sponges. Therefore, general information on gear dimensions and amount of gear, irrespective of the specific gear type, are necessary parameters to record.

The coral guide for the NAFO region should allow consistency of reporting; corals should be identified and recorded to the lowest taxonomic level possible. A similar guide for the identification of sponges is currently being developed. Finally, there may be a need to clarify the time-line for reporting the contents of these forms to the NAFO Secretariat.

Risk assessment methods have not been discussed, but the method described in section 8.b.i can provide an initial avenue to explore these issues.

References

NAFO. 2009. Report of the NAFO Fisheries Commission Ad Hoc Working Group of Fishery Managers and Scientists on Vulnerable Marine Ecosystems (WGFMS). Serial No. N5693. NAFO Fisheries Commission Document 09/6, 19pp.

ToR 8 b) *In light of the use of existing encounter protocols in tandem with the closed areas for corals and sponges:*

i. *assess new and developing methodologies that may inform the Fisheries Commission on any future review of the thresholds levels*

Data from observers on commercial fishing vessels in the NRA and elsewhere have a number of deficiencies that prevent its use in quantitative applications, such as the evaluation of threshold levels. Previously, WGEAFM concluded that this information was useful in recording the presence of corals and sponges but that the biomass associated with this bycatch and the null records are unreliable overall (NAFO 2008). Consequently alternative approaches have to be used to develop scientifically-based encounter protocols that will serve to protect corals and sponges both within the fishing footprint and in new fishing areas.

The NAFO WGFMS used a scaling-up of survey trawl catch quantities to commercial tows to produce threshold levels for corals and sponges. In this scaling-up calculation, the survey catches were prorated to a 40 m wide trawl towed for 4 hours. The WGFMS recognized the uncertainty in this scaling-up exercise (NAFO 2009a) and highlighted as an example that a single trawl was used whereas in commercial fisheries both double and triple trawls are common. There are a number of other problems with this “scaling-up” approach. First, it assumes a linear relationship between the bycatch and tow distance/duration. Second, it assumes that the catchability is the same between research vessel trawls and commercial gear.

A new method involving simulation modeling is currently in development (Kenchington et al. 2010). This approach uses research vessel survey data of sponge catches to produce a biomass map in a GIS framework. Random start positions are placed within the fishing footprint (NAFO SCS Doc. 09/21) with end points of a set distance replicating average commercial tows placed both randomly and using a weighting method to reflect fishing effort. These simulated tows are allowed to cover the entire fishing area in one scenario, and restricted from the coral and sponge closure areas in another. The biomass for each simulated tow is then estimated using the sponge biomass distribution, considering the bathymetry of the surface in calculating tow distance. The process proceeds through multiple (100s) iterations to produce modeled distributions of the sponge catches for each scenario. The distributions of simulated catches that fall outside of the closed areas are compared with those that traverse the closed areas. This method can be adapted to different gear types and tow lengths to estimate commercial threshold values in the NRA for sponges (and other sessile or sedentary benthic taxa recorded in the RV surveys). It will not address the issue of serious adverse impact of such removals but it will allow impacts to be contextualized (e.g., as a proportion of total estimated biomass, or to estimate indirect effects). This method will be peer-reviewed at a Canadian workshop in March, 2010. If this model were to be applied to the NRA, an agreed upon set of gear descriptions and tow duration/lengths for each métier would need to be created. Further estimation of retention efficiencies of the different commercial gears and indirect effects of fishing will be needed to model effects of serious adverse impacts (SAI).

References

Kenchington, E., A. Cogswell, C. Lirette & J. Rice, 2010. A GIS Simulation Model for Estimating Commercial Sponge Bycatch and Evaluating the Impact of Management Decisions. DFO Canadian Scientific Advisory Secretariat Research Document 2010/040. vi + 39 pp.

NAFO. 2008. Report of the NAFO Scientific Council Working Group on Ecosystem Approach to Fisheries Management (WGEAFM). Serial No. N5511 NAFO Scientific Council Summary Document 08/10, 70pp.

