Northwest Atlantic Fisheries Organization

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SC WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT – NOVEMBER 2013

Report of the 6th Meeting of the NAFO Scientific Council
Working Group on Ecosystem Science and Assessment (WGESA)
[Formerly WGEAFM]

NAFO Headquarters, Dartmouth, NS, Canada
19- 29 November 2013

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Report of the SC Working Group on Ecosystem Science and Assessment

19-29 November 2013

Introduction

The NAFO SC Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM) was re-named to Working Group on Ecosystem Science and Assessment (WGESA) during the Scientific Council 2013 June meeting. The reason for this name change was to avoid confusions with the newly created Joint Fisheries Commission - Scientific Council Working Group on the Ecosystem Approach Framework to Fisheries Management, but the core mandate and Terms of Reference for WGESA would remain the same as before. For this reason, the numbering of the meetings (6th for the 2013 meeting) will continue from where the 5th WGEAFM meeting in 2012, left off.

The work of WGESA can be described under two complementary contexts:

a) work intended to advance the "Roadmap for the development of and ecosystem approach to fisheries (EAF) for NAFO" ("*Roadmap*", for short).

b) work intended to address specific requests from Scientific Council (SC) and/or Fisheries Commission (FC).

Scientific Council approved in its 2013 June meeting that the main topics for the 2013 WGESA meeting would be:

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

- Review for Vulnerable Marine Ecosystem (VME) closures.

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

- Update on ecoregions and work towards an integrated ecoregion analysis.

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

- Update on Fisheries Production Potential modeling.

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

- Revised workplan for the assessment of Significant Adverse Impacts on VMEs, towards the development of re-assessments of bottom fishing activities which are due in 2016.

The Fisheries Commisison requests that WGESA has been asked to address are:

- **FC Request # 12.** The Fisheries Commission requests the Scientific Council to continue to develop work on Significant Adverse Impacts in support of the reassessment of NAFO bottom fishing activities required in 2016, specifically an assessment of the risk associated with bottom fishing activities on known and predicted VME species and elements in the NRA.
- **FC Request # 13**.Considering that the current closures for VME indicators (i.e. species and elements in Annex I.E VI and VII) established under Chapter II of the NAFO Conservation and Enforcement Measures (NCEM) are due for revision in 2014, the Fisheries Commission requests the Scientific Council to:
    a) Summarize and assess all the data available collected through the NEREIDA project, CP RV surveys, and any other suitable source of information, to identify VMEs in the NRA, in accordance to FAO Guidelines and NCEM.
    b) Based on these analyses, evaluate and provide advice in the context of current closures specified in the NCEM for the protection of VMEs and prioritize areas for consideration by the Ecosystem Approach to Fisheries Working Group.
- **FC Request # 15**. The Fisheries Commission Working Group on Vulnerable Marine Ecosystems (WGFMS-VME) considered the scientific advice available at the time of its last meeting held in April 2013. No consensus was reached between Contracting Parties regarding specific management measures that are best suited in

> protecting areas 13 and 14 as reflected in Figure 2 of the Working Group report (NAFO/FC Doc. 13/3) and defined by the coordinates indicated in page 10 of that report.
>
> New information from the EU Flemish Cap survey was expected to be available on sea pens later in 2013, which would help to clarify what type of management measures would best suit areas 13 and 14.
>
> The Fisheries Commission requests the Scientific Council to provide the Fisheries Commission with the preliminary results or analysis, regarding occurrence of sea pens in areas towed close to areas 13 and 14 and advise if these reveal significant concentrations of VME indicators.

These Fisheries Commision requests fall under the general scope of WGESA Terms of Reference, and WGESA is actively engaged in developing those studies as an integral part of the development of the *Roadmap*. FC Request # 12, maps onto the topic targeted under ToR 4, FC Request # 13 is the review already planned under ToR 1, and FC Request #15, can be considered a specific element within FC Request # 13. Under these considerations, the information and analyses required by SC to address these FC Requests will be provided by WGESA as part of their work already planned for the 2013 meeting under ToRs 1 and 4.

Terms of Reference for the 6th NAFO SC WGESA meeting

The above Fisheries Commission requests, together with the agreed topics under the *Roadmap* have been amalgamated in the ToRs for the 6th WGESA meeting. In addition to these, additional topics which have benn the subject of past requests, and for which results are becoming available, have also been included among the ToRs to further advance the *Roadmap* work.

Theme 1: Spatial considerations

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

- **Part A.** New information
- **Part B.** Fisheries Commision Requests #13 and #15. Review of VMEs in the NRA, and current closures to protect them.

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

ToR 2.1. [*Roadmap*] Update on integrated ecoregion analysis for the entire Northwest Atlantic.

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.

ToR 3.1. [*Roadmap*]. Report progress on the development of Fisheries Production Potential Models for NAFO ecosystems.

ToR 3.2. [*Roadmap*]. Report progress on trophic ecology/species interactions studies for the Grand Banks (NAFO Div 2J3KLNO).

ToR 3.3. [*Roadmap*]. Report progress on trophic ecology/species interactions studies for the Flemish Cap (NAFO Div 3M).

ToR 3.4. [*Roadmap*]. Review of evidence for ecosystem function of VMEs in the NAFO area.

ToR 3.5. [*Roadmap*]. Oceanographic conditions around Flemish Cap.

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 4.1. [FC Request # 12]. Report progress on the assessment of Significant Adverse Impacts on VMEs, with emphasis on analysis of the risk associated with bottom fishing activities on known and predicted VME species and elements in the NRA.

ToR 4.2. [*Roadmap*]. Update workplan for the assessment of Significant Adverse Impacts on VMEs, towards the development of re-assessments of bottom fishing activities by 2016.

Theme 1: Spatial considerations

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

Part A. New Information

1.A.1. New data on deep-water corals and large sponges from bottom trawl groundfish surveys in the NAFO Regulatory Area (Divs. 3LMNO): 2011-2013

During the 6th NAFO WGESA meeting new data on deep-water corals and sponges were presented based on Spanish/EU and Canadian bottom trawl groundfish surveys for the period 2011-2013 in order to make these data available to the NAFO WGESA and improve the mapping of sensitive species in the NAFO Regulatory area (Divs. 3LMNO).

During the meeting, new quantitative spatial analyses were applied to the corals and sponges with all of the available data, including those reported here. This produced the following thresholds for analyses of significant concentrations of coral and sponges: 75 kg per tow for sponges, 0.6 kg per tow for large gorgonians, 0.15 kg per tow for small gorgonians; and 1.4 kg per tow for sea pens. Positions of these tows are provided (Table 1.1) together with their mapped position and the closed areas (Figures 1.1 to 1.4).

Data used in this study come from four different bottom trawl groundfish surveys:

1. The Spanish 3NO Survey, carried out by the Instituto Español de Oceanografía (IEO), samples the Grand Bank of Newfoundland (NRA, Divs. 3NO) between 42 and 1462 m depth (González-Troncoso *et al*., 2013).
2. The EU Flemish Cap Survey, carried out by the IEO together with the Instituto de Investigaciones Marinas (IIM) and IPIMAR (Portugal), samples all the Flemish Cap (NAFO Div. 3M), and currently a depth range between 132 and 1450 m (Casas and Gonzalez-Troncoso, 2013).
3. The Spanish Fletán Negro-3L Survey carried out by the IEO, samples the Div. 3L in the NRA between 112 and 1478 m depth (Román *et al*., 2013).
4. DFO NL Multispecies Surveys (NRA Divs. 3LMNO), carried out by Fisheries and Oceans, Canada between 47 and 723 m (Healey *et al*, 2012).

In order to follow the same groups previously used by WGEAFM, deep water corals were grouped into large gorgonians (Alcyonacea), small gorgonians (Alcyonacea) and sea pens (Pennatulacea); and all of the sponges were grouped together (Porifera).

A total number of 448 (432 Spain/EU and 16 Canada) bottom trawl hauls were studied for corals and 810 (688 Spain/EU and 122 Canada) for sponges. DFO NL Multispecies Surveys use to cover the Divisions 3LNO and sporadically the Division 3M, and for this reason, only the Spanish/EU surveys that cover uniformly the entire study area in the NRA (Divs. 3LMNO) have been used for the calculation of the percentage of presence for the different groups of corals and sponges.

Most (78.6%) of the catches of sponges above the threshold for identification of VME are inside of the closed areas, however for corals the results are different according to the group considered. For large gorgonians 87.5% of the new data locations are outside, for sea pens 75% and all small gorgonians are outside of the closed areas.

Distribution maps of new records (2011-2013) for presence and catches above the threshold for identification of VME of sponges, large gorgonians, small gorgonians and sea pens are presented (Figures 1.1 to 1.4).

Location of the corals and sponge records was assigned to the start position of the survey fishing tows. The coordinates and weight of the catches above the threshold for identification of VME are provided in Table 1.1.

Table 1.1. Start positions of tows with corals and sponges catches above the threshold for identification of VME in the NRA (Divs. 3LMNO) **outside** of the closed areas with their corresponding weight for the period 2011-2013.

Country	**Year**	**Start position**		**VME species**	**Weight (kg)**
		Lat (N)	**Lon (W)**		
Spain/EU	2013	47º 08´16.80´´	43º 30´29.88´´	SPONGES *≥ 75 kg*	6655.003
Spain/EU	2011	46º53´44.99´´	43º 34´50.41´´		5691.200
Spain/EU	2013	46º 51´25.20´´	43º 45´15.48´´		3599.151
Spain/EU	2013	45º 59´02.40´´	47º 41´45.60´´		779.063
Spain/EU	2012	45º 47´55.21´´	47º 43´47.39´´		674.632
Spain/EU	2013	44º 01´18.59´´	48º 51´20.41´´		585.644
Spain/EU	2012	45º30´05.40´´	48º24´34.20´´	LARGE GORGONIANS *≥ 0.6 kg*	36.900
Spain/EU	2012	46º20´50.39´´	45º59´01.79´´		9.330
Spain/EU	2013	46º53´16.80´´	46º36´01.08´´		8.560
Spain/EU	2013	46º 33´51.59´´	47º05´27.60´´		5.298
Spain/EU	2013	46º51´25.20´´	43º45´15.48´´		2.700
Canada	2012	47º54´47.99´´	46º57´54.00´´		2.360
Spain/EU	2012	46º17´14.39´´	45º47´04.20´´		0.880
Spain/EU	2013	43º17´36.60´´	51º43´15.60´´	SMALL GORGONIANS *≥ 0.15 kg*	1.791
Spain/EU	2011	43º00´14.40´´	49º16´15.60´´		0.292
Spain/EU	2013	43º17´36.60´´	51º43´15.60´´	SEA PENS *≥ 1.4 kg*	9.946
Spain/EU	2012	47º11´49.81´´	46º40´10.20´´		4.968
Canada	2011	43º21´36.00´´	51º43´54.00´´		1.500

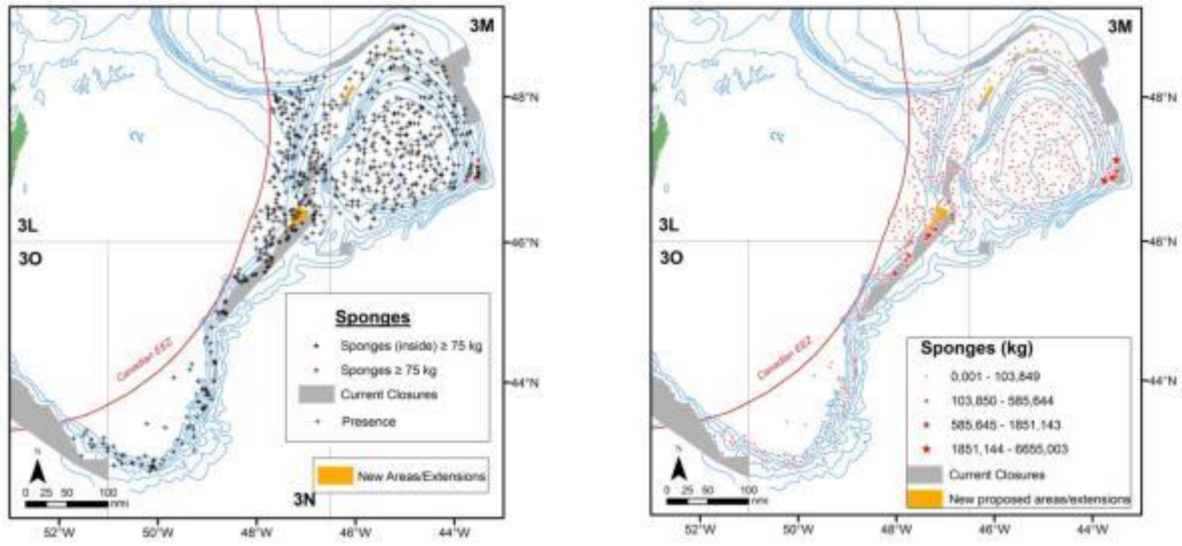


Figure 1.1. Distribution of catches above the threshold for identification of VME and presence of sponges in the study area (NAFO Divs. 3LMNO) (left). Sponges catch distribution with graduated symbols (right).The location of all areas currently closed to protect significant concentrations of corals and sponges in the NRA (Divs. 3LMNO) are also indicated (NAFO, 2012a) including extensions effective January 1, 2014.

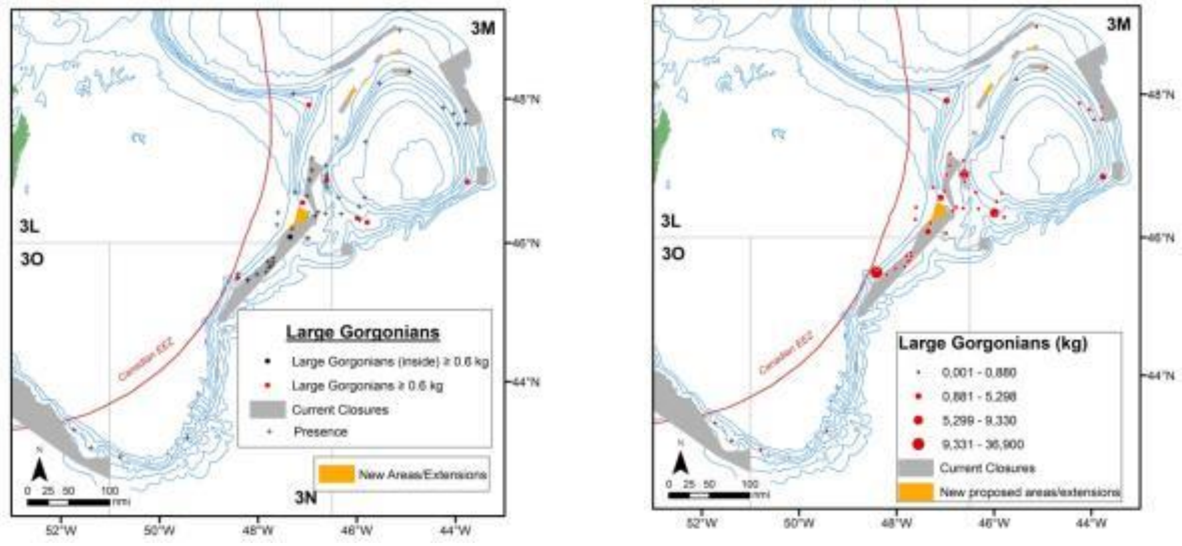


Figure 1.2. Distribution of catches above the threshold for identification of VME and presence of large gorgonians in the study area (NAFO Divs. 3LMNO) (left). Large gorgonians catch distribution with graduated symbols (right).The location of all areas currently closed to protect significant concentrations of corals and sponges in the NRA (Divs. 3LMNO) are also indicated (NAFO, 2012a) including extensions effective January 1, 2014.

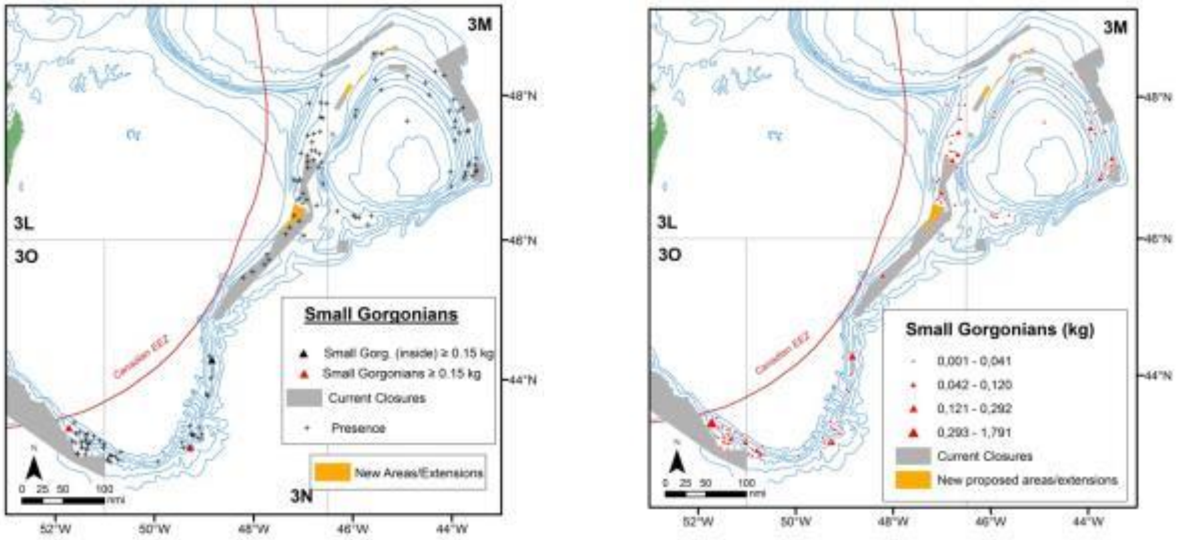


Figure 1.3. Distribution of catches above the threshold for identification of VME and presence of small gorgonians in the study area (NAFO Divs. 3LMNO) (left). Small gorgonians catch distribution with graduated symbols (right).The location of all areas currently closed to protect significant concentrations of corals and sponges in the NRA (Divs. 3LMNO) are also indicated (NAFO, 2012a) including extensions effective January 1, 2014.

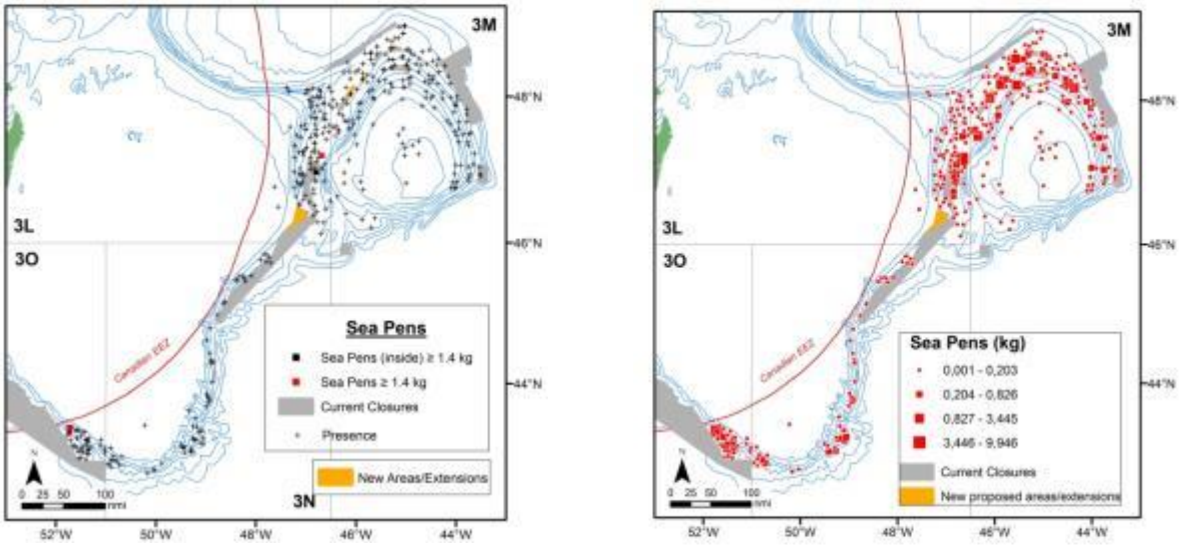


Figure 1.4. Distribution of catches above the threshold for identification of VME and presence of sea pens in the study area (NAFO Divs. 3LMNO) (left). Sea pens catch distribution with graduated symbols (right).The location of all areas currently closed to protect significant concentrations of corals and sponges in the NRA (Divs. 3LMNO) are also indicated (NAFO, 2012a) including extensions effective January 1, 2014.

Catches above the threshold for identification of VME of sponges for the new data analyzed were found around the same areas as those obtained in 2009 (NAFO, 2009b) and 2011 (Murillo *et al.*, 2011c) and only 6 of the 28 catches were found outside of the closed areas.

For large gorgonians, the most of the catches above the threshold for identification of VME were recorded outside of the closed areas including one of 36.9 kg. For small gorgonians the catches above the threshold for identification of VME were localized in the south of Grand Bank outside of the closed areas. Three catches of sea pens above the threshold for identification of VME were recorded outside of the closed areas, but in close proximity to them. Catches above the threshold for identification of VME in the northeast of Flemish Cap were not observed in contrast to the period 2008-2010 (Murillo *et al*., 2011c).

1.A.2. Preliminary Analysis and Summary of NEREIDA Box-Core Samples

Box-core samples were acquired under the NEREIDA programme to extract and quantify benthic infauna, as well as physical information. Upon landing of the box-core sample on the deck of the survey vessel and before any extraction of data, a photograph was taken of the undisturbed sample surface. Such photographs represent a visual record of the seabed surface at each location a box-core sample was taken. Many samples included organisms living on the seabed surface (i.e., the epifauna), which were captured in the photographs. Each photograph has been studied in detail and the observed organism identified to the highest taxonomic level possible (often just morphotaxa), together with an estimation of their abundance on a SACFOR scale (Superabundant, Abundant, Common, Frequent, Occasional or Rare). In addition, a description of the sediment plus any evidence of disturbance on the sediment surface, such as burrows or tracks, was also recorded.

In all, 331 sample surface photographs were available for analysis, spanning the extent of the NEREIDA survey footprint. The list of taxa extracted from all photographs was converted to a taxon-by-sample matrix, which was subsequently subjected to standard multivariate analysis to identify statistically distinct groups of samples based on shared taxa. Taxa represented within each statistically distinct group of samples were identified and collectively referred to as a distinct assemblage or community. Distinct assemblages containing taxa indicative of VME were mapped and their correspondence with known areas of VME noted.

The number of taxa recorded from each photograph ranged between 0 and 10. The average number of taxa per sample across the entire survey area was 2.4. The number of samples with 5 taxa or more identified on the surface was 36. These relatively taxon-rich samples were distributed mostly on the steep slopes of the Grand Banks and Flemish Cap, coincident with the location of the larger closed areas (Figure 1.5).

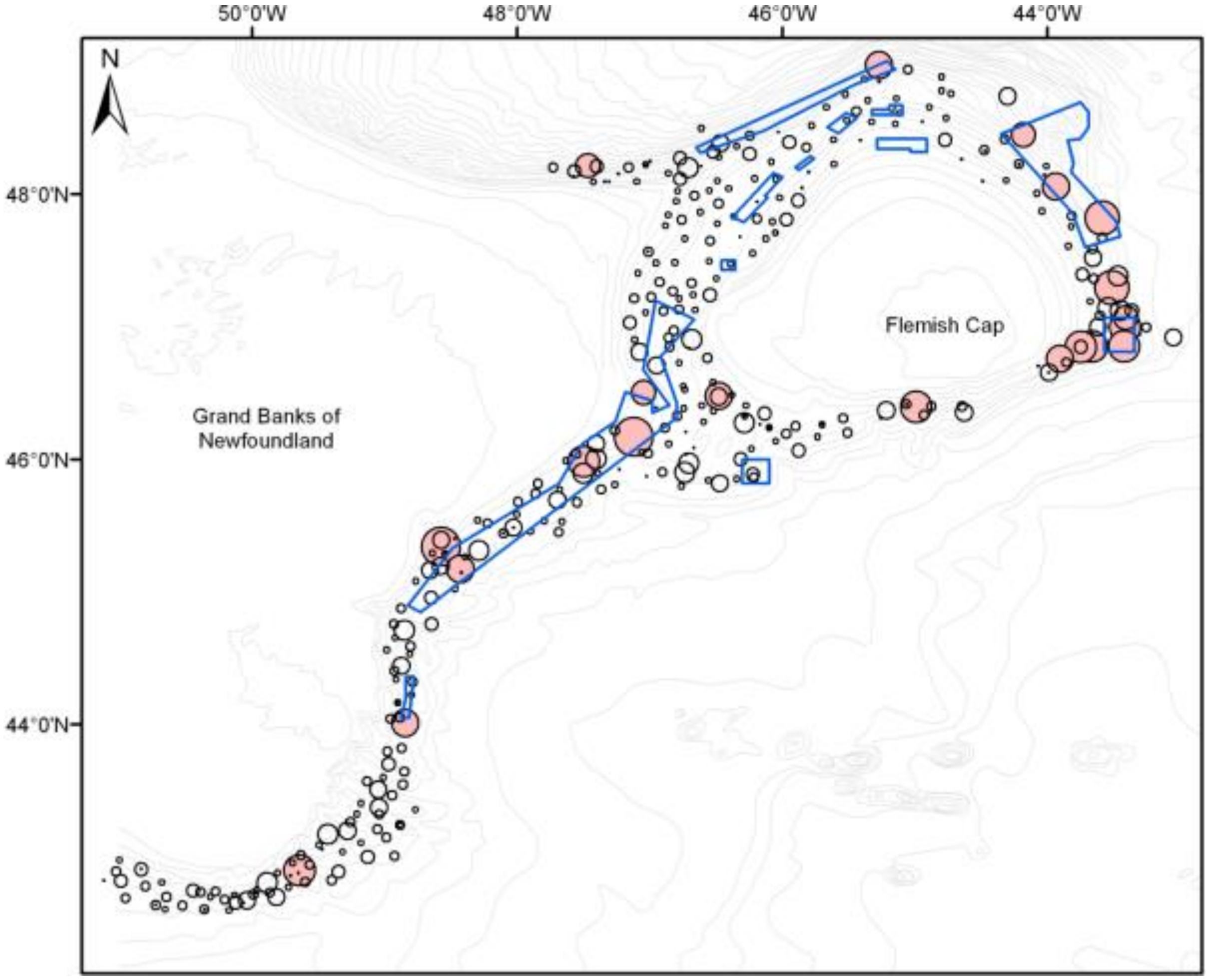


Figure 1.5. Distribution of box-core samples across the NEREIDA survey area. Size of circles is proportional to the number of taxa recorded on the surface of each box-core sample. Circles shaded in red are those with >5 taxa observed on the sample surface. Polygons represent the areas closed to bottom-contact fishing gear.

Multivariate analysis identified 18 statistically distinct groups of samples (labelled a to s), each group represented by a varying number of samples. The distinct assemblage characterised by the most taxa (assemblage h) also contained the most VME indicative taxa (sponges, sea pens and crinoids). The distribution of this VME indicative-rich assemblage is presented in Figure 1.6. Many of the samples belonging to assemblage h fell within and in close proximity to the closed areas. Concentrations of samples belonging to assemblage h also occurred on the southern and southeast-facing slopes of the Flemish Cap.

VME-indicative taxa not represented in assemblage h were the characterising taxa of another two distinct assemblages represented by only five samples (assemblages i and d). Collectively, these two assemblages did not harbour many other taxa, but contained sea pens. The distribution of both these assemblages was mostly on the north-facing slopes of the Flemish Cap and occasionally on the steep sided flanks of the Grand Banks (Figure 1.6). Only one of the samples representing these two assemblages fell within the boundary of the closed areas.

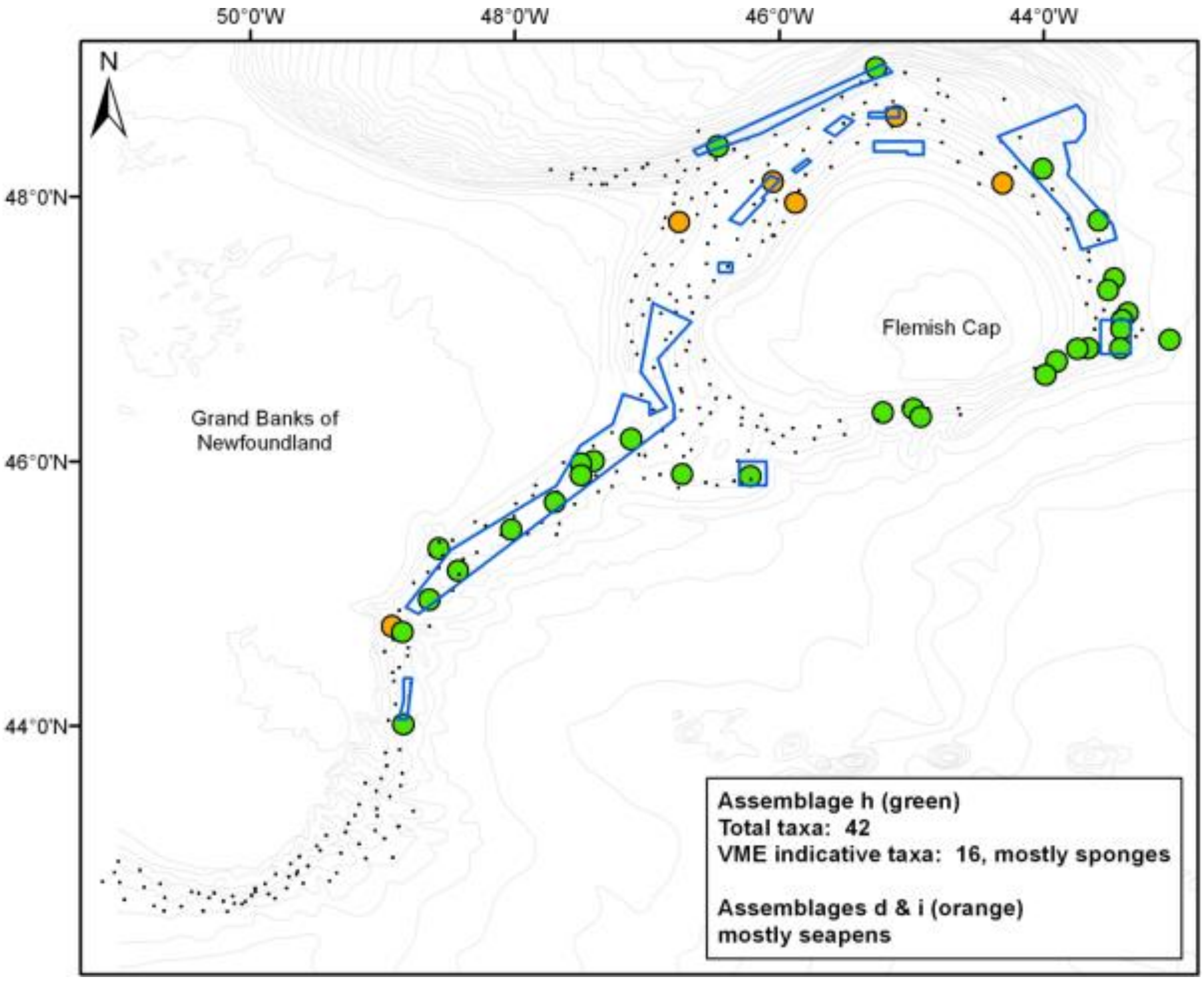


Figure 1.6. Distribution of distinct assemblages h, d and i, identified through multivariate analysis of taxon presence per sample data. Polygons represent the areas closed to bottom-contact fishing gear.

The assemblage represented by the most number of samples was assemblage p (166 samples), and was spread across the survey area (Figure 1.7). Although assemblage p hosted a relatively high total number of taxa (22), the number was likely inflated by the large number and widespread distribution of all its samples.

Table 1.2 presents the relative contribution of each taxon to the similarity within each of the identified distinct assemblages.

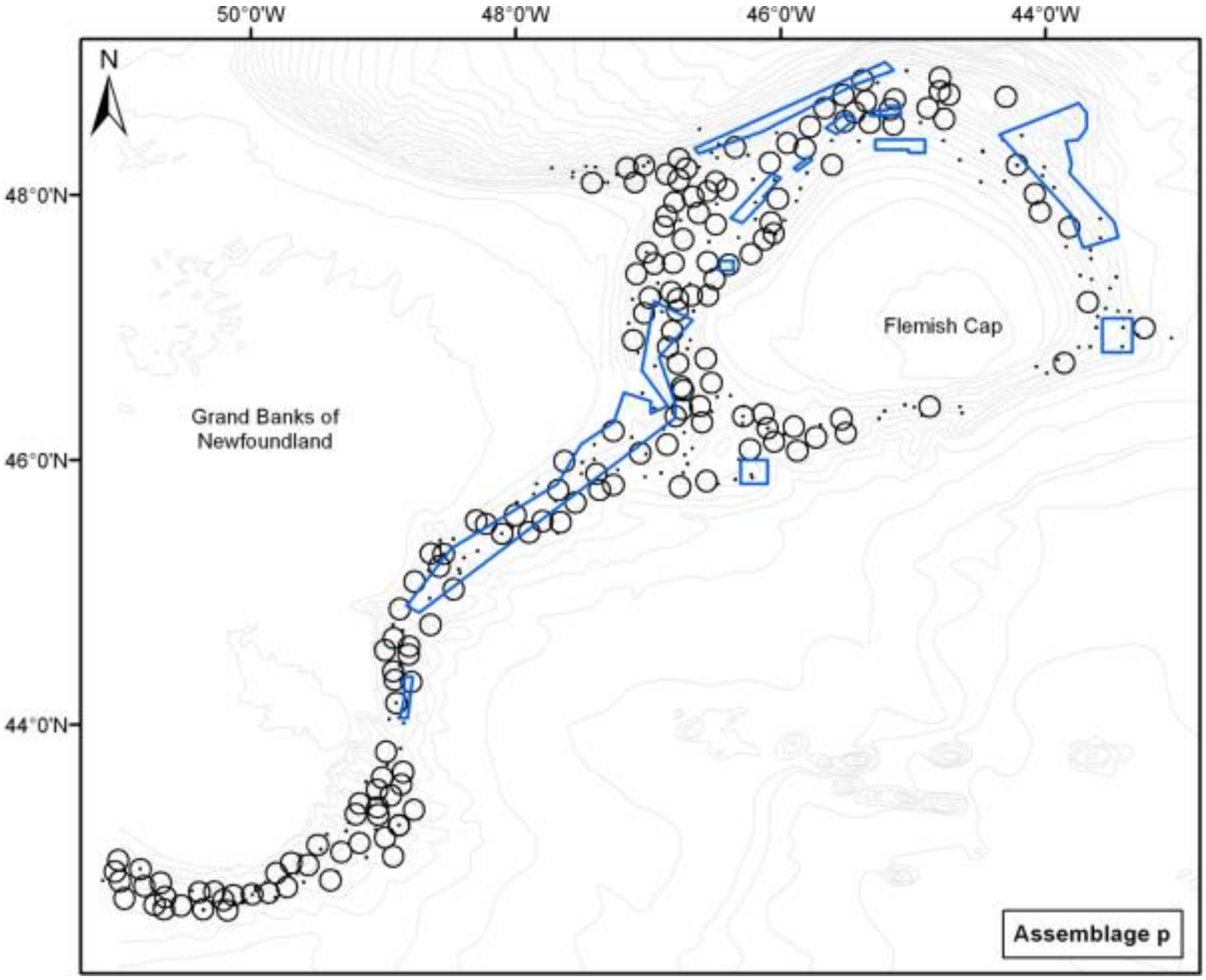


Figure 1.7. Distribution of distinct assemblage p, mostly outside of the closed areas. Polygons represent the areas closed to bottom-contact fishing gear.

Table 1.2. Relative contribution of taxa to the overall similarity within each of the statistically distinct assemblages identified through multivariate analysis of taxa observed on the surface of box-core samples. Colour coding identifies low (greens), moderate (yellows) and high (reds) contributions to the similarity within the assemblage. Distinct assemblages represented by a single sample are not shown. VME indicative taxa are written in red.

Taxa	**h**	**p**	**j**	**k**	**c**	**l**	**q**	**m**	**o**	**r**	**n**	**i**	**d**	**g**	**s**	**f**
Annelida/Polychaeta/		0.04	0.06	0.2	0.67				0.17							
Annelida/Tubes/	0.67	1	0.71	0.9		0.85	0.5	1	1	0.8	1	0.5				
Arthropoda/Amphipoda?/dense	0.03				0.17											
Arthropoda/Decapoda/red					0.17											
Arthropoda/Pycnogonidae/	0.03															
Arthropoda/Tanaidacea?/						0.04										
Brachiopoda/Brachiopoda/	0.06															
Bryozoa/Alcyonidium?/smooth		0.01														
Bryozoa/Bryozoa/	0.06	0.01														
Bryozoa/Bryozoa/branching	0.24		1	0.1	0.33	0.08			0.5							
Bryozoa/Cnidaria/Bryozoa/ Cnidaria/	0.18	0.06		0.1			1	0.33		0.07						
Bryozoa/Reteporella/white lacy	0.09				0.17											
Chordata/Ascidiacea/	0.21		0.06	0.1	0.33		1		1							
Chordata/Ascidiacea/transparent	0.03					0.04										
Chordata/Ascidiacea/white	0.12															
Cnidaria/Acanella/orange	0.06	0.02	0.06	0.1	0.33											
Cnidaria/Anthomastus/red	0.06	0.02		0.1	0.17							1				
Cnidaria/Anthozoa/															0.67	
Cnidaria/Anthozoa/pink			0.06													
Cnidaria/Duva florida/red	0.09	0.01	0.06													
Cnidaria/Hydrozoa/	0.15	0.01	0.24								0.5					

Table 1.2. Relative contribution of taxa to the overall similarity within each of the statistically distinct assemblages identified through multivariate analysis of taxa observed on the surface of box-core samples. Colour coding identifies low (greens), moderate (yellows) and high (reds) contributions to the similarity within the assemblage. Distinct assemblages represented by a single sample are not shown. VME indicative taxa are written in red.

Taxa	**h**	**p**	**j**	**k**	**c**	**l**	**q**	**m**	**o**	**r**	**n**	**i**	**d**	**g**	**s**	**f**
Cnidaria/Hydrozoa/stalked	0.03															
Cnidaria/Keratoisis grayi?/						0.04										
Cnidaria/Kophobelemnon?/	0.03															
Cnidaria/Penatula aculeata/		0.02										0.25	1			
Cnidaria/Pennatula/skelleton	0.03	0.01		1												
Echinodermata/Asteroidea/	0.03	0.01														
Echinodermata/Astropectinidae/ sand star	0.03	0.01														
Echinodermata/Comatulida/	0.03	0.01														
Echinodermata/Crinoidea/	0.12		0.18	0.1	0.17	0.04								0.33		
Echinodermata/Echinoidea/															0.33	
Echinodermata/Holothuria/	0.03															
Echinodermata/Ophiuridae/large	0.06	0.02		0.1				1								
Echinodermata/Ophiuridae/small	0.67	0.01	0.12	0.2		0.04	1			1			0.5			
Indet./Indet/	0.03															
Mollusca/Astarte/yellow, ribbed		0.01	0.24	0.2	0.17	1					0.5					
Mollusca/Gastropoda/	0.12	0.04				0.08	0.5									
Mollusca/Nuculana/elongate											1					
Mollusca/Scaphopoda/		0.05				0.23		0.33	0.17							1
Mud cast/Echiura?/	0.03	0.13	0.06							0.4				1		
Porifera/Asconema foliata/	0.21		0.06													
Porifera/Chonelasma?/erect	0.03															
Porifera/Geodidae/large	0.15							0.33								

Table 1.2. Relative contribution of taxa to the overall similarity within each of the statistically distinct assemblages identified through multivariate analysis of taxa observed on the surface of box-core samples. Colour coding identifies low (greens), moderate (yellows) and high (reds) contributions to the similarity within the assemblage. Distinct assemblages represented by a single sample are not shown. VME indicative taxa are written in red.

Taxa	**h**	**p**	**j**	**k**	**c**	**l**	**q**	**m**	**o**	**r**	**n**	**i**	**d**	**g**	**s**	**f**
Porifera/Hymedesmia/green	0.45		0.06	0.1				0.67		0.07						
Porifera/Porifera/brown	0.06															
Porifera/Porifera/cream									0.17							
Porifera/Porifera/dirty/brown	0.03	0.01	0.06							0.07						
Porifera/Porifera/encrusting	0.06															
Porifera/Porifera/globular encrusting	0.03															
Porifera/Porifera/grey	0.03						0.5									
Porifera/Porifera/massive	0.27															
Porifera/Porifera/smooth ball	0.03				0.17											
Porifera/Tentorium semisuberites?/brown	0.24	0.02	0.18	0.2												
Porifera/Tetillidae/small, dirty	0.76		0.24	0.3		0.08										
Sipuncula/Sipuncula/	0.03															
Total taxa	**42**	**22**	**17**	**15**	**11**	**11**	**6**	**6**	**6**	**6**	**4**	**3**	**2**	**2**	**2**	**1**

1.A.3. Summary of the Location of VME Indicator Species on the Slope of the Flemish Cap, Flemish Pass, and the Sackville Spur Collected with Underwater Cameras through the NEREIDA Program

As part of the NEREIDA program, benthic imagery collected from the Flemish Cap area in 2009 and 2010 has been analyzed for the abundance of epibenthic megafauna (Beazley *et al*., 2013a). These data are the only NAFO data set of *in situ* species occurrence. The location of the analyzed transects are shown in Figure 1.8 (labelled by their consecutive operation number, described in Tables 1.3 and 1.4).

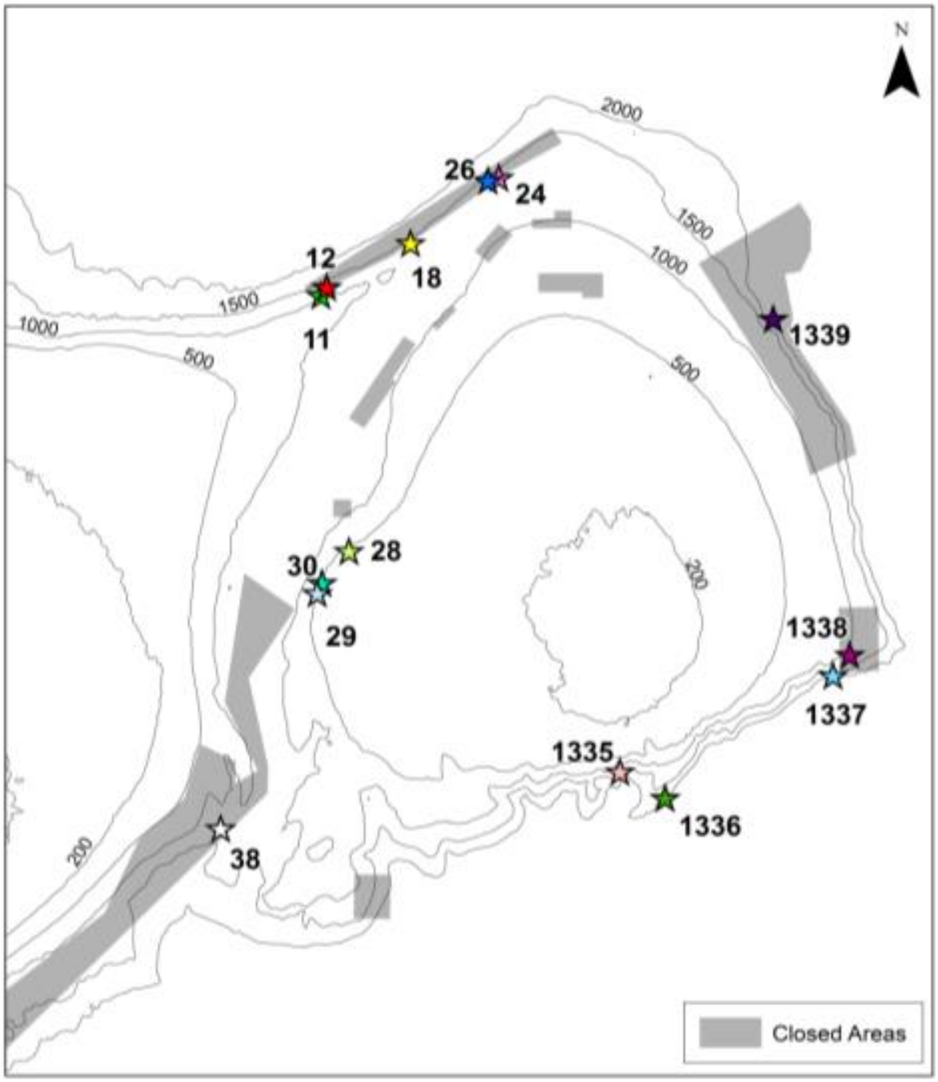


Figure 1.8. Location of benthic imagery transects collected and analyzed as part of the NEREIDA program. Transects are labelled with their consecutive operation number. Details of each transect are outlined in Tables 1.3 and 1.4.

During the C.C.G.S. *Hudson* cruise in 2009, nine benthic imagery transects were collected and analyzed from the Sackville Spur and western Flemish Cap slope/Flemish Pass region (called the Flemish Pass area herein) using the 4K camera (‘4KCam’) and Campod (Table 1.3). The 4KCam (Figure 1.9a), built by the Geological Survey of Canada in 2008, is capable down to 4000-m depth, and houses a high-resolution digital camera and two flashes inside an aluminum roll cage. The system hovers along the seabed until it is lowered via a winch to trigger the camera and flashes. Campod (Figure 1.9b) is a tripod camera system that is equipped with two video cameras, one obliquely-facing and one downward-facing, and a single digital camera for high resolution photos (downward-facing). Campod is controlled on deck via a winch, and hops along the seabed collecting video continuously and images at a predetermined interval. Although video footage of the seabed was continuously recorded on the ‘Campod’ transects, only images were analyzed as part of this study.

Table 1.3. Summary of the benthic imagery collected and analyzed from the *Hudson* 2009 cruise to the Flemish Cap area.

Location	**Transect ID**	**Inside closure?**	**Gear**	**Transect length (m)**	**Depth range (m)**	**# Photos**
Sackville Spur	11	Mostly	4KCam	6 211	1080 – 1545	167
	12	Yes	4KCam	6 343	1313 – 1723	172
	18	Yes	4KCam	5 238	1336 – 1478	92
	24	Yes	4KCam	4 974	1290 – 1427	145
	26	Yes	4KCam	3 212	1381 - 1409	38
Flemish Pass area	28	No	Campod	2 431	461 - 479	92
	29	No	Campod	3 197	444 - 471	132
	30	No	4KCam	6 101	455 - 940	174
	38	Yes	4KCam	2 978	1328 - 1411	75

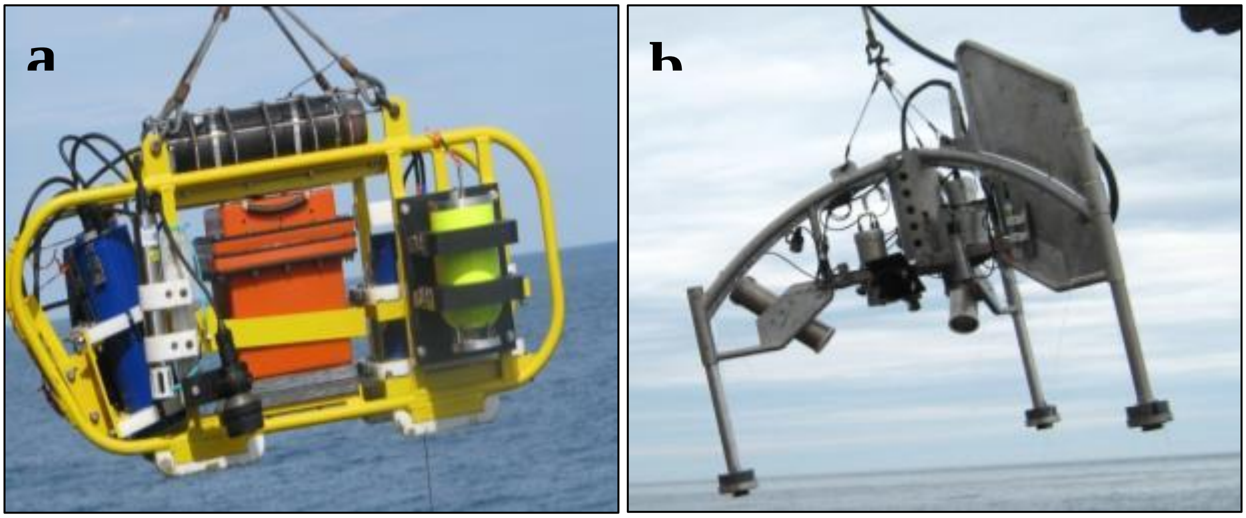


Figure 1.9. **a)** 4K camera (4KCam) and **b)** Campod camera systems used to collect benthic imagery during the 2009 *Hudson* cruise on the Flemish Cap.

Table 1.4 summarizes the details of the analyzed transects that were collected using the ROV ROPOS (Figure 10a) during the *Hudson* 2010 cruise to the Flemish Cap. ROPOS (Remotely Operated Platform for Ocean Science), a tethered submersible owned by the Canadian Scientific Submersible Facility (CSSF), is equipped with a manipulator arm and specimen collection box, and was used to collect high-resolution video and images of the seabed. Downward- and forward-facing video was continuously recorded for each ROPOS dive (note that only downward-facing video was analyzed for this study). Depending on the objective of the ROPOS dive, some ROPOS transects sectioned into different 'modes' ('transect' and 'explorer' mode; see Fig. 1.10b for example). During 'transect mode', the ROV was kept at a constant speed and distance from bottom, and no collections were made. During 'explorer mode', the ROV was allowed to stop for specimen and image collection.

Due to their different objectives, the method used to analyze each transect varied. For instance, for transect 1335 and the explorer mode portions of transect 1337, only those megafauna that were large (~10 cm) and clearly visible were recorded. Transect 1336 was not analyzed in detail after its collection, and thus only the megafauna recorded during the *in situ* collection of the video was summarized. For transect 1338, three sections of the transect (one trawled line, two untrawled lines; ~ 3 km in total) was analyzed every 10 m for corals and sponges only. All visible megafauna were analyzed from the entire length of transect 1339.

Table 1.4. Summary of the benthic video collected and analyzed using the ROV ROPOS in 2010 during the *Hudson* cruise to the Flemish Cap (FC) area.

Location	Transect ID	Inside closure?	Transect length (m)	Depth range (m)	Analysis details
Southern FC slope	1335	No	8 292	873 - 1853	Explorer mode. Analyzed in detail; frame by frame.
	1336	No	11 555	2212 – 2970	Explorer mode. Transect not analyzed in detail ('live' recordings summarized).
Southeast FC slope	1337	No	14 475	1011 – 2191	Transect and explorer mode. Explorer mode analyzed frame by frame; every 10 m analyzed for transect modes.
	1338	Yes	11 195	1029 - 1088	Explorer and transect. Three sections were analyzed (1 trawled, 2 untrawled) every 10 m for the abundance of sponges and corals.
Northeast FC slope	1339	Yes	8 624	1344 - 2462	Explorer mode. Data extracted from 10 m intervals.

Only epibenthic megafauna, defined as the group of organisms ≥ 1 cm living on or close to the seabed, were recorded for both the 2009 photographic and 2010 video analysis. Organisms were identified down to the lowest taxonomic classification possible. Taxonomic identifications were aided by voucher specimens collected during the ROPOS 2010 survey, and the 2009 and 2010 NEREIDA surveys onboard the RV *Miguel Oliver*. The Integrated Taxonomic Information System was used as the taxonomic authority. Organisms that could not be identified down to the species level were given mutually exclusive morphotype designations at the genus level or higher based on superficial features.

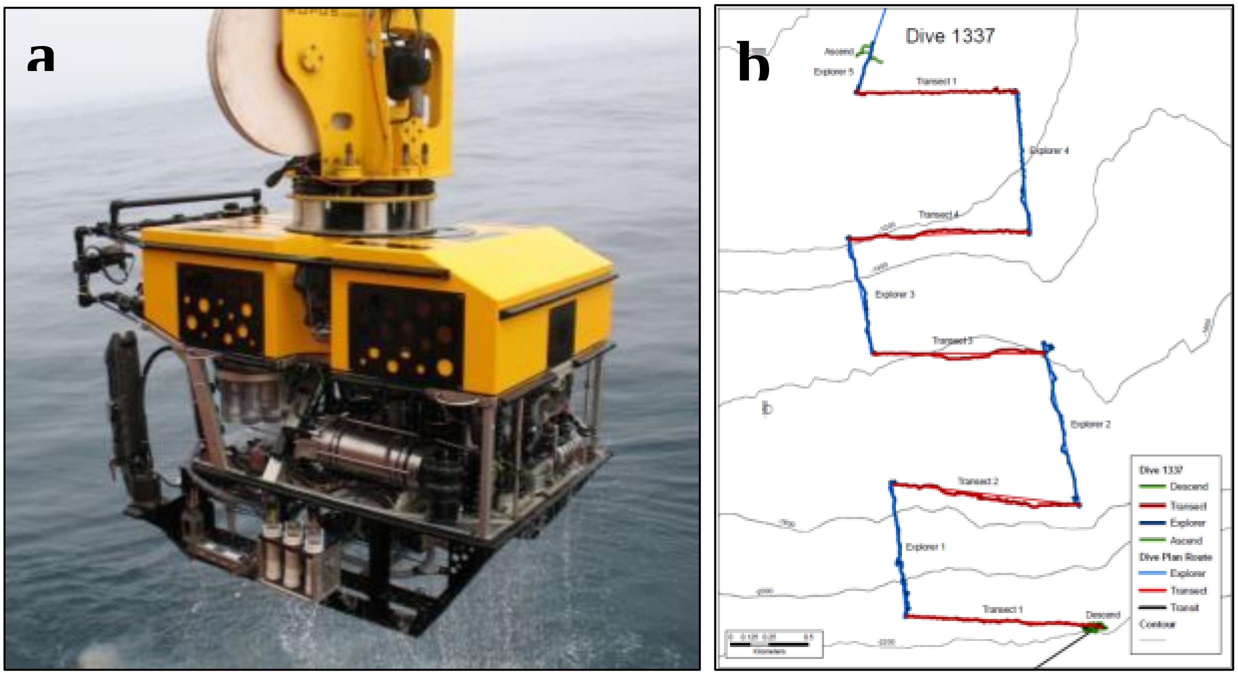


Figure 1.10. a) ROV ROPOS used to collect benthic imagery during the *Hudson* 2010 cruise to the Flemish Cap; **b)** example of a ROPOS transect consisting of both transect (red) and explorer (blue) modes.

All potential VME indicative taxa were extracted for each transect. These taxa were grouped into broad categories based on the common name of its taxonomic group following Table 1 of NAFO SCS doc. 12/19 (NAFO (2012b) hereafter). Taxa identified to the family level and above that could possibly represent VME indicative species were included in the analysis. For instance, all members of the Family Polymastiidae were included as they may potentially be *Polymastia* spp., a VME indicative taxon.

Of the 9 groups of VME indicative taxa listed in Table 1 of NAFO (2012b), 6 groups were present in the Flemish Cap study area. Their distribution on the transects is discussed in detail below. No VME indicator taxa from the sea squirt, erect bryozoan, and stony coral VME indicative groups from NAFO (2012b) were observed on any of the transects. Although black corals were not listed in this table, given their “iconic” status their presence on the transects was discussed.

Due to the difference in sampling gear and thus area sampled between the 2009 and 2010 data, only VME group presence, not abundance, is displayed. However, notable comments on the abundance of each VME indicator group and their constituent taxa are made.

Small gorgonian corals

Records of small gorgonians (Figure 1.11) consisted almost entirely of Acanella arbuscula, with a single unknown isidid coral observed in the Flemish Pass area. A. arbuscula occurred in low abundances on nearly all transects and were absent from the majority of the Sackville Spur. However, this species had a continuous distribution near the end of transect 1335 on the southern Flemish Cap slope.

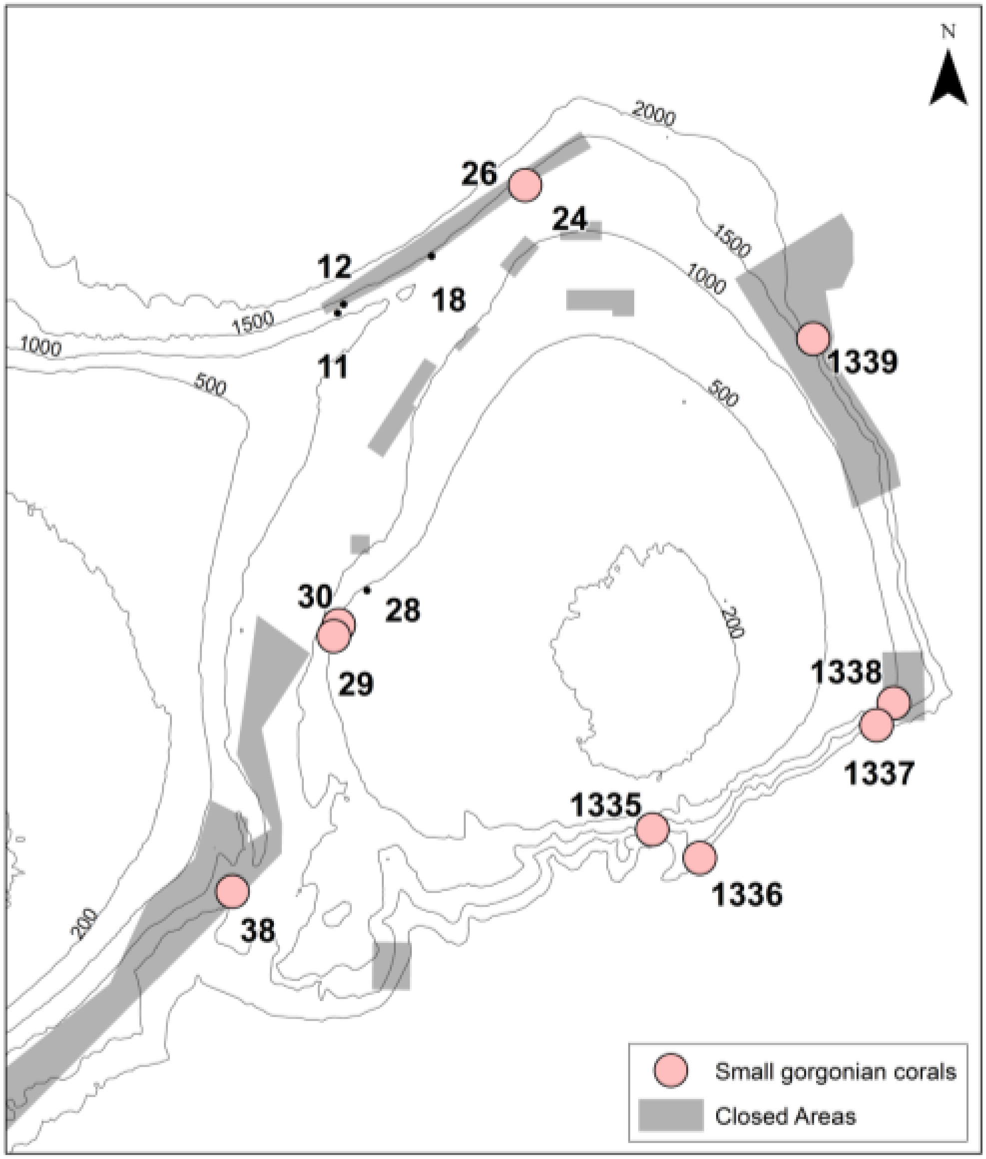


Figure 1.11. Presence of small gorgonian corals (pink circles) on each transect. Small circles indicate the absence of small gorgonians on the transect.

Large gorgonian corals

Large gorgonians were absent from the entire Flemish Pass area, but were present on the two westerly Sackville Spur transects and all transects from the northeast, southeast, and southern Flemish Cap slope (Figure 1.12). All taxa under this group were observed in low abundances. Some species observed include Primnoa resedaeformis, Keratoisis sp., Paramuricea spp., and Acanthogorgia sp. Three Parastenella atlantica colonies were observed on transect 1337, and several Corallium sp. colonies were observed on transects 1337 and 1339. Paragorgia johnsoni was observed on transect 1339, which may represent the most northerly record of this species to date.

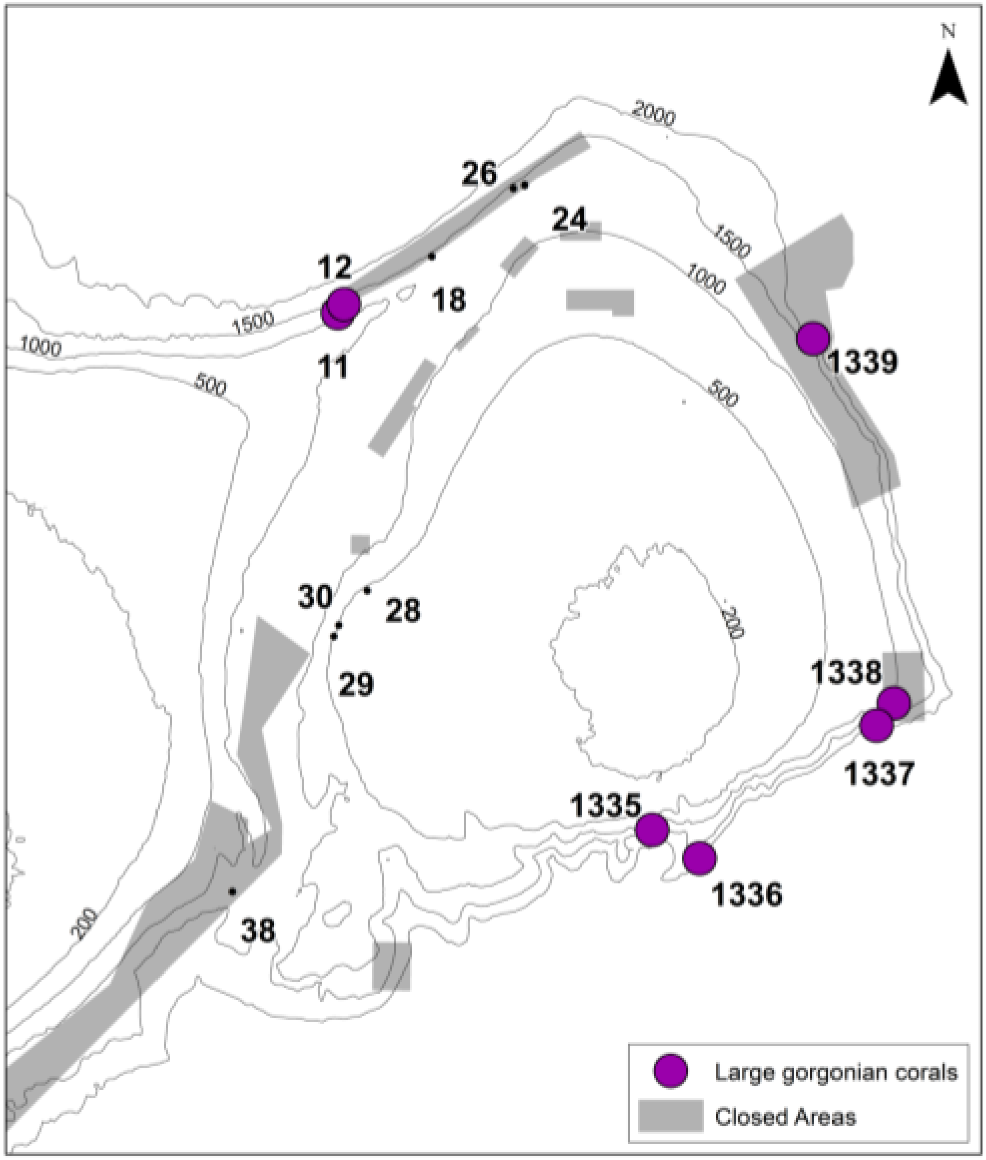


Figure 1.12. Presence of large gorgonian corals (purple circles) on each transect. Small circles indicate the absence of large gorgonians on the transect.

Black corals

Black corals were present in low abundances (1-2 colonies) on several transects in the Flemish Pass area and southern Flemish Cap slope (Figure 1.13). *Stauropathes arctica* was observed in the Flemish Pass, while a single record of *Telopathes magna*, a newly described species of black coral (MacIsaac *et al.*, 2013), was observed on transect 1335 on the southern Flemish Cap slope.

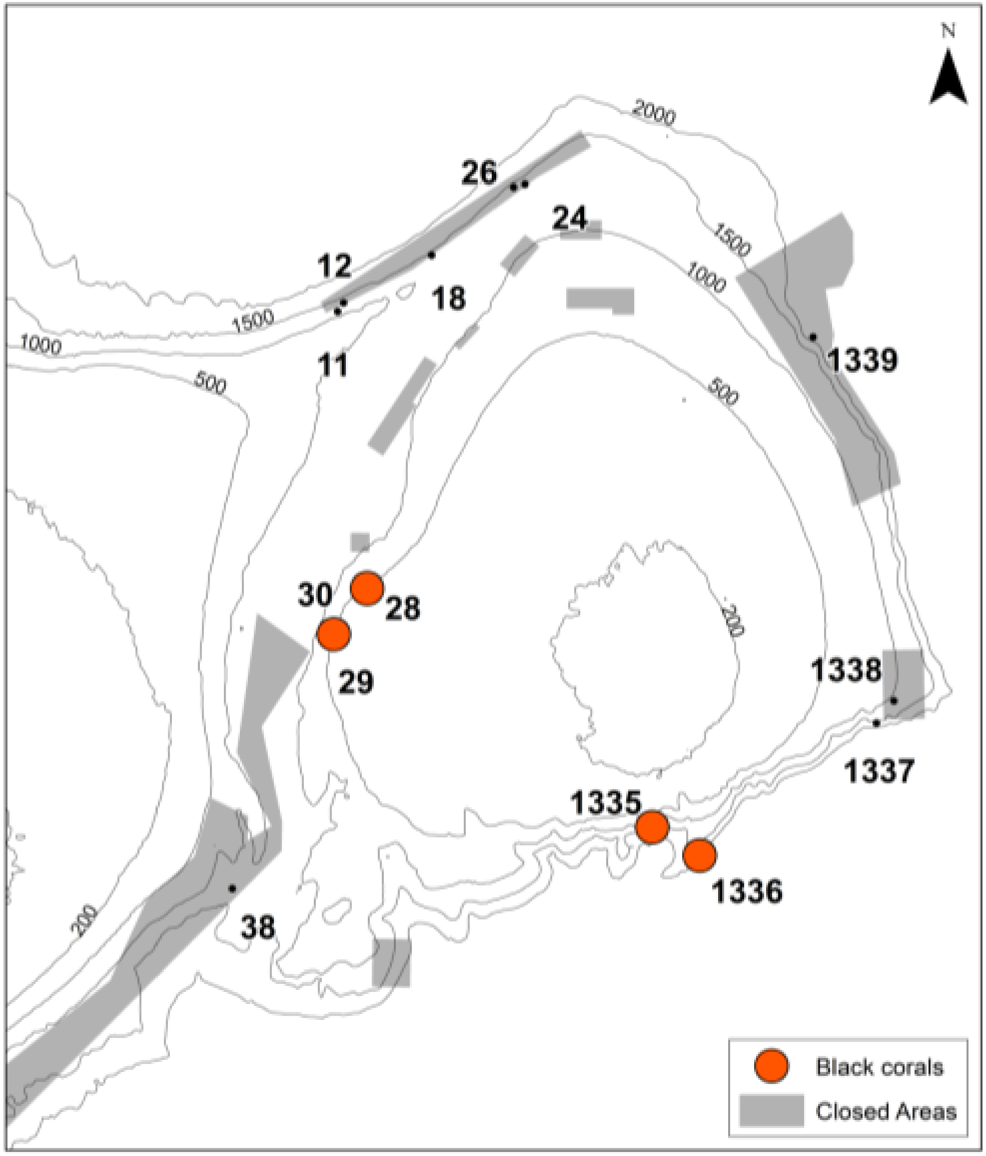


Figure 1.13. Presence of black corals (orange circles) on each transect. Small circles indicate the absence of black corals on the transect.

Sea pens

Several species of pennatulaceans were observed across the Flemish Cap (Figure 1.14). However, no species occurred in dense concentrations and therefore do not constitute VMEs. Kophobelemnon sp. was the most abundant of all sea pens observed, and occurred on transect 30 in the Flemish Pass. Pennatula spp., Anthoptilum sp., and Halipteris sp. were also observed in the area.

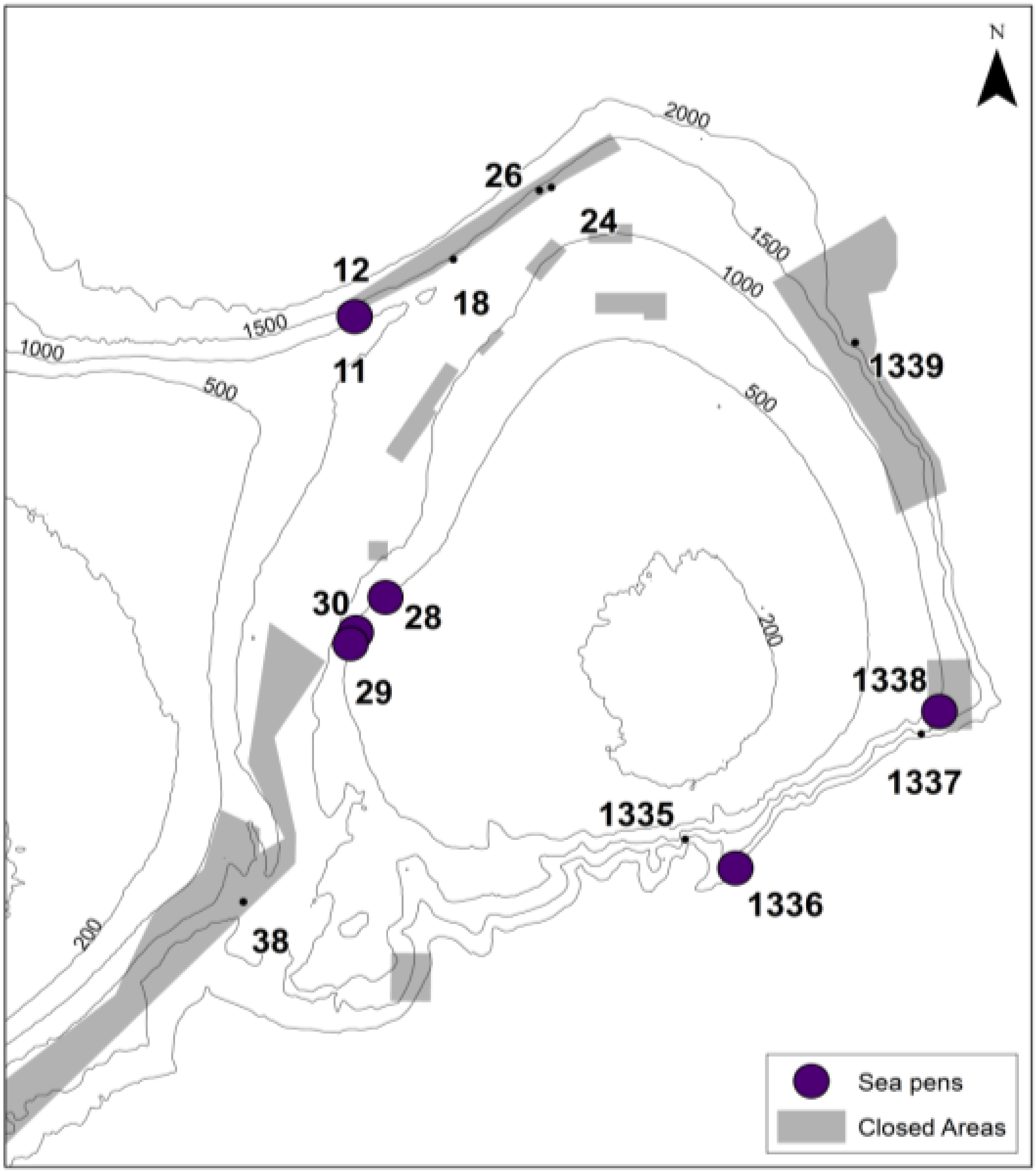


Figure 1.14. Presence of sea pens (dark purple circles) on each transect. Small circles indicate the absence of sea pens on the transect.

Tube-dwelling anemones

Tube-dwelling anemones were observed on several transects across the Flemish Cap (Figure 1.15). The lack of taxonomic details from the photographs and video prevented the identification of these organisms past the family level (Cerianthidae). However, these cerianthids were not large, erect species, and do not appear to be the VME indicator species listed in NAFO (2012b), Pachycerianthus borealis. Although their ability to form habitat for other species may be limited, these cerianthids formed dense fields (Figure 1.16) on the southern Flemish Cap slope that may indicate VMEs, particularly if their bioturbation activities significantly affect infaunal community structure.

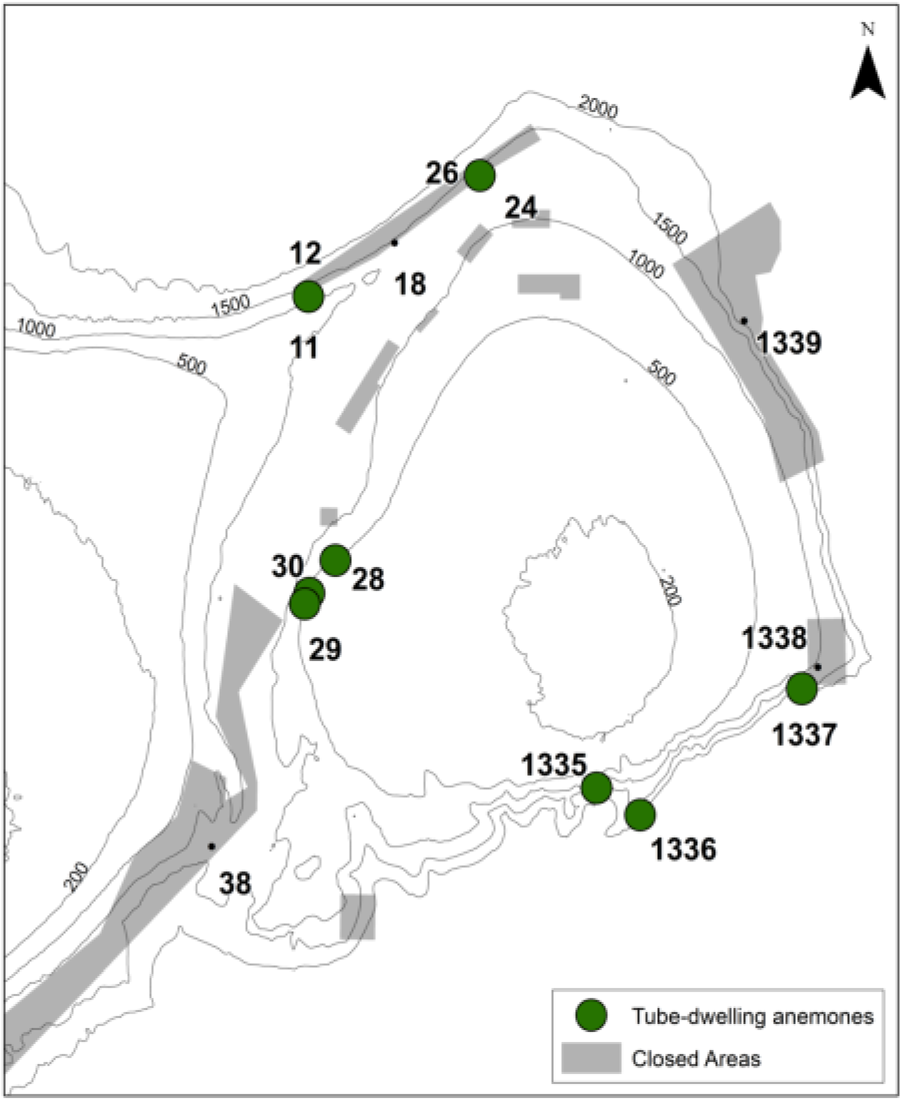


Figure 1.15. Presence of tube-dwelling anemones (green circles) on each transect. Small circles indicate the absence of tube-dwelling anemones on the transect.

Figure 1.16. Field of cerianthid anemones on the southern Flemish Cap slope (transect 1335). Also shown is a vase sponge of the Family Rosselidae.

Large-size sponges

Dense aggregations of structure-forming sponges were observed at depths below 1300 m on the Sackville Spur, Flemish Pass, and on the Flemish Cap slope (Figure 1.17). The main taxa forming these sponge aggregations were members of the Family Geodiidae. Unknown members of the Order Astrophorida were present in high abundances on the ROPOS 2010 transects. At shallower depths sampled in the Flemish Pass (~450 – 950 m), fan-shaped sponges (Family Axinellidae) and polymastiid sponges were the dominant structure-forming sponges. Large-sized sponges were absent only on transect 1336. However, this may be due to the low taxonomic resolution of the taxa on this transect and the grouping of structure-forming sponges with other sponges at the phylum level.

