Northwest Atlantic Fisheries Organization

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SC WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT – NOVEMBER 2015

Report of the 8th Meeting of the NAFO Scientific Council (SC) Working Group on Ecosystem Science and Assessment (WGESA)
[Formerly SC WGEAFM]

NAFO Headquarters, Dartmouth, NS, Canada
17- 26 November 2015

Contents

Report of the SC Working Group on Ecosystem Science and Assessment

17-26 November 2015

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 8th meeting on 17-26 November 2015 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.

Development of ToRs for the 8th WGESA meeting

Preliminary ToRs from SC June 2015

During its June 2015 meeting, SC approved the following ToRs as focus for the 8th 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 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.

- Topics under this ToR to be defined after NAFO Annual General Meeting (AGM) in September 2015.

Additional comments done by SC in June 2015

With regard to the reassessment of bottom fishing activities pertaining to their impact on VMEs, SC recommended WGESA to further consider the role of environmental variables to define the fine scale features of VME boundaries, and to take into account the VME areas outside the NAFO fisheries footprint in the calculation of the VME area not exposed to risk of Significant Adverse Impacts.

Comments and recommendations from FC-SC Working Group on Ecosystem Approach Frameworks to Fisheries Management (WGEAFFM) in July 2015

During its meeting in July 2015, WGEAFFM identified work priorities for the further development and implementation of the Roadmap (Annex 3). In addition to these priorities, it also provided comments and recommendations relevant to the work WGESA would carry out at its 8th meeting in September 2015.

Comments:

These comments pertain to the presentation of the preliminary results of the SAI-VME analysis. The bold type has been added to highlight key comments.

"The WG noted the preliminary nature of the work presented and thanked SC for the extensive effort which has gone into the assessment to date. It was noted that **benthic fisheries for shellfish on the tail of the Bank** were included in the preliminary assessment**. It was, agreed that these fisheries should be excluded from further analysis as NAFO has no management jurisdiction in this regard. It was also noted that mid-water trawl fisheries should not be included in the description or the analysis of bottom fisheries.**

"It was felt that the understanding of the SAI analysis would be improved if SC were to **compile, define and agree on terminology used in the reassessment of bottom fisheries, with particular emphasis on the definitions of SAI**. It was further suggested that the evaluation of SAI would be **improved** if in addition to **considering the VME areas derived from the kernel density analysis, biomass distributions of VME indicator taxa were also taken into account**, e.g. assess the **proportion of biomass within and outside current closures.** In addition, it was suggested that the **VME kernel density analysis polygon boundaries could be refined by taking into account current understanding of VME species distribution patterns in relation to environmental variables**."

Recommendations:

In relation to Progress of the Workplan on SAI in support of reassessment of bottom fisheries in 2016:

1. that Scientific Council should take into account the protection afforded to VME areas outside the NAFO fisheries footprint in the calculation of the VME area and biomass at risk of bottom fishing impact;
2. that Scientific Council refine VME kernel density analysis polygon boundaries,taking into account current understanding of distribution patterns in relation to environmental variables.

FC Request to SC from AGM in September 2015

After reviewing the full set of FC Requests with the SC chair, WGESA has been asked to provide input on the following FC requests:

> **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 further requests that:

a) that Scientific Council should take into account the protection afforded to VME areas outside the NAFO fisheries footprint in the calculation of the VME area and biomass at risk of bottom fishing impact;

b) that Scientific Council refine VME kernel density analysis polygon boundaries, taking into account current understanding of distribution patterns in relation to environmental variables.

FC Request #5. FC requests the Scientific Council consider widening the scope of the NAFO coral and sponge identification guides to include other relevant species on seamounts.

FC Request #11. Article 23 NCEM foresees a reassessment of bottom fishing activities in 2016. The NAFO Roadmap for Developing an Ecosystem Approach to Fisheries extends the work of the Scientific Council to include the assessment of potential impacts of activities other than fishing. Also, impacts of human activities in ecosystems should not be analyzed in isolation since cumulative effects might occur representing more than the sum of the individual factors. The Scientific Council is therefore requested to develop a work plan at its meeting in 2016 that will allow to address and analyse analyze the potential impact of activities other than fishing (eg. oil and gas exploration, marine cables, ocean dumping, marine transportation) on NAFO VMEs, in particular VME closed areas.

FC Request #15. The Fisheries Commission requests the Scientific Council to review the results of the 2015 Canadian in situ photographic surveys for non-coral and sponge VME indicator species on Grand Bank (tail of Grand Bank) in relation to previous analyses presented in 2014 (that modelled their distribution using research vessel survey trawl by-catch data), and to identify areas of significant concentrations of non-coral and sponge VME indicator species using all available information.

Terms of Reference for the 8th NAFO SC WGESA meeting

Taking into account the ToR topics approved by SC in June 2015, the relevant FC Requests from the NAFO AGM in September 2015, the recommendations from FC/SC WGEAFFM, and topics added while discussing the ToRs at the beginning of the NAFO SC WGESA 8th meeting, the final set of ToRs addressed by WGESA at its 8th meeting were:

Theme 1: Spatial considerations

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

ToR1.1 (*includes* FC Request #15). Update on VME-related analyses and surveys.

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.

ToR 3.1. Progress on multispecies and ecosystem analyses.

ToR 3.2. Progress on expanded single species, 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.

ToR 4.1. Improving the effectiveness of the science advice process in NAFO.

ToR 4.2 (FC Request #4). Assessment of bottom fishing activities pertaining to the impacts on VMEs.

ToR 4.3 (FC Request #11). Workplan towards the assessment of potential impacts of activities other than fishing on NAFO VMEs.

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

ToR 5.1. 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.

ToR 6.1 (FC Request #5). Update of NAFO VME Guide.

THEME 1: SPATIAL CONSIDERATIONS

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

ToR1.1 (*includes* FC Request #15). Update on VME-related analyses and surveys

ToR 1.1.1. New data on deep-water corals and large sponges from Spanish and Canadian surveys in the NAFO Regulatory Area (Divs. 3LMNO): 2013-2015

During the 8th NAFO WGESA meeting new data on deep-water corals and sponges were presented based on Spanish/EU bottom trawl groundfish surveys for 2015 and the Canadian multispecies surveys for 2013-2015. The data was made available to the NAFO WGESA to 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. Based on these thresholds, “Significant” catches of deep-water corals and sponges are provided and mapped together with the actual closed areas (Figures 1.1.1.2-5).

Data used in this study come from four different surveys:

1. The EU-Spanish 3NO groundfish survey, carried out by the Instituto Español de Oceanografía (IEO), sampling the Grand Bank of Newfoundland (NRA, Divs. 3NO) between 45 and 1420 m depth.
2. The EU Flemish Cap groundfish 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 133 and 1426 m.
3. The EU-Spanish Fletán Negro-3L groundfish survey carried out by the IEO, sampling Div. 3L in the NRA between 112 and 1458 m depth.
4. The Canadian Department of Fisheries and Oceans multispecies survey, sampling Div. 3LNO in the NRA between 40 and 1333 m depth.

For the Spanish/EU bottom trawl groundfish surveys for 2015 a total number of 408 bottom trawl hauls (sets) were analyzed (Figure 1.1.1.1).

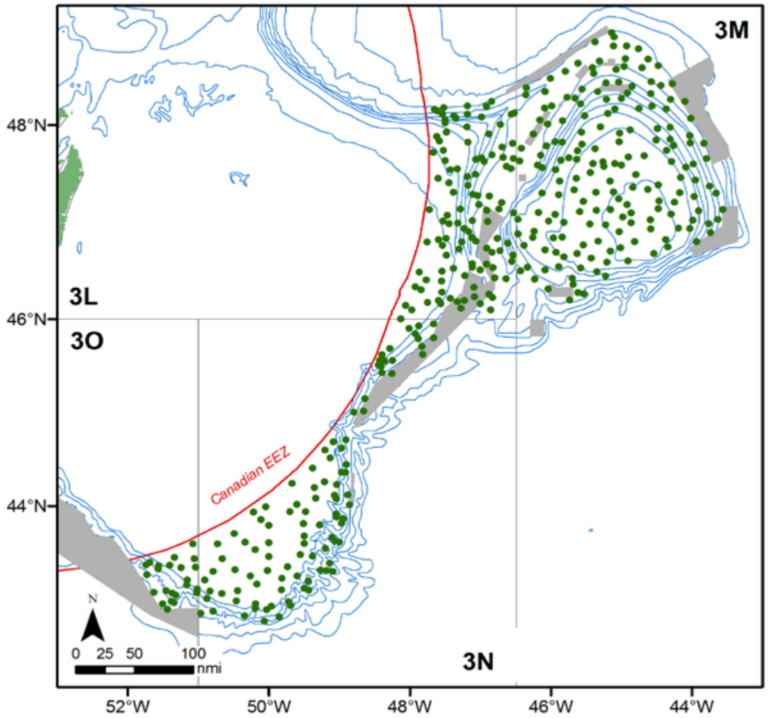

Fig. 1.1.1.1. Spanish/EU survey 2015 start position tows

For the Canadian multispecies surveys for 2013, 2014 and spring 2015 a total number of 310 bottom trawl sets were analyzed (Fig. 1.1.1.2).

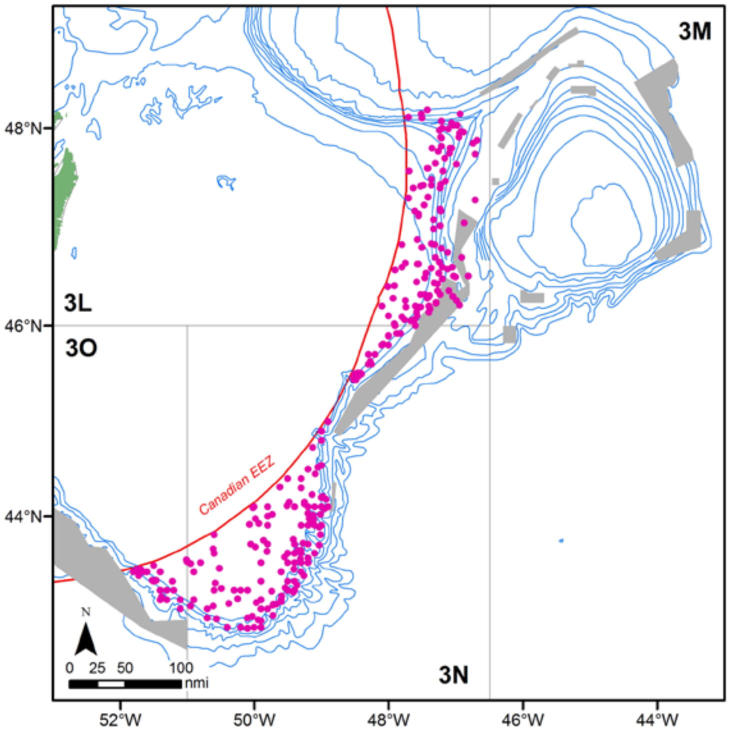

Fig. 1.1.1.2. Canadian survey 2013-2015 start position tows

In order to follow the same groups previously used by WGEAFFM, deep water corals were grouped as large gorgonians (Alcyonacea), small gorgonians (Alcyonacea) and sea pens (Pennatulacea); with sponges grouped together. Some of the data presented here have been previously published (see 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 significant catches of sponges, large gorgonians, small gorgonians and sea pens are presented (Figs. 1.1.1.3 to 1.1.1.6). Location of the corals and sponge records was assigned to the start position of the survey fishing tows. The start position coordinates and weights of the significant catches are provided in Table 1.1.1.1:

Table 1.1.1.1. Start positions (decimal degrees) of tows with coral and sponge catches above the threshold defined as significant catch in the NRA (Divs. 3LMNO) with their corresponding depth and weight.

VME Indicator Species	Year	Survey	Start Position Lat (N)	 Long (W)	Depth (m)	Weight (kg)
SPONGES >= 75 kg	2015	EU	46.2627	-46.8770	1319	5053.7
	2015	EU	44.0138	-48.8527	1420	2995.0
	2015	CAD	46.26	-46.9933	1333	2502.7
	2015	EU	46.5747	-46.9160	1243	1630.7
	2015	EU	46.1998	-47.2242	805	484.2
	2015	EU	46.1650	-47.0038	1429	472.2
	2015	EU	45.8037	-47.6620	1347	256.3
	2015	EU	45.6320	-47.8188	1381	199.6
	2015	EU	48.2422	-44.0942	1193	189.2
	2015	EU	45.7145	-47.8307	1178	111.6
	2015	EU	46.7418	-46.9107	1231	108.4
	2015	EU	45.4272	-48.2507	1375	100.5
	2015	EU	46.3372	-47.0893	878	100.0
	2015	EU	46.2348	-47.0838	1076	89.5
	2015	CAD	46.2966	-47.0416	949	83.7
LARGE GORGONIANS >= 0.6 kg	2015	EU	46.5747	-46.9160	1243	16.9
	2015	EU	46.1858	-47.3248	640	4.1
	2015	EU	46.7418	-46.9107	1231	2.0
	2015	CAD	43.0775	-51.3483	584	1.18
	2014	CAD	46.5066	-47.0316	678	0.74
SMALL GORGONIANS >= 0.15 kg	2015	EU	42.9088	-49.6873	1130	1.2
	2015	EU	48.2650	-45.2063	517	0.5
	2015	EU	42.8432	-50.7913	981	0.3
	2015	EU	42.8678	-51.4407	1381	0.3
	2013	CAD	43.0983	-51.4041	650	0.19
SEAPENS >= 1.4 kg	2015	EU	46.7010	-46.8313	1232	2.2
	2015	EU	48.2853	-45.7702	980	2.1
	2015	EU	43.3753	-49.1378	1160	1.5

Sponges

For the Spanish/EU 2015 data, sponges were recorded in 233 of the total tows (57% of the total tows analyzed) with depths ranging between 56 and 1460 m. For the Canadian 2013-2015 data, sponges were recorded in 159 of the total tows (51.3% of the total tows analyzed) with depths ranging between 40 and 1333 m.

Significant catches (≥ 75 kg/tow) were found in 13 EU tows and 2 CAD tows, located mainly in the Flemish Pass, Flemish Cap and slope of the Grand Bank (Table 1.1.1.1 and Fig. 1.1.1.3). Of the total 15 tows, only 1 was recorded outside of the closed areas. Sponge catches for these tows ranged between 83.7 and 5053 kg

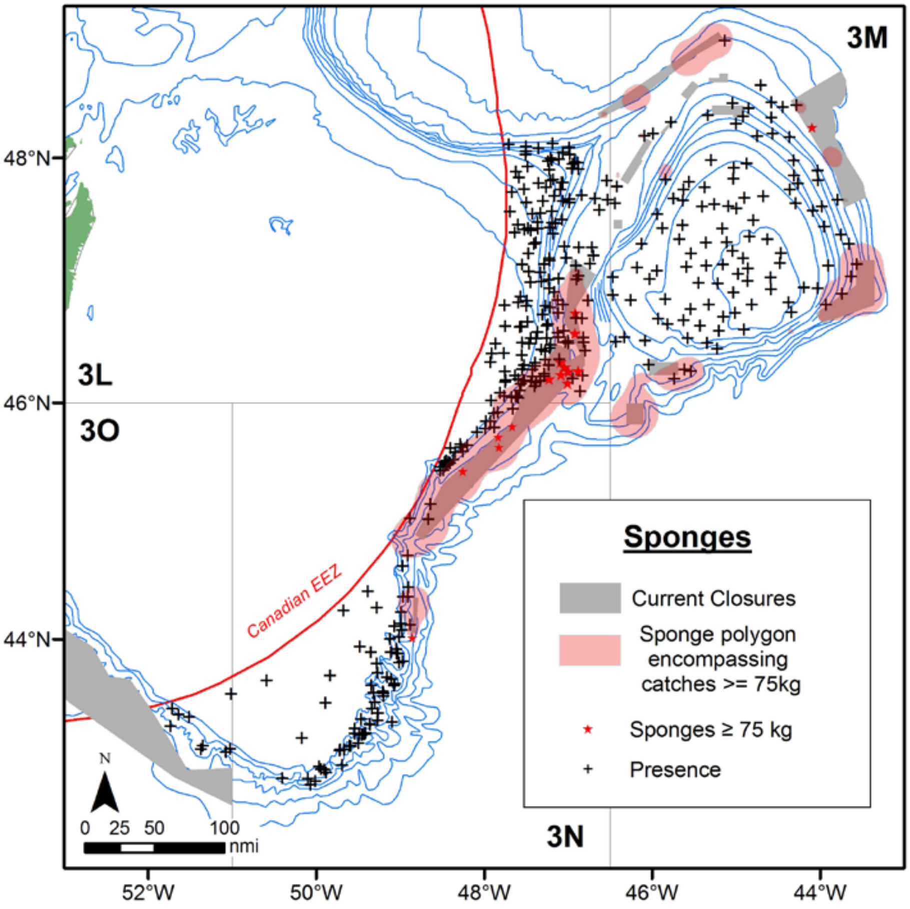

Fig. 1.1.1.3. Distribution of significant catches and presence of sponges in the study area from Spanish/EU (2015) and Canadian data (2013-2015) (NAFO Divs. 3LMNO).

Large gorgonians

For the Spanish/EU 2015 data, large gorgonians were recorded in 14 tows (3.2% of the total tows analyzed) with depths ranging between 578 and 1268 m. For the Canadian 2013-2015 data, 10 tows were recorded (4.1% of the total tows analyzed) with depths ranging between 75 and 678 m. Significant catches (≥ 0.6 kg/tow) were found in 3 EU tows and 2 CAD tows, ranging in weights from 0.74-16.9kg (Table 1.1.1.1; Fig. 1.1.1.4).

All significant catches, for the exception of 2, fall inside the actual closed areas.

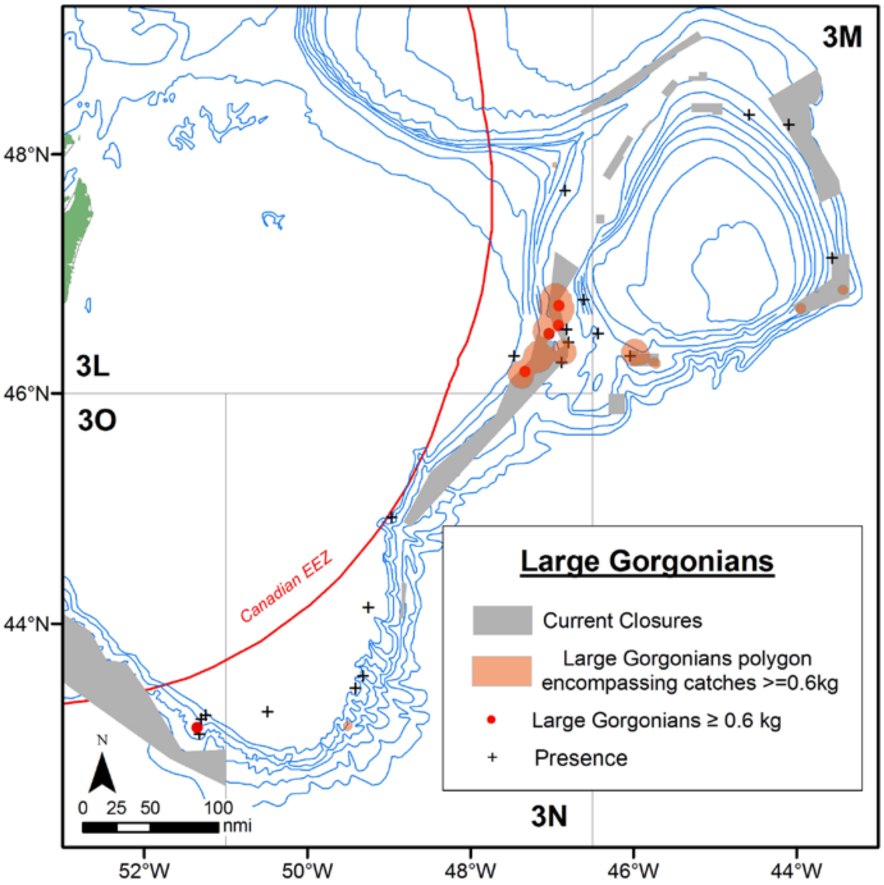

Fig. 1.1.1.4. Distribution of significant catches and presence of large gorgonians in the study area from Spanish/EU (2015) and Canadian data (2013-2015) (NAFO Divs. 3LMNO).

Small gorgonians

For the Spanish/EU 2015 data, small gorgonians were recorded in 57 tows (14% of the total tows analyzed), with depths ranging between 446 and 1381 m. For the Canadian 2013-2015 data, 9 tows were recorded (2.9% of the total tows analyzed), with depths ranging between 95 and 650 m.

Significant catches (≥ 0.15 kg/tow) were recorded in 4 EU tows (1% of the total tows) and 1 CAD tow (Table 1.1.1.1; Fig. 1.1.1.5) with one tow falling on the edge of the 30 closed area.

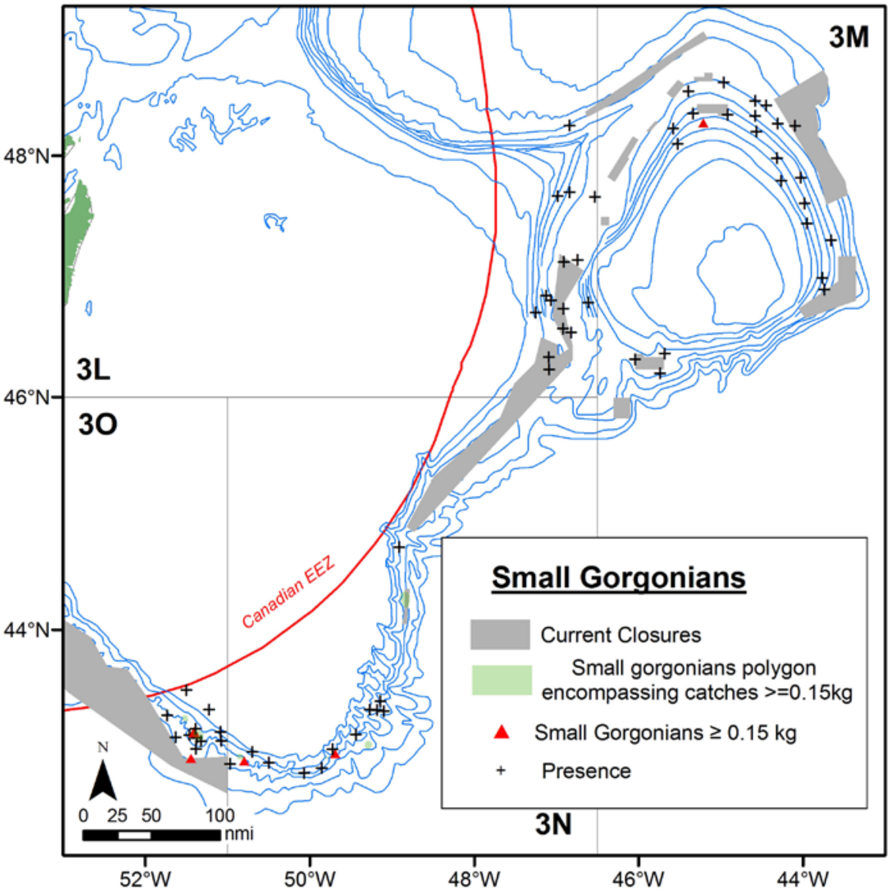

Fig. 1.1.1.5. Distribution of significant catches and presence of small gorgonians in the study area from Spanish/EU (2015) and Canadian data (2013-205) (NAFO Divs. 3LMNO).

<u>Sea pens</u>

For the Spanish/EU 2015 data, sea pens were recorded in 147 tows (36 % of the total tows analyzed) with depths ranging between 173 and 1458 m. For the Canadian 2013-2015 data, 16 tows were recorded (5.2% of the total tows analyzed) with depths ranging between 67 and 662 m.

Significant catches (≥ 1.4 kg/tow) were found in 3 EU tows located outside closed areas (Table 1.1.11; Fig. 1.1.1.6).

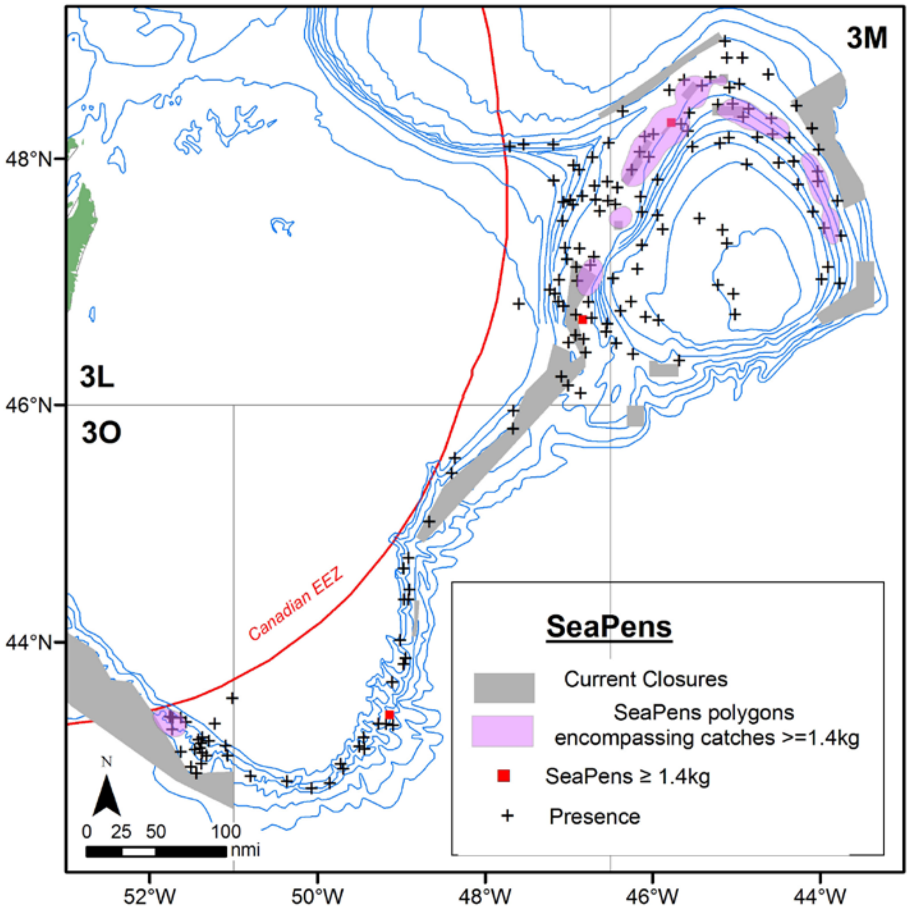

Fig. 1.1.1.6. Distribution of significant catches and presence of sea pens in the study area from Spanish/EU (2015) and Canadian data (2013-2015) (NAFO Divs. 3LMNO).

Table 1.1.1.2. Summary of the records of deep-water corals and sponges for the Spanish-EU 2015 data and CAD 2013-2015 data.

	Presence (number of tows)	% of the total tows	Tows with Significant Concentrations	% of tows with Significant Concentrations
Spanish-EU data 2015				
Sponges	233	57%	13	3.2%
Large Gorgonians	14	3.4%	3	0.7%
Small Gorgonians	57	14%	4	1%
Sea pens	147	36%	3	0.7%
Canadian data 2013-2015				
Sponges	159	51.3%	2	0.6%
Large Gorgonians	10	4.1%	2	0.6%
Small Gorgonians	9	2.9%	1	0.3%
Sea pens	16	5.2%	0	0

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ToR 1.1.2. Highlights from Admunsen 2015 Expedition, and other VME-related projects

Department of Fisheries and Oceans, Newfoundland and Labrador Region provided a summary to the WGESA on new benthic research conducted in the Northwest Atlantic. Research highlights included: a summary of the 2015 ArcticNet Multidisciplinary Survey; new publication and ongoing research on sea pen growth rates; new VME and fishing impacts; and introduced the new Coral and Sponge Conservation Strategy for Eastern Canada released this year.

ArcticNet Multidisciplinary Survey

ArcticNet is a network that brings together scientist and managers to study the impact of climate change in Canada's Arctic (http://www.arcticnet.ulaval.ca/). In October 2015 ArcticNet, in partnership with DFO and several Canadian Universities, conducted a multidisciplinary expedition in Baffin Bay (NAFO Div. 0A) on the Canadian Coast Guard Ship Amundsen. Sampling consisted of traditional equipment (i.e. box cores, CTD casts) in conjunction with the Remotely Operated Vehicle (ROV) Super Mohawk (SuMo) - the primary activity during all dives was the acquisition of video data.

The goal was to study coral and sponge habitats, to discover previously unknown coral and sponge biodiversity, other invertebrate and fish biodiversity, and previously under-sampled habitat types in the Canadian Arctic. Particular emphasis was placed on steep and deep hard-bottom habitats that cannot be sampled effectively using traditional oceanographic sampling methods, as well as identify and characterize corals and sponges in areas of the Arctic that have not previously been impacted by commercial fishing activities.

Dive targets were selected on the basis of their bathymetry, slope, and surficial geology. Other sites were chosen based on previously identified sponge diversity and abundance hotspots (e.g. Cape Dyer). A total of five locations in Baffin Bay were chosen to be surveyed with the ROV: Navy Board Inlet, Pond Inlet, Scott Inlet, Cape Dyer, and Frobisher Bay.

The diversity of sponges, corals, other invertebrates and fish was documented at all surveyed sites. Observations show corals co-occur with sponges as well as other benthic animals (e.g. fish, octopus, shrimp, hydroids, brittle stars, sea anemones, and bryozoans).

At Qikiqtarjuaq dive site, giant sea anemones were observed and formed dense fields with up to 2.8 individuals/per m^2 in soft muds (Figure 1.1.2.1). Other notable species included giant *Umbellula* sea pens (Figure 1.1.2.2), with one individual ~ 230 cm in height, 75 cm width, having 56 polyps, and estimated to be ~60 years of age based on new research (Neves et al., in prep). Preliminary observations highlight the ecological importance of this site, and further ROV investigation is recommended.

Fig. 1.1.2.1 Giant sea anemones forming dense fields (photo credit ArcticNet, 2015).

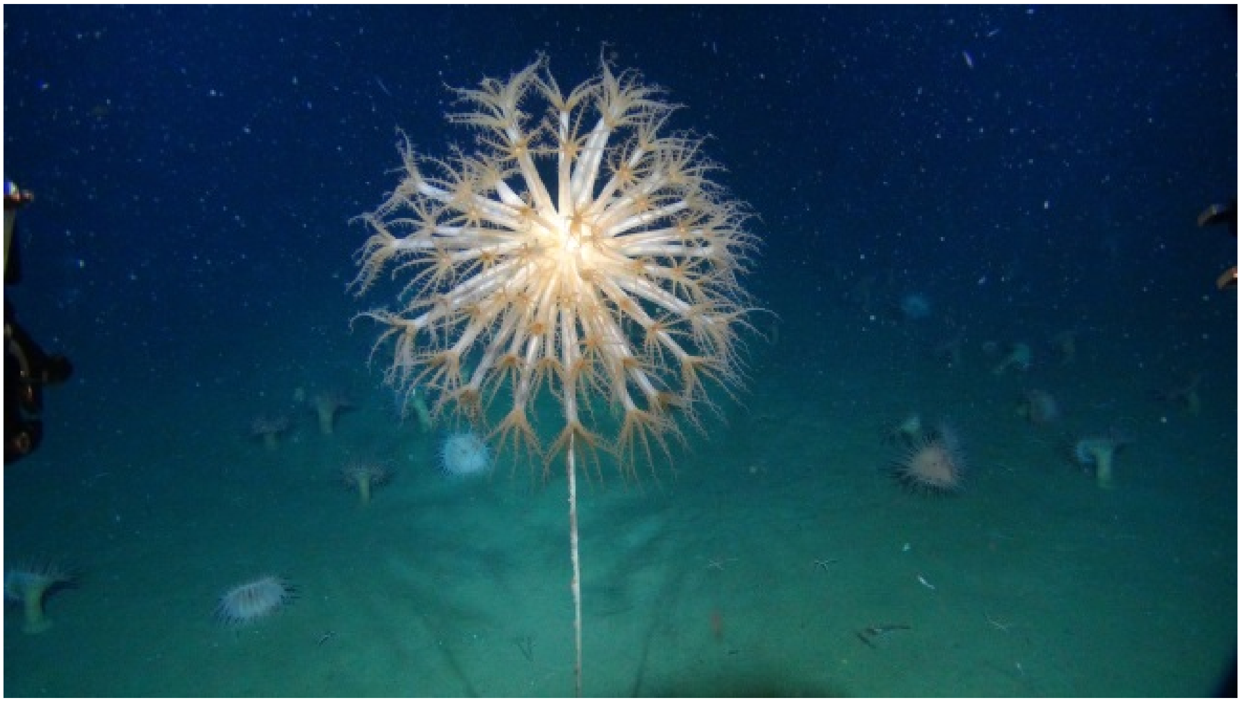

Figure 1.1.2.2. Large Umbellula sea pen ~230 cm in height (photo credit ArcticNet, 2015).

At Cape Dyer and Frobisher Bay, observations indicate high sponge concentrations and species richness. Biomass in Cape Dyer appeared to be much lower than expected, but based on multibeam data acquired after the dive, it is suspected the area has been impacted by fishing at a higher level than previously thought.

The highlight of the expedition was the discovery of dense sponge garden, dominated by arborescent sponges and ascidian fields in the Frobisher Bay area. The garden appeared to be dominated by sponges with many other associates including; crustaceans (isopods), sea cucumbers, crinoids, ophiuroids, sea stars, sea anemones, and tube polychaetes. These results are preliminary and a more detailed video analysis will follow.

Results presented provide insight in to other potential VME candidates (e.g. sea anemones) and highlight the importance of using a range of sampling equipment, from traditional box cores to modern ROV's for groundtruthing, to help identify and delineate VMEs.

New Research

Information on growth rates of sea pens has been lacking until now. New studies from Northwest Atlantic have shown linear growth rates for several species including: *Halipteris finmarchica* to be 4.87 ± 1.1 $cm.yr^{-1}$ (Neves et al., 2015), and preliminary results for *Umbellula encrinus* and *Pennatula grandis* to be 4.51 ± 2.2 $cm.yr^{-1}$ and 1.9 ± 0.6 $cm.yr^{-1}$ consecutively (Neves et al., 2014a). Based on these new findings and observed heights for *U. encrinus* (230 cm) and *P. grandis* (40 cm), longevity estimates can reach 60 years of age for *Umbellula*, and >20 years of age for *Pennatula*. These results indicate sea pens impacted by anthropogenic disturbances would require decades to recover.

Other results in Neves et al., (2014b) reiterated the severity of the first initial pass of a trawl on a VME. The study provided video of a dense bamboo coral forest in Baffin Bay and the impact on it by a single scientific research trawl in 1999. The site was re-surveyed in 2013 utilizing a ROV. Living colonies were observed as dense patches ~55 m patch length x 1 m colony height – due to the high density of the bamboo coral, width of individual colonies could not be determined (Fig. 1.1.2.3). The trawl track showed no evidence of recovery after 14 years (Fig. 1.1.2.4).

Fig. 1.1.2.3. Forests of Keratoisis sp. (from Neves et al., 2015)

Fig. 1.1.2.4. Coral fragments close to the 1999 trawl path (from Neves et al., 2015)

In 2015 the Department of Fisheries and Oceans Canada announced the new Coral and Sponge Conservation Strategy for Eastern Canada. The strategy was developed to outline the current state of knowledge of corals and sponges, to provide the international and national context for coral conservation, and to outline new and existing research and conservation efforts in eastern Canadian waters. The document will facilitate the conservation and protection of Sensitive Benthic Areas, analogous to VME, in the Arctic and Northwest Atlantic through collaborations and integrated ocean management. For further information see http://dfo-mpo.gc.ca/oceans/publications/corals-coraux-eng.html.

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ToR 1.1.3. (FC Request #15). Summary of 2015 Canadian in situ photographic survey on the Grand Bank, and its implications in the context of prior survey and modelling work

> **FC Request #15.** The Fisheries Commission requests the Scientific Council to review the results of the 2015 Canadian in situ photographic surveys for non-coral and sponge VME indicator species on Grand Bank (tail of Grand Bank) in relation to previous analyses presented in 2014 (that modelled their distribution using research vessel survey trawl by-catch data), and to identify areas of significant concentrations of non-coral and sponge VME indicator species using all available information.

Large sea squirts and erect bryozoans were identified as VME indicators in Murillo et al. (2011) and accepted by NAFO (NAFO, 2012). In 2013 the working group collated the research vessel survey catch data for these taxa and presented a kernel density analysis for each, following previously established methods and assessment criteria (NAFO, 2013). The analysis performed well and clear threshold values were established for each taxon creating a number of polygons. However, the WGESA recommend that *in situ* camera surveys be done to evaluate the nature of these areas given that nothing is known about the catchability of the trawls for these taxa (NAFO, 2013). Such ground-truthing of the models was done for the corals and sponges (Kenchington et al., 2014), leading to the adoption of the coral and sponge polygons as VMEs (NAFO, 2014). Until such ground-truthing could be done, the WGESA referred to the kernel density-derived polygons for large sea squirts (*Boltenia ovifera* only) and erect bryozoans as “significant concentrations” (NAFO, 2013).

The location of the significant concentrations of large sea squirts and erect bryozoans on the tail of Grand Bank is shown in Figure 1.1.3.1. Recent fishing (2010-2013) has only minimal overlap with the location of these significant concentrations (NAFO, 2013).

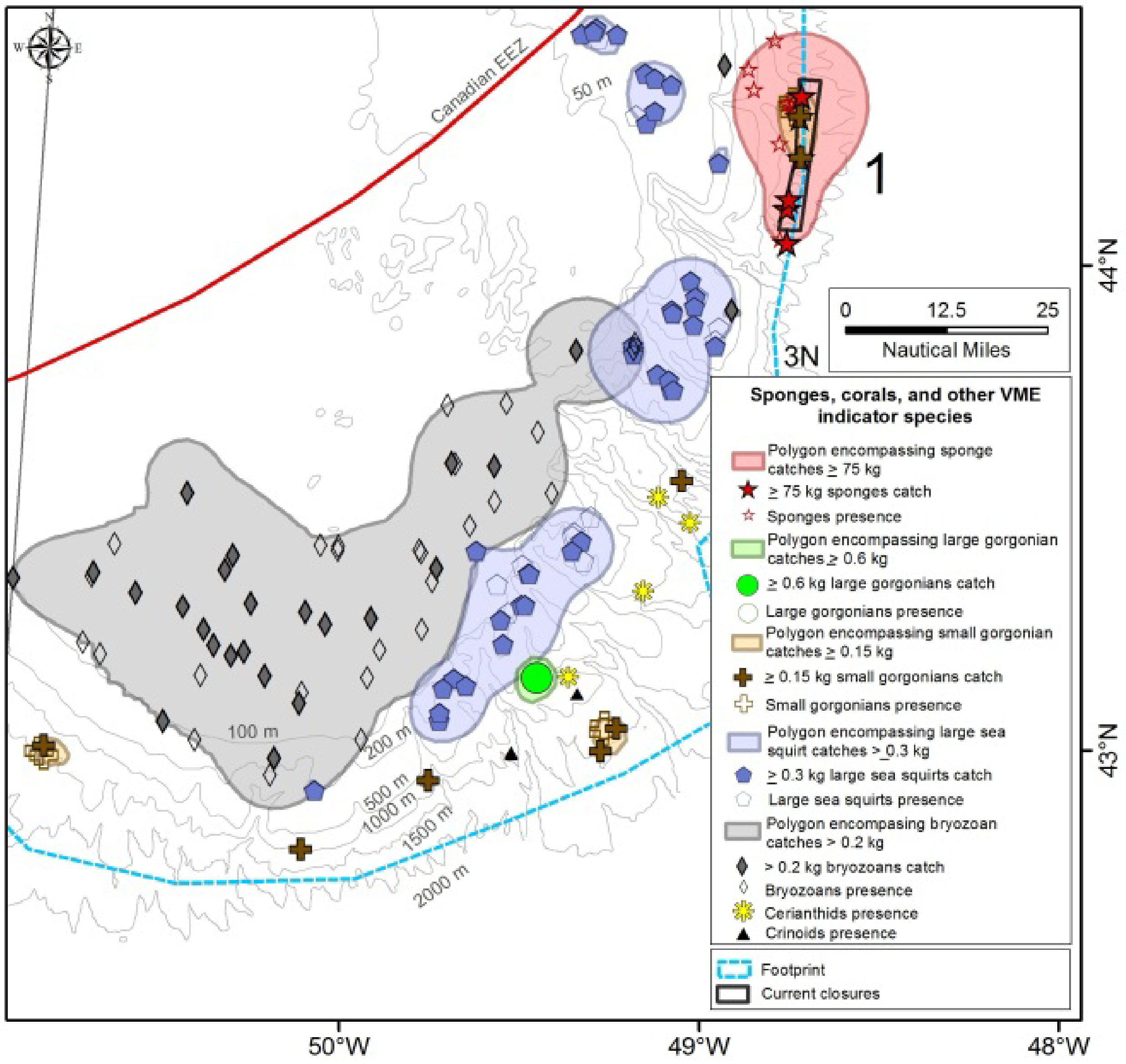

Fig. 1.1.3.1. Location of significant concentrations of large sea squirts and erect bryozoans on the tail of Grand Bank (Figure from NAFO, 2013).

Results of the 2015 Canadian *in situ* Photographic Surveys

Fisheries and Oceans, Canada conducted *in situ* photographic surveys on the Tail of Grand Bank during June 2-18th, 2015. The mission, HUD2015-011: Identification & Characterization of Benthic VMEs and ESBAs on the Scotian Shelf, Grand Banks, and Laurentian Channel, used a drop camera system referred to as the 4KCam. This system, built in 2008 by the Geological Survey of Canada, is an aluminium frame that contains a Canon Rebel Eos Ti 12 megapixel camera with two Canon flashes. The 4KCam was lowered with a winch until an attached lead weight hit the bottom, automatically triggering the camera. Subsequent photos were taken by raising and lowering the camera off the sea bed. Six transects were completed; five inside the polygons for significant concentrations of erect bryozoans or large sea squirts, where they were positioned over significant catches (Table 1.1.3.1). The transect lines covered 7 km and 288 photos of good quality were collected (Table 1.1.3.1).

Table 1.1.3.1. Summary of *in situ* Benthic Transects on the Tail of Grand Bank.

Code	**Event Code**	**Depth (m) (Start/End)**	**Length**	**Comment**
		Central Tail of Grand Bank		
TGB 2	CON_025	75/74	1.2 km	Inside polygon for significant concentrations of erect bryozoans; transect falls 34 m away from start position of tow recording significant bryozoan catch (7.843 kg); 54 photos.
TGB 3	CON_026	63/63	1.1 km	Inside polygon for significant concentrations of erect bryozoans; transect falls 6 m away from start position of tow recording significant bryozoan catch (2.86 kg); 52 photos.
		Southeast Shoal		
SES 1	CON_027	103/109	1.2 km	Inside polygon for significant concentrations of erect bryozoans and large sea squirts; transect falls 55 m away from start position of tow recording significant *Boltenia* catch (0.43 kg); 50 photos.
SES 2	CON_028	50/51	1.1 km	Inside polygon for significant concentrations of large sea squirts; transect fall 3 m away from start position of tow recording significant *Boltenia* catch (2.35 kg); 42 photos.
SES 3	CON_029	52/50	1.2 km	Outside polygons for significant concentrations of large sea squirts; 41 photos.
SES 4	CON_030	52/52	1.2 km	Inside polygon for significant concentrations of large sea squirts; transect falls 149 m away from start position of tow recording significant *Boltenia* catch (1.52 kg); 49 photos.

Erect Bryozoan Polygon

Two transects were completed inside the polygon for erect bryozoans (Fig. 1.1.3.1) (CON_25, CON_26). The first transect (Fig. 1.1.3.2) was heavily populated with brittle stars (*Ophiura sarsi*) but there was no evidence of erect bryozoans. The second transect (Fig.1.1.3.1) did record erect bryozoans (*Eucratea loricata*) but these were small colonies, likely attached to broken shells and not forming turf habitat. The soft bottom of this area is not suitable for attachment and turf habitats are likely found on patches of hard substrate that are scattered throughout the area.

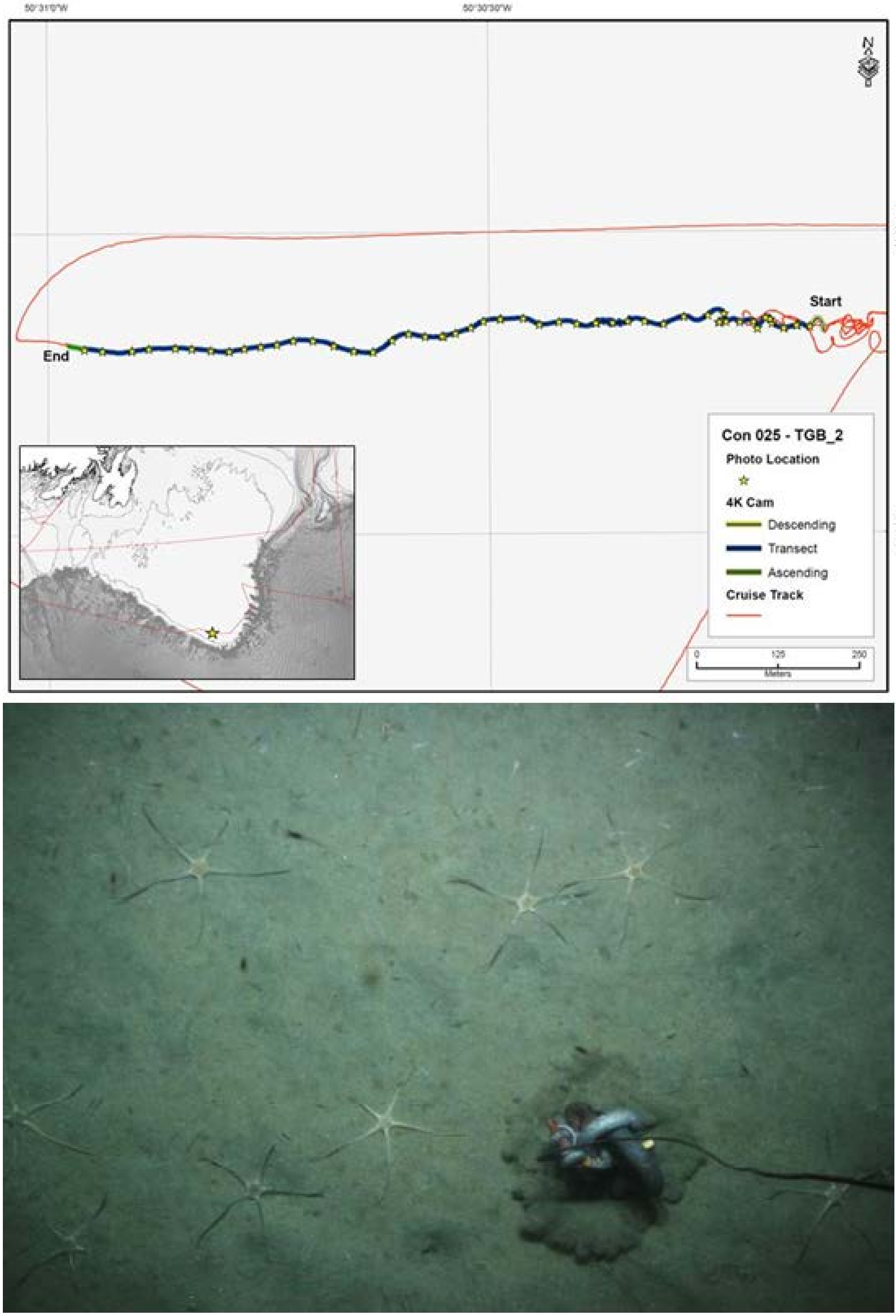

Fig. 1.1.3.2. Position of CON_25 (upper panel) and representative photo (lower panel) showing brittlestars.

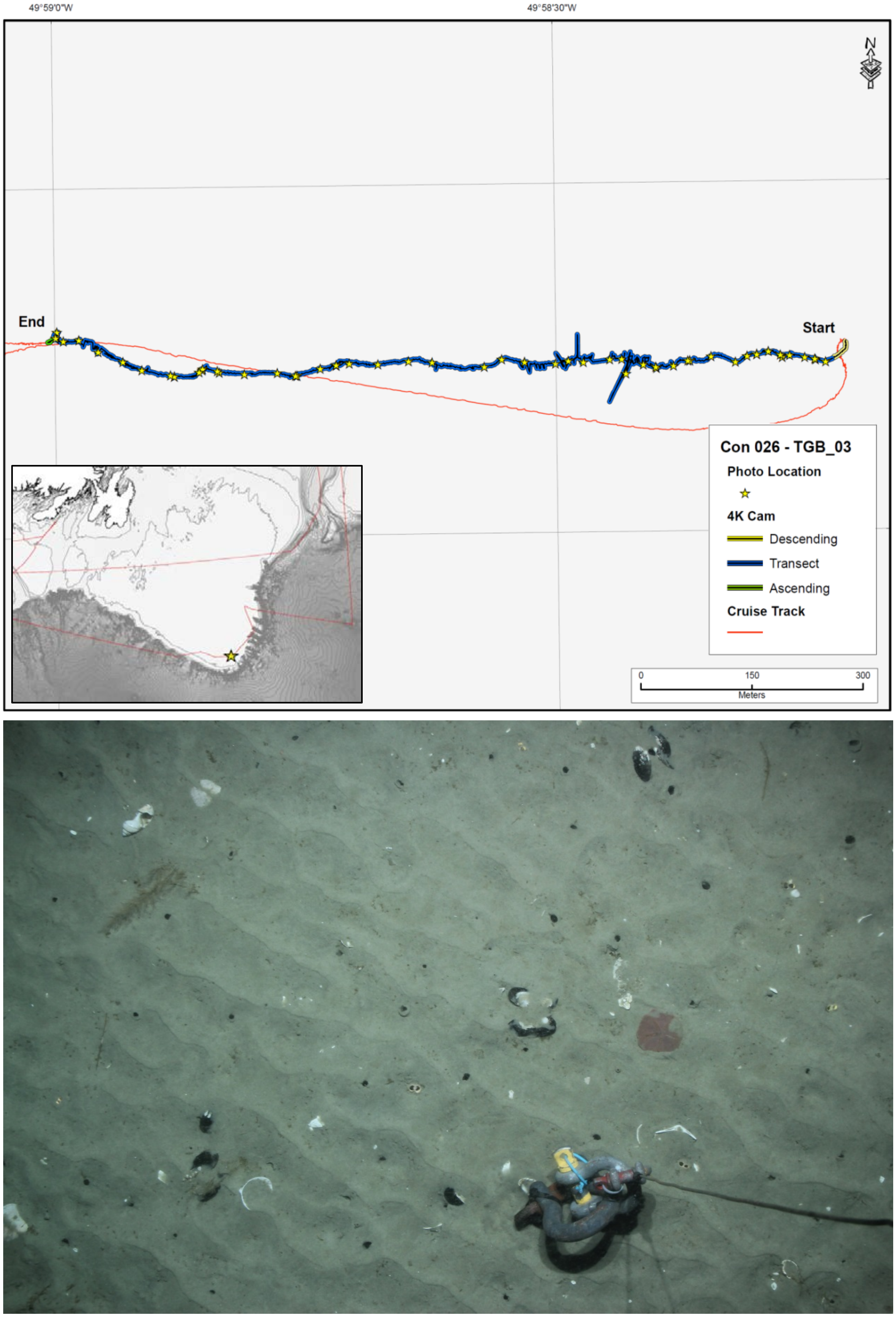

Fig. 1.1.3.3. Position of CON_26 (upper panel) and representative photo (lower panel) showing erect bryozoans.

Large Sea Squirt Polygons

Three transects were completed inside the polygons for large sea squirts and one was run outside (Table 1.1.3.1). The first transect (Fig. 1.1.3.4) was heavily populated with sand dollars (*Echinarachnius parma*) but there was no evidence of large sea squirts. The second transect (Fig. 1.1.3.5) was over an area of broken shell with small pebbles. A number of megafauna were observed, including sea cucumbers, large starfish, sand dollars and crabs, but there were no large sea squirts. The third transect did record large sea squirts but they were of a species that was not stalked (i.e., not *Boltenia* sp.) and these were not forming dense aggregations but rather appeared amongst soft corals (Fig. 1.1.3.6). The bottom was variable on this transect going from soft sand with sand dollars to shell hash through to cobble. The transect completed outside of the large sea squirt polygons on the Southeast Shoal was over shell hash bottom with high abundance of sea cucumbers in some areas. The broken shells showed evidence of drill holes indicating that at least a portion were produced through whelk predation. The camera transects did not identify significant concentrations of large sea squirts.

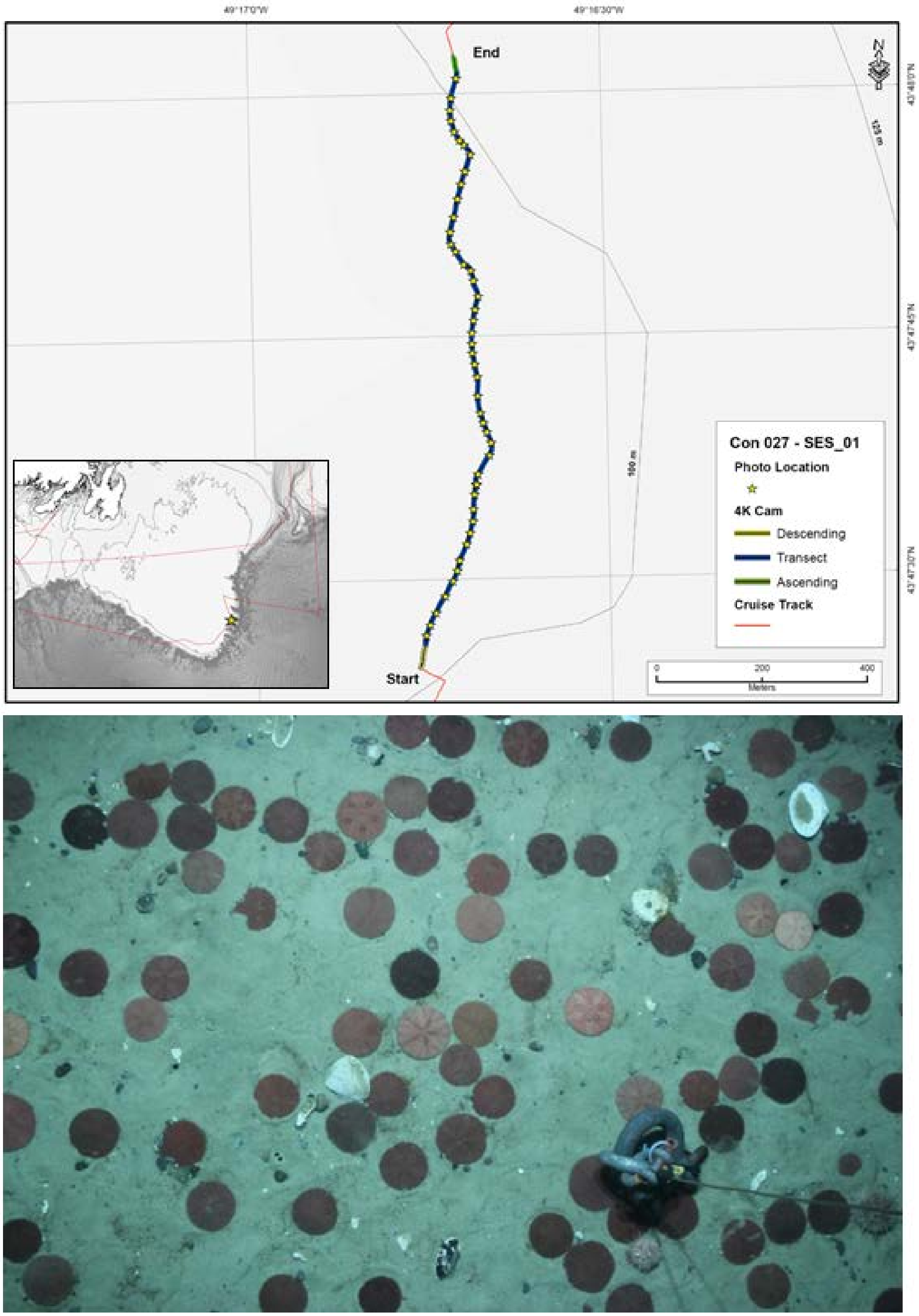

Fig. 1.1.3.4. Position of CON_27 (upper panel) and representative photo (lower panel) showing sand dollars.

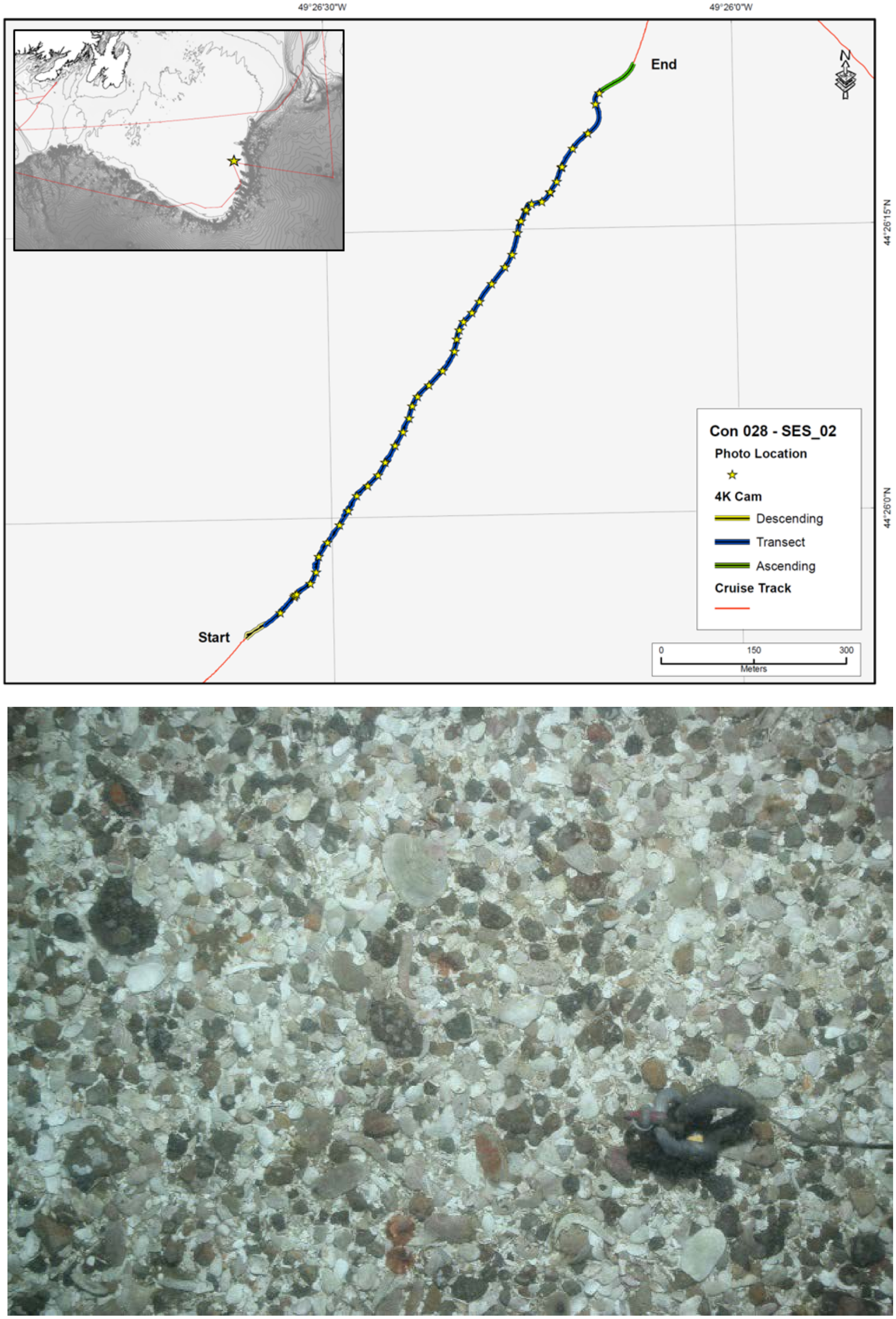

Fig. 1.1.3.5. Position of CON_28 (upper panel) and representative photo (lower panel) showing broken shell and small pebbles.

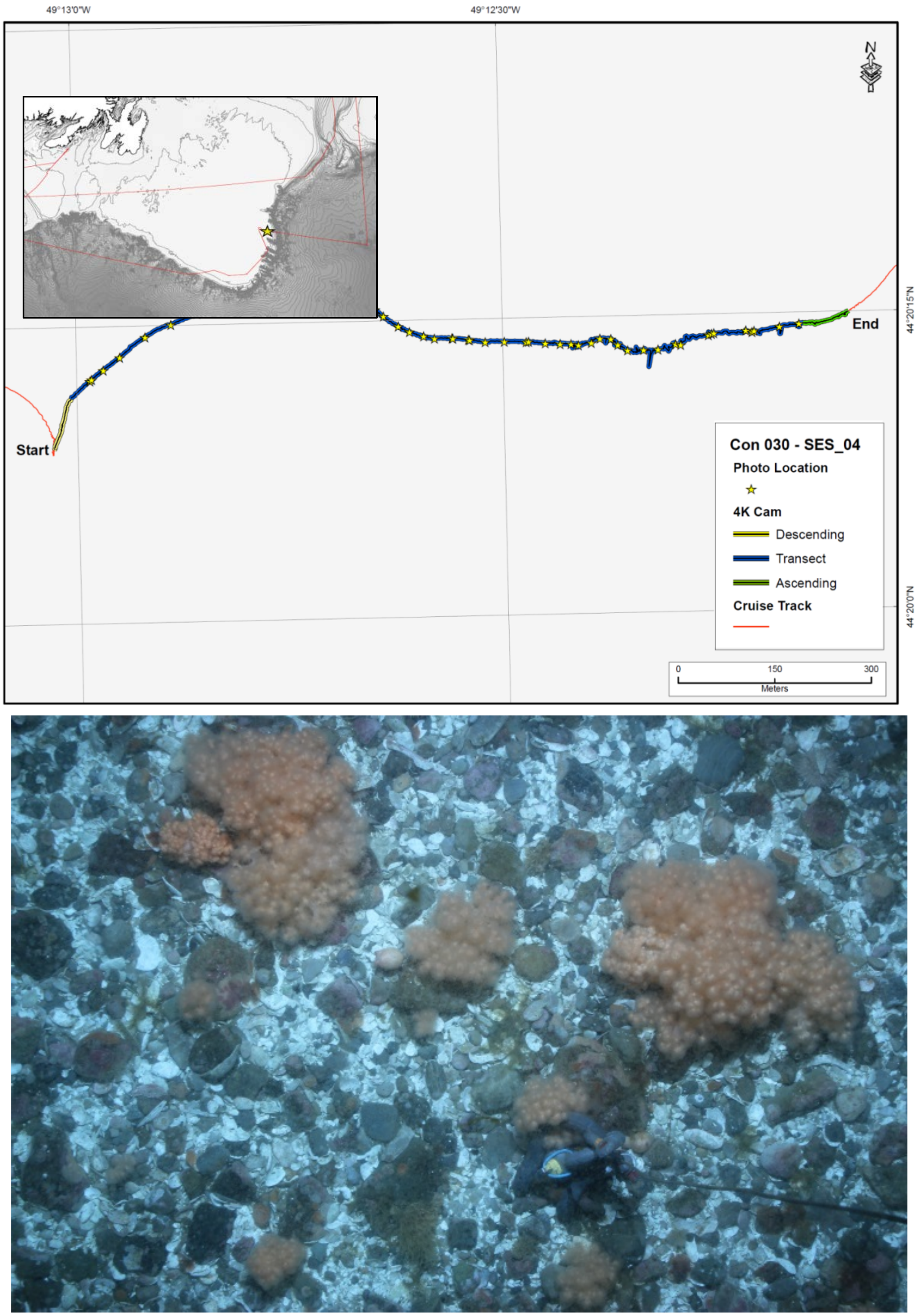

Fig. 1.1.3.6. Position of CON_30 (upper panel) and typical photo (lower panel) showing broken shell and small pebbles with soft corals and a sea squirt of unknown taxonomic identity (possibly *Halocynthia aurantium*).

New Records from Research Trawl Surveys

Erect Bryozoans

Nine significant catches of bryozoans were reported from the 3NO and 3L Spanish 2014 and 2015 surveys (catches above the 0.2 kg threshold; Table 1.1.3.2) and 1 from the DFO NL Multispecies Surveys (NRA Divs. 3LMNO), carried out by Fisheries and Oceans, Canada (see ToR1.1.1 above). Five of the significant catches were within the polygons identified from the kernel analysis, and five outside (Fig. 1.1.3.7). Several species could be recorded under the "bryozoans" category, although the species that constitute most of the biomass, mainly on the continental shelf of the Tail of the Grand Bank (Fig. 1.1.3.7) is the erect bryozoan *Eucratea loricata.* The RV catches of bryozoans overlain with the cruise track of each trawl set are shown in Figures 1.1.3.8 and 1.1.3.9 for each of the areas shown in Fig. 1.1.3.7 (left panel). Exact positions of significant catches are provided in Table 1.1.3.2.

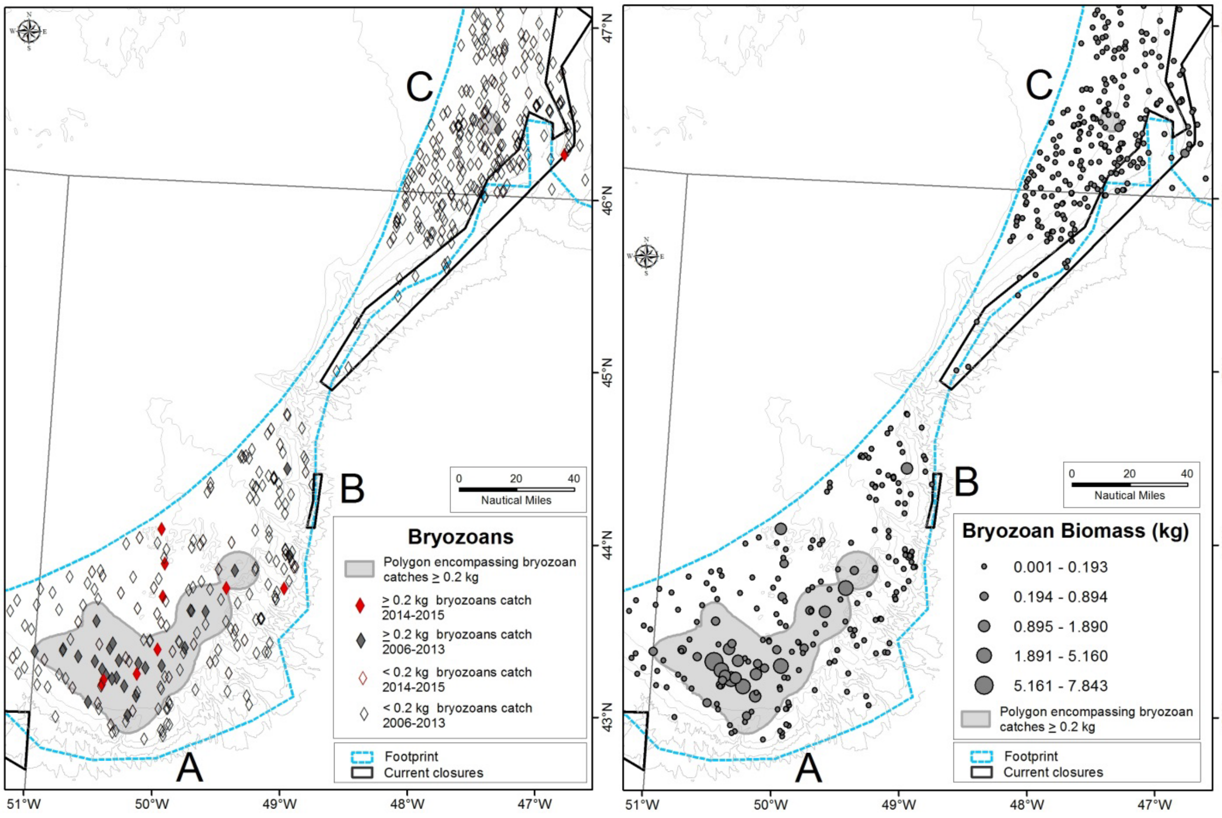

Fig. 1.1.3.7. Left panel. Location of catches of bryozoans on the Tail and Nose of the Grand Bank in relation to the kernel density polygons. Right panel. Bryozoan biomass (kg) on the Tail and Nose of the Grand Bank in relation to the kernel density polygons.