NAFO. 2009a. Report of the NAFO Fisheries Commission Ad Hoc Working Group of Fishery Managers and Scientists on Vulnerable Marine Ecosystems (WGFMS). Serial No. N5693. NAFO Fisheries Commission Document 09/6, 19pp.

NAFO. 2009b. Delineation of Existing Bottom Fishing Areas in the NAFO Regulatory Area. Serial No. N5676. NAFO Fisheries Commission Document 09/21, 9pp.

ii. *review and report on new commercial bycatch information as it becomes available, and*

There were no new commercial bycatch data available. WGEAFM noted that lack of information on corals and sponges from commercial fisheries makes determination of encounter protocols much more difficult. It is not expected that significant amounts of new data will be available in the immediate future.

iii. *in light of i.) review the ability of the current encounter threshold values of 60 kg live coral and 800 kg sponge to detect new VME areas as opposed to cumulative catches of isolated individuals.*

The WGEAFM anticipates that the new methodology being developed (see ToR 8bi) will allow for an evaluation of the current encounter thresholds in future but this will require a discussion regarding the data input to use. Still, WGEAFM notes that it will be difficult to evaluate the encounter threshold for live coral given the number of species present in the NRA and the large differences in their morphology and biomass (Fuller et al. 2008). Given the identification of sea pens, small gorgonians, large gorgonians and black coral as components of VMEs, the same encounter threshold could cause significant adverse impacts to one group but not to another.

Further, the working group noted that the encounter protocols were not gear specific, and that different gears have different retention factors. Also, the fishing duration will differ among metiers. All of this information should be considered when developing a meaningful encounter threshold.

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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. Serial No. N5524. NAFO Scientific Council Research Document 08/22, 24pp.

ToR 9 (Scientific Council Chair Request based on Fisheries Commission Request 9). *Recognizing that areas closed to all bottom fishing activities for the protection of vulnerable marine ecosystems as defined in Article 15, including inter alia:*

• Fogo Seamounts 1

• Fogo Seamounts 2

• Orphan Knoll

• Corner Seamounts

• Newfoundland Seamounts

• New England Seamounts

and associated protocols for vessels conducting exploratory fishing in those areas, expire on December 31, 2010.

Mindful of the call for review of the above measures based on advice from the Scientific Council, Fisheries Commission requests that Scientific Council:

ToR 9a *- Review any new scientific information on the Fogo Seamounts 1, Fogo Seamounts 2, Orphan Knoll, Corner Seamounts, Newfoundland Seamounts and New England Seamounts which may support or refute the designation of these areas as vulnerable marine ecosystems.*

Here we report the limited scientific information that has been published since the seamount closures were put in place. Evidence is drawn primarily from 3 research programs: 1) a Canadian program collecting physical oceanographic data from the vicinity of Orphan Knoll which can be used to predict whether endemic fauna are likely to occur there, 2) Spanish research reported to the WGEAFM in 2008 but not discussed fully by Kulka et al. (2007), and 3) preliminary data from US surveys on the New England and Corner Rise seamount chains from 2001 through to 2005. We conclude with recommendations on the future of these seamount closures.

Orphan Knoll

Canada has undertaken physical, chemical and biological oceanographic research on Orphan Knoll which supports isolation of this seamount from the nearby adjacent continental shelves. In situ evidence includes data from hydrographic surveys, near bottom current meters and a compilation of data from Argo floats in the region. A theoretical calculation of a blocking parameter also strongly suggests the presence of a Taylor Cone above the seamount, which would enhance retention of water over this topographic feature (Greenan et al. 2010.).

The Orphan Basin-Orphan Knoll region is biologically rich and complex, and strongly influenced by local processes and advection. In the spring, the lower trophic level dynamics are likely dominated by the seasonal large-scale spring bloom event which would certainly mask any ‘knoll-effect’. Investigations in other periods of the year could provide further insight into the role of this topographic feature in the lower trophic level dynamics.