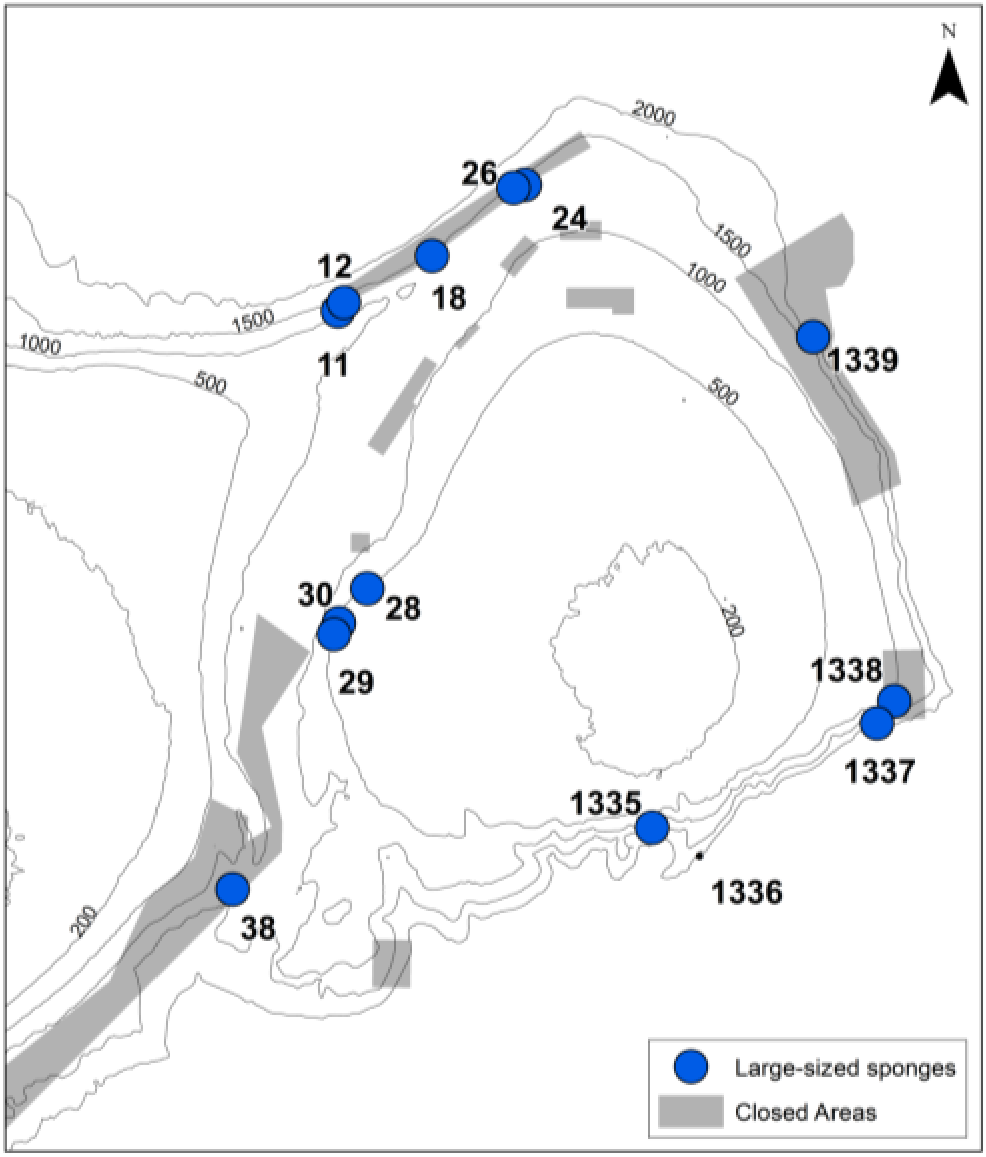


Figure 1.17. Presence of large-sized sponges (blue circles) on each transect. Small circles indicate the absence of large-sized sponges on the transect.

Sea lilies (Crinoidea)

The stalked crinoid *Conocrinus lofotensis*, a VME indicative species, was observed in high abundances on the Sackville Spur, but was completely absent from the Flemish Pass area (Figure 1.18). Video analysis revealed dense fields of the stalked crinoid *Gephyrocrinus grimaldii* on the southern, southeastern, and northeastern slope of the Flemish Cap. This species was completely absent on transects from the Sackville Spur and Flemish Pass area. Unstalked crinoids were not observed in high abundances on any transect analyzed.

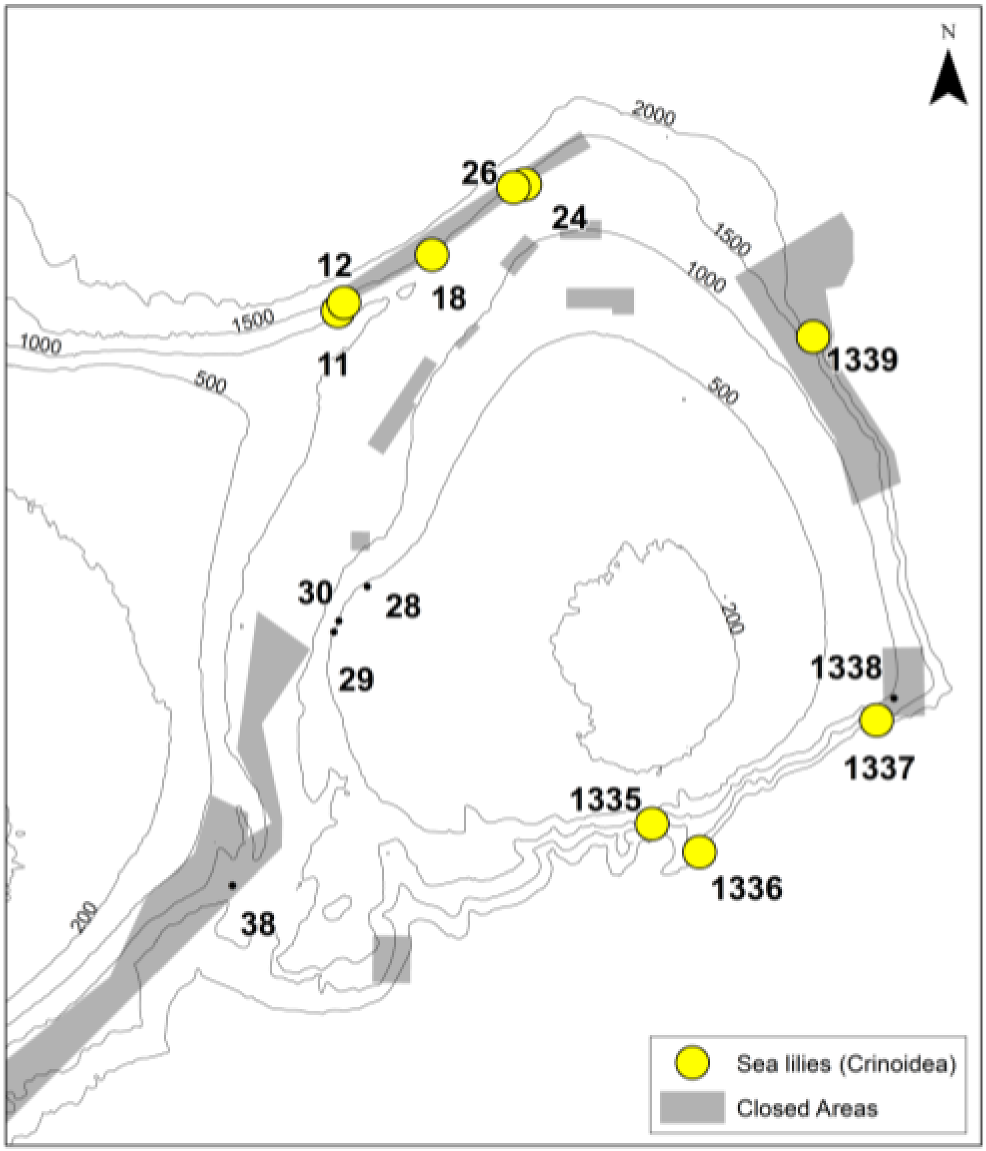


Figure 1.18. Presence of sea lilies (Crinoidea; yellow circles) on each transect. Small circles indicate the absence of sea lilies on the transect.

The presence of these VME indicative groups on each transect are shown in Table 1.5. This table allows for the comparison of the different VME indicator groups that are present on transects located within and outside of the closed areas. Transect 18 in the Sackville Spur and transect 38 in the Flemish Pass, both located in closure areas, have the fewest number of VME indicator groups present (2 of 7). The two transects on the southern slope of the Flemish Cap (1335 and 1336), which currently do not fall within a closure area, had the highest number of VME groups present (6 of 7), with sea pens absent from 1335, and large-sized sponges absent from 1336,

Table 1.5. Presence of potential VME indicative taxa grouped by their common name as per NAFO (2012b). Transects are grouped by whether they fall inside or outside of a closed area. Note that transect 11 falls partially outside of closure area 6.

				VME Common Name						
	Transect	**Closure area description**	**Location**	**Small gorgonian corals**	**Large gorgonian corals**	**Black corals**	**Sea pens**	**Tube-dwelling anemones**	**Large-sized sponges**	**Sea lilies (Crinoidea)**
Inside Closure	11	Sackville Spur (Area 6)	Sackville Spur		X		X	X	X	X
	12				X				X	X
	18								X	X
	24			X				X	X	X
	26								X	X
	38	Flemish Pass/Eastern Canyon (Area 2)	Southern Flemish Pass	X					X	
	1338	Eastern Flemish Cap (Area 4)		X	X		X		X	
	1339	Northeast Flemish Cap (Area 5)	Northeast FC slope	X	X				X	X
Outside Closure	28		Flemish Pass area			X	X	X	X	
	29			X		X	X	X	X	
	30			X			X	X	X	
	1335		Southern FC slope	X	X	X		X	X	X
	1336			X	X	X	X	X		X
	1337		Southeast FC slope	X	X			X	X	X

although the latter could be a function of the low resolution of the taxonomic identifications on that transect (see Table 1.5 and text under ‘Large-sized sponges’ header). This suggests that the southern Flemish Cap slope may be a hot spot for the presence of potential VME indicators.

1.A.4. Updated Trawl Survey Data for the 3O Closed Area

History of the Closure

In 2006 the United Nations General Assembly (UNGA) tasked Regional Fisheries Management Organizations from around the globe to respond to a 2006 UNGA sustainable fisheries resolution related to the protection of vulnerable marine ecosystems (VME). This included the protection of deep sea corals, seamounts and hydro-thermal vents. Canada played a key role in preparing data and analysis for review by the full Northwest Atlantic Fisheries Organization (NAFO) Fisheries Commission at their 29th annual meeting in September 2007.

To address the protection of VMEs in the NRA a Canadian NAFO Delegation Working Group was assembled in February 2007. The working group was acting as a sub-committee of the full Canadian NAFO delegation. Working group members included Canadian representatives from DFO, Industry, and Provincial participants. The mandate of the group was to develop a proposal on Ecosystem-Based Management Initiatives to be presented at the NAFO AGM in June 2007.

Presentations on Canada’s Policy to Manage the Impacts of Fishing on Sensitive Benthic Areas, Deep Sea Corals, NAFO Science and Seamounts were provided as background information. A range of possible NAFO policies, measures, and/or processes were discussed. The working group proposed a closed area specifically designed for coral protection with southwest Grand Banks as the prime candidate.

Data included CAD DFO RV Survey by-catch data (2004-2006) and by-catch observations by Fisheries Observers (2004-2006). Point data were organized into coral groups (sea pens, small gorgonians, large gorgonians, soft corals, and stony corals) and mapped along with fishing effort data from Vessel Monitoring System. However these were only mapped as corals and sponges.

An Engagement Strategy for Ecosystem-based Initiative was developed by the working group for Non-Government Organizations (e.g., WWF) and Academic Institutions (Memorial University). Information provided at the session outlined the proposed closure location and the data used to delineate the boundaries.

The proposed closure was presented at the NAFO AGM in June 2007 and an official announcement followed at the NAFO AGM in September 2007. It should be noted that the Scientific Council did not review the proposal and that there was no assessment against the FAO criteria for the identification of vulnerable marine ecosystems (FAO, 2009) which was not available at the time.

This NAFO closure is unique for many reasons. It was initiated by Canada in 2007 and implemented by NAFO contracting parties. It was the first fishing closure that was created to protect deep-sea corals in the NRA and within the Newfoundland and Labrador Region. It is the largest closure with ~14,040 km^2 in size, and it is the only closure that straddles national and international waters. It was based on the best available information and strongly influenced by socio-economics issues at the time. Overall, the closure was a great first step particularly freezing the fishing footprint in deeper waters below 800 m. However, for corals documented in shallower waters < 800 m the closure provides no protection from anthropogenic impacts (e.g., bottom contact fishing gear).

Updated RV Trawl Survey Data for the 30 Area

Since the closure addition information on coral distributions has become available (see Figures 1.19 and 1.20; Wareham and Edinger 2007; Edinger *et al*., 2007; Wareham, 2009; Murillo *et al*., 2011c). As well, two important analyses have been completed.

In 2010, distribution data was analysed using a kernel density spatial analysis (see Kenchington *et al.*, 2009). This approach had been used in NAFO and was applied to Canadian survey data from the Scotian Shelf to the Eastern Arctic. Results identified significant locations of sea pens, small and large gorgonians on the southwest Grand Banks (Kenchington *et al.*, 2010; Murillo *et al*., 2011c).

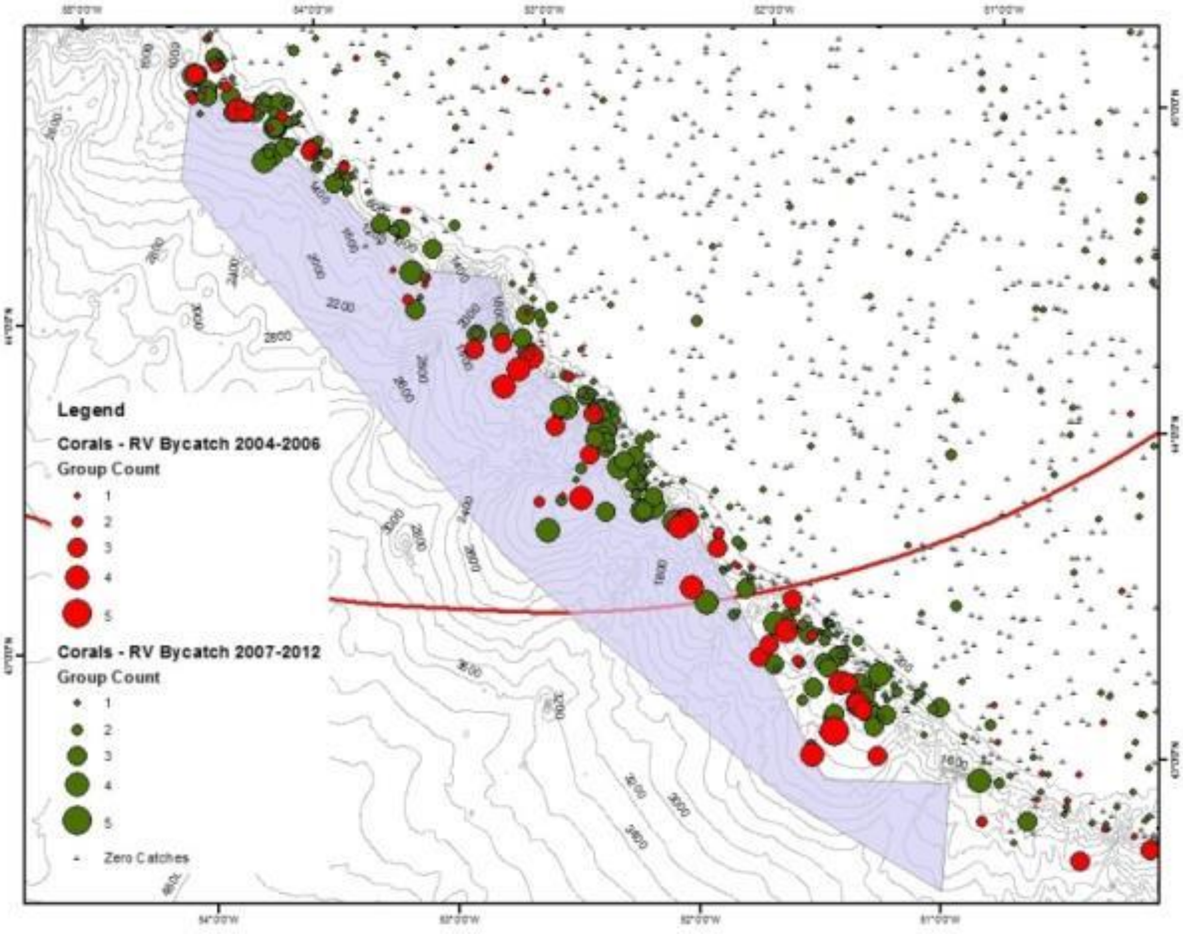


Figure 1.19. RV Survey data of coral by-catch presented by count of group (red = 2004-2006, green = 2007-2011; triangles = null catches).

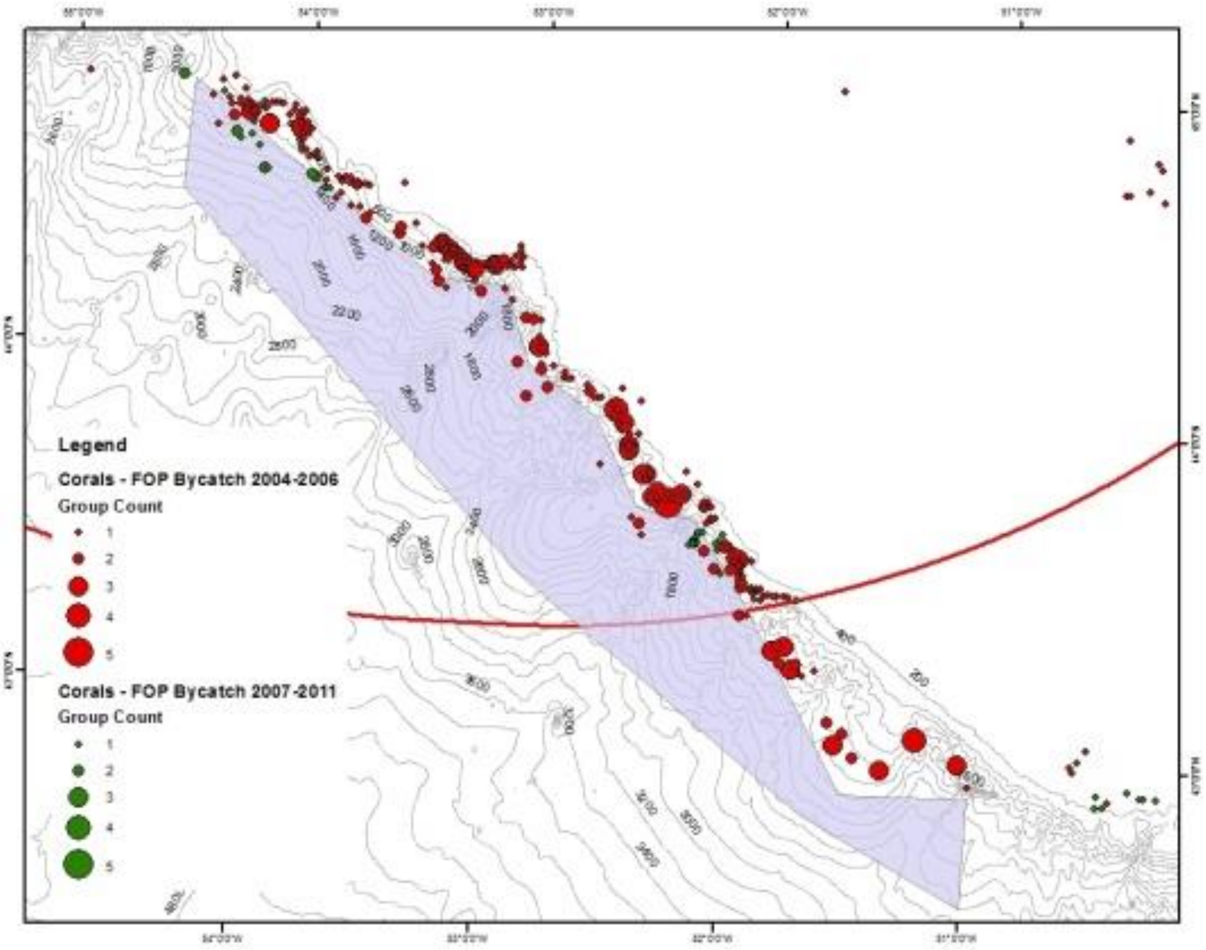


Figure 1.20. Fisheries Observer data of coral by-catch presented by count of group (red = 2004-2006, green = 2007-2011). Note: records in green found within the closure occurred in 2007 prior to the Sept. 2007 closure announcement.

Detailed analyses using *in situ* video data was carried out by Baker *et al*. (2012). Results show concentrations of large and small gorgonian corals, as well as extensive sea pen fields not protected under the current closure because they are located at shallower depths then the 800 m upper boundary limit.

1.A.5. Review of the Seamount Closures with Updated Information

History of the Seamount Closures

The United Nations General Assembly (UNGA) resolution 61/105 (2006) requested RFMOs to, in accordance with the precautionary approach and ecosystem approaches, assess whether bottom fishing activities would have significant adverse impacts (SAIs) on vulnerable marine ecosystems (VMEs) and ensure that proper conservation and management measures are put into place to prevent such impacts. It also requested RFMOs to close areas to bottom fishing where VMEs (including seamounts and cold water corals) are known to occur or are likely to occur (based on the best available scientific information) and ensure that such activities do not proceed unless conservation and management measures have been established to prevent SAIs on VMEs. Following a review of the implementation of UNGA Resolution 61/105, the UNGA Resolution 64/72 (2009) emphasized that impact assessments are to be conducted in accordance with the FAO International Guidelines for the Management of Deep-

Sea Fisheries in the High Seas (FAO Guidelines) criteria. In addition, this resolution requested RFMOs and flag states to ensure that vessels do not engage in bottom fishing until such assessments have been carried out.

As a result of the 2011 review of the implementation of the UNGA resolutions 61/105 (2006) and 64/72 (2009) by RFMOs, UNGA Resolution 66/68 (2011) called for the strengthening of the procedures for carrying out assessments to take into account individual, collective and cumulative impacts. It also encouraged RFMOs to consider the results available from marine scientific research, including those obtained from seabed mapping programmes concerning the identification of areas containing VMEs and to adopt proper conservation and management measures, including closures. A review of the implementation of these UNGA resolutions provisions will be held in 2015 by the General Assembly.

Seamount ecosystems are sensitive to anthropogenic disturbance because the fishes and invertebrates they are comprised of are mostly slow growing, long-lived, late to mature, and experience low natural mortality (Morato *et al*., 2004; Stocks, 2004). Deep-sea fishes aggregate on seamounts and filter-feeding invertebrates – including corals and sponges – are often found attached to the hard substrates associated with these features (Clark *et al*., 2006).

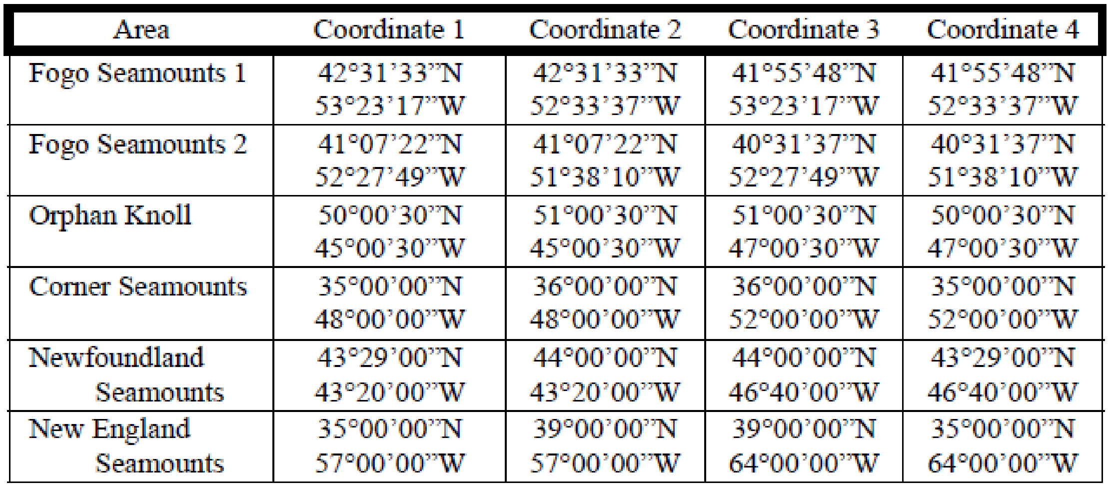
Several distinct seamount chains can be found in the NRA along with a few isolated knolls, which are smaller, more rounded seamounts. The majority of these features are located in deep water well beyond the continental slope, with the prominent groupings including the New England Seamounts, the Corner Rise Seamounts, and the Newfoundland Seamounts. Other seamounts and knolls in the NRA include: the Fogo Seamounts, Orphan Knoll and Beothuk Knoll.

As of January 2007, NAFO has closed four areas of seamounts to protect VMEs in accordance with the UNGA resolution:

- Orphan Knoll;
- Corner Seamounts;
- Newfoundland Seamounts; and
- New England Seamounts.

Two additional seamount areas south of the Grand Banks (Fogo seamounts 1 and 2) were closed in 2008. These closures were set to expire on December 31, 2010. Following a proposal by Canada, NAFO Contracting Parties agreed to continue these closures, subject to a review by the Scientific Council in 2014. The closures aim to protect these sensitive marine ecosystems from the potentially significant, adverse impacts of bottom-contact fishing. The closed areas are defined by connecting the following coordinates (in numerical order and back to coordinate 1).

Table 1.6. NAFO seamount areas protected from bottom fishing in January 2007 and 2008 (NAFO, 2009a).



Area	Coordinate 1	Coordinate 2	Coordinate 3	Coordinate 4
Fogo Seamounts 1	42°31’33”N 53°23’17”W	42°31’33”N 52°33’37”W	41°55’48”N 53°23’17”W	41°55’48”N 52°33’37”W
Fogo Seamounts 2	41°07’22”N 52°27’49”W	41°07’22”N 51°38’10”W	40°31’37”N 52°27’49”W	40°31’37”N 51°38’10”W
Orphan Knoll	50°00’30”N 45°00’30”W	51°00’30”N 45°00’30”W	51°00’30”N 47°00’30”W	50°00’30”N 47°00’30”W
Corner Seamounts	35°00’00”N 48°00’00”W	36°00’00”N 48°00’00”W	36°00’00”N 52°00’00”W	35°00’00”N 52°00’00”W
Newfoundland Seamounts	43°29’00”N 43°20’00”W	44°00’00”N 43°20’00”W	44°00’00”N 46°40’00”W	43°29’00”N 46°40’00”W
New England Seamounts	35°00’00”N 57°00’00”W	39°00’00”N 57°00’00”W	39°00’00”N 64°00’00”W	35°00’00”N 64°00’00”W

Information on the ecology and species associated with the seamounts and knolls of the NRA is quite limited (Kulka *et al*., 2007b) but several NAFO Contracting Parties have carried out research and fishing activities on a subset of these features. Vinnechenko (1997) described the deep-sea fishes encountered during periodic Soviet Union/Russian research and commercial activities on the Corner Rise Seamounts since the mid 1970s.

Kulka *et al.* (2007a) reviewed the available information on the occurrence of coldwater corals on seamounts in the NRA. Corals have been documented on the New England (Moore *et al*., 2001) and Corner Rise Seamounts (Kulka *et al*., 2007a; Waller *et al*., 2007) but information on detailed distribution is lacking. Waller *et al.* (2007) explored five of the Corner Rise Seamounts using an ROV and documented pristine coral areas as well as “dramatic evidence of large-scale trawling damage” on the summits of Kukenthal peak and Yukutat Seamount. Murillo et al. (2008) described the occurrence structure forming corals and “extremely rough bottom” on two New England Seamounts based on the results of an experimental trawl survey during 2004. Less coral was encountered on the Corner Rise Seamounts (7% of sets contained coral). Large carbonate mounds have been identified through seismic research on Orphan Knoll (Enachescu, 2004).

At the time an 80% rule was adopted, under which 80% of these areas were closed and 20% would be subject to an exploratory fishery protocol submission. Given the difficulties in applying such a rule, in 2012 NAFO revoked the 80% rule and made it clear that these areas are 100% closed subject to an exception. The exception states that fishing can only occur in these areas after exploratory fishery protocols and previous impact assessments have been submitted to and approved by the Scientific Council and the Fisheries Commission. In response to a request from the FC on the fishable areas on the seamounts, the Scientific Council responded that “it does not have sufficient data on which to provide advice on the areas which could be fished on each seamount.” (NAFO, 2007).

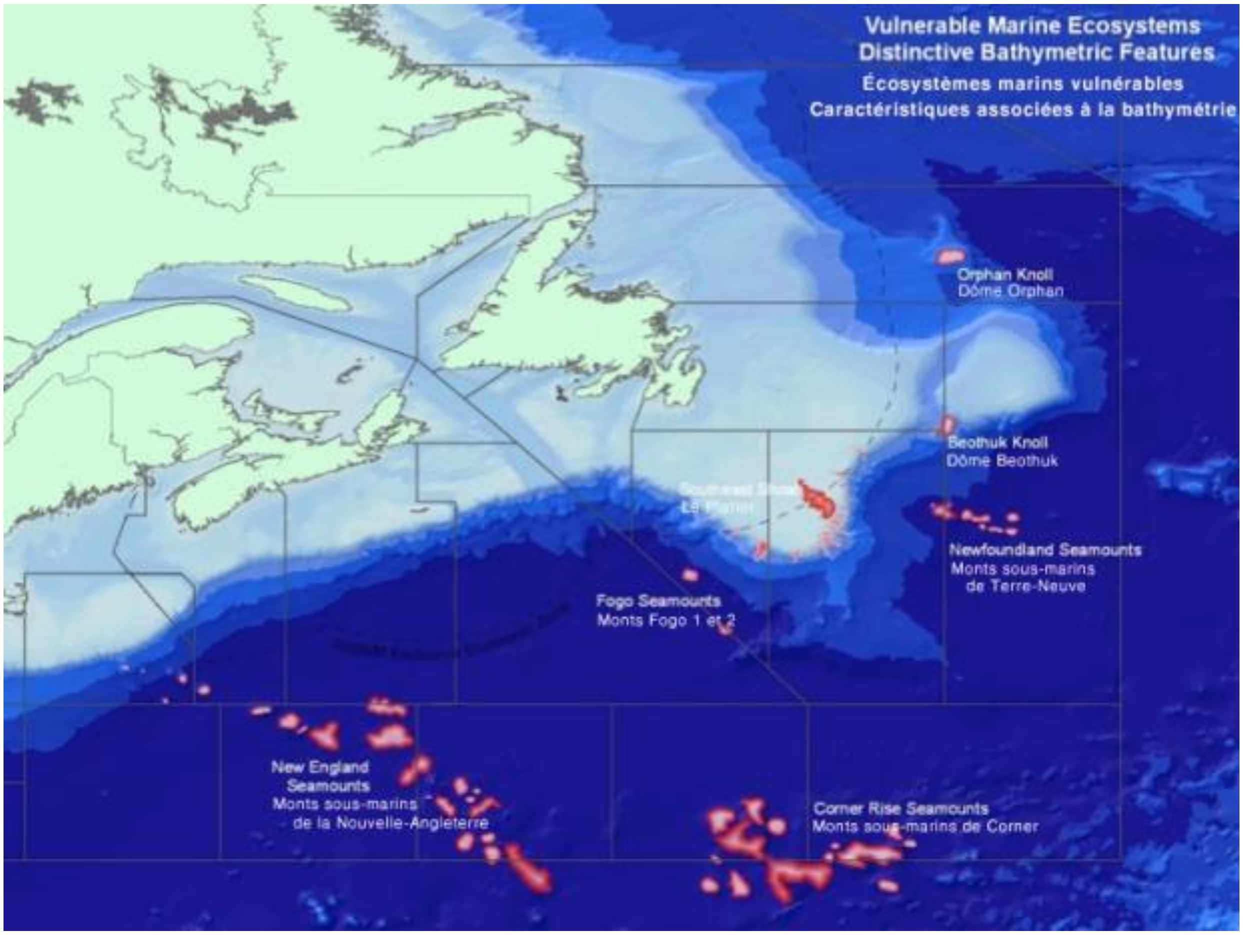


Figure 1.21. NAFO seamount areas protected within NAFO Regulatory Area.

In September 2010, the Scientific Council noted that although there is no *in situ* data for the Fogo and Newfoundland seamounts, the available information for all other seamounts (e.g. findings and research summarised in WGEAFM reports, results from the NEREIDA project) indicates the presence of VME-defining corals and sponges." (NAFO, 2010b, at p. 243). In the same response to the Fisheries Commission, the SC noted that mid-water trawls are often used to fish on seamounts and that "in many cases the gear is used very close to or sometimes even touching the bottom. In such cases there is an increased potential or contact and damage to corals and sponges. These gears can also affect fish species with VME-defining life history traits." (NAFO, 2010b, at p. 244) It also applied the FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO Guidelines) VME criteria (Art. 42) to the seamounts and concluded that these areas meet the following criteria: uniqueness or rarity; life-history traits, functional significance of the habitat.

Overall, despite the lack of detailed survey information, there is evidence of the occurrence of coldwater corals and potentially vulnerable deep-sea fishes on the seamounts of the NRA. Given the presence of these ecosystem components, the seamounts and knolls of the NRA should be considered VMEs.

New information on VME, VME indicators, VME elements

Fogo Seamounts

The Fogo Seamounts are located on oceanic crust in the central North Atlantic Ocean, southwest of the Grand Banks of Newfoundland and form a broad zone of volcanoes that parallels the transform margin (Figure 1.22, 1.23). This zone is narrowest in the northwest and widens to 200 km in the southeast. This pattern differs from the narrow linear arrangement of a typical seamount channel, such as the Newfoundland and New England Seamounts (Pe-Piper *et al*., 2007).

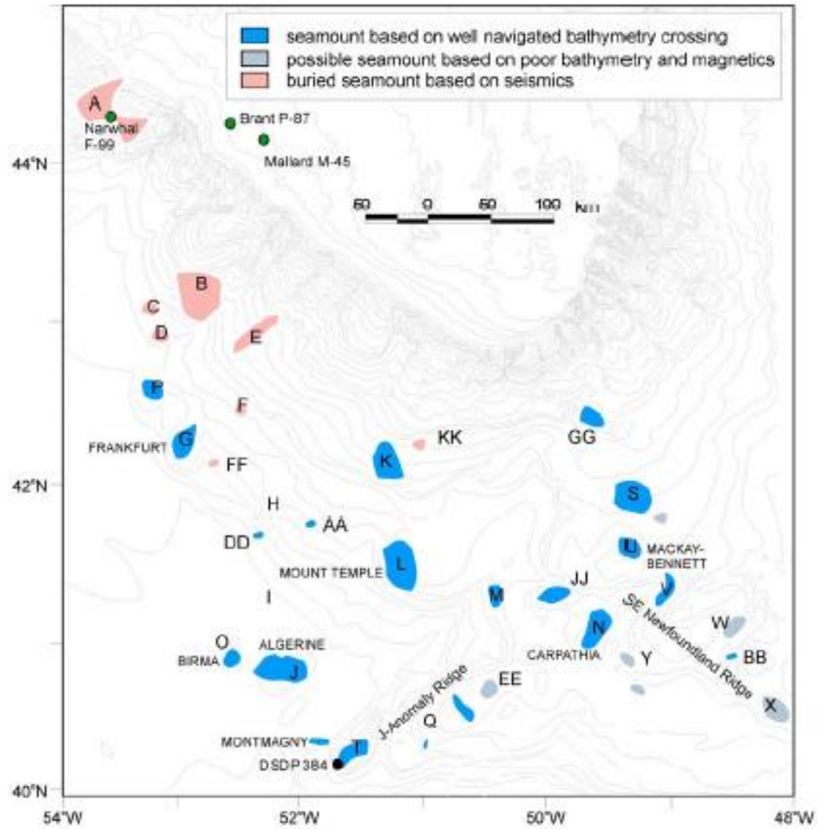


Figure 1.22. Map of the Fogo Seamounts and other seamounts south of the Tail of the Banks. Modified from Pe-Piper *et al.* (2007). Largest seamounts have official names (after the ships that came to the aid of the Titanic). Other geological seamounts may be buried or are otherwise low features. Letter codes refer to Table 2 of GSC Open File 5182 which lists sources of data. (SCR Doc. 11/73)

NAFO SCR Doc. 11/73 highlights that:

"Since January 1, 2007, two areas to protect the Fogo Seamounts were closed to all bottom fishing activities (NAFO 2010a). At this point only a small part of the area was closed (Figure 1.3.3.2) and several seamounts remained outside of the closures. Most of the seamounts are deeper than 2000 m depth and outside of the current fishery footprint, so interactions with fishery activities and seamounts at this moment is quite improbable. However, since new information on distribution of Fogo Seamounts is available (Pe-Piper et al. 2007) that should be considered when these areas are revised together with the other seamounts closures in 2014 (NAFO 2012a)."

In 2012, the Fisheries Commission listed all Fogo Seamounts (Div. 3O, 4Vs) as VME indicator elements, but the closures have not been extended yet. Based on this recent information, it is recommended that the existing closure be extended to all Fogo Seamounts.

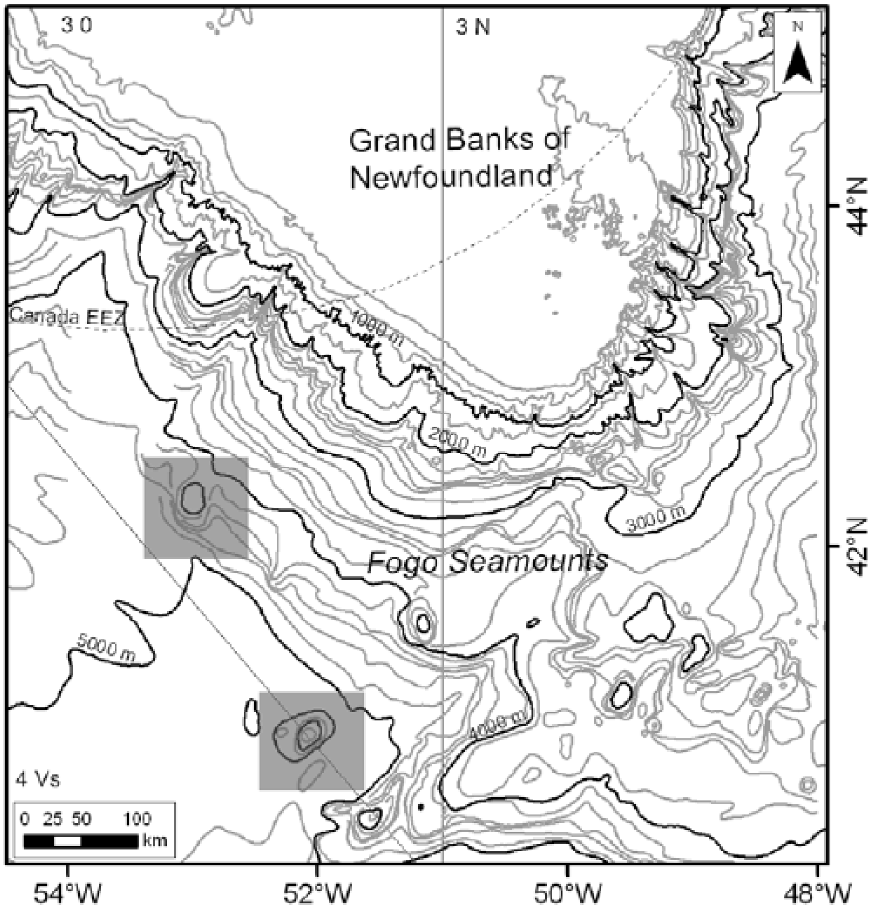


Figure 1.23. Map of the localization of the Fogo Seamounts current closures.

Orphan Knoll

Orphan Knoll is a single peak, with no depths shallower than 1800 m. The area has been visited by seismic surveys in relation to oil and gas exploration. Seismic data collected by Geological Survey Incorporated (GSI) was donated to MUN for research, and Enachescu (2004) published a paper on deepwater submarine mounds in the north-eastern

Orphan Basin and on the Orphan Knoll. He noted that the presence in the Orphan Knoll area of giant, deepwater mounds was known previously, and that a comprehensive account on the subject, history of mound discovery and record of the attempts to dredge them is given by van Hinte and Ruffman (1995). Other researchers have published papers on this feature as well, dating back to the early 1970's, although it was not speculated that these mounds may be biological in origin.

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'. In 2010, this Working Group highlighted that investigations in other periods of the year could provide further insight into the role of this topographic feature in the lower trophic level dynamics (SCS 10-19 Vigo meeting).

The mounds were found at depths of between 1800–2300m. Details of these "seamounds", which were named in the Enachescu paper, are as follows: Einarsson Mound is 1500-2000 m wide and 300m tall, and Nader Mound is between 400-800m wide and 300 m tall (Enachescu 2004), including the height of the base (root) which is covered in sediment. He concluded that based on seismic characteristics, regional mapping, their location in proximity to deep seated fault zones, and comparison with similar features identified and sampled in Northwest Atlantic margin, these mounds are interpreted as large deep water bioherms (ancient organic reef of mound-like form built up by invertebrates) or live colonies connected to water bottom vents. Enachescu (2004) proposed "a mixed organicinorganic origin for the mounds, which implies the existence of deep, coldwater marine organisms feeding from either hydrocarbon rich vents or hydrothermal fluids rising through deep-seated faults at the water bottom." He noted that other mounds were also detected, covered by sediment, ie. not protruding from the ocean floor.

This paper also noted that "Ten years ago Canadian scientists discovered deep sea corals in the Orphan Knoll area", although no details were given. This was the only reference made to species being found on Orphan Knoll.

Enachescu (2004) noted that "a comprehensive inventory of the mounds and study of their genesis has to be undertaken. If an organic origin is proven, these mounds will be the most northerly, deepest cold water North American large reefal structures or organic build-ups ever encountered. If mounds are bioherms or colonies around hydrocarbon/hydrothermal vents, a Natural Protected Area (NPA) would need to be established for the conservation of these formations."

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.). A 2010 expedition with ROPOS (see Figure 1.10a) identified coral and sponges in the current closed area. This work forms part of a MSc thesis at Memorial University and has not yet been published.

Corner Seamounts

The Corner Rise seamounts are the shallowest rising to 828 m depth and some 1274 km^2 above 2000 m depth. The shallowest of these is at the western edge of the closed area, with the next shallowest at 1500 m depth on the eastern edge of the closure. There also exist two shallow seamounts just to the south of the closed area at 900 m and 1000 m depth.

Spanish exploratory fishing was carried out on the Kükenthal seamount, also known as Bank Perspective (35º27'-35º40' N, 51º50' - 52º05' W). Although the initial plan of the experimental fishery was one month the final fishing days were only five, from 19th July to 23rd July 2012 (SCR 13/20). This seamount is one of the west Corner Rise Seamount complexes. There is some fishery information available about this area from previous experimental fishery carried out by UE (Spain) in 2004 (Duran *et al*., 2005) and from the commercial fishery (González-Costas and Lorenzo, 2007; Thompson and Campanis, 2007).

A total of 14 hauls were made during the Spanish experimental fishery, two of them were nulls and the total fishing effort was 49 hours and 20 minutes. Two different gears were used during the experimental fishery: Pedreira (Bottom Trawl) and Gloria (Pelagic Trawl).

No VMEs were found based on the NAFO Conservation and Enforcement Measures encounter definition at the time. No NAFO coral and sponge VME indicators were found in the experimental fishery hauls.

Duran *et al.* (2005) summarized the catches of deep-sea fish species in experimental one trawl survey on several of the New England and Corner Rise Seamounts in 2004. Alfonsino was the main species caught on the Corner Rise Seamounts during this survey (Duran *et al*., 2005; Murillo *et al*., 2008). This species appears to aggregate near certain seamounts in the NRA, making it vulnerable to exploitation, but they are relatively fast growing and not long-lived (10-15 years) and thus do not possess the biological traits typical of many other deep-sea species. Other fishes that were caught in significant amounts during the Spanish survey are slow growing and long-lived, which indicates they are vulnerable to overexploitation. Cardinal fish (*Epigonus telescopus*), for example, are considered highly vulnerable.

González-Costas and Lorenzo (2007) identified Kukenthal Peak and, more generally, the western portion of the Corner Rise as areas of high fish species diversity and abundance compared to other parts of the Corner Rise Seamounts based on catches collected between 2005 and 2007. The most abundant species encountered were alfonsino, black scabbardfish (*Aphanopus carbo*), and wreckfish (*Polyprion americanus*).

The 2013 SC report noted that the New England and Corner Rise Seamounts chains

“(...) support complex coral and sponge communities, including numerous endemic species, which provide habitat for diverse invertebrate communities that are highly dependent on them (Watling 2007, Waller et al 2007, Cho 2008, Simpson and Watling 2011, Pante and Watling 2011, Shank 2010). These seamounts also host populations of deep-water fish and are important as aggregating and spawning areas for splendid alfonsino (*Beryx splendens*). Generally, deep-sea and seamount fish stocks are particularly vulnerable to exploitation because the fish are, take longer to reach sexual maturity, and have lower fecundities (Norse et al 2012).”

Fisheries (using bottom trawl and mid-water trawl) for splendid alfonsino has taken place on a regular basis from 1976 to 1996 (Vinnichenko, 1997) on the Corner Rise Seamounts followed by a 9-year hiatus and again starting in 2004 (SC Report Sept 2013). The SC has noted that in most recent years, a directed commercial fishery using mid-water trawl had been conducted since 2005. Catches for this fishery ranged from about 50 to 1200 t and effort ranged from 4 days to 50 days. Although today this fishery is generally small (catches of 302 t in 2012), the SC has concluded that this mid-water trawl commercial fishery is not covered under Chapter II of the NCEM (i.e. Bottom Fisheries in the NAFO Regulatory Area) or any other chapter, and that this gap in the NCEMs could result in an ongoing fishery that is unregulated. Bycatch of other vulnerable species, such as small-tooth sand tiger shark (listed as vulnerable under the IUCN Red List for Threatened Species) has been identified in the current fishery (SC WP 20/13).

The Corner Rise Seamounts and the New England Seamounts’ chains are located in an area that meets the ecologically or biologically significant area (EBSA) – namely, the Sargasso Sea. In response to the Fisheries Commission request to the Scientific Council to comment and advise on whether the Sargasso Sea provides forage area or habitat for living marine resources that could be impacted by different types of fishing; and on whether there is a need for any management measure including a closure to protect this ecosystem, the Scientific Council recommended, *inter alia*:

1. The polygons of the closures for both the New England and corner Rise seamounts be revised to the north, east and west in the NAFO Convention Area to include all the peaks that are shallower than 2000 metres (Figure 1.24).

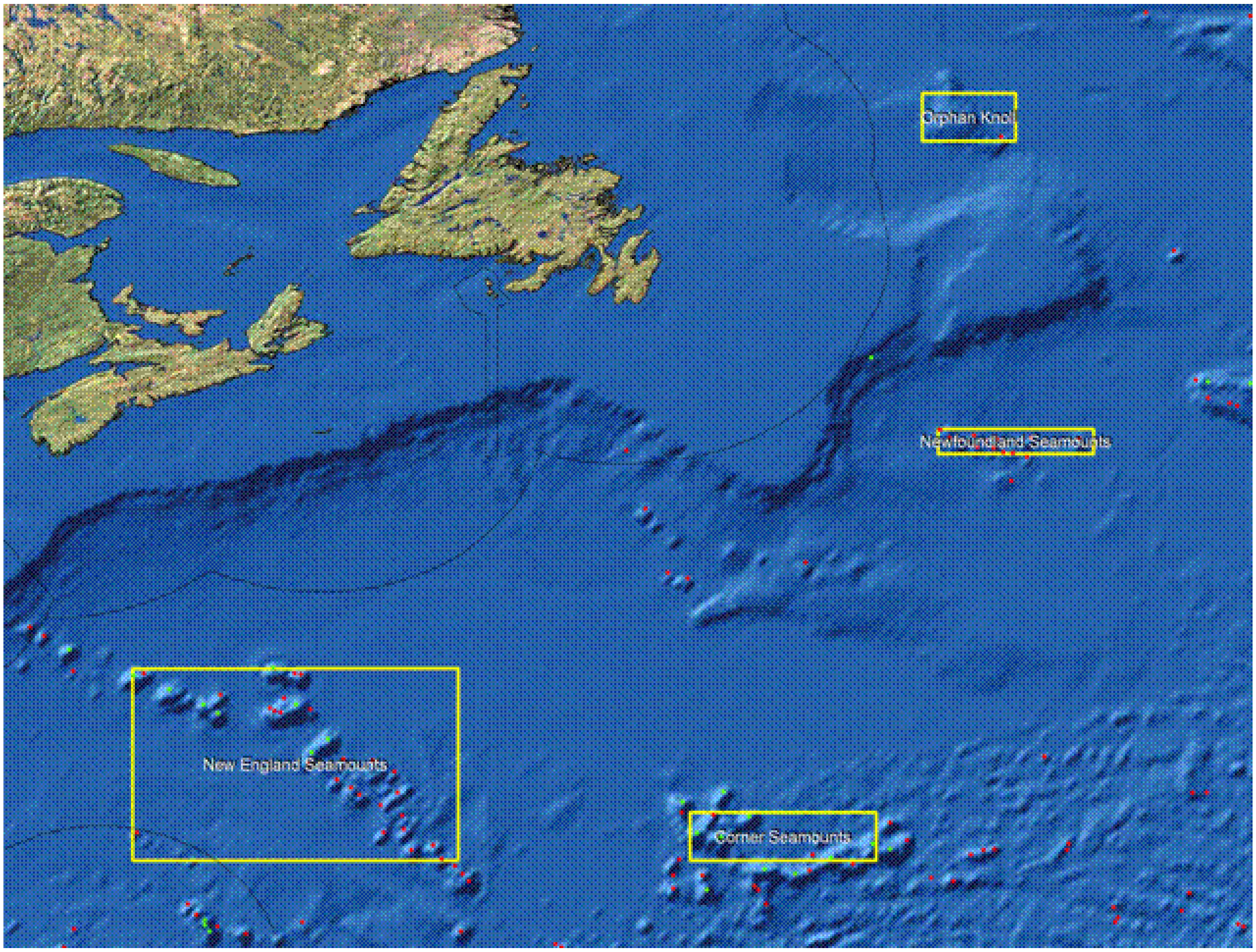


Figure 1.24. Area of closure on and around four seamounts in the NAFO Regulatory Area effective 1 January 2007 to 31 December 2010. Seamount peaks marked with green dots rise above 2000 m depth, those marked with red dots have peaks below 2000 m depth. (Map produced by Michael McKee and Peter Auster, National Undersea Research Center at The University of Connecticut, CI USA)

2. Expansion of the Exploratory Fishing protocol to include all types of fishing, specifically the current mid-water trawl gears.

3. Precautionary regulations for mid-water trawl be put in place for historically fished areas with respect to mid-water trawl fishery. (NAFO, 2013)

This advice will be reviewed by the NAFO Working Group of Fisheries Managers and Scientists on ecosystem approach to fisheries management in July 2014.

In addition, Shank (2010) notes that one of the longest seamount tracks in the Atlantic Ocean was formed by the Great Meteor or New England hotspot. He highlights that “This more than 3000-km-long hotspot track formed both the New England and Corner Rise seamounts, with a pause in volcanism 83 million years ago as evidenced by the morphological gap between chains” (Shank, 2010).

Highly diverse oceanographic settings contribute to these seamounts harbor complex coral and sponges ecosystems and many associate species (Shank *et al*., 2006; Mosher and Watling, 2009; Shank, 2010). Shank (2010) notes that these seamounts are now the focus of intense ecological and evolutionary studies, with over 270 morphospecies observed within this region. He also underscores that:

“ ~ 75 morphotypes [are] unique to the Corner Rise and ~ 60 [are] unique to the New England Seamounts (Cho, 2008). Interestingly, a variety of invertebrates are revealing differing levels of specificity to their host corals, ranging from "facultative" to "obligate" (see Shank, 2010). For example, the galatheid *Uroptychus* has been observed only on the antipatharian *Parantipathes sp.*, and the ophiuroid *Ophiocreas oedipus* only on the coral *Metallogorgia melanotrichos"* (Figure 1.25).

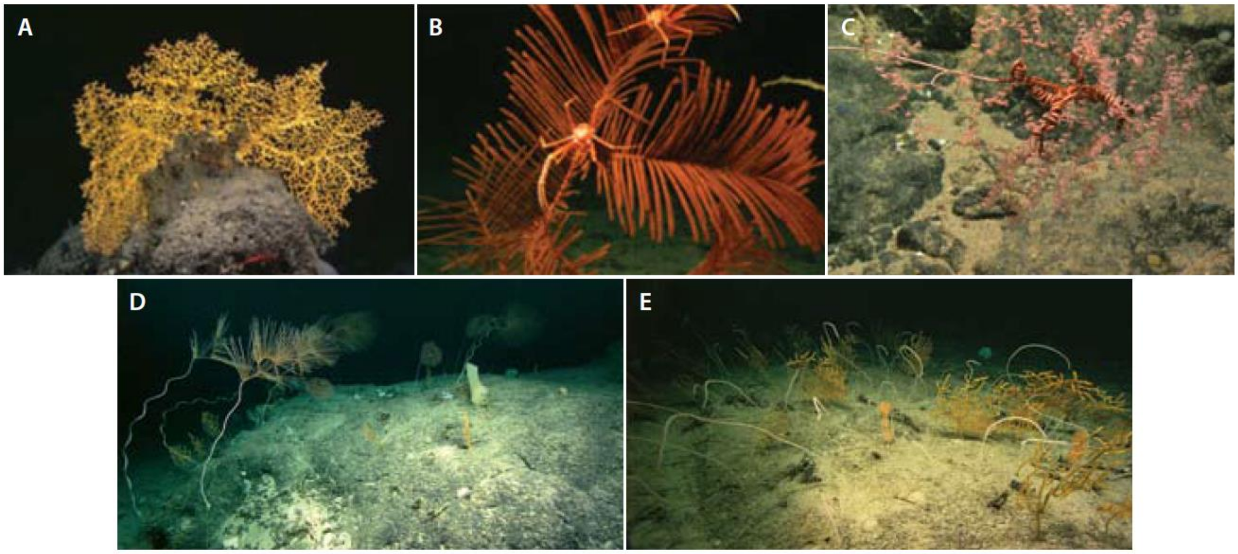


Figure 1.25. Characteristic features of the New England and Corner Rise seamounts. Habitat-forming coral ecosystems support diverse invertebrate associations on the New England and Corner Rise seamounts, including (a) ophiuroids, shrimp, hydroids, and galatheid crabs associated with the scleractinian Enallopsammia on Lyman Seamount (1450m), (b) chyrostylid crabs on the antipatharian Plumapathes on Kükenthal Seamount (915m), (c) Ophinocreas oedipus ophiuroid wrapped around the coral Metallogorgia melanotrichos, (d) spiraling Iridogorgia corals along with Metalogorgia corals and sponges living on an outcrop on the Corner Rise Seamounts, and (e) a soft coral community of Paramuricea sp., Calyptrophora sp. , and Chrysogorgia sp. from Corner Seamount (1220 m). Shank (2010)

The CBD EBSA Summary Report (UNEP/CBD/SBSTTA/16/INF/7), which was approved by the eleventh Conference of the Parties (COP 11) in 2012, expressly refers to the Corner Rise Seamounts chain as home to specialized, fragile and endemic communities.

The CBD Summary Report makes a number of references to the Corner Rise Seamounts as well as the New England Seamounts, including reference to the NAFO closures:

"Fisheries landings for many species in the North Central Atlantic have declined significantly in the last 50 years, indicative of impacts on those populations (Sumaila *et al*., 2011; Pauly and Watson, 2005; Pauly *et al*., 2005). Regulatory actions by ICCAT aim to address this. Bottom trawling between 1976 and 1995 on the Corner Rise seamounts caused extensive destruction of the benthic fauna (Vinnichenko, 1997; Waller et al., 2007; Shank, 2010). As a precautionary management measure, 13 fishable seamounts, including 25 peaks shallower than 2,000 m on the New England and Corner Rise seamounts were closed to demersal fishing by the Northwest Atlantic Fishery Organization (NAFO) from 1 January 2007. This closure was recently extended until 31 December 2014 (NAFO 2011a). The recovery of these habitats in the coming years should be monitored." (UNEP/CBD/SBSTTA/16/INF/7, pp. 114)

In addition to matching the vulnerability criterion, these seamount chains were also highlighted in the CBD report as of special importance for life history stages of species: "The Corner Rise and New England Seamounts host abundant populations of deep-water fish and, despite heavy commercial exploitation, remain important as aggregating and spawning areas for the alfonsino (*Beryx splendens).*" (p. 115)

As for the biological diversity criterion, the report states that:

"Benthic diversity is very high on the Corner Rise and New England seamount chains, where there are numerous endemic and novel species of coral that host specific commensal invertebrates, and some 670 species have been found (Watling, 2007; Waller *et al*., 2007; Cho, 2008; Shank, 2010; Simpson and Watling, 2011; Pante and Watling, 2011; ICES, 2011)." (CBD, Summary Report, p. 118). However we have not been able to validate the reference to 670 species from the cited material or elsewhere.

Newfoundland Seamounts

Most of the information is on the geology of the area (Sullivan and Keen, 1977). No information was found on significant species, or any commercial fishing or research surveys. We examined 6 seamount peaks in this area, none of which were shallower than 2400 m (Table 1.6; Figure 1.21), and most of which were > 3500 m.

New England Seamounts

The New England Seamounts are a 1200-km-long chain of about 30 volcanic peaks in the North Atlantic within the US EEZ, extending from Georges Bank to the eastern end of the Bermuda Rise (Figure 1.24; see Spotlight 4 on page 104 of this issue [Shank, 2010]). This seamount chain has not been extensively fished, and recent explorations revealed very rich and diverse benthic communities, many new distributional records, and a new species of gorgonian coral (Moore *et al*., 2003, Stiles *et al*., 2007). In 2007, two New England Seamounts (Bear and Retriever) were recognized as Habitat Areas of Particular Concern (HAPC) by the New England and Mid-Atlantic fishery management councils (United States). Despite the lack of commercial fishing activities, the councils are developing management measures that could protect the two seamounts from deep-sea bottom trawling in the future (Stiles *et al*., 2007).

Two studies from the New England Seamounts were examined, the Moore *et al*. (2001) study on Bear Seamount, and results from an exploratory fishery by a Spanish trawler in 2004 (Duran *et al*., 2005). In the latter paper, the specific locations of fishing effort in Division 6EF (containing the New England Seamounts), were not specified, so it was not possible to determine which seamounts may have been fished. Heirtzler *et al.* (1977) also reported on research on the New England and Corner Rising Seamounts.

Updated VME-related information is provided by Shank (2010) (see above – Corner Rise Seamounts section). In addition to this, NOAA ship Okeanos Explorer has conducted a New England Seamount Chain exploration in June 2013 (NOAA, http://oceanexplorer.noaa.gov/okeanos/explorations/ex1303/welcome.html (accessed on 25 November 2013).)

1.A.6. Data on deep-water corals and sponges from observations aboard Russian commercial fishing vessels

Targeted sampling of VME data has been carried out onboard Russian commercial fishing vessels only in the NAFO RA since 2008. In the subsequent years these Russian observations were conducted on a regular basis (ICES, 2011; ICES, 2013).

VME data were collected by observers during 22 cruises of commercial fishing vessels. The observations were conducted over a large area of the Flemish Cap, the Flemish Pass and the Grand Banks (42°46'-48°52'N, 44°00'-51°50'W, 60-1350m depth) where 2671 bottom hauls were performed (Figure 1.26, Table 1.7) by the Turbot 45.7, Selstad 640, Selstad 444/520 and Jose Manuel Landin Soto bottom trawls with minimal 130 mm codend mesh size. Haul duration varied between 0.5-9.0 hours at 3.1-3.5 knots.

The observations included:

- recording of VME indicator species in catches;
- species identification using relevant manuals (Kenchington *et al.*, 2009; Best *et al.*, 2010) for corals since 2009 and for sponges since 2010;
- weighing and measurement of indicator species;
- photography of corals and sponges for subsequent laboratory identification;
- coral encounter positions based on GPS data.

Observation results have shown deep-water corals to occur in different parts of the study area at 280-1300m depth (Figure 1.27). Sponges were found relatively seldom, mainly in the south of the Flemish Cap at 160-510m. There was only one sponge by-catch on the Grand Banks in the north of Div.3N taken at 1020m depth.

VME indicator species were caught in small numbers. By-catches of corals per haul varied from 1 to 2,500 g (mainly 10-70 g), those of sponges usually did not exceed 1,000 g, the highest one being 5,020 g.

Catches of corals included 11 species from 4 orders, in particular, Alcyonacea, Antipatharia, Pennatulacea and Gorgonacea, with the prevalence of *Anthoptilum* spp., *Duva florida*, Nephtheidae spp., *Pennatula aculeata* and *Pennatula borealis*. In addition, *Anthomastus* spp., *Gersemia* spp., *Halipteris* spp., *Radicipes gracilis*, *Stauropathes arctica* and *Pennatula phosphorea* were observed in small amounts.

Table 1.7. Information on VME studies onboard Russian commercial fishing vessels in the NAFO RA (revised data).

Year	Positions		Fishing depths, m	Number		By-catch weight, g	
	N	W		Cruises	Hauls	Corals	Sponges
2008	43°10'-48°50'	45°25'-50°49'	240-1350	3	402	< 500	
2009	45º23'-48º44'	46°30'-48°30'	770-1300	2	378	1-820	5020
2010	42°46'-48°12'	46°35'-50°03'	280-1275	4	319	4-2190	
2011	42º27'-48°15'	44°00'-51°48'	290-1205	4	330	6-2500	
2012	42°50'-48°19'	44°30'-51°50'	125-1250	5	649	< 1000	
2013	42°50'-48°52'	44°10'-51°41'	60-1145	4	593	< 1000	< 1000
Total	42°46'-48°52'	44°00'-51°50'	60-1350	22	2671	1-2500	< 5020

On the Flemish Cap, 16 species of sponges were found, with the predominance of *Phakellia* spp., *Lophon piceum*, *Polymastia* spp. and *Homaxinella* spp. One sponge by-catch taken on the Grand Banks consisted of *Geodia* spp.

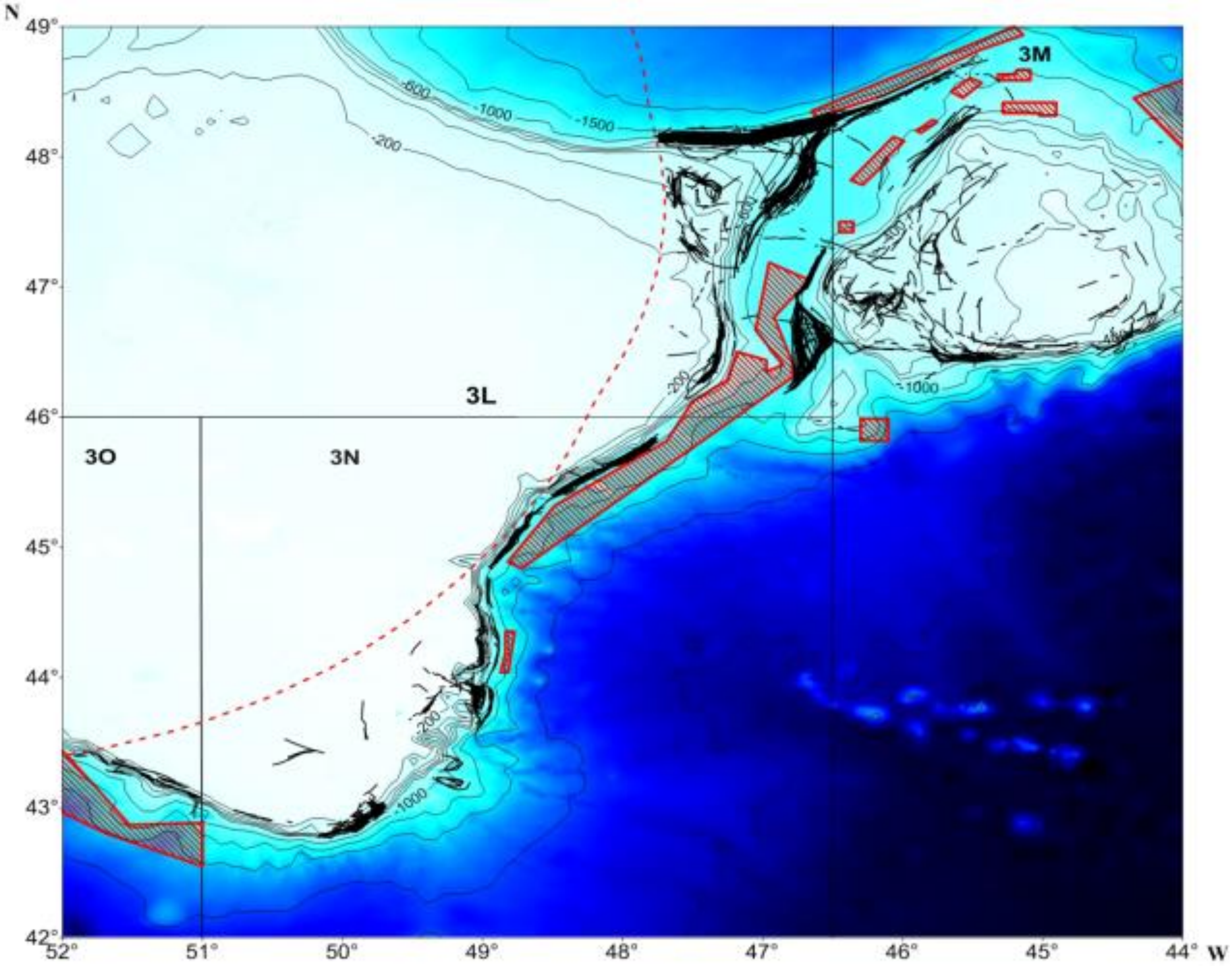


Figure 1.26. Haul tracks (VMS data) of the Russian commercial fishing vessels with observers onboard in the NAFO RA from 2008-2013.

◌- boundary of 200-mile zone, ▨ - closed areas, — - haul tracks

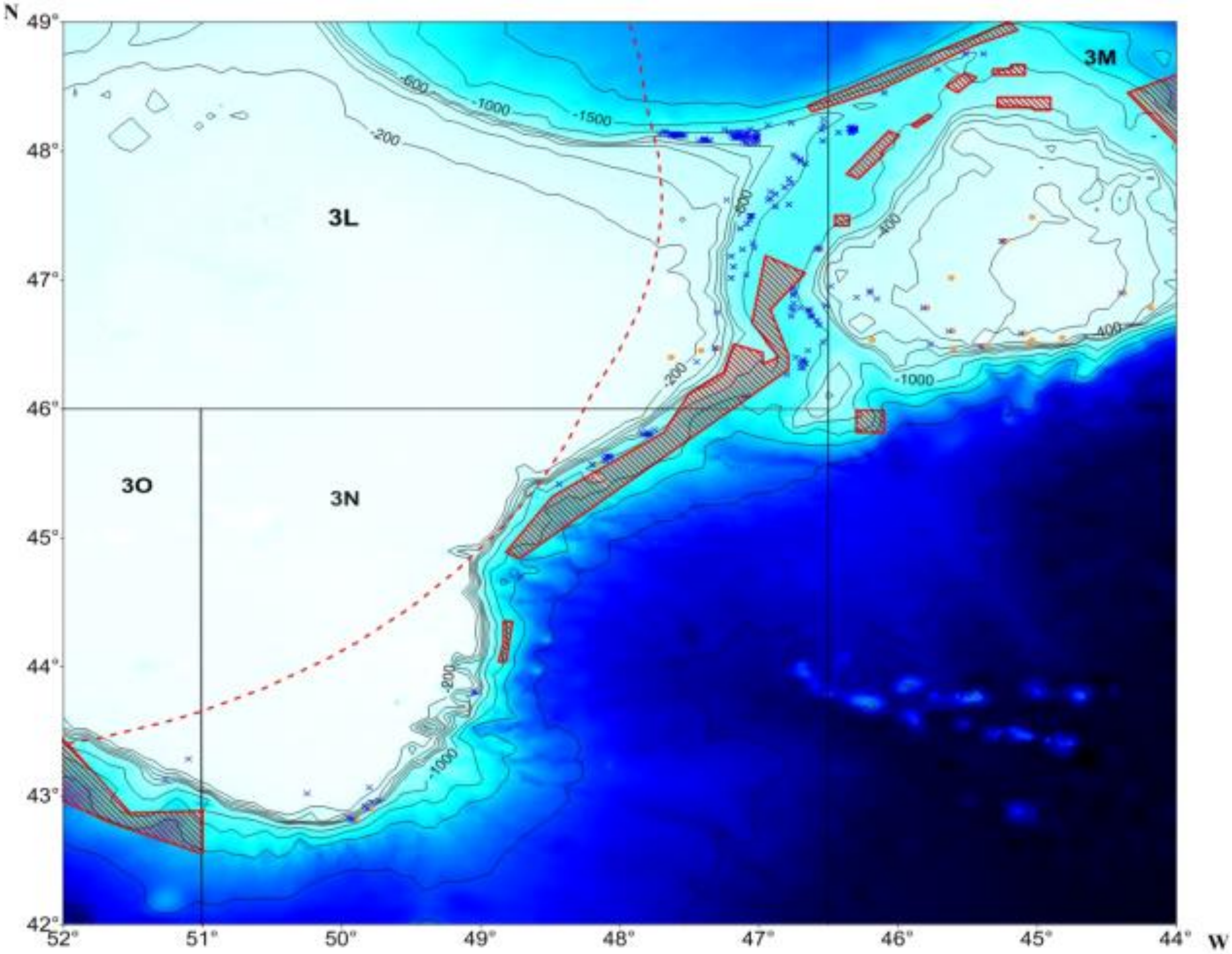


Figure 1.27. Occurrence of deep-water corals (2,500 g maximum by-catch) and sponges (5,020 g maximum by-catch) in the NAFO RA in 2008-2013.

◌- boundary of 200-mile zone, ▨ - closed areas, x - corals, ● - sponges

Part B. Fisheries Commission Requests

FC Request # 13

Considering that the current closures for VME indicators (i.e. species and elements in Annex I.E VI and VII) established under Chapter II of the NAFO Conservation and Enforcement Measures (NCEM) are due for revision in 2014, the Fisheries Commission requests the Scientific Council to:

a) Summarize and assess all the data available collected through the NEREIDA project, CP RV surveys, and any other suitable source of information, to identify VMEs in the NRA, in accordance to FAO Guidelines and NCEM.
b) Based on these analyses, evaluate and provide advice in the context of current closures specified in the NCEM for the protection of VMEs and prioritize areas for consideration by the Ecosystem Approach to Fisheries Working Group.

1.B.i. Identification of VMEs in the NRA

Review of VMEs and VME elements in the NRA

Summary of Data Sources

Data available were obtained from research vessel trawl surveys (Table 1.8), benthic imagery collected through the NEREIDA program (Tables 1.9 and 1.10) and from NEREIDA box cores samples (Table 1.11) and rock and scallop dredges (Table 1.12).

Table 1.8. Data sources from contracting party research vessel surveys; EU, European Union; DFO, Department of Fisheries and Oceans; NL, Newfoundland and Labrador; IEO, Instituto Español de Oceanografia; IIM, Instituto de Investigaciones Marinas; IPMA, Instituto Português do Mar e da Atmosfera.

Programme	Period	NAFO Division	Gear	Mesh size in codend liner (mm)	Trawl duration (min)	Average wingspread (m)
Spanish 3NO Survey (IEO)	2002 - 2013	3NO	Campelen 1800	20	30	24.2 – 31.9
EU Flemish Cap Survey (IEO, IIM, IPIMAR)	2003 - 2013	3M	Lofoten	35	30	13.89
Spanish 3L Survey (IEO)	2003 - 2013	3L	Campelen 1800	20	30	24.2 – 31.9
DFO NL Multi-species Surveys (DFO)	1995 - 2012	3LNO	Campelen 1800	12.7	15	15 - 20

During the CCGS *Hudson* NEREIDA cruise in 2009, 9 benthic imagery transects were conducted on the Sackville Spur and western Flemish Cap slope/Flemish Pass region using the 4K camera (4KCam) and Campod (Beazley *et al*., 2013a). Although video footage of the seabed was continuously recorded on the ‘Campod’ transects, only images have been analyzed to date.

Table 1.9. Summary of the benthic imagery collected and analyzed from the CCGS *Hudson* NEREIDA 2009 cruise to the Flemish Cap area.

Location	**Transect ID**	**Inside closure?**	**Gear**	**Transect length (m)**	**Depth range (m)**	**# Photos**
Sackville Spur	11	Mostly	4KCam	6 211	1080 – 1545	167
	12	Yes	4KCam	6 343	1313 – 1723	172
	18	Yes	4KCam	5 238	1336 – 1478	92
	24	Yes	4KCam	4 974	1290 – 1427	145
	26	Yes	4KCam	3 212	1381 - 1409	38
Flemish Pass area	28	No	Campod	2 431	461 - 479	92
	29	No	Campod	3 197	444 - 471	132
	30	No	4KCam	6 101	455 - 940	174
	38	Yes	4KCam	2 978	1328 - 1411	75

Table 1.10 summarizes the details of the analyzed transects that were collected using the ROV ROPOS during the CCGS *Hudson* NEREIDA 2010 cruise to the Flemish Cap. Downward- and forward-facing video was continuously recorded for each ROPOS dive (only downward-facing video has been analyzed to date). Due to their different objectives, the method used to analyze each transect varied. The ROV operated in two modes. In transect mode it kept a near constant speed and distance from bottom, did not stop and travelled to a predetermined waypoint. In explorer mode it stopped to collect specimens and although end waypoints were set the route to the waypoints was directed by the investigators and was biased towards interesting observations. Speed varied as did distance from the bottom. For instance, for transect 1335 and the explorer mode portions of transect 1337, only those megafauna that were large (~10 cm) and clearly visible were recorded. Transect 1336 was not analyzed in detail after its collection, and thus only the megafauna recorded during the *in situ* recording of the dive was summarized. For transect 1338, three sections of the transect (one trawled line, two untrawled lines; ~ 3 km in total) were analyzed every 10 m for corals and sponges only, but non-coral and sponge VME indicators were extracted from the *in situ* collection of the video. All visible megafauna were analyzed from the entire length of transect 1339.

Table 1.10. Summary of the benthic video collected and analyzed using the ROV ROPOS in 2010 during the CCGS *Hudson* NEREIDA cruise to the Flemish Cap (FC) area.

Location	**Transect ID**	**Inside closure?**	**Transect length (m)**	**Depth range (m)**	**Analysis details**
Southern FC slope	1335	No	8,292	873 – 1,853	Explorer mode. Analyzed in detail; frame by frame.
	1336	No	11,555	2,212 – 2,970	Explorer mode. Transect not analyzed in detail ('live' recordings summarized).
Southeast FC slope	1337	No	14,475	1,011 – 2,191	Transect and explorer mode. Explorer mode analyzed frame by frame; every 10 m analyzed for transect modes.
	1338	Yes	11,195	1,029 – 1,088	Explorer and transect. Three lines were analyzed (1 trawled, 2 untrawled) every 10 m for the abundance of sponges and corals. Non-coral and sponge observations extracted from 'live' recordings.
Northeast FC slope	1339	Yes	8,624	1,344 – 2,462	Explorer mode. Data extracted from 10 m intervals.

Table 1.11. Summary of the box cores samples collected and analyzed from the NEREIDA Programme on board the RV *Miguel Oliver*.

Programme	**Period**	**NAFO Division**	**Gear**	**Data extracted**	**Number of samples**
NEREIDA	2009-2010	3LMN	Box-corer	Epibenthos visible on box-corer surface photograph	331

Table 1.12. Summary of the rock dredge and scallop gear sets collected and analyzed from the NEREIDA Programme on board the RV *Miguel Oliver*.

Programme	**Period**	**NAFO Division**	**Depth range (m)**	**Gear**	**N valid sets**	**Trawl duration (min)**
NEREIDA	2009 - 2010	3LMN	502 - 1991	Rock dredge	88	15
NEREIDA	2009	3M	870 - 1137	Scallop gear	7	15

Overview of Analytical Methods

Kernel Surfaces and Significant Area Polygons

The primary tool used previously to quantitatively determine significant concentrations of VMEs is kernel density analysis. This analysis identifies "hotspots" in the biomass distribution. Using the kernel surface, polygons are drawn around successively smaller catch values and the area occupied by each polygon is calculated (Kenchington *et al.*, 2009; 2010). When applied to a highly aggregating species the area occupied by polygons created by successively smaller catch weights follows a repeated pattern:

Phase 1: rapid increase in area as the areas with the highest biomass are established;

Phase 2: little change in the area occupied by successively smaller catch weights due to the aggregative nature of the species;

Phase 3: a rapid change in area as the contribution of isolated individuals over a broad area are incorporated.

Phases 2 and 3 may occur more than once in a profile. When interpreting the catch weight defining the significant concentrations a number of criteria are simultaneously considered:

1) identification of the catch weights which show the largest change in area after the initial establishment of the habitat areas;

2) consideration of the number of data points contributing to the change in area between successive catch thresholds;

3) examination of the spatial relationship of the polygons greater and less than the potential threshold using GIS and the position of the new data points.

In this last step area can increase by the joining of two or more high density polygons. If this occurs the evidence for connecting the areas (i.e., number of points between the smaller areas) is reviewed. The threshold is considered to be valid when there is increase in area through a reasonable number of widely spaced data points. Cases for rejecting the threshold other than insufficient data include:

1) joining of smaller polygons with little evidence for a continuous distribution within the newly formed area;

2) a gradual increase in area with every new polygon added, creating a situation where no one successive change in area is especially larger or smaller than others (this indicates that there is no aggregation);

3) an increase in area established by creation of new areas of very low density;

4) no large increase in area.

Lastly, once the catch weight for defining the significant concentrations are established each VME area is evaluated by reviewing all of the data records (including null values) around each VME to evaluate whether the area is extensive enough to qualify as a VME.

