Northwest Atlantic Fisheries Organization

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SC WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT – NOVEMBER 2014

Report of the 7th Meeting of the NAFO Scientific Council (SC) Working Group on Ecosystem Science and Assessment (WGESA) [Formerly SC WGEAFM]

NAFO Headquarters, Dartmouth, NS, Canada
18- 27 November 2014

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Report of the SC Working Group on Ecosystem Science and Assessment

18-27 November 2014

Introduction

The NAFO SC Working Group on Ecosystem Science and Assessment (WGESA), formerly known as SC Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM), had its 7th meeting on 18-27 November 2014 at the NAFO Headquarters, Dartmouth, NS, Canada.

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

a) work intended to advance the "Roadmap for the development of an ecosystem approach to fisheries (EAF) for NAFO" ("Roadmap" for short, see Annex 1 for a summary of the current Roadmap structure).

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

The overall activities of WGESA are guided by a set of long-term Terms of Reference (ToRs) (Annex 2); at each meeting the work is focused on specific topics that fall under these long-term ToRs. These topics are selected on the basis of the overall state of progress of the different Roadmap components, the feedback required by SC on ecosystem-related issues, and the Requests made by FC and/or the FC/SC Working Groups to SC.

During its June 2014 meeting, SC approved the following ToRs as focus for the 7th WGESA meeting:

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.

- Update of the NAFO Guide of the Identification of Vulnerable Marine Ecosystem (VME) indicator taxa.

During the NAFO Annual General Meeting in September 2014, FC made a number of requests for scientific advice to SC. Among these FC Requests, the following ones were identified by the SC Chair and SC WGESA Co-chairs as requests for which WGESA could provide specific input to be used by SC in the elaboration of its response.

> **FC Request #4**. 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 #11. The NAFO 2011 Performance Review Panel encouraged NAFO to consider whether activities other than fishing in the NAFO Convention Area may impact the stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area. Such activities might include oil exploration, shipping and recreational activities. Some work has been carried out as part of the ecosystem approach.

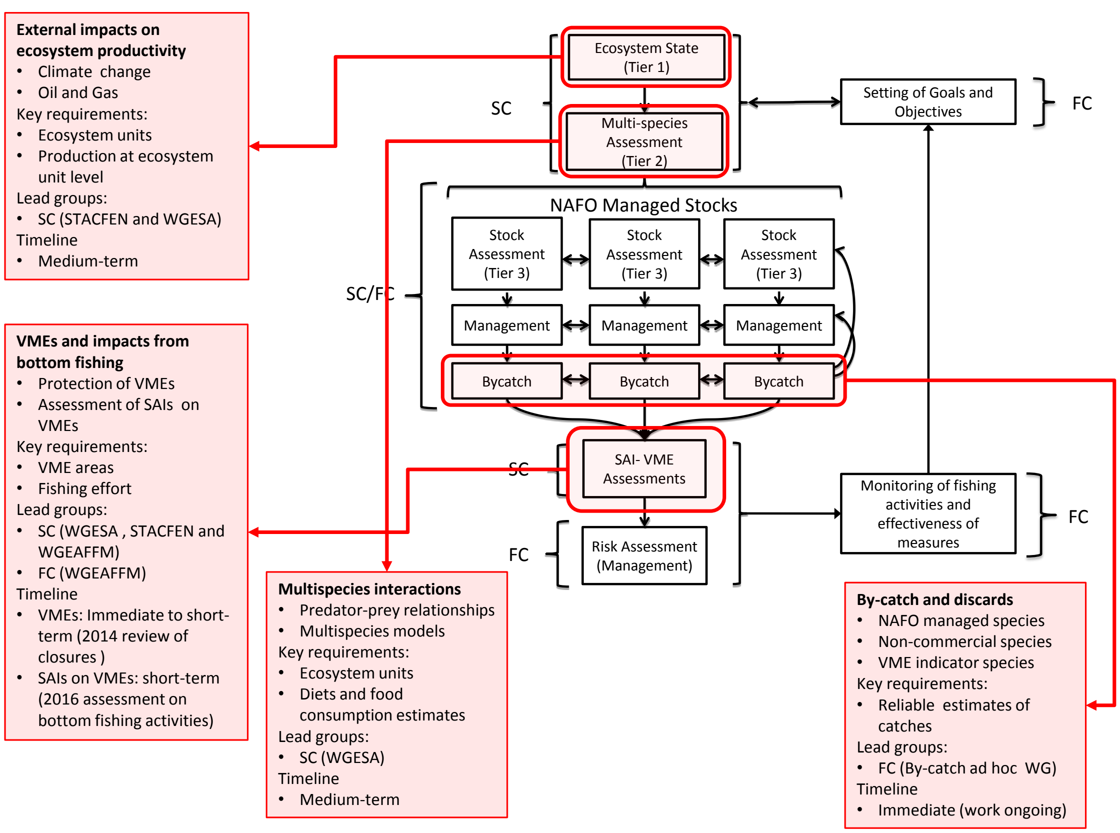
As the first step in the assessment of such impacts and for the implementation of the priorities of the Ecosystem Roadmap, could the Scientific Council provide a literature survey that would indicate what the risks are to the fish stocks and ecosystems in the NAFO Regulatory Area by looking at comparable situations.

FC Request #12. The Fisheries Commission requests the Scientific Council to evaluate the impact of mid-water trawls on VME indicator species in those instances when the gear makes contact with or is lost on the bottom.

In addition to the above FC Requests, there are number of recommendations from SC-FC Working groups to SC that WGESA should also take into account. Among all these recommendations, those from the FC/SC Working Group on the Ecosystem Approach Framework to Fisheries Management (WGEAFFM) are the ones that could affect WGESA work more closely (NAFO FC/SC Doc 14/03). These recommendations were approved by FC during the NAFO AGM meeting in September 2014, and include topics like:

- That the FC and SC support continuing analysis on VMEs in areas on the Tail of the Grand Bank (Div. 3O closure and related areas), and on the Eastern Flemish Cap (candidate areas 13 and 14).

- In the context of the development and implementation of the Roadmap, that priority attention by FC and SC and their constituent bodies be given to the components highlighted in the following figure:



- That the SC provide annual updates to the FC-SC WGEAFFM pertaining to the 2016 review of significant adverse impacts of NAFO bottom fisheries on VMEs in the NRA.

Terms of Reference for the 7th NAFO SC WGESA meeting

Taking into account the ToR topics approved by SC in June 2014, the relevant FC Requests from the NAFO AGM September 2014, the recommendations from FC/SC WGEAFFM, and topics added while discussing the ToRs at the beginning of the NAFO SC WGESA 7th meeting, the final set of ToRs addressed by WGESA at its 7th meeting were:

Theme 1: Spatial considerations

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

> **ToR 1.1.** 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.

> **ToR 2.1.** 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.

> **ToR 3.1.** Analysis on benthic communities in Flemish Cap and NL

> **ToR 3.2.** Progress on expanded single species, multispecies and ecosystem production potential modelling

> **ToR 3.3.** Progress on multispecies and ecosystem analyses

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 #4]*** 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 4.2.** ***[FC Request #11]*** Review of existing information on the potential impacts of activities other than fishing (e.g. oil and gas, shipping, recreation), and the risks they may pose, for the stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area.

> **ToR 4.3.** ***[FC Request #12]*** Review of information and analyses on the impact of mid-water trawls on VME indicator species in those instances when the gear makes contact with or is lost on the bottom.

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

> **ToR 5.1.** Update of the NAFO Guide of the Identification of Vulnerable Marine Ecosystem (VME) indicator taxa.

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.

> **ToR 6.1**. Evaluation of Research Vessel (RV) surveys footprint on VME closures.

Theme 1: Spatial considerations

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

ToR 1.1. Update on VME data analyses and VME distribution analyses in relation to ecoregions and VME elements.

ToR 1.1.1. Results from box-core analyses from NEREIDA project

The following section provides an account of the findings from the analysis of biological and environmental datasets extracted from box-core samples collected by the NEREIDA project in support of identifying or confirming known areas of VME.

1.1.1.1. Methods

Many of the datasets used in the present investigation have been acquired or generated under the auspices of other projects, however, it is felt important that a brief account of how such datasets were created should be presented here.

1.1.1.1.1. Sample collection

The NEREIDA data collection programme comprised two, three-month long research cruises conduced between May and July of 2009 and 2010, aboard the Spanish research vessel *Miguel Oliver*. In 2009, surveys were conducted to the east, north and west of the Flemish Cap, whereas in 2010, surveys covered the area south of the Flemish Cap and along the slope or 'tail' of the Grand Banks of Newfoundland.

Several sampling and data collection methods were employed during the NEREIDA cruises, including 100% coverage multibeam bathymetry, seismic sub-bottom profile boomer, regular CTD dips (to measure chlorophyll, temperature and salinity at all depths throughout the water column), and rock-dredge and box-core deployments (to collect epifauna, infauna and sediment samples). More detail is provided on those methods most relevant to the present investigation.

1.1.1.1.2. Biological data acquisition

A mega box-core sampler (0.25 m^{-2} sampling area) was deployed over 370 times during the NEREIDA surveys, although not all of them were successful for the extraction of all intended data types (surface fauna, sediment and stratigraphy samples, infauna). Upon recovery of the box-core, a photograph was taken of the sample surface. If the sample integrity was not compromised during recovery (through sediment wash-out or slumping), measurements of surface sediment temperature and depth of redox boundary were taken. In addition, subsamples of sediment were removed for later stratigraphic and particle size distribution analyses. Lastly, after the removal and cataloguing of large conspicuous organisms from the sample surface, infauna were extracted from the sediment by washing the top 5 cm of sediment over a 0.5 mm mesh sieve, and the retained material stored in buffered 4% formaldehyde solution. The remaining sediment was also washed over a 0.5 mm mesh sieve and the retained material preserved separately.

Samples of the top 5 cm of the box-core sediment were processed by separating the organisms from any retained inorganic material, and the identification of all organisms to morphotaxa (i.e., the identity of the organism most evident without having to refer to the formal taxonomic literature). This approach was favoured over a more formal and detailed identification protocol because of the large volume of samples to process, the taxonomic variety of organism likely to be encountered, and the desire for a rapid assessment of all the material within the available time and budget. Once identified, each organism was blotted, weighed and preserved in 70% industrial methylated spirit (IMS). On completion, a taxon-by-sample matrix of wet-weight biomass was produced, ready for analysis. In a parallel exercise, photographs of the intact box-core sample surface were also processed by inspecting each photograph in detail, identifying and recording all organisms and features observed. This also resulted in a taxon-by-sample matrix, although not all taxa observed were identified beyond the level of phylum or morphotype.

1.1.1.1.3. Environmental data acquisition

1.1.1.1.3.1. Direct measurement

Measurements of several physical and environmental variables were taken during the NEREIDA surveys, including water depth at each sampling location, surface water temperature, seabed sediment temperature (upon retrieval of the box-core sample), as well as the deployment of a CTD sensor. Sediment characteristics were derived from the analysis of particle size distribution analyses and the measurement of organic and inorganic carbon content.

1.1.1.1.3.2. Modelled data

The data acquired from the NEREIDA multibeam echosounder survey were processed using ArcGIS to derive several attributes of the seabed, including a continuous bathymetry layer, seabed slope, aspect, rugosity and roughness.

Environmental data recorded by the CTD deployments, direct measurements from the box-core surface, together with existing oceanographic data, were integrated and standardised to a common spatial resolution and layers produced for maximum, minimum and mean bottom surface temperature, and maximum, minimum and mean bottom current speed. A measure of fishing effort per unit area within the NRA was derived from VMS values (2008-2013) and expressed as the number of trawl lines within a radius of 200 m of a box-core sampling location (VMS 200).

1.1.1.1.4. Data analyses

Total and log-transformed biomass records per box-core, together with those belonging to each constituent taxon, have been compared statistically between different sample treatments using a General Linear Model ANOVA test. Treatments included whether the samples fell inside or outside the defined fishing footprint, as well as within areas identified as having incremental levels of fishing intensity. Taxa have also been categorised according to whether they are considered indicative of VME or not, and comparative tests repeated using each category of taxa.

Multivariate analyses on log-transformed taxon-per-sample matrices were performed to explore pattern in benthic assemblage structure within the dataset. Taxa recorded from each of the box-core surface photographs were also analysed, using presence/absence data. In addition, normalised environmental variables per box-core were analysed to ascertain which variables, in isolation or in combination, exerted the most influence on any observed pattern in the distribution of the benthic faunal assemblage. Multivariate analyses included selected routines within the PRIMER software package (Clarke and Gorley, 2006). The spatial distribution of results from all analyses were visualised by projecting them onto maps using ArcGIS 10.1.

1.1.1.2. Results

1.1.1.2.1. Modelled physical, oceanographic, and environmental data layers

Bathymetry data acquired using a multibeam echosounder have been gridded to a cell size of 75 x 75 m, followed by the application of a 5-cell neighbourhood mean filter to remove small scale artefacts introduced by the gridding process. Gridded bathymetry data have subsequently been used to calculate a number of proxy topographic derivatives, such as slope, roughness (3-cell neighbourhood), rugosity (5-cell neighbourhood), eastness, northness, and a suite of benthic position index values encompassing several different numbers of neighbouring cells (BPI100, BPI25, BPI50, BPI75).

Layers for the percentage of clay, silt, sand, total carbon and organic carbon in the sediment were created at 75 x 75 m grid resolution using data from box-core sediment samples and a universal kriging function. Bathymetry, BPI150 and roughness were used as covariants, as the method accounts for the correlation between substrate and bathymetry whilst using interpolation on the residual deviance to infer autocorrelated spatial structure.

Modelled oceanographic data – monthly bottom temperature and bottom flow velocity values at 1/12 degree resolution from 1990 to 2010 – were used to create layers of mean annual minimum, overall and maximum bottom temperature values, and maximum and mean current velocity values. Each layer was interpolated to the chosen 75 x 75 m grid resolution using the empirical Bayesian kriging function to match the other data layers.

Lastly, a proxy of fishing intensity was created by calculating trawling line density (derived from VMS ping data from 2008-2010) inside a 2 km radius for each 75 x 75 m grid cell in the study area. Trawling intensity was further categorised into percentiles at incremental 5% intervals.

The resulting data layers for all of the above analyses are presented where relevant in the ensuing analyses.

1.1.1.2.2. Distribution of surface-dwelling organisms

The distribution of surface-dwelling organisms throughout the area of study was assessed using data extracted from the box-core surface photographs. The mean number of taxa per sample falling outside the fishing footprint was significantly greater (mean ± 95% CI = 2.8 ± 0.4) than that of samples falling inside the fishing footprint (1.9 ± 0.2).

Multivariate analyses revealed several statistically distinct surface-dwelling faunal assemblages represented by varying numbers of samples (distinct assemblages labelled a to ag). Several of the identified assemblages were characterised by VME indicative taxa (Figure 1.1.1.1). The assemblage containing the largest number of taxa also contained large sponges on the surface (assemblage ag; large red squares in Figure 1.1.1.1). Most of the samples representing assemblage ag, and most of those representing other assemblages containing VME indicative taxa, fell outside of the fishing footprint.

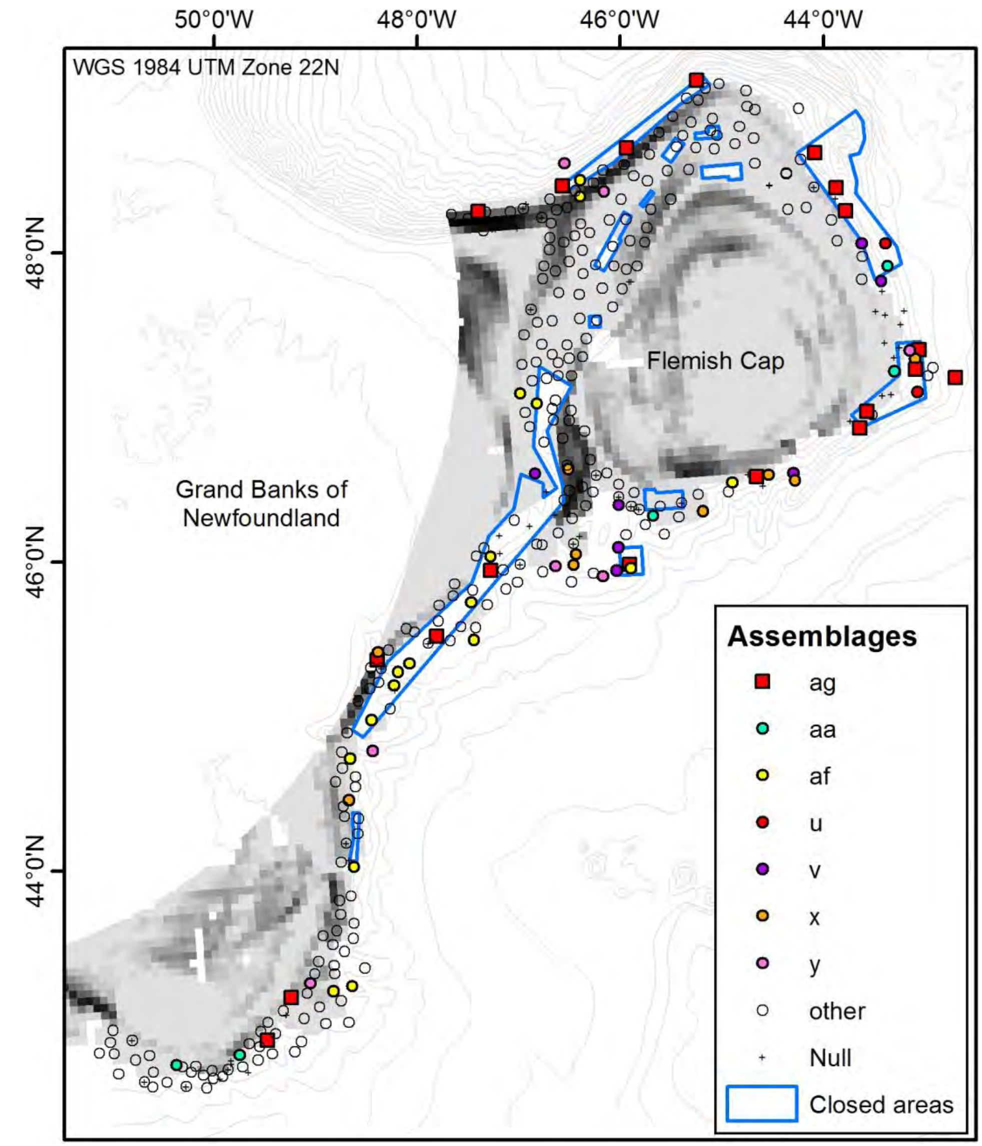


Figure 1.1.1.1. Distribution of assemblages containing VME indicative taxa (coloured symbols) identified from the analysis of surface-dwelling taxa observed on box-core surface photographs. Gradations of grey in background represent fishing effort intensity.

1.1.1.2.3. Distribution of Sediment-dwelling Organisms

The box-core sampler targets primarily infauna, small organisms that live within the sediment, and is not expected to sample effectively the diversity or abundance of large, surface-dwelling organisms such as sponges and larger, more motile echinoderms such as starfish, urchins, brittle stars and sea cucumbers. Despite its relative ineffectiveness at sampling these larger organism, those that were captured by the box-core have been retained in the present analyses, as they represent the whole assemblage present at the point of sampling. In addition, all the analyses conducted on the entire dataset extracted from the box-cores have also been conducted on two subsets of the whole dataset: (i) taxa considered indicative of VME – mostly larger, surface-dwelling organisms such as sponges and sea pens, and (ii) all other taxa not considered indicative of VME (hereafter referred to as nVME taxa).

Wet-weight measurements per taxon per sample were transformed (log X+1) prior to analyses, to remove the influence of the larger bodied organisms on whole faunal assemblage discrimination. Mean faunal biomass per sample was not significantly different between samples falling inside and outside the fishing footprint. Biomass of VME indicative taxa was significantly higher in samples falling outside than inside the fishing footprint, whereas biomass of nVME taxa was slightly higher inside than outside the fishing footprint, but not significantly so (Figure 1.1.1.2).

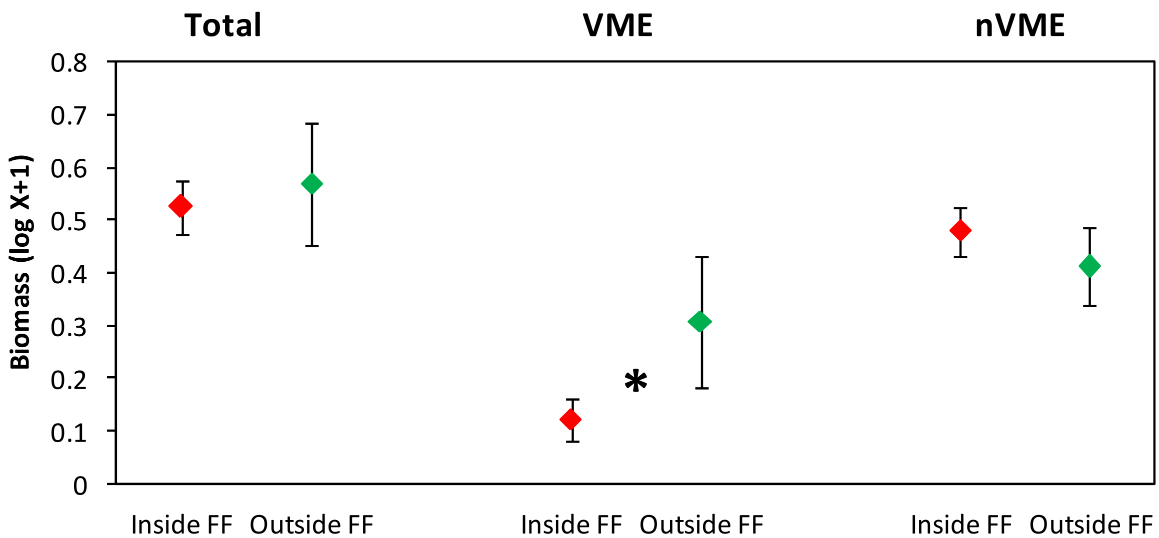


Figure 1.1.1.2. Difference in mean biomass (log transformed) per sample between samples falling inside and outside the fishing footprint (FF) for various subsets of the data (total dataset, VME indicative taxa only, and nVME taxa only). Asterisk denotes a statistically significant difference.

When the whole dataset was broken down by taxon, the mean biomass per sample of sponges (Porifera), brittle stars (Ophiuroidea) and peanut worms (Sipuncula) was significantly higher outside the fishing footprint than inside, and conversely, that of the bristle worms (Annelida) and bivalve molluscs (Bivalvia) was significantly higher inside the fishing footprint than outside. No other taxa showed a significant difference in their biomass distribution between inside and outside the fishing footprint.

The distribution of biomass across areas of increasing fishing intensity has been explored using a main effects plot followed by plotting the mean biomass of selected taxa against incremental values of fishing intensity (Figure 1.1.1.3). The mean raw (untransformed) biomass across all samples falling outside of the fishing footprint, where fishing intensity is zero, was 34.2 g. This was far above the mean raw biomass value for all samples (6.4 g). Most mean raw biomass records from samples representing areas with some level of fishing intensity fell below the overall average (Figure 1.1.1.3, top). Two notable exceptions were the peaks in mean biomass observed in the 35-40 percentile and in the 55-60 percentile fishing intensity areas. The first was caused by the increased occurrence of sea pens and soft corals (Octocoralia) and bivalve molluscs (Figure 1.1.1.3, middle and bottom); the second peak was caused by an increase of bivalves and bristle worms in those samples (Figure 1.1.1.3, bottom). There is a suggestion in the plots of Figure 1.1.1.3 that as fishing intensity increases (from left to right), the tolerance of VME indicative taxa to disturbance decreases, and only those taxa less affected by disturbance, such as nVME taxa, can continue to flourish.

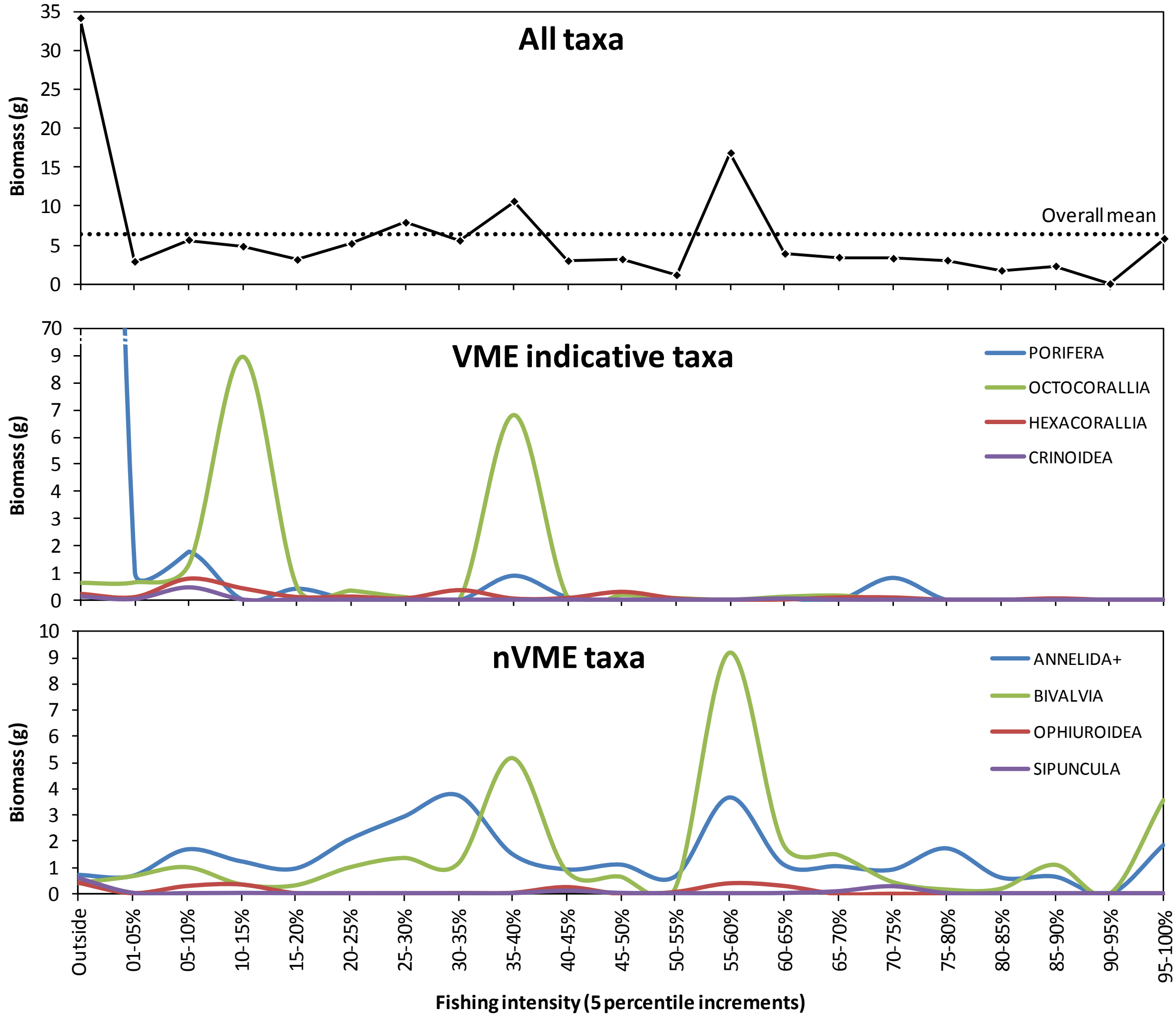


Figure 1.1.1.3. Top: Main effects plot of mean faunal biomass per sample against increasing levels of fishing intensity. Middle and Bottom: Mean biomass per sample of selected taxa representing VME and nVME indicative taxa, respectively.

Multivariate analysis of the log-transformed biomass per sample data revealed 10 distinct infaunal assemblages (labelled a to j). The faunal composition of each assemblage is presented in Table 1.1.1.1. Assemblages d, e and j contained the highest proportion of VME indicative taxa and had a relatively high number of total taxa despite the relatively few samples representing each assemblage (14, 7, and 2, respectively). Assemblage d was the one characterised by the large surface-dwelling sponges. The distribution of these assemblages characterised by a high proportion of VME indicative taxa was restricted mostly to areas outside of the fishing footprint (Figure 1.1.1.4).

Table 1.1.1.1. Relative contribution of each taxon to each of the 10 distinct assemblages identified through multivariate analysis of log-transformed biomass per sample data. VME indicative taxa in red font. Cell shading from red (high) to yellow (medium) to green (low).

	Assemblage									
Taxa	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**
ANNELIDA+	0.01	0.01	0.24	0.57	1.09	0.37	0.69	0.15	2.18	0.15
PORIFERA				3.52	0.74		0.02	0.04	0.27	0.22
CNIDARIA other				0.02	0.11		0.03		3.86	
ASTEROIDEA			4							
OCTOCORALLIA					2.14	0.54	0.04			0.06
BIVALVIA			0.1	0.28	0.55	0.07	0.49	0.04	0.49	
OPHIUROIDEA	0.04		0.99	0.4	0.16	0.04	0.07	0.03	0.12	0.05
HEXACORALLIA		0.02	0.07	0.01	0.05	0.09	0.11	0.03	0.37	0.97
MOLLUSCA other	0.93		0.01		0.35		0.01		0.18	
SIPUNCULA			0.17	0.01	0.33	0.14	0.01	0.01	0.3	0.03
CHORDATA				0.57			0.02	0.02	0.01	
BRYO/HYDROZOA	0.06			0.02	0.25		0.01	0.01		0.12
ANIMALIA frags	0.01		0.01	0.09	0.14		0.03	0.02	0.04	0.11
ARTHROPODA			0.02	0.16	0.06	0.02	0.08	0.03	0.04	0.02
HOLOTHUROIDEA				0.27	0.01		0.04		0.01	0.02
ECHINOIDEA				0.04			0.26			
CRINOIDEA				0.09	0.08			0.01		
SCAPHOPODA					0.01	0.03	0.05	0.01		
GASTROPODA			0.01	0.01	0.02	0.01	0.03	0.01		
ECHIURA							0.05			
CERIANTHARIA							0.01			
Total	1.05	0.03	5.62	6.06	6.09	1.31	2.05	0.41	7.87	1.75
No of taxa	5	2	10	15	16	9	19	13	12	10

Assemblages represented by the largest number of samples were assemblage g (182 samples) and h (80 samples); their distribution was widespread over the study area and overlapped with the fishing footprint (Figure 1.1.1.5). Although both of these assemblages appear to be distributed over the entire survey area, further investigation reveals subtle differences in their distribution and characteristics.

Assemblage g, on average, was spread over shallower and warmer areas than assemblage h (Figure 1.1.1.6, left). Assemblage g also had a greater overall biomass than assemblage h (Figure 1.1.1.6, middle). Fishing effort (as measured by the number of VMS track lines within a 200 m radius of each sampling site) appeared to have no influence over the distribution of each assemblage (Figure 1.1.1.6, right).

All remaining assemblages identified (a, b c, f and i) were represented by either one or two samples only and were characterised by either having very few taxa or by harbouring a singularly large representative of a nVME taxon (e.g., a starfish or anemone).

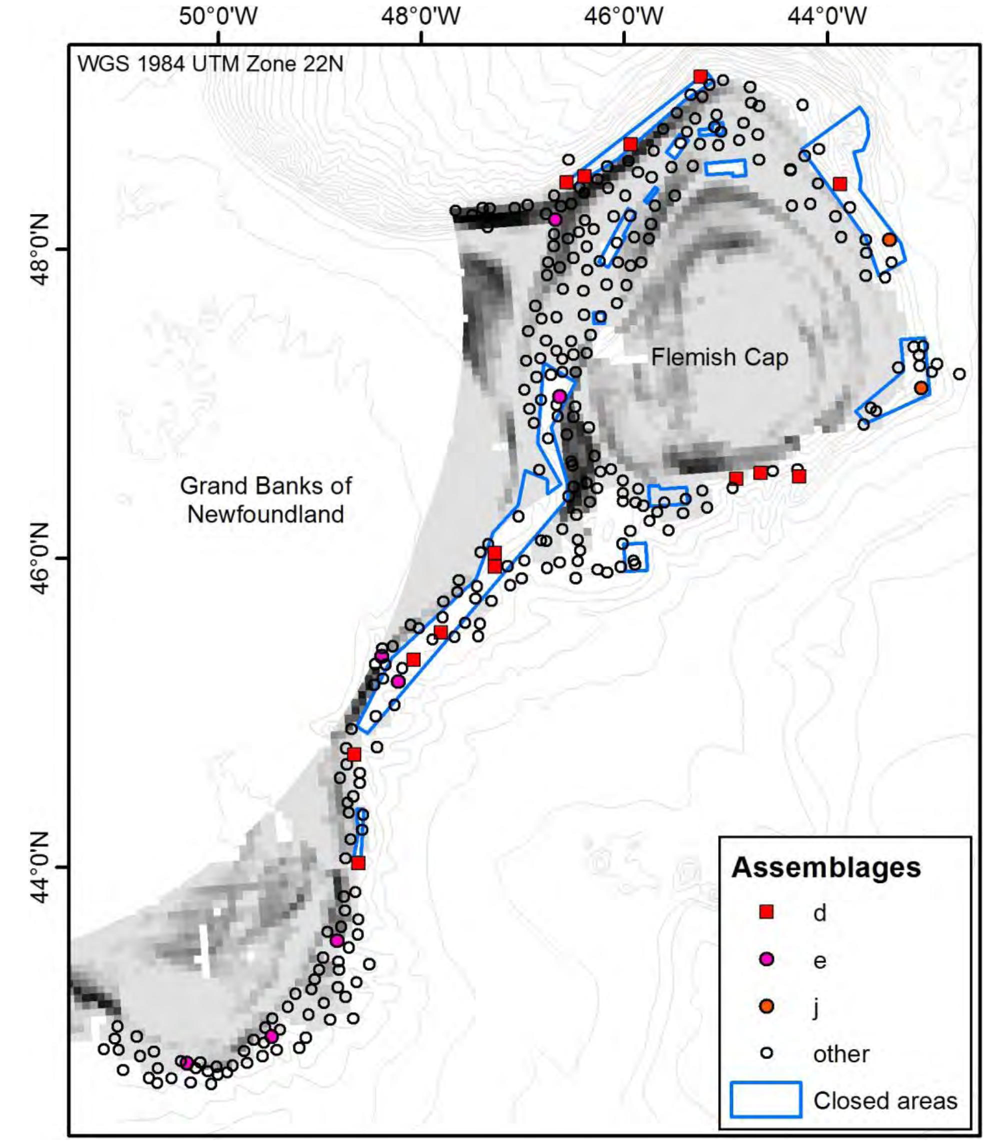


Figure 1.1.1.4. Distribution of assemblages containing VME indicative taxa (coloured symbols) identified from the analysis of box-core biomass records. Gradations of grey in background represent fishing effort intensity.

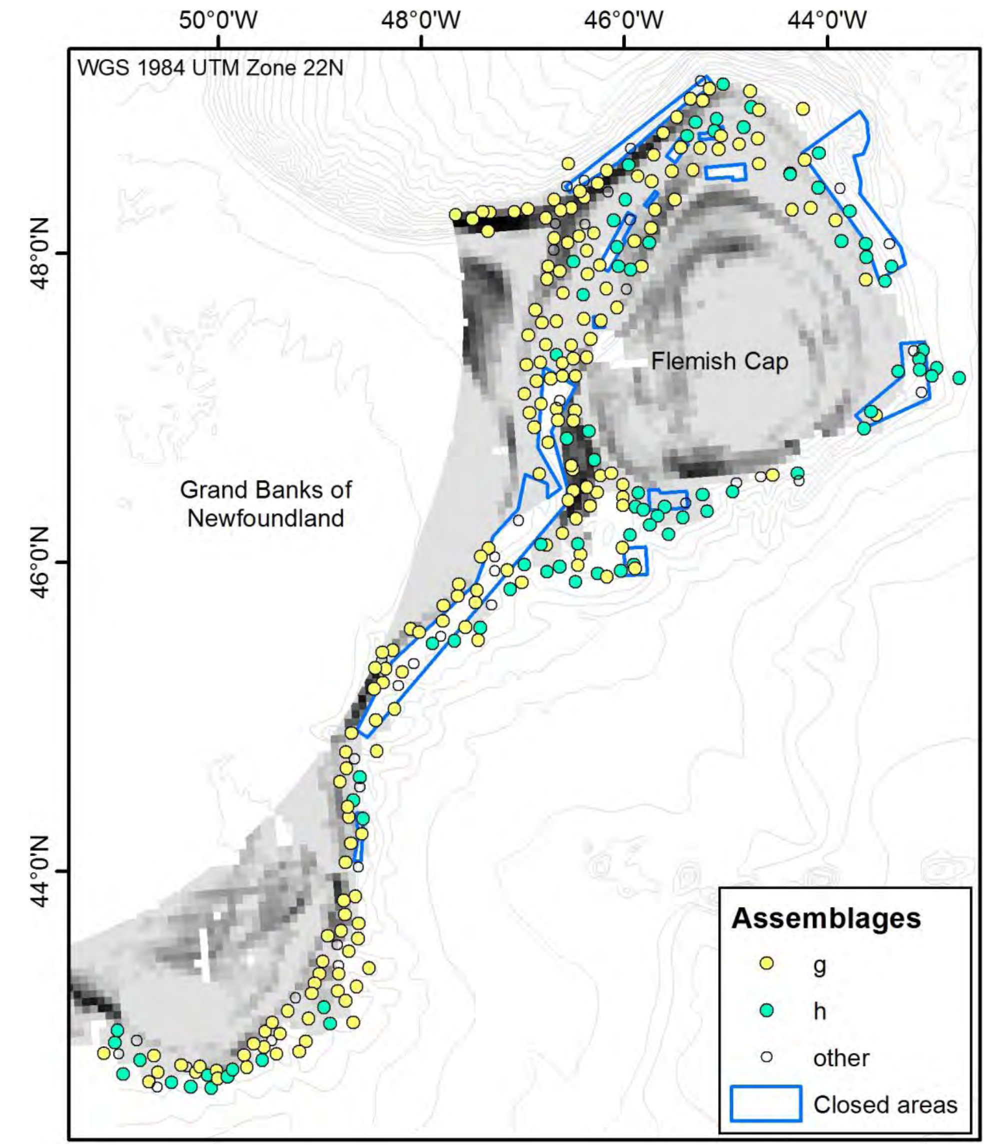


Figure 1.1.1.5. Distribution of the most widespread assemblages identified from the analysis of box-core biomass records. Gradations of grey in background represent fishing effort intensity.

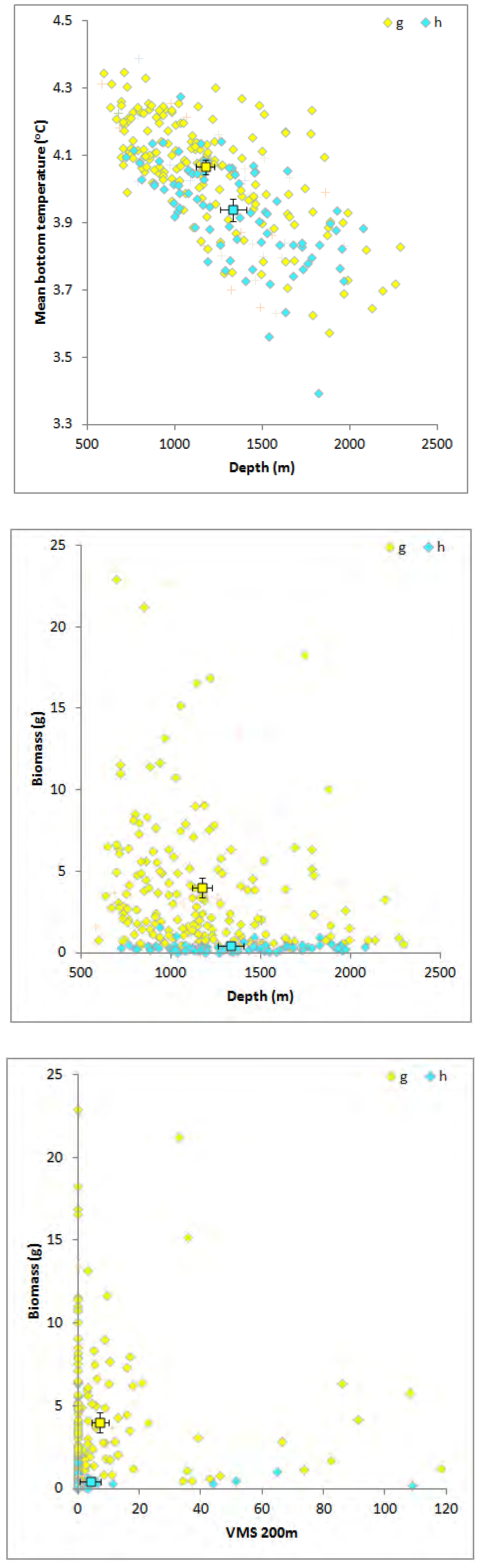


Figure 1.1.1.6. Relationship between depth and mean bottom temperature (top), depth and biomass (middle) and fishing effort and biomass (bottom) for distinct assemblages g and h. Overall mean ± 95% CI values for each assemblage are represented by square symbols with error bars.

1.1.1.2.4. Correlations, Drivers and Projections

Of the measured environmental variables (excluding fishing pressure), the ones with the greatest combined influence on the distribution of the VME rich assemblages (d, e and j) were mean bottom current speed and mean bottom temperature (BIOEVN corr. value = 0.202). The single most influential variable was mean bottom current speed (corr. = 0.193). Similarly, the environmental variables most influential in the distribution of all other assemblages (predominantly comprising assemblages g and h) were mean bottom current speed, mean bottom temperature, the BPI100 index and depth (corr. = 0.185). The single most influential environmental variable on the distribution of these same assemblages was mean bottom temperature (corr. = 0.176). All correlation values are low, denoting the high level of variability in all values within each of the identified assemblages.

It would appear that mean bottom current speed and mean bottom temperature are key environmental variables driving the type and distribution of benthic assemblages, both inside and outside the fishing footprint. To investigate where there are areas of seabed with the potential to accommodate VME indicative taxa such as the large surface-dwelling sponges, the values of mean bottom current speed and temperature for all samples representing assemblage d have been analysed further in an attempt to define thresholds above which it would be likely to find such assemblages.

The range in mean bottom current speed values from samples representing assemblage d (the assemblage characterised by the large surface-dwelling sponges) ranged from 0.056 to 0.216 ms^{-1}. Three quarters of all samples representing assemblage d fell above 0.074 ms^{-1} (this value is known as the fist quartile, or Q1). This Q1 value is taken arbitrarily as a threshold above which it is likely that assemblage d would occur. In the same way, the Q1 value for mean bottom temperature can be obtained (mean bottom temperature range for samples of assemblage d = 3.63-4.16°C; Q1 = 3.80°C), indicating that areas of seabed with a mean bottom temperature above this value would also have an increased likelihood of accommodating assemblage d. By plotting on map areas with mean bottom current speed and temperature values above their respective Q1 values, any areas of overlap between the two variables would have even greater potential to accommodate assemblage d (Figure 1.1.1.7).

Figure 1.1.1.7 (left) shows in black areas where the mean bottom current speed is above the defined Q1 threshold; it also shows in semi-transparent red areas where the mean bottom temperature is above the defined Q1 threshold. The whole of the area covered by both the black and the red areas has the potential to accommodate assemblage d, but in areas where black and red overlap, the potential for assemblage d to occur is increased, as those areas offer the ideal bottom current speed and temperature for that assemblage to settle and thrive. In Figure 1.1.1.7 (right) the boundary of the current areas closed off to bottom-contact fishing practices to protect VMEs are shown, highlighting the high degree of correspondence of the closed areas of known VME distribution with the areas identified here that have the potential to accommodate an assemblage identified as containing VME indicative taxa. Most of the area outside of the closed areas and exposed to the combined higher bottom current speed and temperature values is also under the influence of fishing activities, therefore it is unlikely that an assemblage characterised by large sponges should be found within the fishing footprint. Available data supports this notion.

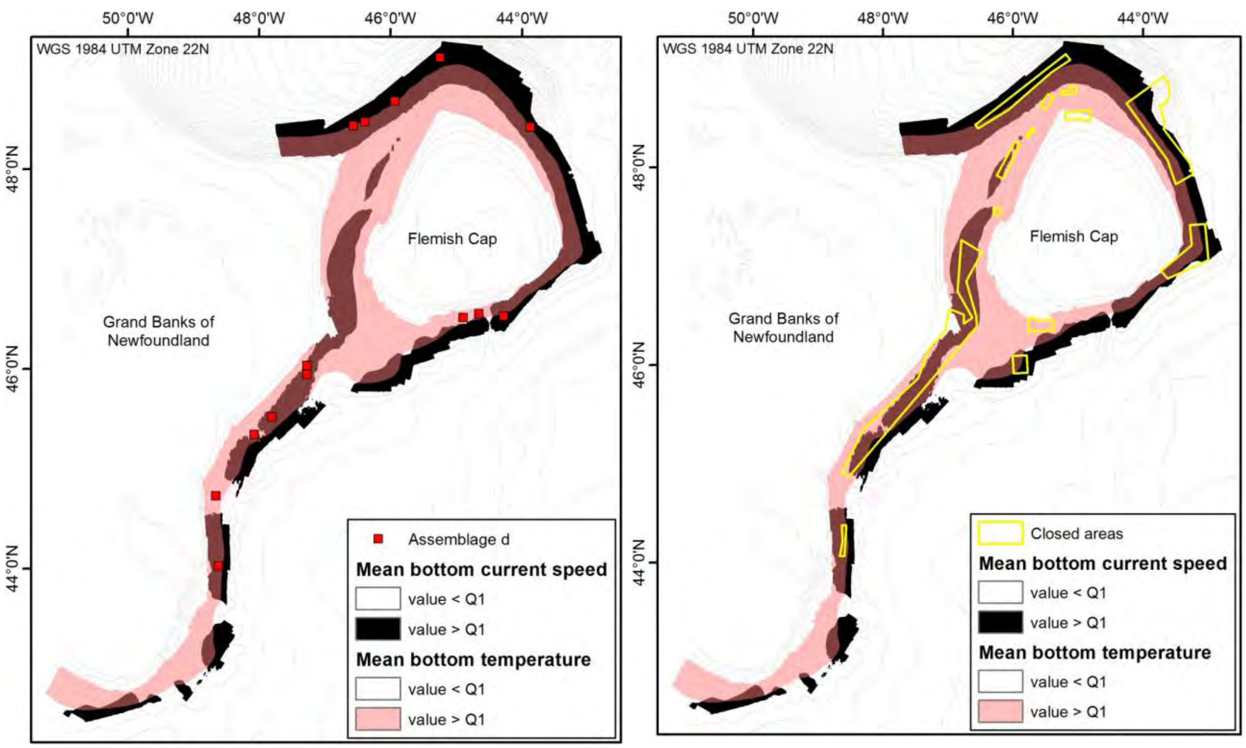


Figure 1.1.1.7. Areas of seabed identified as being exposed to values of mean bottom current speed and temperature above a predefined threshold (first quartile, or Q1) using samples representing assemblage d (left). Areas closed to bottom-contact fishing gears broadly coincide with areas of overlap of high current speed with high temperature (right).

1.1.1.3. Discussion

During the course of this investigation several patterns in the benthic assemblage composition have been elucidated; these are summarised in Table 1.1.1.2.

Table 1.1.1.2. Comparison of assemblages identified as indicative of VME and those that are not.

Non VME assemblages	VME indicative assemblages
▪ Occur inside and outside fishing footprint	▪ Occur mostly outside fishing footprint
▪ Characterised by low number of taxa	▪ Characterised by a high number of taxa
▪ Biomass is slightly (but not significantly) higher inside than outside fishing footprint	▪ Biomass significantly higher outside fishing footprint
▪ Characteristic taxa: Annelida and Bivalvia	▪ Characteristic taxa: Porifera and Ophiuroidea
▪ Biomass increases with increasing temperature and decreasing depth	▪ Biomass increases with increasing bottom current speed and temperature

Assemblages that did not contain VME indicative taxa were present throughout the area of interest, broadly represented by two large assemblages, labelled g and h (Figure 1.1.1.5). Samples representing assemblage g, on average, contained a greater biomass and occurred at shallower depths where temperatures were higher. They were also exposed to the influence of fishing activities. In contrast, samples representing assemblage h, on average, occurred in deeper and cooler waters, and had a lover overall biomass (Figure 1.1.1.6). Since many of the benthic invertebrates that constitute these assemblages are the prey of the fish targeted by the bottom trawling fishery, it is not surprising to find that these assemblages are still found in areas of intensive fishing effort. Such areas appear to have high levels of secondary production, aided by relatively warmer waters, and able to support the fish populations that the fishery is targeting.