Overall, we have little evidence at this point that Orphan Knoll enhances the lower trophic level biology in the water column above the knoll; however, near-bottom anti-cyclonic circulation could have implications for benthic community which will be surveyed in July 2010 (Greenan et al. 2010.).

Canada is planning a benthic survey of Orphan Knoll in July 2010 using photographic and video imaging. Preliminary data on the benthic fauna on Orphan Knoll, which thus far has not been sufficiently described, will be available for the September 2010 meeting of the SC. This survey will determine whether benthic VME taxa are present in this area and whether they represent unique communities relative to the adjacent continental slopes.

New England and Corner Seamounts

During the last quarter of 2004 an Experimental Trawl Survey was conducted in the NAFO Regulatory Area (Divisions 6EFGH and 4XWVs) and adjacent international waters to the south (Duran et al. 2005). Duran et al. (2005) presented preliminary data on benthic invertebrates (i.e., sea anemones, corals, sponges, etc.) which were considered by Kulka et al. (2007). However, a more detailed study of cold-water coral by-catch from this survey was presented in 2008 (Murillo et al. 2008). Three hauls were carried out over two peaks located in the New England Seamounts (Figure 59). Catches of commercial resources were negligible and by-catch of corals was recorded as degraded pieces of dead *Enallopsammia* sp. and *Keratoisis* sp. and a few living corals (*Solenosmilia variabilis* and *Paragorgia johnsoni*, Figure 60). Ninety-two hauls were carried out over one peak located on the Corner Rise

Seamounts (Table 13), with large catches of alfonsino *(Beryx splendens*), and only six hauls showing coral records (*Enallopsamia rostrata*, *Solenosmilia variabilis*, *Madrepora oculata*, *Acanella eburnea* and *Placogorgia terceira*). These corals were present in smaller quantities in comparison with the New England Seamounts (Table 14). The low by-catch of corals on the peak of Corner Rise Seamount could be related to previous alteration of sessile epifauna due to intense fishing activity over the last decades of the 20th century (Vinnichenko 1997). Moreover, Waller et al. (2007) using a remotely operated vehicle (ROV) documented evidence of large-scale trawling damage on the Corner Rise Seamounts.

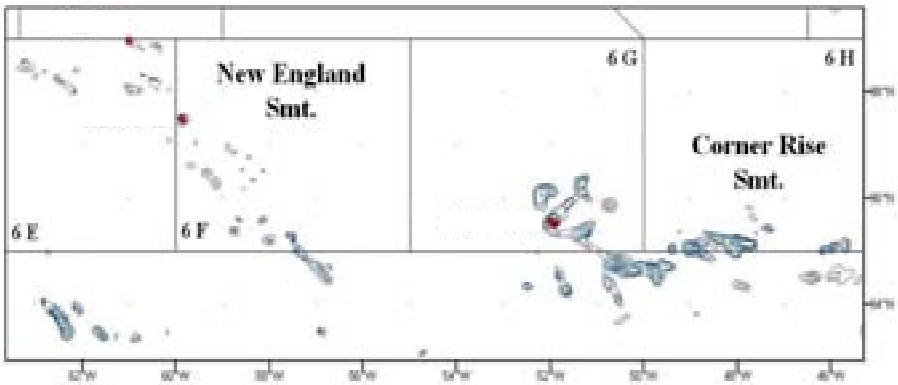

Figure 59. 2004 Experimental Trawl Survey. Location of the *Pedreira* hauls carried out in New England and Corner Rise Seamounts.