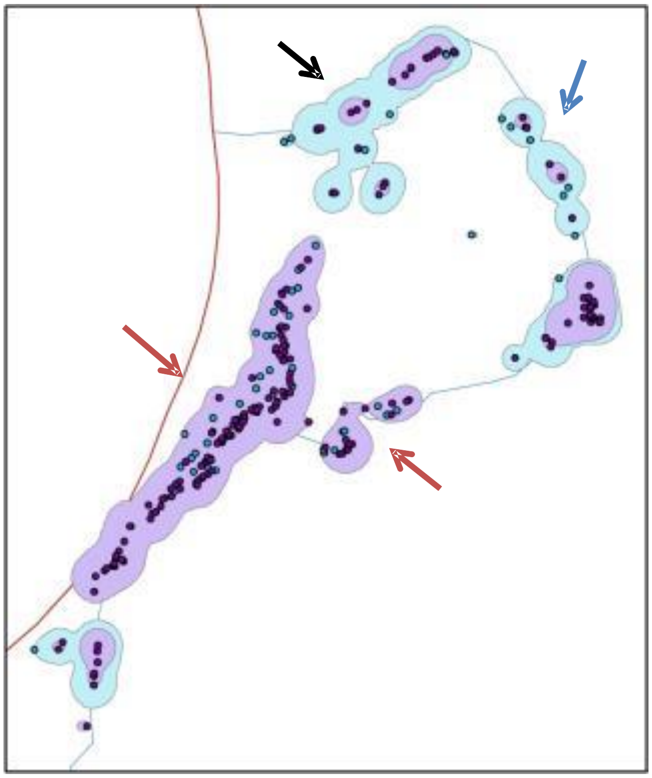


Figure 1.28. Purple polygon and points represent a hypothetical threshold 10kg. Light blue polygon and points represent a hypothetical threshold 11 kg. Example of cases where a threshold value would be rejected: 1) an increase in area (light blue over purple) created through joining of smaller polygons but with **no evidence for a continuous distribution** between the connected polygons, that is no light blue points between the purple ones (indicated by black arrow); 2) addition of lower catch weights within the polygon area established by higher catches (red arrow and light blue points within purple polygon) with **no increase in area**; Example of cases where a threshold value would be accepted: 3) an increase in area (light blue over purple) created through joining of smaller polygons with evidence for a continuous distribution (indicated by blue arrow).

Species Distribution Modeling

Species distribution modeling (SDM) predicts the presence, absence or abundance of a phenomenon (the response variable), typically a species or habitat type, from environmental variables thought to influence it (the predictor variables). SDM has been extensively used in both terrestrial and marine environments to make contemporary distribution maps, to predict species/habitat responses to climate change (Lawler *et al.*, 2009; Knudby *et al.*, 2010), to predict the future range of invasive species (Peterson, 2003; Peterson and Robins, 2003) and more. Recently it has been applied to sponge grounds in the northwest Atlantic, including the NRA (Knudby *et al.*, 2013 a,b). SDMs have been newly created for black corals, large gorgonian corals and sea pen corals and the published prediction surfaces for sponge grounds are incorporated into the assessment of VMEs. These models are particularly valuable in areas where the survey vessels do not sample (e.g., rough bottom, cliffs, depths greater than 2000 m) and for non-aggregating taxa such as the black corals that are present in low frequency and their past occurrence (noted after removal by the trawl) may or may not reflect the presences of other colonies in the same area.

The analyses used for each VME indicator were:

1. Sponge grounds: kernel analyses, SDM
2. Large gorgonian corals: kernel analyses, SDM
3. Small gorgonian corals: kernel analyses
4. Sea pens: kernel analyses, SDM
5. Erect Bryozoans: kernel analyses
6. Large sea squirts: kernel analyses

7. Cerianthid Anemones: distribution
8. Crinoids: distribution
9. Black Coral: SDM

Definitions: Distributions, VMEs, VME Indicators and VME elements

The FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO, 2009) provide general tools and considerations for the identification of Vulnerable Marine Ecosystems (VMEs).

In relation to VMEs, the FAO Guidelines indicate that vulnerability is related to the likelihood that a population, community, or habitat will experience substantial alteration from short-term or chronic disturbance, and the likelihood that it would recover and in what time frame.

Although no formal definitions for VMEs, VME indicators, or VME elements are provided, the FAO Guidelines indicate that VMEs should be identified based on the characteristics they possess, providing criteria that should be used, individually or in combination, for the identification process. These criteria are:

i. Uniqueness or rarity – an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems. These include:

- habitats that contain endemic species;

- habitats of rare, threatened or endangered species that occur only in discrete areas; or

- nurseries or discrete feeding, breeding, or spawning areas.

ii. Functional significance of the habitat – discrete areas or habitats that are necessary for the survival, function, spawning/reproduction or recovery of fish stocks, particular life history stages (e.g. nursery grounds or rearing areas), or of rare, threatened or endangered marine species.

iii. Fragility – an ecosystem that is highly susceptible to degradation by anthropogenic activities.

iv. Life-history traits of component species that make recovery difficult – ecosystems that are characterized by populations or assemblages of species with one or more of the following characteristics:

- slow growth rates;

- late age of maturity;

- low or unpredictable recruitment; or

- long-lived.

v. Structural complexity – an ecosystem that is characterized by complex physical structures created by significant concentrations of biotic and abiotic features. In these ecosystems, ecological processes are usually highly dependent on these structured systems. Further, such ecosystems often have high diversity, which is dependent on the structuring organisms.

The FAO Guidelines also recognize that these criteria should be adapted, and/or additional criteria developed, as experience and knowledge accumulate, or to address particular local or regional needs.

When identifying VMEs, the FAO Guidelines indicate that species groups, communities, habitats, and features often display characteristics consistent with possible VMEs, but they clearly state that merely detecting the presence of an element itself is not sufficient to identify a VME. This has two related and important implications a) the full spatial distribution of a species that meet the VME criteria does **not** constitute a VME, and b) actual VMEs must possess a level of organization larger than the scale of a singular/individual presence.

Another important consideration is that areas were VMEs are likely to occur should also be identified. These VME elements are topographical, hydrophysical or geological features, including fragile geological structures, that potentially support species groups or communities that qualify as VMEs.

In this general context, NAFO has followed the FAO guidelines in defining and identifying:

VME indicator species. These are species that met one or more of the FAO Guidelines criteria for possible VMEs. Their simple presence is not an automatic indication of VMEs, but when found in significant aggregations with conspecifics, or other VME indicator species, can constitute a VME. NAFO has approved a list of taxa that qualify as VME indicator species (NCEM Annex I.E.VI).

VME elements. These are topographical, hydrophysical or geological features which are associated with VME indicator species in a global context and have the potential to support VMEs. NAFO has approved a list of features that qualify as physical VME indicator elements (NCEM Annex I.E.VII).

Higher concentration observations of VME indicator species (a.k.a. "Significant concentrations"). These are specific locations where there are individual records of VME indicator species at densities at or above a threshold value that, for that specific VME indicator species, is associated with the formation of highly aggregated groups of that species. These higher concentration locations have been the basis for the delineation of the polygons referred as "Areas of higher sponge and coral concentrations" in NCEM Article 16.5, which are closed to bottom fishing activities.

Although NAFO has protected areas containing higher concentration observations of VME indicator species, it has not defined VMEs proper. Furthermore, all VME indicator species to date have been identified under the structure-forming criterion, in that they create structural habitats for other species and are thought to enhance biodiversity. For this type of VME indicator species, a VME proper can be defined as:

Vulnerable Marine Ecosystem (VME). Under the structure-forming criterion, it is a regional habitat that contains VME indicator species at or above significant concentration levels. These habitats are structurally complex, characterized by higher diversities and/or different benthic communities, and provide a platform for ecosystem functions/processes closely linked to these characteristics. The spatial scale of these habitats is larger than the footprint of a higher concentration observation. NAFO has used quantitative methods to objectively define areas that contain VME indicator species at or above significant concentration levels. These areas are not simply defined by the individual tows above the threshold value but also all of the smaller catches within the delimited polygon. These smaller catches may represent recruitment or smaller species in the VME indicator group. These larger areas **are** the VMEs proper unless post-hoc considerations suggest otherwise. VMEs occur throughout the NRA and their spatial arrangement may be important to recruitment processes and to overall ecosystem function.

The FAO guidelines call for the identification of areas where VMEs are either **known** or **likely to occur**. NAFO has used quantitative methods (kernel density surfaces and analyses of the polygon areas at specified weight thresholds) to identify these areas. These methods have shown to perform well for those areas that are well sampled, but there are many regions in the NRA that are either undersampled or not sampled at all. Modelled predictions of the probability of occurrence of a VME indicator species or habitats are an essential tool for identifying VMEs in these regions. These models generate continuous surfaces based on a suite of environmental variables which are statistically associated with the observation of a VME indicator species. Contrasting species distribution models with the kernel density surfaces also provide two complementary approaches for decision making and are especially valuable when they re-enforce each other (i.e. validation).

Review of VME indicators

The VME indicators identified by NAFO have thus far all been identified under the *v. Structural Complexity* criterion of the FAO Guidelines (see Definitions: Distributions, VMEs, VME Indicators and VME elements (above)). Recently, new species and genera have been discovered arising from recent collections. It is possible that these may qualify under *the i. Uniqueness or rarity* criterion that is: – an area or ecosystem that is unique *or that contains rare species whose loss could not be compensated for by similar areas or ecosystems*. These include:

- habitats that contain endemic species;
- habitats of rare, threatened or endangered species that occur only in discrete areas; or
- nurseries or discrete feeding, breeding, or spawning areas.

At present, the distributions of these species are not fully known so it is premature to identify them under the Uniqueness/rarity criterion, however this could change in future as the specimen collections are more fully investigated. For this assessment their presence can give weight to current and proposed closed areas. The most likely candidate is a new genus of black coral that does not meet other VME criteria. A single record of *Telopathes magna* (MacIsaac *et al.*, 2013), was observed on transect 1335 on the southern Flemish Cap slope (Beazley *et al.*, 2013a).

New sponge records of species that meet the Structure Forming criterion of VME Indicator Species have been recently published for the NRA. Cardenas *et al.* (2013) revised the taxonomy, biogeography and DNA barcodes of *Geodia* species in the Atlantic boreo-arctic region. *Geodia* species are the main structure former of the sponge grounds of the NRA (Fuller, 2011; Murillo *et al*., 2012) and two species not included in the Annex VI. List of VME indicator species of the NAFO CEM are provided for the NRA (*G. atlantica* and *G. parva*). And Murillo *et al.* (2013) complement data on the hexactinellida fauna of the NRA, often referred as glass sponges, with the description of a new species, *Dictyaulus romani* (Family Euplectellidae), from the Flemish Cap and Flemish Pass around 1332 and 1488 m depth; some fragments of *Aphrocallistes beatrix* (Family Aphrocallistidae) were also identified. Glass sponges meet the criteria of fragility and vulnerability of VME Indicator Species and some of them provide habitat to other organisms, so these two species should also be added to the Annex VI. List of VME indicator species of the NAFO CEM.

The benthic VME identified by NAFO have important ecosystem functions other than increase of biodiversity. They play important roles in benthic-pelagic coupling, benthic remineralization, and carbon sequestration amongst others (See Review in ToR 3. 4).

Review of Significant Concentrations of Large-sized Sponges

New information has demonstrated that the sponge grounds in Flemish Pass locally increase biodiversity (Beazley *et al*., 2013b; see also ToR 3.1.1). Therefore conservation of the sponge ground VME meets the intent of UNGA 61/105 which is to protect the associated biodiversity.

Significant concentrations of *Large-sized Sponges* have been determined previously in the NRA using kernel density analyses and an evaluation of the expansion of the area covered by successive density polygons (NAFO, 2009b). These analyses have been updated using all available data from the RV trawl surveys. Specifically data from the Spanish 3NO survey (2002-2013), EU Flemish Cap Survey (2003-2013), the Spanish 3L Survey (2003-2013) and the DFO-NL Multi-species Surveys (1995-2012) were assessed. These data sources yielded 2593 sponge records (553 from the Canadian surveys and 2040 from the EU-Spanish surveys). However, there were significant differences among the catch series for each survey ($P < 0.001$) likely due to differences associated with gear type, tow length, survey area and sampling protocol. These dissimilarities were driven by differences in the number of small catch weights. When all records less than 0.5 kg were removed, there was no significant difference among the catch distributions ($P=0.279$). Therefore the analyses were performed on 1154 catches ≥ 0.5 kg (391 Canadian records and 763 EU-Spanish records). Following previously established methods and assessment criteria, a kernel density surface was created and the area of successive density polygons calculated. The kernel density distribution identified sponge grounds on the southern portion of Flemish Pass to southwestern Grand Bank, Beothuk Knoll, Sackville Spur and the southwest Flemish Cap (Figure 1.29). The 75 kg/ RV tow density threshold emerged as defining significant concentrations of large-sized sponges (i.e., sponge ground VME). This is the same threshold value that was established previously (NAFO, 2009b). When superimposed on the kernel density surface (Figure 1.29), the 75 kg density polygon captures all of the high density areas from the kernel analysis. Review of the data surrounding these polygons shows that some of the areas are based on single records. In the northwestern part of the Flemish Cap, around 1200 m depth (Figure 1.29), two isolated catches are present. They are surrounded by lower catches, but in some cases include species characteristic of *Geodia* grounds. These are small areas, but they can have special environmental or physical conditions enhancing sponge biomass, that could constitute VMEs. Southern of these two catches, there is an area with two significant catches. These are represented by another species, *Asconema foliata*, also a VME indicator taxon. In the eastern slope of the Flemish Cap there is another isolated catch. No additional records exist within less than 3.5 nmi radius of the point, but this catch seems to belong to the same sponge VME defined to the north and it is included in the closed area 5. Lastly on the southern slope of the Cap, there is another isolated catch, with no additional records less than 8 nmi around the catch, but this catch seems to belong to the same sponge VME defined to the east, in the closed area 4. Consequently all of these catches should be considered as VME unless proven otherswise.

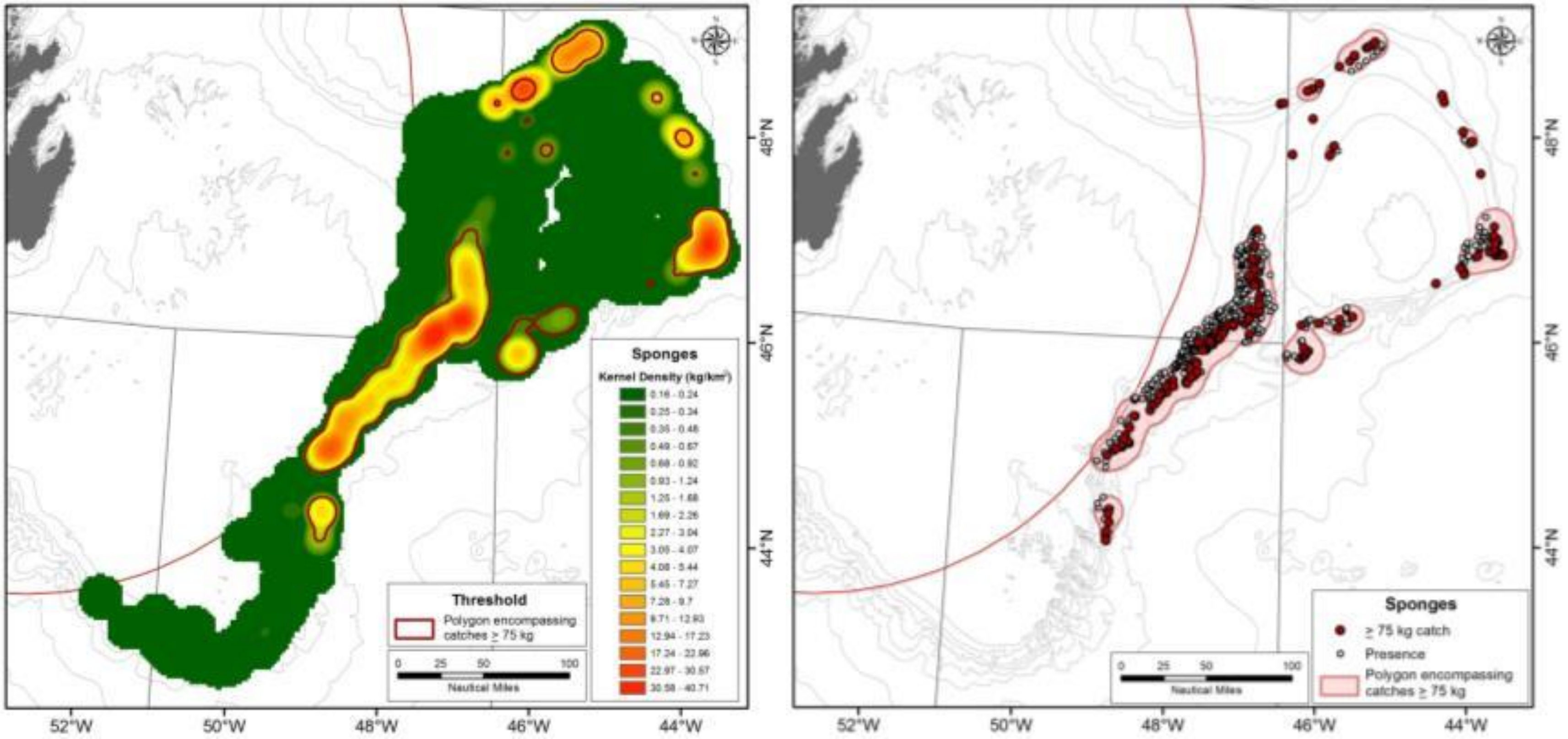


Figure 1.29. Left panel: Kernel density distribution of sponges in the NAFO Regulatory area with the 75 kg density polygons defining the sponge ground VMEs superimposed in red. The green areas represent low sponge densities while the red areas indicate high sponge densities. **Right panel:** The location of catches greater than 75 kg (red circle) and smaller sponge catches (open circles) within the 75 kg density polygons defining the sponge ground VMEs.

Knudby *et al.* (2013a,b) have published species distribution models (SDMs) for the distribution of *Geodia* sponges and sponge grounds in the Northwest Atlantic. Twenty-three predictor variables were drawn from 50 spatially continuous data on the physical and biological ocean environment derived from satellite data and oceanographic models. Response data were based on presence and absence observations of *Geodia* spp. and sponge grounds derived from research trawl catches in the NRA and on the Canadian continental shelves, and to a lesser extent from NEREIDA box core and underwater imagery data. A random forest model was used to create the prediction surfaces. The spatial extent of the model was to 2500 m. Random forest is an ensemble technique based on classification trees in which each split is determined using a random subsample of the available predictors. A random forest model is trained on both presence and absence data from a common area, and is preferably used for SDM when such data are available. The resultant model can be used to predict distributions in non-sampled areas by identifying areas with similar environmental conditions. Model fit was quantified as the Area Under the receiver operating Characteristic (AUC) using 10-fold cross-validation repeated 10 times. AUC values typically range from 0.5 for classifiers that perform no better than random to 1.0 for error-free classifiers. The model for the NRA had an AUC value of 0.982 which is an excellent fit (Figure 1.30). Sponge grounds are primarily observed and predicted to exist in areas with high (> 0.1 m/s) maximum bottom current with depth and minimum salinity also being important predictors. Sponge ground presence is predicted with high probability on the upper continental slope where numerous observations confirm their presence (Figure 1.30). Due to the frequent presence observations with high depth values, predictions of high presence probability also extend into the deeper (unsampled) parts of the area, where validation will require additional field observations. Apart from these unsampled areas, the areas of high predicted presence probability align with the areas of significant concentrations of sponges identified from the kernel distributions derived from biomass data.

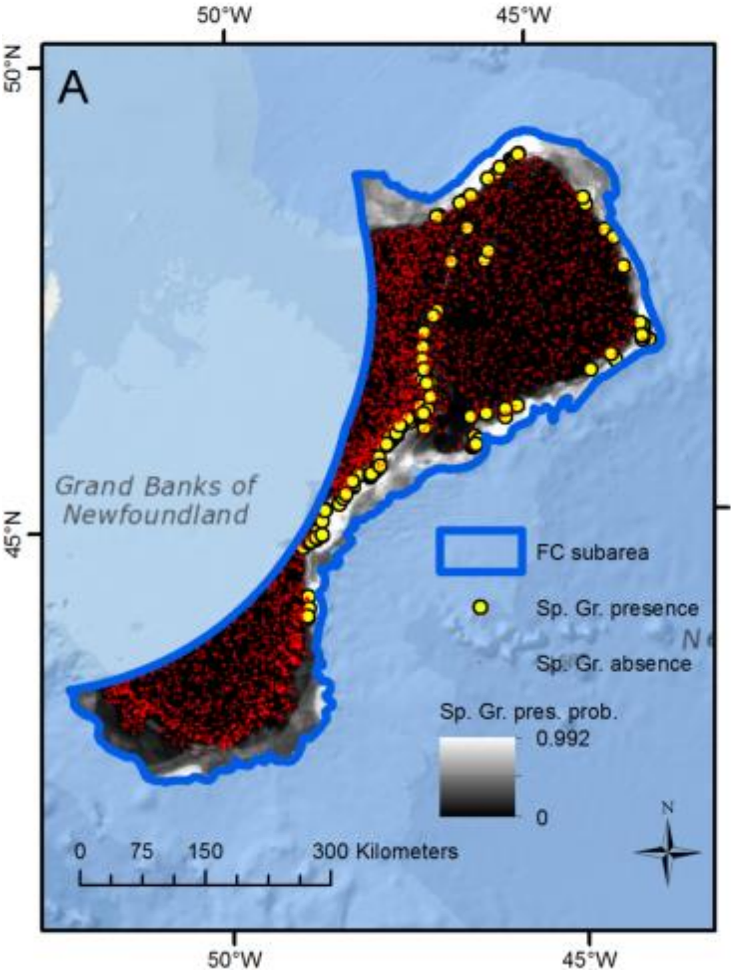


Figure 1.30. Sponge ground presence/absence observations and predictions of presence probability for the NRA. (from Knudby *et al*., 2013b)

Review of Significant Concentrations of Sea Pens

Significant concentrations of *Sea Pens* have been determined previously in the NRA using kernel density analyses and an evaluation of the expansion of the area covered by successive density polygons (Murillo *et al*., 2010), although this was done for all the 3LMNO Divisions, including Canadian waters. These analyses have been updated using all available data from the RV trawl surveys and applied to the NRA area only. Specifically data from the Spanish 3NO survey (2002-2013), EU Flemish Cap Survey (2003-2013), the Spanish 3L Survey (2003-2013) and the DFO-NL Multi-species Surveys (1995-2012) were assessed. These data sources yielded 1310 sea pen records (183 from the Canadian surveys and 1127 from the EU-Spanish surveys). However, as for sponges, there were significant differences among the catch series for each survey ($P < 0.001$) with the Campelen catches being more similar to one another that with the Lofoton catches. These dissimilarities were driven by differences in the number of small catch weights. When all records less than 0.2 kg were removed, there was no significant difference among the catch distributions ($P=0.087$). Therefore the analyses were performed on 262 catches ≥ 0.2 kg (35 Canadian records and 227 EU-Spanish records). Following previously established methods and assessment criteria, a kernel density surface was created and the area of successive density polygons calculated. The kernel density distribution identified sea pen fields on the western, northern and eastern portions of Flemish Cap and on the tail of Grand Bank in 3O (Figure 1.31). The 1.4 kg/ RV tow density threshold emerged as defining significant concentrations of sea pens (i.e., sea pen field VME). This is a higher threshold value (more conservative) than was established previously (0.5kg) (Murillo *et al*., 2010) although similar locations of significant concentrations were generated. When superimposed on the kernel density surface (Figure 1.31), the 1.4 kg density polygon captures all of the highest density areas (red colour on Figure 1.31) from the kernel analysis. Review of the data surrounding these polygons shows that one of the areas is based on a single record. This one large catch (3.686 kg), on the tail of the Grand Bank occurs near two other records at 0.4 and 0.68 nmi distance. These catches are of 0.165 kg and 0.035 kg sea pens respectively. This small area could have special environmental or physical conditions enhancing sea pen biomass (see SDM below), so although there is only one large catch, this could also constitute a VME.

Species distribution models (SDM) were performed on presence/absence data of sea pens from the RV surveys, NEREIDA benthic imagery and rock and scallop dredge samples generally following Knudby *et al*. (2013a) as detailed in Knudby *et al.* (2013c). The response variable data used by Knudby *et al*. (2013a,b) was dominated by the sea pen catches from the research vessel surveys (2409 of 3510 records). Additional records came from the NEREIDA rock and scallop dredge samples (95 records) and from benthic imagery (6 records). The model fit was very good (AUC = 0.888). Eleven predictor variables were used in the model (Knudby *et al*., 2013c) with winter and summer range of chlorophyll being the most important in the permutations to increase AUC. The SDM prediction surface shows a good fit with the training data (Figure 1.32) and should be used when considering the *likely* presence of these species in data poor areas. The prediction surface (Figure 1.32) identifies the area of significant concentrations of sea pens identified using the kernel density analyses (Figure 1.31).

Sea pen fields meet the criteria for VME under the Structural Complexity characteristic (*sensu* FAO 2009) (Fuller *et al*., 2008). They can form dense aggregations where they are the dominant taxon in the area or they can be present in lower densities in mixed benthic assemblages. New information has shown that redfish larvae attach to the sea pen stalks and these habitats may be important nursery areas for *Sebastes* spp. (see ToR 3.1.2). Their distribution on Flemish Cap is continuous, forming a horseshoe pattern at water depths greater than 300 m (Kenchington *et al*., 2011). Catch composition was used to evaluate the dominance of the sea pens in this wider distribution as a means of distinguishing sea pen fields from mixed benthic assemblages containing sea pens. Selected catches were proportioned by biomass contribution of major taxonomic groups and presented as pie charts (Figure 1.33). Large heavy organisms like molluscs can easily dominate such charts when compared with lighter taxa such as the sea pens, however the types of benthic taxa represented can quickly be seen. The VME areas on the eastern Flemish Cap indicate benthic assemblages of sea pens (Pennatulacea), sponges (Porifera) and soft corals (Alcyonacea). Soft corals contribute most to the biomass in this area although sea pens represent 12, 16 and 22% of the biomass in the three tows shown. Given their small individual weight this represents large numbers of individuals; 44, 114 and 37 respectively. Sea pens constitute the main, or second group after Crustacea, of the benthic biomass within the northern Flemish Cap sea pen VME areas (Figure 1.33).

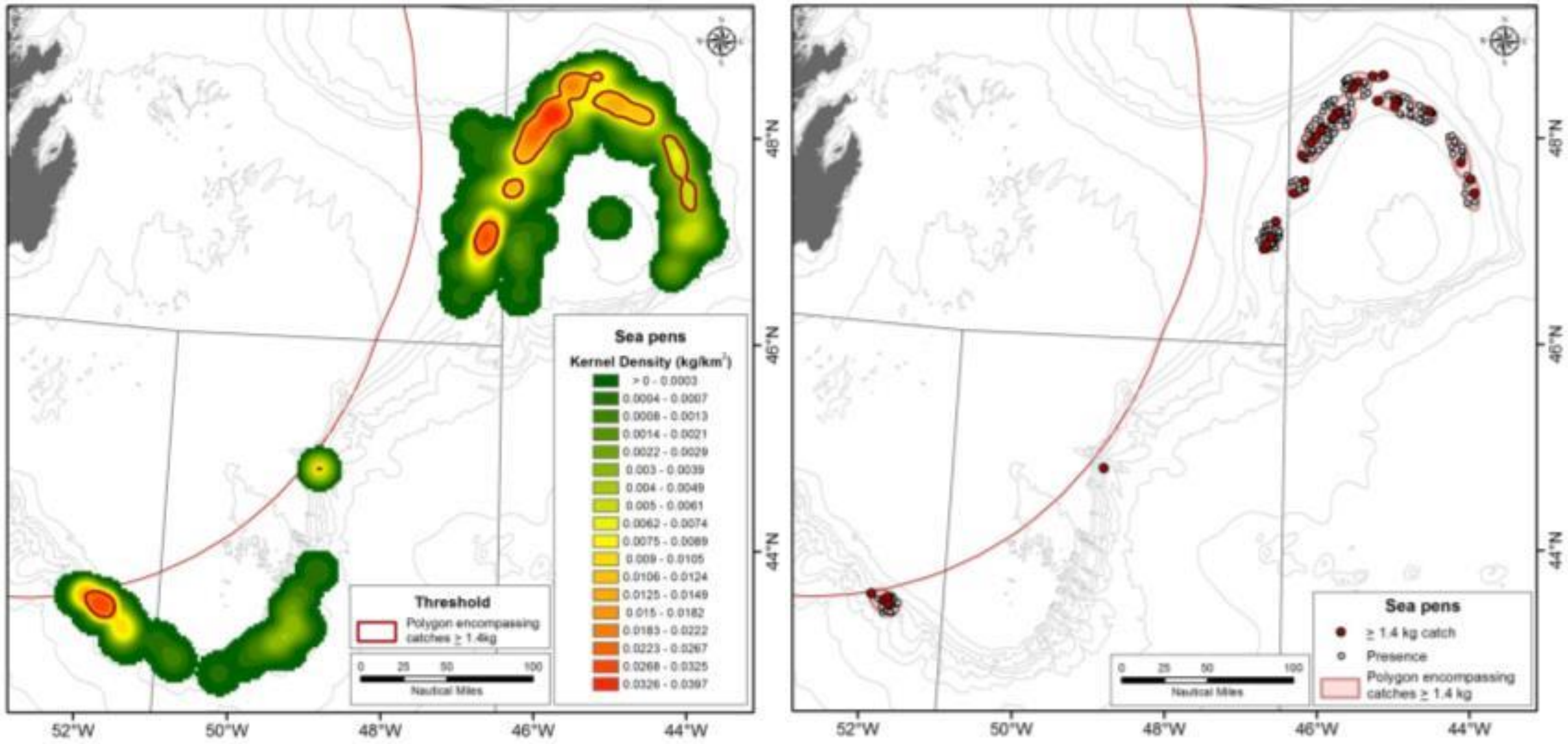


Figure 1.31. Left panel: Kernel density distribution of sea pens in the NAFO Regulatory area with the 1.4 kg density polygons defining the sea pen field VMEs superimposed in red. The green areas represent low sea pen densities while the red areas indicate high sea pen densities. **Right panel:** The location of catches greater than 1.4 kg (red circle) and smaller sea pen catches (open circles) within the 1.4 kg density polygons defining the sea pen field VMEs.

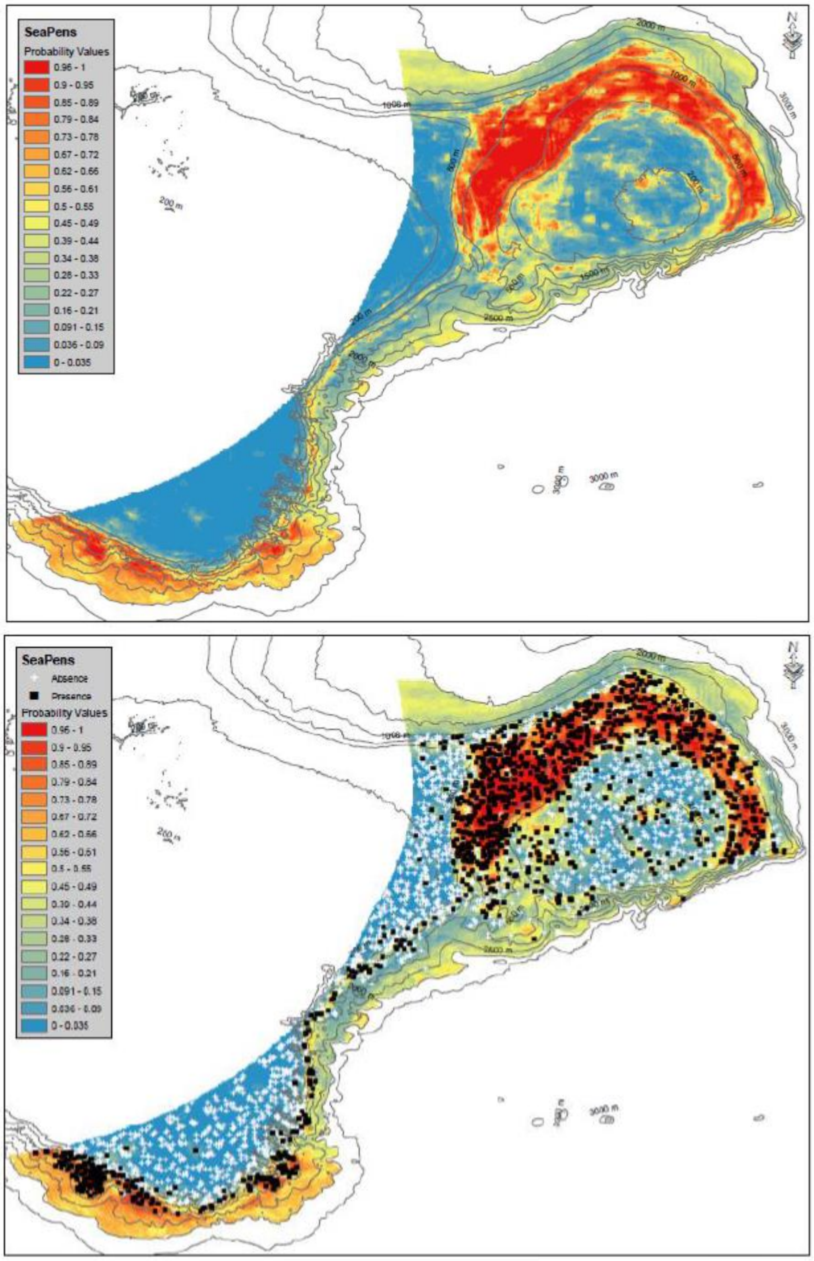


Figure 1.32. Upper Panel: Sea pen presence prediction surface for the NRA based on random forest species distribution modelling of the presence/absence data from the RV surveys and the analysis of 23 environmental variables. **Lower Panel:** The sea pen presence prediction surface showing the location of the presence and absence data used to train the model.

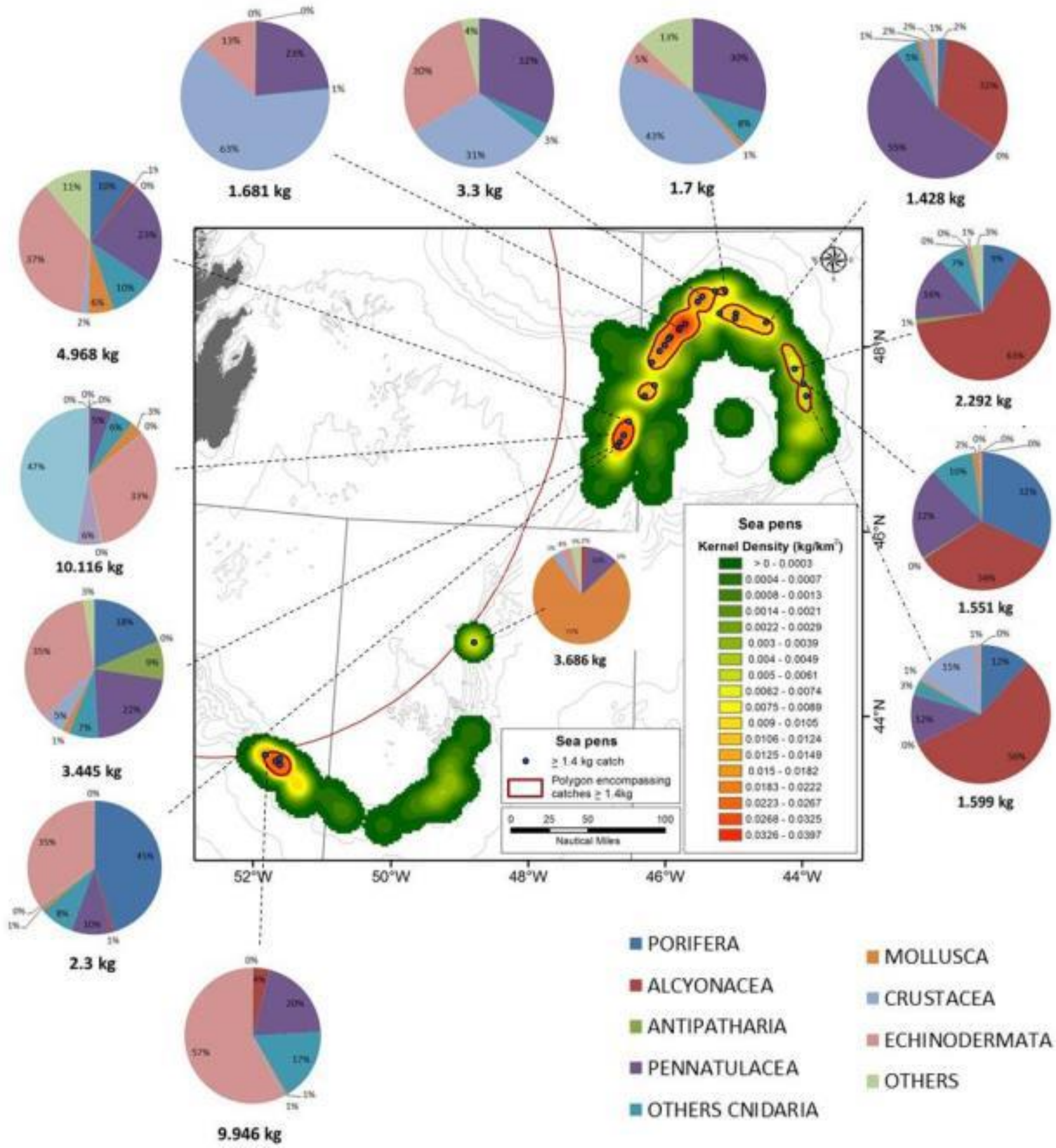


Figure 1.33. Pie charts representing the proportion of benthic taxa biomass in selected RV tows. Sea pen biomass is represented by Pennatulacea (purple colour). The total benthic biomass in the catch is indicated below each diagram in kg.

Review of Significant Concentrations of Small Gorgonian Corals

Significant concentrations of *Small Gorgonian Corals* have been determined previously in the NRA using kernel density analyses and an evaluation of the expansion of the area covered by successive density polygons to generate commercial trawl encounter thresholds based on simulation trawls for commercial fisheries (NAFO, 2012c). These analyses have been done using all available data from the RV trawl surveys. Specifically data from the Spanish 3NO survey (2002-2013), EU Flemish Cap Survey (2003-2013), and the DFO-NL Multi-species Surveys (1995-2012) were assessed. These data sources yielded 404 small gorgonian coral records (87 from the Canadian surveys and 317 from the EU-Spanish surveys). As for sponges and sea pens, there were significant differences among the catch series for each survey (P < 0.001). However, unlike those other VME indicators there was no weight threshold above which these differences were non-significant until the 0.1 kg threshold was reached (P = 0.408) at which level there were insufficient data to perform the analyses (N=36; less than 10% of the total number of small gorgonian records).

Consequently we examined the data by area. In the 3O Division, the small gorgonian weight catch distribution does not present significant differences for values ≥ 0.01 kg. In the 3L Division, where the small gorgonians seems to be more isolated, the weight catch distribution presents significant differences for all catches. In the 3N Division catches ≥ 0.02 kg were non-significant and could be combined for analyses (P=0.968). Combining data from Divisions 3NO, no significant differences in catch were found above 0.02 kg (N =85). Therefore separate analyses were run for Divisions 3NO and for Division 3M in order to maximize the amount of data that could be used (35 Canadian records and 227 EU-Spanish records). It seems that when small gorgonians are aggregated, the length or wide of the trawl set does not affect the catch, but with isolated colonies, higher swept area and longer trawl sets have more probability to caught larger catches.

Following previously established methods and assessment criteria, a kernel density surface was created for each area and the area of successive density polygons calculated. In 3NO the kernel density distribution identified small gorgonian VME in 3O with 3 VME areas on the slopes of Grand Bank in the southern portion of 3N along with some single record observations (Figure 1.34). The 0.15 kg/ RV tow density threshold emerged as defining significant concentrations of small gorgonian corals in this area (i.e., small gorgonian coral VME). When superimposed on the kernel density surface (Figure 1.34), the 0.15 kg density polygon captures all of the highest density areas (red colour on Figure 1.34) from the kernel analysis. Review of the data surrounding these polygons (Figure 1.35) shows that three of the areas are based on single records with null records surrounding them. These are not considered to be VME, although more research should be done around these areas. Those same data strengthen support for the high concentrations of small gorgonian corals in 3O being VME (Figure 1.35).

There were 145 records of small gorgonians in the catches for the Flemish Cap area (Division 3M). The majority of these were small catches (≤ 0.01 kg) with only 1 catch greater than 0.2 kg and 6 greater than 0.1 kg. These small catches were not highly aggregated and the analyses of the area occupied by successive density polygons supported that observation.

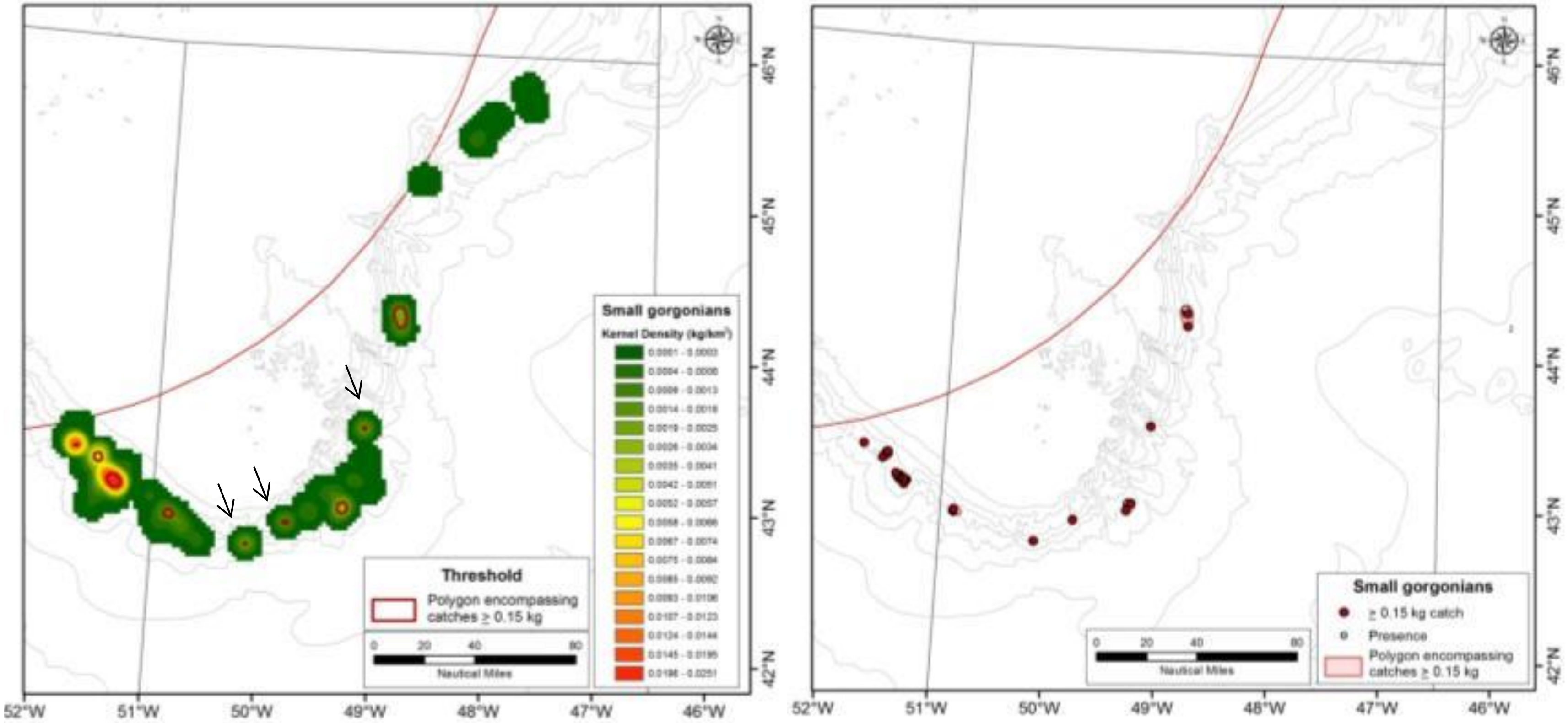


Figure 1.34. Left panel: Kernel density distribution of small gorgonian corals (primarily *Acanella arbuscula*) on the tail of Grand Bank in the NAFO Regulatory area with the 0.15 kg density polygons defining the small gorgonian coral VMEs superimposed in red. The green areas represent low small gorgonian coral densities while the red areas indicate high small gorgonian coral densities. Arrows point to catches that are not considered to be VME (see text). **Right panel:** The location of catches greater than 0.15 kg (red circle) and smaller small gorgonian coral (open circles) within the 0.15 kg density polygons defining the small gorgonian coral VMEs.

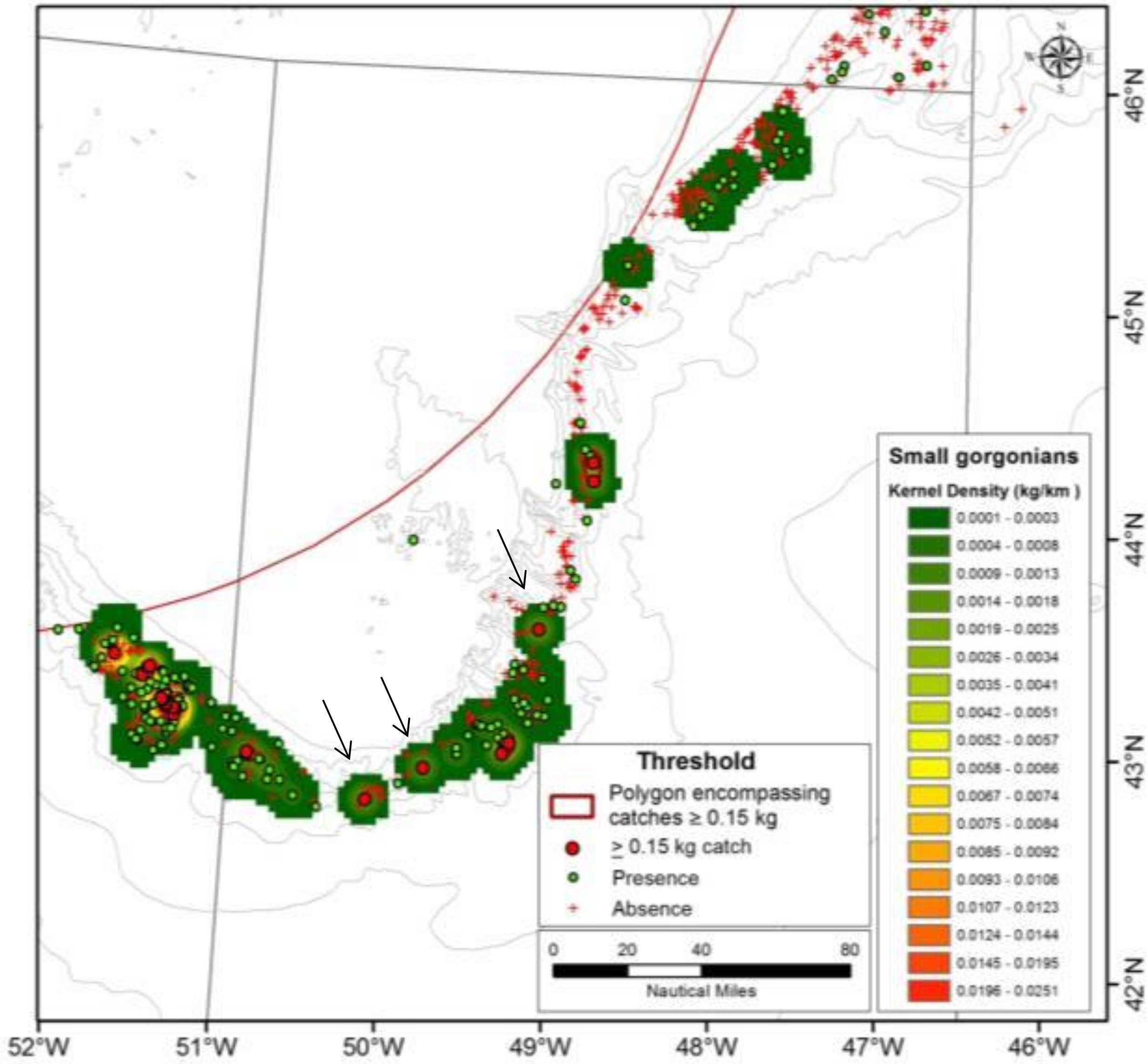


Figure 1.35. Kernel density distribution of small gorgonian corals (primarily *Acanella arbuscula*) on the tail of Grand Bank in the NAFO Regulatory area with the 0.15 kg density polygons defining the small gorgonian coral VMEs superimposed in red. The green areas represent low small gorgonian coral densities while the red areas indicate high small gorgonian coral densities. Catches greater than 0.15 kg of small gorgonian corals and all other catches are displayed. Valid records of null catches deeper than 400 m are also shown. Arrows point to catches above 0.15 kg that are not considered to be VME based on the number of observations in the area and the presence of null records.

Review of Significant Concentrations of Large Gorgonian Corals

Significant concentrations of *Large Gorgonian Corals* in the NRA were previously identified using the cumulative catch distribution (NAFO, 2008). Kernel density analyses and associated evaluation of the kernel surface were not applied to the Large Gorgonian Corals because it was known that these species are very fragile and their representation in the catch is most often in the form of coral fragments rather than whole colonies. It was thought that application of the approach would not represent the *in situ* abundance to the same degree as for sponges, sea pens and small gorgonian corals which are mostly caught as complete individuals. However, when plotting the distribution of the large gorgonian catches a highly aggregated pattern was observed and so the kernel analyses were performed.

These analyses have been updated using all available data from the RV trawl surveys. Specifically data from the Spanish 3NO survey (2002-2013), EU Flemish Cap Survey (2003-2013), the Spanish 3L Survey (2003-2013) and the DFO-NL Multi-species Surveys (1995-2012) were assessed. These data sources yielded 195 large gorgonian coral records (42 from the Canadian surveys and 153 from the EU-Spanish surveys). However as seen previously, there were significant differences among the catch series for each survey ($P < 0.001$). When all records less than 0.1 kg were removed, there was no significant difference among the catch distributions ($P=0.242$). Therefore the analyses were performed on 58 large gorgonian coral catches ≥ 0.1 kg (13 Canadian records and 45 EU-Spanish records). Following previously established methods and assessment criteria, a kernel density surface was created and the area of successive density polygons calculated. The kernel density distribution identified large gorgonian coral VME in Flemish Pass, on Beothuk Knoll and on the southeastern corner of Flemish Cap (Figure 1.36). The 0.6 kg/RV tow density threshold emerged as defining significant concentrations of large gorgonian corals (i.e., large gorgonian coral VME). When superimposed on the kernel density surface (Figure 1.36), the 0.6 kg density polygon captures all of the highest density areas (red colour on Figure 1.36) from the kernel analysis and other smaller catches are found within the defining polygons. Four of the areas are based on single records. Of these four, the catch closest to the area of highest densities in the western section of the Flemish Cap, around 500 m depth, is surrounded with other large gorgonian catches below the threshold and this could also constitute a VME. However, the other three catches (north Flemish Pass and slope of the tail of the Grand Bank) are surrounded with null records, so they are not considered to be VME at the moment, although more research should be done around these areas using benthic imagery. Therefore the analyses performed well despite the assessment of coral fragments rather than of whole colonies.

Species distribution models (SDM) were performed on presence/absence data of large gorgonian corals from the RV surveys, NEREIDA benthic imagery and rock and scallop dredge samples generally following Knudby *et al.* (2013a) as detailed in Knudby *et al.* (2013c). The response variable data used by Knudby *et al.* (2013a,b) was dominated by the sponge catches from the research vessel surveys. For large gorgonian corals, many records came from the NEREIDA benthic imagery which accumulated large numbers of observations over small spatial scales. This produced distorted predictions surfaces in the analyses. In order to balance the scale of these observations to match the scale of the prediction we divided the analytical extent into 0.017 degree cells and each grid cell was given a presence/absence or no data value, with only the presence/absence cells being used. The spatial extent of the model was to 2500 m. The model fit was very good (AUC = 0.885) although not as high as for the sponge grounds (see above). Eleven predictor variables were used in the model (Knudby *et al*., 2013c) with minimum shear and depth being the most important in the permutations to increase AUC. The large gorgonian corals have a high prediction presence when minimum bottom shear is greater than 0.005 Pa and depth is greater than 1400 m. The SDM prediction surface shows a good fit with the training data (Figure 1.37) and should be used when considering the *likely* presence of these species in data poor areas. The prediction surface (Figure 1.37) identifies the area of significant concentrations of large gorgonian corals in Flemish Pass identified using the kernel density analyses (Figure 1.36) but the area of highest probability of occurrence is along the deep south and eastern slopes of Flemish Cap where there is little data available from the surveys. This is consistent with the influence of the North Atlantic Current (see ToR 3.2). The model also predicts that large gorgonian corals will be present in the deeper water of the Sackville Spur area. Although underwater cameras have confirmed the presence of large gorgonian corals in the eastern portion of this area they did not appear in the western transects (Beazley *et al*., 2013a). Although the habitat may be suitable on Sackville Spur the dense sponge grounds in this area may out compete the coral.

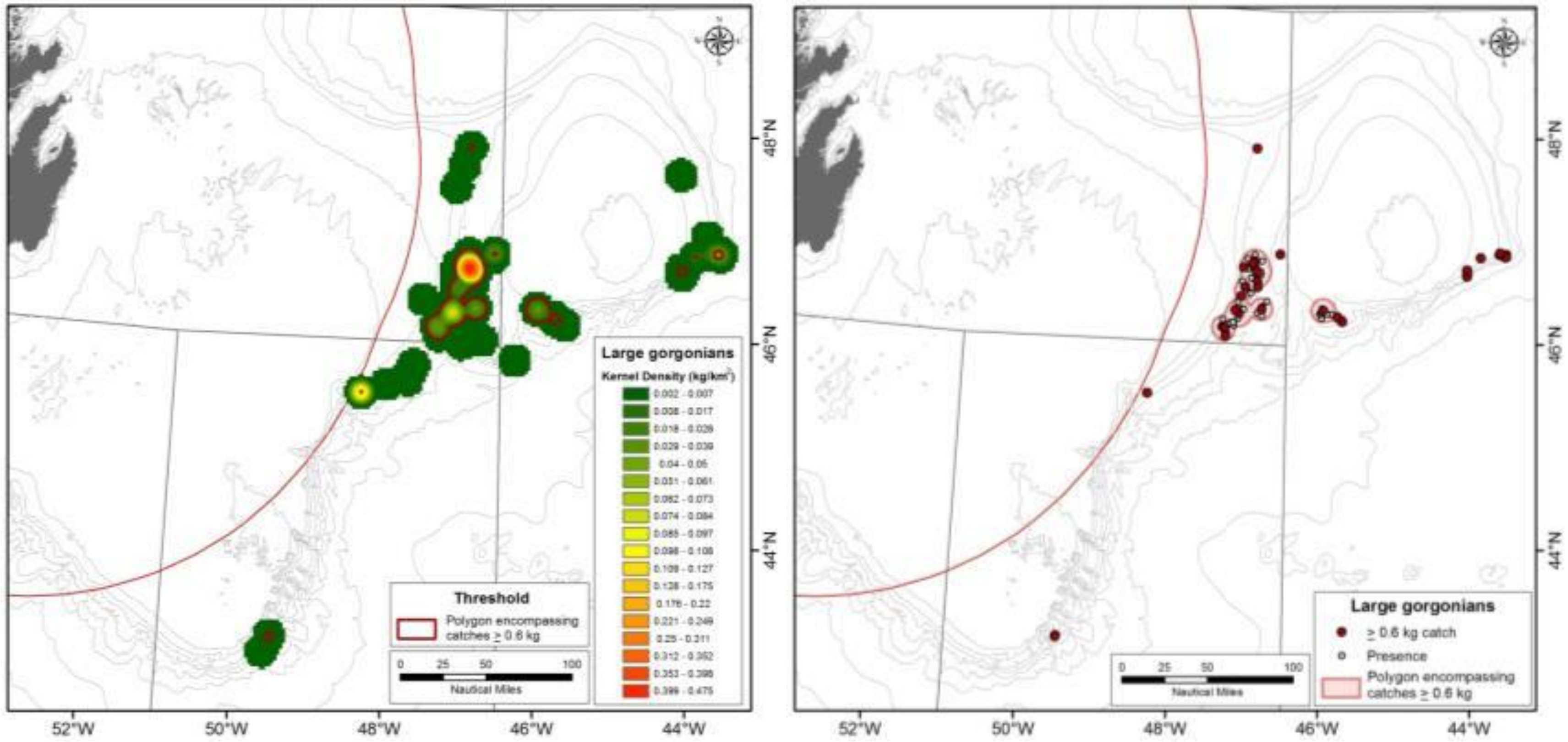


Figure 1.36. Left panel: Kernel density distribution of large gorgonian corals in the NAFO Regulatory area with the 0.6 kg density polygons defining the large gorgonian coral VMEs superimposed in red. The green areas represent low coral densities while the red areas indicate high coral densities. **Right panel:** The location of catches greater than 0.6 kg (red circle) and smaller coral catches (open circles) within the 0.6 kg density polygons defining the large gorgonian coral VMEs.

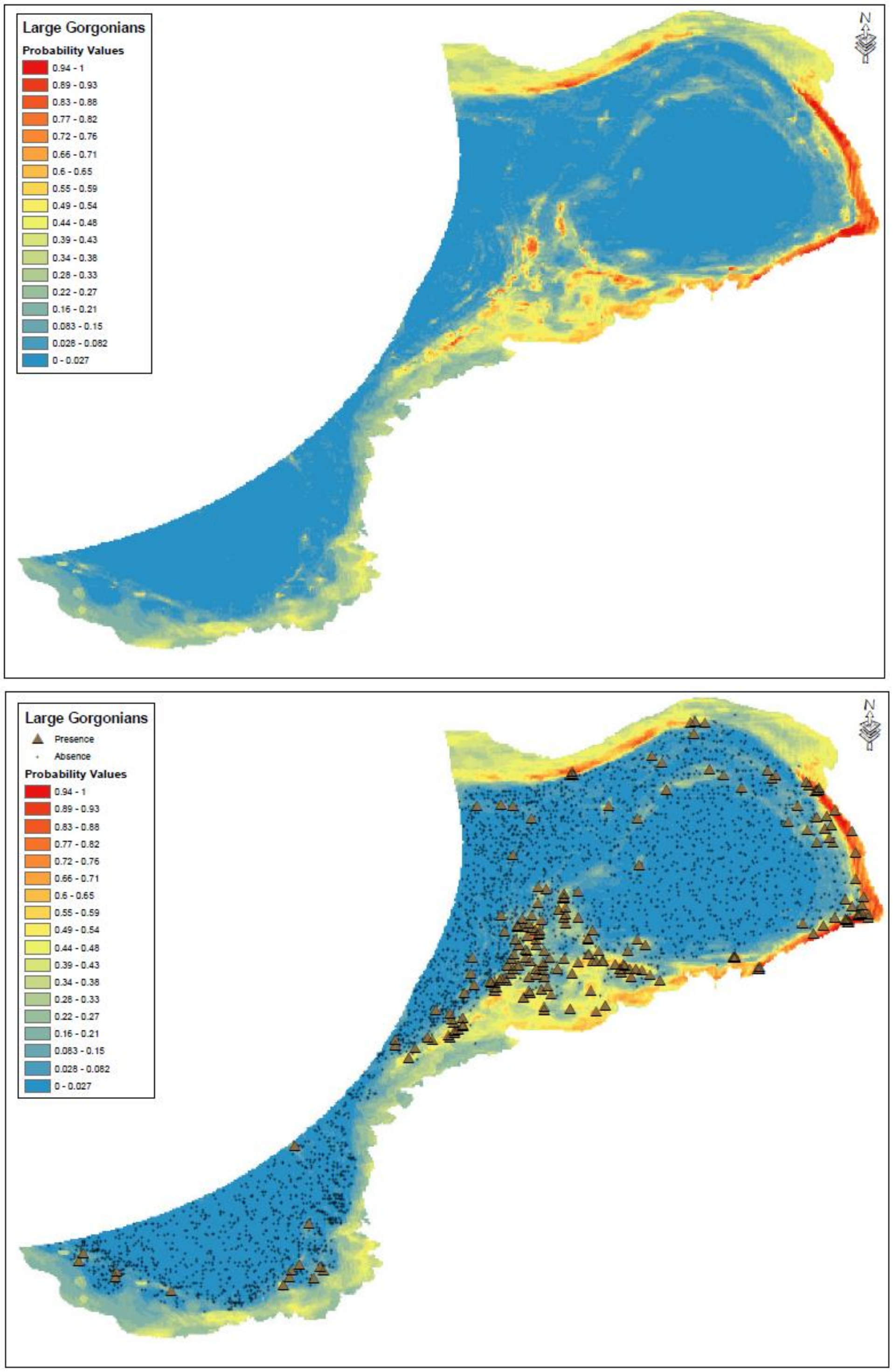


Figure 1.37. Upper Panel: Large gorgonian coral presence prediction surface for the NRA based on random forest species distribution modelling of the presence/absence data from the RV surveys and the analysis of 23 environmental variables. **Lower Panel:** The large gorgonian coral presence prediction surface showing the location of the presence and absence data used to train the model.

Review of Significant Concentrations of Tube-dwelling Anemones

Tube-dwelling anemones were observed on several *in situ* photographic transects across the Flemish Cap (Figure 1.38). The lack of taxonomic details from the photographs and video prevented the identification of these organisms past the family level (Cerianthidae). However, these cerianthids were not large, erect species, and do not appear to be the VME indicator species listed in NAFO (2012b), *Pachycerianthus borealis*. Although their ability to form habitat for other species may be limited, these cerianthids formed dense fields (Beazley *et al*., 2013a) on the southern Flemish Cap slope that may indicate VMEs, particularly if their bioturbation activities significantly affect infaunal community structure. Similarly the data from the RV surveys and NEREIDA rock and scallop dredge samples were only identified to Order (Ceriantharia) and may contain non-VME cerianthid species.

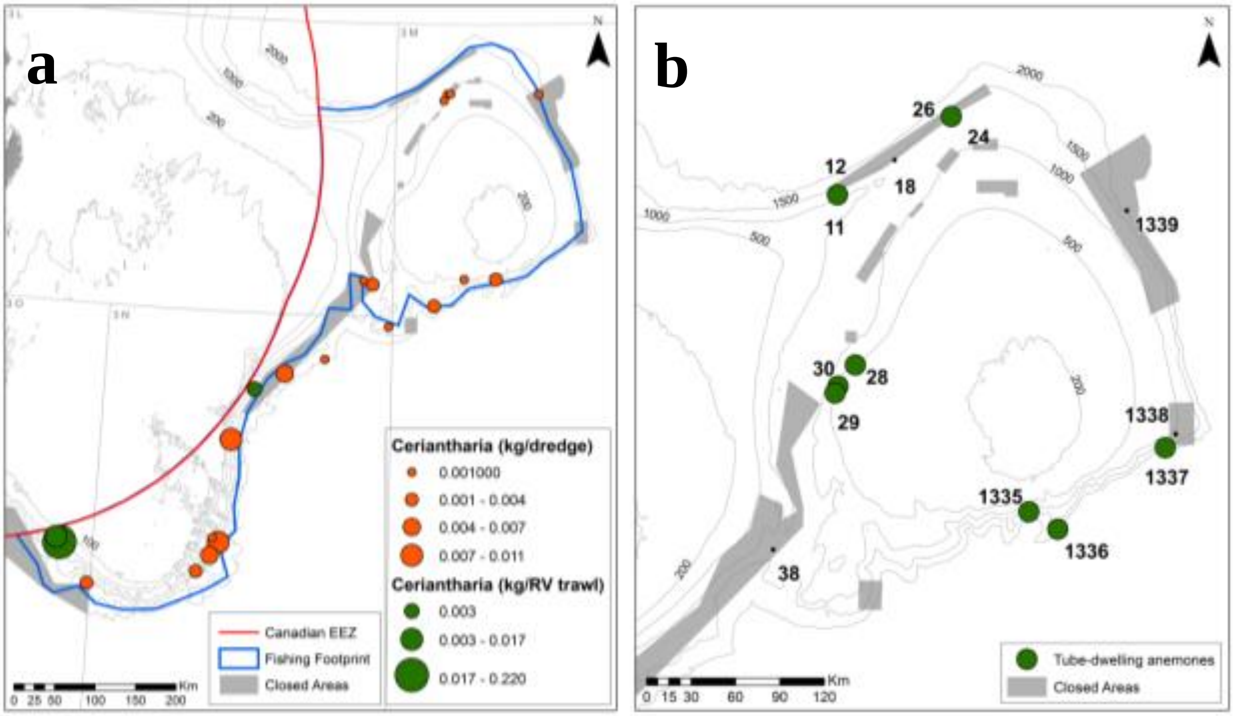


Figure 1.38. a) Relative abundance of Ceriantharia collected in the NRA during the NEREIDA surveys between 2009-2010 using a rock dredge (orange) and EU-Spain research trawl surveys between 2006-2013 (green), b) Presence of tube-dwelling anemones (Family Cerianthidae) on video and photographic transects collected from the Flemish Cap area in 2009 and 2010.

Review of Significant Concentrations of Erect Bryozoans

Significant concentrations of *Erect Bryozoans* in the NRA have not previously been identified using kernel density analyses and associated evaluation of the kernel surface. A kernel analysis is presented here for Erect Bryozoans on the tail of Grand Bank using all available data from the RV trawl surveys. Specifically data from the Spanish 3NO and 3L surveys (2002-2013) were assessed. These data sources yielded 340 erect bryozoan records. Following previously established methods and assessment criteria, a kernel density surface was created and the area of successive density polygons calculated. The kernel density distribution identified significant concentrations of erect bryozoans on the tail and nose of the Grand Bank (Figure 1.39). The 0.2 kg/RV tow density threshold emerged as defining significant concentrations of erect bryozoans. The percent change in area was 73.1 between polygons created by 0.2 kg and those created by 0.1 kg with 9 additional points used to create the 0.1 kg polygon. When superimposed on the kernel density surface (Figure 1.39), the 0.2 kg density polygon captures all of the highest density areas (red colour on Figure 1.39) from the kernel analysis and other smaller catches are found within the defining polygons.

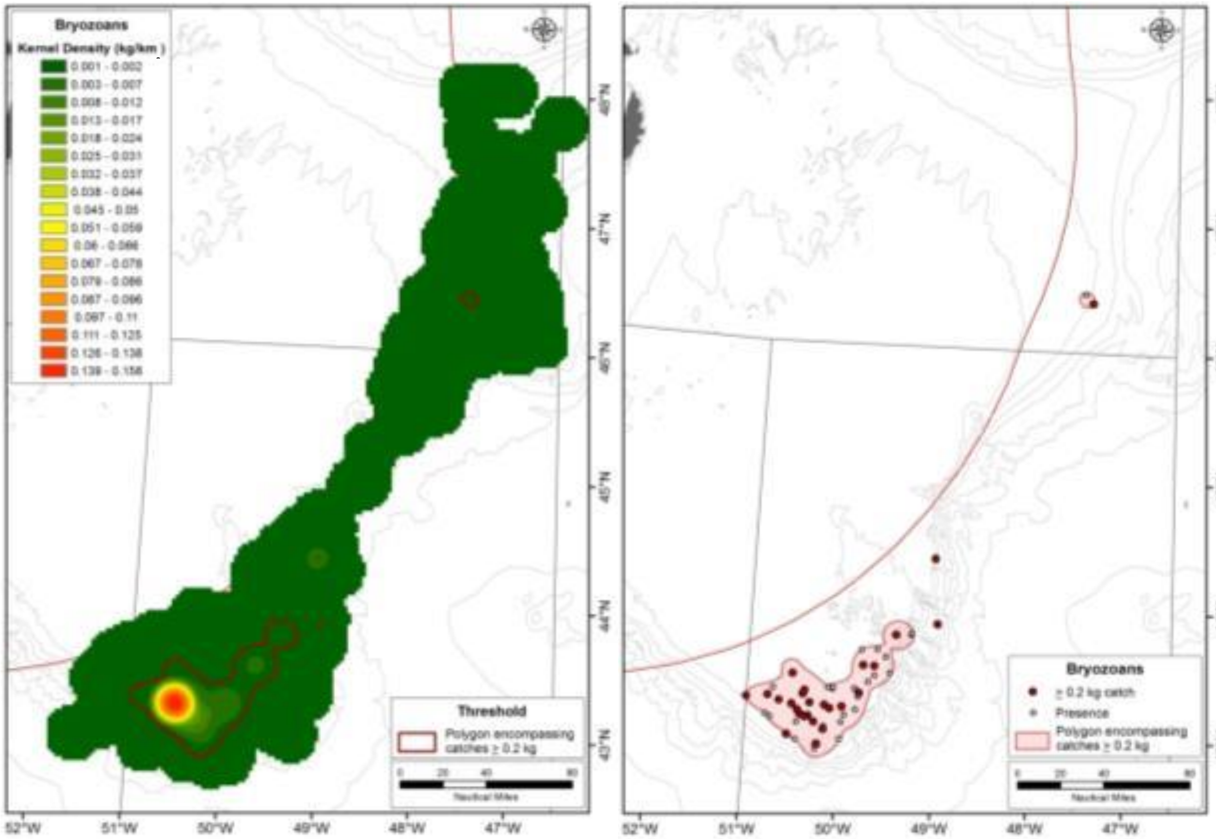


Figure 1.39. Left panel. Kernel density distribution of erect bryozoans on the tail and nose of the Grand Bank of Newfoundland and Flemish Pass with the 0.2 kg density polygons defining the bryozoans VMEs superimposed in red. The green areas represent low bryozoan densities while the red areas indicate high bryozoan densities. **Right panel.** The location of catches greater than 0.2 kg (red circle) and smaller bryozoan catches (open circles) within the 0.2 kg density polygons defining the bryozoan VMEs.

Therefore the analyses performed well and can be used to identify significant concentrations. Two of the locations identified are comprised of single catches greater than 0.2 kg. These are on the tail of Grand Bank. The catch closest to the large polygon demarcating the significant concentration of erect bryozoans is surrounded by smaller catches and should be considered a significant concentration. The catch to the north is surrounded by null records, however there are smaller catches in the general area. The WGESA recommend that *in situ* camera surveys be done to evaluate the nature of these significant concentrations given that nothing is known about the catchability of the trawls for this taxon. The main bryozoan species that constitutes the significant concentrations is *Eucratea loricata*.

Review of Significant Concentrations of Crinoids

Crinoids are delicate organisms that are not well-sampled by trawl nets although they are represented in the catch (Figure 1.40a). The NEREIDA photographic transects provide *in situ* evidence for dense aggregations of this VME indicator (Figure 1.40b). The stalked crinoid *Conocrinus lofotensis*, a VME indicator species, was observed in high abundances on the Sackville Spur, but was completely absent from the Flemish Pass area. Video analysis revealed dense fields of the stalked crinoid *Gephyrocrinus grimaldii* on the southern, southeastern, and northeastern slope of the Flemish Cap. This species was completely absent on transects from the Sackville Spur and Flemish Pass area. Unstalked crinoids were not observed in high abundances on any transect analyzed. The data from the RV surveys were only identified to Class (Crinoidea) but do identify crinoids in Flemish Pass and on Grand Bank that were not seen with the benthic imagery.

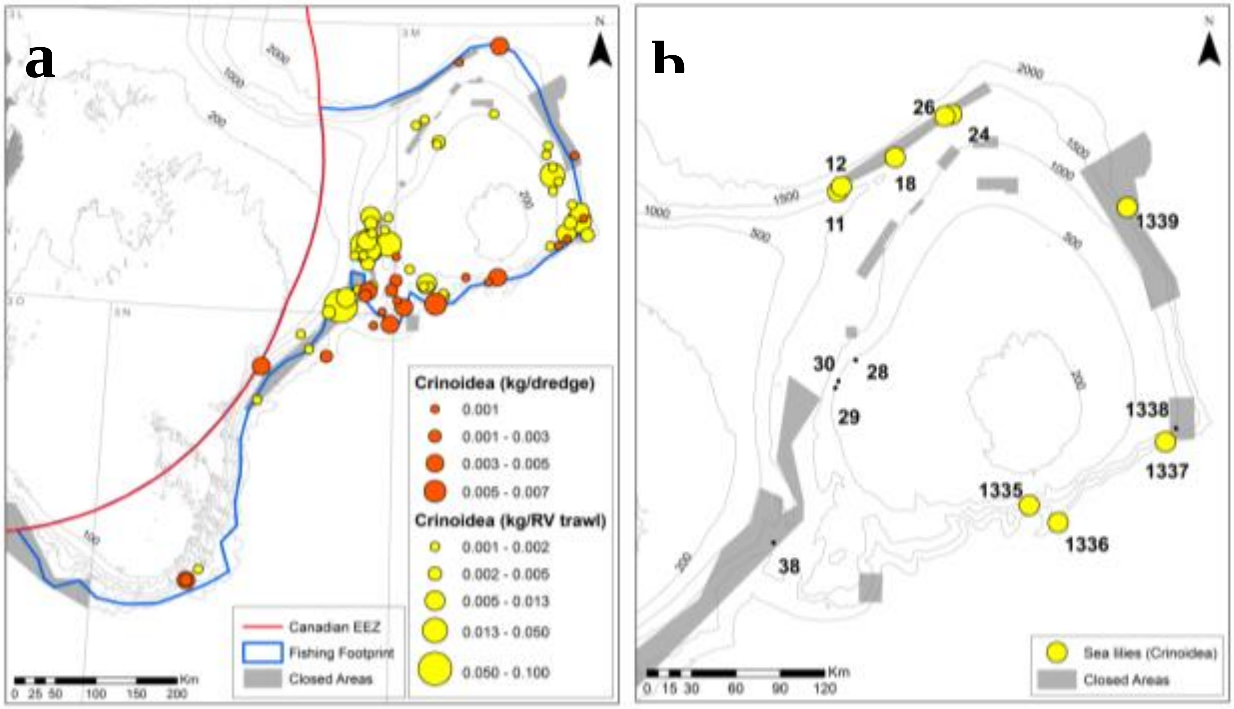


Figure 1.40. a) Relative abundance of Crinoidea collected in the NRA during the NEREIDA surveys between 2009-2010 using a rock dredge (orange) and EU-Spain research trawl surveys between 2006-2013 (yellow), b) Presence of sea lilies (*Conocrinus lofotensis* and *Gephyrocrinus grimaldii*; Crinoidea) on video and photographic transects collected from the Flemish Cap area in 2009 and 2010.

Review of Significant Concentrations of Large Sea Squirts

Large sea squirts (specifically stalked tunicates) were identified as VME indicators in Murillo *et al.* (2011b) and accepted by NAFO as such (NAFO, 2012b). Maps of their distribution in the NRA have been prepared previously but no quantitative assessment had been undertaken. There are 87 records of Large sea squirts, mainly of *Boltenia ovifera*, a habitat-forming stalked tunicate VME indicator, and all are located on the tail of Grand Bank. Beazley *et al.* (2013a) did not observe any on their photographic transects on Flemish Cap, and none were collected in the NEREIDA box cores or rock and scallop dredge samples.

Following previously established methods and assessment criteria, a kernel density surface was created and the area of successive density polygons calculated. The analysis performed well and a clear threshold value of 0.3 kg was established. There was a 104% increase in area going from the 0.3 kg density polygon area to the 0.2 kg density polygon area. This was the largest percent increase in area in the series after the establishment of the initial areas at 3 and 2 kg. The polygon area enclosed by the 0.2 kg catches was increased through joining smaller VME areas and only 5 additional points created the increased area. The kernel surface and the location of the 0.3 kg polygons representing the stalked tunicate VMEs are illustrated in Figure 1.41. The VME areas coincide with the highest density areas of the kernel analysis. Review of the data surrounding the areas based on single records shows other nearby smaller catches except for the most northern record which is surrounded by null records. The northern record is not considered to be VME at the moment, although more research should be done around these areas. The others should be considered VME. Therefore the analyses performed well and can be used to identify significant concentrations. The WGESA recommended that *in situ* camera surveys be done to evaluate the nature of these significant concentrations given that nothing is known about the catchability of the trawls for this taxon.

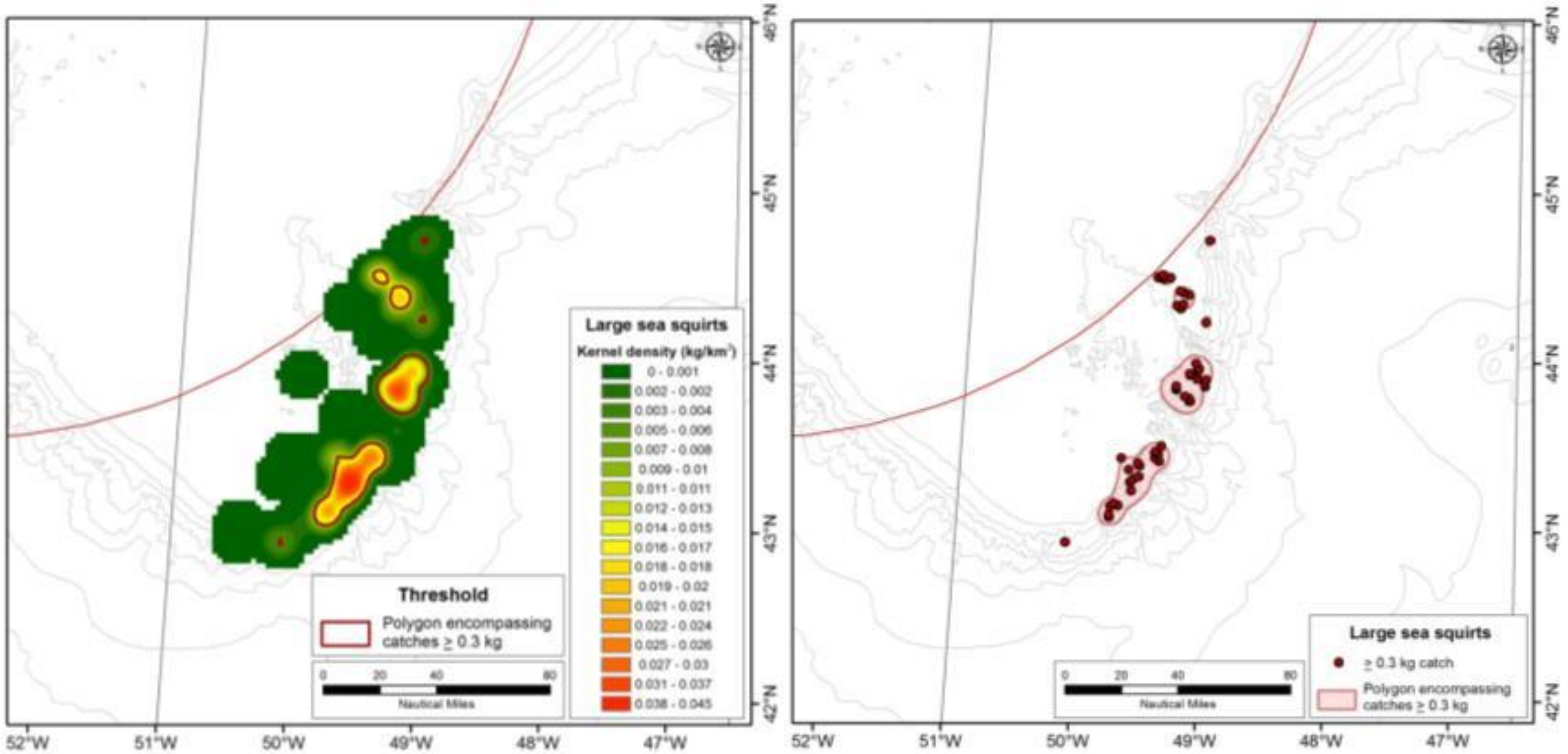


Figure 1.41. Left panel: Kernel density distribution of large sea squirts (mainly *Boltenia ovifera*) in the NAFO Regulatory area with the 0.3 kg density polygons. The green areas represent low large sea squirt densities while the red areas indicate high densities. **Right panel:** The location of catches greater than 0.3 kg (red circle) within the 0.3 kg density polygons.

