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SC WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT – NOVEMBER 2019

Report of the 12th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA)

NAFO Headquarters, Dartmouth, Canada
19-28 November 2019

Contents

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WG-ESA Meeting Participants

19-28 November 2019

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Report of the SC Working Group on Ecosystem Science and Assessment (WG-ESA)

19-28 November 2019

I. INTRODUCTION

The NAFO SC Working Group on Ecosystem Science and Assessment (WG-ESA), formerly known as SC Working Group on Ecosystem Approaches to Fisheries Management (WG-EAFM), had its 12th meeting on 19-28 November 2019 at NAFO Headquarters, Dartmouth, Canada.

The work of WG-ESA can be described under two complementary contexts:

a) work intended to advance the Ecosystem Approach to Fisheries Management (EAFM), which typically involves medium to long-term research, and

b) work intended to address specific requests from Scientific Council (SC) and/or Commission (COM), which typically involves short to medium-terms analysis, aligned to Ecosystem Approach priorities.

ToRs to be addressed in 2019 were:

Theme 1: Spatial considerations

> **ToR 1.** Update on identification and mapping of sensitive species and habitats in the NAFO area. In support of the EAFM develop research and summarize new findings on the spatial structure and organization of marine ecosystems with an emphasis on connectivity, exchanges and flows among ecosystem units in the NAFO Convention Area.

Theme 2: Status, functioning and dynamics of marine ecosystems

> **ToR 2.** Develop research and summarize new findings on the status, functioning, productivity of ecosystems (including modelling multi-species interactions) in the NAFO Convention Area.

Theme 3: Practical application EAFM

> **ToR 3.** Develop research and summarize new findings on long-term monitoring of status and functioning of ecosystem units (including ecosystem summary sheets) and the application of ecosystem knowledge for the assessment of impacts and management of human activities in the NAFO Convention Area.

Theme 4: Specific requests

> **ToRs 4+.** As generic ToRs, these are placeholders intended to be used when addressing expected additional requests from Scientific Council or Fisheries Commission that don't fit in to the standing ToRs above.

Work under these themes served to address the following Commission Requests (COM Doc. 19-29):

[3] The Commission requests that Scientific Council continue its evaluation of the impact of scientific trawl surveys on VME in closed areas, and the effect of excluding surveys from these areas on stock assessments ***[ToR 3].***

[5] The Commission requests the Scientific Council to continue to refine its work under the Ecosystem Approach and report on these results to both the WGEAFFM and WGRBMS. ***[ToR 3].***

[6] In relation to the assessment of NAFO bottom fisheries in 2021, the Scientific Council should: ***[ToR 2]***:

- Assess the overlap of NAFO fisheries with VME to evaluate fishery specific impacts in addition to the cumulative impacts;

- Consider clearer objective ranking processes and options for objective weighting criteria for the overall assessment of significant adverse impacts and the risk of future adverse impacts;
- Maintain efforts to assess all of the six FAO criteria (Article 18 of the FAO International Guidelines for the Management of Deep Sea Fisheries in the High Seas) including the three FAO functional SAI criteria which could not be evaluated in the current assessment (recovery potential, ecosystem function alteration, and impact relative to habitat use duration of VME indicator species).
- Continue to work on non-sponge and coral VMEs (for example bryozoan and sea squirts) to prepare for the next assessment.

[7] The Commission requests Scientific Council to conduct a re-assessment of VME closures by 2020, including area #14 ***[ToR 1]***.

[12] The Commission request that the Scientific Council present the Ecosystem Summary Sheet for 3LNO for presentation to the Commission at the 2020 Annual Meeting. ***[ToR 3]***.

[16] The Commission requests Scientific Council to continue to monitor and provide updates resulting from relevant research related to the potential impact of activities other than fishing in the Convention Area (for example via EU ATLAS project), and where possible to consider these results in the on-going modular approach concerning the development of Ecosystem Summary Sheets ***[ToR 3]***.

[18] The Commission requests the Scientific Council to provide information to the Commission at its next annual meeting on sea turtles, sea birds, and marine mammals that are present in NAFO Regulatory Area based on available data ***[ToR 1]***.

1. Impact of Trawling on Stock Assessments

COM Request [3] and **ToR 3.3.** ***The impact of scientific trawl surveys on VME in closed areas and the effects of excluding surveys from these areas on stock assessment metrics.***

Analysis conducted by WG-ESA in 2016 (SCS Doc. 16/21) concluded the risk of impact on VME arising from scientific trawls within VME closed areas was significant, especially with regard to the sponge VME. However, the analysis to assess the impact of removing survey sets from closed areas on stock assessment metrics has yet to be finalized. In anticipation the analysis will be completed soon (next year), WG-ESA considers the need to investigate and develop alternative appropriate cost-effective non-invasive monitoring techniques essential to ensure the continuity in the monitoring and assessment of VMEs in the NRA.

Discussions held by WG-ESA in 2016 concluded that "non-destructive sampling surveys are preferred, for example camera-based surveys, but there would be trade-offs to consider in regard to obtaining adequate biological sampling. Another consideration was whether calibration of non-destructive surveys with bottom trawl surveys was possible to enable a combined series of the data for monitoring purposes. The WG suggested an *ad hoc* WG be created to explore the feasibility of non-destructive monitoring surveys with the aim of developing objectives for future monitoring as well as, to the extent possible, enable meaningful comparisons to existing bottom trawl surveys. Experts in both sampling methods should be sought".

WG-ESA therefore ***recommends*** *that Scientific Council investigates the use of non-destructive cost effective sampling techniques to monitor VMEs and the options for integrating such techniques and the data they generate into the existing scientific trawl surveys, possibly through the establishment of an ad hoc WG on non-invasive survey methods.*

2. Fishery Production Potential

COM Request [5] and **ToR 3.2.** ***Review of Ecosystem Production Potential (EPP) model structure, sensitivity, and its use for fisheries advice*****.**

The NAFO Commission (COM) and Scientific Council (SC) joint Working Group on the Ecosystem Approach Framework to Fisheries Management (WGEAFFM) have raised concerns about the underlying reliability of the Ecosystem Production Potential (EPP) model, and the rationale and robustness of the 25th percentile of the

Fisheries Production Potential (FPP) distribution -after adjusting for ecosystem productivity state- as the metric to be used for defining the Total Catch Index (TCI).

Given these concerns, consolidating previous analyses, and adding to them by investigating specific questions, and comparing results with other models should improve the foundation on which FPP estimates, and related TCIs can rest. It is also important to clearly outline underlying assumptions of the EPP model and their potential impact on predictions. Such analyses could affect the applicability of the advice in decision-making, and allow an assessment of how the estimated TCIs may be altered by changes in ecosystem state (e.g. annual primary production and nutrient inventories).

As part of this process, during its 2019 June meeting, SC committed to undertake the following tasks:

1. Assess whether the 25th percentile of the FPP distribution is the correct precautionary metric to define TCI (i.e. fishery carrying capacity).
2. Explore development of a dynamic version of the EPP model to develop projections and further inform the assessment of ecosystem-level risks.
3. Assess whether the historical biomass and proportional distribution of functional feeding groups is an appropriate representation of a fully functional/high productivity ecosystem state.
4. Evaluate whether ecosystem productivity (i.e. from lower to upper trophic levels, as possible) has changed following the major changes in ecosystem status.
5. Undertake sensitivity assessment of the sources of uncertainty in EPP model projections
6. Contrast sustainable exploitation rates from EPP and other approaches (e.g. maximum sustainable yield) and investigate alternative scenarios in the distribution of exploitation rates among functional groups

In support of SC work on this topic, WGESA addressed these points at its 2019 meeting. While some specific elements still remain to be fully explored due to workload issues and availability of resources (e.g. dynamic version of EPP model), the substance of the concerns raised was thoroughly investigated.

The Ecosystem Production Potential (EPP) model

Ecosystem Production Potential (EPP) models are simple network models that track the production generated by primary producers up the food web (Fogarty et al., 2016; Koen-Alonso et al., 2013; Rosenberg et al., 2014). This work was used to support the first guidelines for total catches in NAFO, and by FAO to derive estimates of Fisheries Production Potential (FPP) for Large Marine Ecosystems (LMEs) around the world (Fogarty et al., 2016; NAFO, 2015; Rosenberg et al., 2014). The basic premise of the EPP model is that the primary production generated by phytoplankton is the ultimate limit for fish production in the marine ecosystem. Therefore, tracking how this production moves up the food chain would allow estimating the production of the trophic levels that support fisheries, providing an upper bound for total fisheries catches.

The EPP model allows this tracking because production of a trophic level is estimated as a fraction of the production of the trophic level that feeds into it. This fraction is the transfer efficiency. This also means that the EPP model, at least it its current form, is not dynamic. It represents productivity conditions integrated over a medium-term horizon (e.g. 3-5 years).

The model assumes that all available production from one trophic level becomes production in the next and that the system is fully functional, that each trophic level is abundant enough to use all the production available to it. The food web structure in the current EPP model (v2) represents three main energy channels in the ecosystem, the pelagic, benthic, and microbial loop pathways (Figure 2.1).

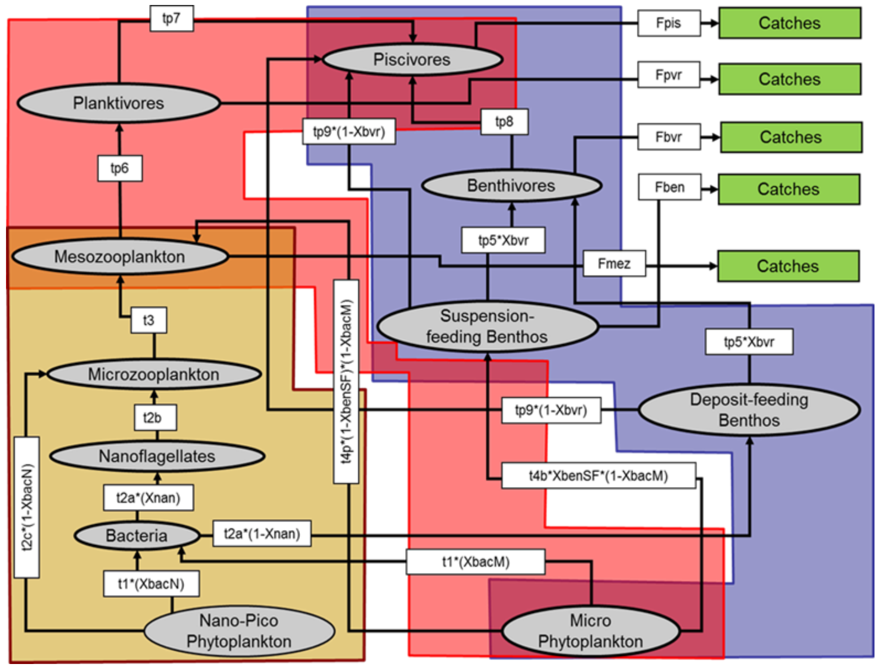

Figure 2.1. Structure of the EPP model (v2). Ovals represent nodes [functional guilds], and arrows indicate the trophic flows between nodes. The equations along the flows indicate the parameters/factors in each flow (i.e. transfer efficiency, transfer efficiency times fraction available, or exploitation rate). The red, blue, and brown backgrounds indicate the pelagic, benthic, and microbial loop energy pathways. While the current model allows fishing on five (5) nodes [functional guilds], mesozooplankton, planktivores, suspension feeding benthos, benthivores, and piscivores, mesozooplankton is not considered a fishable node in NAFO ecosystems.

The EPP model is implemented as a Monte Carlo simulation to account for the uncertainty in inputs and model parameters. Transfer efficiencies outside the microbial loop are modeled using beta distributions whose parameters are derived from a compilation of existing network models (35 models for Arcto-Boreal ecosystems, 58 models for Temperate ecosystems) (Fogarty et al., 2016; Rosenberg et al., 2014). Main model input is size-partitioned primary production derived from remote sensing data and associated analyses (Fogarty et al., 2016; Koen-Alonso et al., 2013; Rosenberg et al., 2014).

Characterizing EPP model behavior

Behavior of the EPP model was examined using the Grand Bank (3LNO) Ecosystem Production Unit (EPU) as a test case. The EPP model was characterized by examining the distribution of production among nodes [functional guilds], the correlation among productivities within energy pathways, and the correlation between primary production and fishable nodes (i.e. suspension-feeding benthos, benthivores, planktivores, and piscivores). Total heterotrophic ecosystem production is highly dominated by production associated with the microbial loop, while the nodes [functional guilds] associated to fisheries, even those targeting highly productive species like small pelagics (i.e. planktivore node), have productions orders of magnitude lower. For example, the estimated production from bacteria and nanoflagellates nodes are 37 and 7 times larger respectively than production in the planktivore node. Therefore, even small relative changes in these lower trophic levels could potentially have substantial cascading impacts on trophic nodes relevant to fishing.

The examination of the correlations among nodes and pathways (Figure 2.2) shows that the EPP model predicts a diffuse linear connection between total PP (i.e. aggregating nano-pico and micro-phytoplankton production) and fishable nodes (r=0.33-0.36), but production within energy pathways shows much more structure. Production within the microbial loop and pelagic pathways are highly coherent (average r=0.77 and r=0.67 respectively), while production along the benthic pathway is more diffuse (average r=0.47). This is consistent with ecological theory which indicates that real ecosystems are characterized by a majority of weak links, and asymmetric energy channels which differ in productivity and turnover rate (e.g. a fast pelagic pathway vs a slow benthic pathway) (Koen-Alonso, 2009; McCann et al., 1998; McCann et al., 2005; Rooney et al., 2006).

From a fisheries perspective, this indicates that it is necessary to consider food web structure and energy pathways to adequately track how PP becomes fisheries production (Friedland et al., 2012; Stock et al., 2017). While the food web structure in the EPP model allows for a better characterization of the uncertainty and energy pathways, the magnitude of the estimated production is still consistent with the simple and well-established food chain approximation of the Ryther's (1969) model, which estimates 594 thousand tonnes y^{-1} for piscivores in the Grand Bank (3LNO) EPU while the EPP model forecasts piscivore production of 620 thousand tonnes y^{-1}.

Correlation Matrix Grand Bank (3LNO) EPU (Base Run)	PP (nano-icoplankton)	PP (microplankton)	**PP (total)**	Bacteria	Nanoflagelates	Microzooplankton	Mesozooplankton	Deposit Feeding Benthos	Suspension Feeding Benthos	Planktivores	Bentivores	Piscivores	**Total (heterotrophic)**
PP (nano-picoplankton)	1.00												
PP (microplankton)	0.02	1.00											
PP (total)	0.89	0.48	1.00										
Bacteria	0.89	0.48	1.00	1.00									
Nanoflagelates	0.67	0.37	0.76	0.76	1.00								
Microzooplankton	1.00	0.07	0.90	0.90	0.74	1.00							
Mesozooplankton	0.45	0.54	0.64	0.64	0.52	0.47	1.00						
Deposit Feeding Benthos	0.32	0.16	0.35	0.35	-0.34	0.24	0.18	1.00					
Suspension Feeding Benthos	0.01	0.48	0.23	0.23	0.18	0.04	0.19	0.07	1.00				
Planktivores	0.28	0.33	0.40	0.40	0.33	0.30	0.61	0.09	0.09	1.00			
Bentivores	0.21	0.25	0.30	0.30	-0.19	0.17	0.17	0.70	0.35	0.09	1.00		
Piscivores	0.28	0.33	0.40	0.40	0.16	0.28	0.50	0.35	0.21	0.75	0.47	1.00	
Total (heterotrophic)	0.90	0.44	0.99	0.99	0.76	0.92	0.71	0.33	0.24	0.46	0.30	0.45	1.00

Figure 2.2. Pairwise correlations among estimated node [functional guild] productions, and including some relevant aggregates (Total PP, Total heterotrophic production), from the EPP model (v2) for the Grand Bank (3LNO) EPU. All correlations are calculated using the Pearson correlation coefficient and based on 1000 runs of the model. The background color indicates the value of the correlations, with dark green indicating high negative correlations, and strong orange high positive correlations.

Sensitivity analysis

A comprehensive examination of the model requires an evaluation of its structural uncertainty; how the model responds to changes in the topology of the food web. Because total heterotrophic ecosystem production is dominated by production associated with the microbial loop, which could potentially have substantial impacts on trophic nodes relevant to fishing, the analysis focused on topological changes affecting the microbial loop. The results from each sensitivity run were represented as fractions of the median of the base run.

The microbial loop has a key role in driving deposit feeding benthic production through benthic-pelagic coupling (detritus pathway). Weakening the microbial loop boosts suspension-feeding benthos production, but has negative impacts on deposit-feeding benthos (Figure 2.3). A stronger microbial loop generally reduces productivity in the pelagic pathway, and consequently on some fishable nodes like planktivores and piscivores, while the effect on benthivores is less consistent and depends on how the different pathways are affected (Figure 2.3).

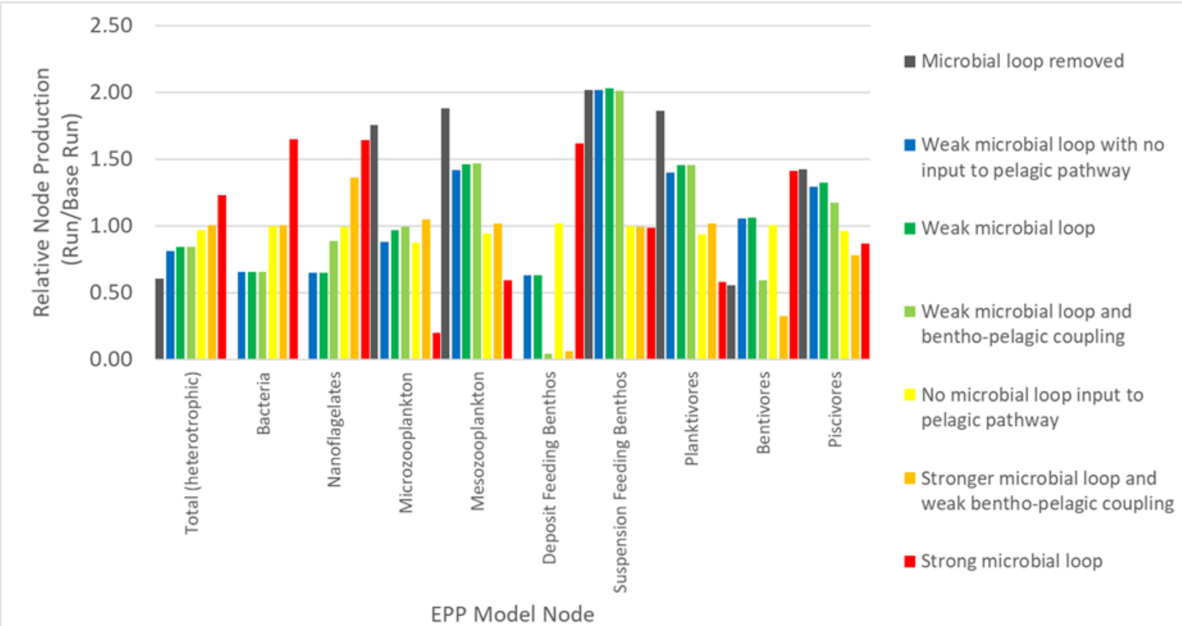

Figure 2.3. Results from the EPP model (v2) sensitivity runs for the Grand Bank (3LNO) EPU. Runs are ordered by increasing strength of the microbial loop.

Overall, the EPP model properly captures basic ecosystem features, and can serve as a simple and practical platform to explore impacts/changes at different trophic levels. It allows linking primary production and lower trophic levels with those of interest to fisheries, and hence, can provide a first order approximation to the production potential of trophic guilds relevant to fisheries.

From EPP to fisheries advice

The EPP model estimates the potential production of the ecosystem under the assumption that the ecosystem is fully functional (i.e. its maximum potential for production). Using these estimates for the provision of fisheries advice in NAFO requires 1) defining what is a sustainable catch level in the context of an EPP model, 2) evaluate the level of ecosystem functionality and, if required, scale down the model results to consider the actual/current ecosystem state, and 3) present these results in a way that is in line with NAFO management principles and frameworks.

Sustainable catch level

In traditional fisheries science the idea of sustainability is often related to the Maximum Sustainable Yield (MSY) which corresponds to the maximum level of catch that can be annually extracted from the stock while keeping the stock size at a stable level. Sustained catches above MSY will drive the stock down.

The EPP model simply tracks the faith of primary production in the food web. Iverson (1990) proposed that that fish production appeared to be "controlled by the amount of new nitrogen incorporated into phytoplankton biomass" based on the concepts of new, regenerated/recycled, and total primary production associated to the nitrogen cycle in the ocean. Primary production is dependent on "new" inorganic sources of nitrogen (e.g. upwelling, winter mixing) and a "recycled" organic source generated from metabolic processes from phytoplankton and other organisms (i.e. waste products). The *f*-ratio is the fraction of primary production that relies on a "fresh/new" source of nutrients, and provides a metric of the sources of nitrogen that would replenish what is harvested from the sea by fisheries. The *f*-ratio can by approximated using the ratio between micro-phytoplankton production and total primary production, and Rosenberg et al (2014) compiled estimates of these ratios for 54 Large Marine Ecosystems around the world. The median ratio from those LMEs was 0.205, which translates to an upper limit for sustainable fishing in the context of the EPP model of ~20%. Applying this exploitation rate to the fishable nodes in the EPP model would render, in principle, an estimation of the maximum production that could be sustainably extracted by fisheries, the Fisheries Production Potential (FPP).

However, practical applications also require an idea of what fraction of the production of the node [fishing guild] is actually of potential fisheries relevance. Only four nodes [functional guilds] in the EPP model are considered to contain species targeted by fisheries or of potential fisheries relevance: piscivores, benthivores (e.g. young stages of groundfish and smaller taxa, shellfish), plantktivores (e.g. capelin, herring), and suspension-feeding benthos (e.g. scallops, clams). The proportion of each node relevant to fishing was assumed to be 100% of piscivore and benthivore production, 50% of planktivore production, and 10% of suspension-feeding benthos production. The production of piscivores and benthivores was also aggregated into the Standard Demersal Component (SDC), which considers that production of some commercial species can be shared between these nodes because of their trophic plasticity.

Estimates of FPP were produced for three EPUs within the NAFO Convention Area, the Newfoundland Shelf (2J3K), the Grand Bank (3LNO), and the Flemish Cap (3M). Results indicate that, if these ecosystems were fully functional, the Newfoundland Shelf, the Grand Bank, and the Flemish Cap would be able of sustaining total fisheries catches up to 577, 889, and 157 thousand tonnes per year, respectively. Traditional groundfish and shellfish fisheries (the SDC) would represent slightly less than half of these yields, and piscivore yields around 10% (Figure 2.4), with differences across ecosystems mostly driven by differences in ecosystem area.

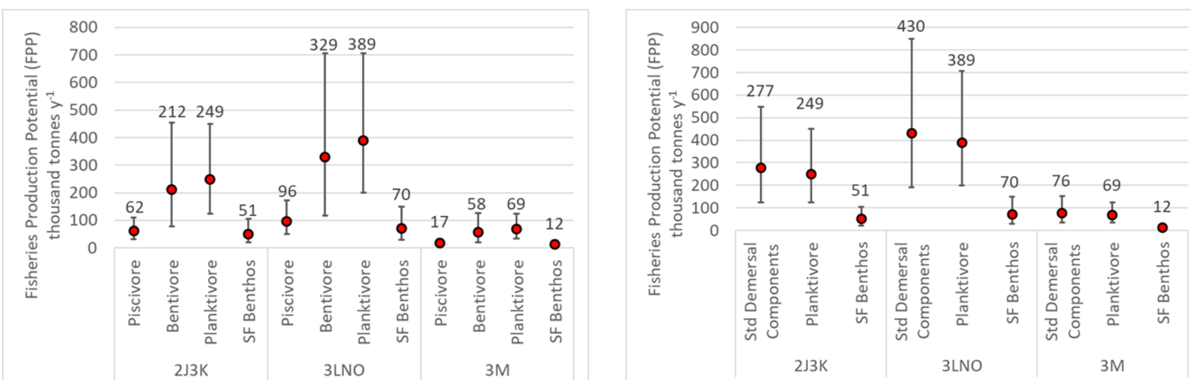

Figure 2.4. Fisheries Production Potential (FPP) for the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Flemish Cap (3M) EPUs. Left: FPP by fishable node [functional guild], Right: FPP with piscivore and benthivore nodes aggregated into Standard Demersal Components (SDC). Red dots indicate the medians, whiskers the 10-90% range, and the numbers above are the numerical value of the medians. The differences in magnitude across EPUs is mostly a reflection of the differences in areal extent of these ecosystems. All these estimates assume these ecosystems are fully functional.

These FPP estimates are consistent with MSY estimates from aggregate biomass surplus production models. A comparative analysis of 12 Northern hemisphere marine ecosystems, which also included the Newfoundland-Labrador Shelves, found that MSY ranged between 1-5 tonnes km^{-2} yr^{-1} and that the associated exploitation rates were 0.1-0.4 yr^{-1}, with most ecosystems showing values around 0.2 yr^{-1} (Bundy et al., 2012). These results for exploitation rate are consistent with the F=20% derived from the *f*-ratio rationale, while the MSY range fully encompass the FPP estimates for the EPUs considered here (Figure 2.5). Furthermore, the specific results from Bundy et al. (2012) for the Newfoundland-Labrador system show MSY values around 1 tonne km^{-2} yr^{-1}, which if we consider that their analysis relied on bottom trawl survey data, makes the similarity between their results and the SDC FPP estimate (Figure 2.5) particularly remarkable.

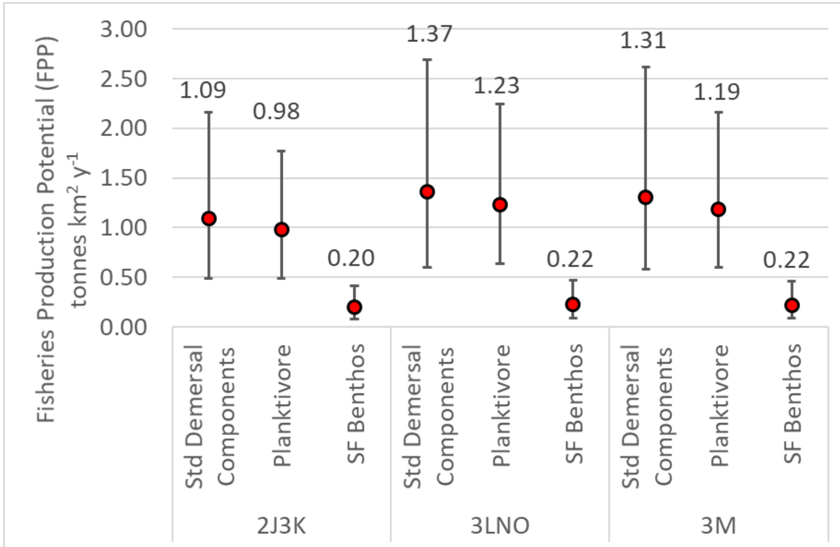

Figure 2.5. Fisheries Production Potential (FPP) per unit area for the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Flemish Cap (3M) EPUs, with the FPP for piscivores and benthivores aggregated into Standard Demersal Components (SDC). Red dots indicate the medians, whiskers the 10-90% range, and the numbers above are the numerical value of the medians. All these estimates assume these ecosystems are fully functional.

Adjustment for ecosystem functionality

While FPP estimates assume that the ecosystem is fully functional and relatively stable, real ecosystems are often far from equilibrium, and relatively stable conditions do not necessarily imply full functionality or productivity. The Newfoundland Shelf (2J3K), Grand Bank (3LNO) and Flemish Cap (3M) EPUs have experienced important changes in total biomass over time (Figure 2.6). The Flemish Cap appears to have maintained a relatively stable total biomass but the Newfoundland Shelf (2J3K), and Grand Bank (3LNO) currently have total biomass levels that are far lower than the ones observed before the early 1990s.

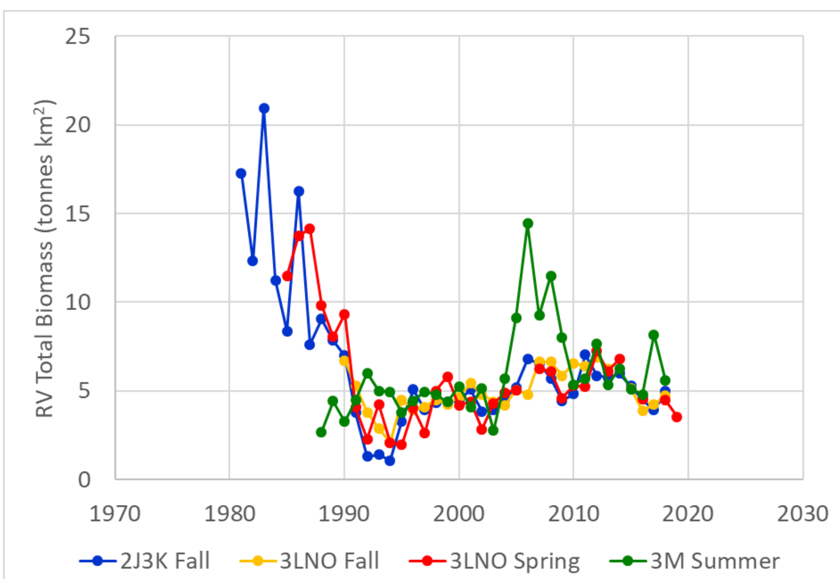

Figure 2.6. Total RV Biomass Density indices for the Newfoundland Shelf (2J3K) (Fall), the Grand Bank (3LNO) (Spring and Fall), and Flemish Cap (3M) (Summer). The 2J3K and 3LNO series have been scaled pre-1995/1996 to correct for the change in the survey gear in the DFO surveys.

As a result, FPP estimates need to be adjusted to reflect their reduced productivity state before they can be used to evaluate the sustainability of total catches in these ecosystems for a given period of time. This adjustment was based on the production/biomass ratio (P/B ratio) concept (Banse and Mosher, 1980; Randall and Minns, 2000). The P/B ratio is often assumed constant for any given species or taxa which implies that production and biomass are directly proportional. Adopting a similar assumption at the ecosystem level allows using the fraction between a current total biomass and the maximum total biomass as a proxy for the current productivity state relative to maximum productivity (i.e. fully functional ecosystem). In the case of the Newfoundland Shelf (2J3K) and Grand Bank (3LNO) EPUs, the trajectories of total RV Biomass as a fraction of the median of total RV Biomass between 1981-1985 for 2J3K, and between 1985-1987 for 3LNO were used to define a penalty scheme to adjust FPP estimates. This scheme assumes that these ecosystems were fully functional prior to the collapse. Applying this adjustment to FPP generates estimates of current Fisheries Production Potential (FPPc), which reflect the actual productivity state of the ecosystem at given period of time (Figure 2.7).

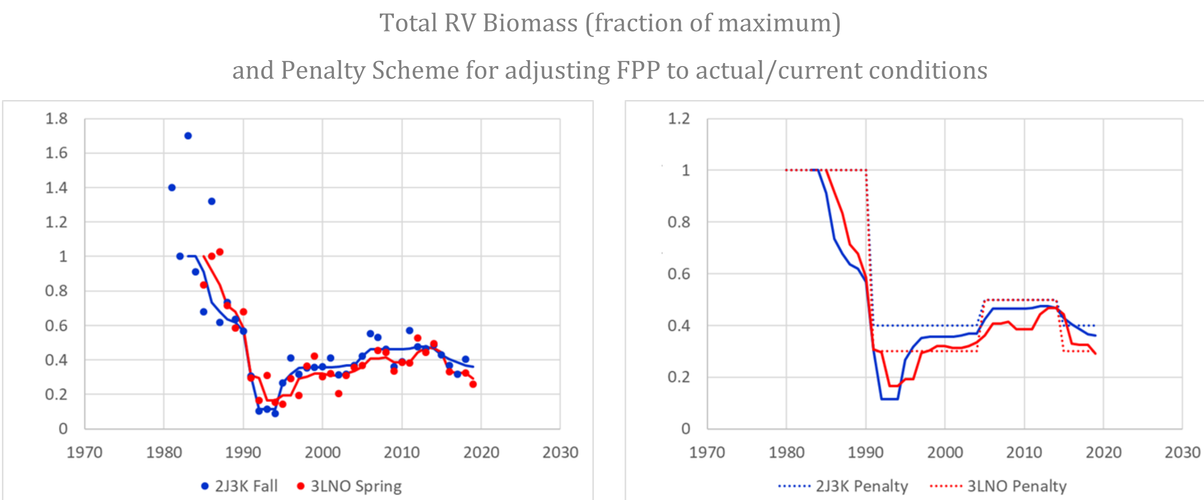

Figure 2.7. Total RV biomass for the Newfoundland Shelf (2J3K) (Fall survey) and Grand Bank (3LNO) (Spring Survey), and corresponding penalty scheme used for adjusting the FPP estimates to past-to-current productivity state. Left: Total RV Biomass expressed as a fraction of the 1981-1985 median for 2J3K and the 1985-1987 median for 3LNO; lines correspond to the 5yr running median. Right: Filled lines correspond to the running medians from the left panel, and dotted lines represent the abstracted penalty scheme to represent the productivity state over time, where 1 corresponds to a fully functional ecosystem. Blue dots and lines: 2J3K; Red dots and lines: 3LNO.

Considering that the EPP model results represent an integrated view of ecosystem productivity over a medium-term horizon (e.g. 3-5 yr), adjustment of FPP values to actual/current conditions also needs to be based on some reasonable integration over a medium-term period. That is the reason behind defining a penalty scheme instead of directly using the running median of the ratio between current and maximum biomass (Figure 2.7). If the penalty factor is 1, it implies that the ecosystem is fully functional, and no real adjustment is required; if the penalty factor is less than 1, then full ecosystem functionality is compromised to some degree, and fisheries productivity has to be adjusted down accordingly.

Total Catch Indices (TCIs) and Guidelines for Total Catches

The analyses described so far generate a framework to estimate fisheries production potential for a given ecosystem, and to adjust these estimates to represent current ecosystem productivity conditions, but their use in advice needs to be consistent with NAFO management principles and practices, chiefly among them being the Precautionary Approach and the Ecosystem Approach (Koen-Alonso et al., 2019).

The current Fisheries Production Potential (FPPc) (i.e. FPP adjusted for ecosystem functionality), is derived from the concept of a maximum exploitation rate which is consistent with sustainable catch levels from an ecosystem perspective. The NAFO Precautionary Approach indicates that the probability of exceeding a maximum sustainable exploitation rate should be low, and nominally characterizes low probability as around 20% (although the actual value is to be set by managers). Following a similar rationale, a simple way to ensure that the probability of exceeding FPPc is low, is to use the 25th percentile of the FPPc distribution as the operational threshold for evaluating if total catches are within the ecosystem-level sustainability envelope. This operational threshold (25th percentile of the FPPc distribution), consistent with the NAFO PA, is the Total Catch Index (TCI).

Furthermore, guidance on total catch level also requires mapping the species being caught to the functional guilds represented in the EPP model nodes, keeping in mind that attribution of catches for some commercial species may need to be split between different EPP model nodes as a result of ontogenetic changes in diet (e.g. cod start off as planktivores but ultimately becomes a key piscivores).

Based on the principles outlined above, the estimated TCIs, and median FPPc for comparison, were calculated for the Newfoundland Shelf (2J3K), Grand Bank (3LNO) and Flemish Cap (3M) EPUs (Table 2.1), which take into account the penalty schemes developed for 2J3K and 3LNO.

Table 2.1. Total Catch Indices (25th percentile) and medians of the current Fisheries Production Potential (FPPc) distributions for each fishable model node [functional guild] and Standard Demersal Components (SDC) aggregate (SDC=benthivore+piscivore) for the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Flemish Cap (3M) EPUs. Penalty factors were applied for 2J3K (0.4) and 3LNO (0.3).

		Total Catch Index (TCI)			
		Total (thousand tonnes y^{-1})		Density (tonnes km^2 y^{-1})	
		TCI (25th)	Median	TCI (25th)	Median
2J3K	SDC	74	111	0.29	0.44
	Piscivore	18	25	0.07	0.10
Area:	Benthivore	51	85	0.20	0.33
254.32	SF Benthos	13	20	0.05	0.08
thousand km^2	Planktivore	70	100	0.28	0.39
	Total FPPc	416	543	1.63	2.14
3LNO	SDC	86	129	0.27	0.41
	Piscivore	21	29	0.07	0.09
Area:	Benthivore	59	99	0.19	0.31
315.18	SF Benthos	14	21	0.04	0.07
thousand km^2	Planktivore	83	117	0.26	0.37
	Total FPPc	468	612	1.49	1.94
3M	SDC	50	76	0.86	1.31
	Piscivore	12	17	0.21	0.30
Area:	Benthivore	35	58	0.60	1.00
57.83	SF Benthos	8	12	0.14	0.22
thousand km^2	Planktivore	49	69	0.84	1.19
	Total FPPc	274	359	4.74	6.21

Based on the temporal changes in penalty factors (Figure 2.7) total catches by functional guild summarized as a fraction of the corresponding TCI demonstrate that in the 1960-1995 period, catches from the piscivore guild were consistently above TCI levels in all ecosystems, while the other functional guilds were mostly within their sustainability envelope (Fig. 2.8). After 1995, catches from the benthivore guild, mostly driven by shellfish species, have also been above the TCIs in all three ecosystems, while piscivore guild catches above the TCIs keep occurring in 3LNO and 3M.

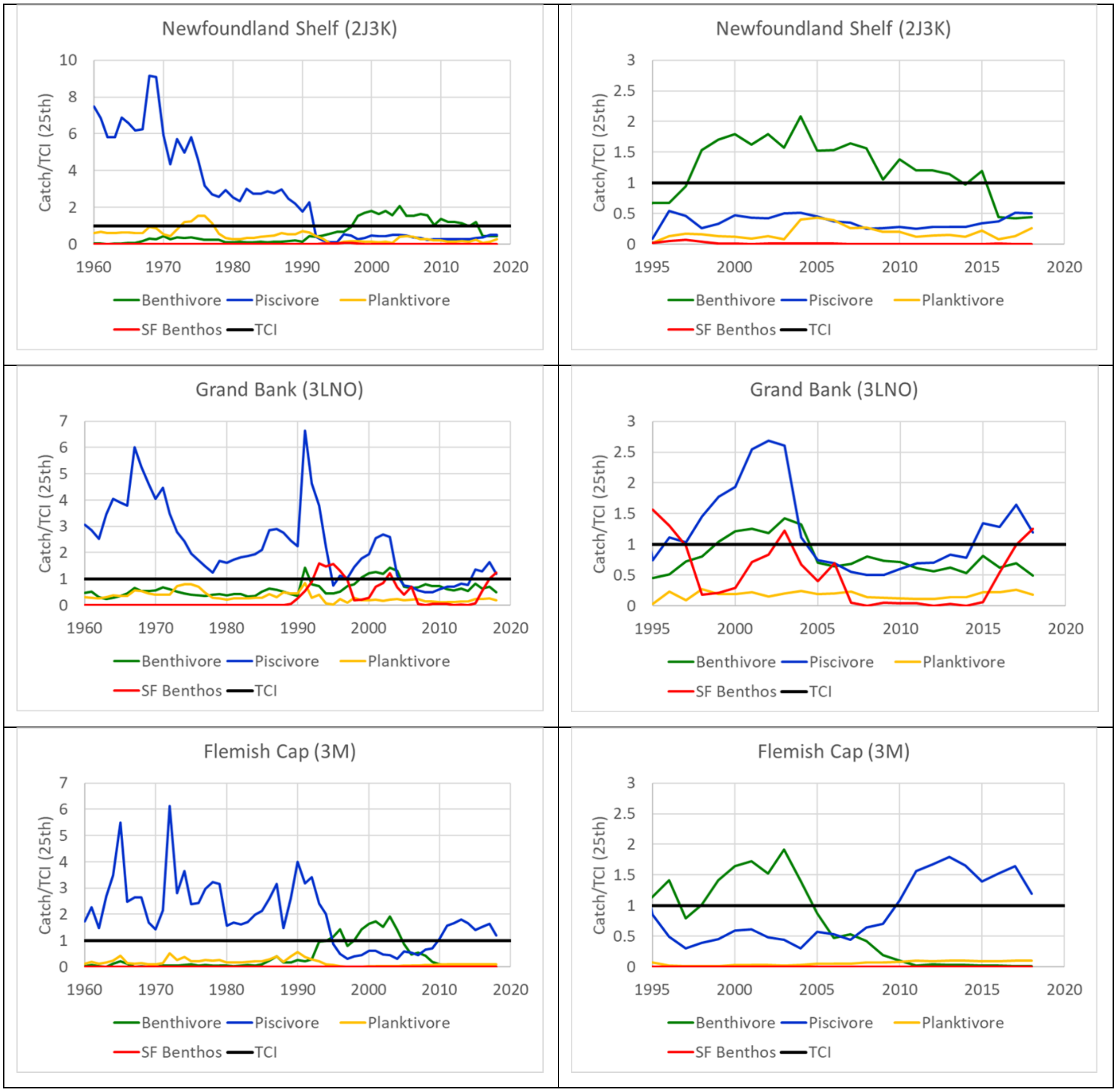

Figure 2.8. Time series of Catch/Total Catch Index (TCI) by functional guild for the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Flemish Cap (3M) EPUs. Left panels shown the full time series, while right panels zoom in on the most recent decades.