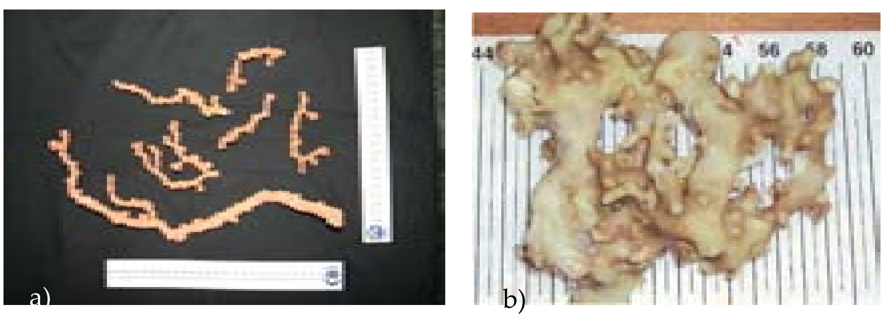

Figure 60. Coral taxa recorded from the New England Seamounts during the Spanish Experimental Trawl Surveys there. a) *Paragorgia johnsoni*; b) *Solenosmilia variabilis* (Murillo et al. 2008).

Table 13. 2004 Experimental Trawl Survey. *Pedreira* hauls carried out in New England and Corner Rise Seamount Complex: Total hauls and hauls with cold-water coral presence (Murillo et al. 2008).

	New England SeamountComplex		**Corner Rise Seamount Complex**
	Div. 6E	**Div. 6F**	**Div. 6G**
Nº of hauls carried out	1	2	92
Nº of hauls with coral presence	1	2	6

Table 14. 2004 Experimental Trawl Survey. By-catch of cold-water corals (kg) in New England and Corner Rise Seamount Complex. (1) alive; (2) dead; (3) sub-fossil-like; (4) unknown status (Murillo et al. 2008).

Cold-water coral species	New England Seamount Complex		Corner Rise Seamount Complex
	Div 6E	Div. 6F	Div.6G
Enallopsammia rostrata			0.022(1)
Solenosmilia variabilis	0.57(2)	0.471(1)	0.225(4)
Madrepora oculata			0.015(4)
Enallopsammia sp.		70.422(3)	
Keratoisis sp.		2(3)	
Paragorgia johnsoni		0.156(1)	
Acanella eburnea			0.02(1)
Lepidisis sp.		1(1)	
Placogorgia terceira			0.004(1)
Thouarella grasshoffi	0.011(1)		
Metallogorgia melanotrichos		0.02(1)	
Antipatharia indet. 1		0.150(1)	
Antipatharia indet. 2			0.005(1)

The United States has conducted a number of video surveys on the New England and Corner Rise seamount chains from 2001 through to 2005 (Malakoff 2003, Auster 2008). In a report to the Trans-Atlantic Coral Ecosystem Study (TRACES) workshop in Wilmington, North Carolina in February 2008 (http://www.lophelia.org/pdf/Linkages_Shank.pdf), Walter Cho and Tim Shank (Woods Hole Oceanographic Institution) report preliminary findings which indicate that there are 60 species found only on the New England Seamounts, 75 species found only on the Corner Rise Seamounts and 135 species common to both.

Conclusion

After considering all the information that has accrued since the original decision to close the seamounts (NAFO 2006), as well as current understanding on the ecology of seamounts (structure and function) and the effects of human impacts on them (Clark et al. 2010, see also 9c below), WGEAFM concludes that the available information supports the continued designation of these areas as VMEs.

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ToR 9 b. *Review any exploratory fishing activity on the seamounts in the context of significant adverse impact to vulnerable marine ecosystems and review current exploratory fishing data collection protocols operating in the seamount closure areas as defined in Article 15 for their usefulness in providing scientific information.*

To date, there have been no notifications to the NAFO Secretariat of exploratory fishing in the closed seamount areas, and Scientific Council is not aware of any current exploratory fishing data collection protocols that pertain only to seamounts. VMS data provided by the NAFO Secretariat indicated the presence of fishing vessels in the Corner Rise Seamount closed area during 2007 and 2009. Fishing has been reported to Scientific Council in NAFO Div. 6G in 2009 where Alfonsino (*Beryx splendens*) were reported as well as smaller catches of Black Cardinal Fish (*Epigonus telescopus*), Oilfish (*Ruvettus pretiosus*) and Smooth-hounds (*Mustelus mustelus*). This fishing was conducted using a midwater trawl gear. Fishing effort was 28 days. Length distributions for alfonsino for both sexes were reported with the smallest fish being 26 cm, but no other information was available to assess impacts. No coral/sponge bycatch was reported.