Assemblages whose characteristic taxa included VME indicative taxa were distributed mostly outside of the fishing footprint. The biomass of sponges in particular was severely reduced by even the slightest exposure to fishing intensity (Figure 1.1.1.3). Other VME indicative taxa, such as sea pens, did not appear to be so intolerant of low levels of disturbance by fishing. The correspondence in spatial distribution between assemblages thought to represent VME identified from box-core surface photographs and from the fauna extracted from the box-cores was good, as both assemblage ag (identified from photographs) and assemblage d (identified from analysis of infauna) occurred in areas of similar environmental characteristics (Figure 1.1.1.8). The occurrence of VME indicative assemblages, together with areas predicted by this study to have the optimal conditions for the occurrence of sponge dominated VME (Figure 1.1.1.7) also coincided with areas modelled by Kenchinton et al. (2014) as having high sponge density (Figure 1.1.1.9, left). In turn, areas predicted to contain a high density of sponges appear to be protected by the existing closed areas (Figure 1.1.1.9, right).

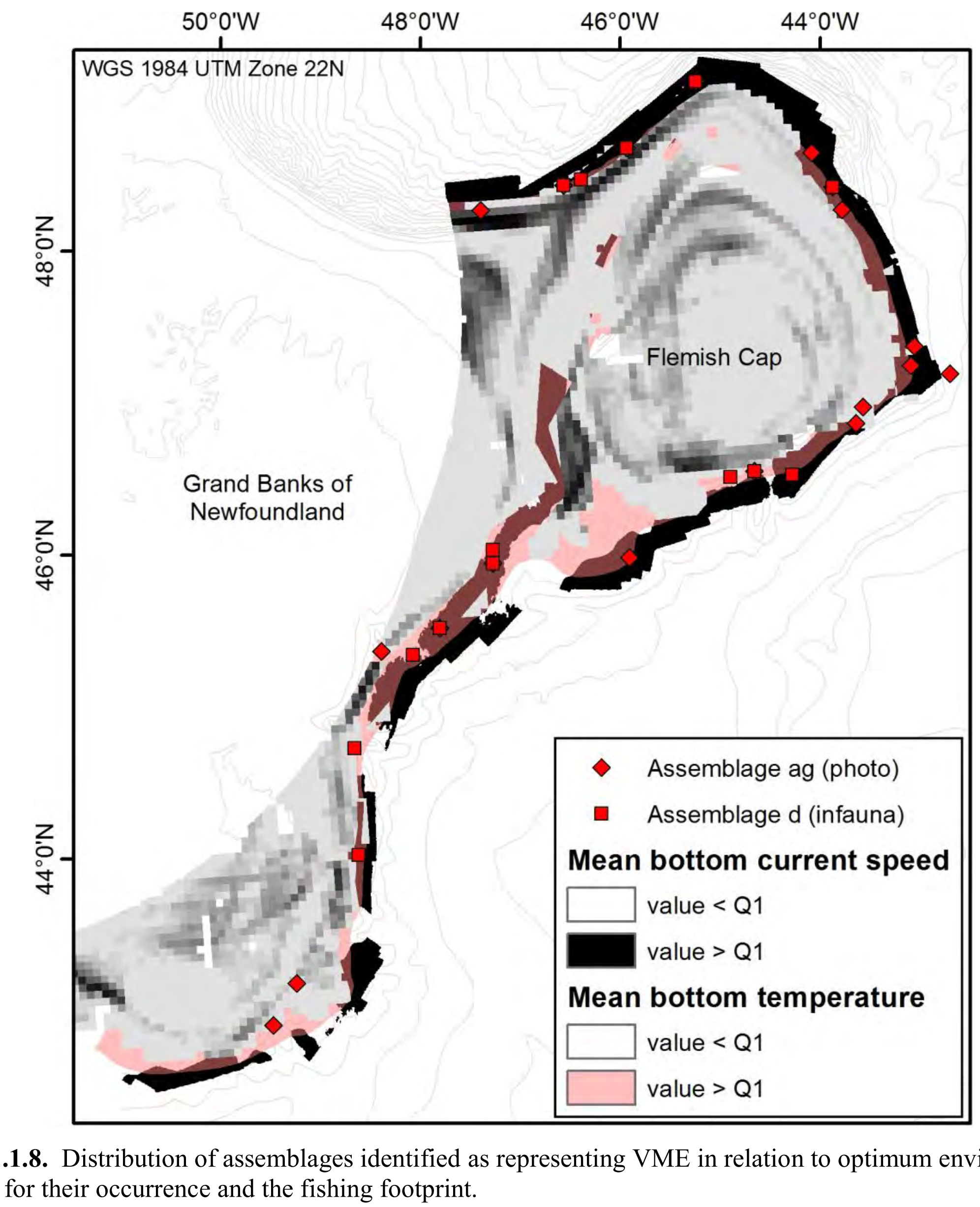


Figure 1.1.1.8. Distribution of assemblages identified as representing VME in relation to optimum environmental conditions for their occurrence and the fishing footprint.

The taxonomic resolution afforded by the dataset used in the present investigation, in which fauna extracted from box-core samples were identified only to morphotaxa, may be considered a hindrance to detect more subtle patterns in the dataset. To investigate this, a comparison has been performed using a subset of 40 samples that were previously processed to a much greater level of taxonomic resolution (i.e., to family or genus; see Barrio Froján et al. (2012)). Using only those 40 samples at both available levels of taxonomic resolution, a RELATE test revealed a correlation value of R = 0.819 (0.1% significance) between the two datasets, indicating that the pattern observed at the coarser taxonomic resolution is very similar to the pattern observed at the finer level of taxonomic resolution. Therefore, it is reassuring to know that the patterns reported in this study using the entire dataset at a coarse level of taxonomic resolution are likely to be a good representation of real structure within the sampled benthic assemblage.

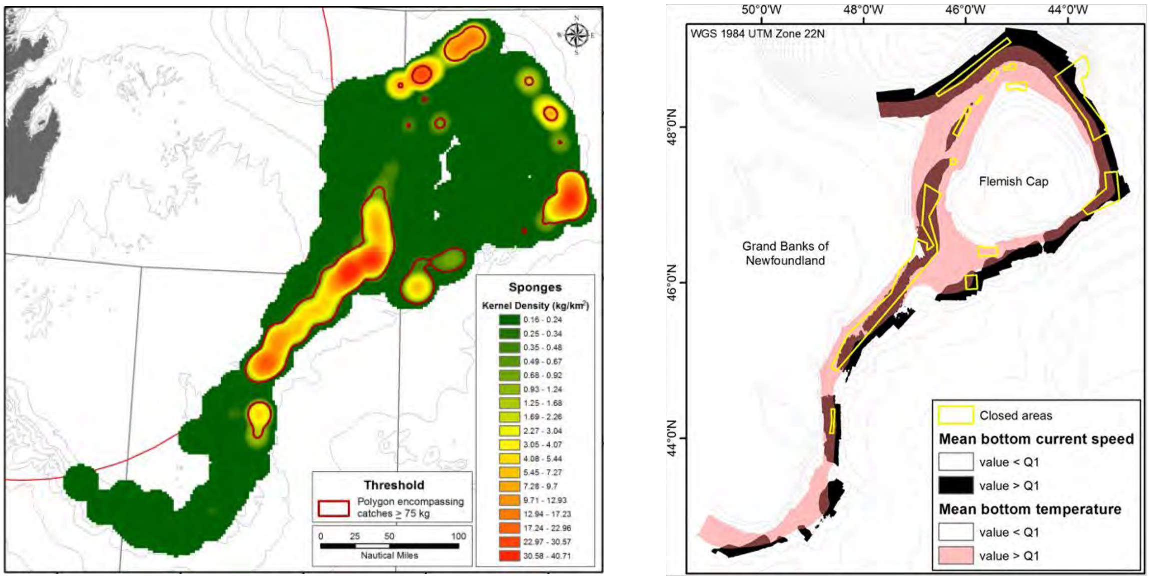


Figure 1.1.1.9. Left: Results from kernel density analysis of sponge biomass used to define areas of VME (by Kenchington et al., 2014). Right: Location of areas likely to contain VME indicative assemblage d in relation to areas closed to bottom-contact fishing gears.

1.1.1.4. Conclusions

Through the processing of samples and the analysis of the acquired data, the presence of VME indicator taxa in the NAFO Regulatory Area (NRA) has been quantified. In addition, distinct assemblages representative of VME have also been identified and mapped. In doing so, it was found that most assemblages that were indicative of VME tended to occur outside of the fishing footprint in the NRA, despite environmental conditions being suitable for their occurrence in areas covered by the fishing footprint. The possibility exists that historic fishing activity has removed VME indicative assemblages from areas where conditions are suitable for them to occur.

Many of the samples that contained VME indicative taxa were found in areas predicted to contain VME, and much of the extent of those areas already falls within the boundaries of areas that are closed to bottom-contact fishing gears. Such high level of correspondence between modelled or predicted extents of VME and observed occurrences of VME, together with the location of existing VME protection measures, reinforces the correct placement of those protection measures, and provides a basis for the continued enforcement of those protection measures long into the future. As long as the environmental conditions that are conducive to VME formation do not change drastically over time, it is likely that VME indicative taxa will continue to thrive in those same areas if bottom-contact fishing practices continue to be excluded.

1.1.1.5. References

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ToR 1.1.2. Update on EU survey results on VMEs

During the 7th NAFO WGESA meeting new data on deep-water corals and sponges were presented based on Spanish/EU bottom trawl groundfish surveys for 2014 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 6th WGESA meeting, new quantitative spatial analysis were applied for corals and sponges for all the available data and different thresholds were selected for significant concentrations of coral and sponges as follows: 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. Catches above the identification threshold for RV data of deep-water corals and sponges are provided and mapped together with the actual closed areas (Figures 1.1.2.1 to 1.1.2.4).

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

1. The Spanish 3NO survey, carried out by the Instituto Español de Oceanografía (IEO), sampling the Grand Bank of Newfoundland (NRA, Divs. 3NO) between 44 and 1305 m depth
2. The EU Flemish Cap survey, carried out by the IEO together with the Instituto de Investigaciones Marinas (IIM) and IPIMAR (Portugal), sampling the Flemish Cap (NAFO Div. 3M), and currently a depth range between 135 and 1471 m.
3. The Spanish Fletán Negro-3L survey carried out by the IEO, sampling Div. 3L in the NRA between 14 and 1411 m depth.

A total number of 411 bottom trawl hauls surveys were analyzed.

In order to follow the same groups previously used by WGEAFM, deep water corals were grouped in large gorgonians (Alcyonacea), small gorgonians (Alcyonacea) and sea pens (Pennatulacea); and all the sponges were grouped together. Some data of the species of corals and sponges present in the area have been previously published (Wareham and Edinger, 2007; Wareham, 2009; Fuller, 2011; Murillo *et al*., 2011a; Murillo *et al*., 2011b; Murillo *et al*., 2012).

Distribution maps of presence and catches above the identification threshold for RV data of sponges, large gorgonians, small gorgonians and sea pens following the thresholds are presented (Figures 1.1.2.1 to 1.1.2.4). Location of the corals and sponge records was assigned to the start position of the survey fishing tows. The start position coordinates and weight of the significant catches are provided in Table 1.1.2.1.

Table 1.1.2.1. Start positions of tows with corals and sponges catches above the threshold defined as significant catch in the NRA (Divs. 3LMNO) with their corresponding weight.

Start position		VME indicator species	Weight (kg)
Lat	Lon		
46º 50´44.52 N	43º 47´01.32 W	SPONGES ≥ 75 kg	3253.2
46º 02´06.00 N	47º 25´37.81 W		1377.8
46º 23´52.08 N	46º 50´07.08 W		804.9
48º 20´07.08 N	46º 35´36.96 W		454.5
46º 02´25.80 N	47º 22´30.00 W		448.3
48º 55´32.88 N	45º 07´55.92 W		371.5
45º 36´16.20 N	47º 53´24.00 W		320.3
46º 37´31,08 N	46º 54´14.40 W		185.7
46º 37´31.08 N	46º 54´14.40 W	LARGE GORGONIANS ≥ 0.6 kg	34.3
48º 05´31.20 N	46º 02´ 58.92 W	SEA PENS ≥ 1.4 kg	2.3
48º 31´48.00 N	45º 36´ 20.88 W		1.4

Sponges

Sponges were recorded in 198 of the total tows (48% of the total Spain/UE tows analyzed), mainly in the Flemish Pass, Flemish Cap and slope of the Grand Bank between 56 and 1460 m. Catches above the identification threshold for RV data (≥ 75 kg/tow) were found in 8 tows (Table 1.1.2.1 and Figure 1.1.2.1). Of the total 8 tows, only 1 was recorded outside of the closed areas. The sponge catch of these tows ranged between 185 and 3253 kg.

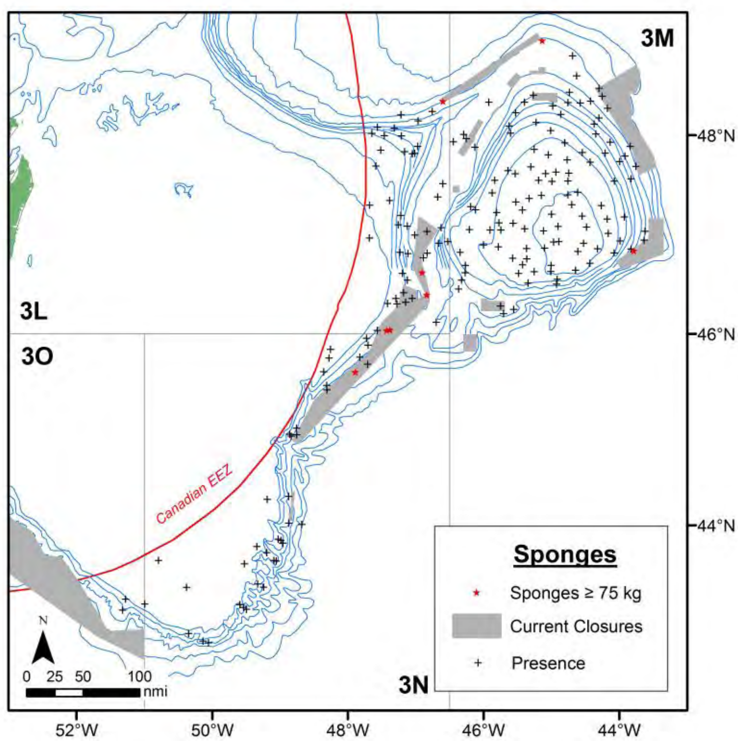

Figure 1.1.2.1. Distribution of catches above the identification threshold for RV data and presence of sponges in the study area (NAFO Divs. 3LMNO).

Large gorgonians

They were recorded in 4 tows (1% of the total tows analyzed) between 800 and 1275 m. One catch above the identification threshold for RV data (≥ 0.6 kg/tow) was found with a weight of 34.3 kg (Table 1.1.2.1; Figure 1.1.2.2)

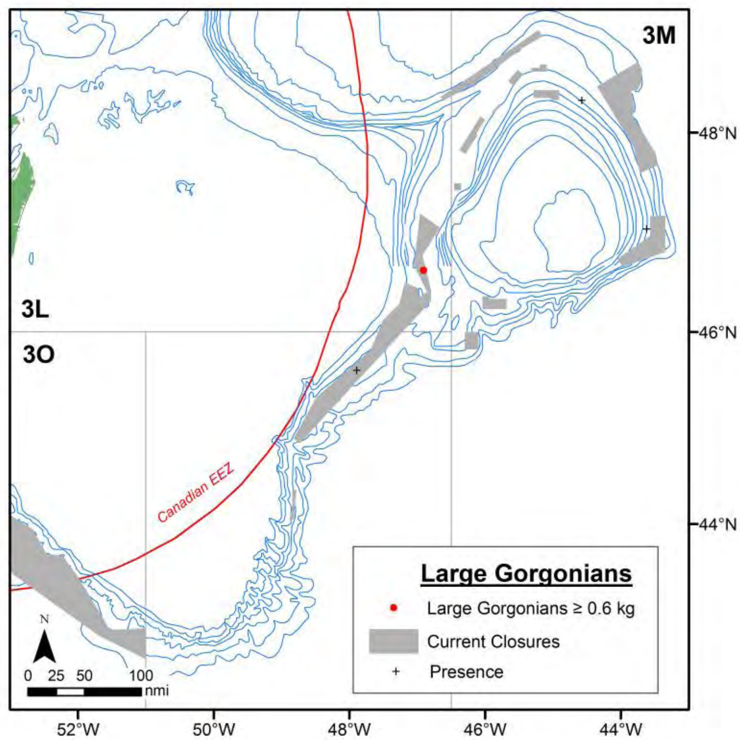

Figure 1.1.2.2. Distribution of catches above the identification threshold for RV data and presence of large gorgonians in the study area (NAFO Divs. 3LMNO).

Small gorgonians

They were recorded in 39 tows (9% of the total tows analyzed), mostly in the slope of the Grand Bank, Flemish Cap and Flemish Pass between 360 and 1349 m. No catches above the identification threshold for RV data (≥ 0.15 kg/tow) were recorded (Table 1.1.2.1; Figure 1.1.2.3)

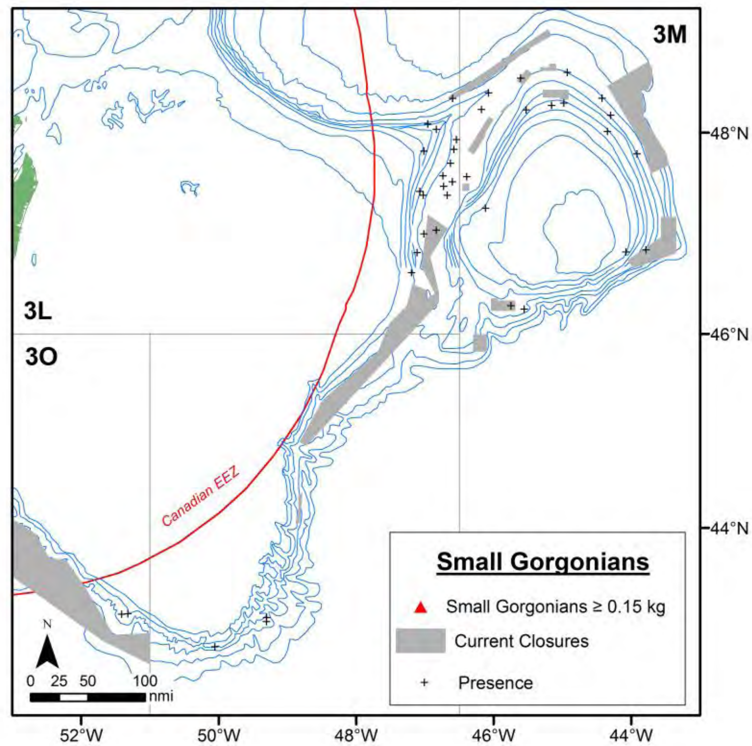

Figure 1.1.2.3. Distribution of catches above the identification threshold for RV data and presence of small gorgonians in the study area (NAFO Divs. 3LMNO).

<u>Sea pens</u>

Sea pens were recorded in 151 tows (37 % of the total tows analyzed) between 190 and 1460 m. Catches above the identification threshold for RV data (≥ 1.4 kg/tow) were found in 2 tows located inside closed areas 9 and 10 (Table 1.1.2.1; Figure 1.1.2.4).

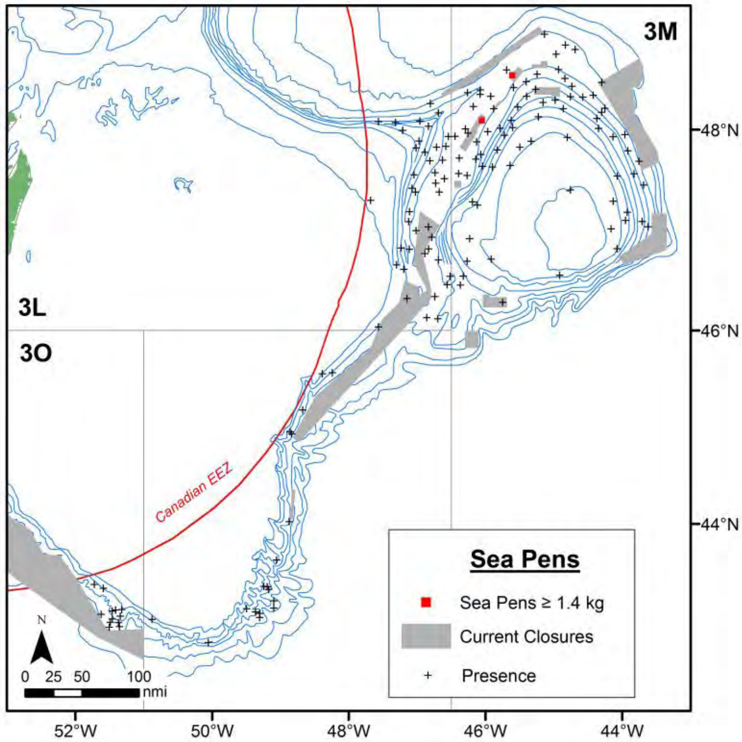

Figure 1.1.2.4. Distribution of catches above the identification threshold for RV data and presence of sea pens in the study area (NAFO Divs. 3LMNO).

1.1.2.2. References

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

ToR 2.1. Final results on integrated Northwest Atlantic ecoregions analysis, and delineation of candidate ecosystem-level management units

2.1.1 Results of the integrated Northwest Atlantic ecoregions analysis

A necessary element for developing an Ecosystem Approach to Fisheries is to identify the region in space that, in practice, bounds the ecosystem that is intended to be managed in an integrated way, and an element of the *Roadmap to EAF*. During previous meetings (NAFO 2010a, 2010b, 2011, 2012, 2013), extensive work had been reported on consolidated multivariate data sets that reflected the physiographic, environmental, oceanographic and demersal resource base throughout each of the four major biogeographic regions (bioregions) on the east coast of North America (i.e. Newfoundland & Labrador Shelf, Flemish Cap, Scotian Shelf, and US northeast continental Shelf [Gulf of Maine (GoM)/Georges Bank/Mid-Atlantic Bight]). Geographic Information Systems (GIS) served to develop consistent data layers within each bioregion which were then summarized using a combination of multivariate analyses, based primarily on principal components analysis (PCA) to reduce the dimensionality of the information layers. The information derived from those analyses, in the form of scores along principal axes, was then grouped using clustering algorithms to identify areas with common combinations of characteristic and geographically distinct features that represent ecoregions within each bioregion (Fogarty and Keith 2009 – unpublished; Pepin et al. 2010, 2012; Pérez-Rodriguez et al. 2010; Zwanenburg et al. 2010). The degree of definition of ecoregions within each bioregion was, to some extent, dependent on the number of distinct information layers that was available in each bioregion. For example, there were a large number of data sources for the analyses of both the US northeast continental Shelf (Fogarty and Keith 2009 – unpublished) and the Scotian Shelf (Zwanenburg et al .2010) that resulted in a high degree of differentiation of among ecoregions in each locale. In contrast, there was less information available on the Newfoundland Shelf and Flemish Cap, which resulted in a lower degree of resolution to identify distinct ecoregions (Pepin et al. 2010; Pérez-Rodriguez et al. 2010). The contrast in results based on differences in the level of information available highlights the potential significance of knowledge in identifying features that may require different considerations and/or approaches in the provision of scientific advice and decision making.

To identify areas appropriate for ecosystem-based management, we undertook to consolidate the information from all bioregions. The analytical approach was essentially identical to that applied at the scale of the bioregion but carried out at the scale of the western north Atlantic (Labrador to mid-Atlantic Bight) (Figure 2.1.1). However, some modifications had to be applied. Because of differences in data available, the number of variables used in the analysis had to be limited to the eight data types (Table 2.1.1), which provide some information physiographic, environmental, oceanographic and demersal resource base. However, following preliminary analyses, the presence/absence of coral was dropped from the consolidation effort because the uniqueness of those ecosystem elements resulted in sites (rasters) with coral being grouped separately without consideration of geographic contiguity. It is clear that these elements are important features that define habitats within bioregions, and their occurrence within the broader context of ecosystem management units necessitates special consideration, but the information was not helpful in the delineation at large scales.

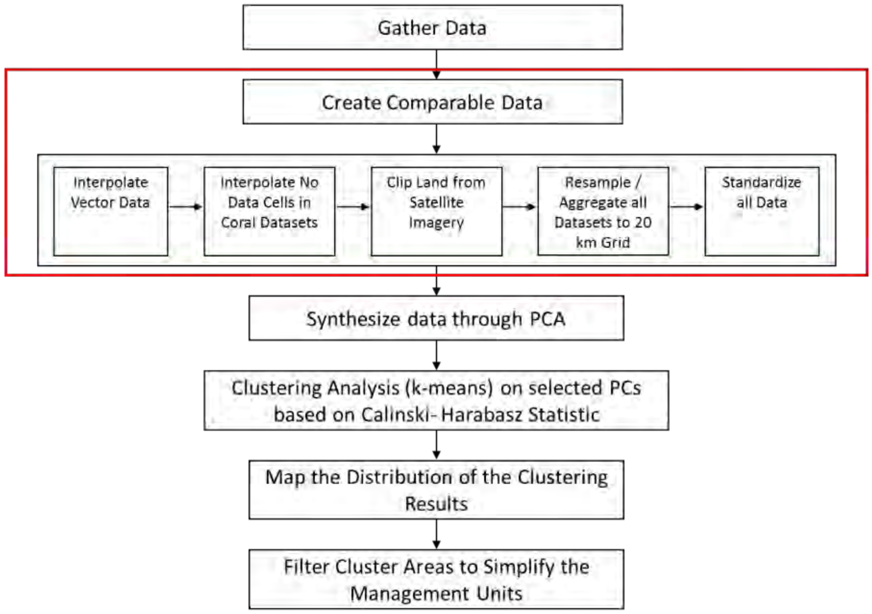

Figure 2.1.1. Flow chart of the analytical approach used to consolidate the data.

Table 2.1.1. The variables used as input for the PCA and clustering analysis showing their original data type, source, units, and time period.

Variables	Data Source	Units
Bathymetry	GEBCO (1' Grid)	Meters
Sea Surface Temperature	NOAA AVHRR Satellite (4km Grid)	^{0}C annual average
Bottom Temperature	Temperature at fishing	^{0}C from multi-species surveys
Chlorophyll-a	SeaWiFS Satellite (4 km)	mg/m^3 (annual average)
Primary Production	SeaWiFS Satellite (1.5 km)	mg/m^3/year (cumulative)
Demersal Biomass	Multi-species Survey	kg/standard tow
Demersal Diversity	Multi-species Survey	Shannon's evenness index

The results of the PCA explained 59% of the variance in the first three axes (PC) in the seven variables (PC1 23.2%; PC2 18.4%; PC3 17.2%), and highlighted the gradient in conditions from coastal areas to the deep ocean (1000 m isobath) and the contrast between warm bottom waters that also have higher biomasses of demersal fish with, with colder areas with more uniform distribution of taxa in the demersal community. The results of the analysis did indicate the existence of some degree of non-linearity in the relationships between variables but this may reflect the influence of observations or conditions that are at the extremes of the range for certain variables. This was not considered to significantly affect the overall outcome of the analyses. Nine clusters (ecoregions) were identified as the optimal solution balancing the variance within and among clusters based on an unconstrained K-means analysis of the scores of the raster scores along the first three principal components. The results revealed a high degree of geographic contiguity of ecoregions over broad spatial scales with limited fragmentation within a bioregion although there was evidence of a high degree of heterogeneity (Figure 2.1.2). Strong latitudinal and bathymetric gradients were apparent in the distribution of ecoregions across the NAFO area but each ecoregion was not restricted to a single bioregion or portion thereof. For example, the ecoregion that occurs over the central Grand Banks also occurs over much of the eastern Scotian Shelf as well as on the southern flank of Georges Bank and in the central mid-Atlantic Bight (Figure 2.1.1.2). Similarly, conditions that predominate over much of the western Scotian Shelf can also be found over parts of the Flemish Cap, along the southwestern edge of the Grand Banks and in the northern portion of the mid-Atlantic Bight (Figure 2.1.2). Although the distribution and spatial arrangement of ecoregions helped to qualitatively identify broad areas that included one or several ecoregions (e.g. Flemish Cap or Grand Banks), the spatial heterogeneity in the distribution of ecoregions can lead to uncertainty in the delineation of management units.

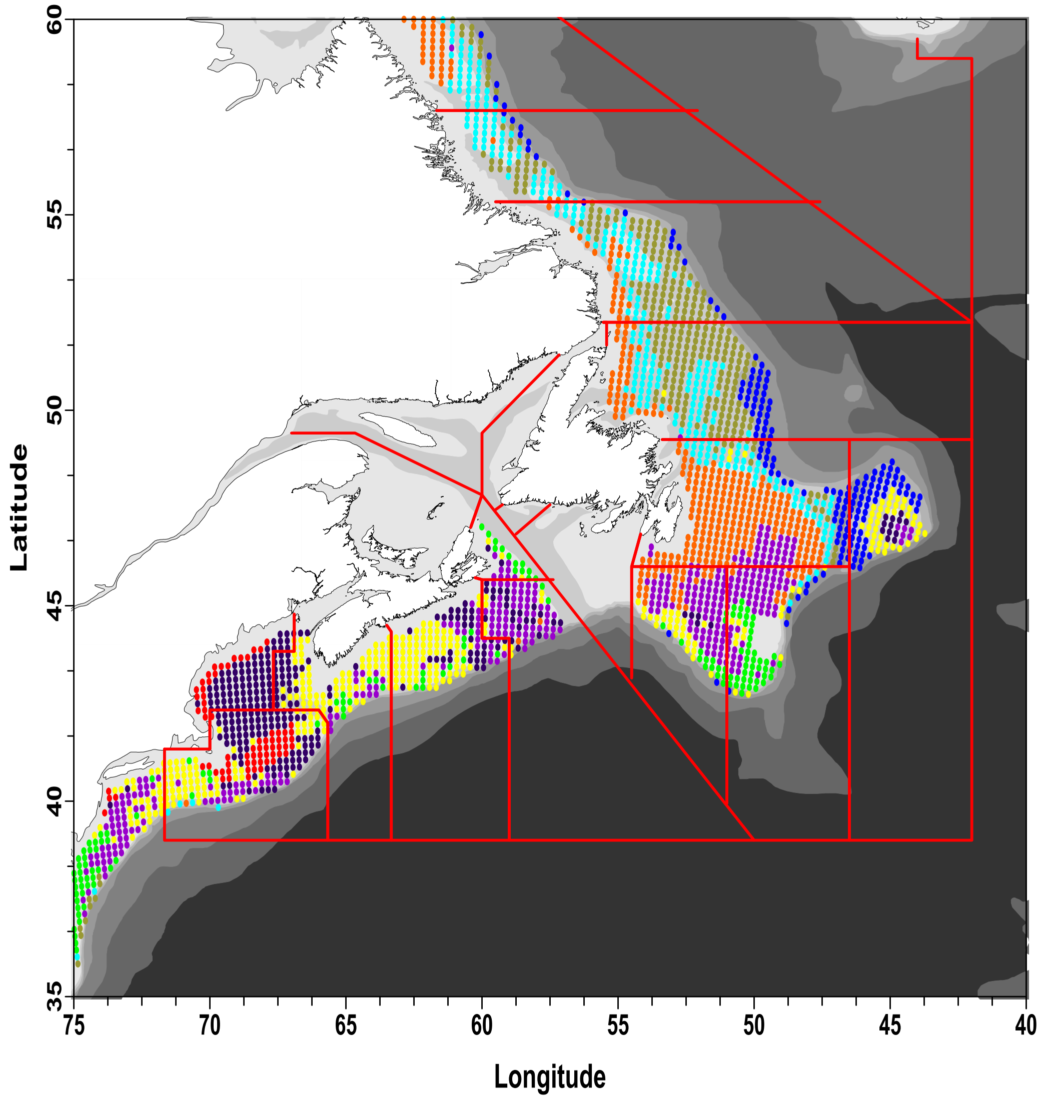

Figure 2.1.2. Map of unconstrained k-means clustering results of the first three principal components. Each colour represents a different cluster.

To overcome this concern, K-means clustering was repeated on the first three PCs with the addition of positional (latitude, longitude) information in an attempt to include spatial proximity in the delineation of management units. The optimal solution identified 7 clusters across the NAFO area (Figure 2.1.3). Although generally informative, the analysis also revealed the overwhelming influence of geographic proximity and distance in the definition of each cluster which appeared to overshadow the combination of environmental characteristics identified ecoregions in the unconstrained analyses. For example, the cluster centered over the Georges Bank/GoM area (Figure 2.1.3) extends onto the western Scotian Shelf in an apparent disregard of the distinct environmental conditions that separated the two areas in the unconstrained analysis (Figure 2.1.2), and also does not correspond accurately to the spatial separation of major fish stocks in the region. Exploration of other proximity constrained solutions around the optimal number of clusters revealed that that a greater number of clusters could serve to delineate smaller management units on the Scotian and US northeast continental Shelves but again, the solution did not appear to be a realistic reflection of several regional biological aspects that were not included in the analytical assessment of the information.

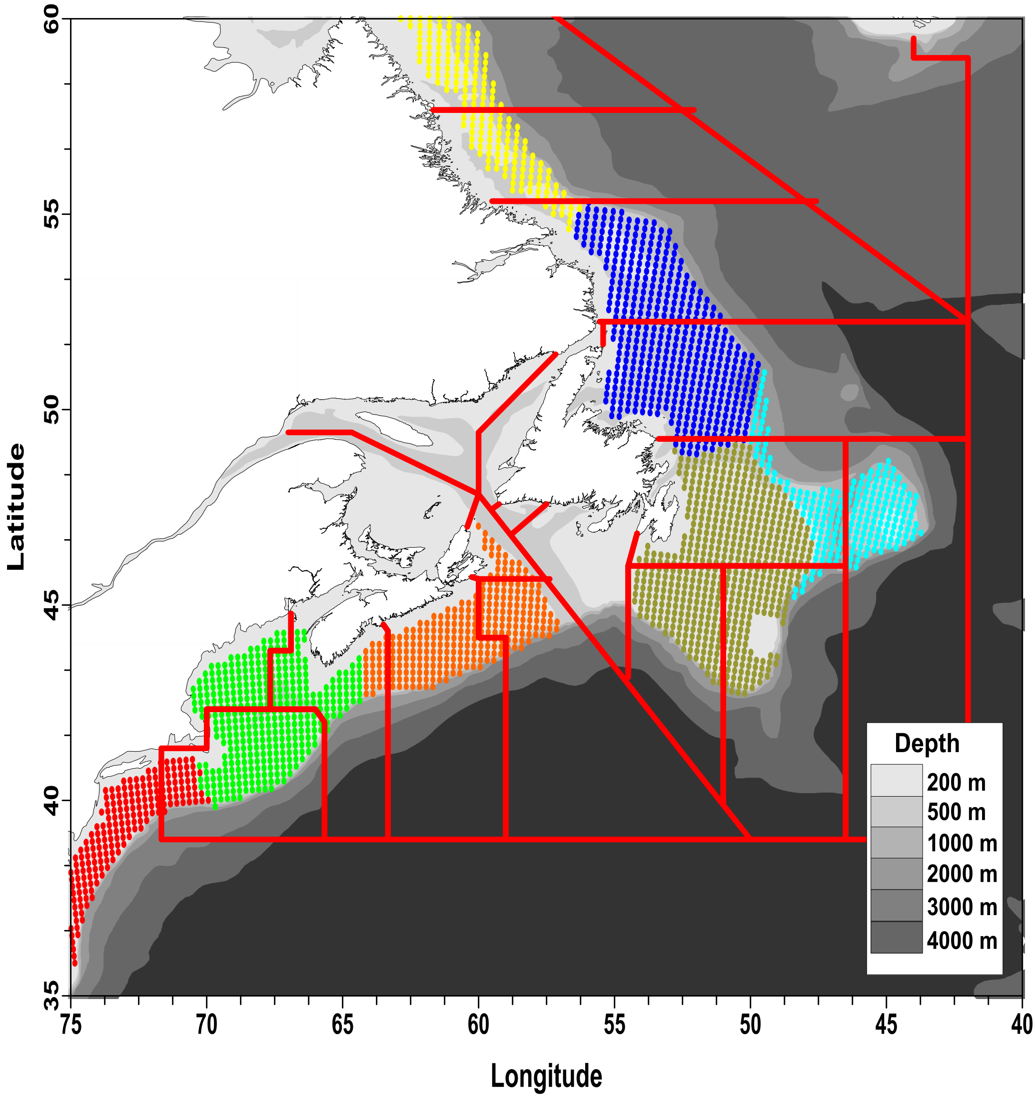

Figure 2.1.3. Map of geographically constrained k-means clustering results of the first three principal components. Each colour represents a different cluster.

2.1.2 Spatial scales for ecosystem summaries and candidate ecosystem-level management units

Because of the limitations associated with either analytical approach, WGESA decided to use both sets of results as guides, along with expert knowledge that would include and consider previous bioregion-specific ecoregion analyses (Fogarty and Keith 2009 – unpublished; Pepin et al. 2010, 2012; Pérez-Rodriguez et al. 2010; Zwanenburg et al. 2010), the location of ecoregions, knowledge of the distribution of major marine resources and fish stocks, as well as geographic proximity in the delineation/definition of potential management units. This was done with the clear understanding that ecoregions in themselves do not define all ecologically important elements but that instead represent an intermediate level of delimitation of ecosystem elements in a hierarchy of spatial scales pertinent to the provision of management advice and action. Furthermore, WGESA members acknowledged that the current assessment does not explicitly take into consideration the functional nature of the ecological elements that are necessary for ecosystem integrity and stability. The process was iterative to some degree as results and observations were combined but the spatial extent of the management units identified through this process essentially reflected the major features of the analytical results, with only details about the location of the boundaries of management units being the source of discussion.

The initial integration of the results rendered eight aggregate ecosystem-level units (Figure 2.1.4). These units consist of a combination of ecoregions, which represent elements with different physical and biological characteristics based on the analytical criteria applied, and define areas for which it would be reasonable to estimate fisheries production potential.

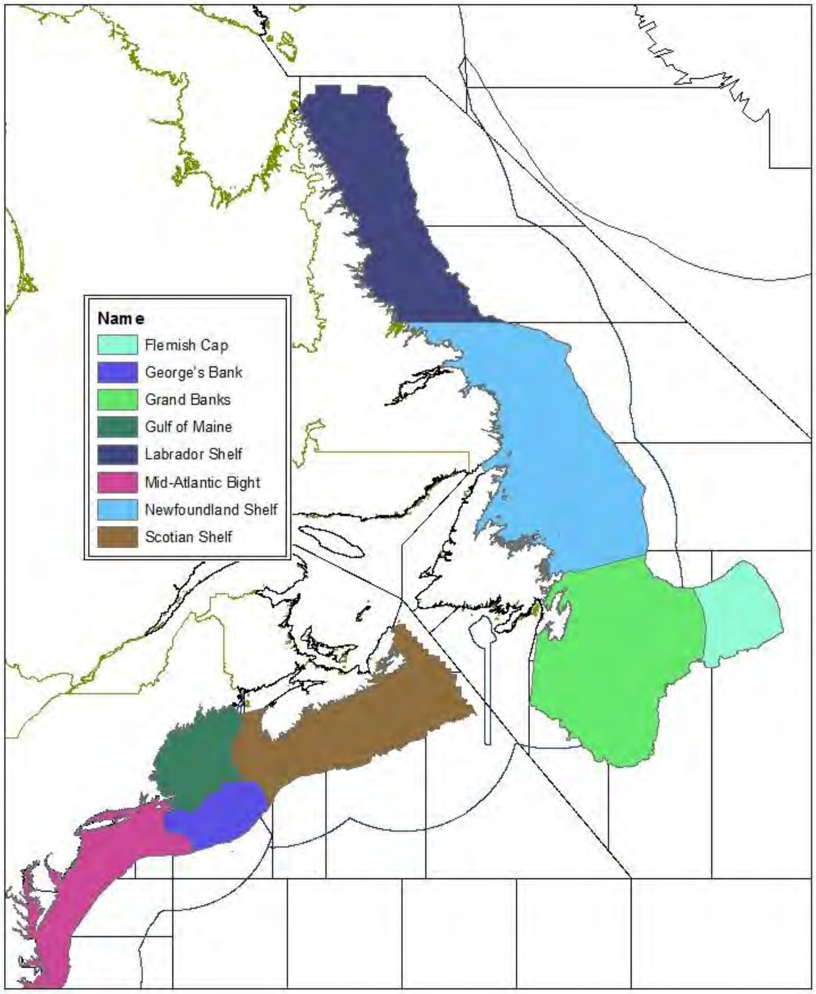

Figure 2.1.4. Initial consensus map of major production units identified as a result of ecoregion analysis and expert opinion.

Given the relatively modest discrepancies between the boundaries of some of these units and existing NAFO Divisions (e.g. between the northeastern Newfoundland Shelf, the Grand Banks and the Flemish Cap), and considering the practical aspects of the provision of management advice and action, including existing stock and administrative boundaries, the borders of some of these initial consensus areas where further revised to define Ecosystem Production Units (EPUs) that could be used in practice as candidate ecosystem management units.

The final results identify eight major Ecosystem Production Units (EPUs) that could be considered as candidate management units (from the coast seaward to the 1500 m isobath) that consist of the Labrador Shelf (NAFO subareas 2GH), the northeast Newfoundland Shelf (subareas 2J3K), the Grand Bank (subareas 3LNO), Flemish Cap (subarea 3M), the Scotian Shelf (subareas 4VnsWX), Georges Bank (parts of subareas 5Ze and 5Zw), the Gulf of Maine (subarea 5Y and part of 5Ze) and the mid-Atlantic Bight (part of subarea 5Zw and subareas 6ABC) (Figure 2.1.5). It is worth highlighting how well the existing NAFO divisions and their boundaries map onto the areas emerging from the full suite of ecoregion studies. This is likely because "*The NACFI (North American Council on Fisheries Investigations) lines were chosen to correspond as far as possible with natural divisions of the fish populations or with barriers to fish migrations. Barriers to migrations presumably were of topographic or* *oceanographic nature*" (Halliday and Pinhorn 1990) which proved to be apparent in the more quantitative approach used in WGESA's analyses.

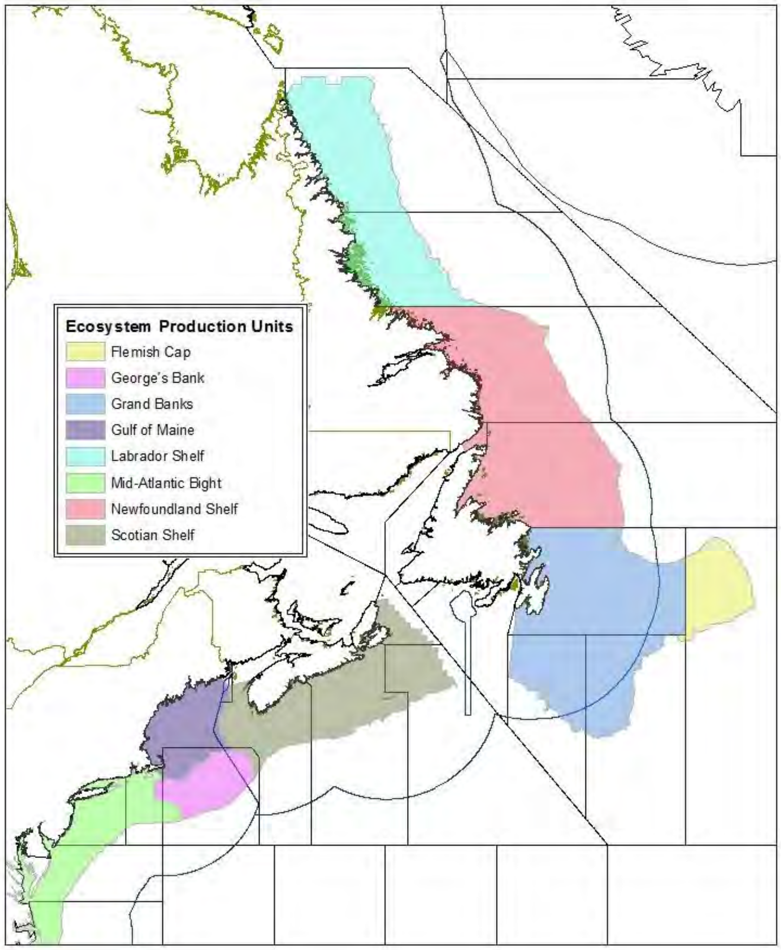

Figure 2.1.5. Consensus map of Management Units identified as a result of ecoregion analysis and expert opinion.

WGESA noted that the solution provided in Figure 2.1.5 represents a compromise that aims to define management units based on the boundaries of existing NAFO subareas. This may not perfectly reflect the underlying production areas that contribute to the actual Ecosystem and Fishery Production Potential (EPP and FPP, respectively) in a given management unit but the differences are considered subtle, so that application of models to estimate EPP and FPP at the management unit scale is deemed a reasonable and acceptable approximation.

Based on the full suite of ecoregion analyses, and in the context of developing and implementing ecosystem approaches to fisheries management, WGESA identified three major spatial scales that could be considered relevant and useful for the development of ecosystem summaries and management plans (Table 2.1.2). The broadest scale corresponds to bioregions, which are conceptually equivalent to Large Marine Ecosystems (Sherman and Alexander 1989), and correspond to Newfoundland and Labrador Shelves, Flemish Cap, Scotian Shelf, and US northeast continental Shelf (Gulf of Maine/Georges Bank/Mid-Atlantic Bight).

The proposed candidate management units correspond to the Ecosystem Production Units (EPUs) that define major areas within the bioregions which contain a reasonably well defined food web/production system; these areas provide the spatial scale with which to estimate fishery production potential (*ToR 3.2.3*) (Figure 2.1.5). Although EPUs are proposed as candidate management units, it should not be assumed that they are fully closed systems; transfer of production across EPU boundaries within a bioregion is to be expected. Whenever possible, these transfers should be estimated and considered when setting cath levels, but until those estimates are available, attention to the EPP and FPP of neighbouring EPUs should be paid when developing ecosystem-level management plans.

Each of the EPUs consists of a combination of ecoregions, which represent elements with different physical and biological characteristics based on the analytical criteria applied. Ecoregions in themselves do not define all ecologically important elements but that instead represent an intermediate level of delimitation of ecosystem elements in a hierarchy of spatial scales pertinent to the provision of management advice and action. However, it is the ecoregion scale, the one expected to provide the context for defining more precise habitats, including Vulnerable Marine Ecosystems (VMEs).

More detailed knowledge of a broader range of elements than was considered in the synthesis as well as greater spatial resolution of the input data would provide greater scope to identify important or significant ecosystem elements. WGESA therefore recommends that careful consideration be assigned to the results of earlier the regional analyses (Fogarty and Keith 2009 – unpublished; Pepin et al. 2010, 2012; Pérez-Rodriguez et al. 2010; Zwanenburg et al. 2010) in the development and implementation of ecosystem management measures within the proposed management units to ensure that decisions are based on the best available information.

Table 2.1.2. Basic spatial scales identified as relevant and useful for ecosystem summaries and management plans in the context of developing and implementing Ecosystem Approaches to Fisheries Management.