Review of Black Coral Distribution

Black corals are extremely long-lived fragile species that are widely distributed at low density in the NRA and in the broader North Atlantic and for this reason they are not considered VME indicators by NAFO, but rather as iconic species (NAFO, 2011b). The most common species in the NRA is *Stauropathes arctica*. They are non-aggregating and therefore are not suitable candidates for the kernel density models used for other VME indicators. Consequently it has been difficult to advice on conservation strategies for this group. The species distribution modeling of the benthic sponges in the NRA (Knudby *et al*., 2013a,b) was very successful and a similar approach has been used here to identify areas where there is a high probability of black coral occurrence.

Species distribution models (SDM) were performed on presence/absence data of black corals from the RV surveys, NEREIDA benthic imagery and rock and scallop dredge samples following Knudby *et al*. (2013a) as reported in Knudby *et al.* (2013c). The spatial extent of the model was to 2500 m. As most data came from the RV surveys there was no need to reduce the number of records in an area as for the large gorgonian corals. The model fit was excellent (AUC = 0.937) with the known occurrences and absences fitting well within their predicted areas. Seven predictor variables were used in the best fit model: maximum surface salinity, average bottom temperature, minimum surface temperature, depth, average winter chl *a*, minimum bottom shear and maximum bottom salinity (Knudby *et al*., 2013c). The prediction surface (Figure 1.42) shows a ring around the Flemish Cap with high prediction areas on the eastern portion. Black coral have a low probability of occurrence on the tail of Grand Bank.

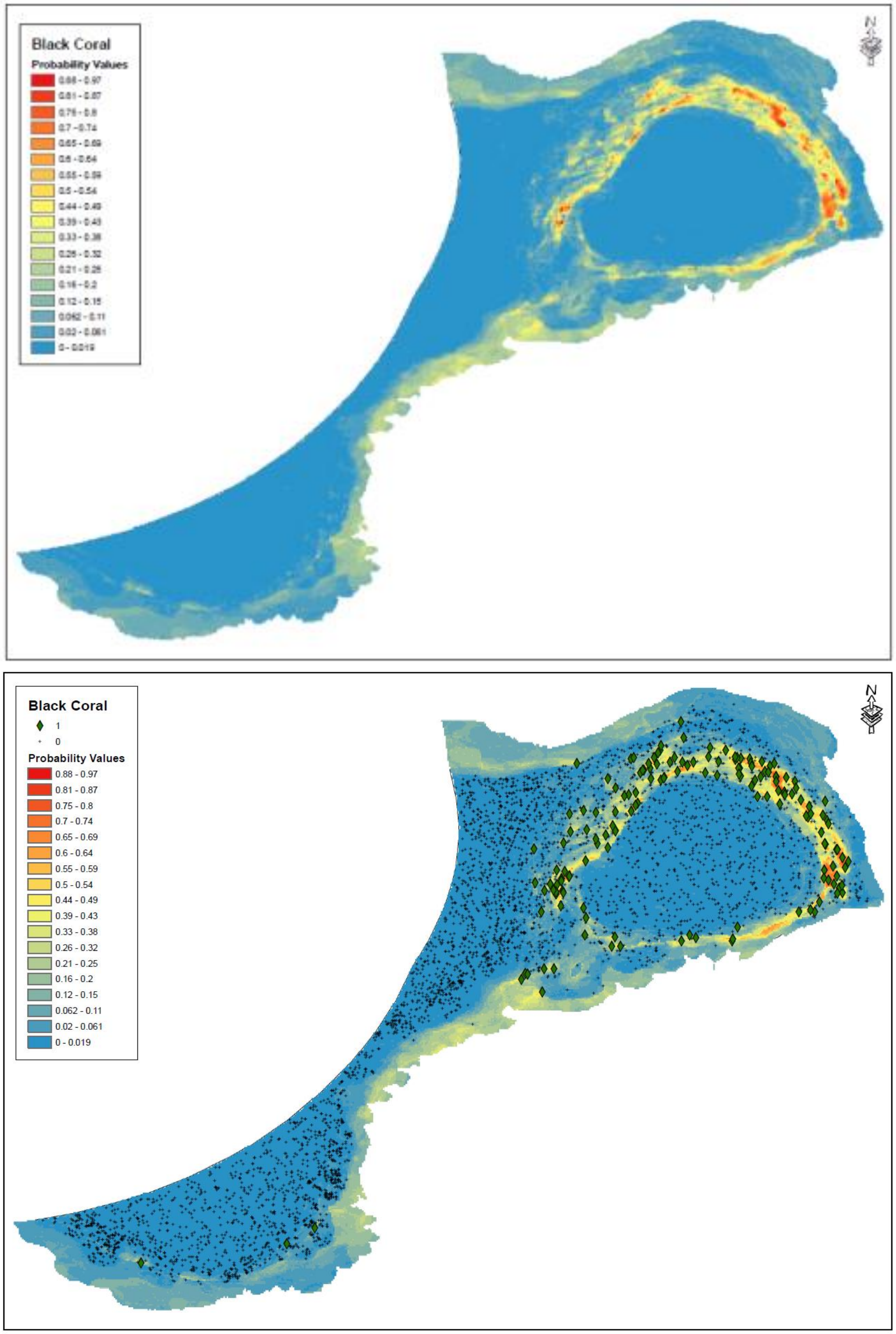


Figure 1.42. Upper Panel: Black coral presence prediction surface for the NRA based on random forest species distribution modelling of the presence/absence data from the RV surveys and the analysis of 23 environmental variables. **Lower Panel:** The black coral presence prediction surface showing the location of the presence and absence data used to train the model.

1.B.ii. Evaluate and provide advice on effectiveness of current closures and prioritize areas for WGEAFFM

Review of Closed Areas in the NRA

For each of the existing closed areas in the NRA an assessment of the effectiveness of the closure, with justification, is provided. To assist in evaluation two panels of maps are presented for each area. In the first panel all VMEs (VME polygons with associated catches within them for sponges large and small gorgonian corals and sea pens), significant concentrations of other VME taxa (erect bryozoans, large sea squirts) and presence of biological VME indicator taxa (Crinoidea, tube dwelling anemones) as well as black corals are illustrated. This same map is reproduced with the available VMS data (2010 – mid 2013) overlain to show the current fishing patterns. The last map in the first panel shows the location of the VME elements and NEREIDA multibeam data where available. The second panel presents the species distribution models with probability of occurrence for black corals, large gorgonian corals, sponges and sea pens. Superimposed on these maps, for reference to the first panel, are the catches from within the VME polygon areas shown in the first panel and the presence of black corals. Full information on the location of all data used in the SDMs are presented above under the Review of VME and VME elements in the NRA.

Division 3O Coral Closure

Only the portion of 3O in the NRA considered in the analyses based on the request from FC.

Assessment: Inadequate

Justification/Rationale (Figures 1.43 and 1.44): There are no data to support the presence of VME or VME indicators in the closed area. Sea pen and small gorgonian VME are found immediately adjacent to the existing closure. The species distribution models (SDMs) for large gorgonian corals and sponge VME indicators and black coral do not show large areas of high probability of occurrence in this area. The SDM for sea pens shows moderately high probabilities of occurrence within the closed area and high probabilities in the areas where the VME polygons have been identified. There is a very high probability of occurrence in the notched area of the closure between 800 and 1000 m where small gorgonian VME have been identified.

VME elements: shelf indenting canyons and canyons with heads > 400 m in the closed area have potential to have VME; Only a partial picture of the canyons is available due to the extent of the NEREIDA multibeam bathymetric data coverage.

VMS data show high density of fishing activity close to the unprotected VME areas which pose a high risk to those VME.

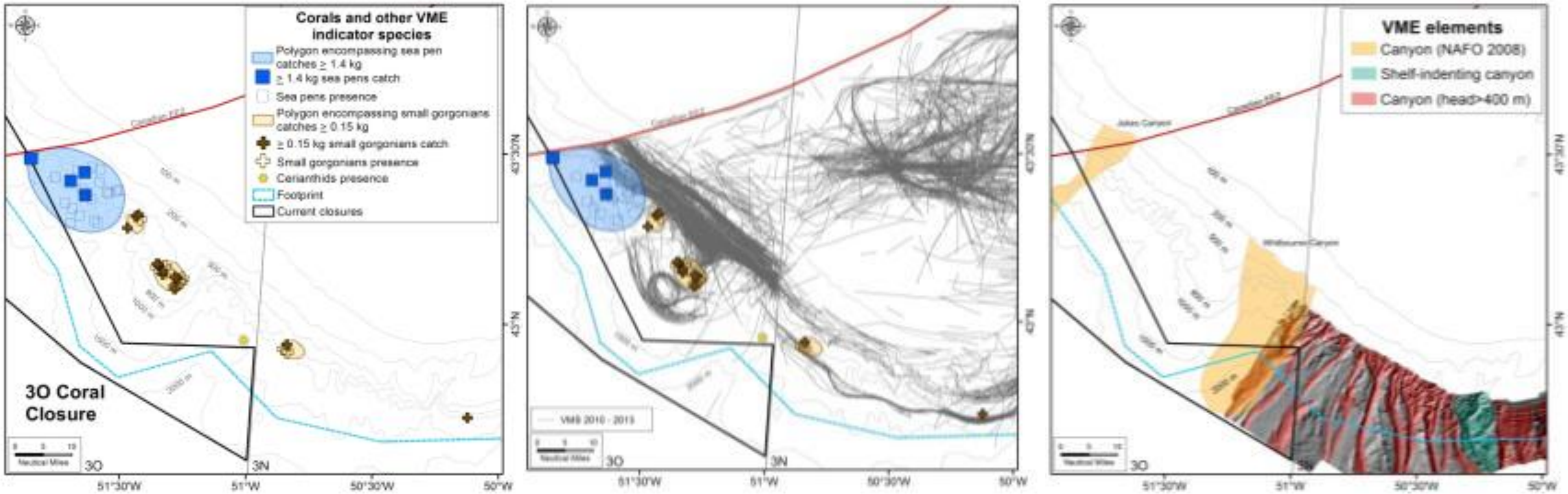


Figure 1.43. Area of 3O Coral Closure. VMEs and VME indicator species (left), VMS data (middle), and VME elements and NEREIDA multibeam (right).

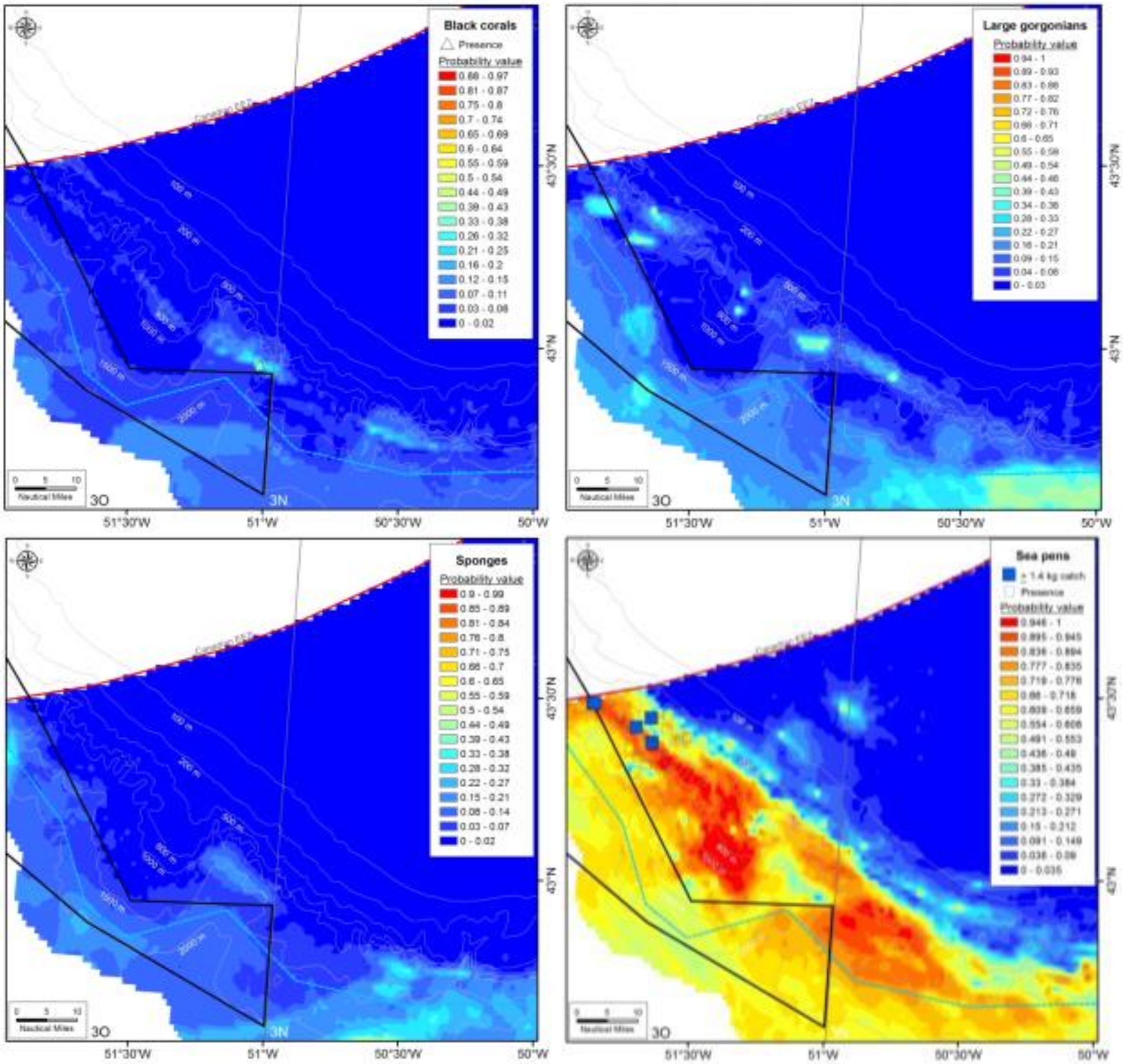


Figure 1.44. Area of 3O Coral Closure. Black coral probability of occurrence (upper left), large gorgonian corals probability of occurrence (upper right), sponge grounds probability of occurrence (lower left), sea pen corals probability of occurrence (lower right).

Area 1 Tail of the Bank

Assessment: Inadequate for general area but area 1 is partially adequate for sponges

Justification/Rationale (Figures 1.45 and 1.46): A portion of sponge VME is protected. Very high probability of occurrence (80-84%) of sponge grounds VME in the deeper waters east of the closure and inadequate coverage of the sponge VME polygon.

Relatively unique to NRA but spatially extensive areas of new VME indicator taxa, stalked tunicates (large sea squirts) and bryozoans which are in an area of significant fishing activity. The close proximity of the large gorgonian coral VME, small gorgonian VME and presence of crinoids with the significant concentrations of sea squirts and bryozoans gives priority to that area in terms of risk and significance (this is a good area for a depth related closure). This area also appears to have a different geomorphology in that there is a high concentration of canyons indenting the shelf than in other areas along the slope. The SDM for sea pens indicates high probability of occurrence in the deeper waters in this area.

The SE Shoal is a prominent feature in the area and has previously been designated as a candidate VME. This shallow water area could be a good upper limit to depth related closures.

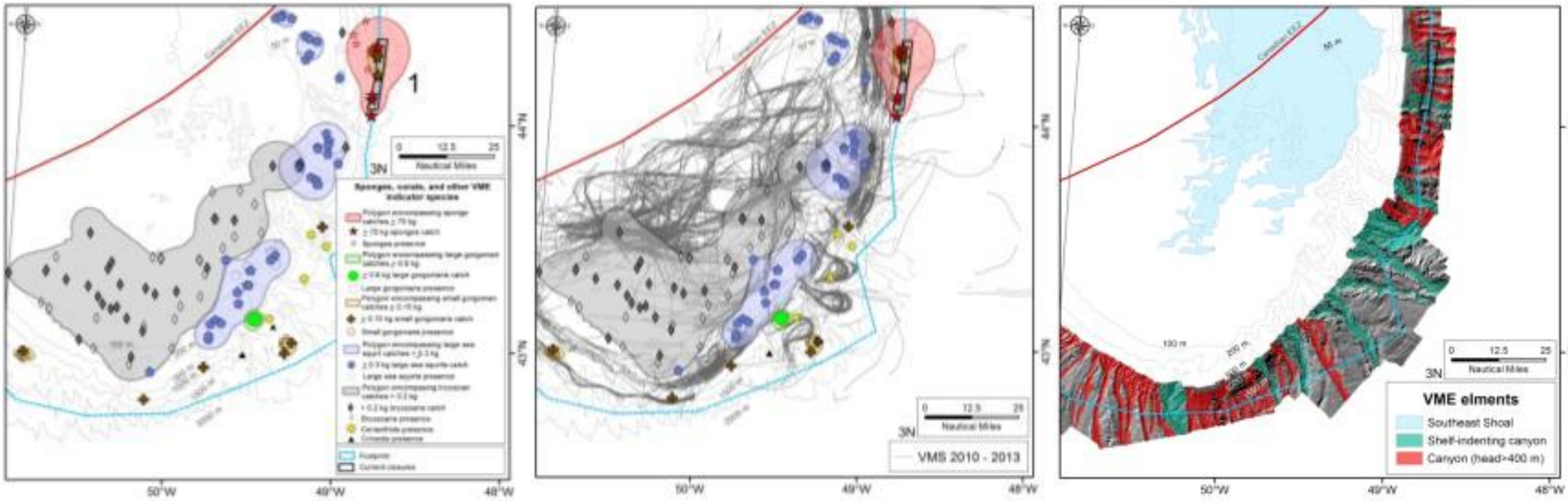


Figure 1.45. Area 1. VMEs and VME indicator species (left), VMS data (middle), and VME elements and NEREIDA multibeam (right).

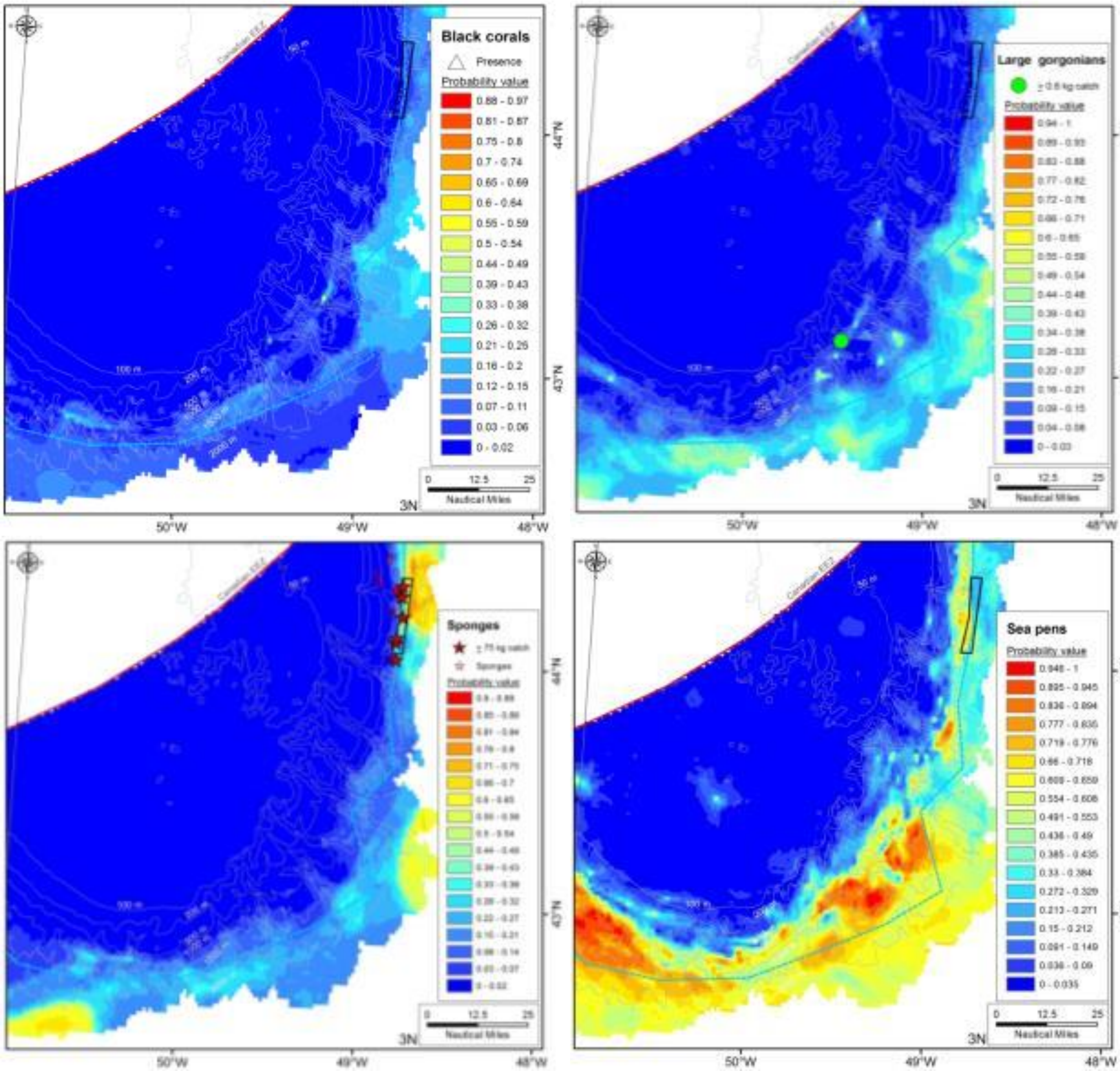


Figure 1.46. Area 1. Black coral probability of occurrence (upper left), large gorgonian corals probability of occurrence (upper right), sponge grounds probability of occurrence (lower left), sea pen corals probability of occurrence (lower right).

Area 2 Flemish Pass/Eastern Canyon Southern Portion

Assessment: Adequate in southern area.

Justification/Rationale (Figures 1.47 and 1.48): Closure is capturing the areas of highest probability of occurrence of sponges. Sponge catches outside the closed area within the VME area should be considered. There are large gorgonian coral present outside the closed area as well. Probability of occurrence of large gorgonians is high in the closed area. SDMs do not indicate high probabilities of occurrences of black corals or sea pens.

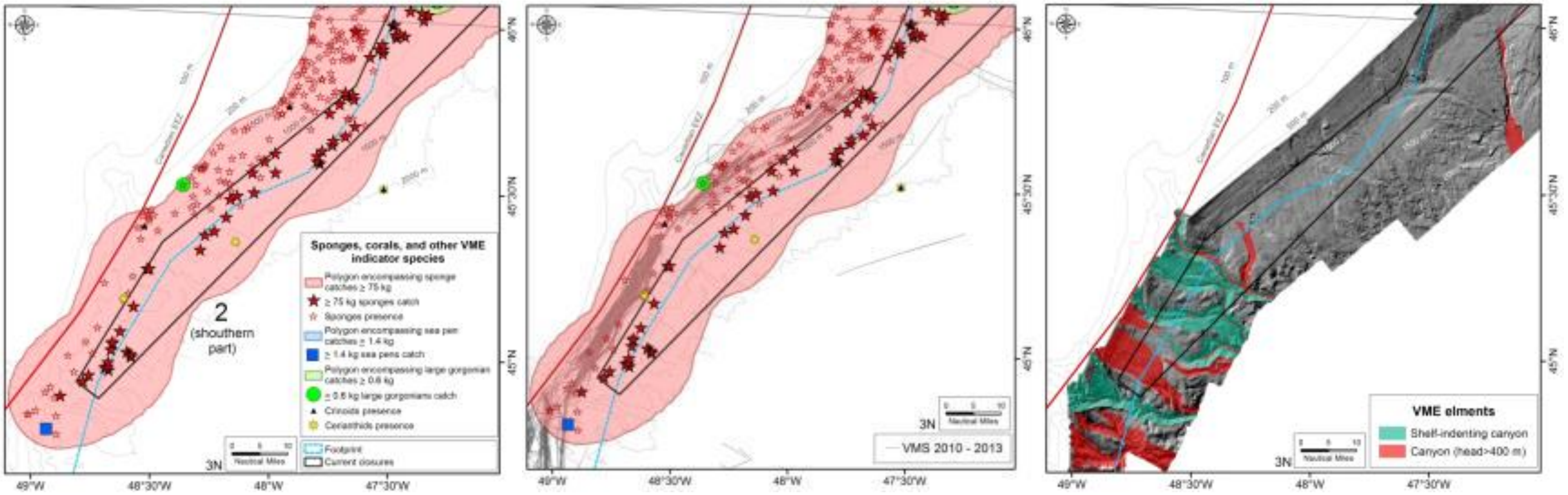


Figure 1.47. Area 2 Southern Portion. VMEs and VME indicator species (left), VMS data (middle), and VME elements and NEREIDA multibeam (right).

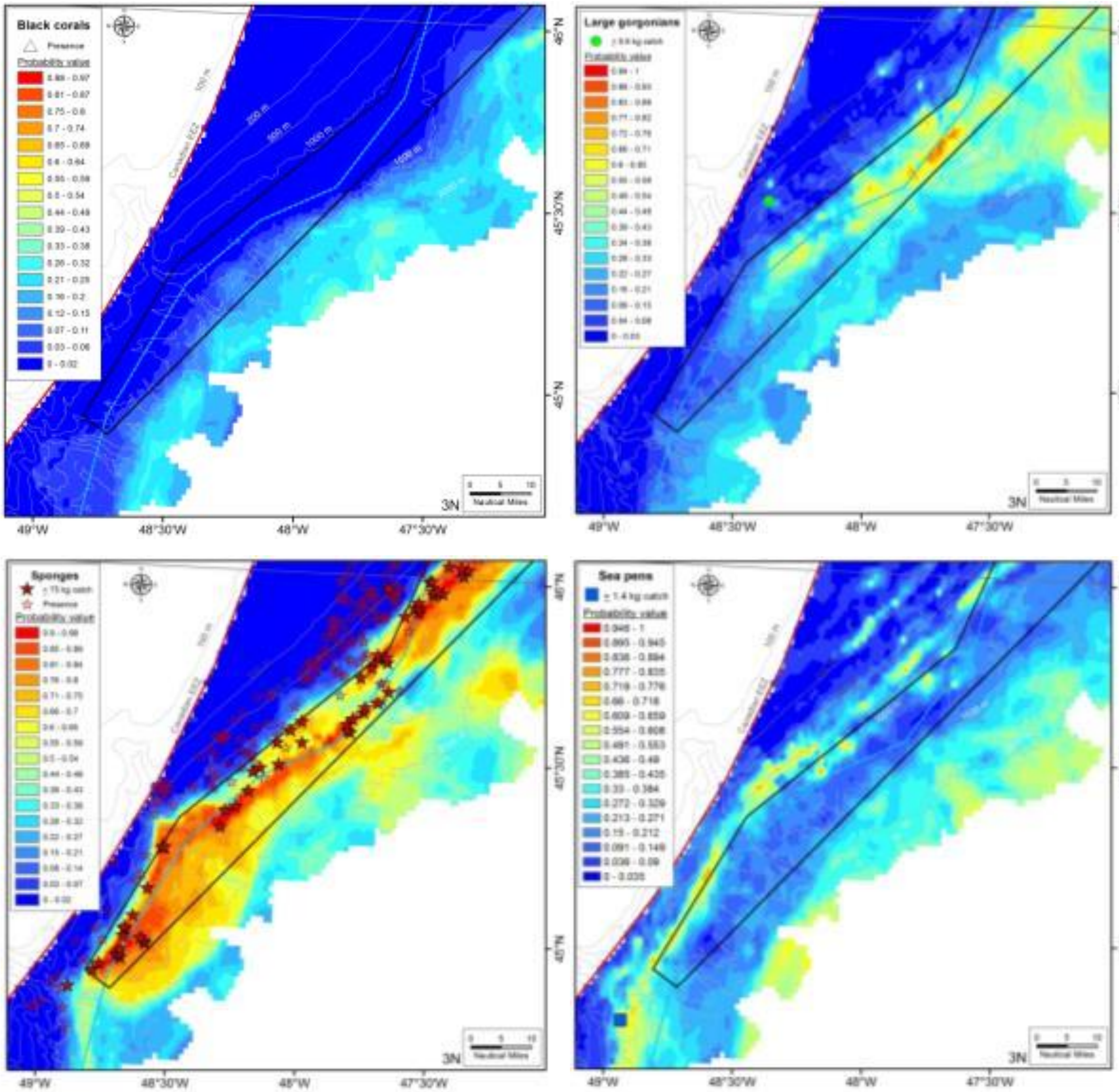


Figure 1.48. Area 2 Southern Portion. Black coral probability of occurrence (upper left), large gorgonian corals probability of occurrence (upper right), sponge grounds probability of occurrence (lower left), sea pen corals probability of occurrence (lower right).

Area 2 Upper Flemish Pass Portion including Area 3 Beothuk Knoll

Assessment: Area 2 Upper Flemish Pass Portion: Inadequate in northern area.

Justification/Rationale (Figures 1.49 and 1.50): Black coral high probability of occurrence areas could be captured through an extension of the current closure. Large gorgonians adequately covered but probability of occurrence outside identifies an area that overlaps with the black coral. There is also a large catch of large gorgonians there, as well as the presence crinoids and cerianthid VME indicators. There is currently no fishing in this area. There is a high probability for the presence of sea pens north of the current closure, part of which is captured in the current closure. In notched area there is sponge and gorgonian corals VME and that part is inadequate. VME elements in the area would be better captured in the notched area as well.

This is also an area where there is no survey as the bottom is considered too rough. This may be a relatively pristine area within the fishing footprint of Flemish Pass.

Assessment: Area 3 Beothuk: Adequate of itself, inadequate for the larger area.

Justification/Rationale (Figures 1.49 and 1.50): Justification for a new closure in the area based on the presence of crinoids, large gorgonian VMEs, sponge VME. This area is not fished at present. VME elements include the steep flanks and canyons with heads greater than 400 m.

Outside the fishing footprint there is an area of high probability of occurrence of large gorgonians and sponges that extends across the southern wall of FC to area 4. There are steep flanks and canyons with heads greater than 400 m along this area. This southern wall should be included in a closed area.

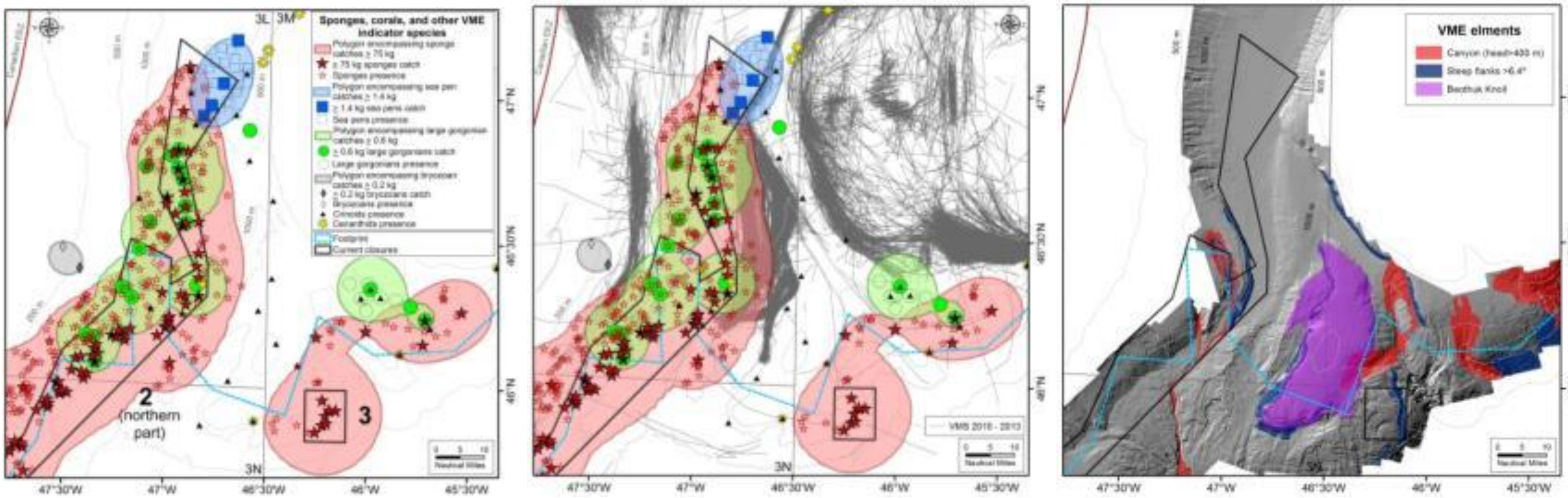


Figure 1.49. Area 2 northern portion and Area 3 Beothuk Knoll. VMEs and VME indicator species (left), VMS data (middle), and VME elements and NEREIDA multibeam (right).

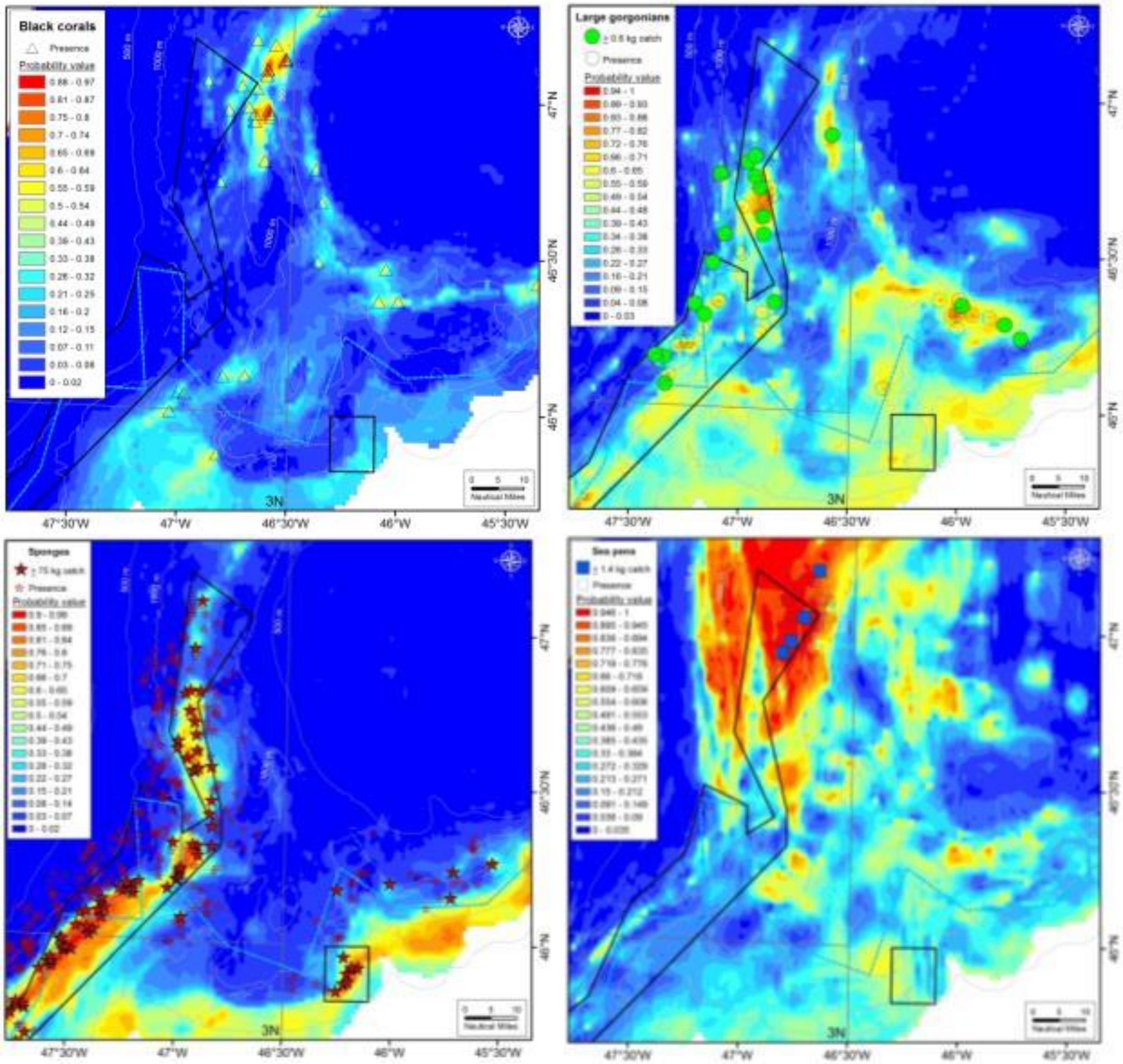


Figure 1.50. Area 2 northern portion and Area 3 Beothuk Knoll. Black coral probability of occurrence (upper left), large gorgonian corals probability of occurrence (upper right), sponge grounds probability of occurrence (lower left), sea pen corals probability of occurrence (lower right).

Area 4 Eastern Flemish Cap

Assessment: Inadequate

Justification/Rationale (Figures 1.51 and 1.52): High probabilities of black corals, large gorgonians and sponges as well as large catches which support the models are outside the closed area. Sponge VME is more extensive than the current closure and there is a high probability of occurrence of sea pens west and north of the current closure. There is relatively low current fishing effort in this area. Data for this area has been influenced by the 2013 survey data. The area has a lot of VME elements to the south and west and to the north. The presence of VME indicators in some of these areas has been corroborated with benthic imagery.

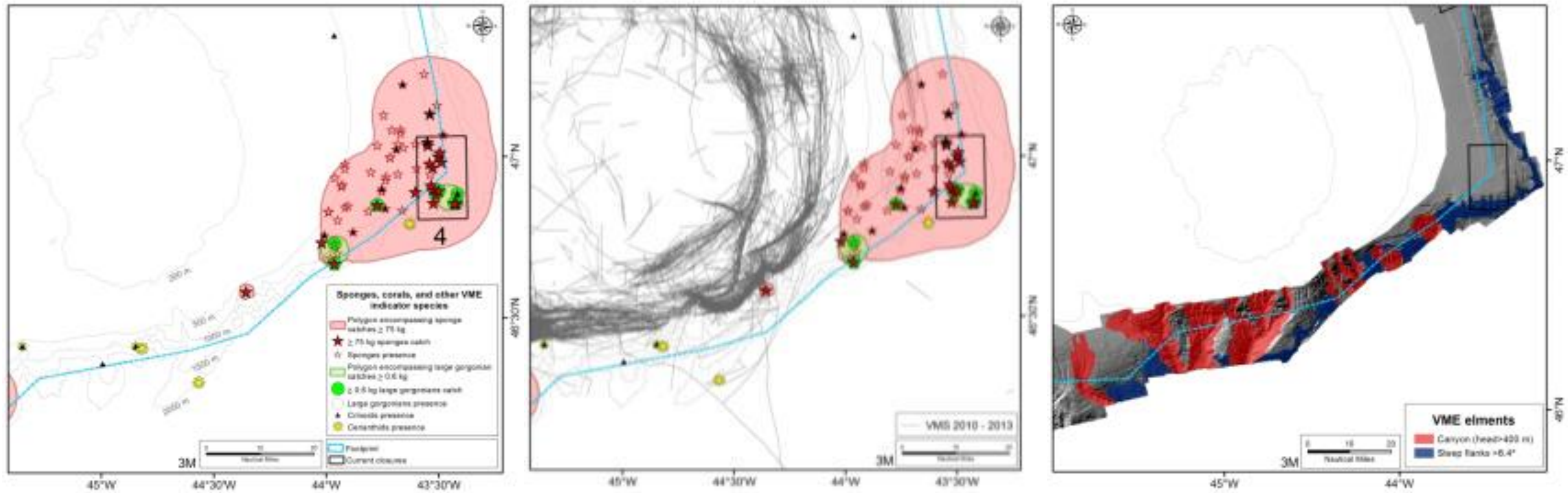


Figure 1.51. Area 4. VMEs and VME indicator species (left), VMS data (middle), and VME elements and NEREIDA multibeam (right).

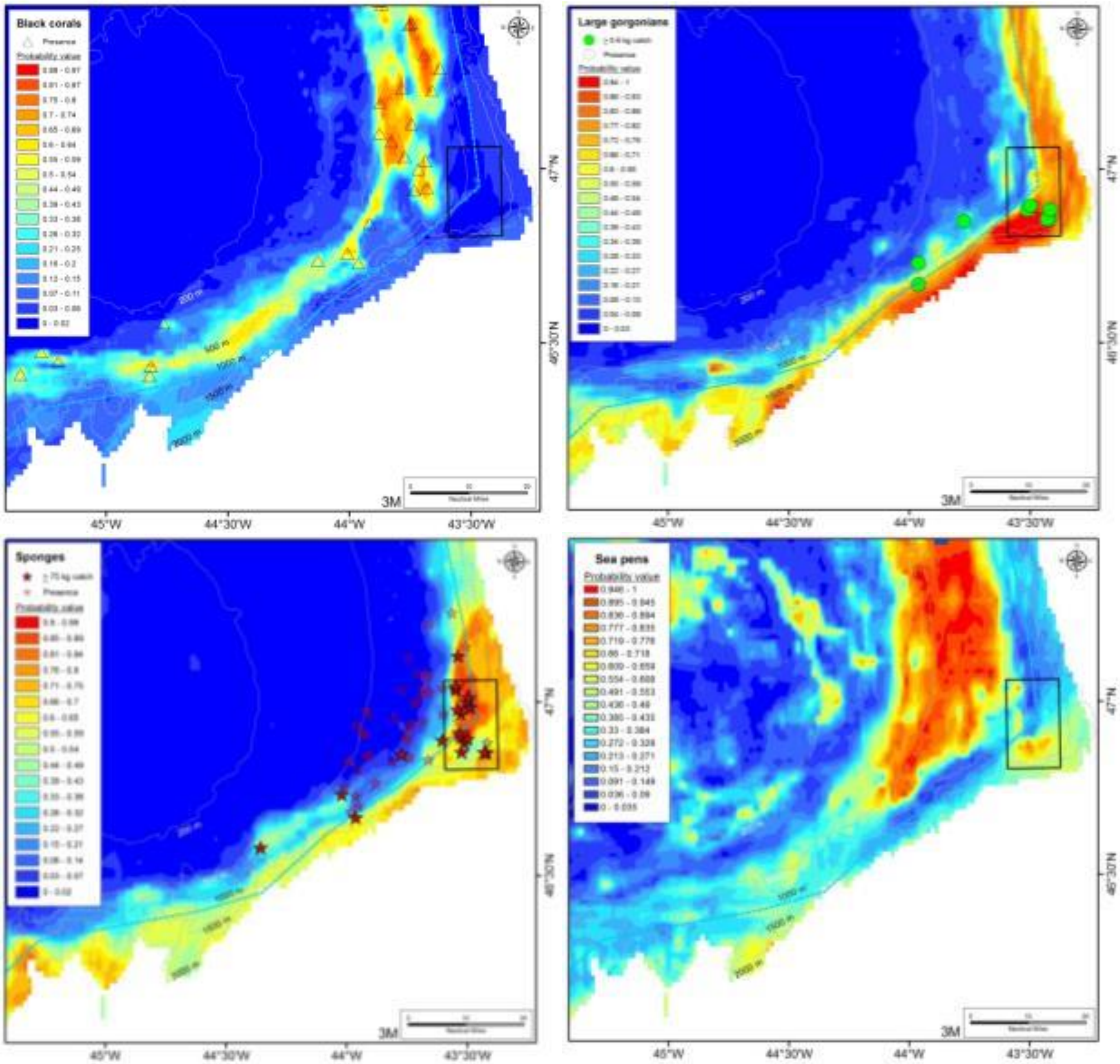


Figure 1.52. Area 4. Black coral probability of occurrence (upper left), large gorgonian corals probability of occurrence (upper right), sponge grounds probability of occurrence (lower left), sea pen corals probability of occurrence (lower right).

Area 5 Northeast Flemish Cap

Assessment: Area adequate of itself and partially adequate for the larger area (room for improvement) based on southern extension.

Justification/Rationale (Figures 1.53 and 1.54): Appropriate for sponges but could be extended to the south for large gorgonians and sponges based on the probability of occurrence there. Sponge ground probability of presence is 60-65%. There is also the presence of crinoids and cerianthids. Steep flanks are the VME element in the closed area. The extension into deep water fits the area of high probability of occurrence for the large gorgonians. Black corals are discussed in Areas 7+. It is a particular hotspot for the black corals and this area should be protected either through extension of this area or others. Sea pens are also discussed under areas 7+.

Figure 1.53. Area 5. VMEs and VME indicator species (left), VMS data (middle), and VME elements and NEREIDA multibeam (right).

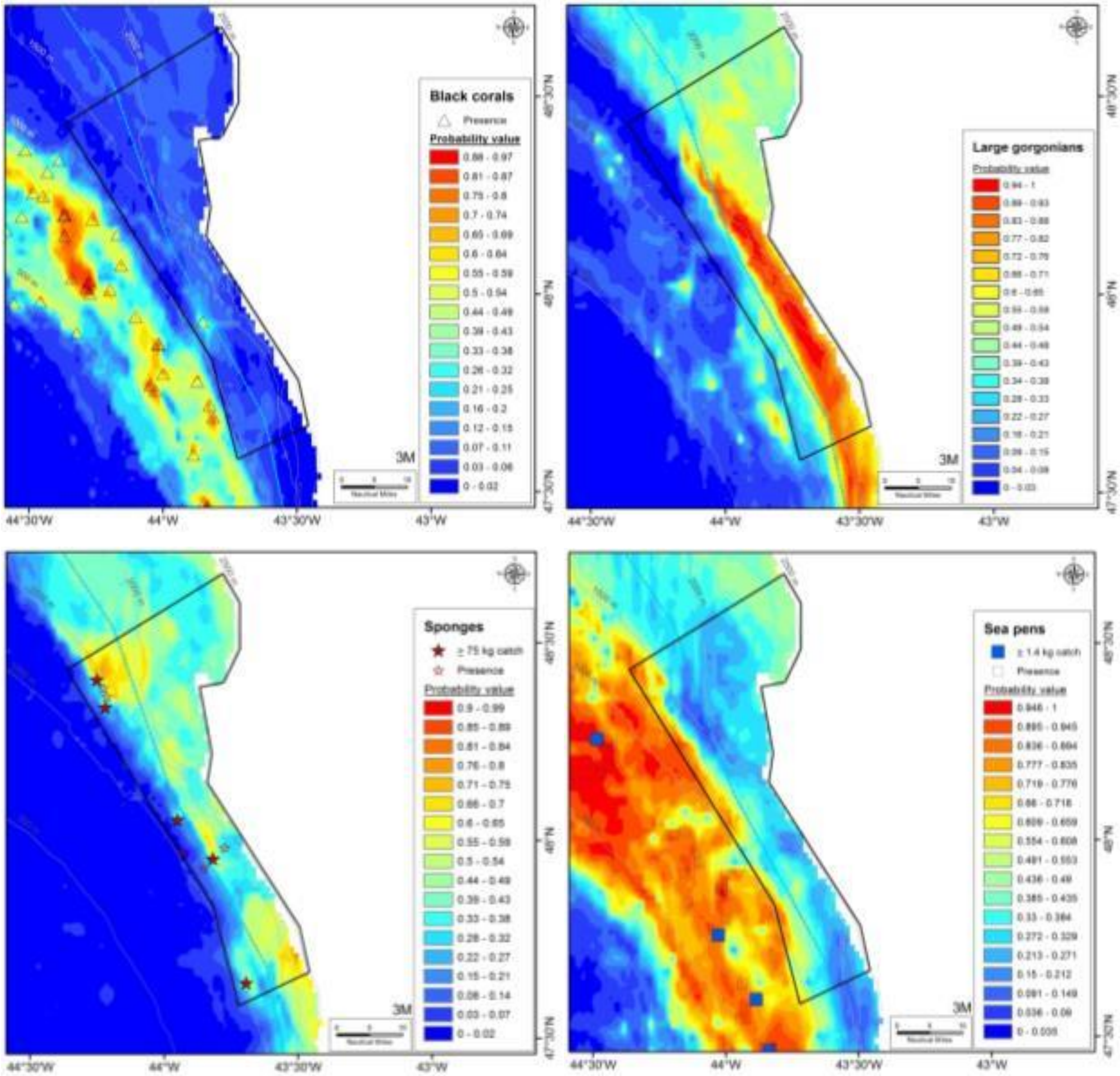


Figure 1.54. Area 5. Black coral probability of occurrence (upper left), large gorgonian corals probability of occurrence (upper right), sponge grounds probability of occurrence (lower left), sea pen corals probability of occurrence (lower right).

Area 6 Sackville Spur

Assessment: Area adequate of itself. Partially adequate for the larger area (room for improvement) based on the NE area and deeper water extension.

Justification/Rationale (Figures 1.55 and 1.56): This area protects important sponge grounds and most of the area is covered but the model predicts presence in deeper areas where samples are not available especially in the deeper NE area and further to the east at the northern boundary. There is low current fishing effort in this proposed area. Large gorgonian coral presence is predicted in deeper areas for modeled data as well. There are no VME elements in this area, and there is a low probability of occurrence for black corals and sea pens. Sponge VME into shallower water were not supported by the SDM.

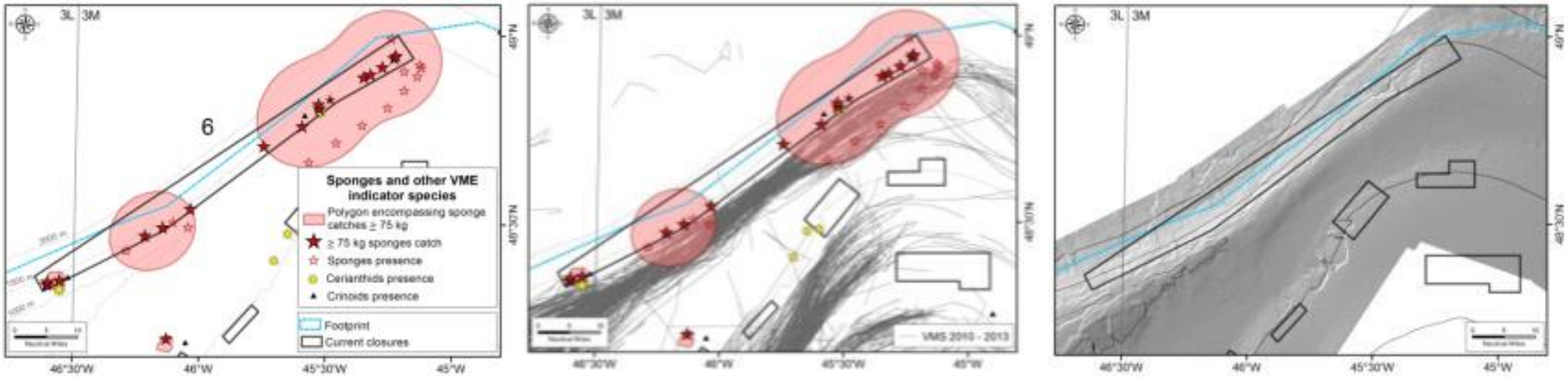


Figure 1.55. Area 6a. VMEs and VME indicator species (left), VMS data (middle), and VME elements and NEREIDA multibeam (right).

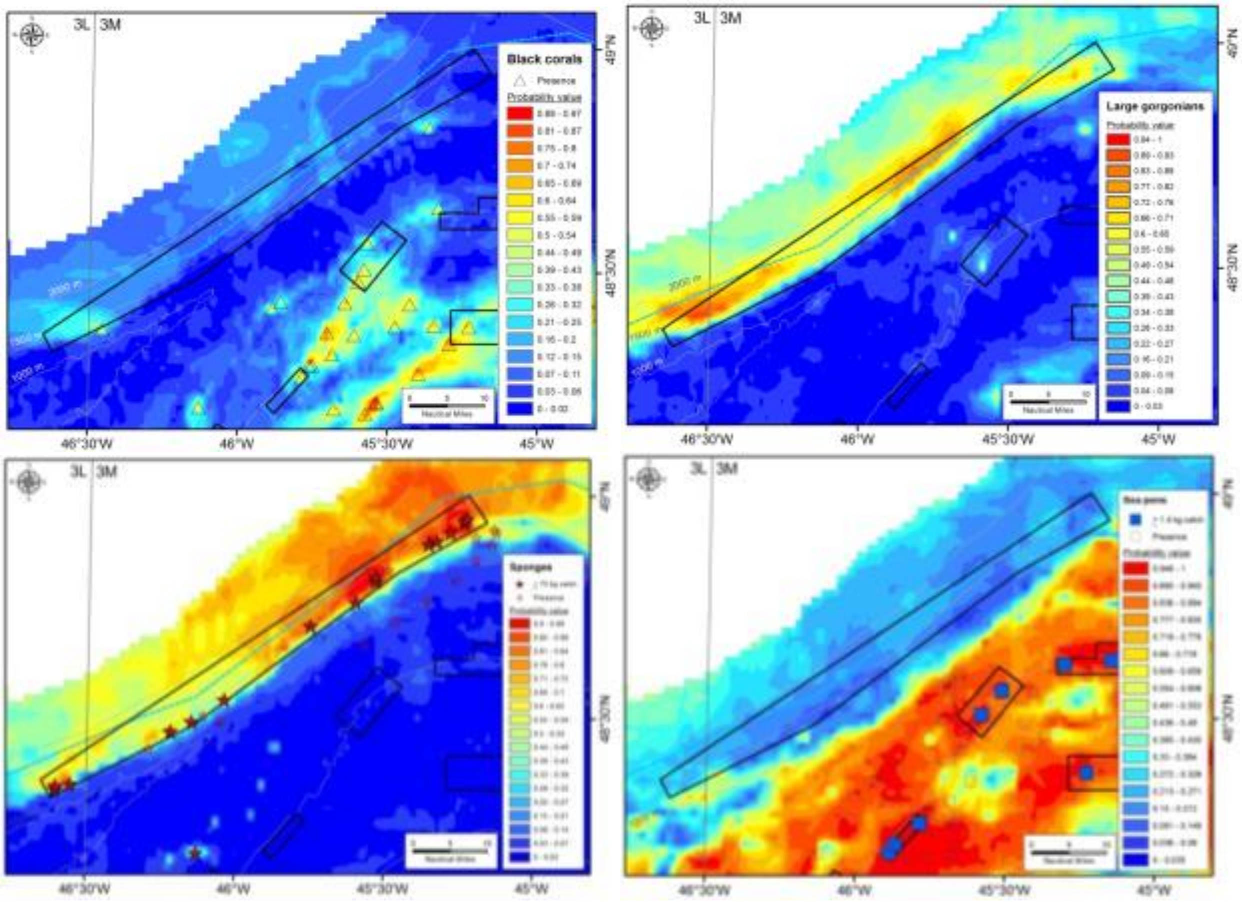


Figure 1.56. Area 6b. Black coral probability of occurrence (upper left), large gorgonian corals probability of occurrence (upper right), sponge grounds probability of occurrence (lower left), sea pen corals probability of occurrence (lower right).

Areas 7, 8, 9, 10, 11, 12 Northern and Northwestern Flemish Cap Including Proposed Areas 13, 14

Assessment: Inadequate collectively

Justification/Rationale (Figures 1.57 and 1.58) and further assessment: All of these closures are covering a system of sea pen VME identified in the SDM and verified with trawl survey data. As such the lack of protection for the entire eastern part of their distribution is of concern for the long term sustainability of these VME given the lack of knowledge of recruitment processes and connectivity. Given this, the areas between 13 and 14 should be linked for sustaining connectivity in this system and the added presence of crinoid VME indicators as well as the validated and modeled presence of black coral. In the context of this system we can distinguish 4 VME units within the more broadly based distribution. Going from west to east, Closure 11 corresponds to VME unit 1, Closures 8, 9, 10, 12 correspond to another VME unit 2, Closure 7 corresponds to VME unit 3 and candidates 13 and 14 together correspond to VME unit 4.

Closure area 11 is inadequate as it only covers a small portion of VME unit 1. Closures 8, 9, 10, 12 are partially adequate of themselves but inadequate in the context of the entire VME unit 2. Between 12 and 9 and south of 11 there are presence of cerianthids (the point near 11 could be discussed in the upper Flemish Pass area 2 closure). There are sponge ground VME to the east and west of 10. Closure 7 is inadequate as it only covers a small portion of the whole VME unit 3 and there is also crinoid presence in that VME unit. High probabilities of occurrence of black coral are in close proximity to this VME unit. Candidate closures 13 and 14 are inadequate as they only cover a small portion of the VME unit 4. VME unit 4 has the presence of crinoid VME indicators as well as the validated and modeled presence of black coral.

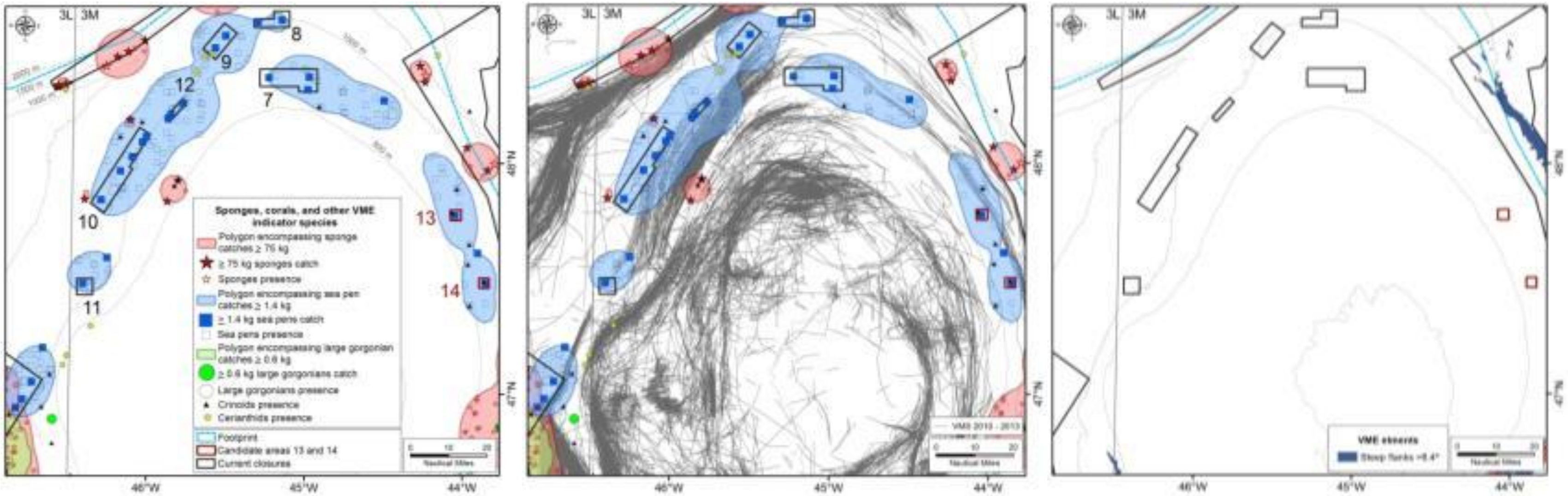


Figure 1.57. Areas 7-12 and candidate 13 and 14. VMEs and VME indicator species (left), VMS data (middle), and VME elements and NEREIDA multibeam (right).

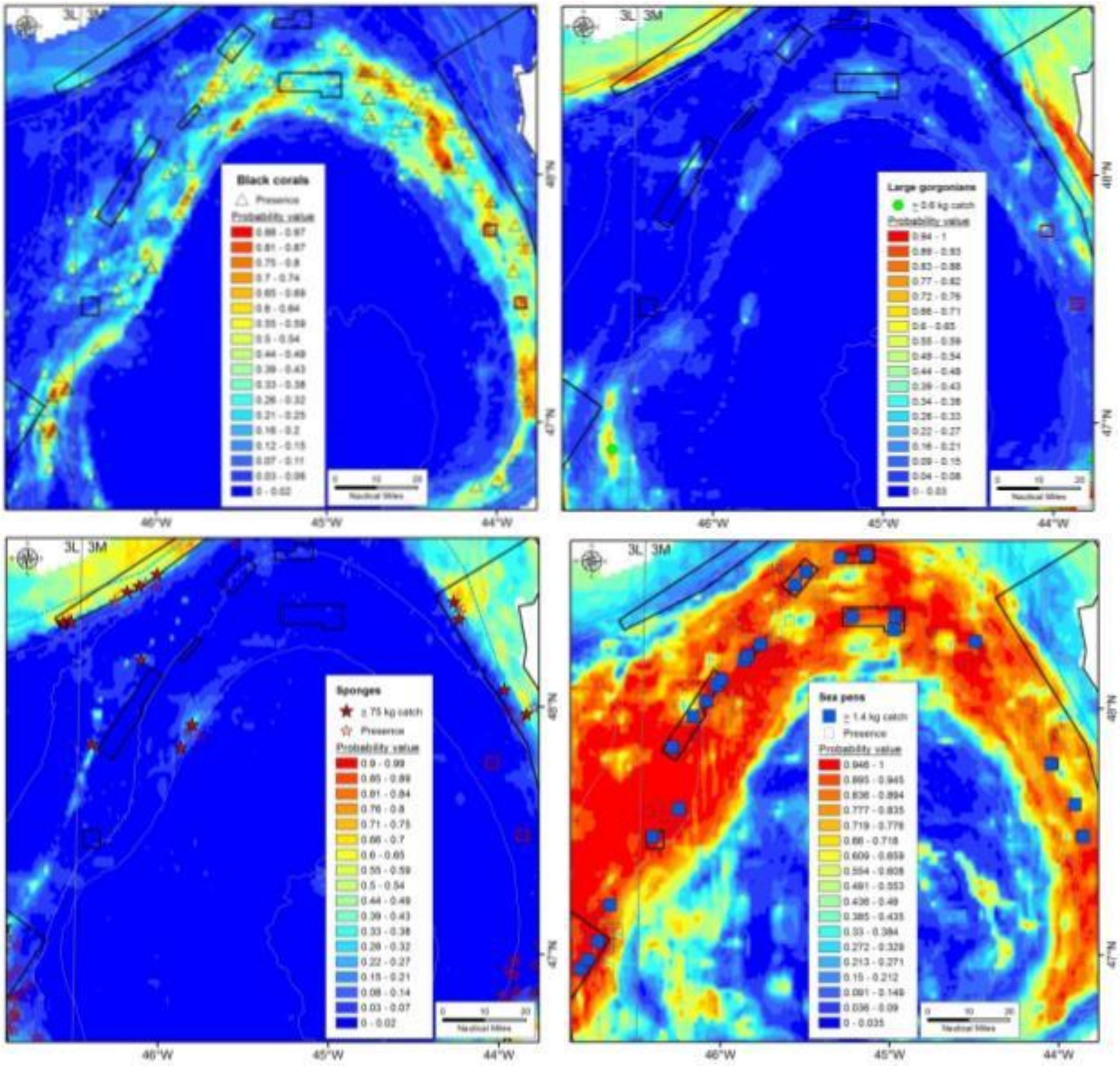


Figure 1.58. Areas 7-12 and candidate 13 and 14. Black coral probability of occurrence (upper left), large gorgonian corals probability of occurrence (upper right), sponge grounds probability of occurrence (lower left), sea pen corals probability of occurrence (lower right).

General Evaluation of Current Closed Areas in the NRA by VME

Large-sized Sponges

The current closed areas capture important sponge grounds in Flemish Pass/Eastern Canyons, Beothuk Knoll, Sackville Spur and Eastern Flemish Cap but those on the southern slopes of Flemish Cap are not protected (Figure 1.59). Only one small area is protected on the tail of the bank.

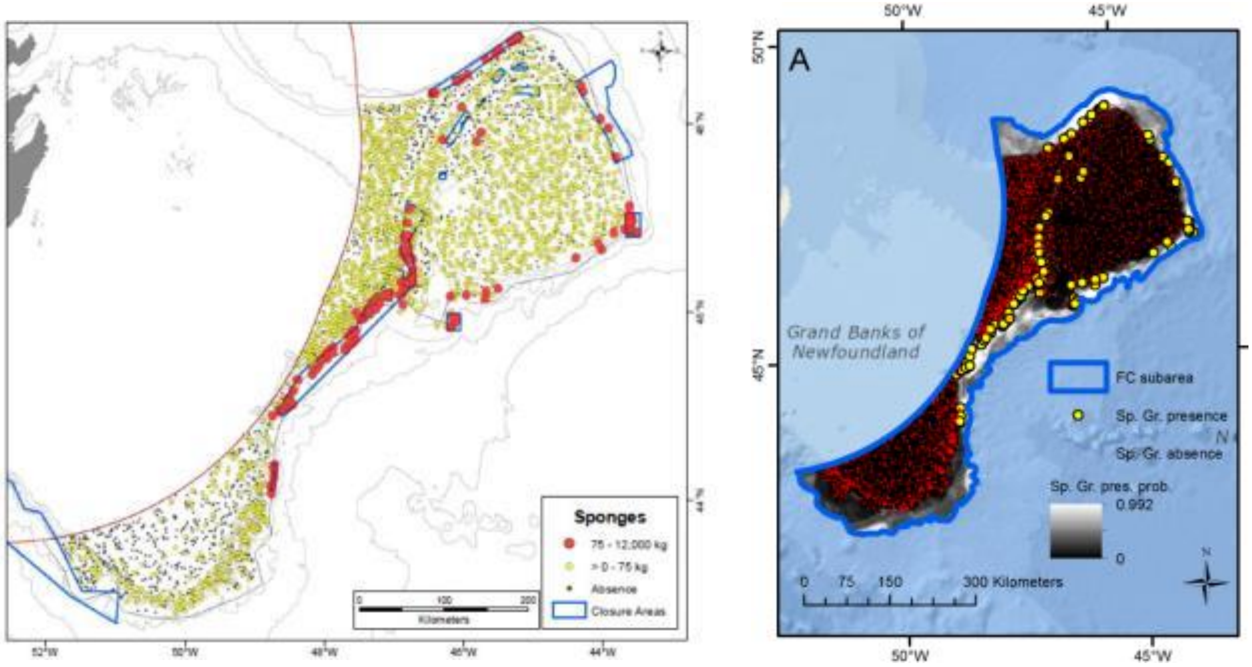


Figure 1.59. Left panel. Distribution of sponges in the NAFO regulatory area in relation to the closed areas. These data include all sponge records (not just those of the large-size sponges which are VME indicators). **Right panel.** Probability of sponge ground occurrence derived from SDM.

Large Gorgonian Corals

The current closed areas capture important areas with large gorgonian corals in the Flemish Pass area but those on the southern slopes of Flemish Cap are not protected (Figure 1.60). These organisms are not well represented in the trawl catches and the predicted models suggest that they are distributed in deeper water outside of the survey area where there is no specific protection.

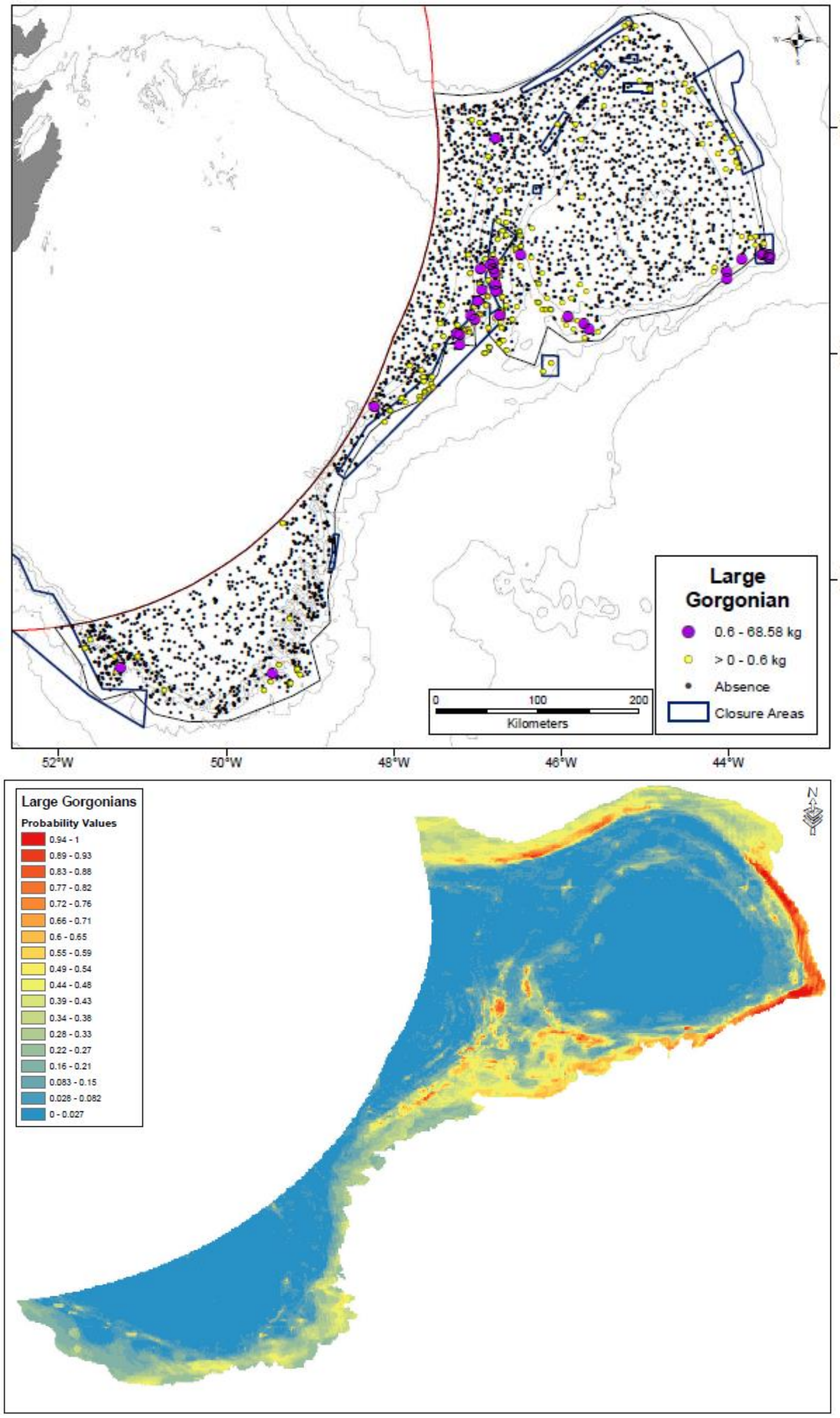


Figure 1.60. Upper panel. Distribution of large gorgonian corals in the NAFO regulatory area in relation to the closed areas. **Lower panel.** Probability of large gorgonian coral occurrence derived from SDM.

Small Gorgonian Corals

Two of the current closed areas protect areas with large catches of small gorgonian corals but overall protection of small gorgonian corals is not good (Figure 1.61). In particular the small gorgonians in the tail of the bank are not protected.

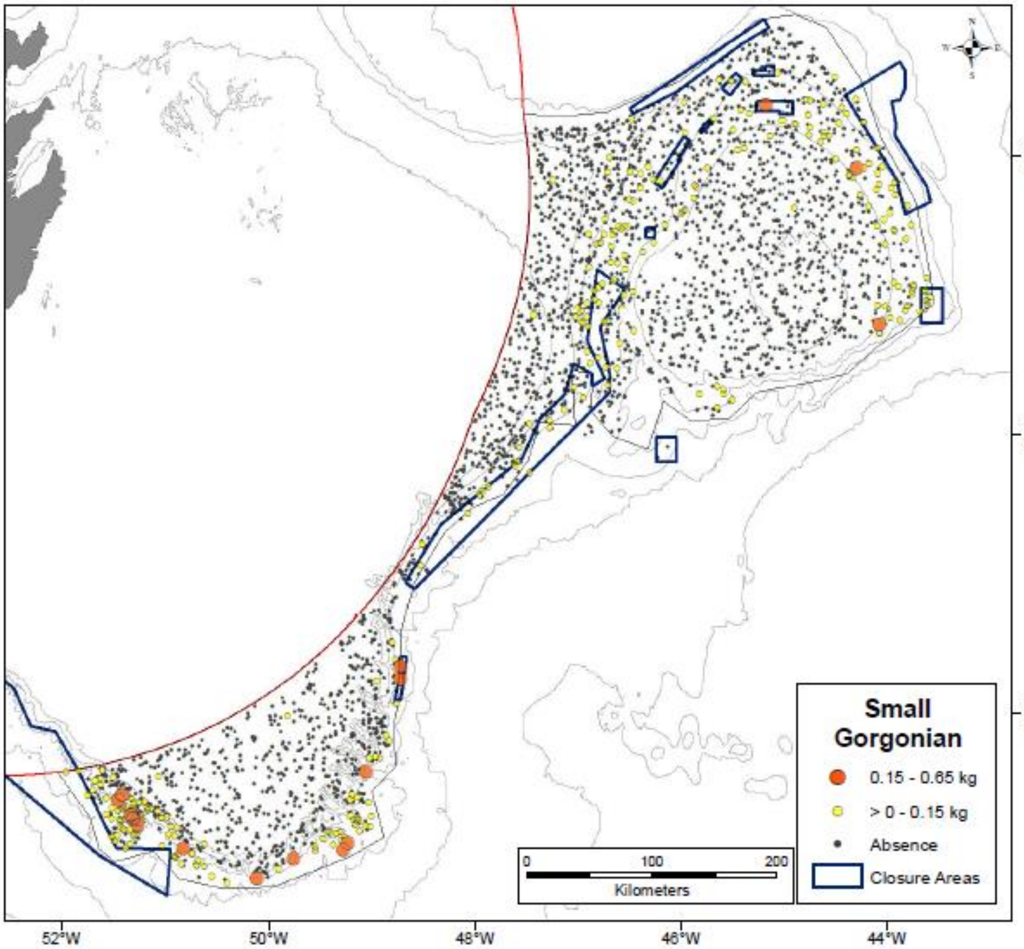


Figure 1.61. Distribution of small gorgonian corals in the NAFO regulatory area in relation to the closed areas.

Sea Pens

Although there is some level of protection of sea pen on the western side of FC as a system of VME which emerges from the overall distribution there is limited protection for sea pen VME as a whole (Figure 1.62). There is notable absence of protection on the eastern FC. All of the sea pen closures are covering a system of sea pen VME. As such the lack of protection for the entire eastern part of their distribution is of concern for the long term sustainability of these VME given the lack of knowledge of recruitment processes and connectivity.

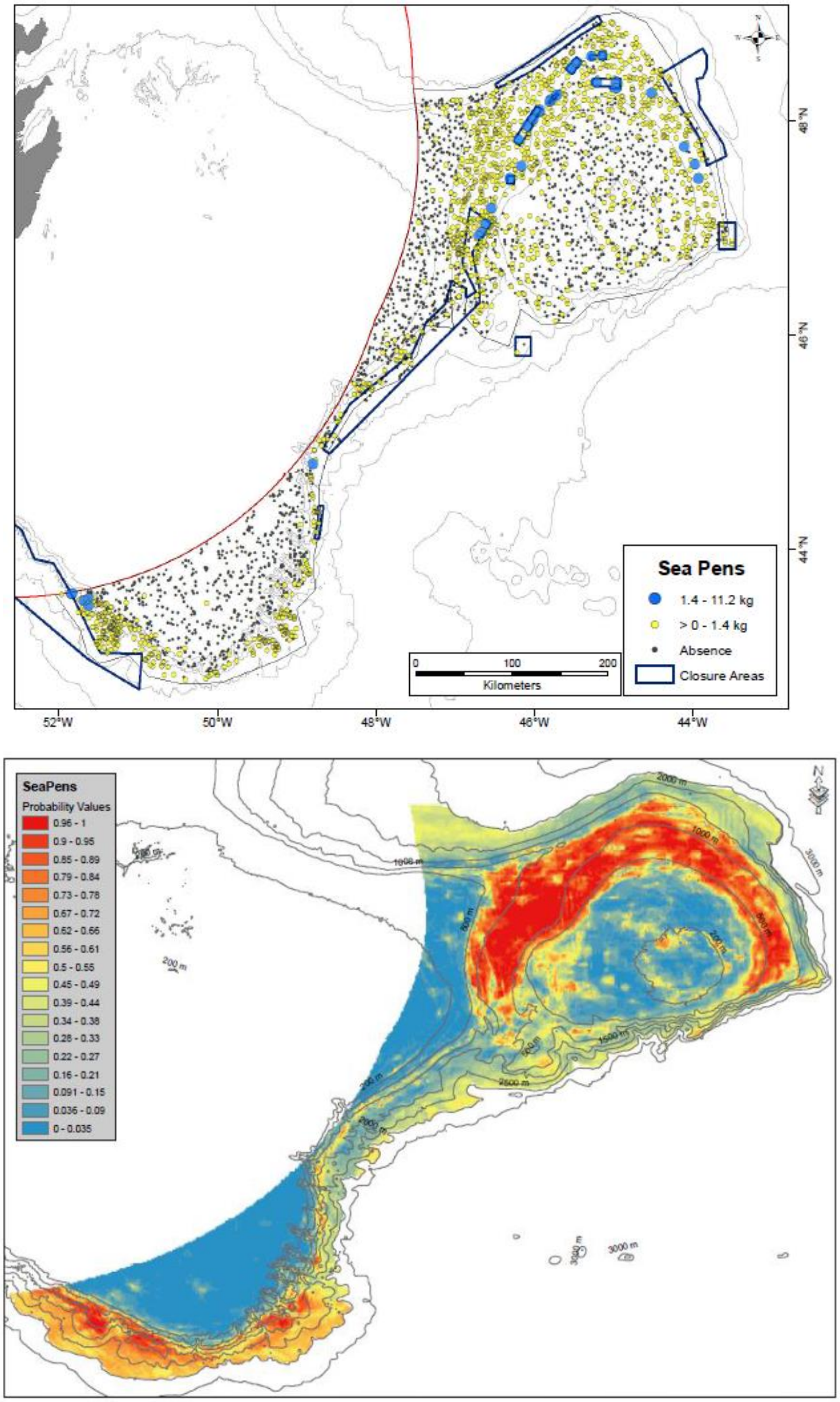


Figure 1.62. Upper Panel. Distribution of sea pens in the NAFO regulatory area in relation to the closed areas. **Lower panel.** Probability of sea pen occurrence derived from SDM.