Evaluating the effectiveness of TCI as guidance level for total catches

To evaluate the effectiveness of this approach, it is important to recognize that FPPc and TCI are intended as strategic metrics capturing signals integrated over a period of time (e.g. 3-5 years), and that changes in ecosystem trends and productivity are not solely related to fishing. If TCIs are effective guidance reference levels for total catches, fishing above these levels would be expected to erode ecosystem functionality, leading to declines in biomass at the functional guild level.

This expectation was evaluated by comparing the growth rates from smoothed functional guild biomass trajectories with the corresponding 5yr running average of the yearly catch/TCI ratios. Growth rates by functional guild from the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Flemish Cap (3M) EPUs were integrated into a single analysis by standardizing each series with respect to its standard deviation.

The analysis was restricted to the piscivore and benthivore functional guilds because most catches are mapped onto these groups. Catch data was obtained from the NAFO STATLAN 21A database, while functional guild biomass was calculated from DFO RV surveys for 2J3K (Fall) and 3LNO (Spring), and the European Union (EU) survey for 3M.

Results of this evaluation indicate that catches above TCI levels are clearly associated to negative biomass trends in functional guild biomass, while catch levels below TCI show a fairly even distribution of positive and negative biomass trends (Fig. 2.9). Average relative growth rate for catch levels above TCI was -0.450, while average growth rate for catch levels below TCI was 0.073; this is a significant difference (p-value < 0.001). Fishing above TCI is clearly associated with negative growth rates, while fishing below TCI improves the odds of positive growth rates. The even distribution of positive and negative growth rates when fishing below TCI is also consistent with the premise that, if fishing is sustainable, other factors would control functional guild growth rates. There are positive growth rates with catches above TCI but most observations are either close to zero growth or represent catch levels only slightly above TCI=1.

Overall, TCI performs reasonably well at mapping a space of catch levels associated with negative trends in functional guilds. Taking into consideration the generality of the approach used to derive TCIs, the consistency in the response between functional guilds, and the coherence among ecosystem units, it can be concluded that TCI is a sensible metric for providing strategic guidelines on total catches.

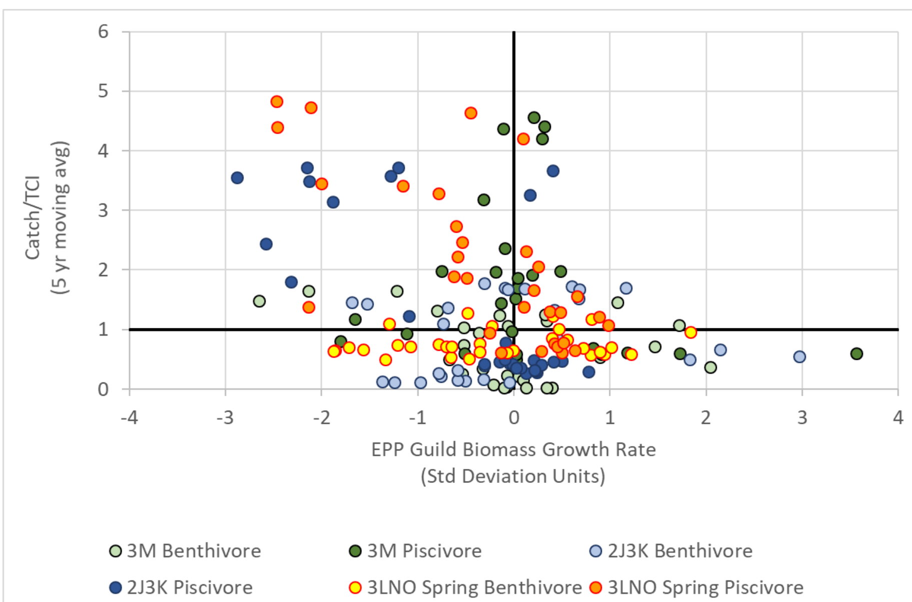

Figure 2.9 Relationship between functional guild biomass trends (growth rate) and catch level expressed as a fraction of the corresponding Total Catch Index (TCI) for the piscivore and benthivore guilds in the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Flemish Cap (3M) EPUs. Catch levels below 1 indicate sustainable exploitation levels from the perspective of TCI.

Exploring trade-offs among functional guilds

In the context of fisheries, considering the trophic interactions among exploited species is a prime example of trade-off that would need direct and explicit management attention. The EPP model-based approach also allows to perform some initial evaluations of trade-offs. FPP calculations can be done assuming that not all the fishable nodes will be fished. For example, the planktivore and suspension-feeding nodes feed into the piscivore and benthivore nodes, fishing on these lower trophic level nodes has an impact on the production of the higher trophic levels.

To explore the potential consequences of these trade-offs, FPP estimates for benthivores and piscivores (i.e. assuming full ecosystem functionality), were evaluated using scenarios in which one or both of the planktivore and suspension-feeding nodes were not harvested. The results indicate that piscivore and benthivore FPP increased around 10-20% depending on the fishing scenario, but these gains are achieved at a substantial loss in total FPP.

Concluding Remarks

The analyses, and rationale presented here summarizes the work done by WGESA towards developing a framework for making operational the Tier-1 of the NAFO Roadmap to EAF. This tier is aimed at assessing the sustainability of fisheries catches at the ecosystem level, and the use of Total Catch Indices emerges as a scientifically robust and effective way for informing this level of assessment.

The EPP model provides a good approximation to ecosystem production based on primary production, while the FPPc distributions and TCI values are reasonable metrics to characterize the upper boundary to sustainable fisheries exploitation. TCI performs well in defining a space where fishing is mostly associated to negative ecosystem trends, but should not be taken as a hard limit; it is recurrent and/or persistent fishing above TCI what would be expected to lead to ecosystem level declines. More significantly, these analyses indicate that, even in situations where management decisions at the single stock level are deemed sustainable (e.g. fishing levels in recent years), their aggregate impact at the ecosystem level may not be. This ecosystem level assessment provides a solid way to start identifying and addressing these situations.

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3. Update of Empirical Analysis

COM request [6] and **ToR 2.1.** ***Empirical trawl track assessment to better estimate assessment of SAI (NEREIDA project)***

Empirical determination of seabed impact and validation of resilience model

An important requirement when assessing SAI is knowledge of the actual area of impact associated with a given level of fishing pressure or effort. The impact of bottom fishing on VME indicator species biomass is particularly sensitive to the assumptions concerning trawl track line density and orientation. To address this uncertainty the 'actual' trawl track line density and orientation has been assessed from speed filtered VMS ping data.

Further, we investigated how the line data can be used to link the biomass of sea pens to fishing effort more accurately than in the previous analyses, and how the biomass curves can be improved and then applied for subsequent analysis of SAI.

i) Method

Line features representing the tracks of fishing vessels, derived from VMS pings collected between 2010-2018 were obtained from the NAFO secretariat. The tracks each relate to the movement of individual fishing vessels interpolated from VMS pings that have been filtered to speeds between 0.5-5 knots, based on known fishing speeds derived from log-book data. Each line was also attributed with the type of fishing gear used by the vessel.

The scientific trawl data combines Spanish (2011-19) and DFO (2005-18) data. For the purpose of this analysis, all scientific trawls were plotted as lines in GIS using their start and end coordinates. Only lines less than 10 km long were included in the analysis dataset to exclude tows with incorrect coordinates. Scientific trawls acquired before 2011 were excluded from analysis to allow for at least one year of VMS data to precede the tows. The sample of scientific trawls was further limited to those located inside the outermost KDE contour from 2016 that includes at least trawls with >0.5kg of sea pens, acting as a proxy for suitable sea pen habitat. There are 1,122 lines included in the analysis., sampled 2011 or later, that intersect the extended KDE polygon.

When allocated to a 1 km^2 grid, 34,090 grid cells had fishing effort associated with them. To reduce processing time, it was necessary to select a subset of areas for comparison. In comparison, the simulations in 2016 and 2018 were run using 100 cells per run. To make the sample areas most relatable to the scientific trawl data to be used for the biomass curves, the estimates needed to reflect the areas sampled by the scientific trawls. In the original analysis the fishing effort associated with each trawl was extracted from a 5 km^2 grid of fishing effort (as hours fished.$year^{-1}$.km^{-2}) by intersecting the start point of the trawl with the grid. As illustrated in figure 3.1, the effort value assigned to each scientific trawl from the 5 km^2 grid may not accurately represent the actual effort. Consequently, effort was estimated in a given area around each scientific trawl, established by buffering the scientific trawl line to 500 m in all directions (Figure 3.1). These buffer areas constitute the sample boxes and are referred to as such in the following text.

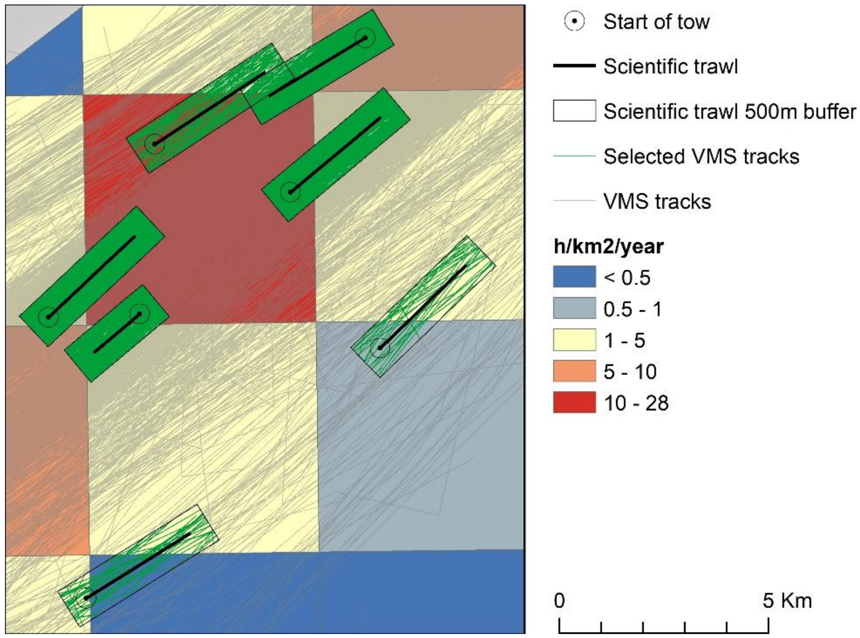

Figure 3.1. Example showing the 5 km^2 fishing effort layer used in 2016, VMS lines crossing the area, start points and lines plotted from start to end of tow of scientific trawls, the 500 m buffers used as sample plots for VMS lines and the VMS lines selected to represent effort for each scientific tow.

The VMS track dataset was clipped to the sample area polygons and each set of lines was allocated the unique sample ID of the scientific trawl it relates to. The 'Gear' column in the VMS track data was used to exclude tracks from vessels using long lines and fishing patrol vessels. On inspection of the tracks in sample areas, it was clear that across such a limited area, vessels engaging in fishing activities largely follow the same tow orientation (Figure 3.2a). Consequently, lines that do not to follow the direction of other lines are likely to be erroneous, resulting from vessels travelling at fishing speeds but not fishing. The VMS track lines were disaggregated at vertices, to ensure correct calculation of orientation from start and end coordinates. The main bearing (circular median) and standard deviation (sd) for lines in each square was calculated Bearing was calculated using the bearing function in the 'circular' package in R (Figure 3.2b). Bearings were calculated as directions at 360 degrees, but for presentation and filtering all west facing direction were inverted 180 degrees to east facing for ease of interpretation. Tracks with bearings falling outside ± 1sd were excluded from the data.

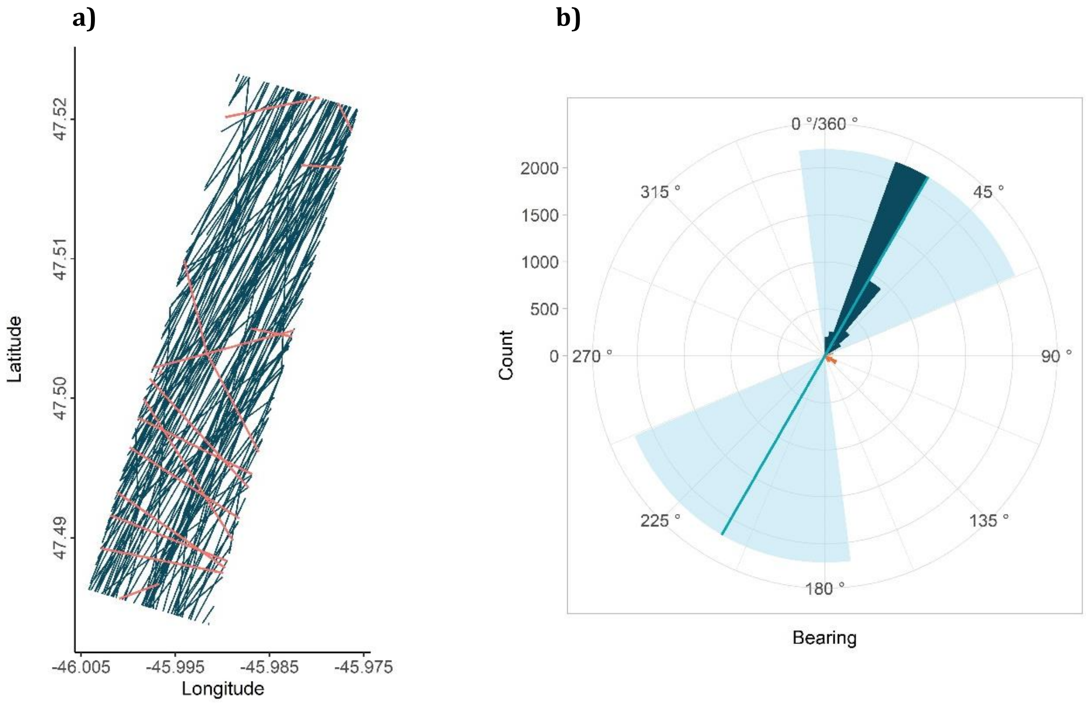

Figure 3.2. Map (a) and circular histogram (b) showing VMS tracks inside (blue) and outside (orange) 1 standard deviation (light blue highlight) of the main direction (circular median, line on histogram) for one sample area.

To account for the difference in the length of scientific trawls, and to make the output comparable to the 1 km^2 simulation runs, the length of line calculated in each sample area was divided by its area, to standardise all data to the unit of $km.km^{-2}$ of VMS track.

Biomass of all sea pens were combined by scientific trawl. Biomass from total catches was converted to $Kg.Km^{-2}$ using the length of trawl (straight line from start to end coordinates) and an estimated swept width of 14m for Lofoten trawls and 24m for Campelen trawls. The simple calculation does not account for the effect on the catch of the different heights of the net opening or the size of cod-end, but these are less important for sea pens than they are for fish.

ii) Results and Discussion

Accumulation of effort

Lines in each sample area were buffered one by one in order of their time-stamps, to create polygons of 150 m swath. Accumulating line length and percent of area covered by each added polygon were recorded until 100% of the sample area was covered. The line lengths were converted to $km.km^{-2}$ by dividing by the size of the sample area. Figure 3.3 shows a comparison of the relationship of track length to percent of sample area covered by accumulating lines buffered to 150 m from the simulation using a wide normal distribution to allocate line positions and VMS tracks. The comparison shows that the simulated line accumulation using the wide-normal line density distribution is a good match to real-world condition in the sample areas.

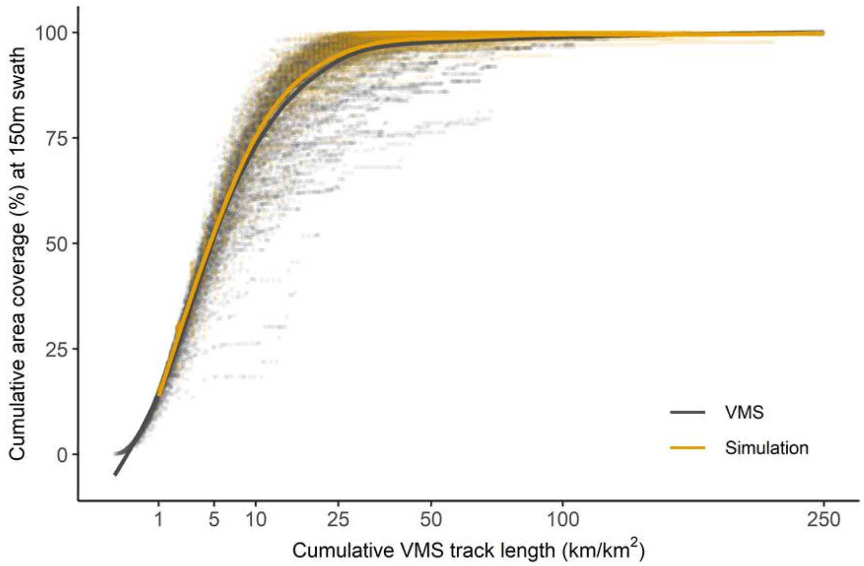

Figure 3.3. Cumulative length of track vs. area covered for 'wide-normal' simulated line density distribution and VMS derived lines buffered to 150 m.

Biomass accumulation curves

The accuracy of the biomass accumulation curve is important for accurately estimating resilience and subsequently assessing SAI. The resilience calculations rely on the assumption that the rate of accumulation of biomass over the fishing effort gradient reflects, all other factors being equal, the percentage of the sea pen biomass associated with a given level of fishing effort. For the curve to accurately reflect the relationship between fishing effort and sea pen biomass, it is essential that both effort and biomass are spatially estimated as accurately as possible and are spatially co-located. The new methodology for effort estimation utilising VMS tracks covering the period 2010 – 2018 has the potential to represent fishing effort at the location of the scientific trawl much more accurately than gridded effort from VMS pings. Ping-based grids are, by definition, spatially coarse to account for location of the vessels in-between pings. The new methodology associates the scientific trawl biomass (from survey trawls) directly to the fishing effort in the immediate vicinity of the survey trawl.

Figure 3.4 (a) shows a comparison of biomass accumulation curves plotted using the gridded fishing effort data following methods employed in 2016 and 2018 and the new effort data derived from the VMS lines covering the same period. The comparison utilized the same scientific trawl data for both datasets (i.e. scientific trawls between 2011 - 2016). The fishing effort data assigned to each survey trawl location is an average of the yearly effort in years preceding the scientific trawl. To maintain comparability with the original biomass curves produced in 2016 and 2018, the $hrs.year^{-1}.km^{-2}$ included effort determined in 2008 and 2009, whilst the 2019 biomass curves only include VMS data starting from 2010. Furthermore, the vessel speed selected to convert time to distance has an effect on the biomass accumulation curve, therefore the calculations using the extended VMS fishing effort data in the 2016 and 2018 assessments are shown using two vessel speeds, 2 knots and 4 knots, respectively.

The apparent difference between the curves in Figure 3.4(a) may be explained, in part, by the inclusion of VMS data from 2008 – 2009 in the analysis conducted in 2016 and 2018 that was not included (due to lack of reliability) in the present analysis which uses VMS data from 2010 onwards. However, the primary difference in the shape of the curves is most likely explained by the result shown in Figure 3.4(b) which indicates that the coarse grid of time-based effort (used in 2016 and 2018) tends to overestimate fishing effort in comparison to the line-based effort. The coarse grid is not able to accurately account for the concentration of effort to linear features following bathymetric contours at a spatial scale directly relatable to the scientific trawls (Figure 3.1). WGESA therefore considers that using VMS line-based effort, estimated at the location of the scientific trawl, be used to update the biomass accumulation curves for all VMEs for use in the 2021 SAI assessment and for estimating subsequent VME indicator species resilience.

A key conclusion of utilizing this more spatially accurate method is that the overall cumulative biomass fishing effort plots will tend to have a steeper gradient in the lower fishing effort categories (as shown in 3.9 (a)). Such a response is indicative of greater species biomass sensitivity to fishing impact than was previously observed using the gridded VMS fishing effort method alone. Therefore, VME indicator species recovery times (including those estimated for sea pen) are likely to be longer than previously estimated.

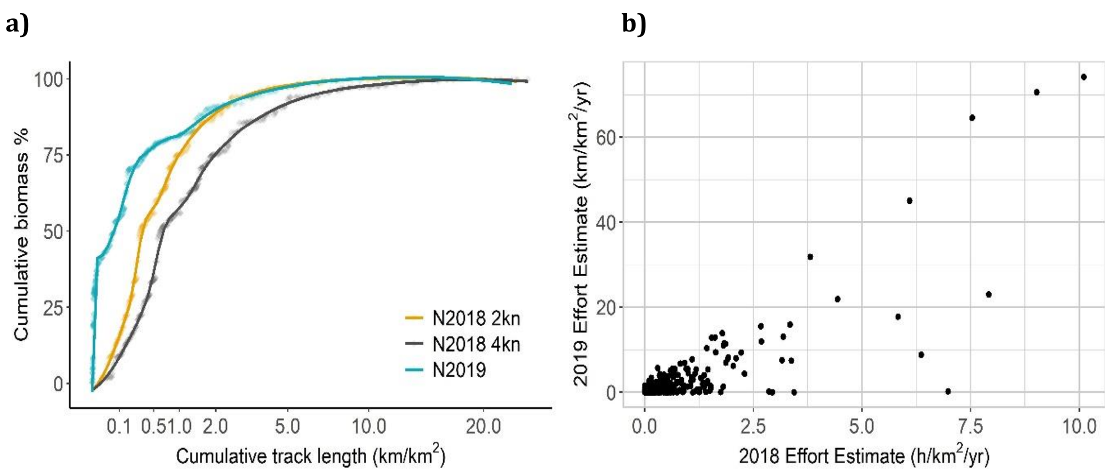

Figure 3.4. (a) Comparison of sea pen biomass accumulation curves plotted using biomass data from scientific trawls collected between 2011-2016 and (b) fishing effort in fishing vessel track length as km.km^{-2} derived from VMS tracks (N2019) and hours fished.year.km^{-2} converted to distance using vessel speeds of 2 knots (N2018 2kn) and 4 knots (N2018 4kn).

A further consideration for the biomass accumulation curves is how well the total biomass of VME in scientific trawls corresponds to the associated fishing effort. With the scientific trawls covering on average a distance between 2 - 3 km, some of the sample boxes cover areas with varying track density (Figure 3.5a)). To account for representativeness of the sample, the amount of sample box that contains 95% of the total line density was recorded, to differentiate between areas with same line length but different swept area. Most sample areas have an even distribution of VMS track across their whole area (Figure 3.5(b). A scientific trawl which crosses an area with no effort to high effort may have a similar effort estimate to a scientific trawl collected in a less intensively but consistently fished area. There is no way to account for the sampled biomass being collected in only part of the trawl, therefore it is recommended that the biomass from scientific trawls with high effort over only part of the area surrounding the trawl be excluded.

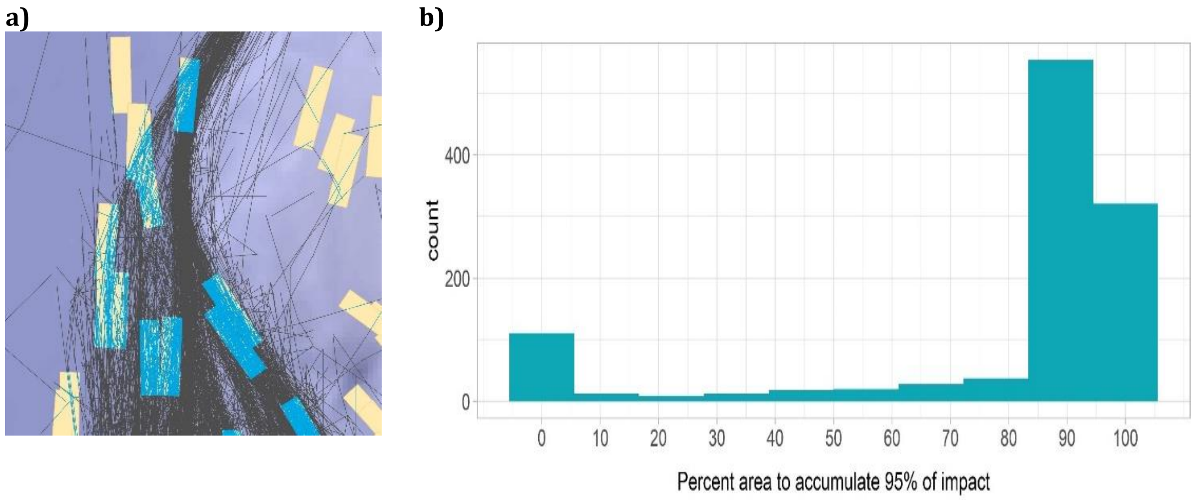

Figure 3.5. Sample areas in relation to VMS track density (a) and the distribution of spatial coverage of tracks across sample areas (b).

The results of these empirical-based line density analyses will be used in conjunction with the up-dated VME polygons, the improved mapping of fishing effort and VME indicator species biomass, to generate new cumulative VME indicator species biomass/fishing effort response curves to be in the assessment of SAI for the reassessment of bottom fisheries to be conducted in 2021.

4. Update of NEREIDA Analysis overlap of NAFO Fisheries with VME

COM Request [6] and **ToR 2.1** ***Assess overlap of NAFO fisheries with VME to evaluate fishery specific impacts in addition to the cumulative impacts.***

Highlights:

1. 2018 Haul-by-haul logbook data was merged with the 2018 vessel monitoring system (VMS) data to map fishing effort from VMS positions that occurred within the reported fishing time interval.
2. The use of haul-by-haul logbook data permitted VMS pings to be extracted and mapped if they occurred within reported start and end times for fishing. This provided a more accurate measure of when vessels were trawling and allowed each haul to be assigned to a fishery.
3. The haul-by-haul effort maps were considered to be an improvement over past effort maps derived from a 1 – 5 nautical mile per hour speed filter because it reduced spurious effort points.
4. New thresholds and KDE VME polygons were presented during the 12th WGESA meeting using additional scientific survey trawl data since 2013. As these new polygons have not yet been accepted by SC, all the overlapping calculations and figures in this analysis were done with KDE VME polygons accepted at present time.

During the 10th WGESA it was agreed that they would like to see ongoing yearly mapping of the cumulative and fisheries-specific fishing effort. This will help understand if and how fishing effort is changing over the years.

This analysis details the 2018 fishing footprint maps derived from vessel monitoring system (VMS) and haul-by-haul catch data.

Logbook data and VMS are complementary, and the coupling of both datasets has already proven powerful for describing the spatial distribution of fishing activity at a much finer resolution. Figure 4.1 illustrates the flowchart with the main steps involved on the procedure of linking VMS with logbook data.

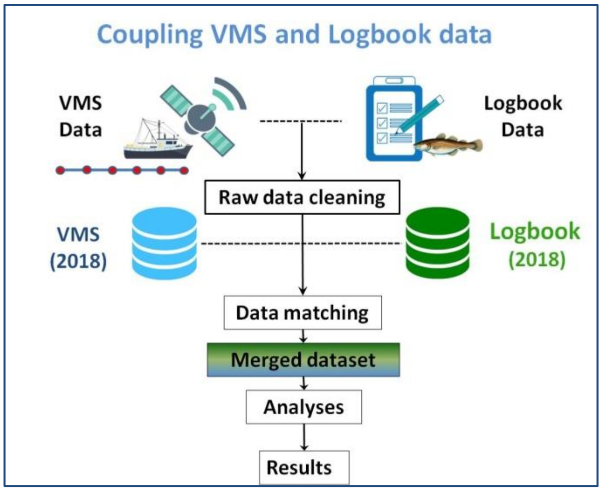

Figure. 4.1. Flowchart with the main steps involved on the procedure of coupling VMS and logbook data.

The first important step is the "Raw Data Cleaning". In many instances, both VMS and logbook data contain erroneous entries namely: points with incomplete timestamps; wrong vessel positions; duplicated records; Headings outside a compass range, etc.

Once the cleaning has been performed both datasets are ready for the "Data Matching" by using the Vessel ID and the Date as common fields between both databases. This step is particularly important as all subsequent analyses depend on the success of the linking. From the "Merged dataset" we can start to do the "Analyses" and get the final "Results".

Haul-by-haul catch data is logbook data collected during vessel fishing activities. Specifically, timestamps and geographic coordinates for gear deployment and retrieval are recorded, as well as the catch and discard weight for each species caught. This new data format, implemented in 2016, is an improvement over 2015 where data was recorded only for only the top three species by weight and did not include fishing timestamps.

Use of the haul-by-haul data permits VMS pings to be assigned as "fishing" or "non-fishing" based on whether or not they fall within fishing time intervals reported in the haul-by-haul data (match in time window, see Figure 4.2). That is, start and end of fishing timestamps from the logbooks are used to extract relevant VMS points which are then mapped in space to represent fishing effort. Because these VMS points are directly within the reported fishing times interval, they are considered to be associated with fishing activity.

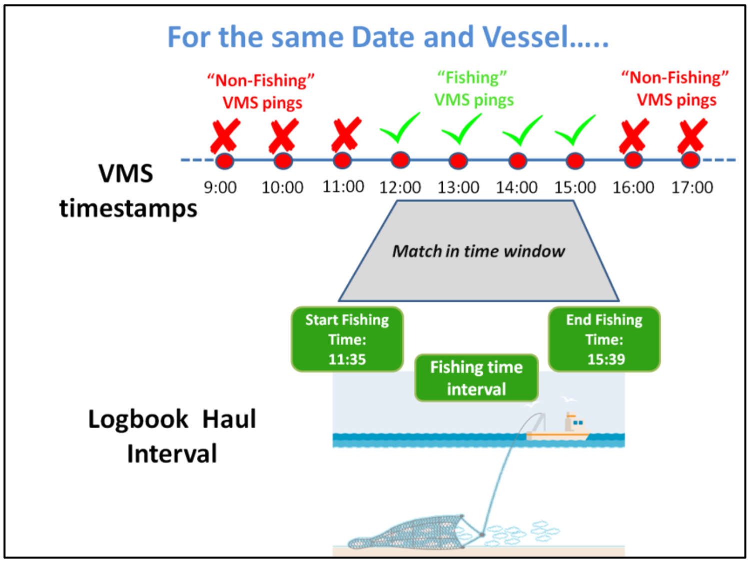

Figure. 4.2. Match in time window procedure.

In previous years, a simple speed filter of 1 – 5 knots (rounded to the nearest integer) was used to filter VMS points and assign them as fishing activities, but it was challenging to decide which thresholds were appropriate across entire fleets. While applying a speed filter is a very common method for extracting VMS points associated with fishing, there will inevitably be some points that are misclassified at a rate that is difficult to quantify.

Through this updated analysis, fishing footprint layers were created for fisheries-specific and cumulative fishing effort using VMS data and new haul-by-haul catch data (logbook) from the year 2018.

To create fishery-specific effort maps, VMS points were assigned to a fishery based on the species with the highest retained catch weight in the logbook during the corresponding logbook fishing time interval. This definition of fishery is based solely on the main species in the catch and in some cases this may differ from the main species sought.

Filtered VMS points were assigned a "ping-time" interval to represent the duration of fishing. This value was calculated as the forward difference in time between VMS points. Typically, ping intervals were approximately one hour, so if the interval exceeded 2 hours, it was assigned to be 2 hours to avoid inflating effort within a cell. The last VMS point in a vessel's series was assigned the mean ping-time interval for that vessel. The VMS points were aggregated over a 0.05 x 0.05 degree grid and the ping-time intervals were summed to represent the hours fished in each cell.

A second set of fishing effort layers were produced from the same data using the methods in NAFO (2015). VMS points were assigned to a fishery based on the main catch from the daily catch records, and VMS points were filtered if they reported a speed between 1 – 5 knots. Effort was represented by VMS ping time, i.e. the time intervals between consecutive fishing pings, which were summed and applied to a 0.05 x 0.05 degree grid.

The fishing effort layers, referred to as "logbook haul-time filter" for the haul-by-haul data and "simple speed filter" for the 1 – 5 knot speed data, were compared side by side and visually examined for congruence.

Overall, the areas represented by the logbook haul-time filter method and the simple speed filter method showed fishing activities in the same general areas with similar patterns of intensity. However, the footprint from the logbook haul-time method was considered an improvement because it tended to have fewer spurious points outside of the main footprint area (Figure 4.3). With the new method, there were also fewer cells displaying fishing effort within the vulnerable marine ecosystem (VME) closures, and if we assume the closures are being respected, this would indicate that the simple speed method over represents fishing effort in some cells, particularly where effort appears to be low. In the logbook haul-time filtered maps there were still some points outside of the NAFO fishing footprint, in deep waters, likely due to VMS points associated with steaming. This probably occurred because of an incorrect start/end time, or delayed reporting of fishing "end time".

Simple Speed Filter Logbook haul-time filter

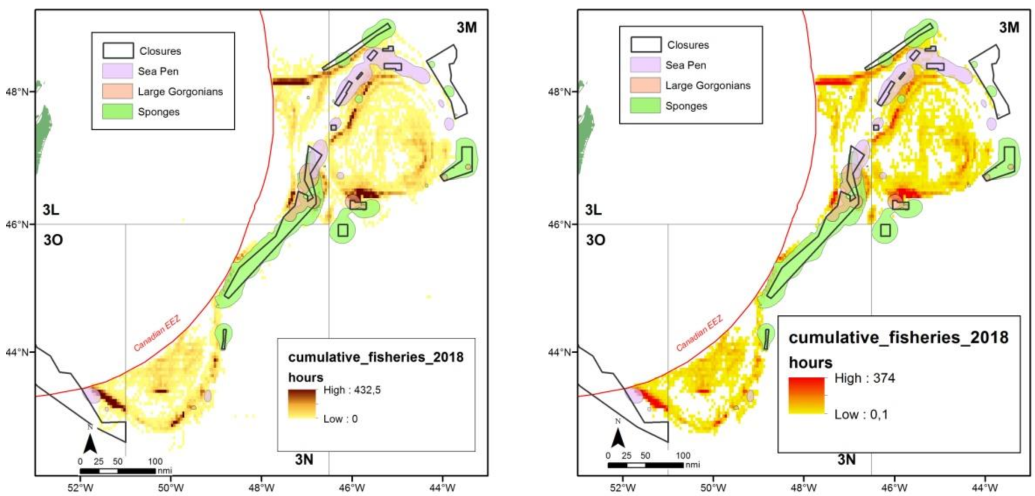

Figure 4.3. Cumulative fishing effort maps (hours fished per cell) from 2018 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

Fishing effort layers and comparison figures are shown below.

Greenland halibut appeared to have fewer spurious cells (individual cells) as part of the fishing footprint when using the logbook haul-time filter (Figure 4.4), such as on the top of the Flemish Cap. Also, cells on the tail of the Grand Banks (Division 3N) that were represented as part of the fishing footprint with the simple speed filter (left panel) were no longer represented in the layer with the logbook haul-time filter (right panel).

Simple Speed Filter Logbook haul-time filter

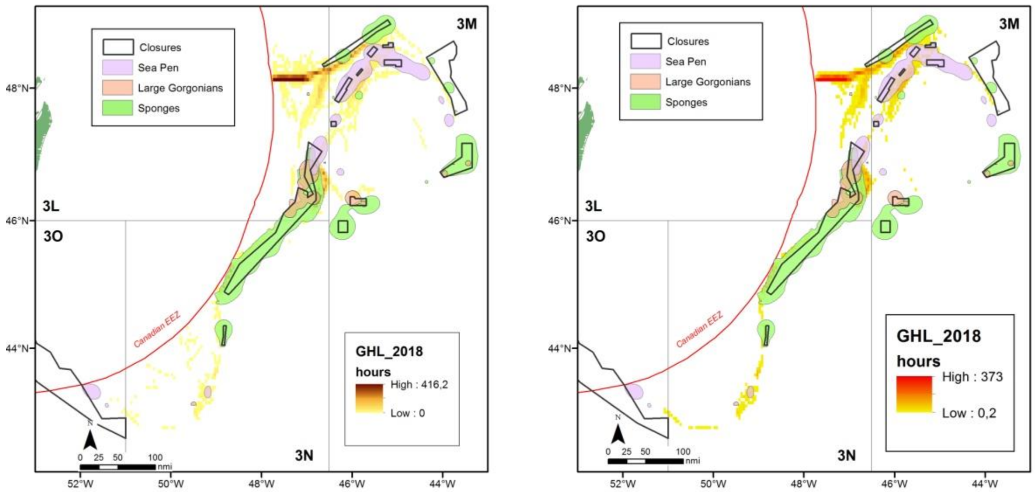

Figure 4.4. Greenland halibut fishing effort maps (hours fished per cell) from 2018 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

The ability to filter VMS points that are within reported fishing times allowed us to examine the speed frequency histograms as a means to evaluate the efficacy of the original assumption that speeds between 1-5 knots represented fishing effort. Histograms of speeds for the various fisheries generally occurred within 1 – 5 knots but also had slower speeds, and in some cases such as Atlantic halibut, there were some speeds > 5 knots (Figure 4.14). This is not unexpected given the method of deployment for these fixed gears.