Name	General operational description	Examples in NAFO Convention Area
Bioregion	Large geographical area characterized by distinct bathymetry, hydrography, and which contains one or more reasonably well defined (but still interconnected) major marine communities/food web systems.	• Newfoundland and Labrador Shelves • Flemish Cap • Scotian Shelf • US northeast continental Shelf
Ecosystem Production Unit (EPU)	Within a bioregion, a major geographical subunit characterized by distinct productivity and a reasonably well defined major marine community/food web system.	• Northeast Newfoundland Shelf (2J3K) • Grand Bank (3LNO) • Flemish Cap (3M) • Georges Bank
Ecoregion	Within an EPU, geographical area with consistent physical and biological characteristics. Often corresponds to a broadly defined seascape and/or major habitat type/class; its precise delineation and extent can vary depending on data availability and the analytical criteria applied. It is within this spatial scales that more precise habitats can be identified (e.g. VMEs).	• Inshore areas in the Northeast Newfoundland Shelf • North region of the Grand Bank (~3L) • Top of the bank in Flemish Cap • Slope areas

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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. Analysis on benthic communities in Flemish Cap and NL

ToR 3.1.1. Epibenthic assemblages of the Tail of the Grand Bank and Flemish Cap (Northwest Atlantic)

Structure, composition and distribution of epibenthic invertebrate megafaunal assemblages in the international waters on the Tail of the Grand Bank of Newfoundland and Flemish Cap were investigated based on the analysis of trawl samples between 45 and 1400 m and 135 and 1500 m water depth respectively, and the key factors that shape their spatial distribution were identified. 287 depth-stratified random trawls were processed and all epibenthic invertebrate fauna retained by the nets were identified to the lowest possible taxonomic level, counted when possible and weighed. Faunal groups were identified using clustering algorithms based on species presence/absence and detrended correspondence analysis was used to ordinate the species data and correlate it with the abiotic variables. We examined the role of regional variables: depth, substrate type, water temperature and salinity, in shaping benthic community composition. And we quantified the relationship between recent (2001-2009) fishing intensity and benthic community structure. Benthic biomass was dominated by Echinodermata and Porifera, owing to the presence of large-bodied species in each of these groups. 439 benthic invertebrates were identified, 321 from the Tail of the Grand Bank and 288 from the Flemish Cap. Maximum number of species was found along the continental slope in both areas. A clear separation between three large groups of benthic fauna based on bathymetry and spatial distribution was found at major partitions: (I) the continental shelf of the Tail of the Grand Bank, typified by the echinoderms *Cucumaria frondosa*, and *Echinarachnius parma*; (II) the upper slope of the Grand Bank and top of Flemish Cap, typified by the sponges *Radiella hemisphaerica*, and *Iophon piceum* and by the sea star *Ceramaster granularis*; and (III) the lower slope of the Grand Bank and Flemish Cap, typified by the sea urchin *Phormosoma placenta* and the sea pens *Anthoptilum grandiflorum* and *Funiculina quadrangularis.* At minor partitions, depth and sediment type related to the oceanographic conditions were important determinants. The assemblages found showed a similar pattern to the fish assemblages described in this area where the major clusters were “associated” with bottom depth and oceanographic features. High fishing was associated with the clusters with the least spatial cohesion which may reflect the different pressures exerted on this anthropogenic driver from those of the environmental factors which shape the majority of the assemblages. This study fills an important gap in our knowledge of benthic communities in this area of the northwest Atlantic Ocean that bodes well for incorporating benthic data into ecosystem-based models in future for fisheries management and for achieving conservation objectives aimed at protecting representative areas.

ToR 3.1.2. Update on box-core community analyses in the NRA

Analysis of the fauna extracted from box-core samples taken during the NEREIDA surveys is complete at a coarse level of taxonomic resolution (see ToR 1.1.1). Work on the identification of organism at finer taxonomic resolution is ongoing, with two PhD students at the University of Oxford presently working on the Polychaetes and the Peracarid crustaceans. Results of their work are due in 2016/17.

ToR 3.2. Progress on expanded single species, multispecies and ecosystem production potential modelling

ToR 3.2.1. Progress report on the modelling Flemish Cap foodweb

3.2.1.1. GADCAP: A Gadget multispecies model for the Flemish Cap

Motivation

The opposite trends observed in the survey biomass indices of cod, redfish and shrimp since early 1990s (Pérez-Rodríguez et al, 2011a) in conjunction with the strong trophic interactions and feeding consumption over this period (Pérez-Rodríguez et al 2011b; Pérez-Rodríguez et al, 2012; González et al, 2012) highlighted the need for considering a multispecies approach in the management of these commercial stocks. This was already expressed in the Fisheries Commission request 10 of year 2011 (NAFO, 2011):

"On the Flemish Cap, there seems to be a connection between the most recent decline of the shrimp stock, the recovery of the cod stock and the reduction of the redfish stock. The Fisheries Commission requests the Scientific Council to provide an explanation on the possible connection between these phenomena. It is also requested that SC advises on the feasibility and the manner by which these three species are maintained at levels capable of producing a combined maximum sustainable yield, in line with the objectives of the NAFO Convention."

During the 4th Meeting of the WGEAFM (currently WGESA), a generalized predator-prey Lotka-Volterra model including cod, redfish and shrimp was presented (NAFO, 2011). Results from this first multispecies approach although with important assumptions, already highlighted the importance of considering multispecies interactions when estimating maximum sustainable yields for all three stocks.

Previous studies have pointed to the high isolation of the shallowest Flemish Cap demersal stocks (Templeman and Fleming 1963, Konstantinov 1970, Morgan and Bowering 2004, Bentzen et al. 1996, Carr and Marshall 2008). The Flemish Pass would hinder migration of adult individuals, while the quasi-permanent anti-cyclonic gyre that could retain eggs and larvae and limit the exchange with adjacent populations (Konstantinov et al. 1985, Borovkov et al. 2006). These features are important from a demographic and genetic perspective, and would support the development of a multispecies model for the Flemish Cap, as well as being in line with the delineation of the NAFO Ecosystem Production Units.

Financial support: Marie Curie program

The European Union, through its Marie Curie program is currently financing Alfonso Pérez Rodríguez with a two years Postdoc contract to develop the project GADCAP, a Gadget multispecies stock assessment model for the cod, redfish and shrimp Flemish Cap stocks. This project will be developed along years 2014 and 2015, in Bergen, Norway, under the supervision of Daniel Howell at the Institute of Marine Research.

Goals

The global goals of GADCAP are:

Objective 1: Single species models

Assemble for cod, redfish and shrimp independent single species models considering all landings, biological and oceanographic data and survey indexes of biomass and abundance.

Objective 2: Multispecies model

Combine the three single species models to create a unique multispecies model that evaluates the predatory and competitive interactions between species but considering the combined effect of fishing on the different species.

Objective 3: Model projections

Project population dynamic and future state of all the species modeled under different recruitment levels, species interactions and variable fishing pressure.

Collaborators

There is a large number of people from a suite of institutions collaborating on this project:

- Spain:
  - IIM-CSIC: Fran Saborido-Rey, Rosario Domínguez, Antonio Vázquez and Mónica Mandado.
  - IEO, Oceanographic Centre of Vigo: Fernando González, Diana González and Mikel Casas.
- Portugal:
  - IPMA: Ricardo Alpoim and Antonio Avila.
- Canada:
  - DFO: Mariano Koen-Alonso and Joanne Morgan
- Norway:
  - IMR: Daniel Howell and Bjarte Bogstad.

Data

A very important data source is the scientific surveys conducted in the Flemish Cap from 1977 to 2014. From 1977 to 1985 the Department of Fisheries and Oceans of Canada DFO conducted annual bottom trawl surveys on February. Since 1988 to nowadays a new series of bottom trawl surveys started, conducted annually on July and result of the collaboration of the Institute of Marine Research of Vigo (IIM-CSIC), the Fisheries Technological Institute of the Basque Country (AZTI-Tecnalia up to 2008), the Spanish Institute of Oceanography (IEO) and the Portuguese Sea and Atmospheric Institute (IPMA). Data were collected in these surveys in a set by set basis: catches by species, size distribution, biological sampling (maturity state, otoliths (ageing), size, and weight), stomach content and oceanographic conditions.

In addition to the database from the EU and DFO surveys, scientist observers onboard of Spanish commercial vessels have collected information about catches, size distribution and biological data that will be the basis to model the fishing activity in the Flemish Cap, in conjunction with the aggregated information presented to NAFO by several contracting parties.

Gadget

Gadget (Globally applicable Area Disaggregated General Ecosystem Toolbox) is a powerful and flexible framework that has been developed to model marine ecosystems within a fisheries management and biological context. Gadget allows the user to include a number of features of the ecosystem into the model: considering one or more species, each of which may be split into multiple components; multiple areas with migration between areas. Different ecological and biological processes can be modeled, like predation between and within species, growth, maturation, reproduction and recruitment, including the effect of multiple commercial and survey fleets taking catches from the populations (Begley and Howell 2004).

Gadget works by running an internal forward projection model based on many parameters describing the ecosystem, and then comparing the output from this model to observed measurements to get a likelihood score. Parameters can then be adjusted and the model re-run, until an optimum is found, which corresponds to the model with the lowest likelihood score. This iterative, computationally intensive process is handled within Gadget using the Hooke & Jeeves and Simulation annealing search algorithms.

Gadget has predefined functions that allow the implementation of biological and ecological processes in several different ways (see Gadget userguide at http://www.hafro.is/gadget/userguide/userguide.html). Currently there exist seven different growth functions (some of them connect growth with food consumption); four functions to model maturation; functions that penalizes the spawning process with higher mortality and loss of weight; recruitment can be connected to the spawning stock in a closed life-cycle and migration to and/or out of the modeled area can be considered in the model. Prey-predator relations are specified by defining a suitability function, prey preference, consumption and feeding parameters. Currently there exist 7 suitability functions which define the relation between predator-prey lengths. The consumption, which determines how much of a given prey is consumed by the predator, not just produces a reduction in the prey abundance, but can also affect the growth of the predator depending on the growth function selected. The preference of the predator for the prey is represented with a functional response that relates consumption with the abundance of a prey.

In Gadget, each fleet is treated as a simplified "predator", it does not grow, nor mature, migrate, recruit or reproduce, it just 'consume' an amount of the "prey stocks", the targeted commercial species. The effect of each fleet in the model can be simulated in two different ways: by specifying the biomass of the fish that is caught by the fleet or by specifying a fishing effort parameter. The proportion of fish at different length ranges "consumed" by each fleet is estimated by means of a modeled suitability function.

Single species models

During the first year of the project, the main goal is the development of the three single species models. At this stage databases have been prepared for the modeling process, setting the structure of models and optimizing the values of parameters for most of the features that will be included in the multispecies model.

All single species models at this stage consider the period 1988-2012 (that will be increased up to year 2014) and are modeled in a seasonal basis, with Flemish Cap as a whole (i.e. not area differentiation is considered). The simple von Bertalanffy growth function is being used for all three stocks, although for multispecies model consumption and temperature will be probably included as drivers of growth (WeightJones growth function in Gadget). Maturation has been modeled with the fixedlength function for all the three species, which will be improved in future models modeling the maturation process with a sigmoid function. Changes in mortality and growth due to the spawning process are not being included. Although the simplest approach for recruitment is being considered at this moment (fitting recruitment as a parameter by year) a closed life-cycle connecting the SSB with recruitment will be proved at least for cod. In this project, migration from and towards the Flemish Cap will probably not be considered.

In relation to the structure of stocks, cod have been split only in mature/immature stocks due to the lack of size distribution by size from the EU survey. Redfish, which are actually three different species (*Sebastes mentella, S. marinus* and *S. fasciatus*), are being modeled at this stage together, although they have being split by sex since differences in growth and maturation have been observed between sex and size distribution is available for this stock. Shrimp has been split into male, female primiparous (immature female) and female multiparous (mature female).

For each species, considered fleets are trawlers and gillnetters for cod, trawlers for redfish (considering also another fleet which is the by-catch from trawl shrimp fishery) and trawlers for shrimp.

Search algorithms are the same in all three models, Hooke & Jeeves and Simulated Annealing.

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ToR 3.2.2. Global analysis of Ecosystem Production Potential (EPP)

3.2.2.1. Introduction

The WGESA initiative to determine Ecosystem Production Potential (EPP) within the NAFO area is related to a similar initiative to estimate EPP for most of the Large Marine Ecosystems around the globe (the exceptions are very high latitude systems where satellite coverage is problematic and some inland seas). This work is part of a prototype analysis commissioned by the Fisheries and Aquaculture Department of the FAO. This project – Developing New Approaches to Global Stock Status Assessment and Fishery Production Potential of the Seas – was designed to explore new approaches to (1) determining single-stock status with particular reference to assessments in data-limited situations and (2) developing estimates of ecosystem-level production potential. To meet the second objective, a prototype model of energy flow in fishery systems was developed. This model has also been employed by WGESA. The principal elements of the WGESA approach have been documented in previous reports to the Council. This section highlights some of the broader dimensions of the global initiative that complement the work now underway in WGESA.

3.2.2.2. Methods and Data Sources

For this analysis designated LMEs were used as strata (Figure 3.2.2.1). LMEs are differentiated by similar physical and ecological features, such as hydrography, productivity, and tropically dependent populations (Sherman & Alexander 1986a; Sherman 1991a), and account for approximately 80-90% of the global fisheries catch (Christensen et al. 2008). To account for some of the near shore versus offshore variability in production within some regions, each LME was subdivided using the 300 m isobath. The < 300 m subareas included the characteristically more productive continental shelf areas and the nearshore areas of the upwelling regions. In general, the > 300 m subareas were characterized by lower overall levels of production by microplankton. Inland seas and high latitude regions, including Hudson Bay, Black Sea, Arctic Ocean, Kara Sea, Laptev Sea, East Siberian Sea, Beaufort Sea, Chukchi Sea, and Antarctica, were not included in this analysis due to the seasonal effects of cloud cover and high solar zenith angles on estimates derived from satellite coverage in these regions.

Three of the LMEs in this global analysis: (1) Labrador-Newfoundland Shelf, (2) Scotian Shelf, and (3) Northeast U.S. Continental Shelf coincide with the area of concern in the WGESA analysis, although the WGESA analysis also examines the region in finer spatial detail.

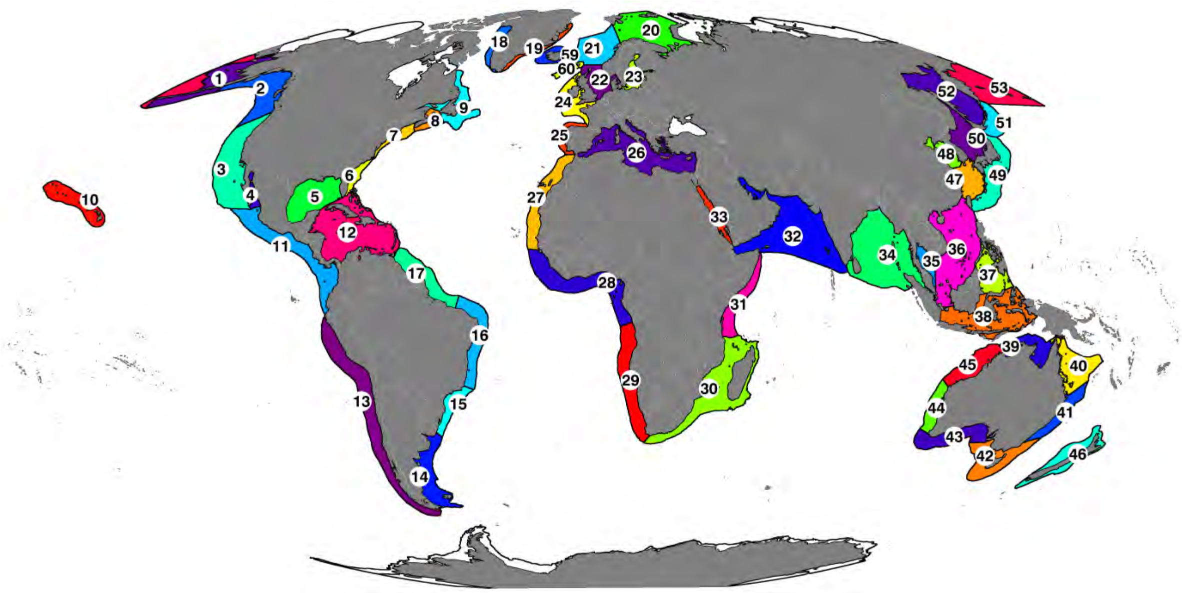

Figure 3.2.2.1. Strata used in estimating global ecosystem production potential based on LME boundaries (individual LMEs designated by color; LME numbers in circles.

3.2.2.2.1. Transfer Efficiencies

Ecosystem network models have now been applied for all the LMEs considered in this report using the well-known Ecopath-Ecosim (EwE; Christensen et al. 1992; 2005) formulation based on the original developments by Polovina (1982). To objectively assess trophic transfer efficiencies, 240 published Ecopath with Ecosim (EwE) models were compiled. Rather than assume or assign trophic transfer efficiencies at different steps in the food web for the models for each LME, these model estimates were used to define probability distributions characterizing transfer probabilities at different steps in the food web. The characterization of transfer efficiencies between discrete trophic levels based on these Ecopath models followed the approach of Ulanowicz (1993).

3.2.2.2.2. Primary production

Ocean color remote sensors provide an unprecedented view of the global ocean and are the only means to obtain basin-scale, synoptic high frequency measurements of global primary production. Annual estimates of primary production were calculated using data from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS, NASA) and a modified version of the Vertically Generalized Productivity Model (VGPM; Behrenfeld & Falkowski 1997). This modified VGPM model replaces the original temperature-dependent description of photosynthetic efficiencies with the exponential Eppley function (Eppley 1972).

To estimate the proportion of primary production attributed to the microplankton (> 20 µm) component, first the microplankton total chlorophyll *a* (i.e. biomass) fraction was estimated, and then an empirical relationship to calculate percent of microplankton production was applied. Recent advances in ocean color remote sensing have led to the development of several phytoplankton size class (PSC) and phytoplankton functional type (PFT) models. The diatom and dinoflagellate biomasses were combined to represent the microplankton fraction and the remaining functional groups were combined in the nano-picoplankton (< 20 µm) group.

3.2.2.3. Results

3.2.2.3.1. Primary Production

Chlorophyll concentration and primary production are highest in coastal locations characterized by important inputs of nutrients from land and strong mixing processes driven by winds and tides (Figure 3.2.2.2). High chlorophyll and production levels are concentrated in upwelling regions. Overall primary production is dominated by nano-picoplankton production, especially in the deeper coastal locations and the ocean basins. Within the 300 m isobath, microplankton production accounted for 25.1% of the total production on average. For deeper water components (>300 m) within individual LMEs, microplankton production accounted for 20.1% of the total production. As expected, the microplankton contribution to production was smallest (14.2%) in the open ocean regions outside LME boundaries

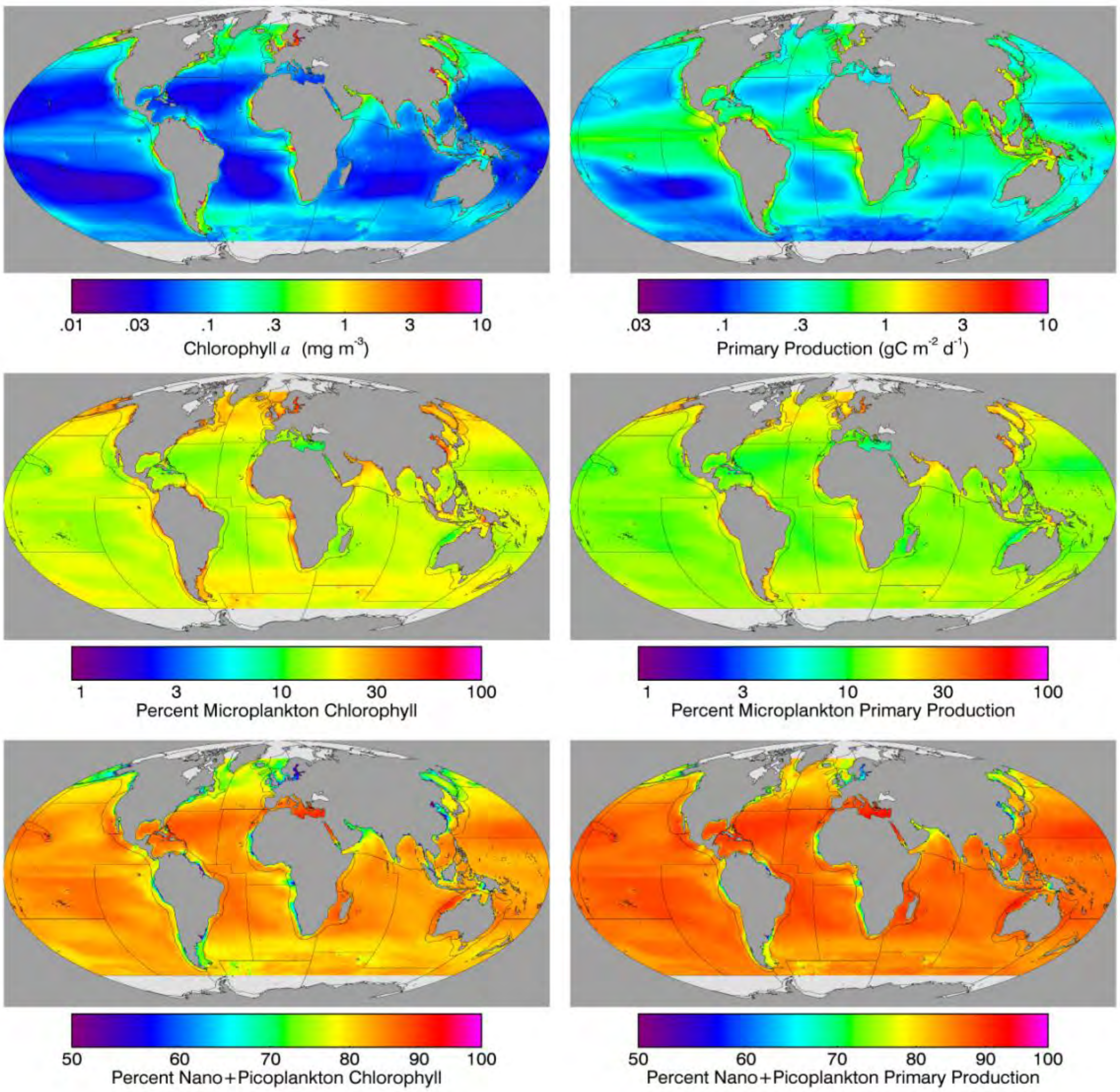

Figure 3.2.2.1. Distribution patterns for total chlorophyll a (mg m^{-3}) and primary production (g C m^{-2} d^{-1}) (upper); percent microplankton chlorophyll a and primary production (middle); and percent nano-picoplankton chlorophyll a and primary production (lower).

3.2.2.3.2. Production by Functional Group

Production estimates for the major functional groups of potential or realized importance to harvesting are provided in Figure 3.2.2.3 by LME. Recall that individual species can be represented in more than one trophic level compartment, reflecting both ontogenetic shifts in diet and mixed or omnivorous feeding strategies. Characteristically high production levels for these groups are found in the dominant upwelling regions of the world ocean and in regions where at least seasonal upwelling patterns are important (e.g the Arabian Sea). Western boundary current regions are characterized by moderately high production levels (e.g. the Oyashio and Kuroshio Current systems, the Northwest Atlantic LMEs and the Agulhas Current region). Intermittent and localized upwelling patterns in these regions, coupled with high nutrient concentrations in several of these systems, contributes to relatively high production levels.

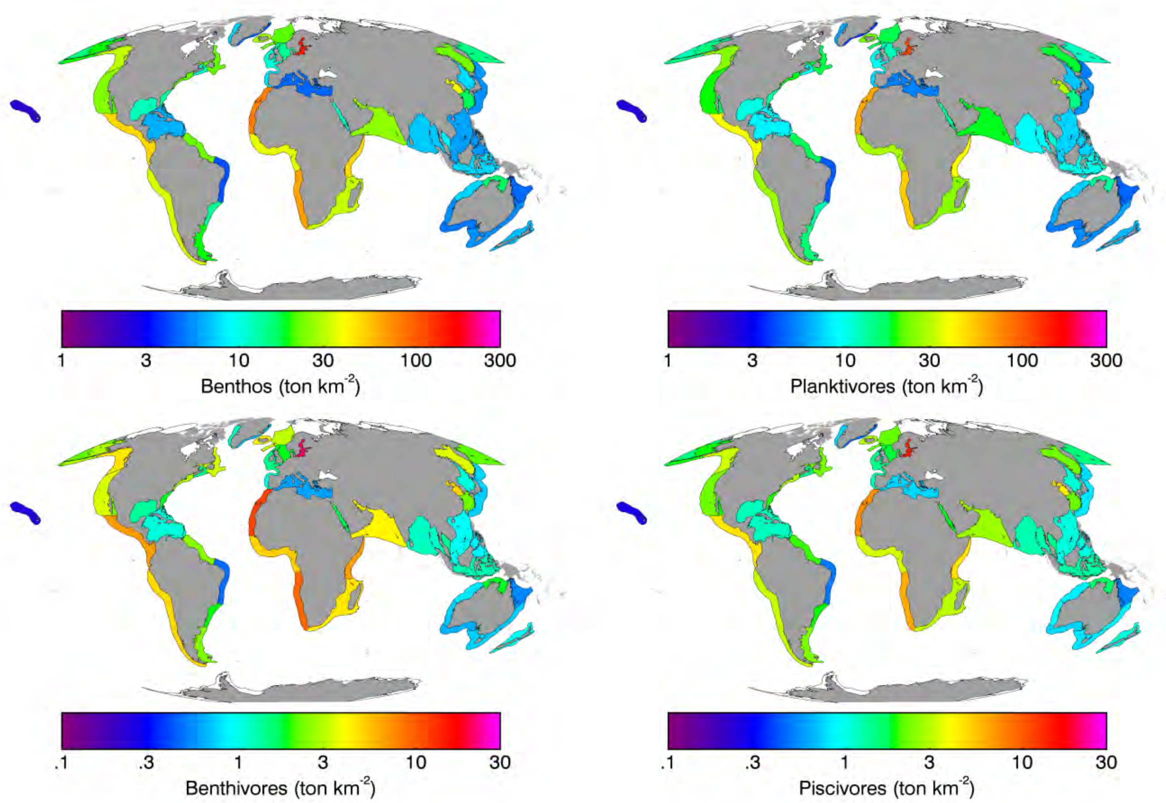

Figure 3.2.2.3. Estimated production levels (t km^{-2}) in the absence of exploitation by functional group for LMEs represented in this study. Note change to logarithmic scale for the benthivore and piscivore functional groups.

3.2.2.3.3. Fishery Production Potential

Estimates of fishery production potential depend on the available production at different trophic levels, the proportion of the production comprising species suitable for harvest (including considerations of species composition, marketability, and economic efficiency of harvesting operations) and the determination of sustainable exploitation levels. Estimates of the overall available production by ecotype and functional group for potentially harvestable components of the LMEs were developed.

An overall potential yield of approximately 140-180 million tons for the benthivore, planktivore, and piscivore functional groups for the LMEs considered here was estimated. In addition a potential yield of approximately 50 million tons of benthic organisms is projected if up to 10% of the benthic production is suitable for harvest. Although this level of benthic fishery yield may not be fully attainable by capture fisheries under current market preferences and economic conditions, it was noted that the energetic pathways supporting natural benthic production could also potentially support enhanced mariculture production for molluscs in particular. Aquaculture production has been rapidly increasing (FAO 2012) and although freshwater aquaculture remains dominant, important increases in mariculture are possible but would of course require adequate environmental controls.

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ToR 3.2.3. Ecosystem Production Potential (EPP) and Fisheries Production Potential (FPP) for Northwest Atlantic ecosystems: progress to date and guidelines for ecosystem level total catch ceilings

3.2.3.1. Introduction

The NAFO Roadmap to EAF addresses sustainability of fisheries exploitation as a 3-tier process (NAFO 2010a, 2012, 2013a). The first step is the definition of an ecosystem-level ceiling for total catches in a given ecosystem. Fulfilling this step requires two basic elements, a) the definition of an ecosystem-level management area that is considered a reasonable approximation of the underlying ecosystem production unit, and b) an estimation of the maximum level of total fisheries removals that the ecosystem in that defined area can tolerate without compromising its structure and functioning.

Regarding the definition of ecosystem-level management units, WGESA has carried out a series of spatial analyses (generally referred as "ecoregion analyses") which have allowed to a) define a simple hierarchy of spatial scales for developing ecosystem summaries and management plans, and b) identify candidate ecosystem-level management units which are consistent with current understanding of ecosystem structure (see ToR 2.1 for details). The defined spatial scales hierarchy captures major levels of ecosystem organization in space, while provides a limited-enough number of spatial resolutions for the management system to handle in practice. The proposed management areas capture the core of the underlying ecosystem production units, but also respect, whenever feasible, existing management boundaries; this should allow for an easier transition from current single-species management practices into more integrated ecosystem-based approaches by leveraging as much as possible on existing databases, assessments, and management procedures.

With respect to the estimation of ceilings for total catches at the ecosystem level, WGESA has been developing Ecosystem Production Potential (EPP) models which provide estimates of the maximum level of productivity that could be expected from the ecosystem (NAFO 2012, 2013b, Koen-Alonso et al. 2013). These estimates of EPP provide the basis for estimating the maximum amount of that productivity that could be sustainably taken by fisheries if the ecosystem were producing at its maximum potential; this upper limit of fishing exploitation is referred to as Fisheries Production Potential (FPP). This approach to estimate FPP using EPP models is consistent with analyses done by FAO to estimate global fisheries production potential (Rosenberg et al. 2014, see ToR 3.2.2 for a summary of this work). However, FPP estimates assume that the ecosystem is fully functional, and that all the primary production in the system is effectively transferred to the rest of the food web. This assumption may be reasonable in some cases, but not in others. Therefore, defining ecosystem level ceilings using FPP estimates also requires assessing if this assumption holds; if not, the actual ecosystem level ceiling would be some fraction of FPP.

In this context, the objectives of this ToR are to update the existing FPP estimates using the Ecosystem Production Units (EPUs) defined in ToR 2.1, and to provide some initial guidelines for total catch ceilings for some of these EPUs on the basis of the EPP and FPP results. The work was focused on the Newfoundland Shelf, Grand Bank, and

Flemish Cap EPUs due to its relevance for NAFO-managed stocks; EPP and FPP were also estimated at the bioregion level for the Scotian Shelf and US northeast continental Shelf for comparative purposes.

3.2.3.2. Ecosystem Production Potential (EPP) model structure

The EPP model is a simple food web model that describes the flow of energy in the ecosystem (Fig. 3.2.3.1). Because of its simple structure, and the fact that the initial input for the model is the estimated primary production at the ecosystem level, this modelling approach allows representing the production of the entire biological system under basic constraints derived from first principles (e.g. conservation of biomass, simple thermodynamics).

The current version of the model (Koen-Alonso et al. 2013, Rosenberg et al. 2014, Fogarty et al. in press) recognizes two avenues for transfer of primary production in the system, the metazoan grazing food web tracking the production from microplankton (phytoplankton cells > 20 μm; principally diatoms and large dinoflagellates), and the production through the microbial loop, which originates with combined nanoplankton (2-20 μm) and picoplankton (< 20 μm) production (i.e., nano-picoplankton in Figure 3.2.3.1). The metazoan grazing food web also distinguishes the two "classical" energy pathways of this food web, the benthic and pelagic pathways (Figure 3.2.3.1).

The functional groups represented by the nodes in the food web model (Figure 3.2.3.1) do not correspond to taxonomic groups. In the case of the upper trophic level nodes, individual taxa may occupy more than one of them, reflecting both ontogenetic shifts in diet, and generalist feeding strategies.

In terms of implementation, the areas considered in the current exercise correspond to the Ecosystem Production Units (EPUs) identified in ToR 2.1(Figure 2.1.4). Given their relevance for NAFO-managed stocks, model implementation was focused on the Newfoundland Shelf, the Grand Bank, and Flemish Cap EPUs; the Scotian Shelf and the US northeast continental shelf were also included, but the models were run at the bioregion level for comparative purposes. The parameterization of the models themselves was similar to previous exercises (NAFO 2013b, Koen-Alonso et al. 2013).

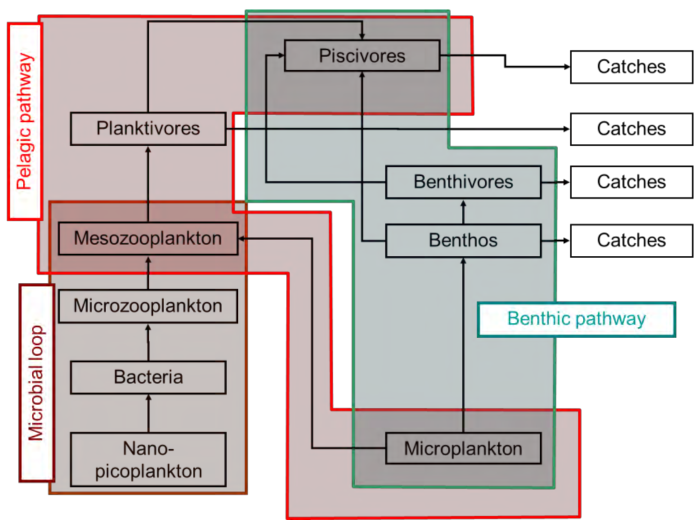

Figure 3.2.3.1. Food web structure employed in this analysis. Nano-picoplankton, bacteria, and microzooplankton comprise the microbial food web in this representation. The classical grazing food web is fuelled by microplankton production and is represented by the pelagic and benthic pathways. Species characterized by ontogenetic shifts in diet and/or mixed feeding strategies can occupy multiple compartments in this representation.

3.2.3.2. Estimation of Fisheries Production Potential (FPP)

The current implementation of the model assumes that fishing can target species in four model compartments, benthos, benthivores, planktivores, and piscivores (Figure 3.2.3.1).

As in previous exercises (Koen-Alonso et al. 2013, Rosenberg et al. 2014, Fogarty et al. in press), and following Iverson (1990), it was considered that the f-ratio (the ratio of new primary production to total primary production) in marine systems is a sensible upper limit (i.e. a limit reference point) for exploitation at the ecosystem level. Since there are limited direct estimates of the f-ratio for large marine ecosystems, the ratio of microplankton production to total primary production was adopted as a first-order approximation. On this basis, exploitation rates of 20-30%

were selected as limit reference points for exploitation. These exploitation rates were used to derive initial FPP values, but in the case of benthos and planktivores, further reductions to the estimated FPPs were applied by considering that many species included in these groups are not currently of commercial value. It was assumed that only 10% of the benthos and 50% of the planktivores production were of interest to harvesters.

Production of benthivores and piscivores (Figure 3.2.3.1) was also combined to better reflect the overall fisheries production potential of demersal species as a generic target group for fisheries. It is important to highlight that these Standard Demersal Components (SDC) include traditional commercial groundfish species like Atlantic cod and American plaice which may vary in their reliance on benthos as they grow, but also commercial shellfish like shrimp and snow crab. The amalgamated SDC group is better suited for comparisons with catch levels which are often dominated by groundfishes and shellfish, and because a number of piscivorous species also prey on benthic organisms and have broadly omnivorous feeding patterns.

3.2.3.3. Ecosystem and Fisheries Production Potential results

In terms of total heterotrophic production (trophic levels 2+), there were clear differences in total annual production potential (Figure 3.2.3.2). These differences in production potential were driven by the different areal extents of these systems; when the production potential density (i.e. production potential per unit area) is considered, all systems show a more similar production capacity, although the results suggest a latitudinal cline in production potential density (Figure 3.2.3.2). Northern systems appear to have lower production capacity than southern ones.

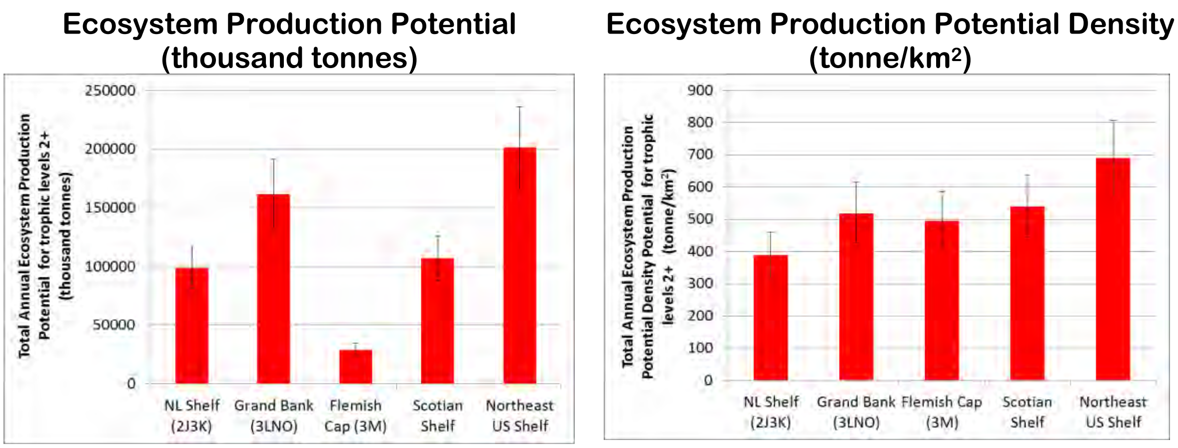

Figure 3.2.3.2. Estimates of total annual ecosystem production potential for trophic levels 2+ (i.e excluding primary producers). The left panel indicates the absolute estimate for the total ecosystem, while the left panel indicates the production potential density (i.e. per unit area). Bars correspond to medians, while error bars correspond to the 25-75% quantile interval.

In general, fisheries production potential showed a similar pattern as total ecosystem production potential (Figure 3.2.3.2). Major differences in FPP were associated with the area of the ecosystems, but the FPP densities were very similar (Figure 3.2.3.3). Overall, the uncertainty around FPP estimates was higher than the one estimated for total ecosystem production potential. This is to be expected; total ecosystem estimates integrate production from all components of the system, and hence, are unaffected by distribution of production among components. FPP estimates are derived from the production of some components of the system, so the variability in the distribution of production among them gets reflected in its uncertainty.

Unlike total ecosystem production, the FPP density does not suggest any clear latitudinal cline; FPP densities are very similar among ecosystems, and all of them well within their ranges of variation (Figure 3.2.3.3). If anything, these results hint to a slightly higher FPP density in the Scotian Shelf system (Figure 3.2.3.3).

The two exploitation rates considered as limit reference points in this analysis indicated total FPP densities of around 2-3 tonne/km^2, with a general variability ranging around 1-5 tonne/km^2. These figures are interesting when compared with Maximum Sustainable Yields (MSYs) obtained from aggregate biomass production models for a suite of marine ecosystem (Bundy et al. 2012). These aggregate MSYs rendered values in the order of 1-5 tonne/km^2, which is remarkably consistent with the figures obtained here, and suggests that the estimated magnitudes are likely robust ones.

The estimated FPP densities for SDC components were around 0.6-1 tonne/km^2, while their variability ranged around 0.4-2 tonne/km^2 (Figure 3.2.3.3). The dominant factor in the difference between total and SDC estimates is the contribution of planktivores (e.g. forage fishes) to the total FPP, although the benthos contribution is not trivial. The closer match between Bundy et al. (2012) estimates of MSY and total FPP, rather than SDC FPP could be explained by the inclusion of forage species like herring and capelin in the aggregate biomasses for some of the ecosystem considered by Bundy et al. (2012).

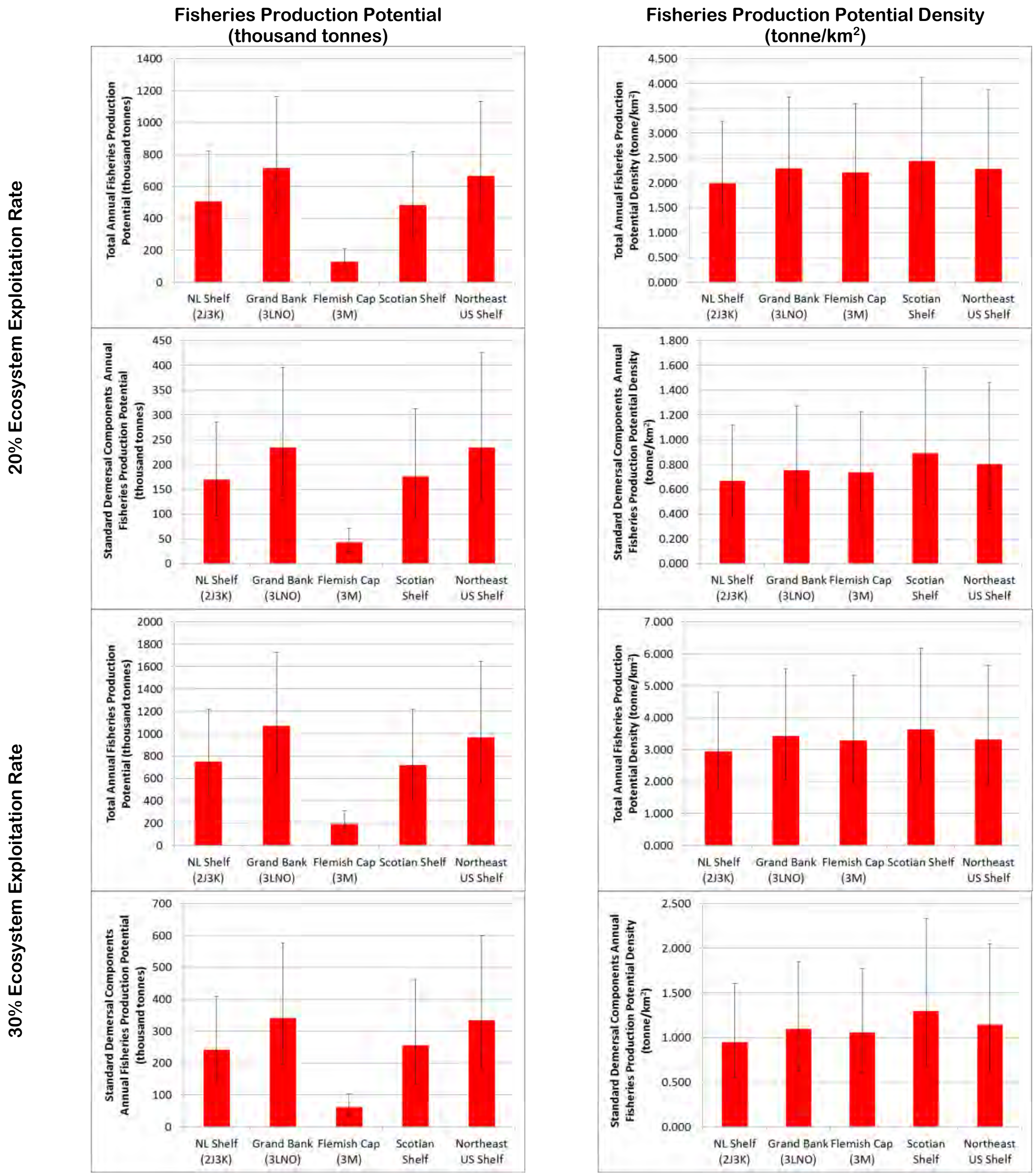

Figure 3.2.3.2. Estimates of total and Standard Demersal Components fisheries production potential considering under ecosystem exploitation rates of 20% and 30%. The left panels indicate the absolute estimate for the total ecosystem, while the right panels indicate the production potential density (i.e. per unit area). Bars correspond to medians, while error bars correspond to the 25-75% quantile interval.

3.2.3.3. Guidelines for ecosystem level total catch ceilings

Given the NAFO commitment to develop and implement the Roadmap to EAF, and considering that most stocks managed by NAFO inhabit the Newfoundland Shelf, Grand Bank, and Flemish Cap EPUs, it was considered pertinent to focus the attention on these EPUs when developing total ecosystem catch ceilings.

The existing version of the EPP models for the Newfoundland Shelf, Grand Bank, and Flemish Cap EPUs are considered adequate to start providing advice for total catch ceilings in these candidate ecosystem-level management units. Taking into account that this is the first attempt to explore these models and results in a management advice context, it is important to highlight the "proof of concept" nature of the exercise. Both managers and scientist at large need to develop a clear understanding of the outputs of the models, as well as its limitations, so that meaningful management measures can be developed based on this science advice. Therefore, the results on ecosystem-level catch ceilings provided here should be simply considered as guidelines for these ecosystem-level limit reference points, and not "set in stone" values. They are intended to help managers to begin assessing how current catch levels measure up to this additional management dimension, as well as stimulate the dialogue on how best to implement this new ecosystem-level limit reference point.

As initial step, it is relevant to compare historical catch levels with estimated FPPs (Figure 3.2.3.3). Although this comparison exercise was initiated by WGESA in 2013 (NAFO 2013b), FPP estimates have been updated based on the EPUs defined in ToR 2.1. The differences with the 2013 exercise are only minor. This analysis indicates that the total FPP for these ecosystems was never realized, but when catches are compared with SDC FPP, they clearly indicate that catches in the NL Shelf and Grand Bank EPUs were much higher than what these systems can sustain, while the Flemish Cap EPU saw catches at the level of its SDC FPP (Figure 3.2.3.3). Considering that most catches in these ecosystems are demersal species, the comparisons with SDC estimates are more meaningful for understanding the potential impacts of fishing in these systems. On this basis, the NL Shelf and Grand Bank EPUs were clearly over-exploited at the ecosystem level in the past, while the Flemish Cap was exploited at its limit.

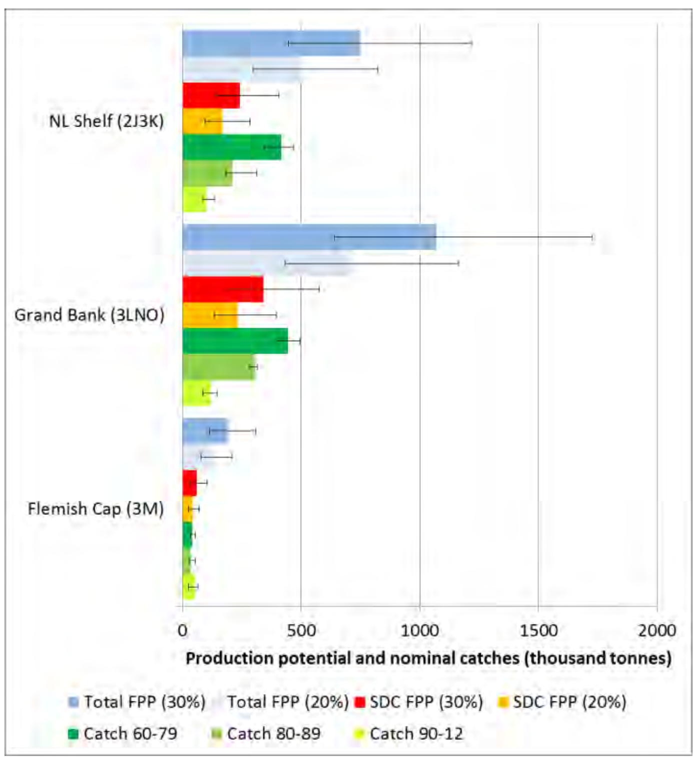

Figure 3.2.3.3. Comparison between catch levels and the corresponding fisheries production potential (FPP) for the NL Shelf, Grand Bank, and Flemish Cap Ecosystem Production Units (EPUs). Catch levels are characterized by the nominal total landings in three time periods (1960-1979, 1980-1989, and 1990-2012). Fisheries production potential is characterized by the estimated Total and Standard Demersal Components (SDC) Fisheries Production Potential for these EPUs under a 20% and 30% ecosystem exploitation rates scenarios. Bars correspond to medians, while error bars correspond to the 25-75% quantile intervals.

These ecosystems underwent important changes over the last 30 years, and current understanding indicates that a conjunction of fishing and environmental changes where the drivers behind them (e.g. NAFO 2010a, 2010b, 2011, 2012, 2013b, Koen-Alonso et al. 2010, Pérez-Rodriguez et al. 2011, 2012, Dawe et al. 2012, Buren et al. 2014a, 2014b).

In the NL Shelf and Grand Bank EPUs, these changes led to the collapse of the fish community, and current total fish biomass is estimated to be around 40-50% of the pre-collapse levels (NAFO 2013b, see also ToR 3.3.4 in this report). This indicates that the changes experienced by these systems eroded their production capacity, which remains impaired to this date. However, the build-up of some key groundfish stocks in recent years suggests that these systems may be recovering production capacity, and possibly moving towards pre-collapse productivity levels. Notwithstanding these positive signals, it cannot be assumed that these systems are currently producing at their full potential, and hence, their FPP values should be considered overestimates of the current maximum exploitation that they can sustainably tolerate. Therefore, ecosystem-level catch ceilings for these EPUs should be set at some fraction of the estimated FPP.