Other VMEs

The crinoid, stalked tunicate, erect bryozoan and cerianthid anemone VME indicators and significant concentrations are not adequately protected.

VME elements

There is poor protection of the fauna associated with VME elements. On Flemish Cap Area 5 and Area 6 include steep flanks, with this VME element best represented in Area 5. No shelf-indenting canyons or canyons with heads < 400 m are completely protected although Area 2 offers partial protection to portions of canyon systems.

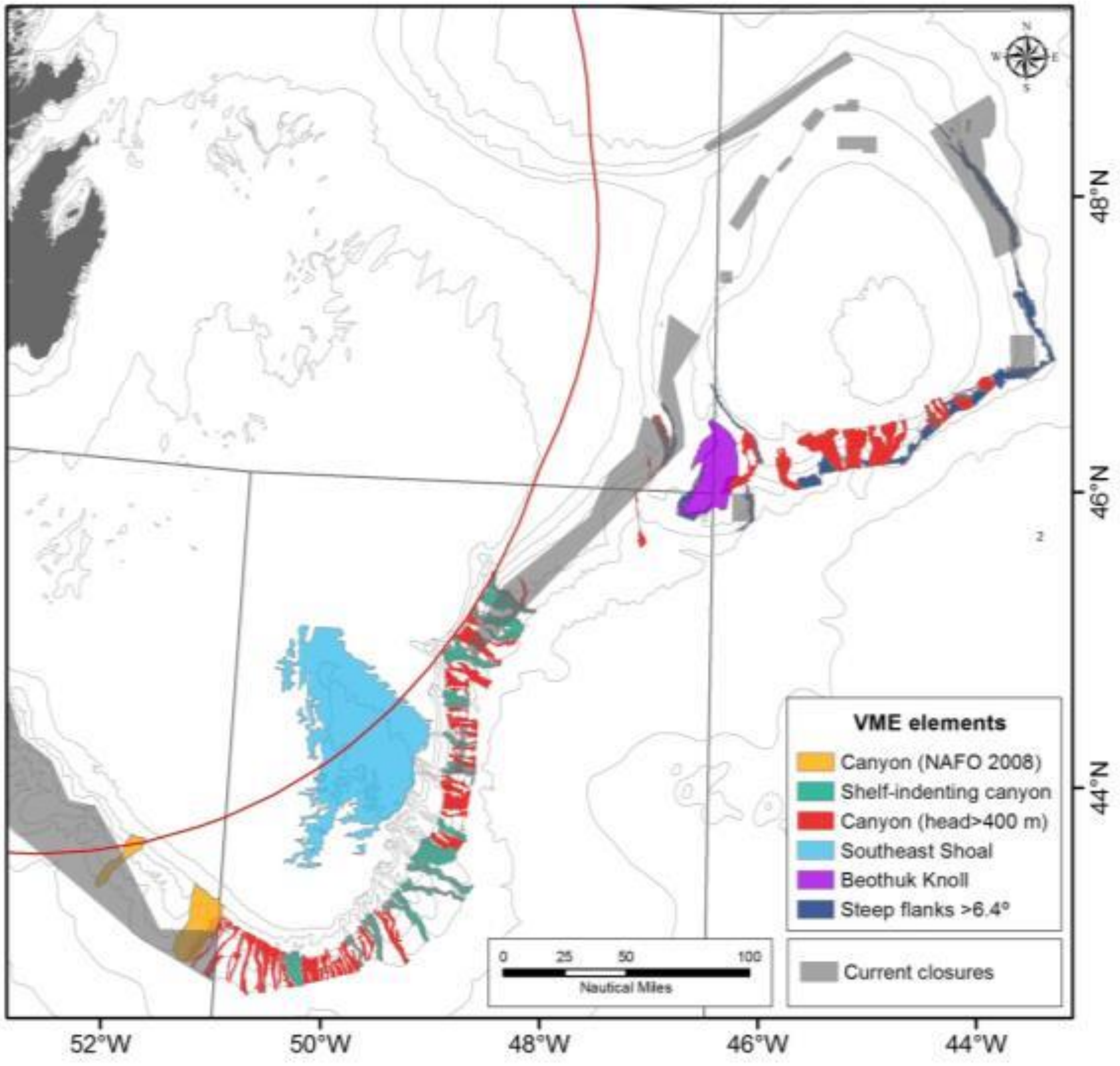


Figure 1.63. Map of the VME elements identified in the NRA (excluding seamounts). The locations of all areas currently closed to protect significant concentrations of corals and sponges are also indicated.

Review of Seamount Closed Areas in the NRA

In 2010, this Working Group considered all the information that has accrued since the original decision to close the seamounts, and the knowledge on the ecology of seamounts in terms of structure and function, as well as the effects of human impacts on them (Clark *et al*., 2010). The working group concluded that the available information supported the continued designation of these areas as VMEs. Since then, additional seamounts of the Fogo Seamounts chains have been identified as areas that could be included in the current closures. Other peaks of the Corner Rise Seamounts chain were also recommended for area closure by the Scientific Council (SC, Sept. 2013).

Most recent information compiled above also supports these seamounts' VME designation and their respective closures.

Prioritization for Consideration by the Ecosystem Approach to Fisheries Science Working Group

Process for setting priorities

WGESA considered what area will benefit most from management action when considering this part of the request. WGESA notes that this is not an evaluation of the relative importance of VME as we don't have enough information to do this. All VME are treated equally important in terms of their functionality. WGESA also notes that the closed areas should be viewed as connected systems.

Higher priority is given to those areas based on:

- multiple VME presence;
- the proportion of the VME that is protected in the NRA;
- close proximity to an existing closed area as this may imply continuity of the habitats;
- proximity to high fishing activity which could endanger the VME (increased threat);
- the number of VME indicators and VME elements
- areas with no current protection

Priorities

NRA

Considering the area specific evaluations and overall protection for each VME group noted above the priorities are seen as follows:

1. The tail of Grand Bank, Flemish Cap to the south taking in the northern part of Area 2 and to Area 4 and considerations highlighted there in detail above;
2. Dealing with the system of sea pen VMEs on Flemish Cap.

Seamounts

Corner Rise: Not all sea mount peaks are closed and shallower peaks could be closed and are under threat. Corner Rise seamounts be revised to the north, east and west in the NAFO Convention Area to include all the peaks that are shallower than 2000 metres. This is already a recommendation from the SC.

FC Request # 15

The Fisheries Commission Working Group on Vulnerable Marine Ecosystems (WGFMS-VME) considered the scientific advice available at the time of its last meeting held in April 2013. No consensus was reached between Contracting Parties regarding specific management measures that are best suited in protecting areas 13 and 14 as reflected in Figure 2 of the Working Group report (NAFO/FC Doc. 13/3) and defined by the coordinates indicated in page 10 of that report.

New information from the EU Flemish Cap survey was expected to be available on sea pens later in 2013, which would help to clarify what type of management measures would best suit areas 13 and 14.

The Fisheries Commission requests the Scientific Council to provide the Fisheries Commission with the preliminary results or analysis, regarding occurrence of sea pens in areas towed close to areas 13 and 14 and advise if these reveal significant concentrations of VME indicators.

Relevant information for a SC Response: There is a system of sea pen VME on Flemish Cap. As such the lack of protection for the entire eastern part of their distribution is of concern for the long term sustainability of these VME given the lack of knowledge of recruitment processes and connectivity. Given this, the areas between 13 and 14 should be linked for sustaining connectivity in this system and the added presence of crinoid VME indicators as well as the validated and modeled presence of black coral. In the context of this system we can distinguish 4 VME units within the more broadly based distribution. Going from west to east, Closure 11 corresponds to VME unit 1, Closures 8, 9, 10, 12 correspond to another VME unit 2, Closure 7 corresponds to VME unit 3 and candidates 13 and 14 together correspond to VME unit 4. Candidate closures 13 and 14 are inadequate as they only cover a small portion of the VME unit 4.

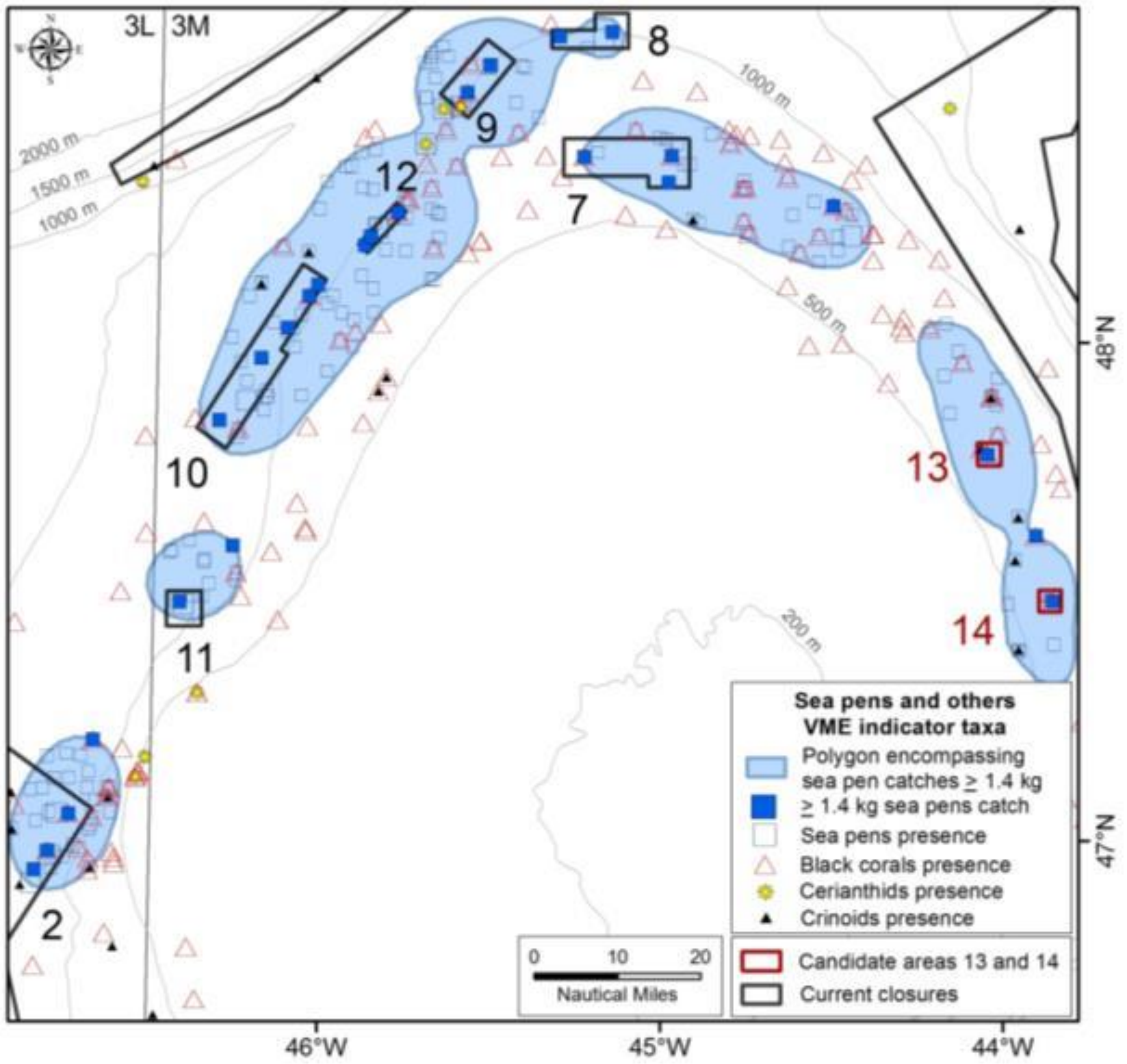


Figure 1.64. Location of sea pen VME in relation to the candidate closure areas 13 and 14.

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

ToR 2.1. [*Roadmap*] Update on integrated ecoregion analysis for the entire Northwest Atlantic.

Ecosystem approaches to management are essentially place-based approaches; they aim to provide management provisions and advice encompassing multiple stocks which inhabit a common and geographically-defined area. These "ecosystem management" units, and the scale at which they are defined, ideally would capture the core of a functional ecosystem, though other considerations should also be taken into account in defining them (e.g. jurisdictional boundaries and legal issues, main fisheries and fleets, operational issues regarding surveillance and enforcement, etc.). A necessary starting point in the process of defining "ecosystem management" units is the delineation of ecosystem boundaries and identification of major ecosystem subunits.

Previous work of this WG had provided a substantive delineation of ecoregions on the US Northeast Atlantic Shelf (Fogarty and Keith, unpublished; Areas 4X5YZe6ABC), the Scotian Shelf (Zwanenburg et al., 2010; Areas 4VsnWX) and the Newfoundland Shelf (Pepin et al., 2010; Areas 2J3KLNO) to identify potential management units for the EAM. The approach used in ecoregion delineation essentially relies on producing quantitative layers that link different features of the ecosystem, both physical and biological, through principal components analyses to define areas with similar features based on clustering algorithms (hierarchical agglomerative clustering that group spatially resolved information. WGEAFM (2010) concluded that in general terms, the ecoregion analyses presented to date provided a robust basis for the discussion and identification of ecosystem-level units to be used for the initial development and implementation of the "Roadmap to EAF". However, some key aspects of the analysis that were identified as needed to further strengthen the ecoregion delineation that would provide a sound biological basis against which WGEAFM could evaluate the current delineation process relative to earlier approaches (e.g. Halliday and Pinhorn, 1990). Pepin et al. (2010) concluded that for the Newfoundland Shelf, environmental variables were so strongly linked that the fundamental spatial structure of the ecoregions remained apparent when subsets or classes of information were removed from the analysis, which resulted in a robust definition of ecoregions. Pepin et al. (2012) further concluded that changes in ecosystem associated with the collapse of demersal stocks did not alter the delineation of ecoregions, and that the inclusion of community structure serve to strengthen the separation among ecoregions and subareas.

The in-depth evaluation of the effects of information content served to confirm that previous efforts to provide a quantitative basis for the delineation of management units was likely to be robust to changes in data availability if objective criteria were used to identify biogeographic zones and the ecoregions (possible management subunits) within major Large marine ecosystems (LMEs). The final step in the Working Group's efforts to provide comprehensive recommendations on the delineation of ecoregions was to conduct a workshop aimed at unifying approaches across the NAFO region by integrating data at the scale of the western north Atlantic (Labrador to mid-Atlantic Bight). Because of difficulties in obtaining and merging the various sources of information, the workshop had to be delayed until February of 2014. The analyses presented below will be augmented with bottom temperature data as well as the information from the Flemish Cap.

The approach applied in the synthesis was essential the same as has been applied previously. The variables selected for inclusion in the analyses presented here were based on the reduced set used in the final recommendations by Pepin et al. (2010) and include: bathymetry, surface and bottom temperatures, chlorphyll *a* concentrations, primary productivity, and biomass, richness and evenness derived from multispecies bottom trawl surveys. This is considerably fewer variables than the information content used on the analyses performed for the US continental shelf areas (Fogarty and Keith 2009) but the analyses presented by Pepin et al. (2010) provided clear evidence that the overall biogeographic structure of the Newfoundland Shelf and Grand Banks could be defined reliably using the subset of data chosen for this analysis. After the various data types were normalized, smoothed and interpolated to a common grid, data were standardized and synthesized using principal component analysis (PCA). Scores from the first three PCA axes, which explained 59.9% of the variance, were used in a k-means clustering procedure to classify the data. K-means clustering is an unsupervised non-hierarchical classification technique, meaning there is no prior knowledge on what information classes exist in the data. The optimal number of clusters was identified using the Calinksi-Harabasz (C-H) statistic (Legendre 2001).

As before, the effects of changes in information content were investigated to determine if the conclusions derived from analyses of the Newfoundland situation could be generalized across the entire NAFO area from 2J to 6C. We considered the results of using PC1-3 based on [1] all seven variables, [2] Excluding Bathymetry and SST (i.e. the physical elements), and [3] Excluding Chlorophyll and Primary Production (pelagic elements). We also considered a fourth case where [4] the effects of using the seven was considered.

In the case that included all the variables, the optimal identified 3 clusters as representative of the data, with a secondary optimum with 5 clusters. Although the optimal number of clusters provides a large scale view of the region (Fig.2.1a), it does identify major discontinuities in the spatial arrangement of clusters that corresponds roughly to the major ecoregions previously identified (Newfoundland Shelf, Grand Banks, Scotian Shelf (with indications of east and west components), Georges Bank/Gulf of Maine (GB/GoM), and the mid-Atlantic Bight (MAB). Although there is greater spatial fragmentation in the distribution of clusters, these features remain apparent with the secondary optimum (Fig.2.1b) with the additional features that closely reflect the cross-shelf gradients in environmental conditions that have been identified as important in GB/GoM and the Scotian Shelf. Excluding the physical variables provides no clear structure on the Scotian Shelf and GB/GoM, but there remain clear separation of the MAB as well as the distinction of the Newfoundland Shelf and the Grand Banks (Fig.2.1c). Exclusion of the pelagic variables yields an optimum number of 7 clusters that provides more detailed structure for the Newfoundland area but a messier outcome south of the Laurentian Channel (Fig.2.1d).

The spatial distribution and fragmentation of clusters highlighted the fact that to date clustering results had been based strictly on environmental similarity that did not take into consideration geographic proximity. To investigate the potential significance of this issue, a final analysis using PC1-3 as well as latitude and longitude was performed. Also, a comprehensive assessment of the spatial distribution of clusters around the optimal solution was also carried out to better understand how the variations in the data affect the strength of the boundaries and thereby the delineation of subareas within ecoregions. The addition of proximity provided clear delineation of the major areas based on an optimum of 5 clusters (Fig.2.2a). The spatial distribution of clusters does not match precisely current NAFO boundaries but does provide evidence of separation of the Newfoundland Shelf and Grand Banks, and separation of the MAB from GB/GoM. The GB/GoM cluster extends into the Bay of Fundy and the western edge of the Scotian Shelf while the Scotian Shelf appears as distinct from the surrounding areas with no indication of a break between eastern and western areas. The spatial distribution of the 3 cluster solution identifies the areas of Newfoundland, the Scotian Shelf and the US waters as distinct (Fig.2.2b). Increasing the number of clusters to 7 provides greater separation of subareas off eastern Newfoundland but do not affect the spatial arrangement of clusters south of the Laurentian Channel (Fig.2.2c). It is in the 8 cluster solution that the eastern and western parts of the Scotian Shelf become distinct, and the boundary with the GB/GoM moves further to the west than in the solutions with fewer clusters (Fig.2.2d). It is noteworthy that the position of the boundary separation the Scotian Shelf is not located at the current boundary used to divide the eastern and western parts of the area. Increasing the number of clusters further subdivides regions, probably as a result of the growing effect of proximity.

The boundaries identified in these analyses do not correspond precisely with the current delineated ecoregions but they come very close. The original delineation of NAFO areas had been based principally on knowledge pertinent to the distribution and movement of major commercial resources, which probably explains to some degree the close correspondence between the results of this analysis and current boundaries. This could be included in future analyses through the addition of multivariate layers from the analysis of dissimilarity matrices based on presence/absence of multiple major stocks throughout the entire NAFO convention area. However, the current analyses do appear to indicate that the general structure of the regional ecosystems boundaries could be revised to better reflect the structure in the environment.

Completed analyses and sensitivity assessments will be provided at the 2014 meeting of WGESA.

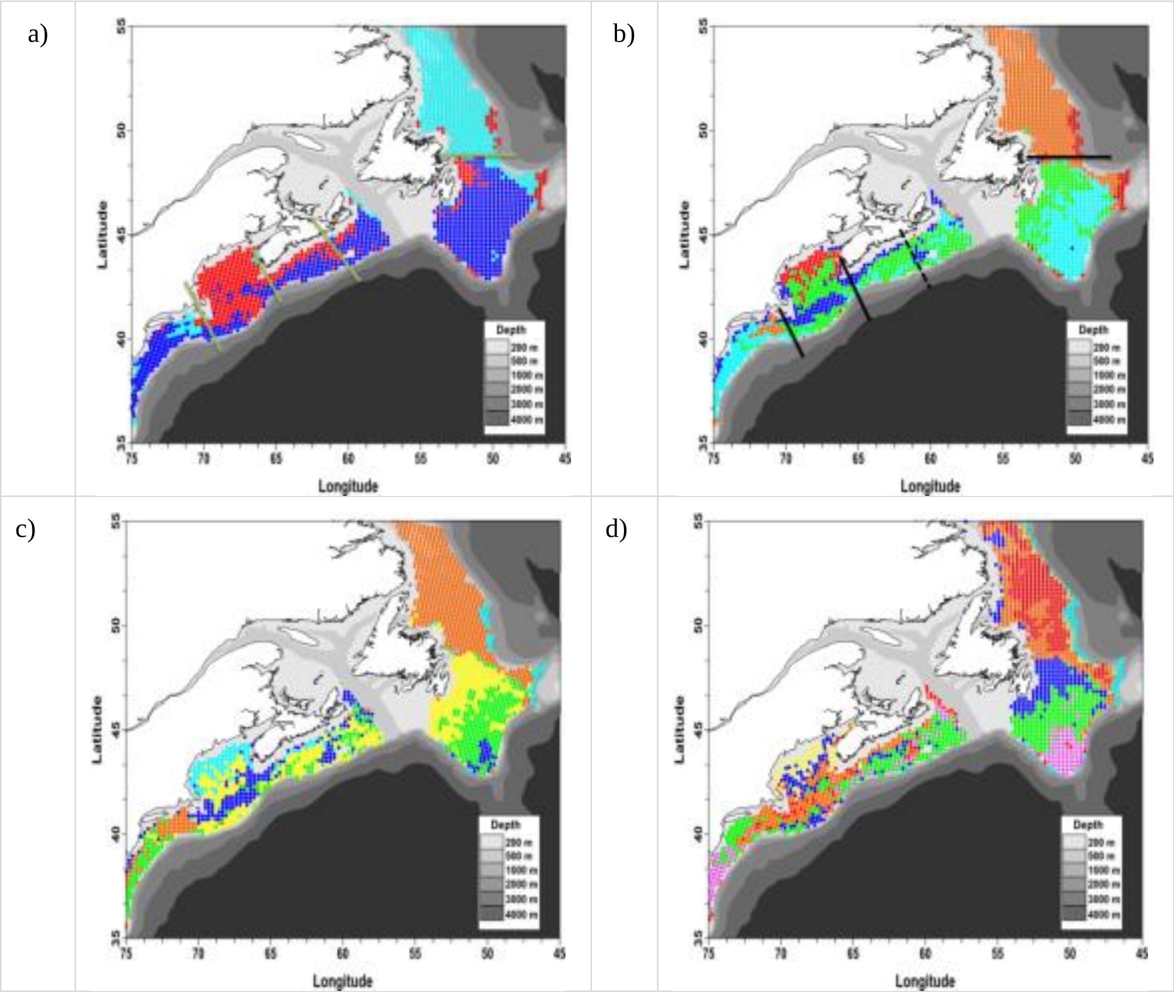

Figure 2.1. Spatial distribution of the clusters (identified by different colours) for a) the optimal number of clusters (3) for the analysis using all data (lines represent apparent boundaries between ecoregions), b) the secondary optimum number of clusters (5) for the analysis using all data (lines represent apparent boundaries between ecoregions), c) the five cluster solution for the analysis that excludes bathymetry and sea surface temperature, and d) the optimal number of clusters (7) for the analysis that excludes chlorophyll *a* concentration and primary production.

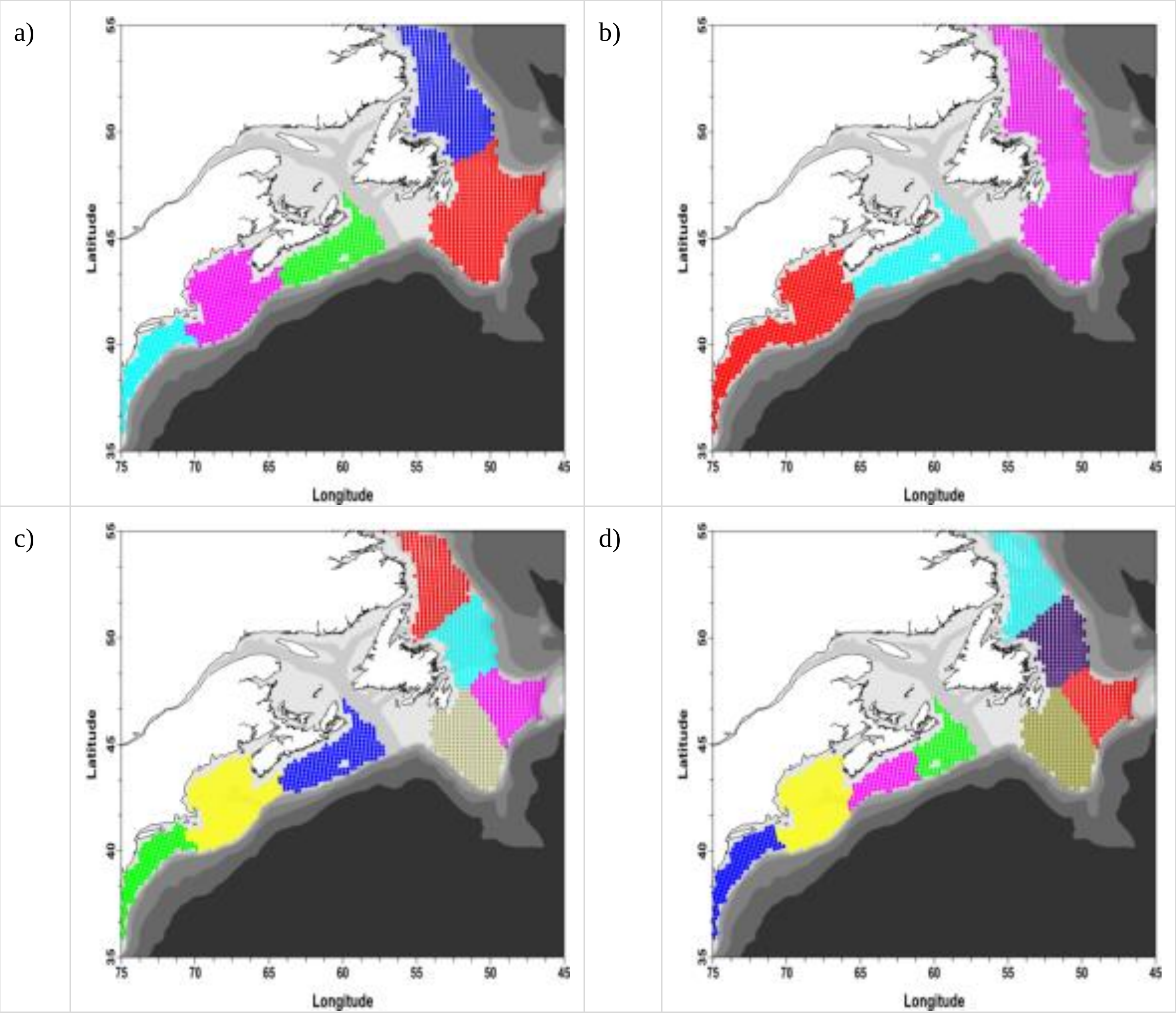

Figure 2.2. Spatial distribution of the clusters (identified by different colours) for a) the optimal number of 5 clusters for the analysis using PC1-3 using all data as well as position, b) the solution with 3 clusters, c) the solution with 7 clusters, and d) the solution with 8 clusters.

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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.

ToR 3.1. [*Roadmap*]. Report progress on the development of Fisheries Production Potential Models for NAFO ecosystems.

Introduction

The ecosystem production potential for a region is a function of the amount of primary production elaborated, the fraction of this production retained and available to higher trophic levels, the transfer efficiency between successive trophic levels, and the number of trophic levels through which energy must be transferred. In 2013, the WGESA continued its work in estimating Ecosystem Production Potential (EPP) for the NAFO convention area with a focus on the Newfoundland Shelf. Complementary work using the same methodology is underway in NAFO Statistical Areas 5 and 6 on the Northeast Continental Shelf of the United States.

Methods

Ecosystem production units

For this exercise, production units were based on some of the candidate ecosystem management units identified so far. The core ecosystems units considered in this analysis were the northern Newfoundland and Southern Labrador Shelf (NAFO Div. 2J3K), the Grand Bank (NAFO Div. 3LNO), the Flemish Cap (NAFO Div. 3M), the Scotian Shelf (NAFO Div. 4VsWX), and the Northeast US Continental Shelf (aprox. NAFO Div. 5+6ABC).

Basic model structure

The approach taken to estimating ecosystem production potential is an expansion of the Ryther-Ware method (Ryther 1969; Ware 2000) which traces production processes through a food chain. Unlike the original Ryther-Ware food chain representation, in which yield is extracted at a specified mean trophic level, the version implemented by WGESA utilizes a simplified food web structure within which yield can be extracted at different trophic levels.

The current EPP model recognizes two pathways for transfer of primary production in the system: the classical grazing food web tracing the fate of production of microplankton (phytoplankton cells > 20 μm; principally diatoms and large dinoflagellates) and production involving transfer through the microbial food web originating with combined nanoplankton (2-20 μm) and picoplankton (< 20 μm) production (i.e., nano-picoplankton; Figure 3.1.1). The former involves grazing by mesozooplankton and filtering of diatom production by benthic invertebrates (e.g. bivalves). The latter pathway entails ‘consumption’ of nano-picoplankton by heterotrophic bacteria (principally in the form of dissolved organic carbon –DOC-) and feeding of microzooplankton on bacteria. In this representation, carnivorous zooplankton (mesozooplankton) prey on microzooplankton. The microbial pathway therefore involves two or more trophic transfer steps before reaching mesozooplankton as a bridge to higher trophic levels. Although both dissolved and particulate organic carbon (POC) derived from other sources in the food web and are utilized by bacteria, in this simplified representation, we follow the approach of Ware (2000) and assume that most of the POC and DOC utilized by bacteria are from nano-picoplankton sources. We note that the functional groups represented in the upper food web depicted in Figure 3.1.1 do not correspond to taxonomic groups. Individual taxa may feed at multiple trophic levels, reflecting both ontogenetic shifts in diet and generalist feeding strategies with life stages.

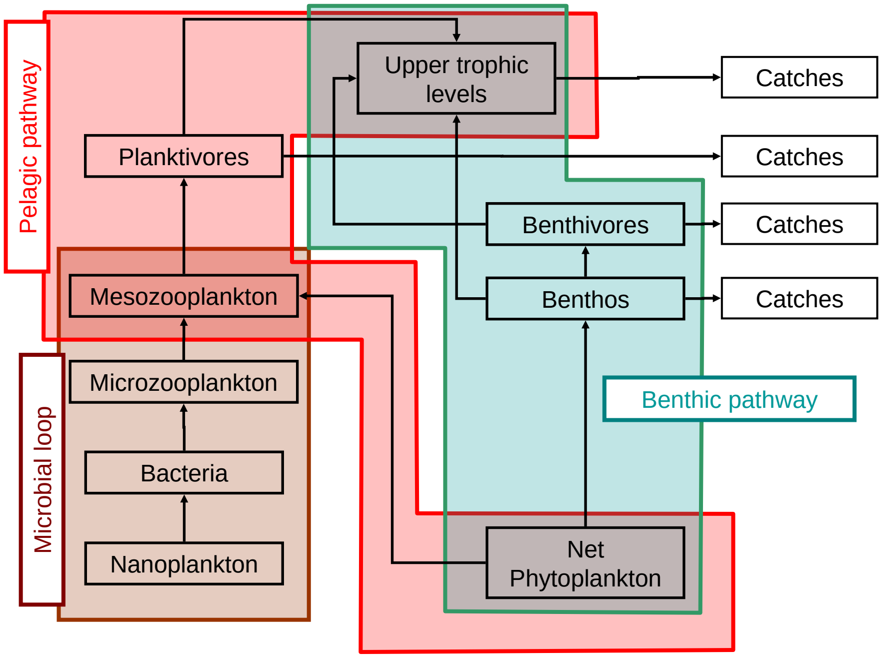


Figure 3.1.1. Food web structure employed in this analysis. Nano-pico plankton, bacteria, and microzooplankton comprise the microbial food web in this representation. The classical grazing food web is fuelled by microplankton production. Species characterized by ontogenetic shifts in diet and/or mixed feeding strategies can occupy multiple compartments in this representation.

Within this structure, production at a given node *i* is a function of the transfer efficiency from other nodes (*j*) to node *i*, the inputs from other locations and losses from the i^{th} node:

$$P_i = TP_j + A_i - L_i$$

where P_i is a vector of production values over all nodes. *T* is a matrix of ecological transfer efficiencies from node *j* to node *i*. A_i represents the addition of production to node *i* from other sources. *L* represents a loss term from node *i* (e.g. advective loss, removals due to harvest etc.).

Primary production

In all cases satellite observations were a fundamental data input for the estimation of primary production, but the specific models used differed depending on the location of the ecosystem under consideration. Based on the availability/quality of data and models, comparisons among primary production models were made to the extent possible. The results of these comparative analyses were used to select which approach for estimating primary production seemed to work better for each ecosystem.

Primary production estimates for the Grand Bank, Newfoundland and Labrador Shelves, Flemish Cap, and the Scotian Shelf were based on remotely sensed satellite observations from ocean color (SeaWiFS and MODIS-Aqua) and thermal (AVHRR, MODIS-Aqua and MODIS-Terra) sensors (1997-2013). The method that most closely corresponds to *in situ* estimates of primary production consists of the Nearest-Neighbour Method (NNM) of primary production estimation (Platt et al. 2008). The approach relies on observations of surface chlorophyll concentrations and temperature coupled with information from a climatological archive of photosynthesis-irradiance relationship parameters, as well parameters that describe the vertical structure of chlorophyll and temperature based on ship observations from the same region. The procedure is based on known variation of bio-optical properties of phytoplankton with chlorophyll and temperature as well as through consideration of the seasonal variation of water column stratification and its effect on the vertical pigment profile.

Primary production for the Northeast US continental shelf was also calculated on the basis of data from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS, NASA); in this case a modified version of the Vertically Generalized Productivity Model (VGPM; Behrenfeld and Falkowski 1997) was used. This modified VGPM model replaces the original temperature-dependent description of photosynthetic efficiencies with the exponential Eppley function (Eppley 1972), which was modified by Morel (1991).

The estimates of productivity from these models were coupled with phytoplankton taxonomic composition information (e.g. Uitz et al. 2009; 2010; Pan et al. 2011) to estimate size fractionated primary production. The phytoplankton community was divided into two main size categories, microplankton (>20m), and pico-nanoplankton (<20m) for their incorporation into the EPP models (labeled “Net phytoplankton” and “Nanoplankton” respectively in Fig. 3.1).

Transfer Efficiencies

Early laboratory studies by Slobodkin (1961) indicated that the expected transfer efficiency was on the order of 10%. Clear thermodynamic constraints place limits on the transfer efficiency between successive levels in the food chains comprising a reticulated food web. The canonical value of 10% as an ecological transfer efficiency was supported by Pauly and Christensen (1995), who estimated that the transfer efficiency of biomass between trophic levels in aquatic ecosystems, although variable, had a mean of 10%. However, more recent studies have suggested higher transfer efficiencies at lower levels in the food web and a general decline in transfer efficiency from lower to higher trophic levels..

To better assess trophic transfer efficiencies throughout our generic food web, we evaluated estimates of transfer efficiencies derived from published Ecopath with Ecosim (EwE) models for subarctic-boreal-temperate systems compiled by the *Sea Around Us* Project of the University of British Columbia. Rather than assume or assign trophic transfer efficiencies at different steps in the food web for the models, we used these model estimates to define probability distributions characterizing transfer probabilities at different steps in the food web. Our characterization of transfer efficiencies between discrete trophic levels based on these Ecopath models followed the approach of Ulanowicz (1993).

Benthic-Mesozooplankton Pathway

To determine transfer efficiencies from the microplankton, we examined energetic pathways from Ecopath models and assigned a proportion to the microplankton group and determined the production flowing to mesozooplankton and benthos. As there are three main food chains, in addition to the transfer efficiencies we need the proportion of the primary production flowing to zooplankton versus the proportion flowing to benthic invertebrates. We examined published Ecopath models for Arcto-boreal-temperate systems to infer the split between benthos and mesozooplankton from microplankton.

Fishery Production Potential

The model represented by Figure 3.1.1 allows estimating the total ecosystem production potential, but the actual production available for fishing is only a fraction of this total production. This fraction will be a function of the production potential at the nodes being harvested, and the harvesting rate imposed on those nodes. If we discriminate between losses of production due to fishing (C_i) (including both discarded and landed components) and all other sources of removals (L'_i). the basic model equation can be re-written as

$$P_i = TP_j + A_i - L'_i - C_i$$

For the purposes of our analysis, we assume that inputs and losses from sources other than fishing are in balance at each node. Then, harvest extracted from node i can be expressed as

$$C_i = E_i P_i$$

where E_i is the fractional exploitation rate applied to the production at node i.

Although standard reference points have not been fully established to guide overall extraction policies for marine ecosystems, Iverson (1990) proposed that exploitation rates should not exceed the *f*-ratio (the ratio of new primary production to total primary production) in marine systems. This suggestion is based on the underlying recognition that new production (primarily by larger phytoplankton species) is more readily available to fuel production at the higher trophic levels of principal economic interest while the production derived from the nano-picoplankton is largely (but not exclusively) consumed within the microbial food web. Although direct estimates of the *f*-ratio are not broadly available for large marine ecosystems throughout the world ocean, we can consider the ratio of microplankton production to total primary production as a first-order approximation. On this basis, we have initially considered exploitation rates of 20-30% as our limit reference points for exploitation.

As initial step, and considering that many species included in the benthos (e.g. polychaetes, brittle stars) and planktivores (e.g. myctophids) nodes are not (currently) of commercial value, the fisheries production potential of these nodes was further bounded by assuming that only 10% of the benthos and 50% of the planktivores production were currently of potential commercial value.

Production of benthivores and piscivores (labelled upper trophic levels in Fig. 3.1.1) was also combined to better reflect the overall fisheries production potential of groundfishes as a generic target group.

Treating Uncertainty

To represent uncertainty in key input parameters to the production potential model, we specified empirically derived probability distributions for primary production, transfer efficiencies, and the split between transfer of energy from microplankton to benthos and mesozooplankton.

We used (truncated) normal probability distributions to represent variability in microplankton and nano-picoplankton production. We computed the means and, based on an examination of the the interannual variability of the primary production combined with the uncertainty in the empirical models relating Chl a to primary production, coefficient of variations of 30% were used to represent the variance of interannual phytoplankton production for both phytoplankton components.

For transfer efficiencies between microplankton and higher components of the food web we used Beta distributions at each level based on our compilation of EwE results as described above. Transfer estimates are constrained between 0 and 1 and are appropriate for application of the Beta distribution. To obtain reasonable sample sizes to characterize these probability distributions, we pooled model estimates over major ocean ecotypes (Subarctic Boreal Shelf and Temperate Shelf systems).

Energetic pathways involving the benthos differed substantially in different food web models we examined. In recognition of the limitations in using these models to characterize uncertainty in energetic pathways involving the benthos, we used uniform probability distributions bounded by the upper and lower quartiles of the range of observed splits between the benthos and mesozooplankton in our analyses.

Many of the EwE models we examined did not partition phytoplankton production by size class and therefore did not allow treatment of the microbial food web as specified in our model (Figure 3.1.1). In those cases, we used literature values for ecotrophic efficiencies (proportion of production consumed within the microbial food web and the gross growth efficiency of bacteria and microzooplankton (Straile 1997; Ware 2000). It was not possible to define these elements according to Ecotype or to fully represent the uncertainty in these estimates.

Results

For the systems under consideration, total annual ecosystem production potential (EPP) for trophic levels 2+ (i.e. not primary producers) varied from 23to 322 million tons (Fig. 3.1.2, Table 3.1.1). Although absolute differences in EPP across ecosystems are essentially driven by the areal extent of the ecosystems, temperate shelf systems like the Scotian Shelf and the Northeast US shelf showed higher production potential “density” than the subarctic-boreal systems.

Previous estimates of fishery production potential typically assumed that 50-70% of production at a defined mean trophic level could be extracted as catch (e.g Graham and Edwards 1962; Ryther 1969; Schaefer 1965; Ricker 1969; but see Moiseev 1994). These proposed extraction rates were predicated on prevailing single-species recommendations based on the (implicit) assumption that fishing mortality rates could equal natural mortality for the stock (Pauly & Christensen 1995). It is now recognized that these earlier target levels for single-species management were too high and led to risk-prone decisions (Pauly & Christensen 1995).

Here we have followed Iverson (1990), and considered that sustainable ecosystem exploitation rates cannot be higher than the ratio of new primary production to total primary production, and we have approximated that ratio from the relationship between microplankton production and total primary production. This allowed us to define two ecosystem exploitation rate scenarios that should provide an initial envelope for what could be considered a sustainable exploitation at the ecosystem level. These scenarios corresponded to exploitation rates of 20 and 30%.

These exploitation rates were applied to all nominally fishable nodes in the EPP model (benthos, planktivores, benthivores, and piscivores); this allowed incorporating the impact of fishing lower in the trophic web to the productivity of higher trophic levels. In the same sense that considering the *f*-ratio as an initial proxy for exploitation rate could be interpreted, in a financial analogy, as living from the interest without touching the capital of the investment, the simultaneous exploitation of all fishing nodes allows incorporating the effect of "lost revenue" in the higher trophic level nodes (i.e. the production that will not occur because the required input production from lower trophic levels has already been reduced by fishing).

The results of applying these exploitation rates are the estimates of fisheries production potential (FPP) (i.e. the production potential available to fisheries). The FPPs from benthivores and piscivores nodes have been added to produce a single "Groundfish" (GF) FPP value; this amalgamated GF FPP is better suited for comparisons with catch levels which are often dominated by groundfishes, and because a number of piscivorous species also prey on benthic organisms and have broadly omnivorous feeding patterns. Table 3.1.1 summarizes the key results for a baseline run without exploitation and the two exploitation rate scenarios considered; for the runs with exploitation, the production potential available to fisheries (i.e. fisheries production potential) and available to the ecosystem (i.e. for sustaining ecosystem functioning –non-provisioning ecosystem services-) is discriminated.

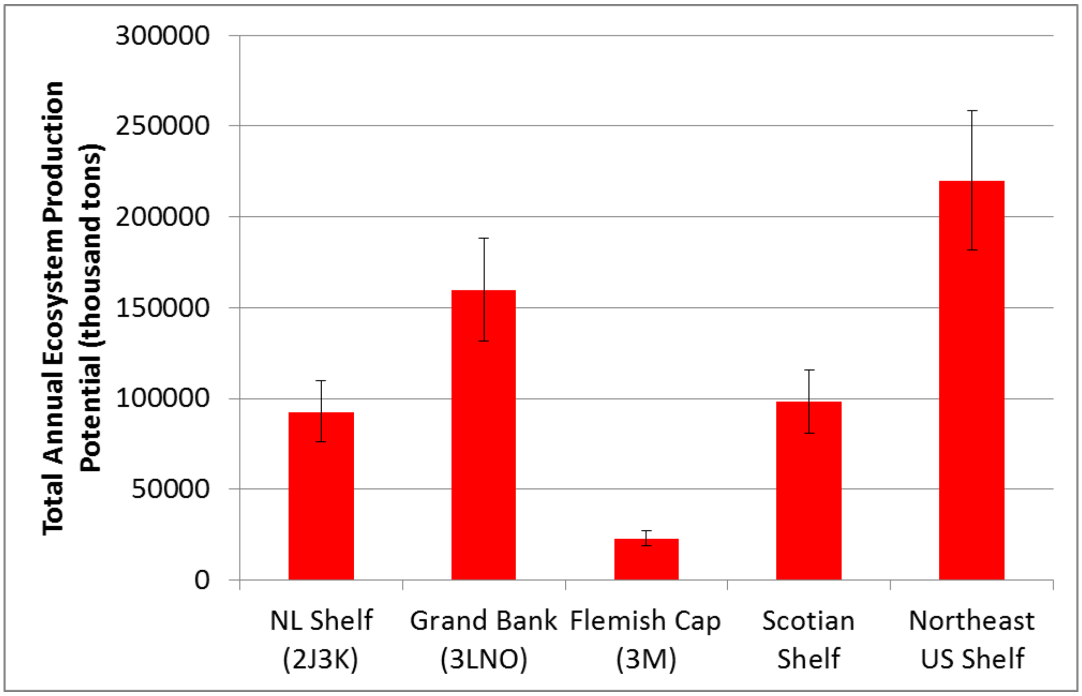


Figure 3.1.2. Median values for the estimates Total Annual Ecosystem Production Potential in trophic levels 2+ (not primary producers) for Northwest Atlantic ecosystems. The error bars correspond to the 25-75% quantile intervals.

In terms of fisheries production potential, the two exploitation rate scenarios provide an initial envelope for the level of fishing that these Northwest Atlantic ecosystems could tolerate in a sustainable manner (Fig. 3.1.3). It is clear that groundfish components only represent around 30% of the total FPP, the remainder being associated with planktivores and benthos (Fig. 3.1.3, Table 3.1.1).

Table 3.1.1. Ecosystem production potential (EPP) estimates for Northwest Atlantic ecosystems. These estimates are based on three scenarios: a) base case with no exploitation, b) ecosystem exploitation rate set at 20%, and c) ecosystem exploitation rate set at 30%. For those nodes in the EPP model with exploitable species, EPP is discriminated between what is estimated as potentially available for the ecosystem (to allow ecosystem functioning), and what is potentially available to fisheries (i.e. fisheries production potential). The groundfish component was approximated by the sum of the piscivores and benthivores nodes in the EPP model (Figure 3.1.1). Each estimate of EPP is characterized by its median and 25-75% quantile range. The All EPP estimates are in thousands of tons.

Ecosystem		**NL Shelf (2J3K)**	**Grand Bank (3LNO)**	**Flemish Cap (3M)**	**Scotian Shelf**	**Northeast US Shelf**
Ecosystem type		Subarctic-Boreal Shelf	Subarctic-Boreal Shelf	Subarctic-Boreal Shelf	Temperate Shelf	Temperate Shelf
Area (thousand km2)		238.944	305.854	46.197	181.589	321.974
Scenario: No Exploitation						
Total EPP in trophic levels 2+ (not primary producers)	median	92481	159534	23004	98348	219955
	25% quantile	76144	131866	18966	81027	181822
	75% quantile	109624	188272	27086	115769	258483
EPP of fishable nodes available to Ecosytem	median	6945	10218	1493	7618	12012
	25% quantile	4020	5986	878	4388	6927
	75% quantile	11413	16767	2440	12492	19739
EPP of fishable nodes available to Fisheries	median	0	0	0	0	0
	25% quantile	0	0	0	0	0
	75% quantile	0	0	0	0	0
EPP of groundfishes available to Ecosystem	median	847	1246	180	890	1377
	25% quantile	488	730	106	478	748
	75% quantile	1420	2086	302	1562	2453
EPP of groundfishes available to Fisheries	median	0	0	0	0	0
	25% quantile	0	0	0	0	0
	75% quantile	0	0	0	0	0
EPP of planktivores available to Ecosystem	median	2466	3714	541	1917	3281
	25% quantile	1516	2312	342	1103	1977
	75% quantile	3838	5840	841	3202	5299
EPP of planktivores available to Fisheries	median	0	0	0	0	0
	25% quantile	0	0	0	0	0
	75% quantile	0	0	0	0	0
EPP of benthos available to Ecosystem	median	3632	5259	772	4811	7353
	25% quantile	2016	2944	430	2807	4201
	75% quantile	6155	8841	1297	7728	11988

EPP of benthos available to Fisheries	median	0	0	0	0	0
	25% quantile	0	0	0	0	0
	75% quantile	0	0	0	0	0

Scenario: ecosystem exploitation rate at 20%

Total EPP in trophic levels 2+ (not primary producers)	median	92103	157823	22892	97522	220165
	25% quantile	76200	130093	18812	80841	180451
	75% quantile	108682	187709	27004	114836	256781
EPP of fishable nodes available to Ecosytem	median	6405	9524	1371	6971	10978
	25% quantile	3690	5591	805	3984	6309
	75% quantile	10455	15477	2219	11646	18107
EPP of fishable nodes available to Fisheries	median	475	713	103	444	724
	25% quantile	283	431	62	249	412
	75% quantile	765	1145	165	759	1222
EPP of groundfishes available to Ecosystem	median	634	941	134	650	1013
	25% quantile	364	545	78	346	543
	75% quantile	1052	1570	226	1163	1814
EPP of groundfishes available to Fisheries	median	158	235	34	163	253
	25% quantile	91	136	20	87	136
	75% quantile	263	393	56	291	454
EPP of planktivores available to Ecosystem	median	2195	3333	490	1684	2952
	25% quantile	1365	2110	303	967	1742
	75% quantile	3420	5170	753	2808	4807
EPP of planktivores available to Fisheries	median	244	370	54	187	328
	25% quantile	152	234	34	107	194
	75% quantile	380	574	84	312	534
EPP of benthos available to Ecosystem	median	3576	5250	746	4637	7013
	25% quantile	1961	2936	424	2671	4024
	75% quantile	5983	8737	1241	7674	11486
EPP of benthos available to Fisheries	median	73	107	15	95	143
	25% quantile	40	60	9	55	82
	75% quantile	122	178	25	157	234

Scenario: ecosystem exploitation rate at 30%

Total EPP in trophic levels 2+ (not primary producers)	median	91316	157966	22810	96377	220849
	25% quantile	75047	129338	18732	79626	181767
	75% quantile	107785	186921	26930	113677	257621

EPP of fishable nodes available to Ecosytem	median	6097	9039	1319	6797	10603
	25% quantile	3554	5302	771	3844	6179
	75% quantile	10045	14758	2146	11214	17597
EPP of fishable nodes available to Fisheries	median	700	1053	152	659	1072
	25% quantile	420	636	92	366	619
	75% quantile	1130	1690	245	1130	1815
EPP of groundfishes available to Ecosystem	median	533	785	115	551	861
	25% quantile	306	452	66	292	464
	75% quantile	893	1311	190	1003	1537
EPP of groundfishes available to Fisheries	median	229	337	49	236	369
	25% quantile	131	194	28	125	199
	75% quantile	383	562	81	430	659
EPP of planktivores available to Ecosystem	median	2058	3168	453	1581	2763
	25% quantile	1294	2009	287	902	1670
	75% quantile	3191	4891	706	2638	4530
EPP of planktivores available to Fisheries	median	363	559	80	279	488
	25% quantile	228	355	51	159	295
	75% quantile	563	863	125	466	799
EPP of benthos available to Ecosystem	median	3506	5086	751	4665	6979
	25% quantile	1954	2841	418	2650	4045
	75% quantile	5960	8556	1251	7573	11529
EPP of benthos available to Fisheries	median	108	157	23	144	216
	25% quantile	60	88	13	82	125
	75% quantile	184	265	39	234	357

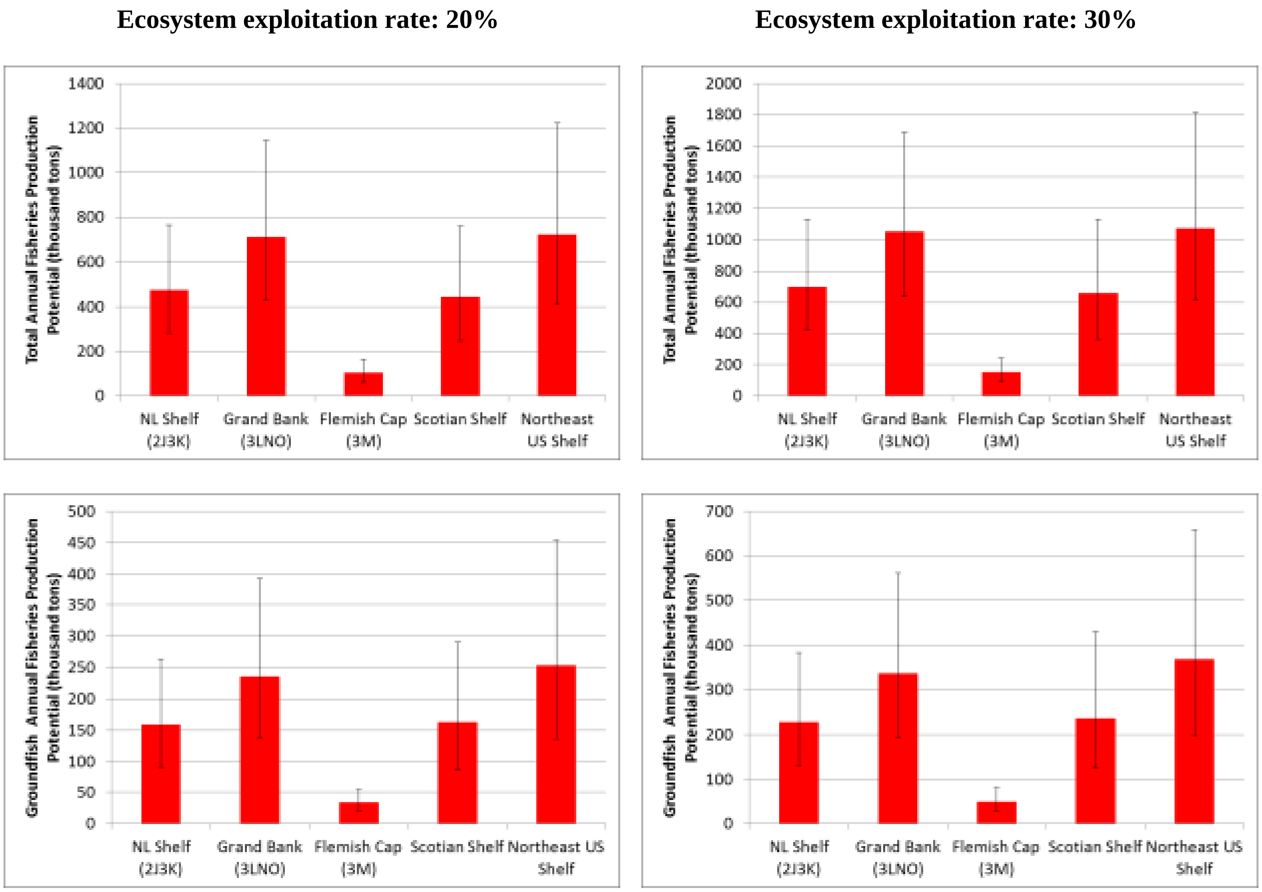


Figure 3.1.3. Median values for the estimated Total (top row) and Groundfish (bottom row) Fisheries Production Potential for Northwest Atlantic ecosystems under a 20% (left column) and 30% (right column) ecosystem exploitation rates scenarios. The error bars correspond to the 25-75% quantile intervals.

It is important to highlight that FPP estimates effectively are the maximum fishing production that these ecosystems could generate within a context of general ecosystem sustainability. Fishing above these levels would be expected to start hindering the capacity of the system to be fully functional, since it would start eroding the biomass structure needed to generate the production.

In this context, there is a significant and important difference between the FPP for an ecosystem, and the actual level of exploitation that the system can sustainably tolerate at a given point in time. These initial estimates of FPP are derived from a model that has a purposely simple (but still reasonable) structure, and where several approximations and assumptions are made regarding the values, distribution and variability of its parameters. Key to it all, it is the assumption that transfer efficiencies are the ultimate limiting factor in production; this is what it defines the "potential" of the system. However, if the biomass level in a particular node is not adequate, the capacity of that node to utilize all the production available from lower trophic levels could be impaired. In such a case, the "standing stock" biomass of the node would become the limiting factor for production (e.g. if there is not enough piscivores to eat/process all the planktivore production available, the potential production of piscivores -which assumes that all the planktivore production will be used- would not be realized). Therefore, these FPP level can only be achieved if the ecosystem is "healthy" in the sense that there is enough biomass in each node to process all the production that feeds into that node. If this is not the case, the actual fishing production that the system can generate sustainably would be lower.

This issue was started to be explored by focusing on the Newfoundland-Labrador and Flemish Cap ecosystems. We compared the median annual nominal catches for the Newfoundland-Labrador Shelf, the Grand Bank, and Flemish Cap during three time periods (1960-1979, 1980-1989, and 1990-2012), with the corresponding median Total and Groundfish FPPs for these systems (Fig. 3.1.4).

For these systems, total catches never exceeded the estimated envelopes of Total FPP, but they systematically exceed the GF FPP in the earlier period for all systems, they were at par during the 1980s, and during the most recent period they have been below GF FPP for the NL Shelf and Grand Bank, and slightly above it for the Flemish Cap. Even though some pelagic species have had important catches, most of the catches in these systems corresponded to groundfishes (here we include shellfish in the benthivore node).

If we consider that these systems underwent dramatic changes in the late 1980s and early 1990s, when among other things the overall fish biomass of the systems declined, these results suggest that these ecosystems have been under excessive fishing pressure overall. It could be expected that the ecosystem erosion derived from the earlier ecosystem overfishing of its groundfish components would have reduced the production capacity of the systems, and hence, maintaining these systems in an overfished state regardless of the reduction in catch levels. The further reductions in overall catch levels in the more recent years in the NL shelf and Grand Bank may have been a contributing factor, together with changing environmental conditions, in the recent positive trends observed in the groundfish community for these systems.

Although these are only preliminary observations, they are compelling suggestions that these systems not only have been systematically overfished in the past, but may have continue to be overexploited even after the collapses in the late 1980s and early 1990s. Furthermore, these results suggest that the current overall levels of exploitation are either close to the current capacity of these ecosystems or perhaps above. WGESA will continue developing these models and analyses to further explore these questions, but at the present time, increases in overall catch levels would not be advisable from an overall ecosystem sustainability perspective.

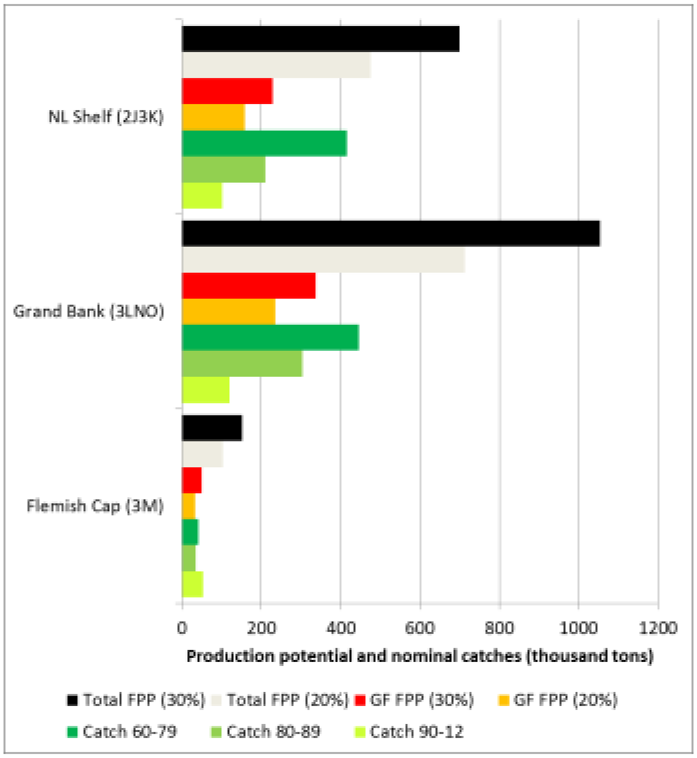


Figure 3.1.4. Comparison between catch levels and the corresponding fisheries production potential (FPP) for Newfoundland-Labrador and Flemish Cap ecosystems. Catch levels are characterized by the median nominal total catches in three time periods (1960-1979, 1980-1989, and 1990-2012). Fisheries production potential is characterized by the estimated Total and Groundfish (GF) Fisheries Production Potential for these ecosystems under a 20% and 30% ecosystem exploitation rates scenarios.

ToR 3.2. [*Roadmap*]. Report progress on trophic ecology/species interactions studies for the Grand Banks (NAFO Div 2J3KLNO).

3.2.1. Exploring trophic structure and food consumption in the Newfoundland and Labrador Shelves marine ecosystem (NAFO Divs. 2J3KLNO)

Introduction

Ecosystem management units should be linked, ideally, to ecosystem production units. In that functional context, changes in energy pathways from primary and secondary producers to the upper trophic levels (e.g. large fishes) can alter overall productivity of the ecosystem.

Furthermore, since natural mortality is variable; changes in the order of magnitude of predation, and its main targets, can affect the sustainability of a given exploitation strategy.

Hence, the implementation of the Roadmap requires an operational understanding of the trophic structure, the order of magnitude of predation at the ecosystem level, and how these characteristics of the system can change.

In the case of the Newfoundland and Labrador Shelves marine ecosystem, two major subunits have been identified as candidate ecosystem management units. These subunits correspond to the northern Newfoundland-Labrador Shelf (2HJK, although due to data limitations it is often restricted to 2J3K), and the Grand Bank (3LNO). The northern Grand Bank (3L) is considered as a transition zone between these two major subunits; some key stocks either have 3L as their nominal northern (e.g. 3LNO yellowtail flounder) or southern (e.g. 2J3KL Atlantic cod) area of distribution.

Therefore, the effectiveness of the proposed candidate ecosystem management units would require understanding the characteristics of the transition between the northern NL shelf and the Grand Bank, the levels of total food consumption by the fish community, discriminated whenever possible by prey categories, and a reliable characterization of trophic structure (e.g. trophic levels) to inform and validate the development and implementation of ecosystem models (e.g. the ecosystem production potential –EPP- models described in ToR 3.2.1).

The progress made by WGESA on these issues is described below.

NAFO Div. 3L as transition zone between the northern NL Shelf and the Grand Bank

The nature of NAFO Div 3L as a transition zone was explored from the perspective of its general productivity related to its northern and southern neighboring regions.

Methods

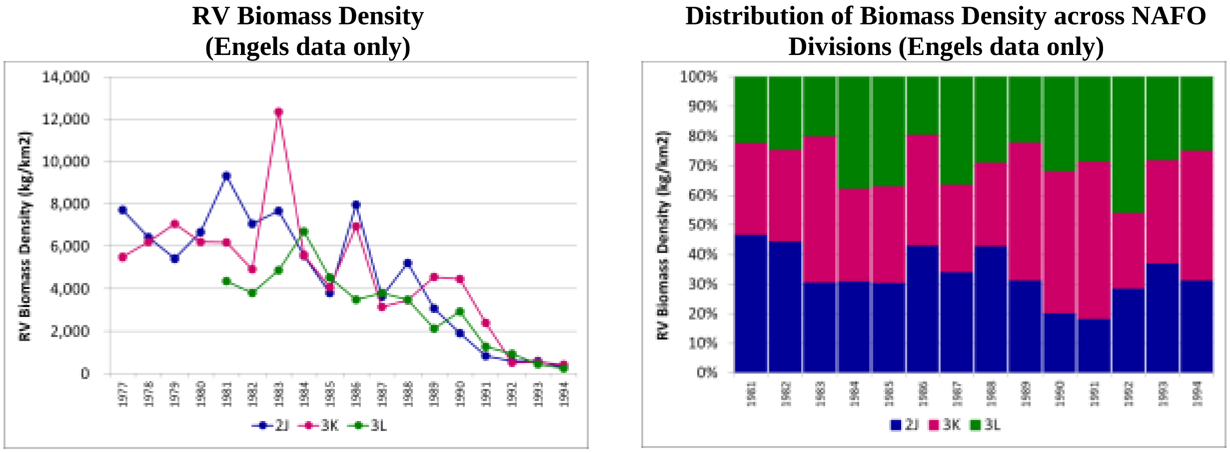
NAFO Div. 3L was compared with 2J3K and 3NO on the basis of the fish biomass density estimated from DFO RV Fall Surveys, and taking into account the differences emerging from the gear change in 1995 (the Engels gear was replaced by the Campelen gear). Species were grouped in fish functional groups. The general procedures used to generate RV Biomass indices follow NAFO (2010).

Results

Considering fish biomass density as a proxy for productivity, 3L appears to be the less productive among the NAFO Div. comprising the Newfoundland and Labrador Shelves marine ecosystem (2J3KLNO). During the Engels period (1981-1994), only 2J3KL were consistently covered by DFO RV Fall surveys; even with this more limited coverage, 3L shows a, albeit slightly, lower fish biomass density than 2J and 3K (Fig. 3.2.1).

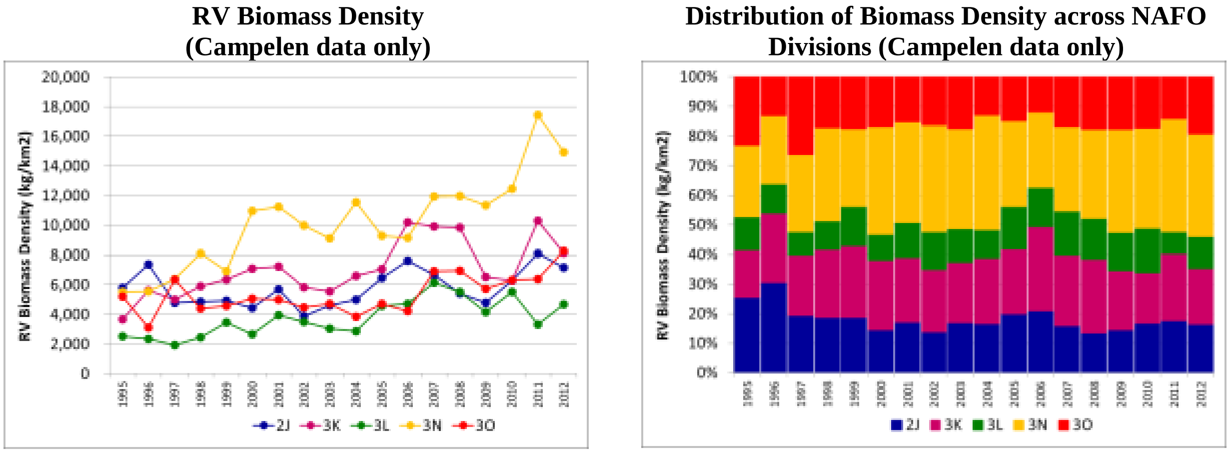
The lower fish biomass density in 3L becomes clearer during the Campelen period (1995-2012), when 3L can be compared with both northern and southern NAFO Divisions (Fig. 3.2.2).

The examination of the biomass density by fish functional groups allows to characterize 3L as a transition zone not just in terms of lower fish biomass density (Fig. 3.2.3.a), but also in terms of composition of the fish community. The northern NL Shelf (2J3K) is dominated by shellfish (mainly *Pandalus* shrimp), in the southern Grand Bank (3NO) the contribution of shellfish to the fish biomass density is minimal, while 3L clearly shows the transitional pattern between these two extremes (Fig. 3.2.3.b).


RV Biomass Density (Engels data only)

Distribution of Biomass Density across NAFO Divisions (Engels data only)

Figure 3.2.1. Total fish RV Biomass density during the Engels period from DFO RV Fall surveys.


RV Biomass Density (Campelen data only)

Distribution of Biomass Density across NAFO Divisions (Campelen data only)

Figure 3.2.2. Total fish RV Biomass density during the Campelen period from DFO RV Fall surveys.

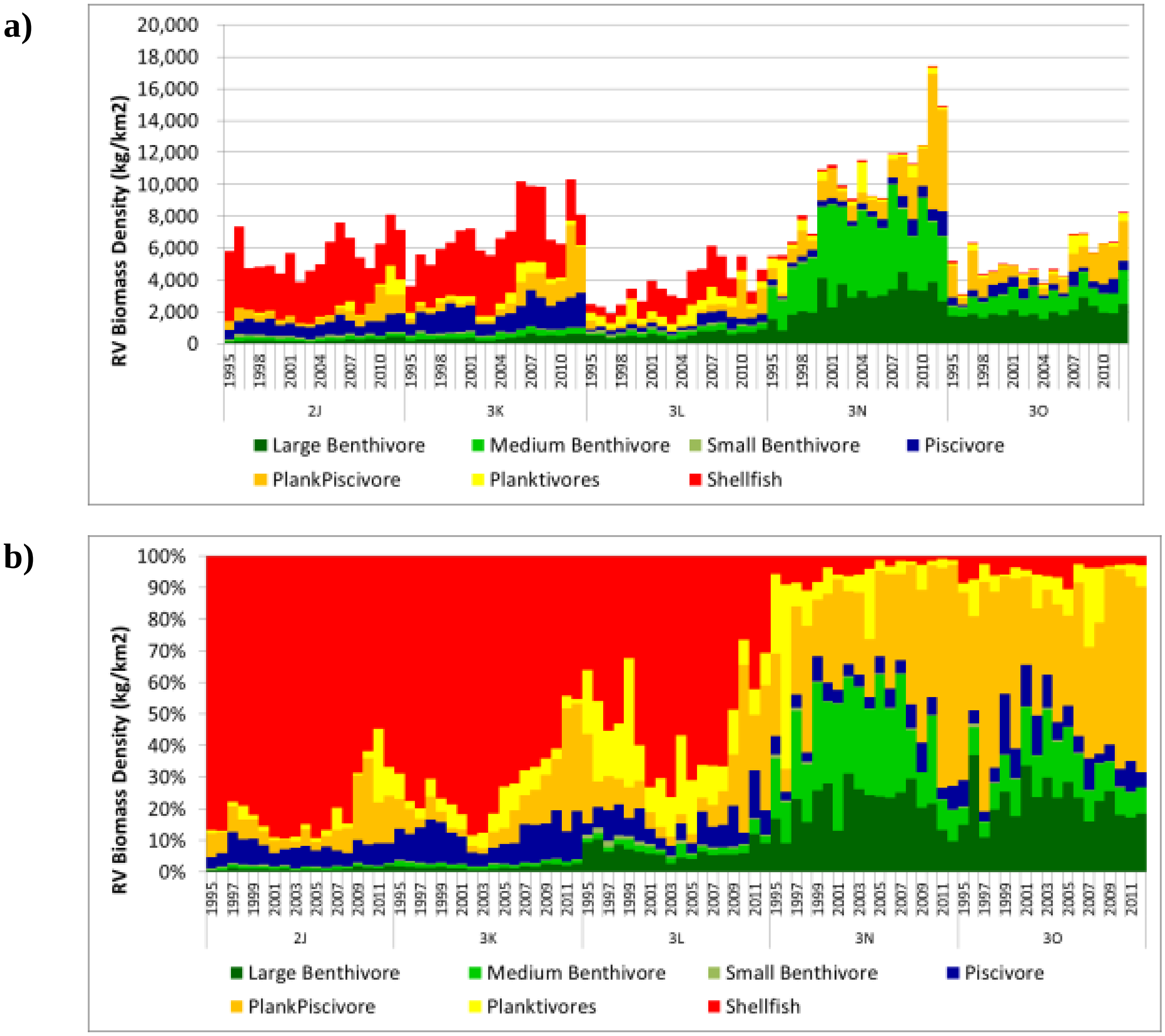


Figure 3.2.3. RV biomass density by NAFO Division during the Campelen period discriminated by fish functional groups; a) absolute RV biomass density indices, b) relative composition of RV biomass density indices.

Since it is well known that this ecosystem underwent dramatic changes in the late 1980s and early 1990s, it is important to determine if transitional characteristics like the ones observed in 3L during the Campelen period (i.e. after the collapsed) could also be found in the pre-collapse period.

Unfortunately, accurate comparisons between Engels and Campelen periods are not possible at the present time due to the lack of conversion factors for most fish species (they are available only for key commercial ones; work to try to develop alternative conversion factors for non-commercial species is ongoing), and unreliable recording of shellfish in the RV surveys during the Engels period.

Still, some crude comparisons can be made by using a generic conversion factor of 2.8, derived from the conversion factor for cod, which was the most abundant fish species in the northern NL shelf prior to the collapse. This approach is only illustrative, and simply provides a very coarse approximation to the order of magnitude of the changes that occurred. Nonetheless, it seems to indicate that 3L was a transition zone with lower biomass density prior to the collapse, that the current fish biomass density is probably somewhere between 30-50% of the pre-collapse level, and that even prior to the collapse, 3L showed a different fish functional group composition than the northern NAFO divisions with a larger proportion of benthivores (Fig. 3.2.4).

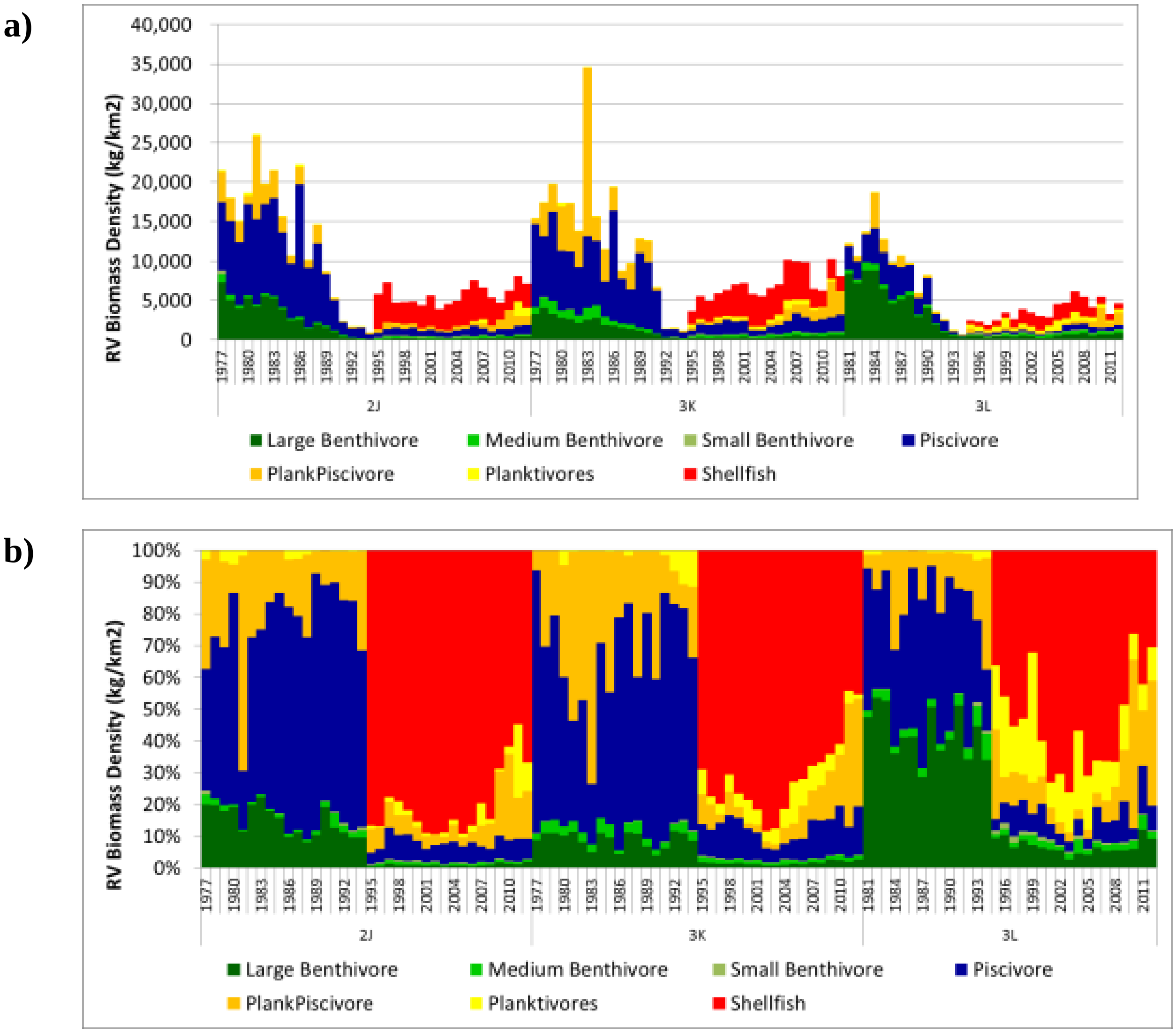


Figure 3.2.4. RV biomass density by NAFO Division by fish functional groups; a) absolute RV biomass density indices, b) relative composition of RV biomass density indices. The data for the Engels period was multiplied by a factor of 2.8 to provide a coarse visual approximation of the overall relative levels before and after the collapse. The Engels period do not contain shellfish data.

Interestingly enough, the more spatially resolved data layers utilized for the ecoregion analysis described in ToR 2.1 also shows lower biomass in the northern Grand Bank; this region also has lower levels of chlorophyll (Fig. 3.2.5).

All these results clearly support the notion that the northern Grand Bank (3L) is a transition zone between the two major ecosystem subunits within the Newfoundland and Labrador Shelves marine ecosystem. This transition zone is characterized by lower levels of fish biomass density, suggesting that productivity in 3L may be lower than in neighbouring regions. The lower chlorophyll level observed in the northern Grand Bank gives credence to the lower productivity hypothesis. NAFO Div 3L also exhibits a transitional fish functional group composition.