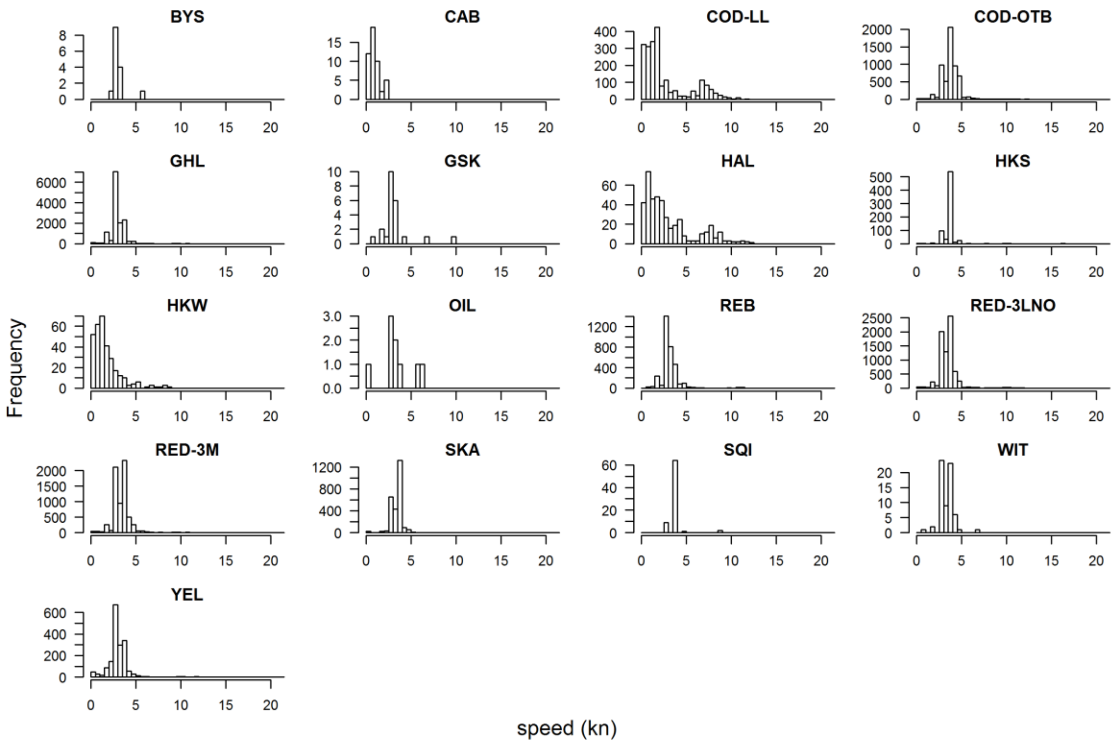

Figure 4.14. Fishery-specific speed histograms from VMS points within haul-time intervals. BYS = Splendid alfonsino, CAB= Northern wolfish, COD-LL= cod long line, COD-OTB = cod bottom otter trawl, GHL = Greenland halibut, GSK = Greenland shark, HAL = Atlantic halibut, HKS = silver hake, RED = redfish, SKA = skates, SQI = Northern squid, WIT = witch, YEL = yellowtail flounder.

We conducted a simple overlay analysis to estimate the area of VME polygons that is overlapped by the 2018 cumulative fishing footprint and fisheries-specific footprints (Figure 4.15). The fishing effort layers used were based on logbook haul-time filtering. Overall, we found that 22.1% of the total VME area had some degree of fishing in 2018, with fishing activities occurring in each of the three KDE VME taxa polygons. Large gorgonian, Sea pens, and sponge VMEs respectively had 20.9%, 33.4% and 16.7% of their area within the 2018 fishing footprint.

The Greenland halibut fishery had the greatest areal overlap with the KDE VME polygons, for each of the VME taxa (sea pen: 27.9%; sponge: 14.9% and large gorgonian: 8.8%). Redfish in 3M and 3LNO together with Cod bottom otter trawl fisheries had the next largest overlaps in the three VME types.

The fishing effort overlay analysis using the logbook haul-time filtering on 2018 data are in agreement with results of the previous WG-ESA meeting (NAFO 2016) where the overlay analysis was conducted on fishing for the 2012-2015 time period. Those results also showed that Greenland halibut bottom otter trawl fishery appeared to have the largest footprint in the various VME polygons, followed by redfish fisheries. When several years of fishing data are combined into one fishing footprint layer, the extent is larger than that of a single year; therefore, the absolute percentage of VME overlapped was higher.

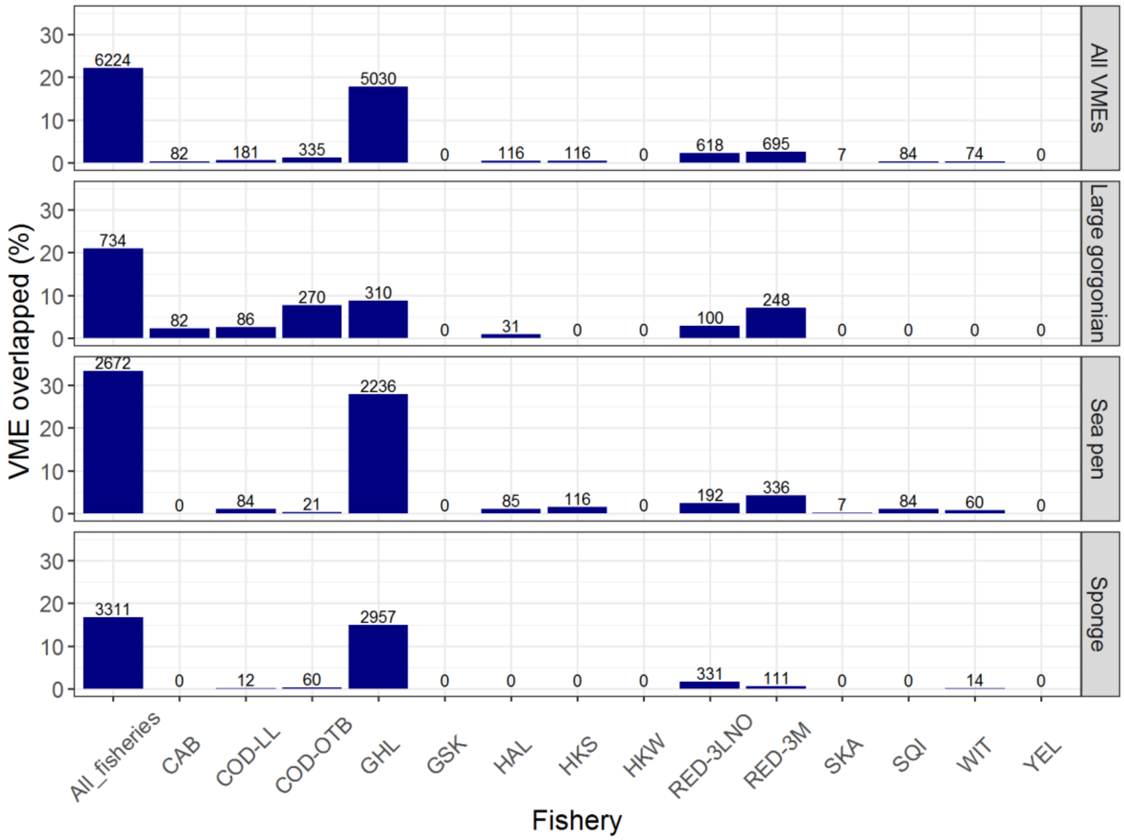

Figure 4.15. The percent of KDE VME polygon overlapped by cumulative fisheries (far-left bars) and fisheries-specific footprints using the haul-by-haul time filtering of 2018 VMS records. The top panel represents the area of all VMEs combined, and the bottom three panels represent the specific VME polygons by taxa. The number on top of each bar represents the absolute area of VME (km^2) that is overlapped by the fishing footprint. Note that the VME polygons are not the same as the VME closure areas. The fisheries abbreviations are given in the caption for Figure 4.14.

Overall, the haul-time method appears to improve the fishing effort spatial layers in several ways. First, only points that are within reported fishing times are mapped, and provided that the reported start and end times are correct, this reduces the likelihood that non-fishing points are included in the effort. Second, using this new method reduces effort that is represented inside of VME closures. Third, there are fewer points that appeared to be spurious effort, i.e. individual cells with low levels of fishing, often in deep waters. Finally, the ability to assign fisheries on a haul-by-haul basis provides more detail and certainty to the fishing activity associated with each VMS ping. However, it is important to keep in mind that the resolution used is coarse with a 0.05 x 0.05 degree grid cell size and does not allow us to evaluate the fine-scale impacts that occur on the sea floor.

References:

NAFO. 2015. Report of the 8th Meeting of the NAFO Scientific Council (SC) Working Group on Ecosystem Science and Assessment (WG-ESA) [Formerly SC WGEAFM]. NAFO SCS Doc. 15/19, Serial No. N6549, 176 pp.

5. VMS Data and Availability

COM Request [6] and **ToR 2.1:** ***VMS Data Products and Availability: Fishing Effort GIS layers***

Background

Spatial coverage and accumulation of fishing activities is represented by data acquired via the Vessel Monitoring System (VMS). The hourly VMS pings indicating the location of an individual vessel are mostly collated into full spatial coverage by aggregating the number of pings in a regular grid of a set cell size. The cell size is decided based on the time interval between pings. A small cell size will represent the pings more accurately but will underrepresent the fishing effort occurring in between pings and create a speckled appearance of fishing effort. A large cell size will extend coverage to the whole area of interest, but it will not represent edges of activity particularly well and will overestimate activity in areas where activity is restricted to a part of the grid square. The latter issue is especially pertinent in areas, such as the deep waters of the study area, where the tracks of individual fishing sets concentrate around specific localized 'corridors' along bathymetric contours (**Error! Reference source not found.**). The most commonly used cell size is 0.05 d egrees, which corresponds to approximately 5 kilometres.

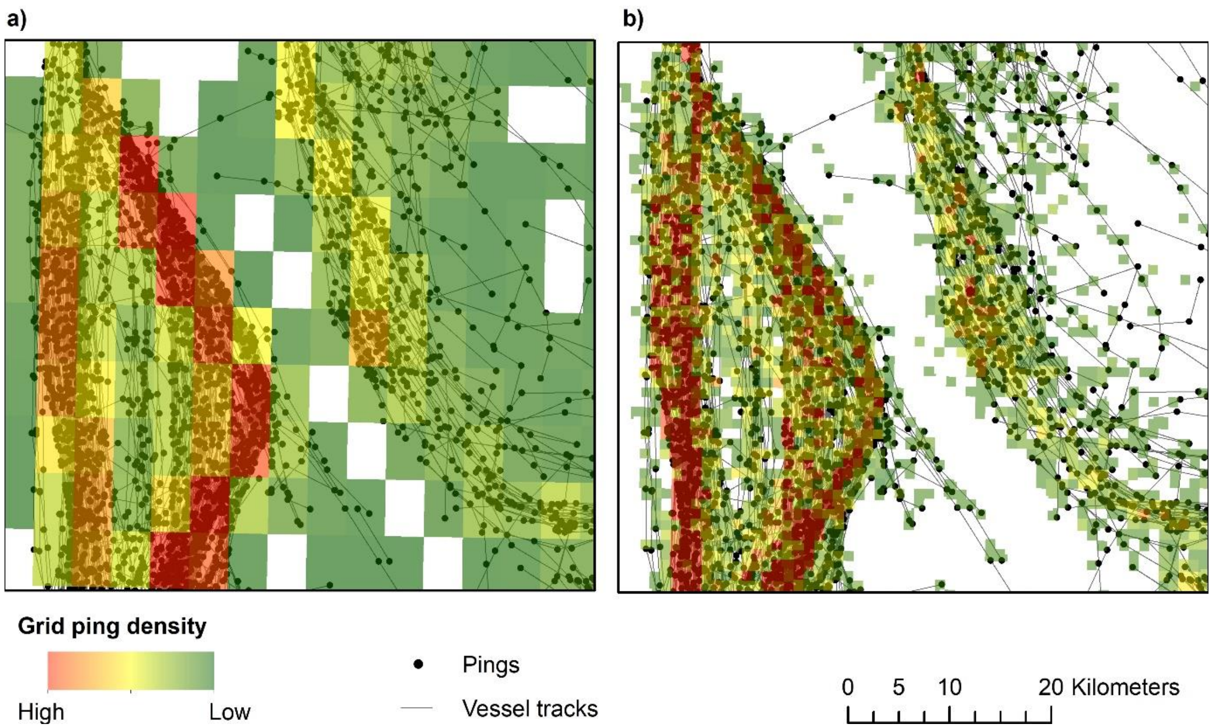

Figure 5.1 Example of spatial aggregation of fishing effort in raster format represented by the density of VMS location pings using a cell size of (a) 0.05 degrees (~5km) and (b) 1km

With access to line features representing the likely tracks travelled by fishing vessels, derived from speed-filtered VMS ping data, it was possible to produce raster surfaces representing the spatial accumulation of fishing effort in a finer resolution, better representing the localised effort, whilst accounting for the likely location of vessels in between pings.

a) Layers created in 2019

Vessel tracks

Line features representing the tracks of fishing vessels corresponding to individual fishing events (trawl tows or longline sets) were created by the secretariat using VMS data received between 2010 and 2018. Points were considered to belong to the same fishing event based on the following criteria:

- vessels were considered to be fishing if their speed was between 0.5 and 5 knots (where vessel speed was not registered, average speed was calculated based on the mid-points between the current ping and the previous and following pings)
- a fishing event was a sequence of two or more consecutive points where:
    - speed was continuously within the 0.5 to 5 knot range
    - time between consecutive points was not greater than 2 hours
    - the average speed between consecutive points (distance travelled/elapsed time) was not greater than 5 knots

Points were plotted in ArcGis and converted to lines corresponding to fishing events.

Raster grids

Line features representing the tracks of fishing vessels were derived from VMS pings collected over 2010-2018. The tracks each relate to the movement of individual fishing vessels interpolated from VMS pings that have been filtered to speeds between 0.5-5 knots, based on known fishing speeds derived from log-book data. Each line was also attributed with the type of fishing gear used by the vessel.

Fishing effort was defined as kilometers of trawl track travelled per Km^2 per year. This is a departure from the previously used effort unit of hours fished per Km^2 per year, which was calculated from the accumulation of the hourly VMS pings. The benefit of using the VMS tracks instead of raw pings is in accounting for the ship's trajectory between pings, allowing more resolved accumulation of effort.

VMS tracks resulting from trawlers and long-liners were considered separately. Whereas the distance travelled by the fishing vessel is clearly related to bottom impact for trawlers as the trawl travels on the sea floor, the impact of the long line on the sea floor is less clearly related to the ship's location whilst laying and hauling the line. Consequently, the fishing effort layer used in further analyses included trawl fisheries only. A separate raster grid was produced for fishing effort from long lining fisheries for comparison.

The effort layer was produced using a moving window approach. The total length of VMS track within a specified neighbourhood was calculated using the ArcGIS Spatial Analyst 'Line Statistics' tool (ArcGIS 10.5). The cell size of the output raster layer was 250 m. Radius of the circular neighbourhood was set at 500m to achieve a moving average output. The tool calculates the line length within the specified neighbourhood for each raster cell in meters. The output was converted to the unit of $Km/Km^2/Year$ by first converting meters into kilometers and dividing the line length by the area of the neighbourhood (0.8 Km^2) and then by the number of years of data (9) included in the VMS tracks line feature (Figure 5.2).

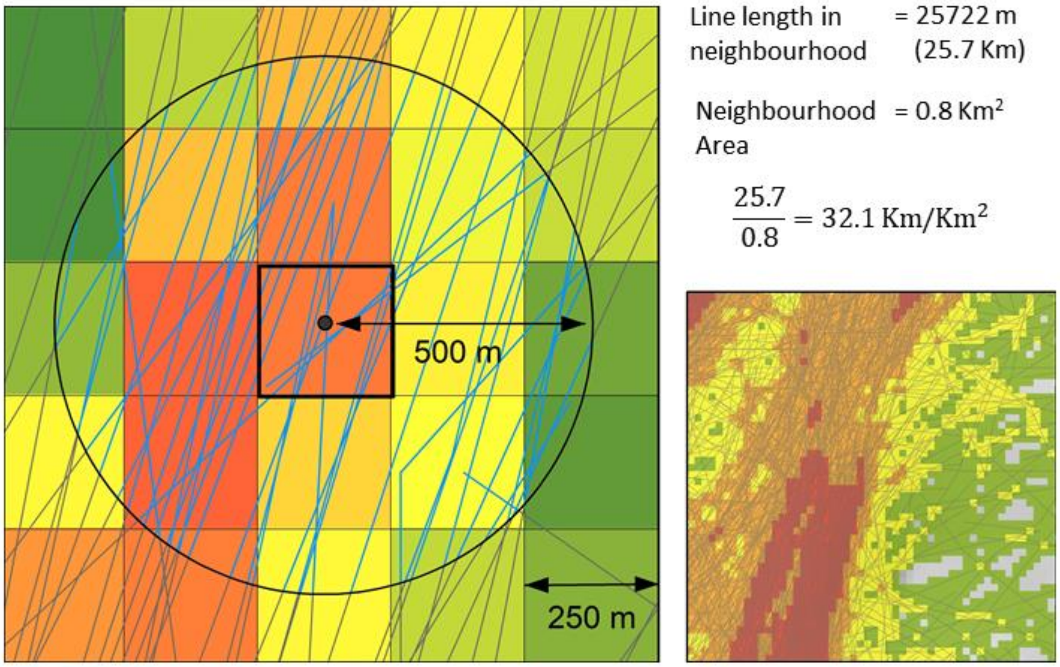

Figure 5.2. Moving window calculation of fishing effort in Km/Km2. Length of VMS track for each 250 m raster cell is calculated using a circular neighbourhood with a 500 m radius and dividing by the neighbourhood area.

The final output raster layers of fishing effort calculated from VMS tracks for the long line and trawl fisheries are shown in Figure 5.3. Whilst trawl fisheries show high effort along the banks of the Flemish Cap and Sackville Spur as well as on the Grand Banks, effort for long line fisheries is concentrated on top of the Flemish Cap and along the shelf edge on the tail of the Grand Banks (Figure 5.2). Most of the fishing footprint falls into areas that are predominantly (one gear type accounts for > 66% of the effort) fished by trawl or long lines reflecting their preferential use on different ground types (Figure 5.4).

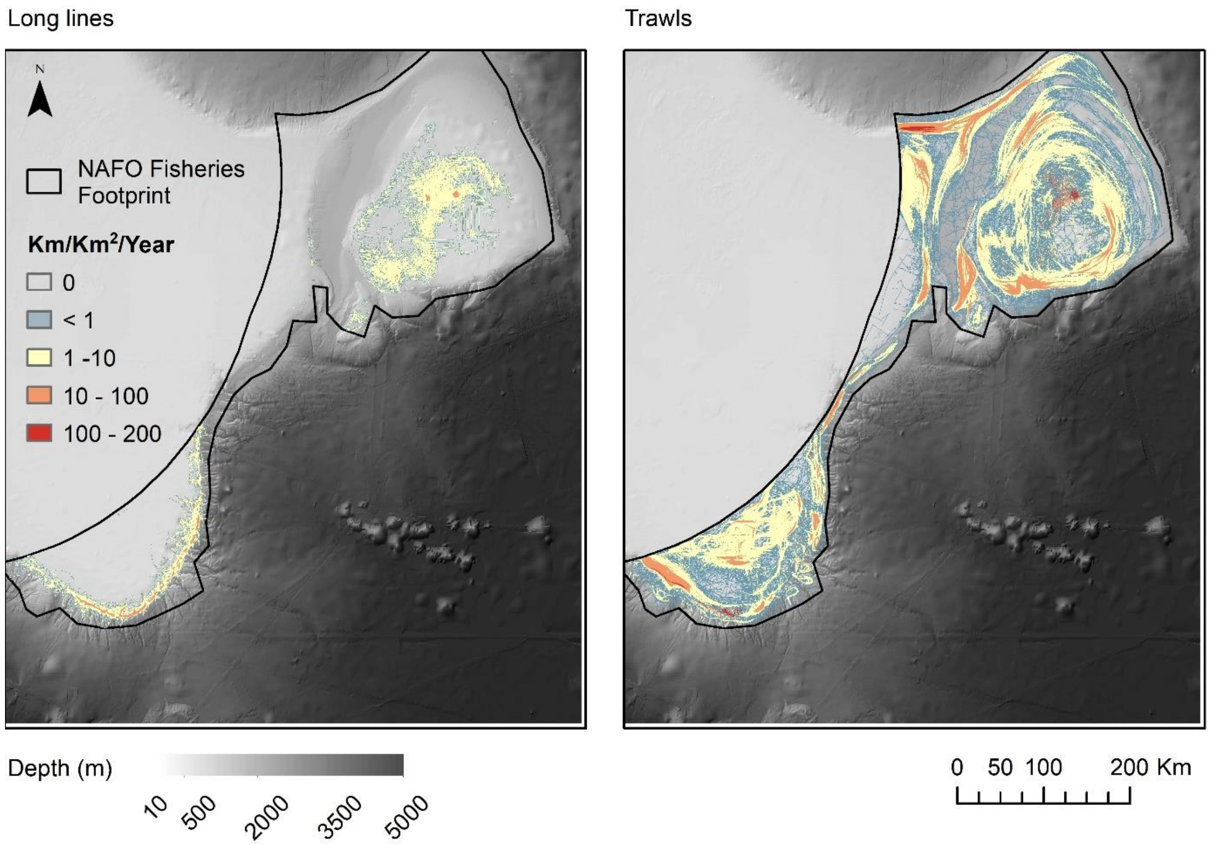

Figure 5.3. Fishing effort (Km/Km2/Year) in the long line (left hand panel) and trawl (right hand panel) fisheries 2010-2018.

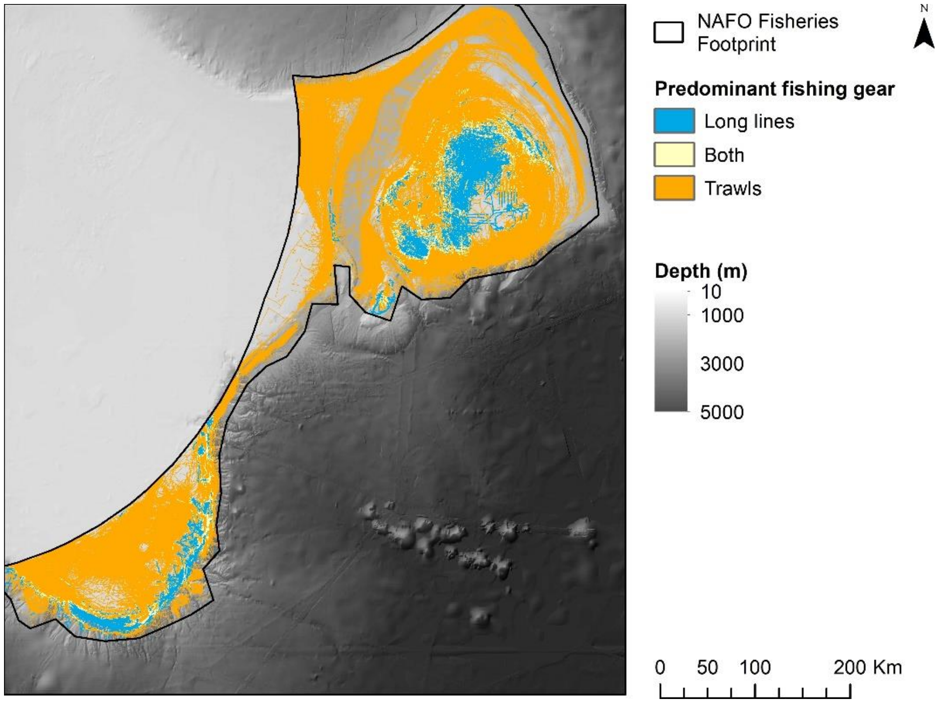

Figure 5.4. NAFO fishing footprint 2010-2018, partitioned into areas dominated by trawl and long line fisheries. The predominant fishing gear is determined as contributing >66% of the total effort in a location.

Future improvements

i) Standard VMS data products for WG-ESA

It was agreed at the meeting that the working group should specify standard VMS data products that will be produced and updated annually to be shared with the whole group. The standard data products will ensure all analyses are using the same information and the methods for the data products are well documented.

Data products will include vector data of individual vessel tracks and raster layers of combined fishing effort. Vessel tracks will be produced using VMS pings, filtered according to agreed rules. Some testing of rules to be applied is required to assure the most accurate representation of ship tracks during fishing activity only. A more detailed description of methods for filtering pings and tracks that will be tested and applied is given in the following section. The vessel track products will be used to create the fishing effort layers. We will continue to separate fishing activity for long lines and trawls into their own products. Whilst the tracks recorded for trawls correspond relatively well to the general location of bottom impact, we need to address the spatial estimation of impact from long lines differently and research is needed into translating the ship track to the footprint on the seafloor. A literature review of previous published work can be used as a starting point.

Rules for creating tracks from VMS pings

1. Years when there are no logbook data available:
   a. 2010 onwards.
   b. VMS points are filtered to speed. Speed rules: 0.5-5kn – will investigate if this rule could be improved upon based on the histograms from logbook associated data. Validation of speed filters.
   c. Only consecutive points from same vessel are joined into one line, if vessel increases speed or drops to below 0.5 fishing operation ends.
   d. If there is a gap longer than 2h the track breaks.
   e. If the calculated average speed between two point is greater than 5 knots starts a new fishing operation.

    f. If the resulting line crosses a set depth range it is not likely to be a trawl, it can be a long line though. This threshold yet to be decided by analyzing the data.
    g. Filter out points outside realistic fishing depths.
2. Years where logbook data exists:
    a. Get the start and end times from logbooks to decide start and end points for lines.
    b. Estimate human error in logbook entries.
    c. Tracks will also be created using the method used in 1. above to allow comparison and to identify consistent differences that could be used to apply post processing to the non-logbook years.
3. Will look into the occasions of short hauls with only one ping and very long hauls to get an idea how prevalent they are and whether it will be necessary to formulate rules calculate likely locations for tracks from single pings or split the long tracks.

Attribute information included for vessel tracks

Lines will include information on the average speed vessel was travelling based on speed reported in pings and the gear used in the fishing operation.

1. Years where no logbook data exists:
    a. Per vessel registration: gear listed on license
    b. Where no information available looked on online resources with IMO/call sign - sleuthing
2. Years where logbook data exists (going forward):
    a. Gear based on catch for years until now, going forward requested gear to be included in the logbook data. Hopes for gear dimension estimates in the future.

Gear dimensions will be added in the future, estimated on a target fishery basis.

ii) Methods development for producing effort grids

The fishing effort grids produced in 2019 were primarily aimed for inclusion in distribution modelling of fish. Thus, the cell size used was dependent on the cell size of other layers in that specific analysis. It was agreed at the meeting that in the future effort grids will be calculated using a similar line statistics method, but with 1km^2 cell size. The level of spatial smoothing in the output increases with window size. Some investigation will be needed to how much the neighbourhood size of the moving window affects the output to check the assumptions that the moving window approach does not skew the results. The window size selected will be somewhat arbitrary. Suggested approaches include using a window that (1) reaches the edge of the raster cell (500 m), (2) reaches the corners of the raster cell (707 m), and (3) covers an exactly 1km^2 neighbourhood (560 m, Figure 5.5). Whichever window size is selected, in the resulting raster each raster cell will represent the length of track accumulated within 1km^2 and the grids values will be in km/km^2/year.

The average speed vessels travelled along each track can be calculated from the information contained in the VMS data. The same neighbourhood line statistics method can be used to produce a raster representing the median speed of vessels travelling through each raster cell, which in turn can be used to convert the distance-based effort raster to a time-based effort raster for backwards compatibility and comparison. Consequently, the suggested standard raster outputs are 1 km grids of effort both in km/km^2/year and h/km^2/year for each individual year starting from 2010 and an average over all years available. Additional grids can be calculated from these e.g. to look at standard deviation between years, the number of times a cell is fished over a time period.

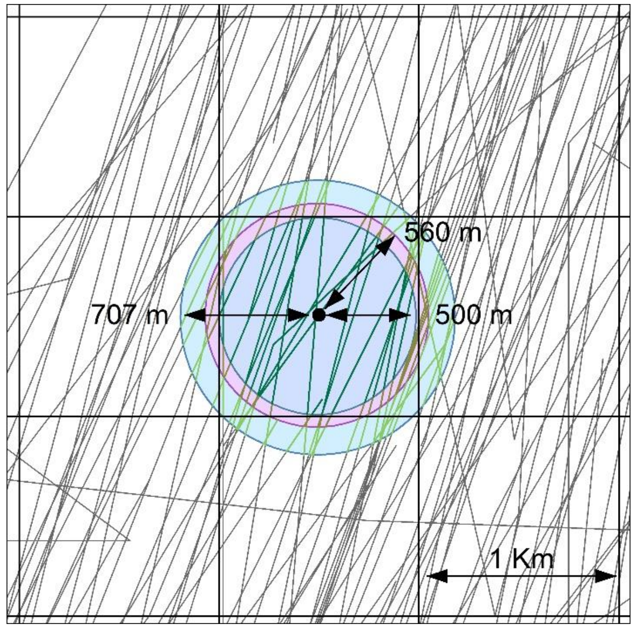

Figure 5.5. Illustration of the different approaches to defining the size of the moving window neighbourhood for line statistics.

6. Fish Habitat Modelling

COM Request [6] and **ToR 2.1** ***Determining and mapping essential fish habitat in relation to VME***

The associations between fishes and habitats become of paramount importance in the development of ecosystem-based approaches to fisheries management. Essential Fish Habitats (EFH) include spawning and nursery grounds, provide specific feeding resources, shelter from predators or form part of a migration route of fish (Benaka, 1999; Rosenberg *et al*., 2000). Identification of offshore EFH is wrought with difficulty because knowledge of the distribution of fish throughout their life history is often unavailable. As a first step to establishing important habitats for fish in the NRA, species-specific biomass data from the scientific trawls were correlated to GIS layers of environmental conditions to predict biomass distribution of selected fish species across the NAFO footprint. The models and their predictions provide a very broad description of the relative spatial concentration of fish biomass over the footprint, during the summer months (May-August) although there are limitations resulting from differences in the timing of the surveys in different parts of the NRA.

Many VME features such as continental slopes and deep-sea canyons, appear to function as feeding grounds and natural refugia, as well as a potential source new recruits to adjacent fished areas, indicating their contribution to EFH (Yoklavich *et al*., 2000; Buhl-Mortensen, et al. 2010). Whilst the main driving force behind fish assemblages in the NAFO management area appears to be depth, studies by Kenchington et al. (2013) and Devine et al., (2020) have shown associations between certain fish species and varying densities of sponge grounds and dense corals. Both Buhl-Mortensen, et al. (2010) and Devine et al., (2020) concluded that habitat association were mainly related to structural complexity, whether provided by physical or biogenic habitat features. In most cases, however, the challenge is determining causality between the occurrence of fish and invertebrates, beyond their similar environmental preferences.

To investigate fish habitat distribution in relation to VME, a comparison was made of the predicted biomass distribution of fish and updated VME polygons to identify spatial overlap between the main physical habitat preferred by the commercially important fish and the updated VME areas (Kenchington et al., 2020). More subtle connections between VME indicator taxa and fish biomass spatial distribution we investigated by including the presence of various epifaunal taxa was as predictors in models, where appropriate. A positive or negative effect of a habitat building species on fish biomass in a model, given the same environmental conditions, can indicate a beneficial relationship.

i) Method

Environmental data

A bathymetry layer covering the study area was produced by mosaicking the Multibeam echosounder bathymetry (gridded to 75m cell size) produced by the NEREIDA project with a bathymetry layer sourced from The Global Multi-Resolution Topography synthesis v3.6 (GMRT, 100 m grid downloaded 14/10/2019 from https://www.gmrt.org/). GThe SAGA 'Fill sinks (Wang & Liu)' tool with a slope threshold of 0.005 was used to smooth out artefacts in the bathymetry before calculating a set of derivative layers describing topographic attributes.

SAGA GIS tools for QGIS (v. 3.2; Conrad *et al*., 2015) were used to calculate a set of terrain variables, which are described in detail in Kenchington, et al. (2020).

Marine Geospatial Ecology Tools (MGET v.0.8a72; Roberts *et al*., 2010) were used in ArcGIS to extract Caoylla-Cornillon fronts[1] in sea-surface temperatures (SST) from MODIS satellite images. Monthly composite images of SST from 2011-2018 were used, extracting fronts present in each image. A front was identified where a minimum of 2 ^{0}C difference was present between two distinct water masses inside a moving window. The frequency of fronts was calculated as the percentage of times each pixel of the corresponding SST image that was a candidate for a front (not in cloud-masked area) was found to contain a front. Distance to fronts was calculated as the Euclidean distance from each cell to the nearest front. A front, in this case, was defined as a group of connected cells with a minimum area of 15 km^2, where a front was identified on average at least four months of a year.

Oceanographic layers were produced using data downloaded from the E.U. Copernicus Marine Service Information (CMEMS, http://marine.copernicus.eu). Monthly means of bottom current velocity for 2018 and bottom temperature for 2011-2018 were extracted from Global Ocean 1/12° Physics Analysis and Forecast product. Dissolved oxygen (DO) and silica (Si) were extracted from the Global Ocean 1/4° Biogeochemistry Hindcast product. Raster surfaces matching the extent and resolution of the bathymetry for mean and maximum current speeds, mean DO and Si, minimum DO were interpolated using the Empirical Bayesian Kriging function in ArcGIS10.5 Geostatistical Analyst (with default settings). Bottom temperature layers were produced for mean, minimum, maximum and standard deviation of temperatures across the whole-time period, as well at the mean and maximum of the annual range for each individual year.

Composite seasonal 4 km resolution Chlorophyll-a surfaces were downloaded from the NASA Ocean Colour portal[2]. The layers were interpolated to match the bathymetry extent and cell size with the 'Align Rasters' tool in QGIS 3.2 using a cubic spline. A fishing effort layer derived from VMS data covering 2010-2018 was included as a predictor. The layer is described in more detail in Section XX of this report.

Biological data

Data on the biomass of fish and invertebrates were obtained from survey trawls acquired during annual fishery surveys conducted by the European Union (Spain) between 2011 and 2019. The study area, delineated by the extent of the NAFO fishing footprint in 3LMN, contained 3379 survey trawls.

The scientific trawls, on average, span between 2-3 km in tow length. As the predictor data layers are gridded at 250 m, the predictor values corresponding to each scientific trawl were averaged over points placed at 500 m intervals along the full scientific trawl track.

[1] Fronts identified using the Cayula and Cornillon (1992) single image edge detection (SIED) algorithm.

[2] (MODIS Aqua Level-3 Standard Mapped Image;DOI:10.5067/AQUA/MODIS/L3M/CHL/2018).

ii) Modelling approach

Random forest regression models on square root transformed response biomass were built individually for the main target species in the NAFO managed fisheries (northern shrimp, Greenland halibut, American plaice, yellowtail flounder, witch flounder, thorny skate, redfish, Atlantic cod, capelin, white hake).

Random Forest is an ensemble 'statistical modelling' method, where a large number of decision trees (typically 500-1000) are built using random subsets of the data. Regression trees are used for response variables consisting of continuous data and classification trees for factor variables. In the regression models' predictions are based on averages from all trees (Breiman, 2001; Cutler *et al*., 2007). The models were built in the free statistical computing software R (v.3.5.1, R Development Core Team, 2018) using the 'randomForest' package (Liaw and Wiener, 2002). The models were run using the default settings of the randomForest function, using 1000 trees.

Preliminary predictor variable selection was achieved by applying an iterative permutation procedure testing the effect the removal of each variable in turn has on the decrease in mean internal model accuracy in comparison to randomized variables. The *Boruta* algorithm in the 'Boruta' package in R (Kursa and Rudnicki, 2010) compares the importance of a variable as calculated by random forest to the importance of a random permutation of the same variables over several iterations. The variables included as predictors were further reduced by inspecting correlations among predictors and removing any variables that had a higher than 0.65 correlation score with another predictor. Out of a pair of highly correlated variables the one with a higher random forest importance score was retained in the model.

Two models were built for each species. The first model included only environmental variables as predictors and was the one used to produce spatial predictions. The second model also included the presence /absence of selected epifaunal taxa (Acanella sp., Actiniaria, Alcyonacea, Anthoptilum sp., Antipatharia, Asconema sp., Asteroidea, Astrophorina, Flabellum sp., Geodiidae, Halipteris finmarchica, Heteropolypus sp., Hydrozoa, Isididae, Pennatula sp., Polymastiidae, Tetillidae) as potential predictor variables in the Boruta step and, where selected by the Boruta algorithm as better than random, predictors in the model. No spatial prediction was made from the second model because full coverage spatial layers of presence for all the taxa were not available.

Models were validated using a bootstrap cross-validation procedure. For each response variable, the data was randomly subsampled 10 times into train and test data (80/20 split). Accuracy measures used to validate the models include the goodness-of-fit statistic R^2 and root mean squared error (RMSE) value, calculated using the 'caret' package (Kuhn and Johnson, 2013). For the purposes of comparison between responses RMSE was normalised to a percentage of the range of observed biomass values for each specific response (NRMSE). Final predictions were achieved using a full model, including all available data.

The predicted relative spatial distribution of biomass for fish species with reasonably performing models (mean R^2 in excess of 0.3) were plotted together with polygons of VME extent for biomass of large and small gorgonians, sponges and sea pens, as described in Kenchington *et al*. (2020).

iii) Results and Discussion

All models predicted biomasses with a mean error within 6% of the range of the observed biomass for the taxa. Only the models for *Pandalus* spp. (R2=0.62), *Reinhardtius hippoglossoides* (R2=0.55), *Hippoglossoides platessoides* (R2=0.53) and *Limanda ferruginea* (R2=0.59) achieved mean R^2 values in excess of 0.5, indicating good correlation between predicted and observed values and hence good model performance. The mean R^2 for *Sebastes fasciatus* (R2=0.36) and *Sebastes mentella* (R2=0.40) is in excess of 0.3, indicating fair model performance.

The distribution of the northern shrimp (*Pandalus* spp.) biomass in the model is mainly driven by increasing distance from temperature fronts, low maximum bottom current velocity and high minimum oxygen conditions. The fish species with acceptable models, namely *Reinhardtius hippoglossoides*, *Hippoglossoides* *platessoides*, *Limanda ferruginea*, *Sebastes fasciatus* and *Sebastes mentella*, were all predominantly responsive to variables related to depth and temperature.

Greenland halibut is the only fish species where the predicted high biomass areas (i.e. area with the most suitable physical environment to support high biomass) overlaps with the VME polygons to a notable extent (Figure 6.4). High biomass for Greenland halibut extends to much deeper waters than the other fish species presented. This species overlaps to a large extent with the sea pen VME and, to lesser degree, with sponges. *Pandalus* spp. biomass also shows some overlap with gorgonians (Figure 6.4). The models show that other fish species appear to occupy habitats higher up the slope where the observed biomass of VME indicator taxa is lower. The lack of overlap is not wholly unexpected since fishing fleets have good knowledge of where the fish occur in relatively high densities and target those areas. On the other hand, the VME polygons represent areas with the highest biomass of VME indicator taxa, which occurs mainly in areas that are not currently heavily fished. Areas of high fish biomass do occur in the immediate vicinity of the VME polygons and further investigations on the proximity of a VME polygon could yield more information on links between VME and fish biomass.

Despite the limited overlap between the VME polygons and high predicted fish biomass for most species, the presence of particular VME indicator taxa and other epifauna does, however, appear to have a positive effect on the observed biomass of four out of the six modelled fish species. The second set of models, incorporating the presence / absence information of epifaunal taxa as predictor variables, indicate that a number of fish taxa have positive associations with one or more epifaunal species (Table 6.7). A positive effect is inferred where the presence / absence of an epifaunal taxon was selected by the Boruta algorithm as a significant variable and the response biomass was higher in the presence than in the absence of the taxon in given environmental conditions. The magnitude of positive association was estimated based on the importance of the taxon variable in relation to the environmental variables in the model and the effect size.