The ratio between production and biomass (P/B ratio) is a well-known quantity, widely applied in ecology to characterize productivity of individual taxa and aggregate functional groups (e.g. Allen 1971, Banshe and Mosher 1980, Peters 1983, Mertz and Myers 1998). Although actual P/B ratios are not expected to be constant, they are often considered “invariant enough” to be used as taxa-specific vital rates (Robertson 1979, Hopkins 1988, Randall and Minns 2000, Randall 2002). These constant P/B ratio parameters can be construed as representing the per capita production rate (actually, per unit of biomass) under average conditions. Henceforth, it would be reasonable to consider a relative constancy in the relationship between production and biomass at the overall ecosystem level. Taking into account that current total biomass in the NL Shelf and Grand Bank EPUs is in the order of 40-50% of pre-collapse levels (see ToR 3.3.4), and assuming a nearly constant P/B ratio at the ecosystem level, it would be reasonable to expect a similar reduction in the FPP of these systems. Following this rationale, a fraction of 50% was applied to calculate the guideline values for total catch ceilings (i.e. proxy for actual FPP) for the NL Shelf and Grand Bank EPUs. This fraction can be interpreted as a penalty factor associated with the current state of these ecosystems, which presents an eroded productive capacity.

Unlike the NL Shelf and Grand Bank EPUs, the total biomass of the Flemish Cap ecosystem is currently at or above the levels observed prior to the collapse in the early 1990s. Atlantic cod, a key groundfish species in the system, experienced declines that led to the closure of its fishery, but it had since recovered and the fishery was recently re-opened. Strong trophic interactions in this ecosystem have been associated with the fluctuations over time of core species like Atlantic cod, redfish, and northern shrimp. However, the overall biomass in the system, after experiencing lower levels in the 1990s and early 2000s, increased significantly since the late 2000s initially driven by increases in redfish, and later Atlantic cod. Current total biomass levels do not suggest that the overall productive capacity of this system is reduced, and hence, there is no need to apply a penalty factor to the FPP estimate to calculate a guideline value for total catch ceiling in this ecosystem.

Based on the above considerations, guideline values for total catch ceilings in the NL Shelf, Grand Bank, and Flemish Cap were calculated. The ceiling values for NL Shelf and Grand Bank were obtained by applying a penalty factor of 50% to the FPP estimates for these EPUs. The ceiling value for the Flemish Cap was based on the FPP estimate for this system without any penalty. A summary of these guideline ceiling values for total catches are summarized in Table 3.2.3.1 and Figure 3.2.3.4.

Table 3.2.3.1. Guideline values for total catch ceilings for the NL Shelf (NAFO Divs 2J3K), Grand Bank (NAFO Divs 3LNO), and Flemish Cap (NAFO Div. 3M) Ecosystem Production Units (EPUs). These guideline value correspond to the estimated Fisheries Production Potential (FPP) for these systems; FPP is presented as Total (Piscivores+ Benthivores + Planktivores + Benthos), and Standard Demersal Components (SDC) (Piscivores + Benthivores). FPP estimates were derived considering ecosystem exploitation rates of 20% and 30%. A 50% penalty factor was applied to the NL Shelf and Grand Bank EPUs due to current ecosystem state. Median nominal landings for different time periods are also shown for comparative purposes; these nominal landings coarsely correspond to SDC species.

	Median Fisheries Production Potential (FPP) (thousand tonne/yr)				Median Total Nominal Landings (thousand tonne/yr)		
	Total FPP (20%)	Total FPP (30%)	SDC FPP (20%)	SDC FPP (30%)	1960-1979	1980-1989	1990-2012
NL Shelf (2J3K) 50% penalty applied	253	374	85	121	416	210	102
Grand Bank (3LNO) 50% penalty applied	357	534	117	171	446	304	119
Flemish Cap (3M)	129	192	43	62	42	34	53

The Standard Demersal Components (SDC) is the subset of FPP that coarsely correspond to the species traditionally targeted by fisheries in these ecosystems. The comparisons between SDC guideline ceiling values and catches indicate that, for these three ecosystems, current exploitation is above their median SDC values under a 20% ecosystem exploitation rate, but still below the estimates under a 30% exploitation rate (Table 3.2.3.1). Although these values are only guidelines and refinements are to be expected, these initial results are deemed robust enough to warrant attention. They indicate that current catch levels are at the limit of what these ecosystems can sustainably tolerate. In this context, it would be advisable that any increase in Total Allowable Catch for a given stock should be compensated with a decrease in another, in order to avoid a net increase in total catches. Increasing total SDC catches could lead to ecosystem over-exploitation, potentially eroding the ecosystem productive capacity in the case of the Flemish Cap, and preventing (or even reverting) the current recovery/build-up being observed in the NL Shelf and Grand Bank.

Finally, these guidelines constitute a first step towards implementing the first component of the 3-tier process described in the NAFO Roadmap to EAF (NAFO 2010a, 2013a). Further refinements on this component are expected as work progresses. Current work involves improvements in the structure of the basic EPP model, as well as more detailed matching between target species with the FPP components (e.g. which species should be considered SDC, and which ones may be better classified as planktivores or benthos). Other elements also expected to inform this component in the future include updated versions of aggregate biomass production models for these systems (NAFO 2012, Bundy el al. 2012).

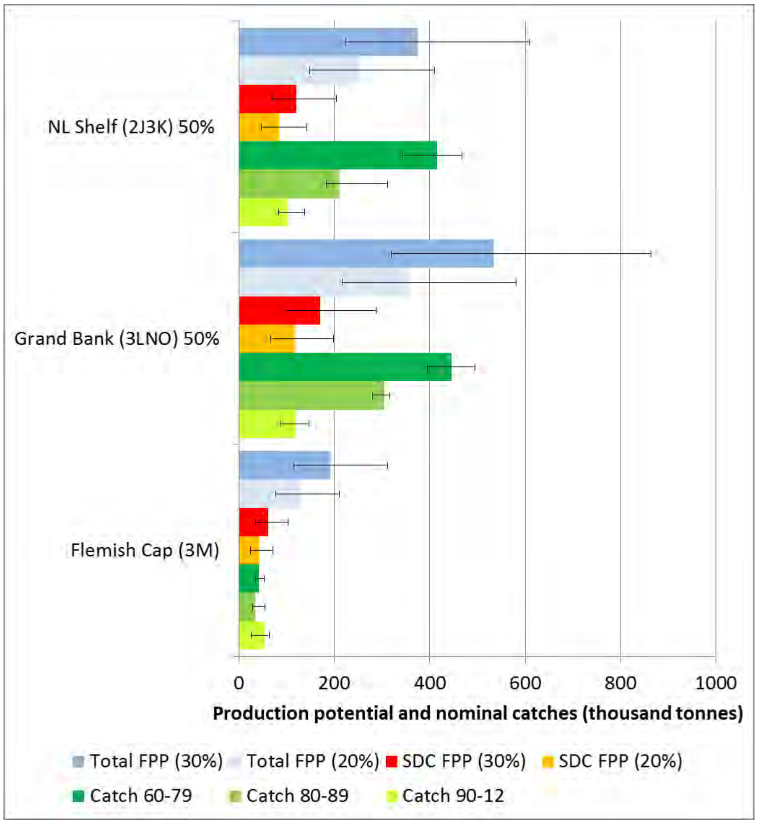

Figure 3.2.3.4. Comparison between catch levels and the proposed guidelines for total catch ceilings for the NL Shelf, Grand Bank, and Flemish Cap Ecosystem Production Units (EPUs). These guideline values are based on 50% of the FPP estimates for the NL Shelf, Grand Bank, and the full FPP estimate for the Flemish Cap (see text for rationale). Fisheries production potential is presented for Total and Standard Demersal Components (SDC), and was calculated considering 20% and 30% ecosystem exploitation rates scenarios. Catch levels are characterized by the nominal total landings in three time periods (1960-1979, 1980-1989, and 1990-2012). Bars correspond to medians, while error bars correspond to the 25-75% quantile intervals.

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ToR 3.3. Progress on multispecies and ecosystem analyses

ToR 3.3.1. Ecosystem research and modelling program for Greenland halibut in Greenland

3.3.1.1.Introduction

The Greenland halibut (*Reinhardtius hippoglossoides,*Walbaum) is widely distributed in the North Atlantic, being a deep-water boreal species (Kennedy et al., 2009), found along the west coast of Greenland where it occurs inshore in most fjords and offshore from at least 78°N to Cape Farewell at 60°N (Sünksen et al, 2009) and considered part of a larger stock complex inhabiting all the Northwest Atlantic (NAFO, 2005). The West Greenland Halibut (*WGH*) is a key species for food safety and the economy of Greenland: early studies by Jensen (1925, 1935) described some of the biological and life-history aspects of *WGH* (biometry, reproduction, early-life pelagic drift, spatial distribution, among other factors) and the importance of this species as a resource. A century after the first fisheries biological expeditions, the *WGH* remains as a high value target species on which exploitation has increased over the last decades (Gundersen et al., 2002). Also, it supports one of the major demersal fisheries of the Northwest Atlantic and its biological stock structure is an important management concern (Pomilla et al., 2008). Several contemporary studies have addressed the timing and spatial aspects of spawning on the shelf of the Davis Strait (Smidt, 1969; Gundersen et al., 2004; Simonsen and Gundersen, 2005), the northward transport of the early life stages due to the West Greenland Current, and the settlement of juveniles on the nursery grounds on the banks South of Disko Bay (Smidt, 1969; Riget and Boje, 1988; Boje and Simonsen, 2004). Also, migrations toward deeper offshore waters and back to the spawning grounds as they become mature (Smidt, 1969; Jørgensen, 1997), the potential contributions to the *WGH* physical environment by the colder Baffin Bay and relatively warmer Greenland currents (Ribergaard and Buch, 2004) and effects of temperature on the survival, density dependence of early age classes and individual growth have been proposed by several authors (Wieland, 2003; Wieland et al., 2004; Fonds et al., 1992; Burel et al., 1996; Otterlei et al., 1999; Sünksen et al, 2009). There is an increasing body of evidence suggesting that population dynamics are complex processes characterised by dependencies and strong correlations, lags, feed-back mechanisms, and -among other factors- speed changes in population growth due to the combined effects from the variable carrying capacity of the environment (i.e. the environmental forcing which may be reflected by system wide indicators) and differential responses to fishing mortality regimes (Solari et. al. 2010). However, there are three key aspects which remain unsolved for the *WGH*: (i) the environmental forcing (assuming memory, lags, the between and within years variability, minima, maxima in the series and possible feed-back mechanisms); (ii) the non-linear dynamical modelling (both uni/multivariate and system approaches) and (iii) proposals for sustainable fishing strategies, adapted both to the combined density-dependent and density-independent co-factors which may govern the spatio-temporal evolution of the system. The main purpose of this line of work is to improve our knowledge on halibut dynamics in order to contribute to advances both in the fields of modelling for sustainability, biological conservation and fisheries management in Greenland.

3.3.1.2. Assumptions

Some of the fundamental assumptions we make for such a framework are as follows: *(i)* The spatio-temporal evolution of population processes are non-linear dynamical systems, resulting from the interactions between the physical environment, biotic factors and harvesting regimes: such systems show strong dependencies to the external forcing, memories (on preceding values), lags, periodicities and feed-back mechanisms which are driven both by density-dependent and density-independent co-drivers; *(ii)* The carrying capacity (K_i) and other population parameters ("reference points") such as the rate of increase (r_i) and natural mortality (M_i) are variable and will show both ceiling and floor values and several inflection points due to changes in the speed or slope in the processes, as a consequence of an ever changing transition scheme; *(iii)* Population responses to the combined effects from the environment and fishing mortality (F_i) are differential, depending on whether the stock shows either (density-dependent and density-independent) positive (compensatory) or negative (depensatory) growth trends, (i.e. above or below linear and non-linear equilibrium values).

3.3.1.3. Assessment issues

WGH assessment is based on series of yearly mean values without taking into account the analysis for the variability in the data and the combined effects from the environmental forcing and past fishing mortality. The omission of analyzing maxima, minima, outliers and missing values, local trends, (uni- and multivariate) dependencies, memories, lags, spectrum and the decomposition of different frequencies or temporal patterns in the series: such features are common to dynamical systems and their omission from the analysis may result in the *(i)* underfitting of the (density-dependent and density-independent) population processes which leads both to *(a)* the underestimation of recruitment and the spawning and fishable stocks at the relatively higher abundances (i.e. under-exploitation) and *(b)* what is most important, to their over-estimation at the relatively lower abundances and overfishing (shown in Fig. 3.3.1.1). Also, a one year lag is used (catches are based on the estimated abundance from the preceding year whicg results in a mismatch as local trends and inflection points are omitted) and there is a three year pattern in the catch series which obeys to logistical requirements from the commercial fleet increasing, further the cummulative impact of fishing. Herein, the concepts of "higher" and "lower" abundances refer to both linear and non-linear equilibrium values. For further details on the assessment issues, see Solari (2014).

a) b)

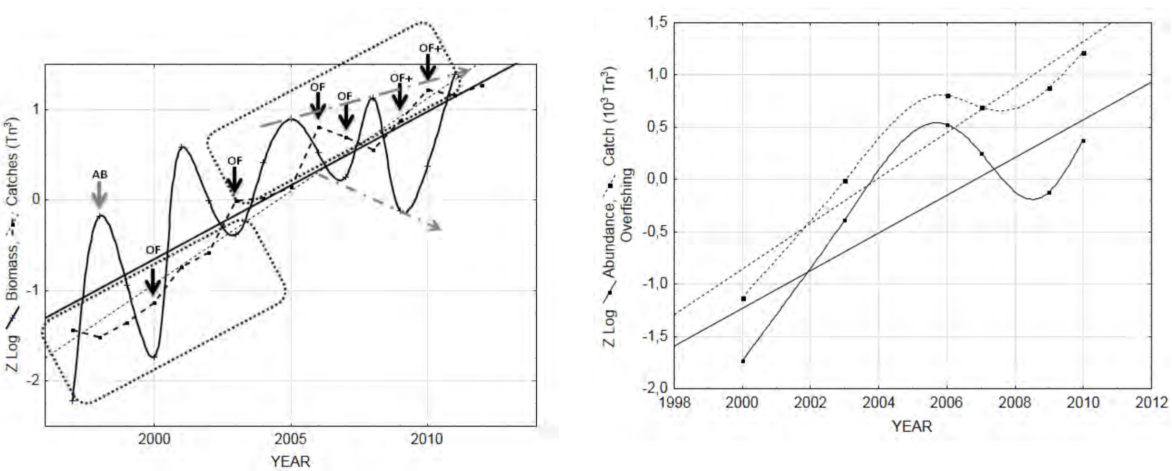


Figure 3.3.1.1. a) The log transformed (Log) and standardized (Z) West Greenland halibut (*WGH*) biomass and catches (10^3 Tn^3, thicker dashed line; data after Jørgensen (2012) and Jørgensen and Treble (2014)). AB and OF denote abundance and overfishing, respectively. Local trends in maxima (dotted-dashed lines with arrow) indicate the increasing amplitude (a density-dependent driven consequence of overfishing). Both simple linear, Bayesian and non-linear analysis suggest that the level of exploitation on the stock has been above equilibrium values, during the lower abundances periods since year 2003 (rectangular, dotted polygon). The statistical routines of the assessment and the lack of an operational population model based on full signal analysis are key factors contributing to the overfishing situation.**b)**. The temporal evolution of the overfishing (non-linear dotted line) upon the *WGH* stock represented by the log transformed (Log) and standardized (Z) *WGH* biomass (continuous lines) and catches (dotted lines) for the lower abundance (10^3 Tn^3) since year 2000. The straight lines are simple regressions. Overfishing increases with a significantly higher slope than abundance. Two distinct levels of overexploitation may be observed: before and after year 2006 in which a clear divergence started with further impact on the density-dependent processes (divergence between maxima and minima).

3.3.1.4. Current modelling

At the present time, there is no operational model for *WGH*. We used a *Bayesian/MCMC* approach with the modified Logistic equation incorporating a term which integrated either normally distributed random numbers (e^v) or the variability of the Sea Surface Temperature (SST_{SD}, lagged 6 years which is the approximate time for recruitment). It was suggested that the Bayesian framework may be useful, provided that the population model that underlies the simulations has the sufficient degree of resolution to describe the complex dynamics which may drive both recruitment and abundance. While the incorporation of the environmental forcing resulted in a forecasted biomass series that approximates non-linear approaches developed by the author on other species (Solari et al., 1997, 2004, 2010 and Solari, 2008), estimates and reference points were considered rough proxies (of proxies) and the resolution of the Bayesian method was insufficient to explain the (highly non-linear) mechanics behind the data. The Bayesian/Logistic approach is unable to discriminate between results from either random or auto-correlated residuals with a clear memory effect in the series (common in such dynamical systems). The (between years) variability is "crunched down" by the method which approximates series of means with no dispersion (linear methods may be inappropriate to address the variability in the signal unless they are carried out upon series of maxima and minima). The linearization of the highly non-linear signals may be a key factor contributing to overfishing at the lower abundances, as the stock is most vulnerable (i.e. in practical terms, a replication of the assessment based on series of mean values). To address these issues, we have proposed the use of memories longer than a year, lags, dynamic reference points, differential intrinsic rates of increase, variable carrying capacity, environmental forcing, dependencies and differential effects of fishing mortality to improve both the assessment and modelling on *WGH*.

Also, we are using the so called *Multi-Oscillatory System Approach* (*MOSA*), after Solari et al. (1997) which proposes recruitment/abundance to the population, area and fishery, production per Spawning Stock Biomass (*R/SSB*) and CPUE as a system or summation of non-linear functions allowing for stable, periodic and chaotic dynamics. The model incorporates variable carrying capacity, ceilings and floors, density dependent and density-independent compensation/s and depensation/s, variable population parameters, interdependencies and lags with system wide external variables and -among other factors- the combined effects from both the environmental forcing and differential effects of fishing mortality. The *MOSA* framework (validated on small and medium pelagics, demersals, tunas, sharks and cephalopods of commercial interest) is highly flexible and it can incorporate several co-factors allowing for a systems approach onto stock dynamics. Also, the frameowk is useful to explain causal mechanisms behind the data, estimate abundance in the short term (4-8 years) and propose sustainable fishing strategies adapted to a changing environment and past exploitation levels. Furthermore, there are spatial and geometric spin-offs which may be used for a non-linear spatial management of the stock and be used by managers. A graphical representation of the model is given in Fig. 3.3.1.2. For further details, see Solari et al. (1997, 2004, 2010) and Bas et al. (1999).

a) b)

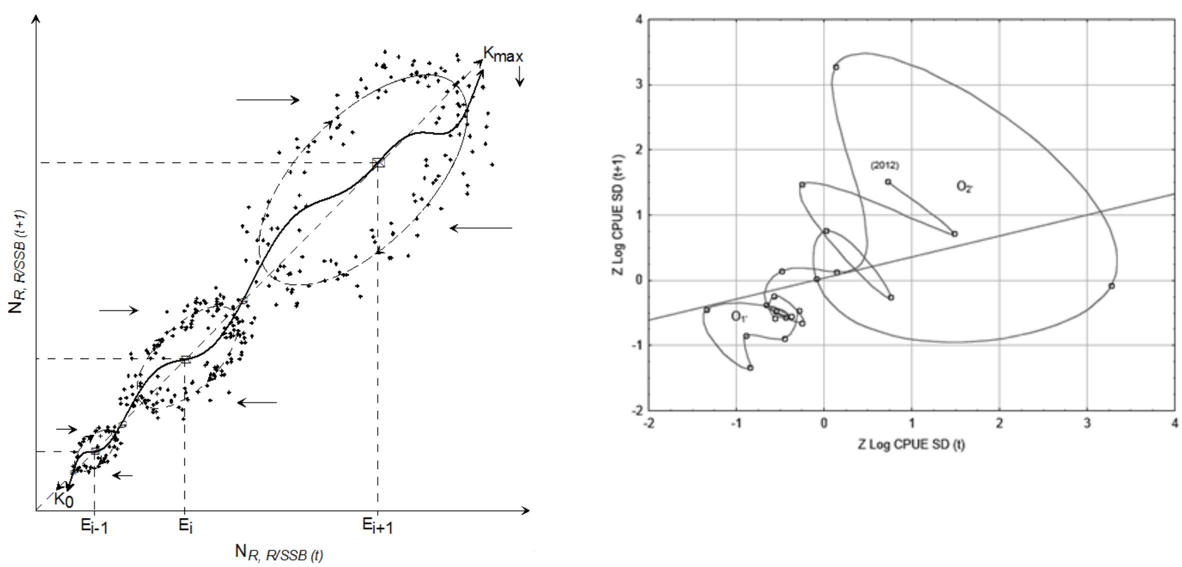


Figure 3.3.1.2. a). The *MOSA* (Multi-oscillatory System Approach) after Solari et al. (1997). The framework (a *GAM*) allows for temporal, spatial and geometric approaches both for the scientific community and personnel without mathematical background. The dynamical continuum (represented by the non-linear fit and overall linear equilibrium values) consist of several orbits of stability with corresponding “steady states” (E_i), maximum carrying capacity (K_{max}) and minimum viable population (K_0). Also, every orbit will be limited by a local ceiling (K_i) and floor (K_{0i}). Arrows indicate positive (→) and negative (←) growth. **b)**. The phase plane (lagged 1 year) of the log transformed (Log) and standardized (Z) standard deviations (SD, dispersion of the signal with auto-correlated residuals, around the mean) of Catch Per Unit Effort (*CPUE*) for the *WGH* in the *NAFO* Area *A0B* and years 1990-2012. Amplitude changes between both orbits of stability ($O_{1'}$ and $O_{2'}$) show the variable carrying capacities (ceilings), density dependence and dynamical similarity at two distinct levels of numbers ($p<0.05$). The relationship validates the concepts of variable carrying capacity and population reference points, memories, similar dynamics (at several scales of numbers), auto-correlated residuals and differential effects of fishing mortality.

3.3.1.5. Environmental forcing, life history and interactions

Fish stocks are are highly complex dynamical systems and population processes are strongly influenced by the physical environment. Sustainability and conservation require both the knowledge on the causal mechanisms and descriptions of the systems with flexible models with a high resolution. In order to seach for the basis for such a resolution from the field, we combine both in-situ, satellite and otolith data. We chose to work on environmental proxies which are known as meso-scalar, system wide variables which may affect the dynamics in the mixing layer, during the the drift of age classes 0 and 1. For instance, the North Atlantic Oscillation (NAO) and Optimum Interpolated Sea Surface Temperature (SST), as well as radar data on hydrographic phenomena.

There are several highlights from our results (April, 2015) which are both useful for development of models for the spatio-temporal harvesting strategies oriented toward sustainability and conservation: *(i)* Age 1 and abundance lagged 6 years (1997-2011) may be related ($p<.05$) to (a) the *variability* of the SST in the area of the early life drift and (b) recruitment and the fishable stock can be estimated from age class 1 (lagged 5 years); *(ii)* Abundance and CPUE were found to follow cycles at two levels of numbers and *(iii)* Relationships were analysed with lagged dependencies, memories and appeared to respond to trends in temperature minima. Partial results are shown in Fig. 3.3.1.3.

Furthermore, the life history changes (due to growth, recruitment, migrations, feeding, reproduction, among other processes) can be tracked through otolith biochemistry where *Ba*, *Sr*, *Mg*, *Mn*, *Ca* and *Ba* can provide accurate information as identifiers of population ecology (on-going work, see Fig. 3.3.1.4): the incorporation of such information into the modelling approaches may provide further insights on the variable reference points (such as r_i and K_i) due to differential population responses caused by pulses in the external environment and density dependent processes (in which fishing mortality can be a key co-factor).

a) b)

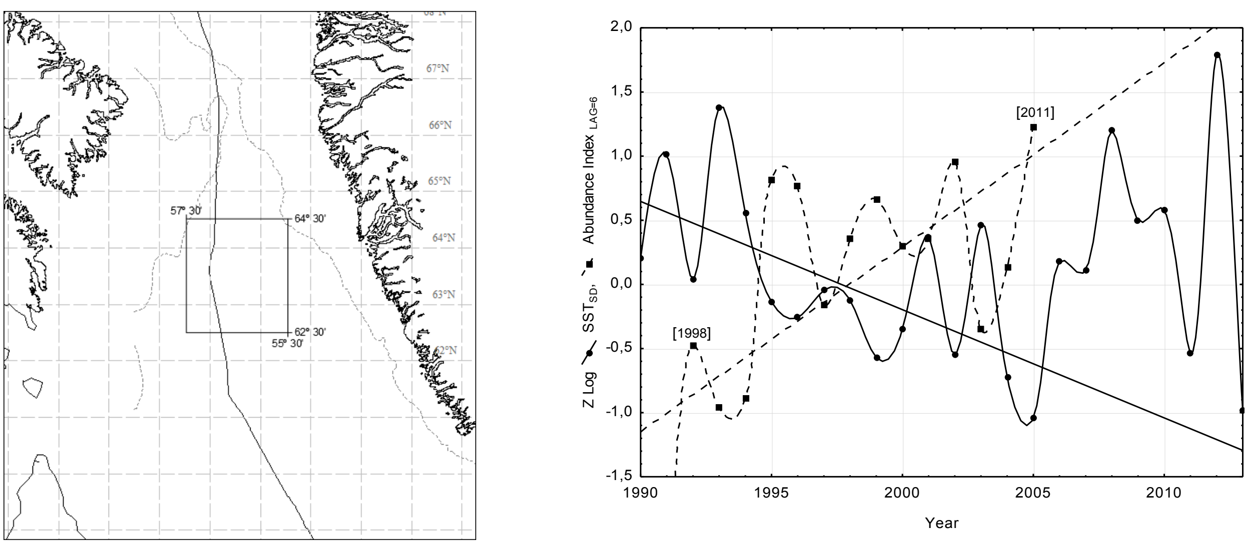
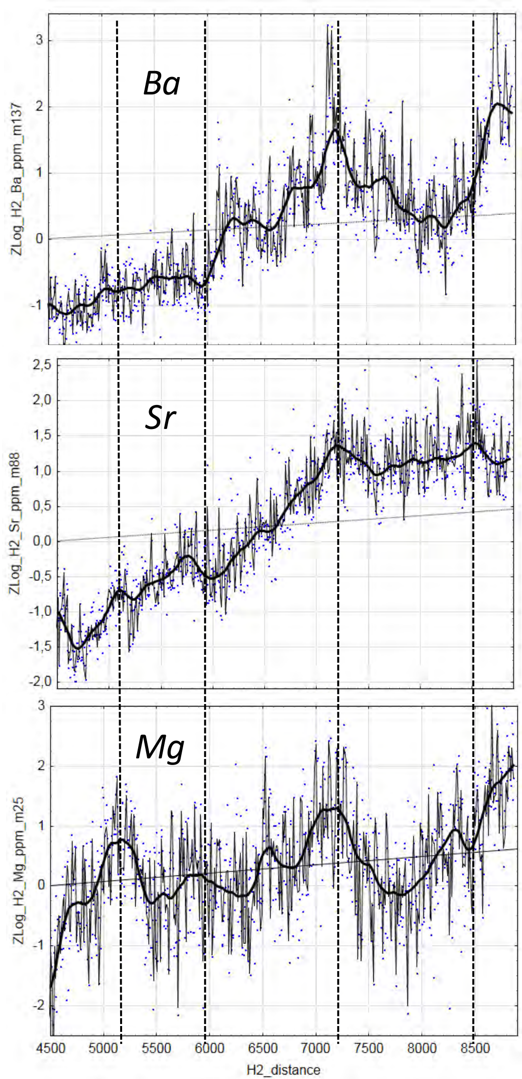


Figure 3.3.1.3. a). The *SST* was sampled from the juvenile drift area (Davis Strait) in the mixing layer: relationships between this environmental co-factor and Age class 1 (with lag 5) and overall abundance (with lag 6) were found to be significant ($p<0.05$). SST can be considered a meso-scalar environmental co-factor. **b)** The standardized (Z) log transformed (Log) SST variation (SST_{SD}, ^{o}C, continuous line), after IGOSS (2013) for the halibut juvenile pelagic drift area within Lat. 62.5-64.5$^{\underline{o}}$N and Long. 55.5-57.5$^{\underline{o}}$W and Abundance Index series (lagged 6 years) from 1997-2011 (N=15), interpolated by a cubic spline (dashed line). It is suggested that recruitment (at age class 6) and abundance in *WGH* may respond as the inverse to *SST* variations around the mean ($p< 0.05$) within the pelagic drift area. Floor and ceiling values in abundance are expected as the inverses of the external forcing. The positive and negative trends and amplitudes determined by the peak values may be useful to propose a (non-linear) range of sustainable catches adapted to the variable carrying capacity of the environment.

a)



b)

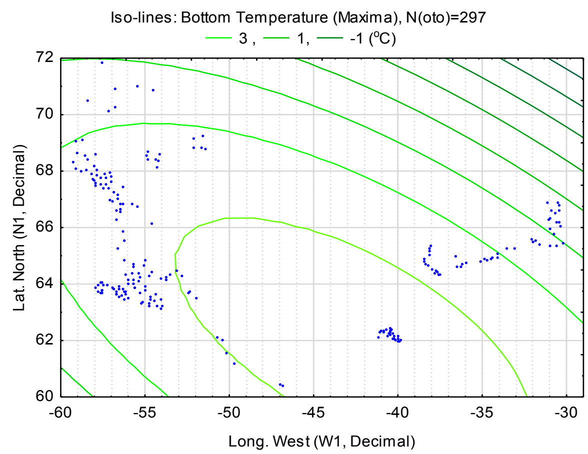


Figure 3.3.1.4. a) The Barium, Strontium and Magnesium (highly correlated, $p<.05$) series from a (circa) 20 years old halibut (Solari et al., ongoing work), **b)** Geographical reference as per Lat./Long. and bottom temperature ranges of the sampled *WGH* otoliths (N=297). Recruitment in this species appears to be highly correlated to trends in temperature minima in the mixing layer. Combining both ranges of temperatures from the early life drift and bottom of the sea (for adults) can be a key co-factor for the spatial management and sustainability of the fishable stock.

To retrieve records of life history events, movement and feeding behaviours, stored in annually grown layers in otoliths from *WGH* is carried out by using laser ablation and mass spectrometry. The method has been applied to wide variety of freshwater and marine fish in the past decade. Elements like Sr and Ba have been used to identify occupancy of marine, estuarine and riverine environments. Barium levels may also include information on feeding behaviors in addition to baseline water chemistry. Manganese shows a consistent signal in some species connected to concentrations in water and periodic excursions can identify exposure to anoxic conditions. Beyond this, elements such as Cu, Zn, Pb, Se, Cd, Li and Cs have been connected with specific environments connected to anthropogenic influence.

The series resulting from this method may contribute to advance the field of both fish stocks dynamics and fisheries management. We are sampling/analyzing otoliths from: *(i)* The largest possible individuals by gender (>70 cm of length) in order to extract as much information; *(ii)* Batches from contemporary surveys (NAFO 1-A, B and C, Disko Bay, Uppernavik and Ummanaq), covering both the in- and off-shore systems and high and low density areas. Furthermore, otoliths from the century old, historical collection at the *GINR* will be analyzed in order to find out whether we may detect life history changes in relation to relatively longer frequencies due to changes in the environment (climate change).

Species interactions, in a first stage, shall be addressed through the analysis of both shrimp and polar cod which appear to be key foraging resources for halibut for which we aim to incorporate abundance data on both species into the system modelling approach (on-going work, 2015).

The main challenge in this line of work will be to further identify the proxies on which we may rely our systems approach in order to reduce the number of parameters and reflect accurately the spatio-temporal evolution of the system.

3.3.1.6. Acknowledgements

This modelling work is possible due to a team effort (managers, surveys, data base management, otolith science, fish stock assessment, oceanography and other disciplines. Funding bodies are the *Government of Greenland* and the *GINR*. The following scientists, take part (alphabetically ordered): *N. Halden* and *Zhe Song* (geology/laser-spectro otolith readings, U. of Manitoba). From the the *GINR*: *Fish Division*: *N. Hammeken (survey data base); S. Jeremiasen and Jørgen Sethsen* (otolith collection/readings and by-catches); *R. Nygaard* (halibut assessment inshore); *H. Siegstad* (division management); *A. P. Solari* (modelling); *Climate Group*: *C. Arendt* (primary production) and *J. Mortensen* (oceanography). Personnel from the Danish Geological Survey (*GEUS*) and all of the colleagues at the NAFO/Ecosystem Science Assessment council.

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ToR 3.3.2. Marine mammals update

3.3.2.1. Summary

Over 30 marine mammals (pinnipeds and cetaceans) regularly occur in the northwest Atlantic. Good data on abundance, population trends and diet are available for only a few species (e.g. harp and hooded seals) while our knowledge of other such as the large cetaceans and other seals is less complete. For many, particularly species found primarily offshore, we know very little.

Although we have a large amount of data on the distribution of cetaceans interpreting these data and using them to determine abundance is limited because of the lack of sighting effort. A large scale survey, the Trans-North Atlantic Sighting Survey (TNASS), was carried out in 2007 to estimate abundance of cetaceans in Canadian waters. Small cetaceans such as the Common dolphin (*Delphinus delphis*) and White-sided dolphin *(Lagenorhynchus acutus*) were the most abundant species (~220,000). The minke whale (*Balaenoptera acutorostrata*) was the most abundant (~20,000) large cetacean (Lawson and Goselin, unpublished data). The vast majority of cetaceans winter in southern waters, migrating northward to feed during the spring and summer. Lower than expected numbers were observed on the Labrador shelf during the 2007 surveys, likely due to a delay in the timing of the northward migration.

Two species of seals are common within the NRA, the harp seal (*Pagophilus groenlandicus*) and the hooded seal (*Cystophora cristata*). Harp seals are the most abundant marine mammal in the North Atlantic. The NW Atlantic population is migratory, summering in the waters of the eastern Canadian Arctic and west Greenland. Harp seals winter off Newfoundland and in the Gulf of St. Lawrence where they give birth on the pack ice in late February and early March. Harp seals occur primarily on the Canadian and Greenland continental shelves although they occasionally cross the Labrador Sea. The NWA harp seal population increased from less than 2 million seals in the early 1970s to a little over 7.5 million by 2008. Since then, the population has remained relatively stable and was estimated to be 7.4 million (SE=656,000) in 2014 (Hammill et al 2014).

Hooded seals are the second most abundance pinnipeds in the northwest Atlantic. Like harp seals, hoods summer in the Arctic (primarily Greenland and Baffin Bay) and migrate southward for the winter. However, hooded seals utilize the deeper water along the edge of the continental shelves and Labrador Sea. The last assessment of hooded seals was carried out in 2006 when the population was estimated to be 593,500 (SE 67,200) (Hammill and Stenson 2006).

Prey consumption by marine mammals in Div. 2J3KL was estimated using a bioenergetics model that integrated information on the numbers at age, age-specific energy requirements, seasonal distribution, and diet. Energy requirements were estimated using a simple allometric model based on body mass. For harp and hooded seals, the proportion of energy obtained in Div. 2J3KL was estimated using data obtained from satellite telemetry and traditional tagging studies. The diet of seals in nearshore and offshore waters during winter (October – March) and spring (April – September) was determined by reconstructing the wet weight and energy content of prey in stomachs collected in 1982 and 1986 to 2007. Uncertainty in the consumption estimates was approximated by incorporating the uncertainty in the numbers at ages, diets, energy requirements, and seasonal distribution.

Total prey consumption by Harp Seals in Div. 2J3KL during 2008 was estimated to be approximately 4.2 million metric tons (Stenson 2012). However, this estimate was imprecise with a 95% confidence interval (C.I.) being 3.2 million – 5.4 million tons. Consumption of individual prey species varied greatly depending upon the assumed diet. Using the same approach, hooded seals were estimated to consume 362,900 my in Div 2J3KL and approximately 36,000 mt in Div. 3M (Hammill and Stenson 2000). No recent estimates of hooded seals abundance or consumption are available.

The abundance of harp seals was updated recently. Using the same assumptions as in the previous analysis but applying the current estimate of abundance has reduced the mean estimate of consumption to 3.7 million mt. Data on the diet of harp seals between 2007 and 2011, and new estimates of size at age will be available to update this estimate of consumption further by the next meeting. It will also be possible to provide consumption estimates for additional areas (e.g. 2GH) as requested.

Although data on diets and seasonal distribution of cetaceans in 2J3KL are limited, preliminary estimates of prey consumption can be calculated (Lawson, unpublished data). Using the abundance estimates obtained from the 2007 surveys, diets from other regions and approximate timing of northern migrations, it is estimated that cetaceans consume ~1.8 million mt of prey/year in 2J3KL. However, this may be negatively biased as many of the cetaceans observed in more southern areas would likely move north into 2J3KL for at least part of the year. Including all of the cetaceans estimated to be in Canadian waters in 2007 increased the estimate of consumption to ~3.9 mt (Lawson, unpublished data).

The results of recent studies on the impact of climate change on harp seals were also presented. As the northern hemisphere continues to warm, declines in sea ice seriously impact species such as harp and hooded seals that rely on ice for reproduction and/or feeding. Unfortunately, little is known about the impact of climate change on ice-dependent species in sub-Arctic areas, even though the associated ecosystem changes are likely to be most rapid along the southern edge of the ice. Reduced seal ice during the spring has been shown to affect harp seals directly through increased mortality of young (Stenson and Hammill 2014). However, climate change can also impact indirectly through changes in prey and subsequent reproductive rates. Estimates of late term pregnancy and abortion rates of Northwest Atlantic harp seals were estimated from samples collected between 1954 and 2014 off Newfoundland. Since the early 1980s, pregnancy rates have declined while inter-annual variability increased with late term pregnancy rates among mature females falling to <0.3 in 2011. While the general decline in fecundity is associated with increased population size, including late term abortion rates captured much of the large inter-annual variability. Changes in abortion rates can be described by a model that incorporated late January ice cover and capelin biomass. It is likely that ice cover is also a proxy for ecosystem changes in prey (Stenson et al 2014). Thus it appears that the Northwest Atlantic harp seal population will be negatively impacted by the general warming trend and reduced ice coverage predicted under climate change scenarios.

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ToR 3.3.4. Fish community trends and trophic interactions in Newfoundland and Labrador (NL) waters

3.3.4.1. Update on fish community trends and structure

The marine community in the Newfoundland-Labrador (NL) shelves underwent dramatic changes over the last 30 years. These changes involved declines in many groundfish stocks, including the collapse of Northern cod, increases in the abundance of harp seals and shrimp stocks, and significant changes in the biology and availability of capelin (NAFO 2010, Koen-Alonso et al. 2010, Buren et al. 2014). In recent years, shellfish stock had declined, and groundfish components are showing positive signals (DFO 2014).

Current understanding of the changes in this bioregion indicates that total fish biomass is still below the levels observed in the early-mid 1980s (NAFO 2013), however, precise comparisons with pre-collapse levels are still lacking. Fisheries and Oceans (DFO) Research vessel (RV) surveys in the NL shelves replaced the Engel gear with the Campelen one in the mid 1990s, but conversion factors were only developed for key commercial groundfish species (e.g. cod, American plaice, Greenland halibut). Furthermore, commercial shellfish species (i.e. shrimp and crab) were only started to be reliably recorded in the RV surveys with the advent of the Campelen gear. Given these limitations, comparing total biomass levels has become a serious challenge, and a real limitation for ecosystem-level analyses of trends (Koen-Alonso et al. 2010).

In order to overcome this limitation, coarse conversion factors have been applied to provide illustrative representations of the changes in biomass over time (NAFO 2013). Continuing with these exploratory analyses, all available data from the comparative fishing sets done in the mid 1990s has been compiled, sorted, and used to develop approximate conversion factors by fish functional groups. These conversion factors were based on the ratio of the medians of the biomass distributions by fish functional groups obtained from all Engel and Campelen comparative fishing sets. These conversion factors are still limited in many ways, and should be considered illustrative until further evaluations of their reliability can be performed. Nonetheless, despite their shortcomings, they provide an avenue to generate continuous time series of RV biomass that should bring us closer to reliable quantitative comparisons.

Taking into account the Ecosystem Production Units (EPUs) identified in ToR 2.1., these conversion factors were applied to the DFO RV Fall time series for the NL Shelf EPU (NAFO Divs 2J3K), and to the DFO RV Spring time series for the Grand Bank EPU (NAFO Divs 3LNO). The resulting scaled time series clearly indicate that total biomass in both EPUs is still below pre-collapse levels, with current values in the vicinity of 40-50% of the levels observed in the early-mid 1980s (Figure 3.3.4.1). Detailed biomass trends and species composition by fish functional groups during the Campelen period (1995-2013) are presented in Figures 3.3.4.2 and 3.3.4.3.

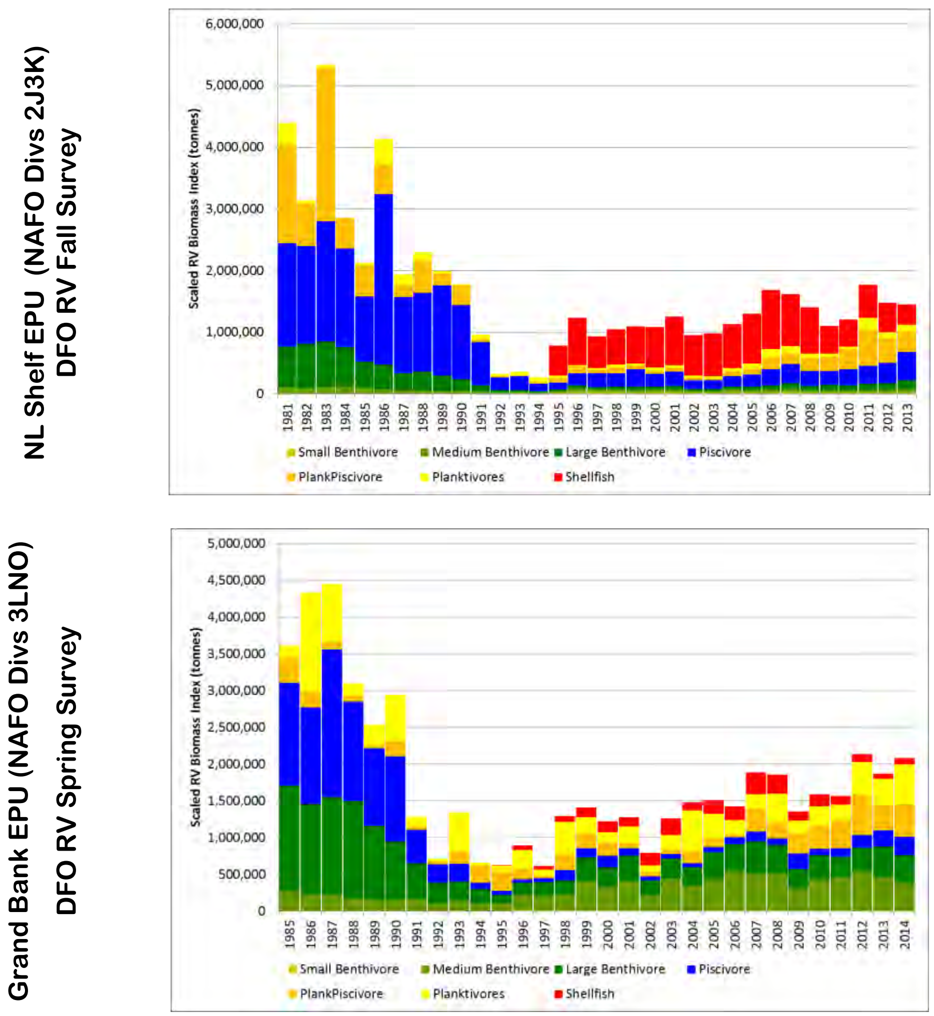

Figure 3.3.4.1. Scaled DFO RV surveys for the NL Shelf (NAFO Divs 2J3K) in the fall, and the Grand Bank (NAFO Divs 3LNO) in the spring. The values are scaled to Campelen units.

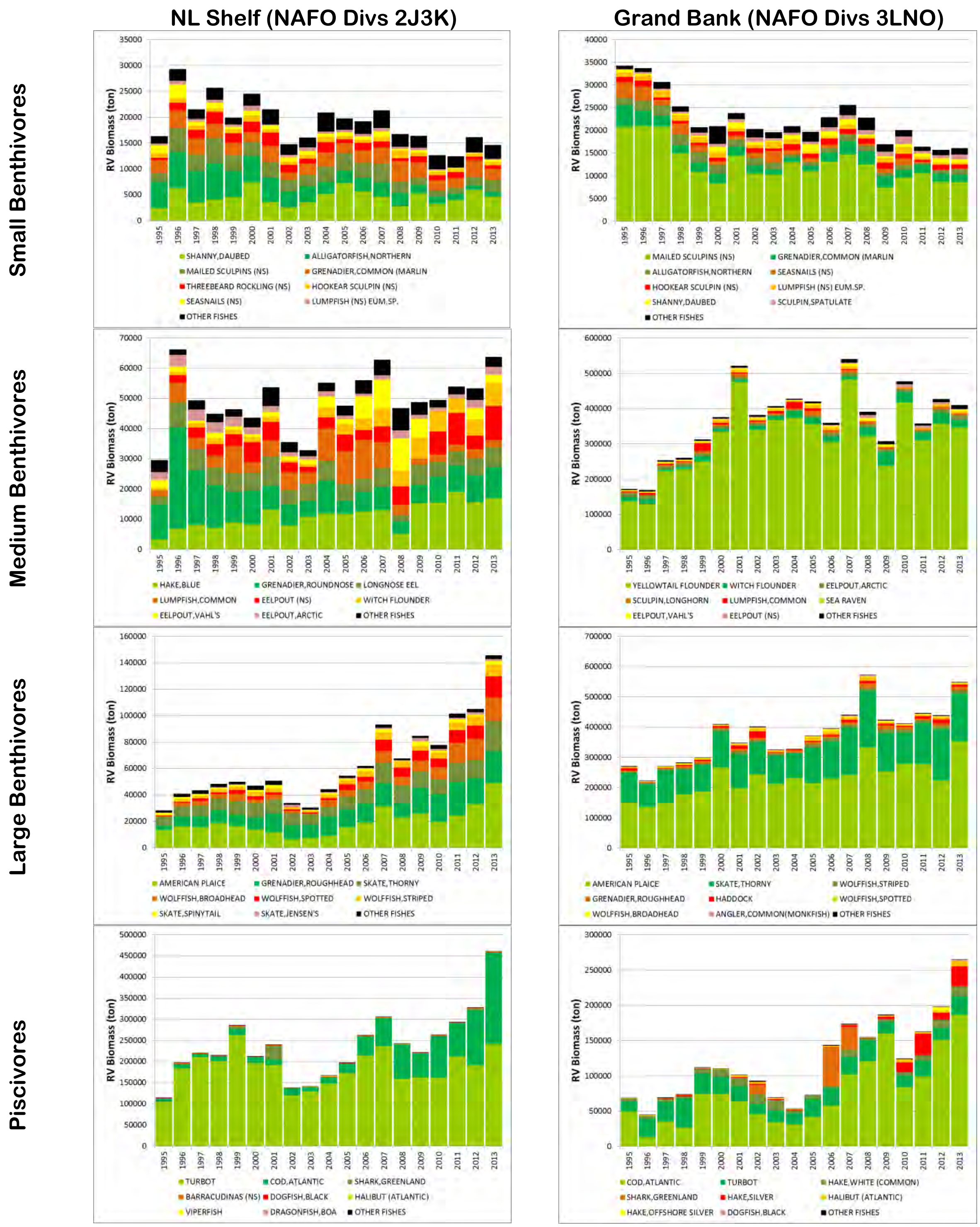

Figure 3.3.4.2. DFO RV Fall survey (Campelen) biomass trends and species composition in the NL Shelf and Grand Bank EPUs by fish functional groups: Small, Medium, and Large Benthivores, and Piscivores.

Figure 3.3.4.3. DFO RV Fall survey (Campelen) biomass trends and species composition in the NL Shelf and Grand Bank EPUs by fish functional groups: Plank-piscivores, Planktivores, and Shellfish.

Among these trends it is worth highlighting the overall declining trend in small benthivores, the overall increasing trends in large benthivores, piscivores, and plankpiscivores (although this last functional group has shown some declines in the last couple of years), and the increase, peak, and later decline in shellfish. One side observation, but of potential relevance, is the emergence of silver hake among the piscivores in the Grand Bank in recent years. This is a warm water species and its increasing occurrence in the Grand Bank, being driven by its increase in NAFO Div. 3O, may represent the beginning of the kind of species distributional changes that could be associated with climate change. This species also became the dominant piscivore by biomass in the neighbouring ecosystem of NAFO Div. 3Ps in 2014.