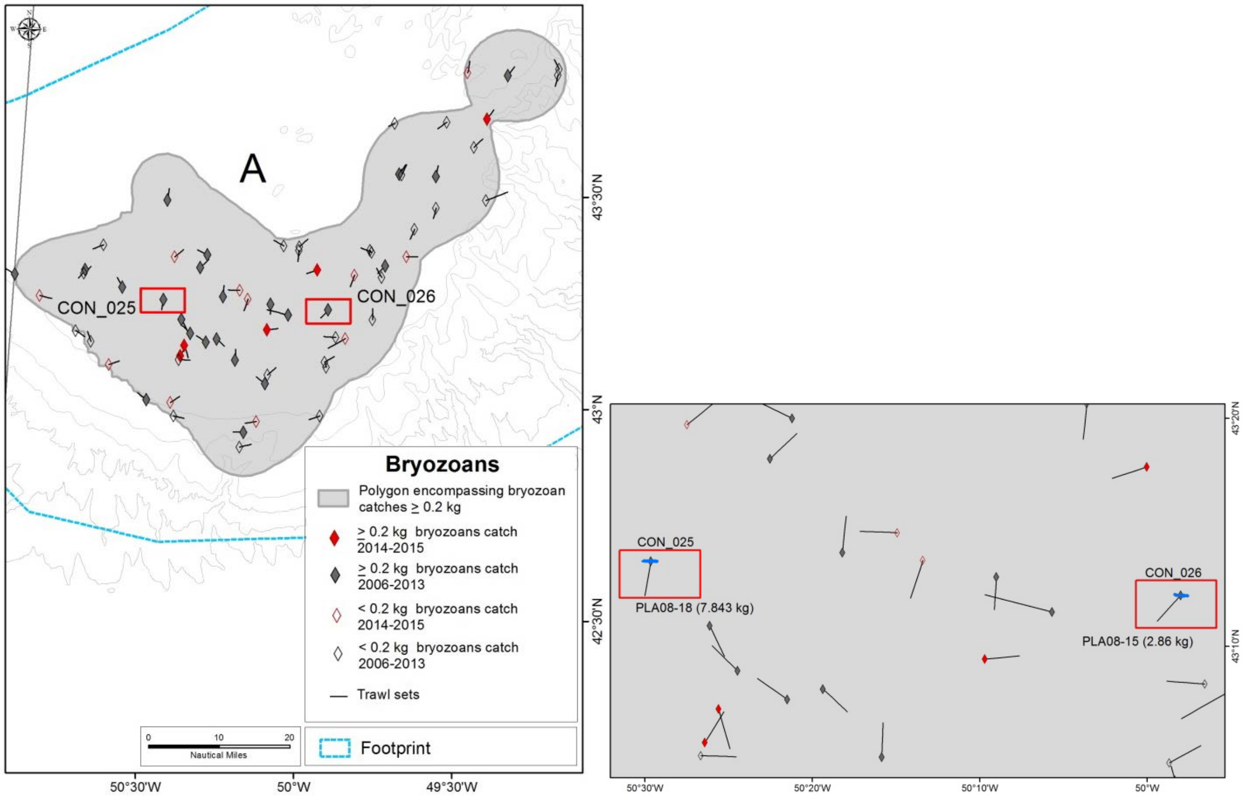

Fig.1.1.3.8. Left panel. Location of catches of bryozoans in the area overlain with the cruise tracks of each trawl set. The benthic transects CON_025 and CON_026 of the HUD2015-011 mission are indicated. Right panel. Location of the benthic transects CON_025 and CON_026 (blue lines) in relation to two bryozoan significant catches (PLA08-18, 7.843 kg and PLA08-15, 2.86 kg).

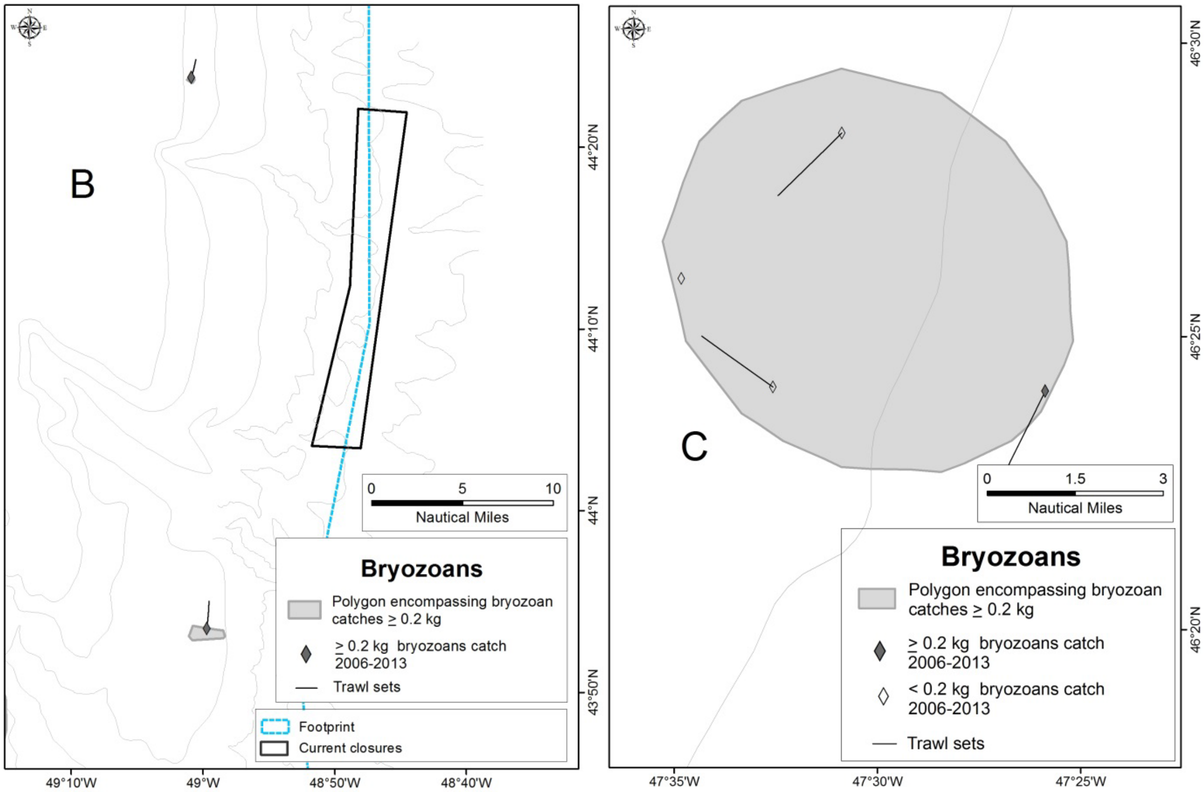

Fig.1.1.3.9. Left panel. Location of catches of bryozoans in the area B overlain with the cruise tracks of each trawl set. Right panel. Location of catches of bryozoans in the area C overlain with the cruise tracks of each trawl set.

Table 1.1.3.2. Start positions of significant RV catches of bryozoans with their corresponding weight.

Survey	**Year**	**Start position**		**Weight (kg)**
		Lat (N)	**Lon (W)**	
Spain 3NO Survey	2008	43° 12' 09.6"	50° 30' 29.4"	7.843
Spain 3NO Survey	2015	43° 40' 22.8"	49° 29' 57.6"	5.16
Spain 3NO Survey	2009	43° 09' 30"	50° 26' 43.2"	3.85
Spain 3NO Survey	2011	43° 06' 29.4"	50° 21' 48.0"	3.08
Spain 3NO Survey	2008	43° 12' 07.2"	49° 58' 37.8"	2.86
Spain 3NO Survey	2008	43° 04' 13.2"	50° 15' 55.2"	2.55
Spain 3NO Survey	2011	44° 22' 52.2"	49° 03' 26.4"	1.7625
Spain 3NO Survey	2015	43° 08' 48.0"	50° 10' 07.8"	1.504
Spain 3NO Survey	2008	43° 31' 49.8"	49° 39' 12.6"	1.47
Spain 3NO Survey	2007	43° 16' 60.0"	50° 23' 45.6"	1.45
Spain 3NO Survey	2011	43° 01' 09.0"	50° 09' 52.8"	1.41
Spain 3NO Survey	2007	43° 07' 36.0"	50° 24' 52.8"	1.362
Spain 3NO Survey	2008	43° 13' 05.4"	50° 19' 03.0"	1.28
Spain 3NO Survey	2009	43° 07' 02.4"	50° 19' 42.0"	0.962
Spain 3NO Survey	2015	43° 17' 40.2"	50° 01' 07.2"	0.894
Spain 3NO Survey	2015	43° 04' 21.6"	50° 26' 33.0"	0.776
Spain 3NO Survey	2009	43° 52' 34.8"	49° 00' 11.4"	0.741
Spain 3NO Survey	2011	42° 54' 07.2"	50° 13' 25.8"	0.62
Spain 3NO Survey	2011	43° 46' 39.6"	49° 26' 19.2"	0.62
Spain 3NO Survey	2007	43° 12' 26.4"	50° 09' 44.4"	0.476
Spain 3NO Survey	2007	43° 13' 28.8"	50° 38' 31.8"	0.444
Spain 3NO Survey	2011	43° 18' 49.8"	50° 22' 34.8"	0.437
Spain 3NO Survey	2008	43° 26' 13.2"	50° 30' 58.8"	0.426
Spain 3NO Survey	2014	43° 05' 52.2"	50° 25' 52.2"	0.37
Spain 3NO Survey	2008	43° 18' 48.6"	49° 48' 03.6"	0.33
Spain 3NO Survey	2008	43° 15' 38.4"	50° 45' 56.4"	0.3
Spain 3NO Survey	2011	43° 11' 03.0"	50° 06' 16.2"	0.297
Spain 3NO Survey	2008	43° 14' 16.8"	50° 59' 26.4"	0.251
Spain 3NO Survey	2011	42° 57' 51.0"	50° 32' 30.6"	0.246
Spain 3L Survey	2013	46° 23' 60.0"	47° 26' 09.0"	0.242
DFO NL Multispecies Surveys (Canada)	2013	43° 41' 18.0"	49° 02' 12.0"	0.23
Spain 3NO Survey	2013	43° 31' 53.4"	49° 46' 25.8"	0.227

Large Sea Squirts

The Spanish 3NO Survey reported 4 significant catches of large sea squirts (all the stalked tunicate *Boltenia ovifera*) from the 2014 and 2015 surveys (catches above the 0.3 kg threshold; Table 1.1.3.3), three of which were within the polygons identified from the kernel analysis, and one outside (Fig.1.1.3.10 and ToR 1.1.1). The RV catches of large sea squirts overlain with the cruise track of each trawl set are shown in Figs. 1.1.3.11 and 1.1.3.12 for each of the areas shown in Fig.1.1.3.10. These locations appear to be associated with the flanks of canyons (VME elements) where there is likely greater hard substrate for attachment compared with higher on the bank. Exact positions of significant catches are provided in Table 1.1.3.3.

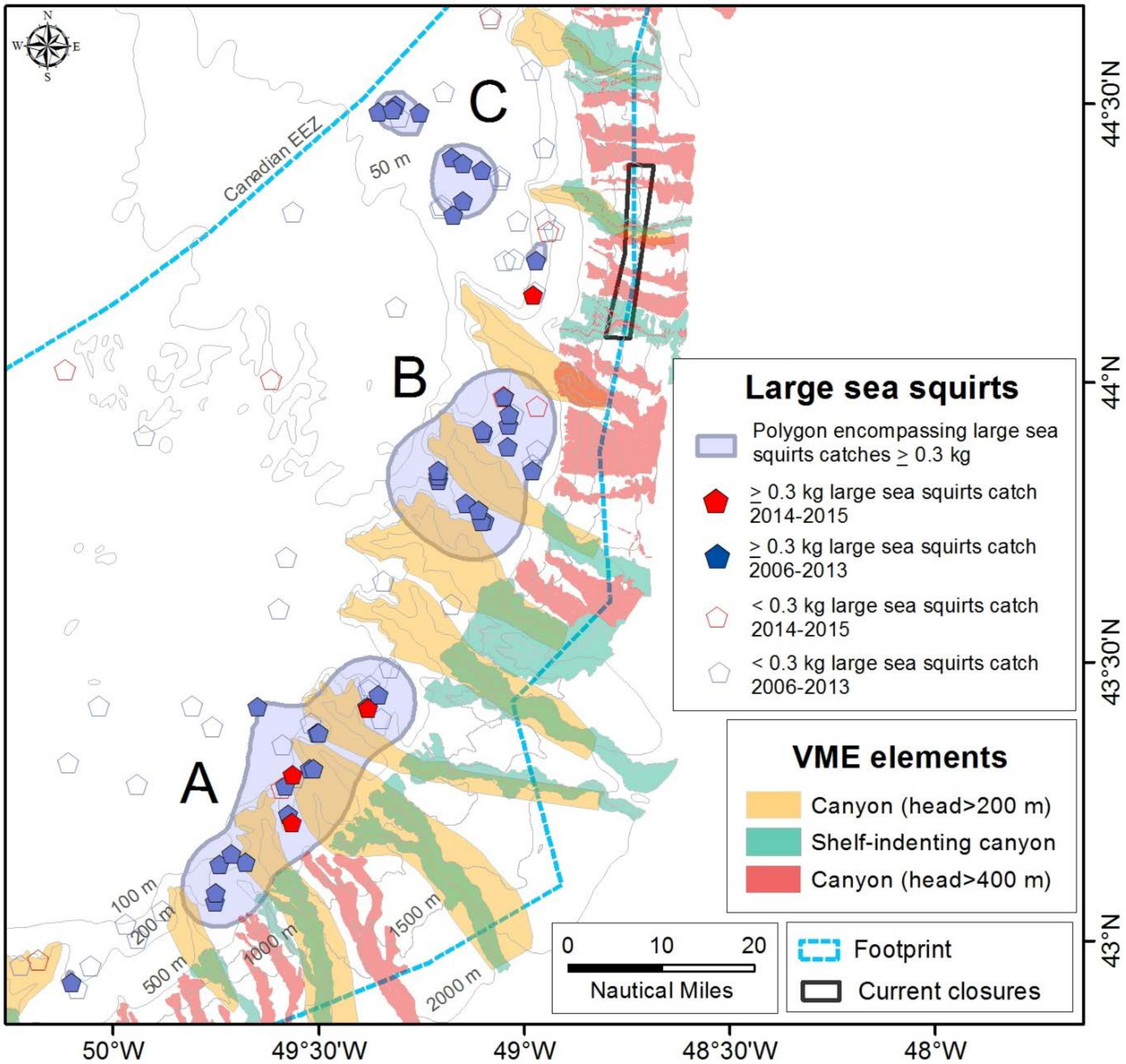

Fig. 1.1.3.10.Location of catches of large sea squirts on the Tail of Grand Bank in relation to the kernel density polygons and canyons of the Tail of the Grand Bank (VME elements).

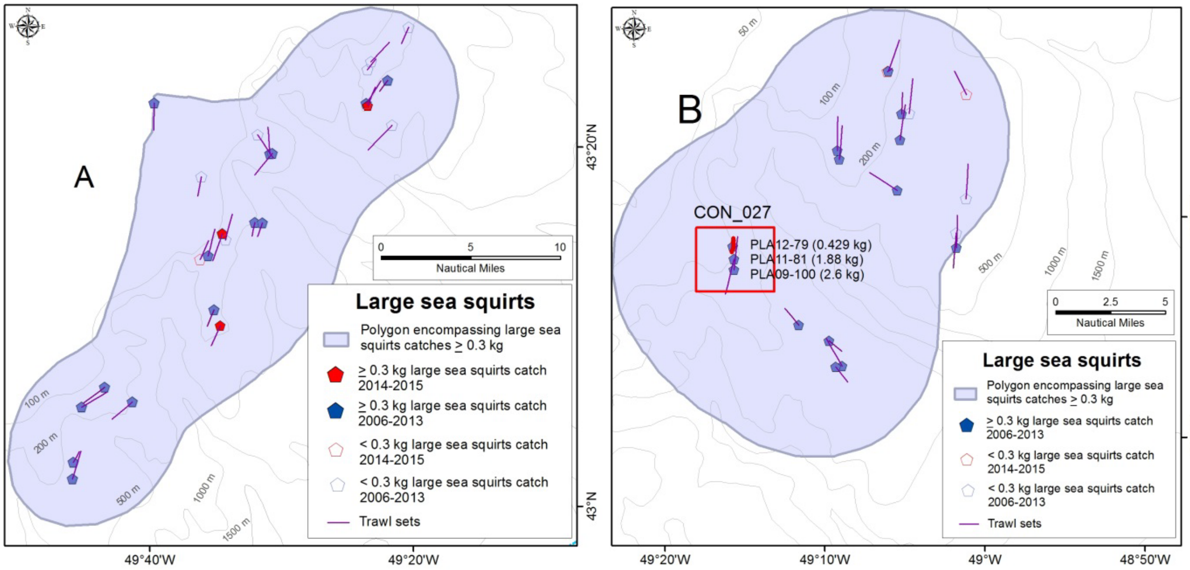

Fig. 1.1.3.11.Left panel. Location of catches of large sea squirts in the area A overlain with the cruise tracks of each trawl set. Right panel. Location of catches of large sea squirts in the area B overlain with the cruise tracks of each trawl set and the benthic transect CON_027 of the HUD2015-011 mission in an area of three large sea squirts significant catches (PLA12-79, 0.429 kg, PLA11-81, 1.88 kg and PLA09-100, 2.6 kg).

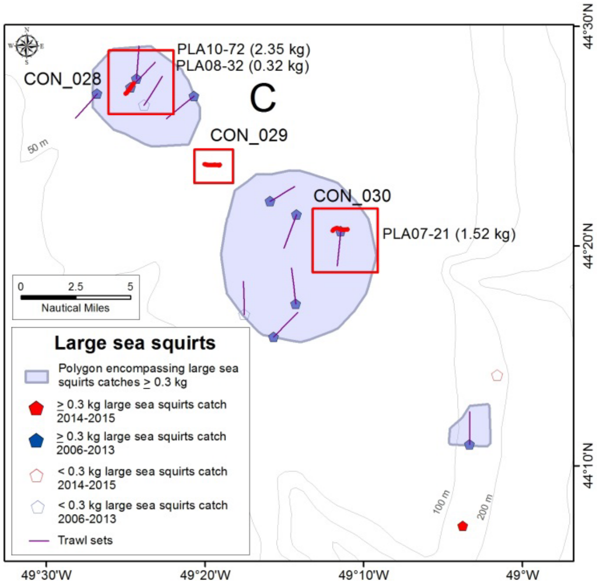

Fig.1.1.3.12. Location of catches of large sea squirts in the area C overlain with the cruise tracks of each trawl set and the benthic transects CON_028, CON_029 and CON_030 of the HUD2015-011 mission. CON_028 overlaps to two large sea squirts significant catches (PLA10-72, 2.35 kg and PLA08-32, 0.32 kg, whereas CON_30 overlaps to one large sea squirt significant catch (PLA07-21, 1.52 kg).

Table 1.1.3.3. Start positions of significant RV catches of large sea squirts (specifically the stalk tunicate *Boltenia ovifera*) with their corresponding weight.

Survey	**Year**	**Start position**		**Weight (kg)**
		Lat (N)	**Lon (W)**	
Spain 3NO Survey	2015	43° 14' 09.6"	49° 35' 48.0"	6.05
Spain 3NO Survey	2009	43° 21' 50.4"	49° 25' 19.2"	4.55
Spain 3NO Survey	2012	43° 09' 52.2"	49° 36' 06.6"	4.5
Spain 3NO Survey	2013	43° 14' 52.8"	49° 32' 46.2"	3.52
Spain 3NO Survey	2012	43° 44' 15.0"	49° 12' 19.2"	2.8
Spain 3NO Survey	2009	43° 12' 52.2"	49° 36' 46.8"	2.79
Spain 3NO Survey	2009	43° 46' 36.0"	49° 16' 34.2"	2.6
Spain 3NO Survey	2009	43° 21' 12.6"	49° 41' 32.4"	2.41
Spain 3NO Survey	2010	44° 26' 10.8"	49° 26' 19.2"	2.35
Spain 3NO Survey	2011	43° 14' 52.2"	49° 33' 21.0"	2.167
Spain 3NO Survey	2008	43° 04' 29.4"	49° 41' 56.4"	2.06
Spain 3NO Survey	2011	43° 47' 05.4"	49° 16' 36.0"	1.88
Spain 3NO Survey	2014	43° 21' 42.6"	49° 25' 12.6"	1.85
Spain 3NO Survey	2012	43° 54' 03.6"	49° 06' 31.8"	1.74
Spain 3NO Survey	2009	43° 00' 57.6"	49° 46' 09.0"	1.702
Spain 3NO Survey	2007	43° 00' 01.8"	49° 46' 08.4"	1.58
Spain 3NO Survey	2007	44° 20' 09.0"	49° 12' 30.0"	1.52
Spain 3NO Survey	2013	43° 52' 15.0"	49° 10' 27.6"	1.5
Spain 3NO Survey	2010	44° 16' 43.8"	49° 15' 07.8"	1.197
Spain 3NO Survey	2012	43° 23' 10.8"	49° 23' 47.4"	1.102
Spain 3NO Survey	2012	44° 21' 21.0"	49° 17' 04.2"	1.06
Spain 3NO Survey	2007	43° 42' 28.2"	49° 09' 28.8"	1.03
Spain 3NO Survey	2009	42° 50' 27.0"	50° 06' 22.2"	0.904
Spain 3NO Survey	2009	44° 10' 44.4"	49° 03' 40.2"	0.898
Spain 3NO Survey	2012	44° 15' 10.8"	49° 16' 24.0"	0.84
Spain 3NO Survey	2013	44° 20' 48.0"	49° 15' 22.2"	0.743
Spain 3NO Survey	2012	43° 05' 13.8"	49° 44' 05.4"	0.665
Spain 3NO Survey	2008	43° 52' 52.8"	49° 06' 33.6"	0.612
Spain 3NO Survey	2012	44° 39' 42.6"	49° 03' 34.8"	0.6
Spain 3NO Survey	2015	44° 07' 00.6"	49° 03' 51.0"	0.587
Spain 3NO Survey	2014	43° 09' 01.2"	49° 35' 33.6"	0.576
Spain 3NO Survey	2010	43° 18' 46.2"	49° 32' 19.2"	0.555
Spain 3NO Survey	2010	43° 04' 03.0"	49° 45' 46.2"	0.512
Spain 3NO Survey	2011	44° 25' 57.0"	49° 22' 16.2"	0.441
Spain 3NO Survey	2007	43° 51' 52.2"	49° 10' 18.0"	0.43
Spain 3NO Survey	2012	43° 47' 39.6"	49° 16' 43.2"	0.429
Spain 3NO Survey	2009	44° 25' 49.2"	49° 28' 24.6"	0.379
Spain 3NO Survey	2011	43° 55' 58.8"	49° 07' 30.0"	0.378
Spain 3NO Survey	2010	43° 50' 34.8"	49° 06' 34.2"	0.373
Spain 3NO Survey	2013	43° 43' 35.4"	49° 10' 22.2"	0.351
Spain 3NO Survey	2009	43° 18' 44.4"	49° 32' 29.4"	0.325
Spain 3NO Survey	2008	44° 26' 36.0"	49° 25' 58.2"	0.32
Spain 3NO Survey	2011	43° 42' 25.8"	49° 09' 52.2"	0.32
Spain 3NO Survey	2009	43° 48' 07.2"	49° 02' 40.2"	0.3

Identification of Areas of Significant Concentrations of Non-coral and Sponge VME Indicator Species

The results of the photographic surveys indicate that the patch size of the non-coral and sponge VME indicator species, that is, erect bryozoans and large sea squirts, is less than 1 km. These VME indicators require hard substrate to attach to. It is likely that areas with high catches are also areas with rocky outcrops or more extensive hard bottom. If it were possible to get detailed information of the surficial geology of the area, perhaps from RV surveys using RoxAnn or other remote sensors, then the habitats created by these species might be better defined.

The WGESA recommends that the location of the significant catches within the kernel-density derived polygons, rather than the full kernel density polygon areas, be used to identify significant concentrations of these taxa.

References

Kenchington, E. F.J. Murillo, C. Lirette, M. Sacau, M. Koen-Alonso, A. Kenny, N. Ollerhead, V. Wareham and L. Beazley. 2014. Kernel density surface modelling as a means to identify significant concentrations of vulnerable marine ecosystem indicators. PLoS ONE 9(10): e109365. doi:10.1371/journal.pone.0109365.

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.

NAFO. 2012. Part A: Scientific Council Meeting – 1-14 June 2012. SC 1-14 Jun 2012, 192 pp.

NAFO. 2013. Report of the 6th Meeting of the NAFO Scientific Council (SC) Working Group on Ecosystem Science and Assessment (WGESA) [Formerly SC WGEAFM]. NAFO SCS Doc. 13/24, Serial No. N6277, 209 pp.

NAFO. 2014. Part E: Scientific Council Meeting, 31 May - 12 June 2014. SC 31 May-12 Jun 2014, 238 pp.

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

There was no additional work done 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.

ToR 3.1. Progress on multispecies and ecosystem analyses

ToR 3.1.1. Summary of research on fish communities in the tail of the Grand Bank amd Flemish Cap

Introduction

An ecosystem approach that incorporates environmental, social and economic concerns is widely recognised as desirable for fisheries management. There is an increasing need for moving from single-species management to Ecosystem Approach to Fisheries (EAF) that takes into account not only the state of the exploited populations of marine resources but also the entire ecosystem (Pauly *et al.*, 2000; Zabel *et al.*, 2003; Shin *et al.*, 2000; Nogueira *et al.*, 2015, 2016). To contribute to the implementation of an EAF, a fist step is the description of assemblages in the fishing grounds and to evaluate variation through time (e.g. Tolimieri and Levin, 2006; Nogueira *et al.*, 2014). A second step is to examine trends and temporal changes in the ecosystem by selection and application of indicators in each assemblage (e.g. Trenkel and Rochet; Nogueira *et al.*, 2015). Here we compare two exploited ecosystems, both part of the Labrador Newfoundland Large Marine Ecosystems (LN LME): the Southern Grand Banks of Newfoundland (NAFO Regulatory Area Divisions 3NO) and the Flemish Cap (NAFO Regulatory Area Divisions 3M).

Since the collapse in the 90s, six fisheries have been developed in 3NO and 3M. In 3MNO, a fishery for Greenland halibut (*Reinhardtius hippoglossoides*) exists at depths > 600 m. This fishery also catches roughhead grenadier (*Macrourus berglax*) and black dogfish (*Centroscyllium fabricii*) as main bycatch. Between 200 and 600 m, the fishery targets redfish (*Sebastes spp*). In 3NO, at depths < 200 m there are two fisheries: a mixed fishery that includes American plaice (*Hippoglossoides platessoides*), yellowtail flounder (*Limanda ferruginea*), cod (*Gadus morhua*) and skates (*Raja spp*) in Div. 3N, and another that targets skates with American plaice, yellowtail flounder and cod as main by-catch species. In 3M, until 2011 when the moratorium was imposed, there was a Northern shrimp (*Pandalus borealis*) fishery between 300 and 500 m, and at depths between 150-550 meters a fishery targets cod since 2010, after a 10-years moratorium (González-Costas, 2012).

The objectives of this study were (1) to identity, describe and map broad groundfish assemblage over a wide depth range (38-1460 m in 3NO and 129-1460 m in 3M); (2) to evaluate whether and in which manner the main demersal groundfish assemblages have responded to different levels of exploitation, and to contribute to the diagnosis of the ecosystem status in the different depth strata. We selected two categories if indicators: (i) population indicators and (ii) community metrics to summarize community properties. Note that not all the analysis have been already done in the two groundfish.

Data source and methods

We used data from two stratified random sampled bottom trawl surveys performed by the Spanish Administration and the European Union (EU): the Southern Grand Banks (3NO survey) (NAFO Regulatory Area Divisions 3NO), from 2002 to 2014 (*Paz et al.*, 2000), and the Flemish Cap (3M survey) in July since 1988 (NAFO Regulatory Area Division 3M), from 1991 or 1993 (no count data for all species before) to 2014 (*Vázquez*, 2000; Casa,2015).

The main variable used was depth. This is the factor which most influenced the distribution of species. Changes in relation to depth probably related other parameters like temperature, productivity or oxygen levels (Bianchi, 1991; Tolimieri and Levin, 2006)

Before determining groundfish assemblages, exploratory analyses were conducted to examine if zonation existed, how species were distributed by depth and where depth boundaries occurred. We used an application of the chi-square test to examine the distribution of species boundaries and establish patterns of zonation and box-plots to visualize the distribution of species by depth. To describe semi-quantitative trends in biomass with depth, we constructed graphs of the cumulative distribution of the catches and compared with the empirical cumulative distribution of the depths of the hauls. Finally, in order to quantify zonation, we identified potential depth boundaries by calculating the percentage similarity (PS) between the regions involved.

We then used multivariate analyses to better define the composition of species assemblages. Cluster analysis was applied to confirm the boundaries found in the PS analysis. Two other multivariate analyses were used in order to validate the cluster analysis results and to determine which species make up each assemblage: Correspondence Analysis (CA) and Principal Component Analysis (PCA). We used non-metric multidimiensional scaling (nMDS) to examine temporal changes in the structure of fish assemblages.

A full suite of indicators is needed to detect changes in ecosystem attributes and processes. We chose those indicators that can help to determine the effects of fishing at population and community levels. We selected two categories of indicators: (i) population indicators: abundance and biomass, intrinsic population growth rate, and mean length (ii) community metrics to summarize community properties: ABC curves, proportion of non-commercial species, mean length in community, size spectra, mean trophic level and indices about faunal diversity (Shannon-Weaver, Pielou's evenness, Gini-Simpson evenness, species richness and species density).

For MTL and species evenness, we conducted a two-step analysis to examine whether the variables of interest varied among years and whether any variability was directional. First we used linear models, to test whether MTL, for example, varied among depth zones and years—not necessarily directionally. Second, we used generalized additive mixed models (GAMMs) to test whether MTL increased or decreased over time—potentially non-linearly. For species richness and species density we completed only the second step because the sample-based rarefaction produced one estimate per depth zone per year, not per haul as with MTL and species evenness. In the first step, we used comparison of AIC values to choose the best-fit model.

Results

The examination of all exploratory and multivariate analyses revealed the existence of 3 groups associated with the continental shelf and the slope in 3NO and in 3M. In 3NO, cluster I (Shallow or "Continental Shelf") comprised the strata with depths less than 300 m; cluster II (Intermediate or "Upper Continental Slope") contained the depth strata between 301 and 600 m; cluster III (Deep or "Medium-Lower Slope") (Deep or "Lower Slope") the depths greater than 601 m (Fig. 3.1.1.1). In 3M, cluster I (Shallow or "Continental Shelf") comprised the strata with depths less than 250 m; cluster II (Intermediate or "Upper Continental Slope") contained the depth strata between 251 and 600 m; Cluster III (Deep or "Medium-Lower Slope") the depths greater than 601 m (Fig. 3.1.1.2). A map illustrates the three different strata identified in the cluster analysis (Fig. 3.1.1.3). Table 3.1.1.1 summarizes which species make up each assemblage. Therefore, we summarized the catch data into the depth categories found in each assemblage for calculating the biomass estimate (Fig. 3.1.1.4). The nMDS (Fig. 3.1.1.5) ordination analysis supported differences between years in the three assemblages of 3NO. In 3M, it was interesting to observe low differences among years 2009-2014 and 1991-1995 in the shallow assemblage that confirmed similarities between the period pre and post collapse in the shallow zone (Fig. 3.1.1.3).

Table 3.1.1.1. Scientific name, common name, FAO code, and assemblage designation according to depth (shelf 38-300 m; upper slope 301-600 m; lower-medium slope 601-1460 m for 3NO survey, and shelf 129-250 m; upper slope 251-600 m; lower-medium slope 601-1460 m for 3M survey) for the 28 and 29 most important demersal species collected during the 2002-2014 3NO survey and 1991-2014 3M survey.

SURVEY 3NO			**SURVEY 3M**		
Main Fish Species	**Common name**	**FAO Code**	**Main Fish Species**	**Common name**	**FAO Code**
SHELF ASSEMBLAGE			**SHELF ASSEMBLAGE**		
Limanda ferruginea	Yellowtail flounder	YEL	*Hippoglossoides platessoides*	American plaice	PLA
Hippoglossoides platessoides	American plaice	PLA	*Glyptocephalus cynoglossus*	Witch flounder	WIT
Ammodytes dubius	Northern sand lance	SAN	*Gadus morhua*	Atlantic cod	COD
Tryglops murrayi	Moustache sculpin	TGM	*Anarichas lupus*	Atlantic wolfish	CAA
Mallotus villosus	Capelin	CAP	*Sebastes marinus*	golden redfish	REG
Gadus morhua	Atlantic cod	COD	*Anarichas minor*	Spotted wolfish	CAS
Hemitripterus americanus	web sculpin	SP1			
Anarichas lupus	Wolfish (Catfish)	CAA			
Amblyraja radiata	Thorny skate	RJR			
Lophius americanus	American angler	ANG			
UPPER SLOPE ASSEMBLAGE			**UPPER SLOPE ASSEMBLAGE**		
Sebastes sp	Redfish	RED	*Sebastes fasciatus*	acadian redfish	REN
Anarichas minor	Spotted wolfish	CAS	*Sebastes mentella*	deepwater redfish	REB
Lycodes reticulatus	Arctic eelpout	LCT	*Lycodes reticulatus*	Arctic eelpout	LCT
Anarichas denticulatus	Northern wolfish	CAB	*Amblyraja radiata*	Thorny skate	RJR
Urophycis tenuis	White hake	HKW	*Phycis chesteri*	Longfin hake	GPE
Glyptocephalus cynoglossus	Witch flounder	WIT	*Bathyraja spinicauda*	Spinytail skate	RJQ
Phycis chesteri	Longfin hake	GPE	*Anarichas denticulatus*	Northern wolfish	CAB
LOWER-MEDIUM ASSEMBLAGE			**LOWER-MEDIUM ASSEMBLAGE**		
Reinhardtius hippoglossoides	Greenland halibut	GHL	*Reinhardtius hippoglossoides*	Greenland halibut	GHL
Antimora rostrata	Blue antimora	ANT	*Antimora rostrata*	Blue antimora	ANT
Macrourus berglax	Roughhead grenadier	RHG	*Macrourus berglax*	Roughhead grenadier	RHG
Nezumia bairdi	Marlin-spike	NZB	*Nezumia bairdi*	Marlin-spike	NZB
Centroscyllium fabricii	Black dogfish	CFB	*Centroscyllium fabricii*	Black dofish	CFB
Coryphaenoides rupestris	Roundnose grenadier	RNG	*Coryphaenoides rupestris*	Roundnose grenadier	RNG
Syphobranchus kaupii	Northern cutthroat eel	SSK	*Synaphobranchus kaupii*	Northern cutthroat eel	SSK
Amblyraja hyperborea	Arctic skate	RJG	*Amblyraja hyperborea*	Arctic skate	RJG
Notacanthus chemitzii	Snubnosed spiny eel	NNN	*Notacanthus chemitzii*	Snubnosed spiny eel	NNN
Bathyraja spinicauda	Spinytail skate	RJQ	*Chauliodus sloani*	Sloane's viperfish	CDN
Harriota raleighana	longnose chimera	HCR	*Lycodes vahlii*	Vahl's eelpout	SP3
			Stomias boa	Scaly dragonfish	SBB
			Serrivomer beanii	Bean's sawtoothed eel	ASB
			Gaidropsarus ensis	Threadfin rockling	GDE
			Apristurus sp.	Demon catshark	API
			Lampanyctus	Lanterfish	SP4

^{1,2,3,4} non-FAO codes

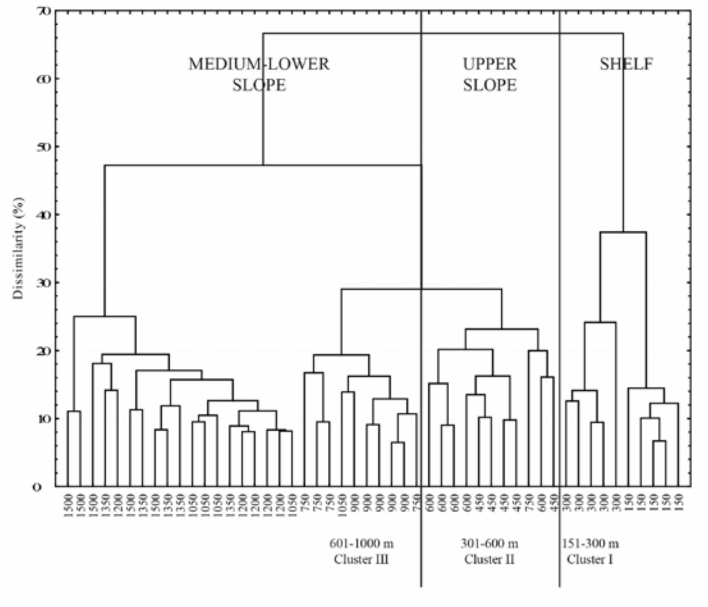

Fig. 3.1.1.1. Dendogram showing the classification of 1160 sets grouped in 10 depth class of 150 m by two years (2002-03, 2004-05, 2006-07, 2008-09, 2010-11) based on mean abundance of fish fauna species composition by depth class. Catch was root-root transformed before comparing stations using the Bray-Curtis measure, and the dendogram formed by group-average sorting. Three clusters are distinguished: Shelf (<300 m deep); Upper Continental Slope (301-600 m); and Medium-lower Continental Slope (>601 m).

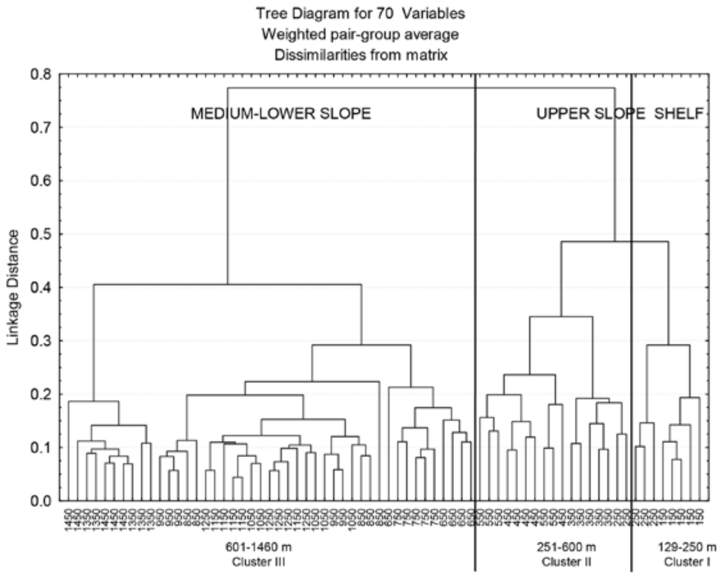

Fig. 3.1.1.2. Dendogram showing the classification of 1699 sets grouped in 10 depth class of 100 m by two years (2004-05, 2006-07, 2008-09, 2010-11, 2012-2013) based on mean abundance of fish fauna species composition by depth class. Catch was root-root transformed before comparing stations using the Bray-Curtis measure, and the dendogram formed by group-average sorting. Three clusters are distinguished: Shelf (<250 m deep); Upper Continental Slope (251-600 m); and Medium-lower Continental Slope (>601 m).

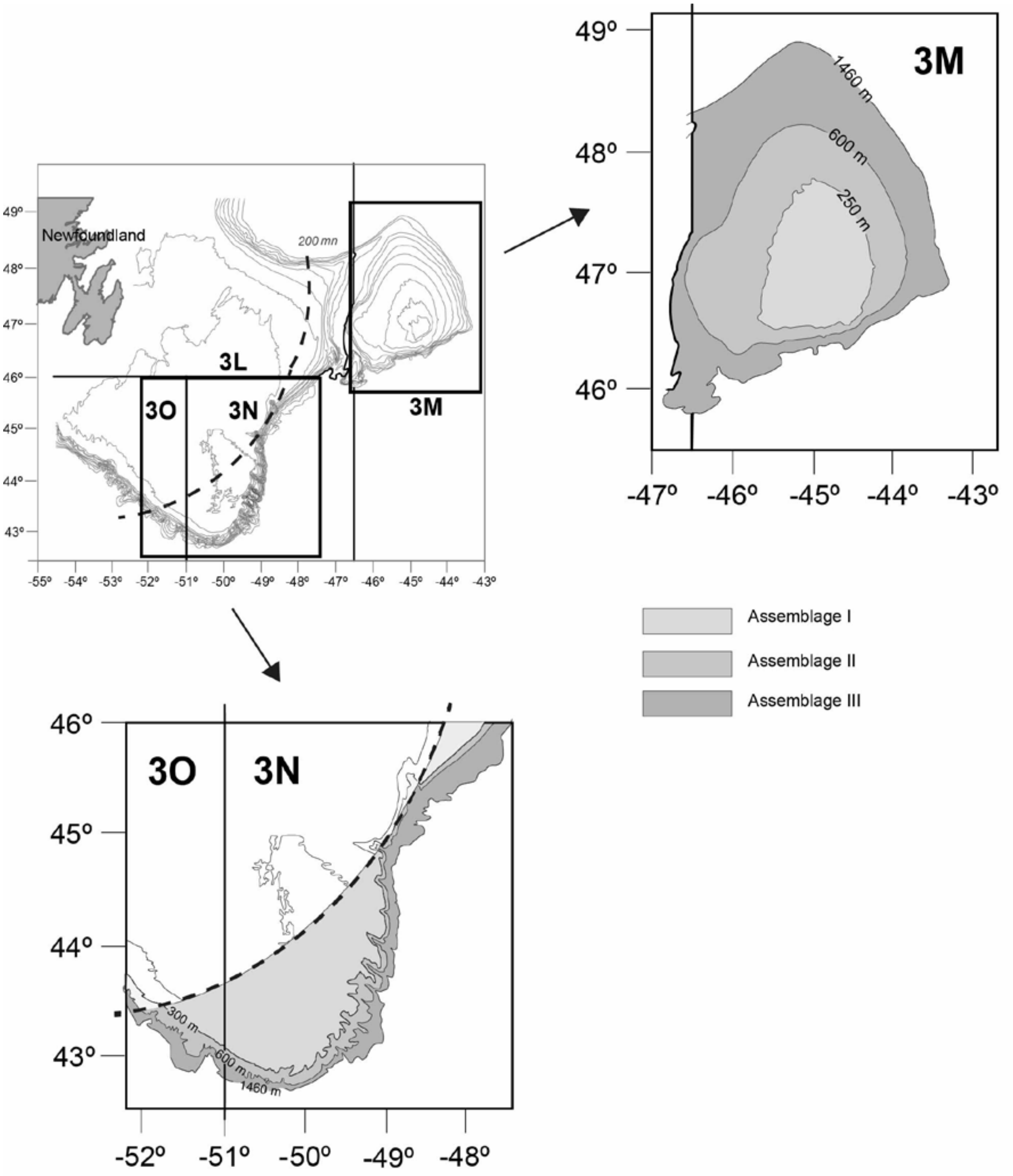

Fig. 3.1.1.3. Chart of NAFO Regulatory Area showing Divisions 3LMNO of the Grand Banks. Spanish bottom trawl in Division 3NO and EU bottom trawl in Division 3M, both in NAFO Regulatory Area, are marked.

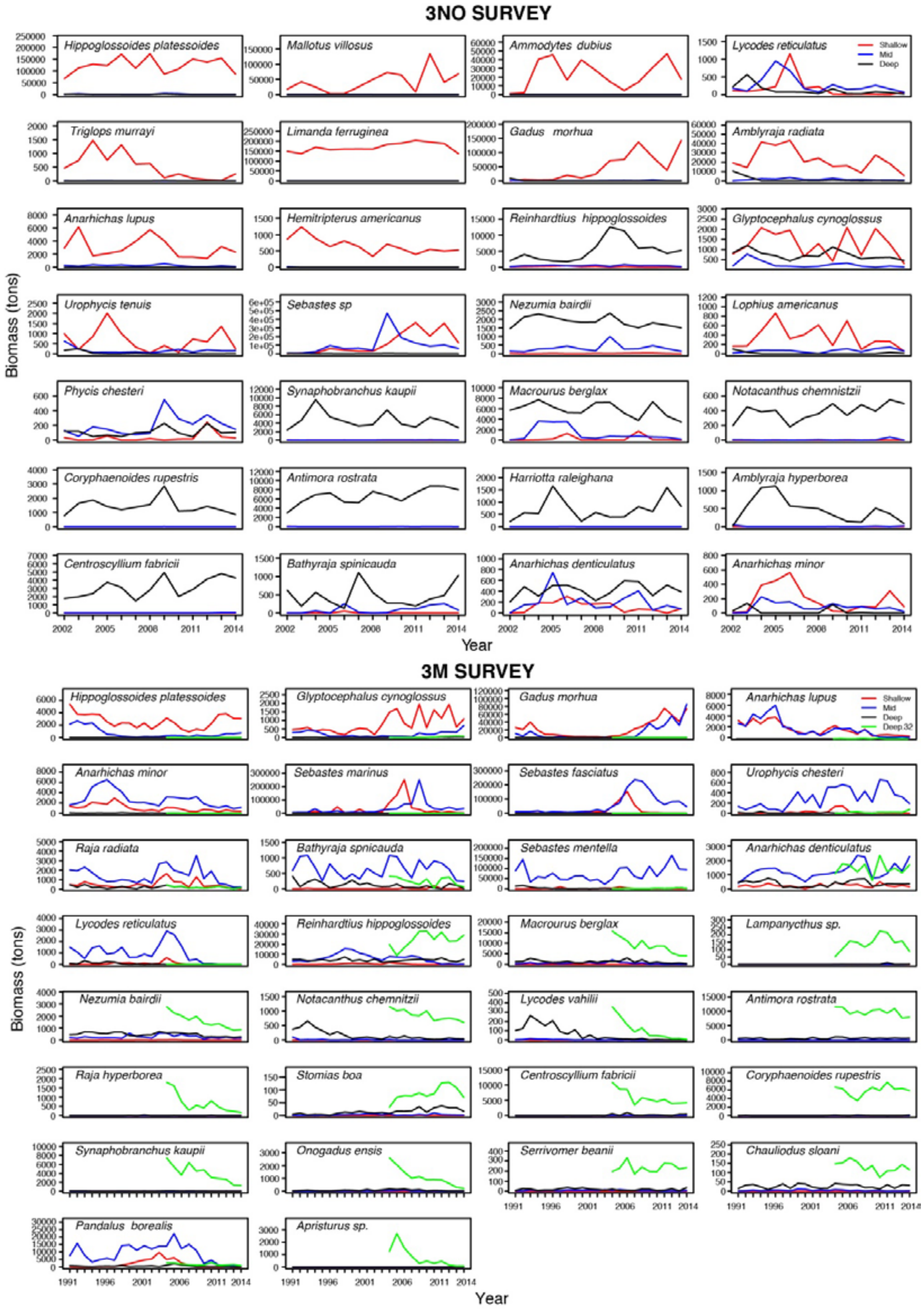

Fig.3.1.1.4. Biomass estimate for the main species from Spanish bottom trawl survey Divisions 3NO (2002-2014) and from EU bottom trawl survey Division 3M (1991-2014) in each depth zone (≤ 300 m, 301-600 m and ≥601 m for 3NO survey and ≤ 250 m, 251-600 m and ≥601 m for 3M survey).

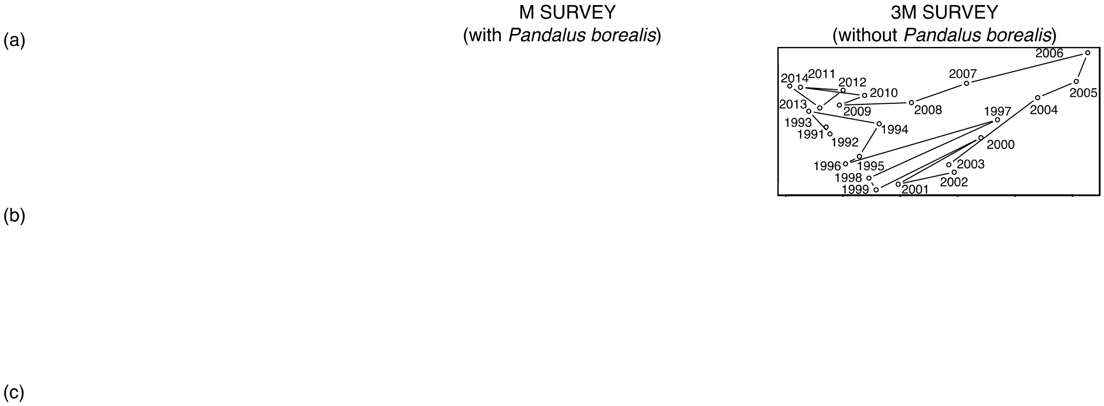

Fig.3.1.1.5. nMDS ordination for (a) the shelf assemblage, (b) the upper slope assemblage, and (c) the medium-lower slope assemblage, of the 13 years for 3NO survey in all assemblages, 24 years in 3M survey in the shelf and the upper slope, and 11 years in 3M the medium-upper slope. Based on Bray-Curtis similarities.

Results in the Southern Grand Banks did not detect strong temporal changes, mostly due to the slight fishing pressure during the studied period. However, different trends and results were found between the three assemblages (Figs. 3.1.1.5 and 3.1.1.6). This reflects different levels of exploitation during the period before the study, corresponding to different fisheries and management plans in each assemblage. In the shallow stratum, ABC curves revealed a disturbed state of the ecosystem with an increase in the main commercial species that could indicate rebuilding after a long period of moratorium under those species. In the intermediate stratum, two community indicators, proportion of non-commercial/commercial species and curvature of size spectra, show that this community is not significantly impacted by fishing, and ABC curves indicate that is moderately disturbed. Lastly, in the deep stratum, ABC curves indicate a disturbed state. Only one community indicator, the proportion of non-commercial/commercial species, indicates impacts of fishing. The mean length for the community and mean length of the two commercial species (Greenland halibut and roughhead grenadier) and black dogfish increased, which could indicate a decreasing impact of fishing during last years (Fig. 3.1.1.5 and 3.1.1.6). No trend in MTL was observed in the shallow and deep depth zones, while a decreasing trend in the upper medium slope was consistent with the increase of redfish in that depth (Fig. 3.1.1.7).

	POPULATION INDICES	
	r	Mean lenght
SHELF	*H.platessoides* ↗ *G.morhua* ↗ *T.murrayi* ↘	*L.ferruginea* ↗ *H.platessoides* ↗ *G.morhua* ↗ *A.radiata* ↗
UPPER SLOPE	*Sebastes spp* ↗	*A.minor* ↗ *P.chesteri* ↗
MEDIUM-LOWER SLOPE	*C.fabricii* ↗ *A.rostrata* ↗	*R.hippoglossoides* ↗ *M.berglax* ↗ *N.bairdii* ↗ *C.fabricii* ↗ *A.rostrata* ↘ *S.kaupii* ↘

Fig. 3.1.1.6. Qualitative results or trends for population indicators: Abundance/Biomass, intrinsic population growth rate (r) and mean length.

	COMMUNITY INDICES					
	Abu / Bio	ABC	Diversity	NoCom/Com	Mean lenght	Size spectra
SHALLOW	↗	↗	Fluctuate	Fluctuate	→	→
INTERMEDIATE	↗	→	↘	↘	→	↗
DEEP	Fluctuate	↗	→	↗	↗	→

Fig. 3.1.1.7. Qualitative results or trends for community indicators: Abundance/Biomass, ABC curves, W-statistics, Shannon-Wiever and Evenness indices (diversity), ratio of non-commercial/commercial species for abundance and biomass, mean length and size spectra

On the other hand, some interesting changes were observed in 3M due to the longer time-series analyzed and by the closing in 1999 and re-opening in 2010 of the cod fishery. We also detected different trends and results between the three assemblages in the two areas. In shallow and to a lesser extent in the mid strata, MTL reflected the recovery of cod in 3M and collapse of Northern shrimp; diversity indices decreased. In the deep assemblage, where the time-series was shorter, the community was characterized by some sign of recovery of Greenland halibut and a reduction in the biomass of the rest of species (Figs. 3.1.1.8, 3.1.1.9, 3.1.1.10).

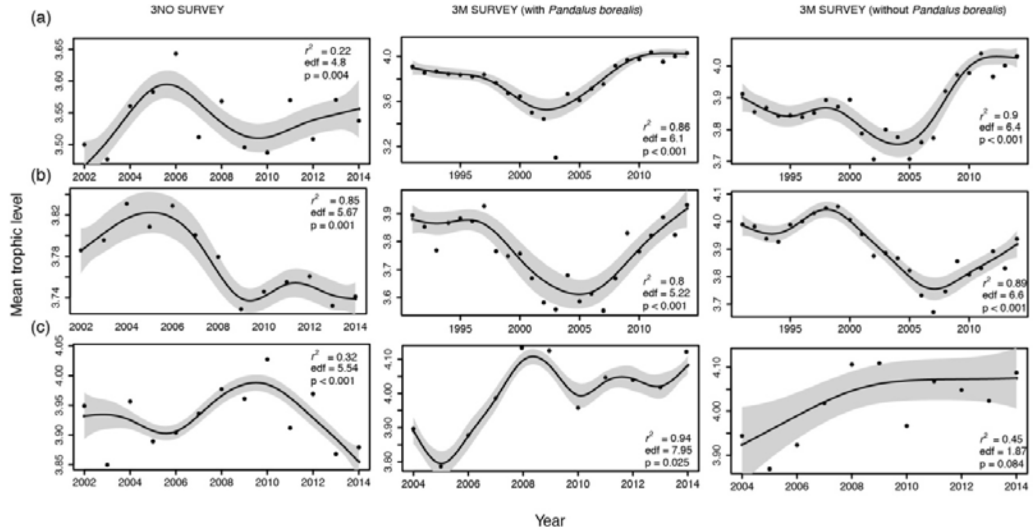

Fig. 3.1.1.8. Trends in Mean tropic level (MTL) (black points) through time in the 3NO Survey (2002-2014 for all assemblages) and 3M Survey (1991-2014 for the shallow and upper assemblages and 2004-2014 for the medium-upper slope assemblage), for (a) the shelf assemblage, (b) the upper slope assemblage, (c) the medium-upper slope assemblage. Lines show predicted trends from GAMMs. GAMM included identity link and Gaussian error distribution with 1/variance as weights. Temporal autocorrelation was included in 3NO.The grey bands show 95 % confidence intervals for the model. Note the different scales.

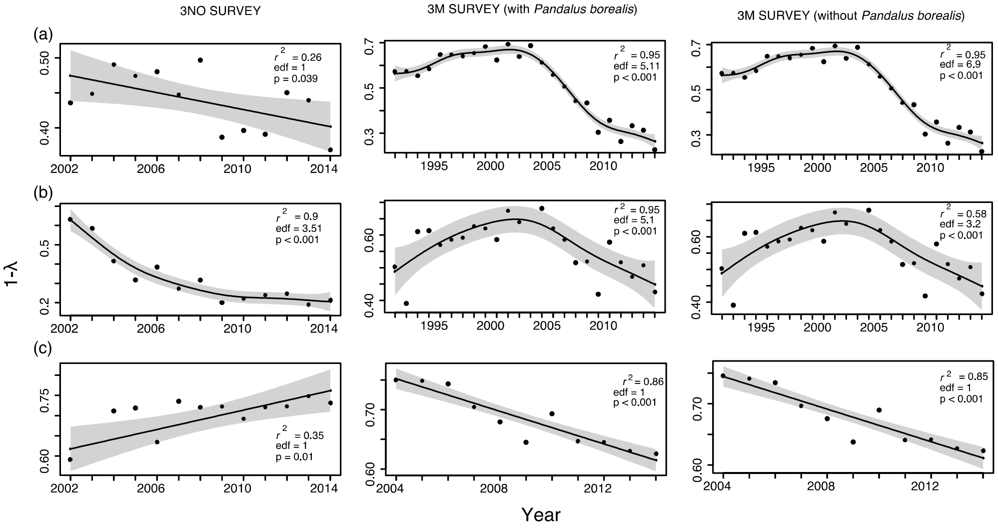

Fig.3.1.1.9. Trends in species evenness (Gini-Simpson index, 1-λ) for (a) the shelf assemblage in 3NO, (b) the upper slope assemblage, (c) the medium-upper slope assemblage. Note the different scales. Lines show predicted trends from GAMMs. GAMM included logit-link and beta-error distribution with 1/variance as weights. Temporal autocorrelation was included in 3NO. The grey bands show 95 % confidence intervals for the model.

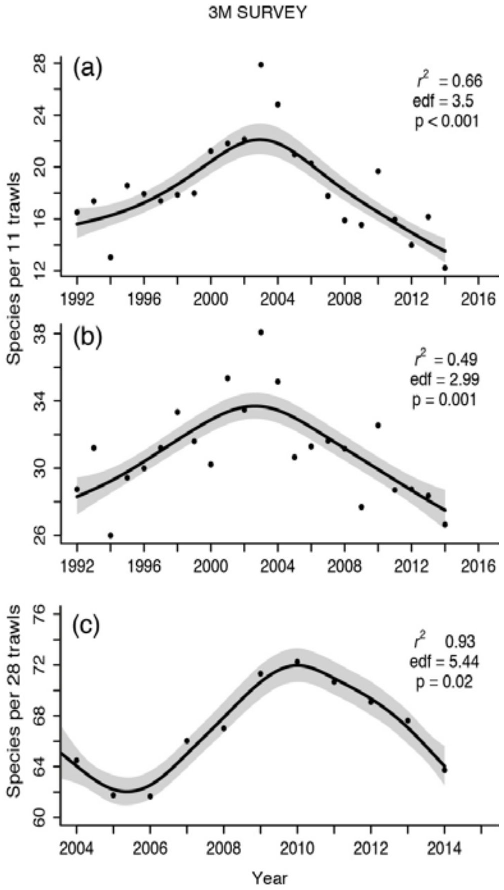

Fig. 3.1.1.10.Trends in species evenness (Gini-Simpson index, 1-λ) for (a) the shelf assemblage in 3NO, (b) the upper slope assemblage, (c) the medium-upper slope assemblage. Note the different scales. Lines show predicted trends from GAMMs. GAMM included logit-link and beta-error distribution with 1/variance as weights. Temporal autocorrelation was included in 3NO. The grey bands show 95 % confidence intervals for the model.

Conclusions

This study reveals a period of stability in 3NO but a period of changes in 3M. The changes are consistent with regulatory reforms and the resulting modifications in fishing pressure, although other drivers such as climate are also likely to have played a role. This work demonstrates that the grouping of species into assemblages that have similar resource requirements could be used as an effective tool for bycatch, and that calculating multiple indicators in each assemblage could be applied to understand patterns in the community structure.

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ToR 3.1.2. Identifying optimal sets of ecosystem indicators: A comparative study of data analysis methods and regional results

Many of the world's living marine resources are overexploited, and there is a growing understanding that conventional, single species fisheries management is incomplete. There has been a global call to adopt more holistic approaches such as Ecosystem Based Fisheries Management (EBFM), which explicitly considers interactions between multiple species (target and non-target) in the context of changing environment, human use, and social well-being. Implementing this type of management requires information on these components of the ecosystem, which can be provided by data-based indicators. Dozens of indicators have been proposed, but no single metric captures complex ecosystem dynamics. Hence, indicators are evaluated in sets to provide information on ecosystem status and trends to scientists and decisions-makers. Recommendations on how to select and integrate indicators that can address EBFM objectives are vague and largely qualitative.

We investigate quantitative approaches to identifying sets of indicators that can simultaneously predict several measures of ecosystem status while accounting for connections among ecological, environmental and human factors. We defined "ecosystem status" by the biomasses of three key functional groups (benthivores, planktivores, and piscivores) for two distinct regions of the Northwest Atlantic (Grand Banks and Georges Bank), which each represent data-rich, historically important fishing grounds with different management strategies and environmental conditions. Indicators were synthesized from diverse data sources, including research surveys, commercial data, and environmental monitoring for the past 30 years. Sophisticated regression and neural network methods were each used to identify sets of indicators with the highest explanatory power and least redundancy. Pros and cons of each method were presented, and preliminary results discussed in the context of management decisions and environmental drivers associated with each region.

ToR 3.1.3. Update on ecology and status of marine mammals, including estimations of food consumption in NL shelves

Estimating Marine Mammal Consumption

The amount of biomass consumed by marine mammals is estimated using a bioenergetics model. These models assume that the energy requirements of a population can be estimated and that the marine mammal obtains the energy required. Estimating prey consumption requires information on population size, energetic requirements, diet composition, and distribution of feeding effort, as well as size classes and energy density of the prey (Hammill and Stenson 2000, Stenson 2012).

We model fish consumption by Northwest Atlantic harp seals, taking into account seasonal changes in feeding and variability in seal abundance, distribution, and diet composition. All possible sources of uncertainty are incorporated into the estimates.

Prey consumption by harp seals in 2J3KL was estimated by:

$$C_{jt} = \sum_{s=1}^{s=S} \sum_{a=1}^{a=A} \sum_{i=1}^{i=I} N_{it} E_i D_{ias} P_{jas}$$

Where:

C_{jt} = Consumption of prey species j in year t.
N_{it} = No. of seals in age class i in year t.
E_i = Annual gross energy required by a seal aged i.
D_{ias} = Prop.of the total annual energy obtained by a seal aged i in area a during season s.
P_{jas} = Prop. of prey species j in the diet of seals in area a during season s.
I = Total no. of age classes, currently 13 (ages 0 - 11 and 12+).
A = Total no. of areas.
S = Total no. of seasons, currently 2 (Winter and Summer)

Changes in abundance of Northwest Atlantic harp seals over time were estimated using a population model that incorporates annual estimates of human removals throughout their range and age specific pregnancy rates, and periodic independent estimates of pup production obtained from surveys (Hammill et al 2015). Uncertainty (mean and standard deviation in the numbers in each age group (0 through 11 and12+) for each year was estimated from the population trajectories and incorporated into the consumption model. Harp seal abundance declined during the 1950s and 1960s to a little less than 2 million seals in 1971. Since then, it has increased steadily to approximately 8.3 million (95% CI=7,300,000-9,000,000) in 2008. In recent years it is estimated to have declined slightly due to increased mortality of young due to poor ice conditions and lower reproductive rates (Hammill and Stenson 2011).

Age-specific energy requirements were calculated using a simple allometric equation based on body mass:

$$GEI_i = GP_i * (AF*293 *BM_i^{0.75}) /ME$$

where:

GEIi = Daily gross energy intake (kjoules/day) at age i,
GP, = Growth premium (i.e. the additional energy required by young seals < age 6).
AF = Daily activity factor
BMi = Body mass (in kg) at age i
ME = metabolizable energy

Because of seasonal changes in body size and energy consumption, monthly growth curves were used. These were based upon average body size of harp seals sampled between 1979 and 2004. They were not adjusted for interannual changes in condition.

Harp seals are highly migratory and our knowledge of their seasonal distribution is primarily based on historical catch data, tag returns and anecdotal reports. More recently, studies of harp seal movements using satellite telemetry have improved our understanding of seasonal distributions significantly. Northwest Atlantic harp seals summer in the Canadian Arctic and/or West Greenland. During the fall and early winter, seals move southward along the Labrador coast. One component of this population remains off the east coast of Newfoundland/southern Labrador (i.e. 2J3KL) while the other moves into the Gulf of St. Lawrence in December. In the late spring, the animals return to the Arctic. Annual changes in ice conditions or food availability likely affect the seasonal movements of the population. The proportion of energy obtained from various areas was assumed to be equal to the seasonal residency in that area.

The diet of harp seals was estimated using reconstructed wet weights of stomach contents from animals collected in various areas between 1986 and 2011. Prey lengths and weights were estimated from hard parts using part length – total length and part length – and/or length – weight regression equations. Reconstructed wet weights were converted to energy densities using published energy values for each prey species. Diets were found to vary between years as well as with season and area. A generalized, overall consumption was estimated using the average diet over the time period.

Total prey consumption by harp seals in 2J3KL during 2014 was estimated to be approximately 3.2 million metric tonnes (95% CI 2.1 mt – 4.9 mt). Of this, approximately 2.6 million mt (81%) was obtained from 2J3K and 0.6 million mt (19%) from 3L. These estimates are lower than previous due to a lower estimate of harp seal abundance and changes in the diet resulting from more recent samples.

No new data on the diet or abundance of hooded seals (*Cystophora cristata*) are available. However, it was reported at our last meeting that using the same approach, hooded seals were estimated to consume 362,900 mt in Div 2J3KL and approximately 36,000 mt in Div. 3M (Hammill and Stenson 2000).

Similarly, the estimates of consumption by cetaceans presented last year were not updated. Using the same approach as for seals, abundance estimates obtained from 2007 surveys, diets from other regions and approximate timing of northern migrations, Lawson et al (unpublished data) 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 million mt (Lawson, unpublished data).

Incorporating environmental influences into the assessment of Northwest Atlantic harp seals

As the northern hemisphere continues to warm, the associated decline in sea ice will have serious impact on species that rely on ice for reproduction and/or feeding. Harp seals feed and give birth on ice along the southern edge of the seasonal pack ice. Unfortunately, little is known about the impact of climate change on ice-dependent species, even though the associated ecosystem changes are likely to be most rapid along the ice edge.

Reduced sea ice during the spring has been shown to affect harp seals directly through increased mortality of young (Stenson and Hammill 2014). Assessments of Northwest Atlantic (NWA) harp seals rely upon periodic estimates of pup production, and Hammill and Stenson (unpublished data) have shown that this mortality must be accounted for in order to understand the dynamics of this population. Failure to do so can result in significant reductions in the population before declines in pup production will be recognized. To ensure that this does not occur, the NWA population model explicitly incorporates mortality of young of the year into the estimation process. The level of mortality (expressed as survival) is based upon the extent of the negative ice anomalies in the Gulf of St. Lawrence and off southern Labrador.