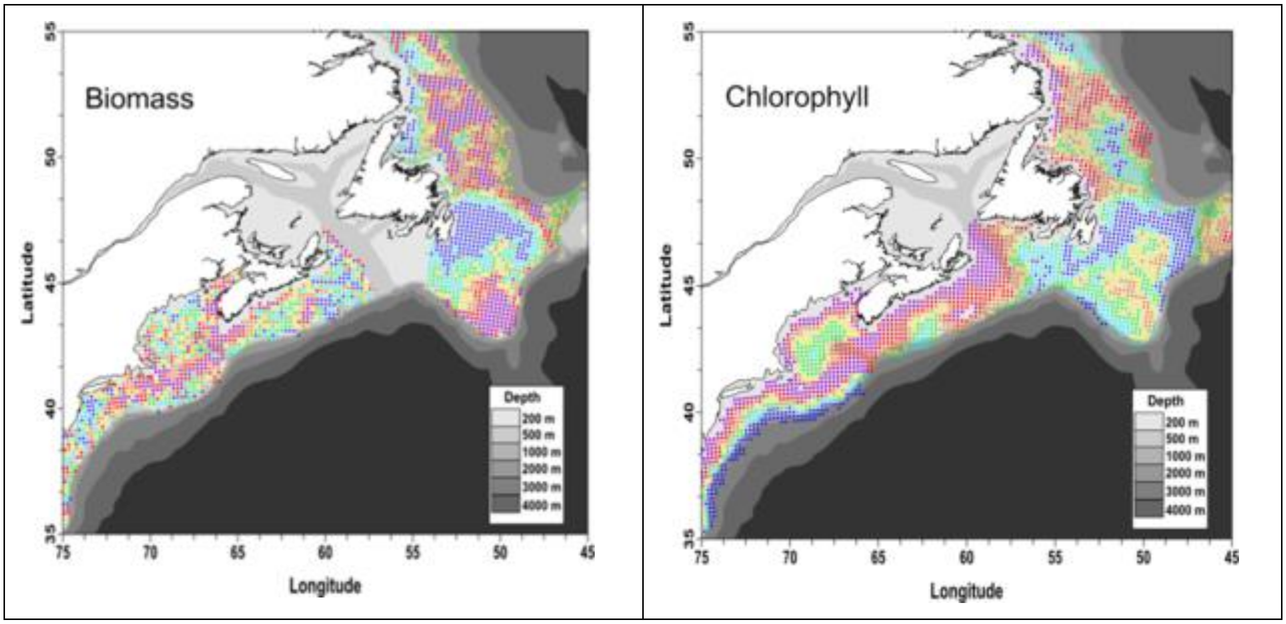


Figure 3.2.5. Normalized RV biomass (left) and chlorophyll (right) layers used for the ecoregion analysis described in ToR 2.1. Note that in both cases, the northern Grand Bank shows the lower values within the general Newfoundland and Labrador Shelves marine ecosystem.

Estimates of Consumption for the Newfoundland-Labrador fish community

Estimates of food consumption are important to the development and implementation of the Roadmap on many fronts. On a direct approach, consumption estimates can be used to estimate predation mortality that can be incorporated into stock-assessment models, but in the context of ecosystem production potential (EPP) models (see ToR 3.1), estimations of consumption can also be used as independent sources to verify/validate the consistency of EPP modelling results. For this application, it is important to estimate consumption for the entire fish community.

Methods

The aim of this analysis was to make a preliminary estimate of the order of magnitude of food consumption by the fish community at large, not to produce fine-tuned estimates for specific species.

Food consumption by each fish species in the survey was estimated by the product of a per-unit of biomass annual consumption rate, and the estimated Total RV Biomass index for that species.

Total RV Biomass and Abundance indices were derived from DFO RV Fall surveys from 1995-2012. These swept-area estimates were not corrected for gear catchablity. Since the Campelen gear used in these surveys is reasonably effective for both small and large-sized fishes, the impact of the lack of catchability correction on the results is thought not to be major, but it must not be disregarded either. Consequently, the estimates obtained here likely reflect minimum values. The RV Biomass/Abundance ratio (BA ratio) was used as a proxy for individual mean weight.

In order to provide a reasonable envelope for consumption, four different per-unit of biomass annual consumption rates were considered; two of them were derived from specific models, while the other two were simply daily rations estimated as fractions of average individual body mass.

Model 1: Yodzis and Innes

The first model considered was derived from a bioenergetic-allometric consumer-resource modelling framework (Yodzis and Innes 1992), and is based on empirical allometric scaling relationships. This model was chosen based on its simple structure and ease of application to the maximum number of species occurring in the Newfoundland and Labrador shelves ecosystem. The equation used was:

$$J_{max} = f_j a_j m_{BA}^{-0.25}$$

where J_{max} = asymptotic maximum consumption rate of species i; f_j = fraction of maximum physiological capacity to metabolize food realized by species i; a_j = allometric coefficient of the maximum physiological capacity to metabolize food of species I; and m_{BA} = mean weight of species i determined by calculating the biomass/abundance ratio in each year and NAFO Division. Consumption was then calculated by simply multiplying J_{max} by the biomass of each fish species. This model was used to estimate consumption by the majority of fish in the community (n=339). Parameters were assigned to each species based on best approximations from the literature (Yodzis and Innes 1992, Yodzis 1998).

Model 2: Palomares and Pauly

A multivariate statistical model (Palomares and Pauly 1998) was also used to estimate consumption by fish, but the number of species parameterized was fewer, due to lack of information in the literature. The equation used was:

$$Q/B = (10\text{\textasciicircum}(7.964 - 0.204\log W_{inf} - 1.965T + 0.083AR + 0.532h + 0.398d))$$

Where Q = consumption by species i; B = biomass of species i; W_{inf} = asymptotic weight of species i; T = mean habitat temperature for fish population expressed as 1000/(Tc+273.1) (and Tc = temperature in degrees Celcius); AR = aspect ratio of the caudal fin for species i; and h and d are binary (dummy) variables which identify type of food consumed (herbivores or detritivores).

Mean temperature data by NAFO Division and year were mostly derived from DFO RV survey databases.

W_{inf} was calculated based on maximum length data in the survey database and was available for 150 species in all NAFO Divisions. H and d were applied based on known feeding type for each species. AR data were extracted from literature sources dated post 1990 (Palomares and Pauly 1998, Sambilay 1990, Garcia and Duarte 2002, Sherwood and Rose 2003, Froese and Pauly 2014) provide references including Fishbase) for fish species that made up the top 90% of the biomass. For some species, especially those that make up a large portion of the biomass, the aspect ratio of the caudal fin was calculated using enlarged pictures of the fishes, as per Sambilay (1990). For all other species a category of AR was applied based on caudal fin shape.The total number of species for which these parameters (h, d, AR2) were available was 197. However, as W_{inf} was the limiting factor the total number of species included in the model was 86.

Daily rations

A third approach assumed daily rations as a percent fraction of body weight. For fishes, we assumed two daily ration scenarios of 1% and 2%.

Diet composition for key fish species

Diet composition was available for five key groundfish species (Atlantic cod, Greenland halibut -a.k.a turbot-, American plaice, redfish and yellowtail flounder), and two key pelagic species (capelin and Arctic cod). These diet compositions were estimated from stomach contents sampled during DFO RV Fall surveys in 2008-2012. The proportions in the diets were used to partition the estimated total food consumption for these key fish species into prey categories.

Results

Overall annual food consumption by the fish community was estimated to be increasing during the 1995-2012 period (Fig. 3.2.6). In the northern NL shelf (2J3K) it increased from 1-6 million tons in 1995 up to 2-10 million tons by 2012, while the estimated total food consumption in the Grand Bank went from 2-8 to 3-16 million tons in the same period (Fig. 3.2.6). From all the approaches used, model 2 (Palomares and Pauly 1998) consistently rendered the lowest consumption estimates, while model 1 (Yodzis and Innes 1992) and a 2% daily ration were the ones rendering the highest consumption estimates (Fig. 3.2.6). In the case of model 2, the estimated values are artificially lower because this approach could only be applied to 86 nominal taxa from the total of 339 considered with the other methods.

In addition to the overall increasing trend in consumption, the distribution of this consumption has also changed since the mid 1990s. The fraction of the total consumption represented by key groundfish species (Atlantic cod, turbot, American plaice, redfish , and yellowtail flounder) increased from 20-40% in 1995 to 50-70% in 2012 in 2J3K , and from ~60% to 80% in the Grand Bank (Fig. 3.2.7). The increased dominance in consumption by these key groundfish species is linked to the recent positive trends on these groundfish species, most of which showed significant declines during the fish community collapse in the late 1980s and early 1990s.

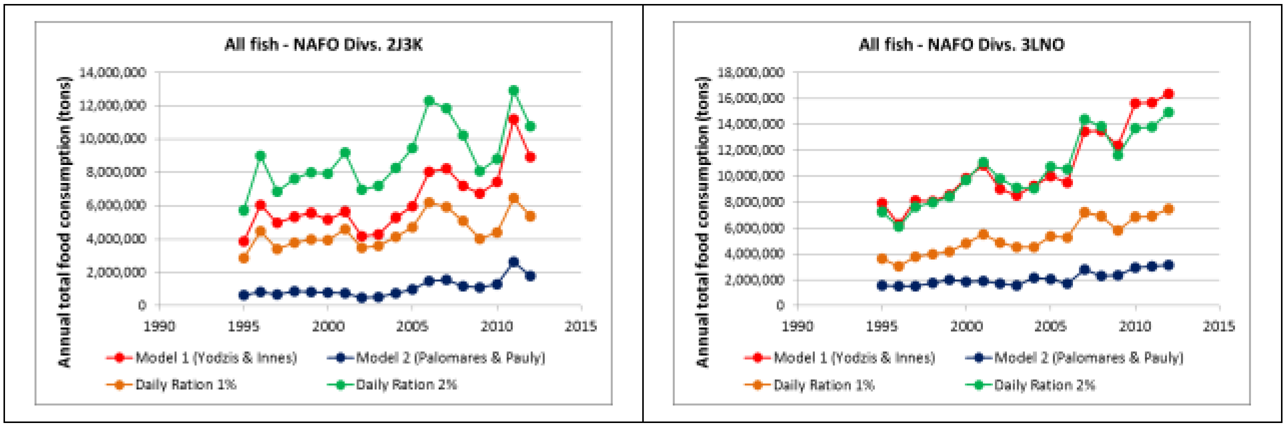


Figure 3.2.6. Estimated annual food consumption by the fish community in the northern NL shelf (left), and Grand Bank (right) based on four per-unit of biomass consumption rates. The estimates from Model 2 (Palomares and Pauly, 1998) are artificially lower because this method could not be applied to all species due to data constraints.

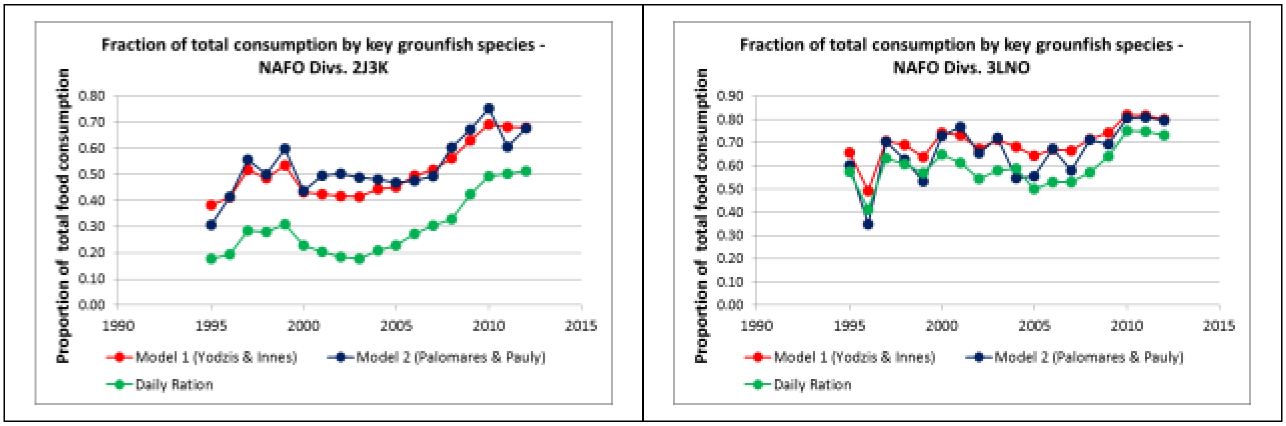


Figure 3.2.7. Fraction of the estimated annual food consumption by the fish community in the northern NL shelf (left), and Grand Bank (right) corresponding to the key groundfish species considered (Atlantic cod, turbot, American plaice, redfish , and yellowtail flounder). Only three series are displayed because the two daily ration scenarios considered render the same curve; this curve literally represents the relative fraction of the total RV Biomass represented by the key groundfish speices.

The distribution of consumption among fish functional groups can be examined on the basis of model 1 and the daily ration approaches; model 2 cannot be used because it couldn’t be applied to shrimp, which is a key species in the Newfoundland and Labrador Shelves marine ecosystem. Furthermore, since daily ration scenarios render consumption estimates directly proportional to the estimated RV biomass composition by fish functional groups, only one of the two scenarios considered is sufficient to examine the distribution of consumption.

On the basis of model 1 and the 2% daily ration scenarios, it is clear that the approach used has a significant impact on the perception of how consumption is distributed among fish functional groups (Fig. 3.2.8). Daily ration approaches estimate a much larger consumption for shellfish than model 1, derived from bioenergetic-allometric consideration. This is much more evident in 2J3K where the shrimp stock represented virtually half of the total fish biomass estimated by the RV surveys (Fig. 3.2.8). This variability highlights the need to continue improving the methods used for estimating consumption rates.

Model 1 (Yodzis & Innes) **Daily Ration 2%**

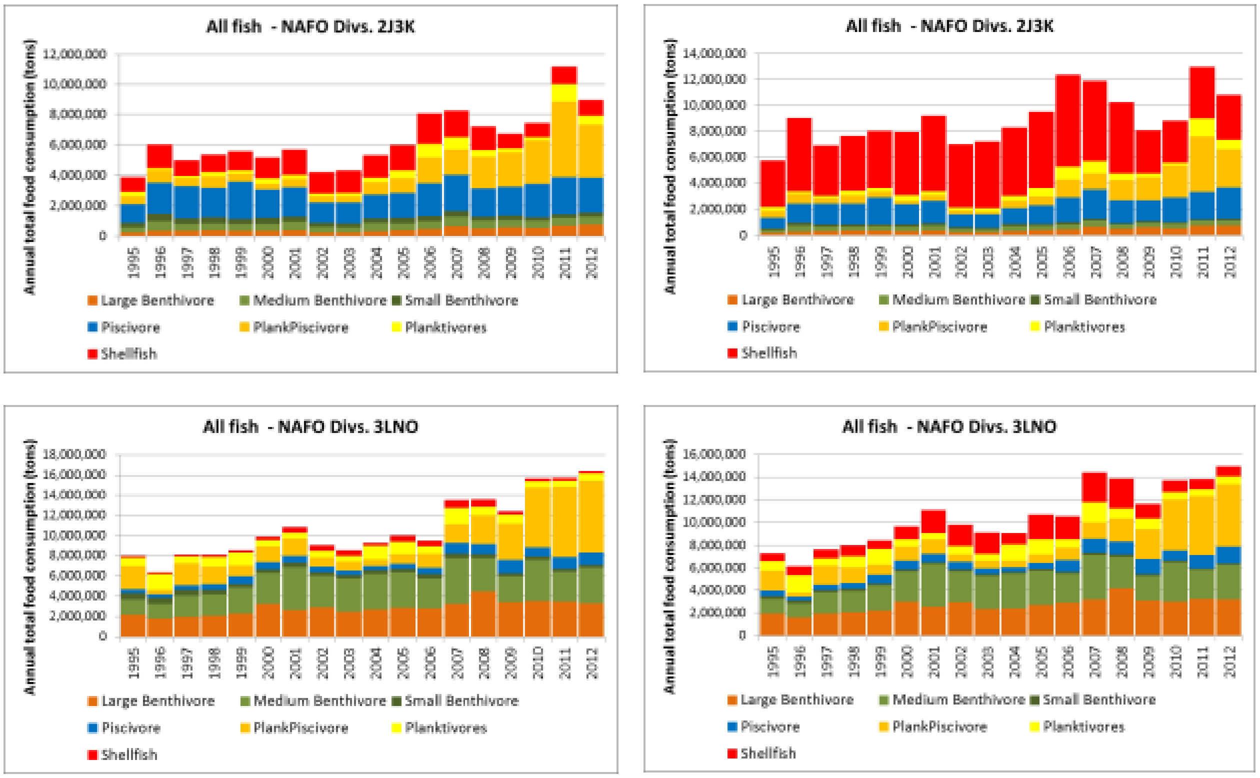


Figure 3.2.8. Estimated annual food consumption by fish functional groups using model 1 (Yodzis and Innes 1992) (left column) and 2% daily ration approach (right column) for the northern NL shelf (top row), and Grand Bank (bottom row).

For those key species for which diet composition is available, it is interesting to highlight the differences between diet composition and actual consumption. Using the results from model 1 as an illustrative example, the diets of American plaice and Atlantic cod had a much higher dominance of shrimp as key prey than Greenland halibut (a.k.a. turbot) and redfish in 2J3K, but the estimated consumptions of shrimp by these last two predators were of similar or higher magnitudes than the ones estimated for American plaice and cod (Fig. 3.2.9). Similarly, the diet of Greenland halibut (a.k.a. turbot) in the Grand Bank is highly dominated by capelin, but the actual consumption of capelin by this predator is estimated to be lower than the capelin consumed by American plaice or redfish, which have a much lower proportion of capelin in their diets. These observations are particularly relevant in the context of identifying sources of predation mortality for species of interest; although diet composition is important, taken in isolation it could be a misleading cue about the actual origin of the processes that drive natural mortality.

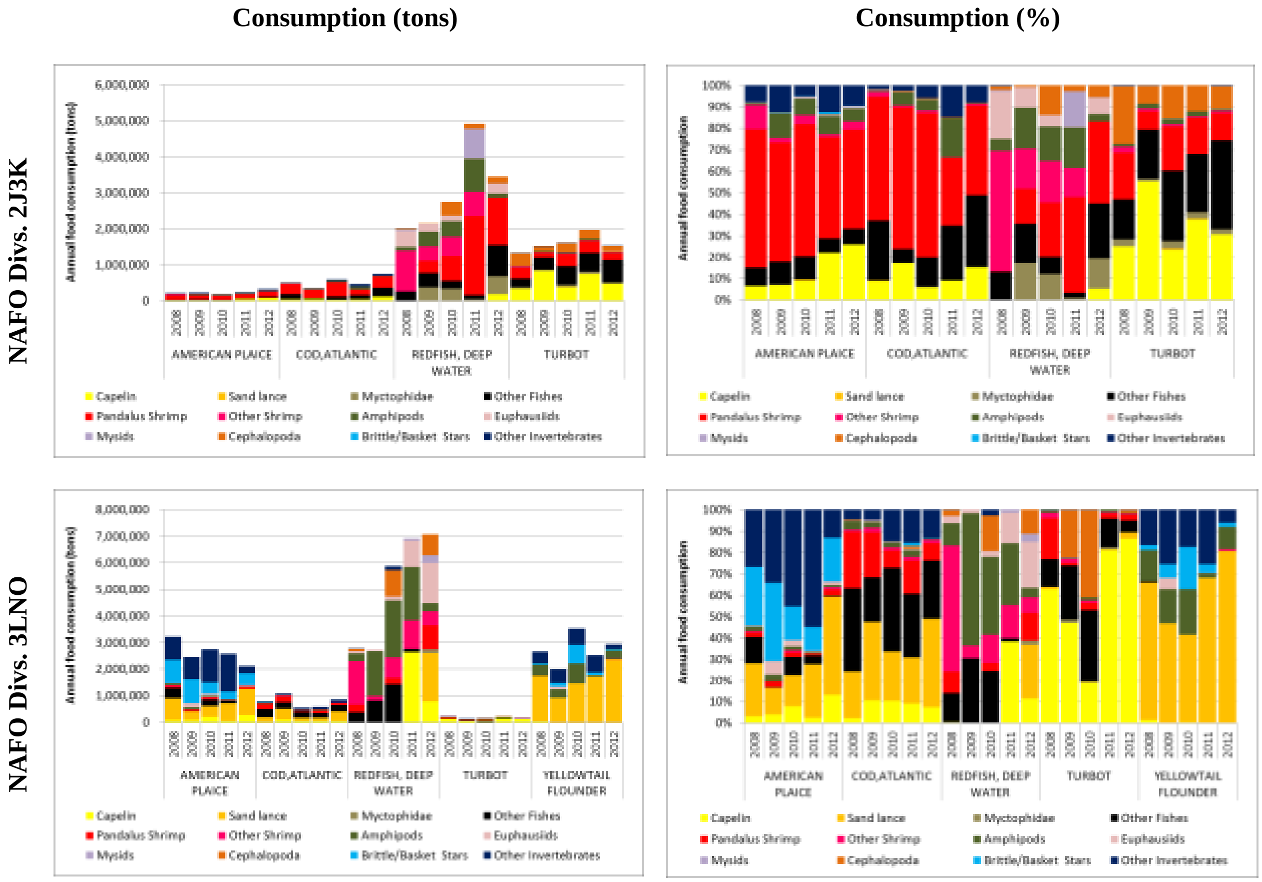


Figure 3.2.9. Estimated annual food consumption by key groundfish species discriminated by prey categories (left column), and the data expressed as proportions in the diet (right column) for the northern NL shelf (top row), and Grand Bank (bottom row).

With respect to the key forage species for which diet is available, the estimates of consumption are likely underestimated; the recent RV surveys use a bottom trawl Campelen gear, and bottom trawling is not considered the best method to estimate biomass of pelagic species. Still, they provide at least a minimum estimate of consumption. In this case, the consumption by Arctic cod was dominated by amphipods, while capelin consumption was primarily on copepods, although euphasids and amphipods were also important (Fig. 3.2.10).

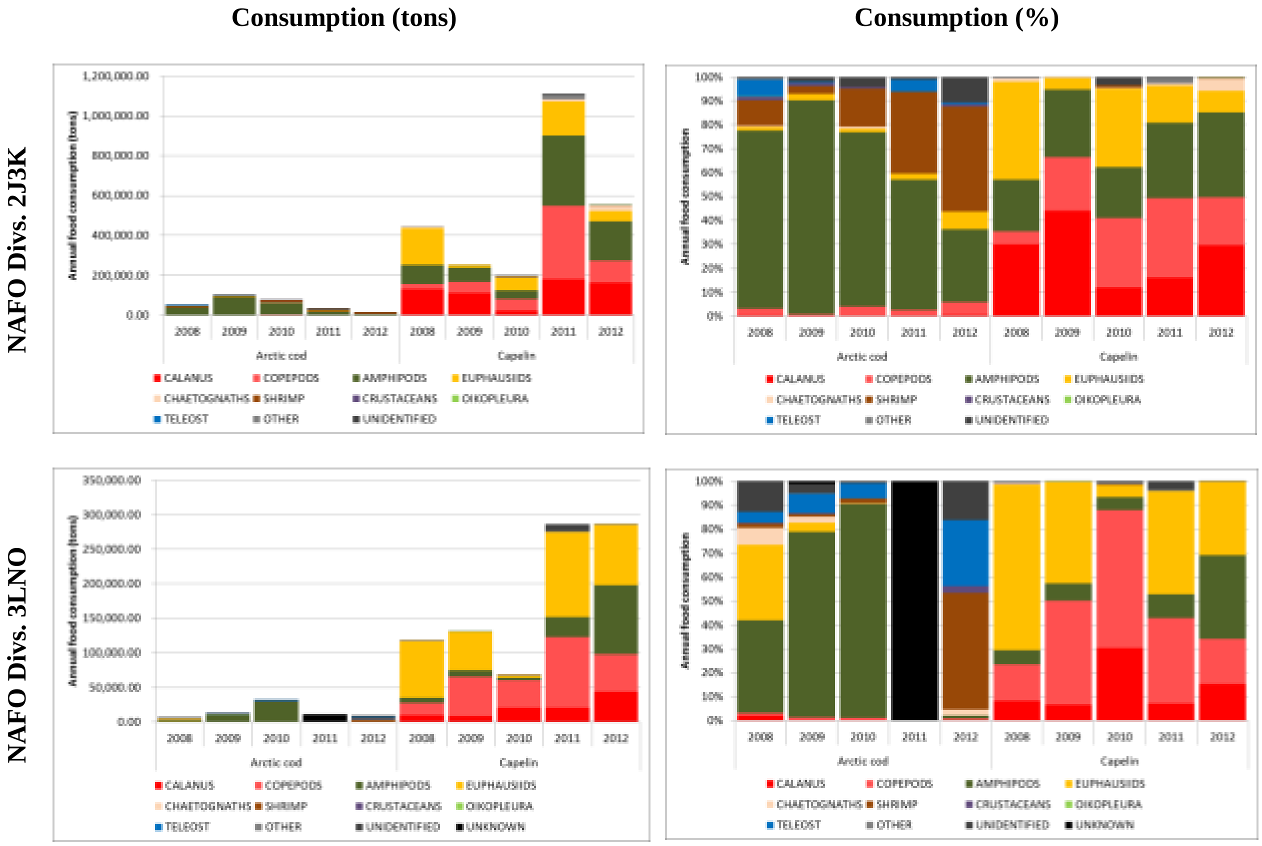


Figure 3.2.10. Estimated annual food consumption by key forage fishes discriminated by prey categories (left column), and the same data expressed as proportions in the diet (right column) for the northern NL shelf (top row), and Grand Bank (bottom row). Since the RV bottom trawl surveys are not considered a robust tool for estimating biomass of pelagic species, these values are likely underestimations of the actual consumptions.

Overall, these preliminary estimates of consumption seem to be consistent with the results obtained from the EPP models (see ToR 3.1). The food consumed by the fish community considered in this analysis is essentially produced by the mesozooplankton, benthos, planktivores, benthivores, and piscivores [labelled “upper trophic levels” in Fig. 3.1.1] nodes in the EPP model described in ToR 3.1. Hence, the EPP model baseline runs (i.e. no fishing) for the northern NL Shelf and the Grand Banks can be used to calculate the median production for the “fish food source” nodes indicated above. This “fish food source” production can be compared with the estimated annual food consumption; the expectation would be that, if the ecosystems are producing at its maximum potential, the systems would be at a [loosely defined] dynamic stable state, and both estimates should be of a similar magnitude. If the EPP estimates are lower than consumption, then there is a problem with one or both estimates. On the other hand, if consumption is lower than the EPP estimates, it can be interpreted that the system is producing at a lower level than EPP (i.e. the bottleneck for production are not the transfer efficiencies; for example, a reduced biomass level in one or more nodes –depleted stocks- could be limiting the productivity of the system). Table 3.2.1.1 summarizes these calculations. Furthermore, the median of all total annual consumptions estimates for 2012 approximately represents a 30% of the median estimated EPP for the “fish food source” nodes (Table 3.2.1.1), suggesting that these ecosystems could sustain biomass levels three times the size of what we observe today. If we also consider that consumption by marine mammals in 2J3KL is in the order of 6-7 million tons per year (aprox. 4.5 million by seals and 2 millions by cetaceans) (NAFO 2011, and G. Stenson pers. comm.), then total consumption in the entire 2J3KLNO may get closer to 40-50% of the EPP. Interestingly enough, the approximations done in the previous section (“NAFO Div. 3L as transition zone between the northern NL Shelf and the Grand Bank”) to produce Fig.

3.2.4, also rendered a coarse figure suggesting that current biomass levels are between 30-50% of the pre-collapse ones. The coherence among all these independently derived estimates suggests that the general picture being developed on the state and characteristics of these ecosystems seems to be a fairly consistent one.

Table 3.2.1.1. Comparison between estimates of annual food consumption by the fish community and the outputs from ecosystem production potential (EPP) models for the northern NL Shelf (2J3K) and Grand Bank (3LNO) ecosystems. Unless otherwise indicated, all values correspond to the medians and are expressed in units of thousand tons

	2J3K	3LNO
Total Annual EPP in trophic levels 2+ (not primary producers)	92481	159534
Combined Annual EPP for fish food source nodes (mesozooplankton, benthos, planktivores, benthivores, and upper trophic levels)	24213	36679
Total Annual food consumption for 2012 (median of 4 models)	7159	11204
Minimum	1797	3165
Maximum	10774	16385
Fraction of EPP from fish food source nodes represented by the median 2012 consumption estimates	0.30	0.31

Preliminary stable isotope analyses

Trophic level is an important feature for evaluating if models like the Ecosystem Production Potential ones used in ToR 3.1 are properly reflecting the structure of the modeled ecosystems, and to properly interpreting the results. Even though trophic level can be estimated on the basis of stomach content composition (Cortés 1999), it can also be done using stable isotope analysis.

While stomach contents provide direct evidence of prey consumption and instantaneous proportions of different prey types, they do not provide information on assimilation or longer term diets. Stable isotopes of carbon, nitrogen and sulphur (C, N and S) are now used to distinguish both the original carbon sources of food web components (phytoplankton, benthic algae, seagrasses, chemotrophes, etc., Wing et al. 2008) and the trophic position of the species of interest (e.g. Dennard et al. 2009).

In this context, a research project aimed to characterize the food webs in the Newfoundland and Labrador Shelves ecosystem using stable isotope analyses of C, N and S, in concert with the stomach content analyses, was initiated in 2012. Some preliminary results of this research were presented during the WGESA meeting, but more complete and detailed analysis will be presented at future WGESA meetings.

In a general sense, a more depleted (lower) carbon signature indicates a more pelagic foodweb base (zooplankton vs benthos). In the case of nitrogen, a higher nitrogen signature indicates a higher trophic level (typically 3.2 between marine trophic levels).

Although still in its early stages, the available results for C and N allows identifying pelagic and benthic pathways in the foodweb, where shrimp characterizes the base of the benthic pathway, while capelin and sandlance are at the base of the pelagic one (Figure 3.2.11). At the top of the food web, predators like Atlantic cod can be described as located on the vertex of the imaginary inverted parabola that connects the base of the two energy pathways (e.g. Rooney et al. 2006).

In terms of trophic levels, the observed difference in N between successive putative trophic levels appears smaller than expected. This could be associated with a higher reliance on invertebrate diets, which seem to show significantly lower trophic shifts than high protein diets (McCutchan et al. 2003). This interpretation is consistent with the higher dominance of shrimp in the diet of top predators observed in recent years, and it also hints at a higher importance of the benthic pathway, also evidenced by the similarities in C signatures between shrimp and top predators like Atlantic cod.

Since flows of energy through benthic pathways are “slower” than pelagic ones (Rooney et al. 2006), the higher reliance on the benthic pathway suggested by the stable isotopes may have implication for recovery times and could help understand overall observed dynamics.

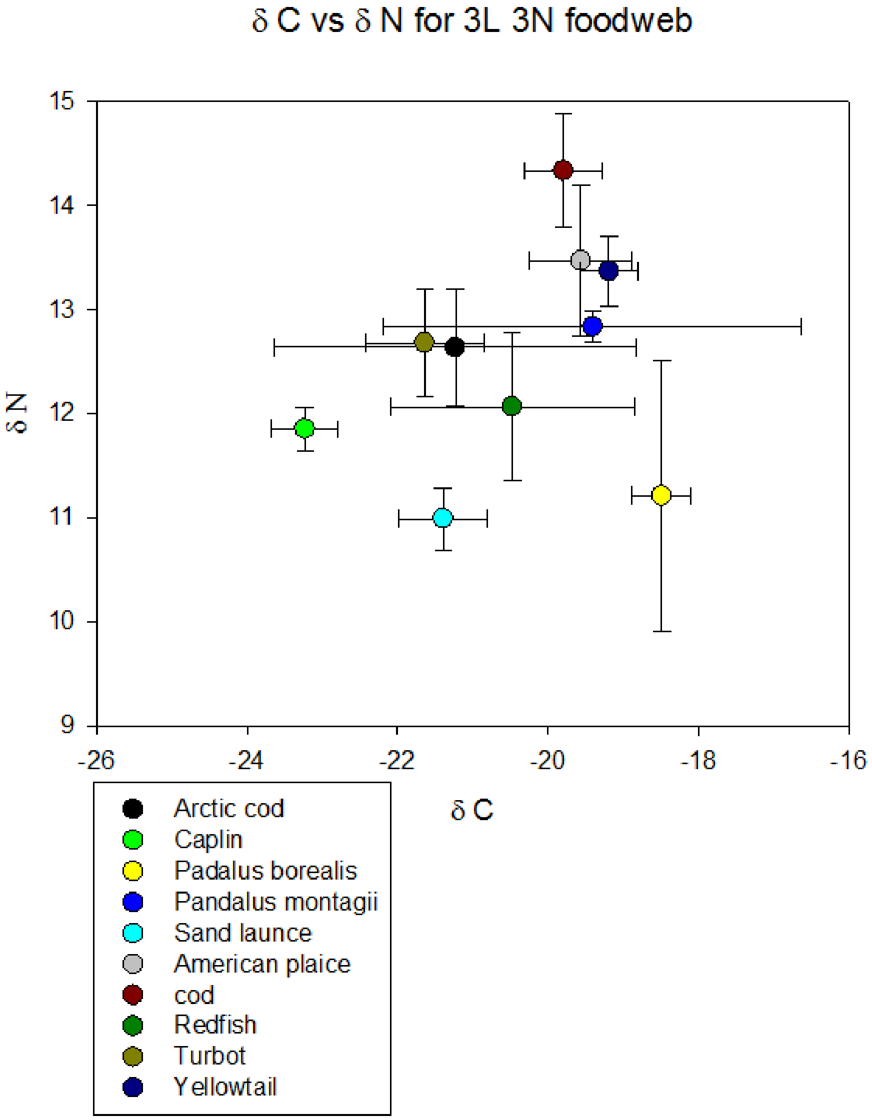


Figure 3.2.11. Average stable isotope ratios of carbon and nitrogen for key food web components from NAFO Divs. 3L and 3N. Error bars are the 95% confidence intervals for δ C and δ N. Trophic level is indicated by δ N, while source of carbon (benthic vs pelagic) is indicated by δ C.

3.2.2. Summary of Workshop on Community trends of the Newfoundland Shelf

A group of researchers from several universities (McGill, Université du Québec Montréal, Université du Québec Rimsouski, University of Heidelberg, Northeastern University, and University of Toronto) undertook an analysis of the multispecies trawl survey dataset from the Newfoundland and Labrador Shelf to [1] Identify spatial and temporal patterns of groundfish biodiversity on the Newfoundland shelf, and [2] Use that information to investigate the creation of predictive models of individual species dynamics and the 1990s groundfish collapse. The analyses are being carried out as part of three workshops (Fall 2013, Spring 2014, Fall 2014) to [1] Quantify spatial and temporal patterns of biodiversity, [2] Investigate approaches to predicting patterns of variation of individual species using community data, and [3] Investigate methods of predicting the 1990s groundfish regime shift. This section reports on the outcome of the first workshop.

Key features the dataset

The DFO trawl dataset has been collected in the fall from 1976 to 2011, although 1976 was sparsely sampled, so was excluded from our analysis. The data consists of benthic trawls taken at random depth stratified locations in each NAFO division region off the Newfoundland shelf. 2J, 3K and 3L were all sampled throughout the time period, but 3N and 3O were only sporadically sampled prior to 1990.

Prior to 1995, trawls were conducted using an Engels trawl with a relatively large mesh size, but from 1995 onwards, trawls were done with a smaller mesh Campelen net, to improve the coverage of small fish and invertebrates collected. As this represents a significant change in sampling structure, the analyses were structured into pre and post-gear change.

Calculating Local, Regional, and Beta Diversity

To calculate average ‘local’ diversity measures for each NAFO regions, the group applied a variety of diversity metrics (e.g. richness, Shannon’s H’) to each trawl separately, then averaged over all the trawls in a given NAFO region in a given year. To calculate regional diversity measures, the group summed up all abundances for a given species in each trawl for a region in a given year, and then applied the same diversity metrics to this summed community matrix. Finally, beta diversity was estimated as the ratio of each regional to local diversity metric. These beta-diversity measures will be equal to one if regional and local diversity are equal and greater than one when regional diversity is greater than mean local diversity.

Phylogenetic Diversity

Phylogenetic diversity measures the diversity of a community based on the phylogenetic relationships of its component species (Webb *et al.* 2002). Phylogenetic diversity was estimated as the standard effect size mean pairwise phylogenetic distance (sesMPD) using the *picante* package in *R* (Kembel *et al.* 2010) and the phylogeny of body fishes (Betancur-R *et al.* 2013). Species from the groundfish dataset were matched to species in the phylogenetic tree at the highest possible taxonomic resolution, generally species or genus, but family was used in some cases. sesMPD provides a measure of how phylogenetically diverse a community is, and is independent from species richness. Presence-absence was used in this analysis rather than biomass data to calculate phylogenetic diversity so that our estimates of diversity would not be directly affected by the large changes in the abundance of cod.

Spatial and temporal changes in community composition

Overall community composition change throughout the study period was investigated using regional ordination plots. For each year, all trawls in each NAFO region were aggregated into regional community matrices. A matrix of Bray-Curtis dissimilarities between each pair of years in each NAFO region, a measure of how different the two communities are, ranging between zero and one, was analyzed using nonmetric multidimensional scaling (NMDS). NMDS ordination arranges a set of points in two-dimensional space so that the dissimilarity between those 2D points is as close as possible to the dissimilarity between the original points (the difference between the two dissimilarity matrices called the stress).

In addition to the NMDS ordinations, we examined how rapidly community dissimilarity changed with distance in space, measuring how composition diverges with distance between trawls. Spatial rate of turnover was calculated by first calculating the Euclidean distances between communities from all trawls taken in a given year. Then, for each year, the community distance between all pairs of trawls was regressed against the distance in space and in depth between the two sites. This was then converted into partial R^2values for depth and distance, measuring how strongly community dissimilarity within each year was predicted by the distance between the two sites and the difference in depth strata between them.

Key Results

Traditional Diversity Measures

Regional species richness (the total number of species observed in all samples in a given year) remained constant throughout the period, but increased with the 1995 gear change (Fig. 3.2.2.1). Local species richness showed a steady decline in all regions before the 1995 gear change, and this trend continued post gear change in the northern NAFO divisions (2L and 3K; Fig 3.2.2.2). There was a rapid increase in beta diversity leading up to the 1995 gear change (Fig 3.2.2.3). Beta diversity decreased in 1995 with the gear change and remained constant for the remainder of the survey. The trends in local and beta richness may be spurious, however. The abundance of many species changed substantially throughout the study period, and the chance of observing a given species in an area is heavily dependent on that species' average abundance on the landscape. This effect is obvious at the gear change: measured species richness increased substantially after the switch to a smaller mesh net. The group is currently considering how to best measure abudance-adjusted species richness measures.

Phylogenetic Diversity

Regional phylogenetic diversity (sesMPD) increased marginally throughout the pre 1995 gear change period (Fig 3.2.2.4). There was little change due to the 1995 gear change and regionally phylogenetic diversity remained fairly constant from 1995 until 2010. In 2011 regional phylogenetic diversity declined sharply, in the region as a whole but not in all divisions.

Local phylogenetic diversity increased throughout the pre 1995 gear change period (Fig 3.2.2.5). The gear change resulted in a decrease in local phylogenetic diversity. Local phylogenetic diversity fluctuated in the post 1995 period, varying between NAFO divisions, but generally remaining constant in the region as a whole. These trends are robust to the removal of cod from the analysis.

Temporal Changes in Community Composition

Regional community composition remained relatively constant from 1977 until 1990 (Fig 3.2.2.6). From 1990 to 1995, there was a rapid directional shift away from the initial community composition. There was no apparent shift in community composition at the 1995 gear change. Post 1995 the rate of change slowed, and there was a possible trend towards the initial, pre-1990 composition. This overall pattern was observed in all three NAFO divisions (3J, 3K, 3L) were data was available before 1990. Stress for the NMDS for the region as a whole was 0.10, and was 0.15 when the region was broken down by division.

Changes in Spatial Structure of Community Composition

The total variance of community distances between pairs of trawls (Fig. 3.2.2.7 top), a measure of average between-trawl community composition differences, stayed relatively consistent throughout the study period (including before and after the gear change). However, the fraction of that variance explainable by distance (Fig. 3.2.2.7 center) and difference in depth strata (Fig. 3.2.2.7 bottom) between sites changed drastically throughout the study. In the years prior to the collapse, a very small part of the variance was explicable by distance between sites, and a much larger fraction was explicable by difference in depth. This implied that sites that were close in space were generally not much closer in community composition than distant sites, but sites at similar depths generally had similar compositions. However, during the collapse, the amount of variance explained by distance increased and the amount explicable by depth differences dropped. Furthermore, from 2000 onwards, variance explained by distance declined again, but the amount explained by depth did not return to pre-collapse levels, implying that while inter-site variability remained at the same level, the system became less spatially structured.

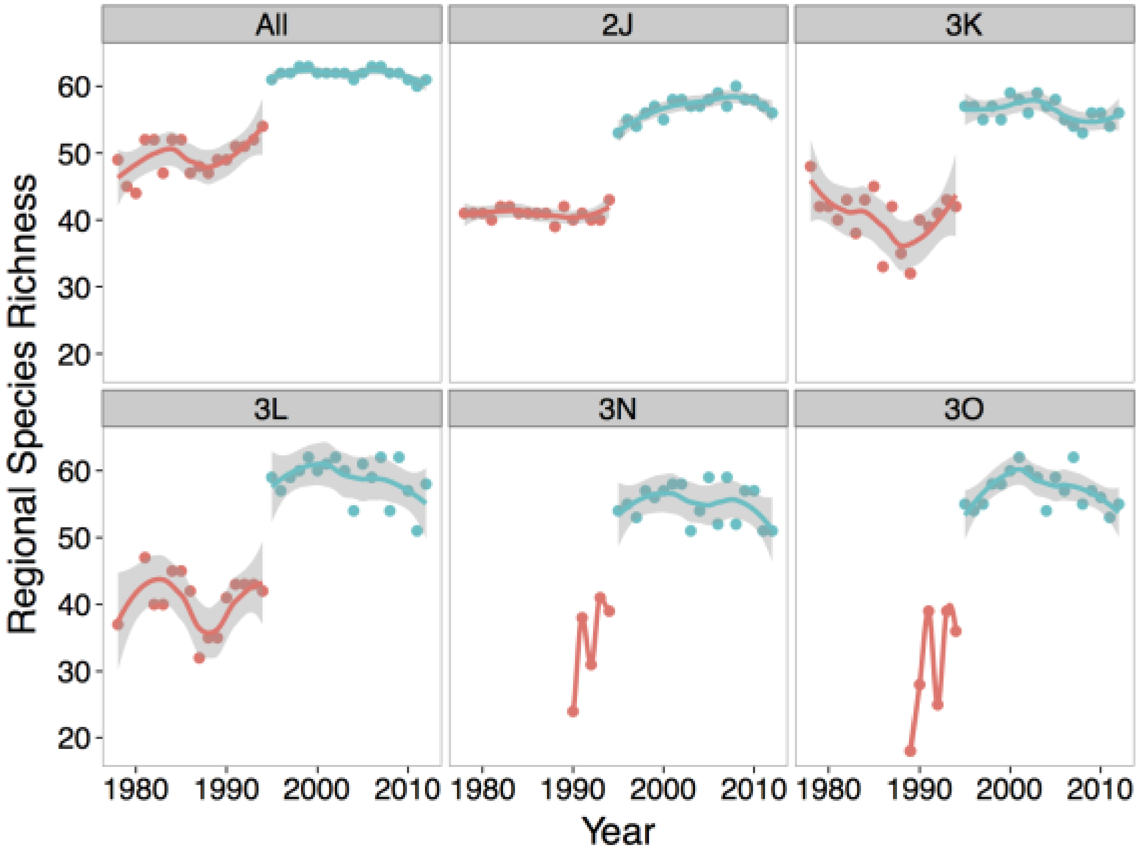


Figure 3.2.2.1. Regional species richness of groundfish in the study area, and the 5 NAFO subdivisions. Engels trawl data are shown in red. Campelen trawl data are shown in turquoise. Trend lines are based on local regression

smoothing and the 95% confidence intervals are shown in grey.

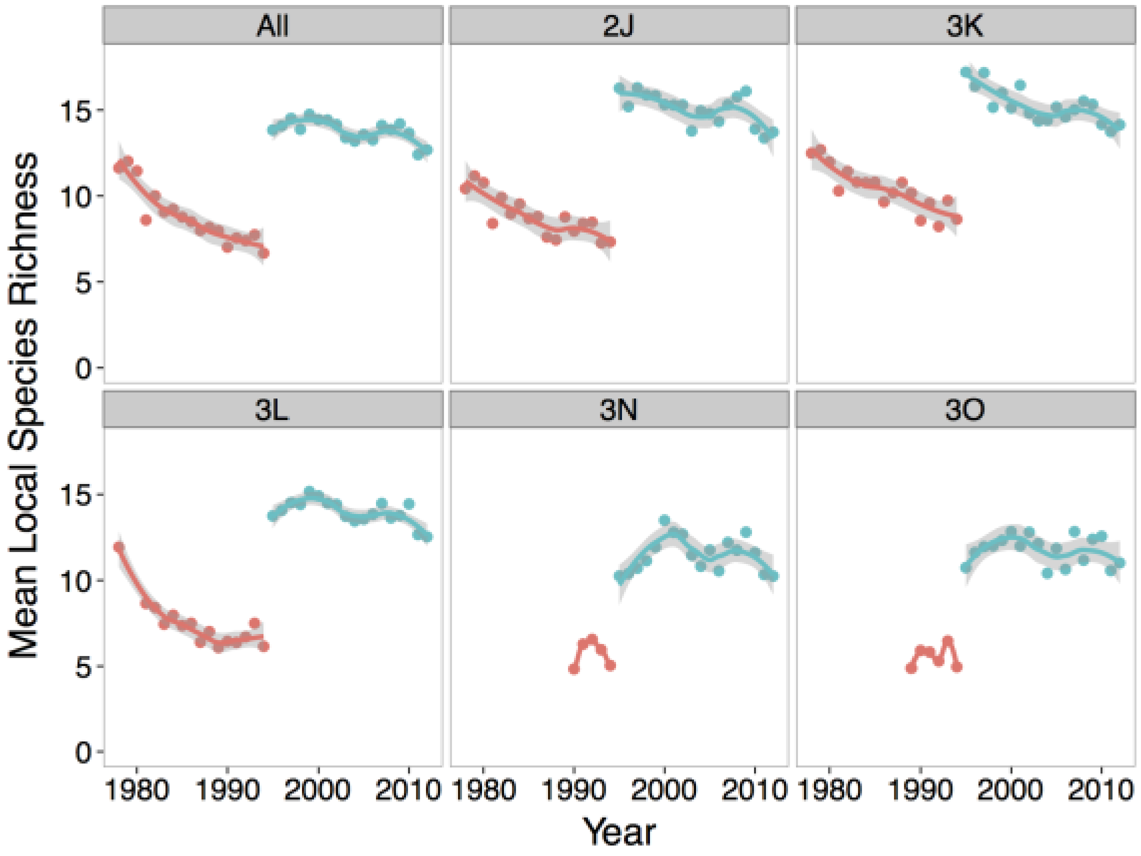


Figure 3.2.2.2. Local species richness of groundfish in the study area as a whole, and the 5 NAFO subdivisions. See Fig 3.2.2.1 description for details.

Figure 3.2.2.3. Beta diversity of groundfish in the study area as a whole, and the 5 NAFO subdivisions. See Fig 3.2.2.1 description for details.

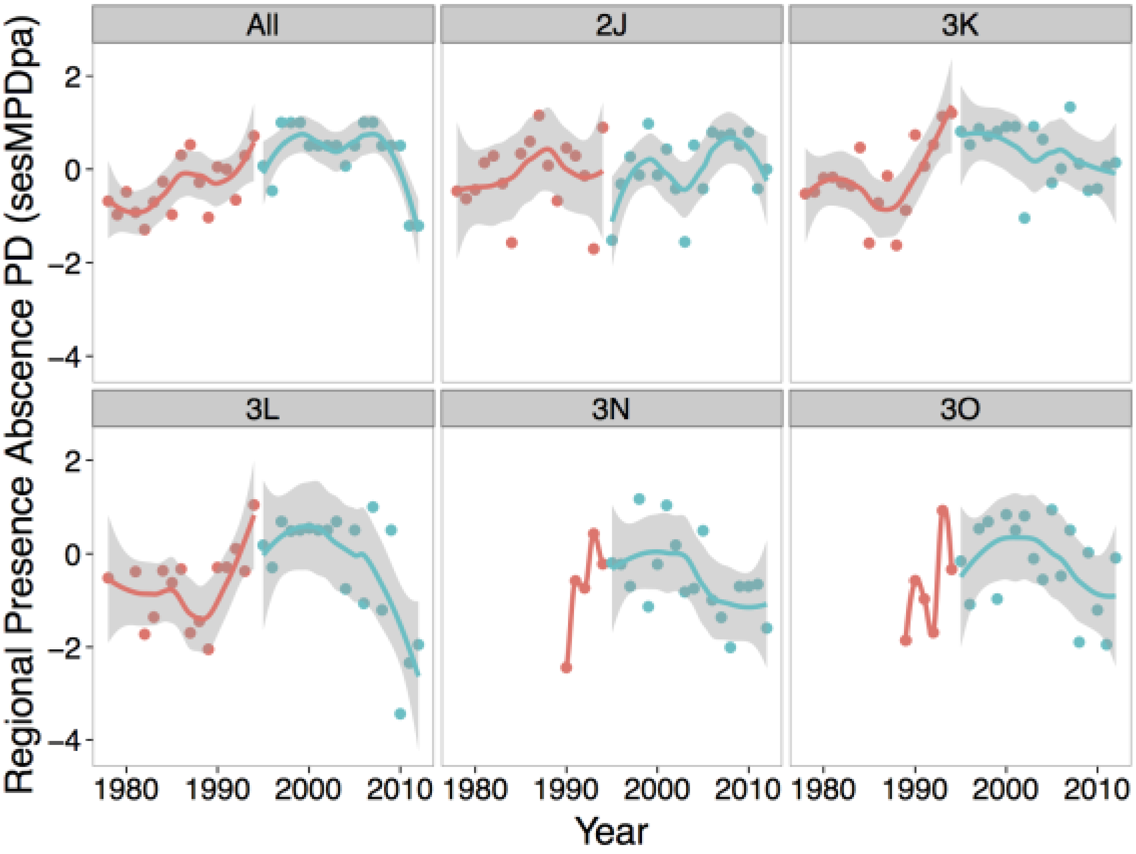


Figure 3.2.2.4. Regional phylogenetic diversity (sesMPD) of groundfish in the study area as a whole, and the 5 NAFO subdivisions. See Fig 3.2.2.1 description for details.

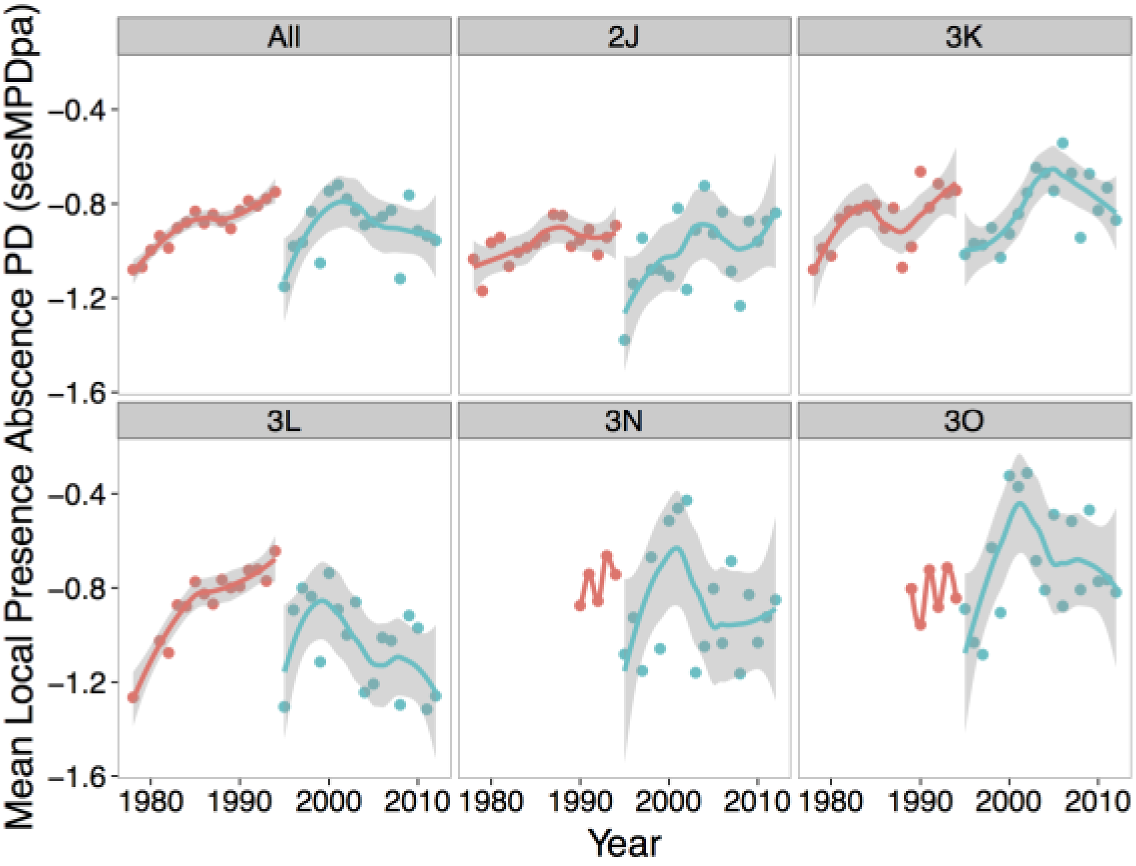


Figure 3.2.2.5. Local phylogenetic diversity (sesMPD) of groundfish in the study area as a whole, and the 5 NAFO subdivisions. See Fig 3.2.2.1 description for details.

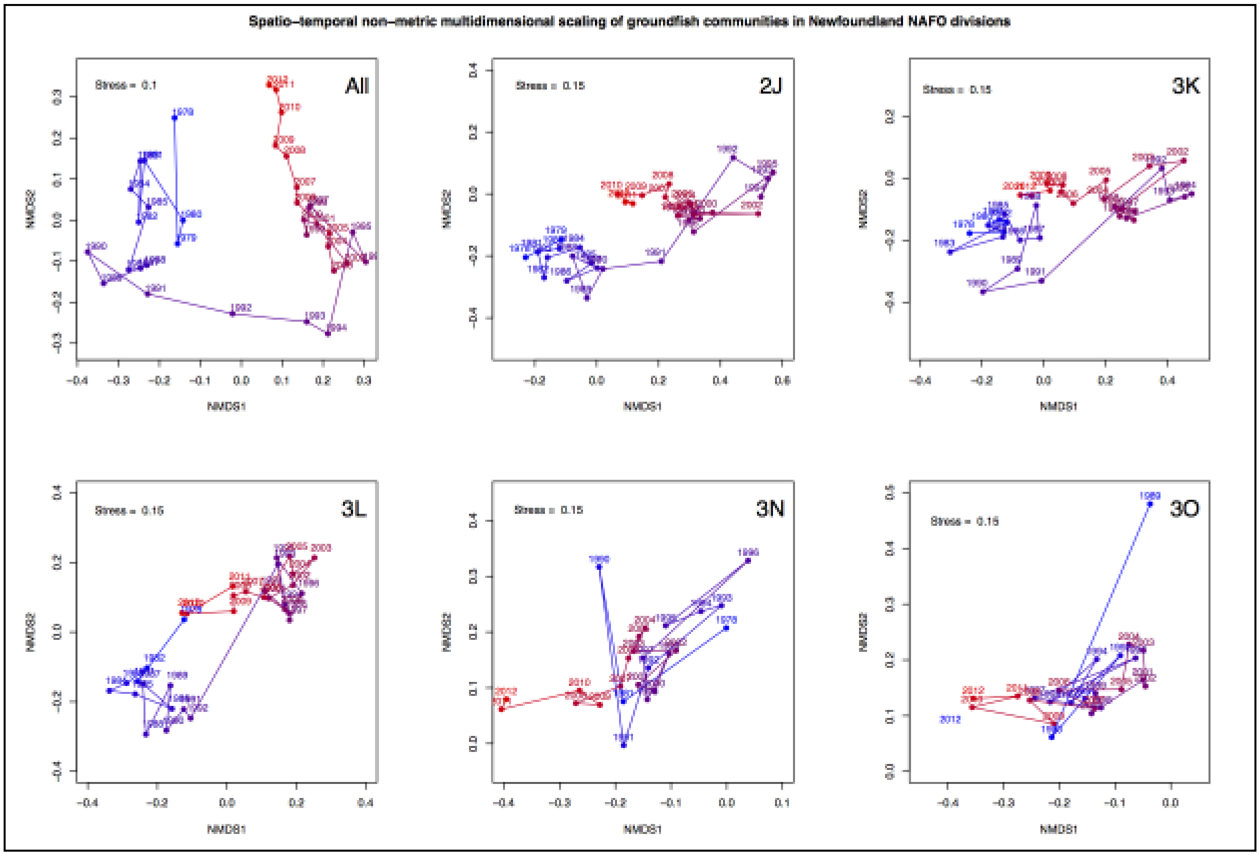


Figure 3.2.2.6. NMDS showing change in mean groundfish community composition per year in the study area as a whole, and the 5 NAFO subdivisions. The colour progression moves from blue for 1978 to red for 2012.

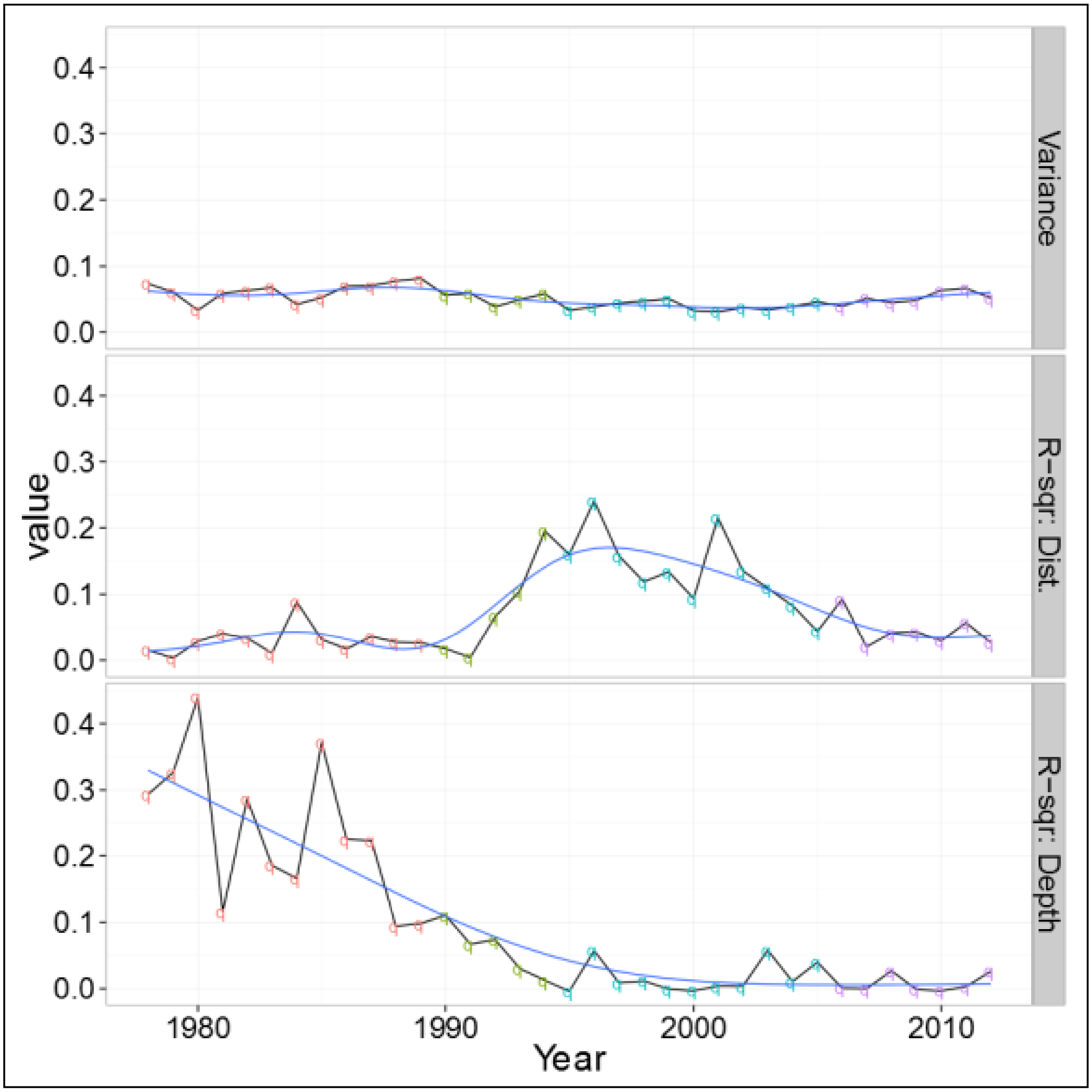


Figure 3.2.2.7. Summary of how community distance between sites changes with distance between the sites. Top: total within-year variance of community distances. Middle: fraction of the variance within the year explained by distance between sites. Bottom: fraction of variance explained by difference of depths between sites.

ToR 3.3. [*Roadmap*]. Report progress on trophic ecology/species interactions studies for the Flemish Cap (NAFO Div 3M).

3.3.1. Cannibalism in the Flemish Cap cod stock

During the period 1988-2012, the most abundant demersal species in the Flemish Cap were cod, redfish, Northern shrimp and Greenland halibut; on average they comprised 83.5% of the estimated RV Biomass index. However, dominance among these species has undergone severe changes since early 1990's (Pérez-Rodríguez et al. 2012). Analyses of the EU surveys showed that as cod approached to the collapse in the mid 1990's Greenland halibut and especially shrimp experienced marked increments (Figure 3.3.1.1). Later on, after the maximum biomass levels of Northern shrimp in 2002, the redfish showed a sudden raise in biomass following successful recruitment events, reaching to biomass levels never observed before in the EU survey time series. Since 2005, cod experienced better recruitments that led to an increment of stock biomass to the levels observed in the late 1980's. Water temperature, fish predation and fishing activity have been suggested as significant drivers of these and other changes observed in other species of the Flemish Cap demersal community (Pérez-Rodríguez et al, 2012).

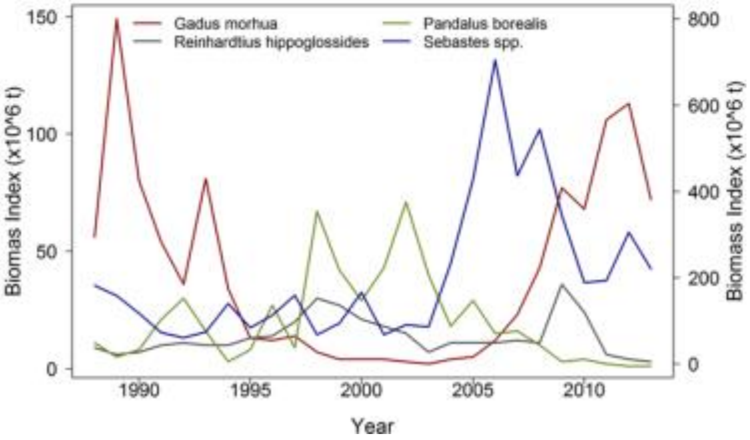


Figure 3.3.1.1. EU survey biomass indices for cod, redfish, Greenland halibut and shrimp in the Flemish Cap over the period 1988-2013.

Since 1989 to 1993, during the last years of high abundance of the Flemish Cap cod stock, redfish and shrimp were its main prey items. During this period fishing on beaked redfish was intense, with catches exceeding 90000 t in 1990. This was coincident with the decline of redfish stocks, following which hyperiids became the main prey item for cod. Throughout 1993-2012 period, feeding habits of cod have showed marked variations (Figure 3.3.1.2) which were related with changes in the availability of its main prey species, i.e. hyperiids, shrimp and redfish (Pérez-Rodríguez et al. 2011). A marked increment in the importance of shrimp in the diet since late 1990's was observed in both "juvenile" (<46 cm) and "adult" (>46 cm) cod trophic species, in parallel to the decline of hyperiids. In addition to this, the "adult" trophic species experienced a greater importance of redfish in the diet since 2000. Pérez-Rodríguez and Saborido-Rey (2012) suggested that these changes in diet, combined with the increment of cod stock since 2005 produced a marked increment of consumption over both shrimp and redfish prey stocks that, in conjunction with fishing activity (especially for shrimp), produced the decline in biomass of this stocks.

Since 2010 shrimp stock was declared collapsed and redfish stocks showed important declines as well. Hence an increasing cod stock, with higher abundance of large individuals (Figure 3.3.1.3) is facing lower prey stock abundances. Since 2009 the most successful recruitment events ever observed for cod stock have been registered, reflected in the EU Survey index of abundance for age 1 cod since 2010 (Figure 3.3.1.2). Previous studies with other cod stocks (Bogstad et al. 1994, Neuenfeldt and Köster 2000), but also the Flemish Cap cod stock (Lilly 1982), concluded that cannibalism was important when abundance and spatial overlap of small and large cod individuals was high. Since 2010, the importance of cod as a prey in cod diet increased remarkably (Figure 3.3.1.3), especially in the "adult" trophic species, which confirm the increase of cannibalism behavior since 2010.

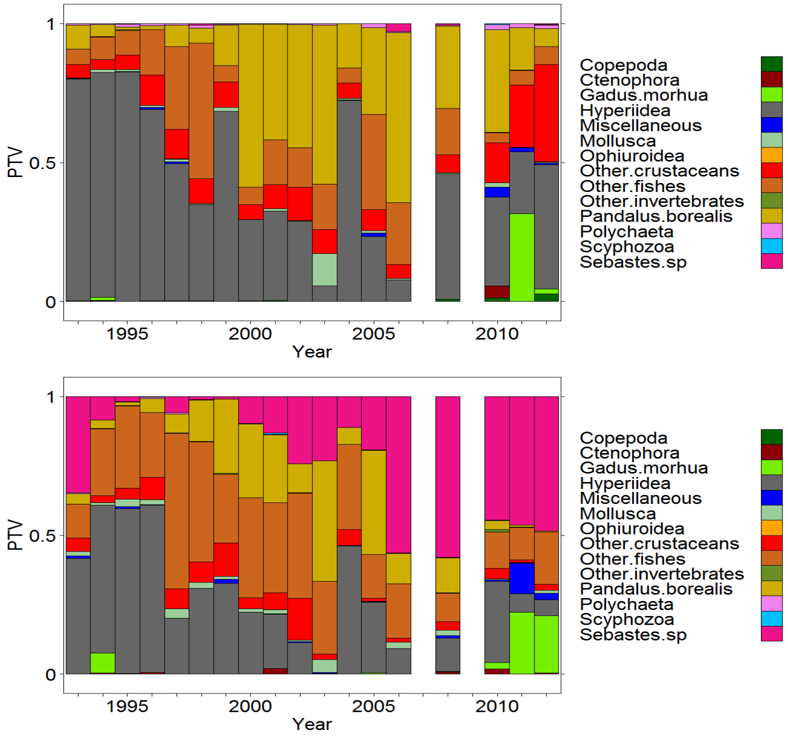


Figure 3.3.1.2. Diet composition as percentage over total food volume (PTV) of "juvenile" (<46 cm; upper panel) and "adult" (>46 cm; lower panel) Flemish Cap cod across the period 1993-2012.

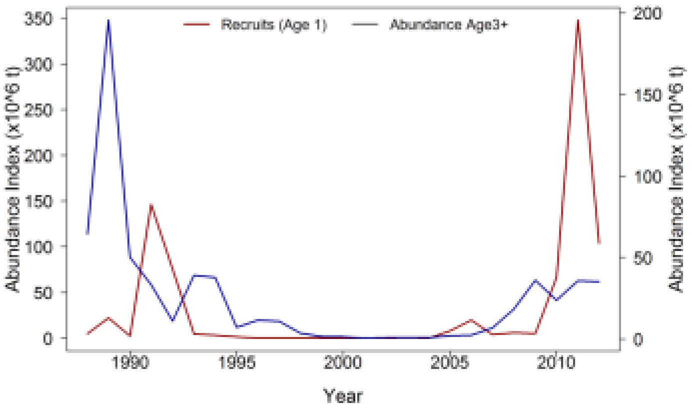


Figure 3.3.1.3. EU survey indices of cod abundance for age 1 old and age 3+ individuals in Flemish Cap.

To estimate the extent of cannibalism in the Flemish Cap cod across the whole time period 1993-2012 total consumption of cod was estimated. Two different approaches were employed: the daily ration method (Hansson et al. 1996) and a Bioenergetic model (Temming and Herrmann 2009).

Daily ration method

The daily ration (DR) is the daily food amount (g) that an individual needs for every 100 g of body weight. In order to estimate the extent of cannibalism using the DR two indices are needed:

Feeding Intensity Index (FI): percentage of individuals with stomach content.

$$FI = \frac{n}{N} \times 100$$

Where n is the number of individuals of cod with stomach content and N is the total number of individuals sampled.

Mean Weight Fullness Index (MWFI):

$$MWFI = \frac{\sum_{i=1}^{n} \frac{W_{sc_i}}{W_{p_i}}}{n} \times 100$$

Where W_{sc_i} is the total stomach content (wet weight) in cod predator *i*, W_{p_i} is the weight of cod predator *i* and *N* is the total number of cod predators.

Consumption on cod was measured also with both indices: FI_{cod} and $MWFI_{cod}$. The first indicates the percentage of individuals of cod eating cod, and the second index quantifies the mean amount (g) of cod consumed per 100 g of wet weight of predator.

The approach to estimate the predation on cod by the Atlantic cod was:

1) Calculate the percentage of this prey ($MWFI_{cod}$) regarding the total consumption (MWFI).

2) There is not daily ration information for the Flemish Cap available, so we use the value indicated in the review of Livingston and Goiney (1984) obtained by Braaten and Gokstad (1980) with a mean value 1.9. Despite daily ration varies with the predator size and the seasonal period we apply the same daily ration across size and period (temporal and seasonal).

3) Cod feeds throughout the year but diminishes the feeding intensity in winter (Albikovskaya and Gerasimova, 1993). Spring-summer would be the main feeding period, even showing considerable differences between both seasons. Therefore, we assume a feeding period from March to November (9 months), and consider only the population biomass eating through the mean feeding intensity (FI) by month obtained from sampling on research and commercial surveys (Figure 3.3.1.4). Since we did not have these samples for the period September to November, we assume that FI in September, October and November would be the same as in May, April and March respectively.

4) We assume that the percentage of $MWFI_{cod}$ regarding the MWFI at the sampling time could be applied to daily ration to estimate the daily consumption on cod. So, it was assumed that the percentage obtained in summer survey is constant throughout the feeding period of 9 month in each year.

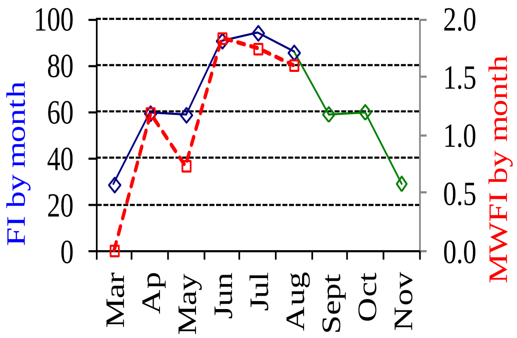


Figure 3.3.1.4. FI (blue line is value observed and green line is value estimated) and MWFI (red line) for cod across 1993-2012 period

Bioenergetic model (Temming and Herrmann 2009)

Fish growth is dependent on two antagonistic processes, anabolism and catabolism.

$$\frac{dW}{dt} = Anabolism - Catabolism = EW_t^m - kW_t^n \tag{1}$$

Where *W* is weight, *t* is time, and *E* and *k* are the constants representing the numerical strengths of the anabolic and catabolic processes, *n* is the catabolic exponent (*n*=1), and *m* is the allometric coefficient of consumption with fish weight. In previous experimental studies with cod and whiting it was determined that *m*=0.8.

Hence, from the whole amount of food ingested by a fish, there is a part that will be allocated to catabolism; it is called the maintenance ration while the remaining portion will be invested in fish growth (Figure 3.3.1.5). If fish consumption is below the maintenance ration, fish weight will decrease. On the contrary, when food intake is higher than the maintenance ration fish starts to grow (increases fish weight) in a proportional way to consumption. This proportionality is defined by the *K3* parameter, which is the slope of the Growth-Food intake relationship.

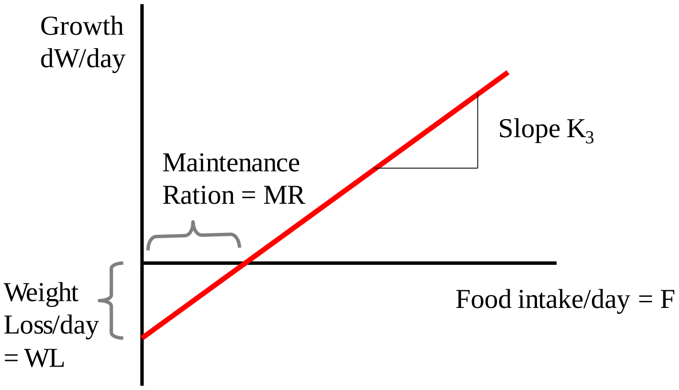


Figure 3.3.1.5. Important concepts of the conceptual framework of bioenergetic models (Adapted from Temming & Herrmann, 2009). The relationship between food intake and growth (slope *K3*) is assumed to be linear.

From Figure 3.3.1.5:

$$\frac{dW}{dt} = \llbracket (K \rrbracket_3 \times F) - WL \tag{2}$$

From equations 1 and 2:

$$E \times W_t^m = K_3 \times F \tag{3}$$

$$F = \frac{1}{K_3} \times E \times W_t^m \tag{4}$$

The constant that determine the strength of metabolism may be defined by means of the parameters from the generalized von Bertalanffy growth function (*GBGF*), W_∞ and *K*:

$$E = 3 \times K \times W_\infty^{1-m} \tag{5}$$

Hence, from equation 4 and 5, fish consumption may be defined by means of:

$$F = \frac{1}{K_3} \times 3 \times K \times W_\infty^{1-m} \times W_t^m \tag{6}$$

In the present preliminary study, in the absence of an alternative *m* value, the value *m*=0.8, utilized by Temming and Herrmann (2009), was assumed for the Flemish Cap cod. From growth feeding studies, *K3* spans between 0.55 (when good food) and 0.35 (bad food), with 0.45 for an intermediate value. *K* and *W∞* where obtained by fitting the *GBGF* to each cohort age-weight relationship:

$$W_t = W_\infty \left[\left(1 - e^{\left(\left(\frac{3D}{-b} \right) \times K \times (t - t_0) \right)} \right)^{\frac{b}{D}} \right] \qquad (7)$$

where b=3 and $D = b \times (1 - m) = 3 \times 0.2 = 0.6$.

Due to the relatively reduced range of ages available for each cohort (usually contained in the range between 2 and 8 years old) in comparison to the actual range in cod lifespan, when the *GBGF* was fitted by cohort group the values obtained for *t0* and *W∞* were extremely variable and were out of the ranges acceptable based in the biological knowledge for these species. As a compromise solution, fixed values were assigned to *t0* and *W∞* based on the biological knowledge: *t0*=0 and *W∞*=14,000g, i.e. we assume that when weight is 0 age is also 0, and that the maximum weight is 14 kg. Hence, finally the only parameter to be estimated in both the equations 6 and 7 was *K* from the *GBGF*, i.e. the growth rate.

With equation 6, the total amount of food necessary across the whole year for an individual of age *a* getting the weight W_t given the growth curve defined by equation 7 was estimated. Next, the mean weight at age, as well as the abundance at age (González-Troncoso et al. 2012), were employed for the estimation of the annual total consumption by the entire Flemish Cap cod stock. In order to split the total consumption among the different prey species, the stomach content information for the Flemish Cap cod, available since 1993 to 2012, was employed. Since no feeding habits information was available for 2007 and 2009, the diet composition for these years was assumed as the average from previous and next years (2006, 2008 and 2010 were employed for this purpose). Next, the percentage of each prey over the total volume of stomach content analyzed was estimated for each 5 cm size class.

Data

The stomach content of 8501 individuals was sampled across the period 1993-2012 in the summer period (no sampling in years 2007 and 2009). From this total amount, 3859 were male cods and 4642 females. Predator size ranged 13 to 125 cm and where distributed in a depth range of 126-624 m. (Table 3.3.1.1)

Table 3.3.1.1. Individuals of Atlantic cod sampled in the bottom trawl Survey on Flemish Cap summer 1993-2012. M = males, F = females

		Sampling depth range (m)	Size range (cm) sampled		Indivs. sampled		
Year	Month		M	F	M	F	Total
1993	Jun/July	132-389	14-95	14-98	408	476	884
1994	July	151-337	14-98	16-94	251	283	534
1995	July	126-308	15-86	14-102	248	235	483
1996	Jun/July	135-315	17-68	18-73	196	258	454
1997	Jul/Aug.	133-315	20-99	19-74	202	288	490
1998	Jul/Aug.	139-306	19-70	24-90	71	106	177
1999	July	133-332	30-90	23-74	70	107	177
2000	July	135-330	15-111	18-113	107	127	234
2001	July	132-343	17-80	16-106	161	209	370
2002	July	130-332	32-102	30-92	110	133	243
2003	June	130-449	15-94	17-92	66	91	157
2004	Jul/Aug.	136-306	32-97	27-99	183	233	416
2005	July	132-256	15-106	15-91	167	216	383
2006	July	134-439	15-98	15-116	345	341	686
2008	Jun/July	131-431	14-106	13-108	397	434	831
2010	Jun/July	132-484	15-110	15-117	261	319	580
2011	Jul/Aug.	139-493	17-105	19-106	215	281	496
2012	Jun/July	139-624	13-111	13-125	401	505	906
Total		126-624	13-111	13-125	3859	4642	8501

Results

Both methodologies, Daily ration (DR) and Bioenergetic model (BM), produced very similar values for cod cannibalism across the period 1993-2012 (Pearson= 0.98, p-value<0.001; Table 3.3.1.2, Figure 3.3.1.6). Cannibalism was observed in 1994, with the third highest value of the study period (DR: 7120 tons; BM: 9132 tons) and was not registered again up to 2005. Since this year cod has been a usual prey in Flemish Cap cod diet until 2012 all years that stomach content information was available (Figure 3.3.1.2), with the exception of 2006. Cannibalism increased remarkably year after year from 2005. The highest consumption was observed in 2011 (DR:

52206 tons; BM: 55642 tons), where upon cannibalism declined but was still high in 2012 (DR: 17039t; BM: 28693t). There were similar levels in 1994 and 2010, and it was minimum in both 2005 and 2008.