3.3.4.2. Update on diet composition for key fish species

The diets of key species in the NL Shelves continued to be monitored. These studies were re-started in 2008 under DFO Ecosystem Research Initiative (ERI) for the NL region, the NEREUS program, and have continued after the ending of the ERI in 2012 with the support of a suite of small projects supported by DFO SPERA and IGS funding envelopes. Sampling from this program has been carried out during DFO RV Fall surveys, but starting in 2013, additional sampling during DFO RV spring survey was initiated. This should allow exploring some aspects of the intra-annual variability in diet composition in the Grand Bank (the spring survey does not cover the NL Shelf EPU). At the present time, diet studies target five groundfish (cod, Greenland halibut or turbot, American plaice, redfish, and yellowtail flounder) and three forage fish (capelin, sandlance, and Arctic cod) species.

In the NL Shelf (NAFO Divs 2J3K), it was observed an increase in capelin and reduction of shrimp in the diets of key grounfishes, most notably in cod and American plaice (Figure 3.3.4.4). Among forage fishes, the diet of Arctic cod was dominated by amphipods, while copepods, mainly *Calanus* sp, were the dominant prey in the diet of capelin (Figure 3.3.4.5).

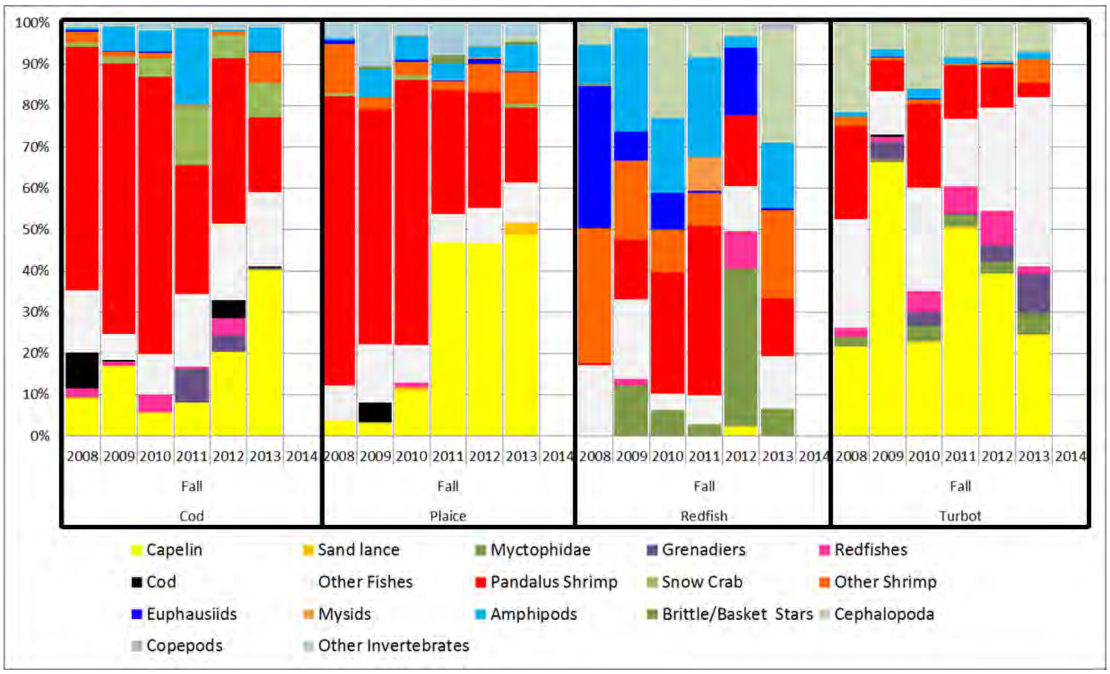

Figure 3.3.4.4. Fall diet composition of key groundfish species in the NL Shelf (NAFO Divs 2J3K)

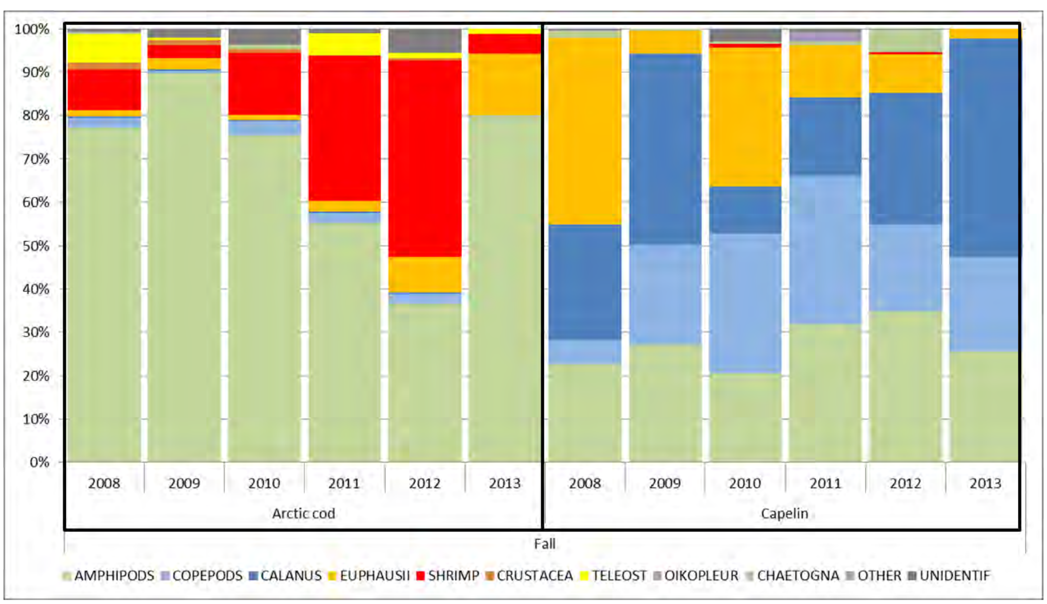

Figure 3.3.4.5. Fall diet composition of Arctic cod and capelin in the NL Shelf (NAFO Divs 2J3K)

In the Grand Bank (NAFO Divs 3LNO), groundfish diets were mostly dominated by sandlance in the fall, with the only exception of Greenland halibut (aka turbot) which had capelin as dominant prey item. In the spring, sandlance remained the dominant prey for American plaice and yellowtail flounder, but it was capelin the most important prey for cod, and it remained as the key prey for Greenland halibut (Figure 3.3.4.6)

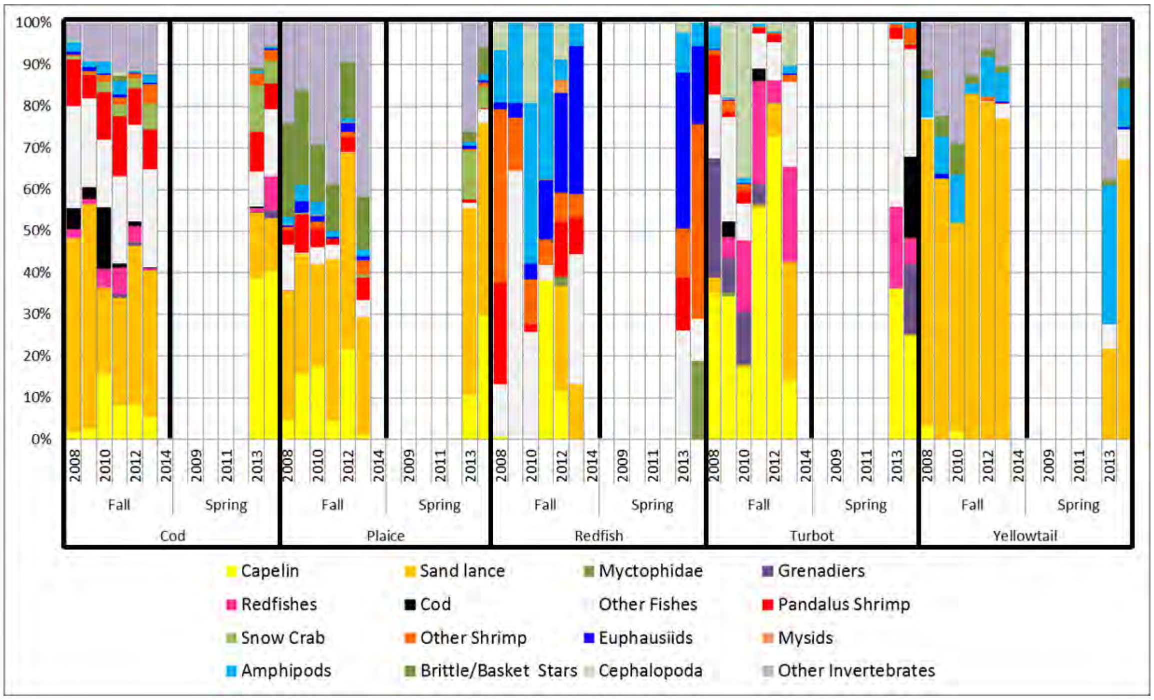

Figure 3.3.4.6. Fall and spring diet composition of key groundfish species in the Grand Bank (NAFO Divs 3LNO).

In the case of forage fishes in the Grand Bank, amphipods were the main prey for Arctic cod, while copepods were the dominat one sandlance and capelin, although euphasiids also had an important role in capelin (Figure 3.3.4.7). The data on spring diets was limited to capelin at the time of this analysis, and indicated a fairly even split between euphasiids and amphipods(Figure 3.3.4.7).

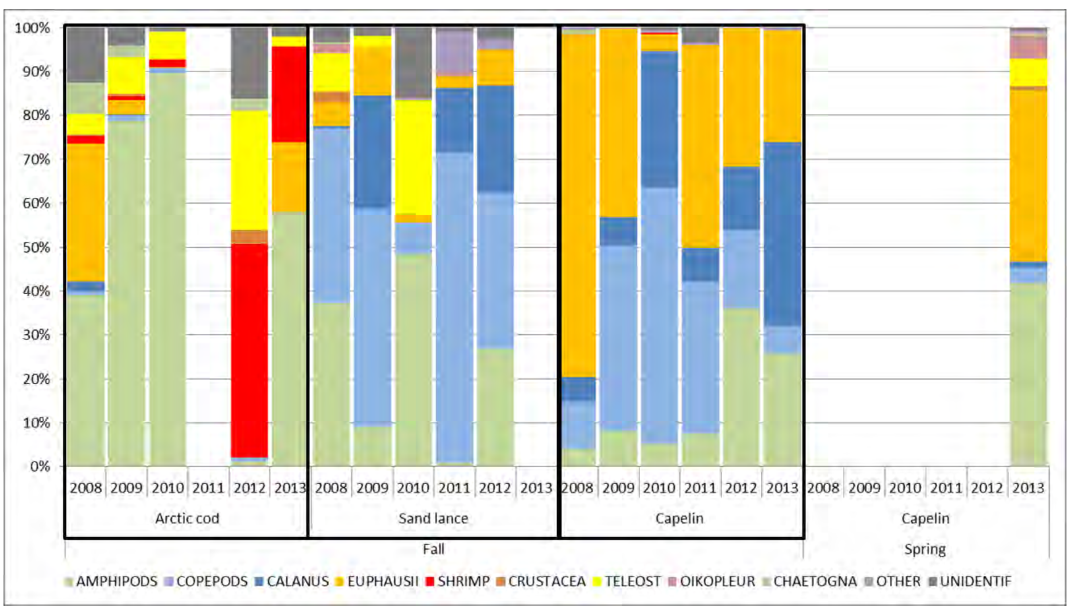

Figure 3.3.4.7. Fall and spring diet composition of forage fishes in the Grand Bank (NAFO Divs 3LNO).

3.3.4.3. References

Buren, A.D., Koen-Alonso, M., Pepin, P., Mowbray, F., Nakashima, B., Stenson, G., Ollerhead, N., and Montevecchi, W.A. 2014. Bottom-up regulation of capelin, a keystone forage species. PLoS ONE 9(2):e87589. doi:10.1371/journal.pone.0087589.

DFO. 2014. Short-term stock prospects for cod, crab and shrimp in the Newfoundland and Labrador region (Divisions 2J3KL). CSAS, NL Region, Science Response 2014/049.

Koen-Alonso, M., P. Pepin, and F. Mowbray. 2010. Exploring the role of environmental and anthropogenic drivers in the trajectories of core fish species of Newfoundland-Labrador marine community. NAFO SCR Doc. 10/037.

NAFO. 2010. Report of the NAFO Scientific Council Working Group on Ecosystem Approach to Fisheries Management (WGEAFM). Institute of Marine Research, Vigo, Spain, Feb1-5 2010. NAFO SCS Doc. 10/19, Serial No. N5815. 101 pp.

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ToR 3.3.5. Trophic positions and carbons sources from stable isotopes in Northwest Atlantic foodwebs

Stable isotopes of carbon and nitrogen were determined for fish and invertebrates collected during DFO multispecies surveys for the fall of 2012 and the spring of 2013. Here we report preliminary results of analyses to determine how foodwebs on the Newfoundland and Labrador shelves vary with NAFO area, Ecosystem Production Unit (see ToR 2.1) and season (Table 3.3.5.1).

Table 3.3.5.1. Results of exploratory analysis of variance to determine effects of size, geographic area and season on stable isotope signatures of fish and invertebrates on the Newfoundland and Labrador shelves. Ecosystem Production Unit (EPU) are defined in ToR 2.1. Stars indicate level of significance of ANOVA.

Factor	del C	del N
Size	American plaice*** Cod*** Capelin*** P. borealis*** Redfish** Snow crab** Yellowtail*	Arctic cod*** Cod*** Herring*** P. montaguii** Redfish** Turbot***
NAFO Area	American plaice** Brittlestars* Cod** Capelin*** Herring** Hyperids* Polychaetes* Redfish*** Snow crab** Yellowtail*	American plaice** Brittlestars*** Cod** Capelin*** Copepods** Euphausids** Herring* Hyperids* Polychaetes*** Redfish***

Table 3.3.5.1. Results of exploratory analysis of variance to determine effects of size, geographic area and season on stable isotope signatures of fish and invertebrates on the Newfoundland and Labrador shelves. Ecosystem Production Unit (EPU) are defined in ToR 2.1. Stars indicate level of significance of ANOVA.		
Factor	del C	del N
Ecosystem Production Unit (EPU)	American plaice** Brittlestars* Cod*** Capelin*** Herring ** Redfish***	Brittlestars*** Capelin*** Herring* Hyperids* P. borealis*** Polychaetes* Redfish***
Season	Capelin*** Yellowtail**	Cod** Yellowtail**

Carbon signatures distinguish pelagic from benthic production at the base of the foodweb. For example, pelagic carbon sources for copepods (δC -22.4) are significantly more depleted than the benthic signature of oligochaetes (δC – 17.4) (Figure
pelagic production r
example (Figure 3.3
indicating a largely

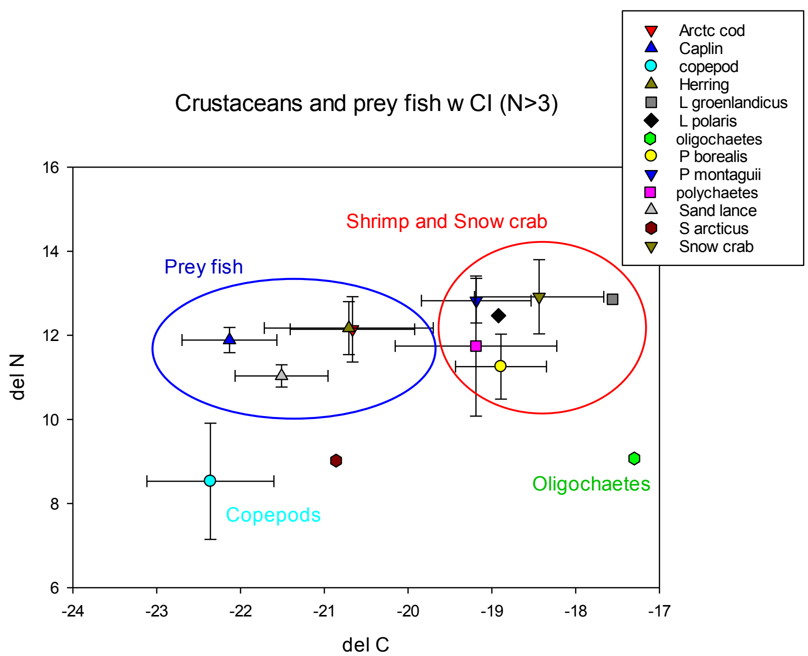


Figure 3.3.5.1. Average stable isotope signatures of crustaceans, oligochaetes, and prey fish. Error bars are the 95% confidence intervals.

Nitrogen signatures are used to distinguish trophic levels as δN increases by a relatively consistent amount between predator and prey. As a result, δN also tends to vary with the size where larger fish eat larger prey. Trophic levels within the foodweb ranged from 2 to over 5 with cod having the highest average trophic level (Figure 3.3.5.2).

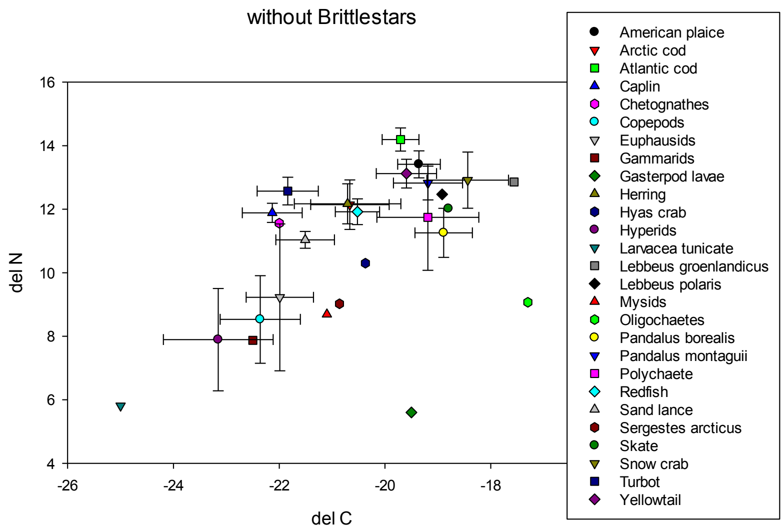


Figure 3.3.5.2. Average stable isotope signatures for fish and invertebrates from the Newfoundland and Labrador shelves. Error bars indicate 95% confidence intervals where n > 3. Brittle stars are not included in this figure as their carbon signature (which includes the test) is significantly less depleted than that of other organisms.

Redfish, capelin, *P. borealis*, and polychaetes from NAFO area 3Ps all had significantly higher δN levels than those from other areas. Atlantic cod tended to have a diet more closely linked to benthic organisms for the more northerly areas of the study (Figure 3.3.5.3). The cod from the Labrador and Newfoundland Shelves ecoregions tended to feed at a lower trophic level and on more benthic prey than cod of similar size in more southern regions. The carbon signature of the cod from the shelves averaged around -19, suggesting that shrimp formed a large part of their diet.

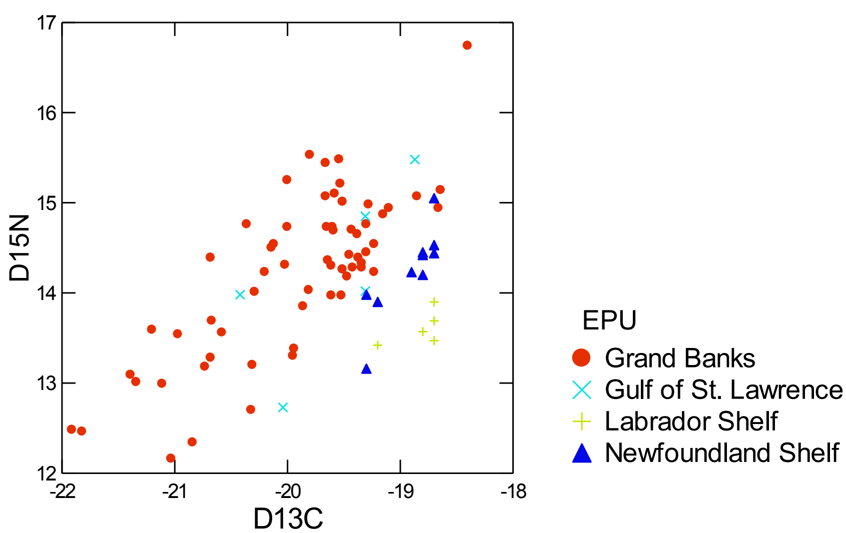


Figure 3.3.5.3. Carbon and nitrogen stable isotope signatures for Atlantic cod (*Gadus morhua*) by Ecosystem Production Unit (EPU). Note: The Gulf of St. Lawrence was not included in the EPU analysis.

Seasonal differences were observed for only two species, capelin (Figure 3.3.5.4) and yellowtail. Capelin tends to have a more pelagic diet in the fall while the converse is true for yellowtail. The differences in δN for Cod with season are likely the result of the differing spatial coverage between the spring and fall surveys.

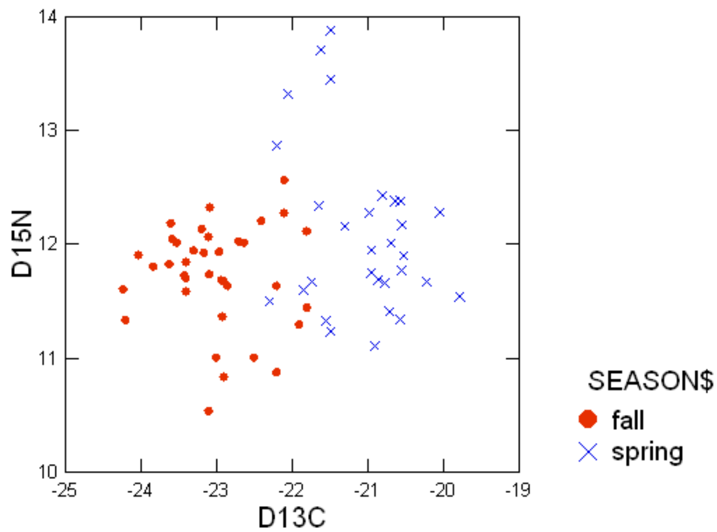


Figure 3.3.5.4. Carbon and nitrogen stable isotope signatures for capelin by season.

ToR 3.3.6. Progress report on the use of ecosystem indicators to characterize ecosystem state

Ecosystem based fisheries management (EBFM) is a new sustainable approach to management being investigated by coastal countries around the world. Implementing EBFM requires scientific support that can be provided by data-based ecosystem indicators, which quantitatively describe marine ecosystem states. Previous work has identified dozens of generic indicators; however, specific subsets are required to characterize specific ecosystems.

Therefore, a MSc research project was initiated at Dalhousie University, with the collaboration of DFO and NOAA scientists, aiming to identify an optimal set of indicators for the Grand Banks, Newfoundland using multiple regression and the innovative technique of neural network analysis. These methods will also be applied to Georges Bank; results of the analyses will be compared and contrasted to highlight important management decisions and environmental drivers in these ecosystems.

ToR 3.3.7. Update on a Workshop on Community trends of the Newfoundland Shelf

A group of researchers from several universities (McGill, Université du Québec Montréal, Université du Québec Rimsouski, Memorial University, 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 three workshops. However, as a result of the outcome of the first workshop, most of the effort of the working group has been directed toward quantifying and understanding possible drivers of spatial and temporal patterns of biodiversity in NAFO areas 2J3KL from the 1980s to present.

The group identified that the collapse and onset of recovery of cod was embedded within a broader community collapse. Community trajectory, based on a multivariate characterization of species composition rather than biomass alone, has proven useful to characterize the collapse and recovery of an ecosystem. The collapse was associated change in spatial structure in the different elements of the fish community. Environmental relationships may have started to rebuild following onset of recovery but trends were weak. There were significant differences in the spatial structure of the collapse and the recovery phases in the 2J3KL groundfish community. The group plans to provide a full summary of their findings in 2015.

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 #4]* 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).

WGESA further advanced the work towards the Reassessment of Bottom Fishing Activities due by September 2016. Progress was made on several areas, including the development of a template for ther reporting of the results of the reassessment, the description of fisheries and fishing effort in the NRA, the beginning of the summary of backgroung ecosystem information, the further refinements on the methods to be using to assess SAIs, and an initial discussion on risk assessment frameworks in the context of SAIs on VMEs. The following sections under ToR 4.1 summarize the progress to date.

ToR 4.1.1. General organization of the document that will describe the assessment of bottom fishing activities pertaining to impacts on VMEs

In June 2015, SC put forward its most recent update on its workplan towards the Reassessment of Bottom Fishing Activities scheduled for September 2016. This workplan identified eight general tasks, seven of which are directly related to the summary of available information, and the assessment of significant adverse impacts on VMEs, and hence under the lead of SC, while the eighth one involves the proposal of mitigation and management measures to be considered by FC, and it is led by FC-SC WGEAFFM (see below).

SC June 2015 Workplan towards the Reassessment of bottom fishing Activities by 2016. List of task, and corresponding lead group within NAFO

No.	Fisheries Assessment Task	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)	WGESA with input from NAFO Secretariat for presentation and approval by Scientific Council 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	WGESA with input from AZMP and STACFEN, for presentation and approval by Scientific Council and STACFEN in 2015.
3	Identification, description and mapping of VMEs known or likely to occur in the fishing area	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	SC WGESA
5	Consideration of VME elements known to occur in the fishing area	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;	SC WGESA
7	Risk assessment of likely impacts by the fishing operations to determine which impacts on VMEs are likely to be significant adverse impacts	SC WGESA
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	Joint FC/SC Working Group on the Ecosystem Approach Framework to Fisheries Management

In following with this workplan, WGESA developed a template for the organization and reporting of the outcomes of these tasks. This template provides the organizational structure of the report that will describe the Reassessment of Bottom Fishing Activities, as well as guidance on the content expected in each section, and which of the tasks is being reported.

Template for the Reassessment of Bottom Fishing Activities report

Section 1: Introduction

Task No 2. "Existing baseline information on the ecosystems, habitats, and communities in the fishing area, against which future changes can be compared"

Approach to the section: This section is intended to be a summary of the environmental and general ecosystem background; detailed VME descriptions will be provided in Task 3. This section is envisioned as a brief introduction to the larger ecosystems where the VMEs are located. If pertinent, references to other more detailed sources can be made in this section, but the section itself should be kept short and to the point.

Template for the section:

1. NRA
    a. General oceanographic processes: currents, water masses, temperature, salinity, bathymetry, etc for the entire region.
    b. Ecosystem Production units: general description, productivity, biological oceanography.
        i. Grand Bank
        ii. Flemish Cap
    c. Fish communities: Species, fish functional groups, community trends.
        i. Grand Bank
        ii. Flemish Cap
    d. Benthic communities: ecoregions, habitats, species assemblages (VME and non-VMEs; the detailed VMEs description will be provided in a separate section).
        i. Grand Bank
        ii. Flemish Cap
2. Seamounts. Only general information. Refer to detailed VME section (Tasks 3 and 5) where seamounts are described as VME elements, unless some broader features are amenable and worthy of a general description.

Section 2: description of VME and VME elements

Tasks No 3 and 5. "Identification, description and mapping of VMEs , and VME elements"

Approach to the section: This section is intended to be a summary of all VMEs and VME elements in the NRA. It should provide a concise summary of the types, and locations of VMEs and VME elements identified in the NRA. This section is expected to heavily rely on the work already done for the evaluation of closures in 2014.

Template for the section:

1. NRA
2. Seamounts

Section 3: Description of the Fisheries

Task No 1. "Description of fisheries"

Approach to the section: This section is intended to be a summary of all fisheries operating in the NRA, including their gear types, target species, areas of operation, etc.

Section 4: Impact analysis

Task No 4. "Analysis of likely impacts on VMEs"

Approach to the section: This section is expected to be focused on likely impacts on VMEs and, whenever possible, to discriminate likely impacts by fisheries. Depending on how the work develops, this section could be merged with Section 5.

Section 5: Risk Assessment

Task No *7*. "Assessment of SAIs on VMEs"

Approach to the section: This section is intended to integrate the analysis of likely impacts (Section 4) in a framework compatible with standard risk assessment approaches that should allow identifying likely Significant Adverse Impacts (SAIs), as well as providing the basic blocks for potentially developing more comprehensive risk assessments if needed (e.g. when addressing Task 8). Depending on how the work develops, this section could be merged with Section 4.

This template is expected to be further discussed at several 2015 meeting (i.e. SC in June, FC/SC in July, AGM in September) so that its final version is available to SC WGESA for its November 2015 meeting, when some of the final analyses for the 2016 Reassessment are expected to be carry out.

ToR 4.1.2. [Workplan for SAI-VMEs Task 1] Classification of fisheries and distribution of effort in the NRA

4.1.2.1. Description of bottom fishing activity

Within the NAFO Regulatory Area (NRA) there are three main classes of fisheries: the groundfish (GRO - primarily in Div. 3KLMNO), shrimp (PRA - primarily in Div. 3LM) and pelagic redfish fisheries (REB - primarily in Div. 1F and 2J).

The first consideration of the task of an assessment of bottom activities to address WGESA ToR 1.2 (FC WP 14/16, Item 4) is to classify various fisheries. For this purpose, it is useful to classify according to the NCEM definition of directed fishery, which states, "…for any one haul, the species which comprises the largest percentage, by weight, of the total catch in the haul shall be considered as being taken in a directed fishery for the stock concerned…"(NCEM Art. 5.2)

It is recognized that different directed fisheries should exert different levels of effort as well as proximity to known and predicted VME species and elements in the NRA. The available data most appropriate for this purpose, Daily Catch Records (DCR) and data from the Vessel Monitoring System (VMS), in many cases does not allow one-to-one matching of these datasets because DCR is reported per day and VMS per hour. The difficulty is that several hauls can be conducted in one day that span different directed fisheries. Therefore, it was decided to classify the fishing activities into groups of directed fisheries that are conducted in a similar spatial area.

The use of the VMS data required some assumptions to be made for determining a 'trawling' event from all other possibilities that is occurring when the VMS data is transmitted (eg. vessel was steaming, weather bound, etc.). In this regard, the data were aggregated by a grid bounded by 0.05 degree latitude and 0.05 degree of longitude where the speed between consecutive points was calculated to be between 0.5kts to 5.0kts.

Considering their target species/stock, main area of operation, and gear, a total of 16 operational fisheries have been initially identified for consideration in the analyses towards the Reassessment of Bottom Fishing Activities (Table 4.1.2).

Table 4.1.2. Operational fisheries initially identified in the NAFO Regulatory Area (NRA) for consideration in the process of developing the Reassessment of Bottom Fishing Activities.

Fishery	Target Species	Main Area of Operation	Gear
Pelagic Redfish Fishery	Redfish	NAFO Div. 1F	Midwater otter trawl
Greenland Halibut Fishery	Greenland halibut	NAFO Divs 3LMN	Bottom otter trawl
3M Redfish Fishery	Redfish	NAFO Div. 3M	Bottom otter trawl
3M Shrimp Fishery (in moratorium)	Shrimp	NAFO Div. 3M	Bottom otter trawl
3M Trawl Cod Fishery	Atlantic Cod	NAFO Div. 3M	Bottom otter trawl
3M Longline Cod Fishery	Atlantic Cod	NAFO Div. 3M	Longline
Skate Fishery	Skate	NAFO Divs 3NO	Bottom otter trawl
Yellowtail Fishery	Yellowtail flounder	NAFO Div. 3N	Bottom otter trawl
Witch flounder Fishery (re-openning in 2015)	Witch flounder	NAFO Divs 3NO (expected area)	Bottom otter trawl
3LNO Redfish Fishery	Redfish	NAFO Divs 3LNO	Bottom otter trawl
3LNO Shrimp Fishery (in moratorium)	Shrimp	NAFO Div. 3L	Bottom otter trawl
White Hake Fishery	White hake	NAFO Divs 3NO	Bottom otter trawl
Squid Fishery	Shortfin squid	NAFO Subareas 3+4 (no directed fishing since 1999)	Bottom and midwater otter trawl
Alfonsino Fishery	Splendid Alfonsino	NAFO Div. 6G (Corner Rise Seamount area)	Midwater otter trawl
Snow Crab Fishery (not managed by NAFO)	Snow crab	NAFO Divs 3LNO	Traps
Arctic Surfclam Fishery (not managed by NAFO)	Arctic surfclam	NAFO Div. 3N	Hydraulic dredge

4.1.2.2. Pelagic Fisheries

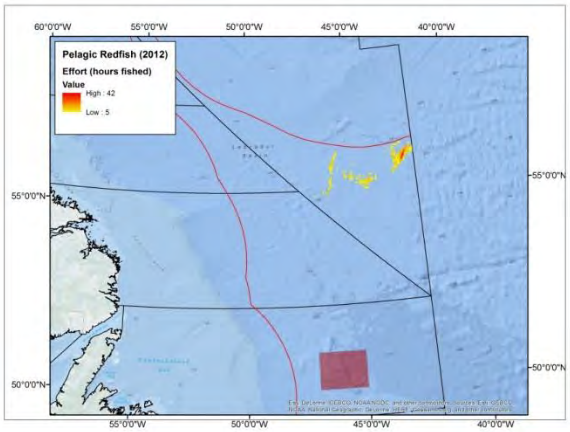
Subarea2+Division 1F at depths greater than 100 meters and less than 800 meters: Pelagic redfish fishery.

This fishery is conducted with 100mm mesh size with a midwater “Gloria” trawl. These fisheries are conducted in the water column at depths less than 800m over very deep ocean bottom depths from 3000-3700m (Fig. 4.1.2.1). Pelagic redfish (*Sebastes mentella*) comprise most the total catches with a very low by-catch of other species.

Division	Target Species	Gear	Mesh Size	Predominant Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
Div 1F	Pelagic Redfish	OTM		<800m over bottom depths of 3000 – 3700m	TBD	TBD	TBD

Spatial Distribution

The depth of water in areas where the pelagic redfish fishery takes place means that accidental bottom contact is highly unlikely.



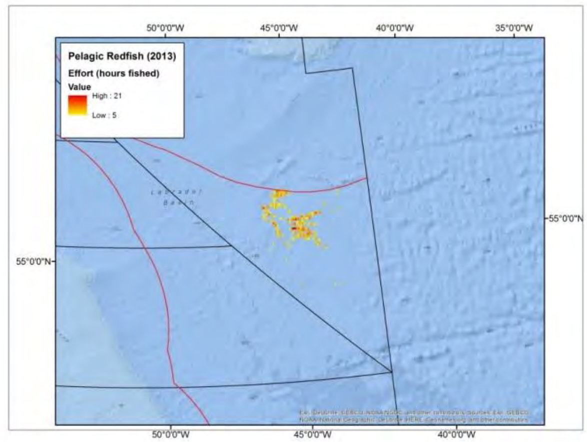


Figure 4.1.2.1. Characteristics of the Pelagic Redfish Fishery. OTM: midwater otter trawl. TBD: to be determined (information has yet to be fully compiled).

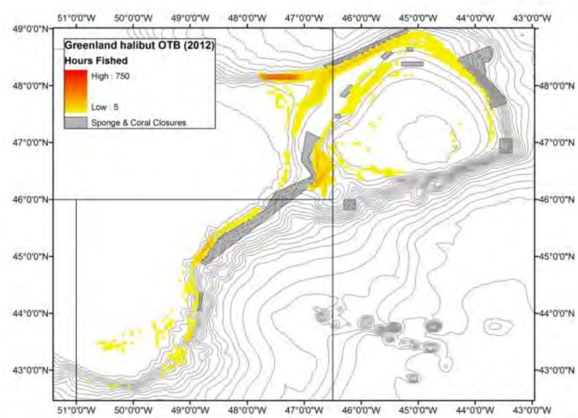
4.1.2.3. Demersal fisheries

The groundfish fisheries were separated into different components depending on the target species, area, depth and gear (mesh size). Based on these aspects, and assuming data available at the WGESA 2014 meeting (Spanish Observer data from 2005-2011) are considered reasonably representative of depths and by-catch, the demersal fisheries in the NRA were initially classified as follows:

Divisions 3LMNO at depths greater than 600 meters: Greenland Halibut Fishery.

The principal fishery is conducted from 800-1400mwith 130 mm mesh size bottom trawls and although widespread throughout the divisions, there were four primary areas. These included, in decreasing area of importance, (1) the northeast of Div. 3L, (2) the northwest of Div. 3M, (3) the southeast of Div.3L along the Div.3LM boundary, and (4) the northeast of Div. 3N (see Fig. xx.2). Greenland halibut comprised the main species in the catches.By-catch species of this fishery are roughhead grenadier (4%) and the redfish (2%).

Division	Target Species	Gear	Mesh Size	Predominant Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
Div. 3LMNO	Greenland halibut	OTB	130mm	800 – 1400m	TBD	TBD	Redfish, Grenadiers
Spatial Distribution (2012)				**Spatial Distribution (2013)**			



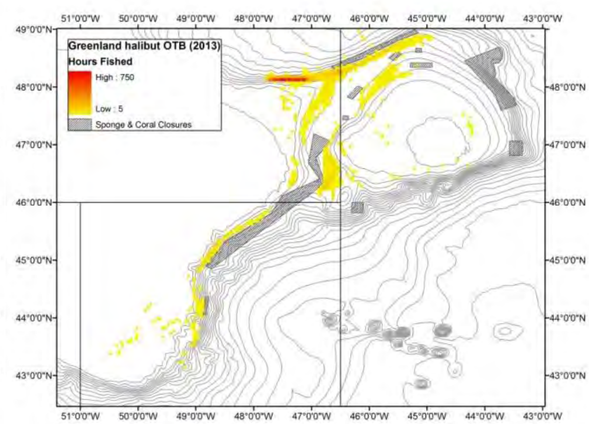


Figure 4.1.2.2. Characteristics of the Greenland Halibut Fishery. OTB: bottom otter trawl. TBD: to be determined (information has yet to be fully compiled).

Division 3M at depths less than 600 meters: Redfish, Cod and Shrimp fisheries.

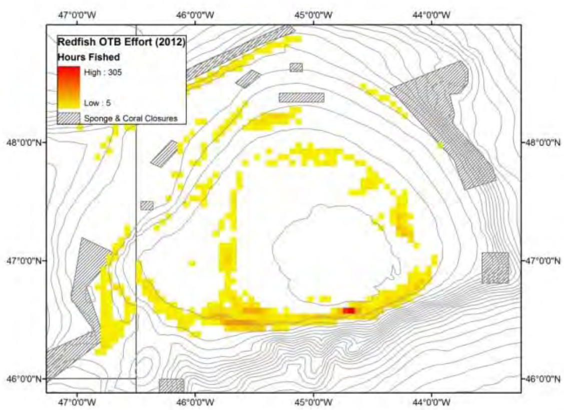
The shrimp fishery was under moratorium in 2012-13 but previous fisheries were conducted with 40 mm mesh size bottom trawls primarily in depths between 300-500 meters. Shrimp comprised 98% of the catches with redfish as main by-catch (2%).

The redfish fishery is conducted with 130 mm mesh size bottom trawl gear primarily within the 200m-600mdepth zone in Div 3M along the southern and north-western slope of the bank (Fig. 4.1.2.3). Redfish comprise 80% of the catch and the main by-catch species were Greenland halibut (4%) and cod (3%).

The cod fishery in Div 3M is conducted with 130 mm mesh size bottom trawl gear at depths between 150-550m with the highest concentrations of effort in the south western and south-eastern areas of the slope of the bank (Fig. 4.1.2.4). Most of the hauls were carried out at depth between 300-400 meters. Cod comprised 92% of the catches and the most important species in the by catch was redfish (7%). A long-line fishery is also conducted for cod between 200-400m in the northwest portion along the slope of the bank (Fig. 4.1.2.5), and the principal by-catch is skate and Greenland shark.

Division	Target Species	Gear	Mesh Size	Predominant Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
Div. 3M	Redfish	OTB	130mm	200 – 800m	TBD	TBD	Cod, Greenland halibut

Spatial Distribution (2012)



Spatial Distribution (2013)

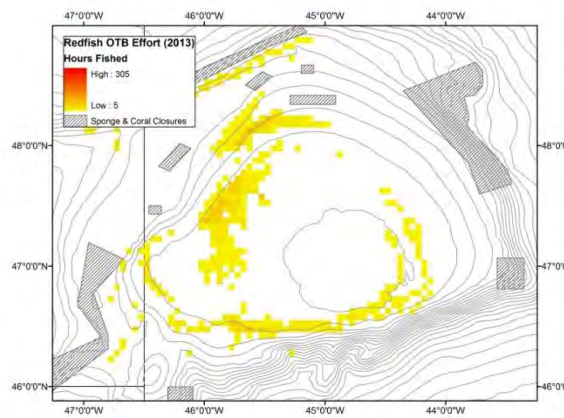


Figure 4.1.2.3. Characteristics of the 3M Redfish Fishery. OTB: bottom otter trawl. TBD: to be determined (information has yet to be fully compiled).

Division	**Target Species**	**Gear**	**Mesh Size**	**Predominant Depth Range**	**Mean Vessel Power (KW, ± range)**	**Mean Vessel Length (m, ± range)**	**Commercial Bycatch Species**
Div. 3M	Cod	OTB (some use of PTB)	130mm (some use of 140mm)	200 – 600m	TBD	TBD	Redfish
Spatial Distribution (2012)				**Spatial Distribution (2013)**			

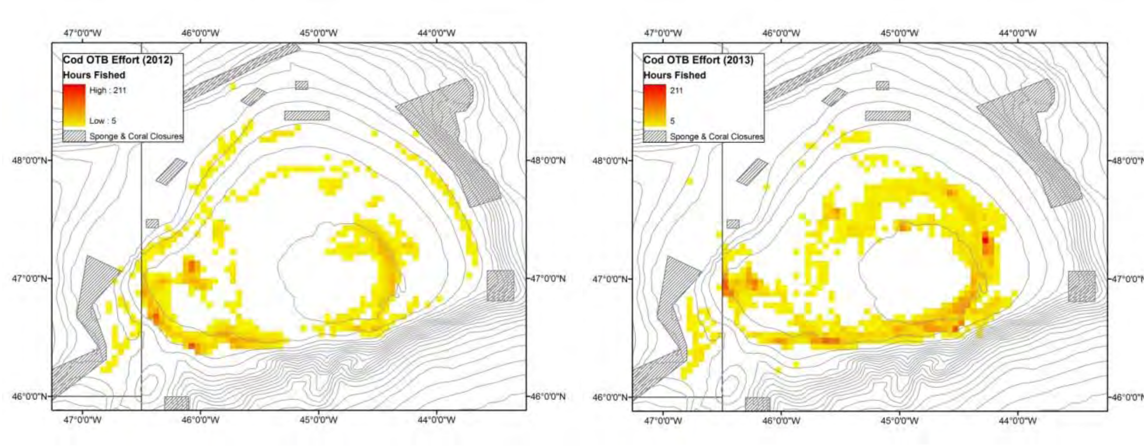
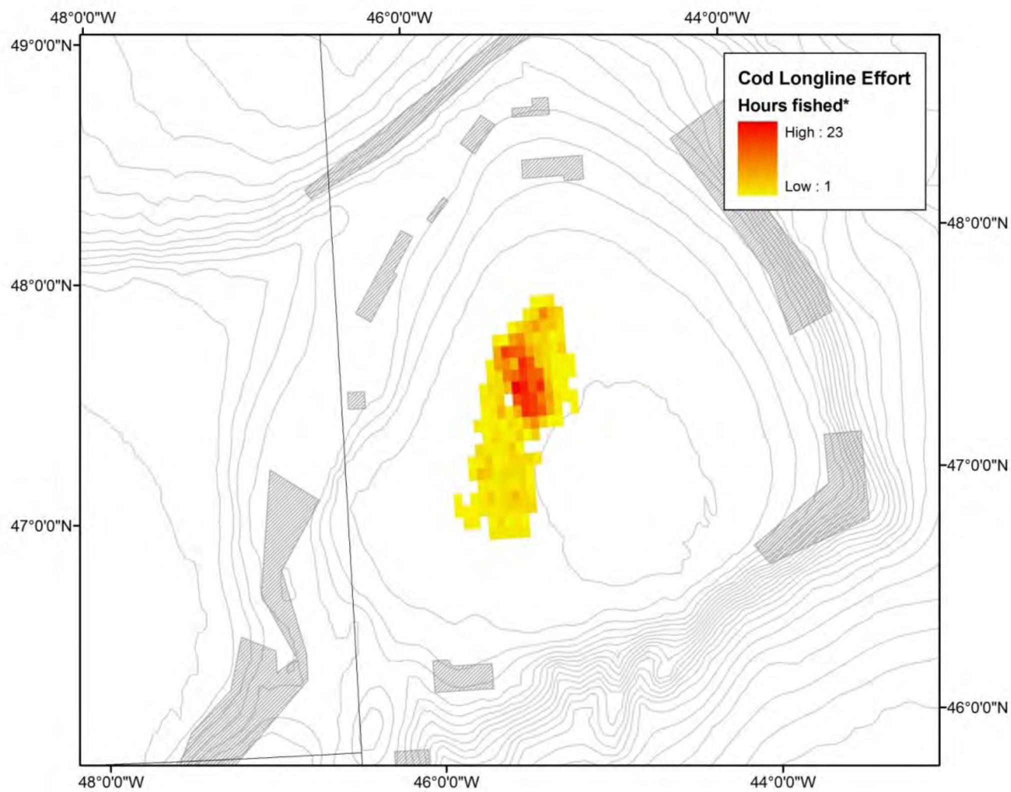


Figure 4.1.2.4. Characteristics of the 3M Trawl Cod Fishery. OTB: bottom otter trawl, PTB: pair bottom trawl. TBD: to be determined (information has yet to be fully compiled).

Division	Target Species	Gear	Mesh Size	Predominant Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
Div. 3M	Cod	LL	NA	200 – 400 m	NA	NA	Skate, Greenland shark

Spatial Distribution (2013)



*** Hours fished from VMS data is considered a poor metric of effort in long-line fisheries**

Figure 4.1.2.5. Characteristics of the 3M Longline Cod Fishery. LL: long-line. NA: not available. TBD: to be determined (information has yet to be fully compiled).

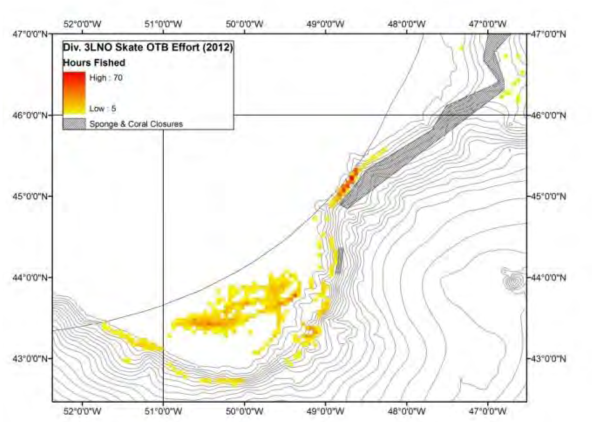
Divisions 3LNO at depths less than 200 meters: Skate and Yellowtail fisheries

The skate fishery is conducted with 280 mm mesh size bottom trawls primarily in depths <100m (Fig. 4.1.2.6) in Divisions 3NO. Skates comprised 63% of the catch with American plaice (19%), yellowtail flounder (10%) and cod (6%) as main by-catch species.

The Yellowtail fishery is conducted with 130-145 mm mesh size bottom trawls in Divisions 3LNO primarily in depths <50m on the southeast shoal in Div. 3N (Fig. 4.1.2.7). The primary by-catch species are skate, American plaice and cod.