In addition to the direct impact on harp seal mortality, environmental conditions may also have indirect impacts on seals through changes in prey and, subsequent reproductive rates. Stenson et al (in press) examined the importance of density dependent and density independent factors on reproductive rates of harp seals over the past 6 decades. Estimates of late term pregnancy and abortion rates were derived from samples collected between 1954 and 2014 off Newfoundland, Canada. Since the early 1980s, late-term pregnancy rates among mature females have declined while interannual variability increased, ranging from 0.2 to 0.86. During this period, harp seals have also undergone a large change in abundance, increasing from less than 1.5 million seals in the early 1970s to approximately 7.4 million seals today (Hammill et al 2015) and, since 1987, late term abortions have been observed. Using a beta-regression model, Stenson et al (in press) found that while the general decline in pregnancy is associated with increased population size, including the rate of late-term abortions captured much of the interannual variability (Figs. 3.1.3.1 and 3.1.3.2).

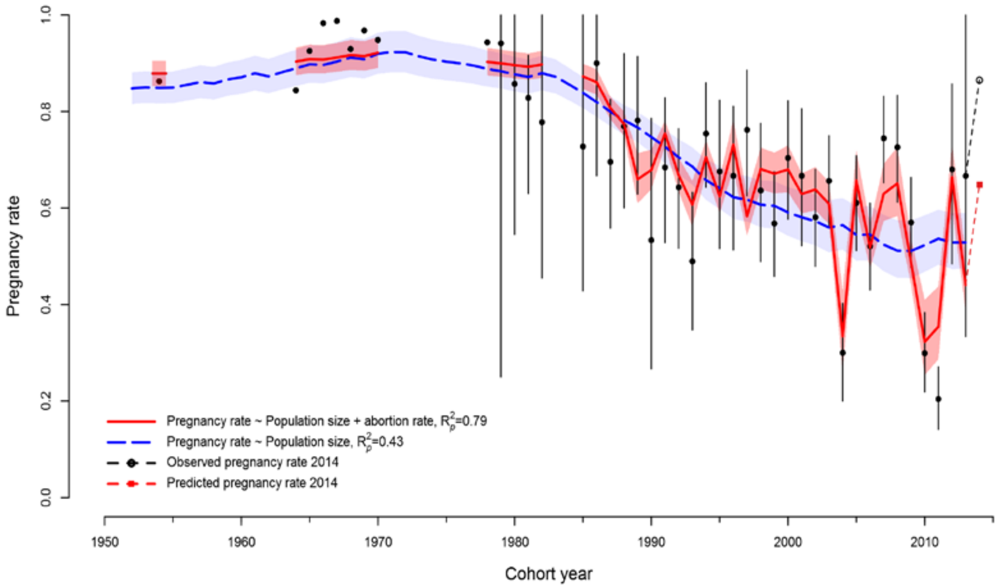

Fig. 3.1.3.1. Fits of the models used to describe pregnancy rate, based on the long-term data series, 1954-2013. Shaded areas around model fits represent 95% confidence intervals. Prediction of the 2014 pregnancy rate from the most parsimonious model, indicated by dotted lines. The fit of the model that incorporates only population size is plotted for comparative purposes (from Stenson et al, in press).

Changes in abortion rates were described by a model that incorporated capelin biomass and mid-winter ice cover. Buren et al (2014) has shown that the abundance of capelin in 2J3KL is influenced by changes in the timing of ice retreat. Thus, it is likely that ice cover is also a proxy for ecosystem changes in prey.

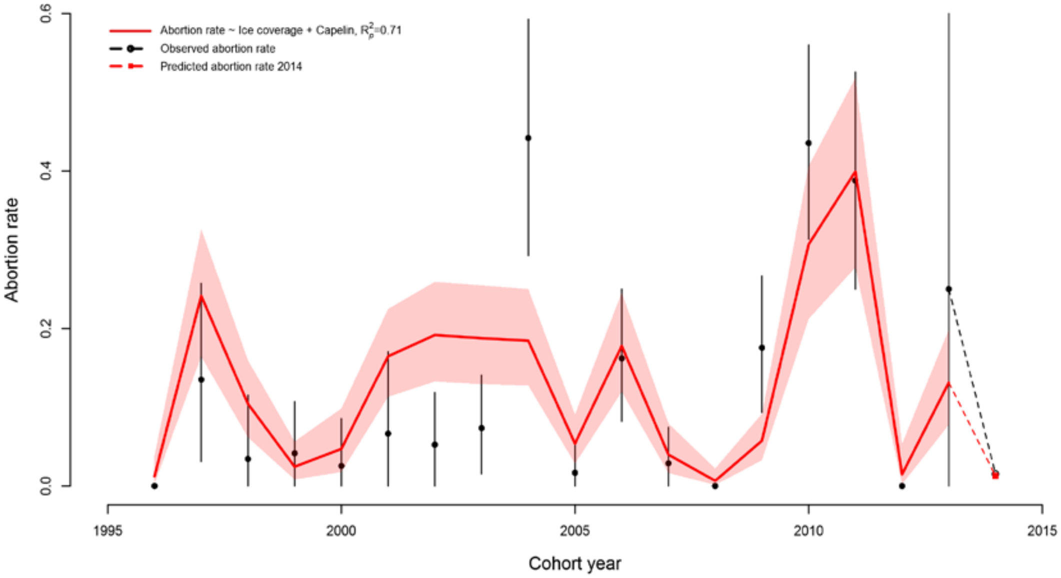

Fig. 3.1.3.2. Fit of the most parsimonious model to describe abortion rate using data from 1996-2013. Shaded area around model fit represents 95% confidence interval. Prediction of the 2014 abortion rate from the most parsimonious model, indicated by dotted lines (from Stenson et al, in press).

Harp seals appear to respond to relatively small variations in environmental conditions when they are at high population levels. The negative impacts of changing climate will likely increase if the general warming trend and associated reduction in ice conditions continue.

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ToR 3.1.4. Progress on stable isotopes research on NL and Flemish Cap systems

Over 1800 stable isotope (carbon, nitrogen and sulfur) samples for fish and invertebrates from the Newfoundland shelves and the Flemish cap sampled over form the research vessel surveys over 3 years have been analysed. Support for these analyses was provided by the Newfoundland- Labrador shelves: DFO-SPERA project *Characterization of diet and trophic structure in the Newfoundland-Labrador Shelves (NAFO Divs. 2J3KLNO) in a period of ecosystem change* (PI: Mariano Koen-Alonso) and Flemish Cap: samples from the EU survey and funding from Alfonso Perez-Rodriguez.

Carbon signatures distinguish pelagic from benthic production at the base of the foodweb. For example, pelagic carbon sources for copepods (δC -23.4) are significantly more depleted than the benthic signature of chestnut clams (δC – 17.5) (Fig. 3.1.4.1). The carbon signature of higher trophic levels indicates the proportion of benthic versus pelagic production moving up the foodweb. The carbon signature for *Pandalus montaguii* and *P borealis* for example is around 19 indicating a largely benthic-sources diet. In contrast, capelin has a δC of -21.5 indicating a largely planktonic diet (Fig. 3.1.4.1).

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 and grenadier species having the highest average trophic levels (Figs 3.1.4.1-2).

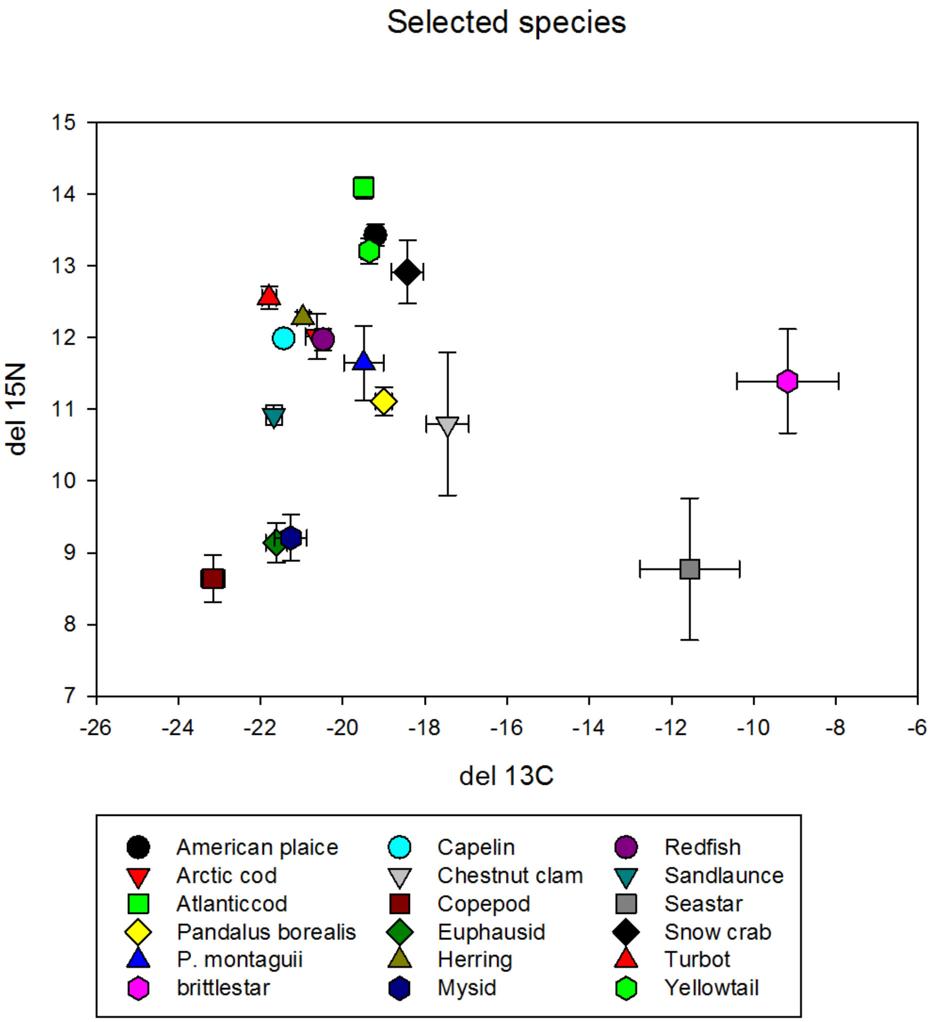

Fig.3.1.4.1. Stable isotope signatures for representative species from the Newfoundland shelves. Symbols indicate the average and lines are the 95% confidence intervals.

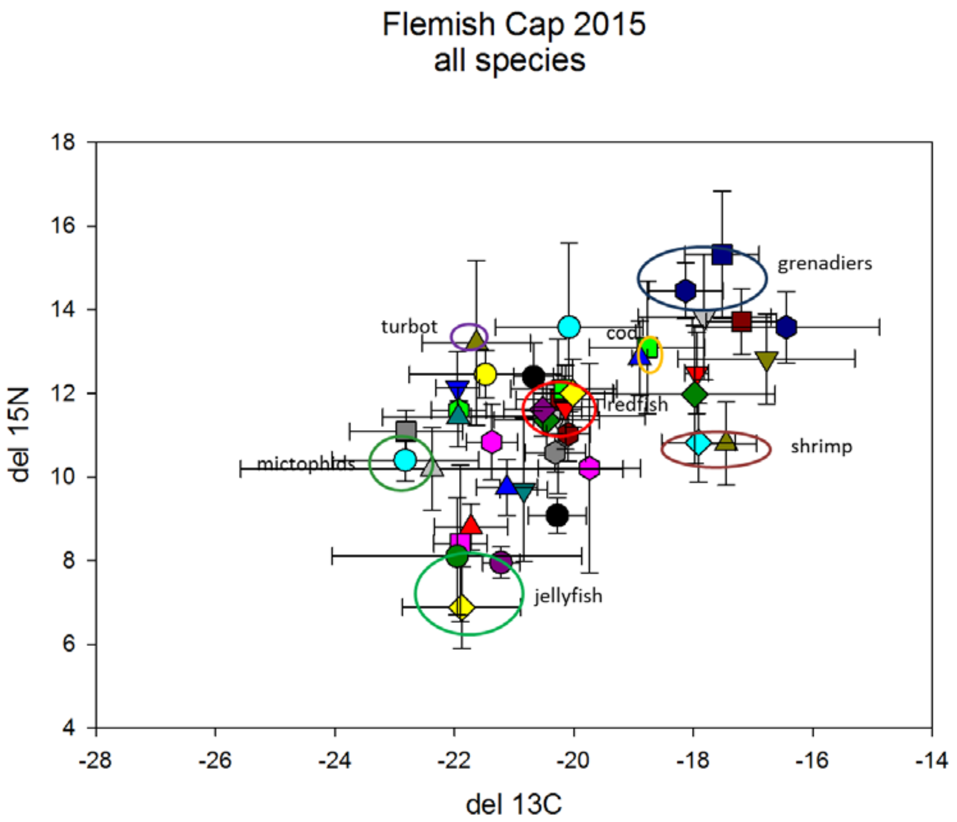

Fig. 3.1.4.2. Stable isotopes for samples collected on the Flemish Cap. Ovals represent species groupings. Symbols represent averages and lines represent the 95% confidence intervals for individual species.

One of the original goals of this project was to determine if stable isotope signatures would provide evidence for dietary changes in top predators as the ecosystem changes from a shrimp dominated system to one where planktivorous fish are the favoured prey items. Preliminary analyses of the stable isotope signatures of cod over the three years of the study tend to support the view that cod are shifting their diets toward planktivorous fish as indicated by a decrease in carbon signatures. This change is also accompanied by a slight drop in trophic level (Fig. 3.1.4.3).

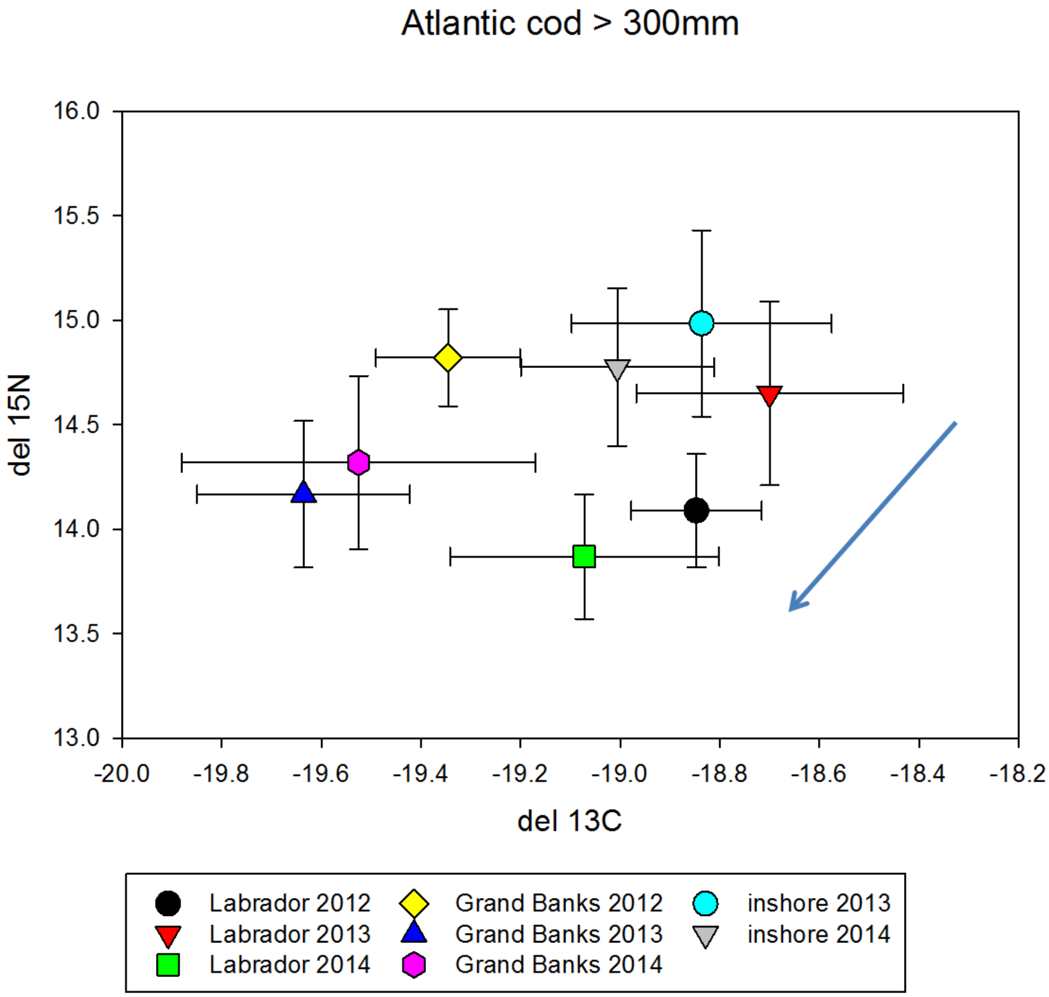

Fig. 3.1.4.3. Stable isotope signatures for cod from 2012-2014 for the Newfoundland shelves. Symbols are the average for each region and year, lines are the 95% confidence intervals.

ToR 3.1.5. Update on ecosystem trends in the NL bioregion

Introduction

WGESA updated and reviewed its ongoing analyses on structure and trends in the fish community in the NL Bioregion. During its 8th meeting, WGESA focused on changes in southern Newfoundland (3Ps), but also highlighted key observations from the Grand Bank (3LNO) and Newfoundland Shelf (2J3K) EPUs.

Southern Newfoundland (3Ps)

Using a series of ecoregion analyses, WGESA formally identified three Ecosystem Production Units (EPUs) within the Newfoundland and Labrador Shelves Bioregion: the Labrador shelf (2GH), the Newfoundland Shelf (2J3K), and the Grand Bank (3LNO) (NAFO 2014, 2015, Pepin et al. 2014). Due to the lack of fall survey data, the southern Newfoundland region (3P) was not included in the ecoregion analysis, but it is widely recognized as part of the NL bioregion (NAFO 2015). The question that remains without a formal treatment is the status of 3P as a functional ecosystem unit. Is this region its own EPU or should be part of the Grand Bank EPU?

The 3P region is open and dynamic, and subject to influences from neighbouring systems like the Gulf of St. Lawrence, the Scotian Shelf, and the Grand Bank. Several fish species in this area are at or near the limits of their distributions, so changes in distributional ranges would be expected to be more noticeable and influential in this region.

Within 3P, there are two areas that are typically discriminated in the context of stock-assessments, NAFO Subdivisions 3Pn and 3Ps. 3Pn is closer to the Cabot Strait, just across the Laurentian Channel from Cape Breton. 3Ps is a larger region than 3Pn, and extends to the east all the way to the Grand Bank. There is a distinct cod stock in 3Ps, while 3Pn is known as mixing area for cod from the Southern Gulf of St. Lawrence and 3Ps. In terms of functional ecosystem units, 3Pn appears more as a mixing area from different ecosystems, but 3Ps is believed to have higher system integrity.

NAFO Subdiv. 3Ps has being subject to both anthropogenic and environmental forcers over time. Fishery landings saw their peak in the late 1960s (around 150-200 thousand tons), collapsed in the early 1990s, and by the early 2010s, total landings are in the order of 30 thousand tons and dominated by invertebrates. On the environmental side, this region has been experiencing an important warming trend since the early 1990s, with bottom temperatures during the spring survey increasing at a rate around 3-4% per year.

The structure and trends in the fish community of NAFO Subdivision 3Ps were analyzed on the basis of Research Vessel (RV) biomass, abundance, and biomass/abundance (BA ratio) indices derived from DFO winter and spring surveys in the 1982-2015 period. These analyses involved the characterization of the community by fish functional groups which, for the most part, are defined considering the species size and general trophic characteristics. These functional groups are small, medium, and large benthivores, piscivores, plankpiscivores, planktivores, and shellfish (this last group only includes commercial shellfish species, like *Pandalus* shrimps and Snow Crab). Reliable data on shellfish are only available since 1996, when the fishing gear used in the survey was changed from an Engels to a Campelen trawl. Since there are no conversion factors available for all species, many analyses were carried out partitioning the times series into Engels (1982-1995) and Campelen (1996-2015) periods.

Changes in total biomass and internal structure of the fish community were described on the basis of trends over time, and analyzed using Bray-Curtis similarity matrices from standardized and non-standardized RV biomass data. Analyses from non-standardized data allow the consideration of differences in magnitude, while those from standardized data allow a focus on internal structure of the fish community. Hierarchical agglomerative cluster analyses, together with Similarity Profile permutation tests were used to identify significant clusters of years within the Engels and Campelen periods. Changes in abundance were described considering the trends over time by fish functional groups, while the changes in fish sizes were evaluated using normalized anomalies of BA ratios by functional group.

Despite the issues associated with changes in timing of the survey (i.e. winter and spring), it is clear that the overall biomass of the fish community increased in the early 1980s, and later declined in the late 1980s and early 1990s (Fig. 3.1.5.1). This decline also involved changes in the structure of the fish community, and a general reduction in fish size (Fig. 3.1.5.2). Results from the cluster analysis of the 1982-1995 period indicate that the changes in community structure have a coherent temporal sequence, where significant clusters typically aggregate consistent periods of time (i.e. consecutive years).

Since the mid-1990s, the overall biomass of the fish community has not changed significantly, but abundance has. Overall abundance increased until 2013, and declined afterwards. These changes in abundance have been mainly driven by planktivores, and to a lesser extent plankpiscivores in the late 2000s (Fig. 3.1.5.1)

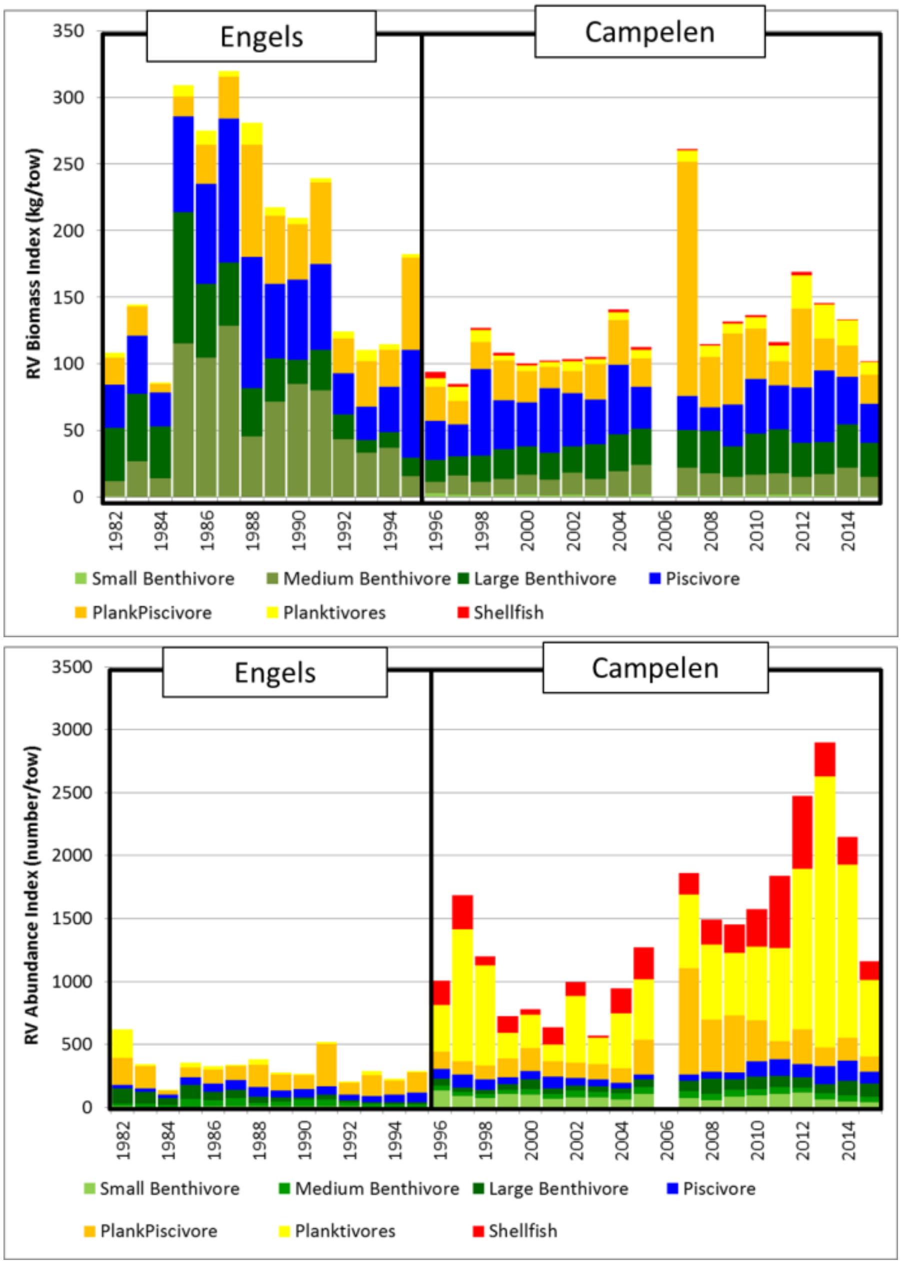

Fig. 3.1.5.1. RV biomass (top) and abundance (bottom) from DFO 3Ps Spring survey by fish functional groups, with indication of the gear used in the survey (Campelen and Engels). Index values are not directly comparable between gears; the Campelen series also includes the Shellfish functional group.

Notwithstanding the relative stability of the overall biomass level during the Campelen period (1996-2015), the biomass structure of the fish community has changed during this time. These changes have involved increases/decreases in biomass at the functional group level, but unlike earlier observations, the overall pattern of change in structure does not seem to follow any obvious temporal sequence. Still, trends among some functional groups are significantly correlated (e.g. small benthivores and shellfish are positively correlated, medium and large benthivores are also positively correlated). During this period, fish size (BA

Ratio) also showed a further decline in the mid-2000s, and remains at that lower level to this day (Fig. 3.1.5.2).

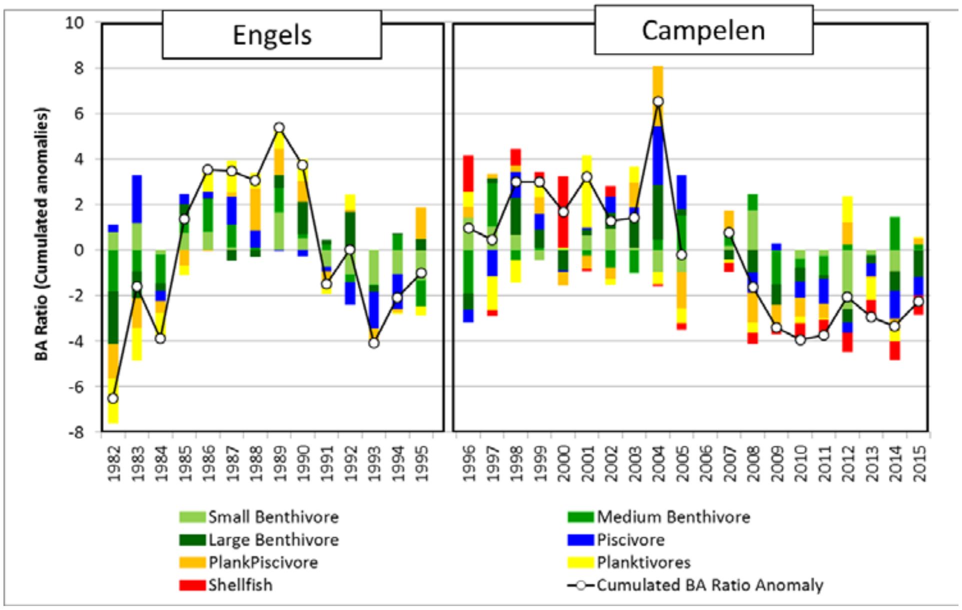

Fig. 3.1.5.2. RV biomass/abundance ratio (BA ratio) normalized anomalies from DFO 3Ps Spring survey by fish functional groups, with indication of the gear used in the survey (Campelen and Engels). The colored bars indicate the anomalies for each functional group, while the line indicates the cumulated anomaly. BA ratio values are not directly comparable between gears.

Recent changes include clear declines in biomass in small benthivores, planktivores, and shellfish over the last five years (Fig. 3.1.5.1). Piscivores show a relatively stable overall biomass level, but experienced important changes in internal structure. Cod used to be the exclusive dominant species within this functional group, but silver hake has increased its dominance, and currently shows biomass levels similar to cod (Fig. 3.1.5.3).

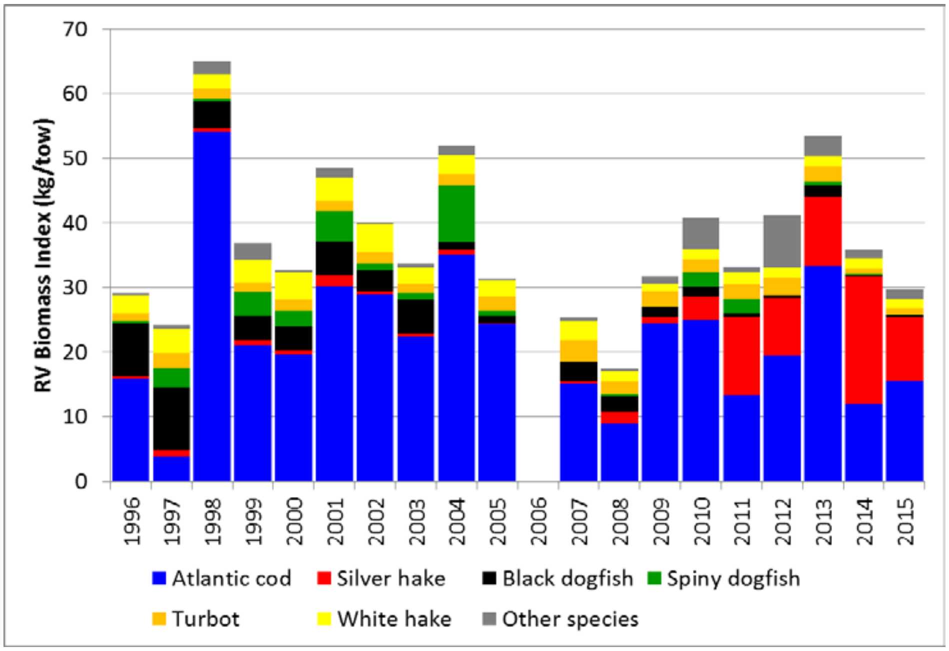

Fig. 3.1.5.3. RV biomass from DFO 3Ps Spring survey for Piscivores functional group during the Campelen period. Note the increased dominance of silver hake during 2010-2015.

Taking into account all these changes together, it seems that the fish community in 3Ps shows evidence of internal structure and coherence, but it also shows signs of lessening in that internal cohesion in the most recent period. The noisier patterns in recent years could be linked to increasing import/export processes and/or increased variability in these fluxes. Therefore, and in terms of ecosystem identity, the marine community in NAFO Subdivision 3Ps possesses enough elements to characterize it as a functional ecosystem, but one that is heavily influenced by neighboring systems (Grand Bank, Gulf of St. Lawrence, and Scotian Shelf).

In summary, within 3P, 3Pn is likely a mixing, transitional zone across several ecosystems units, but southern Newfoundland (3Ps) could be recognized as a fourth EPU within the NL Bioregion. However, as a functional unit, 3Ps appears highly susceptible to external influences. Ongoing warming trends, together with the increasing dominance of warm water species, recent declines in planktivores, and the reduced fish sizes across fish functional groups suggest that this ecosystem is undergoing structural changes, and potentially experiencing reduced productivity conditions. Although complete understanding of these changes, and their full implications for piscivores like cod and white hake, are still lacking, the available evidence suggests that current productivity may be reduced.

Grand Bank EPU (3LNO)

Analyses on structure and trends of the fish community in the Grand Bank were based on DFO RV spring survey. This update focused on trends in the RV biomass index. For comparative purposes, this index was scaled using the coarse conversion factors available and applied at the fish functional group level (NAFO 2014).

In 3LNO the collapse in the 1990s also involved the entire fish community, and a decline in fish size. The collapse was not as severe are in the northern areas. This EPU shows a higher dominance of benthivores, and it was never dominated by shellfish. The groundfish community shows signals of rebuilding, but piscivores have not regained their dominant role. Overall build-up of groundfishes was initially led by medium benthivores and more recently by plank-piscivores (Fig. 3.1.5.4). Although there was a upward trend in fish size in the late 1990s and early 2000s, fish sized has declined since, and has oscillated around the post-collapse average since the late 2000s. In the 2010s the overall biomass has remained relatively stable, but shellfish biomass has showed important declines.

In recent years, it has been observed an increase in silver hake among piscivores (Fig. 3.1.5.5).This increase is being observed in the western portion of the Grand Bank (3O); suggesting that this warm water species, which has significantly increased in the southern Newfoundland EPU (see above), is expanding into the Grand Bank. It is unclear how (or if) this expansion will continue, but this change has not been observed in the past, and could potentially have a major impact in the configuration of the fish community.

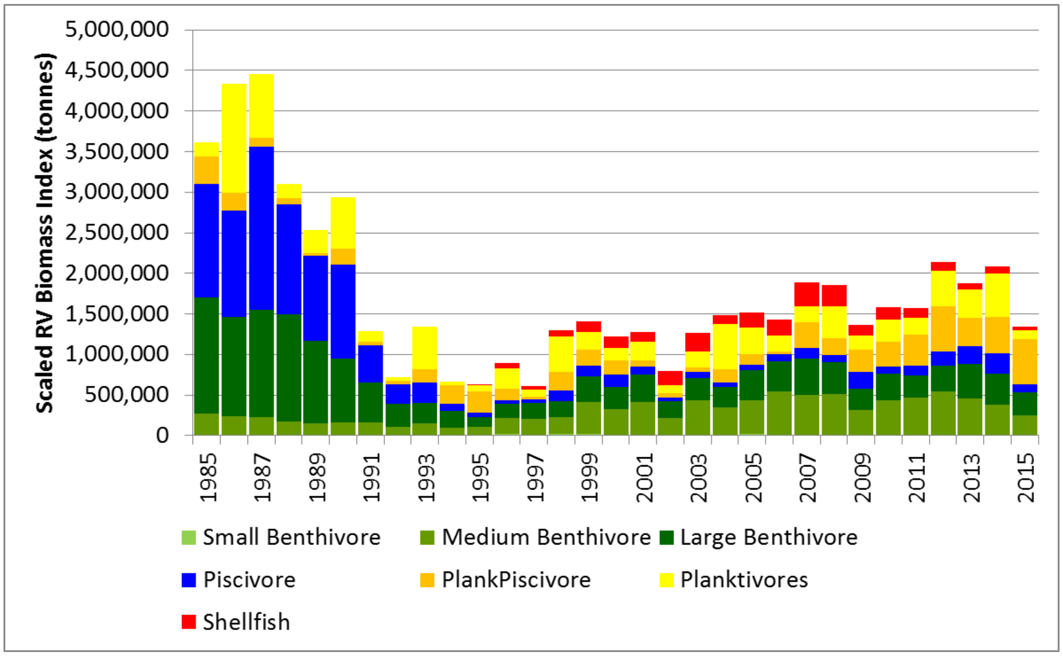

Fig. 3.1.5.4. Scaled RV biomass index from DFO 3LNO Spring surveys. The declined observed in 2015 is associated with an incomplete survey; 3L was not properly surveys due to mechanical problems with the research vessel. Information on shellfish only became available with the change to the Campelen gear.

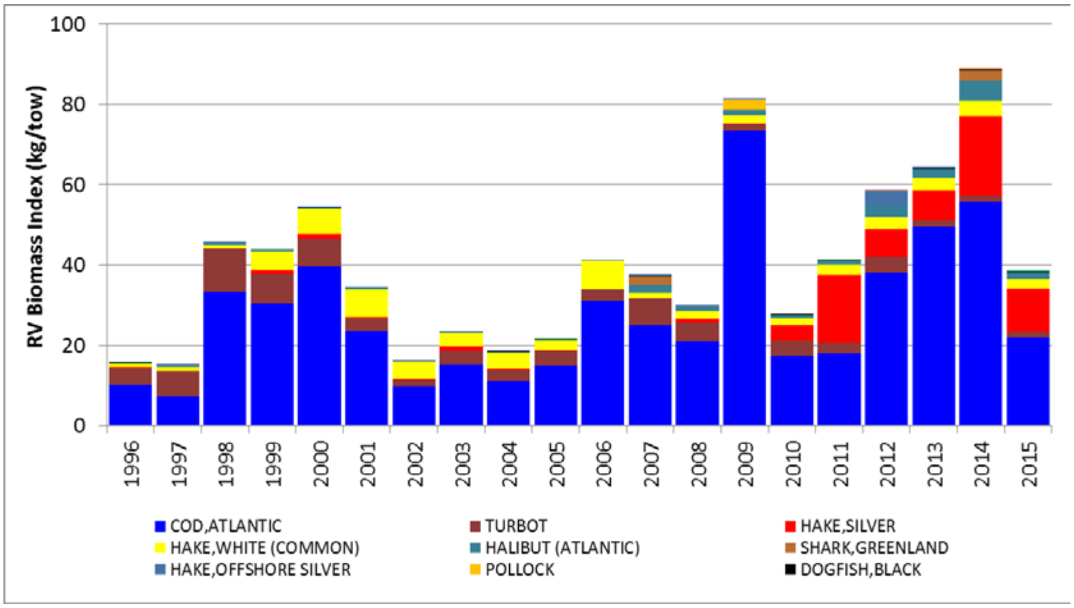

Fig. 3.1.5.5. RV biomass from DFO 3LNO Spring survey for Piscivores functional group during the Campelen period. Note the increased dominance of silver hake during 2010-2015.

Newfoundland Shelf EPU (2J3K)

The update of the structure and trends of the fish community in the Newfoundland Shelf (2J3K) were based on DFO RV fall survey data focused on trends in the RV biomass index. Similarly to the Grand Bank, this index was scaled using the coarse conversion factors available applied at the fish functional group level (NAFO 2014).

In 2J3K, the collapse in the 1990s also involved the entire fish community, and a decline in fish size. After the collapse, the system was highly dominated by shellfish. The changes observed have a coherent internal structure; increases in small fish and shellfish are associated with declines in forage and large fishes. Consistent signals of rebuilding of the groundfish community appeared in the mid-late 2000s (Fig. 3.1.5.6); this signal is also associated with an increase in fish size, and a decline is shellfish.

In the 2010s the overall biomass has remained relatively stable, but with an increased dominance of groundfishes (Fig. 3.1.5.6). Although total groundfish biomass has not increased, the dominance of piscivores has grown during this period (Fig. 3.1.5.6). Furthermore, this increase in piscivores is directly related to the build-up of Atlantic cod (Fig. 3.1.5.7). This is an important difference from the trends observed in the mid-late 2000s, because it implies a redistribution of biomass among groundfishes, and not a net increase in total groundfish biomass. The overall biomass build-up observed in the mid-late 2000s appears arrested.

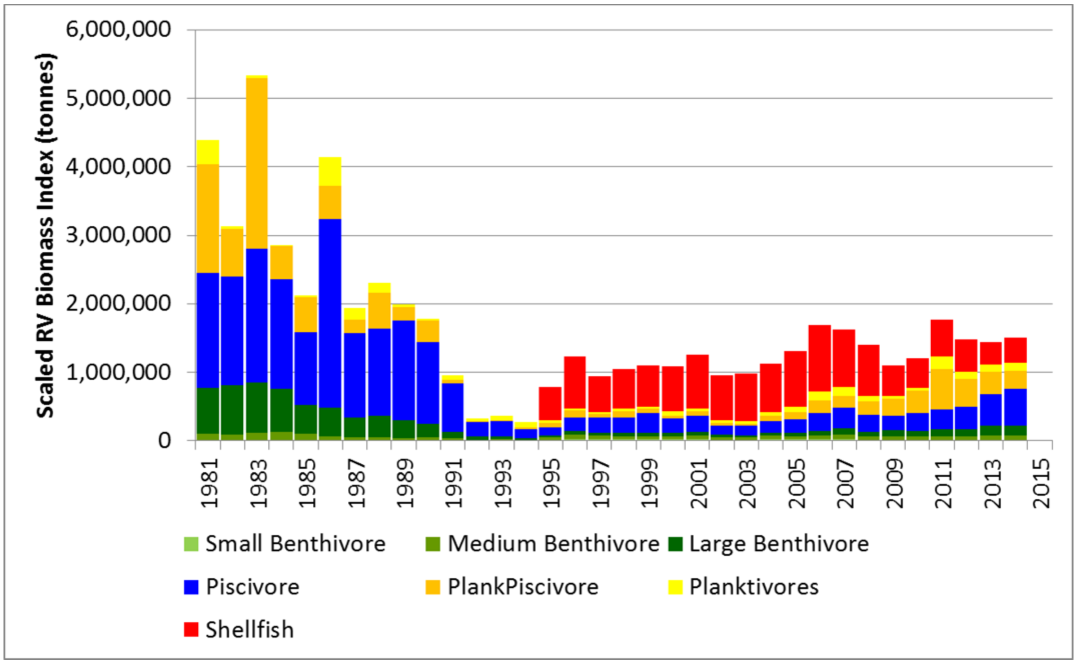

Fig. 3.1.5.6. Scaled RV biomass index from DFO 2J3K Fall surveys. Information on shellfish only became available with the change to the Campelen gear in 1995.

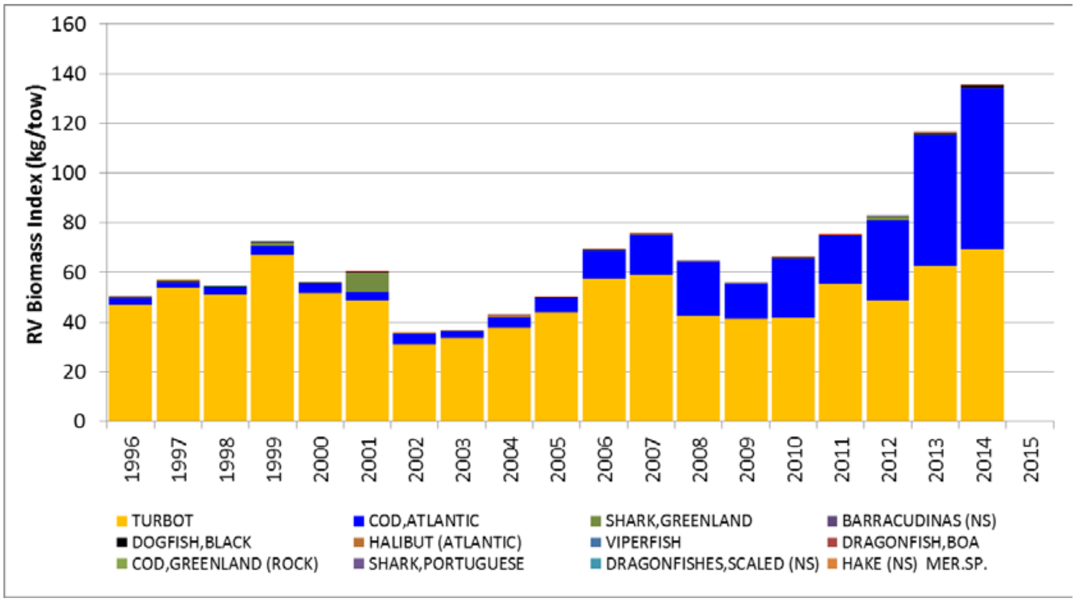

Fig. 3.1.5.7. RV biomass from DFO 2J3K Fall for Piscivores functional group during the Campelen period. Note the increased dominance of silver hake during 2010-2015.

Concluding remarks

The regime shift in the 1990s triggered a cascade of changes in the NL marine ecosystems, which were already under stress due to overfishing. These changes are still working themselves out. The collapse was more severe in the north, and less in the southern regions. The increase and decline of shellfish resources, as well as the recent build-up of groundfishes can be interpreted as part of this process. Rebuilding of grounfishes is not homogenous across all ecosystem production units, but in general terms, it implies reductions of shellfish and small benthivores functional groups. Despite the observed increases in groundfishes, overall biomass is still well below pre-collapse levels. Although the overall perspective appears positive for groundfishes, some signals suggest caution. The build-up of Northern cod (2J3KL) in recent years has not been accompanied by an increase in the biomass of the overall fish community. Also, warm water species like silver hake are increasing in the 3Ps and 3O. This may be a hint of things to come, potentially linked to climate change or at least to a warm phase in climate variability. The full extent of these impacts on ecosystem structure, function, and trends remains largely unknown.

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Pepin, P., Higdon, J., Koen-Alonso, M., Fogarty, M., and Ollerhead, N. 2014. Application of ecoregion analysis to the identification of Ecosystem Production Units (EPUs) in the NAFO Convention Area. NAFO SCR Doc. 14/069.

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

ToR 3.2.1. Progress on modelling Greenland halibut in an ecosystem context in Greenland waters

A new approach looking into environmental forcing for the dynamics of the Greenland Halibut (*Reinhardtius hippoglossoides*, *GH*) was explored. In this exploration, the model is expressed in a quantitative or operational form: the approach is based on the inverse relationship between the variability of the Sea Surface Temperature (SST_{SD}; a key co-factor for age class strength) sampled from a (243 km^2) sector of the early life drift (the mixing layer in the Davis Strait area, Lat. 62.5-64.5ºN, Long. 55.5-57.5ºW) and the fishable stock lagged six years ($p<0.05$, $N=19$). The stock biomass was both retro-calculated between years 2011-1997 ($N=15$), and estimated (forecasted) and validated between years 2012-2015 ($N=4$) with 95% of certainty for the whole series. Variablity or dispersion, memory, dependency and delay are central concepts in the model.

It is inferred that the new approach could be useful for the analysis and management of GH as it allows to estimate local trends and the abudance in a six years time frame with a high degree of certainty and, thus, becoming a basis for further developments and exploitation strategies oriented toward sustainability. An estimation of the biomass is proposed until year 2019 and some of the mechanics behind the data and implications due to the new framework were discussed. Finally, the new approach will be expressed in a qualitative or theoretical form for the scientific community (SC meeting, June 2016) and a geometrical recipe (for the non-mathematically oriented).

In the qualitative form, the model is expressed by a modified logistic equation where the carrying capacity (K) is a constant and the intrinsic rate of increase (r_i) is a variable parameter, based on the function describing the environmental forcing (SST_{SD}).

ToR 3.2.2. Summary of research on multispecies modelling of key components of the Flemish Cap ecosystem

GadCap: A Gadget multispecies stock assessment model for the Flemish Cap cod, redfish and shrimp

Motivation and objectives

In the Flemish Cap, since late 1970s several studies have shown the importance of trophic interactions (including cannibalism) in the population dynamic of cod, redfish and shrimp through the analysis of diet composition (Albikovskaya and Gerasimova 1993, Casas and Paz 1994, González et al. 2006, Lilly 1985) and consumption estimates (NAFO 2013, Pérez-Rodríguez and Saborido-Rey 2012). In addition, the survey indexes of biomass and the commercial catches showed marked variations since the early 1990s for all these three species, with complementary patterns that resembled the dynamic of typical prey-predator relationships (Pérez-Rodríguez 2012). The cumulative number of evidences and the importance of all these three stocks in commercial fishing lead to the Fisheries commission to request the Scientific Council in 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 a first approach with strong assumptions, already highlighted the importance of considering multispecies interactions when estimating maximum sustainable yields for all three stocks.

In 2012 the European Union, through the Marie-Slodowska Curie program financed the project GadCap, which has as main goal the development of a Gadget multispecies stock assessment model including cod, redfish and shrimp to provide an answer to the Fisheries commission request by using the resulting model to:

- Determine the degree of importance that trophic interactions and fishing have had in the dynamic of all the three stocks since 1988.
- Explore the use of this model to estimate MSY and F_{msy} from a multispecies perspective.

Model Structure, data and parameter estimation

Gadget

Gadget is a flexible tool that allows the user to include a number of features of the ecosystem into the model: one or more species, each of which may be split into multiple components; multiple areas with migration between areas; predation between and within species; growth; maturation; reproduction and recruitment;

multiple commercial and survey fleets taking catches from the populations (Begley 2005, Begley and Howell 2004).

Model structure

In GadCap, Gadget was used to model the interdependent dynamic of the Flemish Cap cod, redfish and shrimp populations over the period 1988-2012, the effect of fishing and other environmental factors. The version 2.2.00 was employed (http://www.hafro.is/gadget/index.html) to create an age-length structured multispecies model considering different fleets and sub-populations as well as their interactions. Cod and redfish were considered both as prey and predators; while shrimp was modeled as prey. In addition other groups from the zooplankton, as well as demersal and pelagic fishes were included as exogenous input variables in the model (Fig. 3.2.2.1). In the absence of data about the influence of the availability of prey on recruitment, growth or mortality of predator species (cod and redfish), only the influence of predation on prey stocks was modeled.

The optimal weight given to each likelihood component was estimated with the function gadget.iterative, of the R package Rgadget, which follows the process described in Taylor et al. (2007)

The redfish stock was constituted by the populations of three different species: *Sebastes mentella*, *S. fasciatus* and *S.marinus*. However these three species were separated during the survey only after 1993, when the decline and futher collapse of cod was very advanced, which prevented from modeling the redfish in an specific basis instead of a genus basis. However, due to the important differences among sexes in biological processes like growth and maturation (Saborido-Rey, 1994), male and female sub-stocks were modeled separated. Cod was not split by sex in the model since no size distribution data by sex was available. In the shrimp stock sex was also considered but unlike in redfish, sex was not a fixed state over the entire lifetime but changed at a given length. Northern shrimp is born as male, and after a reproductive life as male it changes to immature female (female primiparous) (Bergström 2000). Sex change was modeled in the same way than the maturation process. All the modeled species were split into immature and mature sub-stocks (Fig. 3.2.2.1; Tables 3.2.2.1, 3.2.2.2 and 3.2.2.3).

For each modeled stock, the substocks the age and length range, and some other processes and parameters defining the structure for each single species model are outlined in tables 3.2.2.1, 3.2.2.2 and 3.2.2.3 for cod, redfish and shrimp respectively.

For all the three species the initial population was estimated as the number of individuals by age in year 1988. Recruitment was estimated annually for all the three species as the number of individuals at age 1 on 1st January. In the redfish stock, the estimated recruits were split into males and females assuming that 50% of individuals at age 1 belonged to each sex. The mean length and standard deviation at recruitment was fit annually for the cod stock, while for redfish three different periods 1988-1993, 1994-1997 and 1998-2012 were considered, and for shrimp two different periods, 1988-2003 and 2004-2012. As part of the Gadget performing, the mean length and standard deviation at age 1 are used to produce the size distribution at recruitment assuming a normal distribution.

Table 3.2.2.1. Model structure, main ecological and biological features for cod.

	Immature	Mature_small	Mature_large
Period	1988-2012		
Time step	3 months		
Age range	0-12		
Length range (cm)	1cm-L50	L50-85cm	85cm-140cm
Length resolution	1 cm		
Fishing fleets	CT_I; CT_II;CG; EUs		
Residual mortality	Age1: 0.2 Age2: 0.1 Age3: 0.05 Age4-12: González-Troncoso & González-Costas (2014)		
Growth	Von Bertalanffy; annual estimate		
Maturation	Biannual maturation ogive		
Maturation date	4th timestep		
Recruitment	Annual estimate		
Age at recruitment	1		
Recruitment date	1st timestep		

CT_I and CT_II: cod trawl fleet 1988-1998 and 1999-2012 respectively. CG: cod gillnet fleet. EUs: EU survey; L50: Length at 50% probability of maturing.

Table 3.2.2.2. Model structure, main ecological and biological features for redfish.

	Male_immature	Male_mature	Female_immature	Female_mature
Period	1988-2012			
Time step	3 months			
Age range	0-25			
Length range (cm)	1cm- L50 male	L50 male-60cm	1cm-L50 fem	L50 fem-60cm
Length resolution (cm)	1 cm			
Fishing fleets	RT_I; RT_II; ST; EUs			
Residual mortality	Age1-2: 0.1 Age3-16: 0.05 Age 17-25: Efimov et al (1986)			
Growth	Von Bertalanffy; 3 periods			
Maturation	One maturation ogive		One maturation ogive	
Maturation date	4th timestep		4th timestep	
Recruitment	Annual estimate		Annual estimate	
Age at recruitment	1		1	
Recruitment date	1st timestep		1st timestep	

RT_I and RT_II: redfish trawl fleet 1988-1998 and 1999-2012 respectively; ST: Shrimp trawl fleet; EUs: EU survey; L50 male and L50 fem: Length at 50% probability of maturing for male and female sub-stock respectively.

Table 3.2.2.3. Model structure, main ecological and biological features for shrimp.

	Male	Female_primiparous	Female_multiparous
Period	1988-2012		
Time step	3 months		
Age range	0-7		
Length range (cm)	0.05cm-L50 sex	L50 sex-L50 mat	L50 mat-3.8cm
Length resolution (cm)	0.05		
Fishing fleets	ST; EUs		
Residual mortality	Age1=0.2; Age2-7=0.1		
Growth	Von Bertalanffy; two periods		
Sex change	Bi-annual ogive		
Sex change date	4th timestep		
Maturation		Bi-annual ogive	
Maturation date		4th timestep	
Recruitment	Annual estimate		
Age at recruitment	1		
Recruitment date	1st timestep		
ST: Shrimp trawl fleet; EUs: EU survey; L50 sex: length at 50% probability change from male to female primiparous. L50 mat: length at 50% probability change from female primiparous to multiparous.			

The Von Bertalanffy growth model was used to define the growth curves for all the three species. For cod, the model was fit to the data annually, while for the redfish and shrimp stocks this model was fit for the same periods defined above for the size at recruitment. For each species the average standard deviation at age around the mean length was defined for the whole time period. In gadget the mean growth in length during a time step is estimated for each length group using the fit Von Bertalanffy growth function. Although Gadget can model all the processes in a monthly basis, in this model a 3 month framework (4 time steps by year) was considered instead. Length distribution around the mean are estimated according to the average standard deviation at age assuming a beta-binomial distribution. A unique length-weight relation was fit for all time steps and years.

The probability of an immature individual to become mature in all the three species, and the probability of change of sex from male to female primiparous in the shrimp stock, was modeled using the equation:

$$P(l) = \frac{1}{1+e^{-4\alpha(l_i - l_{50})}} \qquad (1)$$

where $P(l)$ is the probability of maturing (or changing sex in shrimp) at a given length l, l_i is the middle length of the length group i, l_{50} is the length at which 50% of the individuals become mature (or changing the sex in shrimp) in a given year, and α is a parameter to be estimated. It was assumed that all the three stocks mature or change from male to female in the last time step (4^{th} time step) of the year.

The international commercial fishery in the Flemish Cap was modeled for cod, as two different fleets: trawl and gillnet. The longline fishery was not considered due to its low importance and the shortage of information. For redfish the pelagic and bottom trawl fishery were simplified to a unique trawl fishery due to the lack of information about total catches and seasonal size distribution of catches in the pelagic fleet. The shrimp fishery was also considered for the redfish stock due to the important by-catch of juvenile redfish during the 1990´s, especially before the introduction of a sorting grid. The only fishing gear targeting the shrimp stock was the bottom trawl.

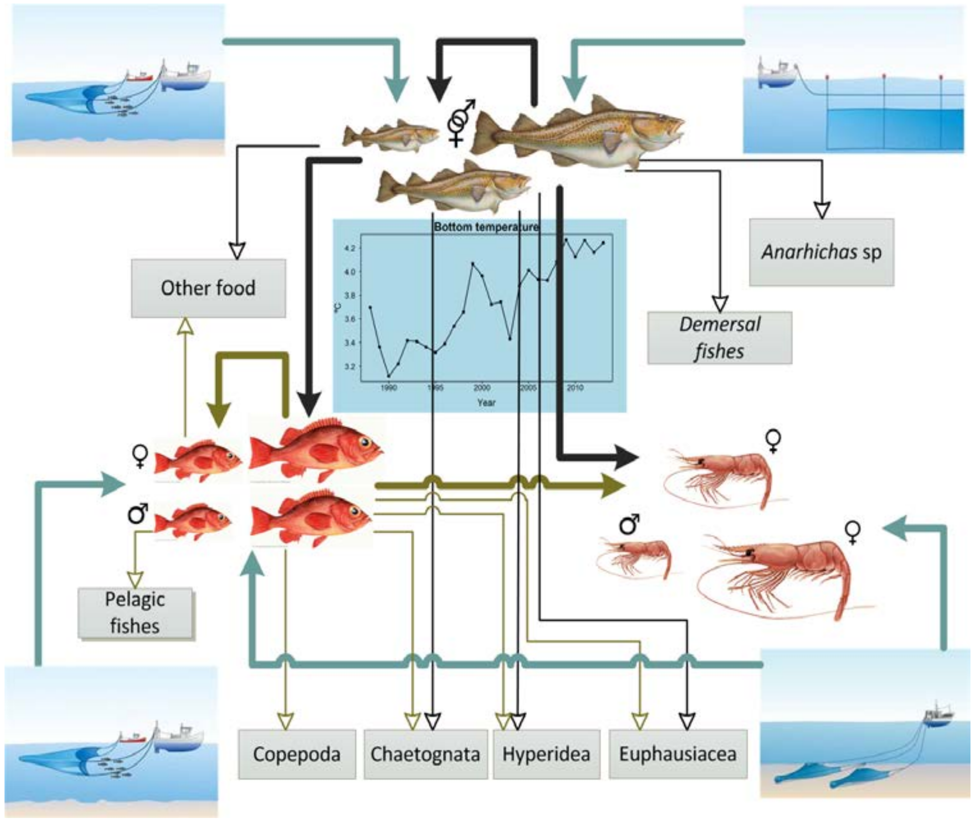

Fig. 3.2.2.1. Species interactions modeled in this study. Cod, redfish and shrimp are fully dynamically modeled, whereas species/prey groups in grey text boxes are incorporated as time series or constant values. The fleets fishing each species are also represented.

Some degree of flexibility around the total catch was allowed for all the fleets considered in this study, including the survey fleet. Total catches were simulated in the model for each fleet and time step through the equation:

$$C_{sl} = ES_{sl}\Delta_t N_{sl} W_{sl} \qquad (2)$$

where C_{sl} is the catch in kg for a given species and length cell, E is the scaling factor for the stock that is to be caught, Δ_t is the length of the time step, N_{sl} is the number of individuals and W_{sl} is the mean weight of that species in the length cell. The parameter E was estimated annually for each commercial fleet, resembling the changes in effort over time. However for the survey fleets only one parameter was estimated for each species, in order to keep the effort constant over time. S_{sl} is defined by the suitability function and defines proportion of the length group that will be caught by the fleet, and as such the suitability values should be between 0 and 1.

The suitability function employed in the model was variable depending on the fleet. Trawl fleets were assumed to fit to a logistic suitability function of length:

$$S(l) = \frac{1}{1+e^{-4\propto(l_i - l_{50})}} \qquad (3)$$

where $S(l)$ is the proportion of the species at a given length l that is potentially caught by the fleet, l_i is the middle length of the length group I, l_{50} is the length at which 50% of the individuals are potentially fished, and α is a parameter to be estimated.

For the cod gillnet fleet and catches of redfish by the shrimp trawl fleet, the suitability curve was assumed to have a dome shaped relation with length, which follow the equation:

$$S(l,L)=\begin{cases} p_0+p_2 e^{\frac{-\left(ln\frac{L}{l}-p_1\right)^2}{p_4}} & if\ ln\frac{L}{l}\le p_1 \\ p_0+p_2 e^{\frac{-\left(ln\frac{L}{l}-p_1\right)^2}{p_3}} & if\ ln\frac{L}{l}\ge p_1 \end{cases} \qquad (4)$$

where $S(l,L)$ is the proportion of the species at a given length l that is potentially caught by the fleet. L denotes the length of the predator, which is a meaningless concept when the predator is a fleet and takes a constant value, the average length of the species. p_0, p_1, p_2, p_3 and p_4 are parameters to be estimated that define the lowest value (assumed to be 0), the length range caught by the fleet, the maximum value (assumed to be 1), the left slope shape and the right slope shape respectively.

With equations 2, 3 and 4, total catches (numbers and biomass) by time step, fleet and species are estimated and distributed by length.

Due to the different pattern of exploitation of cod and redfish expected before and after the collapse of cod stock, the trawl commercial fleets for these species were split into two different periods, 1988-1998 and 1999-2012. Consistently, two different sets of parameters for the suitability functions were fit.

In the present model it was assumed that all the three modeled species stay in the modeled area during their whole lifetime, and that there are no differences by area in mortality (wheter, predation, fishing or residual mortality) or growth over the Flemish Cap. For this reason a unique area was considered for all the species.

The residual natural mortality (other than that due to trophic interactions) in shrimp was assumed 0.2 at age 1 and 0.1 at ages 2 to 7. For cod at ages 1, 2 and 3 (when cannibalism is more important) residual natural mortality was set as 0.1, 0.07 and 0.05 respectively. At ages 4 to 12, when predation was expected to be non-significant, the natural mortality values were taken from González-Troncoso and González-Costas (2014). In redfish natural mortality at ages 1-2 and 3-16 was assumed 0.1 and 0.05. For ages 17-25 residual values for natural mortality were taken from Efimov et al. (1986).

In the multispecies approach (trophic interactions), cod and redfish work as predator but also as prey (Fig. 3.2.2.1). Immature and mature cod preyed on the modeled preys: immature cod (cannibalism), redfish (immature and mature of both sexes), shrimp; and the non-modeled preys: hyperiids, euphasiids, chaetognaths, *Anarhichas* sp., pisces demersales and other food. Redfish preyed on the modeled preys: male and female immature redfish (cannibalism) and shrimp; as well as the non-modeled preys: copepods, hyperiids, euphasiids, chaetognaths, pelagic fishes and other food.

The present model has not been designed for the consumption of any prey having any effect on growth and survival of predators. The exceptions to this are 1) the direct effect of cannibalism, which by affecting the dynamic of the prey it affects the survival of juvenile stages of the predator; 2) the indirect effect that the abundance of alternative prey has over the intensity of cannibalism.

Total consumption by length, for both cod and redfish, was estimated annually for each time step using a bioenergetic model (Temming and Herrmann 2009). In Gadget, these estimates were used to model the consumption as a function of length and water temperature using the same model included in MULTSPEC (Bogstad et al. 1997). Once the average consumption by individual was modeled, the total consumption was estimated by multiplying by the number of predators in each length group, and summing over all groups (Begley 2005):

$$C_p(l,L)=\frac{N_L M_L \psi_L F_p(l,L)}{\sum_p F_p(l,L)} \qquad (5)$$

$$F_p(l,L)=(S_p(l,L)E_p N_l W_l)^d \qquad (6)$$

$$\psi_L=\frac{\sum_p F_p(l,L)}{H\Delta_t+\sum_p F_p(l,L)} \qquad (7)$$

where $C_p(l,L)$ is the total consumption of prey p of size l by the whole predator population at length L, which is determined by N_L, the number of predator in length cell L; M_L the maximum consumption for a predator of length L; $F_p(l,L)$ the consumption of prey p of size l by an individual predator in the length cell L; and ψ_L the feeding level at predator length L. In addition to the sum of $F_p(l,L)$ for all prey species, ψ_L is dependent on the half feeding value H, the biomass of prey required for the predator consuming prey at a half the maximum consumption level. We assume that the total prey consumption by both cod and redfish is independent of the amount of available food, and hence, the half feeding value H was st to zero. $F_p(l, L)$ depends on the suitability function S_p; the prey energy content E_p; N_l the number of prey at length and W_l the average weight of prey at length l. Since M_L was estimated in Kilograms instead of Kilojoules, E_p was set as 1 for all prey species. The parameter d determines the shape of the functional response of predator consumption to the abundance of the prey. In this model d was set as 1, which means a functional response type II (asymptotic).

The maximum total consumption rate M_L (as kg/time step) by an individual predator was modeled as a function of length and water temperature as follow:

$$M_L = m_0 \Delta t e^{(m_1 T - m_2 T^3)} L^{m_3} \qquad (8)$$

The relationship between predator length and prey length was studied for all predator-prey interactions among the modeled species. For these interactions the suitability of a prey for a predator was modeled assuming a dome shape relation, the above mentioned Andersen function (equation 4). For a given predator size, there is a prey size for which suitability is maximum, and decay at both sides. The maximum suitability, the relation between prey and predator size, as well as the asymmetry of this curve will be determined by the set of parameters p_0, p_1, p_2, p_3 and p_4. For those predator-prey interactions with the non-modeled prey species a constant suitability function was assumed and hence, no variations with the predator-prey size ratio were considered.

Prey suitability is a relative index, with values for all the prey species being sorted and starting at 1 for the most preferred prey to the lowest value for the less preferred one. Suitability values are representative of the importance of a prey in the diet related with its relative importance in the ecosystem. These parameters as all the other parameters of the prey-predator size curve and the consumption model were estimated externally. Different grouping of years were explored for the estimation of the prey-predator suitability values that could represent changes in prey selection or accessibility to a predator.

Data

Most of the data employed in the present work have been obtained from the International European Union (EU) bottom trawl surveys, conducted annually on the June-July period since 1988. The surveys followed the NAFO recommendations (Doubleday, 1981) and consisted on a bottom trawl random stratified sampling design (Vázquez et al. 2013). This design allows estimating indexes of total abundance and biomass, as well as the size distribution in the whole bank for all the demersal species, with especial focus on the three species modeled in this work, and also by sex for redfish and shrimp. A detailed biological sampling was carried out for all the three species, consisting on sex, size, weight, age and maturity state, which allows the estimation of length-weight relationship, as well as sex change (for shrimp) and maturity ogives. Although the survey is not designed for pelagic fish species, it can be used as a proxy index of trend in total biomass.

Stomach content information for cod and redfish in Flemish Cap has been collected annually since 1993 as part of the sampling protocol of the EU Flemish Cap July bottom trawl survey, with the exception of years 2007, 2009 and 2011. During the EU survey, on each haul a maximum number of 10 stomachs were analyzed by 10 cm size class and sex for cod and redfish. On average, 500 and 900 stomachs have being sampled annually for cod and redfish respectively. This information was use to calculate the contribution of each prey (in percentage) over the total stomach content as well as the prey-predator length relationship.

Data on temperature was measured from surface to the bottom using conductivity-temperature-depth cast (CTDs). The bottom temperature for each CTD was estimated as the temperature at the maximum depth. The average surface and bottom temperatures was estimated annually for the whole Flemish Cap as the mean value of all CTDs.

Differences in redfish maturation by sex were modeled using the biological information collected during the Department of Fisheries and Oceans of Canada (hereafter DFO) surveys in the Flemish Cap during the period 1978-1985.

The Continuum Plankton Recorder (CPR) survey marine monitoring program of the Sir Alister Hardy Foundation for Ocean Science (SAHFOS; website: http://www.sahfos.ac.uk) collected information from the

Northwest Atlantic surface planktonic organism during the period 1991-2012. CPR data have being used to estimate a five years moving geometric average as semi-quantitative estimates reflecting long term patterns in copepods, hyperiids, chaetognats and euphausiids over this period.

The estimated average ecosystem potential production for the zooplankton and pelagic fishes (Koen-Alonso et al. 2013) was employed to estimate, in conjunction with the CPR and the EU survey index respectively, the total annual biomass of this groups over the Flemish Cap.