Pandalus* spp.** ***Reinhardtius hippoglossoides

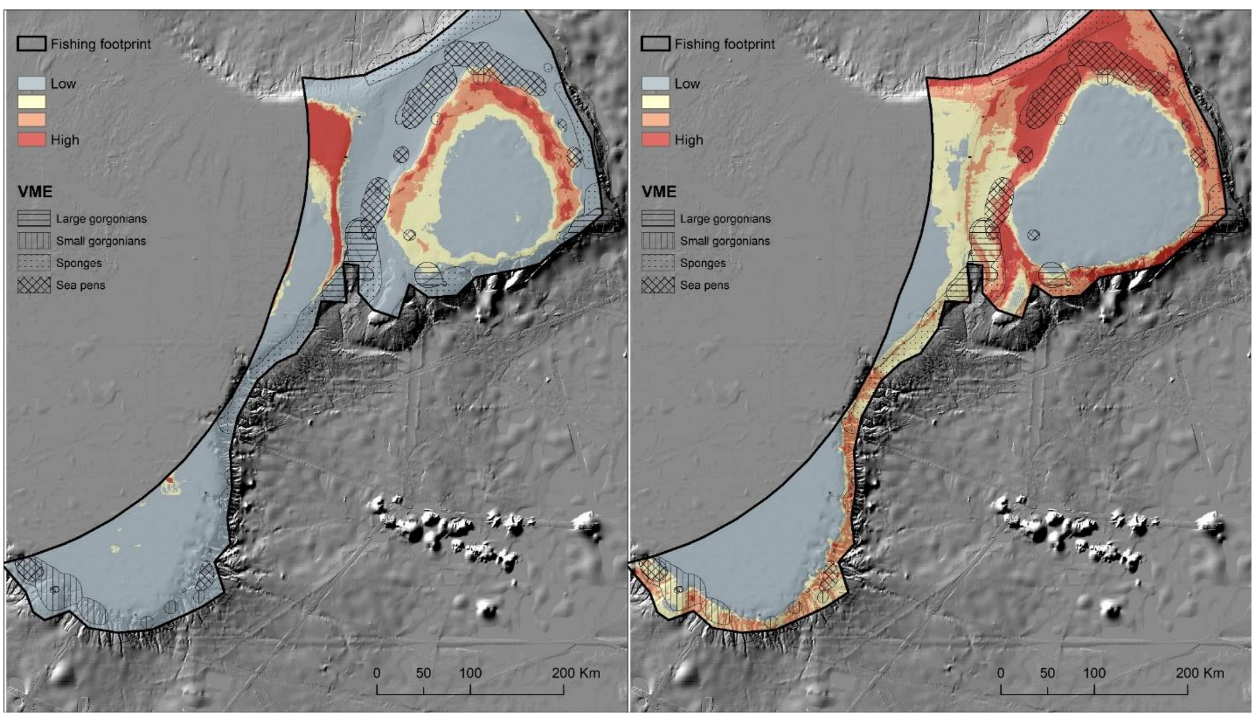

Figure 6.4. Predicted biomass of the northern shrimp (*Pandalus* spp.; left) and Greenland halibut (*Reinhardtius hippoglossoides*; right) and its distribution in relation to VME polygons.

Although the main distribution of high biomass of the northern shrimp (*Pandalus* spp.) was predicted at shallower depths than those occupied by large Geodid sponge aggregations, the presence of Geodiidae appear to have a large positive effect on *Pandalus* biomass. When included in the model, Geodiidae sponges become the most important predictor variable. The biomass predicted in the presence of Geodid sponges is almost double that in their absence when other environmental variables are held at a constant value. The presence of sea anemones (Actiniaria) had a moderate positive effect, while cup corals (*Flabellum* sp.) showed a minor positive effect.

Redfish species (*Sebastes fasciatus* and *Sebastes mentella*) appear to have a moderate positive association with Astrophorid sponges and a minor positive association with *Anthoptilum* sea pens. The effect of Anthoptilum presence on redfish biomass when other environmental variables are held at a constant value is moderate, but variable importance was lower than the environmental variables in the model, suggesting that most of the variability explained by *Anthoptilum* presence was already explained by the environment. *Sebastes fasciatus* also showed a moderate positive association with the small gorgonian *Acanella* sp., whilst *Sebastes mentella* has a better than random association with cup corals (*Flabellum* sp.).

Greenland halibut showed better than random positive association with cup corals, the soft coral *Heteropolypus* sp., Hydrozoa and soft bodied sponges (Polymastiidae), but in each case the variable importance was low and effect size small.

Table 6.7. Positive associations between epifaunal taxa and fish biomass derived from relative variable importance and partial response plots from Random Forest models. Effect is illustrated as: + = Above Random, ++ Moderate effect, +++ Large effect.

	Pandalus spp.	Reinhardtius hippoglossoides	Hippoglossoides platessoides	Limanda ferruginea	Sebastes fasciatus	Sebastes mentella
Acanella					++	
Actiniaria	++					
Anthoptilum					+	+
Astrophorina					++	++
Flabellum	+	+				+
Geodiidae	+++					
Heteropolypus		+				
Hydrozoa		+				
Pennatula						
Polymastiidae		+				

iv) Future improvements to methodology

There is further potential to investigate the links between fish biomass VME utilizing all observations of the presence / absence and biomass of VME indicator taxa in the survey trawls, rather than attributing habitat association between the areas with highest biomass (VME polygons). A more detailed picture of association between fish and VME can be achieved through additional analysis. Multivariate analysis of full trawl communities can be used to further identify potential habitat overlap to investigate whether benthic habitat types derived from epifaunal and environmental data have specific associations with fish. Similarly, joint species distribution modelling (JSDM) methods can help investigate the co-occurrence and co-variance of fish and VME indicator species distribution and biomass over environmental gradients in more detail. By partitioning variability to environmental effect, biological traits (e.g. body size) and residual correlations between species, JSDM can address questions such as whether associations between taxa are separate from environmental co-variance and whether they are more evident in certain environmental conditions or e.g. for fish of certain length.

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7. Agent-based Modelling

COM Request [6] and **ToR 2.2.** ***Evaluation of fishing impacts on sea pens and the effectiveness of fisheries closures in the Newfoundland-Labrador and Flemish Cap bioregions***

As part of the implementation of the Ecosystem Approach to Fisheries (EAF), NAFO reviews the effectiveness of closures for the protection of Vulnerable Marine Ecosystems (VMEs), and re-assesses the risk of Significant Adverse Impacts (SAIs) on VMEs by bottom fishing activities, on a 5-year cycle. The next review on the effectiveness of closures is scheduled for 2020, and the next re-assessment of SAIs on VMEs is scheduled for 2021.

The evaluation of the impacts of fishing on VMEs, and the role of fisheries closures to prevent and/or mitigate these impacts is an integral piece of the assessment of SAIs on these habitats. As part of this work, WGESA has been developing an Agent-based Model (ABM) for sea pens in the Newfoundland-Labrador (NL) and Flemish Cap (FC) bioregions. The sea pen ABM simulates the spatio-temporal dynamics of a generalized sea pen species within the domain defined by the NL and FC bioregions, and allows exploring time scales for colonization, responses to perturbations, and the effectiveness of closures as a mechanism to promote recovery NAFO SCS Doc. 18-023).

The ABM architecture generates sea pen dynamics by tracking the actions and interactions of autonomous agents within a system, while providing a view of the system as a whole. In this model, agents represent collectives of sea pens which follow specific rules associated with life-history processes at each time step (Figure 7.1). These agents operate within a spatially-explicit matrix where each cell has properties that affect the behavioral responses of the agents. The processes/behaviors affecting and effected by the agents have probabilistic components which randomize the dynamics of the system NAFO SCS Doc. 18-023).

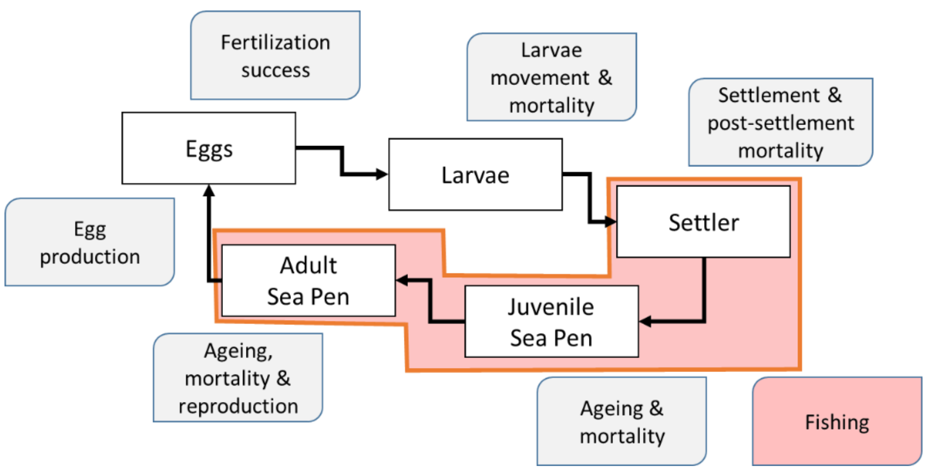

Figure 7.1. Schematic description of the life history stages/processes incorporated in the sea pen ABM. The red background indicates the life history stages impacted by fishing.

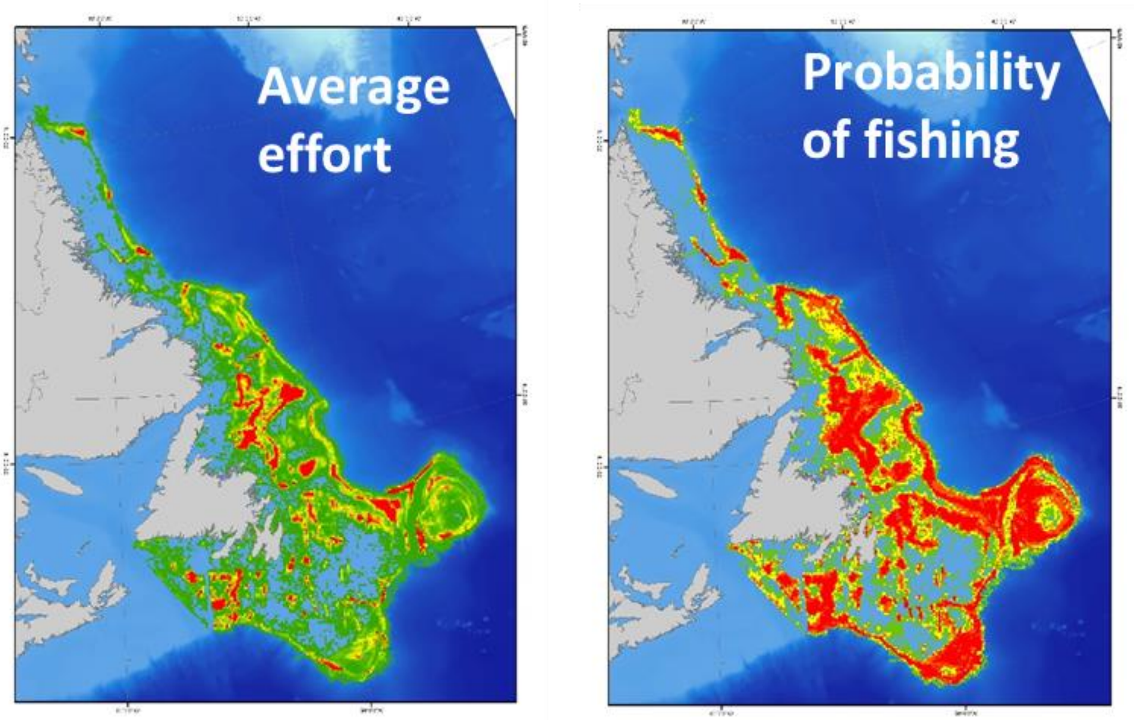

Figure 7.2. Average fishing effort (hours km^{-2}yr^{-1}) (left) and probability of fishing (right) for all bottom-contacting fisheries derived from VMS data from the 2008-2014 period.

The actual procedure to simulated fishing in the sea pen ABM uses a random draw from a Bernoulli distribution to define if a given cell is going to be fished or not in a given year, where the probability of success is the estimated average probability of fishing. For those cells that are being fished, the intensity of fishing (i.e. yearly fishing effort) is randomly draw from distributions centered in the actual average fishing effort of the cell. These steps taken together allow for random variability in the simulation of fishing activity, while keeping a realistic fishing footprint and fishing effort intensity.

This approach to representing fishing assumes that historical fishing patterns were similar to the ones observed in 2008-2014. While this assumption is unlikely to hold, especially for the period prior to the collapse of the groundfish communities in the NL bioregion, it still represents a good approximation to the fishing patterns of the last 30 years. Considering that fishing intensity prior to the collapse was higher than today, using more recent fishing patterns would render a best case scenario for historical impacts.

Simulating fishing impacts within the sea pen ABM

The impact of fishing was implemented as a function of fishing effort. The analyses of sea pen biomass as a function of fishing effort done by NAFO within the NAFO Regulatory Area (NRA) and by DFO in Canadian water show a very consistent picture, with the cumulative sea pen biomass reaching the 95th percentile of the cumulative distribution around a fishing effort of 0.5 hours km^{-2} yr^{-1} (DFO, 2017; NAFO SCS Doc. 13-024.). This 95th percentile threshold has been used to distinguish between VME areas at risk of SAI, when fishing effort is less than 0.5 hours km^{-2} yr^{-1}, from those considered already impacted, where fishing effort is larger than 0.5 hours km^{-2} yr^{-1} (DFO, 2017; NAFO SCS Doc. 13-024). This information, together with the logistic shape of the cumulative curve (NAFO SCS Doc. 13-024), were used to sketch the relationship between fishing effort and sea pen mortality implemented in the sea pen ABM (Figure 7.3). This approach assumes that the cumulative biomass curve is a direct mapping of the mortality curve. The estimated fishing mortality in each cell at a given time step is applied to all settled sea pens in that cell as an additional source of mortality.

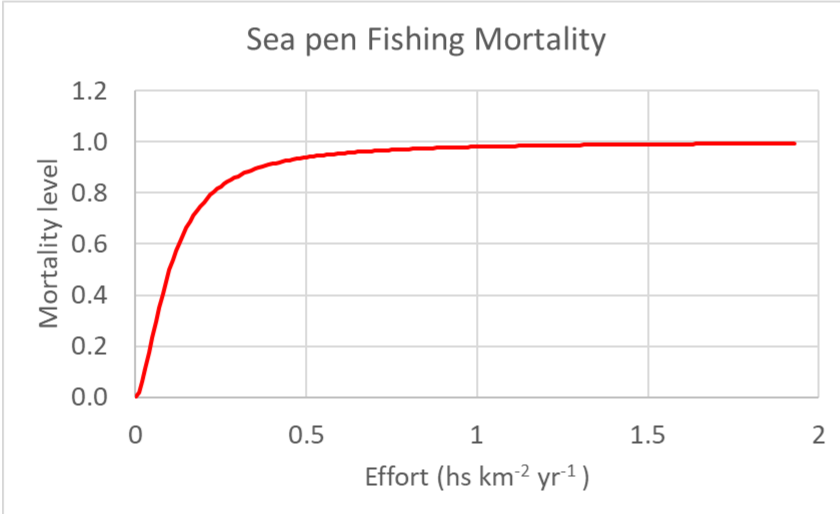

Figure 7.3. Relationship between sea pen mortality and fishing effort used in the sea pen ABM. This curve was sketched based on the observed cumulative sea pen biomass vs fishing effort curves from NAFO and DFO analyses.

Implementation of fisheries closures

In the same way that the sea pen ABM allows for an integrated depiction of the spatio-temporal dynamics in the entire NL and FC bioregions domain, evaluating the performance of fisheries closures also requires considering the fisheries closures implemented by NAFO on the NRA, and by Canada in its jurisdictional waters. In 2019, Canada implemented a series of Marine Refuges (MRs) and a new Marine Protected Area (MPA) in the NL bioregion. The evaluation of the impacts of fishing on VMEs, and the effectiveness of closures to mitigate these impacts, was done considering all fisheries closures (Figure 7.4). Most Canadian closures prohibit all bottom-contacting gears, but some only prohibit mobile gears (e.g. closures numbered 4 and 5 in Figure 7.4). Despite this difference, all analyses were done assuming that all fishing is removed when closures are implemented. This is not expected to have major impacts in the results given the low density of sea pens predicted by the model on middle-shelf areas.

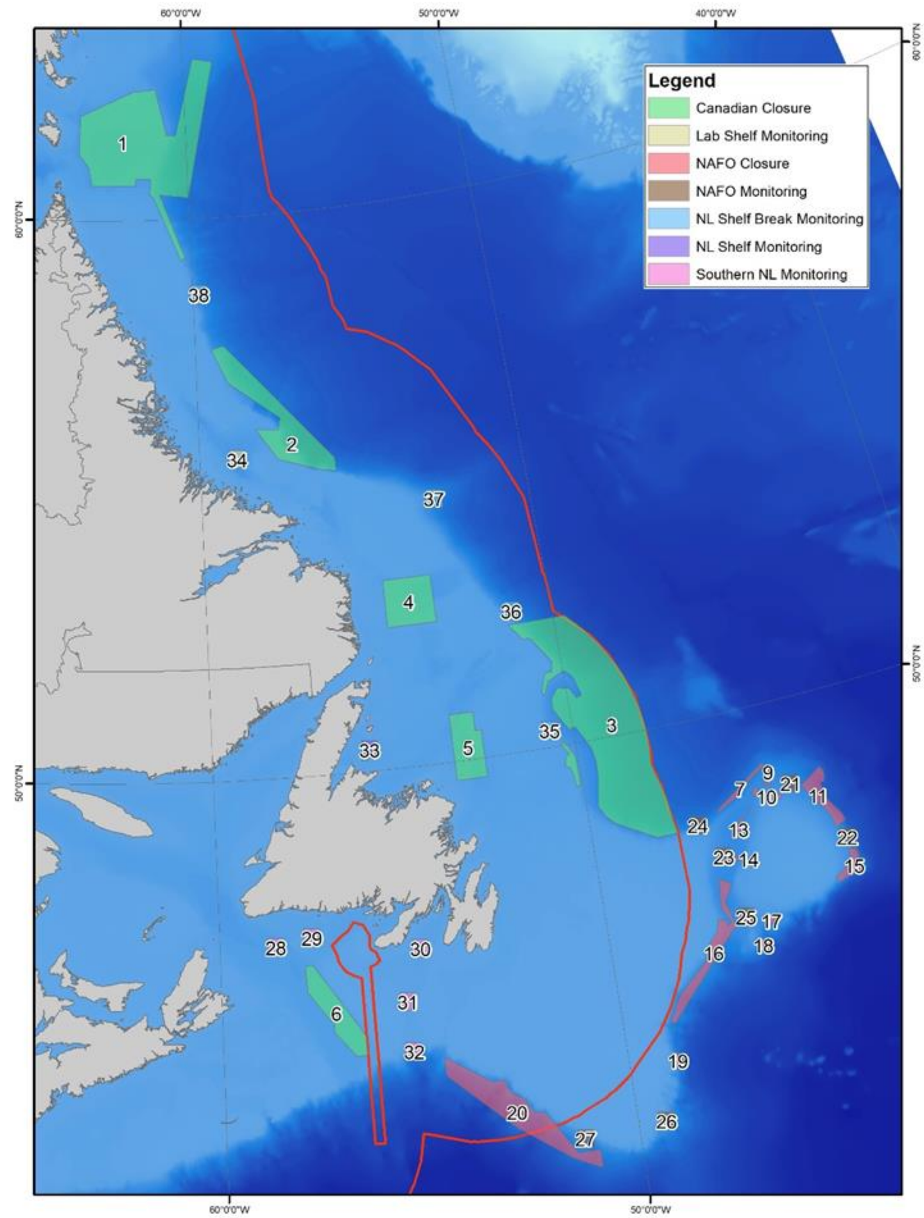

Figure 7.4. NAFO and Canada fisheries closures considered in the sea pen ABM. The numbers in this map correspond to coding conventions within the model implementation and should not be confused with the official numbering of these areas. The monitoring areas identified in this map correspond to locations where local sea pen abundance was tracked within the model to assess sea pen response to perturbations; these areas were never closed to fishing in any of the simulations performed.

Evaluation of the impacts of fishing and the effectiveness of closures

The evaluation of the impacts of fishing and the effectiveness of closures was done by tracking the abundance of sea pens in different local areas within the model domain, as well as aggregates across the entire model domain. The local areas being tracked were the closures themselves, and a series of monitoring boxes outside closures (Figure 7.4). These monitoring boxes represent areas that are never closed to fishing in the model runs, and allow assessing the potential effects of closures in promoting sea pen recovery outside closures (Figure 7.5).

Figure 7.5. NAFO VME closures (pink) and monitoring boxes (grey) in the NRA as implemented in the sea pen ABM. Monitoring boxes are always exposed to fishing; tracking sea pen abundance in these areas allows evaluating the potential role of closures in promoting recovery of sea pens outside the closures. The numbering of these closures and monitoring boxes indicates the id reference of these areas within the model code; they do not necessarily match the official number of the NAFO closures.

The assessment of fishing impacts on sea pens, and the performance of closures was done on the basis of a series of scenario-based model runs. All scenarios involved starting the model without fishing and with the entire domain near carrying capacity, letting it run for 50 years under these conditions, and then implementing fishing without any fishery closure for 100 years. This allows assessing the likely impact of a realistic level of fishing on a pristine sea pen population, and determining the abundance at which the sea pen population stabilizes under this level of fishing effort. While the current pattern of fishing has not been in place for a century, previous analyses indicated that most of the impact takes place in the first few years of fishing (NAFO, 2018); the reason for running the fishing without closures phase this long is simply to verify that the sea pens do not continue declining after the initial impact, and actually reach a stable impacted level.

After 100 years of fishing, fishing closures are implemented. Three scenarios of closures were explored, one implementing all NAFO and Canadian closures, and two others where only NAFO or Canadian closures were implemented. Finally, a control run where fishing was halted after the 100 years of fishing was also implemented. This control run provides a contrast for sea pen recovery between fisheries closure scenarios and no fishing.

Key results

A realistic representation of current fishing effort patterns in the sea pen ABM indicates that fishing has had a significant effect on the sea pen distribution and abundance that we observe today (Figures 7.6-7.7). While reductions in total sea pen abundance from the pristine state could be in the order of 50% (Figure 7.6), the actual figure would depend on the historical patterns of fishing effort. Since historical effort was higher, the current estimate is likely a best case scenario.

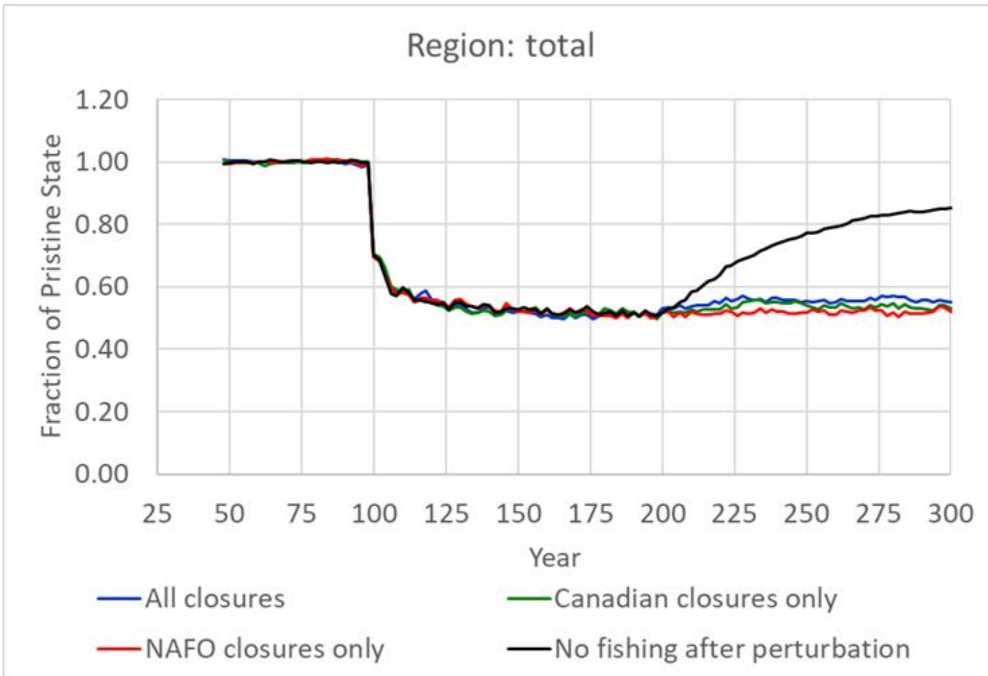

Figure 7.6. Total sea pen abundance trajectory under each one of the four scenarios considered. Implementation of current closures only provides a minor, but still detectable improvement at the scale of the entire model domain (NL and FC bioregions). Even removing fishing altogether does not allow for a full recovery in 100 years.

The current system of closures (NAFO + Canada) only provides a very limited recovery capacity at the population scale (Figures 7.6-7.7). This is not surprising given that closures are typically established around current high concentrations, but do not displace fishing from areas where high concentrations may have existed in the past. Rebuilding of these historically important areas would be required to drive a more substantial recovery at the population scale.

However, closures do promote recovery within their boundaries. Using the NAFO Closures #9 and #10 in the northern and northwest Flemish Cap as an example, it is clear the closing these areas allow sea pen recovery within the closures (Figure 7.8). It is also clear that recovery time is variable between closures, and the smaller closure (NAFO Closure #9, model region r08) appears more sensitive to stochastic processes, and neighborhood conditions (Figure 7.8). As a general observation from the model results, closures can be locally effective, but size and location are important determinants of how effective each closure actually is.

On average, the NAFO closures are located in areas estimated to have experienced reductions in abundance of around 60% (Figure 7.9). In the absence of fishing (control run scenario) these areas would be expected to rebuild in 50 years. However, under current fishing conditions, recovery times are much longer (Figure 7.9). The difference in recovery times between the no fishing and the closures with fishing scenarios highlights the capacity of fishing to impact sea pen connectivity.

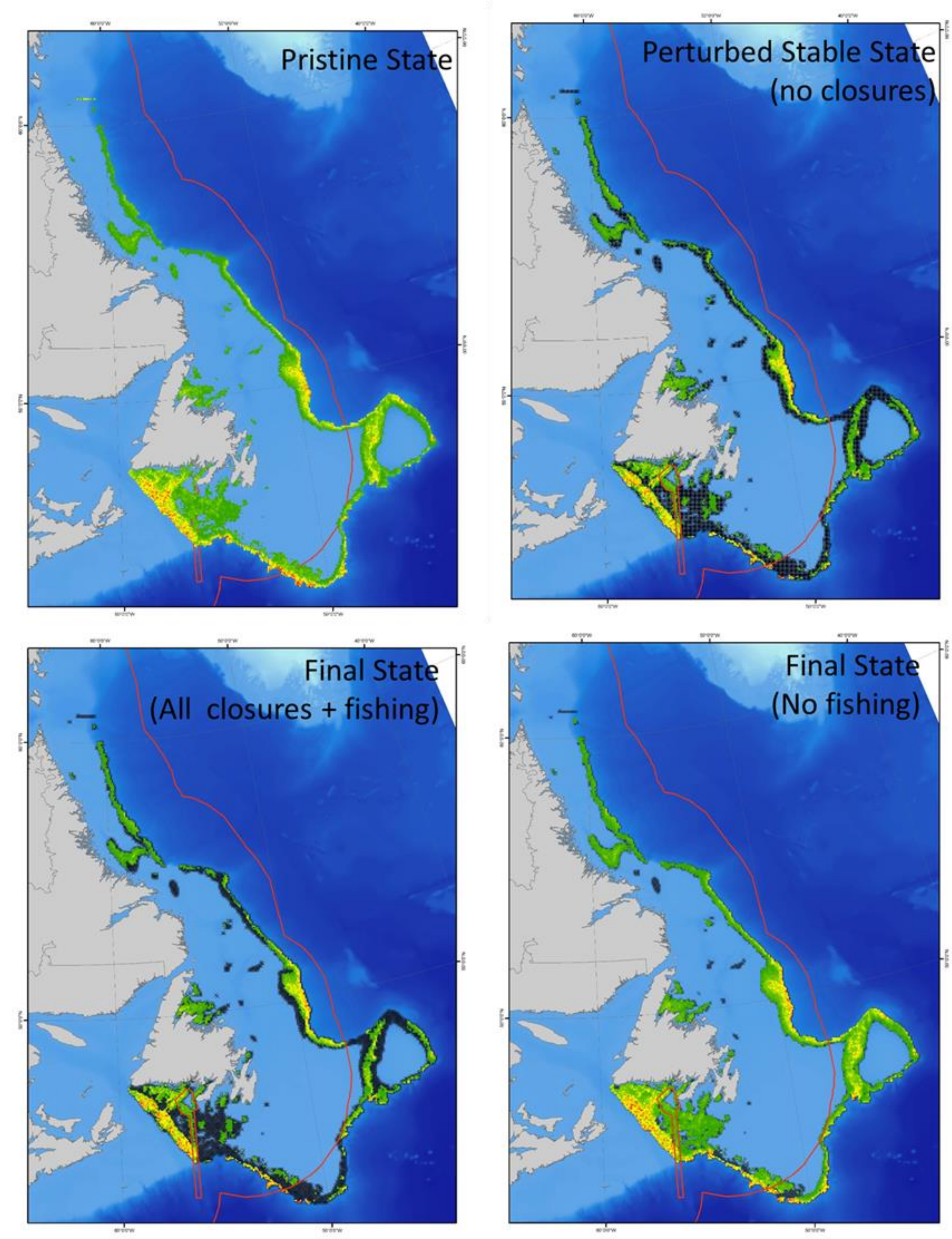

Figure 7.7. Comparison of sea pen distribution at key stages of the scenarios explored. Pristine state (top left), stable perturbed state (fishing without closures) (top right), final state with all NAFO and Canada closures implemented (bottom left), and final state after all fishing was removed (control run) (bottom right).

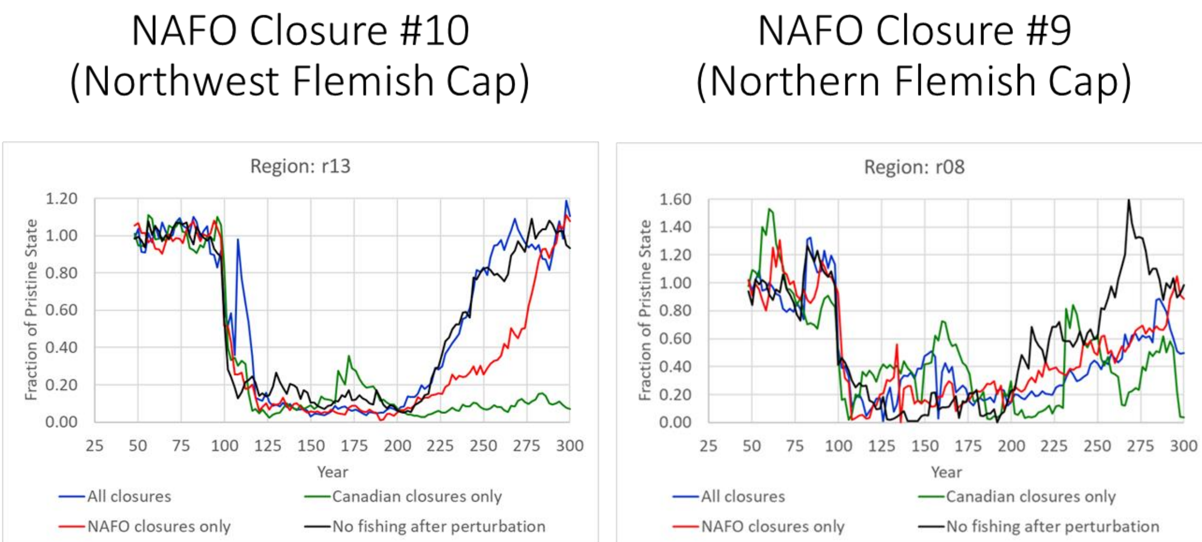

Figure 7.8. Sea pen abundance trajectories under the difference scenarios considered for two NAFO closures in the Flemish Cap, NAFO Closure #9 and NAFO Closure #10 (regions r08 and r13 within the model code respectively, see Figure 7.5).

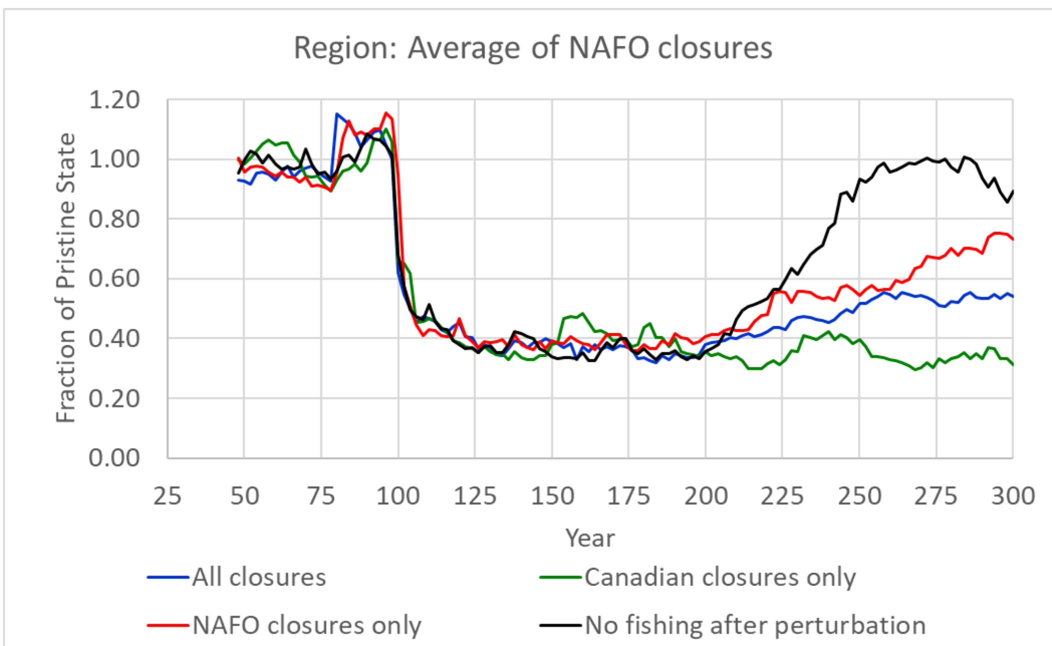

Figure 7.9. Average sea pen abundance trajectories within NAFO closures under the difference scenarios considered.

Conclusions and next steps

While the sea pen ABM reasonably captures the spatio-temporal dynamics of a generalized sea pen, its representation of the distribution in some shallow areas needs improvement. This issue will be revisited for the final version of the sea pen ABM to be used for the re-assessment of SAIs on VMEs. Despite this limitation, the model provides a useful platform for evaluating fishing impacts and the performance of current closures in a strategic sense.

The current system of closures (NAFO + Canada) only provides a very limited recovery capacity at the population scale, but closures can be locally effective. Closure size and location are key determinants of closure effectiveness; many NAFO sea pen closures are likely too small to be effective.

Fishing has the capacity of impacting connectivity, and limiting recovery within closures. These effects are local in nature.

Recovery times within closures depends on local conditions, and the level to which the area has been depleted. For the NAFO closures, the average recovery time under current fishing condition exceeds 100 years, but individual closures can recover in up to 15-25 years. In the absence of fishing, recovery time within NAFO closures is, on average, 50 years.

References

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8. Biological Traits Analysis

COM Request [6] and **ToR 2.3.** ***Up-date on VME biological traits analysis and the assessment of VME functions***.

Biodiversity

The NAFO Convention on Cooperation in the Northwest Atlantic Fisheries includes commitments to the conservation of marine biodiversity in general, and to minimizing the risk of long term or irreversible adverse effects of fishing activities (NAFO, 2017). At the same time, the conservation of marine Biological Diversity of Areas Beyond National Jurisdiction ("BBNJ") has become a high-profile international issue. In June 2015, the United Nations General Assembly adopted Resolution 69/292, calling for the development of an international, legally binding instrument under the United Nations Convention on the Law of the Sea, to address the conservation and sustainable use of BBNJ. While the governance framework has not yet been agreed, it is sure that there will be an increased need for scientific advice to support management of BBNJ, including the documentation of deep-sea biodiversity and how it may be impacted by human activities and by climate change.

Benthic Assemblages

Murillo and colleagues (Murillo et al., 2016) identified the invertebrate epibenthos from the catches of two bottom trawl research surveys carried out in 2007: the Spanish 3NO survey, conducted by the Spanish Institute of Oceanography (IEO), which sampled the Tail of the Grand Bank between 45 and 1374 m depth; and the EU Flemish Cap bottom-trawl survey, conducted by the IEO together with the Spanish Institute for Marine Research-Superior Council of Scientific Investigations (IIM-CSIC) and the Portuguese Institute for Sea and Atmosphere (IPMA), which sampled all of the trawlable area of Division 3M between 138 and 1488 m depth, including Flemish Cap and the eastern side of Flemish Pass, following a depth-stratified random sampling design. The total number of benthic invertebrates identified from the 276 bottom trawl sets studied was 439, representing 12 phyla, 56 of which were taxonomically only identified to genus, family or a higher level, while the others were considered individual species or putative species. Statistical analyses of those data found twelve significantly different epibenthic assemblages (Figure 8.1) with four of those shared between the Flemish Cap and the Tail of Grand Bank in the deeper slope areas (Murillo et al., 2016).

The Closed Areas put in place to protect VMEs also protect 3 of the 12 benthic assemblages identified (Tables 8.1, 8.2) with some assemblages left unprotected (Table 8.3), particularly on the top of Flemish Cap (IIa, IIb, IIc) and the shallower portions of the Tail of Grand Bank (Ia.1, Ia.2, Ib, Ic). Two of these (Ia.2, Ib) contains VME indicator taxa (Table 8.3).

Table 8.1. List of benthic assemblages (following Murillo et al., 2016) protected through the NAFO closed areas.

Closed Area	Benthic Assemblage(s) Protected
Area 1	Not assessed
Area 2	Deep-sea sponge assemblage (IIIc)
Area 3	Not assessed
Area 4	Deep-sea coral assemblage (IIIa); Deep-sea sponge assemblage (IIIc)
Area 5	Deep-sea sponge assemblage (IIIc)
Area 6	Deep-sea sponge assemblage (IIIc)
Area 7	Deep-sea coral assemblage (IIIa)
Areas 8-12	Lower slope assemblage (IIIb.1)
Area 13	Deep-sea coral assemblage (IIIa); Deep-sea sponge assemblage (IIIc)
Area 14	Deep-sea coral assemblage (IIIa)

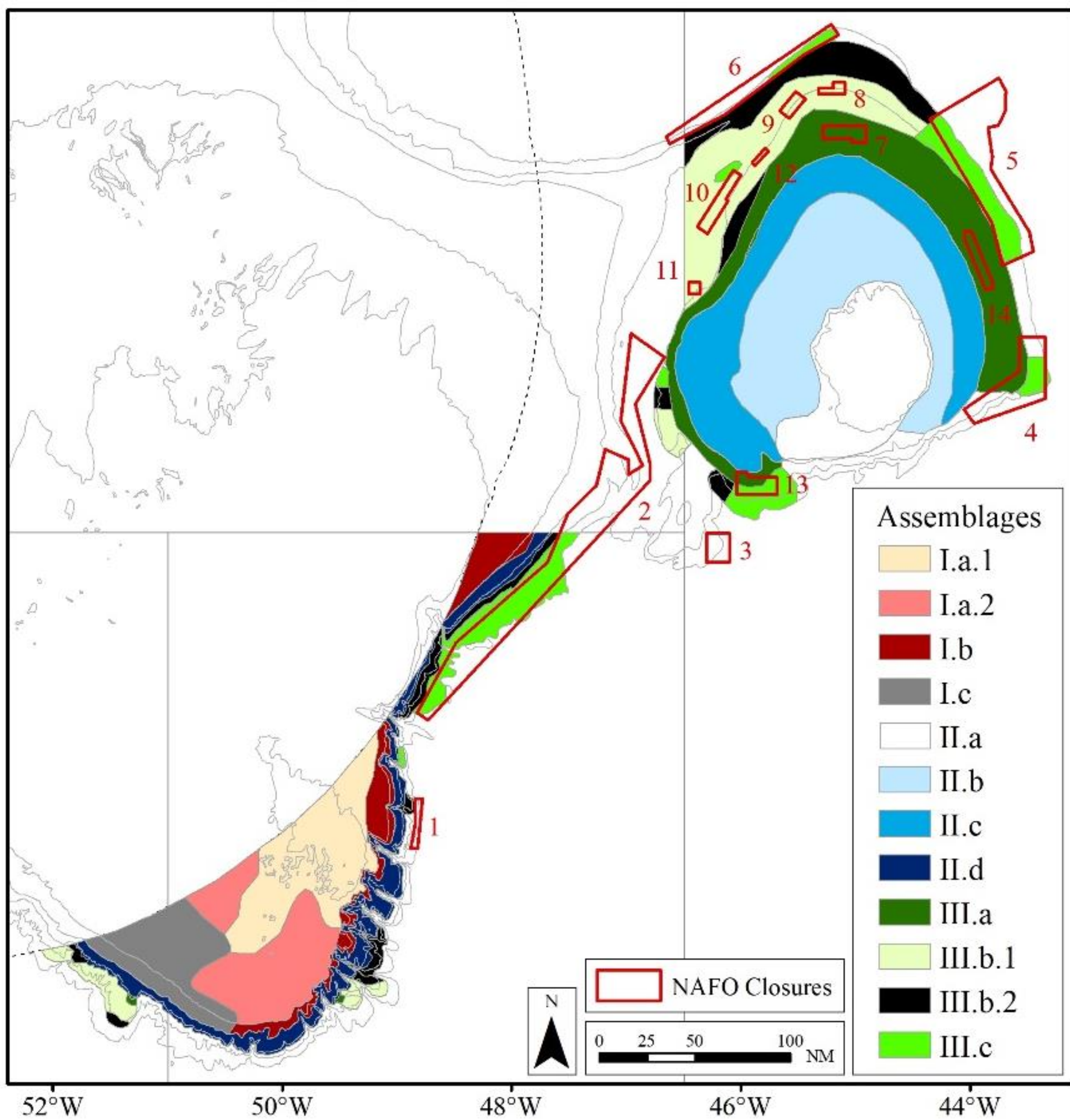

Figure 8.1. A) Map showing the epibenthic invertebrate assemblages identified by Murillo et al. (2016) for Flemish Cap and the Tail of Grand Bank in the NAFO Regulatory Area in relation to the closed areas to protect VMEs. From Murillo et al. (2016).