Division	Target Species	Gear	Mesh Size	Predominant Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
Div. 3LNO	Skate	OTB	280mm	<100m?	TBD	TBD	Witch/ Yellowtail/ American Plaice/ Cod / Redfish

Spatial Distribution (2012)



Spatial Distribution (2013)

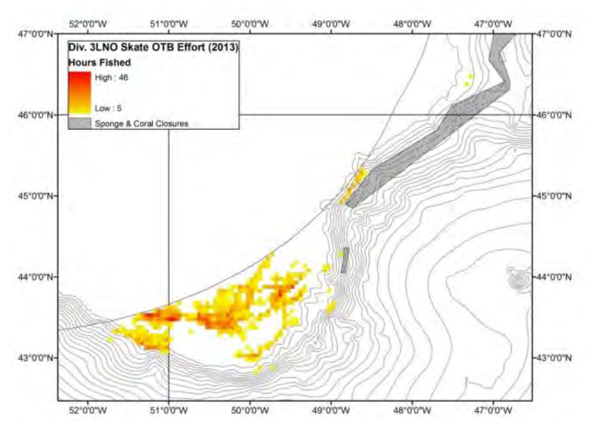
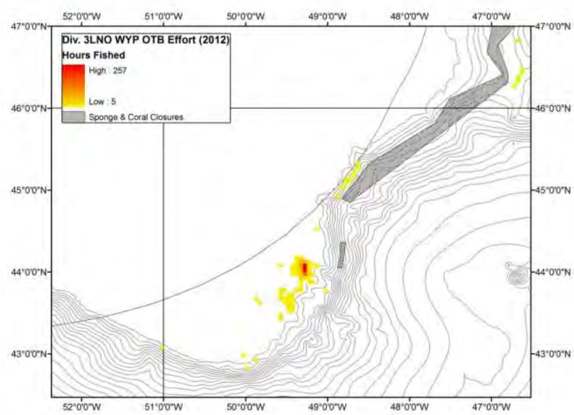


Figure 4.1.2.6. Characteristics of the 3LNO Skate Fishery. OTB: bottom otter trawl. TBD: to be determined (information has yet to be fully compiled).

Division	Target Species	Gear	Mesh Size	Predominant Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
Div. 3LNO	Yellowtail flounder	OTB	130mm	Less than 200m	TBD	TBD	Skate, Cod, Redfish

Spatial Distribution (2012)



Spatial Distribution (2013)

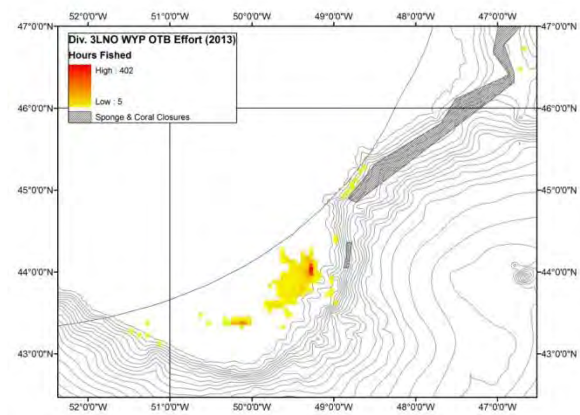


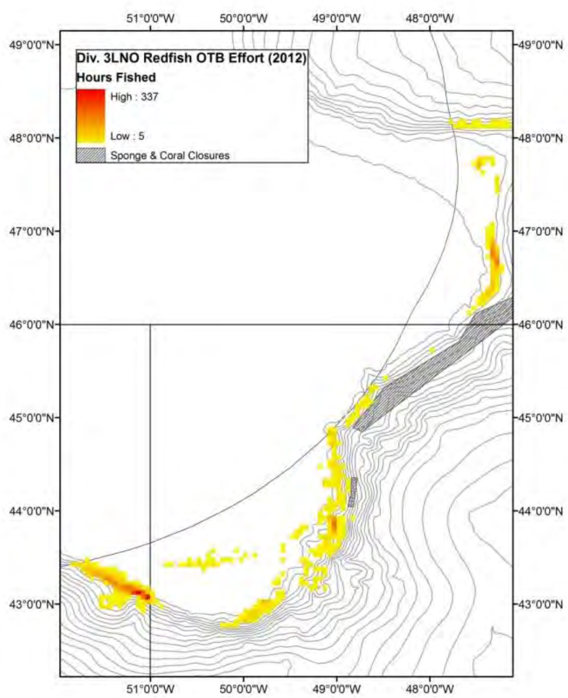
Figure 4.1.2.7. Characteristics of the 3LNO Yellowtail Fishery. OTB: bottom otter trawl. TBD: to be determined (information has yet to be fully compiled).

Divisions 3LNO at depths between 100-600 meters: Redfish and shrimp fisheries.

The redfish fishery is conducted with 130 mm mesh size trawl bottom trawls with the primary areas being the slope area of Div. 3O, the east-central area of Div. 3N and the southeast area of Div 3L near the border with Div. 3N (Fig. 4.1.2.8). Redfish comprise 80% of the catch and the main by-catch species were Greenland halibut (4%), American plaice (4%), cod (3%) and witch flounder (3%). Although mid-water trawling has comprised a significant percentage of redfish fisheries for principal Russian fleet in the past, its use has diminished in recent years and only bottom trawls were deployed in 2013.

The shrimp fishery is conducted with 40 mm mesh size bottom trawls in Div. 3L, primarily concentrated in an area along the central eastern slope in depths between 300-500 meters (Fig. 4.1.2.9), with shrimp comprising with 99% of the catches. This fishery was closed to directed fishing in 2015.

Division	Target Species	Gear	Mesh Size	Predominant Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
Div 3LNO	Redfish	OTB	130mm	100-600m	1900 (600 – 6400)	63 (15 – 85)	TBD
Spatial Distribution (2012)					**Spatial Distribution (2013)**		



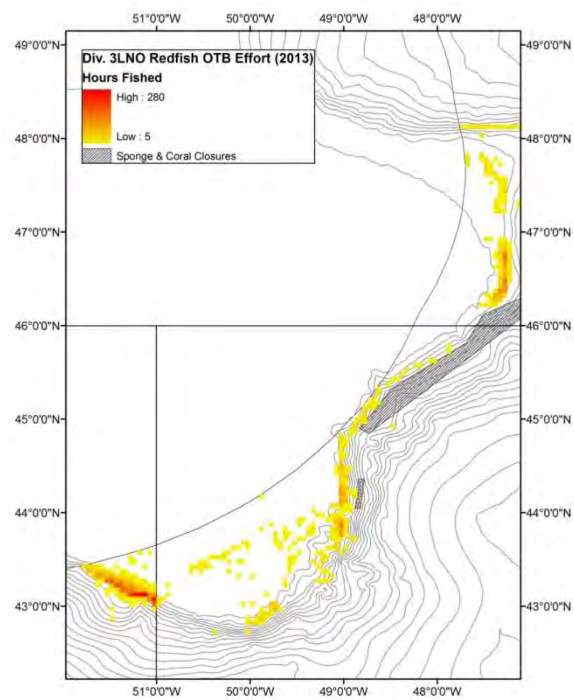
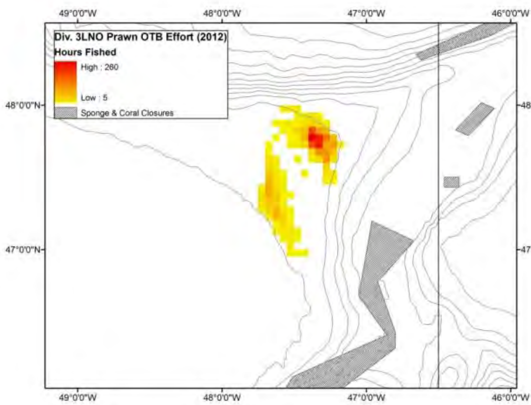


Figure 4.1.2.8. Characteristics of the 3LNO Redfish Fishery. OTB: bottom otter trawl. TBD: to be determined (information has yet to be fully compiled).

Division	Target Species	Gear	Mesh Size	Predominant Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
Div. 3LNO	Northern prawn	OTB	40mm	200 – 400m	TBD	TBD	None
Spatial Distribution (2012)				**Spatial Distribution (2013)**			



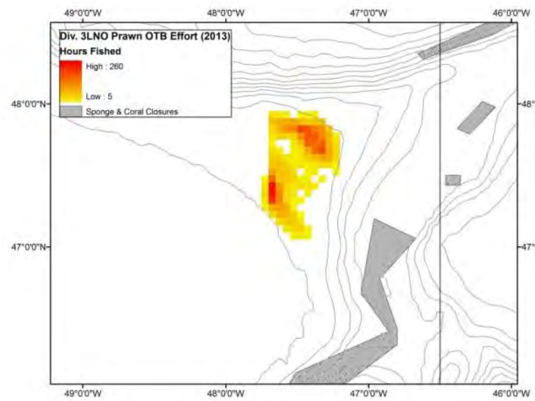


Figure 4.1.2.9. Characteristics of the 3LNO Shrimp Fishery. OTB: bottom otter trawl. TBD: to be determined (information has yet to be fully compiled).

Divisions 3NO at depths less than 800m: Witch flounder fisheries.

A directed fishery for witch flounder was re-established in 2015 for the first time since it was placed under a moratorium in 1995. This fishery will be conducted with 130 mm mesh size and is likely to occur at various depths to 800m. Information on by-catch is not yet available.

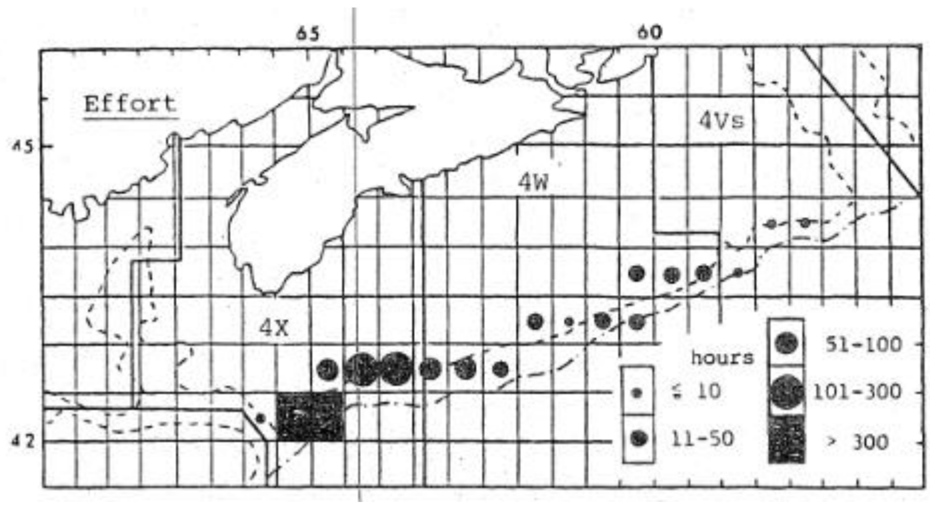
4.1.2.3. Other Fisheries

Subarea 3+4 at depths from coastal waters to 1000m : S: Northern Shortfin (Illex) squid fisheries.

Prior to the mid-1980s, international bottom trawl and mid water trawl fleets participated in directed fisheries in SA 3, 4 5 and 6, mainly along the shelf-break (200-400m). Since 1999, there has been no directed fishery for squid in SA 3+4. Based on fisheries by Japan in 1981 [Fig. 4.1.2.10, from Hatanaka (1982)] effort was conducted from 100m and 1000m along the shelf slopes in Divisions 4Vs4WX. There are also artisanal fisheries conducted with jiggers or traps in coastal waters in Divisions 3KLP during times when squid arrive in sufficient quantity.

Division	Target Species	Gear	Mesh Size	Predominant Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
Subarea 3 + 4	Northern Short-finned squid (Illex)	OTB/OTM	60mm	Coastal depths – 1000m	NA	NA	NA

Prior to the mid-1980s, international bottom trawl and mid water trawl fleets participated in directed fisheries in SA 3, 4 5 and 6, mainly along the shelf-break (200-400m). Since 1999, there has been no directed fishery for squid in SA 3+4.



Fishing effort of *Illex* squid by Japanese trawlers in 1981, including the values by the directed argetine fishery. Depth contours of 100m and 1000m are shown. Hatanaka, H. (1982) Outline of Japanese Squid Fishery in NAFO Subareas 3 and 4 in 1981. NAFO SCR Doc. 82/VI/23

Figure 4.1.2.10. Characteristics of the Squid Fishery. OTB: bottom otter trawl, OTM: midwater otter trawl, NA: not available.

Division 6G at depths greater than 600m: Splendid Alfonsino fisheries.

The splendid alfonsino fishery is conducted in the Corner Seamount area of Div. 6G predominantly with mid-water trawls at depths of 600-1430m (Fig. 4.1.2.11). Black scabbardfish is the main by-catch species.

Division	Target Species	Gear	Mesh Size	Predominant Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
Div 6G	Splendid Alfonsino	OTB/OTM	None defined.	600 – 1430m	TBD	TBD	Black scabbardfish

Spatial Distribution (2012-13)

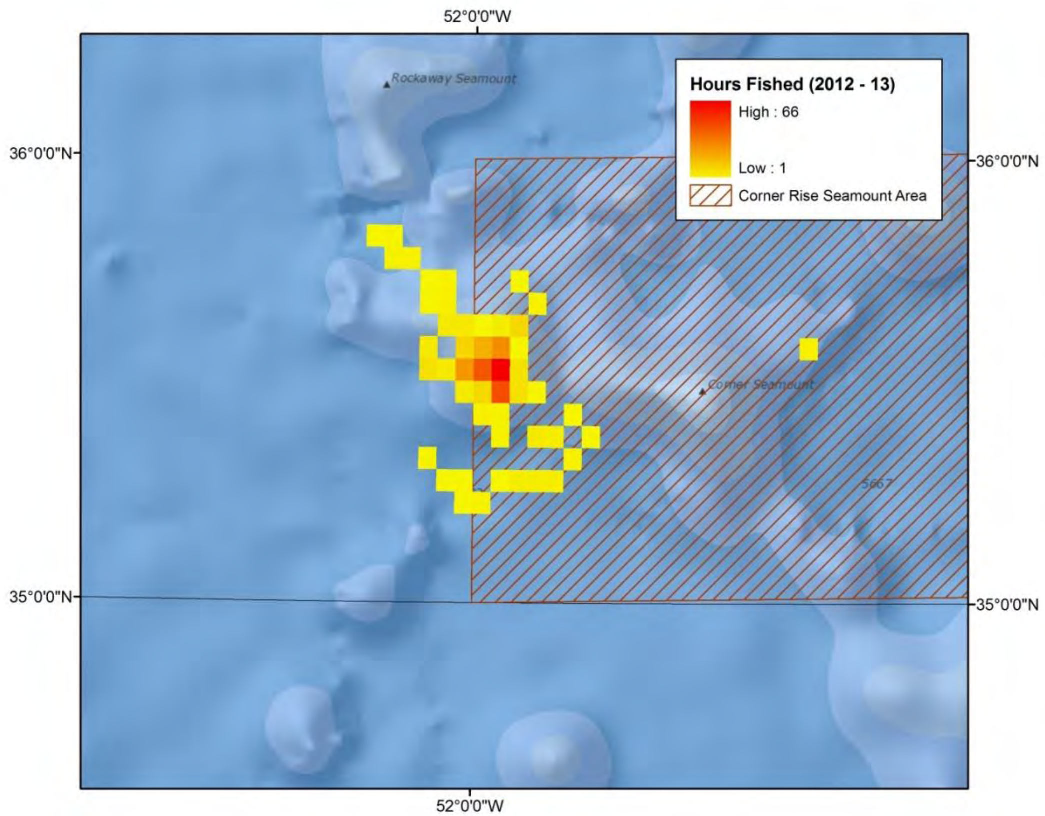


Figure 4.1.2.11. Characteristics of the Splendid Alfonsino Fishery. OTB: bottom otter trawl, OTM: midwater otter trawl. TBD: to be determined (information has yet to be fully compiled).

Divisions 3LNO at depths greater than 30m: White Hake, Arctic surfclam, and Snow crab fisheries

The white hake fishery mostly operates in NAFO Div. 3NO and tends to be an opportunistic fishery and therefore can be quite irregular. The fishery uses 130 mm mesh size bottom trawl gear.

There are other bottom fisheries activities in the NRA not managed by NAFO such as the Grand Bank Arctic surfclam (*Mactromeris polynyma*), and snow crab (*Chionoecetes opilio*).

The surfcalm fishery is conducted offshore, on the Grand Bank, mainly in NAFO Div. 3N. This fishery uses hydraulic dredges to extract the surfclam from sediments. There is normally a near absence of groundfish by-catch in the fishery.

The snow crab fishery in the offshore of 3LNO mostly operates in the Canadian EEZ across the northern portion of the Grand Bank but there is effort in the NRA and along the Div. 3LN slope edge. The fishery is conducted with conical baited traps set in long-lines ('fleets') with a minimum mesh size of 135 mm.

ToR 4.1.3. [Workplan for SAI-VMEs Task 1] Progress on regional analysis of fishing effort

4.1.3.1. Progress report on the spatial analysis of commercial fishing effort and its relationship to Vulnerable Marine Ecosystems in Newfoundland and Labrador waters

A DFO International Governance Strategy (IGS) funded project focused on the spatial analysis of commercial fishing effort and its relationship to Vulnerable Marine Ecosystems in Newfoundland and Labrador waters was started in 2014.

This project is examining the spatial relationships between commercial fishing effort and the distribution of Vulnerable Marine Ecosystems (VMEs) and VME indicator species in the Newfoundland-Labrador marine ecosystem. This study involves the creation of spatially-referenced datasets of commercial fishing effort and VME indicator species biomass, and analyses of how observed VME relates to varying levels of fishing pressure. Whenever possible, analysis of the temporal variability in fishing effort will be conducted to explore the possibility that prior fishing effort may have influenced the VME distributions observed today by comparing current distributions with those predicted by species distribution models.

Initial analyses involve the study commercial catch data in order to characterize the types of fishing activities that take place. Descriptors such as target species, gear, and vessel type are being used to categorize the data and define 'fisheries'. Vessel Monitoring System (VMS) data will then be integrated with the catch data analysis on a daily scale and used to create fisheries-specific maps of effort. These effort maps will then be overlain with areas of known VME to ascertain where VMEs and effort co-occur. This work will feed into the EAF in examining SAI on VME as well as contributing to the upcoming 2016 assessment of bottom fishing impacts.

4.1.3.2. Spatial and seasonal fleet activity and cod distribution in Flemish Cap

The aim of this analysis is to describe the spatial and seasonal fleet activity and cod distribution in the Flemish Cap area in the last years. To analyze the spatial and seasonal cod fishing activity and the seasonal distribution of cod in the NAFO Division 3M (Flemish Cap) the following data sources were analyzed for different periods in this study depending on the data availability and the aim followed: Daily Catch Reports (DCR), Vessel Monitoring System (VMS), Spanish Scientific Observers, EU Flemish Cap surveys.

In relation to spatial and seasonal fishing activity the results shows that the effort was very low in the period 2008-2009 and mainly it was carried out in the western part and close to the 500 m isobaths. In these years as the cod fishery was closed, the main target species were shrimp and redfish with a depth ranging from 300 to 500 m. When the cod fishery was opened in 2010, a significant increase in the spatial area of fishing activity to the east and west of Flemish Cap was observed and changes in the fishing depth were also appreciated (Fig. 4.1.3.2.1).

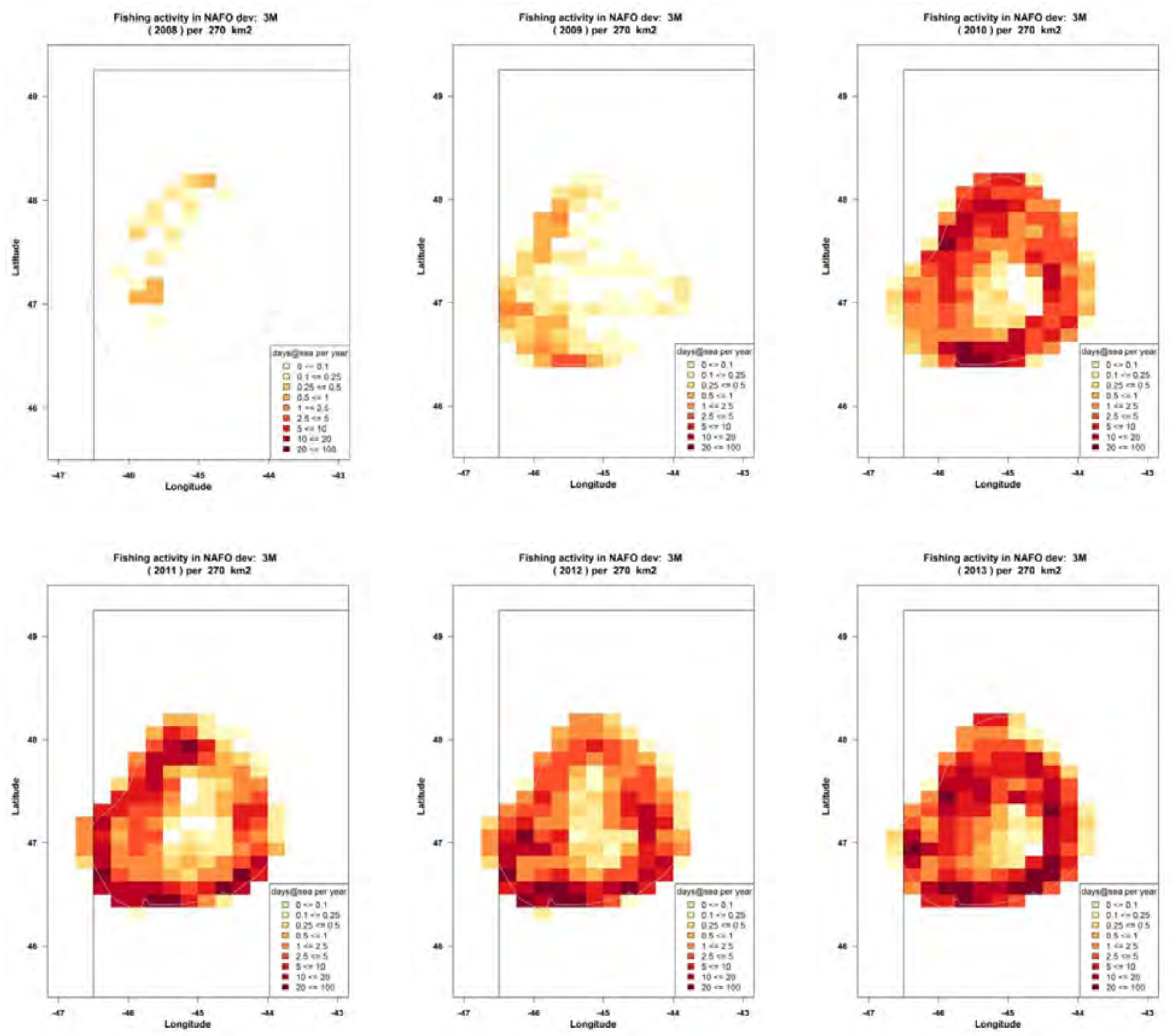


Figure 4.1.3.2.1. DCR effort in fishing days in Division 3M at less than 500 m by 270 km2 cells and year for the period 2008-2013. The 500 m. isobaths is plotted.

Regarding spatial and seasonal distribution of catches, three data sources were used: DCR data, Spanish observers onboard commercial vessels and Flemish Cap Survey data. As DCR data were available only for years 2012 and 2013, these two years CPUE data were compared with the other data sources. The highest cod CPUE based on DCR data are in the south west area of Flemish Cap. When comparing it with the cod CPUE based on Spanish observers data (Fig. 4.1.3.2.2) for the same years, for year 2012 the centroid of CPUE is also in the south west area of Flemish Cap, but the centroid cod CPUE value for year 2013 is in the east part of Flemish Cap. As Observers data used are for Spanish vessels, a possible change in the exploitation pattern of this fleet is detected to eastern shallower waters ranging from 200-300 m. The change in depth to shallower waters is directly linked to a change in cod length distribution were the mean length is smaller, around 40 cm for year 2013 in this depth range from 200-300 m. Finally a comparison of previous commercial information with survey data (Fig. 4.1.3.2.3) was done. For years 2012 and 2013, cod CPUE centroid is in the central area of Flemish Cap and this centroid area is very constant in the last years of the time series analyzed.

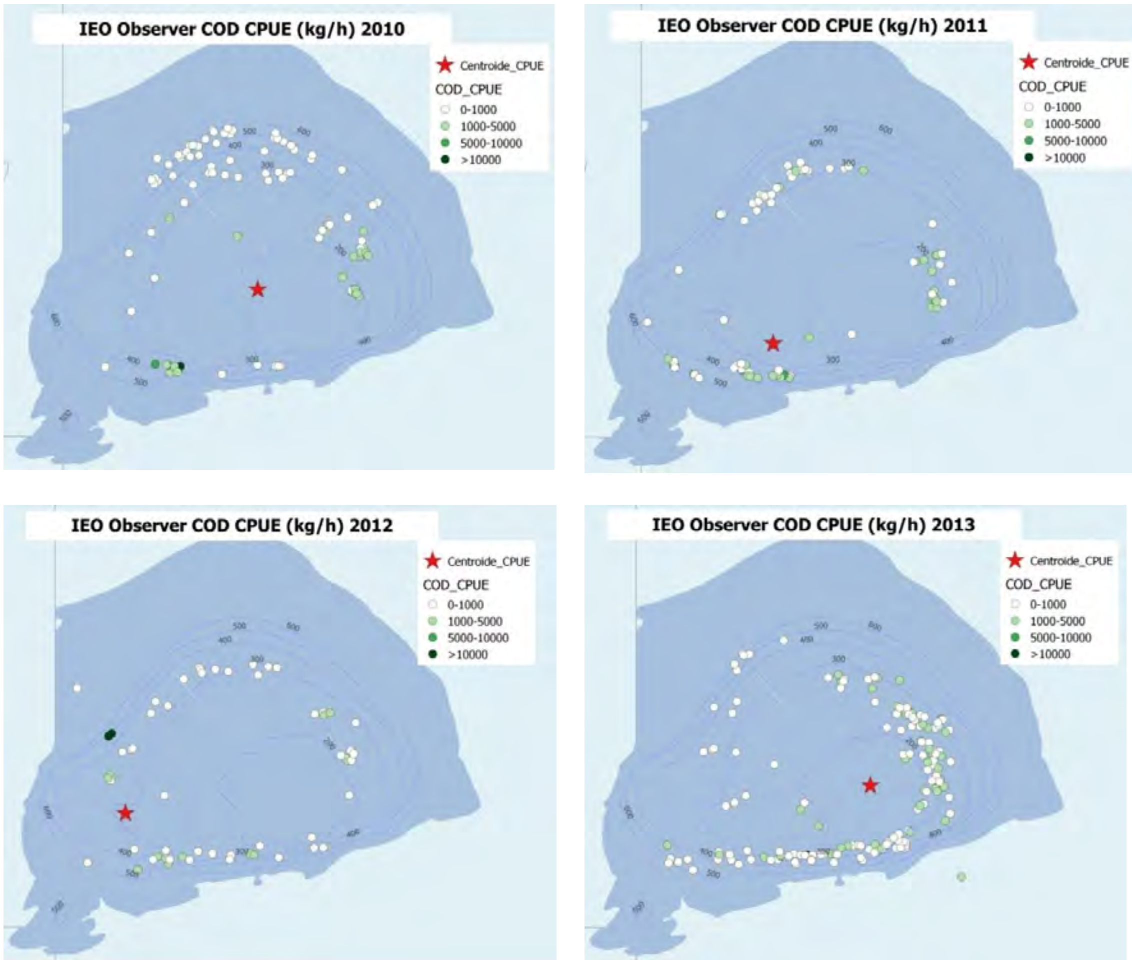


Figure 4.1.3.2.2. Spatial distribution of cod CPUE (Kg/hour) of the Spanish Scientific observers data from 2010 to 2013.

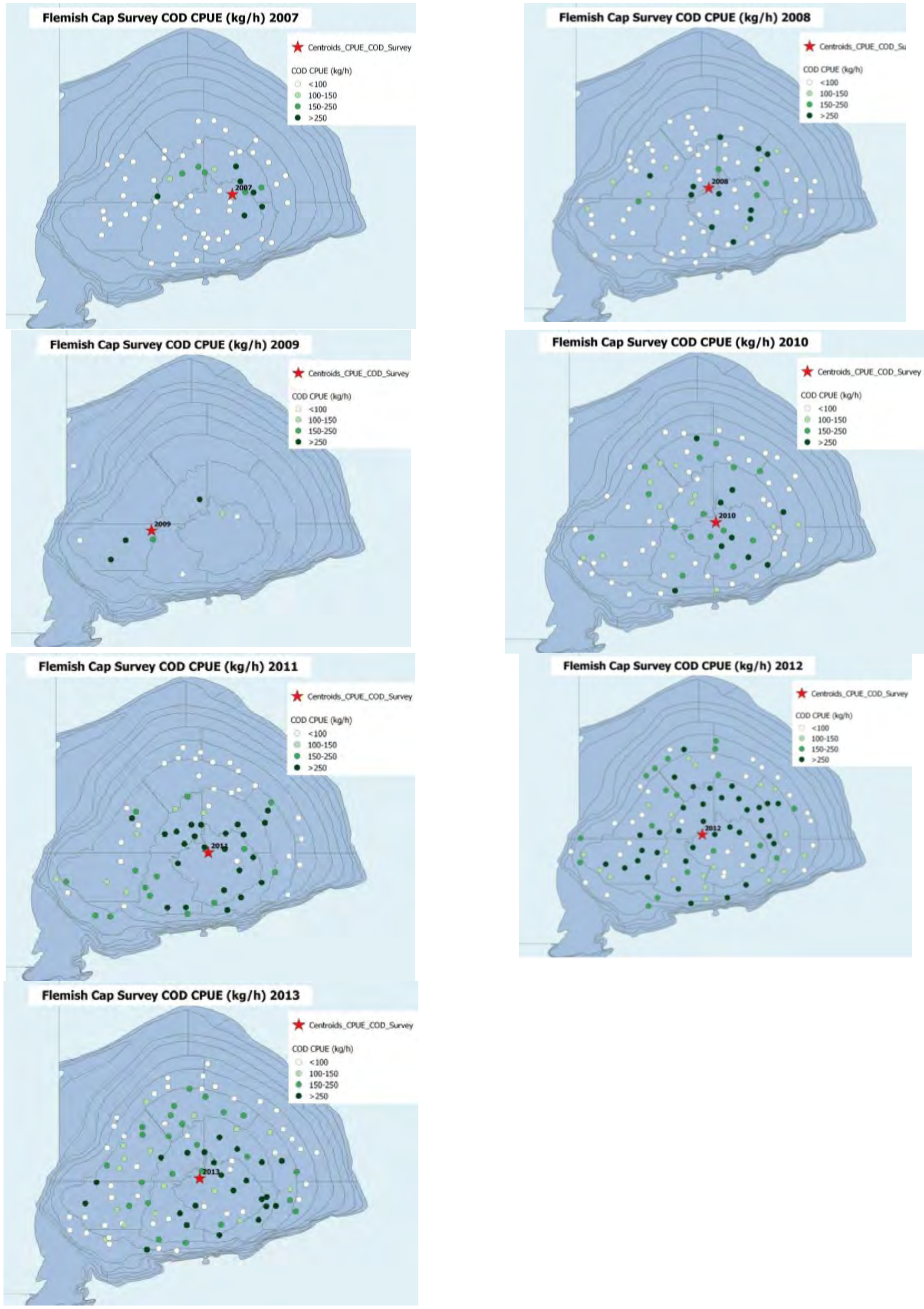


Figure 4.1.3.2.3. Spatial distribution of Flemish Cap Survey cod CPUE from year 2007 to 2013.

Focusing on the areas where spawning aggregations occur survey information has been used. Results show that despite the length 50% maturity changes with the years, the sampled population maintains the same proportion of mature and immature individuals in the time series. The spatial distribution of mature and immature cod female individuals in two periods to separate when the fishery was closed and open do not discover any specific spatial area where spawners or juveniles are more abundant (Fig. 4.1.3.2.4). All individuals seem to be distributed in similar proportions in the studied areas. It can be observed that in the period 2007-2009 when the abundance was lower most of the mature and immature individuals are concentrated in the central east part of the bank, while in the period 2010-2012 where the abundance was higher the individuals are more regularly distributed over the entire bank at depths less than 500 m.

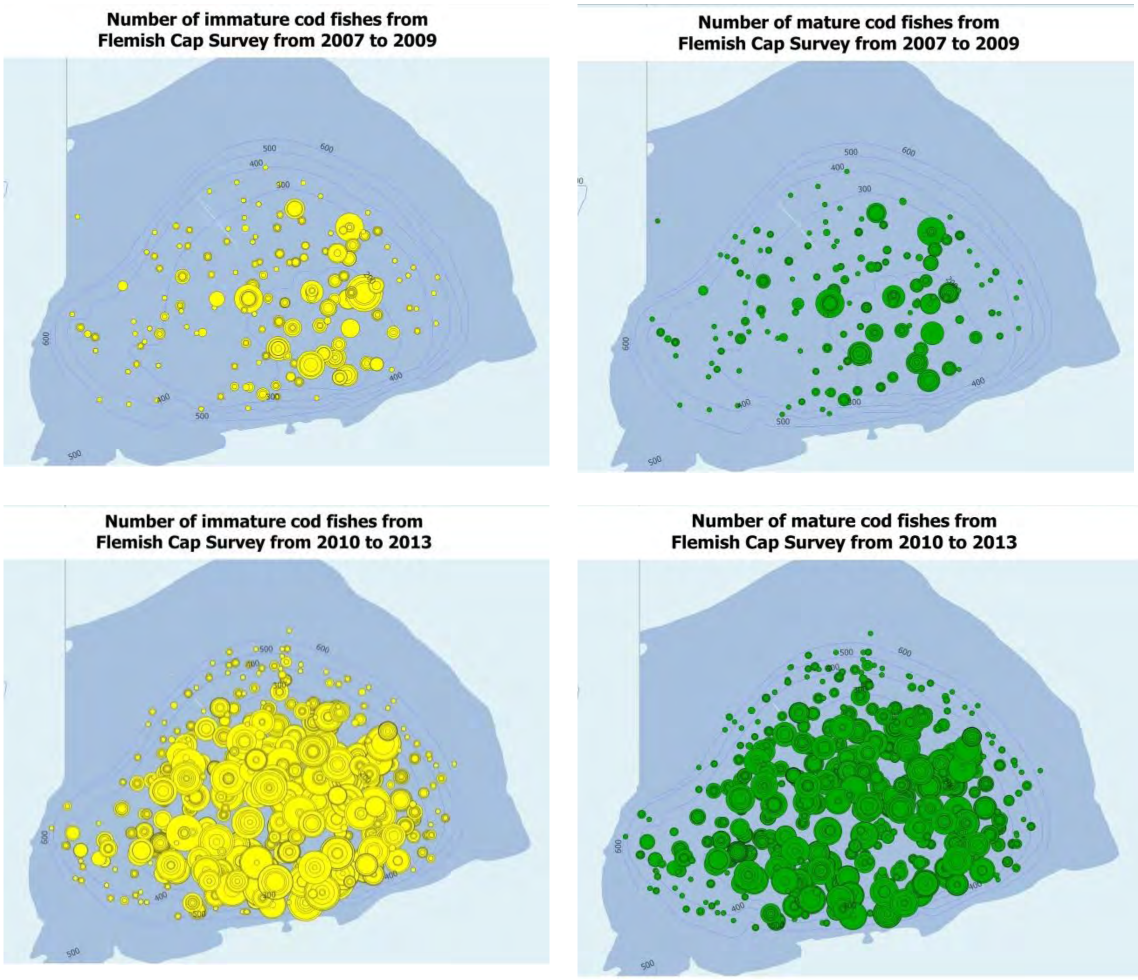


Figure 4.1.3.2.4. Spatial distribution of immature female cod (right panel) and mature female cod (left panel) split in two periods 2007-2009 and 210-2013.

Finally, areas with important concentrations of cod below a minimum conservation size were studied (Fig. 4.1.3.2.5). The proportion of cod below the minimum conservation size has shown a peak in year 2011 due to the big recruitments in the period 2009-2012, but the number of bigger individuals is stable in the time series. Concerning the spatial distribution of concentration of cod bellow a MCS, as in the case of mature and immature individuals, there is not a clear spatial pattern where they could be divided in small fish area and big fish area.

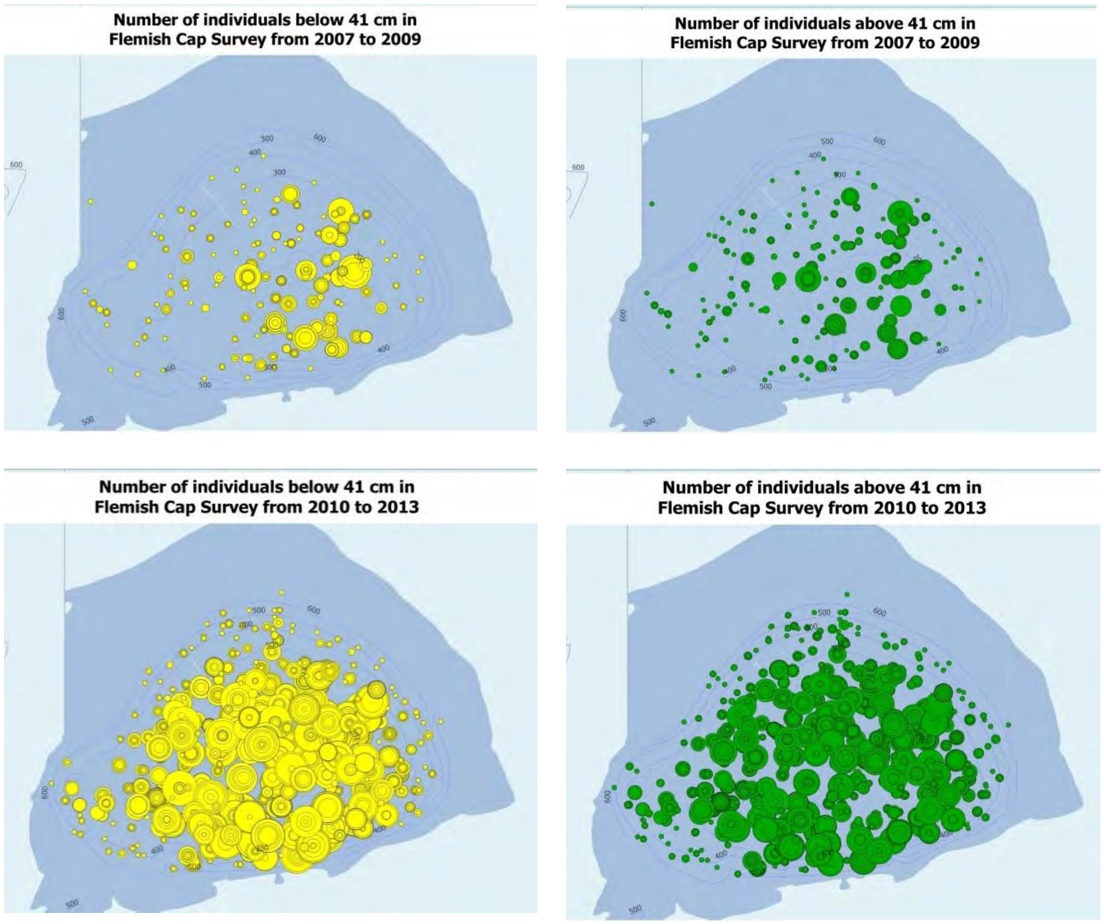


Figure 4.1.3.2.5. Spatial distribution of cod below MCS (right panel) and cod above MSC (left panel) split in two periods 2007-2009 and 210-2013.

ToR 4.1.4. [Workplan for SAI-VMEs Task 2] Summary of background information on ecosystems, habitats, communities

The following section provides an initial summary of available information on the ecosystems, habitats and communities inhabiting the NRA, specifically the Flemish Cap, and the Nose and Tail of the Grand Bank of Newfoundland. This summary of background information provides an example of the level of detail and resolution that is intended in the introductory sections in the "Re-Assessment of Bottom Fishing Activities" being developed for 2016. Once this summary is completed, it will be organized following the general template described in ToR 4.1.1.

4.1.4.1. Ecosystems

The Flemish Cap ecosystem is highly isolated in relation to the near Grand Bank and Newfoundland shelf systems. The Flemish Pass, a channel with depth of c. 1100 m, which hinders the migration of the shallower benthic and demersal fish populations (but not deep water dwelling species), while the quasi-permanent oceanic anti-cyclonic gyre (Colbourne and Foote, 2000) retains eggs and larvae over the cap that will eventually recruit to the Flemish Cap populations.

Primary production is high over the Flemish Cap (Berger et al., 1989), which is related with the existence of a consistently elevated concentration of nutrients on the Flemish Cap very likely due to the entrance of water from the North Atlantic Current (NAC) and advective and mixing processes (Maillet, 2005). This high production supports a high secondary production, with copepods as the main zooplankton group (*Calanus finmarchicus* is the most important Copepod species in terms of biomass, while in terms of numbers, cyclopoid copepods like those of genus Oithona are of higher importance). Other important groups in the zooplankton community are euphausiids, hyperiid amphipods, chaetognaths or ctenophors (Anderson, 1990).

4.1.4.2. Habitats

Perhaps the most notable of benthic habitats found on the seabed within the NRA are those that are biogenic in origin, such as sponge and coral grounds, and aggregations of emergent fauna such as seapens, which collectively can alter local conditions and provide refuge, food or a settling surface for other organisms. Collectively, such habitats can be termed vulnerable marine ecosystems (VME), especially when they are likely to interact with fishing activities.

As part of the Canadian contribution to the international NEREIDA research programme to characterize VMEs in the NRA, in 2009 the Department of Fisheries and Oceans Canada (DFO) collected in situ benthic imagery transects on the western Flemish Cap slope and Flemish Pass, and on Sackville Spur. These image transects were analysed for the diversity and abundance of epibenthic megafauna, i.e. those megafauna that are ≥1 cm. The acquired data were subsequently analysed to determine the influence of structure-forming sponge VME on the abundance, composition, and diversity of the epibenthic megafaunal community in both the Flemish Pass/western Flemish Cap slope and on Sackville Spur. The relative importance of structure-forming sponge VME in influencing the associated epibenthic community was assessed against several environmental variables within each area. The results of these analyses have been published in the primary literature (Beazley et al., 2013 and 2015). These studies revealed diverse epibenthic communities in both areas dominated by large numbers of sponges and ophiuroid brittle stars. Beazley et al. (2013) found that in the Flemish Pass/western Flemish Cap slope, the presence of structure-forming sponge VME was associated with a higher abundance, diversity, and different composition of megafauna compared to areas lacking these sponges. Similarly, Beazley et al. (2015) found that of 49 physical drivers, the abundance of structure-forming sponges was the most important determinant of megafaunal composition on the Sackville Spur. The authors suggest that the sponge grounds of the Sackville Spur are associated with a warm, salty water mass that lies over the seabed between c. 1300 and 1800 m depth.

4.1.4.3. Communities

Fish

During the the European Union fisheries surveys conducted yearly between 1988 and 2008, 129 fish species were identified, 65 of them considered demersal based in FishBase information (www.fishbase.org). As an average value, since 1960, 99% of the declared annual catches corresponded to demersal fish species. This fact points to the demersal dominance of the Flemish Cap fish assemblage. Unlike on the Newfoundland Shelf, pelagic species, such as capelin, herring and sandlance only occasionally appear in the Flemish Cap. Owing to the relatively high mean depth of the bank, the most important pelagic fishes found there belong to the order Myctophidae, especially *Myctophum punctatum*, *Ceratoscopelus maderensis* and *Benthosema glaciale* (Poletayev, 1980). In contrast, as shown by Alpoim et al. (2002), the most diverse fish orders in the Flemish Cap were the Rajiformes, Stomiiformes, Gadiformes, Osmeriformes, Perciformes and Scorpaeniformes, although from a fisheries point of view the most important species were Pleuronectiformes (American plaice and Greenland halibut), Gadiformes (cod and roughead grenadier) and Scorpaeniformes (redfish species).

Across the same 1988-2008 period, the most abundant demersal species were cod, redfish, Northern shrimp and Greenland halibut, all accounting, as an average, for 83.5% of total index of biomass every year. After the collapse of cod population in the early 1990s, the demersal community experienced very important variations (Pérez-Rodríguez et al., 2011). Among the most important variations: (1) shrimp experienced a marked increase since 1993 and reached the highest levels ever observed in the late 1990s; (2) after 2003 the redfish stocks showed a rise in their biomass, which was followed by the decline of shrimp population; and (3) the decline of shrimp as well as redfish stocks became even more pronounced with the recovery of cod population, which, after various successful recruitment events since 2006, reached to the levels of biomass observed in the late 1980s. Water temperature, along with predation and fishing mortality were significant drivers for these changes (Pérez-Rodríguez et al. 2011). The abundance of low abundance demersal species was related with water temperature, with a transition in the species composition between cold and warm periods.

Epibenthos

The structure, composition and distribution of epibenthic invertebrate megafaunal assemblages in the international waters on the NRA have been investigated based on the analysis of trawl samples collected between 45 and 1400 m and 135 and 1500 m water depth respectively, and the key factors that shape their spatial distribution were identified.

In total, 287 depth-stratified random trawls were processed and all epibenthic invertebrate fauna retained by the nets were identified to the lowest possible taxonomic level, counted when possible and weighed. Faunal groups were identified using clustering algorithms based on species presence/absence and detrended correspondence analysis was used to ordinate the species data and correlate it with the abiotic variables. The role of regional variables, such as depth, substrate type, water temperature and salinity, in shaping benthic community composition was also examined. Lastly, the relationship between recent (2001-2009) fishing intensity and benthic community structure was quantified.

Benthic biomass was dominated by Echinodermata and Porifera, owing to the presence of large-bodied species in each of these groups. In all, 439 benthic invertebrates were identified, 321 from the Tail of the Grand Bank and 288 from the Flemish Cap. The maximum number of species was found along the continental slope in both areas. A clear separation between three large groups of benthic fauna based on bathymetry and spatial distribution was found at major partitions: (1) the continental shelf of the Tail of the Grand Bank, typified by the echinoderms *Cucumaria frondosa*, and *Echinarachnius parma*; (2) the upper slope of the Grand Bank and top of Flemish Cap, typified by the sponges *Radiella hemisphaerica*, and *Iophon piceum* and by the sea star *Ceramaster granularis*; and (3) the lower slope of the Grand Bank and Flemish Cap, typified by the sea urchin *Phormosoma placenta* and the sea pens *Anthoptilum grandiflorum* and *Funiculina quadrangularis*. At minor partitions, depth and sediment type related to the oceanographic conditions were important determinants. The assemblages found showed a similar pattern to the fish assemblages described in this area where the major clusters were "associated" with bottom depth and oceanographic features. High fishing was associated with the clusters with the least spatial cohesion which may reflect the different pressures exerted on this anthropogenic driver from those of the environmental factors which shape the majority of the assemblages. These findings fill an important gap in knowledge of benthic communities in this area of the northwest Atlantic Ocean (Murillo et al. submitted).

Infauna

The infaunal community within the NRA has been investigated by analysing box-core samples collected during the NEREIDA sampling programme in 2009-10, aboard the Spanish research vessel *Miguel Oliver*. Findings from these analyses conducted at a coarse level of taxonomic resolution are presented under ToR 1.1.1 of this report, whilst work identifying organisms at a finer taxonomic scale is still ongoing for selected taxonomic groups.

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ToR 4.1.5. [Workplan for SAI-VMEs Task 4] Assessment of Significant Adverse Impacts (SAIs) on VMEs.

4.1.5.1. Introduction

Significant adverse impacts (SAI) are defined as 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 (FAO, 2009).

Several RFMO have made a commitment to investigate the potential for SAI as part of their reaction to the UNGA resolution 61/105 on sustainable fisheries (UNGA, 2006). The resolution calls upon States and RFMO to identify VME in the high seas and to consider whether fishing activities would have SAI on these ecosystems. One of the difficulties in assessing SAI in the NAFO regulatory area (NRA) has been the inaccessibility or lack of data of sufficient quality and resolution, both temporally and spatially, on the extent of fishing activities and of the identity and distribution of VME. Only recently have suitable datasets become available. Capitalising on the availability of such datasets, this investigation has developed an approach for analysing and evaluating SAI, thus contributing to a qualitative risk assessment and management framework to avoid SAI on VME from bottom fishing activities in the NRA.

During the course of this investigation it became apparent that within the proposed approach, a distinction could be made between areas of deep-sea VME which may have already been subjected to SAI from fishing activities in the preceding decades (prior to the introduction of modern spatial monitoring and fisheries management practices), and areas that could still be at risk of potential present-day SAI. The distinction between these two categories of SAI and how to assess their location and extent is explained further in the sections that follow.