The information about total annual catches of cod, redfish and shrimp by the international commercial fishery in the Flemish Cap since 1988 was obtained from the annual reports of the assessment of these stocks published in the NAFO website http://www.nafo.int/publications/frames/publications.html. Annual catches were split into the different fleets and over seasons based in the information presented in the NAFO database STATLANT21B at http://www.nafo.int/data/frames/data.html. Size distributions were gathered from the research reports and the research documents published in the NAFO website http://www.nafo.int/publications/frames/publications.html. Due to the absence of detailed commercial fishing information from several countries fishing in NAFO, most of the information on size distribution and temporal allocation of catches over the year were compiled from the Spanish and Portuguese annual research reports. This is an acceptable assumption since Spain and Portugal are two of the four main countries fishing cod and redfish in the Flemish Cap. For shrimp, the Icelandic fleet was taken as the basis for the size distribution of catches.

Parameter estimation and model validation

Parameters in Gadget are optimized using a two-stage process, combining simulated annealing and a Hooke and Jeeves stepwise estimation procedure (Begley and Howell 2004). For each database a likelihood components was set. The sum of squares likelihood function was used for comparison of observed and modeled catches both for survey and commercial fleets. The same likelihood function was used with the size distributions likelihood components, as recommended by Taylor et al. (2007). The goodness of fit for the stomach content likelihood components was calculated using the SCSimple function by comparing the ratio of the consumption of different preys by a predator in the model to the observed proportions of each prey in the observed diet. The total likelihood score is the result of a weighted sum of the likelihood score of all the components in the model. The optimal weight given to each likelihood component was estimated with the function gadget.iterative, of the R package Rgadget (https://github.com/rforge/rgadget), which follows the process described in Taylor et al. (2007). A sensitivity test was conducted to confirm that an optimum was reached.

Results and discussion

Model fit

Cod

The model produced values of biomass and abundance (including the recruitment index proxy, or smaller than 25cm individuals), as well as catches in kg for the trawl, gillnet and survey fleets, that were very close to the observed values (Fig. 3.2.2.2).

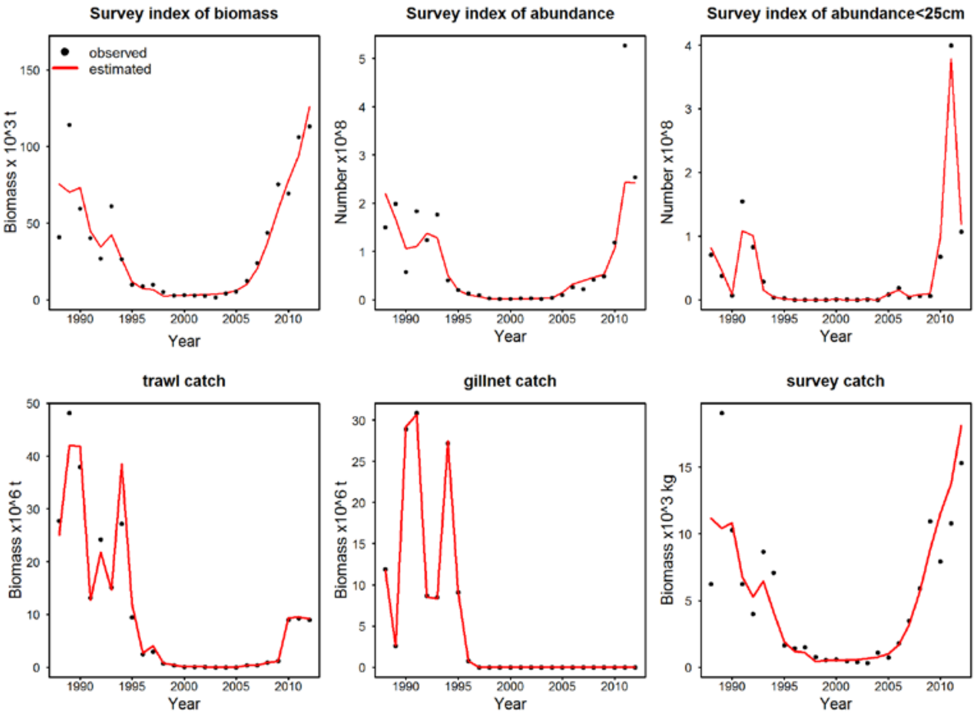

Fig. 3.2.2.2. Cod survey indexes (swept area method) of biomass, abundance and abundance of individuals smaller than 25 cm (from left to right in the first row), and catch in tones by the international trawl and gillnet fleets, and in kg for the EU survey fleet (left to right in the second row).

The estimated size distribution of catches showed also in general a high similarity with the observed distributions for the trawl and gillnet commercial fleets and for the survey fleet (Fig. 3.2.2.3). However, in the trawl fishery there was a marked deviation from the observed size distribution since the reopening of the fishery in 2010, which could be related with a change in the pattern of selectivity of this fleet in the last years. It is interesting also to note that it seems that the survey fleet size distribution tends to estimate higher proportions of individuals at larger sizes than the observed values. This is especially shown in those years of high recruitments, like 1991 or 2010-2012. This fact may be potentially a reflection of two factors: 1) a removal of individuals larger than 50 cm in those years of high recruitments either as result of increased natural mortality or migratory processes; 2) a change in the catchability (maybe dome shaped curve instead of logistic) of larger individuals in those years of high abundance of juveniles. This will need to be explored in the future.

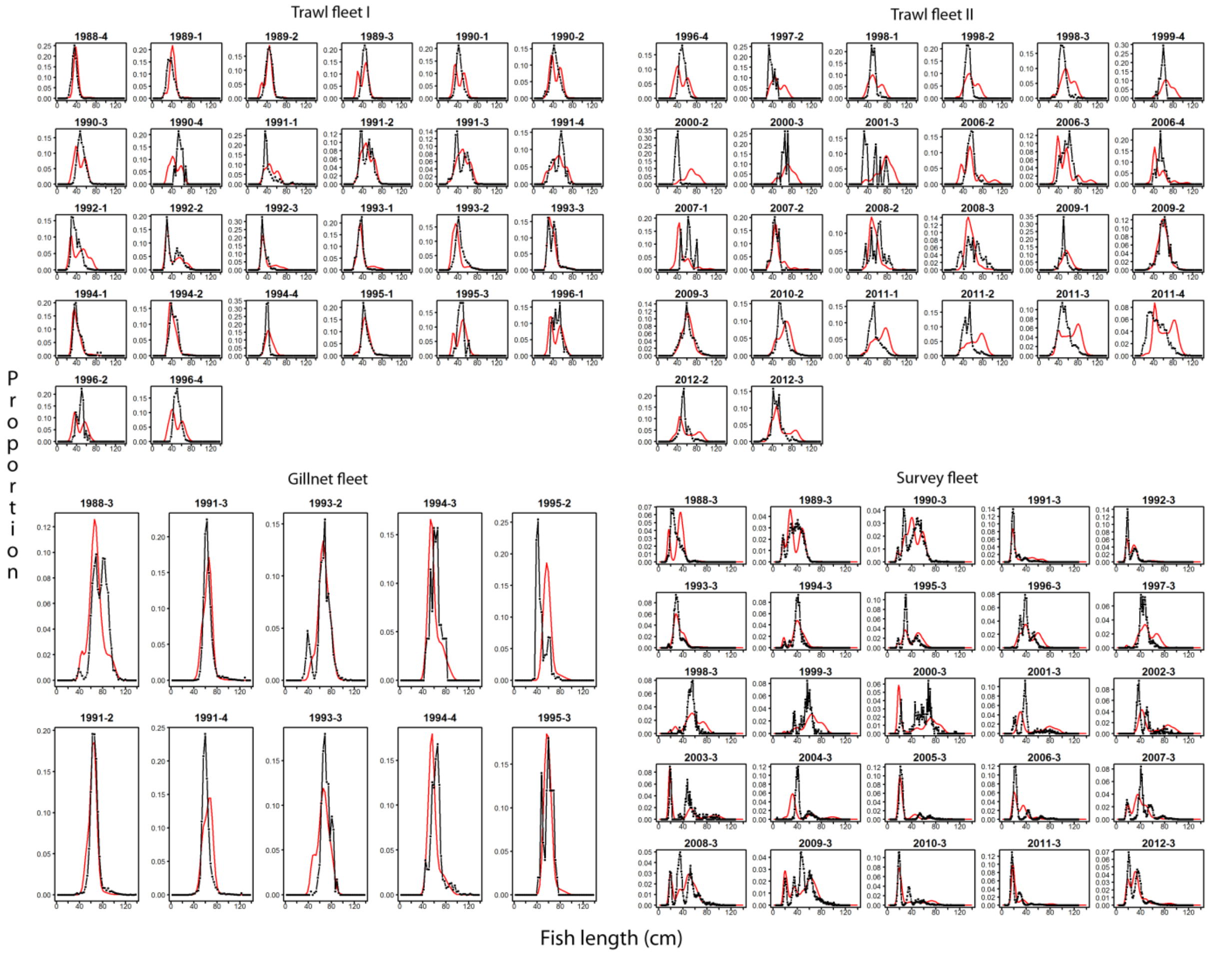

Fig. 3.2.2.3. Size distribution by fish length (in proportion relative to 1) of cod catches in the trawl (upper panels) , gillnet (bottom-left) and survey fleets (bottom-right). The label in each subpanel depicts the year and the season (Years: 1988 to 2012; Seasons: 1 to 4. For example 1988-1 is winter of 1988). Red lines are the estimated values versus black lines which depicts the observed data.

The maturity ogives by length were fit by the model in a two years group basis. The estimated proportion of mature individuals was in general very similar to that described by the observed maturity ogives (Fig. 3.2.2.4), with the exception of year 1994.

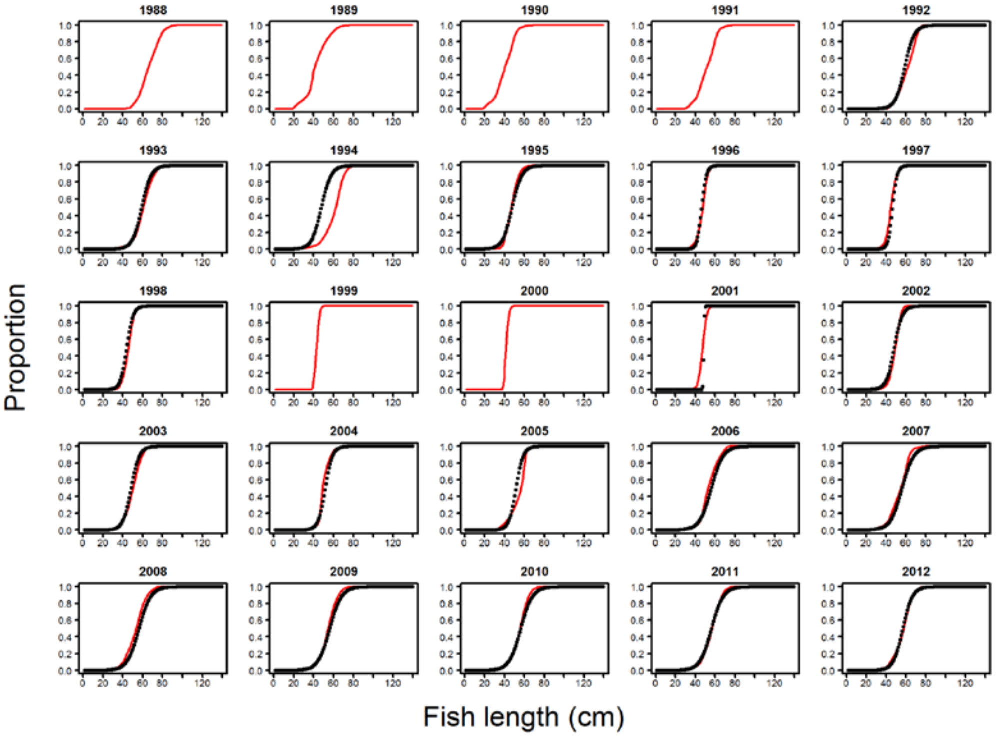

Fig. 3.2.2.4. Cod maturity ogives as probability, relative to 1, of being mature with total fish length (in cm). Estimated probabilities by the fit model in red color lines; Observed proportions in black color points.

Redfish

In the redfish stock, the output from model fit was very similar to the observed indexes of biomass, total abundance and abundance of individuals smaller than 12 cm length. However, in this case there was a higher deviation from the observed index of biomass which was also coherently shown in the EU survey total catch (Fig. 3.2.2.5). The estimated catches by the model was very similar to the reported catches in the redfish and shrimp trawl fisheries.

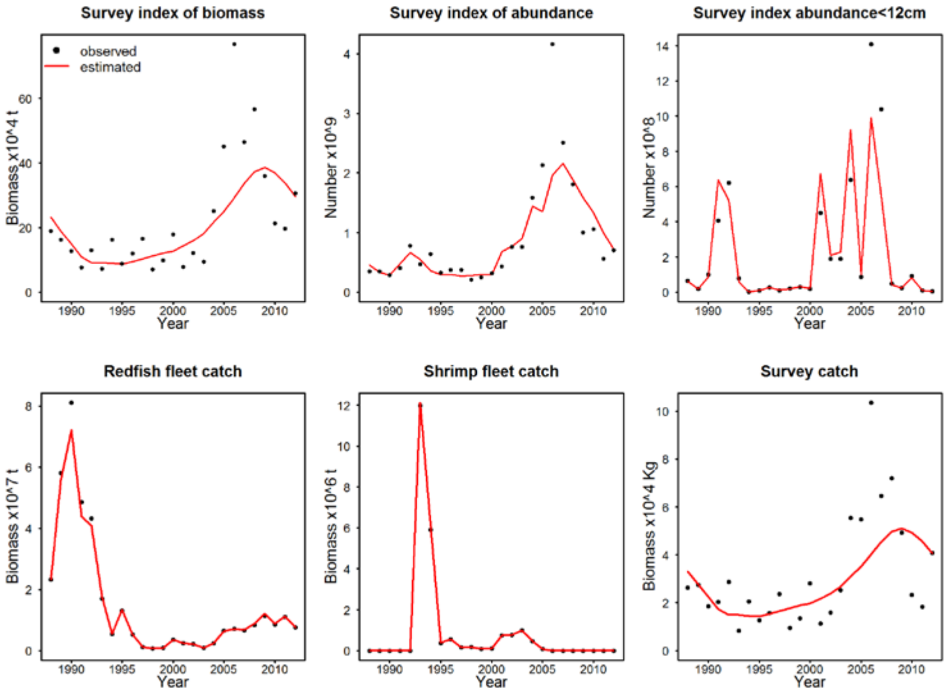

Fig. 3.2.2.5. Redfish survey indexes (swept area method) of biomass, abundance and abundance of individuals smaller than 12 cm (from left to right in the first row), and catch in tones by the international redfish trawl, shrimp trawl (as by-catch) fleets, and in kg for the EU survey fleet (left to right in the second row).

The size distribution of the redfish by-catch from the shrimp trawl fishery was very well fitted by the model (Fig. 3.2.2.6). With the exception of a few seasons in some years, the size distribution of catches from the redfish trawl fishery was also well simulated. The size distribution of catches from the EU survey fleet was also in general well fit. However, it is interesting to note that in those years of high recruitments (as those of 1991 and 2001) the peak in the size distribution that belongs to individuals of size near to 30cm in the previous years (1990 and 2000) suddenly disappeared in the size distribution sampled during the survey. However the model estimates size distributions, as there was no any added source of mortality that remove this individuals from the population in 1991 and 2001 (and years after) still contained these large individuals. This fact, as already mentioned above for cod, may be suggested to be a reflection of either a removal of individuals larger than 30 cm in those years of high recruitments (as result of increased natural mortality or migratory processes), and/or a change in the survey catchability of larger individuals in those years of high abundance of juveniles. This questions need to be explored in the future and will probably require of directed research work as the analysis of the acoustic signal during the EU survey or specific analysis to evaluate the migratory patterns of redfish under different oceanographic and demographic conditions.

Fig. 3.2.2.6. Size distribution by fish length (in proportion relative to 1) of redfish catches in the trawl (left column), gillnet (upper-left) and survey fleets (middle-left). The label in each subpanel depicts the year and the season (Years: 1988 to 2012; Seasons: 1 to 4. For example 1988-1 is winter of 1988). Red plain lines are the estimated values versus black dotted lines which depicts the observed data.

The maturity ogives were, as mentioned in the material and methods section, fit assuming a constant maturity ogive over time. As shown in Figure 3.2.2.7 the observed proportion of mature individuals was well fit by the model.

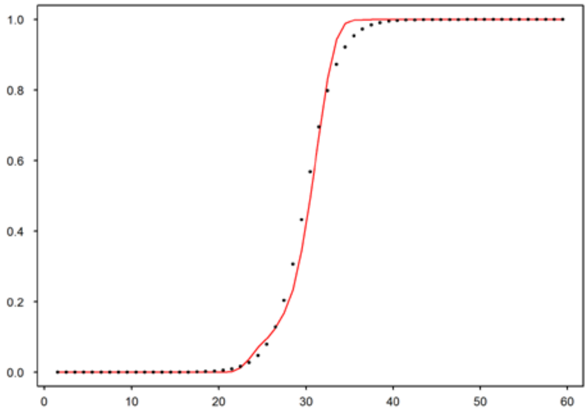

Fig. 3.2.2.7. Redfish maturity ogives as probability, relative to 1, of being mature with total fish length (in cm). Estimated probabilities by the fit model in red color lines; Observed proportions in black color points.

Shrimp

In this species, all the observed data for survey indexes of biomass and abundance, as well as the catches from the commercial and survey fleets showed a very similar pattern, and were well fitted by the model estimated values (Fig. 3.2.2.8).

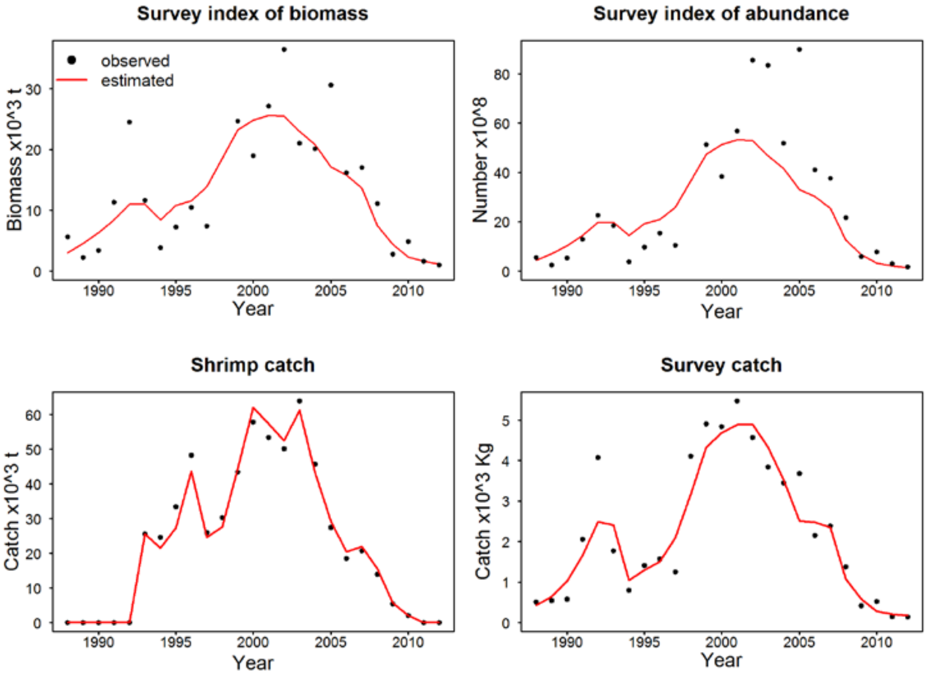

Fig. 3.2.2.8. Shrimp survey indexes (swept area method) of biomass (upper-left panel) and abundance (upper-right), and catch in tones by the international trawl fleet (bottom-left), and in kg for the EU survey fleet (bottom right).

The size distribution of the survey fleet (Fig. 3.2.2.9) despite was globally well fitted, showed important deviations from the observed values, especially in the first and last year of the time series. Since the data from the shrimp trawl fleet was thoroughly sampled by the Icelandic fleet, and this size distribution was very well fitted by the model, the deviation in the survey fleet size distribution was considered not having a bad effect in terms of the shrimp model perform. In addition, it is known that the trawl gear of the survey, both due to its mesh size and its configuration is not the best design for shrimp.

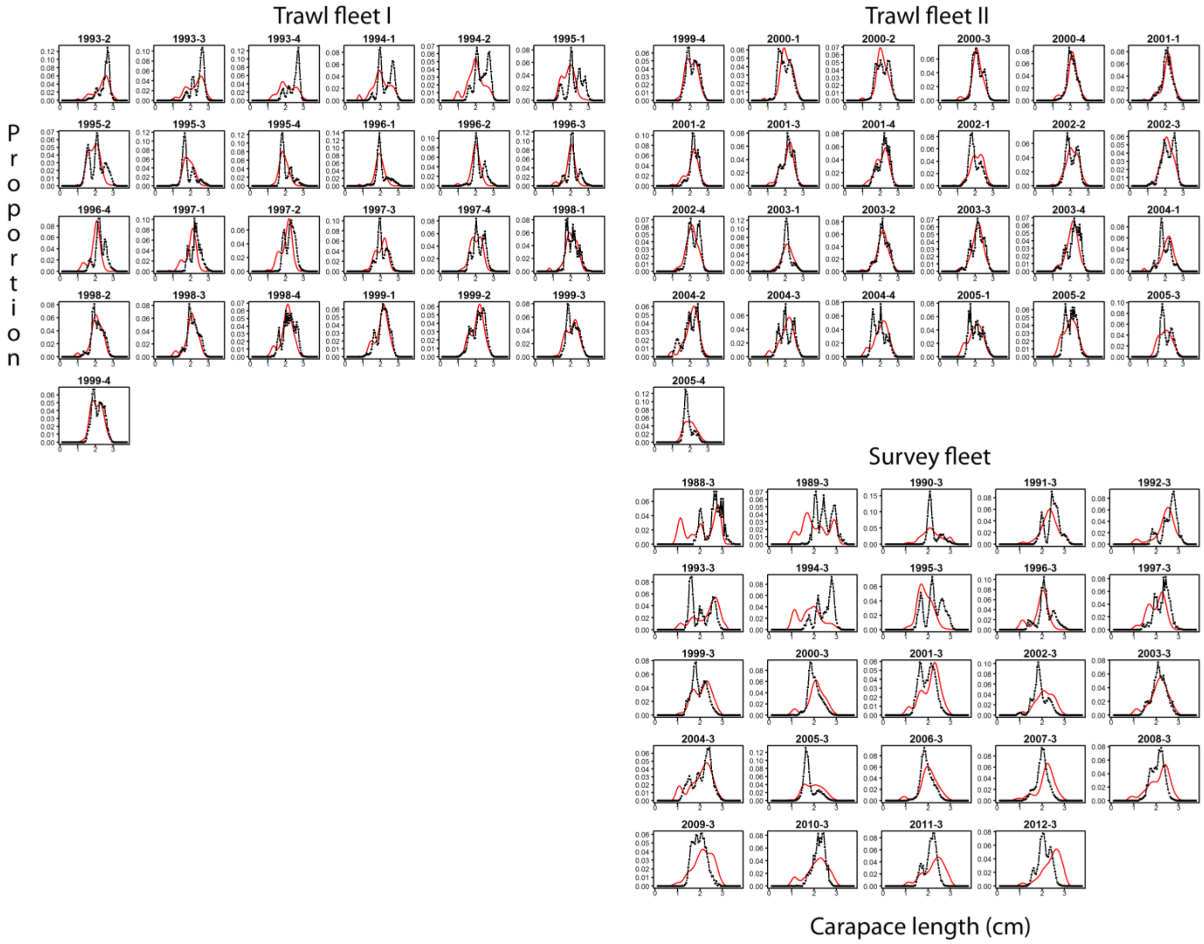

Fig. 3.2.2.9. Size distribution by carapace length (in proportion relative to 1) of shrimp catches in the trawl (upper row)and survey fleets (middle-left). The label in each subpanel depicts the year and the season (Years: 1988 to 2012; Seasons: 1 to 4. For example 1988-1 is winter of 1988). Red plain lines are the estimated values versus black dotted lines which depicts the observed data.

The estimated proportion of males, females primiparous and multiparous was fit from year 1994 onwards by means of optimizing the parameters that defined the female maturity and sex change ogives. These estimated proportions showed some difference in relation to the observed values (Fig.3.2.2.10), especially in the last years. This could be improved in the future, but at this moment is expected to be of low impact in the results.

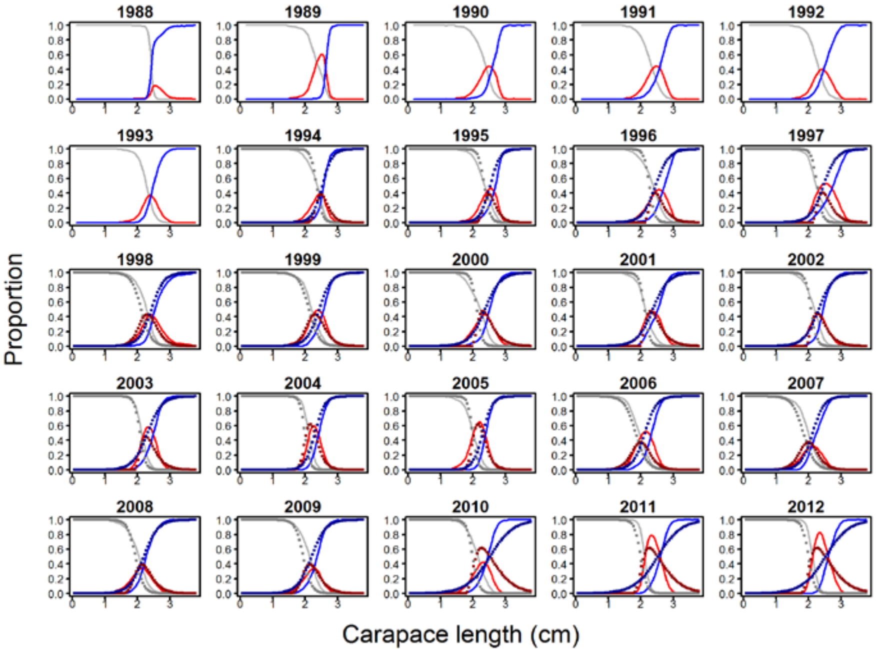

Fig. 3.2.2.10.Shrimp sex change and maturity ogives as probability, relative to 1, of being male (black color), female primiparous (red color) and female multiparous (blue color) with carapace length (in cm). Estimated probabilities by the fit model are depicted by continuous lines while the observed proportions are represented by points.

Diet composition

The estimated diet was also very similar to the observed one, both for cod (Fig. 3.2.2.11) and redfish (Fig. 3.2.2.12). In both species the model represented important changes over the study period, with variations in the relative importance of all modeled and non-modeled preys. The proportion of shrimp exhibited an increasing trend since 1988 both in cod and redfish diets, that reached the highest values in the late 1990s and stayed at similar proportions until 2004-2005. In these years shrimp was around 25-30% of the diet for immature and mature small cod, 15-20% for mature redfish and large cod and 10% for immature redfish sub-stock. Redfish was a relevant prey all over the study period for both small and large mature cod but it was especially since 2000 when its proportion in the diet increased steadily until maximum values in 2009-2010 (25% in the small and 65% in large mature cod). Cannibalism provided an important percentage to the diet of mature redfish those years when recruitment was high, like in the early 1990s and all over the period 2001-2007 (4.5%). In cod, cannibalism was also important and related to successful recruitments in late 1980s and early 1990s (average 12%) and 2010-2012 (average 7.8%).

The estimated percentage of the non-modeled prey in the diet of both cod and redfish was noteworthy. Hyperiids, euphasiids and chaetognats were very important prey for both predators; while copepods were a main prey only for redfish. The four pelagic groups together accounted for c.a. 50% of diet in immature cod, 75% in immature redfish, and 50% in mature redfish. In small and large mature cod, although it was lower, these prey still contributed to an average 35% and 20% respectively. Wolffishes were a very important prey in the diet of large mature cod, until late 1990s, with an average 32% of the diet. Pelagic fishes (mostly myctofiids) had a prominent role as fish prey in immature, but especially in mature redfish (average 5% and 15% respectively).

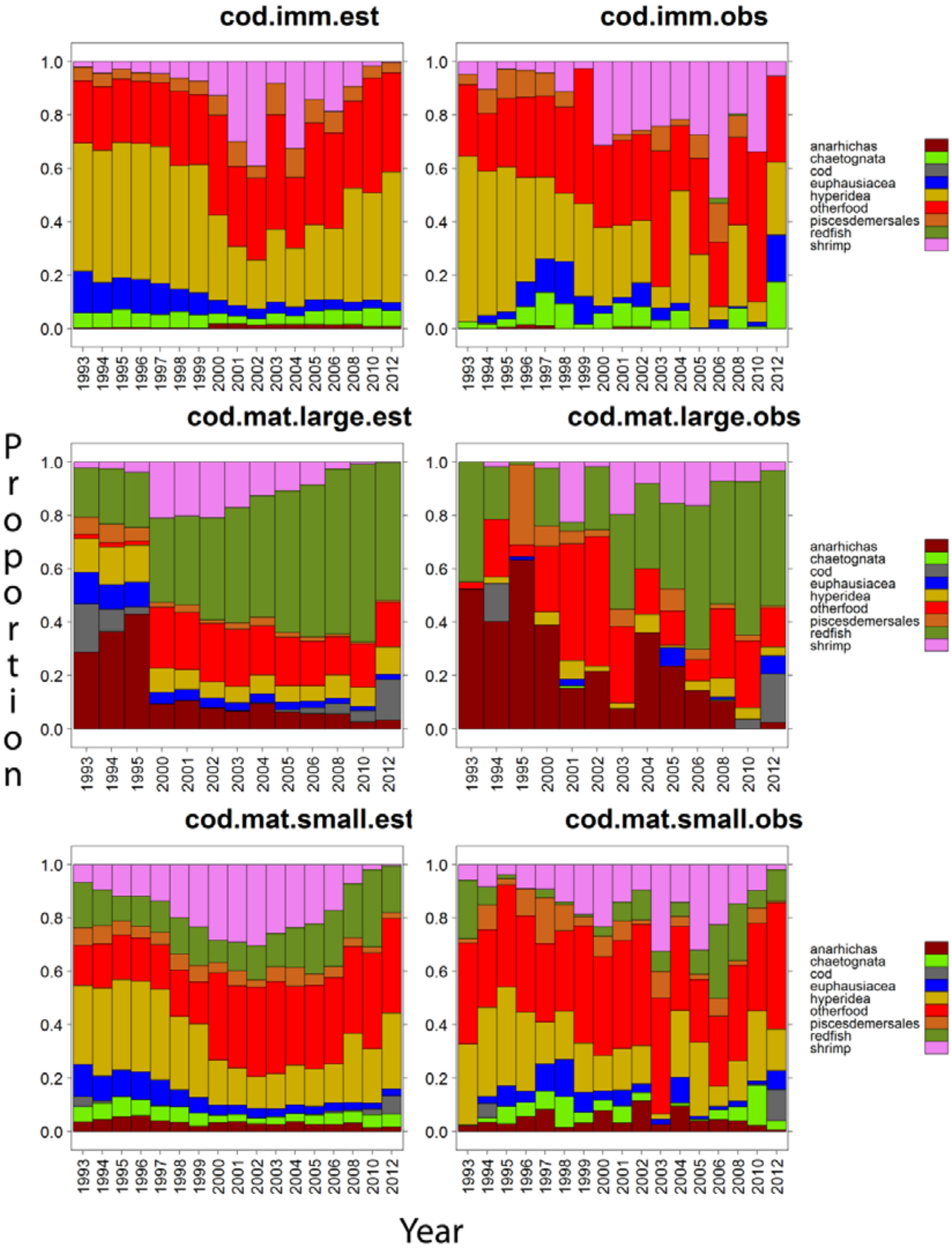

Fig. 3.2.2.11. Estimated (left column) and observed (right column) diet for immature cod (cod.imm), small mature cod (<85cm; cod.mat.small) and large mature cod (>85cm; cod.mat.large).

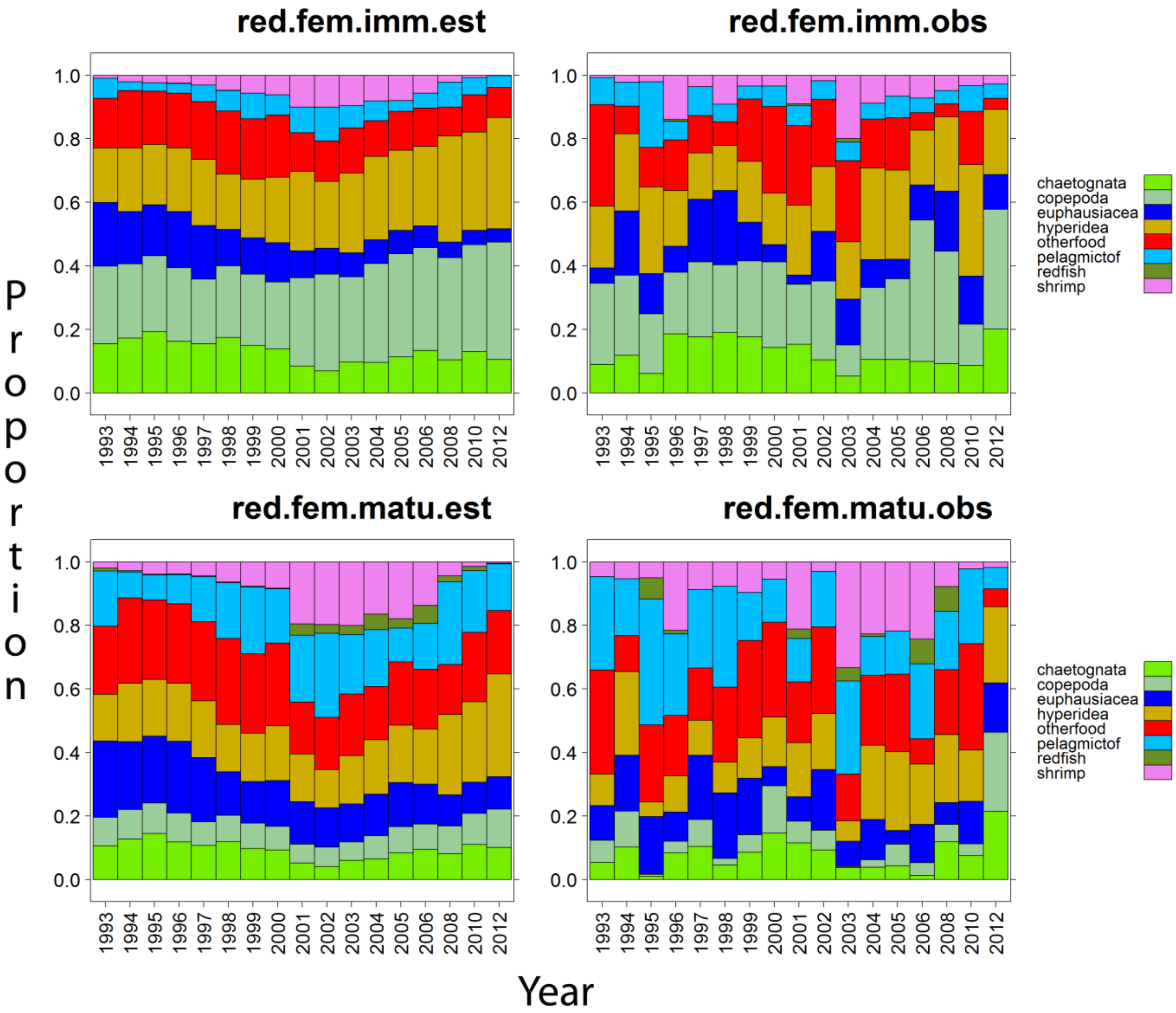

Fig. 3.2.2.12. Estimated (left column) and observed (right column) diet for immature female redfish (red.fem.imm) and mature female redfish (red.fem.matu).

Modeled cod, redfish and shrimp stock dynamic

Model estimates of annual recruitment at age 1, abundance and total stock biomass over the study period were highly variable and showed strong patterns (Fig. 3.2.2.13). Cod recruitment was high in years 1991 and 1992, which was reflected in the raise of total stock abundance. However, this increase was followed by a steep decline in years 1993-1995 coupled with the lack of good recruitments. Cod biomass showed a delayed pattern in relation to abundance and stayed at relative high values up to 1995 when it showed a sharp decline until 1998, when the lowest value in the study period was reached. Over the period 1995-2004 estimates of cod recruitment were very low and consequently stock abundance and biomass continued at minimum values over this period. However, in year 2005 recruitment was above the average in previous years and stayed at similar values until 2009, which produced an increase in the abundance. In the period 2010-2012 recruitments were very high, especially in year 2011 when the highest recruitment of the study period was estimated. Total stock abundance reached the highest values since 1988 in these years, while the total biomass reached the highest value in 2012, when the biomass from the mature stock stemming from cohorts 2005-2009 and the immature stock from recent recruitments (2010-2012) added up.

Estimates of recruitment in the redfish stock were very high in the period 1990-1992 (Fig. 3.2.2.13). This produced a marked increase in population abundance in 1991 which did not have a reflection in total biomass. On the contrary since 1989 there was a marked reduction in total biomass. After the increase in 1991-1992 the stock abundance showed a sharp decline, reaching the lowest values in the late 1990s. However, over the period 2001-2007 the model estimated a series of excellent annual recruitments, which were especially high in 2001, 2004, 2006 and 2007. These recruitments produced the increase of the stock abundance until 2007, when the highest value was attained. The increase in total stock biomass as result of these successful recruitments became more pronounced since 2003 and reached the highest value in 2009. Since 2007 total abundance declined sharply and was reflected in the reduction of total stock biomass since 2010.

Despite being a burning period that needs to be considered carefully, the model indicates that in 1988-1989 the shrimp stock experienced good recruitments (Fig. 3.2.2.13) that produced the increase in the abundance in those years and was the start of a growing trend in the stock biomass. However it was after 1993 when the highest recruitment values were estimated, in a series of successful cohorts that lasted until year 2006. The stock biomass showed a steady increment until the maximum value in 2001 that was followed by a steady and continued decline that was not compensated by the excellent recruitments that kept the abundance at high values until 2004. In 2012 the total biomass reached the lowest value since 1988.

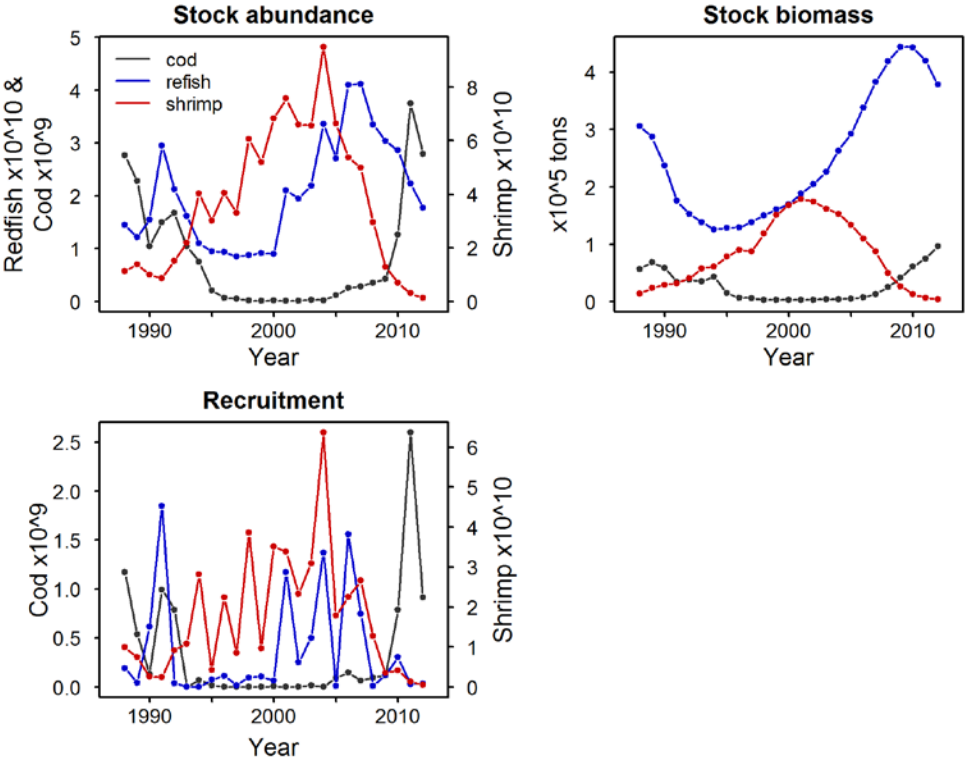

Fig. 3.2.2.13 . Model estimates of recruitment at age 1, total stock abundance and biomass for cod, redfish and shrimp along the study period.

Instantaneous and harvest rates by source of mortality

The mortality rates by age due to predation by cod (Mcod) and/or redfish (Mredfish) and fishing (F) were estimated for each modeled stock (Figs. 3.2.2.14, 3.2.2.15 and 3.2.2.16). In cod cannibalism was the main source of mortality at age 1 all over the study period (Fig. 3.2.2.14), with the highest values in the early and late years. At age 2, cannibalism showed a similar pattern but in this case the highest values occurred in the last years, when the abundance of older and cannibalistic cod was higher. However, since the reopening of the fishery in 2010, both Mcod and F had been similar at this age (close to 0.2). At age 4 and older, cannibalism was negligible and fishing accounted for most of annual mortality, which was extremely high before the collapse (F>1.5 at all ages in 1994). Since the reopening of the fishery in 2010, F at ages 4 and older stayed at relative low values in comparison with the levels of mortality during the 1990s.

In the redfish stock before 1996 the main cause of mortality for individuals younger than age 7 was predation by cod, with Mcod ranging from 0.1 to 0.3 (Fig. 3.2.2.15). This range of ages were also affected by the shrimp trawl fishery in the period 1993-1995, with F=0.18 in average, that removed an important portion of the small population. Cannibalism was important in the early 1990s, but it was since 2000 when Mred showed an increasing trend from 0.07 to 0.36 in 2009 at age 1 and values above of 0.1 at age 2. For redfish older than age 9, the redfish trawl fleet was the main cause of mortality during the first part of 1990s, with values above 0.5 at most ages in years 1990-1992. After 1996, fishing mortality by the redfish trawl fleet decreased and stayed at very low levels despite the slight increase observed since 2007. From 2007-2010, Mcod became the most important source of mortality for all ages, with values above 0.2 for ages 2 to 10 and between 0.1 and 0.2 for ages 11 to 18. The exception to this was the age 1 redfish, for which Mred remained as the main cause of mortality.

Other than the residual natural mortality, before the start of the shrimp fishery in 1993 the main source of mortality for shrimp was cod predation (Fig. 3.2.2.16), with Mcod above 0.2 for age 1, 0.2 for ages 3-4 and over 0.1 for ages 5 to 7. Since 1990 to 1995 Mcod declined steadily. Since 1993 until 1996 F raised to very high values (higher than 1) for ages 3 to 7. Since 1997 to 2005 F was lower for all ages, but it was still above 0.1 for age 2, 0.3 for age 3 and 0.6-1 for ages 5-7. Since 2006 fishing mortality showed a steady decline until 2011 when, with the moratoria, it became again zero. Since 2000, the estimated Mred showed an increasing trend for all ages, but especially at ages 1-3 (higher than 0.7 in 2008 for age 2 shrimp). Mcod increased steadily since 2005 for all ages and by 2012 was very similar to Mred.

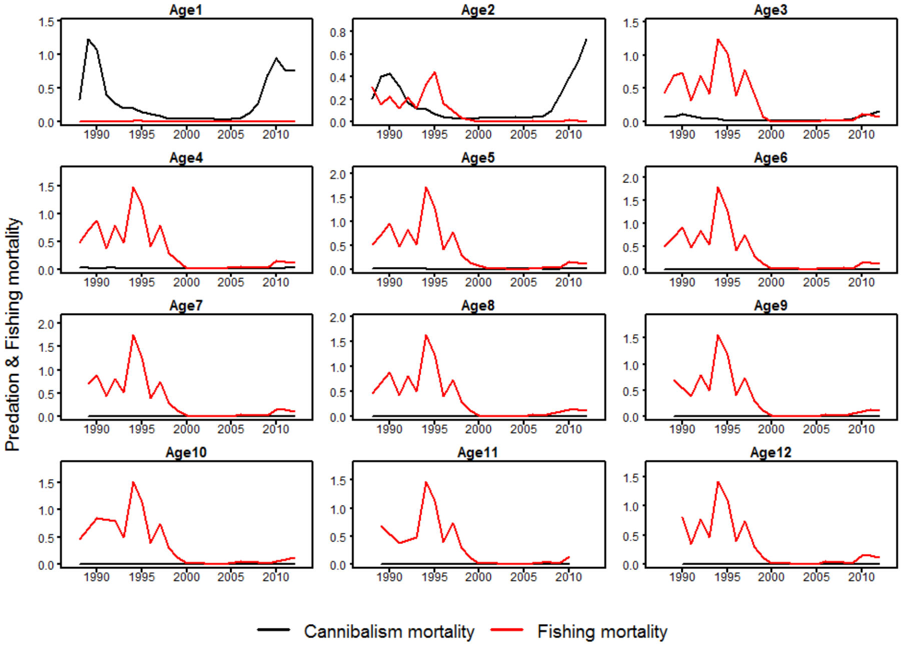

Fig. 3.2.2.14. Predation mortality by cod (Cannibalism mortality) and fishing mortality by age in the modeled cod stock. The Age 12 pannel shows the mortality rates for individuals of age 12 and older.

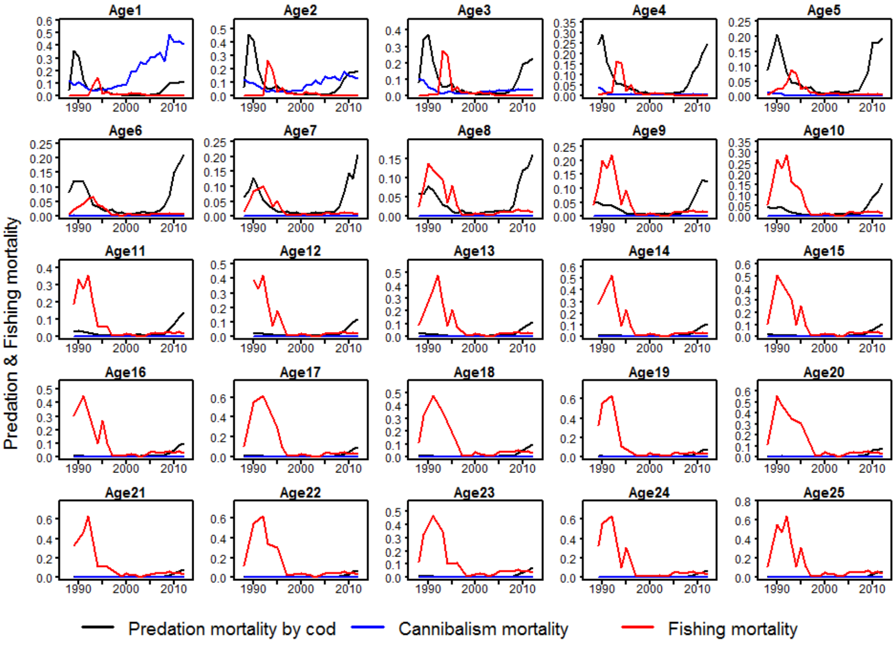

Fig. 3.2.2.15. Predation mortality by age in the modeled redfish stock, by cod, by redfish (cannibalism mortality) and fishing mortality. The Age 25 pannel shows the mortality rates for individuals of age 25 and older.

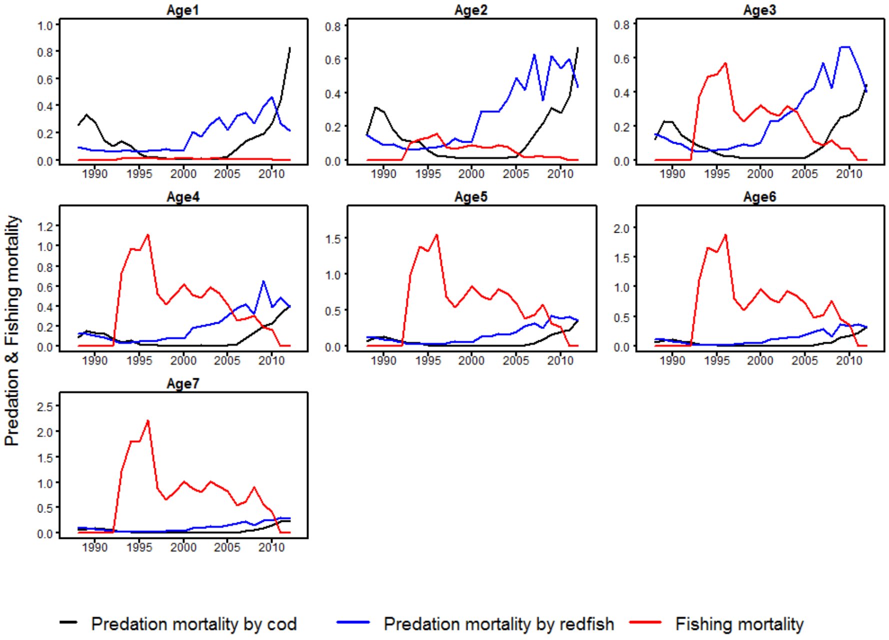

Fig. 3.2.2.16. Predation mortality by cod, by redfish and fishing mortality by the shrimp trawl fleet by age in the modeled shrimp stock. The Age 7 pannel shows the mortality rates for individuals of age 7 and older.

These results allow suggesting that during the recent decline of the shrimp stock, the recovery of the cod stock and the reduction of the redfish stock:

- Since 2005, predation mortality (including cannibalism) has been the main driver in the dynamic of all the three main commercial species in the Flemish Cap.
- In cod, predation (cannibalism) and fishing have occurred mostly at different ages in recent years (excepting age 3), while in redfish and shrimp they have worked simultaneously in a wide range of ages.
- Those years of excellent recruitment, cannibalism has been the main source of mortality both in juvenile cod and redfish, reducing significantly the expectative of increasing stock biomass.
- Predation by redfish, together with fishing have been the main factors driving to the collapse the shrimp stock. Predation by cod contributed to the decline of shrimp especially after 2007-2008.
- The increment of large cod in the stock, especially since 2010, has raised the predation mortality on redfish, and is the main factor inducing the decline of abundance and biomass in the last years.

Comparison with the Single species stock assessment models:

Cod

Trends in the estimates of total population biomass were very similar to the estimated by the current Bayesian XSA single species stock assessment model (Fig. 3.2.2.17) (González-Troncoso 2015). However the multispecies model produced higher values of biomass in the last years, which was due to differences in the estimated Spawning Stock Biomass (SSB). These differences in the total SSB could be partially explained by the higher estimates on recruitment in years 2005 and 2006, as well as by the difference in the age of the plus group. While in the multispecies model the plus group is set at age 12, in the single species model this group is defined at age 8. This difference could lead to a higher biomass in the SSB of the multispecies model in the last years, especially after a long period without fishing activity that would allow in the model a high proportion of survivors for those cohorts after 1996. Estimates of recruitment at age 1 were also higher in the multispecies model since 2010, but also was higher already in 2005 and 2006 which, as will be commented later on when the predation mortality is presented, could be due to cannibalism, not considered in the single species model. All these questions will need further research in the future.

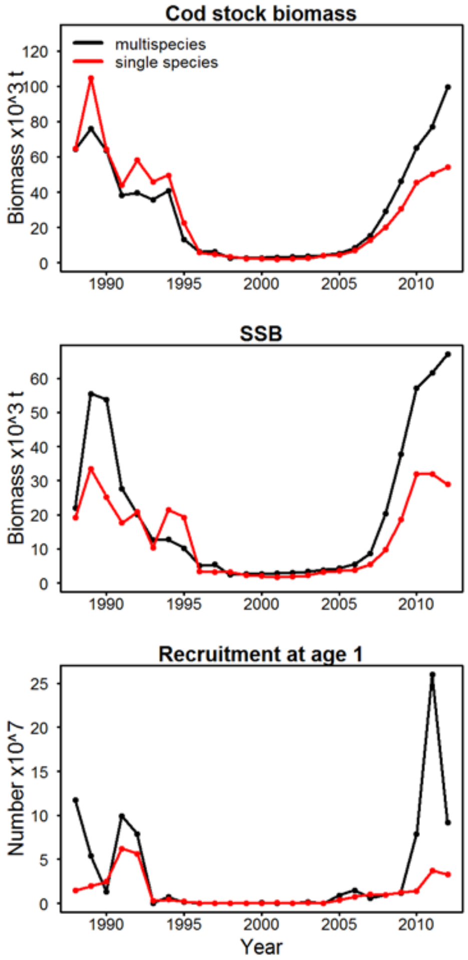

Fig. 3.2.2.17. Comparison of the estimated total cod stock biomass, SSB and recruitment at age 1 by the multispecies (black dotted lines) and the bayesian XSA single species model (red dotted lines).

Redfish

The estimated total stock biomass for individuals older than age 4 (Fig. 3.2.2.18) showed very important differences in relation to the estimates from the single species stock assessment model (Ávila de Melo et al. 2013). This differences, in addition to the fact that they by esence two different model approaches, may be related with different factors: 1) the fact that in the single species stock assessment only the beaked redfish species (*Sebastes mentella* and *S. fasciatus*) are included, while in the multispecies model, in addition to these species *S. marinus* was also considered. 2) Despite the single species stock assessment tried to include in 2013 part of the mortality due to predation (Ávila de Melo et al. 2013), it is not comparable to the modelling of natural mortality by predation considered by the multispecies model, which would lead to higher estimates of biomass. In addition to the potential differences induced by these two factors, despite the important by-catch from the shrimp fishery in these years survivorship of cohorts 1990-1991 is high in the multispecies model, in comparison with the low survivorship of this cohorts estimated in the single species model (Ávila de Melo et al. 2013). In relation to this, during the meeting in Halifax some of the members of the WGESA suggested including somehow the increase in natural mortality that the rise in biomass of Greenland halibut and Wolfish species (which also preyed on redfish in these years) might have induced. This, in addition to other factors as migrations, changes in natural mortality and catchability, as well as the difference due to a different plus group in both models (19+ in the single species model in comparison to the 25+ group in the multispecies model) will be explored in the future.

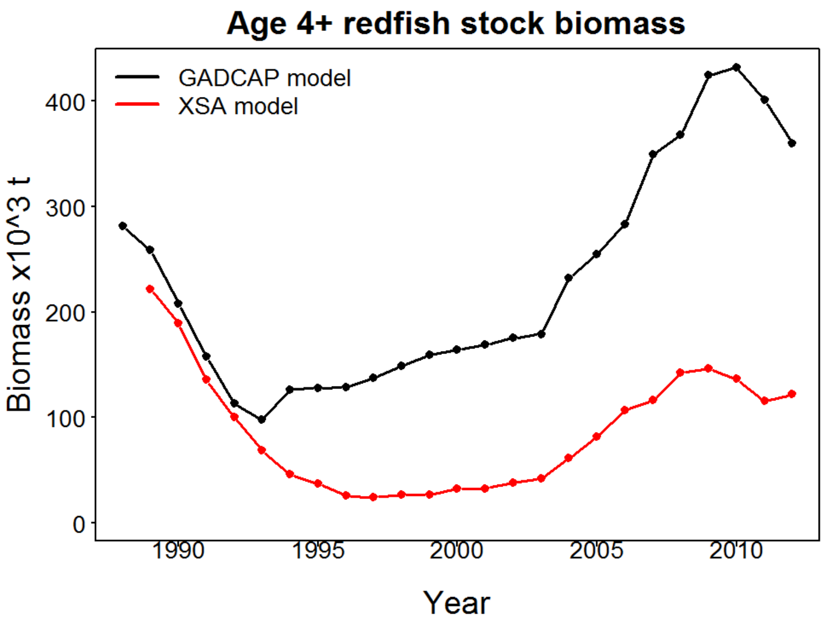

Fig. 3.2.2.18. Estimated total stock biomass by the multispecies (black dotted line) and the XSA single species stock assessment model (red dotted line) (Ávila de Melo et al. 2013) of individuals older than age 4.

Multispecies Maximum Sustainable Yield (MSY) estimates

In order to show the potential of this gadget multispecies model for the estimation of joint MSY for cod, redfish and shrimp a preliminary exercise was conducted. The fit model was employed to perform long term simulations, where:

- Simulation was run for the period 2013-2200
- Length-weight relationship, growth, consumption, and several other life-history related parameters were averaged to the period 2007-2012
- Ricker stock recruitment relationship fit to the model estimates of recruitment and SSB.
- 10 different levels of fishing mortality for each species: 1000 combinations (1000 different runs).
- For each of these 1000 runs estimate stock biomass, SSB, catches and recruitment for each species.
- Explore Stock biomass and MSY estimates using boxplots, categorized by fishing mortality for each species.

Figures 3.2.2.19 and 3.2.2.20 showed preliminary estimations for total stock biomass and MSY respectively. The boxplots depict the 25 and 75 percentiles in the lower and upper box limits, and the median in the black centered line. Despite the model is still in an early stage of development the overall values of biomass and MSY estimated for each species in relation to changes in fishing mortality in the other species were in sensible orders of magnitude. In addition it showed interesting patterns result of the negative effect of fishing mortality in prey or predator stocks. On this regard, it is interesting to note that the expected patterns of decrease in biomass as result of increasing fishing pressure were observed in all the three stocks. But other than this trivial fishing-stock reaction, more interesting secondary reactions were observed like the negative effect of higher fishing mortality on redfish or shrimp in total production and MSY for cod. The effect of prey abundance on predator growth has not been model at this stage, and this negative impact was the result of the increased cannibalism that the reduction in main prey as redfish and shrimp produced in cod stock. It is also interesting the positive effect in redfish biomass and MSY produced by increasing cod fishing mortality. The same is observed in shrimp biomass and MSY in relation to redfish and cod fishing pressure.

In conclusion, estimated stock biomass and MSY values cannot be taken for any management decision at this stage, since the SSB-Recruitment relationships and the multispecies model that produce these estimations still need further work, improvements and checkings. However, it is evident that the multispecies model for the Flemish Cap is already producing estimates and simulations of population dynamic that are in reliable orders of magnitude. The model also reproduces with high fidelity the trophic interactions among species, and can already estimate predation mortality by age, and perform long term simulations to explore different fishing and environmental scenarios. These are two very useful outputs that in the future could be considered for stock assessment and management decisions.

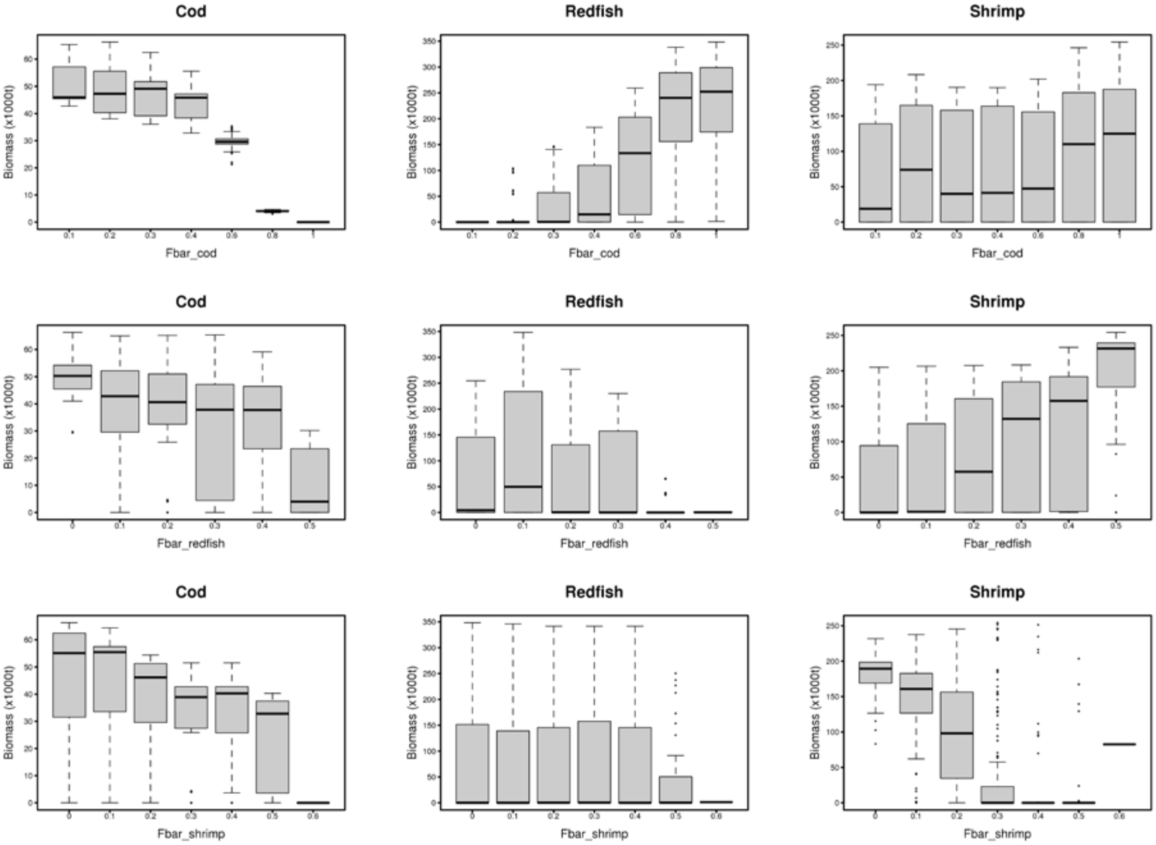

Fig. 3.2.2.19. Estimated stock biomass by species (defined by column) under varying fishing mortality for another species (defined by row). The boxplots contain the variability of estimated stock biomass for all the possible combinations of fishing mortality for the other two species. Thus, the right column depicts the biomass of shrimp on the y-axis under different target fishing mortalities on cod (top), redfish (middle) and shrimp (bottom) on the x-axis.

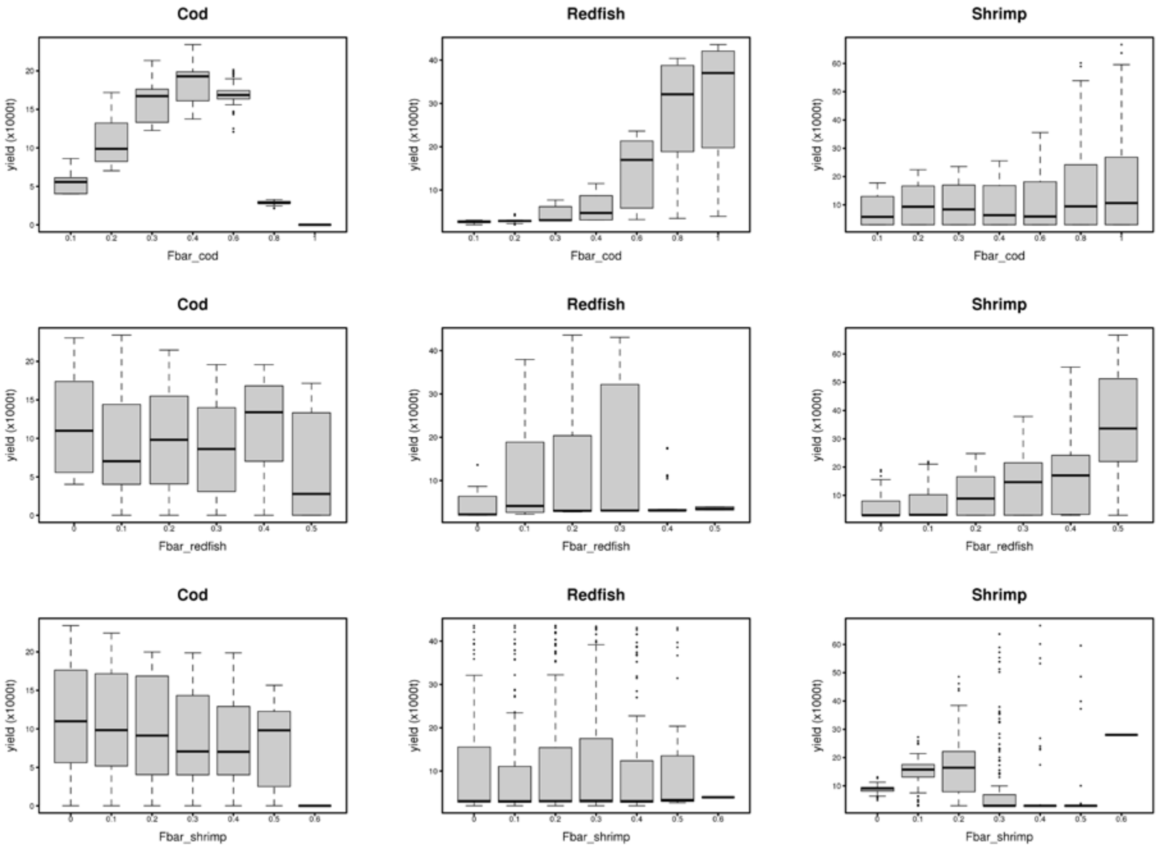

Fig. 3.2.2.20. Estimated MSY by species (defined by column) under varying fishing mortality for another species (defined by row). The boxplots contain the variability of estimated MSY for all the possible combinations of fishing mortality for the other two species. Thus, the right column depicts the MSY of shrimp on the y-axis under different target fishing mortalities on cod (top), redfish (middle) and shrimp (bottom) on the x-axis.

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ToR 3.2.3. Progress on Ecosystem Production Potential (EPP) models, and their application to develop guidelines for Total Catch Ceilings (TCC)

Introduction

The NAFO Roadmap aims at defining sustainable levels of exploitation by using a nested 3-tiered process, where Tier 1 corresponds to total catch levels at the Ecosystem Production Unit (EPU) scale, Tier 2 aims at distribution the total catch at the EPU level among commercial stocks taking into account species interactions, while Tier 3 uses single-species stock-assessments to evaluate the sustainability of the exploitation level defined by the previous two tiers at the stock level.

In 2015, SC produced for the first time a set of Guidelines for Total Catch Ceilings (TCC) for the three EPUs that are currently being targeted for developing pilot EAF exercises, the Flemish Cap (3M), the Grand Bank (3LNO), and the Newfoundland Shelf (2J3K) (NAFO 2014, 2015). These guidelines were based on the Fisheries Production Potential (FPP) for these systems, estimated through Ecosystem Production Potential (EPP) models (Koen-Alonso et al. 2013), in combination with an evaluation of current productivity state, coarsely approximated by the total biomass estimated in these EPUs from Research Vessel (RV) surveys, and considering the assumption of a relatively constant Biomass/Production (B/P) Ratio at the EPU scale (NAFO 2014, 2015). This process indicated that the Flemish Cap appears to be producing at its maximum capacity, while the other EPUs still show impaired productivity, which led to use a penalty factor of 50% when setting the TCCs for these systems in the guidelines developed (NAFO 2014, 2015). Current TCC guidelines group catches into “Standard Demersal Components” (SDC), which aggregates all traditional groundfish and shellfish commercial species, and “Other Components” (OC), which captures pelagic and benthos species, and provides TCC guidance levels for this aggregates.

Key to the process of building a reliable Tier 1 structure, it is the development of EPP models with an adequate level of resolution for the scales involved in this tier, as well as the definition of TCCs for the appropriate aggregates, which can conform to the requirements for Limit Reference Points (LRPs) in the context of the NAFO Precautionary Approach (PA).