With regard to exploratory fishing, Scientific Council, in June 2007, concluded that "it does not have sufficient data on which to provide advice on the areas which could be fished on each seamount. Some seamounts are likely beyond the depth range of existing commercial fishing gear and have never been fished by bottom gears, while other seamounts have experienced heavy fishing in the 1970s and sporadic fishing since then. Before any fisheries are allowed to proceed in the closed areas, Scientific Council requires better information to be able to evaluate the consequences, including baseline studies, mapping data, and information on species distribution, stock structure, biology, population dynamics, and habitat." Scientific Council also recommended that "any research survey in the closed areas should be reviewed first by Scientific Council before proceeding. Priority should be given to develop surveys that undertake bathymetric data collection, multi-beam surveys, taxonomic studies, and gear-mounted camera systems for habitat mapping." WGEAFM does not have any new information to change these conclusions.

ToR 9c*. Review the potential for significant adverse impact of pelagic, long-line and other fishing gear types other than mobile bottom gear on seamount vulnerable marine ecosystems.*

General background

A recent study on the ecology of seamounts: structure, function, and human impacts (Clark et al, 2010) provides useful insights into the effects of fishing on seamount communities. A summary is presented here.

Biological communities on seamounts face a number of threats from human activities. The most widely known of these is fishing, especially trawling. Few of these large-scale seamount trawl fisheries have proved sustainable, with many showing a boom-and-bust pattern (e.g., Uchida & Tagami, 1984, Vinnichenko, 2002). Many deep-sea commercial fish species have characteristics that generally make them more vulnerable to fishing pressure than shallower shelf species. They can form large and stable aggregations over seamounts for spawning or feeding, which enables very large catches and rapid depletion of stock size. Biological factors such as longevity, low fecundity, and slow growth rates make recovery from fishing impacts slow (e.g., Clark 2001, Morato et al. 2008). Once overexploited, it is uncertain if deep-sea fisheries on seamounts can recover, and irregular recruitment levels may be a key factor (Clark 2001, Dunn 2007).

Habitat type is a key determinant of recovery rate of the benthos in shallow environments, with those that are associated with biogenic structures the slowest to recover (Collie et al. 2000, Kaiser et al. 2006). Deep biogenic habitats can be major components of benthic community composition on seamounts where patchy thickets of framework-building scleractinian corals can provide interstices for a diverse mobile fauna (O'Hara et al. 2008) and attachment sites for a great variety of sessile filter feeders (Rogers et al. 2007). These biogenic habitats may accumulate over geological time (many millennia) but can be rapidly reduced by bottom disturbances (e.g., Koslow et al. 2001, Clark & Rowden 2009).

Based on the limited number of seamount studies and the knowledge gained by research from shallower shelf and slope areas, it is likely that recovery trajectories for benthic communities on seamounts will span decades or centuries, especially for widely separated seamounts. There is clearly a need for further research to adequately determine the resilience of seamount habitats to human-induced disturbance, but at present it is reasonable to consider the biological communities of seamounts to be among the least resilient in the marine environment.

Habitat

Most information on exploratory fisheries on seamounts involves mobile gear, primarily trawling. The use of stationary gear (gillnets, longlines, crab pots) on seamount ecosystems is not common. However, in areas with complex and rugged bathymetric features, mobile gears are not conducive therefore stationary gears have been used (see http://nwpbfo.nomaki.jp/Fisheries.html; Hazin et al. 1998, Martins et al. 2005, Mortensen et al. 2008, Penney et al. 2009).