4.1.5.2. Approach to assess past SAI and the risk of potential present-day SAI

According to the Food and Agriculture Organization of the United Nations (FAO, 2009), when determining the scale and significance of the impact of fishing on VME, the following three (out of six) criteria should be considered: (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; and (iii) the sensitivity/vulnerability of the ecosystem to the impact. VME indicator taxa likely to be impacted by demersal fishing activities are usually slow-growing, long-lived and fragile benthic organisms, such as the often gregarious deep-sea corals, sponges and seapens, which offer structural complexity to the seabed and enhance local biodiversity. VME indicator elements, such as spawning grounds, seamounts, canyons and knolls are also recognised as features of ecological importance.

Based on the above criteria, there are three components necessary to advance an assessment of SAI: (i) knowledge of the historical extent and intensity of the fishing activity, i.e., the active fishing footprint through and analysis of fishing effort; (ii) knowledge of the predicted or likely extent of VME and the underlying data on the recorded distribution of VME indicator taxa; and (iii) knowledge of the location of any fishery exclusion zones around VME, i.e., VME closed areas.

A number of assumptions can be made to frame the proposed approach to assess SAI. First, the risk of SAI to VME from fishing inside closed areas is deemed to be very low (at least in terms of direct impact from bottom fishing activities; although there is a recognised secondary risk from re-suspended fine sediment from adjacent fished areas (Boutillier et al., 2013), this has not been assessed in this approach). Second, VME which occurs outside closed areas, but within the active fishing footprint are potentially at risk of SAI from bottom fishing. Third, not all VME which occurs outside the closed areas will be at the same risk of SAI from bottom fishing; e.g. the degree of risk of SAI to these VME will depend upon a combination of present-day and historic fishing intensity, and predicted and/or known VME biomass distributions. Given such assumptions, the following assertion can be made: frequently fished areas of VME will tend to support lower biomass of VME indicator taxa compared with areas of the same VME that have been fished less frequently.

This assumption presents two distinct hypotheses, which can be tested: (i) areas at high risk of SAI are those defined as VME (outside of VME closed areas), but within the active fishing footprint that are subject to a relatively low fishing pressure – these areas constitute present-day areas of potential greatest concern, whereas (ii) areas at low risk of present day SAI are defined as VME (outside of VME closed areas) that are or have been subjected to very high intensity fishing effort over many years, and hence, where VME indicator taxa are found in much reduced densities or biomass; we will refer to these as areas of "historic" SAI. The challenge is how to identify the boundary between these two areas of present-day versus "historic" SAI. Figure 4.1.5.10 illustrates the approach taken to address this challenge.

The active fishing footprint is the area where fishing effort actually occurs within the boundary of the regulatory fishing footprint, which is the general area that has records of fishing. Within the active fishing footprint it is possible to observe a gradient in fishing intensity, by quantifying how often fishing takes place within a given area (usually attained from satellite-derived VMS records over several years). The smaller the unit area in which fishing is quantified, the greater the spatial resolution in the variability of fishing intensity can be assessed. However, the chosen size of the unit area must also be sufficiently large to contain enough records of fishing activity to achieve an accurate estimation of fishing intensity over time. Ideally, the same unit area is chosen to quantify the biomass of VME indicator taxa within the fishing footprint, and similarly, it is constrained by the density of available VME records. If the records are too few and the chosen unit area is too large, the spatial resolution will be too low so as to be of little practical use for the management of fishing practices to prevent SAI to VME.

A hypothetical grid of a fishing footprint with known occurrences of VME indicator taxa is depicted in Figure 4.1.5.10a (note that no indication of fishing intensity across the grid is shown).It may be that areas of observed aggregations of VME indicator taxa have already been closed off to fishing activities (Figure 4.1.5.10b), in which case it can be assumed that the risk of SAI to VME within these areas is very low. For the purposes of assessing the risk of SAI to VME from fishing, such closed areas, however and whenever defined, can be excluded from the assessment, as they are already under some form of protection. Instead, the areas of concern are those which fall outside of the closed areas which represent VME. To ascertain the biogeographical limits of VME, observed data integrated with modelled approaches are used, such as applying habitat suitability models (HSMs) or threshold-defining species kernel density estimation analyses (Figure 4.1.5.10c). Once the predicted extent of VME is determined, the precise area at risk of SAI can be defined (Figure 4.1.5.10d) through an integrated analysis of fishing intensity and the spatial distribution of VME biomass.

The interaction between fishing intensity per grid cell and VME biomass per grid cell can now be assessed, to attempt to identify areas of VME most at risk of SAI from fishing. By ranking every grid cell within the area at risk of SAI (VME excluding close area) on a gradient of increasing fishing intensity and plotting the observed VME biomass along that gradient, a cumulative rate of increase in VME biomass with increasing fishing intensity can be produced (Figure 4.1.5.10e). The point at which the addition of grid cells with higher fishing intensity no longer corresponds with a significant increase of VME biomass denotes a threshold in fishing intensity above which there is no increase in VME biomass observed; grid cells falling above this threshold therefore represent an area of potential past SAI. Grid cells falling below the threshold, which continue to yield high biomass of VME indicator taxa at very low levels of fishing intensity can be considered as defining an area at potential risk of present-day SAI (Figure 4.1.5.10f). The precise location of this threshold along the incremental fishing intensity gradient cannot be pre-defined, but will be predicated by the sensitivity and recoverability of particular VME indicator taxa (among other site specific factors). The threshold can be determined by identifying the point of inflexion on the cumulative plot of VME biomass ranked against increasing fishing intensity for each cell within each of the taxon-specific VME extents.

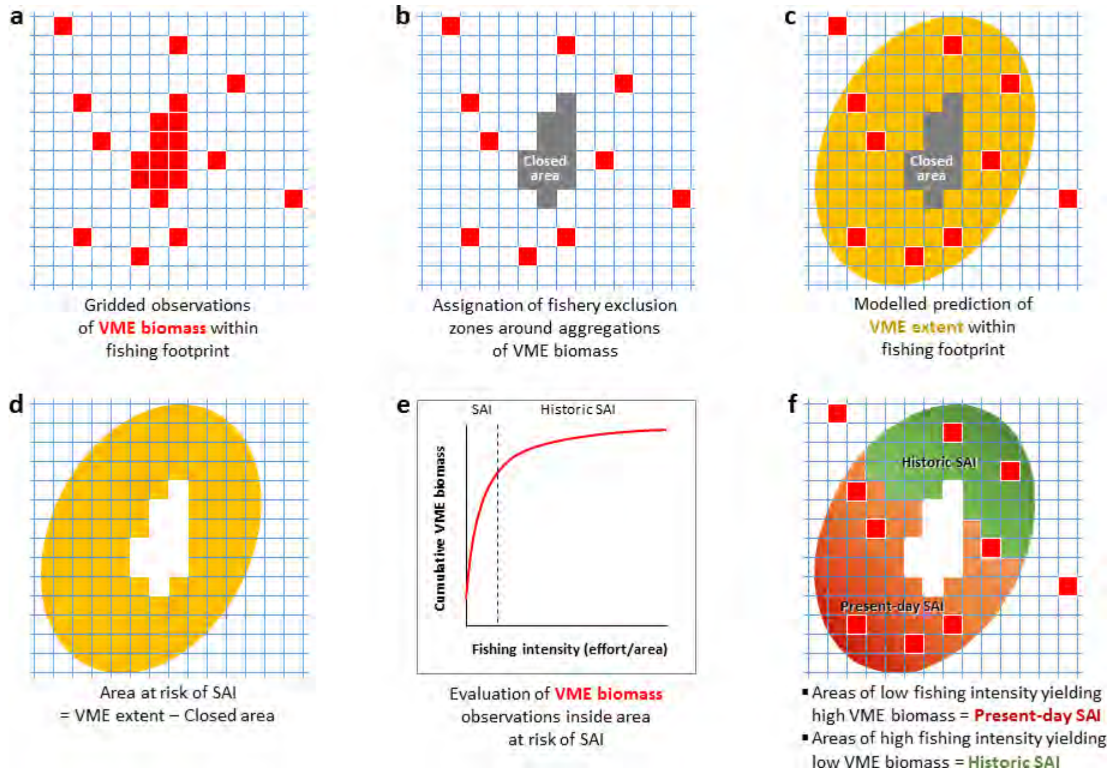


Figure 4.1.5.10. Schematic representation of a method for delineating areas of VME at risk of SAI from fishing. See main text for explanation.

4.1.5.3. Application of proposed approach in the NRA

4.1.5.3.1. The fishing footprint

NAFO delineated a fishing footprint within its regulatory area based on bottom fishing activity data covering a 20 year period (1987-2007) submitted by fishing vessel flag States (NAFO, 2009). The western extent of the fishing footprint intersects the Canadian EEZ, whilst in other directions fishing is mostly restricted to above the 1,600 m depth contour, which would approximate to the maximum depth at which a trawl normally operates.

4.1.5.3.2 Fishing effort calculation

Vessels fishing in the NRA are equipped with a satellite monitoring device (i.e., VMS) that transmits minimally, a time stamp and the vessels' position, from which speed can be derived, heading and speed every hour; each transmission is termed a 'ping'. Vessels typically ping once per hour but this may vary. So, in order to account for this variability, individual pings were converted to 'ping-time' to reflect the actual time between transmissions. VMS data collected from 2008 to 2012 were filtered to include only those speeds between 0.5 and exclude records of vessel speed greater than 5 knots; the assumption being that vessels in the NRA operating between these speeds were below 5 knots were likely to be fishing. Using ArcGIS (ESRI Canada), the NRA was gridded at a resolution of 1 nm x 1 nm cells. For each cell, the total number of pings recorded hours fished, or ping-time, for within it each year was calculated, followed by calculating a yearly average number of pings per cell across all years. This produced a value for annual average number of pings per cell, which can also be expressed as the yearly average number of hours of fishing within a cell, i.e., the fishing effort. The annual average fishing effort per cell value was divided by the total area of the cell, producing a measure of annual average fishing intensity (in hrs km-2) for each cell, i.e., the fishing effort. It is worth noting that where the boundary of a closed area bisected a cell, each portion of the cell falling inside or outside the closed area was treated separately. Lastly, each cell was classified and colour-coded along a gradient of fishing intensity to produce a visual data layer of fishing intensity (Figure 4.1.5.2).

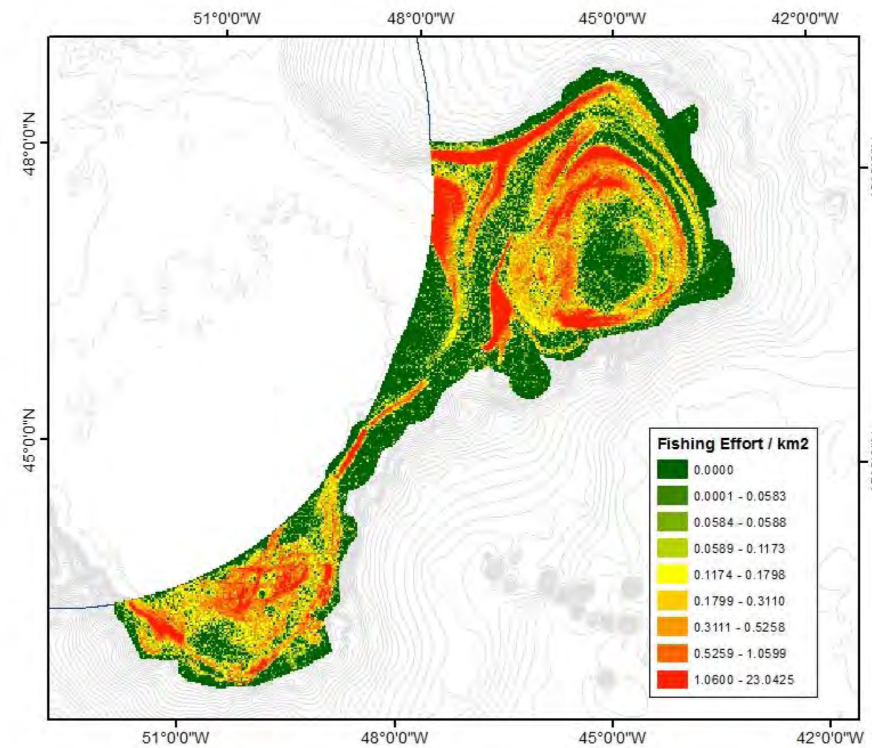


Figure 4.1.5.2. Representation of fishing intensity in the fishing footprint of the NRA based on 2008-2012 VMS data.

4.1.5.3.3. VME biomass observations

Since 1988, Canada and the European Union (Spain) have conducted annual fishery surveys within the NRA to acquire basic fish stock data and information for scientific research and fisheries management. All suitable georeferenced biomass data of sponges (Porifera), large gorgonian corals (Octocorallia) and seapens (Pennatulacea) collected by these surveys (between 2005 & 2013, 2007 & 2013, and 2000 & 2013, respectively) have been used to create a gridded layer of average VME biomass (in kg km^{-2}) at the same spatial resolution as the fishing effort (i.e., 1 x 1 nm grid cell). This then allows for direct spatial comparison and integration with the fishing effort layer.

4.1.5.3.4. Delineation of VME

Kenchington et al. (2014) performed kernel density estimation analyses on fishery survey trawl data from inside the fishing footprint of the NRA to create biomass density surfaces for a selection of VME indicator taxa. In doing so, they were able to identify thresholds in biomass, above which the taxon of interest could be considered aggregated, and thus defined as representing a significant concentration of that taxon (see Figures 6, 8 and 10 in Kenchington et al. (2014) for the kernel density distribution of sponges, seapens and large gorgonian corals, respectively, together with their corresponding thresholds that delineate significant concentrations of each). Such significant concentrations of VME indicator taxa were equated to areas representing VME. Those areas have since been accepted by NAFO Scientific Council and NAFO Fisheries Commission as the VME extent within the NRA. A polygon representing the combined footprint of the sponge, seapen and large gorgonian coral VME extents is presented in Figure 4.1.5.3.

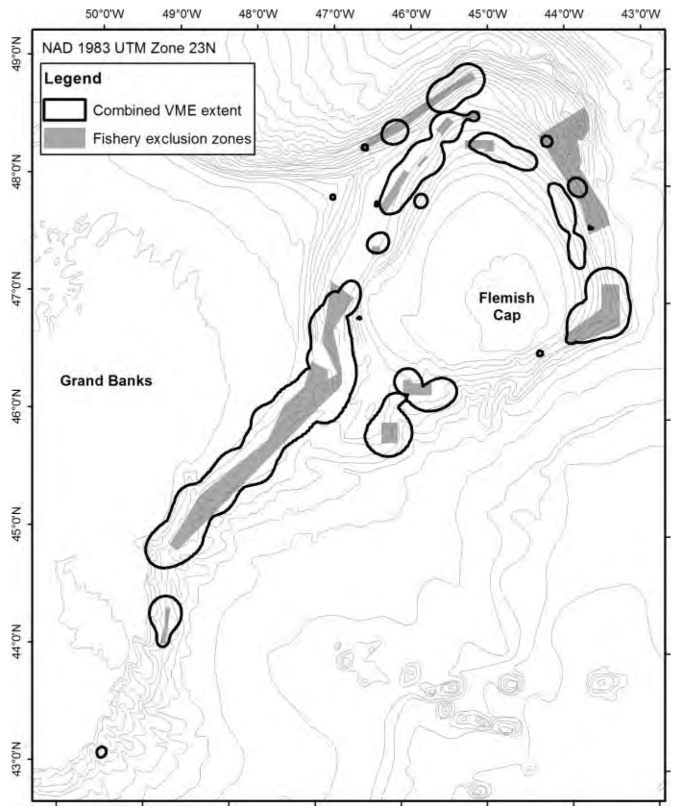


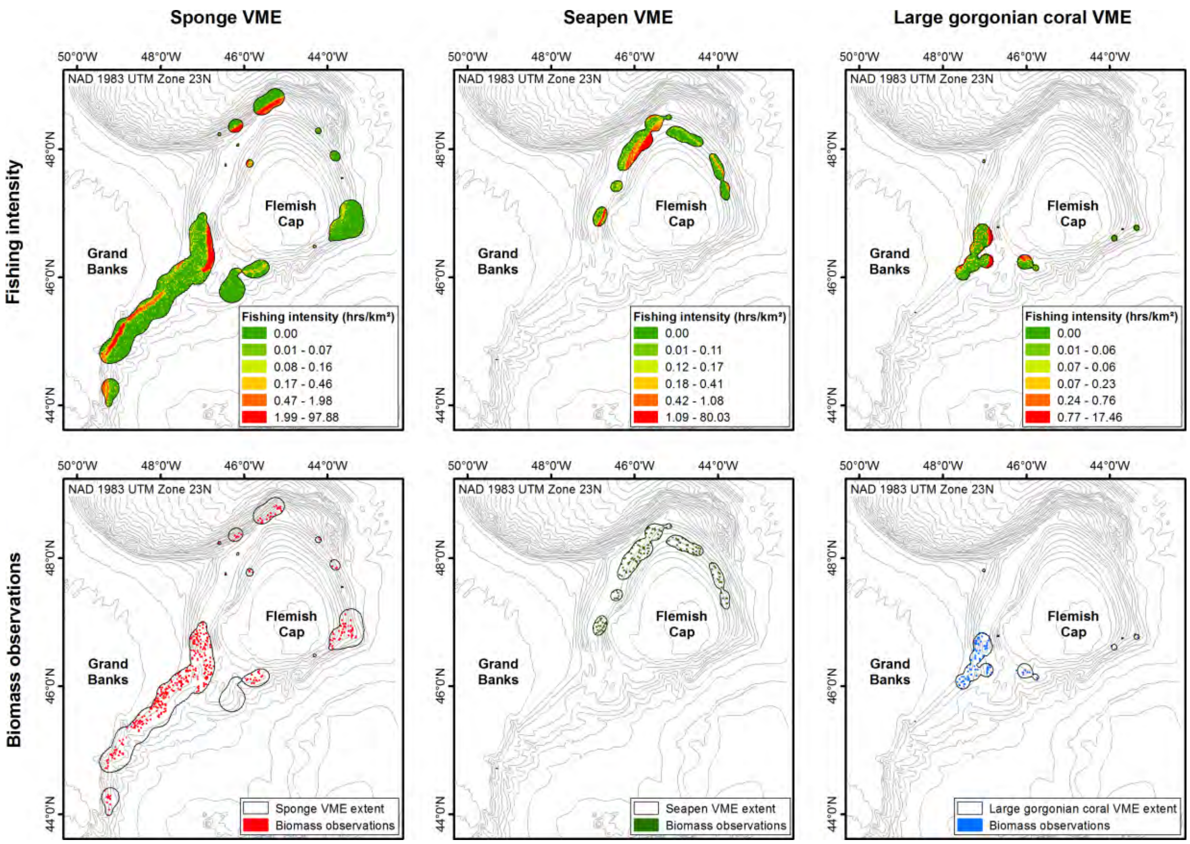
Figure 4.1.5.3. Combined extent of sponge VME, seapen VME and large gorgonian coral VME in the NRA, as defined by kernel density estimation analyses (performed by Kenchington et al., 2014).

4.1.5.3.5. Assessment of present and "historic" SAI

Having acquired all of the information and data layers listed above, it is now possible to perform an assessment of SAI within the NRA. To do so, both the fishing effort layer (Figure 4.1.5.2) and the VME biomass observations layer have been clipped to within the boundaries of the defined VME extent (Figure 4.1.5.3). Given that the selected VME indicator taxa are unlikely to occur in significant concentrations outside of the VME extent boundary, it is declared that the seabed within the fishing footprint remaining outside of the VME extent boundary is not at risk of SAI from demersal fishing (noting that the VME extent presented here is only for selected VME indicator taxa).

Figure 4.1.5.4 presents the extent of three taxon-specific VME that are observed within the NRA. It can be seen that within the extent of some VME (outside of current closed areas) there has been relatively high intensity fishing effort taking place (Figure 4.1.5.4). Closer inspection reveals that areas of higher fishing intensity are those on the shallower flanks and slopes of the Flemish Cap and the Grand Banks of Newfoundland. It can also be seen that observed VME biomass records are scattered throughout the VME extent, although some areas have more observation points than others. Areas devoid of VME biomass observations lie beyond the scientific fishery survey area.

Taking each taxon-specific VME extent in turn, the average VME biomass value (in kg km^{-2}) of every cell in which a VME biomass observation has been made can be added cumulatively along a gradient of increasing average fishing intensity per cell (in hrs km^{-2}) within each VME (excluding any cells/observations within the closed areas). The insert graph in Figure 4.1.5.5 shows the cumulative plot of biomass against increasing fishing intensity. Similarly, insert graphs in Figures 4.1.5.6 and 4.1.5.7 also show how seapen and large gorgonian coral cumulative biomass, respectively, changes with intensifying fishing intensity. In all cases there is a clear point where VME biomass no longer increases markedly after the addition of more cells with increasing levels of fishing intensity. Each of these inflection points is taken to represent a threshold of fishing intensity which separates areas of VME which have been subject to SAI in the past (i.e., cells falling above the defined fishing intensity threshold), and areas of VME which are at risk of present day SAI (i.e., cells falling below the defined fishing intensity threshold).



Error! Reference source not found. **4.1.5.4.** Distribution of fishing effort and biomass observations within the extent f each selected VME.

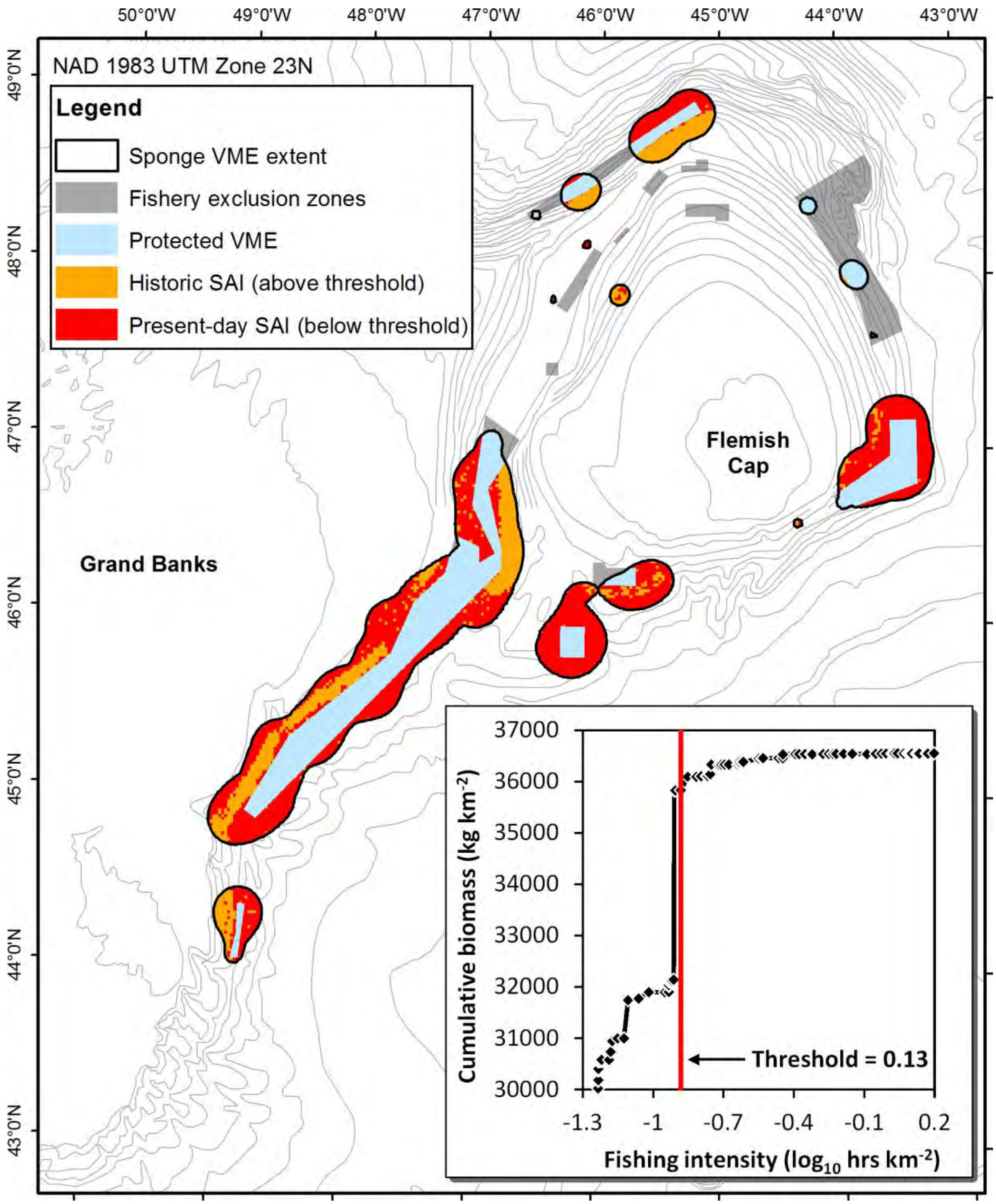


Figure 4.1.5.5. Areas of sponge VME under present-day risk of SAI (red) and exposed to "historic" SAI (orange), according to calculated fishing intensity threshold.

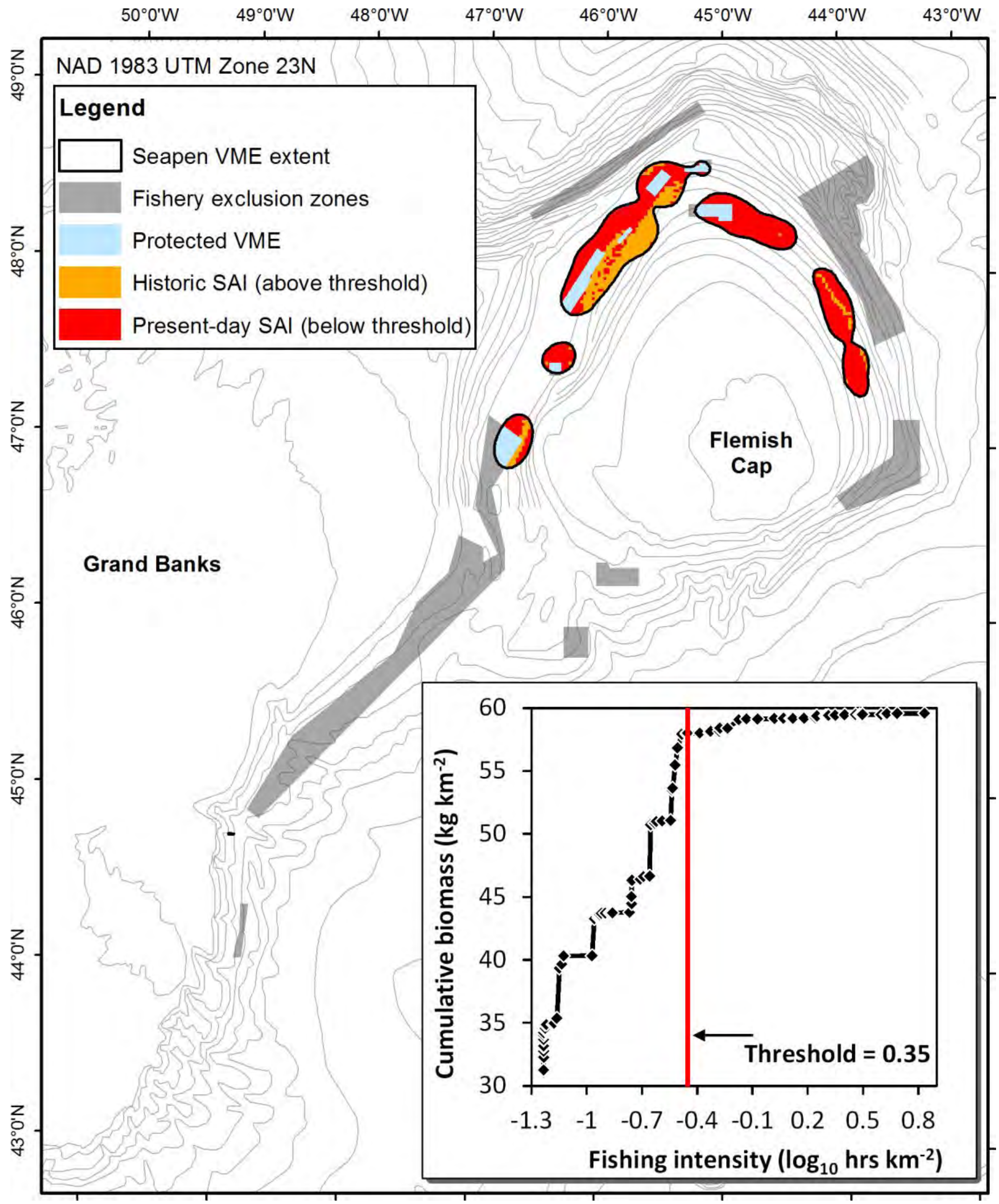


Figure 4.1.5.6. Areas of seapen VME under present-day risk of SAI (red) and exposed to "historic" SAI (orange), according to calculated fishing intensity threshold.

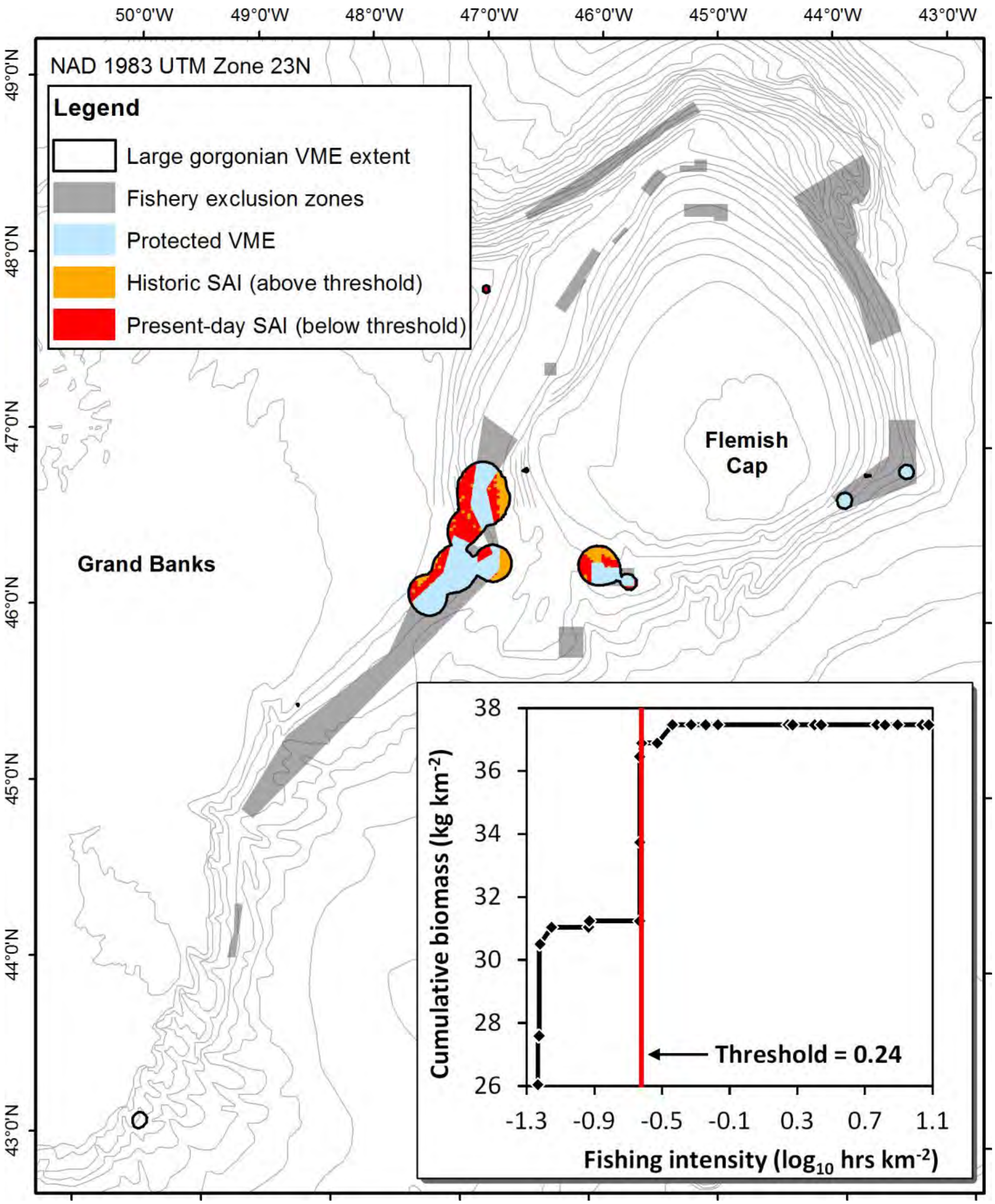


Figure 4.1.5.7. Areas of large gorgonian coral VME under present-day risk of SAI (red) and exposed to "historic" SAI (orange), according to calculated fishing intensity threshold.

4.1.5.3.6. Defining the spatial extent of SAI relative to the area of VME

Each of the threshold values identified above can now be used to classify every cell within each taxon-specific VME extent, and to calculate the proportion of the areas of VME at different levels of risk of SAI. This, in part, addresses the second criteria of the FAO guidance on assessing SAI e.g. that is to assess the "*spatial extent of the impact* *relative to the availability of the habitat type affected*". In Figure 4.1.5.5, cells at risk of SAI (i.e., those outside the fishery exclusion zone) with an average fishing intensity value below the threshold occupy the majority (69.8%) of the sponge VME extent, whereas cells with an average fishing intensity value above the threshold (occupying 30.2% of the area at risk of SAI) are restricted to relatively shallow areas, often between the edge of the sponge VME extent and the boundary of existing closed areas (see north and west of Flemish Cap). Each of these areas represents present-day risk and areas of "historic" SAI, respectively. As a proportion of the total area of sponge VME extent (i.e., including the area of VME inside fishery exclusion zones), the area of "historic" and present-day risk of SAI is 19.4% and 44.8%, respectively (see Table 4.1.5.1).

Within the seapen VME extent (Figure 4.1.5.6), the area represented by cells falling below and above the threshold for seapens covers 74.8% and 25.2%, respectively, of the total area at risk of SAI. Some areas of "historic" SAI appear to bisect the seapen VME extent along a well-defined and narrow depth range (see east of Flemish Cap), suggesting very targeted and spatially aware fishing practices. As a proportion of the total area of seapen VME extent (i.e. including the area of seapen VME inside fishery exclusion zones), the area of "historic" and present-day risk of SAI are 21.3% and 63.1%, respectively (see Table 4.1.5.1).

Lastly, for large gorgonian coral VME, the areas below and above the defined threshold represent 66.3% and 33.7%, respectively, of the total area at risk of SAI. The area at present-day risk of SAI is directly adjacent to the fishery exclusion zone, and the area of potential "historic" SAI is along the shallower slopes of the Flemish Cap (Figure 4.1.5.7). Of the total area covered by the large gorgonian coral VME extent, the area of "historic" SAI is 30.9%, and that at present-day risk is 15.7% (Table 4.1.5.1).

The area of VME protected by current fishery closures is (with the exception of large gorgonian corals) less than 50% of their total extent, with most (60-75%) of the VME occurring outside closures either at present day risk or likely to have experienced SAI in the past. The area potentially subjected to "historic" SAI for all three VME is a relatively small proportion of the total VME extent (between 16% and 21%). By contrast, this analysis shows that up to 63% of the whole extent of seapen VME is at risk of potential present-day SAI.

Table 4.1.5.1. Area (km^2) of VME inside and outside current fishery exclusion zones.

	Sponges	%	Seapens	%	Coral	%	Notes
Total area of VME	22,439	100	6,983	100	3,725	100	
Total area of VME INSIDE Closed Area	8,042	36	1094	16	1,992	53	Not at risk of SAI
Total area of VME OUTSIDE Closed Area	14,397	64	5889	84	1,733	47	Total area of potential SAI
Area of VME OUTSIDE Closure, above threshold	4,351	30	1,484	25	668	39	"historic" SAI
Area of VME OUTSIDE Closure, below threshold	10,045	70	4,404	75	1,064	61	At present-day risk of SAI
Proportion of total VME subject to "historic" SAI	-	20	-	21	-	16	
Proportion of total VME at risk of present-day SAI	-	45	-	63	-	31	

4.1.5.3.7. Statistical testing of the approach

The results from the approach presented above can be tested statistically with the use of permutation tests, to ascertain whether the hypothesised and observed reduction in VME taxon biomass with the addition of cells from each VME extent is indeed related to increasing fishing intensity. To do this, the sequential addition of cells falling within each VME extent is permuted 10,000 times to create 10,000 random biomass accumulation curves. Should it be the case that an increase in fishing intensity does have a detrimental effect on VME taxon biomass, the observed biomass accumulation curve plotted when cells are ranked by increasing fishing intensity would be expected to appear above most of the randomised biomass accumulation curves (i.e., the observed curve would rise more steeply and reach asymptote more quickly than most randomised sequences). Alternatively, if increasing fishing intensity does not have an inverse relationship with VME taxon biomass, then many randomised sequences of cell addition will yield more rapid rates of biomass accumulation than the observed curve (i.e., the observed biomass accumulation curve will rise less steeply and reach asymptote much later than many randomised biomass accumulation sequences). The main plots in Figures 4.1.5.8-10 show how the observed biomass accumulation curves for each of the three VME taxa compare against the randomised sequences. In all three cases, the observed biomass accumulation curve rises more steeply and reaches asymptote more quickly than most randomised biomass accumulation sequences.

Following on from the above permutations, and to test for statistical significance of the observed pattern in biomass accumulation, a frequency distribution of how many cells it takes to account for 95% of the VME taxon biomass is plotted. This represents the *null* hypothesis condition; namely if the number of cells to account for 95% of the total biomass when ranked by increasing fishing intensity is not statistically different from a permutated frequency distribution (the number cells it takes to account for 95% of the total biomass distribution, 10,000 randomised times), then it could be concluded that fishing has no significant effect on the biomass of the VME indicative taxon within its VME extent. The insert graphs in Figures 4.1.5.8-10 illustrate how each of the observed number of cells to reach 95% of the total biomass for each VME taxon performs against the frequency distribution of 10,000 randomised biomass accumulation runs within each of the three VME extents. For sponges, the number of cells (ordered by increasing fishing intensity) required to sample 95% of sponge biomass is within the lowest 5% of all randomised cumulative runs (Figure 4.1.5.8), making the observed spatial pattern of sponge biomass significantly related to fishing pressure. Consequently, fishing intensity is likely to be responsible for the change in sponge biomass across cells with increasing levels of fishing intensity.

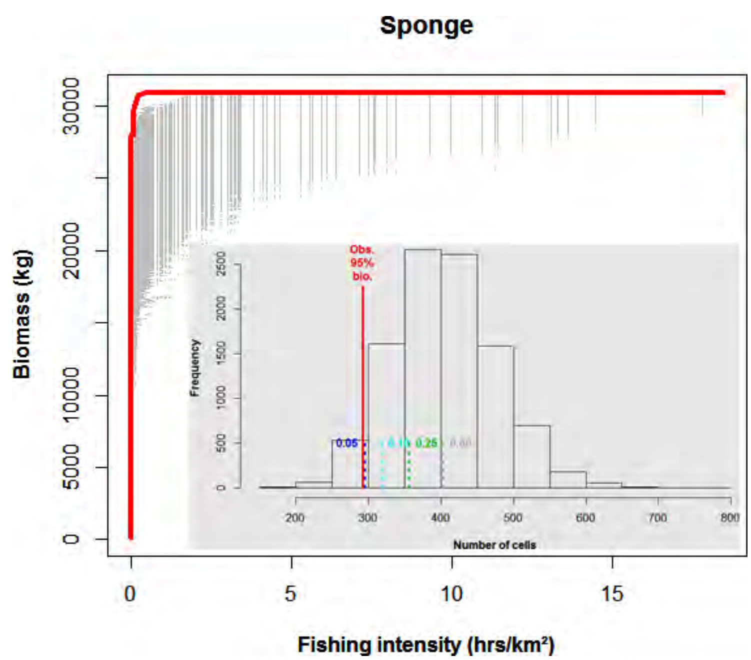


Figure 4.1.5.8. Permutation test of number of cells to account for 95% of the total sponge biomass in the sponge VME polygon (excluding cells within the closed area) with the observed number of cells shown by the red line.

Similarly, for seapens, the number of cells observed to sample 95% of their biomass is close to the lowest 10% of the randomised biomass accumulation sequences (Figure 4.1.5.9), which whilst not statistically significant, could hint at an ecologically significant effect.

Lastly, for large gorgonian corals, there appears to be no statistical significance in the relationship between fishing intensity and coral biomass (Figure 4.1. 5.10), implying that disturbance by fishing has little or no influence on the present day spatial distribution of the large gorgonian coral biomass. It also raises the question of whether SAI to large gorgonian coral VME may have already occurred before 2008, which is the first year from which VMS fishing effort data are available to the present investigation.

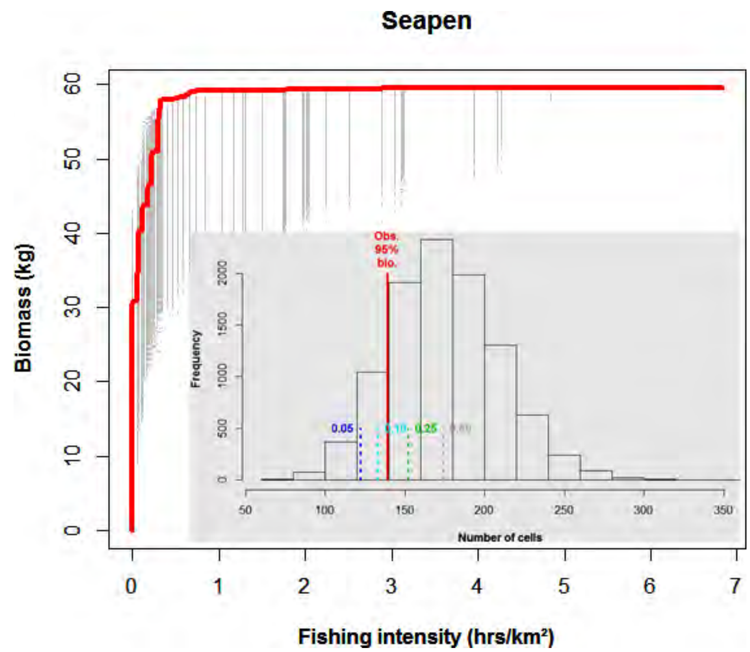


Figure 4.1.5.9. Permutation test of number of cells to account for 95% of the total sponge biomass in the seapen VME polygon (excluding cells within the closed area) with the observed number of cells shown by the red line.

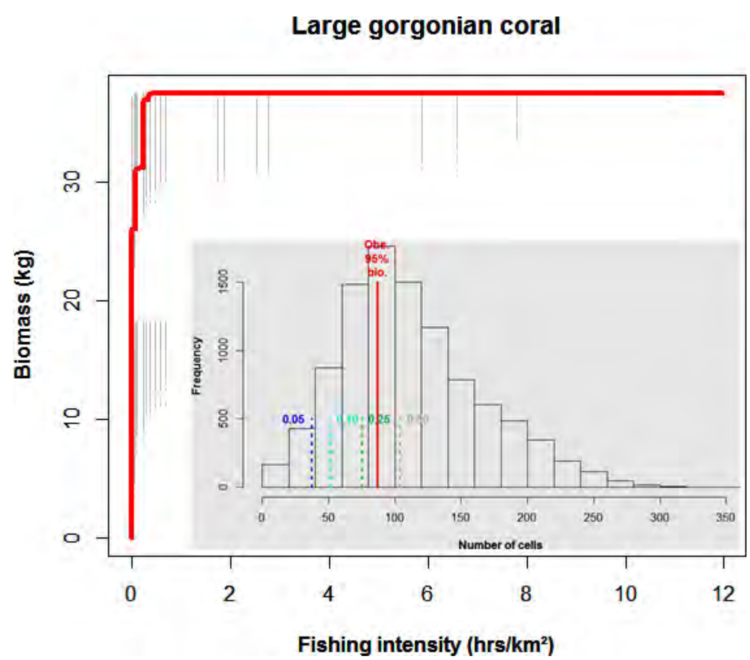


Figure 4.1.5.10. Permutation test of number of cells to account for 95% of the total sponge biomass in the large gorgonian VME polygon (excluding cells within the closed area) with the observed number of cells shown by the red line.

The results presented above were derived from discussions at the last WGESA meeting, but the final analyses were performed subsequently. Results have yet to be discussed fully by the group members. Such discussions are planned for the next time the WG convenes in November 2015.

4.1.5.4. References

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ToR 4.1.6. [Workplan for SAI-VMEs Task 7] General considerations on risk assessments for the impacts of bottom fishing activities on VMEs

4.1.6.1. Summary

As part of the work towards the Reassessment of Bottom Fishing Activities by 2016, WGESA started to discuss the structure and elements of ongoing analyses in the context of risk assessments to make sure that a)they are conceptually and effectively compliant with the standard structure of formal risk assessment analyses, and b) they are suitable to be integrated into broader risk assessment exercises that may take into consideration other components beyond Significant Adverse Impacts (SAIs)

Although this conversation is still ongoing within the working group, WGESA initially focused its attention on existing examples of risk assessments frameworks that have been developed/used for the evaluation of impacts on VMEs (e.g. Martin-Smith 2009, DFO 2013, Penney and Guinotte 2013).

The basic building components for a risk analysis are the identification of the risk elements (i.e. features that could be exposed to hazards and for which we want to evaluate the risk), and the drivers (i.e. the sources of those hazards that we want to consider to evaluate the risk). It is the combination of a given risk element with a given driver what defines the consequence (i.e. impact) of that specific hazard. More precisely, consequence can be described as a function of exposure (i.e. is the risk element susceptible to encounter the driver? how often does it happen?), and sensitivity (i.e. how responsive is the risk element to the driver once encountered?). In principle, both exposure and sensitivity are (or can be) variables; exposure may include levels and/or frequency of encounters with the driver (i.e. degrees of intensity of the exposure), while sensitivity may vary with these levels of intensity of exposure (i.e. the responsiveness changes with exposure levels, not necessarily in a linear form).

On this basis, risk is typically defined in terms of the combination of the likelihood of an event, and the consequences of that event when it happens (Fig. 4.1.6.1). The likelihood is simply the probability of occurrence of the event, which can be derived from quantitative modelling exercises, expert opinion, or a combination of both. The consequence of an event (impact) is defined by the aforementioned combination of exposure and sensitivity.

Although risk matrices are often developed to assess the impacts of a given driver on a specific risk element (e.g. fishery A on VMEs), it is important to acknowledge the potential cumulative and in combination effects associated with the same driver acting multiple times on a single risk element, and/or multiple drivers acting on a single risk element.

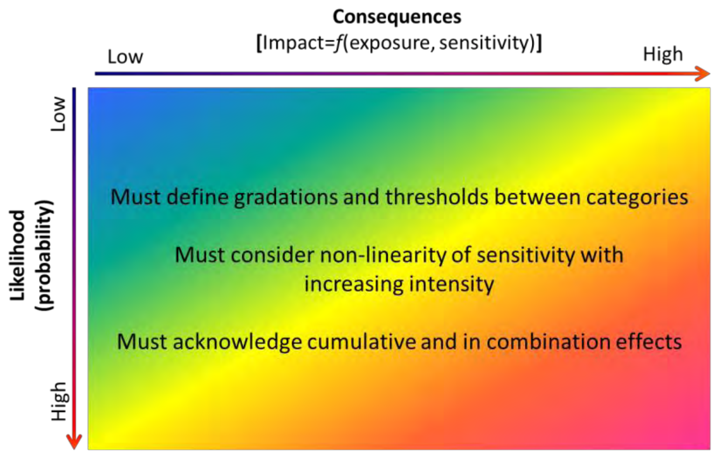

Figure 4.1.6.1. Schematic representation of a risk matrix. The specific combinations of likelihoods and consequences define the risk (vulnerability) associated to that combination. This type of matrix is used to define semi-quantitative risk regions or zones.

In the case of VMEs, and considering bottom fishing activities as a generic driver, exposure could be initially considered as a binary element (i.e. is the VME susceptible to encounter a bottom fishing activity or not?), while sensitivity, in the absence of detailed understanding of the potential degrees of responsiveness to the driver, can also be considered binary in the extreme (i.e. yes or no; VMEs, by definition, are responsive –negatively- to bottom fishing activities, that is why they have been identified as VMEs).