During its 8th meeting, WGESA continued working on improving the EPP models used in Tier 1, as well as on the rationale for using TCC as an LRP. WGESA also examined the level of resolution at with the TCC advice is provided, to explore if the additional insights can be gained by exploring more disaggregated TCC levels.

An updated Ecosystem Production Potential (EPP) model

The model structure used to derive the current guidelines (Fig. 3.2.3.1) can be considered a version 1 of the EPP model (EPP-v1). This model captures the basic energy pathway in a marine ecosystem, and in addition of its use in NAFO (Koen-Alonso et al. 2013), it has been used to provide estimates of Fisheries Production Potential (FPP) for marine shelf ecosystems around the world (Rosemberg et al. 2014). However, this model structure is limited in its ability to provide estimates for some important ecosystem components which are target for fisheries in some ecosystems. The EPP-v1 aggregates productivity of benthos in a single node within the model, so estimation of FPP for some key exploited benthic producers, like bivalves, for which not only wild stocks are fished, but also represent a node from where an important fraction of the aquaculture productivity is based (e.g. open waters mussel farms are deriving its productivity form this node in the context of the EPP model). In addition to this limitation, the EPP-v1 model has a very simplified representation of the microbial loop, which is an important element in regulating overall ecosystem productivity, and it is expected to be particularly sensitive to the impacts of climate change. On this basis, the EPP model structure was updated to provide a more useful (from a fisheries application perspective) representation of benthos productivity, as well as a better resolved depiction of the microbial loop and its connectivity with the benthic energy pathway. This version 2 of the model structure (EPP-v2) is shown in Fig. 3.2.3.2.

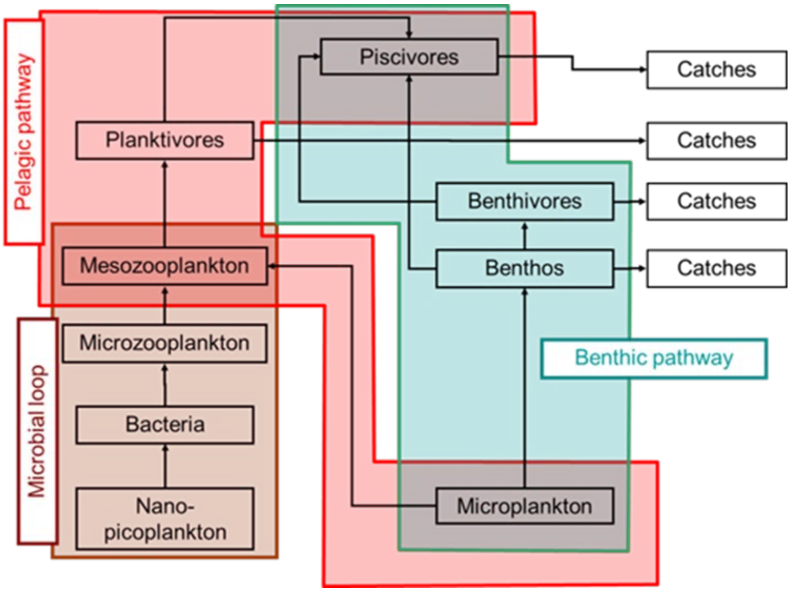

Fig. 3.2.3.1. Model structure for EPP model version 1. This model structure is the one used to develop the TCC guidelines adopted by SC in June 2015 (NAFO 2015).

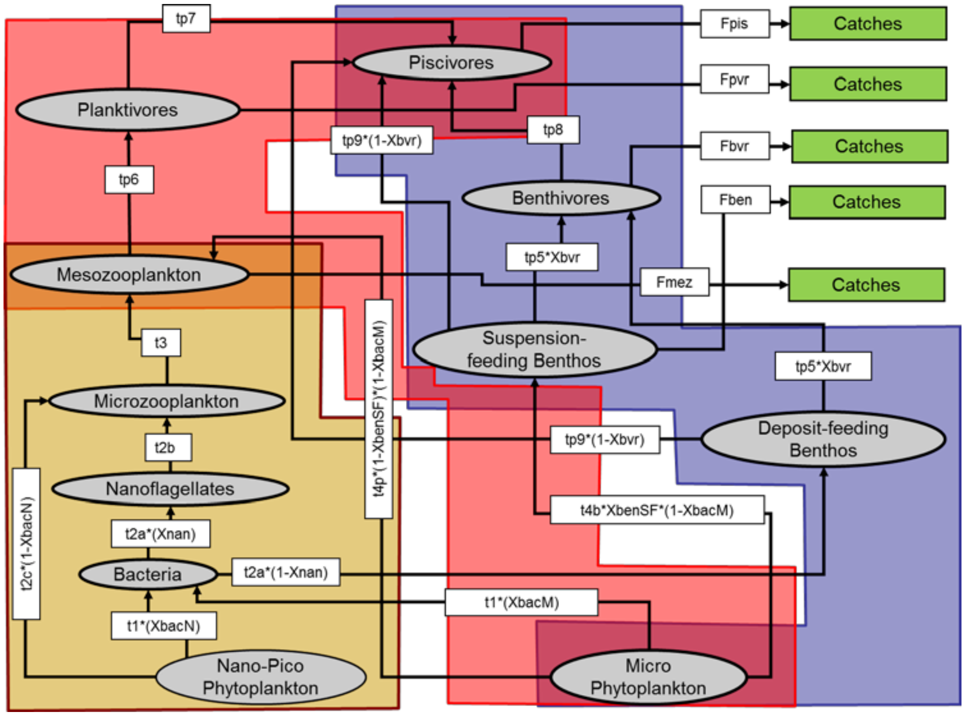

Fig.3.2.3.2. Model structure for EPP model version 2. The labels in the arrows indicates the specific parameters regulating these connections. Although this model structure allows for estimating FPP on mesozooplankton (e.g. krill fisheries), all exercises so far have assumed no fishing on this model component. In terms of energy pathways, the blue background corresponds to the benthic pathway, the red one corresponds to the traditional pelagic pathway, and the yellow one corresponds to the microbial loop.

The two versions of the model were ran with comparable parameterizations to compare the outputs of these two model structures. One key parameter in EPP-v2 is the fraction of bacterial production available to deposit feeding benthos (*1-Xnan*), which effectively defines the strength of the bentho-pelagic coupling in the model. Since there is little information to parameterize this link at the ecosystem level, multiple fractions were considered, and their impact on production in each of the model nodes evaluated. Finally, this fraction was represented using a uniform distribution to incorporate the uncertainty about its actual value (Fig. 3.2.3.3). Overall, the comparison between the two model versions indicated very little difference in the productivity of most exploitable nodes, but highlighted an important increase in overall benthos productivity (Fig. 3.2.3.3). From the perspective of the pilot EAF exercises being developed for the Flemish Cap, Grand Bank and Newfoundland Shelf EPUs, the differences between the two model configurations have only minor impacts, suggesting that production potential of upper trophic levels appears reasonably captured.

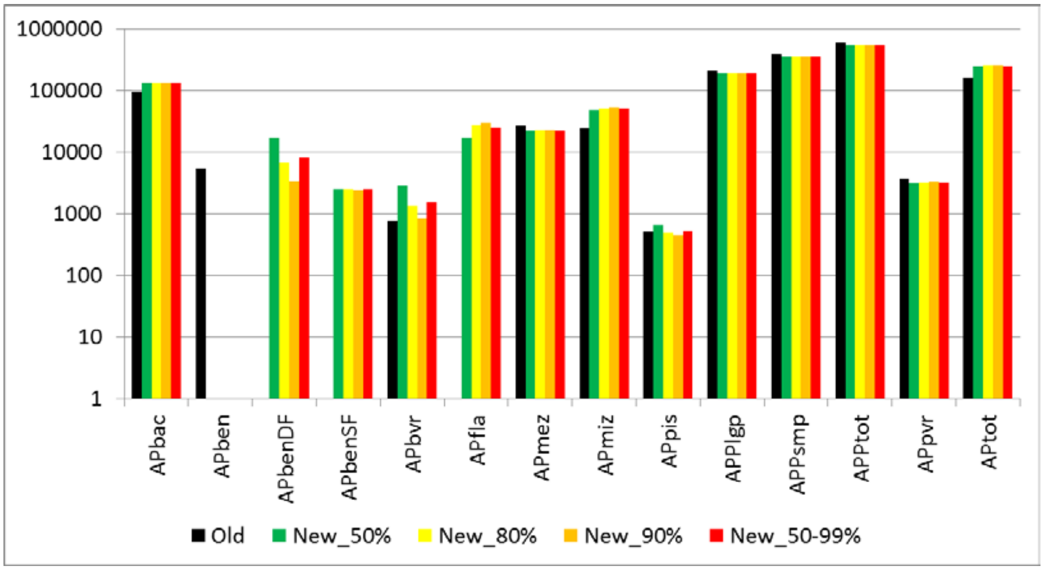

Fig. 3.2.3.3. Comparison of EPP-v1 and EPPv-2 runs. The bars correspond to production at each node, and include multiple runs for EPP-v2 with varying fixed levels for *Xnan*, and a final run using a uniform distribution between 0.5 and 0.99. Since the fraction of bacterial production available to deposit-feeding benthos is defined as *1-Xnan*, this final parameterization implies from a very strong bentho-pelagic coupling (50% of bacterial production production goes the benthos), to a very weak coupling (only 1% of bacterial production going to the benthos).

Developing TCC as an ecosystem level Limit Reference Point (LRP)

The overall process to estimate FPP is summarized in Figure 3.2.3.4. Key to the estimation of FPP is the selection of an ecosystem-level exploitation rate that can be considered sustainable. The current guidelines (NAFO 2015) used a range of exploitation rates of 20-30%, where these values were proxies for the *f-ratio*, the ratio between new and total primary production, which has been suggested as an upper limit for sustainability in these kinds of models (Iverson 1990, Koen-Alonso et al. 2013, Rosenberg et al. 2014). Due to the scarcity of *f-ratio* estimates, it is common to use the ratio of microplankton to total primary production as a first-order approximation (Rosenberg et al. 2014). On this basis, WGESA used the values compiled by Rosenberg et al. (2014), and defined an ecosystem-level maximum exploitation rate as the median of all the microplankton/total production values for large marine ecosystems around the world. This value was 20%.

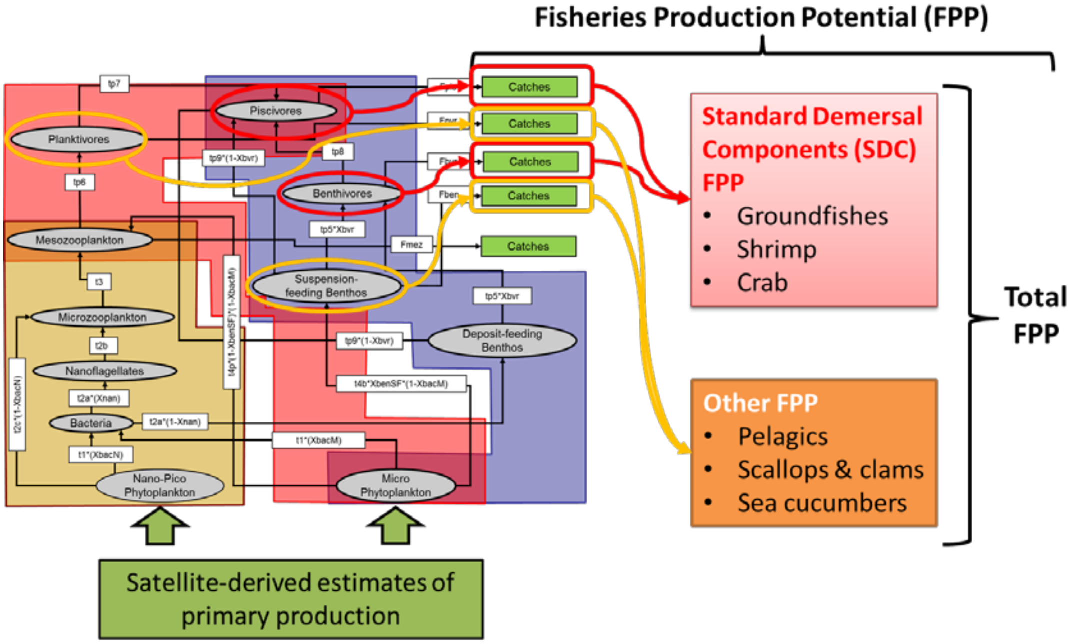

Fig. 3.2.3.4. Schematic depiction of the process to estimate FPP from the EPP model, including the discrimination between SDC and Other FPP.

Using the newly estimated value of 20% for the maximum exploitation rate at the ecosystem level, and in the ideal case of the ecosystem being producing at its maximum capacity, the estimated FPP would indicate the upper limit for sustainable total catches in the ecosystem. In this case, FPP will be the index to use to define a TCC LRP.

If the ecosystem is not fully functional, and its actual productivity is less than its potential, then FPP estimates need to be adjusted downward to reflect the current lower productivity of the system. At the present time, the approximate fraction of total current biomass/total maximum biomass (from RV surveys) is the index being used by WGESA to define the current productivity state, and to define a penalty factor to be applied to the estimated FPP.

The derived TCCs from the full or adjusted FPP estimates are not expected to be updated annually. The EPP models are not dynamic, and they should be used to set overall limits that can be revised periodically (e.g. every 3/5 years) to keep them reflecting the current productivity level of the ecosystem, but tracking short-term interannual variability is beyond the scope of these models. The resolution of analyses at the Tier 1 level is aimed to provide an overall envelope for sustainable levels of exploitation, not to provide precise figures. The goal is to get the overall magnitude right; the following Tiers 2 and 3 are the ones that should narrow down exploitation rates.

In the context of the NAFO PA, the requirement is to have a low probability of exceeding any LRP. Since the flows in the EPP model are defined using distributions, not fixed parameter values, the process defined in Fig. 3.2.3.4 renders distributions of FPP values. Therefore, the emergent distributions of FPP values can be used to define a LRP that has a low probability of exceeding the actual maximum level of sustainable exploitation represented by the FPPs distributions.

If we define the TCC level as either the FPP distribution emerging from the process described in Fig. 3.2.3.4, or that distribution multiplied by a penalty factor if the ecosystem is not fully productive, then that distribution encapsulates the uncertainty associated with the actual productivity at the ecosystem level. Therefore, we can use percentiles of that distribution to define appropriate LRPs at the ecosystem level (Fig. 3.2.3.5). For example, if we choose the median of that distribution as LRP, then there is 50% probability that the true TCC value is above the selected LRP. This probability level cannot be considered a low probability. Furthermore, a LRP defined higher than the median of the distribution would not comply with **any** definition of "low probability" as required by the NAFO PA framework. Following this rationale, WGESA proposed the use of the 25% percentile of the TCC distribution as the value for the LRP. This level will ensure that, if catches actually get to the LRP, there would still be a 75% probability that the catches have not exceeded the true underlying level of maximum sustainable exploitation. This would ensure that the LRP implemented is consistent with NAFO PA principles.

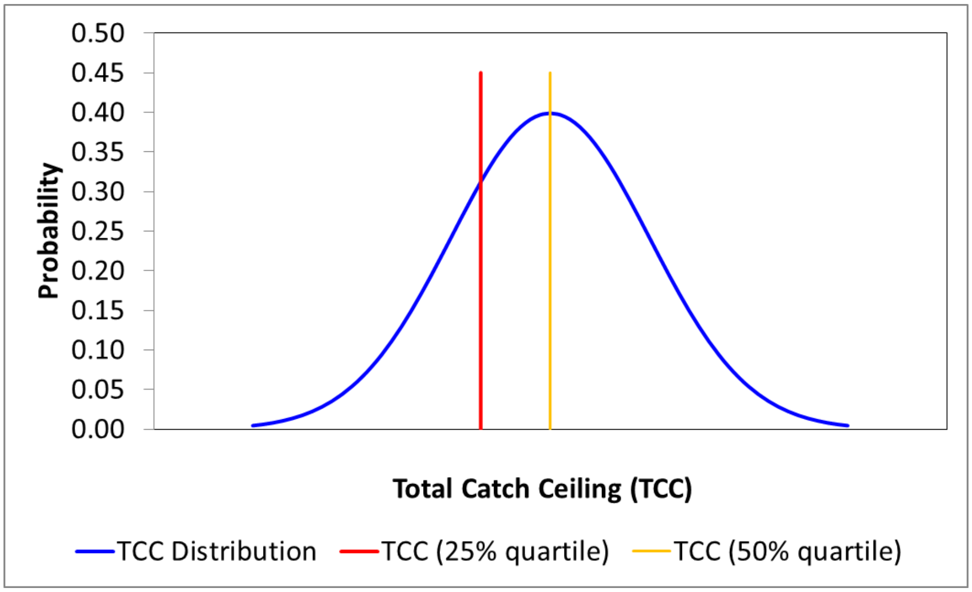

Fig. 3.2.3.5. Schematic representation of the TCC distribution, with indication of the 25% and 50% percentiles. The use of the 25% quartile as point value LRP renders a low probability of exceeding the LRP. The probability of exceeding the LRP corresponds to the area under the TCC distribution to the left of the LRP point value.

WGESA updated the TCC guidelines by considering the FPP distributions obtained from EPP-v2 models, and using similar considerations as in previous exercises (a 50% penalty factor for the Grand Bank and Newfoundland shelf EPUs, and assumptions that only 50% of the pelagic node and 10% of the suspension-feeding benthos node productivity were associated to species of current commercial value).

The estimated fisheries productivity was aggregated into SDC and Other components, and following the *rationale* described above, the 25% percentile of the TCC distributions was proposed as LRP for these aggregates (Table 3.2.3.1). Since the median of these distributions represents the point beyond which, if exceeded, the probability of exceeding the LRP is higher than not exceeding it, the medians are informative because they represent the point where catch levels would be in direct conflict with the NAFO PA framework. All current NAFO fisheries are exploiting the SDC aggregate.

In the Flemish Cap (3M), there are only NAFO managed fisheries, while in the Grand Bank (3LNO) and Newfoundland Shelf (2J3K) there is a combination of NAFO and DFO (Canada) managed fisheries. WGESA did a comparison of the total catches in these EPUs with the proposed TCC Guidelines, including a preliminary compilation of the cumulated TACs in these ecosystem units, both from NAFO and DFO managed fisheries (Fig. 3.2.3.6). The cumulated TAC compilation was done under several assumptions (e.g. when a TAC is given for a stock that straddles across EPU boundaries, the fractions in the catches between EPUs was used to split the TAC between EPUs), so they should only be considered illustrative at the present time.

Table 3.2.3.1. Updated guidelines for Total Catch Ceilings (TCC) for the Flemish Cap (3M), Grand Bank (3LNO), and Newfoundland Shelf (2J3K) Ecosystem Production Units (EPUs). TCCs are provided for the Standard Demersal Components (SDC) and Other Components (OC) aggregates of species. SDC includes traditional groundfish stocks as well as shellfish species (e.g. Atlantic cod, Greenland halibut, American Plaice, Redfish, Yellowtail flounder, Witch flounder, Northern Shrimp, snow crab), while the OC includes pelagic and benthic species (e.g. capelin, herring, scallops, sea cucumbers).

	Standard Demersal Components (SDC)		**Others**	
	Proposed LRP (25% percentile of TCC distribution)	Median (50% percentile of TCC distribution)	Proposed LRP (25% percentile of TCC distribution)	Median (50% percentile of TCC distribution)
Flemish Cap EPU (3M)	52,000 tonnes	83,000 tonnes	75,000 tonnes	115,000 tonnes
Grand Bank EPU (3LNO)	116,000 tonnes	186,000 tonnes	170,000 tonnes	259,000 tonnes
Newfoundland Shelf EPU (2J3K)	87,000 tonnes	140,000 tonnes	130,000 tonnes	202,000 tonnes

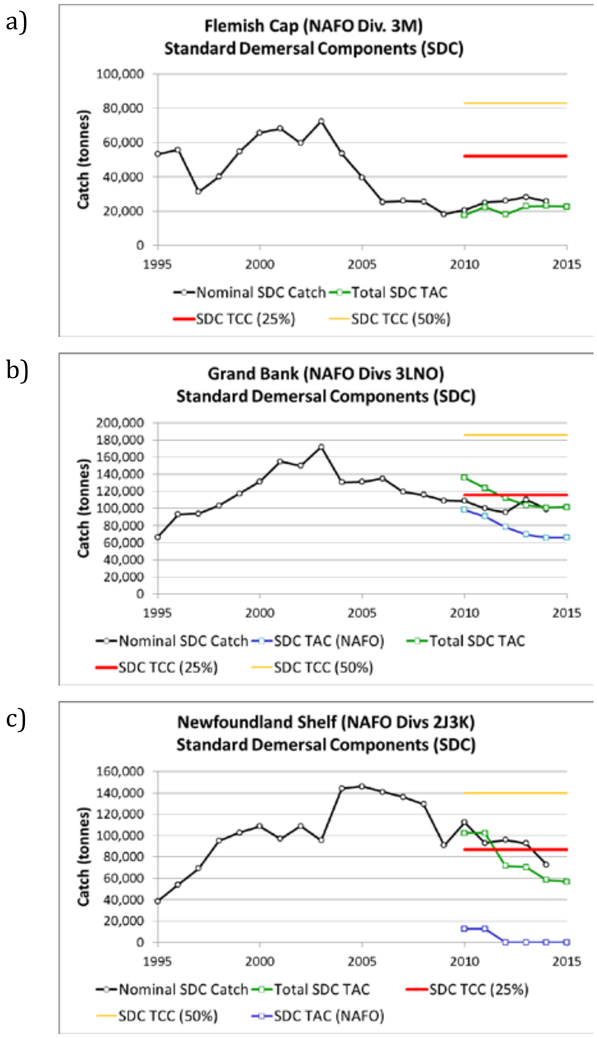

Fig. 3.2.3.6. Comparisons of total nominal catches with the proposed LRP (SDC TCC 25%), the median of the TCC distribution (SDC TCC 50%) and the cumulated Total and NAFO TACs corresponding to SDC stocks for a) the Flemish Cap, b) Grand Bank, and c) Newfoundland Shelf EPUs. The cumulated TAC values should be considered illustrative, and are subject to revision.

The comparative analysis between catches and TCC levels for the Flemish Cap, Grand Bank, and Newfoundland Shelf indicates that total catches are currently at or below the proposed LRP level for the SDC aggregate. However, the time series of catches clearly shows that total catches have been above the proposed LRP in the 2000s, suggesting the overall exploitation levels of these ecosystem units has been until recently beyond what can be considered sustainable at ecosystem level. The preliminary comparison of the TCC LRP and cumulated TACs also shown that in the early 2010s, the cumulated TACs exceeded the proposed LRP, but in recent years these cumulated TACs have come down below the TCC LRP. Some of these reductions in total catches and cumulated TACs are associated with the declines in shrimp stocks and the closing of these fisheries.

These simple comparisons indicate that current total catches at SDC aggregate scale are within a sustainable envelope. From an SDC perspective, catches in the Flemish Cap appear well within a sustainable level, while catches in the Grand Bank and Newfoundland Shelf appear close to the LRP level, suggesting that total catches in these systems should not be increased.

Furthermore, it would important for furthering the implementation of the Tier 1 of the Roadmap, which would include managing against a TCC LRP, that cumulated TACs within these ecosystems units are routinely compiled, presented, and considered as part of the management process.

Preliminary exploration of TCC within the SDC aggregate

The EPP models provide a bird's eye view of the productivity at the ecosystem level. Even though most species can be coarsely assigned to the different nodes in the models, reality is that many species actually spend stages/periods of their life history in different nodes. This is the rationale behind combining the piscivore and benthivore nodes within a single SDC aggregate for the purpose of advising on TCC values.

However, aggregating nodes has the potential drawback of hiding potential imbalances in the distribution of catches within an aggregate. For example, if all catches within SDC are directed to a single benthivore stock, the total catch level would appear as sustainable, even though the benthivore node itself and the specific stock being targeted would likely be overfished.

The Tiers 2 and 3 of the Roadmap are designed to address these issues, but until they are fully implemented and integrated, looking into TCC levels for each node can provide some insights on how sustainable the distribution of catches might be from an ecosystem level perspective. This exploration is possibly pushing the EPP models to their limit. We should be aware that we are exploring a scale and resolution for which ignoring those life history aspects that define how a stock productivity is partitioned among nodes would limit our ability of making strong inferences from the analysis. However, in the absence of Tier 2 models that could shed some light at this level, and considering that most fisheries are directed to adult fishes which would largely be producing within a given node, then this exploration can be useful for completing the advice.

In this context, the TCC reference points were calculated for each one of the two nodes within SDC, piscivores and benthivores, and nominal catches were compared with them. These results are conditional to how some key commercial species have been assigned to the nodes in the EPP model (Table 3.2.3.2). These assignations have been based on life history characteristics, as well as diet and stable isotope information, but they are not perfect. Depending on the specific stock, the actual matching of stock productivity within the assigned EPP node productivity would vary, and the analyses explored here assume a complete match.

Table 3.2.3.2. Assignations to EPP model nodes of key commercial species

Species	Node in EPP Model
American Plaice	Benthivore
Atlantic Cod	Piscivore
Capelin	Planktivore
Redfish	Piscivore
Greenland Halibut	Piscivore
Northern shrimp	Benthivore
Snow Crab	Benthivore
Witch Flounder	Benthivore
Yellowtail Flounder	Benthivore

The comparison between catches and TCC levels at the piscivore and benthivore node level clearly suggest that catches within the SDC aggregate appear unbalanced (Fig. 3.2.3.7). In the Flemish Cap EPU all catch is associated with piscivore node stocks (Fig. 3.2.3.7a); total catches are beyond the median TCC level estimated for this node, suggesting that piscivores are currently been overfished from an ecosystem scale perspective. Since a major driver of this result is the assignation of redfish to the piscivore node, and given the important trophic connection between cod and redfish in this EPU (see ToR 3.2.2), the simple additive nature of this analysis would not be expected to fully reflect the overall implications for sustainability at the node level. In these case, elucidating the full picture would require considering multispecies interactions.

In the Grand Bank EPU current catch levels appear reasonably balanced, with piscivores appearing fully exploited, and with some space for a small increase in catches on the benthivores node (Fig. 3.2.3.7b). However, this ecosystem shows a history of benthivores fully exploited since 2000, while piscivores show a period of important of overfishing between the late 1990s and mid 2000s (Fig. 3.2.3.7b).

In the case of the Newfoundland shelf EPU, catches also show indications of unbalance exploitation within the SDC aggregate during the last couple of decades. Benthivore catches have been consistently above the sustainability boundary at the EPP node level, only falling within it in 2014 (Fig. 3.2.3.7c). On the other hand, piscivore catches have been well within the sustainability envelope since the mid 1990s.

Overall, and taking into account these exploratory results together with the estimates catches and LRPs at the SDC aggregate level, it appears that current catch levels in the Grand Bank and the Newfoundland Shelf EPU are currently within the sustainability envelope, but with little space for growth with perhaps the only exception of piscivores in 2J3K.

The case of the Flemish Cap EPU is quite different. Overall catches at the SDC aggregate level appears well within sustainable bounds, but because this catch is severely biased towards piscivores, the sustainability at the ecosystem levels may be in jeopardy. To prevent impacts on this ecosystem unit, it would be advisable to moderate catches on cod, redfish or both. Even with all its caveats, the preliminary results from the GadCap model (ToR 3.2.2) could shed some light on how best to reduce fishing impacts on these key species of the Flemish Cap ecosystem

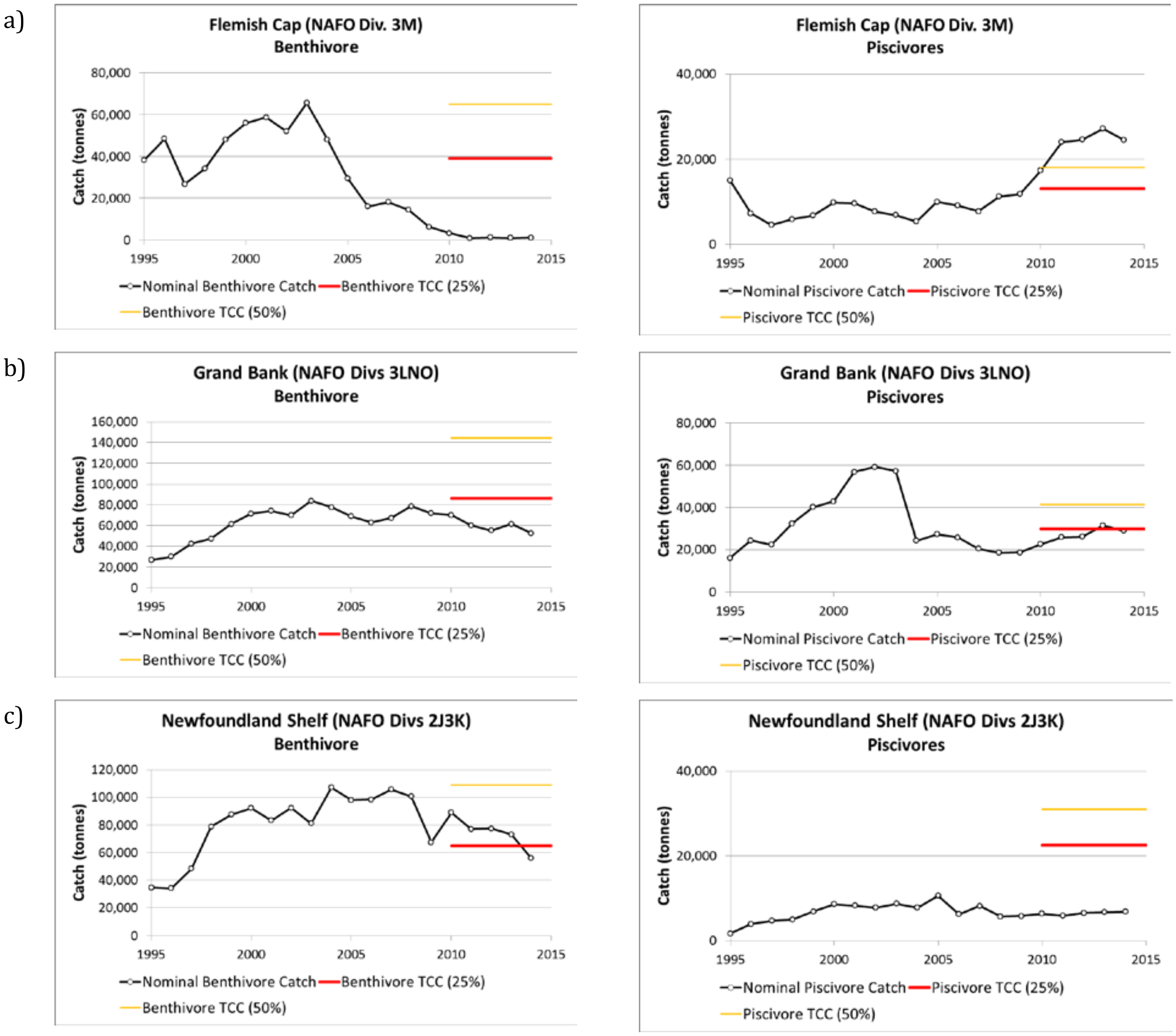

Fig. 3.2.3.7. Comparison of total nominal catches and TCC values at the scale of the piscivore and benthivores nodes in the EPP models. The two TCC values considered correspond to the 25% percentile of the TCC distribution (TCC 25%) (which correspond to the level proposed for the LRP in the TCC guidelines), and the median of the TCC distribution (TCC 50%) for a) the Flemish Cap, b) Grand Bank, and c) Newfoundland Shelf EPUs.

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ToR 3.2.4. Summary of ongoing NEFSC Multispecies and Ecosystem Modeling Efforts in Support of EBFM

Development of multispecies and ecosystem models has an extensive history at the Northeast Fisheries Science Center (NEFSC). Here, we focus on one element of current NEFSC modeling efforts designed to support Ecosystem-Based Fishery Management (EBFM). Other initiatives not explicitly covered here span the spectrum from development of extended single-species models to application of end-to-end ecosystem models (e.g. Atlantis and Ecopath with Ecosim) to evaluate requirements for the broader dimensions of marine ecosystem-based management.

Principal elements of the approach include (1) establishment of a transparent connection between single species and ecosystem-based advice using multispecies assessment models as a natural bridge, (2) development of multiple operating models to test assessment models and candidate management procedures, (3) application of assessment models spanning a spectrum of complexity to evaluate the issue of model uncertainty, (4) application of formal strategies of multimodel inference in applying results from the multispecies assessment models, (5) use of these results to assess uncertainty and risk, and (6) evaluation of tradeoffs in a bioeconomic context. The models under development are designed to accommodate spatial structure and to incorporate consideration of climate variability and change.

As a proof of concept, we have developed a prototype multispecies analysis for a 10 species complex for Georges Bank Data streams feeding into this process encompass fishery-dependent (both ecological and social-economic) sources, fishery-independent surveys, food habits data to identify and quantify biotic interactions among species, and oceanographic and climate data to track external forcing mechanisms.

The core analytical elements of the process involve development and testing of a set of indicators, multispecies assessment models, social-economic modules linked to the assessment models, and forecast models developed outside the assessment model framework to complement predictions made using these assessments (Fig. 3.2.4.1). The interplay between the operating models and the other analytical elements of the approach is an iterative process (Figure 1). The analysis culminates in a risk analysis accounting for key uncertainties and in the context of multiple candidate management procedures. The process is designed to provide management advice in the form of annual catch limits to match existing requirements under current management approaches on Georges Bank. The results will be provided as an interactive web-based product (Fig. 3.2.4.1).

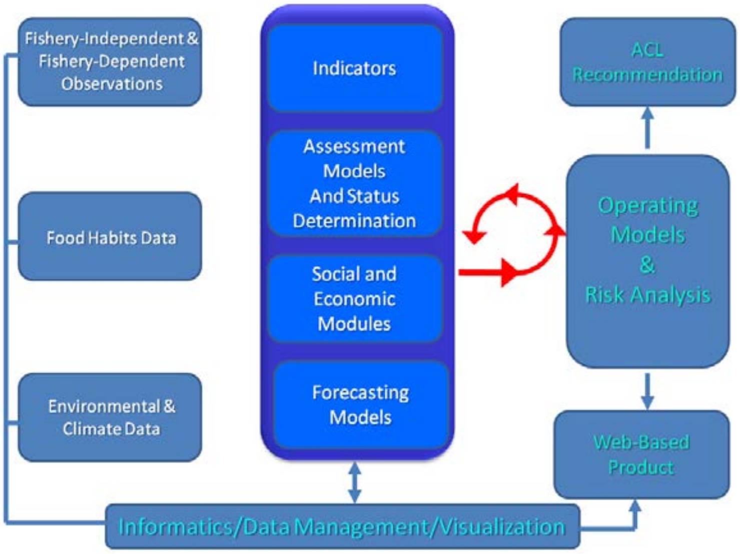


Fig. 3.2.4.1. Key structural elements of the NEFSC prototype multispecies analysis of Georges Bank.

Our overall approach entails the use of three different assessment model types encompassing simple multispecies production models applied both to individual species and to defined functional groups, multispecies delay-difference models that implicitly accommodate simple demographic structure (again for individual species and functional groups), and a complex multispecies statistical catch-at-age model applied to individual species (Fig. 3.2.4.2). Single species analogues of these models are familiar to resource managers in the region and we have deliberately attempted to frame our approach in a way that trades on this familiarity. Multiple estimation techniques including maximum likelihood, state-space, genetic algorithm and Bayesian methods will be applied to the production models in both aggregated and disaggregated forms to assess aspects of estimation uncertainty. We have developed Kraken, a multispecies production model framework designed to encompass a number of different functional forms, model structures, and estimation techniques.

A key issue in assessment and management of the Georges Bank system is the centrality of the mixed-species nature of the fishery. We define our functional groups as species that are caught together and share basic ecological characteristics (similarity in life history attributes, body size, etc.). Our interest in testing the performance of assessment models based on functional groups defined in this way centers both on their importance as key structural elements of the system and recognition that we cannot fully control the fishing mortality rates on the individual species comprising these mixed-species assemblages. These species, *inter alia*, share similar histories of exploitation and environmental forcing. Tests will be made to assess the performance of the functional group models against models in which the full species identity of all components is retained to see if they offer any advantage in assessing mixed-species fisheries.

Economic modules link to the assessment models to produce revenue streams and measures of profitability. They are being developed for direct use in tradeoff analysis. For the economic module we are also employing an empirical multispecies portfolio model approach to assess risk. We are developing forecast models using new methods in nonlinear time series analysis to complement the assessment models. We are using two operating models to serve as a virtual test beds to examine the performance of the assessment models and to evaluate the efficacy of alternative management procedures. These models, Hydra and EcoSim, are currently in different stages of development. Hydra has been developed at NEFSC. It is spatially structured, deals with length structured populations, and allows for multiple fleet sectors. The model is designed to accommodate climate/environment forcing on biological and ecological processes. The operating model will be used to test the performance characteristics of the simpler assessment models that can be used to provide reference points for management action.

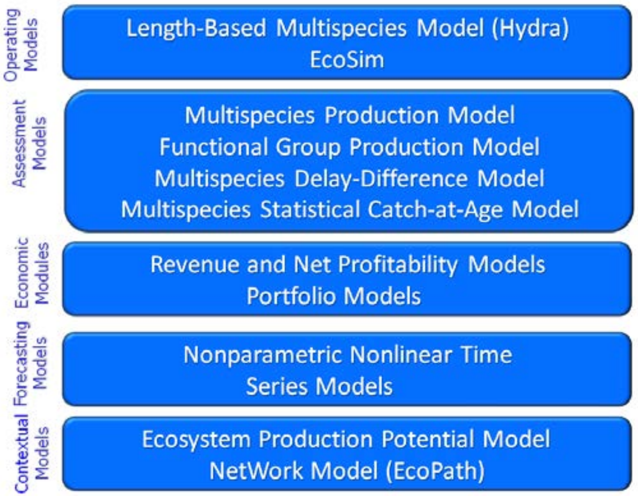


Fig. 3.2.4.2. Modeling elements to be employed in the prototype multispecies bio-economic model for Georges Bank.

ToR 3.2.5. Summary of ongoing research towardsa broader incorporation of benthic communities and function into the NAFO Roadmap to EAF

Ecosystem Approaches to Fisheries (EAF) are seen as essential for sustaining fish stocks and fisheries over the long-term, and require the integration of ecosystem components, typically through multivariate and multifunction analyses (Frid et al., 2008). Ecosystem Approaches to Fisheries (EAF) are intended to ensure that the planning, development, and management of fisheries will meet social and economic needs, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems. Achieving this purpose requires addressing components of ecosystems within a geographic area in a more holistic manner than is used in classical target resource-oriented management approaches. It requires identifying [geographically] exploited ecosystems together with explicit recognition of the many, and often competing, human interests in fisheries and marine ecosystems. As part of its "Roadmap to EAF", NAFO is developing a 3-tiered hierarchical process to define sustainable exploitation levels (Tier 1: ecosystem sustainability, Tier 2: multispecies sustainability, Tier 3: stock sustainability), and it is in the process of defining ecosystem units that can be used for implementing EAF. These units are expected to be the basis for ecosystem-level management areas, and are being used for estimating total fisheries production potential at those spatial scales (Tier 1). The first tier defines fishery production potential at the ecosystem level, taking into account environmental conditions and ecosystem state (overall ecosystem sustainability). The second tier utilizes multispecies assessments to allocate fisheries production among commercial species, taking into account species interactions and the trade-off among fisheries (multispecies sustainability). The third tier involves single-species stock assessment, where the exploitation rates derived from Tiers 1 and 2 are further examined to ensure single-species sustainability. This hierarchical sequence allows considering the sustainability of the exploitation at the ecosystem, multispecies assemblage, and single stock level. Core premises of the Roadmap are a) the approach has to be objective-driven, b) it should consider long-term ecosystem sustainability, c) it has to be a place-based framework, and d) trade-offs have to be explicitly addressed (NAFO, 2014).

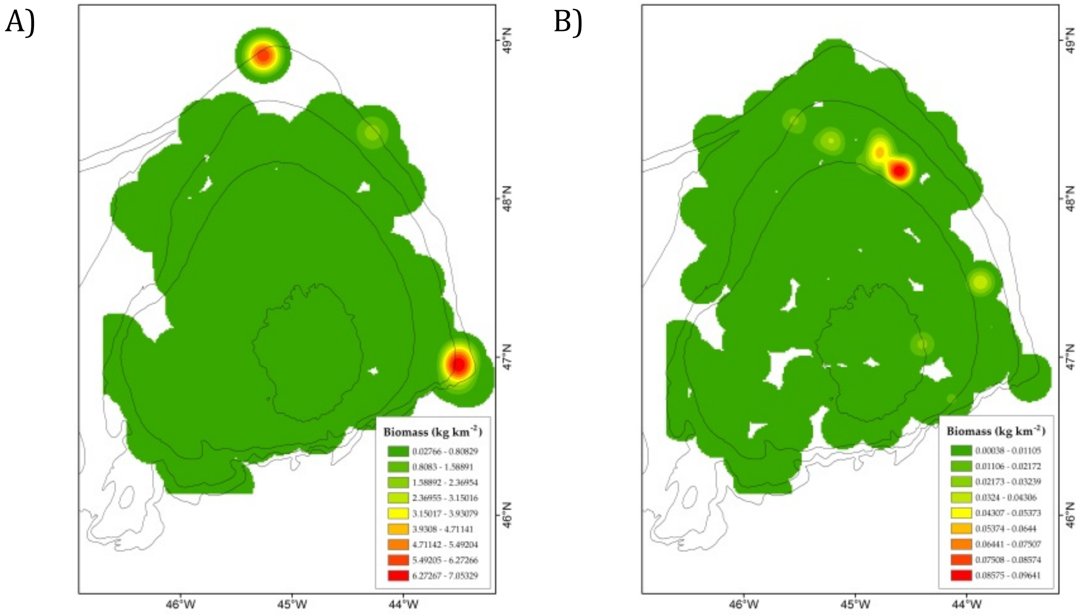
For the most part, considerations of benthic species and habitats has been limited to the assessment of significant adverse impacts on vulnerable marine ecosystems by bottom fishing and a broader analysis of fishing impacts. Although overall production of benthic components is included in the assessment of fisheries production potential (Tier 1, ecosystem sustainability), integration of fishing impacts on the benthos is done outside the assessments through identification of benthic areas of special concern, and setting up of management measures to mitigate/avoid fishing impacts on those areas. Petter et al. (2012) working in terrestrial systems has shown that maps of ecosystem functions can be incorporated into an ecosystem services framework. Building on this experience, we undertook a first analysis that combines biological traits analyses (BTA) with seabed mapping to identify areas according to dominant ecological function which can be incorporated into the Roadmap as part of the assessment of ecosystem sustainability (Tier 1). Large scale functional maps showing the distribution of organisms with particular biological traits (e.g., filter feeders, deposit feeders, carbon sequesters, support functions etc.) can provide a detailed spatial framework for incorporating benthic ecosystem function into the assessment of ecosystem state (Tier 1). Furthermore, identification of the environmental determinants for each function could allow evaluating responses of the function to fishing and future climate change. Spatial representation of the relative provision of benthic ecosystem services across a seascape is critical for considering ecosystem services within the overall EAF. We provide a demonstration of such ecosystem service maps for future incorporation into the EAF.

Methods

Epibenthic invertebrate fauna from a bottom trawl research survey targeting groundfish in the Flemish Cap area (northwest Atlantic) has been used in this example. Recently, the structure, composition and distribution of their epibenthic invertebrate assemblages in relation to environmental parameters and trawling intensity have been identified (Murillo et al. 2015). Seven spatially coherent epibenthic megafaunal assemblages were identified in this area nested within two major regional-scale faunal groups separated around the 500 m isobath. The top 5 species based on biomass and abundance of these two major groups were selected and the biomass of each feeding mode was mapped using kernel density analysis (Kenchington et al., 2014) to identify hotspots.

Results and Discussion

Active suspension feeding involves the organism using its own energy to transport water over its filtration surface. This was the dominant feeding type in the area due to the large captures of sponges in the southeastern and north of Flemish Cap (Fig. 3.2.5.1A), representing more than 97% of the total biomass. Sponges of the species found in this area have a large filtration capacity with up to 3000 litres of water per kg of dry weight (Kutti et al., 2013). Most of the sponge biomass was coincident with areas of high mean bottom current speed (Knudby et al., 2013). Passive suspension feeders use little energy in transporting water and most energy in capturing food brought to them. This group presented the maximum biomass values in the north of Flemish Cap between 500 and 1000 m depth due mainly to high biomass of deep sea corals and tunicates in this area (Fig. 3.2.5.1B), whereas surface deposit feeders (Fig. 3.2.5.1C) where distributed deeper than 1000 m in the north of Flemish Cap, and benthic predators were found along the 500 m isobaths (Fig. 3.2.5.1D). These types of maps representing ecosystem services can be used to identify areas according to dominant ecological function, which can provide a detailed spatial framework for incorporating benthic ecosystem function into the assessment of ecosystem state (Tier 1). Identification of the environmental determinants for each ecological function could also allow evaluating responses of the function to fishing and future climate change.



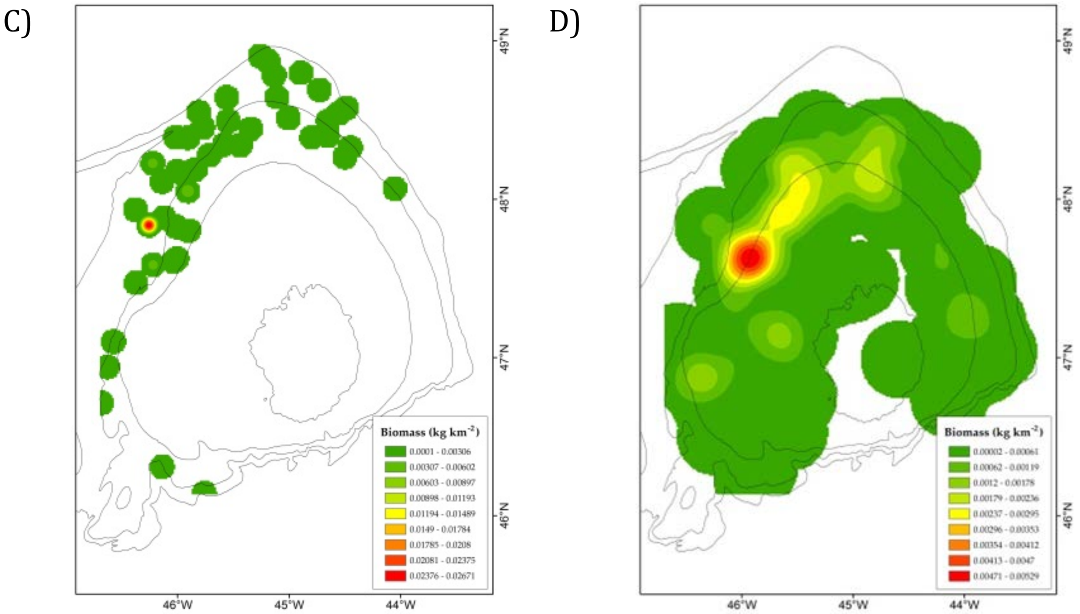


Fig. 3.2.5.1. Feeding Type Biomass (kg km^{-2}). Active suspension feeders (A), passive suspension feeders (B), surficial deposit feeders (C), predators (D).

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THEME 3: PRACTICAL APPLICATION OF ECOSYSTEM KNOWLEDGE TO FISHERIES MANAGEMENT

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

ToR 4.1. Improving the effectiveness of the science advice process in NAFO

ToR 4.1.1. Summary of research on how science advice is used in decision-making in fisheries management organizations

Suzuette Soomai, a member of the Environmental Information: Use and Influence research initiative at Dalhousie University (Observer to NAFO), presented an overview of her doctoral research on the role of scientific information in decision-making for fisheries management (Soomai, 2015). This doctoral research is the first comprehensive, empirical study of the role of fisheries information at the science-policy interface. The research was conducted through internships within NAFO, the Canada Department of Fisheries and Oceans- DFO, and the Food and Agriculture Organization of the United Nations- FAO, using a comparative case study approach and mixed methods. Using qualitative methods, data was collected and analysed from interviews of 78 key actors, e.g., scientists and managers, and direct observations of 15 science and management meetings. The leading drivers, enablers, and barriers in the information pathways (production, communication, and use of information), as well as the actors and information strategies in the organizations were revealed. The common drivers include: the demand for scientific advice; national, regional, and international policy development and organizational collaboration and networking; and trade in fish and fish products.

With regard to NAFO, the formal process of requesting scientific advice, i.e., the FC annual request for advice, is primarily based on questions seeking fish stock advice. However, ecosystem advice is being increasingly generated and used to develop NAFO management measures as questions are being asked on more complex topics related to ecosystems, e.g., risk-based management strategies and VMEs. The NAFO Secretariat plays an important role in facilitating the communication between the Contracting Parties and between the constituent bodies of NAFO, i.e., Fisheries Commission (FC) and the Scientific Council (SC). The key enablers and barriers in the information pathways in NAFO and recommendations for enhancing communication are described in the sections below.

Enablers in the Information Pathways in NAFO

1. Information generated in the formal process for requesting advice in NAFO (i.e., the FC request for annual advice) attains the attributes of credibility, relevance, and legitimacy. The advice is credible as it is produced by the scientists of the Contracting Parties, the technical reports and advice are relevant to the joint fisheries management needs in the Northwest Atlantic region, and the advice is legitimate as it is developed through collaboration among NAFO members. The credibility of the scientific advice is enhanced by the separation of science and management decision-making in NAFO. Advice flows through defined stages to reach the managers and decision-makers, i.e., managers ask the questions, scientists plan and conduct research, and scientists disseminate the findings (scientific advice) to the managers. Iterative communication, i.e., ongoing two-way dialogue between managers and scientists is an outstanding feature of the information pathways in NAFO.

2. The organizational structure of NAFO is being revised to keep pace with the growing complexity of fisheries management. Information flows between the SC and the FC are currently more iterative and formalized in many ways than in the early decades of NAFO and ICNAF. In addition, managers have become more science literate over time, partly due to their long working relationships with the scientists and the frequency of NAFO meetings and their attendance.

Barriers in the Information Pathways in NAFO

1. Scientific uncertainty in decision-making in NAFO was highlighted for ecosystem science. Communicating risk and uncertainty was a greater concern for ecosystem advice than for fisheries science. Communicating ecosystem advice is also challenging because the demand for scientific information in NAFO is driven by the need to manage fisheries and not ecosystems.

2. With regard to issues affecting its Contracting Parties, as demonstrated by Canada, decisions related to the implementation of EAF may be ahead of the ability of scientists to provide the necessary science advice to implement policies in the national organization.

Recommendations/Aspects to be noted for enhancing communication of scientific advice in NAFO

1. The creation of mechanisms to facilitate increased dialogue at NAFO meetings, e.g., joint FC and SC working groups can promote decision-making within more iterative contexts as they serve as communication bridges between the two constituent bodies. Overlapping membership of working groups also facilitates greater dialogue in decision-making. Overlap of memberships among standing committees in the Scientific Council can ensure communication among joint FC-SC working groups.

2. Formal mechanisms by which ecosystem science and advice will be given more weight in the advice to FC are also to be considered, e.g., transforming the current Working Group on Ecosystem Assessments (WGESA) to a Standing Committee dealing with ecosystem science.

3. The interfaces between NAFO and the national fisheries agency of the Contracting Party influence the work agendas in NAFO, the science that is undertaken, and the decisions that are made. Participation by national scientists, managers, and policy-makers of the Contracting Parties at NAFO FC-SC meetings enables information flow at the national and regional levels. Factors influencing policy-making and science in the Contracting Parties can have a direct impact on the success of NAFO in maintaining its mandate, e.g., limited resources for research and travel for collaboration on joint assessments, can weaken the contribution of scientific information by a Contracting Party to NAFO.

4. Stakeholder groups, such as NGOs acting as Observers, play a critically important role in NAFO and the national fisheries agencies of Contracting Parties by increasing attention given to complex issues, such as climate change impacts, at senior-decision-making levels.

Discussions of the Presentation of Results

In the discussions of the doctoral research members of WGESA suggested several topics for future work. These included the use of methods to quantify the measurements of information use and measuring the effectiveness of the organization with regard to use of scientific advice. The role of expert frameworks in the information pathways, such as the "Roadmap for Developing an Ecosystem Approach to Fisheries for NAFO" should be considered. The group also recommended that a similar presentation is delivered to other scientists at the June SC meeting and to NAFO managers at other meetings. The research focused on information pathways in operational-decision-making for fisheries management, however, the group believes that the national managers participating in NAFO play an important role in guiding higher level (strategic) policy-making, given the overlapping memberships of groups involved in operational and strategic decision-making in NAFO and the national fisheries agency of Contracting Parties.

References

Soomai, S. S. (2015). Elucidating the role of scientific information in decision-making for fisheries management. (Unpublished doctoral dissertation). Dalhousie University, Halifax.

ToR 4.2 (FC Request #4). Assessment of bottom fishing activities pertaining to the impacts on VMEs.

> **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 further requests that:
>
> a) that Scientific Council should take into account the protection afforded to VME areas outside the NAFO fisheries footprint in the calculation of the VME area and biomass at risk of bottom fishing impact;

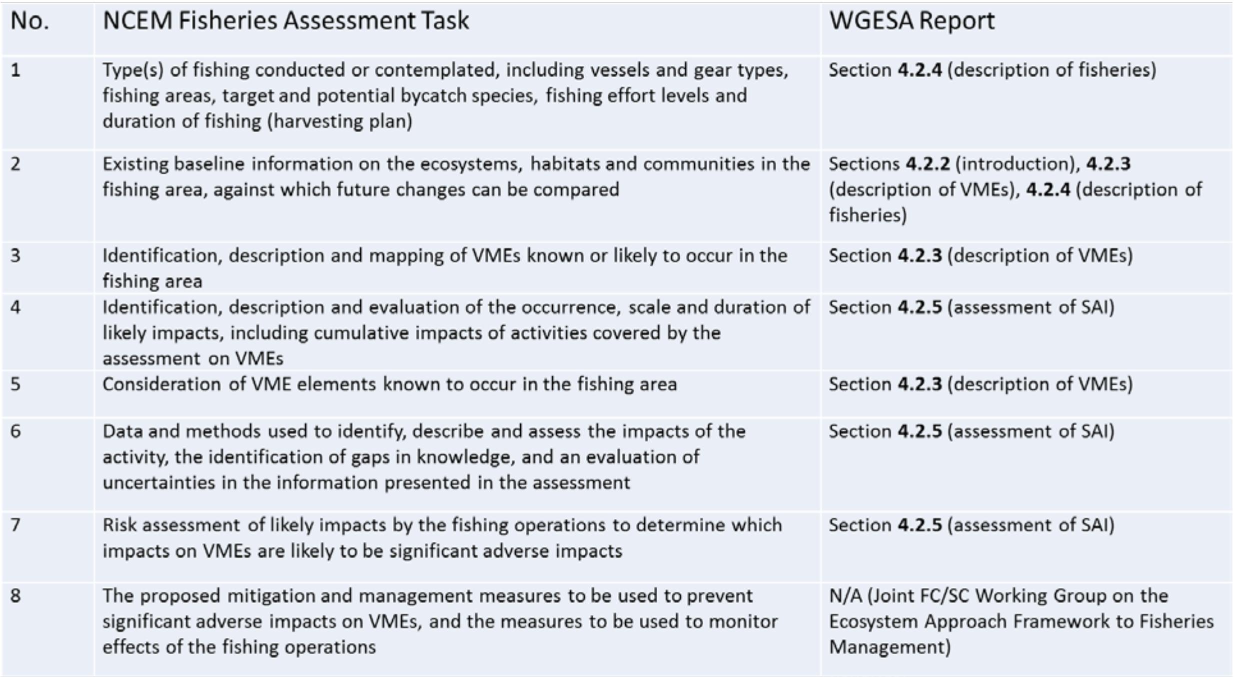
b) that Scientific Council refine VME kernel density analysis polygon boundaries, taking into account current understanding of distribution patterns in relation to environmental variables.

4.2.1. Background to the assessment

In 2012 WGESA was tasked with drafting a work plan for the reassessment of NAFO fisheries in 2016. Specifically, WGESA was requested by NAFO Fisheries Commission to provide guidance on how achieve the reassessment of all NAFO fisheries by September 2016 and every 5 years thereafter, identifying the necessary steps to be taken, as well as the information and resources to do so.

The requirement for the assessment of bottom fishing activities in the NAFO regulatory area (NRA) was broadly defined in the NAFO Conservation and Enforcement Measures (NCEM; NAFO/FC Doc 16/1), which sets out a number of issues to be addressed by the assessment, these in turn have been addressed in the present report as requested by Fisheries Commission in 2015 (see Table 4.2.1.1).

Table 4.2.1.1. NCEM bottom fisheries assessment issues and relevant sections of the present report in which they are addressed.



No.	NCEM Fisheries Assessment Task	WGESA Report
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)	Section **4.2.4** (description of fisheries)
2	Existing baseline information on the ecosystems, habitats and communities in the fishing area, against which future changes can be compared	Sections **4.2.2** (introduction), **4.2.3** (description of VMEs), **4.2.4** (description of fisheries)
3	Identification, description and mapping of VMEs known or likely to occur in the fishing area	Section **4.2.3** (description of VMEs)
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	Section **4.2.5** (assessment of SAI)
5	Consideration of VME elements known to occur in the fishing area	Section **4.2.3** (description of VMEs)
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	Section **4.2.5** (assessment of SAI)
7	Risk assessment of likely impacts by the fishing operations to determine which impacts on VMEs are likely to be significant adverse impacts	Section **4.2.5** (assessment of SAI)
8	The proposed mitigation and management measures to be used to prevent significant adverse impacts on VMEs, and the measures to be used to monitor effects of the fishing operations	N/A (Joint FC/SC Working Group on the Ecosystem Approach Framework to Fisheries Management)

The focus of the assessment is therefore on evaluating the risks of Significant Adverse Impacts (SAI) on Vulnerable Marine Ecosystems (VMEs) by bottom fishing activities. As such, the review of VME fishery closures conducted for NAFO in 2014 (SC Ref), combined with the latest data and information on bottom fisheries activities provides the basis for this assessment.

The content of the report is set out in four sections; dealing with: **4.2.2** introduction (summary of environment and general ecosystem background information), **4.2.3** description of VMEs to be assessed, **4.2.4** description of the fisheries, and finally, **4.2.5** A provisional assessment of SAI.

4.2.2. Introduction

4.2.2.1 Oceanographic conditions in the NRA

The NRA is influenced principally by two major ocean currents: the southward flowing Labrador Current to the east of the Newfoundland Shelf and Grand Banks and north of the Flemish Cap, and the North Atlantic

Current which represents the bulk continuation of the warm Gulf Stream, flowing in an east-north easterly direction to the south and east of the Flemish Cap (Stein 2007).

The Labrador Current is a continuation of the Baffin Bay current, which carries cold and relatively low salinity waters of Arctic origin, with two main branches. The small inshore branch carries approximately 15% of the water transport and hugs the coast of Newfoundland and is unlikely to influence the Cap, whereas the offshore branch follows along the shelf-break. The offshore branch of the Labrador Current splits north of the Flemish Cap, with the main branch flowing through Flemish Pass, east of the Cap and along the eastern side of the Grand Banks, where it is reduced to a width of 50 km and a flow of 30 cm s^{-1} while the weaker side-branch flows in clockwise around the northern and western side of the Cap (Petrie and Anderson, 1983; Stein, 2007). Geostrophic calculations reveal that the body of the Labrador Current reaches a depth of 250-300 m in the Flemish Pass and that the side-branch reaches a depth of ~200 m (Maillet and Colbourne, 2007). According to Stein (2007), the lower end of temperature-salinity profiles of the Labrador Current in the Flemish Pass is achieved at a temperature of 3.3°C and a salinity of 34.8 at a depth of 800 m, while in the side-branch this is achieved a temperature of 3.5°C and a salinity of 34.8 at a depth of 610 m.

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

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

4.2.2.2. 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, hinders the migration of the shallower benthic and demersal fish populations (but not deep water dwelling species) between the cap and the banks, 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 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).

4.2.2.3. Habitats

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 sea pens, which collectively can alter local conditions and provide refuge, food or a settling surface for other organisms. Collectively, such habitats are considered to be VMEs, 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. epifauna 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.

4.2.2.4. Communities

Fish

During the European Union fisheries surveys conducted yearly between 1988 and 2014, 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 conctrast, 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 1988-2014 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 de-trended 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; they are covered in greater detail by 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 have been published in Barrio Froján et al. (2015), whilst work identifying organisms at a finer taxonomic scale is still ongoing for selected taxonomic groups.

4.2.2.5. Description of ecosystem production units

Ecosystems are not homogenous; they are organized in a hierarchical way, where different physical and biological processes operate at different spatial scales. It is the integration of these processes in space and time what defines a functional system, where trophic interactions are main mechanism for transfer of energy among the different biological populations. From this functional perspective, three spatial scales have been identified as relevant for the development of ecosystem summaries and ecosystem-level management plans: Bioregion, Ecosystem Production Units (EPUs), and Ecoregion (DFO 2014, 2015). The EPU is the spatial scale considered more appropriate for integrated fisheries management plans because it defines a major geographical subunit within a Bioregion characterized by distinct productivity and a reasonably well defined major marine community/food web system.

Current analyses in the NAFO Convention area have been focused on continental shelves ecosystems from the northern Labrador to the Mid-Atlantic Bight, and have allowed identifying four major Bioregions (Newfoundland and Labrador Shelves, Flemish Cap, Scotian Shelf and Northeast US Continental Shelf) (NAFO 2014, 2015, Pepin et al. 2014). From these bioregions, only two extend into the NRA. The Flemish Cap Bioregion is entirely within the NRA, and the Newfoundland and Labrador Shelves Bioregion extend beyond Canada's EEZ into the NRA in the areas known as the Nose and Tail of the Grand Bank.

In terms of EPUs, the Flemish Cap Bioregion contains a single EPU (i.e. bioregion and EPU are the same, the shelf area within NAFO Div. 3M), while three EPUs have been properly identified in the Newfoundland and Labrador Shelves Bioregion: the Labrador Shelf EPU (shelf area within NAFO Divs 2GH), the Newfoundland Shelf EPU (shelf area within NAFO Divs 2J3K), and the Grand Bank EPU (shelf area within NAFO Divs 3LNO) (NAFO 2014, 2015, Pepin et al. 2014). Based on preliminary analyses, a fourth EPU in this bioregion can be associated with the shelf area in NAFO Subdiv. 3Ps. On this basis, only two continental shelf EPUs are in the NRA, the Flemish Cap and the Grand Bank. The first one is entirely within the NAFO fishing footprint, while only the Nose and Tail from the Grand Bank EPU are part of the NAFO footprint.

Comparative analysis of the productivity of these two EPUs and overall fishing levels indicate that these ecosystem units have been overfished in the past, with more severe overfishing levels in the Grand Bank EPU (Koen-Alonso et al. 2013, NAFO 2014). These EPUs experienced major changes in their fish communities during the last decades (NAFO 2010, Koen-Alonso et al. 2010, Pérez-Rodriguez 2012). In the case of the Grand Bank EPU, these changes are associated to a regime shift that has been formally recognized for the

Newfoundland and Labrador Shelves Bioregion during the 1990s (Buren et al. 2014). As a consequence of these changes, it is believed that the fisheries productivity of the Grand Bank EPU remains impaired until this day (NAFO 2014, 2015).

Taking into account current catches and productivity level, both EPUs can be considered fully exploited at the present time. The Flemish Cap productivity does not appear impaired, so this EPU is being exploited at its maximum potential. The current Grand Bank EPU fisheries productivity is estimated to be around 50% of its maximum potential, suggesting that rebuilding the functionality of this EPU could allow doubling current catch levels (NAFO 2014, 2015).

4.2.3. Description of vulnerable marine ecosystems

The description of VMEs in this section is in relation to the assessment of potential significant adverse impacts (SAI) on VMEs within the NAFO footprint of bottom fisheries (see Section 4). A full description of all VMEs and VME elements in the NRA can be found in NAFO SCS Doc. 13/024 (NAFO, 2013), including those VME elements not included in the present assessment on account of there being no bottom fishing activities operating in those areas (e.g., seamounts).

4.2.3.1. Defining, recognising and mapping VME

NAFO has identified 8 categories of VME, namely sponge grounds, large gorgonian corals, small gorgonian corals, sea pens, erect bryozoans, large sea squirts, cerianthid anemones, and crinoids (NAFO, 2014). These taxa were selected after a review of all invertebrate by-catch species taken in research vessel surveys, following the FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO, 2009), which provide general tools and considerations for the identification of VMEs. These VME categories are characterized by populations or assemblages of species with one or more of the following characteristics: slow growth rates, late age of maturity, low or unpredictable recruitment, or long-lived. In addition, they all create structural complexity through the provision of habitat for other species, and are characterized by complex physical structures. In these ecosystems, ecological processes can be highly dependent on these structured systems. Further, such ecosystems often have high diversity, which is dependent on the structuring organisms. This has been established for the sponge grounds in the NRA which have been shown to support increased biodiversity compared with non-sponge ground habitat (Beazley et al., 2013; Beazley et al. 2015).

NAFO Scientific Council has adopted formal definitions for many of the terms used in the FAO Guidelines (NAFO, 2014). There, VME are defined as “Under the structure-forming criterion, a VME is a regional habitat that contains VME indicator species at or above significant concentration levels. These habitats are structurally complex, characterized by higher diversities and/or different benthic communities, and provide a platform for ecosystem functions/processes closely linked to these characteristics.” (NAFO, 2013).

NAFO Scientific Council has used quantitative methods to determine the distribution of VME indicator species and define the extent of the VME. The spatial scale of these habitats is often larger than the footprint of a higher concentration observation. The primary tool used to quantitatively determine VMEs is kernel density analysis (KDE; Kenchington et al., 2014). This analysis identifies “hotspots” in the biomass distribution derived from research vessel trawl survey data, by looking at natural breaks in the spatial distribution associated with changes in local density (Figure 4.2.3.1.1). These natural breaks allow defining of significant area polygons. There is minimal interpolation to unsampled areas in this type of analysis (as opposed to species distribution modelling). However, it is recognized that the boundaries of the polygons can be influenced by the search radius used as well as the spatial distribution of the data (Kenchington et al., 2014) and that ecological knowledge (environmental niches) can further refine the polygon boundaries. Consequently, ground-truthing of candidate areas for protection has been recommended (Kenchington et al., 2014).

Experience in WGESA has shown that the KDE as applied to the data available in the NRA, is a robust method for identifying coral and sponge VME. New survey data acquired in subsequent years typically falls within the existing kernel boundaries. Further ground-truthing with benthic camera systems has consistently identified coral and sponge habitats within the KDE polygon boundaries. However, the patch size of erect bryozoans and large sea squirts is smaller than that of the tow length where they are found on the tail of Grand Bank. These taxa are known to attach to hard substrate and likely form aggregations (significant catches) in areas where suitable habitat is found. For these, the KDE polygons are much larger than the VME and the WGESA has recommended that conservation of these VMEs be achieved through protection of the individual tows, rather than the more expansive KDE polygon.