Table 8.2. List of benthic assemblages (following Murillo et al., 2016) protected through the NAFO closed areas. Φ represents the Phi coefficient with is a measure of the strength of association of each species with the assemblages and ranges from 0 (no association) to 1 (complete association).

Benthic Assemblage	Representative taxa (from Murillo et al., 2016)
Deep-sea coral assemblage (IIIa)	Black coral *Stauropathes arctica* (Φ = 0.62), the cup coral *Flabellum alabastrum* (Φ = 0.59), the sea pen *Funiculina quadrangularis* (Φ = 0.52), the soft coral *Heteropolypus sol* (Φ = 0.46) and the small gorgonian coral *Acanella arbuscula* (Φ = 0.41).
Deep-sea sponge assemblage (IIIc)	Typified by high biomass of large sponges mainly from the suborder Astrophorina.
Lower slope assemblage (IIIb.1)	This assemblage is characterized by the sea urchin *Phormosoma placenta* (φ = 0.55), the sea stars *Bathybiaster vexillifer* (Φ = 0.49) and *Zoroaster fulgens* (Φ = 0.42), and the sea pens *Funiculina quadrangularis* (Φ = 0.49), *Anthoptilum grandiflorum* (Φ = 0.45), *Halipteris finmarchica* (Φ = 0.41) and *Pennatula aculeata* (Φ = 0.40).

Table 8.3. List of benthic assemblages (following Murillo et al., 2016) unprotected through the NAFO closed areas. Φ represents the Phi coefficient with is a measure of the strength of association of each species with the assemblages and ranges from 0 (no association) to 1 (complete association).

Benthic Assemblage	Representative taxa (from Murillo et al., 2016)
Shallow Flemish Cap assemblage (IIa)	This sandy bottom assemblage is typified by the sponge *Iophon piceum* (□ = 0.45) and the crustacean *Sabinea sarsii* (□ = 0.40).
200–340 m Flemish Cap assemblage (IIb)	Typified by the sea anemone *Hormathia digitata* (□ = 0.41), and the sea star *Ceramaster granularis* (□ = 0.39), found on silty-sand bottoms with gravel presence.
300–500 m Flemish Cap assemblage (IIc)	Typified by the sea stars *Pontaster tenuispinus* (□ = 0.49) and *Ctenodiscus crispatus* (□ = 0.45) and the sea urchin *Brisaster fragilis* (□ = 0.38).
Coarse bottoms of the Tail of Grand Bank assemblage (Ia.1)	Coarse sands with large accumulations of shell debris, with the holothurian *Stereoderma unisemita* (□ = 0.80), and the mollusks *Buccinum* sp.1 (□ = 0.77) and *Mesodesma arctatum* (□ = 0.61).
Fine to medium sand bottoms of the Tail of Grand Bank assemblage (Ia.2)	Characterized by high biomasses of the bryozoan *Eucratea loricata* (□ = 0.85) present at all localities, and hydroids (mainly *Obelia* cf. *longissima* (□ = 0.87) and several members of the family Sertulariidae).
Edge of the continental shelf of the Tail of Grand Bank assemblage (Ib)	Characterized by the urchins *Strongylocentrotus droebachiensis* (□ = 0.68) and the sand dollar *Echinarachnius parma* (□ = 0.52) present in 94% of the localities, together with some other sertulariid species such as *Thuiaria thuja* (□ = 0.65) and *Sertularia fabricii* (□ = 0.60). The stalked tunicate *Boltenia ovifera* (□ = 0.46) is also significantly associated to this assemblage.
Southwest of the Tail of the Grand Bank assemblage (Ic)	Characterized by the decapod *Argis dentata* (□ = 0.55) and the brittle star *Ophiura sarsii* (□ = 0.53).
Upper slope of the Tail of the Grand Bank (IId)	This assemblage is composed of species with a wide bathymetric and geographic range, such as the sponges *Tentorium semisuberites* (□ = 0.57) and *Polymastia uberrima* (□ = 0.32).
Lower slope assemblage (IIIb.2)	It does not present any typical species. It is the assemblage where most of the fishing activities were observed.

Benthic Invertebrate Functional Trait Diversity on Flemish Cap

A key element of ensuring ecological sustainability is the protection of functional processes, which are affected by the combined functional characteristics of the organisms involved. Through the use of functional trait diversity it is possible to link ecosystem processes and functioning. Murillo et al. (2020) characterized the functional diversity of trawl-caught benthic invertebrate communities for the Flemish Cap, highlighting the relationship between functional and species diversity. A suite of seven biological traits based on biology and life-history attributes (Table 8.4) were chosen for their presumed importance to the structure and functioning of benthic ecosystems or for their sensitivity to perturbations or changes in the environment (response traits). Trait information was based on adults of all taxa and compiled from the literature, online databases, and from expert consultations. In cases where trait information was not available for the faunal taxon, the trait information was inferred from the most closely related taxon for which data were available. Multiple categorical classifications were allowed for taxa with more than one trait category known.

To quantify functional diversity (FD), Murillo et al. (2020) calculated the functional richness (FRic) for each sampling location using the 'FD' package from the statistical computing software R. They first computed the trait dissimilarity matrix based on the Gower distance and then calculated FRic, which reflects the volume of the functional trait space filled by the present species at a location or in a community. The computed values of FRic were compared with the number of species recorded for each of the two major regional-scale faunal groups (top and deep Flemish Cap; Figure 8.1), for the whole of Flemish Cap (all trawling sets), and for the sets included in the current closed areas. These latter were also separated by the conservation target (sea pens or sponges) protected in each closure (NAFO, 2019) such that trawling sets located inside Closed Areas 7 to 12, and 14 were grouped together to assess the FRic of sea pen fields and sets inside closed Areas 4 to 6 to assess the FRic of sponge grounds. Additionally, to study differences in trait composition between the 7 assemblages (Figure 8.1) identified by Murillo et al. (2016) for Flemish Cap they computed community weighted means (CWM) reflecting the structure of trait values at the community level. Finally, the 'adiv' package was used to measure the functional redundancy between communities.

Murillo et al. (2020) used Hierarchical Modelling of Species Communities from the HMSC-R 3.0 package in R to fit a joint species distribution model to the benthic data combining simultaneously information on traits, environmental covariates, and phylogenetic constraints in a single model. Selected ecological functions linked to individual or a combination of biological traits, were mapped.

Table 8.4. The species traits used in the analyses and their hypothesized relationship with factors responsible for spatial patterns in epifaunal assemblages including those traits which help to distinguish between natural and man-induced changes. The categories or units are indicated in the last column. From Murillo et al. (2020). References numbers in Murillo et al. (2020).

Trait	Hypothesized relationship	Categories or units
Maximum adult size	Body size is correlated with many life-history traits and influences a wide range of biological and ecological functions [1-6]. Metabolic rate scales with the 3/4-power of body mass and increases with temperature [7]. We expect small-sized species to be more prevalent in bottom-trawled areas than in similar environments not exposed to fishing impacts [8-9] and to have higher P/B ratios [10] with higher metabolic rates [7]. We expect some species to be ecosystem engineers, locally enhancing biodiversity [11-12] by increasing habitat heterogeneity and modifying the environment [13].	Small (< 2 cm) Medium (2 – 10 cm) Medium large (10 – 50 cm) Large (50 cm)
Longevity	Long-living species have lower relative production due to slow growth and turn-over rates [14-15]. We expect that longer-lived species will be found in deeper waters where light, food availability, temperature and disturbance intensity drive highly predictable distributions [16]. As long-living species are more common in undisturbed habitats, we further expect such species, particularly those of a larger body size, to be rarer in fished areas.	< 5 yrs 5 – 10 yrs 10 – 50 yrs > 50 yrs

Reproductive method	We expect broadcast spawners to decrease with depth and an increase in species with other reproductive methods [17]. Asexual reproduction may be an adaptation to unfavorable environmental conditions and for species where sexual reproduction is uncertain and/or infrequent [18-19]. We expect that asexual reproduction will dominate in areas that have been disturbed by fishing over a long period of time.	Asexual-budding Sexual broadcast spawner Sexual brooder-indirect development pelagic Sexual brooder-direct development demersal or viviparous
Propagule dispersal	Planktotrophic larvae are associated with long pelagic duration and high dispersal capacity while lecithotrophic larvae developing from large eggs, containing a high quantity of yolk, correlate with a short pelagic duration and settlement close to parents [18]. Therefore, we expect that planktotrophic species can recolonize more easily areas that have been disturbed by fishing over a long period of time. Additionally, we expect increase of species with lecithotrophic larvae or direct development with depth [20].	Pelagic planktotrophic Pelagic lecithotrophic Benthic
Motility	Sessile organisms are more subject to changes in the abiotic environment than motile species [21]. Motile and burrowing species are expected to have a better ability to avoid the trawl nets and can recolonize areas by migration [9, 22-23].	Burrow Crawl Swim Sessile
Degree of contagion	We expect large-sized species that form aggregations to create habitat for other species and large spatial scales and thereby increase biodiversity [11-12].	Solitary Patchy Highly aggregated
Feeding mode (trophic position)	The feeding mode is considered to be a proxy for energy fixation/transfer and ecosystem production [24]. Predator–prey relationships and trophic levels are indicators of community structure, and are important for monitoring ecosystem changes enabling quantification of bottom-up linkages with flow webs, top-down linkages with ingestion/production webs and trophic position. Scavengers are attracted to areas where trawling occurs and are expected to be more common in areas of high fishing intensity [9, 22, 23, 25].	Scavenger Predator Deposit-feeder Passive filter-feeder Active filter-feeder

The joint species distribution model was used to predict the spatial probability of occurrence of each trait category (Table 8.4) in the study area. Specific traits were then linked to three important ecological functions provided by benthic communities: A) Bioturbation; B) Nutrient cycling; and C) Habitat provision. Bioturbation was assessed using the motility category 'burrow' which included active and tube burrowers. 'Active filter feeding' mode was used as a proxy of nutrient cycling due to the high volume of water that active filters process, taking nutrients from the water column and making them available to the benthos. To assess the habitat provision function, taxa within trait categories medium and large for 'maximum adult size', sessile for 'motility', and patchy and highly aggregated for 'degree of contagion' were selected (excluding the Orders Actiniaria, Brisingida, and Euryalida) and their logarithmically-transformed biomass combined.

Continuous surfaces of the spatial distribution of these three defined ecosystem functions and the functional richness (Fric) per trawl set were created using random forest (RF) modelling with the 'ranGER' package in R. They used 5000 regression trees and default values for the rest of the RF parameters. Prediction and standard error surfaces were created for each surface. The response variable was the logarithmically-transformed biomass of each function or the functional richness values computed. Seven fixed environmental variables and 45 summary statistics of 15 other environmental variables and fishing effort were used as predictors (Murillo et al., 2020).

Assemblages from the top of the Bank (<500 m depth) were characterized by higher biomass of small- and medium-sized species with short lifespans, whereas large species with longer lifespans, and broadcast spawners where dominant in the deeper assemblages (500 – 1500 m depth). Higher biomasses of crawlers, scavengers and predator species were found in the regularly fished grounds.

Functional richness (FRic) of sampling stations ranged between 1.5 and 39.7, following a similar trend in both the top and deep Flemish Cap major faunal groups. After a positive linear relationship between FRic and the number of species, asymptotic values were reached for trawl sets with roughly more than 30 species. At a smaller scale, the three epibenthic assemblages from the top of Flemish Cap reached similar maximum values of FRic between 20-30 species. However, one of the assemblages (III.b.2) from the deep Flemish Cap, characterized by a lower number of species, did not reach the maximum values of FRic found elsewhere. Assemblages with a lower number of species showed greater variation in functional dispersion which was mostly uniform for trawl sets with more than 20 species. When all the trawl sets were grouped together the FRic was 45.53, whereas this value was 44.78 for the sets outside of the closures and 45.43 inside the closures, indicating that the current closures protect most of the functional diversity in the Flemish Cap as a whole. The FRic of sponge closures was higher than the FRic of sea pen closures, with values of 43.51 and 34.46, respectively. Predicted FRic from random forest modelling was highest on the southeastern side of the Flemish Cap (Figure 8.2). Relatively high values were also observed elsewhere, including on the shallower part of the Cap (< 200 m depth) and in parts of the Flemish Pass. Functional diversity was spatially aligned with ecological diversity based on the number of species (Figure 12.25).

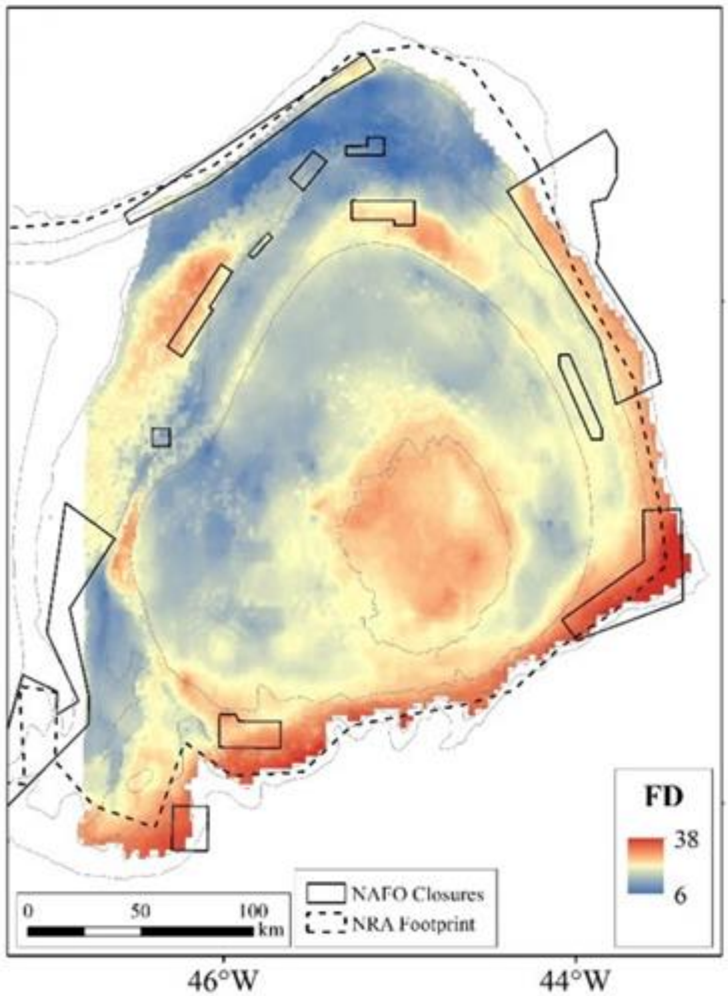

Figure 8.2. Predicted surfaces from random forest modelling of sample Functional Richness (FRic = FD), in relation to the NAFO Closed Areas on Flemish Cap. From Murillo et al. (2020).

The probability of occurrence of each trait category in the study area showed spatial separation between some trait modalities in each trait category. The shallower areas of the Flemish Cap were predicted to contain a higher proportion of small- and medium-size species with shorter lifespan compared to the deeper areas that were dominated by larger and long-living species. Most of the areas were predicted to have a dominance of sessile and highly aggregated species, excluding small areas north and southwest of the Cap. Active filter-feeding was the dominant feeding mode on the top and southeast of the Cap, whereas passive filter-feeding dominated on a ring along the north of the Cap between 500 and 1000m depth, with predator species in the rest of the area.

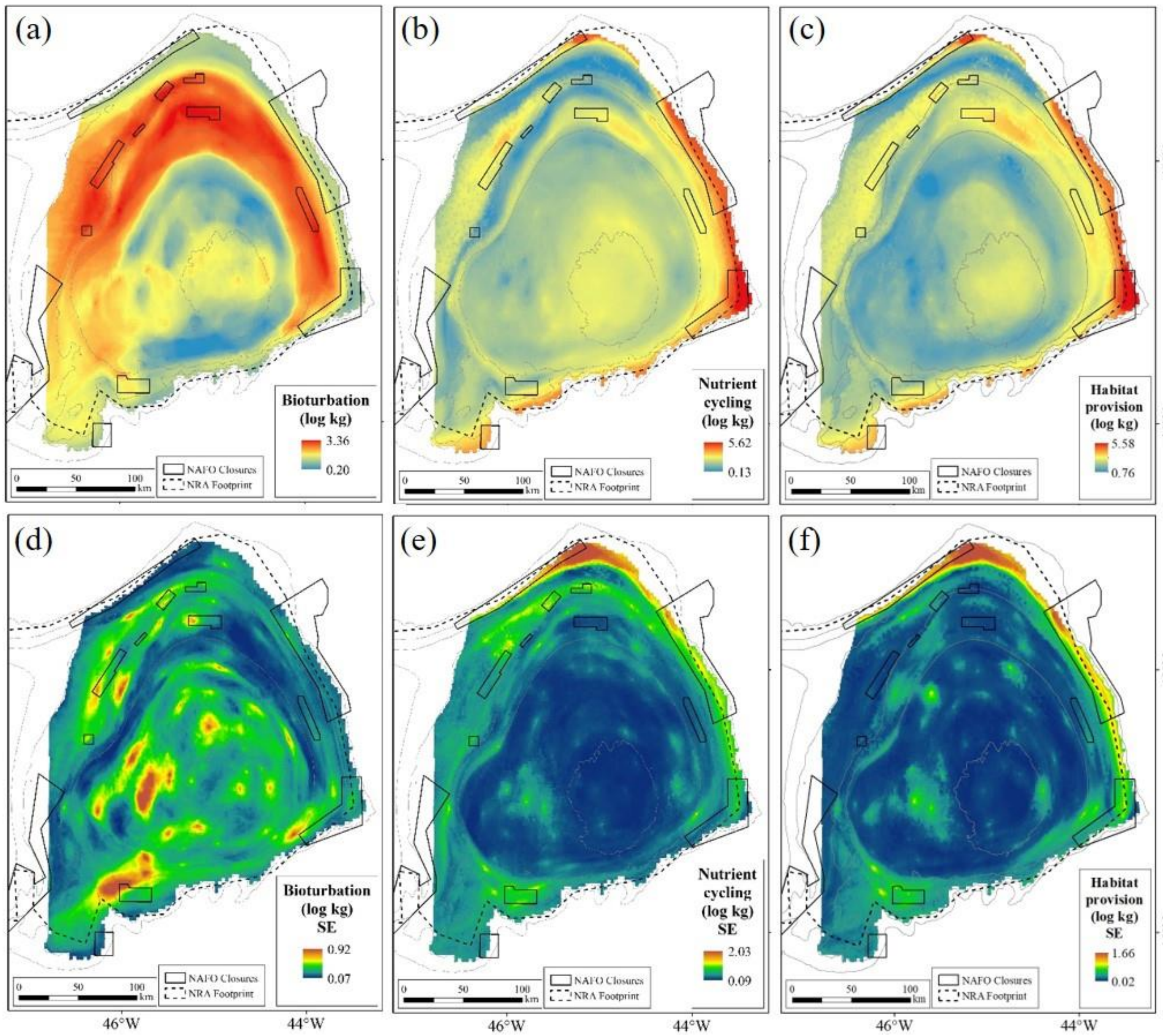

Figure 8.3. Predicted ecosystem functions from random forest modelling of (a) Bioturbation, (b) Nutrient cycling and (c) Habitat provision. d–f) Standard error (SE) associated with each predicted surface. Areas closed to bottom fishing activities to protect sponge and coral concentrations and existing bottom fishing areas (NRA Footprint) are also indicated. From Murillo et al. (2020).

The predicted biomass of the bioturbation function was higher on a ring around the Flemish Cap between 400 and 1100 m depth (Figure 8.3a), mostly associated with low standard error (Figure 8.3d). It was driven mainly by the sea pen *Anthoptilum grandiflorum* which was the heaviest and most common species. The biomass of nutrient cycling and habitat provision functions presented a similar pattern (Figure 8.3b,c), being higher in the deeper waters, in some areas between 600 and 900 m depth and in the shallower part of the Cap. The nutrient cycling function was a bit higher in the shallower part of the Cap compared to the habitat provision function, whereas the latter was higher to the northeast of the Flemish Cap. The higher values of these functions overlap with the highest occurrence probability of the large sponge *Geodia barretti* (Murillo et al., 2020). The standard error surface was also similar for both predicted surfaces (Figure 8.3e,f), except in the east of the Flemish Cap, where high standard error was observed for the habitat provision function, whereas it was medium for nutrient cycling.

Although current closures to protect VMEs from the adverse impacts of bottom fishing activities protect most of the functional diversity, the spatial scale of influence for each of the functions is unknown and therefore we cannot conclude that the high level of functional diversity found in the current closed areas is sufficient to maintain ecosystem processes over the whole of Flemish Cap.

Sponge Functional Traits in the NRA

Pham et al. (2019) produced sponge biomass surfaces for the NRA, created from research survey data using both random forest modeling and a gridded surface approach developed previously in NAFO. Their analysis revealed 231,136 tons of sponges in the area. About 42% of that biomass was protected by current fisheries closures. Using values from the literature they converted the sponge biomass into estimates of ecosystem function: filtration, respiration, carbon consumption and nitrogen flux. They showed that these sponges filter 56,143 ± 15,047 million litres of seawater daily, consume 63.11 ± 11.83 t of organic carbon through respiration, and affect the turnover of several nitrogen nutrients (Table 8.5). Their removal would likely affect the delicate ecological equilibrium of the deep-sea benthic ecosystem in this region.

Within the NAFO fishing footprint area, both the modelling and the grid-cell approaches suggested that most of the sponge biomass (66% and 60%, respectively) was found within NAFO Division 3M (Flemish Cap). The remaining portion of the sponge biomass occurred mostly in Division 3L (Flemish Pass) and Division 3N (Tail of the Bank), while only a small portion (<2%) of the total biomass was found within Division 3O.

Throughout the modelled area, bottom zones closed to protect VME (n=14) cover an area of 12,830.09 km^2. However, when looking at the area that falls inside the NAFO fishing footprint, and so vulnerable to fishing threats if protections were not in place, the closed areas cover 7,884.2 km^2 of seafloor, protecting sponge biomass of 56,800 to 77,466 t as estimated from the modelling and grid-cell methods, respectively (Table 6, Figure 8.4). For both approaches, the majority of sponge biomass was located within four closed areas (Areas 2, 4, 5 and 6).

Table 8.5. Sponge wet weight biomass estimated by the modelling approach and estimates of ecosystem functions in four NAFO Divisions. From Pham et al. (2019).

Area	Biomass (t)	Filtration (x 10^6 litre day^{-1})	Respiration (t O^2 day^{-1})	Carbon consumption (t C day^{-1})	NH_4^+ (t day^{-1})	NO_2^- (t day^{-1})	NO_3^- release (t day^{-1})
3L - Flemish Pass	28 060	6 816 ± 1 827	6.90 ± 1.29	7.66 ± 1.44	0.002 ± 0.001	0.049 ± 0.016	0.79 ± 0.19
3M - Flemish Cap	147 837	35 910 ± 9 624	36.33 ± 6.81	40.37 ± 7.57	0.013 ± 0.003	0.259 ± 0.086	4.16 ± 1.00
3N - Tail of the Bank	51 543	12 520 ± 3 355	12.67 ± 2.37	14.07 ± 2.64	0.005 ± 0.001	0.090 ± 0.030	1.45 ± 0.35
3O -	3 696	898 ± 241	0.91 ± 0.17	1.01 ± 0.19	0.000 ± 0.000	0.006 ± 0.002	0.10 ± 0.03
Total	231 136	56 143 ± 15 047	56.80 ± 10.65	63.11 ± 11.83	0.020 ± 0.005	0.406 ± 0.135	6.50 ± 1.57

Table 8.6. Sponge biomass estimated within each of the areas closed by NAFO to protect VMEs using both the modelling and grid-cell approaches for both the entire study area and the area limited to the NAFO fishing footprint. From Pham et al. (2019).

Closed Area Code	Sponge biomass (t)			
	Total		NAFO fishing footprint	
	Model	Grid	Model	Grid
1	816	685	488	541
2	29 619	58 527	15 727	31 395
3	1 038	729	-	-
4	20 334	21 011	10 174	14 649
5	18 524	18 461	9 750	11 909
6	22 330	18 714	18 716	18 538
7	22	20	22	20
8	8	1	8	1
9	21	25	21	25
10	75	73	75	73
11	9	5	9	5
12	3	1	2	1
13	96	310	96	310
14	3 405	-	1 711	-
Total	96 300	118 562	56 799	77 467

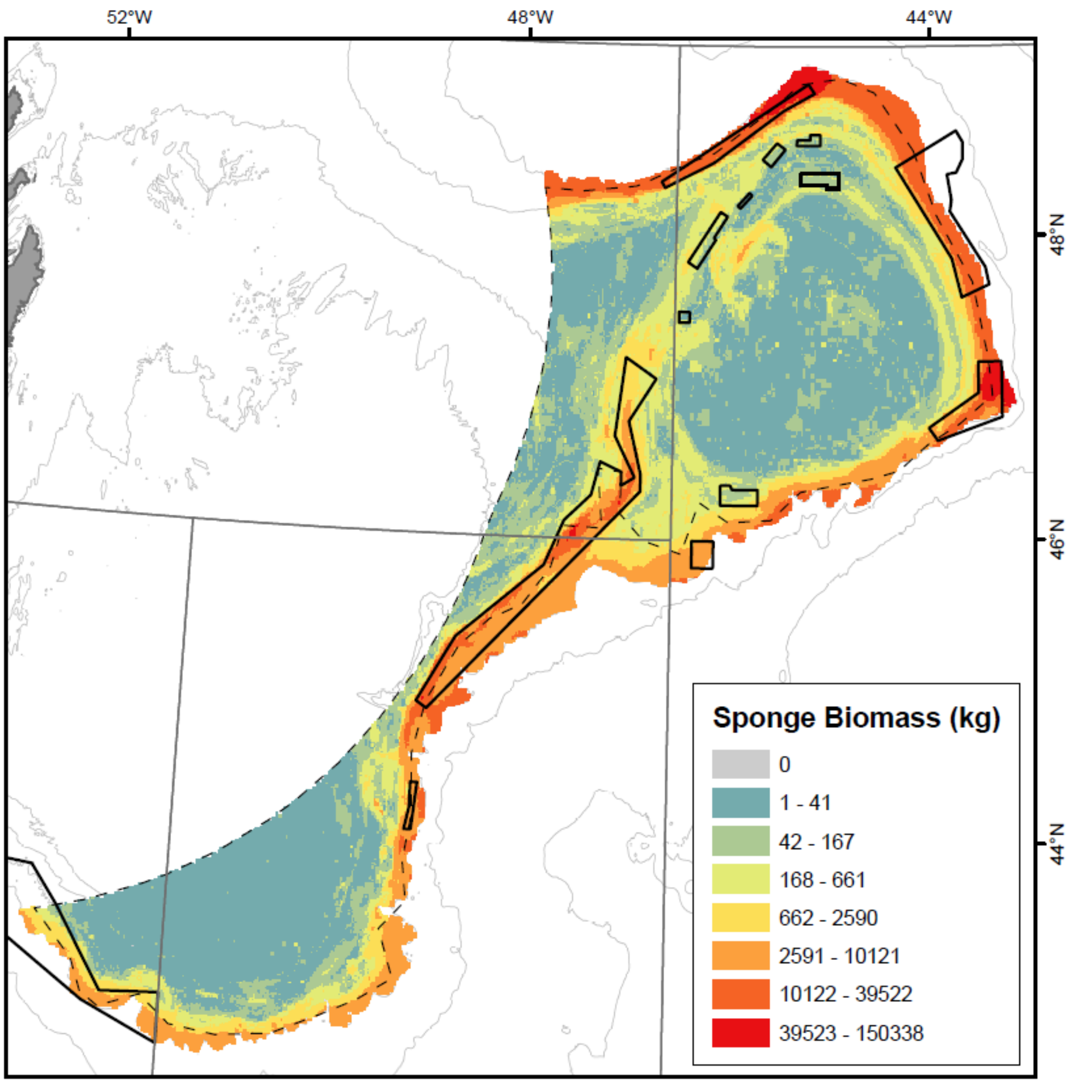

Figure 8.4. Sponge biomass distribution in relation to NAFO Closed Areas and the NAFO fishing footprint (dashed line) showing areas with associated filtration, respiration, carbon consumption and nitrogen fluxes (Table 8.5). From Pham et al. (2019).

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9. Work Plan SAI

COM Request [6] and **ToR 2.4.** ***Work Activities for SAI analysis in 2020"Work Activities for SAI analysis in 2020:***

- Define KDE polygons and thresholds for functions (bioturbation, nutrient cycling, structure forming, functional diversity) – DFO
- Up-date cumulative biomass *vs* fishing effort plots for ALL VMEs using new fishing effort and biomass data – Cefas
- Create new cumulative functional (biomass) *vs* fishing effort plots for each function (bioturbation, nutrient cycling, structure forming, functional diversity) from trawl data – Cefas/DFO
- Calculate SAI using VME and Functional polygon areas and biomass to quantify the 3 risk/impact categories (low risk, high risk, impacted) – Cefas/DFO
- Assess the spatial/temporal relationship between fish, invertebrates, VME indicator species and VMEs using multivariate approaches – Cefas
- Up-date description of NRA fisheries – maps and tables – IEO
- Develop new VME fragmentation index - Mariano/Andy
- Connectivity of VMEs Index
- VME buffer zones – DFO
- Up-date literature review of VME recovery rates – DFO

10. FAO Criteria

COM Request [6] and **ToR 2.5.** ***Assess all six FAO criteria (Article 18 of the FAO international guidelines for the management of deep-sea fisheries in the high seas)***

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".

The guidelines 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."

During the 1st assessment, focus was directed on assessing the first three criteria (i, ii and iii). 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 and is therefore directly related to bottom fishing effort and the type of gears used (e.g. area of bottom contact). Criterion ii, is accomplished through mapping the location of the VME and determining the proportion of the area that is currently impacted by fishing against the area protected by the closed areas (including areas of VME outside the fishing footprint), and the proportion that is at risk of being impacted (VME inside the fishing footprint not protected by VME fishery closures). Criterion iii, is essentially the mapped distribution of the VMEs.

Criteria iv – vi, address mainly the functional aspects of VMEs. Criterion iv, can be estimated (in part) by deriving the VME relative sensitivity (or resilience) from the cumulative biomass *vs* fishing effort plots. Criterion v, relates to impacts of bottom fishing on the functional properties of VME habitat and therefore requires an understanding of the biological traits of the VME indicator species and how they relate to significant functions. A full account of the biological traits and their corresponding functional attributes is given in ToR 2.3, but in summary the VME functions associated with, i. bioturbation, ii. nutrient cycling, iii. habitat structure forming and iv. functional diversity will be assessed in the same way as the VME biomass. That is, the cumulative functional biomass *vs* fishing effort response plots (for each functional type) will be determined and applied to the fishing effort data associated with the VME related functional polygons to estimate the proportion of functional biomass at low risk, impacted and at high risk. These additional functional criteria to be applied in the SAI analysis are highlighted in ToR 2.6.

Criterion vi. relates to the use of habitat by mobile species, emphasizing that some habitats may only become VMEs if it is the use of that location by the mobile species the one that defines the area as a VME (i.e. it is the mobile species the VME indicator species), or that the significance of the VME habitat is further enhance at certain times of the year if some mobile VME indicator species uses the VME habitat on a seasonal basis (e.g. spawning, nursery grounds). In this last case, the place-based VME is define by a sedentary species (e.g. corals, sponges), and hence the habitat is a VME all year round.

NAFO has yet to designate any mobile species (e.g. fishes) as a VME indicator species. Even if there are mobile VME indicator species in the NRA (e.g. rare deep sea fish species), and these species do indeed seasonally utilize the habitats already identified as VMEs, Criterion vi. for those mobile VME indicator species would be covered by the consideration of Criteria i-iv when applied to the sessile VME indicator species and the habitats they generate. For example, if the mobile VME species utilizes sea pen VME as nursery grounds, addressing criteria i-iv for sea pen VME, and minimizing SAIs on this VME, would have the consequence of providing protection for the nursery grounds of the mobile VME indicator species.

11. Weighting objectives SAI

COM Request [6] and **ToR 2.6.** ***Clearer objective ranking and weighting of criteria for the overall assessment of SAI and risk of SAI.***

During the 1st assessment of bottom fisheries conducted by SC in 2016 (SC-03, 16th June 2016) a table of SAI assessment metrics were developed and applied in accordance with the FAO guidelines for the assessment of SAI (FAO, 2009). One of the limitations of this approach, noted by SC, is that all metrics applied to each VME have equal weight, when it is likely that some of the metrics are likely to have greater significance for the assessment of SAI than others. In addition, the *rationale* for assigning the categories of 'high, moderate and low' to VME specific metric values was not clear.

To address these concerns a sub-group of WG-ESA participants was convened during the 2019 meeting.

Consideration of the ranking of SAI assessment metrics

The sub-group first considered the full list of SAI criteria (FAO, 2009) with respect to an expanded list of assessment metrics to be applied to the reassessment of bottom fisheries in 2021 (the 2nd SAI assessment) (Table 11.1). It was noted that the first two SAI criteria are essentially directly related to the management of the fishing activity and therefore their status and trend will largely drive the responses in the remaining 4 criteria (see footnote).

Table 11.1. Full list of SAI criteria (FAO, 2009) with respect to an expanded list of assessment metrics to be applied to the reassessment of bottom fisheries in 2021

	SAI criteria FAO[3]					
Assessment Metrics	i	ii	iii	iv	v	vi
Area/Biomass at low risk	x	x		x		
Area/Biomass impacted	x	x				x
Area/Biomass at high risk	x	x				
Number of overlapping VMEs			x		x	
Index of VME sensitivity			x	x		
Index of fishing stability	x	x				
Index of Risk of VME fragmentation	x	x				
Index of functional sensitivity			x	x	x	
Functional Area at low risk	x	x		x		
Functional Area impacted	x	x			x	x
Functional Area at high risk	x	x			x	
VME connectivity	x	x	x	x		

Accordingly, the metrics which correspond to the assessment of the first two SAI criteria were considered to be of greater importance (and hence influence) in determining the overall assessment of SAI. Nevertheless, the full list of metrics for the 2nd SAI assessment will be developed and applied to meet the requirements of all 6 SAI criteria, including those pertaining to VME functions (see Table 11.1 footnote).

During the 1st SAI assessment a set of assessment metrics were defined, these have been re-evaluated and additional metrics included to assess the functional characteristics of VME and the impacts of bottom fishing activities. The full set of assessment metrics to be applied in the 2nd assessment is shown in Table 11.2.

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

Table 11.2. The full set of assessment metrics to be applied in the 2nd assessment

SAI Assessment Metrics	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.
Index of VME sensitivity	The inverse of VME impact cut-off value is used as a proxy of 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 and the ratio of average low to high risk area associated with the VME.
Index of functional sensitivity	The inverse of functional impact cut-off value (for bioturbation, nutrient cycling, structure forming and functional diversity functions) is used as a proxy of sensitivity as it indicates the point at which trawl duration/length exceeds function indicator patch size within a habitat.
Functional Area at low risk	This refers to the proportion of the area of the VME related functions which are currently at low risk either because they fall within a fishery closure area and/or is in an area outside of the fishing footprint.
Functional Area impacted	Proportion of the area of the VME functions which have been exposed to a level of fishing effort above the defined cut-off point (for each function) within any one year.
Functional Area at high risk	Proportion of the area of the VME functions which fall below the defined cut-off point of fishing effort (for each function) within anyone year.

Consideration of the assignment of 'high, moderate and low' categories to VME specific metric values

In the 1st assessment of SAI, three categories of assessment were applied to each metric value, namely, 'high, moderate and low'. The limits used to define the categories were selected to highlight the relative differences between the VME specific metrics. Although in most cases the differences were sufficiently clear to assign either a high or low assessment category to each metric, the actual significance of the values in relation to ecosystem function and impact is not known. Therefore, those values assessed as being in the low impact category cannot be assumed to be representative of good functional status.

This issue was further discussed in relation to the review of VMEs and the definition of categories used to assess the status of VMEs (see ToR. 1.2) which defined 6 assessment categories ranging from good to poor (Table 11.3). Therefore, to ensure consistency between the review of VME and the assessment of SAI the same categories were applied to the assessment of SAI.

Table 11.3. Definition of categories used to assess the protection status of VMEs. Status definitions (recommendations) are based on definitions from the online Oxford English Dictionary: Good – To be desired or approved of; Adequate – Satisfactory or acceptable in quantity or quality; Incomplete – Not having the necessary or appropriate parts; Limited – Restricted in size, amount or extent; Poor – Of low or inferior standard or quality; Inadequate – Lacking in quality or quantity required.

Recommendation	Proportion of biomass protected	Projected Connectivity Among Closures	Management Action
Good	> 60% VME Biomass	Good connectivity among closures	Beneficial
Adequate	> 60% VME Biomass	Limited connectivity or redundancy	Beneficial
Incomplete	60% - 30% VME Biomass	Good connectivity among closures	Desirable
Limited	60% - 30% VME Biomass	Limited connectivity or redundancy	Desirable
Poor	30% - 15% VME Biomass	Limited connectivity or redundancy	Essential
Inadequate	< 15% of Biomass	Limited connectivity or redundancy	Essential

12. Kernel Density (KDE) Analysis/Review of Closures

COM Request [7] and **ToR 1.2.** ***Re-assessment of VME closures by 2020, including area #14 irrespective of a decision to continue or not continue this closure after 2018***

In response to the Commission request WGESA repeated the suite of analyses used to identify vulnerable marine ecosystems (VMEs) in the 2013 review of the closed areas in the NAFO Regulatory Area (NRA) (NAFO 2013). For most VME indicator taxa, kernel density (KDE) analyses of the research vessel trawl catches and subsequent aerial expansion methods (Kenchington et al. 2014) were applied. Previously, due to data properties, KDEs of small gorgonian corals were performed separately for Divisions 3NO and for Division 3M, but in 2019 with the increase in available data, the areas were combined in a single analysis. We also conducted the first KDE analysis on black corals after observing spatial aggregation in the updated catch data. Following previously established practice (NAFO 2013) species distribution models were used to modify the boundaries of the KDE polygons where they extended into unsuitable habitat (low probability of occurrence). Details of that work are reported in Kenchington et al. (2019). In general there was good spatial congruence between the 2013 and 2019 analyses which is most evident in the comparison of the VME polygons (Figure 12.1). Catch thresholds were the same or similar to those identified previously (Table 12.1). Most VMEs increased in area with the new data (Table 12.1), the exception being erect bryozoans where a change in the KDE search radius enabled by the new data reduced the VME area (Table 12.1). The increase in area for the small gorgonian corals is supported by new data from the 3O surveys (reviewed in Figures 12.29 and 12.30 in detail), and was influenced by an increase in KDE search radius as a result of the change to the spatial extent of the analysis as noted above.