Table 3.3.1.2. Estimated cannibalism (in tons) in the Flemish Cap cod across the period 1993-2012 with Bioenergetic model and Daily ration method. No stomach content information was available for years 2007 and 2009 and hence no estimates of consumption are available.

Year	Bioenergetic model	Daily ration
1993	0	0
1994	7120	9132
1995	0	0
1996	0	0
1997	0	0
1998	0	0
1999	0	0
2000	0	0
2001	0	0
2002	0	0
2003	0	0
2004	0	0
2005	25	28
2006	0	0
2007		
2008	141	61
2009		
2010	3213	2016
2011	55642	52206
2012	28693	17039

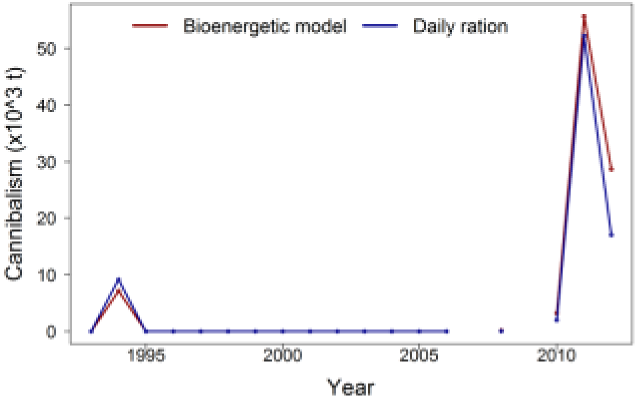


Figure 3.3.1.6. Cod consumption (cannibalism) by the Flemish Cap cod stock across the period 1993-2012 using the Bioenergetic model and the Daily ration method.

As already found by the analysis of cod stomach content in the period 1989-1993 (Casas & Paz, 1996), the analysis of cod prey and predator size (cod size both as predator and prey) from year 2011 (Table 3.3.1.3) showed that most preyed cod were in the range between 10-20 cm (99 of 130 cases) and 20-30 cm (20 cases). These individuals, from the average size by age estimated in previous studies (Pérez-Rodríguez et al. 2013) can be though as age 1 the formers and age 2 the latter. Hence, age 1 and 2 cod individuals accounted for 91.5% of cannibalism in 2011. Meanwhile, cannibals cod ranged mostly between 40 and 90 cm size (87.7% of cases) although the range of 60-69 cm predator size presented the highest value. Those individuals smaller than 30 cm did not feed on cod. When the number of consumed cod was divided by the total number of sampled cod by size range (as ratio in Table 3.3.1.4) conclusions remained similar, although the largest cod individuals showed the highest ratio.

Table 3.3.1.3. Number of cod individuals as prey found in cod stomachs by size of prey (rows) and predator (columns) from samples of year 2011. The number of sampled stomachs by predator size range and the ratio (N prey/N predator) is also shown.

Prey/Predator	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	All predator sizes
5-10				1					1
10-15	5	4	7	16	3	2	1	2	40
15-20		6	12	25	9	4	1	2	59
20-25			1	2	3	3		1	10
25-30				3	4	3			10
30-35					3	3		2	8
35-40								1	1
50-55							1		1
N prey	5	10	20	47	22	15	3	8	130
N predator	49	48	48	81	58	33	13	13	49
Ratio	0.102	0.208	0.417	0.58	0.379	0.455	0.231	0.615	0.102

Results from the MWFI_{cod} analyzing the whole time period 1993-2012 supported the conclusions extracted in the previous paragraph for 2011 (Table 3.3.1.4). It was found that individuals larger than 100 cm tend to present high MWFI_{cod} values, but low FI_{cod}, which means that they rarely prey on cod, but probably ingest several individuals when they do, what lead to a high total consumption, as observed in 2011. Cannibalism increases with increasing predator size (Table 3.3.1.4) and different size groups were identified regarding the amount of cod preyed (<40 cm, 40-59 cm, ≥ 60 cm; Kruskal-Wallis test; $\chi2(2) = 45.792$, $p \leq 0.001$). Table 3.3.1.5 shows the mean value of predation on cod by males and females throughout the period studied. However, males and females at similar size and same year do not show significant differences in predation on cod (MWFI_{cod}) .

Table 3.3.1.4. Annual cod consumption by Flemish Cap cod respect to length predator.

Size range (cm) of predator	1994	2005	2008	2010	2011	2012
30-39	0.039		0.000	0.000	0.153	0.000
40-49	0.062	0.000	0.000	0.030	0.163	0.024
50-59	0.158	0.000	0.000	0.030	0.333	0.074
60-69	0.079	0.000	0.000	0.043	0.284	0.127
70-79	0.000	0.028	0.011	0.010	0.295	0.332
80-89	0.000	0.000	0.000	0.000	0.236	0.382
90-99	0.605	0.000	0.000	0.000	0.447	0.445
100-109		0.000	0.000	0.141	0.188	0.351
110-119				0.000		0.000
120-129						0.765

Table 3.3.1.5. Consumption on cod by sex and length of Flemish Cap cod.

Size range (cm) of cod predator	$MWFI_{cod}$ in males	$MWFI_{cod}$ in females
10-19	0	0
20-29	0	0
30-39	0.049	0.018
40-49	0.053	0.047
50-59	0.035	0.126
60-69	0.111	0.103
70-79	0.073	0.188
80-89	0.052	0.222
≥ 90	0.177	0.253

Conclusions

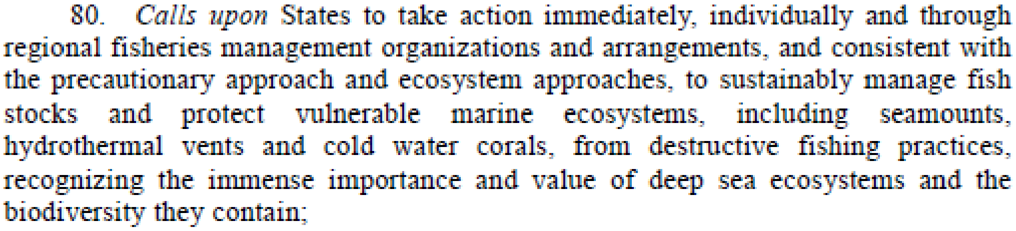
- Since 2005 coincident with the successful recruitments (especially since 2009), the high abundance of large cod, and the decline of alternative prey species, cannibalism behavior has increased remarkably in the Flemish Cap cod.
- Estimates of total cannibalism by cod stock using Bioenergetic models and Daily ration method were significantly similar (Pearson= 0.98, p-value<0.001), and showed very high values since 2009 (above 50000 t in 2011).
- Progress of recent cohorts should be followed in detail to evaluate the degree of impact of cannibalism in population dynamic. The high cannibalism values obtained in the present work points that impact of cannibalism may have subjected to juvenile cods to extreme natural mortality levels.
- These results highlight the importance of maintaining regular stomach content samplings in order to identify and understand the main processes that lead the dynamic of marine populations and communities.

Questions to explore:

- Some issues that have arisen during the development of this work that need to be explored in depth are:
- Offal consumption during the fishing season (spring, summer) and its influence in cannibalism estimates.
- Including available information about changes in diet along year.
- Fractioning the growth along the year in four seasons.
- Explore alternative values for the daily ration and FI across the year, and alternative values for some parameters of the Bioenergetic model.

ToR 3.4. Review of evidence for ecosystem function of VMEs in the NAFO area

The UNGA Resolution 61/105 calls for the protection of vulnerable marine ecosystems (VME) from the harmful effects of fishing gears:



> 80. *Calls upon* States to take action immediately, individually and through regional fisheries management organizations and arrangements, and consistent with the precautionary approach and ecosystem approaches, to sustainably manage fish stocks and protect vulnerable marine ecosystems, including seamounts, hydrothermal vents and cold water corals, from destructive fishing practices, recognizing the immense importance and value of deep sea ecosystems and the biodiversity they contain;

The role that VME play in enhancing biodiversity is highlighted. These VME have other roles in the ecosystem in addition to providing three dimensional structure for other organisms. These are important to consider when assessing SAI and incorporating benthic community data into the ecosystem approach to management. Here we provide a review of the evidence for ecosystem function for the VMEs identified in the NAFO area.

3.4.1. Large-sized sponges

Sponges have been identified as important ecological components of benthic ecosystems across tropical, temperate, and polar environments (reviewed in Bell, 2008). Bell (2008) divided the function of sponges in the benthic community into three different categories: 1) benthic-pelagic coupling (e.g., carbon and nitrogen cycling), 2) impacts on substrate (e.g,. bioerosion and sediment stabilization), and 3) habitat provision for other species (e.g., predation protection). Until the last decade, the function of sponges in the deep sea has been poorly understood (Hogg *et al*., 2010). With increasing awareness of the impact human activities have on these ecosystems, sponges are now emerging as important components of the benthic community, especially in terms of their influence on the diversity of associated species.

Only a few studies have examined the role of sponge feeding on benthic-pelagic coupling in the deep sea (e.g., Pile and Young, 2006; Yahel *et al*., 2007; Kutti *et al*., 2013). Sponges filter large quantities of water, thereby removing microorganisms and nutrients (e.g. carbon) from the water column (Yahel *et al*., 2007; Bell, 2008). Yahel *et al.* (2007) examined the feeding and metabolism of two glass sponges (*Aphrocallistes vastus* and *Rhapdocalyptus dawsoni)* from the deep Antarctic and north Pacific continental shelf. They found that these sponges may have a considerable impact on the deep microbial community by removing large quantities (95%) of bacteria and heterotrophic protists from the water they filter feed. Kutti *et al.* (2013) examined water pumping and respiration rates of *Geodia barretti*, an often dominant taxon in sponge ostur (Murillo *et al*., 2012; Kutti *et al*., 2013). They found that within the 300 m^2 area studied on the Norwegian continental shelf, the population of *G. baretti* is capable of filtering 250 million m^3 of water and consuming 60 t of carbon daily, highlighting the importance of sponges in the cycling of carbon and other nutrients.

Deep-water sponges modify the surrounding seafloor environment via current baffling and subsequent sediment entrapment (Krautter *et al*., 2006), which may influence the distribution of surrounding benthic biota (Beazley *et al*., 2013). Also, deep-water sponges influence the surrounding biota through their formation of spicule mats. When sponges die they release large amounts of spicules which may form thick mats on the seafloor. Sponge spicule mats modify both the composition and structure of the local sediment, and are shown to have a profound effect on the diversity, abundance, and community composition of macro-infauna (Bett and Rice, 1992; Barrio Frojan *et al.*, 2012). For instance, Barrio Frojan *et al.* (2012) examined the macro-infaunal community in and around a NAFO closed area on the Sackville Spur, and found that community composition and relative abundances were greatly altered by the presence of dense sponge spicule mats. Bett and Rice (1992) discussed several mechanisms by which sponge spicule mats directly influence local biota: 1) by providing hard substrate for the settlement of epifauna, 2) by providing refuge and inhibiting predators, and 3) by enhancing food supply by trapping particulate matter and providing an elevated feeding position.

Much like deep-water corals, large, structurally-complex sponges increase the number and complexity of microhabitat available for other species, the effects of which are enhanced in large aggregations of these organisms. The intricate canals of sponges host a wide variety of infauna, which are thought to utilize the continuous flow of suspended matter filtered from the water column, and/or feed on the sponge itself (McClintock *et al*., 2005; Buhl-

Mortensen *et al*., 2010; Bo *et al*., 2012). Ilan *et al.* (1994) observed several species of polychaetes and a snapping shrimp inside the cavities of several deep-water sponges in the Mediterranean.

Few studies have quantitatively examined the influence of large structure-forming sponges on the diversity and abundance of the epifaunal community (but see Bo *et al.*, 2012; Beazley *et al*., 2013). Klitgaard *et al.* (1995) recorded a high number of epifauna species (93% of total taxa observed) associated with 11 demosponge species off the Faroe Islands, northeast Atlantic, but did not compare the number and composition of species with those occurring in surrounding non-sponge habitat. Beazley *et al.* (2013) examined the diversity of epibenthic megafauna associated with structure-forming sponge grounds in the Flemish Pass area between ~440 and 1400 m depth in the northwest Atlantic. They found that the presence of these structure-forming sponges was associated with an increase in diversity and abundance of associated megafauna compared to non-sponge habitat (see Figure 3.4.1). A higher abundance of non-structure-forming sponges and ophiuroids was observed on sponge grounds, similar to the results of Barthel *et al.* (1996).

A study of the megafauna in the sponge-dominated community of the Sackville Spur, northwest Atlantic, is currently underway (Beazley, pers. comm.). The aim of this study is to examine the influence of structure-forming sponges and various environmental factors on the epibenthic megafaunal community, and to determine at what point the abundance of structure-forming sponges begin to affect the composition of this community. Preliminary results indicate that of 61 predictor variables, the abundance of structure-forming sponges is most important for predicting the distribution of megafauna on the Sackville Spur, followed by depth and slope. Beginning at approximately 15 sponges per 1 m^2, the associated megafauna community experiences a large turnover in species composition, with many megafauna species increasing in abundance after this point. Future work on this project will involve determining whether this abundance value corresponds to the weight threshold for significant catches of sponges (75 kg/tow) identified in NAFO (2009, 2013). This will help determine whether the current weight threshold for significant sponge catches appropriately matches the *in situ* abundance at which these organisms begin providing benefits to the ecosystem.

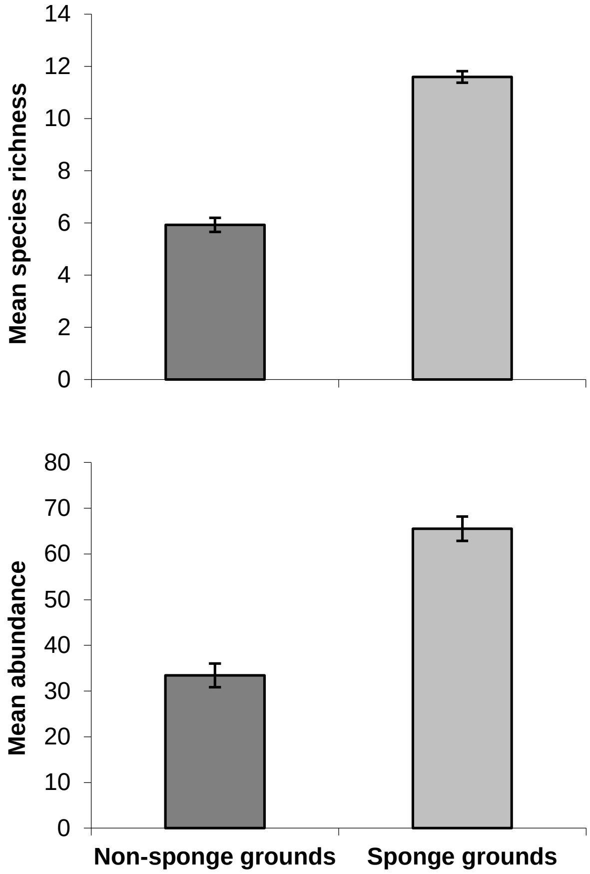


Figure 3.4.1. Mean species richness and abundance per photo of megafauna within sponge grounds and non-sponge grounds. Adapted from Beazley *et al.* (2013).

Sponges provide spawning and nursery grounds, feedings areas, and refuge from predators for a number of fish species (Barthel *et al*., 1996; Freese and Wing, 2003; Cook *et al.*, 2008; Kenchington *et al*., 2013) and other invertebrates (Saito *et al*., 2001; Okutani and Sasaki, 2007; Amsler *et al*., 2009). Glass sponges (hexactinellid) and the shrimp *Spongicola japonica* have developed an association for life. The matting pair lives within the sponge and have evolved adaptations for that particular environment (Saito *et al*., 2001). Okutani and Sasaki (2007) and Fuller *et al.*, (in prep) found *Rossia* squid eggs implanted deep within the tissue wall of several sponge species. The eggs were observed at various stages of development providing evidence of some colonies being repeatedly targeted as prime nursery sites.

3.4.2. Sea Pens

The majority of research on the functional roles of coral in benthic ecosystems has been conducted in tropical regions (Done *et al.* 1996; Glynn, 2012), however in recent years, there has been more research in cold-temperate regions (Buhl-Mortensen *et al.* 2010) following the increase in interest and scientific studies.

Review of the evidence of the functional roles that corals, namely sea pens (Pennatulacea) may includes bioturbation and baffling of sediment flows, providing a food source, creating unique habitats, acting as nurseries for fish and invertebrates and refugia for predator avoidance. Sea pens occur in “fields or patches” in areas of soft sediment on the sea floor. Unlike many benthic invertebrates, sea pen morphology is rather simple with a single stem called ‘rachis’ populated with feeding polyps and a bulbous base called ‘peduncle’ which anchors the colony (Williams, 1995). However, what they lack in structure they compensate in numbers with massive sea pen “fields” observed (Kenchington *et al.,* 2010; Kenchington *et al*., 2011; Baker *et al*., 2012)

Impacts on substrate

Structure forming marine invertebrates impact sea floor complexity in two ways – by bioturbation and altering of sediment flows, and through the addition of complex structure on the sea floor. In mud dominated environments, nutrients are locked in the seafloor, and as a result mostly are biologically inaccessible. However, sea pen (*Umbellula* sp.) are believed to exhibit peristaltic movements which can contributed to mixing of nutrient-rich muds to the surface increasing food availability not only for the sea pens but other invertebrates (Bradley, 1973). This would indicate the function of sea pens in deep water ecosystems as potential bioturbators which can enhance feeding opportunities for other benthic species.

There are few observations of sea pens providing suitable hard substrate for attachment as seen in other coral species however, in the Northwest Atlantic, *Halipteris finmarchia* were observed with commensal sea anemones *Stephanauge nexilis* firmly attached to the rachis (cf. Miner, 1950; Wareham and Edinger, 2007), which may increase food availability located higher in the water column.

Bentho-pelagic coupling

Baker *et al*., (2012), used *in situ* video data found that fish assemblages associated with sea pen dominated habitats (i.e. 'fields' or 'meadows') differ from those in highly complex habitats. Extensive meadows were observed and covered large tracts of muddy seafloor spanning more than 1 km in length. These fields create important refugia and influence prey availability by adding structure in an other-wise low-structured environment (Tissot *et al*., 2006).

This holds true for small invertebrates as well as in larger fish species (Buhl-Mortensen and Mortensen 2004; Roberts *et al.* 2006; Baillon *et al.* 2012). Many invertebrates (e.g. crustaceans, nudibranch) have been observed feeding on sea pens as a primary food source (Birkeland, 1974; Moore & Rainbow, 1984; Krieger and Wing, 2002). Brodeur (2001) observed hundreds of *Sebastes alutus* inside dense aggregations of *Halipteris willemoes* sea pen in the Bering Sea (Brodeur, 2001).

Associations with other organisms

In Baillon *et al*., (2012) five sea pens species and several soft corals have been shown to function as important nurseries for two species of *Sebastes* on the Grand Banks of Newfoundland. The larvae were observed lodged between the polyp leaf and the main rachis with yolk sac still visible.

3.4.3. Small Gorgonian Corals

The functional role that corals play in the deep-sea benthic ecosystem, especially structure- or reef-forming corals, has been well documented in terms of their benefits for other species (see Buhl-Mortensen *et al*., 2010 for review). The structural complexity of these organisms creates additional microhabitat that may be utilized by other organisms as refuge from predators, as spawning and nursery grounds, and as attachment substrate for sessile invertebrates (Fosså *et al*., 2002; Reed, 2002; Costello *et al*., 2005; Tissot *et al*., 2006; Baillon *et al*., 2012). As a result, coral habitat may exhibit different and/or more diverse and abundant assemblages of fauna compared to surrounding non-biogenic habitat (Mortensen *et al*., 1995; Husebø *et al*., 2002; Costello *et al*., 2005). Much less information is available on the ecosystem function of smaller corals, including gorgonians. Size is an important aspect of an organism's ability to form habitat, as larger organisms increase vertical relief and provide additional microhabitat (Tissot *et al*., 2006). Although small, the highly-branched nature of small gorgonians and their ability to form dense aggregations (for examples in the northwest Atlantic see Baker *et al.* (2012) and NAFO (2013)) deems them habitat-forming, especially in areas of low topographical relief (Tissot *et al*., 2006).

The association of species with large deep-water gorgonian corals has been documented in several studies (e.g., Mortensen *et al*., 1995; Heifetz, 2002; Krieger and Wing, 2002; Stone, 2006). On the microscale, deep-water gorgonians offer two different habitats for associated species: 1) the living tissue on the surface of younger parts of the colony, and 2) pockets of detritus and exposed hard skeleton on older parts (Buhl-Mortensen *et al*., 2010). As in shallow-waters (Goh *et al*., 1999), the associated fauna of large deep-water gorgonians is dominated by crustaceans (Mortensen *et al*., 1995; Buhl-Mortensen and Mortensen, 2004), although here gorgonians exhibit higher numbers of echinoderms than shallow species (Buhl-Mortensen *et al*., 2010).

There are virtually no studies dedicated to describing associated species of small deep-water gorgonians. The benefits provided by this group on the microscale are presumably similar to their larger counterparts. The current baffling effect of dense concentrations of small gorgonians may increase the deposition of finer, organically-rich sediments, which may have a profound effect on the diversity of smaller size classes of fauna, such as meiofauna and nematodes as demonstrated in shallow waters (e.g., Cerrano *et al*., 2010).

In a survey of the deep-sea coral assemblages in three submarine canyons off Newfoundland, Baker *et al.* (2012) noted a low diversity of other corals associated with fields of the small gorgonian *Acanella arbuscula*. However, this does not preclude the potential importance of this species for smaller megafauna, motile fauna, and infauna in surrounding sediments not adequately surveyed. For instance, *ex-situ* examination of colonies of *A. arbuscula* revealed an obligate relationship between this species and the actiniarian *Amphianthus inornata,* which lives attached to the branches of its host, presumably to elevate its position in the water column (Bronsdon et al., 1993).

Only one study has inferred a relationship between the distribution of small gorgonians and fish species in the deep-sea. Edinger et al. (2007) examined the association between groundfish and 5 classes of corals, including large gorgonians, small gorgonians, seapens and/or cup corals, soft corals, and the total absence of corals. They found that of all five groups, groundfish species richness was highest in sets containing small gorgonians (*A. arbuscula* and *Radicipes gracilis*), highlighting the potential importance of this group as fish habitat.

3.4.4. Large Gorgonian Corals

Gorgonians, also known as fan corals, are comprised of hard or consolidated internal skeleton constructed of either proteinaceous gorgonin, calcium carbonate (calcite or aragonite) or a mixture of the two (Bayer, 1973). In the Northwest Atlantic, colonies (*Paragorgia arborea)* can exceed 3 m in height, weight 100s of kilograms, and grow perpendicular to rock walls and overhangs (Mortensen & Buhl-Mortensen, 2005; Wareham & Edinger, 2007). They require hard substrates of significant size in order to anchor the colony and to strategically orient perpendicular to current flow in order to maximize feeding (Wainwright & Dillon, 1969; Mortensen & Buhl-Mortensen, 2004, 2005). Colony morphology of large gorgonians has a great influence on feeding efficiency for other suspension feeders (Buhl-Mortensen, *et al.* 2010).

The importance of these habitat forming organisms has been documented *in situ* with underwater video. Dense coral aggregations or 'forests' were observed with associated biological interactions. Other invertebrates were seen between the colonies, as well as within the branches (Krieger and Wing, 2002; Buhl-Mortensen and Mortensen, 2005; Gili *et al*., 2006; Moore *et al*., 2008; Mosher and Watling, 2009; Baker *et al.* 2012).

Fish utilization of such 'forests' as well as other coral habitats is analogous to the interaction between trees and birds. The physical structure of a large gorgonian coral can dissipate energy from localized near-bottom current (Zedel and Fowler, 2009) providing rest areas for smaller marine life (Auster *et al*., 2005; Costello *et al*., 2005; Moore *et al*., 2008).

Large gorgonian corals can also create forage areas for associate species either on the colonies (Buhl-Mortensen *et al*., 2010) or through increased access to food suspended higher in water column (Buhl-Mortensen and Mortensen, 2005; Mosher and Watling, 2009). Moore *et al*., (2008) noted around coral structures the increase access to zooplankton and pelagic prey delivered by rapid currents for the false borefish, *Neocyttus helga* on seamounts in the North Atlantic Basin. Gili *et al*., (2006) observed hydroids using gorgonians as a substrate to gain access to food higher in the water column. Even on small scales, associated fauna may derive nutrition from detritus or micro-organisms trapped in mucus secreted by corals (*P. arborea* and *P. resedaeformis*) (Buhl-Mortensen *et al*., 2010).

The importance of large gorgonians as substrate appears to increase with depth as habitat complexity decreases from the shelf edge and slope into mud dominated ecosystems (Buhl-Mortensen *et al*., 2010).

As well large gorgonian maybe used for harbouring important food sources for demersal fish (Mortensen *et al.* 2005). For example Pandalid shrimp and *Gorgonocephalus* sp. (Ophiuroidea) were observed among the branches of *Paragorgia* colonies (Buhl-Mortensen *et al*., 2010).

Large gorgonian corals can act as barriers between predator and prey, (Buhl-Mortensen and Mortensen, 2005; Krieger and Wing, 2002; Buhl-Mortensen *et al*., 2010; Moore *et al*., 2008). Frequently occurring shimp (*Atlantopandalus propinqvus*) residing within the coral *Corallium* probably use the branches as barriers to avoid predation (Buhl-Mortensen and Mortensen, 2005). Mosher and Watling, (2009) observed similar but obligate associations on New England and Corner Rise seamounts between chrysogorgiid octocoral *Metallogorgia melanotrichos* and the brittle star *Ophiocreas oedipus*. In Gulf of Alaska *Primnoa* spp. were observed with 'protection seekers' in and around the corals including rock fish, crab and shrimp (Krieger and Wing, 2002).

Large gorgonians have been shown to provide safe havens for juveniles and egg masses (Etnoyer & Warrenchuk, 2007; Moore *et al*., 2008; Roberts *et al*., 2009; Concha *et al.* 2010; Henry *et al.* 2012). Concha *et al.* (2010) though that the dusky catshark use deep-water coral branches as a substrate for egg-laying. Henry *et al* (2012) suggest that spawning sharks targets coral colonies because the coral branches provides a labyrinth that could deter egg predators while reducing the risk of eggs drifting away.

Large gorgonians have been shown as micro-habitats, within the tissue walls of the colony. E.G. Neves (pers. comm.) observed 160 individual endoparasitic copepods (Copepoda: Lamippidae) inside calyces of one *Paramuricea* sp. colony. The copepods were found in pairs. Similar functional associations were observed with obligate parasitic copepod *Gorgonophilus canadensis* living inside enlarged polyp galls *Paragorgia arborea* (Buhl-Mortensen *et al*., 2010), as well as anemones, polynoid polychates, *Acarina*, and *Epizoanthus* sp. (Buhl-Mortensen *et al*., 2010). In the Azores a parasitic relationship between epizoan zoanthid and gorgonian *Callogorgia verticillata* was observed where the zoanthid progressively eliminates the coral tissue, and uses the axis structure and support, and sclerites for protection (Carreiro-Silva *et al*., 2011).

The functional role that large gorgonians play in benthic ecosystems is not limited to associations. It is suggested they function as centers of enhanced biodiversity (Buhl-Mortensen, 2010; Buhl-Mortensen and Mortensen, 2005). Buhl-Mortensen and Mortensen, (2005) observed over a 100 associate species, 17 crustaceans, on large gorgonians (*P. arborea* and *P. resedaeformis*) in Atlantic Canada. Many studies have shown faunal abundance and diversity can be significantly greater in the coral habitats than in non-coral areas (Husebø *et al.* 2002; Mortensen *et al.* 2008; Roberts *et al.* 2008; D'Onghia *et al.* 2010; Du Preez and Tunnicliffe, 2011; Auster, 2005).

3.4.5. New Information on Ecosystem Function of Seamounts

Rowden *et al.* (2010) have found supporting evidence that seamount communities are vulnerable to fishing, and have high sensitivity and low resilience to bottom trawling disturbance. The study found plausible evidence that seamounts are stepping stones for dispersal, oases of abundance, biomass, and hotspots of species richness (Rowden *et al*., 2010). Evidence that seamount communities are structurally distinct, that populations of invertebrates are source of propagules for nearby slope sinks as well as that seamounts have acted and can act as biological refugia from catastrophic environmental events was also found plausible, although further investigation is recommended (Rowden *et al*., 2010).

Corals are an important functional group of seamount ecosystems because they can form extensive, complex and vulnerable three-dimensional structures, such as deep-sea reefs built by stony corals (scleractinians) (Freiwald *et al.*, 2004, Roberts *et al.*, 2006) or the coral beds formed by black corals and octocorals (Clark and Tittensor, 2010).

Yesson *et al*. (2012) notes that cold-water octocorals colonies can form a major constituent of structurally complex deep-sea habitats and present the most diverse group of corals with over 3000 described species.

Several studies indicate the importance of octocoral habitats for invertebrates, groundfish, and general associations with a variety of coral habitats (Yesson *et al*., 2012, Edinger *et al*., 2007; Soffker *et al*., 2011) while recognizing them as vulnerable to fishing (Stone 2006, Edinger *et al*., 2007).

It is worth mentioning one additional role that seamounts can play in the marine ecosystems in light of the unprecedented ocean acidification rates (oceans are ~30% more acidic since the industrial revolution, in accordance with the IPCC AR5).

Ocean acidification is one of the major threats to deep-water ecosystems. A technical report of the CBD Secretariat has highlighted that

> "The deepest penetrations of this anthropogenic carbon are observed in areas of deep and intermediate water formation, such as the North Atlantic, and the Southern Ocean, 40–50°S. [evidence] shows that the anthropogenic CO2 signal can be found in depths of up to 2500m in certain areas, although newer studies in the North Atlantic have revealed large changes in CO2 concentrations in deep-water masses between 3,000 and 5,000 metres depth, indicating that the CO2 signal might already have penetrated to this depth in certain locations." (Secretariat of the CBD, 2009, at 15)

The report notes that shoaling of the saturation horizon due to ocean acidification reduces the availability of habitat for calcifying organisms reliant on the carbonate minerals, having implications for ecosystem productivity, function and the provision of services, especially for cold-, deep-water species such as cold-water corals. (CBD, 2009. pp. 19) In this light, it is noteworthy that scientific studies indicate that seamounts' summits and upper slopes can provide refugia for cold-water stony corals from ocean acidification as they lie in shallower waters with a higher aragonite saturation horizon (Tittensor *et al*., 2010; Rowden *et al.*, 2010).

In this context, other relevant international policy instruments complement the UNGA Resolutions on VMEs, stressing the need to increase VME's resilience to ocean acidification. These instruments include the Convention on Biological Diversity Strategic Plan for Biodiversity 2011-2020 and the Aichi Targets 6 and 10 and the Rio+20 outcome document - The Future We Want.

Furthermore, seamounts role in a more acidic ocean should also be highlighted. As noted by Tittensor *et al*. (2010) points to model results that suggests that

> "During past ocean changes of increased acidification, seamounts may have also provided refugia (Veron 2008), and thus acted as reservoirs of diversity for the surrounding benthos. Since the evolution of carbonate-secreting Scleractinia following the post-Permian extinction reef gap (Stanley, 2003), there have been several episodes of high atmospheric CO2. These include major events in the Triassic and the Late Cretaceous or Early–Middle Eocene, the latter associated with periods of rapid acidification (Zachos et al., 2005; Veron, 2008). These events were all associated with significant extinctions of corals and other marine fauna and subsequent low diversity of Scleractinia (Stanley, 2003; Veron, 2008). It is possible that seamounts and the flanks of oceanic islands may have acted as refugia during these times of environmental crisis for azooxanthellate deep-sea corals, and might have acted as sources of calcifying organisms for recolonisation of the deep sea following climatic perturbations of ocean chemistry. Thus, seamounts may have acted not only as spatial stepping stones in the biogeography of corals (Rogers 1994), but also as temporal stepping stones, allowing deep-water corals to survive during periods of ocean acidification in the past." (Tittensor *et al*., 2010, at 222)

In this study, an index of risk for stony corals on seamount summits globally was developed. The index combines a metric of vulnerability measured by the overlap of seamount summits, target fish ranges and likelihood of coral presence with an assessment of likely fisheries impact derived from a fishing intensity effects study and fishing effort-catch data. Some summits of the Corner Rise Seamounts chain were included in the 90th percentile of risk (i.e., high risk) associated with bottom trawl fishery.

In another study, Althaus *et al.* (2009) note the long-standing impacts of bottom trawling on deep-coral ecosystems of seamounts, and recommends that long-term spatial closures are crucial conservation instruments to match the biological time-frame of deep-sea ecosystems.

Supported evidence indicates that seamount communities are vulnerable to fishing, and that these communities have high sensitivity and low resilience to bottom trawling disturbance (Rowden *et al.*, 2010; Morato *et al.*, 2006; Clark *et al.*, 2006; Clark *et al.*, 2007; Margues da Silva and Pinho, 2007; Clark and Tittensor, 2010).

ToR 3.5. Oceanographic Conditions Around Flemish Cap

The Flemish Cap is influenced principally by two major ocean currents: the southward flowing Labrador Current to the east and north and the North Atlantic Current, which represents the bulk continuation of the warm Gulf Stream, flowing in an east-north easterly direction (Stein, 2007).

The Labrador Current is a continuation of the Baffin Bay current, which carries cold and relatively low salinity waters of Arctic origin, with two main branches. The small inshore branch carries approximately 15% of the water transport and hugs the coast of Newfoundland and is unlikely to influence the Cap, whereas the offshore branch follows along the shelf-break. The offshore branch of the Labrador Current splits north of the Flemish Cap, with the main branch flowing through Flemish Pass, east of the Cap, where it is reduced to a width of 50 km and a flow of 30 cm s^{-1} while the weaker side-branch flows in clockwise around the northern and western side of the Cap (Petrie and Anderson, 1983; Stein, 2007). Geostrophic calculations reveal that the body of the Labrador Current reaches a depth of 250-300 m in the Flemish Pass and that the side-branch reaches a depth of ~20 0m (Maillet and Colbourne 2007). According to Stein (2007), the lower end of temperature-salinity profiles of the Labrador Current in the Flemish Pass is achieved at a temperature of 3.3°C and a salinity of 34.8 at a depth of 800 m, while in the side-branch this is achieved a temperature of 3.5°C and a salinity of 34.8 at a depth of 610 m.

The North Atlantic Current is comprised of a combination of cold Slope Water Current and Warm Gulf Stream waters (Mann, 1967). Krauss *et al.* (1976) found that the North Atlantic Current generally looped around the northwest corner of the Cap after which it turns in an easterly direction, but in some circumstances meanders from the Current can result in significant easterly flow before it reaches the Flemish Cap. The lower end of the temperature-salinity profile is achieved at 1.69°C and salinity of 34.92 at a depth of 4025 m (Stein, 2007).

Temperature profiles reveal that waters in areas west and north of the Flemish Cap are similar to conditions found in the Labrador Current and Labrador Sea with relatively weak horizontal gradients. In contrast, conditions on the eastern and southern side of the Cap show strong horizontal gradients in temperature profiles, indicative of the contrast between the side-branch of the Labrador Current the North Atlantic Current. The mean position of the frontal zone is relatively stable throughout the year (Stein, 2007). At the surface, the contrast between Labrador Current and North Atlantic Current waters may be of the order of ~10°C based on Stein's (2007) analyses, while at depth waters surrounding the Cap on all sides are near 4°C. Waters associated with the Labrador Current have slightly higher concentrations of nitrate, silicate and oxygen than those associated with the North Atlantic Current (Maillet *et al.*, 2005).

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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 4.1. [FC Request # 12]. Report progress on the assessment of Significant Adverse Impacts on VMEs, with emphasis on analysis of the risk associated with bottom fishing activities on known and predicted VME species and elements in the NRA.

4.1.1. Introduction

The United Nations General Assembly (UNGA) resolution 61/105 (2006)[1] requested RFMOs to, in accordance with the precautionary approach and ecosystem approaches, assess whether bottom fishing activities would have significant adverse impacts (SAIs) on vulnerable marine ecosystems (VMEs) and ensure that proper conservation and management measures are put into place to prevent such impacts.[2] It also requested RFMOs to close areas to bottom fishing where VMEs (including seamounts and cold water corals) are known to occur or are likely to occur (based on the best available scientific information) and ensure that such activities do not proceed unless conservation and management measures have been established to prevent SAIs on VMEs.[3]

Following a review of the implementation of UNGA Resolution 61/105, the UNGA Resolution 64/72 (2009) emphasized that impact assessments are to be conducted in accordance with the FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO Guidelines) criteria.[4] In addition, this resolution requested RFMOs and flag states to ensure that vessels do not engage in bottom fishing until such assessments have been carried out.[5]

The FAO Guidelines, besides providing guidance on the management of deep-sea stocks, describes what constitutes a VME, defines SAI and provides the criteria for assessing SAIs.[6]

In accordance with the FAO Guidelines, the definition of significant adverse impacts is the following:

> "those that compromise ecosystem integrity (i.e. ecosystem structure or function) in a manner that: (i) impairs the ability of affected populations to replace themselves; (ii) degrades the long-term natural productivity of habitats; or (iii) causes, on more than a temporary basis, significant loss of species richness, habitat or community types. Impacts should be evaluated individually, in combination and cumulatively.[7]"

In addition, the following six factors should be considered when determining the scale and significance of an impact

i. the intensity or severity of the impact at the specific site being affected;

ii. the spatial extent of the impact relative to the availability of the habitat type affected;

iii. the sensitivity/vulnerability of the ecosystem to the impact;

iv. the ability of an ecosystem to recover from harm, and the rate of such recovery;

v. the extent to which ecosystem functions may be altered by the impact; and

vi. the timing and duration of the impact relative to the period in which a species needs the habitat during one or more of its life history stages.[8]

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[1] UNGA Resolution on Sustainable Fisheries, A/RES/ 61/105 (2006), Para. 83.
[2] *Ibid*, Para. 83 (a).
[3] *Ibid*, Para. 83 (c).
[4] UNGA Resolution on Sustainable Fisheries, A/RES/64/72 (2009), Para. 119 (a).
[5] *Ibid.*
[6] Food and Agriculture Organization of the United Nations, International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (Rome: FAO, 2009).
[7] *Ibid*, Para. 17.

[8] *Ibid*, Para. 18.

Temporary impacts are defined as those that are limited in duration and that allow the particular ecosystem to recover over an acceptable time frame. The FAO Guidelines recommends that such time frames is to be decided on a case-by-case basis and should be in the order of 5-20 years, taking into account the specific features of the populations and ecosystems.[9] However, in determining whether an impact is temporary, both the duration and the frequency at which an impact is repeated should be considered. If the interval between the expected disturbance of a habitat is shorter than the recovery time, the impact should be considered more than temporary. In circumstances of limited information, the precautionary approach should be applied with respect to the nature and duration of impacts.

The FAO Guidelines' provisions on SAI (as described above) were endorsed and incorporated by NAFO's Conservation and Enforcement Measures in its Art. 15 (9).[10] In addition, the criteria for assessing SAIs on a given area are also provided by the FAO Guidelines[11] and by NAFO Conservation and Enforcement Measures.[12] The criteria includes, but is not restricted to: fishing plans, baseline information on the ecosystems, habitats and communities; identification, description and mapping of VMEs known or likely to occur in the NAFO area; evaluation of occurrence, scale and duration of likely impacts, including cumulative impacts; VME elements; risk assessment of likely impacts to determine likely SAIs on VMEs; as well proposed mitigation and management measures to prevent SAIs on VMEs, and measures to be used to monitor effects of the fishing operations. The FAO Guidelines determines that the results of the impact assessments will contribute to the determination of proper conservation and management measures to ensure long-term conservation and sustainable utilization of low-productivity fishery resources in addition to measures that confer adequate protection and prevent SAIs on VMEs.[13]

A reassessment of bottom fishing impacts following the criteria described above will be conducted by NAFO by 2016.[14]

4.1.2 Assessing SAI in the NRA

There are essentially two requirements for the development of SAI methods, namely; i. the assessment of the risk and nature of bottom trawling impacts on known and potential VMEs, and ii. the assessment of risk and the nature of bottom trawling impacts on VME indicator species outside of VME closed areas or predicted areas.

By definition, the risk of SAI to VME in areas closed to bottom trawling is not likely to be high (at least in terms of direct trawling impacts), but the closed area VME could be at risk through the secondary effects of trawling (e.g. resuspension of fine sediment; Boutillier *et al*, 2013). However, there is a possibility that VME (e.g. VME not closed to fishing) exists within the NRA and is at risk of SAI as has been shown in the recent review of NRA VME closures under ToR1 of this report. We therefore intend to dvelop and apply models to predict where VME indicator species are likely to be found within the fishing footprint using data from trawls and core samples taken in areas which are not fished.

The assessment of potential secondary impacts on VME arising from bottom trawling activity has not been undertaken to date and it may require additional types of sampling to address this question.

Therefore, the initial focus of the SAI assessment in the NRA will concentrate on addressing the risk and nature of direct bottom trawling impacts on potential VME and VME indicator species (through the application of species distribution models) and the actual impacts of bottom trawling activity on VME indicator species which occur outside of current VME closed areas, but within the fishing footprint.

The approach we have taken, in the first instance, is to assess the spatial relationship between fishing effort for data collected between 2008 and 2013 and to compare this to the observed biomass of two VME indicator species, namely sponge and seapen. These were chosen initially as they have been well studied in the NRA and their biomass distributions have been modeled previously by the working group. The interaction between the fishing effort and biomass layers then provides an overview of areas where SAI could potentially occur. The rationale being, that highly fished areas will tend to have a lower biomass of VME indicator species present compared to

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[9] *Ibid*, Para. 19.

[10] NAFO/FC Doc. 13/1.

[11] FAO Guidelines, Para. 47.

[12] NAFO/FC Doc. 13/1, Annex I.E., Part V.

[13] FAO Guidelines, Para. 47 (vii), and 70.

[14] NAFO/FC Doc. 13/1, Art. 23.

areas which are not fished as intensively. This could be because VME species have long since been removed, or it could be that they never occurred in the area. SDMs can give the probability of occurrence in those areas dependent not on presence information, but on whether the environment is suitable for the VME indicator. Unsuitable habitats may never have supported VME indicators or may not support re-establishment if they have been removed through fishing. The nature of the response (e.g. the relationship between biomass and fishing effort/intensity) can potentially reveal the significance of the impact in terms of interaction area and the ability of the VME indicator species to either withstand a given level of fishing pressure or its ability to recolonise, grow and recover following an impact or cumulative impact. If successful, this approach will be applied to other VME indicator species in addition to sponge and seapen in the EU survey trawl data set.

4.1.2.1. Assessing direct impacts of bottom trawling on VME indicator species

The Significant Adverse Impacts (SAI) analyses examined the spatial relationship between commercial fishing effort and surveyed biomass of selected VME indicator species. Using Vessel Monitoring System (VMS) data from 2008 to 2012, a surface was created that depicted fishing effort as hours trawled per square kilometer (hrs/km^2) while sponge and seapen biomass surfaces were generated using the EU research vessel survey data and expressed as kilograms per square kilometer (kg/km^2). These layers were then overlaid to study how the biomass of each VME indicator taxon varied with fishing pressure.

4.1.2.1.1 Assessing the fishing effort

The Vessel Monitoring System is used to monitor commercial fishing vessels and reports, minimally, a position and time at position. The VMS position and time parameters were used to derive the vessel speeds which were used as a proxy for vessel activity. In order to create an accurate representation of effort it was necessary to extract only those VMS records for when vessels were considered to have been fishing. Vessel speed was determined by calculating the distance travelled and time elapsed between pairs of subsequent VMS pings. A vessel was deemed to have been fishing and data were extracted if the calculated speed was between 0.5 kts and 5.0 kts[15]. The VMS data used includes both ground fish and shrimp fisheries.

Using the filtered data, the effort surface was created by calculating the average number of hours trawled per square kilometer in each grid cell. The surface was created using 5.5km x 5.5km grid cells which ensured several VMS pings were allocated to each cell for areas where fishing occurs. The total annual hours trawled for each cell were then calculated in ArcGIS by using a spatial join between the grid surface and the VMS layers where the grid cells were assigned the sum of the hours fished for all points within that cell. (Figure 4.1.2.1.1)

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[15] NAFO SCR Doc. 13/001

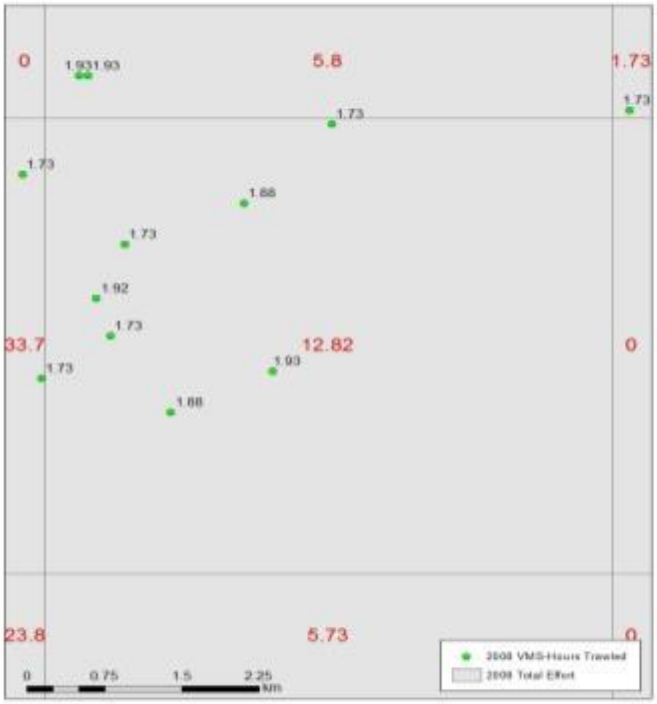


Figure 4.1.2.1.1: Sample calculation of total annual fishing effort. Green points represent filtered VMS pings and the hours related to each ping, and the red text is the total number of hours fished in the cell, based upon the VMS ping data.

This process was repeated for each of the five years the VMS data were available (2008 – 2012). The average of these annual sums was then calculated and divided by the cell area to express the final result as average hours trawled per square kilometer (Table 4.1.2.1.1) and the resulting surface is shown in Figure 4.1.2.1.8. This analysis was also repeated with the sum of effort per square kilometer and the result was exactly the same. This approach provides a relative measure of fishing pressure, that is any one area can be assessed against any other area in terms of fishing effort. It does not allow for a direct comparision of swept area of sea bed impacted. For this we need to use the dimensions of the fishery specific gear type and calculate the total swept area as a proportion of each grid cell – this is a calculation we intend to perform in future analyses.

Table 4.1.2.1.1: Sample of effort calculations. Highlighted row is the cell in Figure 4.1.2.1.1.

Cell ID	Total Hours 2008	Total Hours 2009	Total Hours 2010	Total Hours 2011	Total Hours 2012	Average Hours	Area (km2)	Hours / km2
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1244	12.82	11.88	5.1	2	1	6.55933	30.25	0.216837
1245	8.03	4.02	54.45	55.12	33.05	30.9325	30.25	1.02256
1246	4	6	14.05	23.02	11	11.6127	30.25	0.383891
1247	9.62	8.2	7.02	21.08	38.6	16.9033	30.25	0.558787
1248	0	0	0	0	1	0.2	30.25	0.006612
1249	5.2	4.03	0	0	0	1.84667	30.25	0.061047
1250	33.7	19.97	4.78	0	2	12.0893	30.25	0.399646
1251	0	0	0	1	1	0.4	30.25	0.013223
1252	0	0	1	0	0	0.2	30.25	0.006612
1253	0	0	0	0	0	0	30.25	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

The grid-cell effort surface was then analyzed using percentiles to partition the grid cells into zones of equal fishing pressure following the approach described in the meeting report of WGEAFM (2012). The percentile breaks were determined by using a cumulative percentage curve. The percentage of the total effort was calculated for each effort grid cell which were then sorted from smallest to largest and the cumulative percentages calculated. Break points were then identified at every 5th percentile. This is summarized in Table 4.1.2.1.2 and the results presented as a cumulative curve of effort in Figure 4.1.2.1.2

Table 4.1.2.1.2: Effort percentile calculations, The highlighted rows show the data for the 5th, 10th 95th and 100th percentile. Note that by definition, each 5th percentile has the same amount of effort, but the number of grid cells associated with that effort differes greatly between the lowest to highest percentiles.

Cell ID	Total Hours					Avg Hours	Avg Hours / km2	%	Cumulative Percent	Percentile Group
	2008	2009	2010	2011	2012					
1	0	0	0	0	0	0	0	0	0	5
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1979	6	4	23.12	4	0	7.424	0.2454	0.01	4.994588	5
1980	0	0	16.13	4	17	7.426	0.2455	0.01	5.003155	10
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2419	24.6	4	5	7	23	12.7233	0.4206	0.01	9.988554	10
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
3753	372	437.78	563.9	493.5	450.2	463.523	15.323	0.53	90.185152	95
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
3759	532	761.47	745.2	833.3	816.3	737.602	24.384	0.85	94.206593	95
3760	623	831.9	761.8	863.4	847.5	785.545	25.968	0.91	95.112839	100
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
3765	714	983.55	855.7	962.3	988.3	900.814	29.779	1.04	100	100

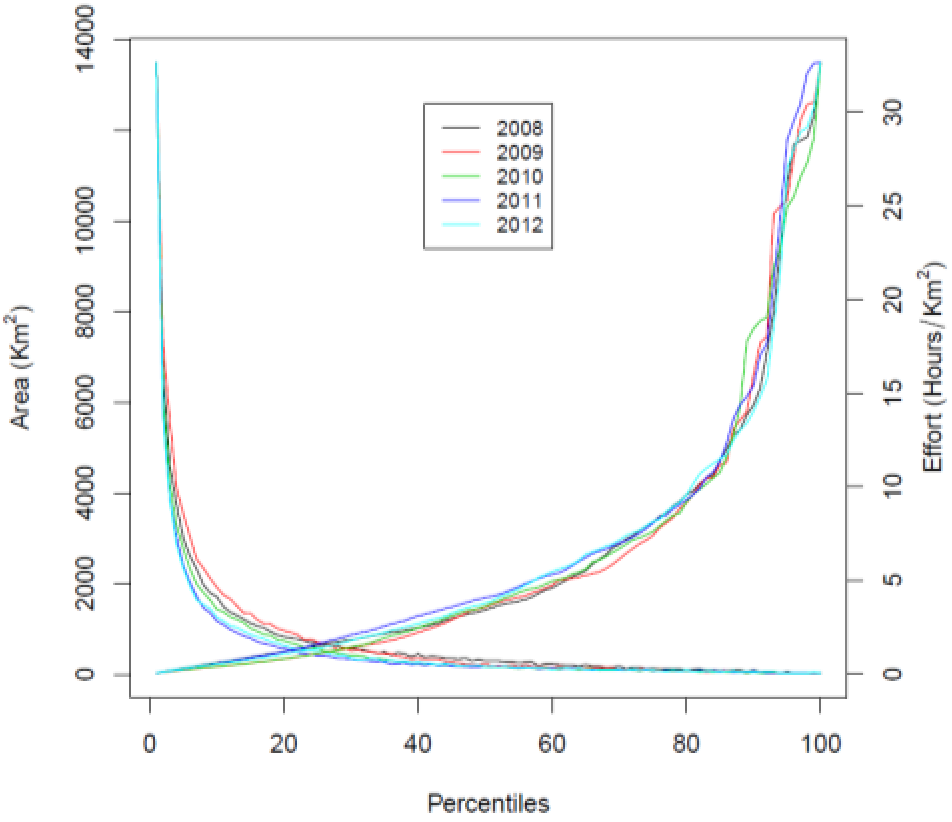


Figure 4.1.2.1.2: VME Fishing effort (hrs trawled/km^2) in each percentile and the total area fished associated with each percentile. Maps of the percentile areas are shown in Figures 4.1.2.1.3-8.

Maps of the effort associated with each 5th percentile category for each year between 2008 and 2012 are shown in Figures 4.1.2.1.3-7 and a map of the average effort is shown in Figure 4.1.2.1.8

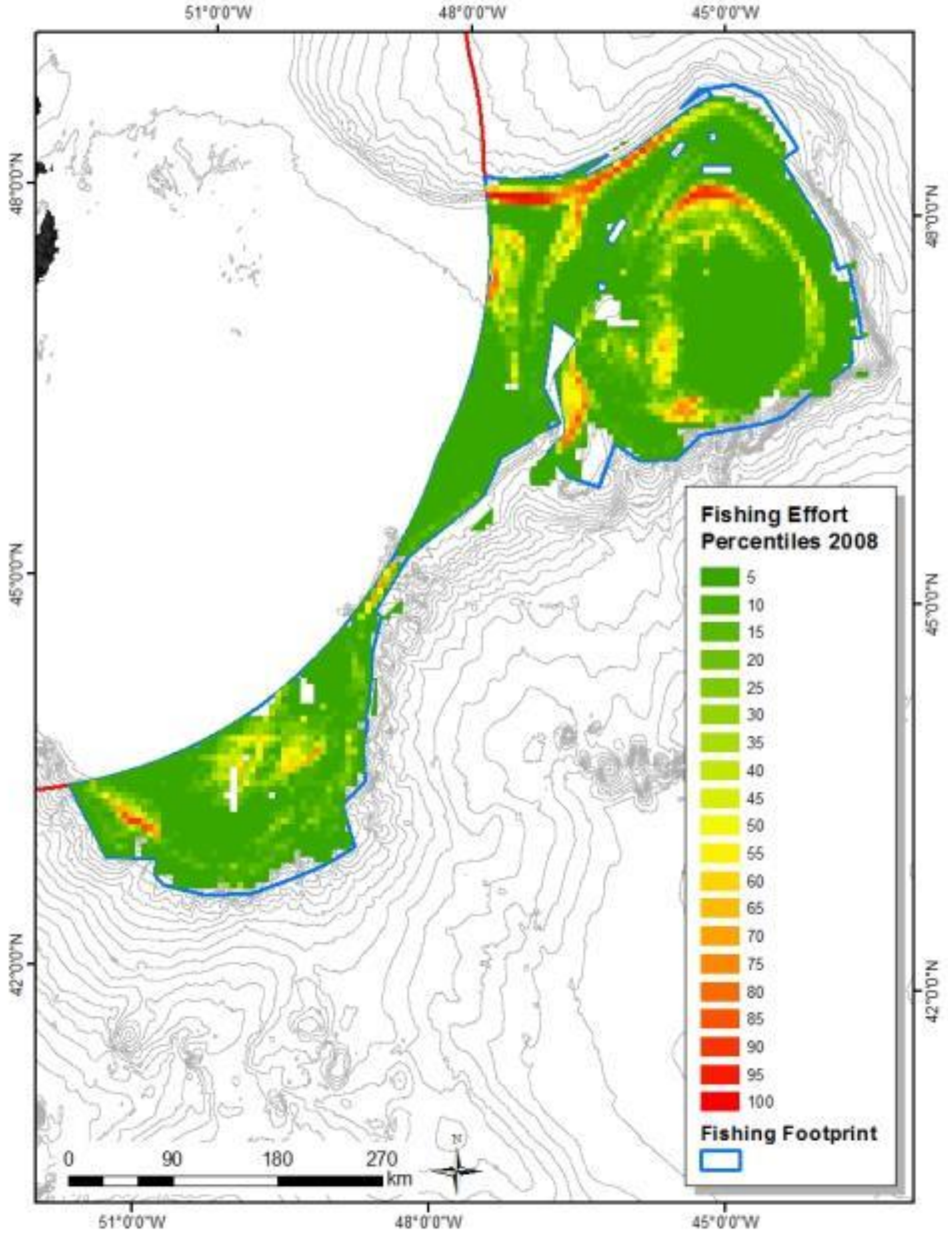


Figure 4.1.2.1.3: Fishing effort in 5th percentile categories 2008.

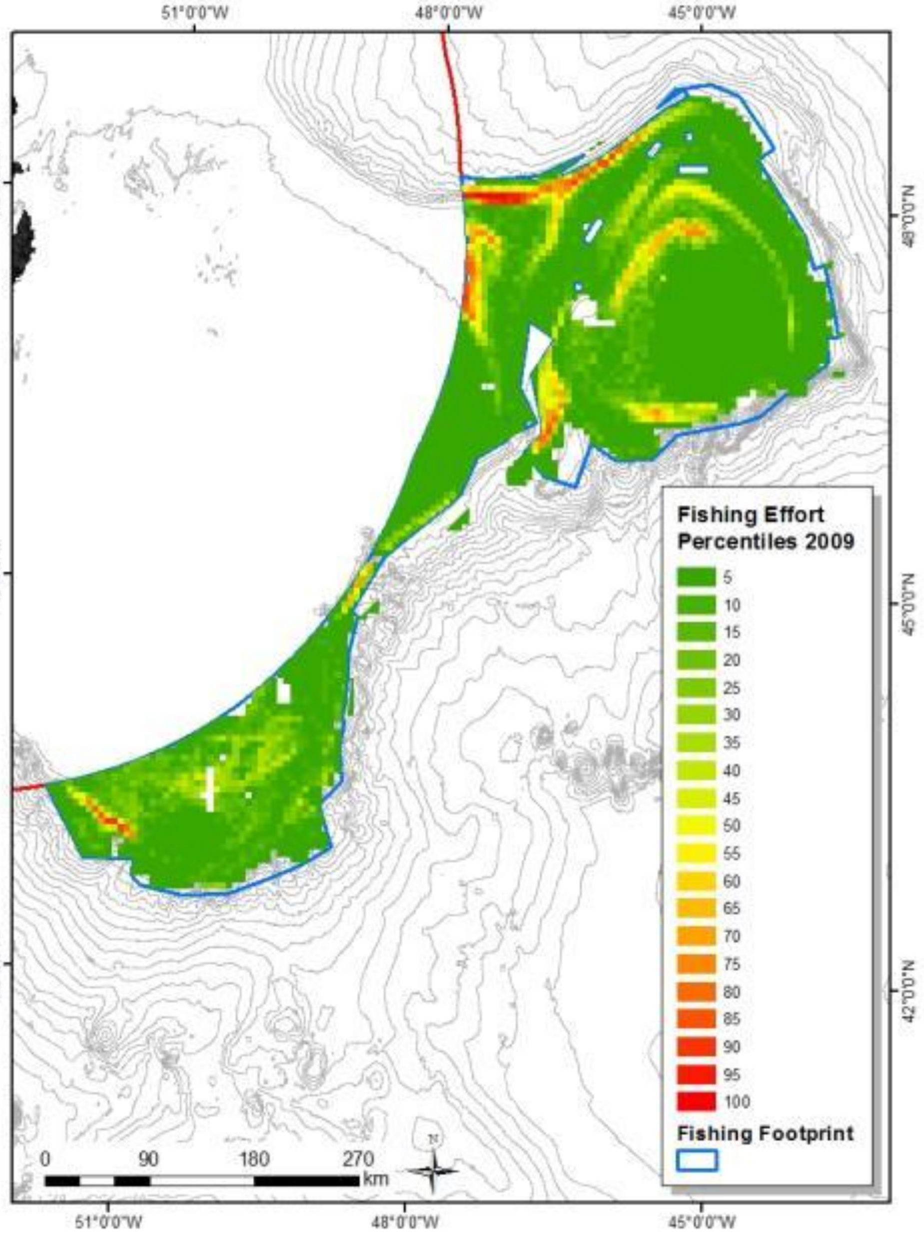


Figure 4.1.2.1.4: Fishing effort in 5th percentile categories 2009.

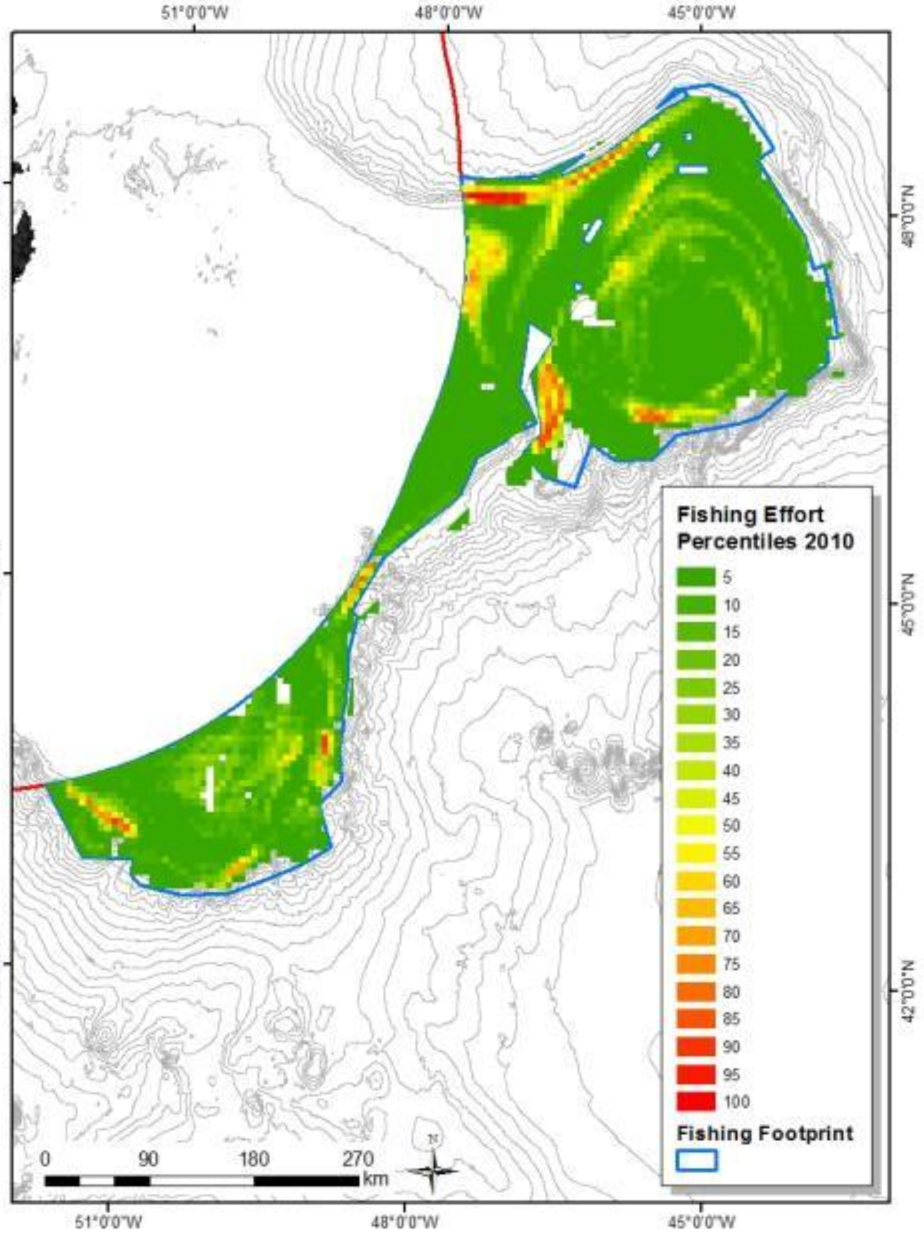


Figure 4.1.2.1.5: Fishing effort in 5th percentile categories 2010.

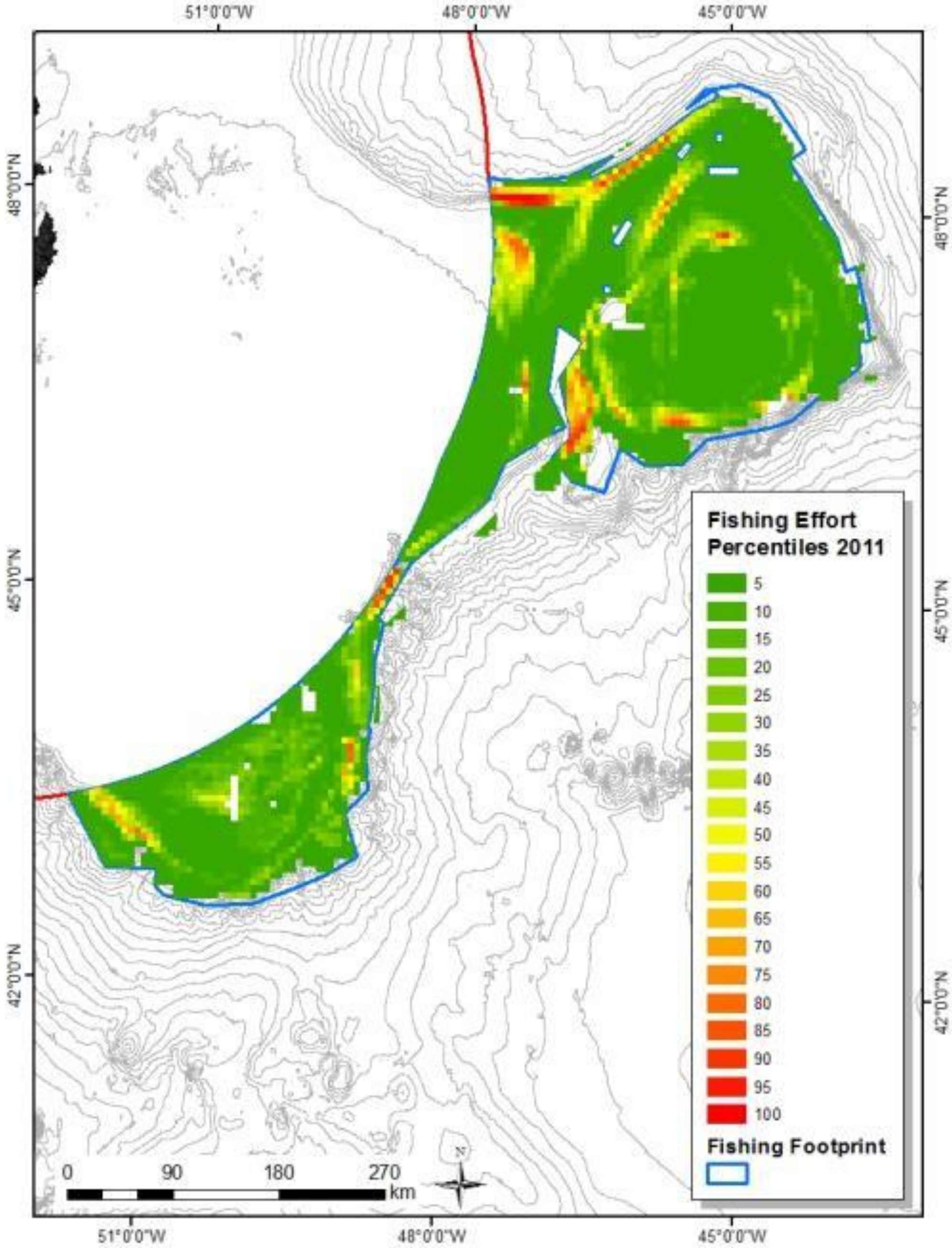


Figure 4.1.2.1.6: Fishing effort in 5th percentile categories 2011.

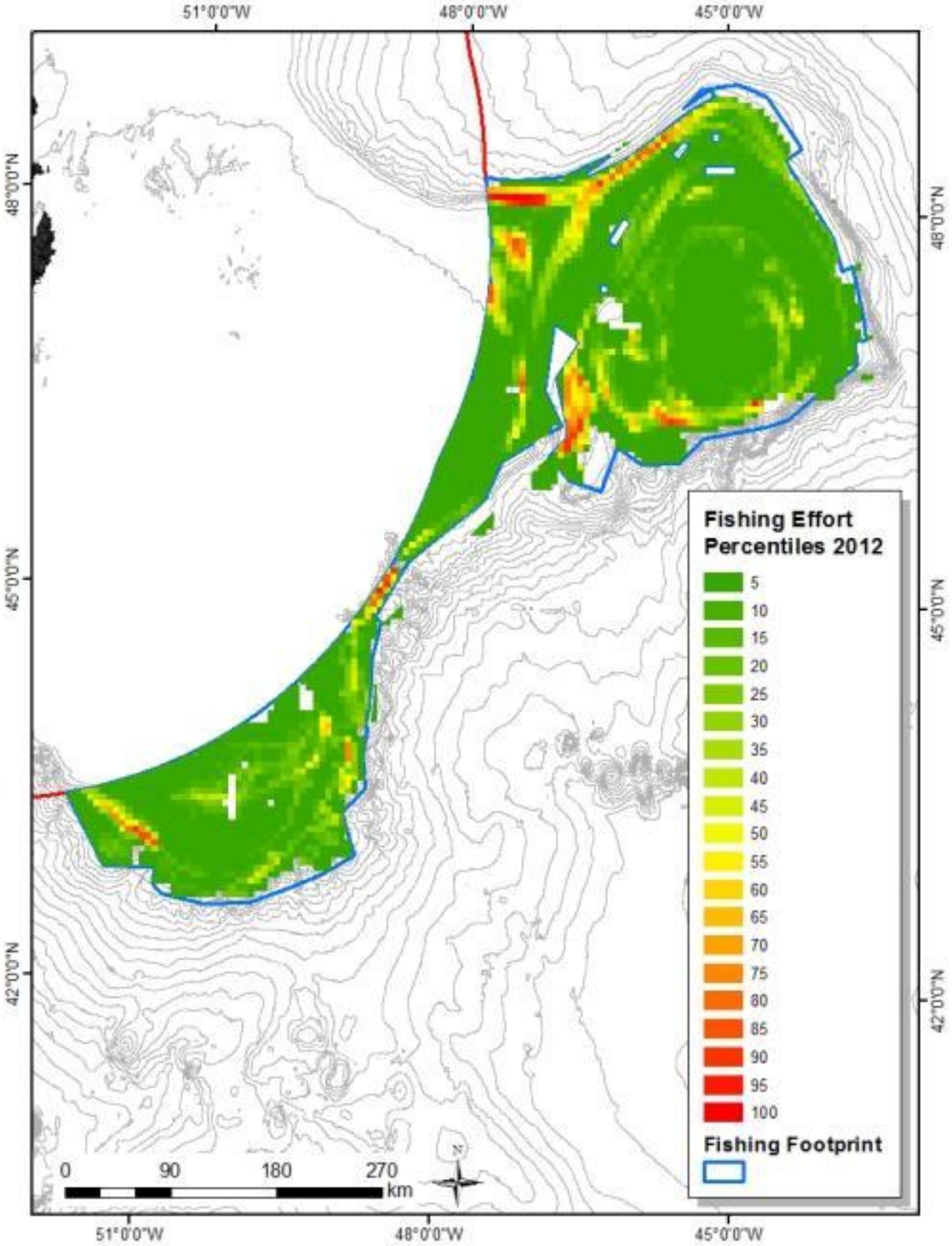
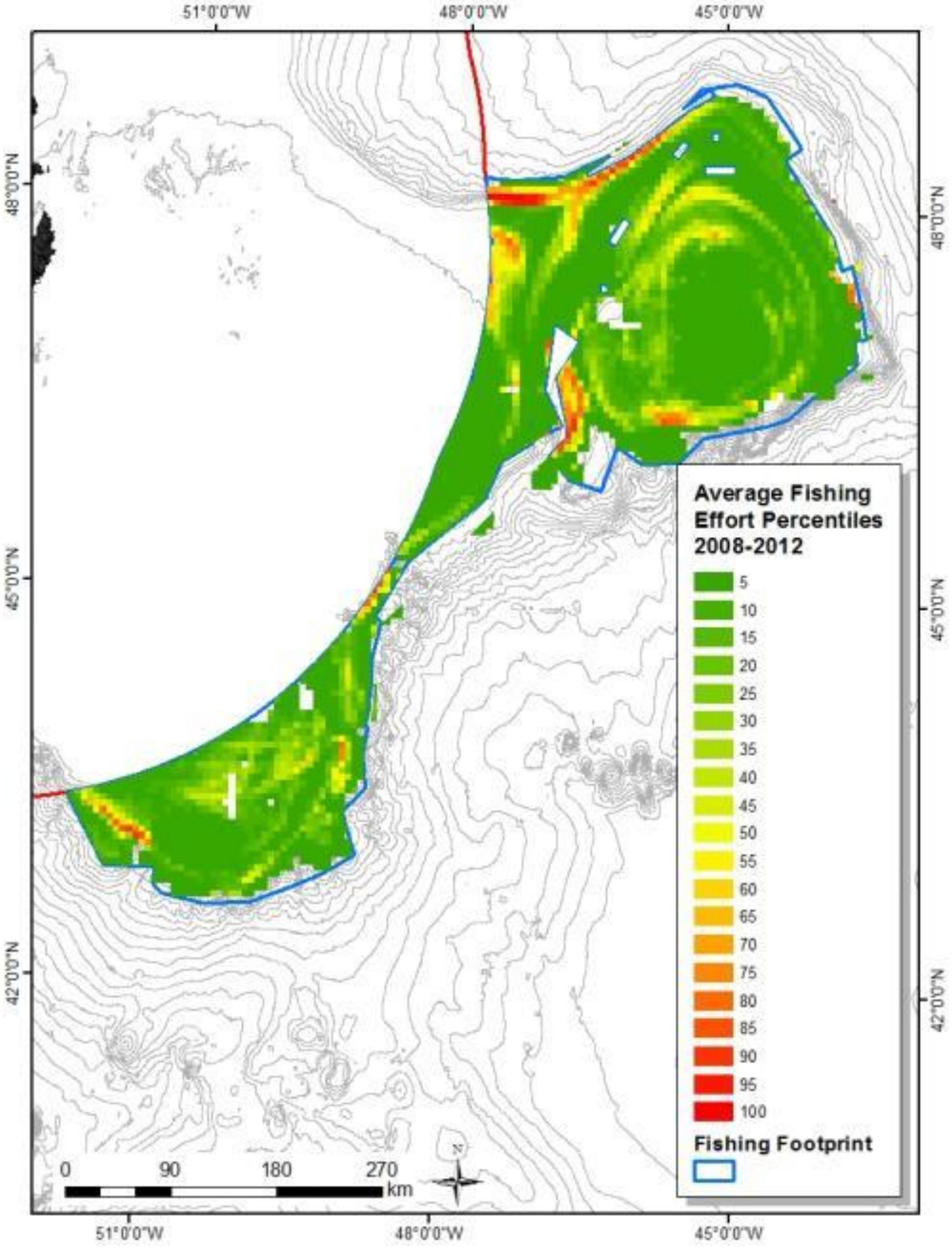


Figure 4.1.2.1.7: Fishing effort in 5th percentile categories 2012.



Figures 4.1.2.1.8: Average fishing effort in 5th percentile categories for VMS data collected between 2008 to 2012.

The resulting average effort layer was comprised of 3765 individual polygon cells. To simplify this layer and to facilitate subsequent analysis the ArcGIS 'dissolve' function was applied that aggregated the individual effort polygon cells into single polygons based upon their calculated effort percentile. Figure 4.1.2.1.9 shows the original effort grid whereas Figure 4.1.2.1.10 shows the dissolved surface that has only 20 polygons, one for each percentile class.

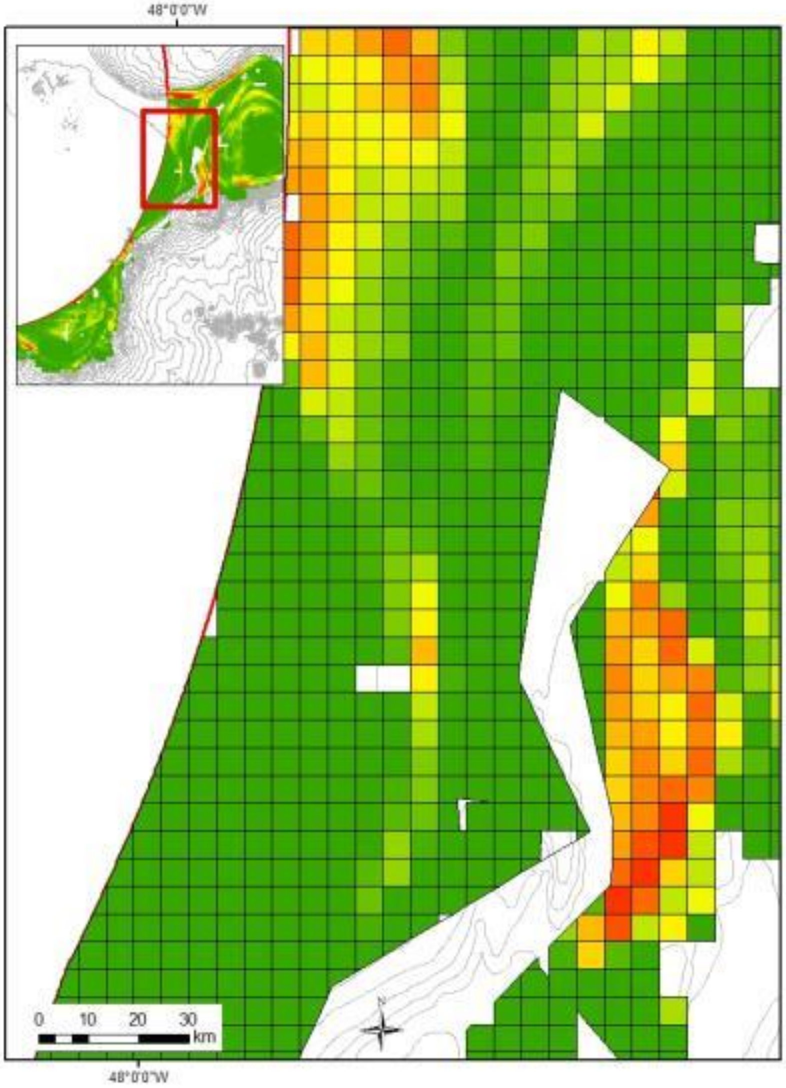


Figure 4.1.2.1.9: The original effort grid cell layer comprised of 3765 polygon cells.