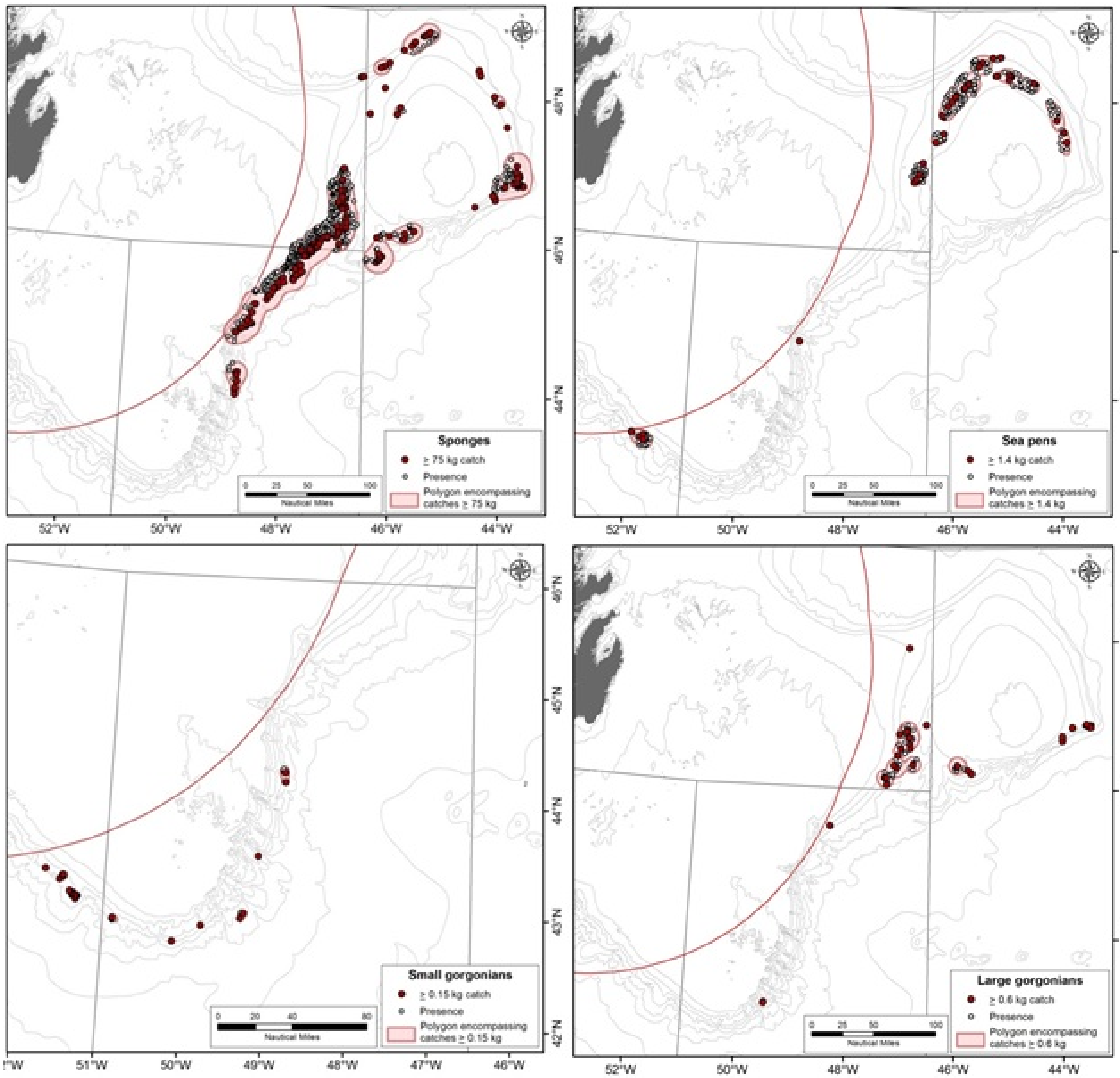


Fig. 4.2.3.1.1. Location of kernel density-derived polygons for sponges, sea pens, small and large gorgonian corals used for the assessment of SAI.

The starting point for the assessment of SAI by members of the WGESA was the KDE polygons produced for the review of the closed areas in 2014 (NAFO, 2013); this approach was endorsed by the SC at its June meeting (NAFO, 2014). The Cerianthid anemones, erect bryozoans and large sea squirts must be assessed for SAI based on the location of individual RV trawls where large catches were taken. For the former there is no quantitative criterion for defining "large catches" but for the others, the KDE can be used to identify significant concentrations (NAFO, 2013).

4.2.3.2. Modified VME polygon boundaries

The KDE method of mapping VME extent (described above) does not explicitly take into account the known data on habitat characteristics associated with the VMEs. As such it was recommended by NAFO Scientific Council in June 2015 that environmental data should be included in the species distribution modelling.

Random forest-generated presence/absence species distribution models have been produced for some of the VME indicators; namely: sponge grounds (Knudby et al., 2013a), large gorgonian corals, sea pens and the black corals (Knudby et al., 2013b), in the NAFO regulatory area using a suite of 10 (sponges) and 23 environmental variables (NAFO, 2014). All models performed well, producing cross-validated AUC values of 0.982, 0.937, 0.885 and 0.888 respectively. Prediction surfaces for the three species groups produced clearly-defined areas of high occurrence probability. Those models used a suite of model-based environmental variables describing seasonal chlorophyll-a, surface and bottom sea temperature and salinity, currents, and bottom shear, as well as depth and slope. The interpolated variables and the distribution models were evaluated with independent data (CTD, NEREIDA box core data, seafloor imagery) to the extent possible.

Downie (2015) presented new random forest models of biomass which focused on benthic variables derived from the NEREIDA surveys. She used multibeam echosounder bathymetry gridded to 75 m cell size to derive a number of derivative spatial data layers describing topographic attributes from the bathymetry. These included bathymetric roughness and standard deviation (calculated within a 3-cell neighbourhood) and rugosity (calculated within a 5-cell neighbourhood). Eastness and northness described the main direction (aspect) of the slope, whilst the Bathymetric Position Index (BPI), described the elevation of each cell in relation to the average in the specified neighbourhood (Downie, 2015). Layers describing sediment composition, namely the percentage values of sand, clay, silt and organic carbon, were produced from 314 box core Particle Size Analysis (PSA) samples (Downie, 2015), although the WG recalled the issues of interpolating such data given the need to consider surficial features such as slumping etc. that occur between data points. Therefore, these variables used a different set of predictor variables from those used previously. Models for sea pens and sponges achieved R^2 values of 0.38, the model for large gorgonians, however, only had an R^2 value of 0.04, indicating very low correlation between predicted and observed values and hence resulted in a poor model that was not used further. That of sea pens was consistent with the KDE and SDM models used previously, but due to the reliance on the multibeam data did not model the full extent of sea pen distribution. That of the sponges was very consistent with previous work (Downie, 2015).

The WGESA used the previously published species distribution model (SDM) outputs to refine the KDE polygons, although it considered the new results of Downie (2015) for each taxon where appropriate. Quantitative methods were used to determine the probability cut offs. For unbalanced species distribution models with unequal numbers of presence and absence, species frequency is termed prevalence, and prevalence in samples should be similar to natural species prevalence, for unbiased samples. Predicted probabilities vary with prevalence or species frequency (Hanberry & He, 2013), which has been recognized under the name of the "unbalanced sample effect" (Hosmer & Lemeshow, 1989). In order to avoid this effect in species distribution modelling, some authors have recommended balancing the modelling prevalence (McPherson et al., 2004; Liu et al., 2005). However, in the case of reliable training data such as that used here from the research vessel surveys, which are neither spatially nor environmentally biased, resampling should be avoided because it would yield a loss of information, especially for rare species with scarce reliable data (Jiménez-Valverde & Lobo, 2006). In addition, Hanberrry & He (2013) found that the use of sampling prevalence produced similar models compared to use of adjusted modelling prevalences. Therefore, they do not recommend balancing the modelling prevalence and propose instead to retain a threshold or cut-off value that is similar to prevalence to maintain fairly constant the error rates (similar to reported by Liu et al. (2005) and Jiménez-Valverde & Lobo (2006)). That is the approach adopted here, and the prevalence values for the sponge grounds, sea pens and large gorgonians used in the species distribution models are provided in 4.2.3.2.1.

Table 4.2.3.2.1. Prevalence values for use as cut-offs in probabilities from Species Distribution Models.

	Presence	**Absence**	**Prevalence**
Sponge grounds	**150**	**3455**	**0.042**
Sea pens	**1327**	**2183**	**0.378**
Large gorgonians	**214**	**3192**	**0.063**

The approach adopted by WGESA to modify the KDE boundaries used a combination of SDM models, which incorporate environmental data to predict species distributions, as shown in Table 4.2.3.2.2.

For example, the two corresponding sponge habitat-based SDM model outputs (Knudby et al 2013a and Downie 2015) were overlaid onto the KDE sponge VME polygon (Kenchington et al 2014) and a revised KDE polygon boundary was redrawn around the extent of the SDM models combined (Fig. 4.2.3.2.1).

Research vessel tows from within the sponge polygons show that there were very small catches of sponges in the zone predicted to have no sponge (Downie, 2015) or sponge grounds (Knudby et al., 2013a). This was done for all of the KDE polygons for sponge grounds and large gorgonian corals (Knudby et al., 2013b). The sea pens were all in high prevalence areas, and the Downie (2015) models showed that these areas, in so much as they had the same spatial extent, support high biomass. Therefore, the existing KDE polygons were used for the sea pens VMEs without any changes to their boundaries. The revised polygon boundaries for sponge and sea pen VME are shown in Fig. 4.2.3.2.2.

Table 4.2.3.2.2. Models used to revise the KDE VME polygon boundaries.

VMEs	Models used for the modification of VME polygon boundaries
Sponge	Biomass SDM (Downie, 2015), Presence/absence SDM (Knudby et al 2013a), KDE (Kenchington et al, 2014)
Sea pen	Biomass SDM (Downie, 2015), Presence/absence SDM (Knudby et al 2013a), KDE (Kenchington et al, 2014)
Large gorgonian	Presence/absence SDM (Knudby et al 2013a), KDE (Kenchington et al, 2014)

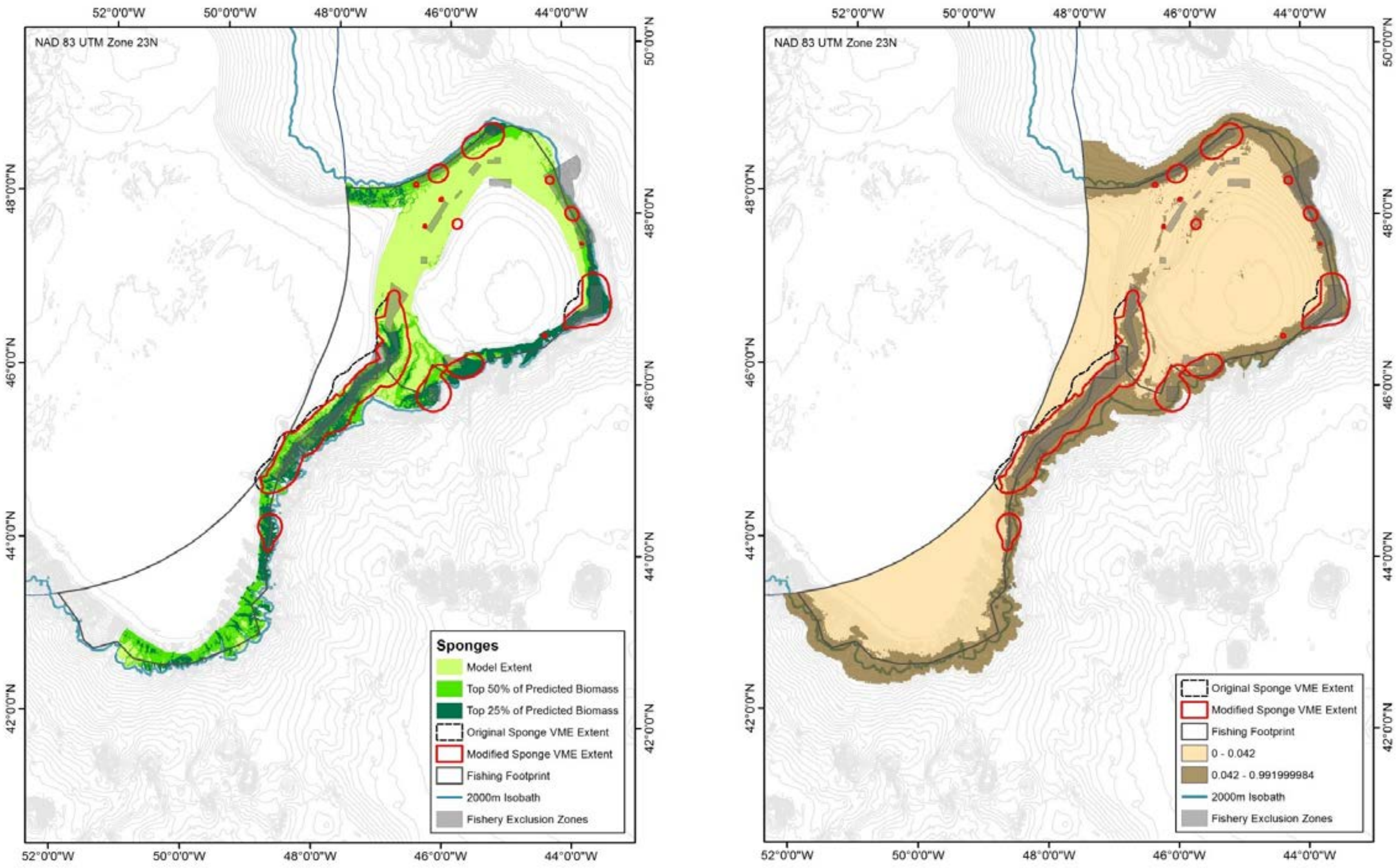


Fig. 4.2.3.2.1. (left panel). Sponge predicted biomass using all sponge data from survey trawls sampled in areas not subject to fishing activity (Downie, 2015). (right panel). Sponge predicted model using presence/absence of significant sponge concentration data from surveys trawls (Knudby et al., 2013a).

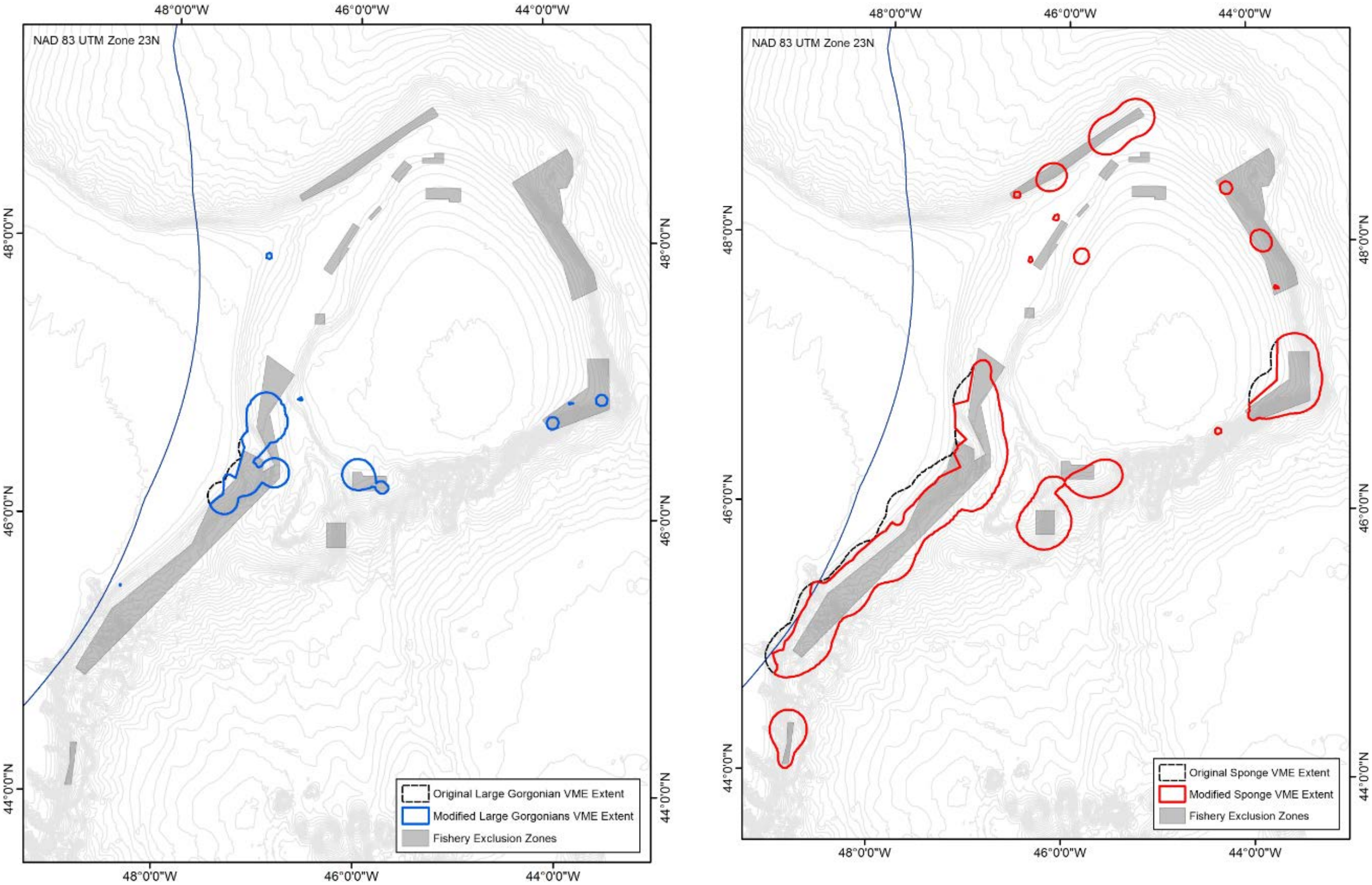


Fig. 4.2.3.2.2. Modified Kernel density-derived polygons for sponge ground and large gorgonian VMEs (sea pens did not change from the KDE analysis). Grey areas indicate coral and sponge closed areas as of January 1, 2016.

4.2.4 Classification of fisheries and distribution of effort in the NRA

4.2.4.1. Description of the fisheries in the NRA

Within the NRA there are three main classes of fisheries: groundfish (GRO - primarily in Div. 3KLMNO), shrimp (PRA - primarily in Div. 3LM) and pelagic redfish (REB - primarily in Div. 1F and 2J). In 2014, WGESA used the Daily Catch Records (DCR) and Vessel Monitoring System (VMS) as the data sources and used the adopted NCEM definition of a directed fishery (NCEM Art. 5.2) to provide a basis to classify various fisheries.

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. In many cases, one-to-one matching of the data sources is not possible because DCR are reported per day and VMS per hour. The difficulty is that several hauls can be conducted in one day that could 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 areas and depth zones.

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

Considering their target species/stock, main area of operation and gear, a total of 11 operational fisheries have been initially identified for consideration in the analyses towards the Reassessment of Bottom Fishing Activities (Table 4.2.4.3.1).

The maps of fishing effort produced to date by WGESA were updated to include the 2014 VMS data. Information on bycatch was extracted and summarized for 2015 based on the provisional logbook information from January to September from those fleets that have sent the data to the NAFO Secretariat. It was noted that the reporting procedure for logbooks in 2015 only required data recording of the top three species which may complicate the interpretation of bycatch percentages in directed fisheries. There was insufficient time at this meeting to map fishing effort based on the recorded start and end positions of tows due to formatting issues amongst the data submissions.

Bottom fisheries not managed under the NAFO convention (eg. snow crab, surf clam), and small-scale fisheries for which NAFO does not set a TAC (e.g. longlining for Atlantic halibut), were not included in the SAI analyses(see Section 4), WGESA did review the spatial information available on their fishing footprint and such fisheries were not considered an important source of SAI as they did not overlap with VMEs. In addition, the redfish fisheries in Div 1F, 2J and 3K, and the *Alfonsino* fisheries on seamounts in Div. 6G were not described herein as they use midwater trawls and not the bottom-contact fishing gears for which the UNGA resolutions call for assessments.

Table 4.2.4.3.1. Operational fisheries identified in the NRA for consideration in the process of developing the Reassessment of Bottom Fishing Activities.

Fishery	Target Species	Main Area of Operation	Gear
Greenland Halibut Fishery	Greenland halibut	NAFO Divs 3LMNO	Bottom otter trawl
3M Redfish Fishery	Redfish	NAFO Div. 3M	Bottom otter trawl
3M Shrimp Fishery (under moratorium)	Shrimp	NAFO Div. 3M	Bottom otter trawl
3M Trawl Cod Fishery	Atlantic Cod	NAFO Div. 3M	Bottom otter trawl and paired bottom trawls
3M Longline Cod Fishery	Atlantic Cod	NAFO Div. 3M	Longline
Skate Fishery	Skate	NAFO Divs 3NO	Bottom otter trawl
Yellowtail flounder Fishery	Yellowtail flounder	NAFO Div. 3N	Bottom otter trawl
Witch flounder Fishery (re-opened 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 (under no directed fishery in 2015)	Shrimp	NAFO Div. 3L	Bottom otter trawl
White Hake Fishery	White hake	NAFO Divs 3NO	Bottom otter trawl

4.2.4.2 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 Spanish observer data from 2005-2011 and preliminary 2015 logbook data are representative of most fleets' general activity, the demersal fisheries in the NRA were initially classified as follows:

Divisions 3LMNO at >800 m: Greenland halibut fishery

The principal fishery is conducted from 800-1400 m with 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 (

Division	**Gear**	**Depth Range**	**Mean Vessel Length**	**Logbook Catch Composition**

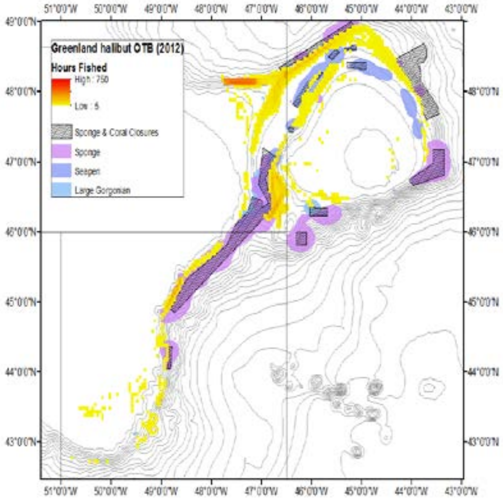
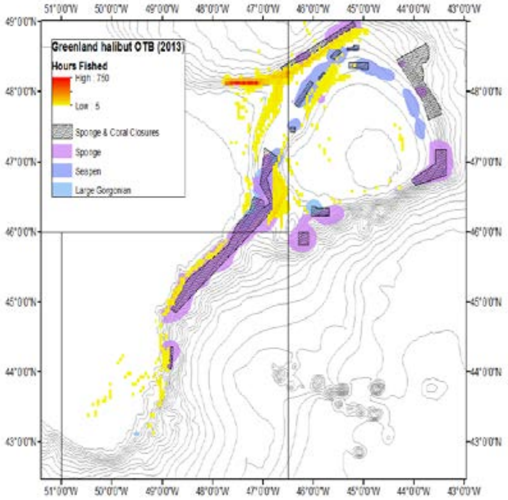
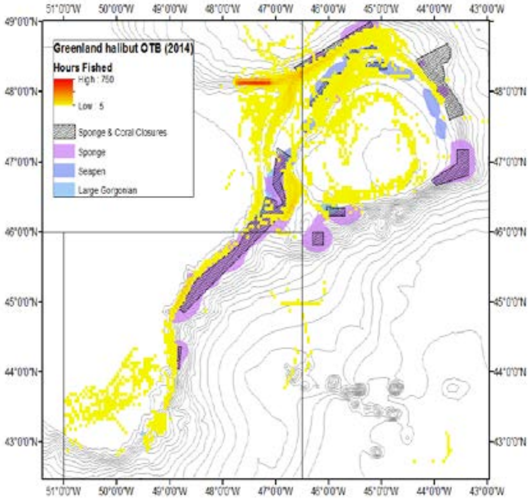
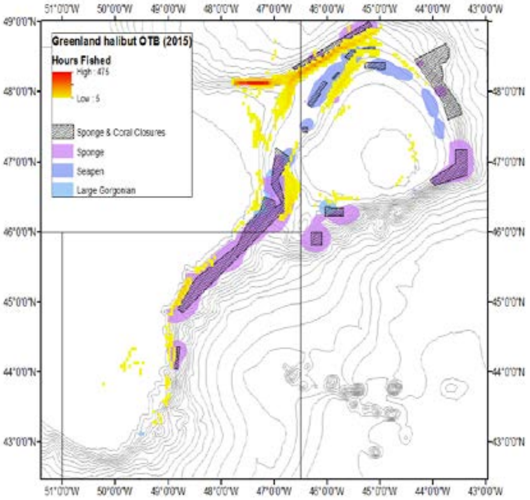
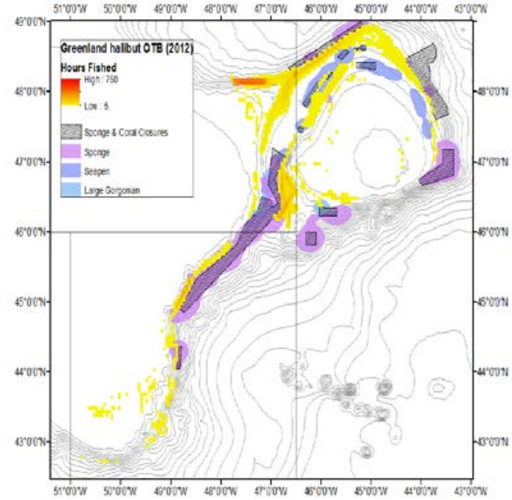
3LMNO	OTB	800-1400 m			
Target Species	**Mesh Size**	**Mean Vessel Power (KW, ± range)**		**Species**	**Percentage of catch (2015)**
Greenland halibut	130mm	1746 (588-4080)	65 (50-85)	Greenland halibut	95%
				Roundnose grenadier	1%
				Roughhead grenadier	1%
				Witch	1%
				Skate	1%
				Plaice	1%
				Others	1%
Spatial Distribution (2012) 			**Spatial Distribution (2013)** 	
Spatial Distribution (2014) 			**Spatial Distribution (2015)** 	

Fig). The maps of fishing effort (Figure 4.2.4.2.1) demonstrate the difficulty in matching VMS with the DCR as Greenland halibut is a deep-water species and there is effort attributed as 'directed' in shallow water on the southern Grand Bank area. Greenland halibut comprised 95% of the catch based on 2015 logbook data and main by-catch are grenadiers, witch, skates and plaice (each species <1%).

Division	Gear	Depth Range	Mean Vessel Length (m, ± range)	Logbook Catch Composition	
3LMNO	OTB	800-1400 m			
Target Species	Mesh Size	Mean Vessel Power (KW, ± range)		Species	Percentage of catch (2015)
Greenland halibut	130mm	1746 (588-4080)	65 (50-85)	Greenland halibut	95%
				Roundnose grenadier	1%
				Roughhead grenadier	1%
				Witch	1%
				Skate	1%
				Plaice	1%
				Others	1%

Spatial Distribution (2012)



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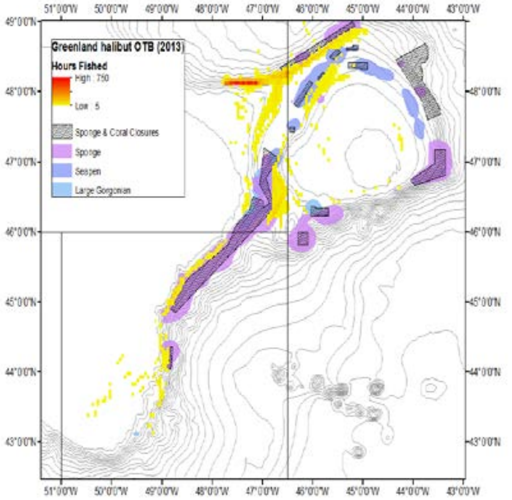

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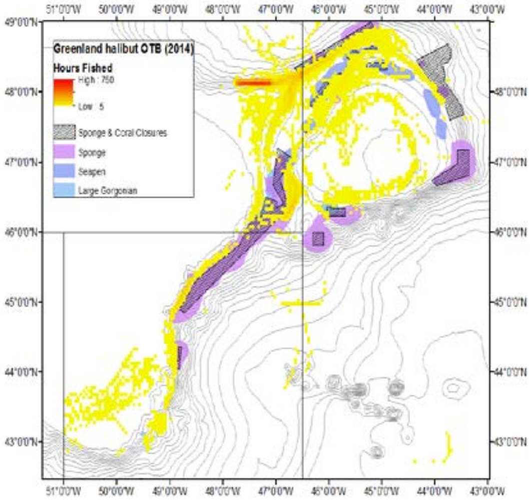

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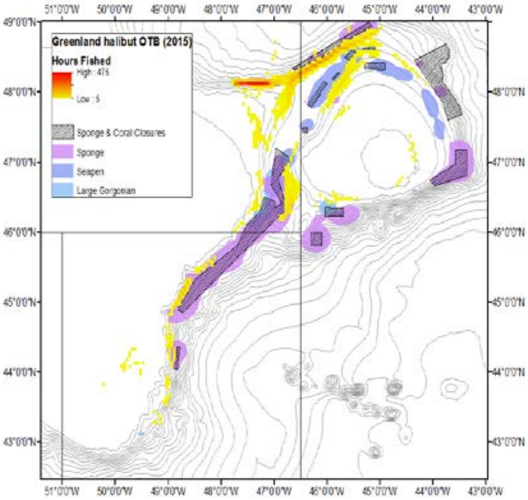

Fig. 4.2.4.2.1. Characteristics of the Greenland halibut fisheries in Div. 3LMNO (OTB = bottom otter trawl).

Division 3M at 150-600 m: redfish, cod and shrimp fisheries

The shrimp fishery was under moratorium since 2012 but previous fisheries were conducted with 40 mm mesh size bottom trawls primarily in depths between 300 and 500 m. 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-600 m depth zone in Div 3M along the southern and north-western slope of the bank (Fig. 4.2.4.2.2). 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 150-550 m, with the highest concentrations of effort in the south western and south-eastern areas of the slope of the bank (Fig. 4.2.4.2.3). Most of the hauls were carried out at depth between 300-400 m. Cod comprised 92% of the catches and the most important species in the by catch was redfish (7%).

Although the maps of OTB fishing effort for redfish and cod are split based on the NCEM definition of directed species, these generally tend to be mixed fisheries.

A long-line fishery is also conducted for cod between 200 and 400 m in the north west portion along the slope of the bank (Fig.4.2.4.2.4), and the principal by-catch is skate and Greenland shark.

Division	Target Species	Gear	Mesh Size	Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
3M	Redfish	OTB	130 mm	200-600 m	1716 (700-3300)	68 (50-85)	Cod Greenland halibut

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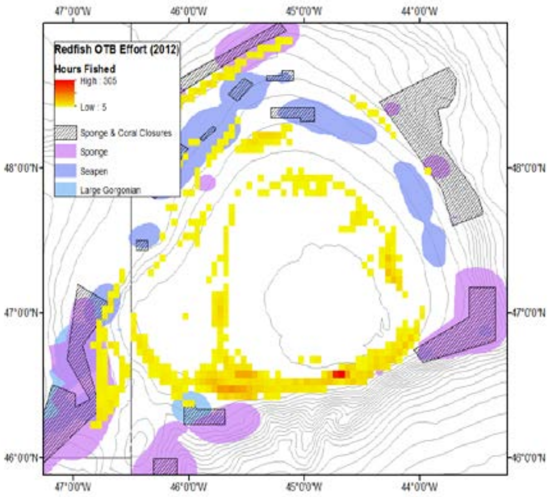

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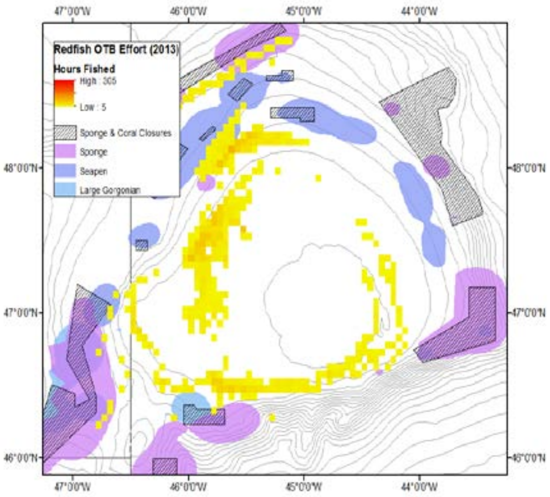

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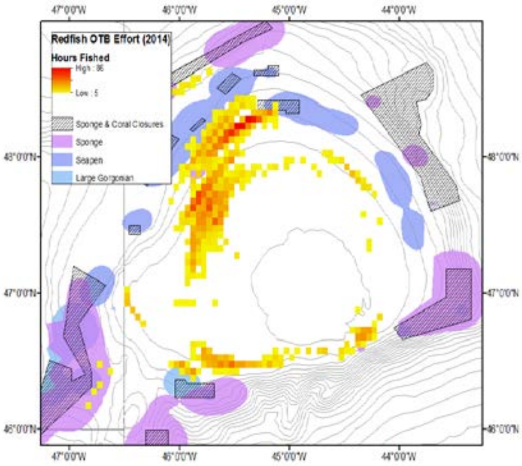

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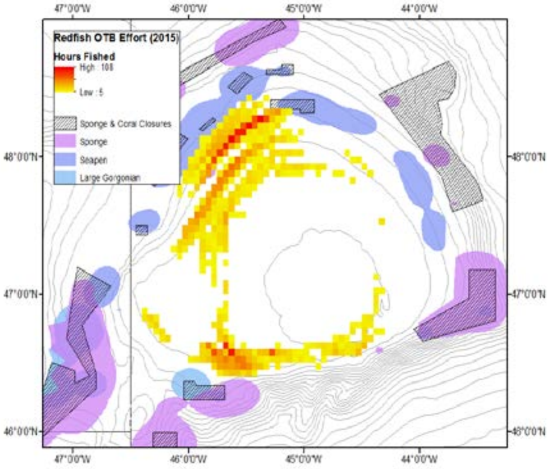

Fig. 4.2.4.2.2. Characteristics of the 3M redfish fisheries (OTB = bottom otter trawl).

Division	Target Species	Gear	Mesh Size	Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Logbook Catch Composition	
							Species	**Percentage of catch (2015)**
3M	Cod	OTB (some use of PTB)	130mm (some use of 140 mm)	200-600 m	1716 (700-3300)	68 (50-85)	Cod	97%
							Redfish	1%
							Plaice	1%
							Others	1%

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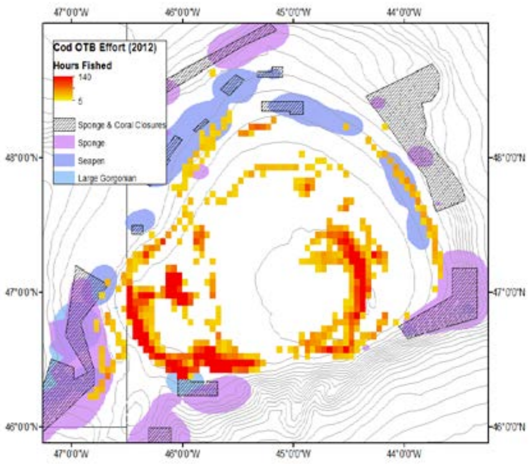

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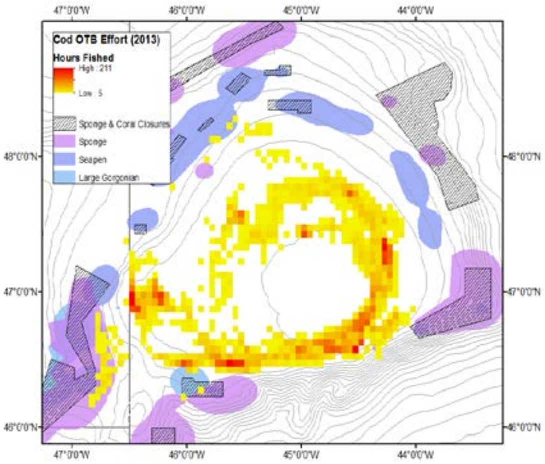

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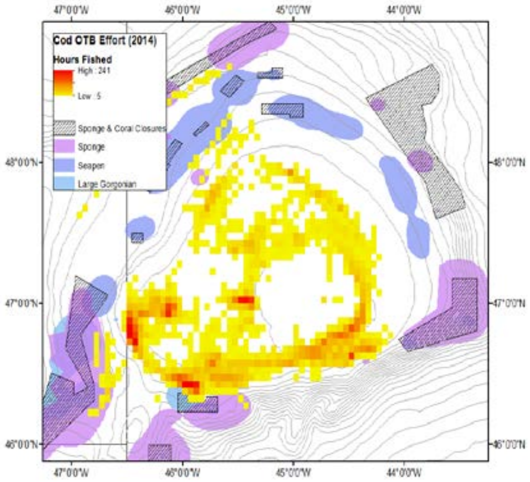

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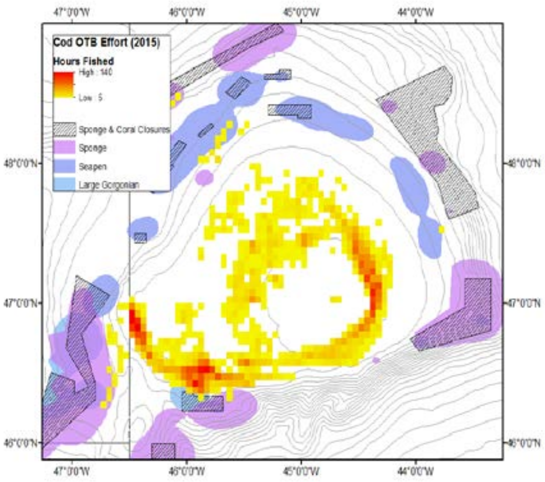

Fig. 4.2.4.2.3. Characteristics of the 3M OTB Cod Fishery.

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

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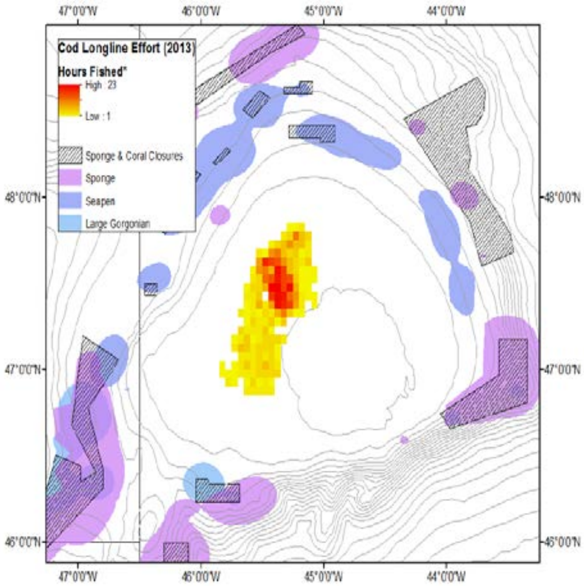

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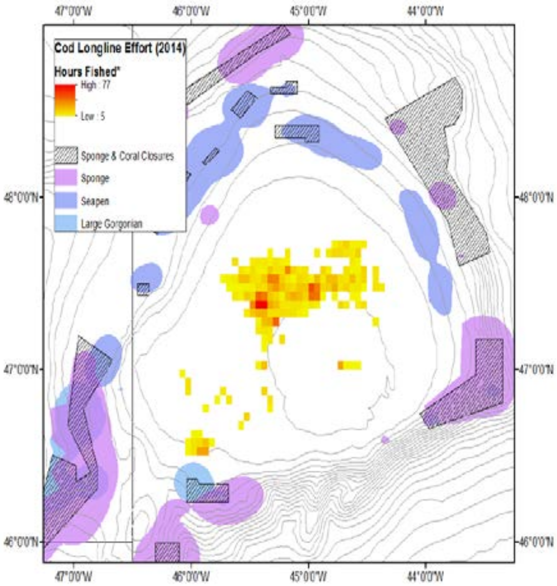

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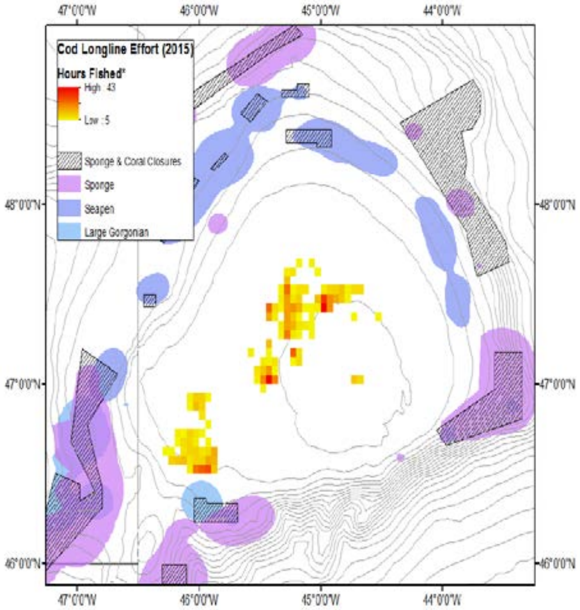

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Fig. 4.2.4.2.4. Characteristics of the 3M Longline Cod Fishery. (LL = long-line, NA = not available, * hours fished from VMS data is considered a poor metric of effort in long-line fisheries).

Divisions 3LNO at <500 m: skate and yellowtail fisheries

The skate fishery is conducted with 280 mm mesh size bottom trawls primarily in depths from 100 to 500 m (Figure 4.2.4.2.5) in Divisions 3NO. Skates comprised 97% of the catch with redfish as the primary by-catch species based on 2015 logbook data.

The yellowtail fishery is conducted with 130 mm mesh size bottom trawls in Divisions 3LNO primarily in depths <50 m on the southeast shoal in Div. 3N (Figure 4.2.4.2.6). The primary by-catch species are skate, American plaice and cod.

<table>
<tr><th rowspan="2">Division</th><th rowspan="2">Target Species</th><th rowspan="2">Gear</th><th rowspan="2">Mesh Size</th><th rowspan="2">Depth Range</th><th rowspan="2">Mean Vessel Power (KW, ± range)</th><th rowspan="2">Mean Vessel Length (m, ± range)</th><th colspan="2">Logbook Catch Composition</th></tr>
<tr><th>Species</th><th>Percentage of catch (%)</th></tr>
<tr><td rowspan="4">3LNO</td><td rowspan="4">Skate</td><td rowspan="4">OTB</td><td rowspan="4">280 mm</td><td rowspan="4">100-500 m</td><td rowspan="4">1352
(588-2648)</td><td rowspan="4">64
(50-84)</td><td>Skate</td><td>97%</td></tr>
<tr><td>Redfish</td><td>2%</td></tr>
<tr><td>Haddock</td><td>1%</td></tr>
<tr><td>Others</td><td>1%</td></tr>
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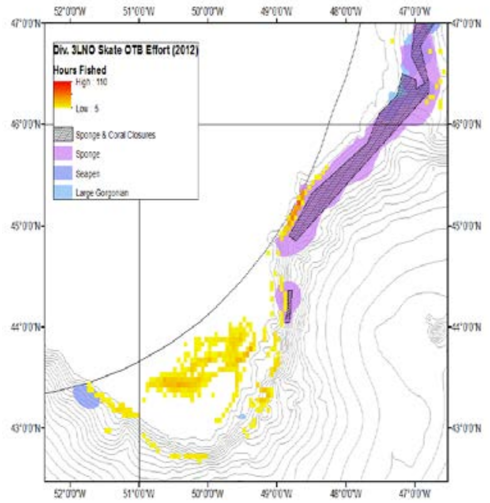
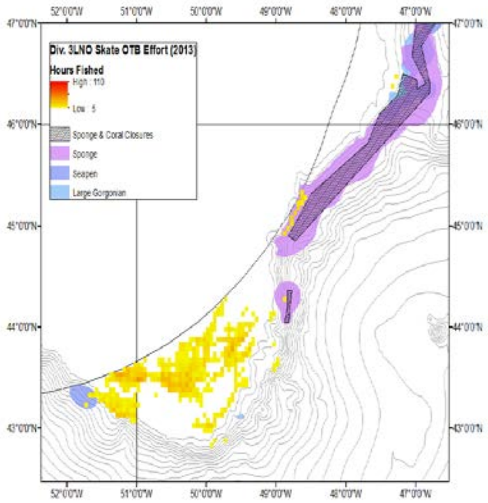
<tr><td colspan="4">
</td><td colspan="5">
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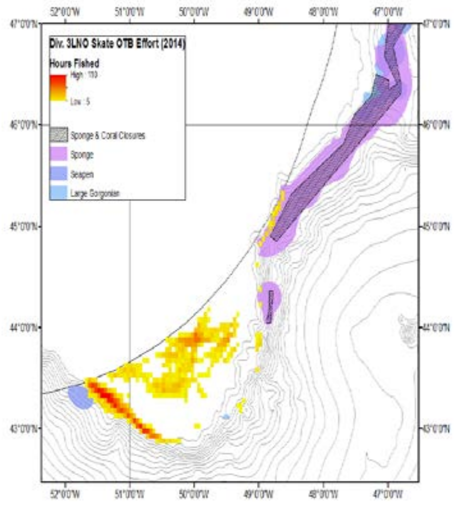
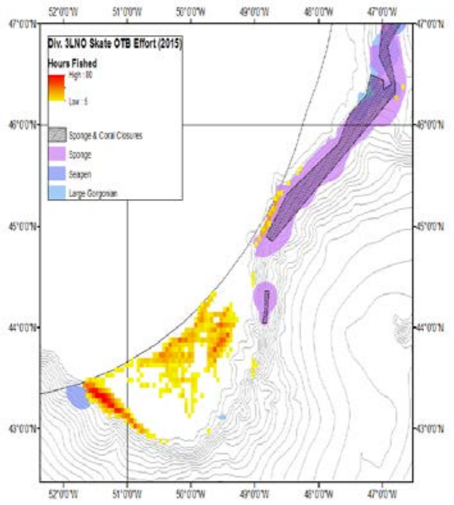
<tr><td colspan="4">
</td><td colspan="5">
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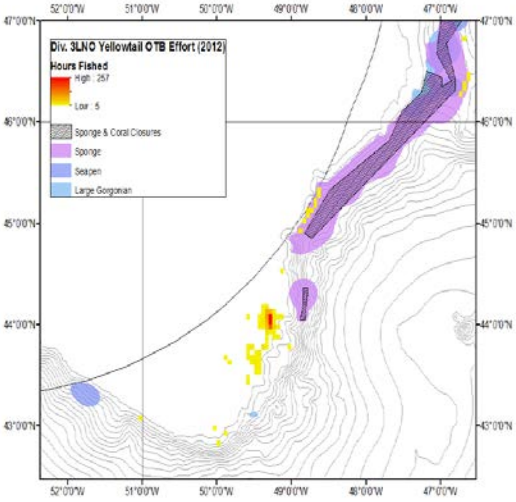
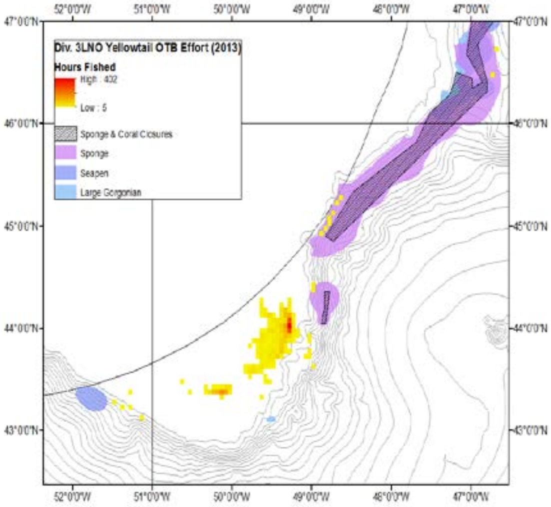
Fig.4.2.4.2.5. Characteristics of the 3LNO skate fishery (OTB = bottom otter trawl).

Division	Target Species	Gear	Mesh Size	Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Logbook Catch Composition	
							Species	**Percentage of catch (2015)**
3LNO	Yellowtail flounder	OTB	130 mm	<200 m	1565 (50-84)	61 (50-84)	Yellowtail	83%
							Plaice	10%
							Skate	3%
							Cod	2%
							Witch	1%
							Silver Hake	1%
							Others	1%

Spatial Distribution (2012)	**Spatial Distribution (2013)**
	
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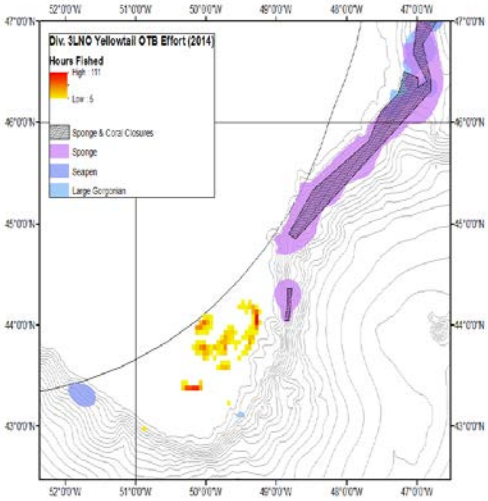
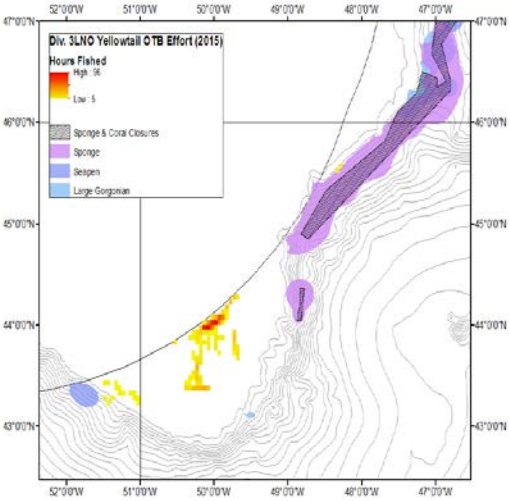
	

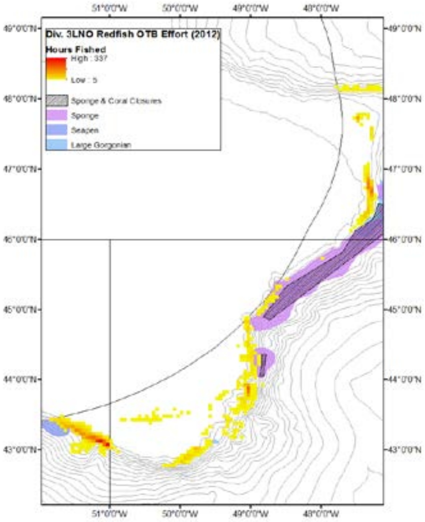
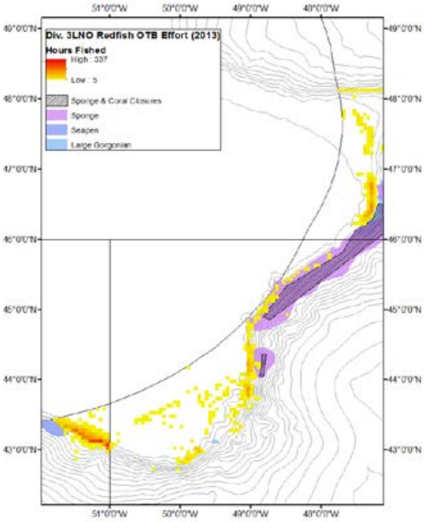
Fig. 4.2.4.2.6. Characteristics of the 3LNO yellowtail flounder fishery (OTB = bottom otter trawl).

Divisions 3LNO at 200-1000 m: 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 in depths <600m (Fig. 4.2.4.2.7). Redfish comprise 90% of the catch and the main by-catch species were American plaice (2%), cod (2%), silver hake (2%) and Atlantic halibut (2%) based on 2015 logbook information. 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 2013-14.

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 and 500 m (Fig. 4.2.4.2.8), with shrimp comprising with 99% of the catches. This fishery was closed to directed fishing in 2015.

Division	Target Species	Gear	Mesh Size	Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Catch and Bycatch	
							Species	**Percentage of catch (2015)**
3LNO	Redfish	OTB	130 mm	200-600 m	1900 (600-6400)	63 (15-85)	Redfish	89%
							Cod	2%
							Silver hake	2%
							Atlantic halibut	2%
							American plaice	2%
							Skates	1%
							Others	2%

Spatial Distribution (2012)	**Spatial Distribution (2013)**
	
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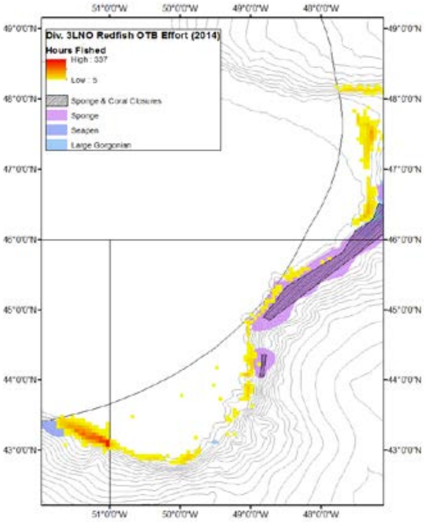	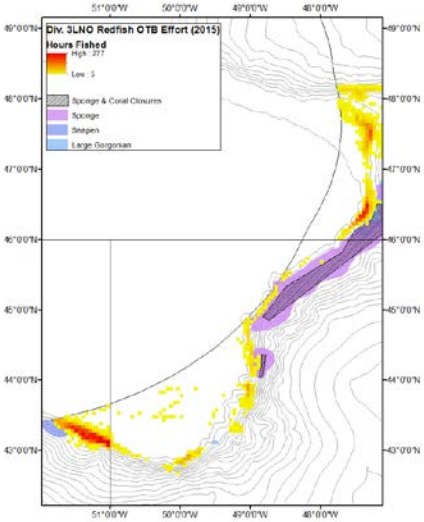

Fig.4.2.4.2.7 Characteristics of the 3LNO redfish fishery (OTB = bottom otter trawl).

Division	Target Species	Gear	Mesh Size	Depth Range	Mean Vessel Power (KW, ± range)	Mean Vessel Length (m, ± range)	Commercial Bycatch Species
3LNO	Northern prawn	OTB	40 mm	200-400 m	2400 (1100-3000)	60 (55-65)	No targeted fishery in 2015

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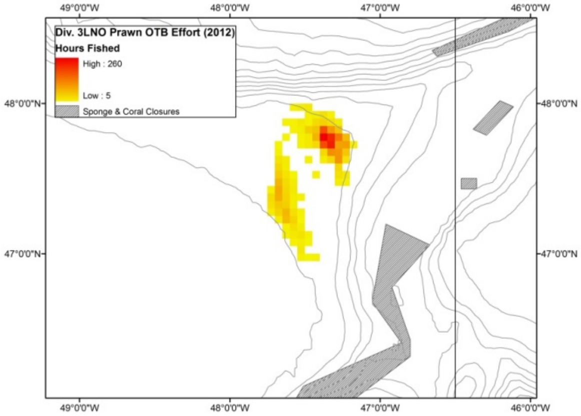

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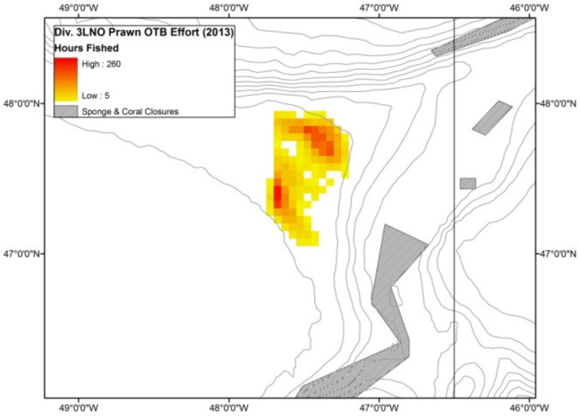


Spatial Distribution (2014)

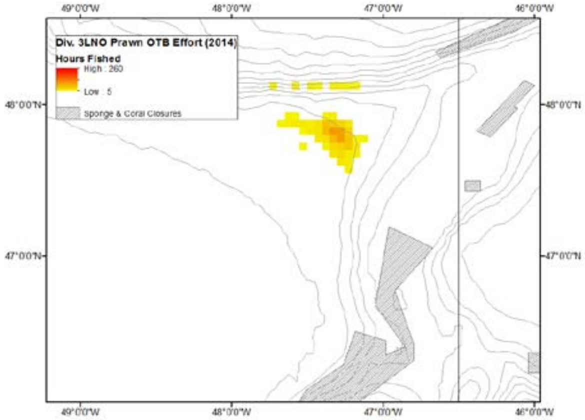


Fig. 4.2.4.2.8. Characteristics of the 3LNO shrimp fishery (OTB = bottom otter trawl).

Divisions 3NO at <800 m: witch flounder fisheries

A directed fishery for witch flounder was re-opened 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 800 m. Information on by-catch is not yet available.

Divisions 3LNO at >30 m: white hake

The white hake fishery operates mostly along the shelf edge of the southern part of 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. A directed fishery for white hake has not taken place in the years 2012-2015 for which VMS and daily catch data are available.

4.2.5. Assessment of SAI on VME

4.2.5.1. Background to SAI and its definition

RFMOs 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, 2006b). The resolution calls upon States and RFMOs 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 NRA in the past 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, scientists in the NAFO WGESA have 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.

The FAO guidelines (FAO, 2009) define SAI 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, and (iii) causes, on more than a temporary basis, significant loss of species richness, habitat or community types".

Very little is known about the life histories of the VME indicator species identified by NAFO (Fuller et al., 2008; Kenchington et al., 2011; Murillo et al., 2011). The reproductive biology of few of the indicator species has been studied to date and recruitment is unknown. Some studies have aged deep-sea corals and shown them to be slow growing, long-lived, with growth rates that will require decades to centuries to recover, and this was considered at the time they were identified as VME indicators (Fuller et al., 2008). Recent evidence has confirmed this. For example, a dense forest of bamboo coral in Baffin Bay (Div. 0A) was impacted by a scientific research trawl in 1999 and re-surveyed in 2013 utilizing a Remotely Operated Vehicle (ROV). Living colonies were observed as dense patches (55 m patch length x 1 m colony height) but the trawl track showed no evidence of recovery (Neves et al., 2014). Sponges are attached to the sea floor and reproduce by broadcasting sperm into the water column which fertilize eggs held in the bodies of neighbouring sponges. If sponges are too far apart then fertilization success may be compromised. An extinction vortex is the term used to describe the process that declining populations undergo when a mutual reinforcement occurs among biotic and abiotic processes that drives population size downward to extinction. Sponges, corals and sea pens, which also have broadcast spawning, may be vulnerable to extinction vortices. The sponges also may have very limited dispersal ability. The fertilized egg usually develops in the sponge and on hatching, larvae are released into the water column where they are only viable for a few days, and in some species, only hours. They then settle and attach. This could mean that the sponges are highly inbred and have very limited dispersal range. If this is the case greater importance is placed on each self-recruiting population. Alternative models include source-sink dynamics, where one or more populations provide the recruitment for other populations and clinal variation, where genetic variation follows the distribution gradient. Each model has different implications for management and very little is known about the population genetics and connectivity of these species.

The FAO guidelines (FAO, 2009) provide further insight into the issue of defining a SAI by stating that "When determining the scale and significance of an impact, the following 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.
iii. The sensitivity/vulnerability of the ecosystem to the impact.
iv. The ability of an ecosystem to recover from harm, and the rate of such recovery.
v. The extent to which ecosystem functions may be altered by the impact.
vi. The timing and duration of the impact relative to the period in which a species needs the habitat during one or more of its life-history stages."

So far, given the data available from within the NRA and in particular the NAFO footprint, the assessment has been possible with regard to the first two criteria (i and ii). Criterion i, the sensitivity or severity of the impact has been shown, through literature review, to be very high on the first pass through all VMEs identified by NAFO. Indeed, it is part of the determination that a taxon is a VME and was reviewed for each VME indicator previously (Fuller et al., 2008; Kenchington et al., 2011; Murillo et al., 2011). Structural sponge habitat is extremely vulnerable to commercial and research trawling, suffering immediate declines through direct removal of sponges and further reductions in population densities of sponges due to delayed mortality (Kenchington et al., 2011). Similarly, gorgonian corals are very fragile and highly susceptible to trawling impacts (Fuller et al., 2008). Sea pens can also be severely impacted on the first pass, however unlike the corals and sponges, they have flexible axial rods and some species are able to re-anchor in the sediment if they are dislodged (Kenchington et al., 2011). Consequently, they may be able to withstand greater disturbance than the other VME indicators, as they are less susceptible to direct mortality. The cut-off values identified in this analysis for these three VME groups are in agreement with these observations, where fishing effort cut-offs were the smallest for gorgonians, and the largest for sea pens.

Criterion ii, has been accomplished in this report. Here, the location of the VME is mapped and the proportion of the area that is currently impacted by fishing is identified, as well as the proportion that is protected by the closed areas, and the proportion that is at risk of being impacted.

Ecosystem function can be defined as the biological, geochemical and physical processes and components that take place or occur within an ecosystem. It can be divided into three categories; regulating, supporting and provisional functions. Regulating functions include processes such as biochemical and water cycling. Biochemical cycling includes processes such as benthic-pelagic coupling and bioturbation. Both contribute significantly to biochemical cycles by turning over nutrients, living or decomposed constituents, in an otherwise nutrient poor environment. Supporting functions include habitat for associated species, nurseries, refuge from predators, and supporting connectivity between populations (e.g. patchiness). The final category is the provisional function including ecosystem basics such as food (e.g., foraging area) and shelter. For a review of ecosystem function see ToR 3.4 (WGESA Report 2013).

Criteria iii-v require knowledge of the ecosystem processes and function of the VME that is not known in sufficient detail to determine the effects of, and recovery from, impacts at an ecosystem level. For example, sponge grounds provide a number of ecosystem services which directly support fisheries in the NRA. As they stand proud of the sea floor, they modify bottom currents and create habitats for other species, while as they die they leave behind spicules which create habitat of their own. Fish use sponge grounds for feeding, reproduction and resting, while sponges filter vast amounts of water on a daily basis (one sponge can filter 25 000 litres per day) and serve broader roles in energy flow linking pelagic and benthic systems and locally increasing biodiversity. At some unknown size and spatial configuration, these ecosystem services will be compromised and each function may have a different ecological tipping point. Further, recovery of these disrupted ecosystem functions and services not only requires knowledge of the life-history of the key species, it requires a thorough understanding of the entire benthic community and the successional processes that occur. Ecosystems have a degree of functional redundancy in them and it could be that some functions are maintained by non-VME indicator species. Knowledge of the degree to which fishing can proceed without compromising ecosystem services is an extremely important question that will require a targeted research program over a number of years to address. Lastly, criterion vi introduces a temporal component to the impacts of criteria iii-v.

WGESA initiated the discussion of how to assess SAI at two basic levels:

i. Assume that any present or past fishing activity impacting VME is significant based on the Precautionary Approach; or
ii. Assume that the present or past fishing activity impacting VME may not be significant as both VME and fishing have co-existed for several decades.

The first scenario was thought, by some, to be applicable to the sponges and large gorgonian corals, but not to the sea pens. The argument for not including sea pens under this scenario was based on their relative resilience at the species level to trawling, as noted above. However, in situ photographs of the sea floor within a heavily fished portion of a sea pen VME polygon showed no megafauna, despite the presence of sea pens in the nearby closed area, indicating that sea pens cannot withstand concentrated and repeated fishing effort. Furthermore, WGESA previously noted that redfish larvae attach to the sea pen stalks and these habitats may be important nursery areas for *Sebastes* spp. (see ToR 3.1.2 of NAFO 2014), thereby increasing the risk to NAFO fisheries should too much sea pen habitat be destroyed. WGESA at its 2013 meeting assessed the protection of sea pens on Northern and North-western Flemish Cap to be "Inadequate collectively" based on the fact that the closures are covering a system of sea pen VME, identified in the SDM and verified with trawl survey data, that is not adequately protected. In particular, the lack of protection for the entire eastern part of their distribution was of concern for the long term sustainability of these VME given the lack of knowledge of recruitment processes and connectivity. Therefore, although they may be more resilient to a first pass of the trawl gear than other types of coral or sponge, sea pens have more of their core VME area unprotected.

This discussion also raised the point of the need to take into account the impact to individual VME polygons as some VME areas may be severely impacted by fishing, while others are not impacted at all. This could lead to the loss of individual patches of VME which could have consequences for other areas of the same VME type depending on source/sink relationships.

The second scenario has some logic to it. Fishing has persisted in these areas for many years and previously WGESA has shown that the areas fished have been remarkably consistent (NAFO 2015). The directed Greenland halibut fishery, that is the main fishery carried out in waters below 700 m depth (Gonzalez-Costas et al., 2011), where the sponge VME occur, began in the early-1960s in this area (Bowering and Brodie, 1995), indicating that impacts of fishing on the sponge VME may have been accumulating for at least 50 years. Therefore, if the current extent and impact of fishing had caused SAI then we would expect to see consequences either to the fisheries or to the VME indicators. A review of existing in situ imagery to assess size distribution and recruitment of VME indicators could give some insight into this issue, and/or targeted in situ monitoring could be conducted. Until research vessel surveys cease to fish in the closed areas, they could be tasked with recording the length frequencies of all VME indicator taxa within the VME polygons.

However, an important consideration for assessing SAI and highlighted in the FAO guidelines, is the need to determine the area of VME impacted as a proportion of the area of VME unimpacted. Studies in other marine ecosystems, in the context of the EU Habitat Directive, had considered that impacts of 25% or more of the total habitat area as the criteria for deeming those habitats to be in unfavourable conditions (Korpinen and Laamanen, 2013). However, this value has no direct scientific derivation, and the ecosystem considered in the study is very different from the ones in the NRA. Although its application in the NRA would provide consistency with other jurisdictions, it would only represent the level of risk that management might deem acceptable. As stated above, it is not possible at the present time to provide a clear cut quantitative assessment of Significant Adverse Impacts.

WGESA therefore concluded that not all impacts on VME should be presumed to be SAI, and an assessment of the relative areas of VME which have been impacted with areas of VME of the same type at risk of impact according to the FAO guidelines (FAO, 2009) is an important step in assessing SAI.

4.2.5.2 Analytical approach for assessing VME impacted and at risk of VME impact

A number of assumptions are made to frame the proposed assessment of impacts. First, the risk of impact to VME from fishing inside either closed areas or in areas outside the fishing footprint 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). Second, VME which occur outside closed areas, but within the fishing footprint, are potentially at risk of impact from bottom fishing activities. However, not all VME which occurs outside the closed areas will be at the same immediate risk of impact from bottom fishing activities; e.g., the degree of risk of impact will depend upon a combination of present-day and historic fishing intensity, and predicted and/or known VME biomass distributions. Given such assumptions, and the innate properties (FAO, 2009) of the species which comprise the VME habitats, the following assertion can be made:

"frequently fished areas of VME will tend to support lower biomass of VME indicator taxa compared to areas of the same VME that have been fished less frequently."