The Multilateral Meeting on Management of High Seas Fisheries in the North Pacific Ocean (see http://nwpbfo.nomaki.jp/Fisheries.html) reported longline gear used on the Southeast Hancock Seamount (1985-1993) to determine and monitor population abundances and recruitment levels of North Pacific armourhead and alfonsino. The environmental impacts and by-catch of these surveys on seamount ecosystems were not disclosed but may be a potential source of information.

Mortensen et al. (2008) conducted video surveys utilizing an ROV on the Mid-Atlantic Ridge between the southern part of the Reykjanes Ridge and the Azores, as well as bycatch from longlines and bottom trawls. Eleven coral taxa were documented with nine out of the 37 sets capturing corals. Direct evidence of fishing impacts were observed on video along with lost fishing gears, which included trawl nets, gillnets, and longlines.

In the Azores region, only benthic longlines are permitted. Since 2007, four benthic surveys have taken place using benthic longline gear. Coral by-catch from these surveys included 168 specimens of deep-water corals from 41 taxa (Sampaio et al. 2009).

Durán Muñoz et al. (2010) report new data on deep-sea communities and cold-water corals /sponges distribution, based on the results from a joint collaboration between the Spanish Institute of Oceanography (IEO) and a longliner, carried out on the Hatton Bank area, Northeast Atlantic, in the summer of 2008. Deep-water sharks dominated the catches contributing 80.4% in terms of weight. Bathymetry was the key factor that structured assemblages found. Bycatches of cold-water corals and small sponges were common along the western flank of the Hatton Bank, while large sponges were found along the eastern part. Additional data on distribution of sea garbage and derelict deep-sea gillnets were collected.

On the Corner Rise Seamounts visual verification of gear impacts were observed. Observations included scars, broken crusts, displaced boulders, upturned corals, and narrow scars and cuts through sponges either from trawl weights or longline components (Waller et al. 2007). Similar impacts (i.e., cuts and slices through glass sponges) can occur and are suspected for ancient glass sponges in the Pacific Northwest (Jamieson et al. 2007).

In other deep-sea habitats evidence of fishing impacts by stationary gears (gillnets and longline) and subsequent coral by-catch is well documented (Husebø et al. 2002, Gass and Willison 2005, Mortensen et al. 2005, Edinger et al. 2007, Wareham and Edinger 2007).

The method of deployment of stationary gear (longlines, pots, and gillnets) is relatively consistent regardless of the area fished whether it is on the continental shelf, rise, slope or seamounts.

Although fixed gears are stationary, spatial coverage can still be significant because the gear is linked. Crab pots can be deployed individually as seen in the Northwest Pacific, however, in the NL region, crab pots are linked together in ‘fleets’ with up to 50 pots per fleet. Coral by-catch occurs when the fleet is retrieved causing the crab pots to be dragged across the seafloor where the gear can ensnarl and entangle corals (Wareham and Edinger 2007).

Benthic longlines are set as strings with a mainline consisting of hundreds of baited hooks, and can be anchored on one end or both. Impacts on sessile organisms occur as a longline string is retrieved. The mainline becomes taut creating a ‘clothes-line’ effect and anything in the path of the longline such as dendroid-shaped coral, will most likely be tipped, entangled, removed, or damaged during the retrieval process (Mortensen et al. 2005). This is particularly significant for large-fan corals that need to maintain an upright position (e.g. gorgonian corals). If the colony is damaged (e.g. branches severed) it may become more susceptible to parasitic organisms such as hydroids, or colonial sea anemones, which has been observed in NL and Maritimes regions (Mortensen et al. 2005, Wareham and Edinger 2007).

Benthic gillnets have been shown to capture and damage corals as well (Mortensen et al., 2005; Gass and Willison 2005, Wareham and Edinger 2007). Benthic gillnets operate under the same principle as longlines, and can be comprised of many panels (91.6 m per panel) strung together with up to 70 panels per fishing set (Benjamins et al. 2008). Impacts on benthic sessile organisms occur when the gillnet panels are set close to or on the seafloor, and become entangled in large megafauna (corals and sponges). Gillnets are constructed of strong monofilament netting and is extremely durable. Once a gillnet becomes entangled, weather it be with the target species or not, the chances of release are low to nil.