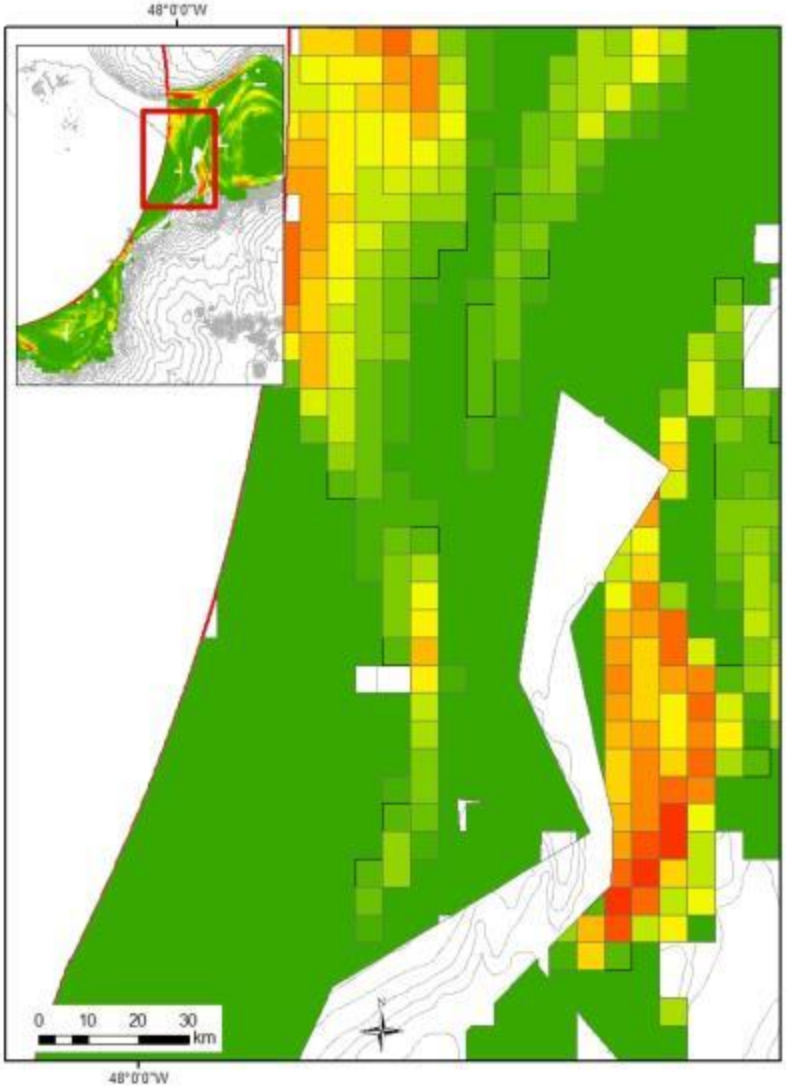


Figure 4.1.2.1.10: The simplified effort 20 polygon layer.

4.1.2.2 Creating the sponge and seapen biomass layers

Biomass data for the two VME indicator species (sponge and seapen) obtained from research vessel trawl EU surveys between 2005 and 2013 were used (Figures 4.1.2.2.1 and 4.1.2.2.2). Using only the data collected outside the closed areas, cell surfaces were created for seapens and sponges and calculated as kg / km^2 on the same 5.5 km x 5.5 km grid cells that were used to create the effort surfaces. Canadian RV survey data was available for some of the NRA however it was not possible to combine with the EU RV data because of differences in gear types and tow duration. Additionally, the Canadian survey did not cover the entire NRA and would have introduced a sampling bias into the stratified-random sampling design.

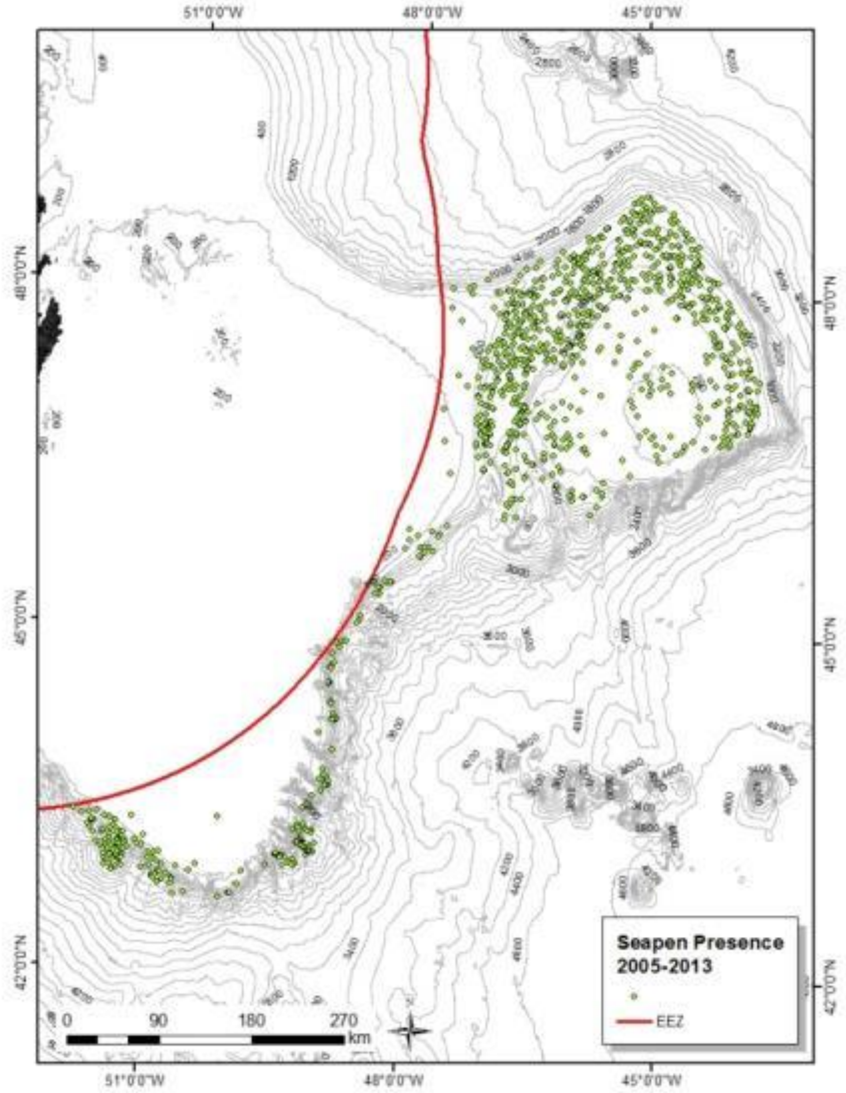


Figure 4.1.2.2.1: Seapen presence as determined from EU surveys between 2005 and 2013.

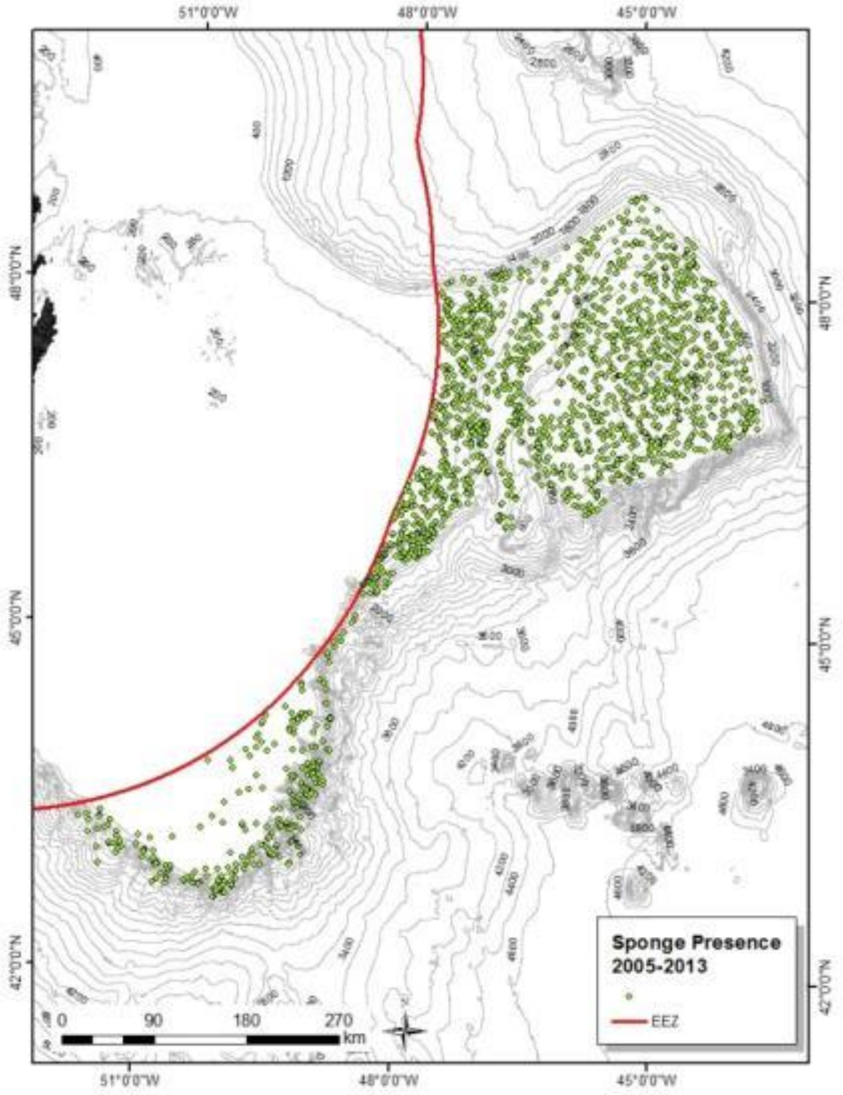


Figure 4.1.2.2.2: Sponge presence as determined from EU surveys between 2005 and 2013.

An ArcGIS spatial join was performed between the catches of each of the VME indicator species and the 5.5 km x 5.5 km grid cells to calculate the average biomass per cell which was then divided by the cell area. The spatial join determines into which cells each biomass point falls then assigns the average of those values to the corresponding grid cell. Figure 4.1.2.2.3 and Table 4.1.2.2.1 illustrate a single average-catch-per-cell of seapen biomass and Figures 4.1.2.2.4 and 4.1.2.2.5 show the resulting biomass surfaces comprised of the individual cell calculations. The areas on the biomass surfaces without any values indicate regions where no sampling occurred and these were excluded from the subsequent interaction analysis with the fishing effort layer. This is because biomass data is absent from these areas and we are only using data from surveys and not modeled data to examine the interaction between biomass and fishing effort.

To facilitate the subsequent fishing effort-biomass interaction analysis the biomass surfaces were then converted to point layers. The ArcGIS'feature to point' function was used to assign the polygon cell value to its calculated point centroid. These layers are shown in Figures 4.1.2.2.6 and 4.1.2.2.7.

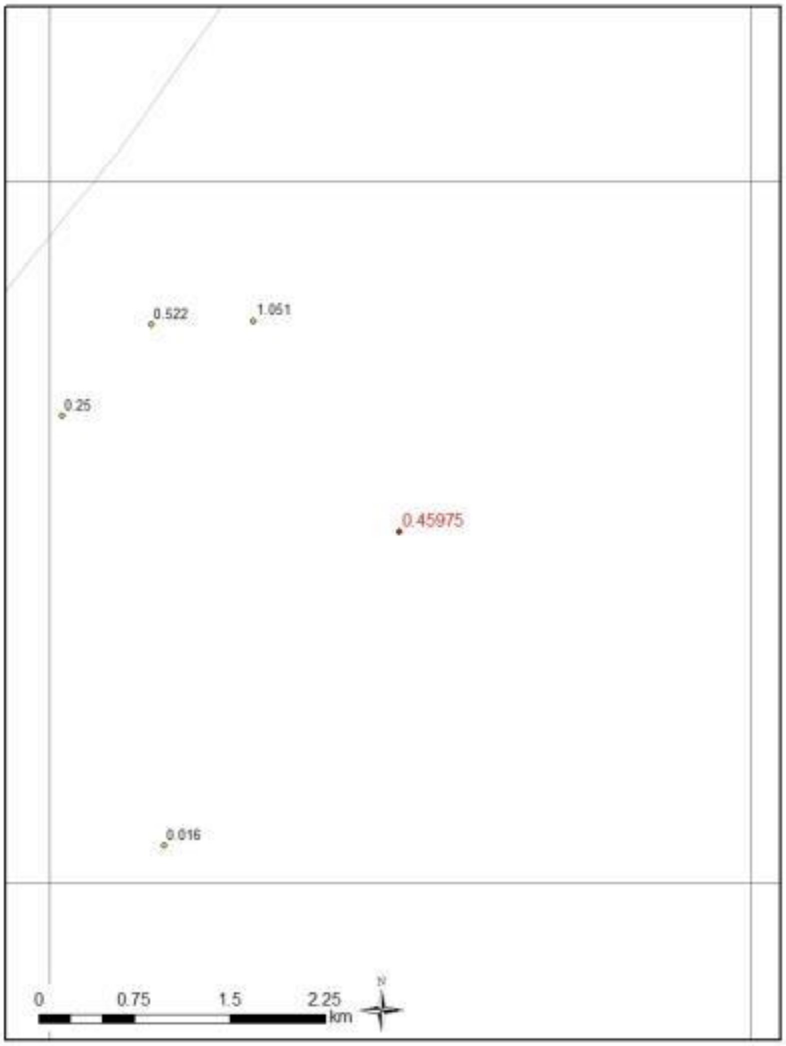


Figure 4.1.2.2.3: Sample calculation of average catch in kilograms of seapen biomass. Green points represent RV survey sets and the kilograms caught related to each set as a point at the start of the set and the red text is the average kilograms caught in the cell.

Table 4.1.2.2.1: Sample biomass calculation. Set count refers to the number of sets that fell within each cell. The highlighted row is the sample cell from Figure 4.1.2.2.3 above.

Cell ID	Set Count	Average Catch (kg)	Area (km2)	kg / km2
⋮	⋮	⋮	⋮	⋮
1726	4	0.45975	30.25	0.015198
1727	3	0.050333	30.25	0.001664
1728	1	0	30.25	0
1729	1	0.445	30.25	0.014711
1730	1	0.65	30.25	0.021488
1731	1	0	30.25	0
1732	1	0.165	30.25	0.005455
⋮	⋮	⋮	⋮	⋮

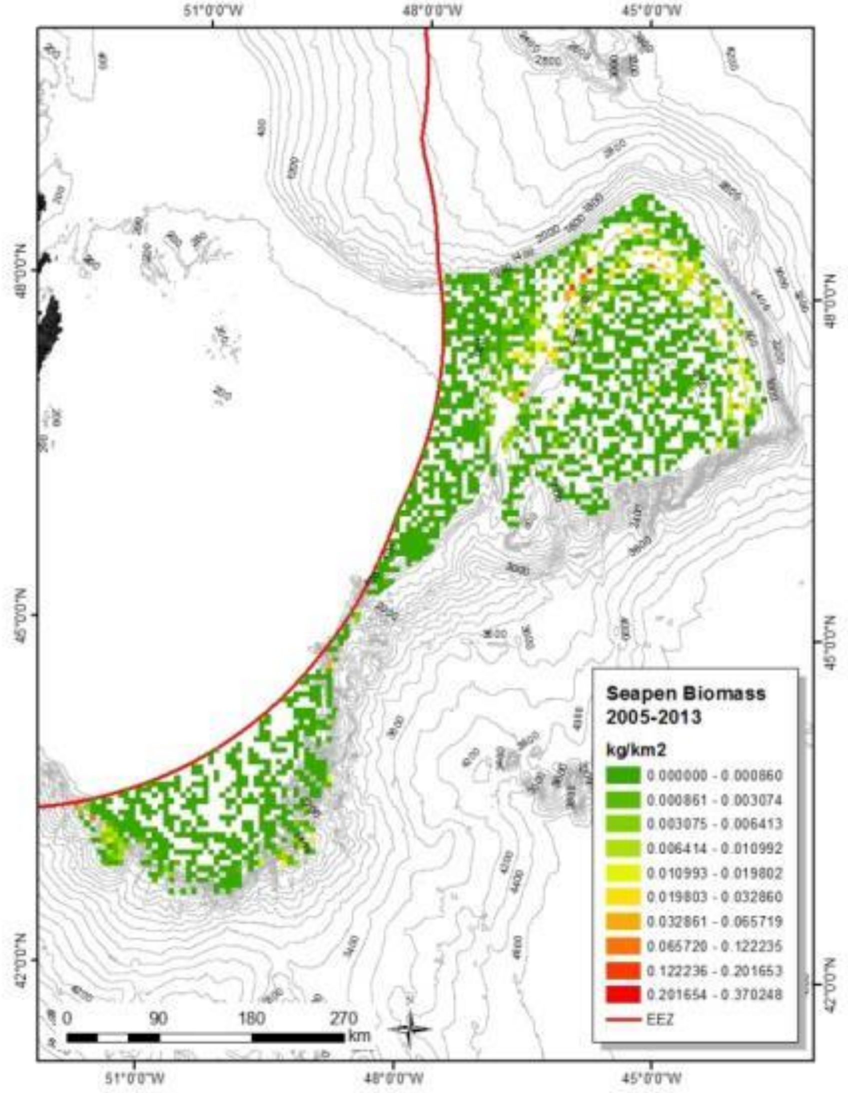


Figure 4.1.2.2.4: Seapen biomass surface as calculated from EU survey data collected between 2005 and 2013. Areas with no biomass cells indicate where no sampling occurred.

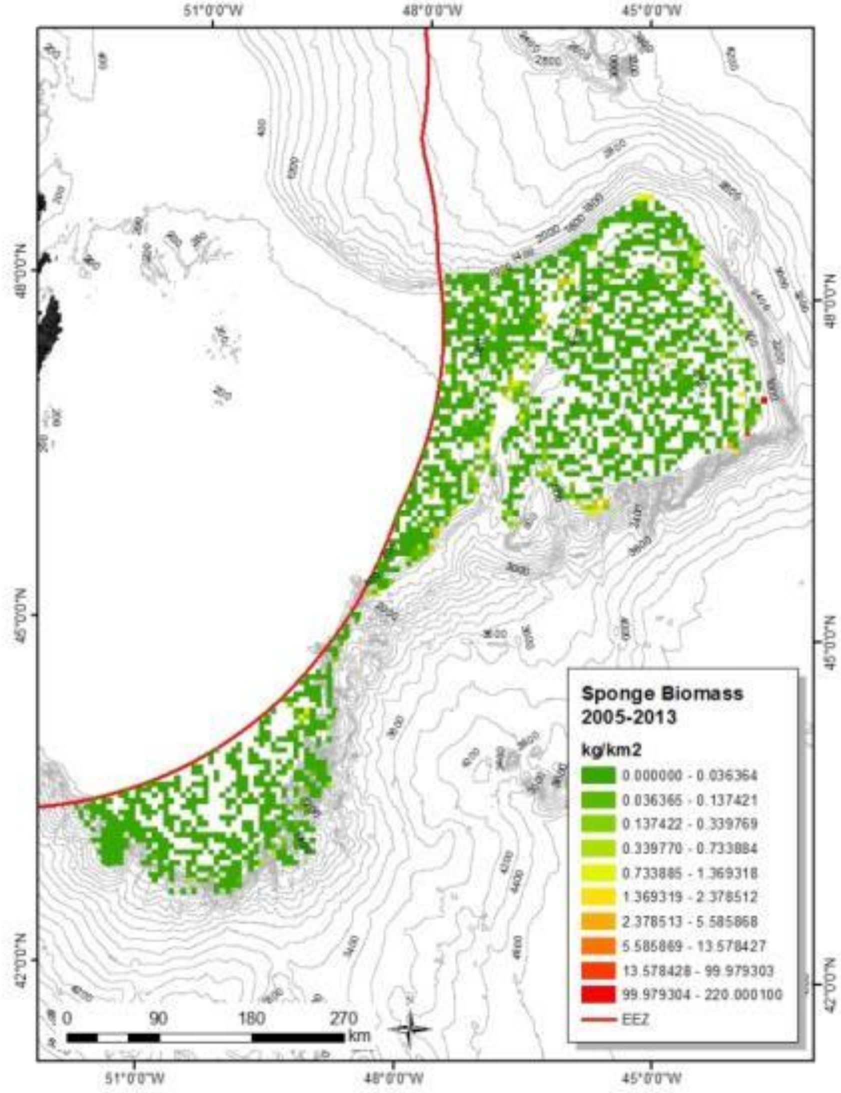


Figure 4.1.2.2.5: Sponge biomass surface as calculated from EU survey data collected between 2005 and 2013. Areas with no biomass cells indicate where no sampling occurred.

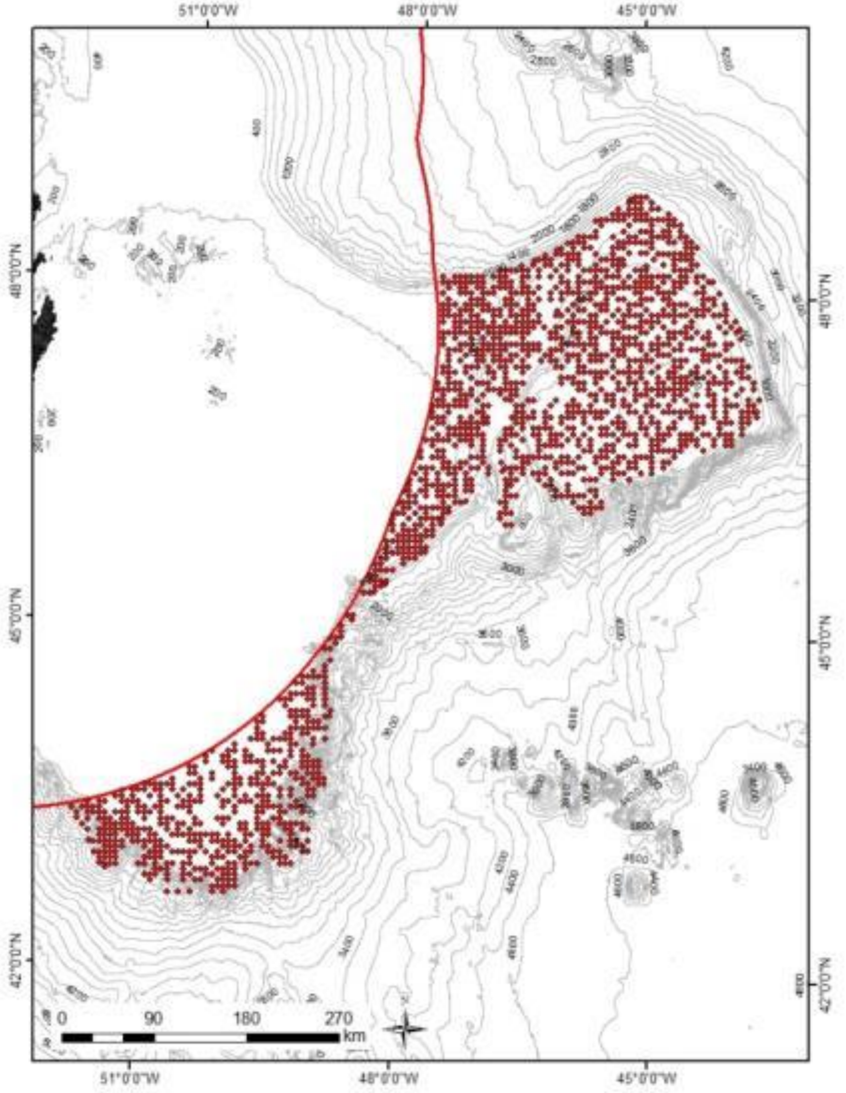


Figure 4.1.2.2.6: Seapen biomass point layer created from calculated biomass cell surface.

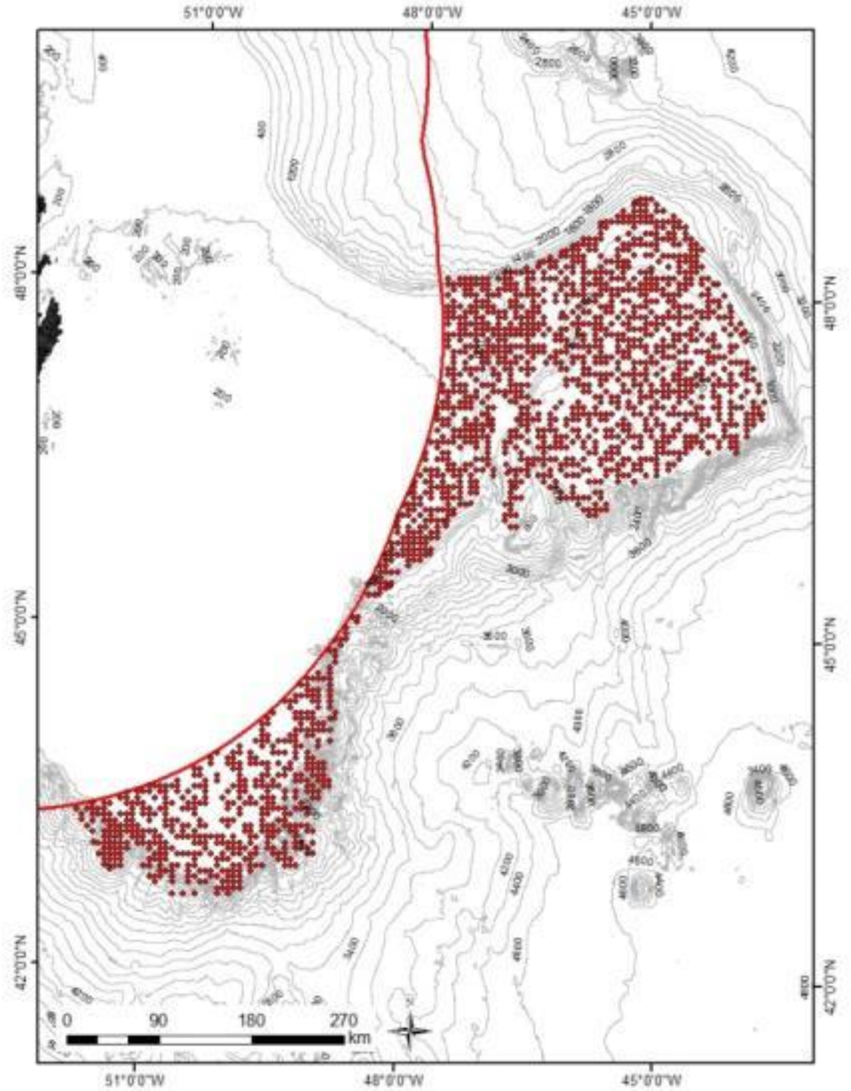


Figure 4.1.2.2.7 Sponge biomass point layer created from calculated biomass cell surface.

4.1.2.3. Assessing the interaction between the fishing effort and VME indicator species biomass

An ArcGIS spatial join was used to examine the spatial relationship between the VMS-derived fishing effort and VME indicator species biomass layers. This analysis involved a spatial overlay of the average five-year effort layer and each of the biomass layers to calculate the average biomass (kg/km^2) for each of the five percentile polygons. (Figures 4.1.2.3.1 – 2)

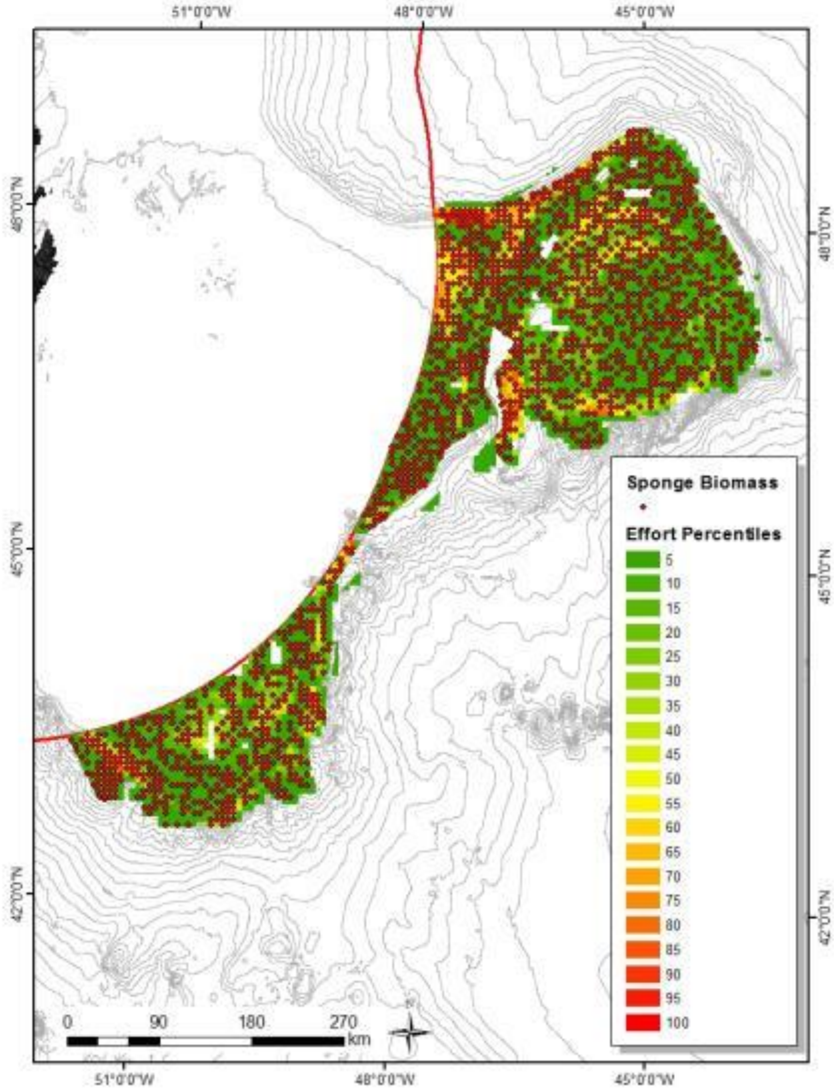


Figure 4.1.2.3.1: Sponge biomass layer overlaid with 5-year average effort surface.

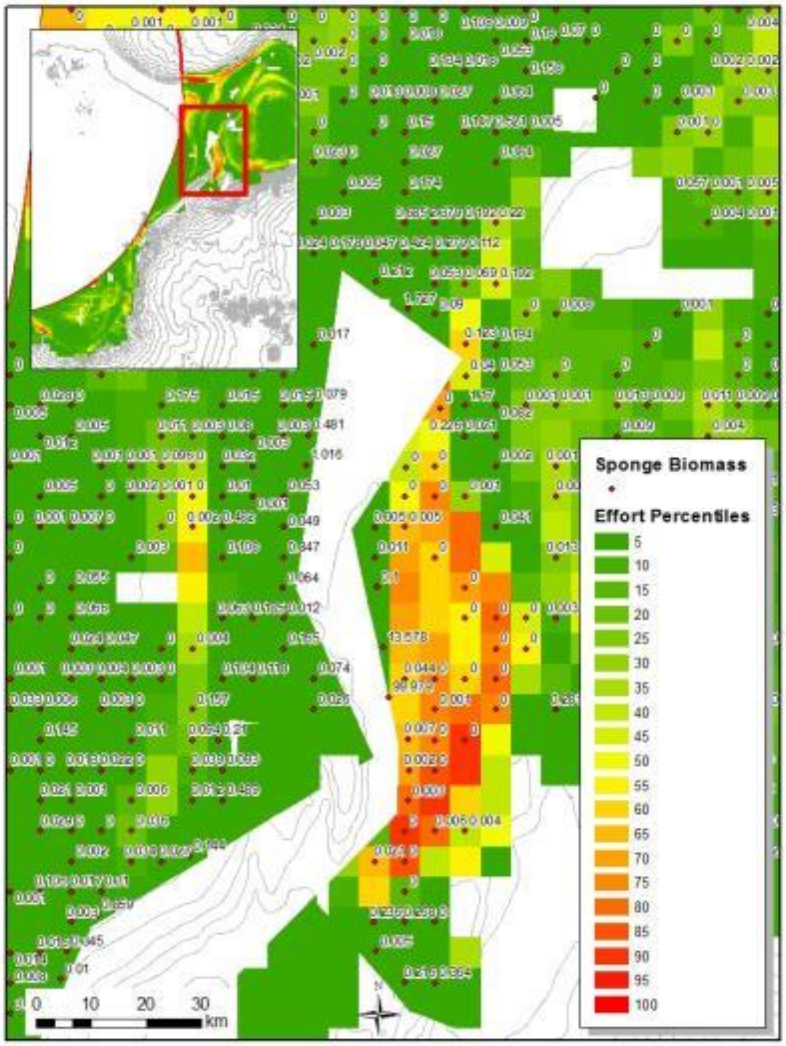
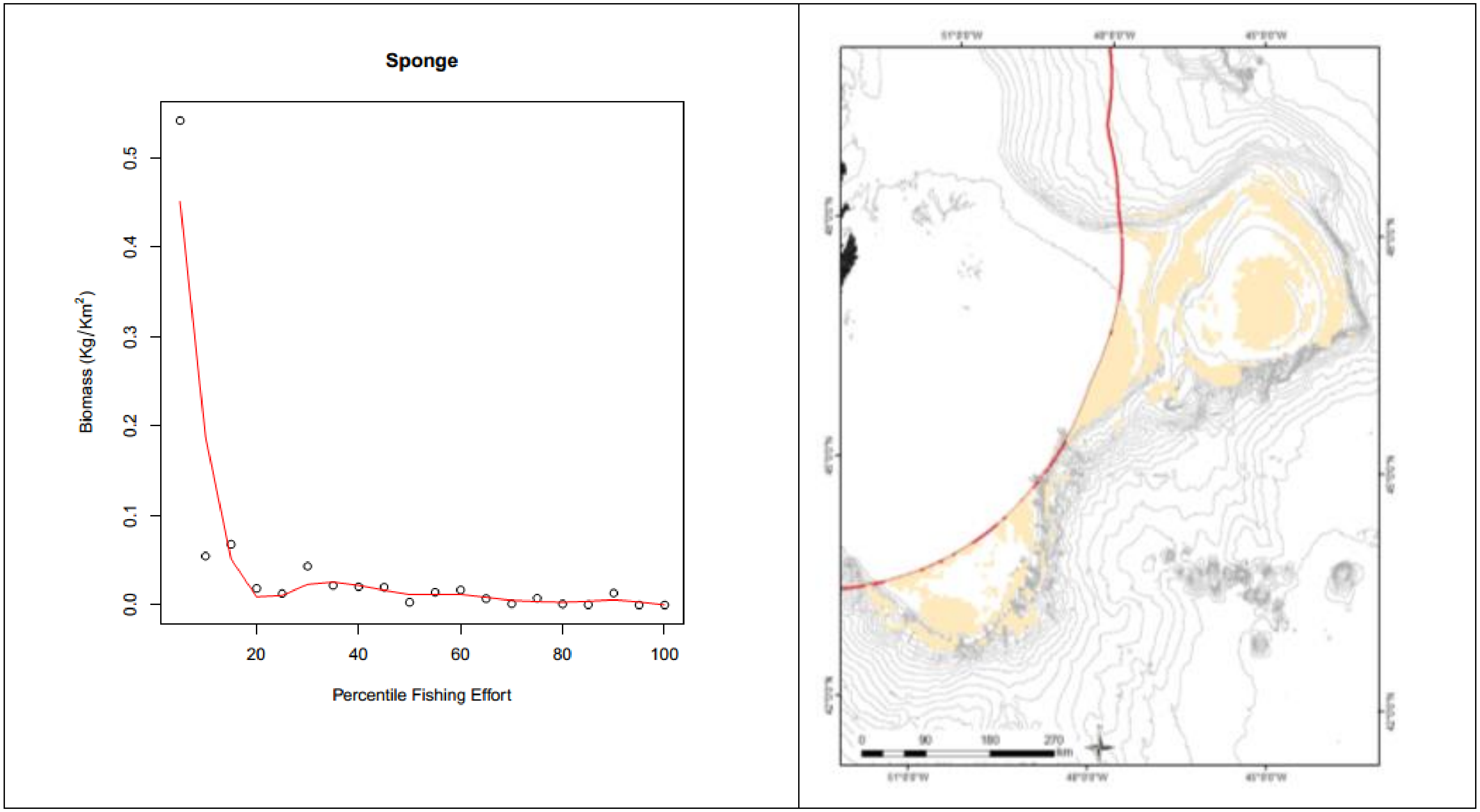


Figure 4.1.2.3.2: Sub region of the NRA in the Flemish Pass showing the sponge biomass overlaid on the 5-year average effort surface. The biomass points are shown in red with their associated values in the black text.

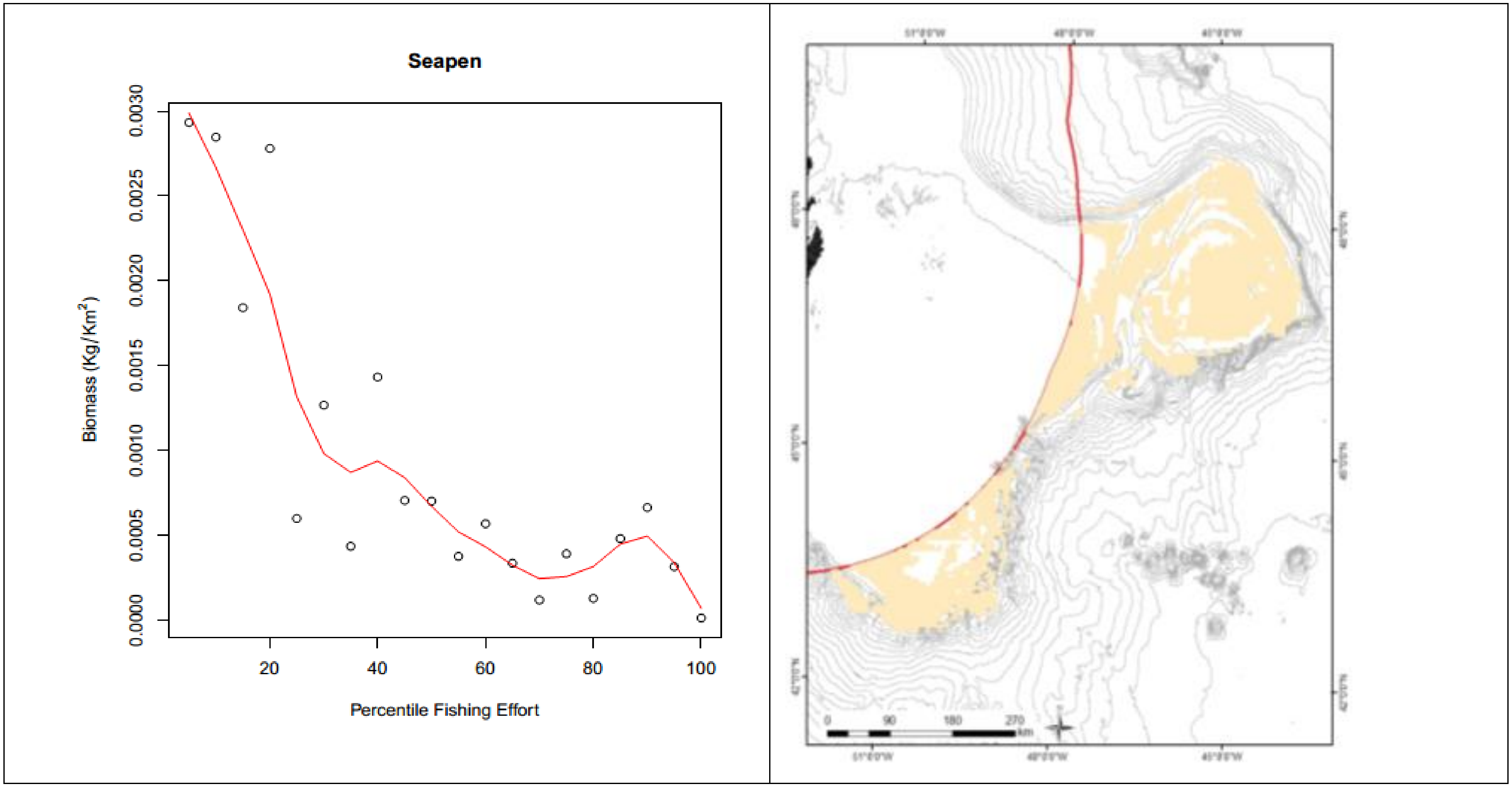
The result of the analysis is shown in Table 4.1.2.3.1 that illustrates how the density of the seapen and sponge changes with increasing fishing effort. For each percentile class the table shows the mean number of hours trawled within that class, the number of biomass points and the average biomass density for each of sponge and seapen. These data are also plotted in Figures 4.1.2.3.3 and 4.1.2.3.4 so as to more clearly observe the relationship between fishing effort percentiles and VME indicator species biomass.

Table 4.1.2.3.1: Fishing effort and biomass interaction results.

Percentile	Average Hours Trawled/km2	Area (km2)	Sponge		Seapen	
			Point Count	Average kg/km2	Point Count	Average kg/km2
5	0.072292	54852.95	917	0.54166	899	0.002934
10	0.325232	13011.17	225	0.054631	223	0.002848
15	0.507387	8358.894	167	0.067747	164	0.001843
20	0.677423	6226.462	110	0.018538	110	0.002781
25	0.862993	4929.329	89	0.012646	86	0.000601
30	1.099174	3825.976	70	0.043281	70	0.001269
35	1.370672	3122.653	55	0.021836	55	0.000437
40	1.666799	2549.093	41	0.020432	40	0.001434
45	2.034185	2057.558	43	0.020008	42	0.000708
50	2.474106	1691.563	38	0.002974	38	0.000704
55	3.020193	1431.042	32	0.01409	32	0.000378
60	3.57903	1201.417	23	0.016758	23	0.00057
65	4.231219	973.5744	24	0.007127	24	0.000338
70	5.015643	840.5439	14	0.001302	14	0.000121
75	5.832882	725.6604	18	0.007559	17	0.000393
80	6.92289	602.6587	13	0.001036	13	0.000131
85	8.419459	486.1076	10	0.000256	10	0.000482
90	10.53619	392.8744	8	0.013223	7	0.000666
95	18.65105	208.1371	5	0.000017	5	0.000317
100	27.66831	181.5	6	0.000026	6	0.000015



Figures 4.1.2.3.3a: Sponge biomass (kg/km^2) versus percentile fishing effort. Each point on the curve corresponds to the average biomass of sponge at each 5th percentile of fishing effort. **4.1.2.3.3b**. The area defined by the 5th percentile of fishing effort shown in beige, that is the area defined by the 5% of effort with the lowest pressure (unit area effort) and corresponds to where there is a greater potential risk of impact to sponge.



Figures 4.1.2.3.4a. Seapen biomass (kg/km^2) versus percentile fishing effort. Each point on the curve corresponds to the average biomass of seapen at each 5th percentile of fishing effort. **4.1.2.3.4b**. The area defined by the 20th percentile of fishing effort shown in beige, that is the area defined by the 20% of effort with the lowest pressure (unit area effort) and corresponds to where there is a greater potential risk of impact to sea pens.

The effort/biomass interaction analyses help to define the potential risk of SAI to sponge and seapen such that at relatively high levels of fishing effort (e.g>5th percentile for sponge and >20th percentile for seapen) there is a significant reduction in unit area biomass of sponge and seapen. Conversly, at areas of low fishing pressure (<5th percentile for sponge and <20th percentile for seapen) there is the potential for increased risk of SAI. The rapid decline in biomass for relatively small amounts of increasing fishing pressure effort is indicative of a low resilient ecosystem, for example if the benthos were able to recolonise and grow quickly following trawling impacts the biomass may be expected to be at higher levels for a lower level of fishing pressure. However, the response curves (rate of biomass decline with increasing fishing pressure) are notably different between the sponge and seapen VME indicator species. For example, the seapen biomass does not fall as sharply as the sponge biomass for a given amount of fishing effort. This is possibly indicative of the seapen having a higher resilience than sponge to the impacts of trawling, or it is because there is larger proportion of unimpacted seapen habitat in the active fishing fishing areas. The spatial extent of the increased area of risk and SAI outside of the closed areas, but within the active fishing footprint is therefore different for the sponge and seapen VME indicator species as shown in Figures 4.1.2.3.3b and 4.1.2.3.4b, respectively. The sponge appears to decline rapidly at about the 5th percentile, whereas seapen declines most markedly at about the 20th percentile. Antoehr, way of looking at the same data is from the perspective of defining areas of relatively low risk of SAI and these areas are defined by the top 95% and 80% of fishing activity, respectively for sponge and seapen. The low risk areas of SAI for sponge and seapen are are shown in Figures 4.1.2.3.5-6.

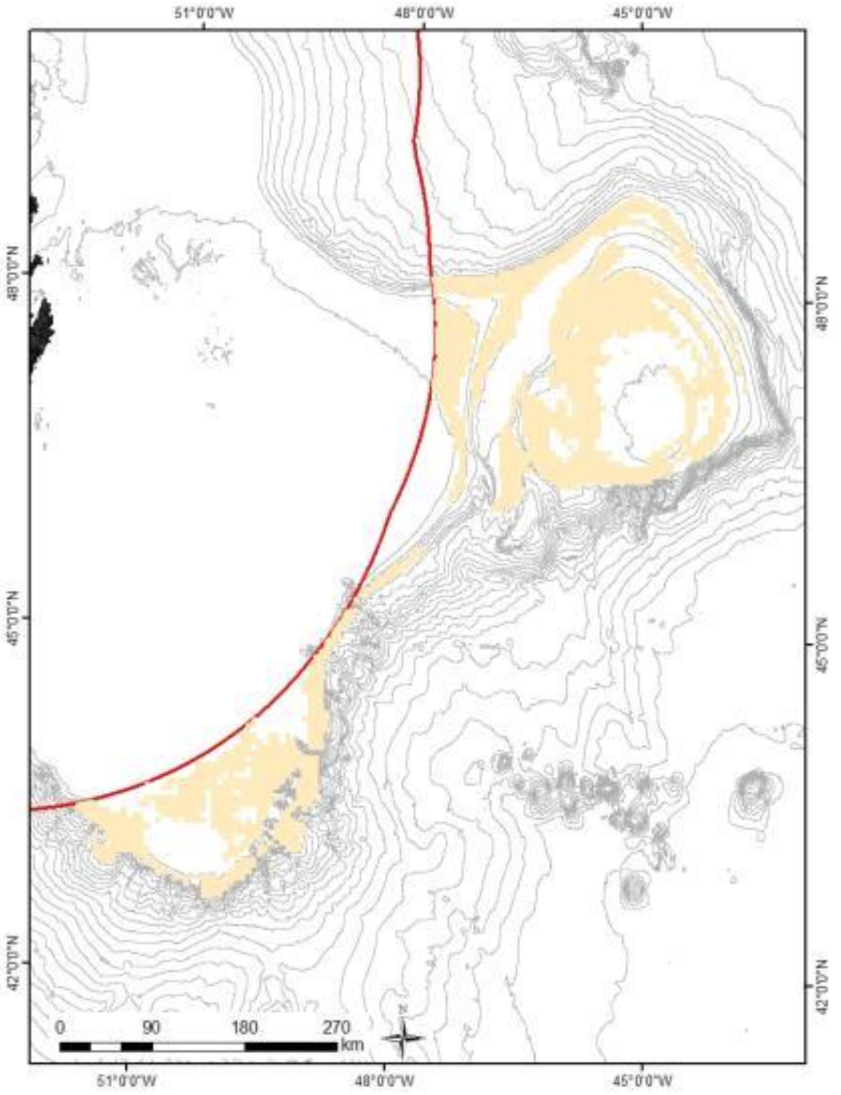


Figure 4.1.2.3.5: Area of low risk of sponge SAI. This area relates to the top 95% of all fishing effort inside the fishing footprint as determined from Figure 4.1.2.3.3.

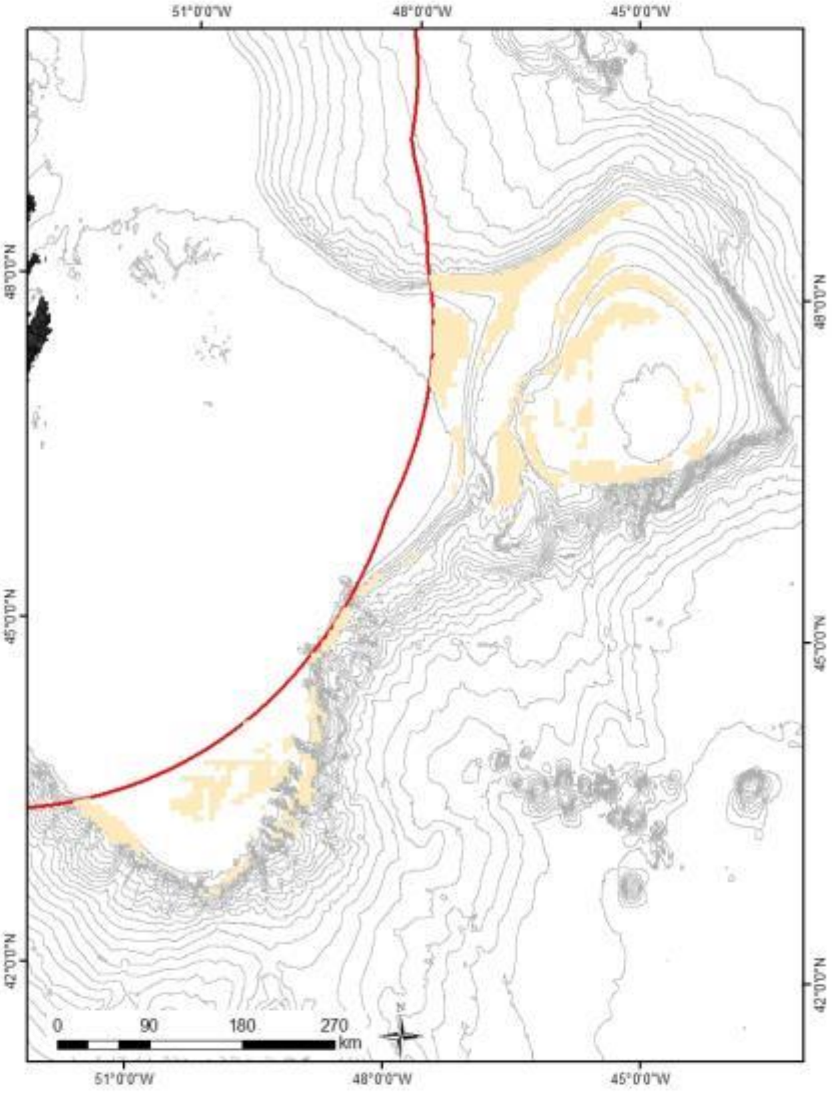


Figure 4.1.2.3.6: Area of low risk of seapen SAI. This area relates to the top 80% of all fishing effort in the fishing footprint as determined from Figure 4.1.2.3.4.

4.1.3 The development of SAI approaches (ongoing and future work – see ToR4.2)

4.1.3.1 Fishing effort VME indicator species biomass interactions

The biomass data used in this analysis is that derived from survey trawl data which is at best semi-quantitative and not site or necessarily habitat specific. In order to improve the accuracy and certaintly of the above approach, we intend to use box core species biomass data and images from underwater camera systems. Both methods of sampling the benthos are quantitative and when combined with site specific trawling intensity data (hrs/km^2) will provide the required quantitative certainy to estimate accurately SAI.

4.1.3.2. Predicting the potential loss of VME and VME indicator species due to fishing within the active fishing footprint

There is also the possibility of predicting the biomass of sponge and seapen in areas outside of current VME closures, both within and outside the fishing footprint using habitat suitability modeling techniques. Using such models to predict the presence of VME and VME indicator species can potentially provide an estimate of their loss due to fishing activities. They can also help to identify potential VME and VME indicator species in areas which have not yet been sampled.

Models have already been developed to predict sponge, seapen, large gorgonians and black corals in the NRA region, which are helping to refine our understanding of their distribution and likely extent, but to help us assess the SAI of fishing on VME indicator species within the active fishing footprint we need to develop models which explicitly take into account the fishing pressure. To achieve this we will need to develop species distribution models using data for which we know there has been little or no fishing impact during the last 7 years (2008 – 2013) using VMS data so as to compare with the observed biomass of VME indiocator species. Species distribution models are trained using physical habitat descriptors and species-specific absence/presence data to predict the probability of finding that species under a set of given environmental conditions.

Using VMS data it is possible to identify the regions of the NRA where little or no fishing has occurred. Figures 4.1.3.2.1 depicts the bottom 5th percentile of fishing effort. This area could be used to train a species distribution model such that any absences could be considered as an absence attributed to unfavorable habitat and not as a result of fishing activity. Taking into account the active fishing footprint in any model is clearly important when needing to assess the likely distribution and abundance of VME indicator species within the fishing footprint. These models would complement the models already developed and applied to predict VME using data from known VME closed areas in the NRA.

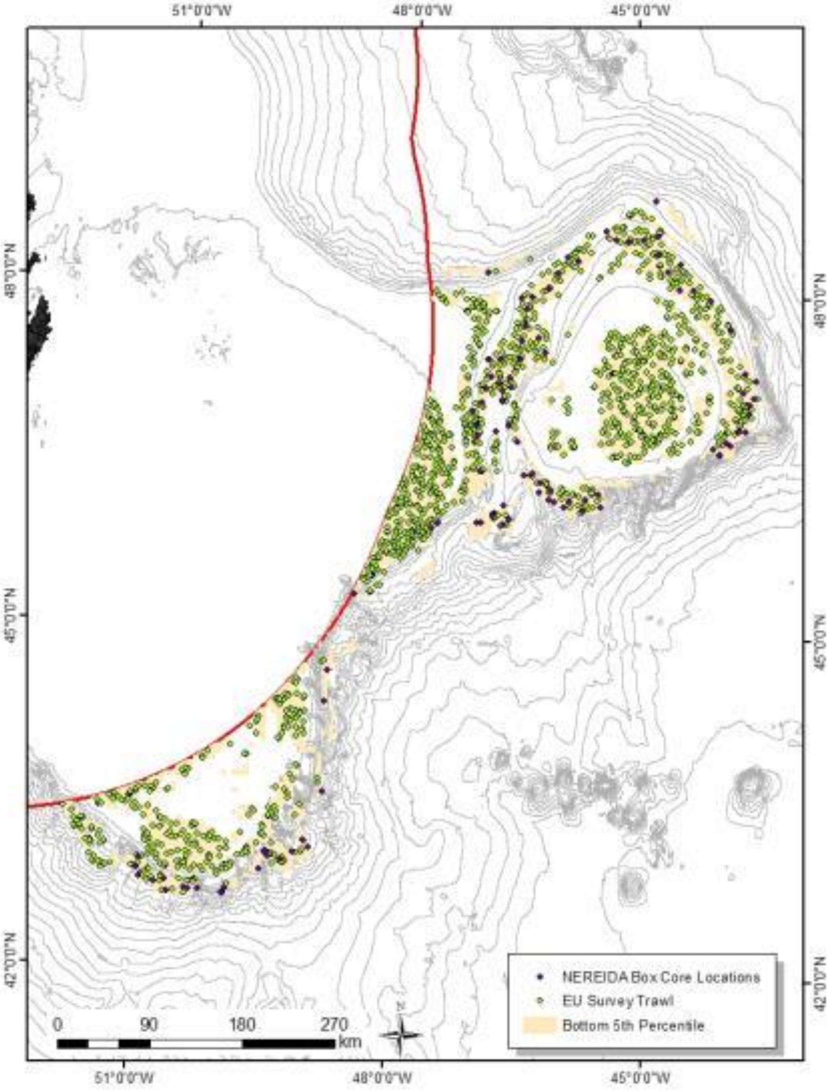


Figure 4.1.3.2.1. Map depicting the region of the bottom 5th percentile effort polygons outside of the closed areas, and also showing the trawl survey and NERIEDA box core sample locations for which VME indicator species biomass is known.

4.1.3.3 The proximity of fishing effort to VME

It has been suspected for some time that a lot of deep sea fishing effort in the NRA occurs in relatively close proximity to known VME (closed areas). It is therefore possible that VME provides some form of important function in supporting deep sea fish stocks. We therefore intend to explore the possible relationship between VME and its role as providing essential fish habitat. In essence to explore the concept that sustaining VME helps to sustain deep sea fish stock and therefore fisheries yield.

A preliminary analysis of the spatial relationship between fishing effort and its proximity to the closed areas was performed. This analysis examined how the VMS-derived fishing effort varied with changing distance from the closures. The ArcGIS ‘buffer’ function was used on the 2012 closure area polygons to create a surface depicting lines of equal distance from the closure areas at intervals of 1, 2, 3, 4, 5, 7.5, 10, 15, 20, 25, 50, 75 and, 100km (Figure 4.1.3.3.1).

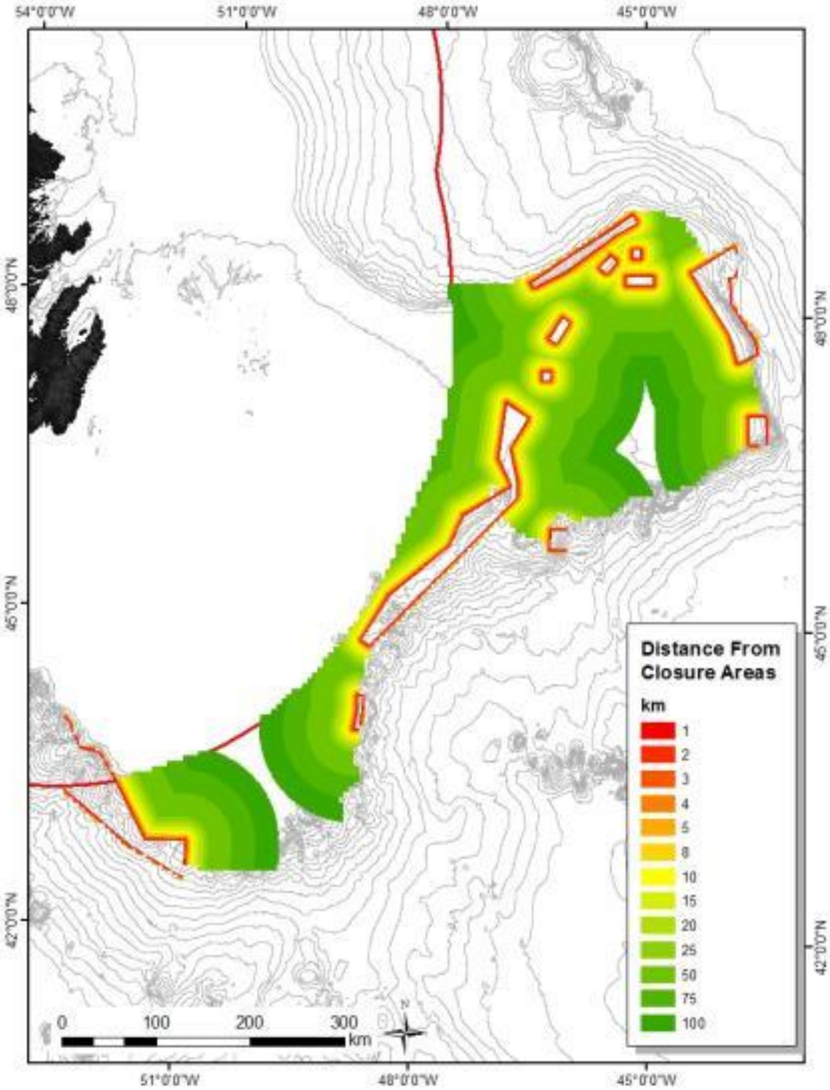


Figure 4.1.3.3.1: Distance isolines as created from the 2012 closure area polygons.

An ArcGIS spatial join was performed between the effort points and the distance-from-closures surface. This overlay determined into which of the distance zones each of the effort points fell and appended that value onto each of the point records (Figure 4.1.3.3.2). Using the calculated buffer zone values, average effort (hrs/km^2) was calculated for each of the distance zones between using the effort data collected between 2008 and 2012, as well as the five year effort average. Cumulative frequency curves were then developed using these data to visualize how fishing effort accumulated as distance from closure areas increased (Figure 4.1.3.2.3).

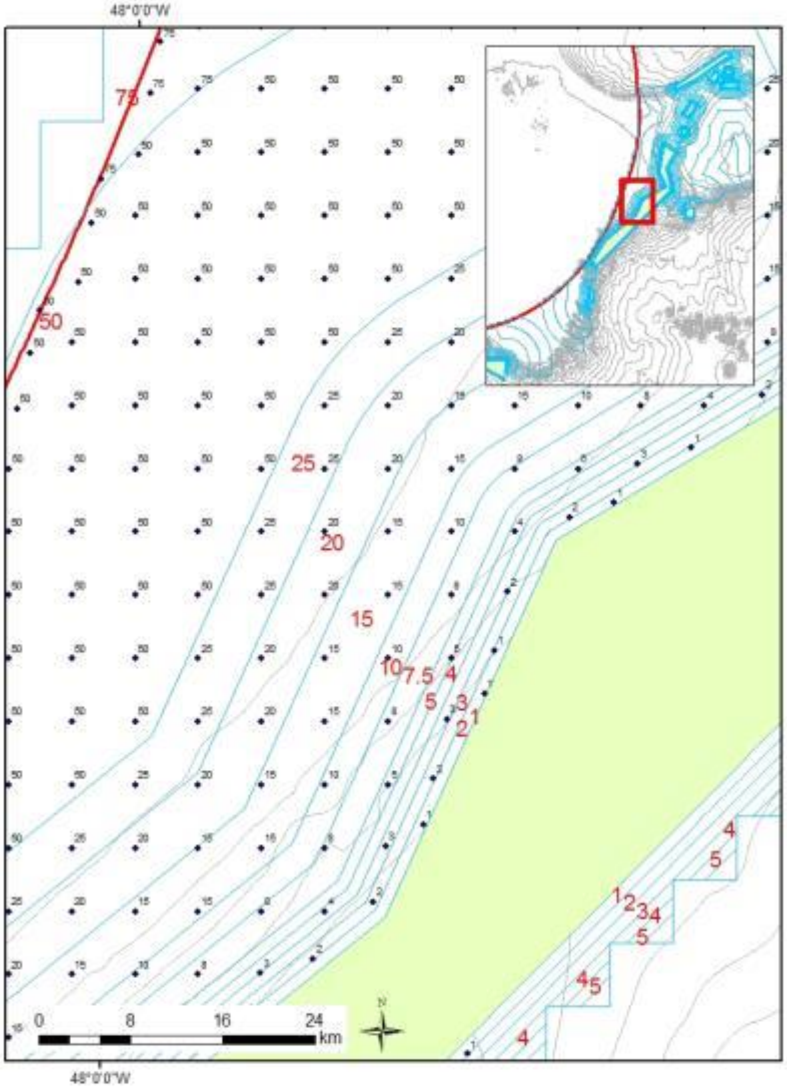


Figure 4.1.3.3.2: Subset of the distance-to-closures near the Flemish Pass. The red text indicates the distance to the closures. The points are the effort data with their associated distance zone as calculated through the spatial join.

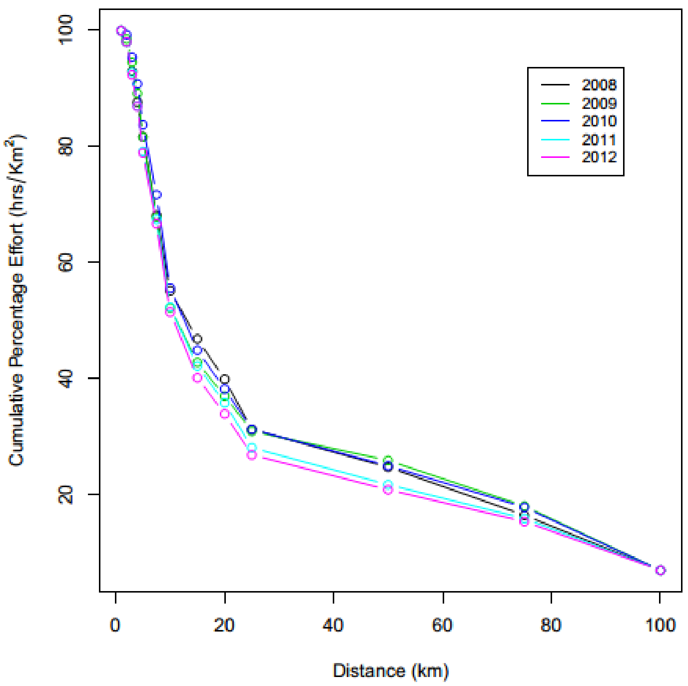


Figure 4.1.3.3.3: Cumulative fishing effort as a function of distance from VME closed areas (km).

Figure 4.1.3.3.3 indicates that about 50% of all the fishing effort occurs within a distance of about 10 km of VME closed areas which is slightly under the average distance for each trawl. Although this is not definitive evidence of the importance of VME in sustaining fish stocks, it does add weight to the need to better understand what is causing the association between fisheries and VME as shown in Figure 4.1.3.3.3.

Future analyses will include examining how other environmental or habitat descriptors vary with changing distance from the closures. This analysis could also be further refined by looking at the distribution of effort as it relates to different fisheries and utlising more quanititive data from video transects to observe how fish and their prey are using VME habitat. These analyses could help better understand what potentially is driving this relationship between fishing effort and VME.

ToR 4.2. [*Roadmap*]. Update workplan for the assessment of Significant Adverse Impacts on VMEs, towards the development of re-assessments of bottom fishing activities by 2016.

In 2012 WGESA was tasked by SC with drafting a workplan for the reassessment of NAFO fisheries in 2016. Specifically Scientific Council was requested by FC in 2012 to provide guidance to develop a workplan to achieve the reassessment of all NAFO fisheries by September 2016 and every 5 years thereafter, identifying the necessary steps to be taken, as well as the information and resources to do so.

The requirement for the assessment of bottom fishing activities in the NRA was broadly defined in the NAFO Conservation and Enforcement Measures (NAFO/FC Doc, 13/1), which set out a number of issues to be addressed by the assessment, *inter alia*?

1. Type(s) of fishing conducted or contemplated, including vessels and gear types, fishing areas, target and potential bycatch species, fishing effort levels and duration of fishing (harvesting plan);
2. Existing baseline information on the ecosystems, habitats and communities in the fishing area, against which future changes are to be compared;
3. Identification, description and mapping of VMEs known or likely to occur in the fishing area;
4. Identification, description and evaluation of the occurrence, scale and duration of likely impacts, including cumulative impacts of activities covered by the assessment on VMEs;
5. Consideration of VME elements known to occur in the fishing area;
6. Data and methods used to identify, describe and assess the impacts of the activity, the identification of gaps in knowledge, and an evaluation of uncertainties in the information presented in the assessment;
7. Risk assessment of likely impacts by the fishing operations to determine which impacts on VMEs are likely to be significant adverse impacts; and
8. The proposed mitigation and management measures to be used to prevent significant adverse impacts on VMEs, and the measures to be used to monitor effects of the fishing operations.

At the WGESA meeting in 2013 the plan was up-dated and specific leads were identified to progress the required fisheries assessment tasks. The plan also indicates how the assessment tasks relate to the FAO criteria for the assessment of SAI which are;

i. the intensity or severity of the impact at the specific site being affected;
ii. the spatial extent of the impact relative to the availability of the habitat type affected
iii. the sensitivity/vulnerability of the ecosystem to the impact;
iv. the ability of an ecosystem to recover from harm, and the rate of such recovery;
v. the extent to which ecosystem functions may be altered by the impact; and
vi. the timing and duration of the impact relative to the period in which a species needs the habitat during one or more of its life history stages

The workplan is shown in the table below:

No.	Fisheries Assessment Task	FAO Criteria	Approach	Lead
1	Type(s) of fishing conducted or contemplated, including vessels and gear types, fishing areas, target and potential bycatch species, fishing effort levels and duration of fishing (harvesting plan)	i	Information and data is required to describe the fleet activities spatially and temporally. This will require integrating VMS data with information on the fishery e.g. fleet register and catch. NAFO has the catch data for the different gear types/fisheries. It was agreed that WGESA will work with NAFO Secretariat to prepare a fisheries data table which can be integrated with the existing VMS data records. Additional long time-series catch/landings data will be summarised at the highest possible spatial resolution. The fisheries data table will be produced before WGESA 2014 and linked to the VMS data for the period 2008 – 2013.	WGESA with input from NAFO Secretariat for presentation and approval by SC and STACFIS in 2015.
2	Existing baseline information on the ecosystems, habitats and communities in the fishing area, against which future changes can be compared	i, ii, iii	The outcome of the “review of fisheries closures” should provide much of the seabed habitat data necessary to address this task. Additional spatial data from the AZMP ecoregion analysis should be integrated with the detailed habitat maps within the NRA to provide broad-scale spatial context. For the NRA as a region. Also analyse the environmental data from the NRA used as part of the habitat suitability modelling so as to assess possible dominant fisheries habitat associations. Time series analysis of the oceanography is required, e.g. long-term changes in production potential, SST, etc. This should include the work of STACFEN in relation to assessing the long-term physical oceanography. The data sources (above) will be identified and collated and a summary meta-data table compiled for presentation at WGESA 2014.	WGESA with input from AZMP and STACFEN, for presentation and approval by SC and STACFEN in 2015.

No.	Fisheries Assessment Task	FAO Criteria	Approach	Lead
3	Identification, description and mapping of VMEs known or likely to occur in the fishing area	iii	The outcome of the "review of fisheries closures" should provide much (if not all) of the necessary information. In addition further work to develop habitat suitability models for VME in the NRA will be useful. E.g. for VME indicator species or assemblages of VME indicator species. At the WGESA meeting in 2014 a plan of what additional information should or could be included in the assessment should be made.	SC WGESA
4	Identification, description and evaluation of the occurrence, scale and duration of likely impacts, including cumulative impacts of activities covered by the assessment on VMEs	i, ii	The work undertaken to address FC Request 16 (2012) and FC Request 12 (2013) by Scientific Council contributes to this task. We interpret this as the impact of the fishery on VME's. We have started to integrate the fishing effort layers (2008 – 2012) with known and predicted VME (from the review) to show which areas (that correspond to a certain level of fishing effort) are at risk of SAI as they are not part of current closed areas.	SC WGESA
5	Consideration of VME elements known to occur in the fishing area	iii	The outcome of the "review of fisheries closures" should provide much (if not all) of the necessary information. An evaluation of the VME elements in relation to their potential to support VME indicator species should be investigated, possibly using model output – this needs to be considered and developed at WGESA 2014.	SC WGESA
6	Data and methods used to identify, describe and assess the impacts of the activity, the identification of gaps in knowledge, and an evaluation of uncertainties in the information presented in the assessment;	N/A	To be done in due course	SC WGESA

No.	Fisheries Assessment Task	FAO Criteria	Approach	Lead
7	Risk assessment of likely impacts by the fishing operations to determine which impacts on VMEs are likely to be significant adverse impacts	ii, iii, iv, v	The work undertaken to address FC Request 16 (2012) and FC Request 12 (2013) by Scientific Council contributes to this task. The development of a risk assessment framework to be planned at WGESA 2014. We have started to integrate the fishing effort layers (2008 – 2012) with combined VME species biomass layers (2005 – 2013) to show which areas (that correspond to a certain level of fishing effort) are at greater risk of fishing impact. Further work is required to model the biomass of VME species whose presence is predicted at levels below VME thresholds. The predicted biomass can then be compared to observed biomass values in areas of fishing activity. This difference can be used to assess the potential for SAI outside closed areas. Furthermore, a method for assessing the resilience of the VME indicator taxa from a combination of fishing pressure and biomass for the same assemblage should be explored – this should be initiated at WGESA 2014. Finally, function can be inferred by examining the proximity of fishing effort (percentiles) to known VME, e.g. more effort (by fleet sector) near to VME. In addition, an assessment of the long-time series of catches (over several decades) in relation to predicted VME extent could be examined . Use of available commercial fishing data on by-catch could also be useful for validating model results.	SC WGESA

No.	Fisheries Assessment Task	FAO Criteria	Approach	Lead
8	The proposed mitigation and management measures to be used to prevent significant adverse impacts on VMEs, and the measures to be used to monitor effects of the fishing operations	N/A	To be done in due course WGESA should provide some possible options at WGESA 2015	Joint FC/SC Working Group on Ecosystem Approach Framework to Fisheries Management

References for ToR 4

Boutillier, J., Masson, D., Fain, I., Conway, K., Lintern, G, O, M., Davies, S., Mahaux, P., Olsen, N., Nguyen, H. and Rutherford, K. 2013. The extent and nature of exposure to fishery induced remobilized sediment on the Hecate Strait and Queen Charlotte Sound glass sponge reef. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/075. viii + 76 p.

Other matters

Update on the ICES Working Group on the Northwest Atlantic Regional Sea (WGNARS)

The long-term objective of the ICES Working Group on the Northwest Atlantic Regional Sea (WGNARS) is to develop the scientific support for Integrated Ecosystem Assessments (IEAs) in the Northwest Atlantic region to support ecosystem approaches to science and management. IEA is "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), in other words, a process to link science to ecosystem-based management decisions. The group's work is organized around the elements of the Levin et al. 2009 IEA framework, including identifying ecosystem management objectives and threats to achieving them, developing ecosystem indicators and targets, risk analysis, assessment of ecosystem status, management strategy evaluation, and monitoring. The WGNARS region extends from the Labrador Shelf to the Mid Atlantic Bight, a geographically extensive but interconnected system that falls under the ecosystem management jurisdictions of four Fisheries and Oceans Canada regions and the NOAA US Northeast Shelf region. The group provides coordination on IEA methods across the region and on NW-Atlantic-scale processes acting across ecoregions, including sharing expertise developed from projects funded in the sub-regions.

The national policy contexts for ecosystem management differ in the US and Canada, but in both nations policy and governance for Ecosystem Approach to Management (EAM) or Integrated Ocean Management (IOM) are not fully implemented. In light of this uncertainty, a critical element of WGNARS work is to build relationships with policy-makers and integrated ocean management practitioners and develop a dialogue as EAM implementation progresses, to make the group's work useful for decision-making. This challenge contrasts with the more clearly defined governance context for an Ecosystem Approach to Fisheries Management in Nafo, a regional fisheries management organization. As part of the ICES Scientific Steering Group on Regional Seas Programs, WGNARS can also find guidance through analogous work by other ICES regional seas working groups.

WGNARS will develop supporting methodology for EAM/IOM by working through pilot examples of how limited IEAs would be implemented in selected regions. In 2013, WGNARS focused on identifying how ecosystem objectives are defined in the context of EAM in the US and Canada, risk assessment methodology and an example risk assessment exercise, and an indicator performance evaluation exercise. The group's multiannual terms of reference for 2014 to 2016 address additional elements required to work through an example IEA process to explore the trade-offs and implications of different management strategies surrounding competing objectives.

High-level conservation objectives are guided by law, international commitments, and national and regional policies, but economic and social objectives are usually less explicitly defined. Two challenges for the group are to unpack high-level objectives to define operational objectives for target regions and to identify relevant economic and social objectives in the context of an example IEA. Unpacking operational objectives should include formal consultation process with input from stakeholders, management and science, but in the absence of a formal process, WGNARS will to identify an set of operation objectives. The status of the operational objectives for ecosystem state is evaluated based on indicators and reference points. A method for identifying indicators thresholds in response drivers was presented at the 2014 meeting. This method uses Generalized Additive Models (GAMs) to identify thresholds in response to one driver and Dynamic Factor Analysis (DFA) for multiple drivers. Indicator thresholds can be used to develop control rules that can be tested in ecosystem modeling simulations of management strategies. Risk assessment will be a critical component for IEA and integrated ocean management to prioritize activities and information needs required for management. A review of risk assessment methodologies identified many well developed standard methods that can be applied to IEA by the group, and the working session identified many of the challenges in applying them.

Reference

Levin PS, Fogarty MJ, Murawski SA, Fluharty D (2009) Integrated Ecosystem Assessments: Developing the Scientific Basis for Ecosystem-Based Management of the Ocean. PLoS Biol 7(1): e1000014. doi:10.1371/journal.pbio.1000014

Documents reviewed and/or produced during this meeting

From the work presented and discussed at this meeting, WGESA reviewed and endorsed the following to be produced as SCR documents:

Koen-Alonso M, M Fogarty, P Pepin, K Hyde, and R Gamble. Ecosystem production potential in the Northwest Atlantic. NAFO SCR 13/075, Serial No: 6273

Beazley LI, LJ Anstey, and ER Kenchington. Summary of the location of VME indicators on the Flemish Cap slope based on in situ benthic imagery analysis. NAFO SCR 13/076, Serial No: N6274

González-Iglesias C, FJ Murillo, V Wareham, M Sacau, and E Román. New data on deep-water corals and large sponges from bottom trawl groundfish surveys in the NAFO Regulatory Area (Divs. 3LMNO): 2011-2013 period. NAFO SCR 13/077, Serial No: N6275

Knudby A, C Lirette, E Kenchington, and FJ Murillo. Species distribution models of black corals, large gorgonian corals, and sea pens in the NAFO Regulatory Area. NAFO SCR 13/078, Serial No: N6276

Place and date for next meeting

It was proposed that the 7th WGESA meeting to take place in November 18-27, 2014 at the NAFO Secretariat in Dartmouth, Canada.

Proposed Terms of Reference for the 7th SC WGESA Meeting

In the context of SC WGESA long-term terms of reference, the topics proposed as specific ToRs for the next WGESA meeting are indicated below. These topics were selected taking into consideration the assessments of bottom fishing activities scheduled for 2016, as well as the continuous development of the Roadmap.

Theme 1: Spatial considerations

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

- Update on VME data analyses and VME distribution analyses in relation to ecoregions and VME elements

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

- Final results on integrated Northwest Atlantic ecoregions analysis

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.

- Analysis on benthic communities in Flemish Cap and NL
- Progress on multispecies and ecosystem production potential modelling

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.

- Work towards the development of assessments of bottom fishing activities (e.g. distribution modelling, classification of fisheries, ecosystem background, template for risk analysis, and advance on assessment of significant adverse impacts on VMEs).

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

- There is no specific topic identified under this ToR.

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.

At the present time resources are constrained, and unfortunately, stable partipation in WGESA work and meetings is expected to decrease. FC Requests from the NAFO September 2014 Annual meeting could only be addressed at the WGESA November 2014 meeting if they involve matters of clarification and/or require relatively modest efforts. Existing WGESA capacity is effectively fully committed to the advancement of the Roadmap and the work towards the assessment of bottom fishing activities by 2016. Addressing any additional major request during the November 2014 WGESA meeting would have a direct impact on the WG ability to deliver on its current commitments within the expected timeframes.

Annex 1. Stable Long-Term Themes and Terms of Reference (ToR) for the NAFO SC Working Group on Ecosystem Science and Assessment (WGESA)

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.

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