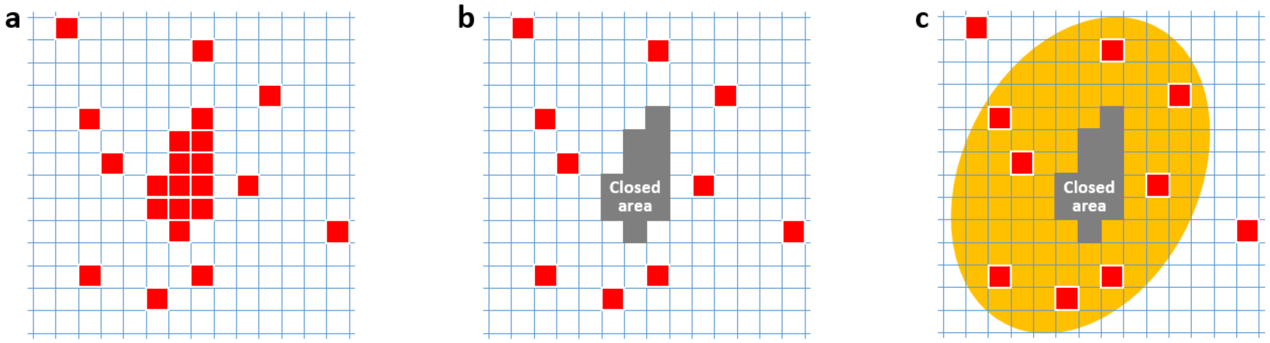
Therefore, areas of VME within the NAFO fishing footprint fall into three impact-risk categories (i) protected areas with low risk of impact, although there is a recognised secondary risk from re-suspended fine sediment from adjacent fished areas (Boutillier et al., 2013); (ii) areas of VME at 'high risk' of impact (and therefore subject to potential SAI) which are subject to relatively low fishing pressure or have not been fished since 2008, and (iii) areas of VME which are impacted and coincide with areas of high fishing effort, and have been fished for many years, and where VME indicator taxa are found in much reduced densities or biomass but according to the species distribution models have potential for recovery.

The present study has quantified the limits in fishing effort which correspond to large changes in VME species biomass. The identified limits (or cut-off values) when applied to the fishing effort data allow areas of impact and areas at risk of impact to be determined. The method uses the cumulative distribution of biomass catch in conjunction with fishing effort (VMS) data to determine cut-offs in VME species biomass in a similar manner to the original identification of significant concentrations of VME (NAFO, 20013). Figure 4.2.5.2.1a-f, illustrates the methodological approach taken to determine the impact 'cut-off' limits.

Within the fishing footprint it is possible to observe a gradient in fishing intensity, by quantifying how often fishing takes place within a given area (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 species biomass 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 within a fishing footprint showing occurrences of VME indicator taxa is depicted in Figure 4.2.5.2.1Figa (note that no indication of fishing intensity across the grid is shown).

It may be that certain areas of observed aggregations of high VME indicator taxa biomass have already been closed to fishing activities to protect the VME (Fig. 4.2.5.2.1b), in which case it can be assumed that the risk of impact to VME within these areas is very low. For the purpose of assessing the risk of impact to VME from fishing, such closed areas can be excluded from the assessment, as they are already under some form of protection. Instead, the areas of concern are those areas of VME which fall outside of the closed areas. To ascertain the biogeographical limits of the VME falling outside current closures, NAFO has used threshold-defining approaches based on area derived from kernel density estimation analyses (NAFO, 2013, 2014; Fig. 4.2.5.2.1c) which uses RV survey biomass data with minimal interpolation (<20 km from the point source). In the present analysis the boundaries of the VME polygons were refined using species distribution models, although those involve interpolation and extrapolation methodology (see section 4.2.3.2). Once the predicted extent of the VME has been determined, the precise area of VME at risk of impact and area of VME potentially impacted can be defined (Fig. 4.2.5.2.1d).

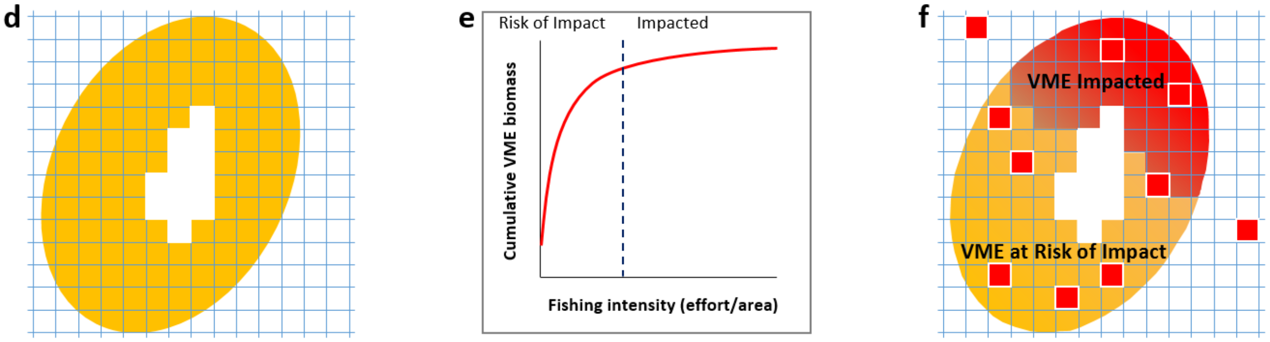
The interaction between observed fishing intensity (total hrs of trawling) and VME biomass (average kg wet weight) is performed at the scale of individual grid cells (1 NM). By ranking every grid cell within the area at risk of impact (VME excluding closed area) on a gradient of increasing fishing intensity and plotting the observed VME biomass along that gradient, a cumulative rate of increase in VME biomass with increasing fishing intensity can be produced (Fig. 4.2.5.2.1e). The plot shows that the grid cells with the least fishing pressure (which tend to support higher biomass of VME indicator species) accumulates biomass more rapidly than cells which are exposed to high fishing pressure (which are more likely to support much reduced amounts of VME indicator species biomass). 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 'cut-off' in fishing intensity above which there is no increase in VME biomass observed; grid cells falling above this cut-off therefore represent an area of potential impact. Grid cells falling below the cut-off, which continue to support high biomass of VME indicator species at very low levels of fishing effort can be considered at risk of impact (Fig. 4.2.5.2.1f). The precise location of this cut-off 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 cut-off can be determined by identifying the point of inflexion on the cumulative plot of VME biomass ranked against increasing fishing intensity for each of the taxon-specific VMEs, or by identifying a cumulative biomass limit. For consistency the cut-off for each VME taxon was determined to be at the point where 95% of the biomass had been accumulated, which closely corresponds to the inflexion point in all cases.



Gridded observations of **VME biomass** within fishing footprint

Assignation of fishery closures around significant aggregations of VME biomass

Modelled prediction of **VME extent**



Area at Risk of Impact = VME extent – Closed Area

Evaluation of **VME biomass** observations inside area at Risk of Impact

- Areas of low fishing intensity and high VME biomass = **Risk of Impact**
- Areas of high fishing intensity and low VME biomass = **Impacted**

Fig. 4.2.5.2.1. Schematic representation of a method for delineating areas of VME at risk of impact and VME impacted from bottom fishing activities. See main text for explanation.

4.2.5.3. Application of the impact assessment method

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, 2009c). The western extent of the fishing footprint intersects the Canadian EEZ, whilst in other directions fishing is mostly restricted to above the 1600 m depth contour, which would approximate to the maximum depth at which a trawl normally operates. However, this footprint was a perimeter and did not acknowledge the many unfished areas in the NRA. Consequently, a new fishing footprint was created for this assessment.

Fishing effort calculation

Vessels fishing in the NRA are equipped with a satellite monitoring device (i.e., VMS) that transmits the vessels' position, heading and speed every hour; each transmission is termed a 'ping'. VMS data collected from 2008 to 2014 were filtered to exclude records of vessel speed greater than 5 knots; the assumption being that vessels in the NRA operating below 5 knots were likely to be fishing. Using ArcGIS (ESRI Canada), the area covered by the fishing footprint within the NRA was gridded at a resolution of 1 nm x 1 nm cells. For each cell, the number of pings recorded within it each year was counted. This produced a value for annual number of pings per cell, which can also be expressed as the yearly number of hours of fishing within a cell, i.e., the fishing effort. The annual fishing effort per cell value was divided by the total area of the cell, producing a measure of annual fishing intensity (in hrs km^{-2}) for each cell. 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 data layer of fishing intensity (Figure 4.2.5.3.1). Note that the green colour in Figure 4.2.5.3.1 represents areas that have not been fished between 2008-2014, demonstrating the general spatial mismatch between fishing effort and VME location, particularly in the deeper waters.

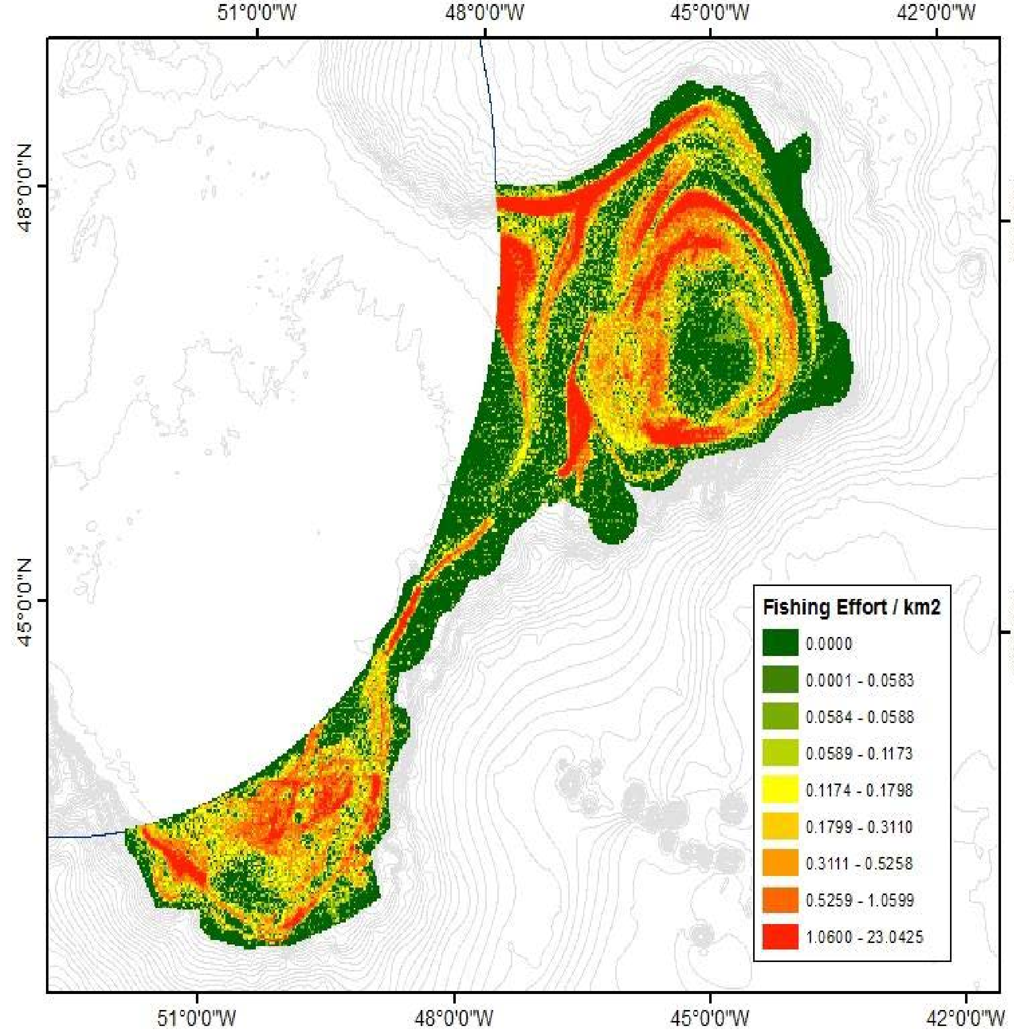


Fig. 4.2.5.3.1. Representation of fishing intensity in the fishing footprint of the NRA based on 2008-2014 VMS data.

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. Georeferenced biomass data of sponges (Porifera), large gorgonian corals (Octocorallia) and sea pens (Pennatulacea) collected by these surveys (between 2005 & 2014, 2007 & 2015, and 2000 & 2015, 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 allows for direct spatial comparison and integration with the fishing effort layer.

Delineation of VME

As described in Section 4.2.3 of this report, Kenchington et al. (2014) performed kernel density estimation analyses (KDE) 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 define polygons for each of the VMEs which have been accepted by NAFO Scientific Council and NAFO Fisheries Commission as the best available approach to define the overall extent of VME within the NRA. A refinement of the VME polygon boundaries was requested by NAFO SC in 2015, specifically to incorporate environmental data into the analysis, to better define the extent of VME habitat. The integration of the KDE polygons with the outcome of the developed SDMs (see Section 4.2.3) provided the basis for refining the VME boundaries as shown in Fig. 4.2.5.3.2. For sea pens, no modification of the VME boundaries were made as the SDMs predicted high presence and/or biomass throughout the entire sea pen polygons. For sponges, the polygons on the Flemish Pass were modified at their shallow boundary using SDM, as both the presence/absence and biomass models were in agreement. Similar modification of the sponge polygons in the Sackville Spur area were not made as the two model types were not in agreement and more investigation of the biomass models is required. The large gorgonian coral VME polygons were modified using the presence/absence SDM (Knudby et al. 2013b). The deepwater closed area on the NE Flemish Cap was put in place based on underwater camera observations and in part lies outside the NAFO Fishing footprint. Otherwise there is general agreement between the closed areas and the VMEs, with the notable exception of the sea pen VMEs on eastern Flemish Cap and the 3O Notch.

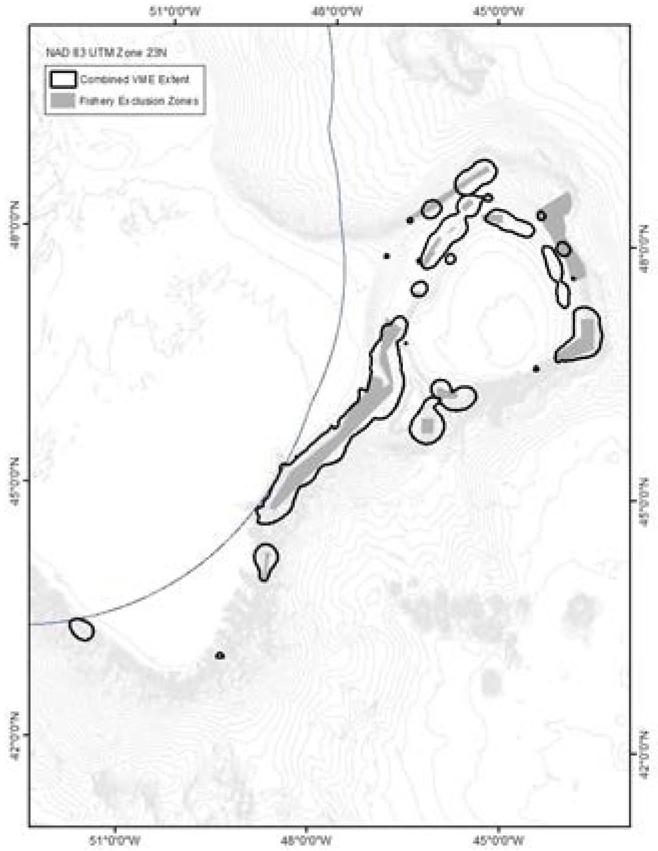


Fig.4.2.5.3.2. Combined extent of the modified sponge VME, sea pen VME and large gorgonian coral VME in the NRA, as defined in Section 4.2.3.

Assessment of VME impact

The fishing intensity (Fig. 4.2.5.3.1) and the VME biomass gridded layers were clipped to within the boundaries of the re-defined VME extent (Fig. 4.2.5.3.2). Given the assumption that selected VME indicator taxa are **unlikely** to occur in significant concentrations outside of the VME extent boundary, it was considered that the seabed within the fishing footprint, but falling outside of the re-defined VME boundary, would be at low risk of impact from bottom fishing (noting that the VME extent presented here is only for selected VME indicator taxa).

Figures 4.2.5.3.3 to 4.2.5.3.5, present the extent of VME species specific biomass observations and fishing intensity within the re-defined VME polygon boundaries. It can be seen that within the extent of some VME (outside of current closed areas) relatively high intensity fishing effort has occurred. Closer inspection reveals that areas of higher fishing intensity tend to occur on the shallower flanks and slopes of the Flemish Cap and the Grand Banks of Newfoundland. It can also be seen that the 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 (due to lack of survey samples) lie beyond the scientific fishery survey area which tends to be at water depths greater than 1,600 m.

For each taxon-specific VME, the average VME biomass value (in kg km^{-2}) of every cell in which a VME biomass observation has been made was added cumulatively against a gradient of increasing fishing intensity per cell (in hrs km^{-2}) using average fishing effort (e.g., 2008-2014) and excluding any cells/observations within the closed areas. Plots of cumulative VME indicator species biomass against ranked fishing intensity were performed for sponge, sea pen and large gorgonians (Fig. 4.2.5.3.6). In all cases there is a clear point where VME biomass no longer increases at a given level of fishing intensity. Each of these inflection points is taken to represent a limit of fishing effort which separates areas of VME which have been impacted (e.g., defined by the cells above the cut-off value), and areas of VME which are at potential risk of impact (e.g., cells below the cut-off value). A test of significance was also applied to the cumulative plots in the form of a randomised permutation test, e.g., the order of the biomass was randomised against the fishing effort to generate 1000 sets of data against which the observed cumulative plot of biomass against fishing effort was compared, the level of significance (p value) is given in the figure caption.

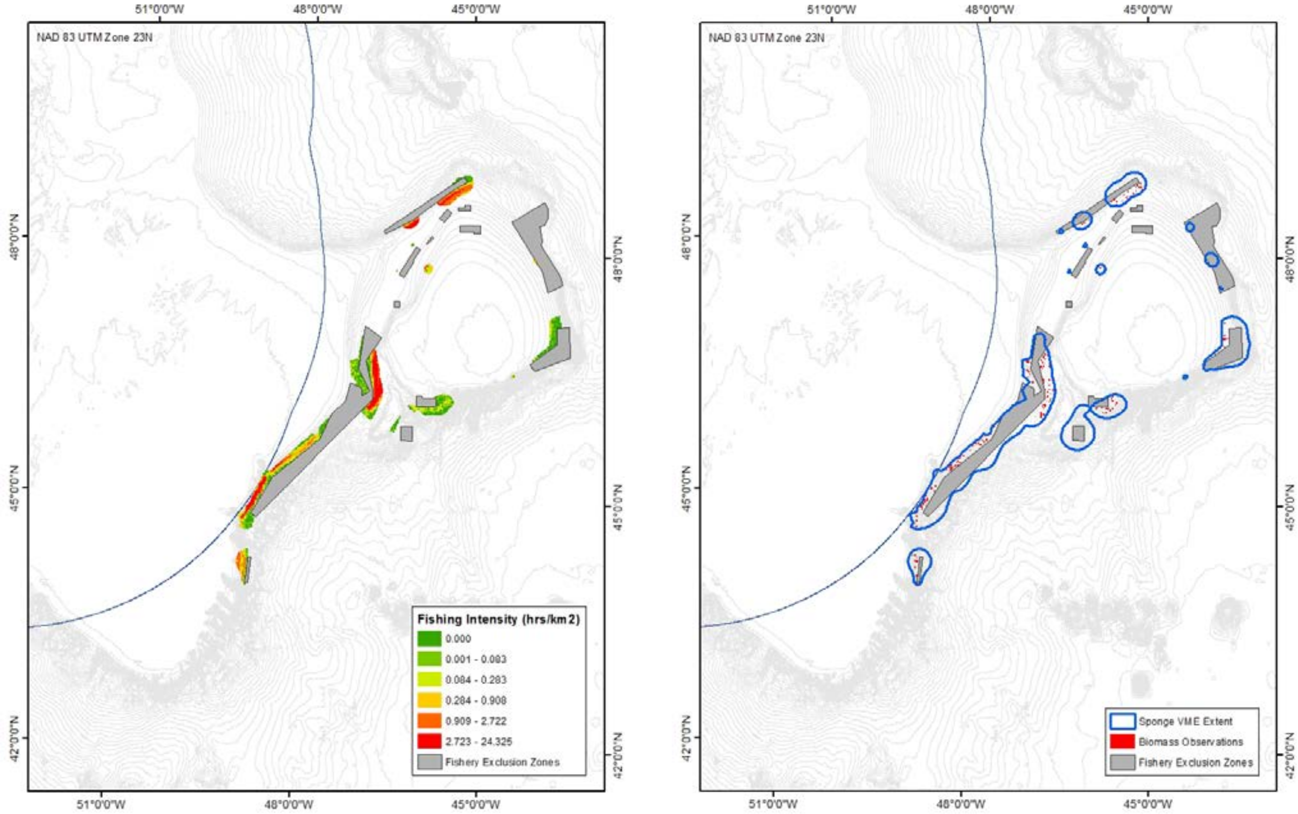


Fig. 4.2.5.3.3. Distribution of fishing effort using VMS data between 2008 and 2014and biomass observations within the extent of sponge VME.

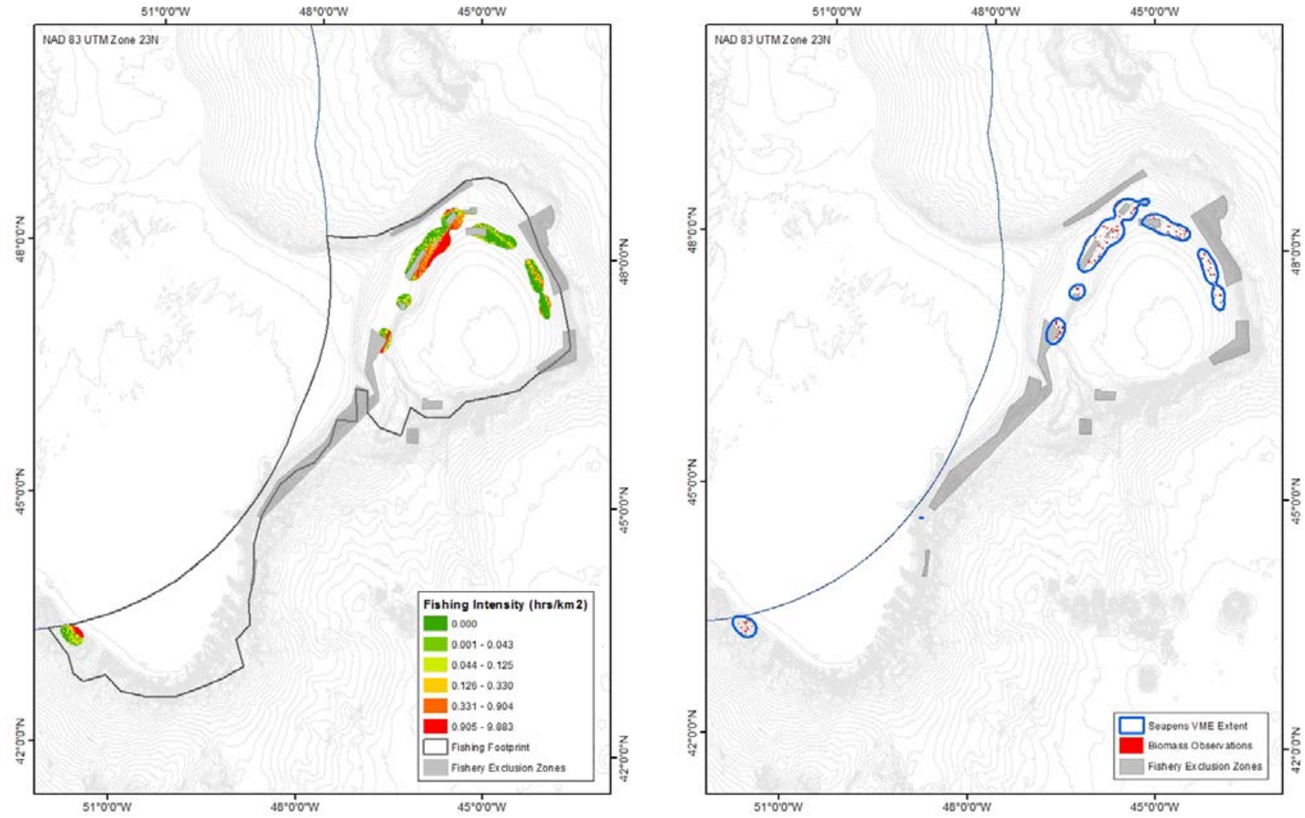


Fig. 4.2.5.3.4. Distribution of fishing effort (2008-2014) and biomass observations within the extent of sea pen VME.

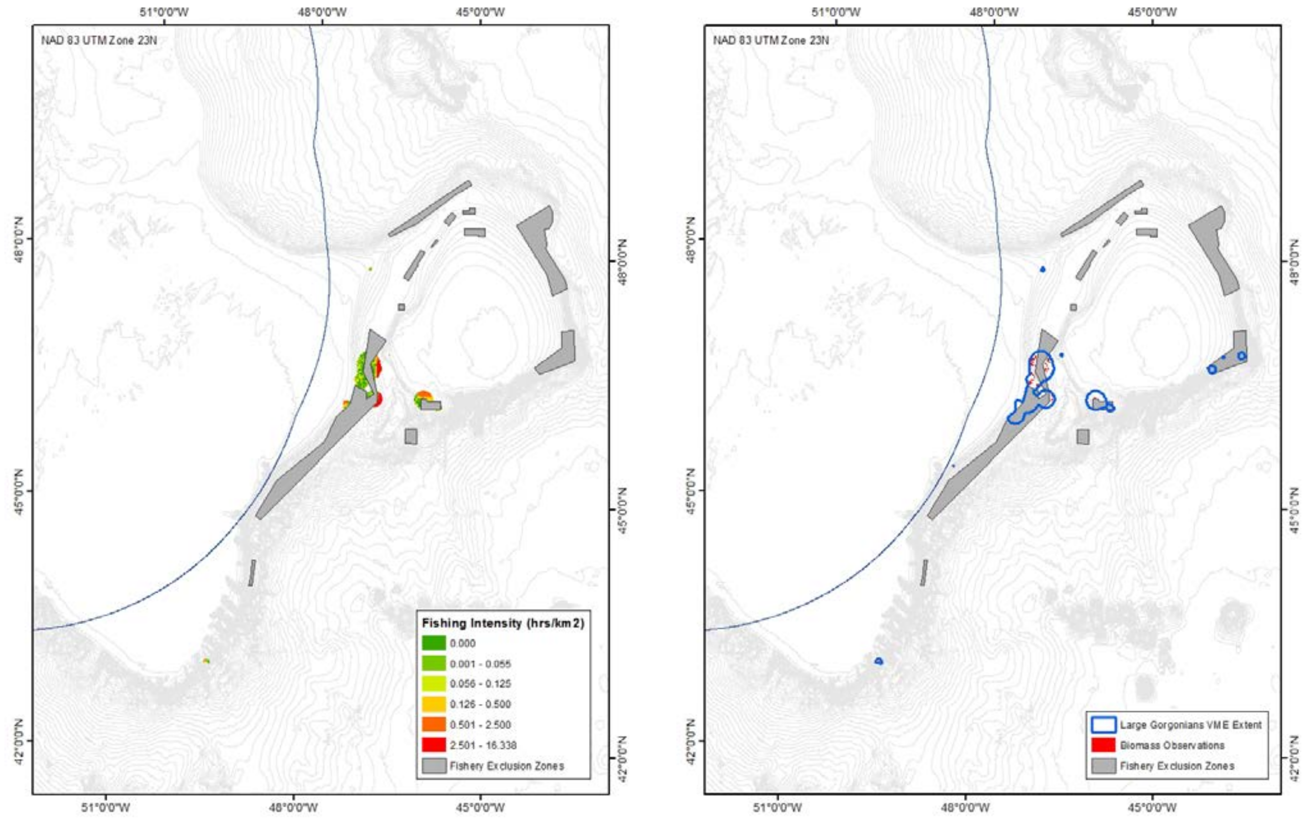


Fig. 4.2.5.3.5. Distribution of fishing effort (2008-2014) and biomass observations within the extent of large gorgonian VME.

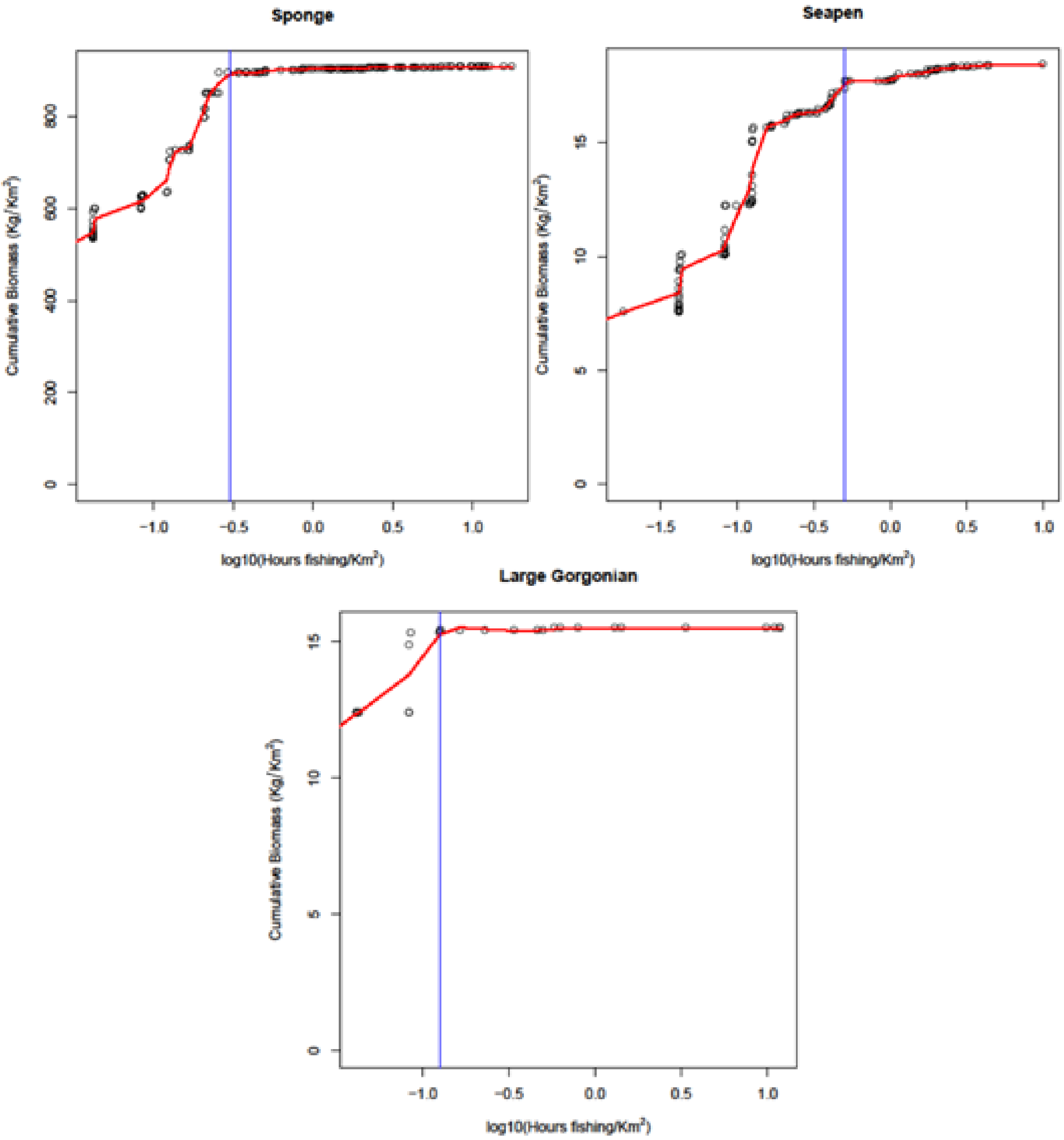


Fig. 4.2.5.3.6. Left: Cumulative plot of sponge VME biomass against fishing effort, inflexion a cut-off value of 0.3 hrs km^{-2}, $p = <0.05$. Centre: cumulative plot of sea pen VME biomass against fishing effort, inflexion cut-off value of 0.5 hrs km^{-2}, $p = >0.05 <0.1$. Right: cumulative plot of large gorgonian VME biomass against fishing effort, inflexion cut-off value of 0.1 hrs km^{-2}, $p = >0.1<0.25$.

Defining the spatial extent of VME impact relative to the area of VME

Each of the defined VME specific cut-off values was applied to the fishing effort corresponding to the respective VME polygons, to calculate the proportion of the VME area at high risk, low risk and impacted. This analysis addresses the second criteria of the FAO guidance, i.e., to assess the "spatial extent of the impact relative to the availability of the habitat type affected". Figure 4.2.5.3.7, shows the area of sponge VME at high risk of impact represents 14% of the total sponge VME area, whereas 21% of the sponge VME has been assessed to have been impacted. Accordingly, a total of 65% of sponge VME falls within the low risk category, either because it is protected by a fishery closure or it is in an area outside of the historical fishing footprint. Figure 4.2.5.3.8, shows the area of sea pen VME at relatively high risk of impact represents 46% of the total sea pen VME area, whereas 38% of the sea pen VME has been assessed to have been impacted. However, only 16% of sea pen has been assessed to be at low risk of impact, either because it is protected by fishery closures or it is in an area outside of the historical fishing footprint. Figure 4.2.5.3.9, shows the area of large gorgonian VME at relatively high risk of impact represents 12% of the total large gorgonian VME area, whereas 31% of the large gorgonian VME has been assessed to have been impacted. Nevertheless, a total of 56% of large gorgonian VME is assessed to be at low risk of impact due to either protection by fishery closures or it is found in an area outside of the historical fishing footprint.

Similar calculations were performed using gridded biomass data for the same defined areas of impact, low and high risk categories. It should be noted that the gridded biomass layer is a modelled biomass layer derived from the KDE analysis (Kenchington et al., 2014) which predicts biomass in areas which have been impacted. The biomass values associated with each of the impact/risk categories are therefore modelled and not actual biomass values.

The total area and biomass of low risk, high risk and impacted categories for each VME assessed is summarised in Tables 4.2.5.3.1 and 4.2.5.3.2, respectively.

Table 4.2.5.3.1. Area (km^2) of VME at low risk, impacted and at high risk.

	Sponges			**Sea pens**			**Large gorgonians**	
	km^2	**(%)**		**km^2**	**(%)**		**km^2**	**(%)**
VME at Low risk	12,874	(65)		1,094	(16)		1,980	(56)
Closure inside footprint	4,227	(21)		1,094	(16)		1,485	(42)
Closure outside footprint	3,679	(19)					495	(14)
Outside fishing footprint	4,888	(25)						
VME Impacted	4,259	(21)		2,662	(38)		1,091	(31)
VME at High risk	2,771	(14)		3,226	(46)		434	(12)
Total area of VME	19,824	(100)		6,983	(100)		3,505	(100)

Table 4.2.5.3.2. Biomass (kg) of VME at low risk, impacted and at high risk.

	Sponges			**Sea pens**			**Large gorgonians**	
	kg	**(%)**		**kg**	**(%)**		**kg**	**(%)**
VME at Low risk	113,157	(73)		20	(19)		132	(63)
Closure inside footprint	49,541	(32)		20	(19)		115	(55)
Closure outside footprint	45,806	(30)					17	(8)
Outside fishing footprint	17,810	(11)						
VME Impacted	25,621	(17)		41	(42)		48	(23)
VME at High risk	16,149	(10)		45	(39)		28	(14)
Total biomass of VME	15,4926	(100)		106	(100)		208	(100)

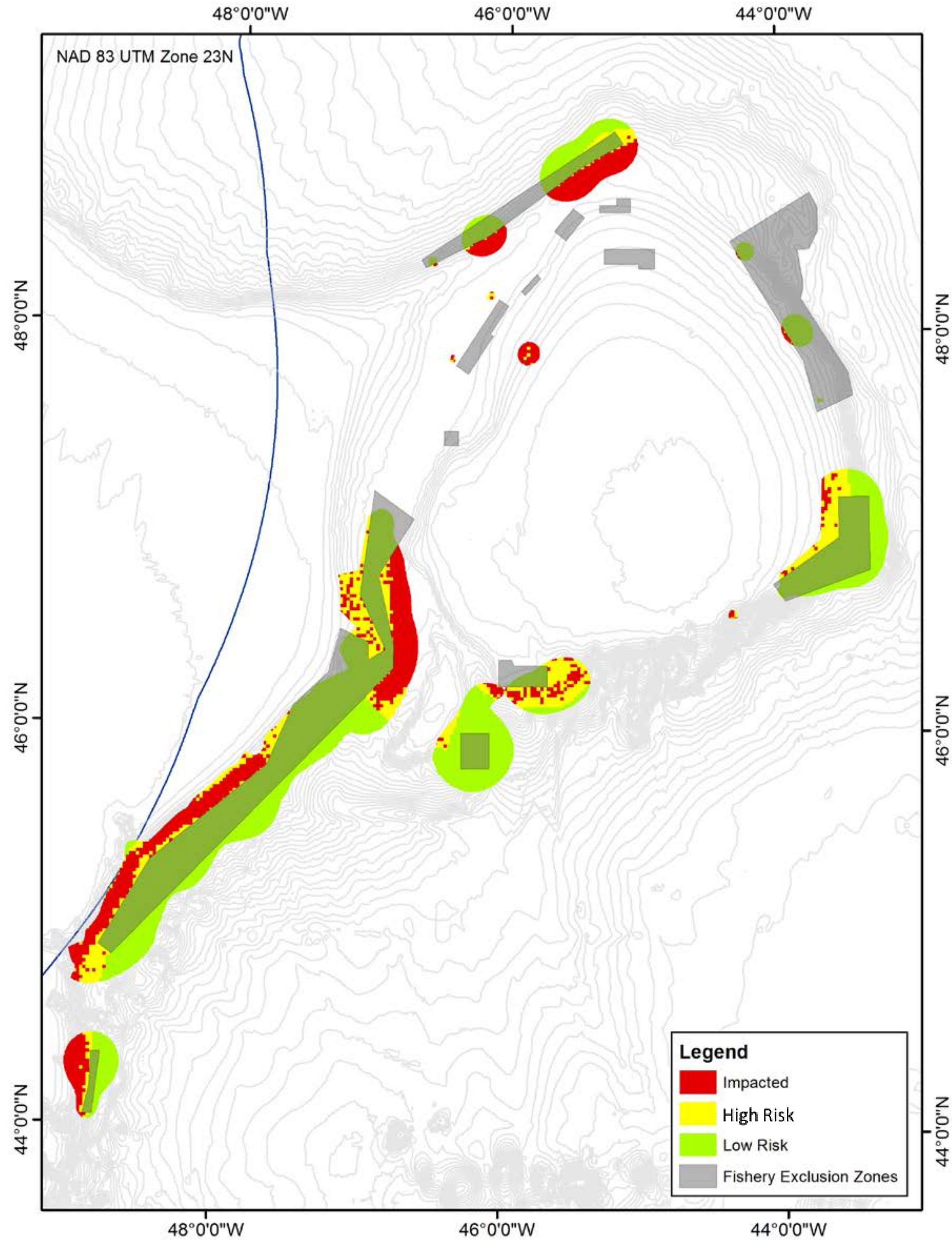


Fig. 4.2.5.3.7. Areas of sponge VME at high risk of impact (yellow), impacted (red) and low risk of impact (green), according to calculated fishing intensity cut-off value.

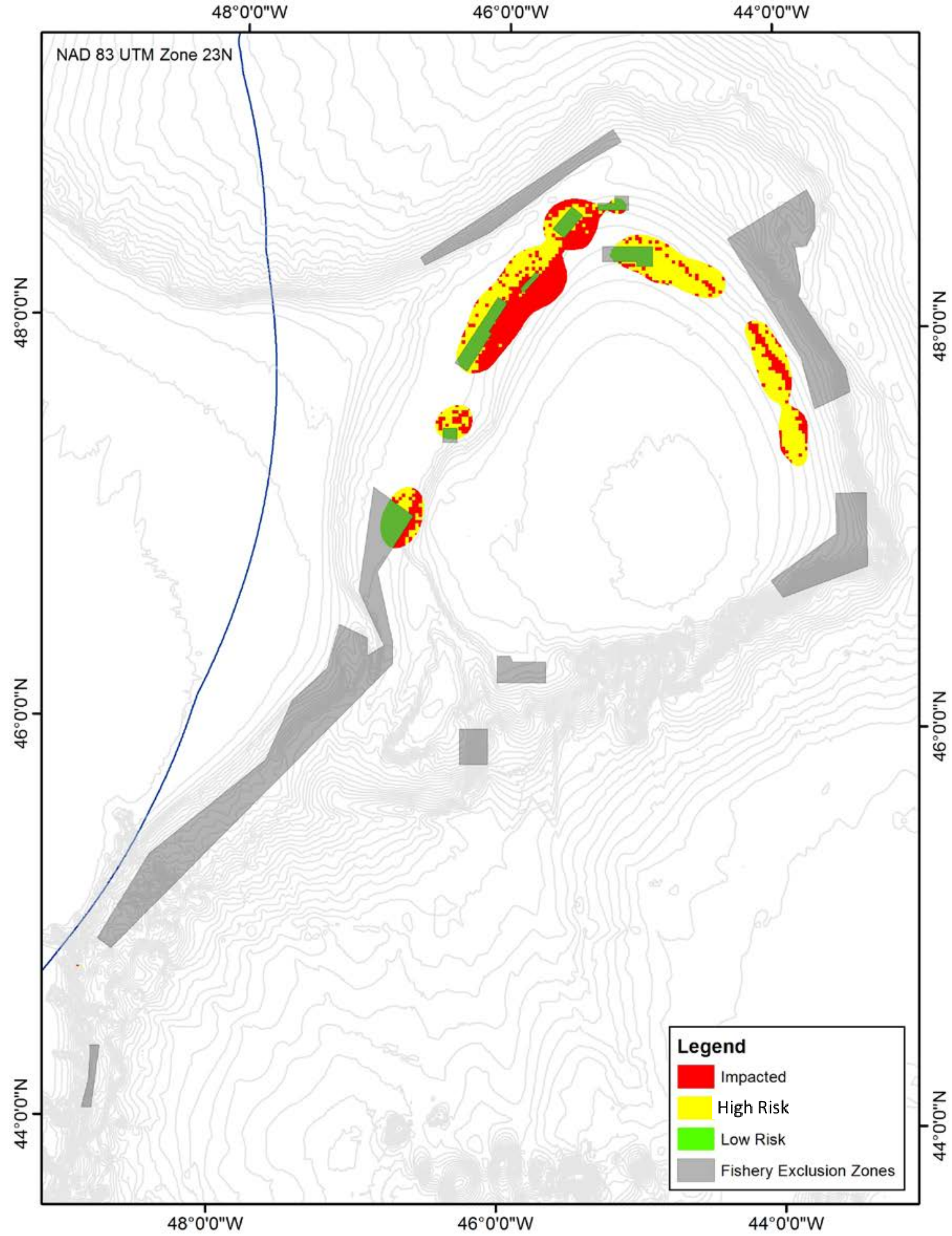


Fig. 4.2.5.3.8. Areas of sea pen VME at high risk of impact (yellow), impacted (red) and low risk (green), according to calculated fishing intensity cut-off value.

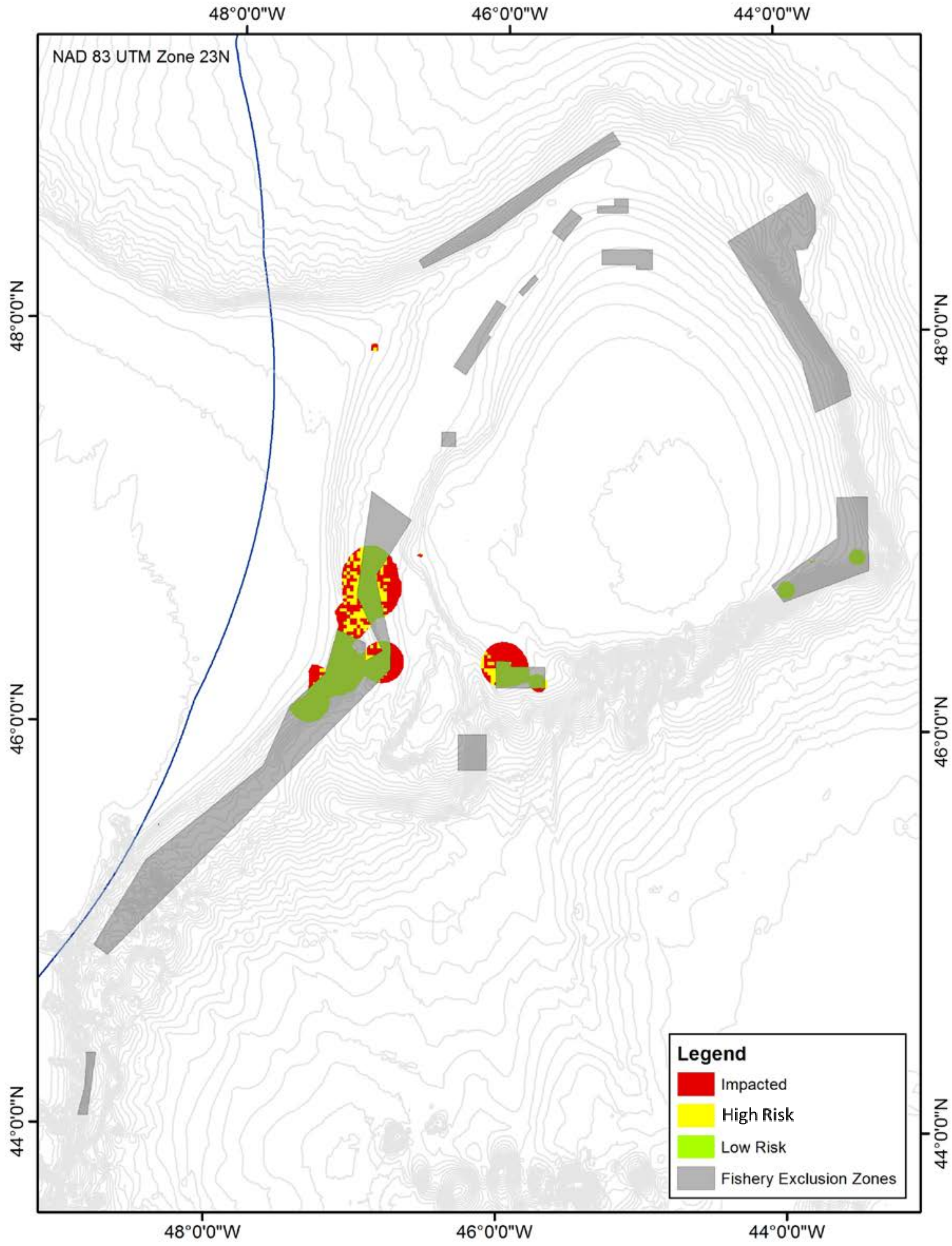


Fig. 4.2.5.3.9. Areas of large gorgonian coral VME at high risk of impact (yellow), impacted (red) and low risk (green) according to calculated fishing intensity cut-off value.

Overall assessment of SAI

Ideally, we would wish to take the output of FAO criterion ii, "the spatial extent of the impact relative to the availability of the habitat type affected", and through consideration of FAO criteria iii through vi, state whether or not the calculated impact on VME is significant. However, as quantitative data are not available for all of the FAO criteria, an evaluation of SAI against such criteria is not possible at this stage. Nevertheless, there are several other attributes of VMEs which can be assessed for which there are data available. For example, i. the proportion of area or biomass of VME which is assessed to be at low risk compared to high risk and impacted, ii. the number and area of overlapping VMEs, iii. the relative sensitivity of VMEs, iv. fishing area stability, and v. the level of VME fragmentation. Each of these criteria, which are defined in Table 4.2.5.3.3, can be quantitatively evaluated and assessed in relation to their relative risk of causing SAI. The results of this are given in Table 4.2.5.3.4. The cumulative impacts have been assessed by applying the calculated fishing pressure cut-off values to each year of VMS data. The cells which exceed the cut-off were then cumulated in order to generate a cumulative map of fishing pressure which exceeds the cut-off value.

Table 4.2.5.3.3. Definition of criteria used to assess SAI in the current study.

SAI criteria	Definition
Area/Biomass at low risk	This refers to the proportion of the area or biomass of VME which is currently at low risk either because it falls within a fishery closure area and/or is in an area outside of the fishing footprint
Area/Biomass impacted	Proportion of the area or biomass of VME which has been exposed to a level of fishing effort above the defined cut-off point within any one year
Area/Biomass at high risk	Proportion of the area or biomass of VME which falls below the defined cut-off point of fishing effort within any one year.
Number of overlapping VMEs	Proportion of area overlapping with other VMEs
Fishing effort/biomass cut-off value (Index of VME sensitivity)	The impact cut-off values for each of the VMEs are used as a proxy of sensitivity (a high cut-off value indicates a low sensitivity) as it indicates the point at which trawl duration/length exceeds VME indicator patch size within the habitat
Index of fishing stability	Number of cells consistently fished above the impact cut-off value over time as a proportion of the total cells impacted
Index of Risk of VME fragmentation	Proportion of discrete VME without protection

Table 4.2.5.3.4. Quantitative evaluation of SAI criteria used in the present overall assessment of SAI for sponge, sea pen and large gorgonian VME in the NRA.

<table>
<tr><th></th><th colspan="2">Sponge</th><th colspan="2">Sea pen</th><th colspan="2">Large gorgonian</th></tr>
<tr><th>SAI criteria</th><th>Area</th><th>Biomass</th><th>Area</th><th>Biomass</th><th>Area</th><th>Biomass</th></tr>
<tr><td>Low risk</td><td>65%</td><td>73%</td><td>16%</td><td>19%</td><td>56%</td><td>63%</td></tr>
<tr><td>High risk</td><td>14%</td><td>10%</td><td>46%</td><td>39%</td><td>12%</td><td>14%</td></tr>
<tr><td>Impacted</td><td>21%</td><td>17%</td><td>38%</td><td>42%</td><td>31%</td><td>23%</td></tr>
<tr><td>VMEs overlapping</td><td colspan="2">11%</td><td colspan="2">2%</td><td colspan="2">74%</td></tr>
<tr><td>Fishing effort/biomass cut-off value (index of sensitivity)</td><td colspan="2">0.3</td><td colspan="2">0.5</td><td colspan="2">0.1</td></tr>
<tr><td>Fragmentation</td><td colspan="2">1%</td><td colspan="2">26%</td><td colspan="2">2%</td></tr>
<tr><td>Fishing area stability</td><td colspan="2">32%</td><td colspan="2">14%</td><td colspan="2">21%</td></tr>
</table>

An expert comparative evaluation of these results (above) was undertaken such each result was assigned a relative risk score of SAI being realised (e.g., low, moderate and high risk). For example, if a VME has a large proportion of its area and/or biomass evaluated at low risk of impact then it would be assessed as having a relatively low risk score for SAI. By contrast, if a VME had a relatively high level of sensitivity (low fishing effort/biomass cut-off value) it would be assessed as having a high risk score of SAI. The overall results of the expert assessment of SAI is given in Table 4.2.5.3.5.

Table 4.2.5.3.5. Overall SAI risk scores for sponge, sea pen and large gorgonian VME in the NRA. The risk scores are relative (e.g, low, medium and high) and determined by expert evaluation of the data presented in Table 4.2.5.3.4

	Sponge		**Sea pen**		**Large gorgonian**	
SAI criteria	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**
Low risk	Low	Low	High	Mod	Mod	Low
High risk	Low	Low	High	High	Low	Low
Impacted	Mod	Mod	High	High	High	Mod
VMEs overlapping	Mod		High		Low	
Index of Sensitivity	High		Mod		High	
Fragmentation	Low		High		Low	
Fishing area stability	Low		High		Low	
Overall risk of SAI	**Low**		**High**		**Low**	

Sea pens

Photographs of the sea floor within a heavily fished portion of a sea pen VME polygon showed no megafauna, despite the presence of sea pens in the nearby closed area, indicating that sea pens cannot withstand concentrated and repeated fishing effort. In addition, WGESA previously noted that redfish larvae attach to the sea pen stalks and these habitats may be important nursery areas for Sebastes spp. (see ToR 3.1.2 of NAFO, 2014), thereby increasing the risk to the long term sustainability of NAFO fisheries should too much sea pen habitat be destroyed. WGESA at its 2013 meeting noted the lack of protection for the entire eastern Flemish Cap part of the sea pen system was of concern for the long term sustainability of these VME given the lack of knowledge of recruitment processes and connectivity. Therefore, although they may be more resilient to a first pass of the trawl gear than other types of coral or sponge, sea pens have more of their core VME area unprotected.

Furthermore, with the current high level of fragmented sea pen closures and exposure to a relatively low level of fishing stability, WGESA consider that there is ongoing high risk of further sea pen SAI (see Fig. 4.2.5.3.7). This could lead to the loss of individual VME polygons which could have consequences for other areas depending on source/sink relationships. In conclusion sea pens are assessed as having experienced SAI (Table 4.2.5.3.5) and also being at high risk of further SAI.

Sponge and large gorgonian corals

Fishing in the vicinity of sponge VME has persisted in the same areas for many years with little change in the impact footprint as evidenced by the relatively high value of fishing stability exposure calculated for these VMEs (Table 4.2.5.3.4). The directed Greenland halibut fishery, that is the main fishery carried out in waters below 700 m depth (Gonzalez-Costas et al., 2011), where the sponge and large gorgonian VME occur, began in the early-1960s in this area (Bowering and Brodie, 1995), indicating that impacts of fishing on the sponge and large gorgonian VME may have been accumulating for at least 50 years. However, based upon the current analysis and assessment of SAI which utilizes the last 7 years of VME effort data, little change is observed in the identified core fishing areas associated with these VMEs. This, combined with an overall greater proportion of sponge and large gorgonian VME protected by fishery closures, results in an overall evaluation of a low likelihood of SAI for these VMEs.

Impacts on non-coral and sponge VME

The WGESA completed the assessment of SAI on the sponges, large gorgonian corals and sea pens. The remaining VME indicators, that is the erect bryozoans, large size sea squirts, crinoids, cerianthid anenomes and small gorgonian corals were not assessed. Previously, WGESA had undertaken kernel density analyses of the small gorgonian corals, erect bryozoans and large size sea squirts, however in situ surveys conducted in 2015, demonstrated that the significant concentration polygons for erect bryozoans and large size sea squirts were not indicative of VME for these species, and WGESA recommended that the location of tows with catches over the threshold be considered the VME. To date, species distribution models have not been conducted on these indicator species, so there is potential for those analyses to assist in the delineation of the VME. In this section we examined the relationship between the tows with significant catches of erect bryozoans and large size sea squirts to determine whether the approach we have used for the sponges, large gorgonian corals and sea pens will be applicable to these taxa. This will allow an evaluation of the cut off levels for the impact but not its spatial extent or significance (until more modelling is completed at the next meeting).

Erect bryozoans

The largest of the significant catches of bryozoans was of 7.843 kg (Figure 4.2.5.3.10). The distribution of the significant catches of bryozoans was localized to the Tail of the Grand Bank (Fig. 4.2.5.3.11) in areas where there has been little fishing effort over the last years (2007 to 2014) (Fig. 4.2.5.3.12). The relationship between the cumulative biomass and average fishing effort reflects this, with the cut-off for fishing being very clear at 2.3 hours (Fig. 4.2.5.3.13).

Fig. 4.2.5.3.10. The largest catch of erect bryozoans from the research vessel surveys. This 2008 catch of ~7.8 kg was from the Tail of Grand Bank.

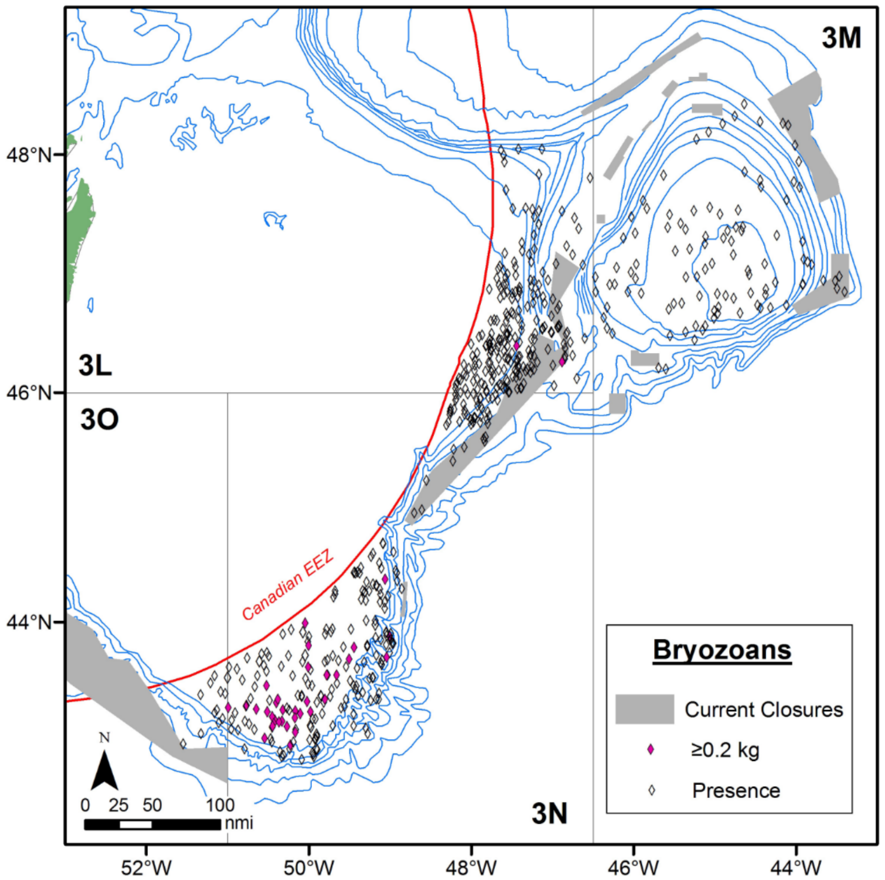


Fig. 4.2.5.3.11. Location of research vessel survey catches of VME indicator erect bryozoans. Significant catches were determined by kernel density analysis and assessment (NAFO, 2013).

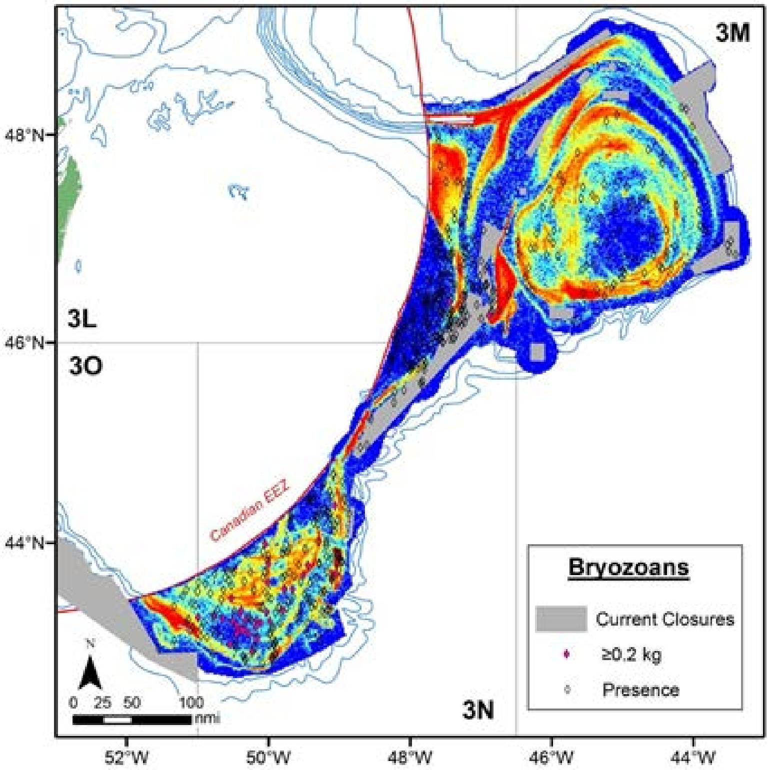


Fig. 4.2.5.3.12. Location of research vessel survey catches of VME indicator erect bryozoans in relation to the average fishing effort from 2008- 2014. Significant catches were determined by kernel density analysis and assessment (NAFO, 2013).

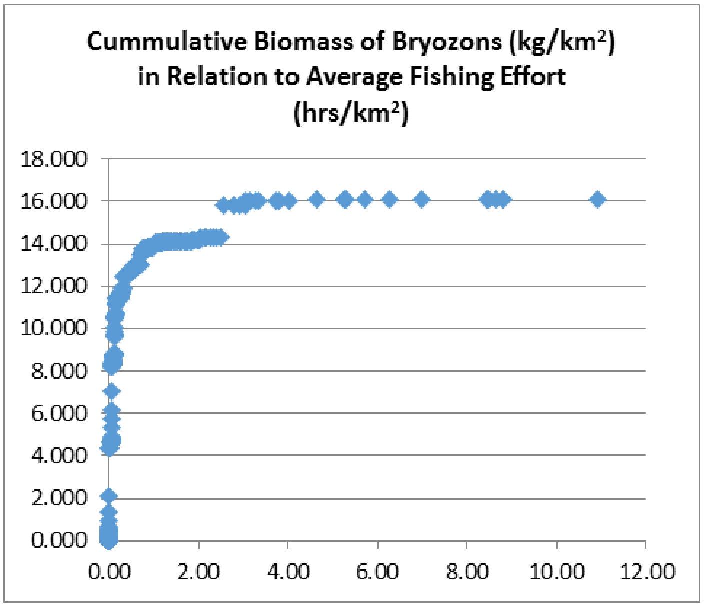


Fig. 4.2.5.3.13. Cumulative distribution of the biomass of erect bryozoans (Y axis) with increase in average fishing effort (X axis).

Large sea squirts

The distribution of the significant catches of large sea squirts, mostly the sea potato or sea onion Boltenia ovifera, was localized to the Tail of the Grand Bank (Fig. 4.2.5.3.14) in areas adjacent to heavy fishing effort over the last years (2007 to 2014) (Fig. 4.2.5.3.15). The relationship between the cumulative biomass and average fishing effort was not as clear as for the erect bryozoans, however the inflection of the curve appears to be between 0.4 and 0.5 hours (Fig. 4.2.5.3.16).

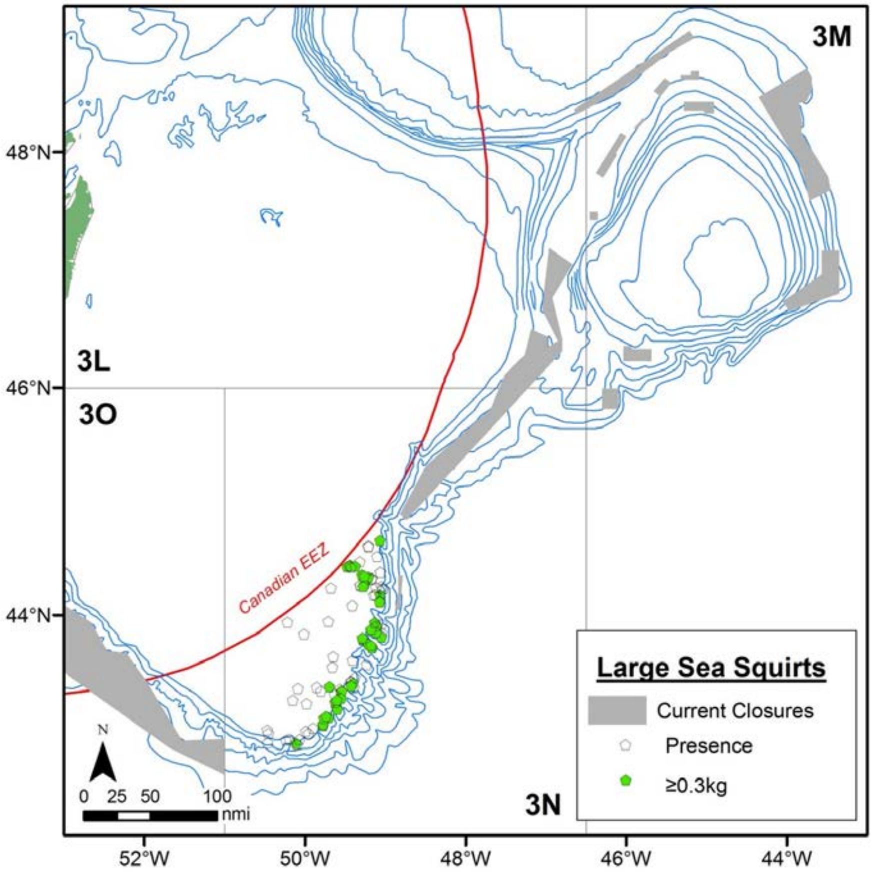


Fig. 4.2.5.3.14. Location of research vessel survey catches of VME indicator large sea squirts. Significant catches (≥0.3 kg) were determined by kernel density analysis and assessment (NAFO, 2013).

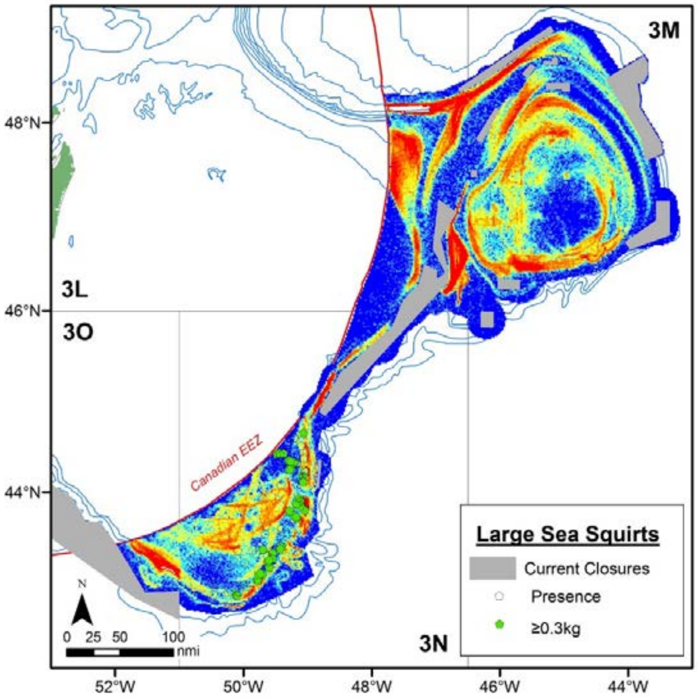


Fig. 4.2.5.3.15. Location of research vessel survey catches of VME indicator large sea squirts in relation to the average fishing effort from 2008-2014. Significant catches were determined by kernel density analysis and assessment (NAFO, 2013).