For fixed gears in general, some mitigation can be achieved through the use of break-away ropes (a rope that breaks when the gear becomes snagged) but this does not eliminate the problem of the lost gear causing damage.

Fish Communities

Concerns about the impact of pelagic or semi-pelagic fishing on and around seamounts include:

- Rapid depletion of indigenous populations of aggregations of deep-sea fish species vulnerable to fishing such as alfonsino (*Beryx* spp). It is known that pulse fishing for this species has occurred on seamounts in the NAFO area (Vinnichenko, 1997).
- The possibility of higher proportions of juvenile fish in catches
- Occasional impact of fishing gear on benthic VMEs, particularly when fishing strategies involve fishing close to the sea bed on the summit and slopes of seamounts.

Despite their importance, the relationships between seamounts, pelagic fishing, pelagic species and benthic VMEs are not well understood. However, there is information that fishing that has impacted on seamounts in the NAFO RA. For twenty years (1976–1996) the Union of Soviet Socialist Republics (USSR) (now the Russian Federation) expended significant effort in the area of the Corner Rise seamounts using both pelagic and bottom trawls (Vinnichenko 1997). As part of a broader study on deep-water corals of the North Atlantic, investigations of 5 seamounts in the Corner Rise complex using a remotely operated vehicle (ROV) in 2005 documented not only pristine coral ecosystems, but also dramatic evidence of large-scale trawling damage on the summits of Kükenthal peak and Yakutat Seamount (Waller et al, 2007).

Additionally, there may be a compliance issue in terms of real-time identification, monitoring and differentiation between pelagic and demersal fishing activity on seamounts.

Conclusion

There is a clear potential for fishing gears other than bottom trawling to produce significant adverse impacts on VME communities. Impacts are typically associated with 1) habitat destruction produced by the gear when in contact with the bottom, and 2) depletion of localized populations. Longlines, gillnets and traps, which are fixed gears, also move when they are being deployed and recovered. These manoeuvres can damage benthic structures and habitats. Given the slow growth/reproductive rates that characterize VME-forming species, these damages can accrue to constitute significant adverse impacts. In case of depletion/overfishing, localized populations are extremely sensitive to exploitation due to its life history characteristics/aggregating behaviour, and typically small population sizes. This type of impact is irrespective of the gear used, but is driven by the exploitation rates imposed, and it may apply to target and bycatch species.

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PART IV. Proposal for Time, Place and Agenda of Next Meeting

Time and Place

It was proposed that the next WGEAFM meeting take place in 1-10 December 2010 at the NAFO Secretariat in Darmouth, Canada.

Agenda

Based on the roadmap presented here it was considered necessary to adapt the long-term themes and ToRs to better fit within this roadmap. The proposed new Themes and ToRs are:

Theme 1: Spatial considerations

ToR 1. Update on identification and mapping of sensitive species and habitats in the NAFO area.

ToR 2. Based on available biogeographic and ecological information, identify appropriate ecosystem-based management areas.

Theme 2: Status, functioning and dynamics of NAFO marine ecosystems.

ToR 3. Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area.

Theme 3: Practical application of ecosystem knowledge to fisheries management

ToR 4. Update on recent and relevant research related to the application of ecosystem knowledge for fisheries management in the NAFO area.

ToR 5. Methods for the long-term monitoring of VME status and functioning.

Theme 4: Specific requests

ToRs 6+. As generic ToRs, these are place-holders intended to be used when addressing expected additional requests from Scientific Council.

The next WGEAFM meeting is proposed to be focused on ***Theme 1: Spatial Considerations*** and ***Theme 4: Specific requests***.

Appendix 1

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