Table 12.1. Change in significant concentration threshold (kg) from research vessel catches and total area (km²) of VME polygons derived from kernel density estimation and species distribution modelling techniques between 2019 and 2013. Also shown is the percent change in polygon area between 2019 and 2013 and the proportion of VME area and biomass protected inside the closed areas in 2019 (Area 14 is included in this calculation). Total biomass (kg/km2) VME indicator taxa inside the 2019 VME polygons derived from KDE density surfaces that is protected (inside closures) versus unprotected (outside closures) in NAFO Divisions 3LMNO.

Common Name	Research Vessel Catch Threshold (kg)		Area of VME in (km²)		Change in Area between 2019 & 2013 (%)	Proportion of VME Area Protected by Closed Areas in 2019 (%)	Total Biomass of 2019 VME in 3LMNO (kg/km²)	Biomass Protected by Closed Areas in 2019 (kg/km²)	Proportion of VME Biomass Protected by Closed Areas in 2019 (%)
	2019	2013	2019	2013					
Large-sized sponges	100	75	24,218	19,824	22	39	20,804	11,753	57
Sea pens	1.3	1.4	8,498	6,983	22	17	20	4	18
Large gorgonian corals	0.6	0.6	5,007	3,506	43	55	55	31	57
Small gorgonian corals	0.2	0.15*	4,540	307	1,377	4	2	0.03	1
Sea squirts	0.35	0.3	4,077	2,193	86	0	41	0	0
Erect bryozoans	0.2	0.2	3,491	6,587	-47	0.14	55	0.01	0.01
Black corals**	0.4	-	2,631	-	-	17	2	0.38	16

*In 2013 KDE analyses for small gorgonian corals were performed for Divisions 3NO and for Division 3M and in 2019 the areas were combined. ** KDE analyses on black coral catches were performed for the first time in 2019.

In order to evaluate the effectiveness of the area closures we calculated the proportion of the VME area and biomass, by VME type, that is protected by the closed areas currently in place and including Area 14 (Table 12.1). In making this calculation the VME area is defined by the KDE polygons for each group (NAFO 2013), and the closed areas are the full extent as defined in the Conservation and Enforcement Measures (NAFO 2018). Biomass for each taxon was determined from the KDE surfaces (see Kenchington et al. 2019 SCR). This comparison is strictly to facilitate the evaluation of the effectiveness of the current closures in terms of position and coverage (Table 12.2) and differs from evaluations of fishing impacts outside of the closed areas elsewhere in this report, which are restricted to within the Existing Bottom Fishing Area (i.e., the fishing footprint). This is consistent with Areas 1, 2, 3, 4, 5 and 6, and some VMEs (primarily large-sized sponges), extending outside of the fishing footprint (Area 3 is completely outside) and with that area potentially subject to exploratory bottom fishing (albeit with an extra layer of protection: NAFO 2019). Further, as different closures and indicator taxa were in place in 2013, we have not calculated the proportion of VME protection afforded at that time. Removing Area 14 from the evaluation would reduce the protection (area and biomass) afforded to the sea pens (Table 12.1).

New to this assessment, the connectivity between closed areas was modeled using a 3-D particle tracking package (Parcels v.2.1) in conjunction with the eddy-resolving Bedford Institute of Oceanography North Atlantic ocean model (BNAM), which uses the NEMO 2.3 (Nucleus for European Modelling of the Ocean) model engine. Simulations run between areas closed to protect the same VME indicator groups (i.e., large-sized sponges, sea pens and large gorgonian corals) showed low overall potential for connectivity which is considered in the assessment of the closed areas for each VME indicator taxon (Part A below). Details are found in Wang et al. (2019).

In undertaking our assessment of the areas closed to protect VMEs we produced *a priori* a rating guide based on expert judgement to produce a more consistent framework for evaluation here and in future (Table 12.2). It considers the proportion of biomass/area protected for each VME type and incorporates the new information on connectivity. The assessment in 2013 did not benefit from such a framework. This guide was used to provide an assessment on the protection afforded to each VME indicator group over the NRA (Part A), and to assess the adequacy of the existing closures relative to all VMEs (Part B). The recommendation is linked to the need for management action (Table 12.2). For Part B we introduce new layers on species diversity and the predicted distribution of the glass sponge *Asconema foliata* on Flemish Cap, a VME indicator that is not adequately protected in the large-size sponge VME due to its light biomass.

Table 12.2. Rating guide based on expert judgement used to evaluate the effectiveness of area closures put in place to protect vulnerable marine ecosystems in the NAFO Regulatory Area and the need for management actions. Connectivity is defined here as physical links between two or more areas; an area is considered to have redundancy when two or more other areas connect to it. These properties relate to the ability of populations to persist. Status definitions (recommendations) are based on definitions from the online Oxford English Dictionary: Good – To be desired or approved of; Adequate – Satisfactory or acceptable in quantity or quality; Incomplete – Not having the necessary or appropriate parts; Limited – Restricted in size, amount or extent; Poor – Of low or inferior standard or quality; Inadequate – Lacking in quality or quantity required.

Recommendation	Proportion of VME Protected	Projected Connectivity Among Closures	Management Action
Good	> 60% VME	Good connectivity among closures	Beneficial
Adequate	> 60% VME	Limited connectivity or redundancy	
Incomplete	60% - 30% VME	Good connectivity among closures	Desirable
Limited	60% - 30% VME	Limited connectivity or redundancy	
Poor	30% - 15% VME	Limited connectivity or redundancy	Essential
Inadequate	< 15% VME	Limited connectivity or redundancy	

Overview of Analyses

The VME polygons generated in 2013 were compared with those generated in 2019 and areas of overlap identified (Figure 12.1). The large increase in area of the small gorgonian coral VME (Table 12.1) can be seen on the Tail of Grand Bank near the 3O closure where the new data expanded the significant concentrations identified in 2013. Similarly the reduction in erect bryozoan VME (Table 12.1) can be seen in this same general area as a result of improved delineation of the areas of high concentration.

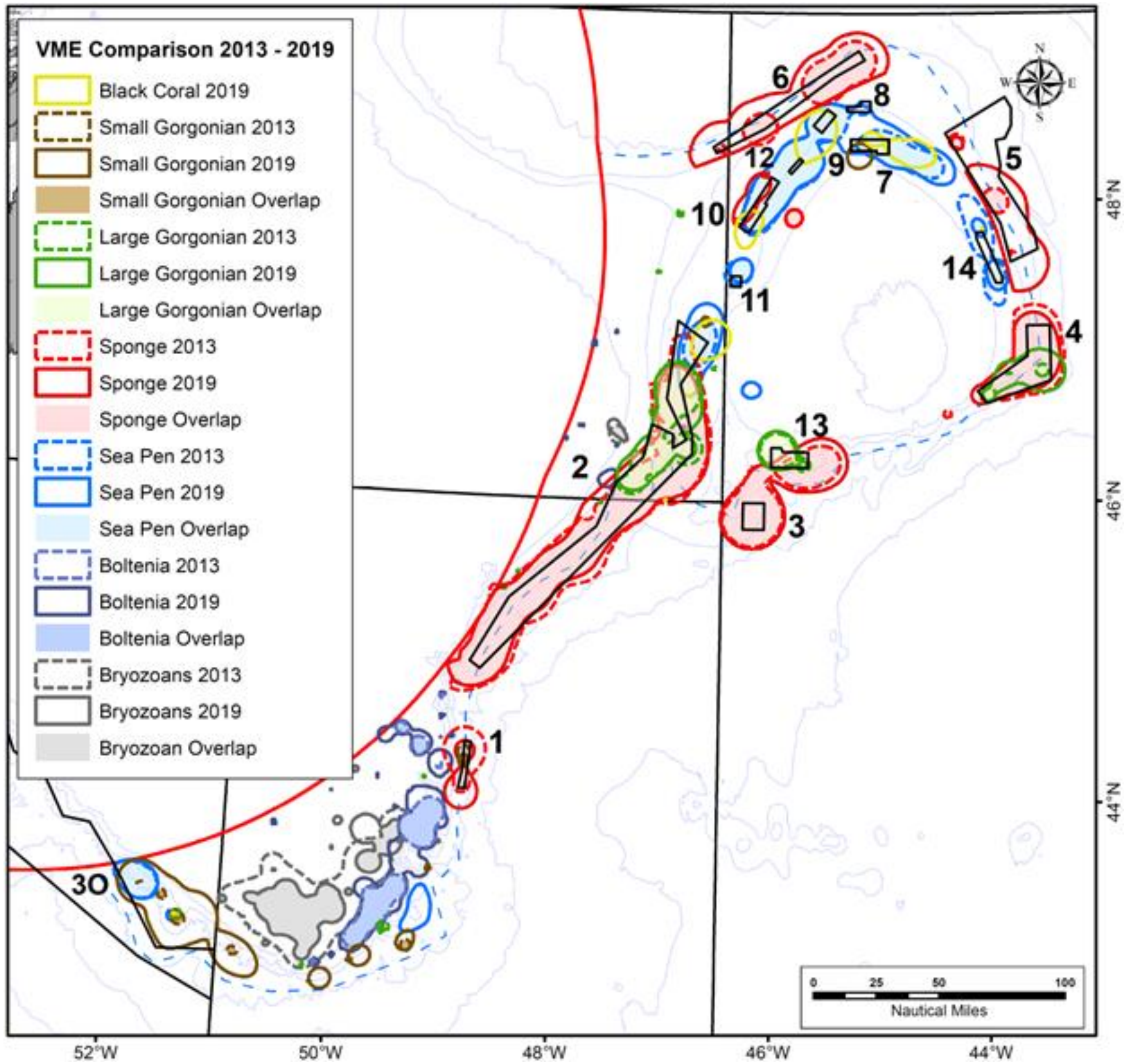


Figure 12.1. Overview map of the location of VME taxa (large-sized sponges, sea pens, small gorgonian corals, large gorgonian corals, erect bryozoans, sea squirts (*Boltenia ovifera*), and black corals) in the NRA, colour coded by taxon. For all taxa the polygons determined from the 2013 analysis are shown in dashed line and compared with those from the 2019 analyses in solid lines. Areas of overlap are shaded. The closed areas are indicated in black outline and their numbers shown near the closure. Dashed blue line is the fishing footprint.

a) New data collected in bottom trawl surveys in 2019

Bottom trawl surveys by the EU-Spain and Canada revealed that VME indicator species were widespread (Sacau et al. 2020). Three significant catches of sponges (≥ 75 kg tow^{-1}) occurred in the EU-Spain survey while two significant catches of large gorgonian corals (≥ 0.6 kg tow^{-1}) and one significant catch of small gorgonian corals (≥ 0.15 kg tow^{-1}) occurred in the Canadian surveys. In EU surveys, sponges occurred in 25.3% of tows; large gorgonian corals in 1.5% of tows; small gorgonian corals in 10.4% of tows and sea pens occurred in 30.9% of tows. During Canadian surveys (2018 and 2019) sponges occurred in 49.3-53.5% of tows; large gorgonian corals occurred in 2.8-5.8% of tows; small gorgonians occurred in 0-1.4% of tows; sea pens occurred in 8.5-10.1% of tows and black corals occurred in 0-1.4% of tows. Preliminary data from EU and EU-Spain surveys in 2019 are presented in SCR Doc. 19/060.

Assessment of Protection for VMEs in the NAFO Regulatory Area

Summary of New Data Sources

Data available were obtained from research vessel trawl surveys (Table 12.5) and used to perform the kernel density analyses (Kenchington et al. 2019 SCR). Benthic imagery, and data from rock and scallop dredges previously collected through the NEREIDA program were used as supporting information (NAFO 2013).

Table 12.3. Data sources from contracting party research vessel surveys; EU, European Union; DFO, Department of Fisheries and Oceans; NL, Newfoundland and Labrador; IEO, Instituto Español de Oceanografia; IIM, Instituto de Investigaciones Marinas; IPMA, Instituto Português do Mar e da Atmosfera.

Programme	Period	NAFO Division	Gear	Mesh size in codend liner (mm)	Trawl duration (min)	Average wingspread (m)
Spanish 3NO Survey (IEO)	2002 - 2019	3NO	Campelen 1800	20	30	24.2 – 31.9
EU Flemish Cap Survey (IEO, IIM, IPIMAR)	2003 - 2019	3M	Lofoten	35	30	13.89
Spanish 3L Survey (IEO)	2003 - 2019	3L	Campelen 1800	20	30	24.2 – 31.9
DFO NL Multi-species Surveys (DFO)	1995 - 2019	3LNO	Campelen 1800	12.7	15	15 - 20

Large-Sized Sponges

Assessment: “Incomplete” (Table 12.2). Management action “Desirable”.

There is a good correlation between the closures and the areas of high concentration of sponges (Figure 121) and in some areas (Flemish Pass) much of the predicted habitat for the Geodia-dominated sponge grounds is protected (Figure 12.2). The re-assessment increased the catch threshold for defining the sponge VME from 75 kg to 100 kg, resulting in some changes to the VME polygons. Notably, the 2019 VME polygon protected by Area 2 is smaller at its northern end in Flemish Pass. Two catches of 75 kg, both inside the closed area, now lie outside the VME, but inside the VME polygons for sea pens. Adjustments of some of the current closures at their lightly fished or unfished deeper boundaries would enhance protection for the *Geodia*-dominated sponge grounds (Figure 12.2). The glass sponge, *Asconema foliata*, a VME indicator (see *Relationship of Structure-forming Invertebrates with Biodiversity* below) has small individual biomass and therefore the kernel density analysis performed on all sponges is biased towards the massive ball sponges forming the *Geodi*a-dominated sponge grounds. *Asconema foliata* is not well protected by the existing closures but is reviewed in Part B.

Some of the closed areas are large (Area 2, Area 5) with Area 2 showing some retention indicative of potential for self-perpetuation (Figure 12.3). The spatial configuration of the closures is good with respect to connectivity. There is a general clockwise flow pattern of downstream interdependence (Figure 12.4) with Area 6 (Sackville Spur) a potential source of recruitment to Area 5 and Area 4 (Figures 12.3, 12.4).

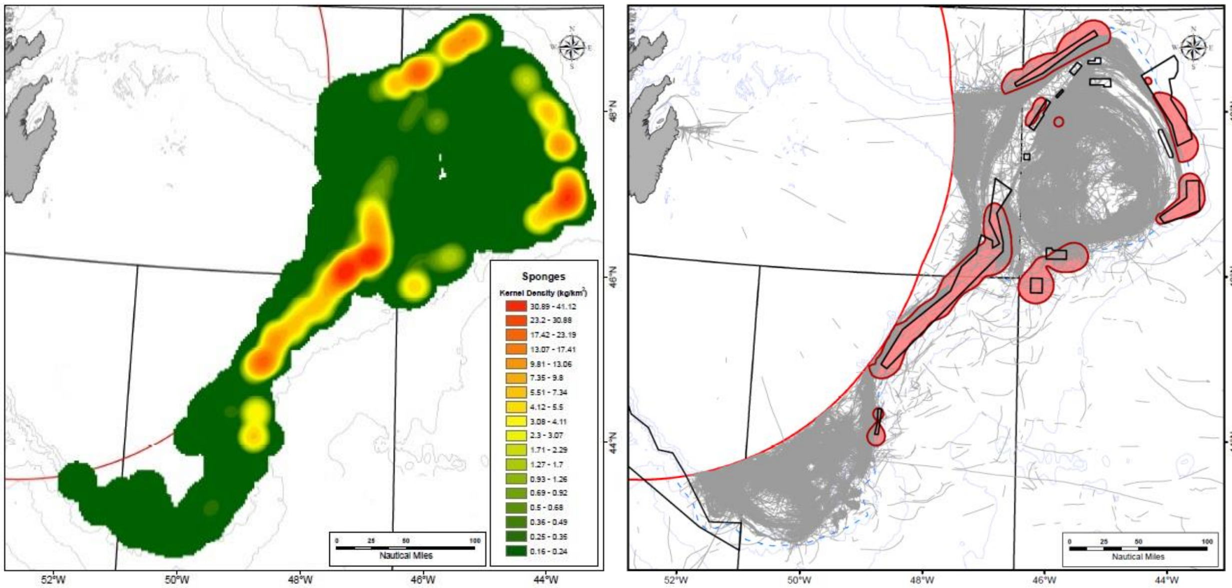


Figure 12.2. Left Panel: Kernel density biomass surface of large size sponges in the NAFO Regulatory Area based on research vessel catch data. Right Panel: Sponge KDE polygons (pink underlay red outline) indicative of sponge VMEs (sensu NAFO 2013), in relation to the 2010-2018 VMS fishing data (grey tracks; NAFO Secretariat 2019) and area closures.

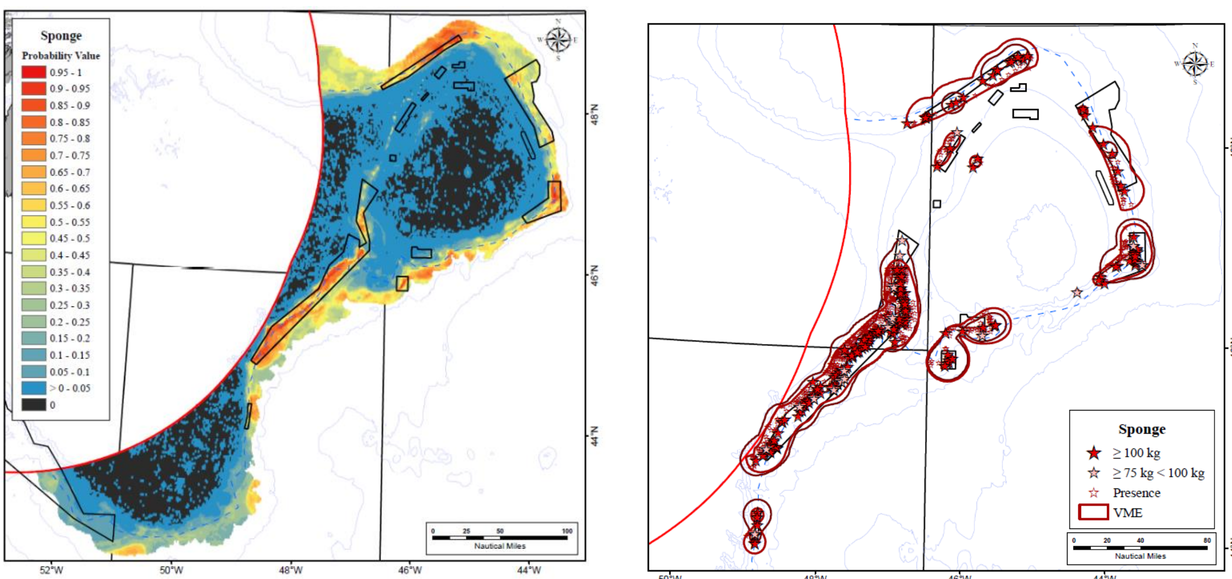


Figure 12.3. Left Panel: Species distribution model surface of probability of occurrence of *Geodia*-dominated sponge grounds in the NRA. Right Panel: Sponge KDE polygons indicative of sponge VMEs (NAFO 2013) and catches within each polygon ≥ 100 kg/RV tow, catches ≥ 75 kg/RV tow (previous polygon threshold, NAFO 2013), and sponge presence, in relation to the area closures. Catches ≥ 75 kg/RV tow outside of the 2019 KDE polygons are indicated.

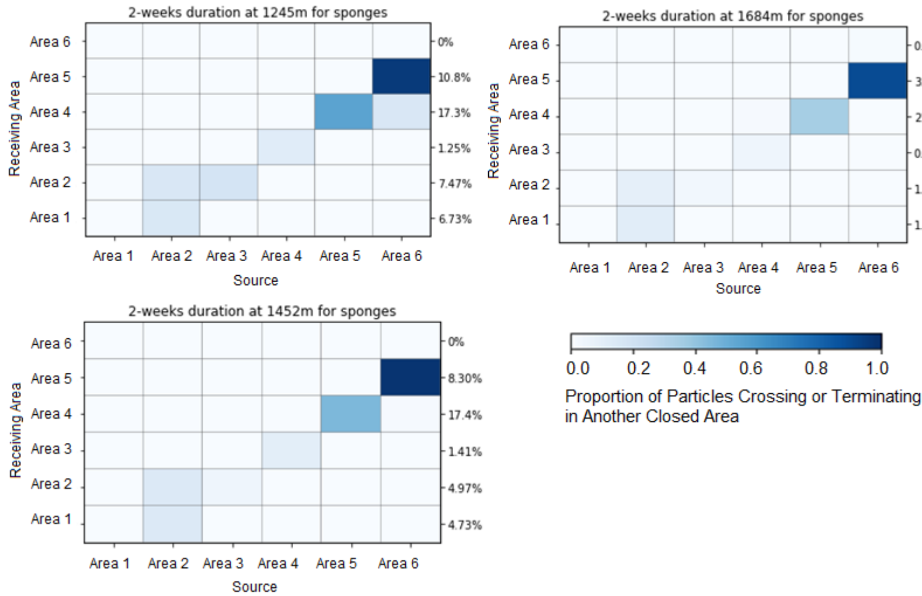


Figure 12.4. The proportion of modeled particles released from each of the 6 areas closed to protect large-size sponges (source areas; Areas 1, 2, 3, 4, 5, 6) and passing over or terminating in another area closed to protect large-size sponges (receiving areas). For each receiving area the percentage of the total number of particles released (from all source areas) are provided. Those values include particles that crossed, terminated or were retained in the receiving area. Drift durations were 2 weeks.

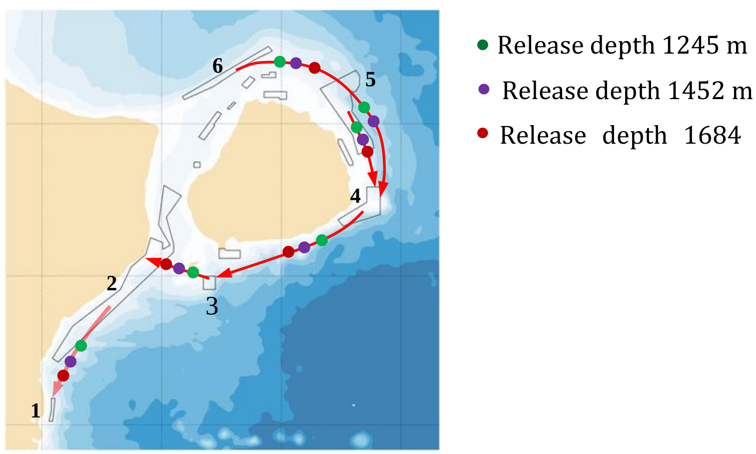


Figure 12.5. Connectivity pathways for particles released at 3 depths in each of the 6 areas closed to protect large-size sponges (Areas 1- 6) showing chain-linking with minimal redundancy in Area 4. Drift durations were 2 weeks.

Sea Pens

Assessment: “Poor” (Table 12.2). Management action “Essential”.

Although there is some level of protection of sea pen on the western side of Flemish Cap (Figure 12.6), as a system of VME which emerges from the overall distribution there is limited protection for sea pen VME as a whole (Figure 12.7). Without Area 14 there is notable absence of protection on the eastern Flemish Cap. Connectivity between the closures on Flemish Cap is poor with very low percentage of particles drifting from one closed area to another with one month duration (Figure 12.8). Areas 7, 8, and 9 are weakly connected at their shallower depths (Figure 12.8) through the cyclonic circulation of the Labrador Current (Figure 12.9). In general, drift at the seabed is counter clockwise with closed areas on the north of the Cap potentially seeding the sea pen VME in Area 2 in Flemish Pass (Figures 12.8, 12.9). The lack of protection for the entire eastern part of their distribution is of concern for the long term sustainability of these VME. There is no protection for the sea pen VME on the Tail of Grand Bank where there is significant activity of bottom-contact fishing gear (Figure 12.6). All of the sea pen closures are small, Areas 7, 8, 9 and 12 in particular, and combining these areas could facilitate retention (Figures 12.8, 12.9).

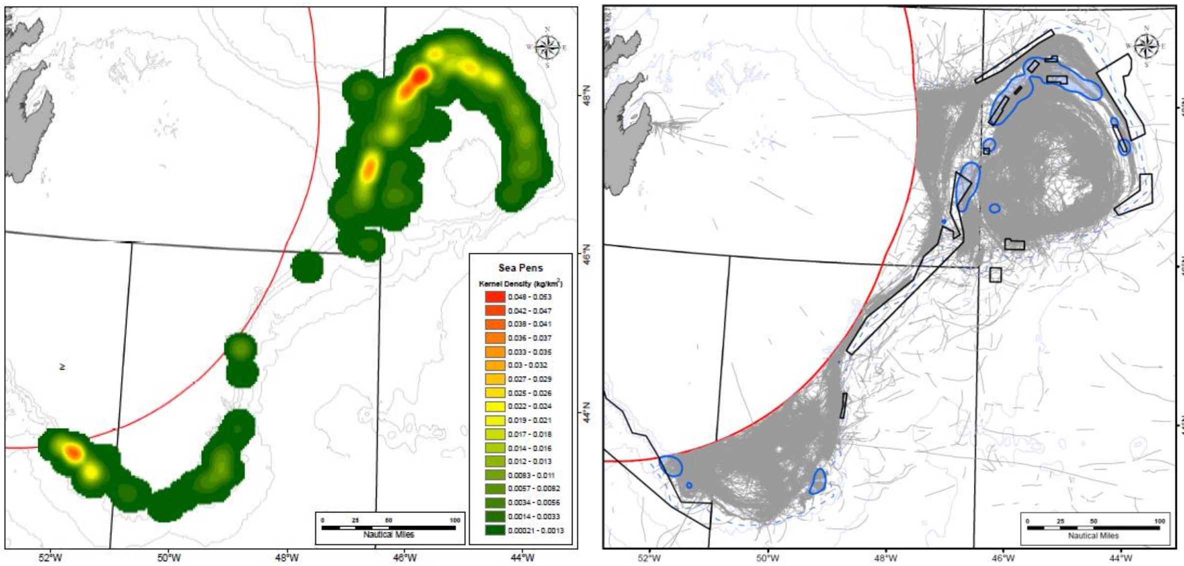


Figure 12.6. Left Panel: Kernel density biomass surface of sea pens in the NAFO Regulatory Area based on research vessel catch data. Right Panel: Sea pen KDE polygons (blue outline) indicative of sea pen VMEs (*sensu* NAFO 2013), in relation to the 2010-2018 VMS fishing data (grey tracks; NAFO Secretariat 2019) and area closures.

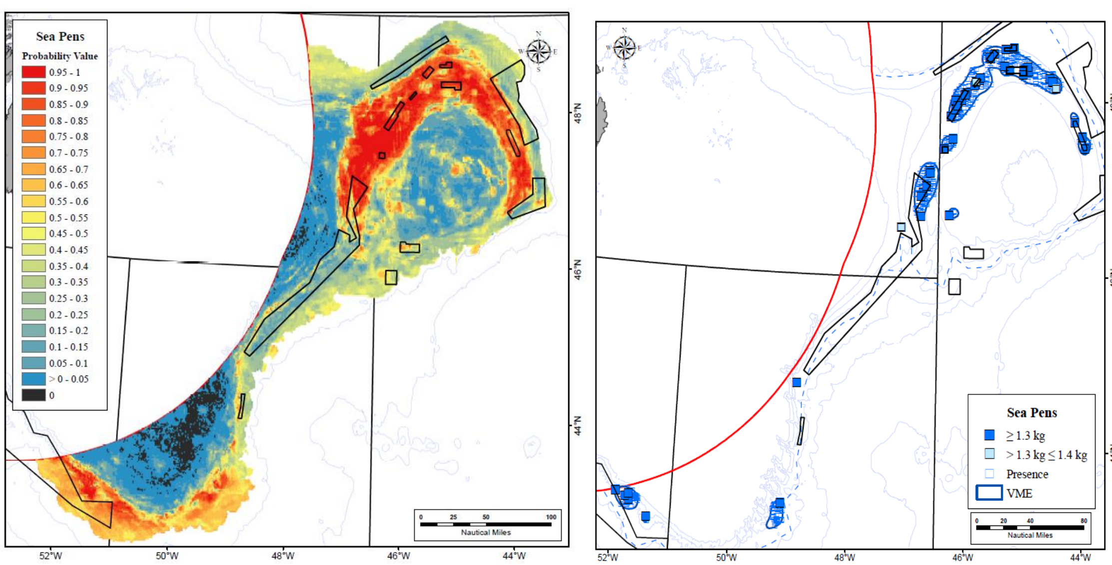


Figure 12.7. Left Panel: Species distribution model of probability of occurrence of sea pens in the NRA. Right Panel: Sea pen KDE polygons indicative of sea pen VMEs (NAFO 2013) and catches within each polygon ≥ 1.3 kg/RV tow, catches > 1.3 ≤ 1.4 kg/RV tow (previous polygon threshold), and sea pen presence, in relation to the area closures. Catches ≥ 1.4 kg/RV tow outside of the 2019 KDE polygons are indicated.

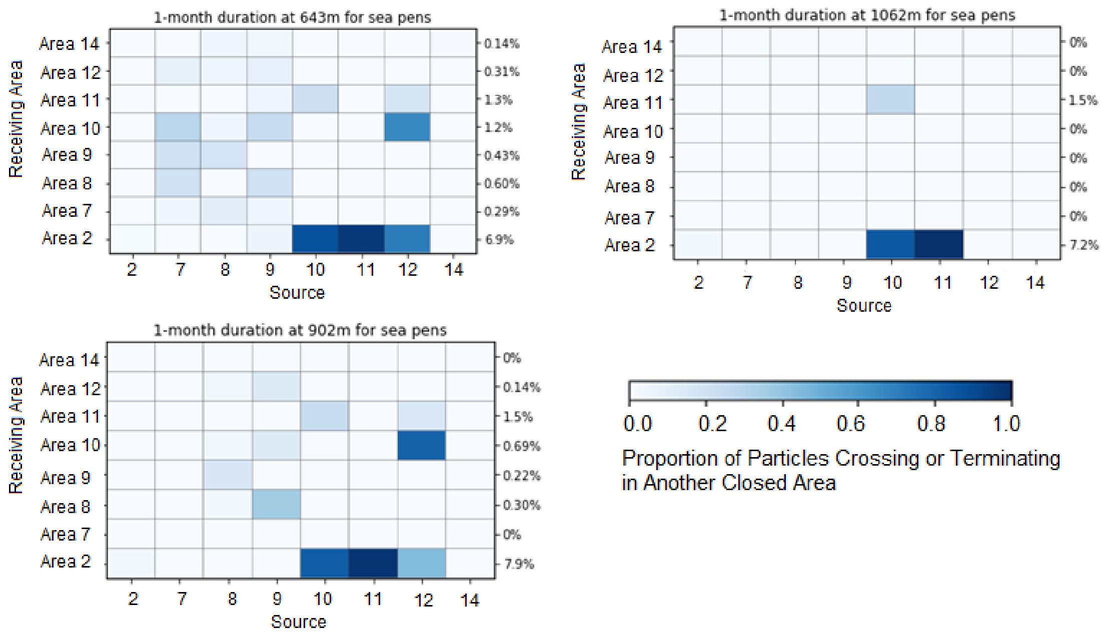


Figure 12.8. The proportion of modeled particles released from each of the 8 areas closed to protect sea pens (source areas; Areas 2, 7, 8, 9, 10, 11, 12, 14) and passing over or terminating in another area closed to protect sea pens (receiving areas). For each receiving area the percentage of the total number of particles released (from all source areas) are provided. Those values include particles that crossed, terminated or were retained in the receiving area. Drift duration was 1 month.

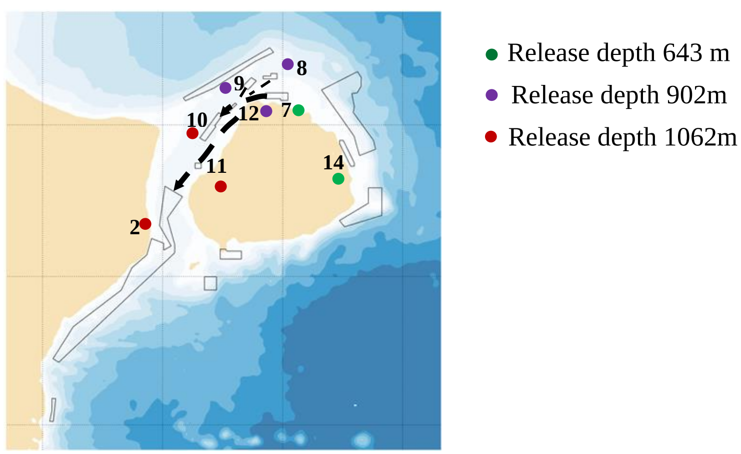


Figure 12.9. Connectivity pathways for particles released at 3 depths in each of the 8 areas closed to protect sea pens (Areas 2, 7, 8, 9, 10, 11, 12, 14). Drift durations were 1 month.

Large Gorgonian Corals

Assessment: "Incomplete" (Table 12.2). Management action "Desirable".

The current closed areas capture important areas with large gorgonian corals in the Flemish Pass and Flemish Cap area (Figure 12.10). These organisms are not well represented in the trawl catches and the predicted models suggest that they are distributed in deeper water outside of the survey area where there is no specific protection, especially in the deep water between Areas 5 and 4 on Flemish Cap (Figure 12.11) which have a relatively high degree of connectivity with ~ 20% of particles connecting at all depths simulated (Figure 12.12), indicating that the region could be an important source of downstream recruitment (Figures 12.13, 12.14).

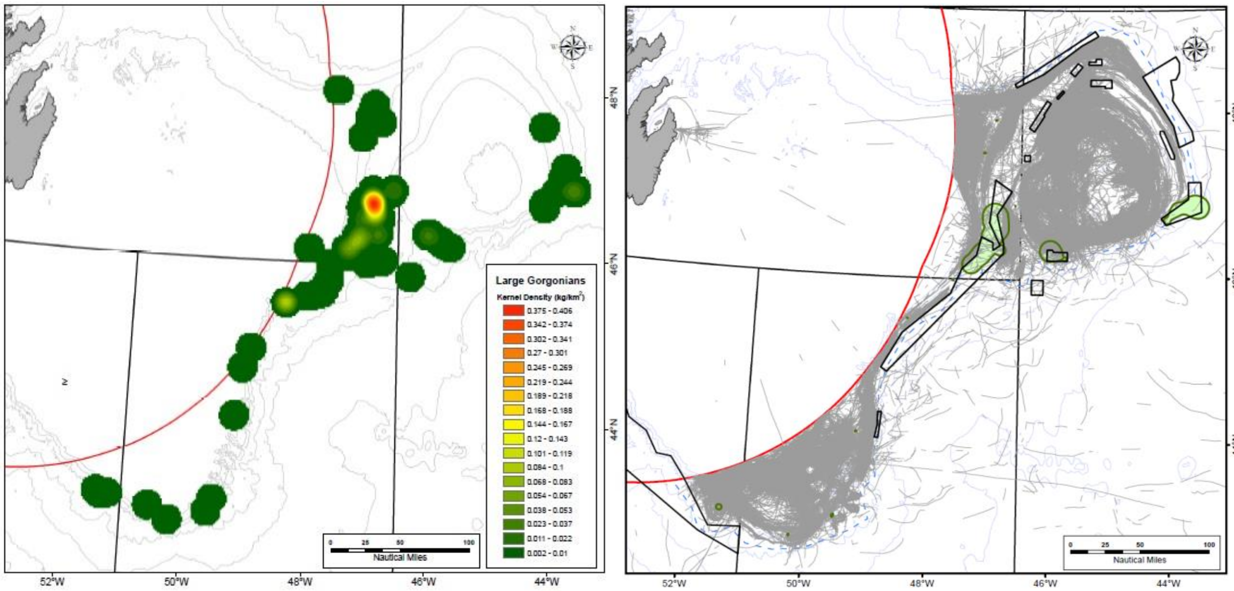


Figure 12.10. Left Panel: Kernel density biomass surface of large gorgonian corals in the NAFO Regulatory Area based on research vessel catch data. Right Panel: Large gorgonian coral KDE polygons (green outline) indicative of large gorgonian coral VMEs (*sensu* NAFO 2013), in relation to the 2010-2018 VMS fishing data (grey tracks; NAFO Secretariat 2019) and area closures.

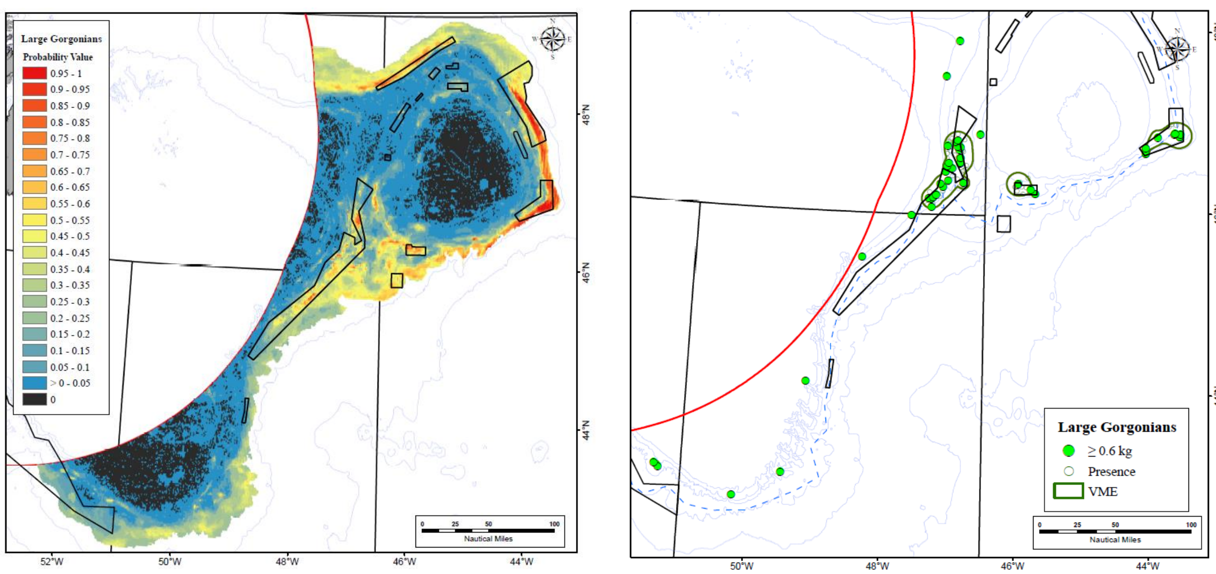


Figure 12.11. Left Panel: Species distribution model surface of probability of occurrence of large gorgonian corals in the NAFO Regulatory Area. Right Panel: Large gorgonian coral KDE polygons indicative of large gorgonian coral VMEs (*sensu* NAFO 2013) and catches within each polygon ≥ 0.6 kg/RV tow, and large gorgonian coral presence, in relation to the area closures.