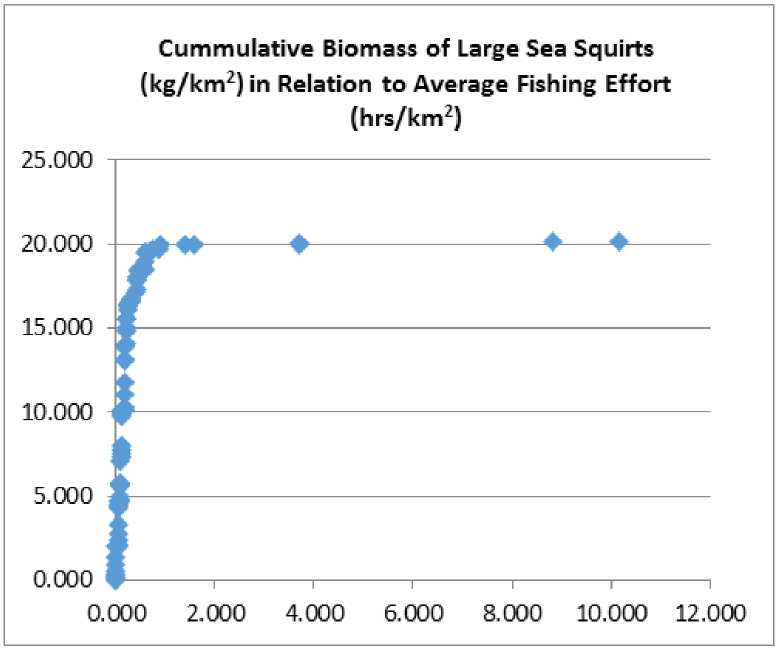


Fig. 4.2.5.3.16. Cumulative distribution of the biomass of large sea squirts (Y axis) with increase in average fishing effort (X axis).

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ToR 4.3 (FC Request #11). Workplan towards the assessment of potential impacts of activities other than fishing on NAFO VMEs.

FC Request #11. Article 23 NCEM foresees a reassessment of bottom fishing activities in 2016. The NAFO Roadmap for Developing an Ecosystem Approach to Fisheries extends the work of the Scientific Council to include the assessment of potential impacts of activities other than fishing. Also, impacts of human activities in ecosystems should not be analysed analyzed in isolation since cumulative effects might occur representing more than the sum of the individual factors. The Scientific Council is therefore requested to develop a workplan at its meeting in 2016 that will allow to address and analyse analyze the potential impact of activities other than fishing (eg. oil and gas exploration, marine cables, ocean dumping, marine transportation) on NAFO VMEs, in particular VME closed areas.

Identification of priority sectors for consideration

At the 2014 WGESA meeting we identified a number of sectors and human activities that have the potential to affect fish, fisheries and habitat in the NAFO area (Table 4.3.1)

Table 4.3.1. Anthropogenic activities and stressors identified in WGESA report for 2014.
* relevant for the NAFO convention area. The others are primarily coastal or nearshore and/or do not currently occur in or affect the NAFO area.

Anthropogenic activity	Stressor
Fishing*	
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*
Waste inputs*	Litter*
	Microplastics*
Cables*	
Pipelines*	
Recreation and tourism	
Marine protected areas (broadly defined)*	
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

While all the activities highlighted above have the potential to affect fish, fisheries and habitat, a subset are of priority interest for Vulnerable Marine Ecosystems (VMEs) identified for conservation within the NAFO convention area (Table 4.3.2). These priority activities include several related to offshore oil and gas exploration and exploitation, including seismic surveys, releases of drilling wastes and produced water, and accidental events (spills) particularly near seabed releases of oil and gas. Marine mining is gaining impetus as technologically feasible and economically viable and profitable. As a result there is an increasing interest in mineral and gas hydrate extraction from the deep sea targeting, sea mounts, deep water muddy plains and hydrothermal vents. Such habitats often support sensitive and vulnerable benthic communities for which we have limited ecological information. VME communities are also affected by waste in the ocean, particularly plastic waste. Litter and microplastics are now recognized to be ubiquitous in the world oceans and have been demonstrated to negatively affect benthic communities and filter feeders. The occurrence of litter and amount of microplastics associated with VMEs requires study as they may be having similar affect the organisms associated with the VMEs.

Current oil and gas activities are occurring the vicinity of the VMEs. While drilling may not be taking place in the VMEs themselves, downstream impacts of these activities may impact sensitive species in the protected areas. The extent to which this is possible is unknown but could be explored using drift models.

Table4.3. 2. Important areas for the NAFO Fisheries Commission to consider for understanding inter sector effects and potential for cumulative effects.

Sector	Activity
Offshore oil and gas exploration	• Seismic surveys
Offshore oil and gas exploration and exploitation	• Drilling waste disposal • Produced water disposal • Accidental events (subsea blowouts)
Marine mining	• Habitat disruption and destruction • Smothering from tailings disposal
Waste	• Litter (large size objects) • Microplastics (<5mm)

Brief description of sector activities and potential effects on VMEs

Offshore oil and gas:

A general description of all offshore oil and gas activities can be found in the recent Strategic Environmental Assessment for Eastern Newfoundland carried out by the Canada Newfoundland and Labrador Offshore Petroleum Board (CNLOPB, 2014 http://www.cnlopb.ca/sea/eastern.php).

Potential impacts of oil and gas exploration and exploitation can occur during the: exploratory (seismic), development (physical footprint on the sea floor) and/or the operational phase (processing or accidental spill due to mechanical or human error).

Seismic surveys:

Seismic surveys are one type of geophysical survey used to capture information about the composition and stratigraphy of the geological stata under the seafloor. In an offshore seismic survey, high-energy sound sources (airguns) are towed behind a survey vessel while it travels along a track line in a prescribed grid crossing known or suspected hydrocarbon accumulations (Fig. 4.3.1). The sound source is fired at regular intervals and directs high energy (low frequency) sound bursts toward the seafloor which can penetrate below the surface. The reflected sound energy is then recorded by sensitive hydrophones (streamers, up to several kilometres in length) which are towed behind the vessel. Computer-based data processing systems then convert the reflected sound (acoustic signals) into seismic data that can be used to map possible hydrocarbon accumulations within the survey area.

Potential effects on VMEs: Sound levels produced by seismic surveys have been shown to impact many marine species, particularly marine mammals. However, the impact on benthic species is not clear. Current studies underway at DFO designed to determine the impact of seismic activities on crab, may provide an indication of possible impacts.

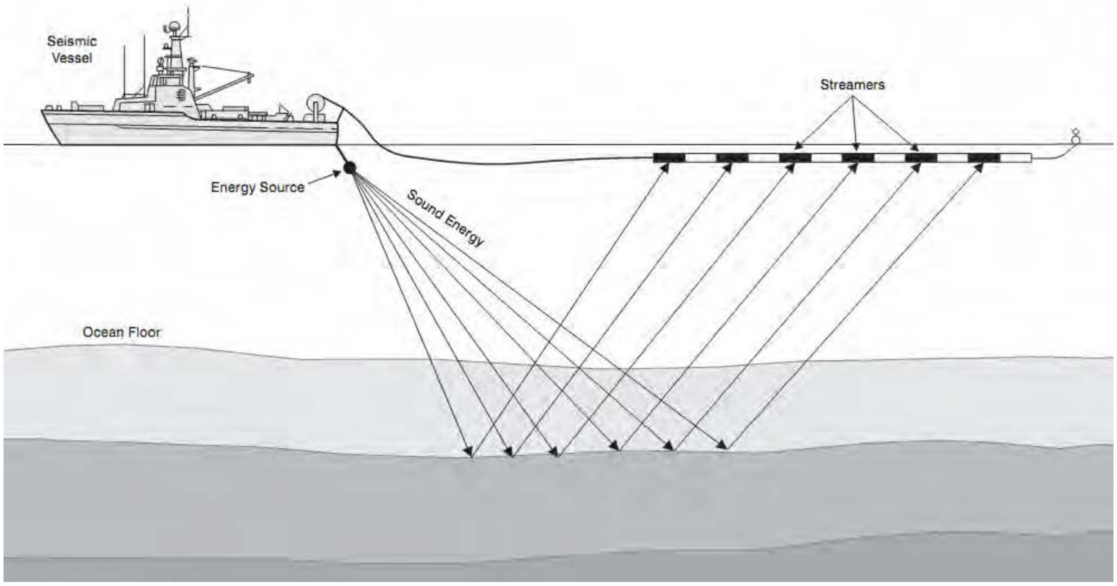

Fig. 4.3.1. Typical configuration of a seismic vessel towing an energy source and the streamers that record sound reflected from the seabed and subfloor features. Image is not to scale as the streamer array can be up to several kilometers in length. Figure from CNLOPB (2014).

Offshore wells drilling:

Exploratory wells are drilled to determine if features of interest identified during the geophysical surveys represent significant reserves of hydrocarbons. Three types of mobile offshore drilling units are used in the Canadian offshore: semi-submersible drilling units; drill ships; and jack-up drilling units. The first two are those most suitable for deepwater drilling. During the exploration phase drilling wastes are released back to the seafloor. These wastes contain cuttings and drilling fluid components and are subject to various restrictions on disposal depending on the type of drilling fluid used (CNLOPB, 2010).

Production facilities in the Newfoundland offshore consist of multiple wells and may use a gravity based structure or a floating production platform (Fig. 4.3.2). Drilling wastes and produced water (a complex mixture of formation water and injected water, the largest volume waste stream from oil and gas production) may be re-injected into the wells, transported to shore for treatment or released into the water column following the Offshore Waste Treatment guidelines (CNLOPB, 2010).

Potential effects on VMEs:

Development phase – Drilling infrastructure can alter the sea floor through the removal of benthic communities. Drilling wastes are usually deposited on the seafloor and can smother nearby sessile communities. There is also evidence of potential for significant transport of fine particulates associated with drill wastes and these may be focusses in deepwater areas and with near bottom currents at shelf break or in shelf edge canyons.

Operational Phase (processing and accidental spills/blowouts)

Potential impacts during the operational phase can occur during the day-to-day processing activities associated with petroleum exploitation. Drill cuttings, a by-product of drilling, are discarded onto the sea floor and can accumulate causing smothering of fauna.

Impacts of production water released into the ocean on VMEs are unknown.

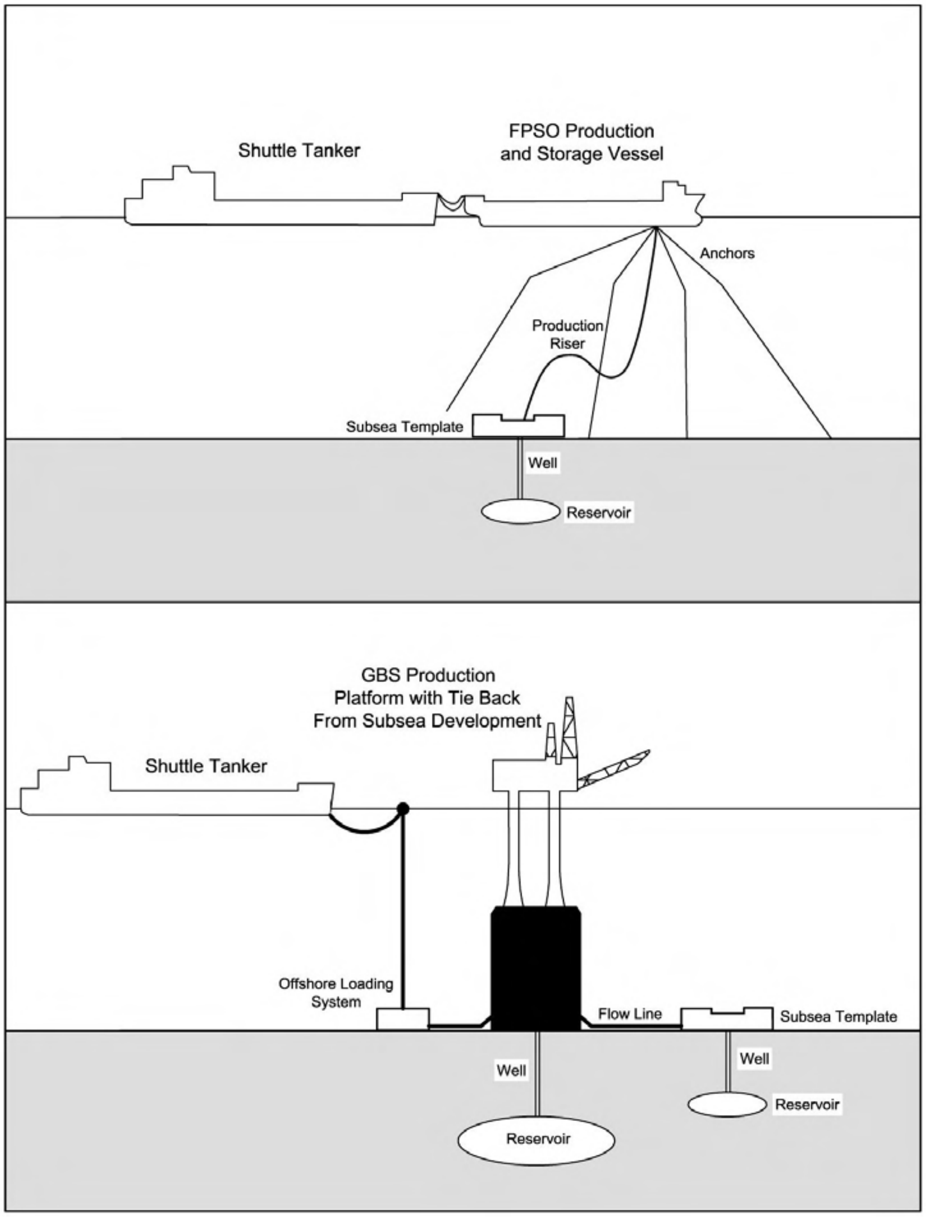

Fig. 4.3.2. Representation of two types of production platforms used in the Newfoundland offshore. Figure from CNLOPB (2014).

The greatest impact can occur as a result of an oil spill. In 2010 a devastating blowout on the drilling unit Deepwater Horizon (DWH) occurred while capping the exploratory Macondo oil well in the Gulf of Mexico. It triggered the largest oil spill in history releasing ~4.6 million barrels of oil in to Mississippi Canyon in the Gulf of Mexico (Griffiths, 2012), and provided a rare opportunity to study the effects of a large scale oil spill on benthic communities (Ryerson et al., 2012; Peterson et al., 2012; White et al., 2012; Hsing et al., 2013; Montagna et al., 2013; Fisher et al., 2014ab; Silva et al., 2015).

The impact of a deep-water oil spills can affect marine ecosystems on many levels: first as buoyant oil (surface impacts), secondly as deepwater plumes as oil sinks and disperses (subsurface impacts) and finally as heavily oiled sediment on the sea floor (benthic impacts) (Fig. 4.3.3: Peterson et al. 2012). In addition, during severe blowout events like the DSH, heavy metals commonly used during offshore oil-drilling operations are also released and deposited into the surrounding ecosystem.

Surface impacts are highly visible (e.g. oil slick on sea surface or washed onto land) and remediation occurs relatively quick. However, as in the Exxon Valdez oil spill, oil can persist when it is buried in anoxic, nutrient-limited sediments, where weathering is inhibited (Boufadel et al. 2010).

Subsurface and benthic impacts are not as visible and unfortunately are left to marine ecosystems to cope with. Ryerson et al., (2012) showed that 35% of the total hydrocarbons from the DWH oil spill were trapped and transported in persistent deep-sea plumes.

Distribution can be further enhanced by inclement weather, increasing mixing and dispersion rates of plumes.

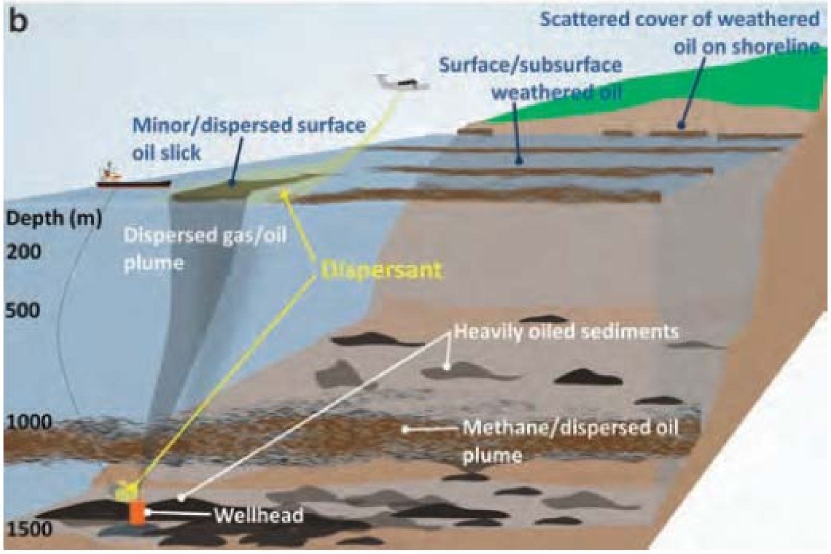

Fig. 4.3.3. Schematic representation of potential impacts from deep-water oil spills. Figure from Peterson et al. (2012)

Six months after the initial blowout, White et al., (2012) documented signs of stress on deep sea corals ~ 11 km southwest from the DWH oil spill using Remotely Operated Vehicle (ROV*) Jason II*. Observations included varying degrees of tissue loss, sclerite enlargement, excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (floc).

Montagna et al., (2013) studied the special extent of immediate impacts from the DWH oil spill on benthic fauna, documenting the most severe impacts occurred within 3 km of the wellhead in all directions (24 km^2). Impacts included reduction of faunal abundance and diversity. "*Benthic effects were correlated to total petroleum hydrocarbon, polycyclic aromatic hydrocarbons and barium concentrations, and distance to the wellhead; but not distance to hydrocarbon seeps. Thus, benthic effects are more likely due to the oil spill and not natural hydrocarbon seepage*". Moderate impacts were observed up to 17 km southwest and 8.5 km northeast from impact source with total affected area covering 148 km^2 (Montagna et al., 2013).

Fisher et al., (2014a) studied the longer term effects of the DWH spill on a deep-sea coral community at varying distances. Communities located 6 km south of the DWH were severally impacted (> 90%) while others located 22 km southeast were lightly impacted. This extended the range and depth (1850-1950 m) of impact further than previously thought.

Silva et al., (2015) observed coral injuries (e.g. bare skeleton, broken and missing branches) on Pinnacle Reef (65-75 m) off Mississippi and Alabama, Gulf of Mexico. Based on photo survey from pre-spill (1997, 1999) and post-spill (2011), this study found significantly more occurrences of injury on corals > 0.5 m in height. It is believed "Tropical Storm Bonnie facilitated and accelerated the mixing process of dispersant-treated hydrocarbons into the water column, resulting in harmful contact with coral colonies at mesophotic depths".

Marine mining

Four forms of deep-sea mineral resources are being considered for commercial exploitation: manganese nodule mining on abyssal plains, cobalt-rich crusts on seamounts, massive polymetallic sulphide deposits at sites of hydrothermal venting and gas hydrates. All of these resources can only be undertaken with significant seabed disturbance (Fig. 4.3.4) as the minerals are retrieved from the seafloor and tailings are winnowed or processed and returned to the bottom.

Marine mining in international waters is regulated by the International Seabed Authority (www.isa.org). While there are currently no active exploration or mining operations occurring in the NRA, there is increasing interest in the resources of the seafloor and the ISA anticipates that there will be increasing activity over the course of the next century https://www.isa.org.jm/sites/default/files/files/documents/isabrochure.pdf .

Potential effects on VMEs

Many sensitive benthic communities are associated with minable habitat (Geinert et al 2015) and effects of mining activities can last for a long time. The mining activity will destroy the substrate where the activity takes place, and its associated communities, and smothering impacts would be expected beyond the active mining area.

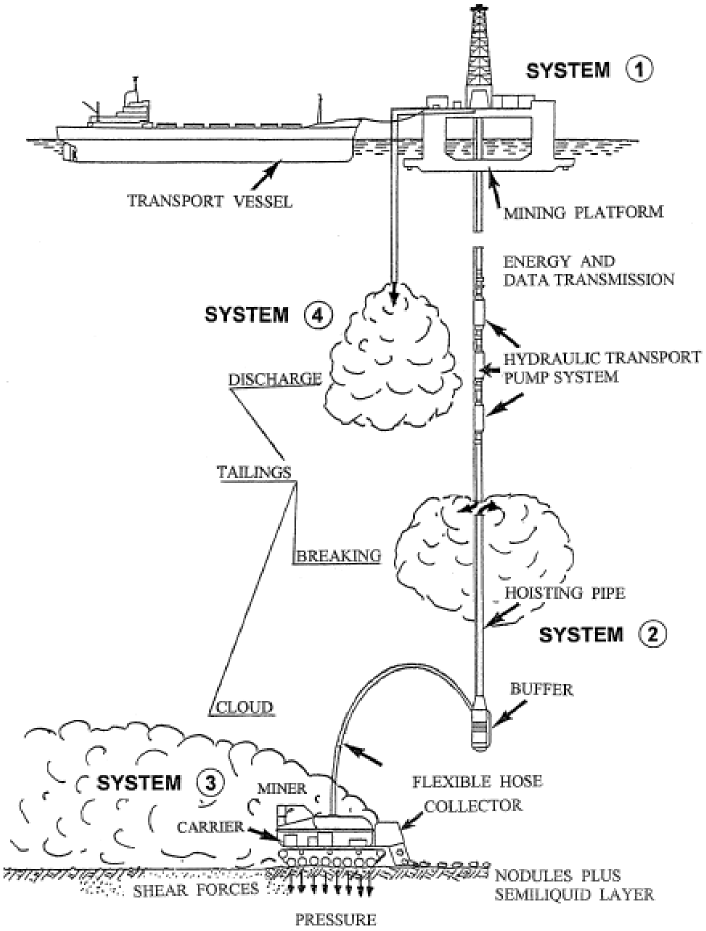

Fig. 4.3.4. Generalized configuration for marine mining showing technology and potential releases. Figure from Oebius et al. (2001).

Litter

The United Nations Environment Programme (UNEP http://www.unep.org/regionalseas/marinelitter/about/default.asp) defines marine litter as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment". The most common litter types found on the deep–sea floor in the Mediterranean and northeastern Atlantic are soft plastic (e.g. bags), hard plastic (e.g. bottles, containers), glass and metal (e.g. tins, cans) (Ramires-Llodra et al. 2011). Such material may smother benthic communities and may also provide an altered substrate for colonization. Even remote areas of the sea floor have been found to accumulate litter. There are no estimates of the amount of litter that may be present in the VME, or surrounding, areas.

Potential effects on VMEs

Microplastics: Microplastics are generally defined as plastic fragments less than 5mm in size (NOAA). They may be positively, negatively or neutrally buoyant. Microplastics can come the fragmentation of larger pieces of plastic or microplastics can be manufactured. These include pre-production industrial plastic pellets and industrial or cosmetic abrasives ("micro-scrubbers" in face wash for example).

The biological impact of microplastics on benthic organisms such as corals, sponges and sea pens is unknown. However, Hall et al (2015) report observations of ingestion and retention of microbeads by scleractinian corals on the Great Barrier Reef and suggest that high concentrations may impair the health of the corals. There are no estimates of the amount of microplastics that may be present in the VME, or surrounding, areas.

Information requirements

Offshore oil and gas:

- Effects of drilling wastes on VMEs
    - Fate and potential for long distance transport of particulates in near bottom currents
    - How the impact of drilling wastes vary with magnitude, duration,
    - Recovery potential of VMEs
- Effects of oil spills (particularly seafloor and deepwater releases) on VMEs
    - Dispersants
    - Deepwater modelling
- Reef effects (human-built structures serve as substrate for benthic organisms)
    - Enhanced productivity, altered community structure and potential contamination

Seismic:

- Effects on benthic organisms (eg: crab)
- Interactions with fisheries
- Preventions and mitigations for protection of benthic organisms

Marine mining:

- Ecology of seamount communities and deepwater benthos (identification of VMEs)
- Benthic habitat disruption/ destruction
    - Sensitivity
    - Recovery potential
- Prevention and mitigations

Wastes:

- Effects of litter on VMEs
    - Smothering
    - Altered substrate
- Effects of microplastics on corals and sponges
- Monitoring

Gathering information

What we already know:

There are a number of studies that have examined both the impact of some of these issues on marine benthos or descried the impact of adverse events that have occurred (e.g. oil spill). A thorough review of the literature would provide guidance that can be used to identify the potential impact of the various stressors and prioritise monitoring and research needed to quantify their impact.

The following topics have been identified as areas where relevant literature exists.

- Follow up to the Macondo Well blowout in the Gulf of Mexico and other oil spills into cold water with long term follow up (Arrow, Exxon Valdez)
    - lessons learned about seabed release of oil and gas in deep water with studies on deepwater coral populations
    - Fate and effects of dispersants
    - Drilling waste studies
- Seismic
    - Reports and studies ESRF etc.
- Marine mining reviews
- Microplastics
- Maps of existing and potential activities for oil and gas seismic and drilling and marine mining

Additional research requirements:

Monitoring and research priorities must be prioritized. Here is a preliminary list of possible research that could be considered:

- Ongoing research
    - Seismic and crabs (Corey Morris, NAFC, DFO) - ESRF Study
    - Oil spill modelling (Blair Greenan, BIO, DFO) - ESRF study
    - Use of multispecies surveys to quantify litter
- Needed
    - Drilling wastes and VMEs
        - Sensitivity and recovery
        - Prevention and mitigations
        - Observation and modeling near bottom transport of drilling wastes incorporating seasonal variation in near bottom currents and mixing
    - Reef effects for drilling rigs (negative, positive?)
    - Seismic and VMEs
        - Effects on sedentary benthic organisms (corals and sponges)
        - Prevention and mitigations
    - Marine mining – seamont and deepsea benthic community ecology
        - VME identification
        - magnitude and duration of effects
    - Quantification of litter in NAFO convention area inside and outside VMEs (easily incorporated into multispecies trawl surveys – litter is returned to shore in any case since al plastic is banned from being dumped from ships under the International Convention for the Prevention of Pollution from Ships (MARPOL))
    - Put the litter into the codes for the trawl surveys to ensure that data is recorded – use established categories
    - Effects of microplastics on VMEs
        - Quantification of ingested microplastics (survey protocols?)
    - Approaches to prevention, mitigations and remediation – what works, where are improvements needed?
    - Fisheries closures, can they be planned to benefit several sectors? (e.g. VME fisheries closures and oil and gas fisheries exclusion zones)
    - Legislative tools and regulatory bodies
    - Policy development
    - Mechanisms for information sharing
    - Improvement/implementation of ecosystem approach
    - Multi sector integrated assessment and planning

The issues identified here are of concern to a large number of organizations. This will allow for collaboration among researchers. Some potential collaborators include:

- Environmental Science Research Fund (ESRF) – Canadian fund for environmental research related to petroleum industry activities
- DFO Oceans Management – opportunities to address questions about the effect of drilling wastes and seismic surveys on seapens and deepwater soft bottom communities in the proposed Laurentian Channel MPA where Oil and gas exploration is a possibility.
- Galway Statement - The Trans-Atlantic Ocean Research Alliance (TAORA) was created when the Galway Statement was signed in May 2013. The Galway Statement commits Canada, US and EU to collaborate on comprehensive science programming for an indefinite period going forward to better understand the North Atlantic Ocean basin. Priority areas have been identified for such collaboration. Several are relevant for the questions raised here including Ocean Health and Stressors, Ocean Observation and Prediction, Characterization of the Seafloor and the Sub-surface, and Information Management and Dissemination.
- Horizon 2020 – The Atlantic Ocean Research Alliance Coordination and Support Action (AORAC-SA). The AORAC project (March 2015 – March 2020) is designed to provide scientific, technical and logistical support to the European Commission in developing and implementing trans-Atlantic Marine Research Cooperation between the European Union, the United States of America and Canada. Under AORAC-SA WP4 Ecosystem Approach (http://www.ices.dk/explore-us/projects/Pages/AORAC Ecosystem-approach.aspx a series of workshops are proposed to take stock of current status with regard to EA and to identify research required for further implementation.

Preliminary workplan

Taking the above observations into account, it is clear that there two key aspects that need to be addressed. One is the consolidation of existing science and the identification of science gaps. The other one is the consolidation, integration, and clarification of the information on the different governance structures associated with the management of these non-fishing activities. The science is fundamental to understand the potential impacts, but understanding the management structure is key for setting objectives that NAFO can reasonably achieve. It is in this context, that WGESA proposes a series of workshops for assessing the effects of other sectors on VMEs in the NAFO Regulatory Area (NRA) including identification and prioritization of stressors and risks (Fig. 4.3.5). The outcomes of these workshops should provide the basis for a fully developed workplan.

Timing:

The literature reviews are the most time consuming step in this preliminary workplan. They can be completed relatively quickly assuming that the subject matter experts are made available for the task.

For workshops 1 and 2 to be effective the working documents identified in the red boxes in Figure 4.3.5 should be submitted in advance of the meeting. The Workshop 1 is intended to clarify the governance structures, identify some general methodologies, and define the scope for the type of actions the could be considered viable to address the potential impacts on VMEs. The Workshop 2 is intended to focalized the research and science analyses in ways that are deemed practical to address the objectives identified in the first workshop.

Ideally, workshops 1 and 2 can be held sequentially, but it would be feasible to hold them simultaneously, possibly with a joint session on the last day/s. This will depend on part in whether some of the same experts are tasked with responsibilities in each workshop. In the case of simultaneous workshops, the joint session should be used to align the science activities to ensure that the management objectives can be addressed.

Resources:

Human resources will be required for literature reviews that are not already available. Resources will also be required to support the workshops. The contracting parties must recognize that the breadth of expertise required for this task goes well beyond fisheries and ecosystem science and that the appropriate subject matter experts must be tasked with the literature reviews. WGESA does not currently have this level of expertise, and not all of these experts will be found amongst government scientists or within departments responsible for fisheries management. For example some of the technical expertise in Canada is in the Natural Resources Canada and Environment Canada. It may also be useful to consider involving NGO, academic, and industry experts as many of these issues are the focus of large multi investigator research programs.

WGESA recommends that the appropriate expertise be gathered together in a series of workshops to develop a program for assessing the effects of activities other than fishing on VMEs in the NAFO Regulatory Area.

The information that will be gathered under this workplan has broader applicability than just NAFO. As such it will contribute to the much wider issue beyond the immediate question posed by the FC. There are therefore many synergies and potentials for collaboration to be found amongst interested groups.

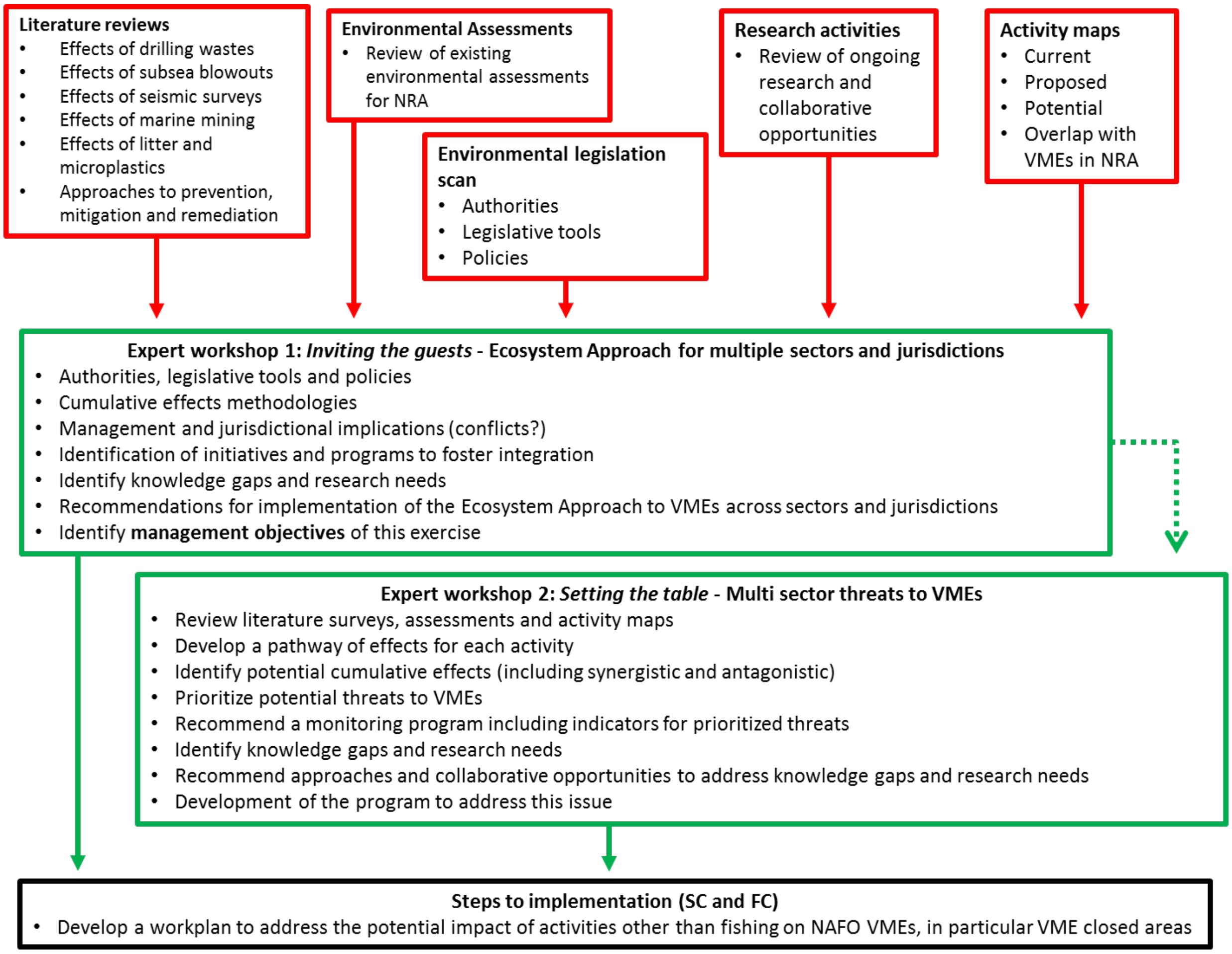

Fig. 4.3.5. Preliminary steps proposed by WGESA to develop a workplan for assessing the impactos on non-fishing activities on VMEs. These steps include the preparation of summary documents and reviews (red boxes), and two expert workshops (green boxes), which lead to the preparation of a workplan.

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

ToR 5.1. Preliminary results on the use of non-destructive sampling to monitor VMEs

Fisheries and Oceans, Canada (DFO) conducted *in situ* benthic surveys as part of the NEREIDA programme in 2009 and 2010. These first *in situ* surveys of the seafloor collected photos and/or video with the intent to gather images from VMEs which can be used for future non-destructive monitoring of the effectiveness of the closed areas (see NCEM for details on closed areas locations and numbering). Areas 2, 4, 5, and 6 were surveyed under NEREIDA. In 2015, DFO conducted further benthic surveys of Area 2 and Areas 10 and 12 to gather information on the areas closed to protect sponge and seapen VMEs, respectively (Fig. 5.1.1, Table 5.1.1). Less work has been done on the seamounts. The Orphan Knoll seamount closed area was surveyed in

2010, including transects on the flat top of the knoll as well as along the sides. In 2015, the first images of the Newfoundland Seamounts were taken from inside the closed area there. Areas not yet surveyed are: Area 1 (Tail of the Bank), Areas 7, 8, 9 and 11 (Northern Flemish Cap), Areas 3 and 13 (Beothuk Knoll), and the Fogo Seamounts 1 and Fogo Seamounts 2 areas. The US has conducted underwater sampling on the New England and Corner Rise Seamount chain, however details of those sites relative to the closed areas, and their suitability as future monitoring locations has not been ascertained. We recommend that monitoring plans be developed for each of the closed areas.

Not all of the images collected by DFO have been analyzed. Images from Areas 4 and 5 have been fully processed but not yet analyzed. Data from the sponge grounds in Areas 2 and 6 have been fully analyzed and demonstrate that sponge grounds enhance diversity and abundance of epibenthic megafauna.

The data from the analyzed surveys for Areas 2 (Transect 38 from 2009) (Flemish Pass/Eastern Canyon) and 6 (Sackville Spur) has been published in the scientific literature:

Area 2 (Flemish Pass/Eastern Canyon):

BEAZLEY, L.I., E. L. KENCHINGTON, F. J. MURILLO & M. del M. SACAU. 2013. Deep-sea sponge grounds enhance diversity and abundance of epibenthic megafauna in the Northwest Atlantic. *ICES Journal of Marine Science* 70: 1471-1490.

Area 6 (Sackville Spur):

BEAZLEY, L., E. KENCHINGTON, I. YASHAYAEV & F.J. MURILLO, 2015. Drivers of epibenthic megafaunal composition in the sponge grounds of the Sackville Spur, northwest Atlantic. *Deep Sea Research I* 98: 102-114.

Experience has shown that it is important to cross-reference the names used in identifying taxa from the photographs with their images. Often taxa are uniquely identified but are given a high level taxonomic assignment (for example, Porifera sp. 1) or are unidentified even to phylum (for example, Unidentified sp. 1). Future analysts need to use the same identification scheme in order to detect change. This type of information is not provided in primary publications due to space constraints. In order to facilitate future monitoring of these closed areas a technical report has been produced (http://waves-vagues.dfo-mpo.gc.ca/waves-vagues/search-recherche/display-afficher/357567) which identifies all taxa analyzed in the benthic images from Areas 2 (Transect 38 from 2009) and 6:

BEAZLEY, L.I. and KENCHINGTON, E. L., 2015. Epibenthic megafauna of the Flemish Pass and Sackville Spur (Northwest Atlantic) identified from *in situ* benthic image transects. *Canadian Technical Report of Fisheries and Aquatic Sciences* 3127: v+496 p.

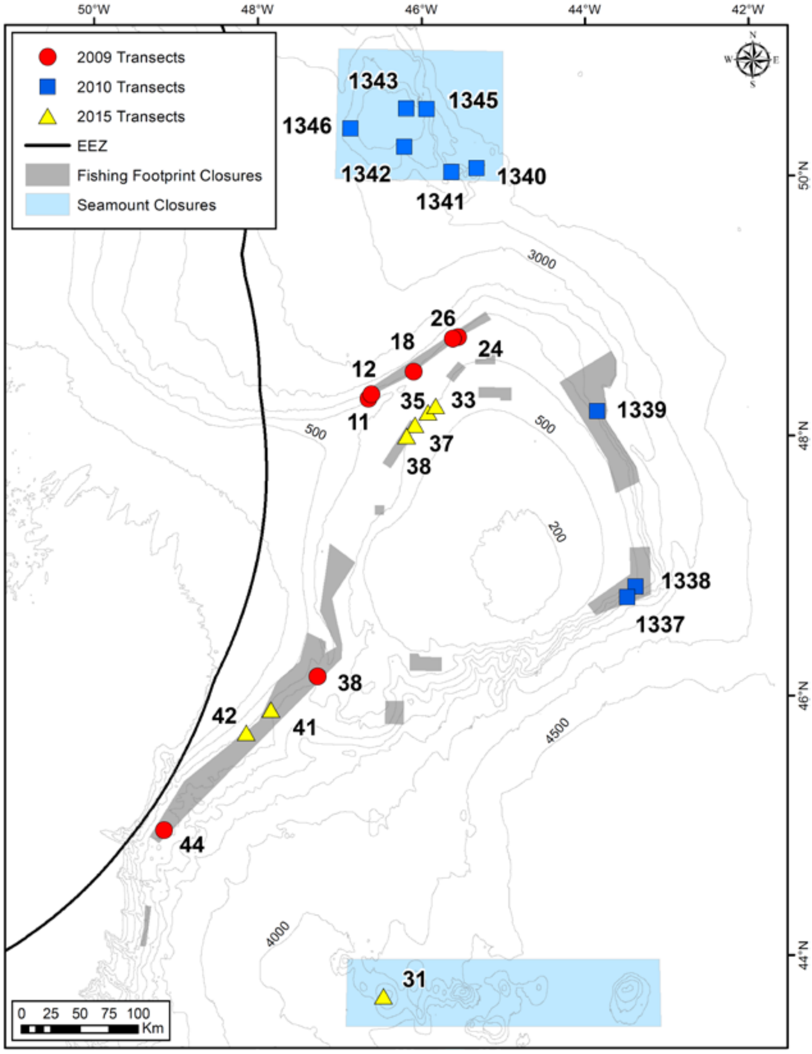


Fig. 5.1.1. Location of benthic imagery transects collected by Fisheries and Oceans, Canada in 2009, 2010, and 2015 that are located directly within Closed Areas (grey) to protect vulnerable marine ecosystems in the fishing footprint and on nearby seamounts. Transects are labelled by their transect ID number. Details of each transect can be found in Table 5.1.1.

Table 5.1.1. Summary of the benthic imagery transects collected by Fisheries and Oceans, Canada in 2009, 2010, and 2015 that are located directly within a NAFO closed area to protect vulnerable marine ecosystems. * The majority of these photos are of poor quality. Continuous video also recorded.

Closure Area	General location	Year	Transect ID	Gear	Coordinates		Approximate transect length (km)	Start - End depth (m)	Number of photos
					Start	End			
2	Flemish Pass/Eastern Canyon	2009	38	4K Cam	46.1712/ -47.0550	46.1840/ -47.0358	4.9	1328 - 1411	75
		2015	41	Deep Imager	45.9044/ -47.5626	45.8948/ -47.5728	1.5	1317 - 1316	315*
		2015	42	4K Cam	45.7210/ -47.8215	45.7084/ -47.8325	1.7	1160 - 1149	43
		2009	44	4K Cam	44.9478/ -48.6767	44.9455/ -48.6901	1.2	1449 - 1280	63
4	Eastern Flemish Cap	2010	1337	ROPOS	46.7963/ -43.6074	46.8308/ -43.6260	7.1	2195 - 1020	Video
		2010	1338	ROPOS	46.8761/ -43.5139	46.8908/ -43.4877	8.6	1053 - 1074	Video
5	Northeast Flemish Cap	2010	1339	ROPOS	48.2317/ -43.9159	48.1991/ -43.9646	8.6	2463 - 1363	Video
6	Sackville Spur	2009	11	4K Cam	48.3199/ -46.5543	48.3735/ -46.5617	9.0	1080 – 1545	167
		2009	12	4K Cam	48.3532/ -46.5225	48.4000/ -46.5390	12.0	1313 – 1723	172
		2009	18	4K Cam	48.5353/ -46.0373	48.5627/ -46.0167	14.1	1336 – 1478	92
		2009	24	4K Cam	48.8015/ -45.5223	48.8275/ -45.5277	13.7	1290 – 1427	145
		2009	26	4K Cam	48.7905/ -45.5855	48.8165/ -45.5424	15.6	1381 – 1409	38
10	Northwest Flemish Cap	2015	37	4K Cam	48.1246/ -46.0146	48.1148/ -46.0300	1.6	1040 - 1054	70
		2015	38	4K Cam	48.0361/ -46.1088	48.0280/ -46.1141	1.0	1074 - 1073	58
12	Northwest Flemish Cap	2015	33	4K Cam	48.2698/ -45.7765	48.2579/ -45.7938	1.9	943 - 949	61
		2015	35	4K Cam	48.2211/ -45.8627	48.2116/ -45.8717	1.3	961 - 597	65
Nfld Seamts.	Nfld. Seamounts	2015	31	4K Cam	43.7204/ -46.2700	43.7225/ -46.2803	0.9	2671 - 2703	52
Orphan Knoll	Orphan Knoll	2010	1340	ROPOS	50.1096/ -45.3173	50.0857/ -45.3596	11.5	3000 – 1922	Video
		2010	1341	ROPOS	50.0762/ -45.6217	50.0592/ -45.6079	7.4	2873 – 2390	Video
		2010	1342	ROPOS	50.2662/ -46.1867	50.2702/ -46.1773	9.9	2156 – 2095	Video
		2010	1343	ROPOS	50.5631/ -46.1710	50.5520/ -46.1931	2.1	1852 – 1727	Video
		2010	1345	ROPOS	50.5583/ -45.9272	50.5627/ -45.9450	3.2	2370 – 2241	Video
		2010	1346	ROPOS	50.3958/ -46.8385	50.4061/ -46.8226	3.0	2269 - 2162	Video

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 (FC Request #5). Update of NAFO VME Guide.

> **FC Request #5.** FC requests the Scientific Council consider widening the scope of the NAFO coral and sponge identification guides to include other relevant species on seamounts.

Fisheries and Oceans, Canada in collaboration with the NAFO Secretariat has recently updated the coral and sponge identification guides to include other VME indicator species (Kenchington et al., 2015). In doing that they revised the previous guides and combined them into a single volume with removable pages to facilitate updates. The guide is intended as a pictorial identification guide for VME indicator species commonly encountered within the NAFO fishing footprint on the Grand Banks of Newfoundland. Some taxa in the guide occur more broadly, including on seamounts. By-catch of cold-water corals from an EU-Spain Trawl Experimental Survey developed during 2004 on three NAFO seamounts was examined (Murillo et al., 2008). Hauls were carried out over two peaks located in Divs. 6EF (New England Seamounts) and in Div. 6G (Corner Rise Seamounts) using "Pedreira" otter trawl gear. Corals observed were the stony corals *Enallopsamia rostrata*, *Enallopsamia* sp., *Solenosmilia variabilis*, and *Madrepora oculata*, the gorgonian corals *Acanella eburnea*, *Placogorgia terceira*, *Lepidisis* sp., *Keratoisis* sp., *Thouarella grasshoffi*, *Metallogorgia melanotrichos*, and *Paragorgia johnsoni* and antipatharians (black corals).Of these only *Enallopsamia* was frequently recorded. The current guide already includes *Paragorgia johnsoni*, *Keratoisis* sp., and another species of *Acanella*.

The USA has undertaken exploratory *in situ* surveys of the seamounts and could add to this provisional list. In keeping with practice to date, rare corals and sponges have not been included and so if additions were to be made to the guide at this time only *Enallopsamia* should be added, assuming that appropriate deck photos were collected. However, the WGESA recommends that scientists from the US who participated on their seamount missions take the lead in suggesting additional species since they have recent expertise in this geographic area. Alternatively, additions could be made if exploratory fishing is undertaken, using the observer records which as of January 2016 will require all by-catch of VME indicator species to be recorded. The guide gives direction on contact information for species not currently in the guide but recorded at sea.

References

Kenchington, E., L. Beazley, F. J. Murillo, G. Tompkins MacDonald and E. Baker. 2015. Coral, Sponge, and Other Vulnerable Marine Ecosystem Indicator Identification Guide, NAFO Area. NAFO Scientific Council Studies, 2015. Number 47. Doi: 10.2960/.v47.m1.

Murillo, F.J., P. Duran Munoz, M. Mandado, T. Patrocinio and G. Fernandez. 2008. By-catch of cold-water corals from an Experimental Trawl Survey in three seamounts within NAFO Regulatory Area (Divs. 6EFG) during year 2004. NAFO SCR Doc. 08/11; Serial No. N5502, 5pp.

OTHER MATTERS

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

WGNARS met in Falmouth, USA, in March of 2016. The overarching objective of WGNARS is to develop Integrated Ecosystem Assessment (IEA) capacity in the Northwest Atlantic region to support ecosystem approaches to science and management. The NW Atlantic region has well-developed ocean observation systems, marine ecosystem surveys and habitat studies, though social and economic data collection systems are less well developed, and steps are being taken throughout the region to organize existing information and effectively communicate it to stakeholders and decision-makers. These continuing synthesis efforts will be review at the meeting. At the meeting the group will continue its work on "worked examples" of integrated assessment for two specific ecoregions within the Northwest Atlantic Regional Sea: the Georges Bank/Gulf of Maine ecoregion and the Grand Banks ecoregion. In this context the meeting advanced two main goals: (1) identifying alternative management strategies to achieve objectives outlined in 2014 and (2) identifying multiscale ecosystem responses to large scale drivers and key human activities outlined in 2014. This work is in preparation for an ecosystem-level management strategy evaluation (MSE) in 2016. An MSE framework will be developed at the meeting for this purpose.

Discussion on the potential merger between WGESA and STACFEN

In following with the SC request to explore the possibility of a merger of WGESA with STACFEN, including the creation of a new NAFO SC Standing Committee, WGESA and STACFEN members engaged in a broad discussion about the available options, their benefits and weaknesses. This process was supported from feedback collected by STACFEN and WGESA chairs form members of these groups that were unable to participate in the discussion held at the WGESA meeting.

The general conclusion emerging from this process was that the merger of STACFEN and WGESA is conceptually a great idea that would enhance the ability of SC to address ecosystem issues in general, and the implementation of the roadmap in particular. However, the logistics of making such a merger happen (e.g. timing of the meeting, ability to provide updated environmental summaries at the SC June meeting, ability of members of both groups to attend given the schedules of existing surveys, potential for separating the environmental scientists from the stock-assessment ones, etc), prevented from finding a viable way for making the merger happen. If the benefit from a merger are to be materialized, there may be a need to review the entire schedule of NAFO SC meetings, and possibly the entire NAFO management cycle, but considering options at this scale was beyond the scope of the topic under discussion. Despite its benefits, the merger would have costs that, based on the general feedback received, SC members at large were not comfortable with.

As an alternative to simply maintaining the status quo, it was mentioned the possibility of merging WGESA and ICES WGNARS into a joint NAFO/ICES working group, and preliminary conversations about the feasibility of such option were planned to be had at the 2016 ICES WGNARS meeting, as well as to present the idea to NAFO SC during its June meeting. If both NAFO SC and ICES see this as a useful way forward, such a merger would need to be analyzed in more detail. The main benefit of such a move would be the an expanded research base to be working on EAF implementation issues in the Northwest Atlantic, but the specific scopes, ToRs, and way of operating of these two groups would need further evaluation to see if this move truly is a viable alternative.

Update of long-term Terms of Reference for WGESA

In considering the progress made over the last five years, WGESA discussed the need to update its long-terms Terms of Reference to better align them to the current direction of the ecosystem work being undertaken at NAFO. The following is the proposed update of the WG long-term ToRs:

Proposed updated NAFO SC WGESA long-term Terms of Reference

These long-term terms of reference are intended to provide support required for the further development and implementation of the Roadmap to EAF.

Theme 1: Spatial considerations

ToR 1. Develop research and summarize new findings on identification and mapping of benthic species, assemblages and habitats in the NAFO Convention area, including but not restricted to VMEs.

ToR 2. In support of the Roadmap, develop research and summarize new findings on the spatial structure and organization of marine ecosystems, with emphasis on connectivity, exchanges and flows among ecosystem units in the NAFO Convention Area.

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

ToR 3. Develop research and summarize new findings related to the linkages between environmental changes and variability on stocks, and community dynamics in NAFO ecosystem units.

ToR 4. Develop research and summarize new findings on the status, structure, trends, functioning, and productivity of ecosystems in the NAFO Convention Area.

Theme 3: Practical application of ecosystem knowledge to fisheries management

ToR 5. Develop research and summarize new findings on long-term monitoring of status and functioning of ecosystem units, and the application of ecosystem knowledge for the assessment of impacts and management of human activities in the NAFO Convention Area.

ToR 6. Develop ecosystem summaries for ecosystem units in the NAFO Convention Area as required, including the provision of information for assessments at the ecosystem, multispecies, and stock level.

Theme 4: Specific requests

ToRs 7+. As generic ToRs, these are place-holders intended to be used when addressing expected additional requests from Scientific Council.

Discussion on the renewal of WGESA co-chairs

There was a broad discussion related to the renewal of the co-chair of WGESA. The current co-chairs have been serving as such since 2008, and there is a clear need for new people to take on the chairing responsibility. M. Koen-Alonso (DFO, Canada) confirmed his intentions to step down from the co-chair position at the NAFO Annual General Meeting in September. A. Kenny (CEFAS, UK) indicated that he was willing to serve one more additional year as co-chair, to help out on the transition process, but made clear his intentions of stepping down from the position after the next WGESA meeting. Christopher Froján-Barrios (CEFAS, UK) indicated his willingness to step-up as co-chair, but participation from A. Kenny and C. Froján-Barrios to future WGESA meetings beyond 2016 is conditional to resource availability (i.e. funding to allow comittements towards WGESA ToRs), which was unclear at the time of the meeting. Even if this support materializes, current commitments only would allow for renewal of one of the two co-chair positions. Without a clear medium-term succession plan for WGESA, the ability of the working group to continue delivering on its long-term ToRs, and the development and implementation of the Roadmap may be severely undermined.

WGESA urges SC, and through it FC and NAFO's CPs that there is a need for stronger commitments towards the Roadmap work, including provision of expertise and stability in participation at WGESA. Without this commitment the ability of continuing with the Roadmap implementation would be in jeopardy.

Documents reviewed and/or produced during this meeting

The following document has been endorsed by WGESA as SCR out of this meeting:

Downie, A., Kenny, A., and Froján-Barrios, C. Predictive models of Vulnerable Marine Ecosystem (VME) indicator taxa biomass in the NAFO Regulatory Area – including the effects of fishing activity.

Place and date for next meeting

It was proposed that the 9th WGESA meeting to take place in November 08-17, 2016 at the NAFO Headquarters in Dartmouth, Canada, but there is work being done to potentially host the meeting at IPMA, Lisbon, Portugal.

Proposed Topics for the Terms of Reference for the 9th SC WGESA Meeting

In the context of proposed update of SC WGESA long-term terms of reference, the topics proposed as specific topics for the ToRs for the next WGESA meeting are indicated below.

Theme 1: Spatial considerations

ToR 1. Develop research and summarize new findings on identification and mapping of benthic species, assemblages and habitats in the NAFO Convention area, including but not restricted to VMEs.

- Update on VME data and VME distribution analyses.

ToR 2. In support of the Roadmap, develop research and summarize new findings on the spatial structure and organization of marine ecosystems, with emphasis on connectivity, exchanges and flows among ecosystem units in the NAFO Convention Area.

- To be determined. No work is currently expected under this ToR.

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

ToR 3. Develop research and summarize new findings related to the linkages between environmental changes and variability on stocks, and community dynamics in NAFO ecosystem units.

- Progress on habitat modelling of zooplankton communities.

ToR 4. Develop research and summarize new findings on the status, structure, trends, functioning, and productivity of ecosystems in the NAFO Convention Area.

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

Theme 3: Practical application of ecosystem knowledge to fisheries management

ToR 5. Develop research and summarize new findings on long-term monitoring of status and functioning of ecosystem units, and the application of ecosystem knowledge for the assessment of impacts and management of human activities in the NAFO Convention Area.

- Progress on the assessment of significant adverse impacts on VME groups not assessed on the 2016 assessment.

ToR 6. Develop ecosystem summaries for ecosystem units in the NAFO Convention Area as required, including the provision of information for assessments at the ecosystem, multispecies, and stock level.

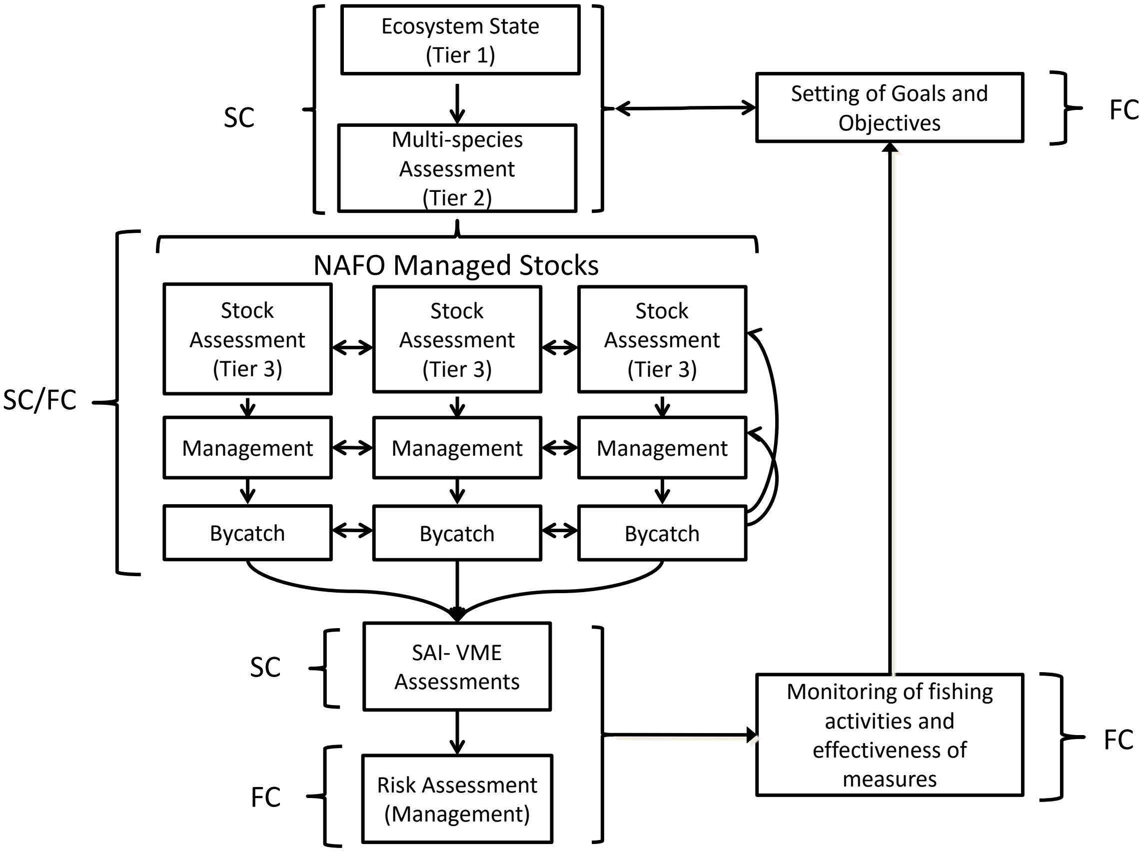
- Work towards developing summary sheets for NAFO ecosystem units.
- Update Guidelines on Total Catch Ceilings for NAFO ecosystem units.

Theme 4: Specific requests

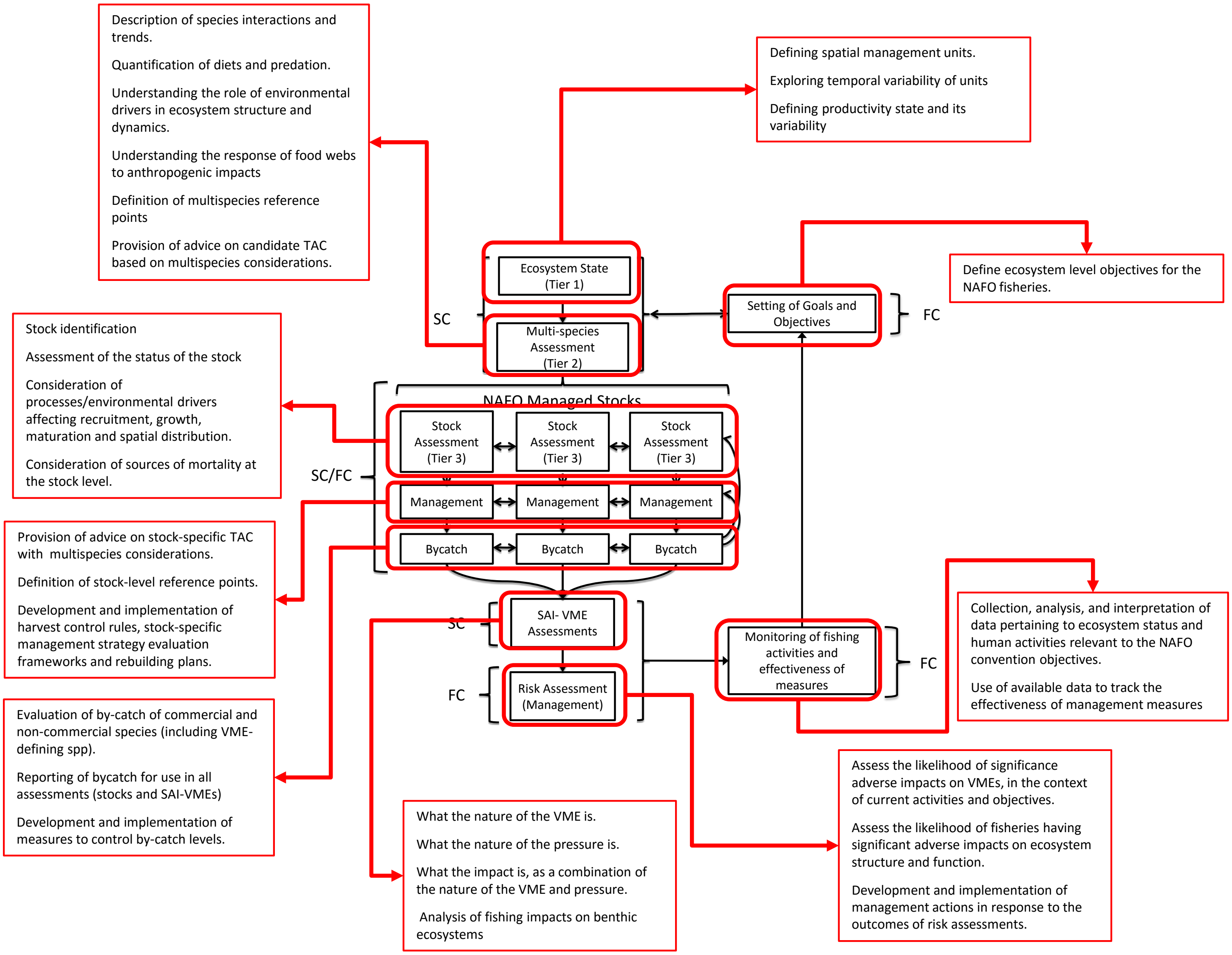
ToRs 7+. As generic ToRs, these are place-holders intended to be used when addressing expected additional requests from Scientific Council.

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



Description of species interactions and trends.

Quantification of diets and predation.

Understanding the role of environmental drivers in ecosystem structure and dynamics.

Understanding the response of food webs to anthropogenic impacts

Definition of multispecies reference points

Provision of advice on candidate TAC based on multispecies considerations.

Defining spatial management units.

Exploring temporal variability of units

Defining productivity state and its variability

Define ecosystem level objectives for the NAFO fisheries.

Stock identification

Assessment of the status of the stock

Consideration of processes/environmental drivers affecting recruitment, growth, maturation and spatial distribution.

Consideration of sources of mortality at the stock level.

Provision of advice on stock-specific TAC with multispecies considerations.

Definition of stock-level reference points.

Development and implementation of harvest control rules, stock-specific management strategy evaluation frameworks and rebuilding plans.

Evaluation of by-catch of commercial and non-commercial species (including VME-defining spp).

Reporting of bycatch for use in all assessments (stocks and SAI-VMEs)

Development and implementation of measures to control by-catch levels.

Collection, analysis, and interpretation of data pertaining to ecosystem status and human activities relevant to the NAFO convention objectives.

Use of available data to track the effectiveness of management measures

What the nature of the VME is.

What the nature of the pressure is.

What the impact is, as a combination of the nature of the VME and pressure.

Analysis of fishing impacts on benthic ecosystems

Assess the likelihood of significance adverse impacts on VMEs, in the context of current activities and objectives.

Assess the likelihood of fisheries having significant adverse impacts on ecosystem structure and function.

Development and implementation of management actions in response to the outcomes of risk assessments.

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

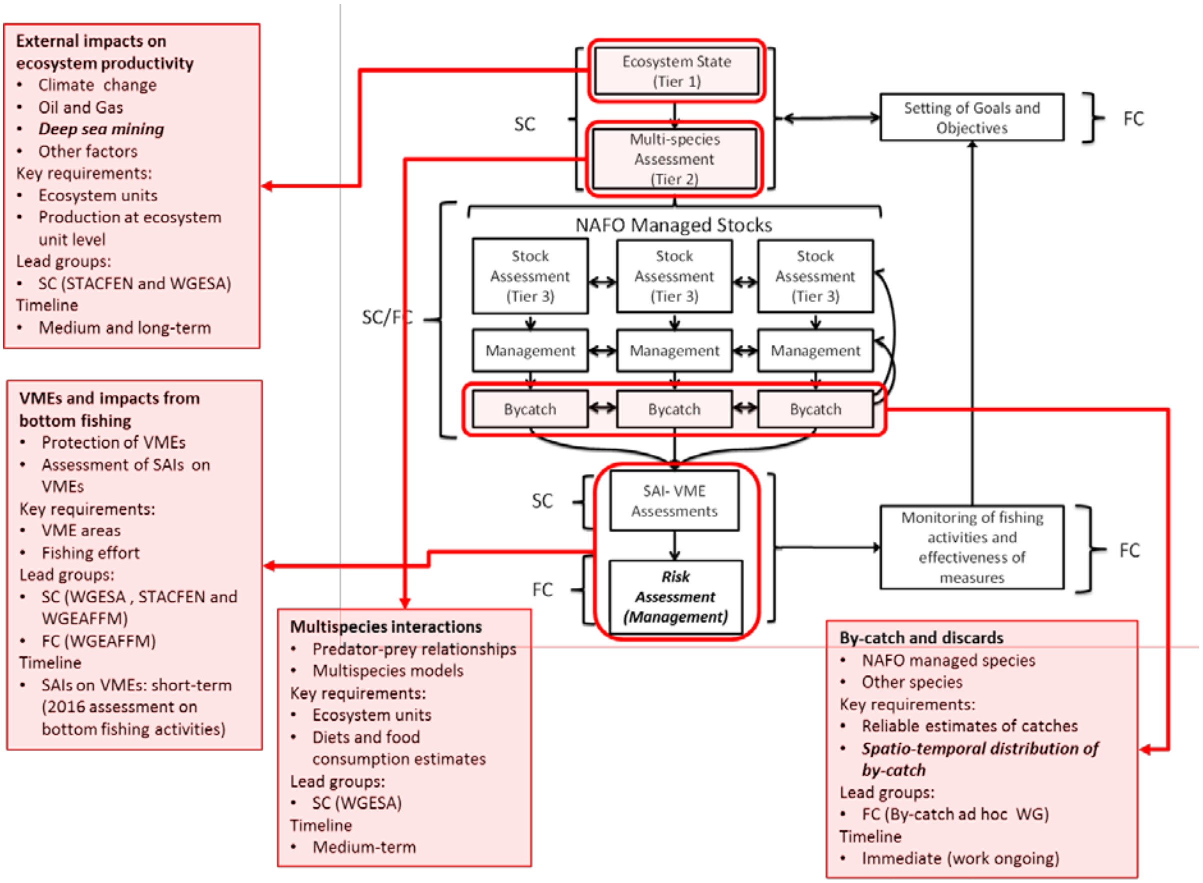
ToR 4. Update on recent and relevant research related to the application of ecosystem knowledge for fisheries management in the NAFO area.

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. CURRENT PRIORITY AREAS OF WORK WITHIN THE "ROADMAP FOR THE DEVELOPMENT OF AN ECOSYSTEM APPROACH TO FISHERIES (EAF) FOR NAFO"



External impacts on ecosystem productivity
- Climate change
- Oil and Gas
- ***Deep sea mining***
- Other factors

Key requirements:
- Ecosystem units
- Production at ecosystem unit level

Lead groups:
- SC (STACFEN and WGESA)

Timeline
- Medium and long-term

VMEs and impacts from bottom fishing
- Protection of VMEs
- Assessment of SAIs on VMEs

Key requirements:
- VME areas
- Fishing effort

Lead groups:
- SC (WGESA , STACFEN and WGEAFFM)
- FC (WGEAFFM)

Timeline
- SAIs on VMEs: short-term (2016 assessment on bottom fishing activities)

Multispecies interactions
- Predator-prey relationships
- Multispecies models

Key requirements:
- Ecosystem units
- Diets and food consumption estimates

Lead groups:
- SC (WGESA)

Timeline
- Medium-term

By-catch and discards
- NAFO managed species
- Other species

Key requirements:
- Reliable estimates of catches
- ***Spatio-temporal distribution of by-catch***

Lead groups:
- FC (By-catch ad hoc WG)

Timeline
- Immediate (work ongoing)

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