However, it is believed that the first interactions between fishing gear and a VME are often the ones that cause the most damage per unit of fishing effort, while subsequent interactions further add to the erosion of the habitat until it reaches some "fully impacted state", which could be a significantly altered state of the VME o even its full elimination. When a VME reaches this fully impacted state, all potential adverse impacts have been realized, and further fishing on the area could be considered more as a factor impeding recovery (if at all possible), than a factor increasing the degradation state of the VME. Therefore, it would be expected that the probability of exerting significant adverse impacts, **within a VME area**, should be inversely proportional to fishing effort; the highest the effort within a VME, the highest the probability that SAIs have been already realized. The areas at most risk **within a VME** are those that have not yet been exposed to fishing, or have received little exposure.

These cosiderations from a general risk assessment analysis perspective are consistent with the analyses being implemented by WGESA. This indicates that the ongoing work is a suitable approach to characterize SAIs in a risk assessment context. Further developements on this topic are expected during the 205 WGESA meeting, when the final analyses to support the Reassessment of Bottom Fishing Activities by 2016 will be carried out.

4.1.6.2. References

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ToR 4.2. ***[FC Request #11]*** **Review of existing information on the potential impacts of activities other than fishing (e.g. oil and gas, shipping, recreation), and the risks they may pose, for the stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area.**

4.2.1. Potential effects of human activities other than fishing on fish stocks and ecosystems in the NAFO convention area

The NAFO 2011 Performance Review Panel already encouraged NAFO to consider whether activities other than fishing in the NAFO Convention Area may impact the stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area. Such activities might include oil exploration, shipping and recreational activities. Further to the Performance Review recommendations, at the September 2014 Annual General Meeting, Fisheries Commission asked Scientific Council to provide a literature survey that would indicate what the risks are to the fish stocks and ecosystems in the NAFO Regulatory Area by looking at comparable situations.

Here we summarize the findings of a literature review of potential effects of anthropogenic activities (Table 4.2.1) presented at the WGESA meeting. Also, general information on the state of the world oceans will be available soon through the UN World Ocean Assessment http://www.worldoceanassessment.org/?page_id=14. The first chapters of that report are currently under review and will be posted soon.

Stressors resulting from human activity operate at different spatial and temporal scales (Figure 4.2.1, Table 4.2.2) and as a result differ in the extent and duration of their effects on marine ecosystems. This spatio-temporal complexity is one of the major impediments to integrated assessment and quantification of cumulative effects relating to these activities (see list of knowledge gaps below). Non-linear responses to environmental drivers (Boyd and Brown, 2015) are also a significant challenge for understanding and evaluating the fisheries and ecosystem responses to anthropogenic pressures.

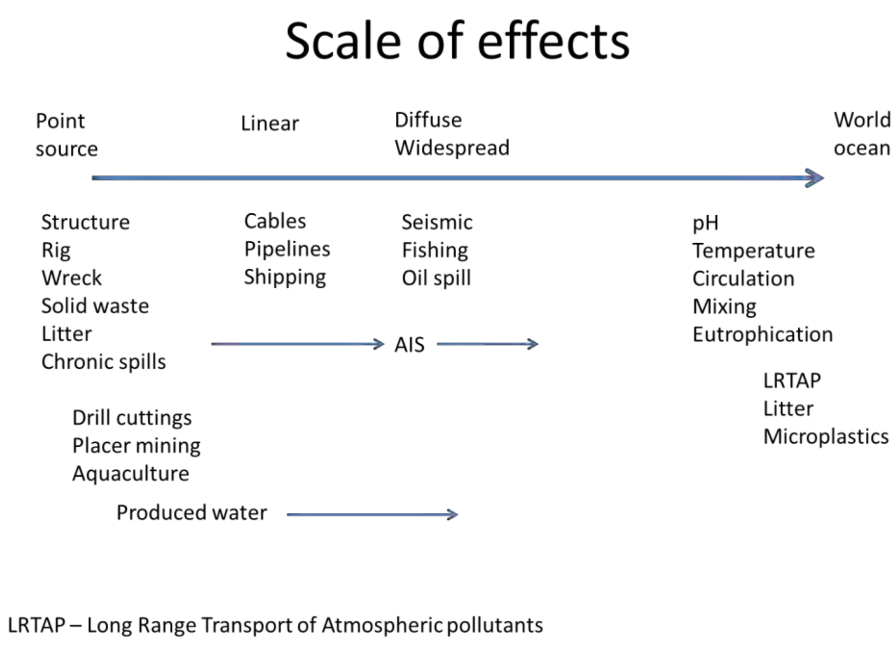

Figure 4.2.1. Scale of effects of anthropogenic activities.

Table 4.2.1. Anthropogenic activities and stressors. The asterisk (*) indicates those that are included in this review. The others are outside the scope or have primarily coastal or nearshore effects and do not affect the NAFO Regulatory Area.

Anthropogenic activity	Stressor
Fishing	Not Applicable to this review
Transportation*	AIS vector Accidental events
Oil and gas exploration and exploitation*	Drilling wastes Produced water Seismic Accidental events
Other energy sources	Wind Tidal
Mining*	Tailings disposal Placer mining* Nodule dredging*
Introduced species*	
Litter*	
Microplastics*	
Cables*	
Pipelines*	
Recreation and tourism	
Marine protected areas	
Defense activities*	Sonar, dumping
Aquaculture	
Dumping solid waste*	Habitat modification/destruction
Coastal infrastructure/ shoreline modification	Habitat modification/destruction
Global change	Climate Weather Ecosystem shifts Acidification Eutrophication

Table 4.2.2. Summary of activities/pressures, responses, potential mitigations for activities other than fishing that could have an impact on stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area.

AIS: Aquatic Invasive Species, BBL: Benthic Boundary Layer, EEM: Environmental effects monitoring , EMF: Electro-magnetic Fields, EnvPP: Environmental Protection Plan, HABs: harmful algal blooms, Hg: Mercury, HVDC/AC: High Voltage Direct Current / Alternative Current , NOx: mono and di-nitrogen oxyides, POPs: Persistent Organic Pollutants. Key references and web links are provided within the table when appropriate. Question marks (?) indicate potential/suspected effects/risks which are generally poorly known / documented.

Activity / sector	**Pressure**	**Stressor**	**Effect / Risk**	**Scale**	**Potential mitigation**
Oil and Gas	Structure	Reef effect (Pickering and Whitmarsh 1997)	Increased habitat complexity in a contaminated environment Substrate for sessile organisms Attraction of mobile organisms	point	Fisheries exclusion zone Taint/contaminant monitoring
	Mobile structure (e.g. drilling rig)	AIS vector – surface fouling community and ballast water (IPEICA, OGP, 2010)	Risk is unquantified Higher for coastal zone?	Point/linear	Antifouling technology Fouling community removal Ballast water exchange / treatment

Table 4.2.2. Summary of activities/pressures, responses, potential mitigations for activities other than fishing that could have an impact on stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area.

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Activity / sector	**Pressure**	**Stressor**	**Effect / Risk**	**Scale**	**Potential mitigation**
Oil and Gas	Drilling waste	Smothering Hydrocarbon/ heavy metal contamination Increased O_2 demand (Ellis et al 2012)	Changes to benthic community structure Reduced feeding for benthic organisms that feed in the BBL Contamination / taint of benthic organisms and demersal fish Smothering, anoxia, contamination of cold water corals (Larsson et al. 2013)	Benthic/BBL Limited area 500 - 6000m (Ellis et al 2012) Movement of fines and flocs in BBL dependant on bottom currents – Ba signature can be seen at great distances (Lepland et al. 2000) Taint is a perceived concern for fisheries (no taint seen in current NL offshore EEM programs)	Fisheries exclusion zone Discharge limits for hydrocarbons associated with cuttings Taint/contaminant monitoring Cuttings reinjection Onshore disposal of used drilling fluids/cuttings Siting of wells away from sensitive areas (directional drilling)
	Produced water	Hydrocarbon/ heavy metal/radionuclide contamination (Lee & Neff, 2011) Nutrients (DOC, N, P, Fe)	Changes in lower foodweb Contamination Difficult to monitor due to complex chemical and hydrological dynamics of plume	Limited to large depending on volume and element of concern (Rivkin et al. 2000)	Fisheries exclusion zone Discharge limits for hydrocarbons associated with produced water Taint/contaminant monitoring Reinjection

Table 4.2.2. Summary of activities/pressures, responses, potential mitigations for activities other than fishing that could have an impact on stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area.

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Activity / sector	**Pressure**	**Stressor**	**Effect / Risk**	**Scale**	**Potential mitigation**
Oil and Gas	Seismic	Noise	Marine mammals – hearing loss, disorientation, mortality Fish behaviour? Catchability? Shellfish? Benthos? Plankton? Gear loss Access to fishing grounds (DFO, 2004; ICES, 2005)	widespread	Ramp up Marine mammal avoidance Timing to avoid marine mammal aggregations Notice to mariners Compensation for gear loss/access EnvPP http://www.dfo-mpo.gc.ca/oceans/management-gestion/integrated management-gestionintegree/seismic-sismique/index-eng.asp
	Accidental events	Hydrocarbons Dispersants Fishery disruptions Increased O_2 demand	Contamination Taint Smothering Changes in benthic and pelagic community structure Mortality of sessile communities (Joye et al. 2014)	Small to widespread Surface or water column/benthos	EnvPP and cleanup capability Dispersants / burning / collection and disposal Cleanup difficult / impossible under ice

Table 4.2.2. Summary of activities/pressures, responses, potential mitigations for activities other than fishing that could have an impact on stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area.

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Activity / sector	**Pressure**	**Stressor**	**Effect / Risk**	**Scale**	**Potential mitigation**
Transportation	Accidental events	Hydrocarbons Dispersants Fishery disruptions Increased O_2 demand	Contamination Taint Changes in benthic and pelagic community structure Mortality of sessile communities	Surface	Safety standards (e.g. double hull tankers) EnvPP and cleanup capability
	Ship strikes		Injury death of marine mammals	Point/linear	Marine mammal avoidance Timing/routing to avoid marine mammal aggregations Speed reductions
	Ballast water exchange Hull fouling	AIS vector	Risk of introduction of pelagic organisms/larvae with alternative ballast water exchange zones in NAFO area	Area Mostly studied for coastal area	Mid ocean ballast water exchange (McKenzie et al 2010)
	Noise	Soundscape modification	Muffling of natural sounds and cues	Large scale / ubiquitous	Quiet ship design
		Naval sonar	Marine mammals – hearing loss, disorientation, mass strandings, mortality (ICES, 2005)	Small to widespread	EnvPP protocols for use

Table 4.2.2. Summary of activities/pressures, responses, potential mitigations for activities other than fishing that could have an impact on stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area.

AIS: Aquatic Invasive Species, BBL: Benthic Boundary Layer, EEM: Environmental effects monitoring , EMF: Electro-magnetic Fields, EnvPP: Environmental Protection Plan, HABs: harmful algal blooms, Hg: Mercury, HVDC/AC: High Voltage Direct Current / Alternative Current , NOx: mono and di-nitrogen oxyides, POPs: Persistent Organic Pollutants. Key references and web links are provided within the table when appropriate. Question marks (?) indicate potential/suspected effects/risks which are generally poorly known / documented.

Activity / sector	**Pressure**	**Stressor**	**Effect / Risk**	**Scale**	**Potential mitigation**
Cables and Pipelines	Habitat modification	Plowing, armouring	Gear entanglement Substrate modification	Linear	
	HVDC/AC	EMF	Interference with prey detection or migration patterns (Normendeau et al. 2011)	Linear Zone of effect dependent upon cable type and configuration (Normendeau et al. 2011)	Armouring Cable positioning Routing
Mining (Ramirez-Llodra et al. 2011)	Placer mining Nodule mining – abysal plains Crusts on seamounts Hydrothermal vents	Habitat modification / destruction Smothering (Oebiusa et al 2001) Direct mortality	Winnowing of fines Modification of grain size Severity of effect dependant on resupply Substrate modification Direct mortality	Local to widespread (Ramirez-Llodra et al. 2011)	Identification and avoidance of sensitive and/or vulnerable habitats Gear/equipment designed to minimize benthic disturbance
Dumping and waste disposal	Reef effect Contamination	Habitat Modification	Increased habitat complexity Attraction to contaminated sites Gear entanglement	Local (Ramirez-Llodra et al. 2011)	Remove contaminants Restrict fishing

Table 4.2.2. Summary of activities/pressures, responses, potential mitigations for activities other than fishing that could have an impact on stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area.

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Activity / sector	**Pressure**	**Stressor**	**Effect / Risk**	**Scale**	**Potential mitigation**
Dumping and waste disposal		Contaminants and radionuclides	contaminants	Point source	Alternative disposal methods (marine disposal of radioactive waste banned in 1988 – MARPOL Convention Annex V)
Litter		Habitat modification Smothering Fishing by lost traps and pots	Changes to benthic community structure Mortality (Ramirez-Llodra et al. 2011)	Long range, ubiquitous (Bergmann & Klages, 2012)	Litter reduction programs at sea and on land (MARPOL Convention Annex V) Lost gear recovery programs
		Floating debris (Moret- Ferguson et al.2010) Accumulation in convergent zones Ghost nets	Ingestion by pelagic organisms (Baulch & Perry, 2014) AIS vector (Gregory, 2009) Entanglement of pelagic organisms	Long range, ubiquitous	Litter reduction programs at sea and on land Ghost net and gear recovery programs
		Contaminant leaching	Endocrine disrupters POPs	Long range, ubiquitous	Litter reduction programs at sea and on land

Table 4.2.2. Summary of activities/pressures, responses, potential mitigations for activities other than fishing that could have an impact on stocks and fisheries for which NAFO is responsible as well as biodiversity in the NAFO Regulatory Area.

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Activity / sector	**Pressure**	**Stressor**	**Effect / Risk**	**Scale**	**Potential mitigation**
Microplastics		Pelagic substrate	Modification of microbial loop Increased sedimentation Ingestion by pelagic and benthic organisms (Watts et al. 2014)	Long range, ubiquitous	Reduce industrial and domestic microplastic use
		Contaminant absorption and leaching (Andrady, 2011)	Endocrine disrupters POPs	Long range, ubiquitous	Reduce industrial and domestic microplastic use (for example, http://www.theguardian.com/environment/2013/jan/09/unilever-plastic-microbeads-facial-scrubs)
Scientific research	Fisheries surveys Moorings and ocean observatories Drifters Fish tracking	Benthic impacts Seal predation AIS transport (Benn et al. 2011 ; Ramirez-Llodra et al. 2011)	Bottom disturbance Substrate modification Seals targeting acoustic tagged fish (Stansbury et al 2014)	Activity specific – ranging from point to linear to widespread (Benn et al. 2010)	

4.2.2. Knowledge gaps and challenges

From the above summary, the following key knowledge gaps and challenges were identified in relation to the potential impacts of activities other than fishing:

- Effects on corals and sponges
  - Drilling wastes
  - Seismic
  - Microplastics
- Effect of microplastics
  - Fish
  - Marine mammals
  - Invertebrates
- Near bottom currents
  - Suspended sediment transport
  - Resuspension
- Better modeling of spills and waste dispersion
  - Oil and gas
  - Drilling wastes
  - Produced water
- Produced water monitoring
- Quantity and distribution
  - Litter
  - Microplastics
- Mining
  - Effect on deep water habitats
- Cumulative effects assessment methods
  - Integration of many scales of effect
- Cumulative effects predictions

Among them, some emerge as particularly relevant for the NAFO regulatory area and the fish stocks under NAFO jurisdiction. The relevant references for these issues were specified in Table 4.2.1.

Cold water corals and sponges: Preliminary studies suggest that some cold water corals may be resistant to smothering by drilling wastes as they are adapted to live in depositional environments. Only a few species have been studied to date and no field based observations are available from active drilling sites. Directional transport and near bottom movement of fines may also influence the deposition rates in and around biogenic habitats even at some distance from drilling waste disposal. Modeling studies of particle transport in such environments are required to adequately assess potential for effects on coral and sponge communities. In Canada, ongoing Environmental Studies Research Funds (ESRF) projects modelling circulation and drift trajectories by Greenan (BIO) and Davidson (NAFC) and Yu (BIO) will provide needed insight into this question. Studies are also required to evaluate the potential for effects of seismic surveys and microplastics on cold water corals and sponges.

Spill and waste dispersion assessment and modeling: The complex fate and distribution of oil and gas from the recent Macondo blowout in the Gulf of Mexico has emphasized the need for improved understanding and modeling of the movement and fate of accidentally released oil and gas. Much of the past effort has gone into studying the response of oil on the surface. Oil and gas released at depth or mixed into the water column are usually ignored. The Gulf of Mexico experience demonstrates that a significant fraction of the hydrocarbons released at depth may never get to the surface and remain in the water column or settle to the bottom. These benthic oil patches may represent the longest lasting impact of such a spill as they smother the cold water communities and prevent rapid recovery. The fate of oil in and under ice is also a concern for northern ecosystems as response capabilities are particularly limited in such environments.

Observation of produced water effluent stream at the Hibernia platform indicates that it does not produce a laminar effluent flow where contaminants are rapidly dispersed as has been supposed in modeling predictions of potential effects. This makes monitoring difficult. In addition the consequences of nutrient loading from produced waters have largely been ignored. This potential effect will increase as more production facilities come on line as the fields age and should be included in consideration of cumulative effects of such activities.

Drilling waste dispersion in bathymetricly and hydrodynamically complex environments are difficult to predict and require detailed studies of near bottom currents as well as suitably scaled models.

Litter and microplastics: Several high profile studies have raised the concern about the ubiquitous distribution of litter (particularly plastics) and microplastics in the ocean. To date however, there have only been limited attempts to adequately quantify the supply and distribution of such plastics or the consequences they have on marine habitat and marine foodwebs. Both filed and laboratory studies are required to adequately quantify this threat to fish, fisheries and marine ecosystems.

Mining: The effect of mineral and aggregate extraction from the deep sea floor and from seamounts has been largely ignored because it has been assumed that the costs and technical complexities associated with such mining outweigh the returns. This is no longer the case. The effect of mining on deepwater habitat, particularly seamounts and deep sea floor manganese nodule flats may be significant. There is a need to better understand the potential for direct mortality of biogenic habitat, substrate modification and ecosystem recovery related to marine dredging and mining.

Cumulative effects assessment methodology and modeling: Methods for quantitative assessment and prediction of cumulative effects are required for ongoing evaluation of anthropogenic impacts at multiple scales. Current practice relies mainly on expert opinion, qualitative or at best semi-quantitative assessment tools that fail to consider ecosystem level and non-linear responses.

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ToR 4.3. [FC Request #12] Review of information and analyses on the impact of mid-water trawls on VME indicator species in those instances when the gear makes contact with or is lost on the bottom.

4.3.1 Summary of information

Mid-water (pelagic) trawls can negatively impact seamounts and associated VME indicator species, as per information provided by the Scientific Council in 2010 (NAFO 2010), which is reiterated here, and complemented by further information presented below. Mid-water trawls are typically used to fish in the upper water layers to catch schooling fish such as sardines, anchovies, herring, hake and mackerel where they have little to no impact on benthic VMEs. However, in some fisheries mid-water trawls are deployed near the seafloor where the behavior of the target species offers increased CPUE over fishing the same species higher in the water column. Examples include fisheries for southern blue whiting (*Micromesistius australis*), orange roughy (*Hoplostethus atlanticus*) and alfonsino (*Beryx* spp.) all of which are fished within meters of the seafloor and are also fished with bottom trawls. Tingley (2014) compiled statistics on the incidence of bottom contact with mid-water trawls by New Zealand vessels fishing alfonsino in the South Pacific Regional Fisheries Management Organisation (SPRFMO) Convention Area, as recorded by government observers on the vessels. He documented an average of 10% (range 6-12%) of 238 mid-water tows with unequivocal evidence of having touched the seabed during fishing in each of three years (2011–2013), and an average of 16% (range 13-19%) with strong evidence for having bottom contact. In certain areas the incidence of strong evidence for bottom contact was as high as 25% which was attributed to local bottom topography interacting with the gear. These results are higher than expected and may be due to the development of stronger nets that can be deployed both on the bottom and in mid-water without gear loss (e.g., Vónin Super Height http://www.vonin.com/default.aspx?pageid=14064&sectionid=145), as no gear was lost in the New Zealand study, although the net was torn in a few cases (Tingley 2014). These results led the SPRFMO Scientific Council (SC) to conclude that "mid-water trawling for bentho-pelagic species (e.g., alfonsino) falls under the description of 'bottom fishing' as defined in paragraph 4 of CMM 2.03". The SPRFMO SC further recommended that the Commission modify their CMM (Conservation and Management Measure) 2.03 to "take into account the relative impact on

VMEs of different fishing methods and practices, and to specifically address midwater trawling for bentho-pelagic species." (SPRFMO 2014).

Interaction between mid-water trawls and the seafloor is expected to be higher on seamounts. Mid-water trawls are difficult to control and often fish erratically in the deep waters overlying seamount surfaces and their steep slopes because such areas are known to have strong, complex gyres and current patterns as a result of their protruding geological features. Consequently, direct contact between the trawl gear and the sessile VME communities inhabiting seamounts is generally unavoidable (Clark et al. 2006). This is consistent with Murillo et al. (2008) who reported 6.5% of mid-water trawl hauls conducted during experimental fishing on the Corner Rise Seamounts contained coral bycatch. On the New England Seamount complex only 3 hauls were conducted but all contained coral bycatch. While these figures are high in and of themselves, they may represent only a portion of the total number of hauls which contacted the bottom as only those with coral bycatch were reported. In New Zealand, strict regulations exist to monitor and control mid-water trawls on seamounts to avoid any bottom contact and consequent impacts on VMEs. To ensure that there is little risk of any gear ever touching the bottom, a buffer zone of 100 m from the seafloor has been set. (http://www.fish.govt.nz/en-nz/Environmental/Seabed+Protection+and+Research/Benthic+Protection+Areas.htm).

It was noted that in most recent years since 2005, a directed commercial fishery using a mid-water trawl had been conducted by Spain on the Corner Rise seamounts. This fishing was conducted both inside and outside of the closed area to protect VMEs. Catches for this fishery ranged from about 50 to 1200 t and effort ranged from 4 days to 50 days. There is no information on the degree of bottom contact during this exploratory fishing. Due to the need to collect more information from areas outside of the existing fishing footprint, the WGESA recommended in 2014 that exploratory bottom fishing activity record all VME indicator bycatch, regardless of the amount caught. WGESA further recommends that the exploratory fishing protocols apply to all fishing outside of the existing fishing footprint. In this way comparable studies to that of Tingley (2014) can be undertaken for the exploratory fisheries in the NAFO Convention Area and enable us to address requests such as this directly.

The request also referred to lost gear and its impact on VME indicator species. Although ghost fishing can occur by nets and cod ends discarded at sea, lost mid-water trawl gear has a low potential for ghost fishing unless it is suspended by floats, in which case the gear can attract pelagic fishes, invertebrates and other marine species. If the net is snagged on the bottom or if burdened with catch which weighs it down after it is lost, it may cause damage to the benthos (Donaldson et al. 2010, and references therein). Murillo et al. (2008) reported the presence of lost pots on the Corner Rise Seamounts (Div. 6G) although they were unable to document the effects on the seafloor.

4.3.2. References

Clark M.R., D. Tittensor, A.D. Rogers, P. Brewin, T. Schlacher, A. Rowden, K. Stocks, and M. Consalvey. 2006. Seamounts, Deep-sea Corals and Fisheries: Vulnerability of Deep-sea Corals to Fishing on Seamounts Beyond Areas of National Jurisdiction. UNEP-WCMC, Cambridge, UK. Available online at: http://www.unep.org/regionalseas/publications/reports/RSRS/pdfs/rsrs183.pdf

Donaldson, A., C. Gabriel, B.J. Harvey, and J. Carolsfeld. 2010. Impacts of fishing gears other than bottom trawls, dredges, gillnets and longlines on aquatic biodiversity and vulnerable marine ecosystems. Canadian Science Advisory Secretariat Research Document 2010/011, 84 pp.

Murillo, J., P. Duran Munoz, M. Mandado, T. Patrocinio, and G. Fernandez. 2008. By-catch of cold-water corals from an Experimental Trawl Survey in Corner Rise and New England Seamount Complex (NAFO Regulatory Area. Divs. 6EFG) during year 2004. ICES CM 2008/C:03, 12pp.

NAFO. 2010. Part C: Scientific Council Meeting, 20-24 September 2010. NAFO Scientific Council Studies Doc 10/21, 28 pp.

SPRFMO. 2014. Report of the 2nd Scientific Committee Meeting. South Pacific Regional Fisheries Management Organisation. Honolulu, Hawaii, USA; 1-7 October 2014.

Tingley, G. 2014. An assessment of the potential for near-seabed midwater trawling to contact the seabed and to impact benthic habitat and Vulnerable Marine Ecosystems (VMEs). Second Meeting of the Scientific Committee. South Pacific Regional Fisheries Management Organisation. SC-02-10, 16pp.

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

ToR 5.1. Update of the NAFO Guide of the Identification of Vulnerable Marine Ecosystem (VME) indicator taxa.

5.1.1. Summary

The working group discussed updating the existing NAFO coral and sponge identification guides (Kenchington et al. 2009, Best et al. 2010) to include the new VME indicator taxa (Murillo et al. 2011). It was decided that a second edition of the guide should be produced with the support of the NAFO Secretariat. The second edition should include all of the VME taxa, including the new taxa which are not in the current guides (i.e., erect bryozoans, stalked crinoids, large sea squirts and tube dwelling anemones). This would result in one book rather than 3 and would allow for updating of the corals and sponges at the same time as the new VME taxa were described.

As a starting point the 67 VME indicator taxa listed in the 2014 NAFO Conservation and Enforcement Measures were examined to determine whether or not they were listed in the existing guides (Table 5.1.1). Of these, 35 VME indicator taxa were not included in the current identification guides (Table 5.1.1). However, 16 of these did not occur inside the existing bottom fishing area (fishing footprint) and were only known from the seamounts or from deep waters on the slope of Flemish Cap or Grand Bank (Table 5.1.1). The working group decided not to include those 16 taxa in the new version of the guide as the faunas of the area outside of the fishing footprint, including that of the seamounts, are not well known. Consequently, the 19 taxa listed in Table 5.1.2, all of which pertain to the fishing footprint only, were examined for potential inclusion in the new guide. From this reduced list, taxa were excluded if they were considered rare, as was the case for inclusion in the existing coral and sponge guides. Ultimately, 11 new taxa were selected for inclusion in the second edition of the identification guides (Table 5.1.2).

In addition it was suggested that the listing of *Acanella* in the current Coral Identification Guide (Kenchington et al. 2009) be changed to *Acanella arbuscula* given that this is the only species reported from inside the fishing footprint. Additionally, the identification sheet for *Stryphnus ponderosus* in the sponge identification guide (Best et al. 2010) should be changed to *Stryphnus fortis* based on recent taxonomic information.

Appropriate images and text for the revised addition of the Identification Guide will be provided to the NAFO Secretariat.

Table 5.1.1. List of Vulnerable Marine Ecosystem (VME) Indicator Taxa with associated VME Indicators as Listed in the 2014 NAFO Conservation and Enforcement Measures (NCEM) and whether they are Currently listed in the NAFO Coral or Sponge Identification Guides. For those not Appearing in the Identification Guides (Grey Shade), Their Location within the NAFO Convention Area (NCA) is Noted as Inside the Fishing Footprint or Outside the Fishing Footprint (Seamounts, Deepwater etc.).

Common Name of VME Taxonomic Group	Known Taxon	In NAFO Coral or Sponge ID Guide? (Listing in Guide)	Location in NCA
Erect bryozoans	*Eucratea loricata*	*X*	Inside Fishing Footprint
Stalked crinoids	*Trichometra cubensis*	*X*	Inside Fishing Footprint
	Gephyrocrinus grimaldii	*X*	Outside Fishing Footprint
	Conocrinus lofotensis	*X*	Inside Fishing Footprint
Large sea squirts	*Boltenia ovifera*	*X*	Inside Fishing Footprint
	Halocynthia aurantium	*X*	Inside Fishing Footprint
Large-sized sponges	*Iophon piceum*	√	
	Stelletta normani	√ (*Stelletta* spp.)	
	Stelletta sp.	√ (*Stelletta* spp.)	
	Stryphnus ponderosus	√	

Table 5.1.1. List of Vulnerable Marine Ecosystem (VME) Indicator Taxa with associated VME Indicators as Listed in the 2014 NAFO Conservation and Enforcement Measures (NCEM) and whether they are Currently listed in the NAFO Coral or Sponge Identification Guides. For those not Appearing in the Identification Guides (Grey Shade), Their Location within the NAFO Convention Area (NCA) is Noted as Inside the Fishing Footprint or Outside the Fishing Footprint (Seamounts, Deepwater etc.).

Common Name of VME Taxonomic Group	Known Taxon	In NAFO Coral or Sponge ID Guide? (Listing in Guide)	Location in NCA
	Axinella sp.	*X*	Inside Fishing Footprint
	Phakellia sp.	√ (*Phakellia* spp.)	
	Esperiopsis villosa	*X*	Inside Fishing Footprint
	Geodia barretti	√ (*Geodia* spp.)	
	Geodia macandrewii	√ (*Geodia* spp.)	
	Geodia phlegraei	√ (*Geodia* spp.)	
	Mycale (Mycale) lingua	√	
	Thenea muricata	√	
	Polymastia spp.	√	
	Weberella bursa	*X*	Inside Fishing Footprint
	Weberella sp.	*X*	Inside Fishing Footprint
	Asconema foliata	√	
	Craniella cranium	√	
Stony corals	*Lophelia pertusa*	√	
	Solenosmilia variabilis	*X*	Outside Fishing Footprint: New England or Corner Rise Seamount
	Enallopsammia rostrata	*X*	Outside Fishing Footprint: New England or Corner Rise Seamount
	Madrepora oculata	*X*	Outside Fishing Footprint: New England or Corner Rise Seamount
Small gorgonian corals	*Anthothela grandiflora*	*X*	Inside Fishing Footprint
	Chrysogorgia sp.	*X*	Outside Fishing Footprint: New England or Corner Rise Seamount; Flemish Cap deep slope; Canadian EEZ (Div. 3O)
	Radicipes gracilis	√	
	Metallogorgia melanotrichos	*X*	Outside Fishing Footprint: New England or Corner Rise Seamount
	Acanella arbuscula	√ (*Acanella*)	
	Acanella eburnea	√ (*Acanella*)	
	Swiftia sp.	*X*	Inside Fishing Footprint
	Narella laxa	*X*	Outside Fishing Footprint
Large gorgonian corals	*Acanthogorgia armata*	√	
	Iridogorgia sp.	*X*	Outside Fishing Footprint: New England or Corner Rise Seamount
	Corallium bathyrubrum	*X*	Outside Fishing Footprint: New England or Corner Rise

Table 5.1.1. List of Vulnerable Marine Ecosystem (VME) Indicator Taxa with associated VME Indicators as Listed in the 2014 NAFO Conservation and Enforcement Measures (NCEM) and whether they are Currently listed in the NAFO Coral or Sponge Identification Guides. For those not Appearing in the Identification Guides (Grey Shade), Their Location within the NAFO Convention Area (NCA) is Noted as Inside the Fishing Footprint or Outside the Fishing Footprint (Seamounts, Deepwater etc.).

Common Name of VME Taxonomic Group	Known Taxon	In NAFO Coral or Sponge ID Guide? (Listing in Guide)	Location in NCA
	Corallium bayeri	*X*	Seamount; Flemish Cap deep slope Outside Fishing Footprint: New England or Corner Rise Seamount
	Keratoisis ornata	√	
	Keratoisis sp.	√	
	Lepidisis sp.	*X*	Outside Fishing Footprint: New England or Corner Rise Seamount; Orphan Knoll
	Paragorgia arborea	√	
	Paragorgia johnsoni	√	
	Paramuricea grandis	√ (*Paramuricea*)	
	Paramuricea placomus	√ (*Paramuricea*)	
	Paramuricea spp.	√	
	Placogorgia sp.	*X*	Inside Fishing Footprint
	Placogorgia terceira	*X*	Outside Fishing Footprint: New England or Corner Rise Seamount
	Calyptrophora sp.	*X*	Outside Fishing Footprint: New England or Corner Rise Seamount
	Parastenella atlantica	*X*	Inside Fishing Footprint
	Primnoa resedaeformis	√	
	Thouarella grasshoffi	*X*	Outside Fishing Footprint: New England or Corner Rise Seamount
Sea pens	*Anthoptilum gradiflorum*	√ (*Anthoptilum*)	
	Funiculina quandrangularis	√	
	Halipteris cf. *christii*	*X*	Inside Fishing Footprint
	Halipteris finmarchica	√	
	Halipteris sp.	*X*	Outside Fishing Footprint
	Kophobelemnon stelliferum	*X*	Inside Fishing Footprint
	Pennatula aculeata	√	
	Pennatula grandis	√	
	Pennatula sp.	*X*	Outside Fishing Footprint: Orphan Knoll
	Distichoptilum gracile	*X*	Inside Fishing Footprint
	Protoptilum sp.	*X*	Inside Fishing Footprint
	Umbellula lindahli	√ (*Ombellula*)	
	Virgularia cf. *mirabilis*	*X*	Inside Fishing Footprint
Tube-dwelling anemones	*Pachycerianthus borealis*	*X*	Inside Fishing Footprint

Table 5.1.2. List of Vulnerable Marine Ecosystem (VME) Taxa Known to Exist Inside the Fishing Footprint and Not Currently in the NAFO Coral and Sponge Identification Guides, with Comments on their Inclusion in the 2nd edition of the Identification Guides.

Common Name of VME Taxonomic Group	Known Taxon	Comment	Decision to Include
Erect bryozoans	*Eucratea loricata*		Yes
Stalked crinoids	*Trichometra cubensis*	Unstalked, rare	No
	Conocrinus lofotensis		Yes
Large sea squirts	*Boltenia ovifera*		Yes
	Halocynthia aurantium	Rare	No
Large-sized sponges	*Axinella* sp.		Yes
	Esperiopsis villosa		Yes
	Weberella bursa		Yes
	Weberella sp.	Rare	No
Small gorgonian corals	*Anthothela grandiflora*		Yes
	Swiftia sp.	Rare	No
Large gorgonian corals	*Placogorgia* sp.	Rare	No
	Parastenella atlantica	Rare	No
Seapens	*Halipteris* cf. *christii*		Yes
	Kophobelemnon stelliferum		Yes
	Distichoptilum gracile		Yes
	Protoptilum sp.	Rare	No
	Virgularia cf. *mirabilis*	Rare	No
Tube-dwelling anemones	*Pachycerianthus borealis*		Yes

5.1.2. References

Best, M., E. Kenchington, K. MacIsaac, V. Wareham, S. D. Fuller and A. B. Thompson. 2010. Sponge Identification Guide NAFO Area. *NAFO Scientific Council Studies*, 43: 1-49. doi:10.2960/S.v43.m1.

Kenchington, E., M. Best, A. Cogswell, K. MacIsaac, J. Murillo-Perez, B. Macdonald, V. Wareham, S. D. Fuller, H. I. Ø. Jørgensbye Hansen, V. Sklyar and A. B. Thompson. 2009. Coral Identification Guide NAFO Area. *NAFO Scientific Council Studies*, 42: 1-18. doi:10.2960/S.v42.m1.

Murillo, F.J., E. Kenchington, M. Sacau, D.J.W. Piper, V. Wareham and A. Munoz. 2011. New VME indicator species (excluding corals and sponges) and some potential VME elements of the NAFO Regulatory Area. Serial No. N6003. *NAFO Scientific Council Research Document* 11/73, 20 pp.

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.

ToR 6.1. Evaluation of Research Vessel (RV) surveys footprint on VME closures.

WGESA started the analysis of the RV survey footprint on VMEs. However, unexpected data format issues prevented this work from being completed during the meeting. Although the nature of the data problem was identified, there was no time at the meeting to further pursue this study. In the interest of time, WGESA referred this analysis back to SC to be addressed at the June 2015 meeting.

Other matters

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

The ICES (International Council for Exploration of the Seas) working group WGNARS (Working Group on the Northwest Atlantic Regional Sea) is one of seven regional seas working groups within ICES. These groups were established to develop approaches to and then capacity for integrated ecosystem assessments (IEA) of the regional seas that would feed in to the ICES advice provision process for fisheries management and subsequently, for other sectors. WGNARS is somewhat unique within this group since ICES does not provide management advice for US or Canadian fisheries (with the exception of Atlantic salmon. There is however an emerging interest in both Canada and the US in the application of Ecosystem Based Management and thus integrated assessment becomes an important tool for this side of the Atlantic. In this context, socio-economic factors must also be considered and WGNARS is the first regional seas working group to incorporate this aspect of IEA.

The regional seas working groups and IEA are at the heart of the new ICES strategic plan. The ICES Strategic Plan 2014-2018* commits to building a foundation of science around one key challenge: *integrated ecosystem understanding*. ICES will produce integrated ecosystem assessments in regional seas as a fundamental link between ecosystem science and the advice required in applying the ecosystem approach.

One of the biggest challenges facing WGNARS is finding the appropriate IEA clients in both Canada and the US. In particular, ecosystem management objectives are determined by ocean resource managers and other clients. While this process should include science advice it is not science driven. Recognizing this, the work of WGNARS has evolved from inventorying and assessing data sources, indicators and approaches to IEA to developing worked examples of application of IEA to ocean management objectives to demonstrate the utility of IEA for integrated management. These worked examples use existing ocean management objectives for two regions in the Northwest Atlantic (Georges Bank Gulf of Maine and the Grand Banks of Newfoundland) and are the focus of the work by the group in 2014-15.

* http://www.ices.dk/explore-us/what-we do/Documents/ICES_Strategic_Plan_2014_2018.pdf

Update on Galway Statement

The Galway Statement commits Canada, the US and the EU to collaborate on comprehensive science programming for an indefinite period going forward to better understand the North Atlantic Ocean basin. The agreement signed at the political level and is supported by a science-based planning and implementation structure and process that started at the original Conference at Galway, Ireland. The Trans-Atlantic Ocean Research Alliance (TAORA) was created when the Galway Statement was signed in May 2013.

In July of 2014 the Canadian Galway Marine Working Group held a workshop to develop a broadly-based list of potential Areas of Research Cooperation in the context of the Trans-Atlantic Ocean Research Alliance (TAORA) and the Galway Statement. The areas to be brought forward for discussion with the EU are;

- Ocean Health and Stressors,
- Ocean Observation and Prediction
- Characterization of the Seafloor and the Sub-surface,
- Aquaculture,
- Information Management and Dissemination.

DFO (Fisheries and Oceans Canada) leads this intitiative in Canada. Co- leads from relevant government departments and from academia or the private sector are being or have been identified (see table below). Workshops developing plans to further focus the objectives under each area have taken place or are being planned.

A high level meeting of EU, US and Canadian leads took place in Ottawa in November 2014 to exchange overarching objectives and to discuss implementation frameworks and opportunities. None of the groups anticipate dedicated funding for this initiative however, several existing funding options and opportunities were discussed.

Leads for Canadian thematic areas for implementation of the Galway Statement

Canadian Thematic Areas	Gov't co-Lead	Academic co-Lead
Ocean Health and Stressors	M. Robin Anderson Northwest Atlantic Fisheries Centre, DFO, St. John's, Newfoundland	Paul Snelgrove Memorial University, St. John's, Newfoundland
Ocean Observation and Prediction	Pierre Pepin Northwest Atlantic Fisheries Centre, DFO, St John's, Newfoundland	Doug Wallace Scientific Director, Marine Environmental Observation, Prediction and Response Network of Centres of Excellence (MEOPAR), Dalhousie University, Halifax, Nova Scotia
Characterization of the Seafloor and the Sub-surface	Stephen Locke Director, Geological Survey of Canada, Atlantic, NRCan, Halifax, Nova Scotia	Randy Gillespie Director, Centre for Applied Ocean Technology, Marine Institute, St. John's Newfoundland
Aquaculture	Jay Parsons Aquaculture Science Branch, DFO, Ottawa, Ontario	To be determined
Information Management and Dissemination - Data accessibility and inter-operability	Tobias Spears Team Leader, Software Services, DFO, Halifax, Nova Scotia	Benoît Pirenne Ocean Networks Canada, Associate Director, Digital Infrastructure
Information Management and Dissemination – Ocean literacy	To be determined	To be determined

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:

- "Spatial and seasonal fleet activity and cod distribution in Flemish Cap" by A. Iriondo , F. González-Costas , N. Hintzen , M. Machiels, D. González-Troncoso, and A. Urtizberea.
- "Potential effects of human activities other than fishing on fish stocks and ecosystems in the NAFO convention area" by M.R. Anderson, J.M. Hanlon, and C. Morris.
- "Application of ecoregion analysis to the identification of ecosystem production units in the NAFO Regulatory Area" by Pierre Pepin, Jennifer Higdon, Mariano Koen-Alonso, Mike Fogarty and Neil Ollerhead.

Place and date for next meeting

It was proposed that the 8th WGESA meeting to take place in November 17-26, 2015 at the NAFO Headquarters in Dartmouth, Canada.

Proposed Terms of Reference for the 8th 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 and VME distribution analyses.

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

- No expected work on this ToR.

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
- Progress on expanded single species, multispecies and ecosystem production potential modelling
- Progress on multispecies and ecosystem analyses

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.

- Assessment of bottom fishing activities pertaining to the impacts on VMEs

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

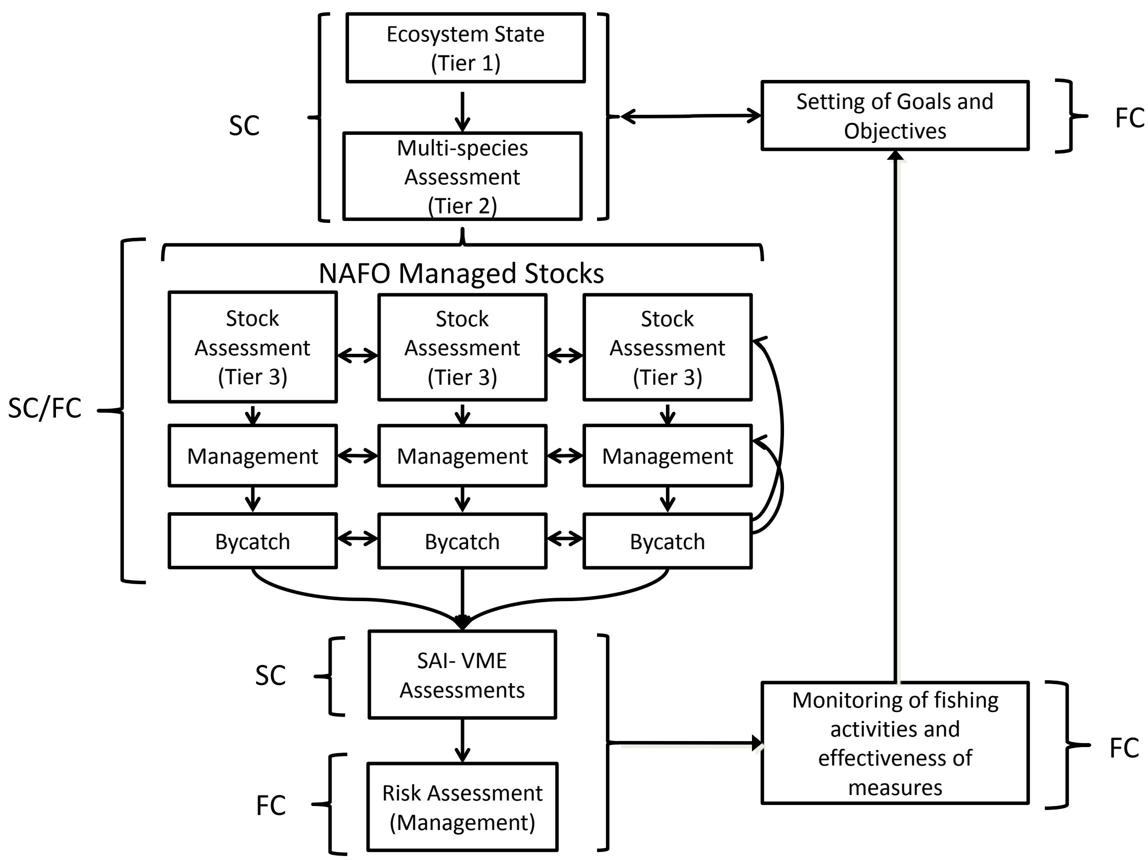
- Preliminary results on the use of non-destructive sampling to monitor VMEs

Theme 4: Specific requests

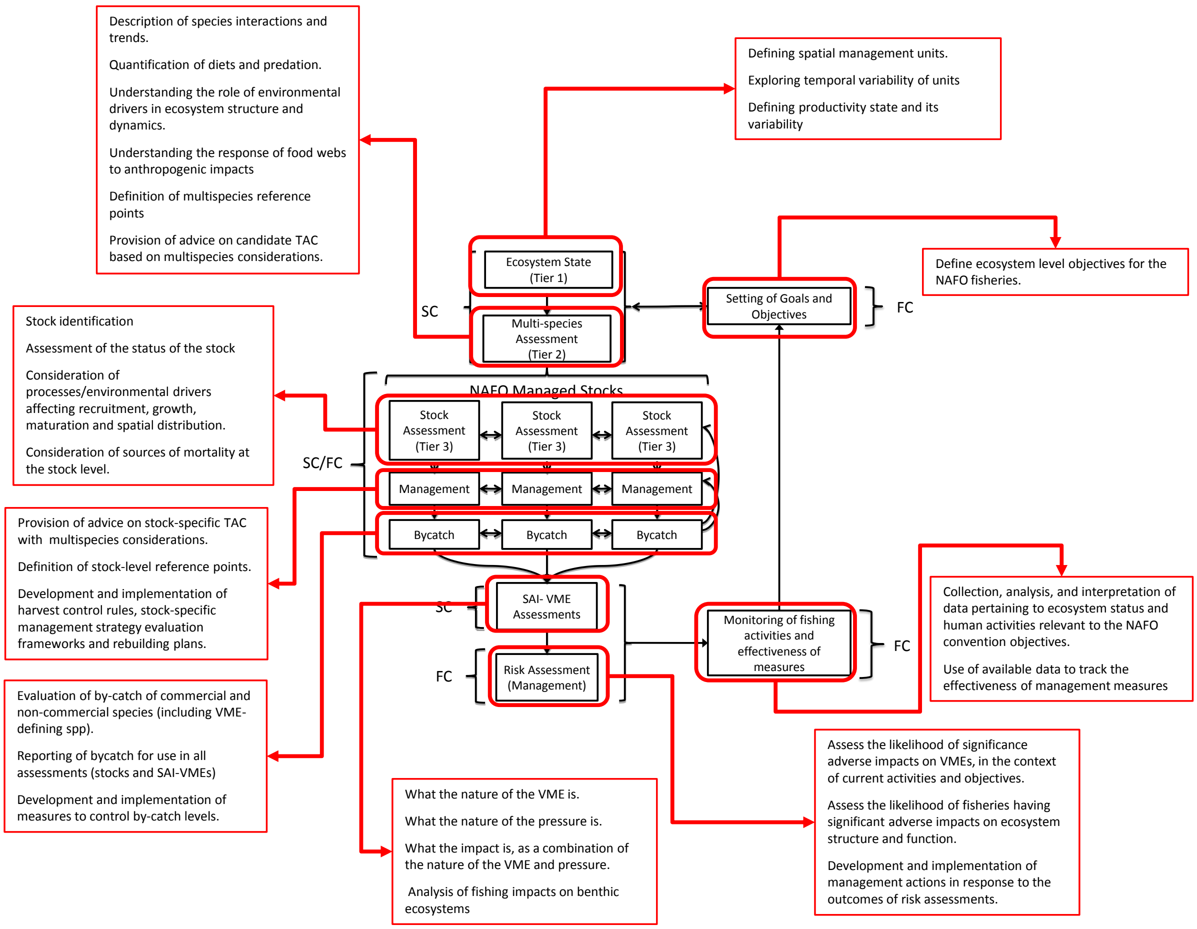
ToRs 6+. As generic ToRs, these are place-holders intended to be used when addressing expected additional requests from Scientific Council.

Annex 1. Current working structure of the "Roadmap for the development of an ecosystem approach to fisheries (EAF) for NAFO"

Current working structure of the Roadmap



Summary description of the Roadmap components



Annex 2. 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.

Annex 3. List of participants

Name	Affiliation	E-mail
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