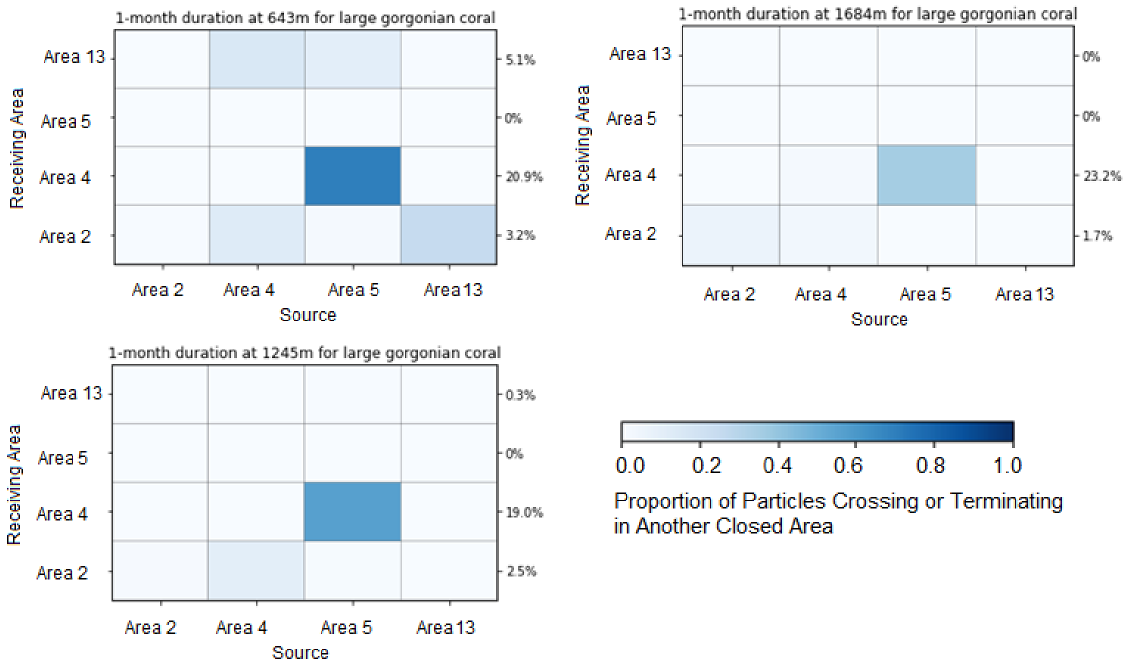


Figure 12.12. The proportion of modeled particles released from each of the 4 areas closed to protect large gorgonian corals (source areas; Areas 2, 4, 5, 13) and passing over or terminating in another area closed to protect large gorgonian corals (receiving areas). For each receiving area the percentage of the total number of crossed, terminated or were retained in the receiving area. Drift duration was 1 month.

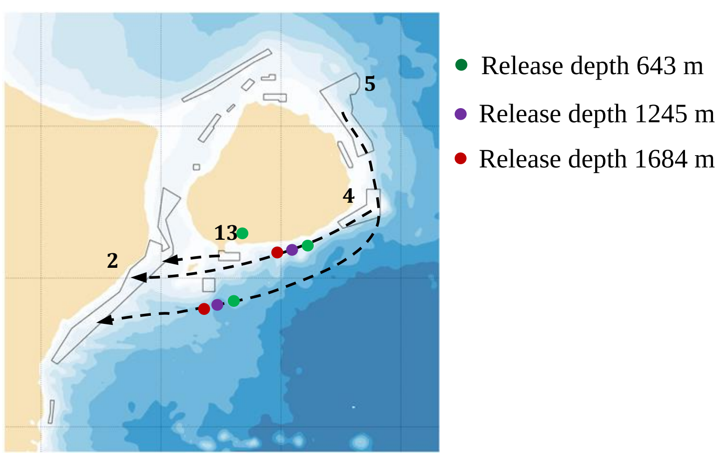


Figure 12.13. Connectivity pathways for particles released at 3 depths in each of the 4 areas closed to protect large gorgonian corals (Areas 2, 4, 5, 13). Area 2 shows some redundancy. Drift durations were 1 month.

Small Gorgonian Corals

Assessment: "Inadequate" (Table 12.2). Management action "Essential". No protection at all except for some overlap with Area 7 closed for sea pens and Area 1 for sponges.

Overall there is poor protection of the small gorgonian corals that are shown to have significant association with biodiversity (see Figure 12.26 below). Large VME areas on the Tail of Grand Bank remain unprotected and overlap with bottom-contact fishing (Figure 12.14). New data collected since 2013 has increased the small gorgonian VME adjacent to the 3O coral closure, linking three separate VMEs identified in 2013. The new larger VME polygon has catches above the threshold (Figure 12.15) and many smaller catches (Figure 12.14).

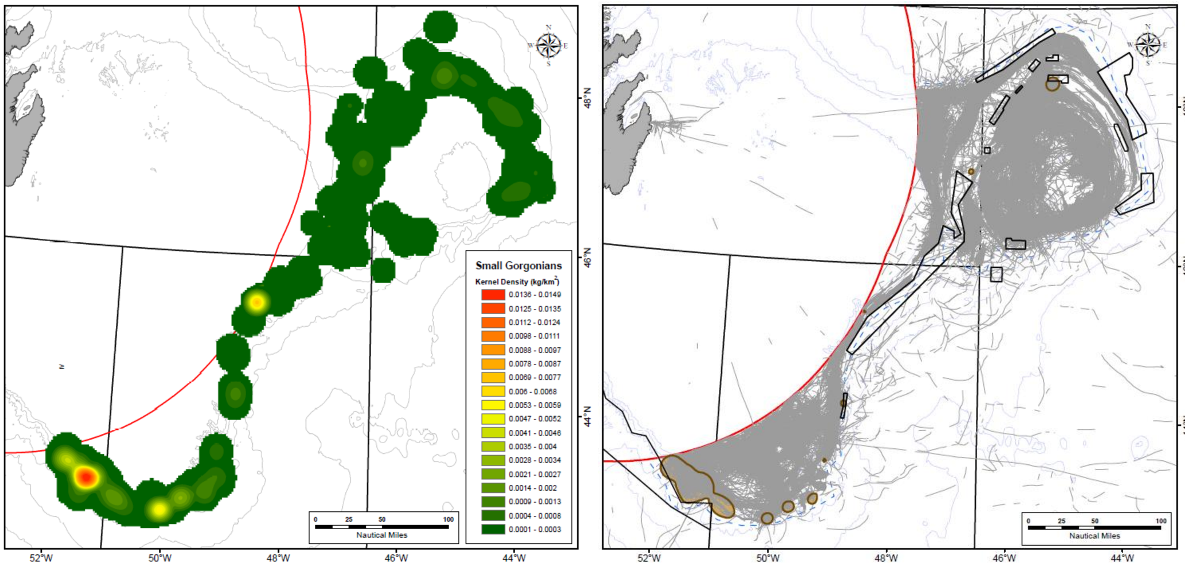


Figure 12.14. Left Panel: Kernel density biomass surface of small gorgonian corals in the NRA based on research vessel catch data. Right Panel: Small gorgonian coral KDE polygons (brown outline) indicative of small gorgonian coral VMEs (*sensu* NAFO 2013), in relation to the 2010-2018 VMS fishing data (grey tracks; NAFO Secretariat 2019) and area closures.

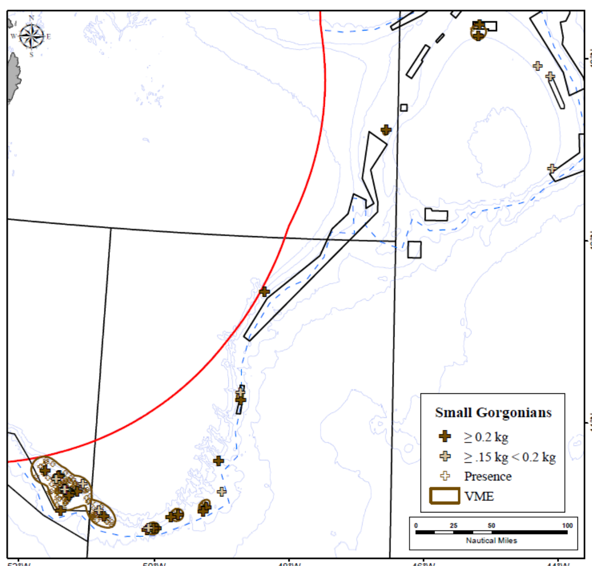


Figure 12.15. Small gorgonian coral KDE polygons indicative of small gorgonian coral VMEs (*sensu* NAFO 2013) and catches within each polygon ≥ 0.2 kg/RV tow, catches ≥ 0.15 kg/RV tow (previous polygon threshold, NAFO 2013), and small gorgonian coral presence, in relation to the area closures.

Sea Squirts **(Boltenia ovifera)**

Assessment: "Inadequate" (Table 12.2). Management action "Essential". No protection at all.

None of the sea squirt VMEs are protected by the current closures. Large VME areas on the Tail of Grand Bank overlap with bottom-contact fishing (Figure 12.16). New models of the occurrence of sea squirts (Figure 12.17) align well with the KDE analysis indicating the that sea squirt VMEs are spatially well-defined.

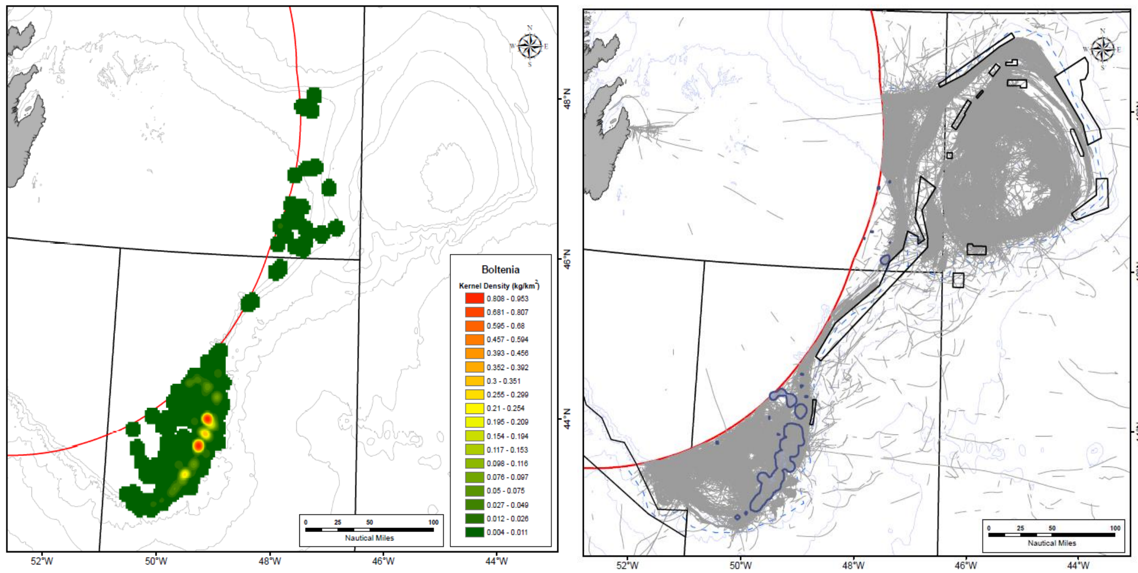


Figure 12.16. Left Panel: Kernel density biomass surface of *Boltenia ovifera* in the NRA based on research vessel catch data. Right Panel: *Boltenia ovifera* KDE polygons (purple outline) indicative of *Boltenia ovifera* VMEs (*sensu* NAFO 2013), in relation to the 2010-2018 VMS fishing data (grey tracks; NAFO Secretariat 2019) and area closures.

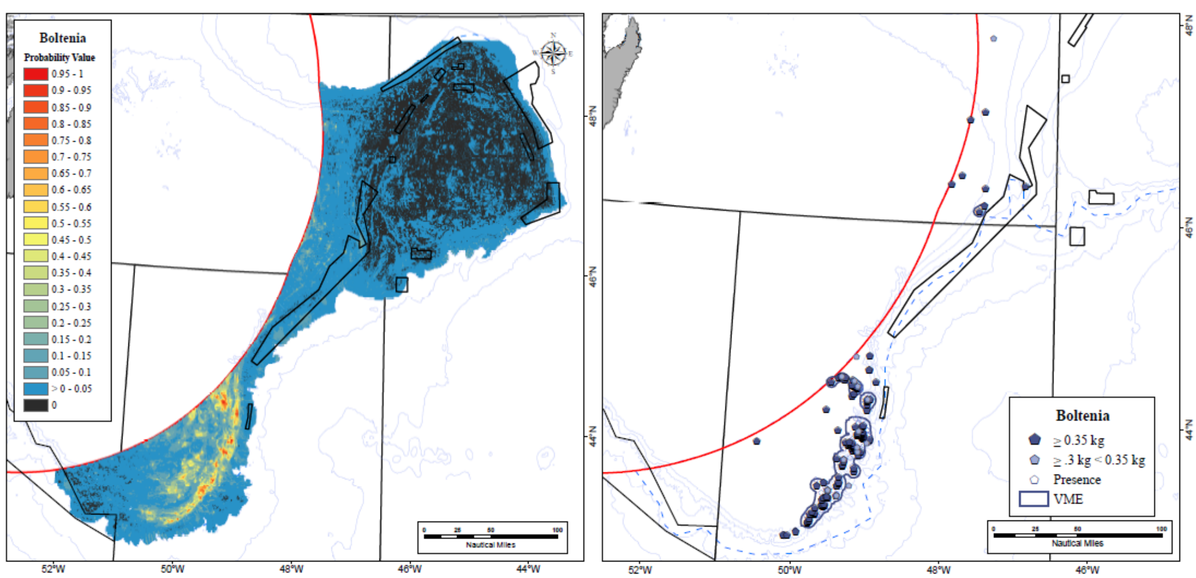


Figure 12.17. Left Panel: Species distribution model of probability of occurrence of *Boltenia ovifera* in the NRA. Right Panel: *B. ovifera* KDE polygons indicative of sea squirt VMEs (*sensu* NAFO 2013) and catches within each polygon ≥ 0.35 kg/RV tow, catches ≥ 0.3 kg/RV tow (previous threshold, NAFO 2013), and *B. ovifera* presence, in relation to the area closures.

Erect Bryozoans

Assessment: “Inadequate” (Table 12.2). Management action “Essential”. Less than 1% protection.

None of the erect bryozoan VMEs are protected by the current closures. Large VME areas on the Tail of Grand Bank overlap with bottom-contact fishing (Figure 18) although there are areas within the largest VME that are coincident with areas of low fishing activity and have the highest catches (Figure 12.18). Catch records are found throughout the large VME but are sparser in the next largest VME to the north (both on the Tail of Grand Bank) (Figure 12.19).

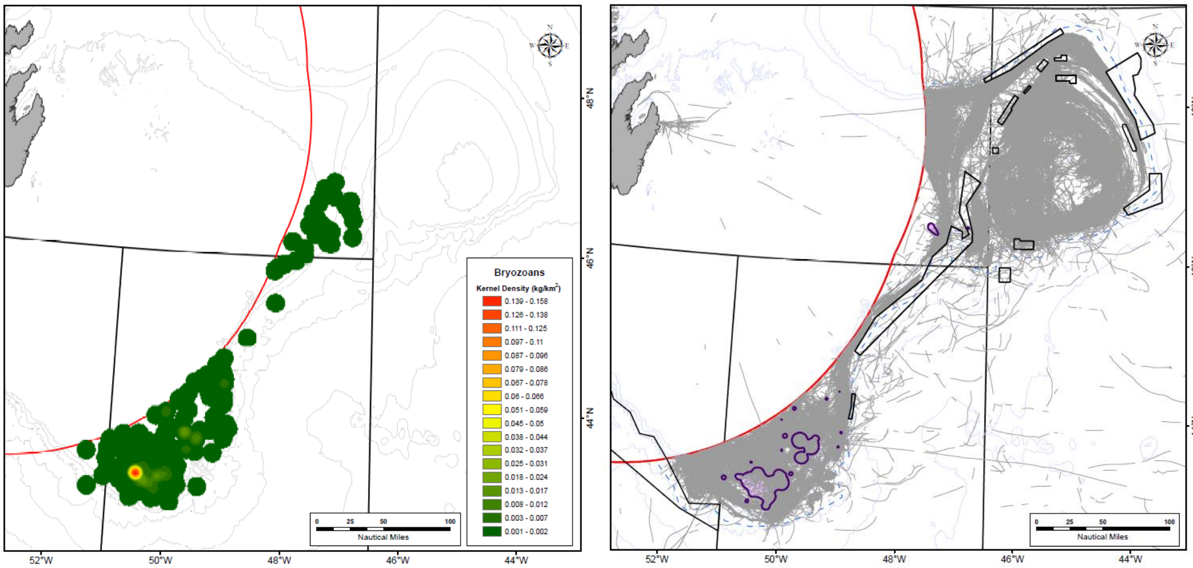


Figure 12.18. Left Panel: Kernel density biomass surface of erect bryozoans in the NAFO Regulatory Area based on research vessel catch data. Right Panel: Erect bryozoan KDE polygons (purple outline) indicative of erect bryozoan VMEs (*sensu* NAFO 2013), in relation to the 2010-2018 VMS fishing data (grey tracks; NAFO Secretariat 2019) and closed areas.

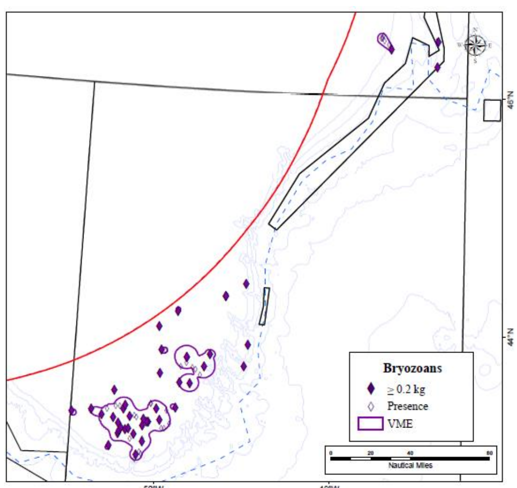


Figure 12.19. Erect bryozoan KDE polygons indicative of erect bryozoan VMEs (*sensu* NAFO 2013) and catches within each polygon ≥ 0.2 kg/RV tow and erect bryozoan presence, in relation to the closed areas.

Black Coral

Assessment: "Poor" (Table 12.2). Management action "Essential".

None of the black coral VMEs are fully protected by the current closures but all are partially protected by areas closed to protect sea pens (Figure 12.20). Predictive models (Figure 12.21) suggest eastern Flemish Cap is potential black coral habitat. Adjustments to the current closures could help protect black coral VME and are coincident with areas of low fishing occurrence (Figure 12.20).

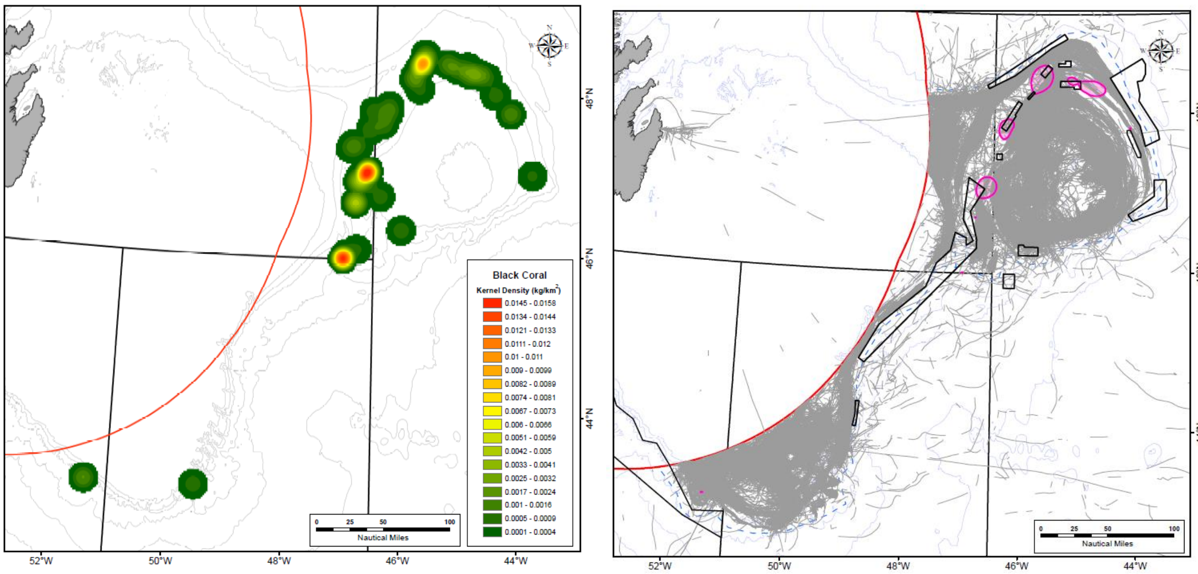


Figure 12.20. Left Panel: Kernel density biomass surface of black corals in the NRA based on research vessel catch data. Right Panel: Black coral KDE polygons (pink outline) indicative of black coral VMEs (*sensu* NAFO 2013), in relation to the 2010-2018 VMS fishing data (grey tracks; NAFO Secretariat 2019) and area closures.

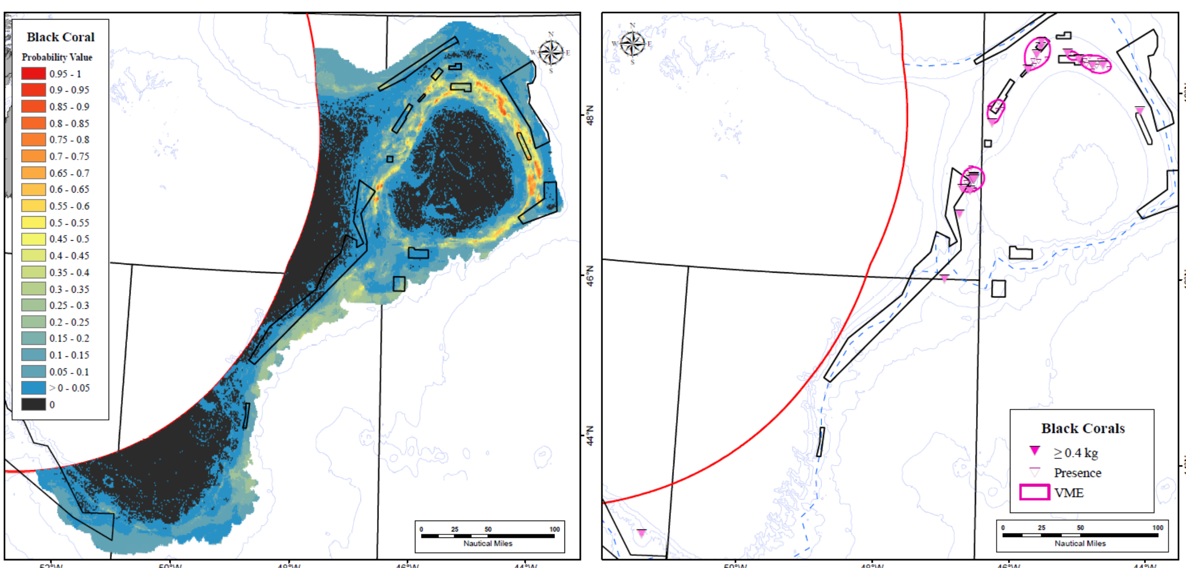


Figure 12.21. Left Panel: Species distribution model of probability of occurrence of black corals in the NRA. Right Panel: Black coral KDE polygons indicative of black coral VMEs (*sensu* NAFO 2013) and catches within each polygon ≥ 0.4 kg/RV tow and black coral presence, in relation to the area closures.

Seamounts

WGESA (NAFO 2013) previously considered information on the ecology of seamounts in terms of structure and function, as well as the effects of human impacts on them. New research with ROVs has reconfirmed the presence of VMEs in the Orphan Knoll closed area (EU Horizon 2020 project SponGES). The working group concluded that the available information supported the continued designation of these areas as VMEs, and WGESA proposed new boundaries for the Corner Rise Seamounts (Area 4 Figure 12.23; Figure 12.24) and Newfoundland Seamounts (Area 2 Figure 12.24; Figure 12.25) to maintain connectivity across the seamount chains and to complete the protection of all vulnerable seamounts in the NRA. The 2019 General Bathymetric Chart of the Oceans (GEBCO) was used to draw the bathymetric contour lines to inform which seamounts previously identified (Kim and Wessel, 2011) were above 2000 m depth. The 2019 ESRI Ocean Basemap (https://www.arcgis.com/home/item.html?id=5ae9e138a17842688b0b79283a4353f6) was used as background layer. It was noted that both the Corner and the New England Seamount chains extend into the Western Central Atlantic Fishery Commission (WECAFC) mandate area. In 2016 WECAFC assigned the status of Vulnerable Marine Ecosystem (VME) to Corner Seamounts, New England Seamounts, Wyoming Seamounts and Congress and Lynch Seamounts bordering the NAFO Convention Area.

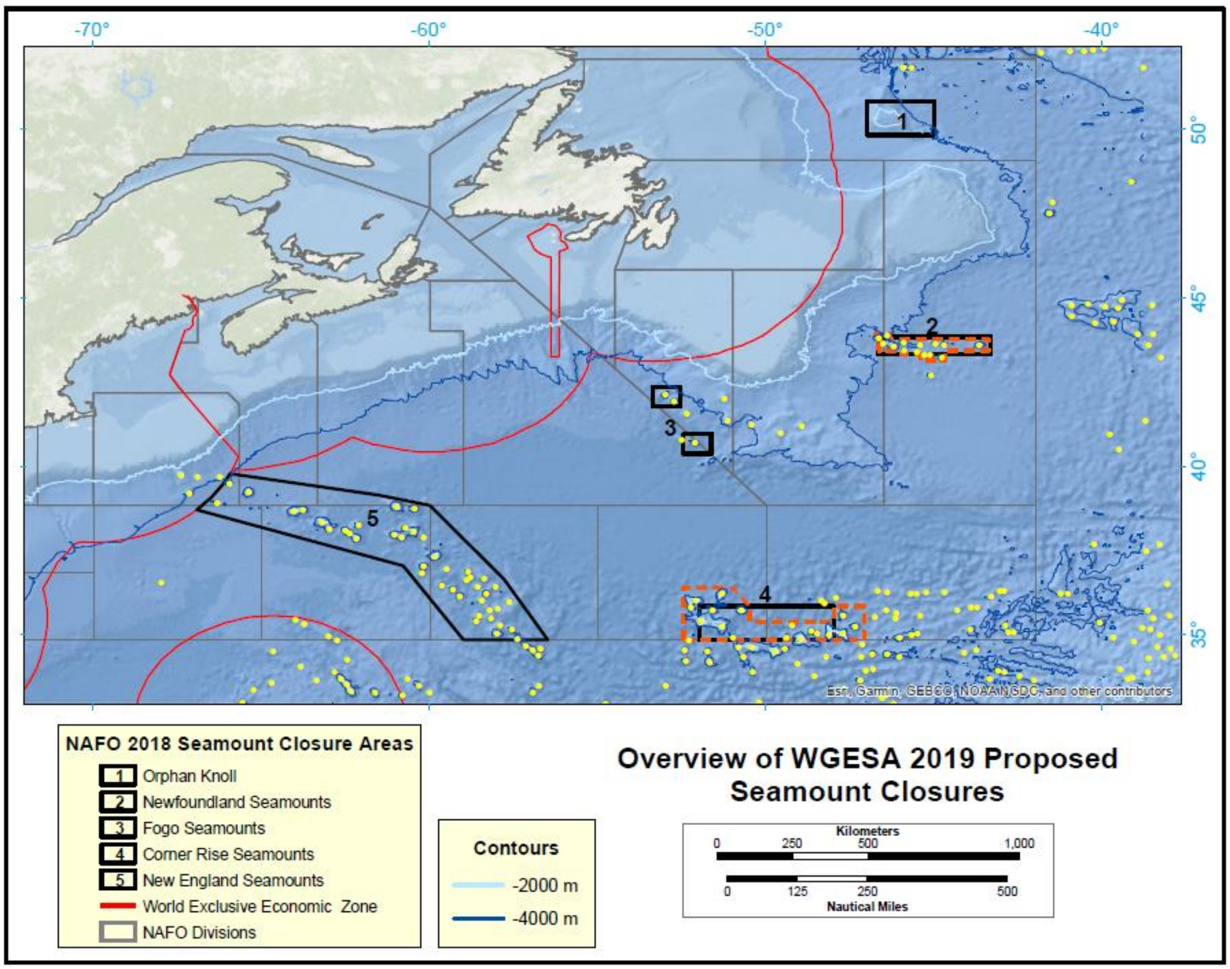


Figure 12.22. Location of the 5 seamount areas in NAFO with closures indicated in black outline. WGESA recommended changes to Areas 2 (Newfoundland Seamounts) and 4 (Corner Rise Seamounts). Yellow dots represent seamounts (source Kim and Wessel, 2011).

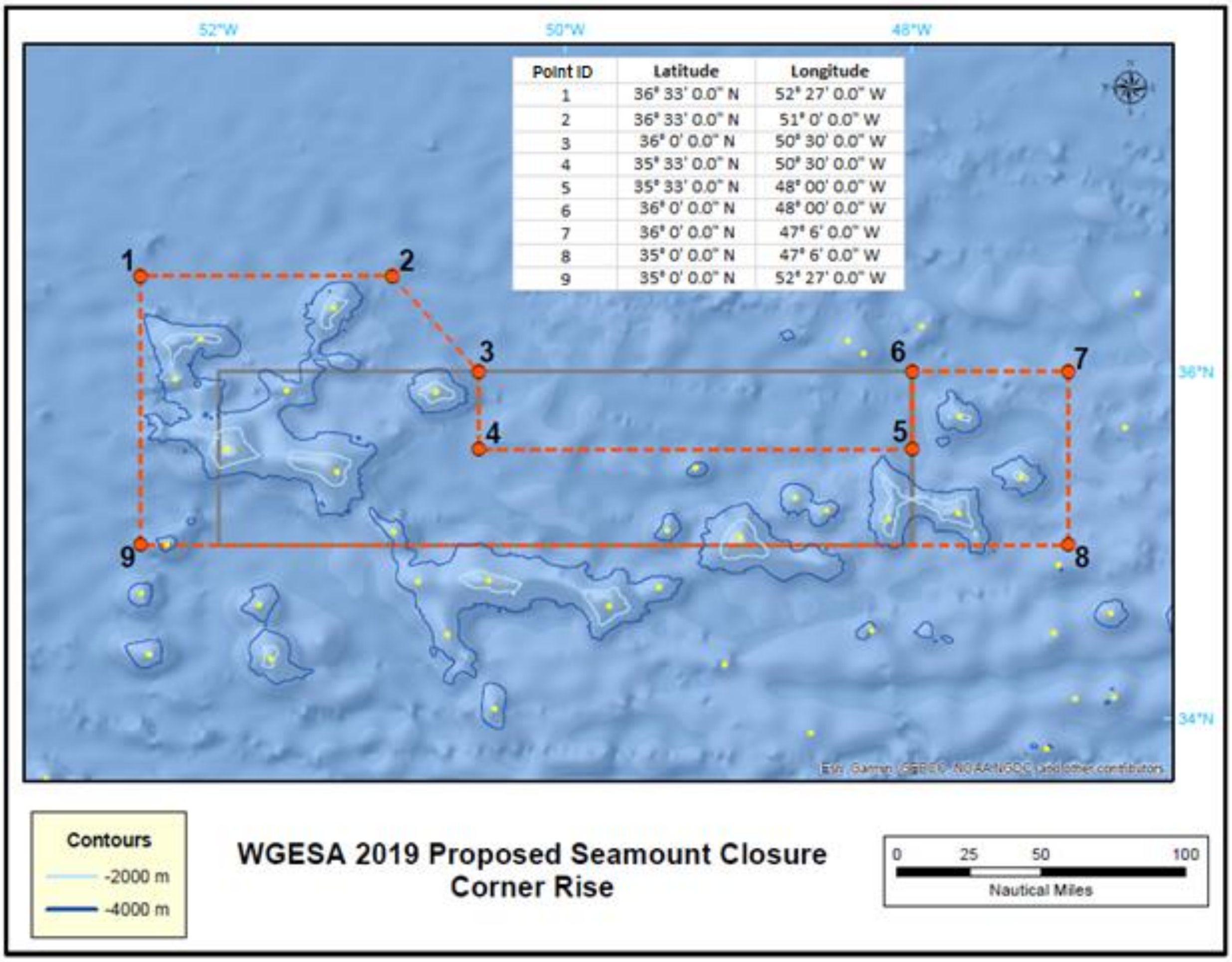
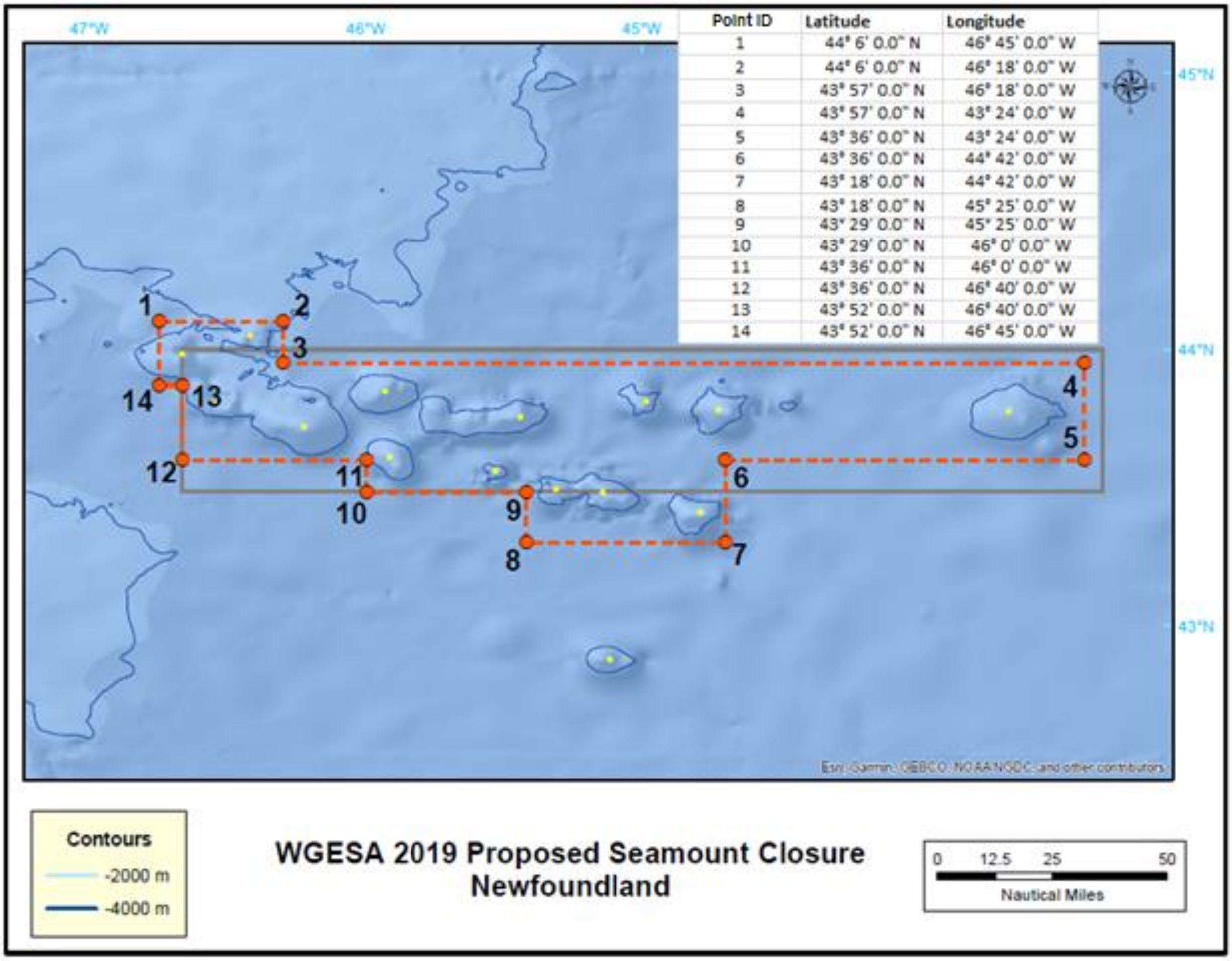


Figure 12.23. Close up of the current closed area to protect VMEs on the Corner Rise Seamounts (grey outline), with proposed boundary changes to capture the unprotected seamounts nearby (red dashed line). Yellow dots indicate seamounts (source Kim and Wessel, 2011), light blue line represents the 2000 m depth contour, the dark blue line represents the 4000 m depth contour. Associated co-ordinates for the new boundary are listed. Note that the seamounts to the south of the bounding box are in the WECAFC area where they are listed as VMEs.



Point ID	Latitude	Longitude
1	44° 6' 0.0" N	46° 45' 0.0" W
2	44° 6' 0.0" N	46° 18' 0.0" W
3	43° 57' 0.0" N	46° 18' 0.0" W
4	43° 57' 0.0" N	43° 24' 0.0" W
5	43° 36' 0.0" N	43° 24' 0.0" W
6	43° 36' 0.0" N	44° 42' 0.0" W
7	43° 18' 0.0" N	44° 42' 0.0" W
8	43° 18' 0.0" N	45° 25' 0.0" W
9	43° 29' 0.0" N	45° 25' 0.0" W
10	43° 29' 0.0" N	46° 0' 0.0" W
11	43° 36' 0.0" N	46° 0' 0.0" W
12	43° 36' 0.0" N	46° 40' 0.0" W
13	43° 52' 0.0" N	46° 40' 0.0" W
14	43° 52' 0.0" N	46° 45' 0.0" W

Figure 12.24. Close up of the current closed area to protect VMEs on the Newfoundland Seamounts (grey outline), with proposed boundary changes to capture the unprotected seamounts nearby (red dashed line). Yellow dots indicate seamounts (source Kim and Wessel, 2011), blue line represents the 4000 m depth contour. Associated co-ordinates for the new boundary are listed.

Biodiversity

The NAFO Convention on Cooperation in the Northwest Atlantic Fisheries includes commitments to the conservation of marine biodiversity in general, and to minimizing the risk of long term or irreversible adverse effects of fishing activities. At the same time, the conservation of marine Biological Diversity of Areas Beyond National Jurisdiction ("BBNJ") has become a high-profile international issue. In June 2015, the United Nations General Assembly adopted Resolution 69/292, calling for the development of an international, legally binding instrument under the United Nations Convention on the Law of the Sea, to address the conservation and sustainable use of BBNJ. While the governance framework has not yet been agreed, it is sure that there will be an increased need for scientific advice to support management of BBNJ, including the documentation of deep-sea biodiversity and how it may be impacted by human activities and by climate change.

Species Density (SpD) on Flemish Cap

Flemish Cap is considered both a bioregion and an ecosystem production unit, based on analyses of a suite of physiographic, oceanographic and biotic variables, while it is treated as a discrete unit, NAFO Division 3M, for management of bottom fisheries. For those reasons, ecosystem-scale biodiversity assessments were undertaken for Flemish Cap only as the Tail of Grand Bank is part of a larger ecosystem extending into Canadian waters.

The data presented in Murillo et al. (2016) were used to quantify diversity metrics based on the benthic invertebrate biomass data from Flemish Cap. Murillo et al. (2016) identified 288 benthic invertebrate taxa, drawn from 11 phyla, in the catches from Flemish Cap. They found seven significantly different epibenthic assemblages on Flemish Cap, between 138 and 1488 m depth. Because the data were derived from the catches taken by standard units of sampling effort (trawl sets), not from collections that each contained a standard number of specimens, the count of species present in the catch from each set was a species density (SpD), rather than a species richness. Sample SpD is not independent of the overall abundance of the catch, though asymptotic values of community richness and SpD are numerically equal. SpD was calculated using the Chao2 estimator in the 'vegan' package from the statistical computing software R 3.5.1.

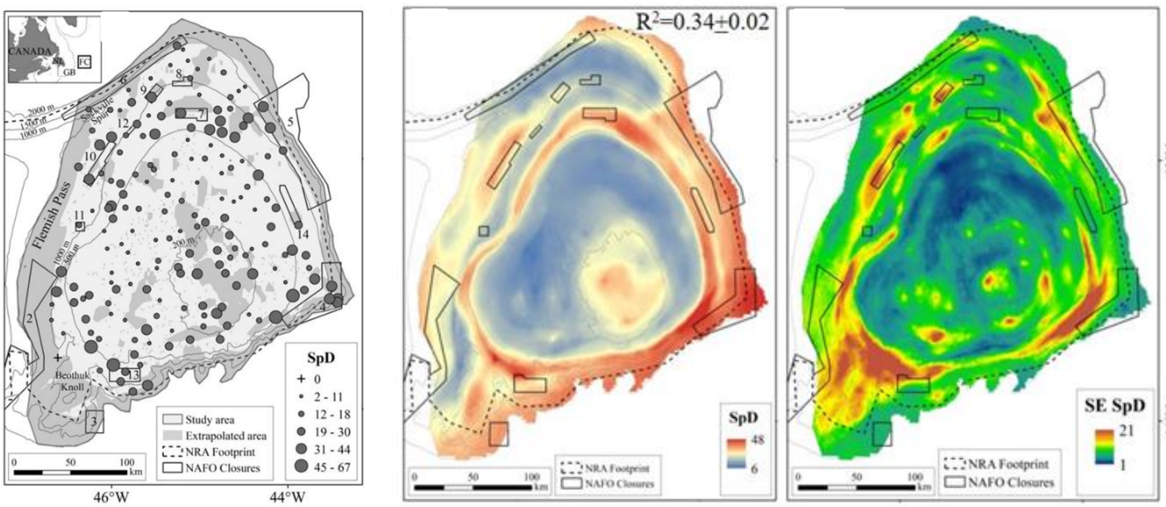


Figure 12.25. Left panel. Map showing the number of benthic invertebrate species (sample SpD) recorded from the catch of each survey set (modified from Murillo et al. 2016). Middle panel. Predicted maps and R^2 from random forest modelling of sample SpD. Right panel. Standard error (SE) associated with the predicted surface. Areas closed to bottom fishing activities to protect sponge and coral concentrations and existing bottom fishing areas (NRA Footprint) are also indicated. From Murillo et al. (2020).

In order to make our results useful for management purposes, we mapped sample SpD using regression random forest (RF) modelling and the 'ranger' package in R. Seven environmental variables and 48 summary statistics of 15 other variables, derived from different sources and with varying spatial resolutions, were used in the modelling as predictor map layers. Prediction and standard error surfaces were created for each biodiversity metric. Goodness-of-fit of each model was evaluated by R^2, calculated using 10-fold cross-validation repeated 10 times (Murillo et al. 2020).

SpD in the catches of individual survey sets varied between 0 and 67 (Figure 12.25). Predicted SpD was highest on the southeastern side of the Flemish Cap, in and near Area 4, and in a ring around the Cap between 500 and 800 m depth, including near Areas 7 and 13 (Figure 12.25). Relatively high values were also observed elsewhere, including on the shallow top of the Cap and in parts of the Flemish Pass. The RF model also predicted high SpD values in deep water to the south of the Cap where data were not available (area of extrapolation, Figure 12.25). Minimum predicted values of SpD were found between 200 and 500 m depth, north of Flemish Cap and south of Flemish Pass. Higher standard error of predicted SpD was found along the southeast of the Cap, at around 500 and 600 m depth, as well as south of Flemish Pass (Figure 12.25). The NAFO closed areas on Flemish Cap are estimated to contain 201 ± 16 (SE) species, representing over 60% of the SpD estimated for the whole of Flemish Cap (326 ± 15 (SE)). Maps of SpD were used to evaluate the closed areas below.

Relationship of Structure-forming Invertebrates with Biodiversity on Flemish Cap

General Additive Models (GAMs) were used to further explore the drivers of sample observed SpD obtained above (Murillo et al. 2020). The GAMs were based on the negative binomial distribution and built using the 'mgcv' package in R. Model selection followed a forward, *stepwise variable*-selection *approach, starting with the independent variable with highest* importance from the base RF Model. The most parsimonious GAM was selected, following the Akaike information criterion (AIC). GAMs examined the effects on SpD of structure-forming epibenthos, here defined as those considered by NAFO to be VME indicators (*viz.* sponges, sea pens, large gorgonian corals and small gorgonian corals), plus black corals and soft corals.

Exploratory analysis showed two patterns in the relationship between SpD and sponge biomass, one driven by the hexactinellid *Asconema foliata* and the other by the remaining sponges. *A. foliata* was therefore considered separately. For each of those seven groups, the biomass taken by each survey set was logarithmically transformed. The dependent variable comprised new sample SpDs calculated from a subset of the catch data that excluded species of corals and sponges belonging to the groups represented among the independent variables. For *A. foliata* we undertook the random forest modeling as described for sample SpD above to model the predicted presence and biomass distribution for this species.

The biomasses of small gorgonian corals and sponges (including *Asconema foliata*) were significantly and positively related to SpD (Figure 12.26). In the Flemish Cap area, the presence of the glass sponge *A. foliata* is associated with higher diversity of epibenthic megafauna, including ophiuroids, crinoids, and other sponges, in Flemish Pass. This glass sponge species reached maximum biomasses on a ring around the Cap between 500 and 700 m depth, mostly outside of the current closures (Figure 12.27). However, four small catches were found in Area 4 and one moderate catch of 1.4 kg inside Area 14 which is currently opened to fishing (NAFO 2019). The results of the present study have shown that small gorgonian corals, considered VME indicators by NAFO, are also positively and significantly associated with SpD in this region.

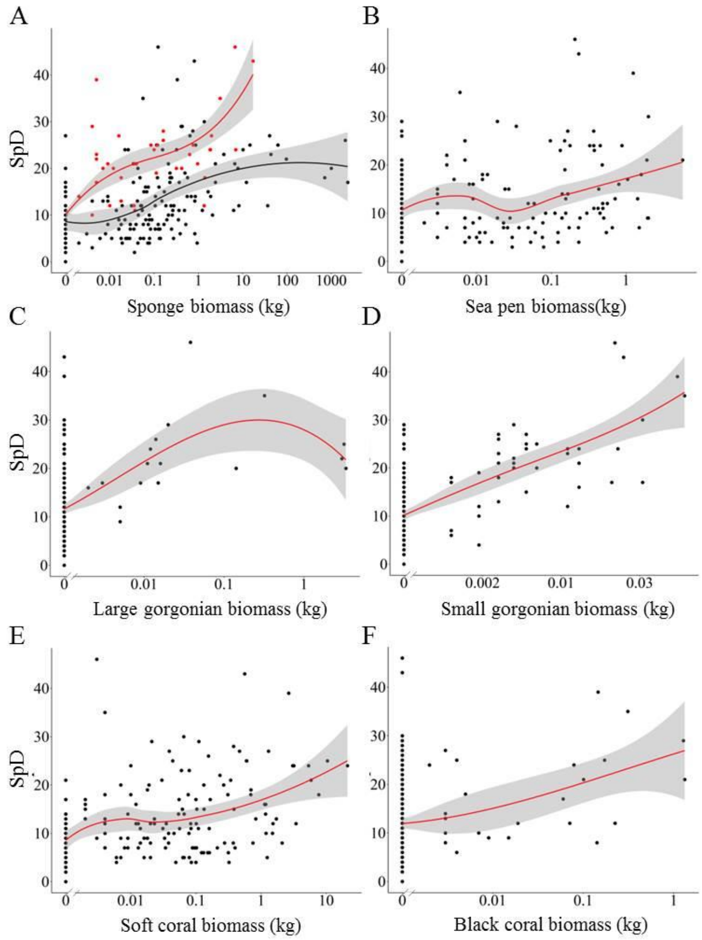


Figure 12.26. Bivariate plots of sample SpD against the biomass of various groups of structure-forming epibenthos taken by the survey sets (plotted on a logarithmic scale, with zero offset). (A) presents data on the biomass of the hexactinellid *Asconema foliata* in red, overlain on the data for other sponges in black. Red and black solid lines are LOESS smoothers (LOESS span of 0.75 for A [black line], B and E. LOESS span of 1 for A [red line], C, D and F). The grey areas represent 95% confidence intervals. From Murillo et al. (2020).

Given the importance of the glass sponge *Asconema foliata* as a VME indicator, the predicted presence distribution of *A. foliata* was determined from random forest modeling using the 'randomForest' package in R with 500 regression trees and default values for the rest of the parameters. Seven environmental variables and 48 summary statistics of 15 other variables, derived from different sources and with varying spatial resolutions, were used in the models as predictor map layers (Murillo et al. 2020). Goodness-of-fit was evaluated by AUC and TSS, calculated using 10-fold cross-validation repeated 10 times (AUC = 0.85 ± 0.01, TSS = 0.58 ± 0.03). Presence and absence observations and predicted distribution of *A. foliata* based on the prevalence threshold of 0.24 of presence and absence observations were plotted (Figure 12.27). Also shown are the areas of model extrapolation (grey polygon may appear red or blue). Maps of the probability of occurrence of the *Asconema foliata* glass sponge (Figure 12.27) were used to evaluate the closed areas on Flemish Cap (below).

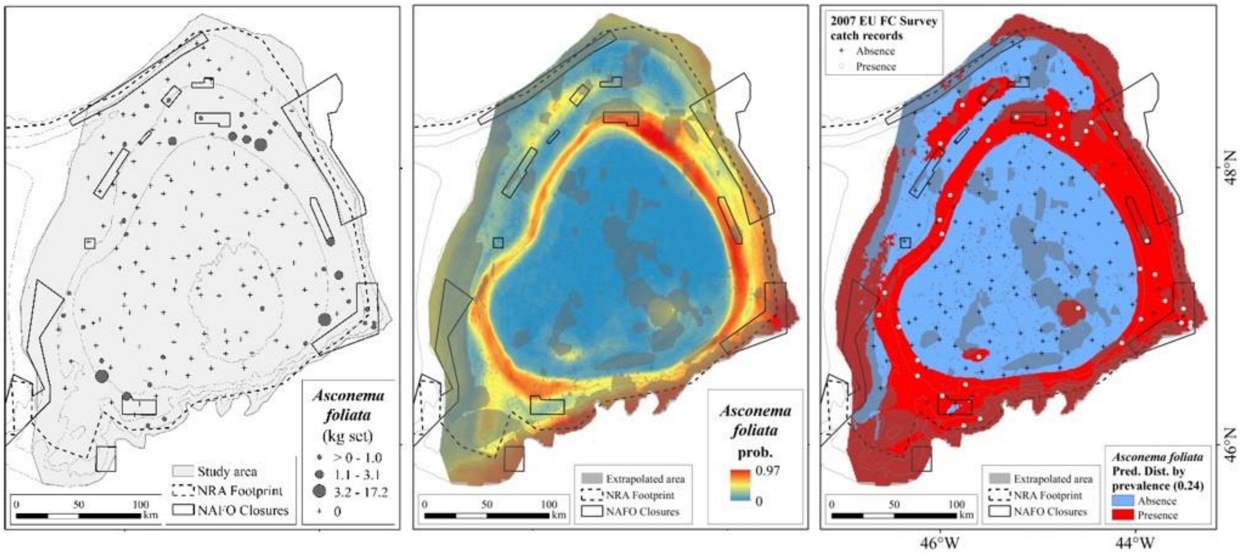


Figure 12.27. Left panel. *Asconema foliata* biomass catches from RV survey in the Flemish Cap area. From Murillo et al. (2020). Middle panel. Predicted presence distribution of *A. foliata* from random forest modeling. Right panel. Presence and absence observations and predicted distribution of *A. foliata* based on the prevalence threshold of 0.24 of presence and absence observations. Also shown are the areas of model extrapolation (grey polygon may appear red or blue).

Effectiveness of Current Closures

Review of Closed Areas in the NRA

For each of the existing closed areas in the NRA an assessment of the effectiveness of the closure, with justification, is provided. The assessment is done on a regional basis. To assist in evaluation, maps are presented for each area. All VMEs (VME polygons with associated catches within them) and presence of biological VME indicator taxa (Crinoidea, tube dwelling anemones) are illustrated. This same map is reproduced with the available VMS data (2010 – 2018) overlain to show the current fishing patterns. Maps of species density and the probability of occurrence of the glass sponge *Asconema foliata* are additionally provided for Flemish Cap. Previously the location of the VME elements and NEREIDA multibeam data as well as the species distribution models with probability of occurrence for black corals, large gorgonian corals, sponges and sea pens were illustrated (NAFO 2013). The former have not changed and so are not repeated here, and the later are shown in Part A with the addition of a model of the probability of occurrence of sea squirts (Figure 12.17).

Division 3O Coral Closure and Area 1 Tail of the Bank

Assessment: "Inadequate", management action "Essential". No protection at all except for sponges.

There are no data to support the presence of VME or VME indicators in the 3O closed area (Figure 12.28). Sea pen and small gorgonian VME overlap in this region and are found immediately adjacent to the existing closure along with cerianthid anemone records and smaller large gorgonian coral and black coral VME (Figure 12.30 right panel). Otherwise there is very little overlap of VMEs between the different habitats (Figure 12.28) . The complete lack of protection of erect bryozoans, sea squirts, sea pens and small gorgonian corals in this region is of high concern. It appears that there are areas of no or light fishing within some of these VMEs (Figures 12.29, 12.30).

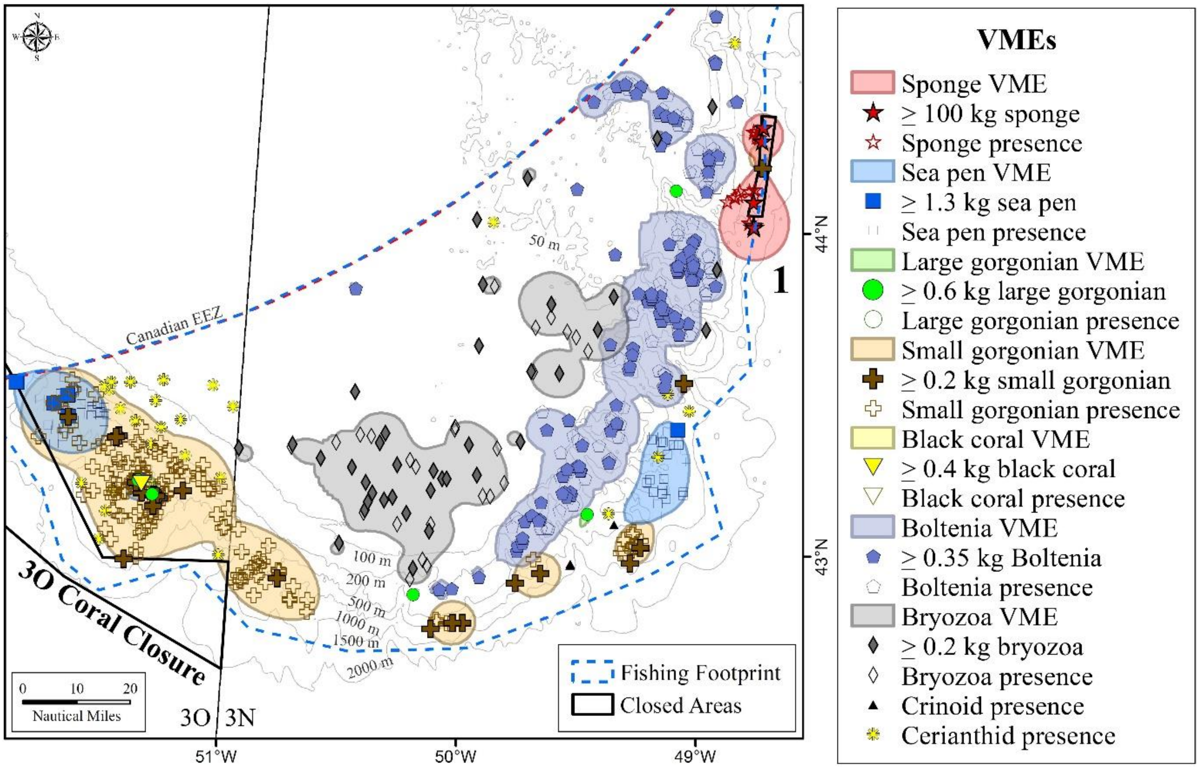


Figure 12.28. Area of 3O Coral Closure and Area 1. VMEs and VME indicator species.

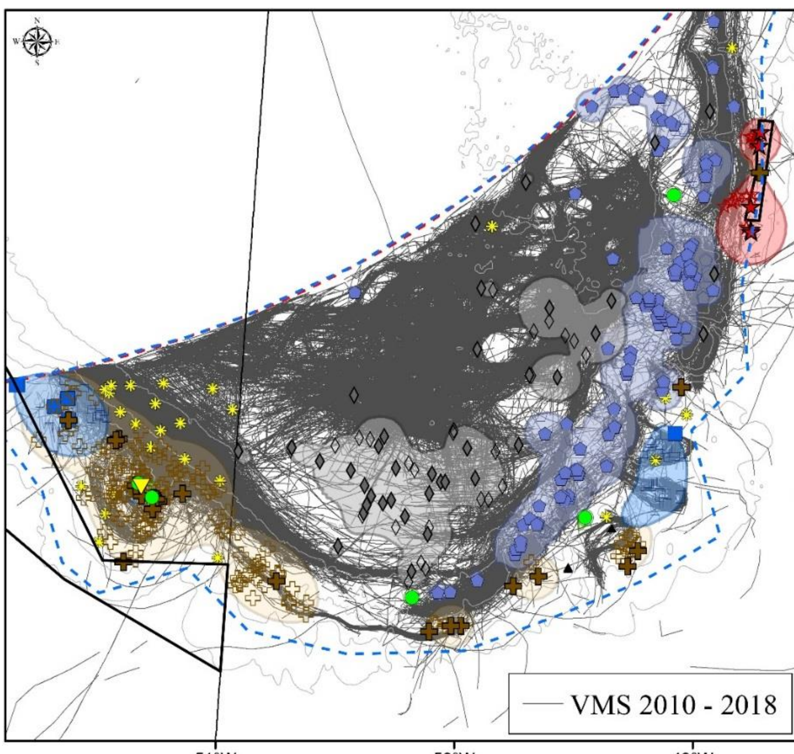


Figure 12.29. Area of 3O Coral Closure and Area 1. VMEs and VME indicator species with VMS fishing data (2010-2018). (See Figure 28 for VME legend).

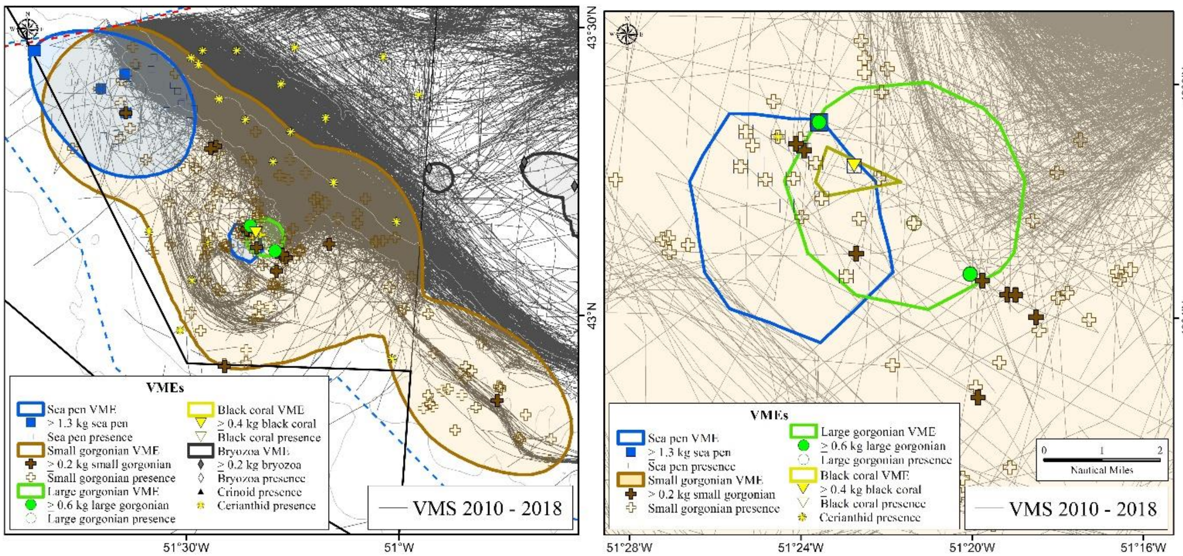


Figure 12.30. Area of 3O Coral Closure. Close ups of VMEs and VME indicator species with VMS fishing data (2010-2018). The area of overlap between VMEs for sea pens, large gorgonian corals and black corals in the small gorgonian coral VME is shown in the right panel.

Area 2 Flemish Pass/Eastern Canyon and Areas 3, 13 Beothuk Knoll

Assessment: “Adequate” for sponges in the south, “Poor” in 3L for sea pens and black corals but adequate for large gorgonian corals, and “Poor” for Area 13, management action “Desirable”.

The Area 2 closure captures the areas of highest probability of occurrence of sponges (Figure 12.31), and capture important areas with large gorgonian corals in the Flemish Pass. Sponge catches outside the closed area within the VME area should be considered. There are large gorgonian coral present outside the closed area as well and the areas overlap in the unprotected notch towards the northern extent of Area 2. Outside of the current closure overlapping black coral and sea pen VMEs occur in areas that appear to be unfished or lightly fished (Figure 12.31). Area 13 boundaries could be adjusted to capture large gorgonian coral and sponge VME (Figure 12.31).

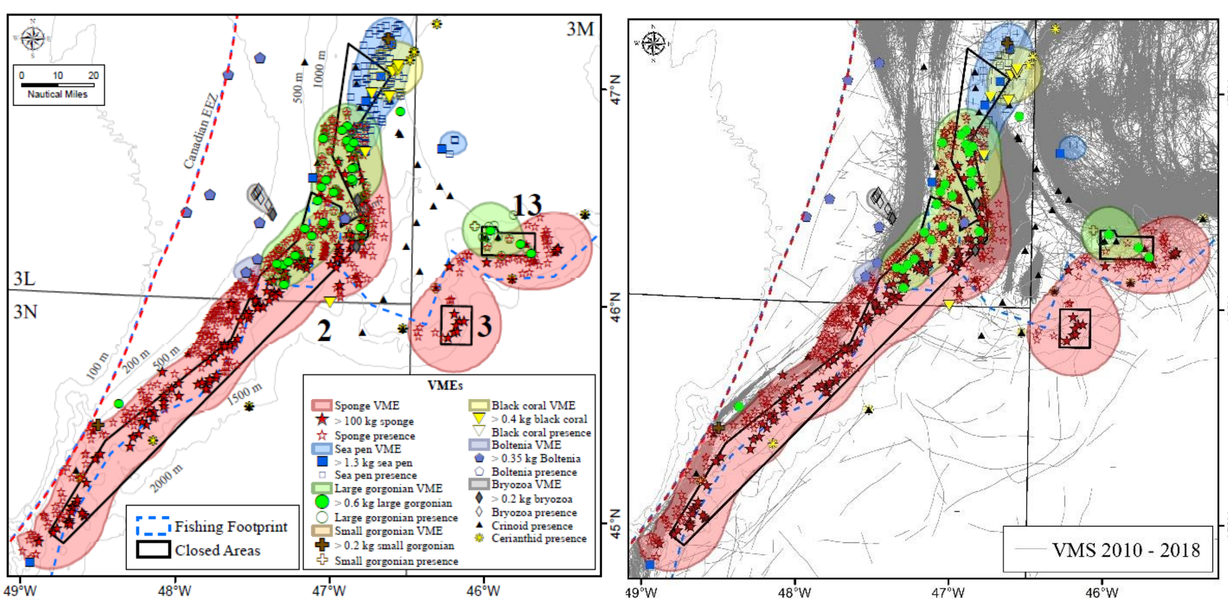


Figure 12.31. Area 2 Flemish Pass/Eastern Canyon and Areas 3, 13 Beothuk Knoll. Left Panel: VMEs and VME indicator species. Right Panel: VMEs and VME indicator species with VMS fishing data (2010-2018).

Areas 4-12 Flemish Cap and Sackville Spur Including Area 14

Assessment: "Inadequate", management action "Essential".

Areas 7, 9, 10, 12, 14 all have two or three VMEs in their boundaries or surrounds and are too small to ensure connectivity among closures. Area 7 and Area 14 are areas where the glass sponge *Asconema foliata* is predicted to occur with high probability and species density is also high (Figure 12.32). Area 10 could be expanded into the area that appears to have low coincidence of fishing, to protect sponge and black coral VME. Areas 7, 8 and 9 could be connected to facilitate connectivity among the areas closed to protect sea pens. Area 7 could be expanded to the east to give adequate protection to black coral VME and sea pen VME facilitating at the same time connectivity between Areas 7, 8, 9 and 14. The area between Area 5 and Area 4 could be protected to protect sponge VMEs and strengthen the connectivity shown to occur there.

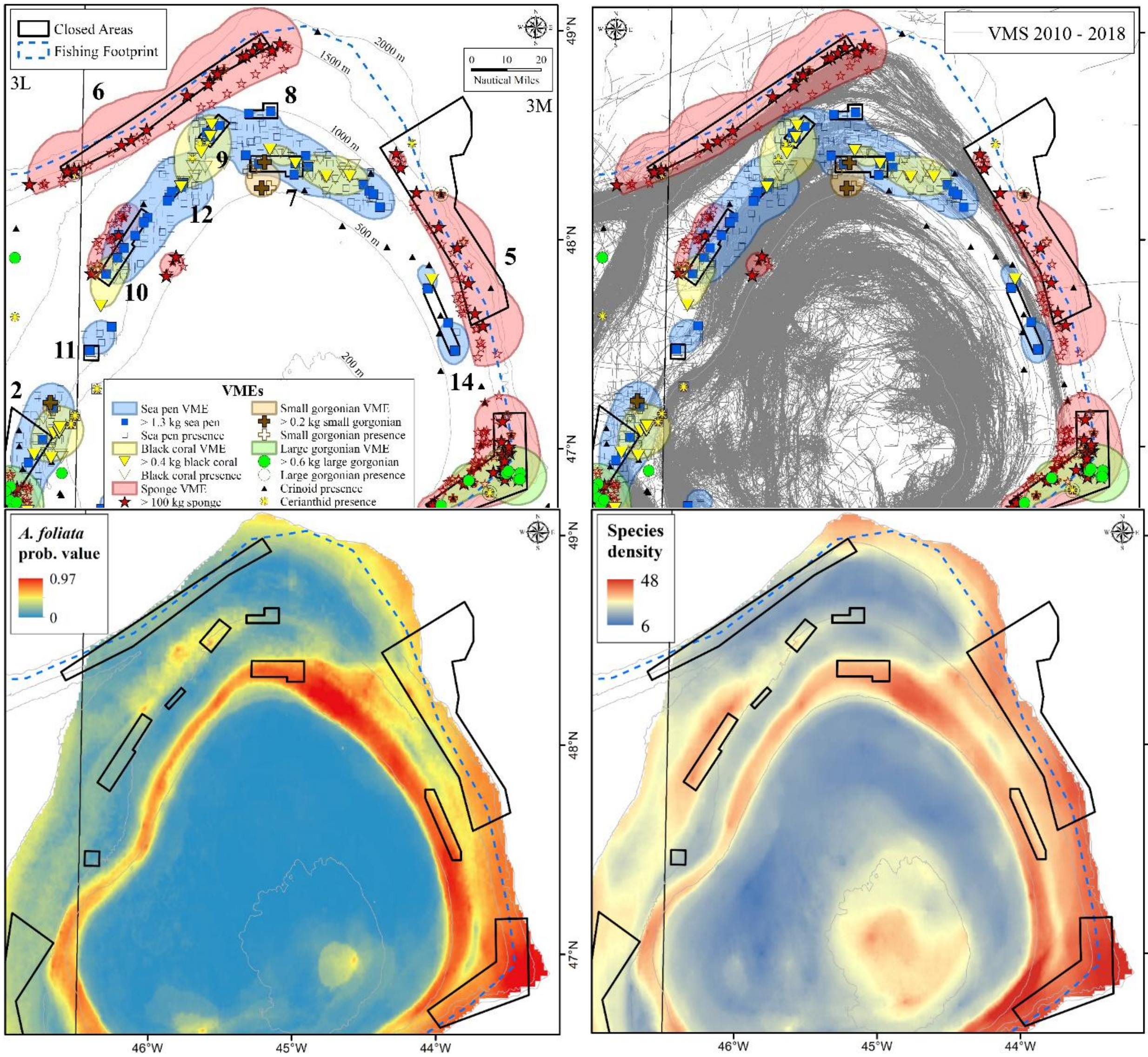


Figure 12.32. Areas 4-12 Flemish Cap and Sackville Spur Including Area 14. Upper Left Panel: VMEs and VME indicator species. Upper Right Panel: VMEs and VME indicator species with VMS fishing data (2010-2018). Lower Left Panel: *Asconema foliata* glass sponge probability of occurrence. Lower Right Panel: Predicted species density (number of benthic invertebrate taxa per RV trawl set).

High Priority Areas for Management Action

The areas requiring urgent management action are the VME areas on the Tail of Grand Bank and the sea pen closures on Flemish Cap. The former have completely unprotected VME (small gorgonian corals, sea squirts, sea pens, and erect bryozoans) while the latter have overlapping VMEs (2-4 habitats including glass sponges), and are too small to ensure protection from fishing and to enable connectivity among closures. New boundaries for seamount closures have been proposed and management action would be desirable.

A summary of the re-assessment of the NAFO closed areas and how each VME taxon is protected based on the information provided above is given in Table 12.4.

Table 12.4. Re-assessment of NAFO closed areas. Overview of recommendations and need for management action (see Table 12.2) for each of the VME taxa considering their overall protection, and regionally-specific assessments of the effectiveness of the closed areas, all ranked by need for management action.

VME Type/Closure	Recommendation	Management Action
Small Gorgonian Corals	Inadequate	Essential
Sea Squirts (Boltenia ovifera)	Inadequate	Essential
Erect Bryozoans	Inadequate	Essential
Black Coral	Poor	Essential
Sea Pens	Poor	Essential
Large Gorgonian Corals	Incomplete	Desirable
Large-Sized Sponges	Incomplete	Desirable
Division 3O Coral Closure and Area 1 Tail of the Bank	Inadequate	Essential
Areas 4-12 Flemish Cap and Sackville Spur Including Area 14	Inadequate	Essential
Area 2 Flemish Pass/Eastern Canyon and Areas 3, 13 Beothuk Knoll	Adequate-Poor	Desirable
Seamounts	Incomplete	Desirable

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13. Review of VME Indicators

COM Request [7] and **ToR 1.2*. Update on identification and mapping of sensitive species and habitats (VMEs) in the NAFO area.***

Review of VME indicator species

During the 11th meeting of the NAFO Scientific Council WG-ESA held in 2018, a comprehensive review of the existing list of vulnerable marine ecosystem (VME) indicator species in Annex 1.E of the NAFO Conservation and Enforcement Measures (NCEM) was conducted in order to prepare for the reassessment of the VME fishery closures in 2020 (NAFO, 2018). Since the last assessment of potential (non-coral and non-sponge) VME indicator taxa of the NRA was conducted (see Murillo et al., 2011), a number of potential VME taxa had been reported from the region, and the nomenclature of existing VME indicators had been revised according to the World Register of Marine Species (WoRMS) database (http://www.marinespecies.org/). During the meeting, a total of 8 VME indicator taxa on the existing list in the NAFO CEM were updated to reflect the current nomenclature. Similarly, 13 newly documented large-sized sponge taxa for the region were reviewed against the biological traits deemed relevant to the FAO guidelines on VME designation (see Murillo et al., 2011) and recommended for inclusion in the list of VME Indicator Taxa in the NAFO CEM.

At the 12th WG-ESA meeting, the working group discussed any known changes to the existing list of VME indicators and found that the taxonomic status of three VME taxa found in the NRA has been recently revised (Table 14.1). The sea pen *Pennatula grandis* has been moved to the genus *Ptilella* by García-Cárdenas et al. (2019), and two gorgonians of the genus *Corallium* have been moved to the genus *Hemicorallium* (Tu et al. 2015). The placement of *P. grandis* in *Ptilella* has been deemed as tentative by the authors, who suggested that a family revision is warranted. For this year, the working group suggested that the taxonomic status of the above-mentioned taxa remain unchanged in the List of Indicator Taxa. **The group proposed that a review of the existing list is conducted each year under a standing ToR and that a running list of such changes to the taxonomy and nomenclature be kept until every third year, when such revisions are submitted as recommendations to SC.** Thus any future changes to the existing list of VME Indicator Taxa will be submitted next to SC in 2021 along with updates to the Coral, Sponge, and Other Vulnerable Marine Ecosystem Indicator Identification Guide, NAFO Area (Kenchington et al., 2015).

Table 13.1. Recent changes to the nomenclature of taxa considered VME Indicator Taxa by NAFO.

Common Name	Known Taxon	Replacement Name or Action	Reason	Reference
Sea Pens (NTW – Pennatulacea)	Pennatula grandis	Ptilella spp.	Re-examination of taxonomic material	García-Cárdenas et al. (2019)
Large Gorgonians	Corallium bayeri	Hemicorallium bayeri	Re-examination of taxonomic material	Tu et al. (2015)
Large Gorgonians	Corallium bathyrubrum	Hemicorallium bathyrubrum	Re-examination of taxonomic material	Tu et al. (2015)

Black corals were previously considered VME indicators by NAFO due to their fragility, vulnerability, and apparent rare distribution across the NRA based on the available information of their distribution (Fuller et al., 2008; Murillo et al., 2011). However, subsequent data collected on black corals from the NEREIDA program revealed a relatively widespread, but low-density distribution across the NRA. At the time, this non-aggregating distribution prevented the application of kernel density estimation techniques to identify areas of higher concentration (NAFO, 2013). However, since 2013, additional data on the distribution of black corals in the NRA has been collected through EU-Spanish and Canadian RV trawl surveys. The spatial distribution and cumulative catch weight distribution of these data were assessed by the working group at the 12th WG-ESA meeting (see SCR-Doc. 19-058) and were found to be suitable for the application of kernel density estimation analyses. The analyses were performed and identified a catch weight threshold of 0.4 kg, with KDE polygons distributed on the north and northwestern Flemish Cap and on the Tail of Grand Bank. The KDE polygons showed good congruence with areas of higher presence probability identified via species distribution modelling techniques (Knudby et al., 2013) and with anecdotal observations on the location of a black coral hotspot (discussed in SCR-Doc. 19-058). The longevity, fragility, and vulnerability of this iconic group warrants their inclusion on the list of VME Indicator Taxa in the NAFO CEM. In the previous assessment of the closed areas conducted in 2013 (NAFO, 2013) the locations of black coral catches were included in the assessment. In order to improve on that *ad hoc* approach, in the 2019 re-assessment of the closed areas the KDE polygons were used to highlight these areas of higher concentration and bring the black corals into the assessment framework applied to other VME indicators. *Sticopathes* sp. and *Stauropathes arctica* are already included in the Coral, Sponge, and Other Vulnerable Marine Ecosystem Indicator Identification Guide, NAFO Area (Kenchington et al., 2015). If approved by SC additional black coral VME indicators will be added.

Recommendation:

Based on the new kernel density estimation (KDE) analyses of black corals conducted during the 12th WG-ESA meeting (see SCR-Doc. 19-058) and the recommendations outlined in *ToR 1.2. Review of VME Indicator Species,* WG-ESA **recommends** to SC *the inclusion of black corals, and its following constituent taxa, in the list of VME Indicator Taxa of the 2021 NAFO CEM:*

Table 13.2. Black coral taxa known to occur in the NAFO Regulatory Area (including seamounts).

Known Taxon	Family	Included in NAFO VME Guide
Stichopathes sp.	Antipathidae	Yes
Leiopathes cf. expansa	Leiopathidae	No
Leiopathes sp.	Leiopathidae	No
Plumapathes sp.	Myriopathidae	No
Bathypathes cf. patula	Schizopathidae	No
Parantipathes sp.	Schizopathidae	No
Stauropathes arctica	Schizopathidae	Yes
Stauropathes cf. punctata	Schizopathidae	No
Telopathes magnus	Schizopathidae	No

References

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14. ATLAS Flemish Cap SDM

COM Request [7] and **ToR 1.2.** ***Update on the Research Activities Related to EU-funded Horizon 2020 ATLAS Project, Flemish Cap Case Study: Species Distribution Models (SDMs) for two deep-water corals in the Flemish Cap and Flemish Pass area (Northwest Atlantic Ocean)***

During the 12th NAFO WGESA meeting, EU ATLAS project (in collaboration with iSEAS project) was presented giving updated information regarding Species Distribution Models (SDMs) for the *Pennatula aculeata* and *Acanella arbuscula* deep-water corals for Flemish Cap Case Study (Flemish Cap and Flemish Pass areas).

ATLAS project is a four-year EU-funded Horizon 2020 project (www.eu-atlas.org) that started in May 2016 and aims to gather diverse new information on sensitive Atlantic ecosystems (including Vulnerable Marine Ecosystems and Ecologically or Biologically Sensitive Areas) to produce a step-change in our understanding of their connectivity, functioning and responses to future changes in human use and ocean climate. This is possible because ATLAS takes innovative approaches to its work and interweaves its objectives by placing business, policy and socio-economic development at the forefront with science.

The main partners involved in this Case Study (Figure 14.1) are the Instituto Español de Oceanografía (IEO), Centro Oceanográfico de Vigo, and Fisheries and Oceans Canada (DFO), Bedford Institute of Oceanography. Both have extensive experience (e.g. NEREIDA project) and have plans to develop future research in the area.

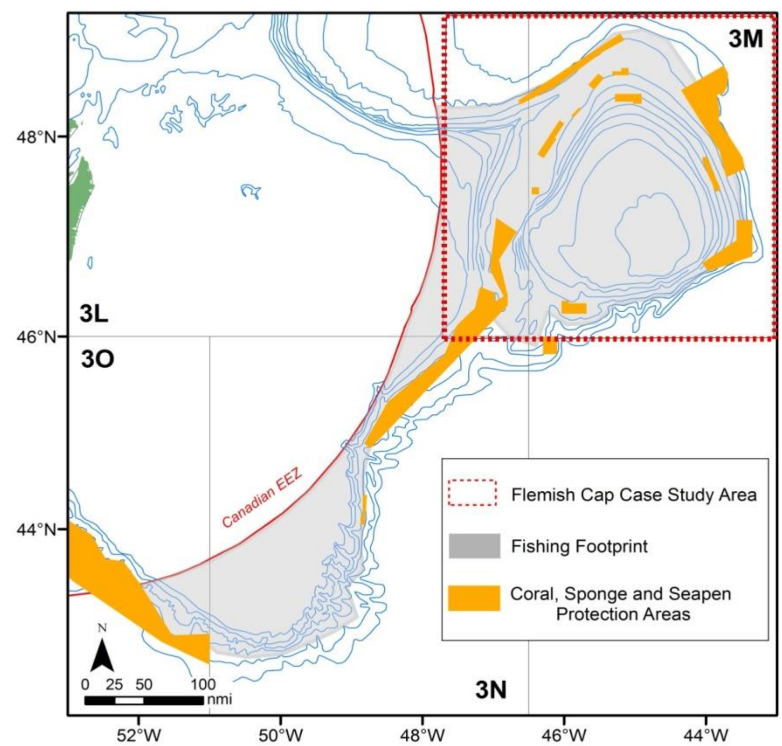

Figure 14.1. Flemish Cap Case Study spatial extent (red dashed line)

Regarding SDMs, different modeling algorithms were presented to classify the probability of habitat suitability for *Pennatula aculeata* and *Acanella arbuscula* as a function of a set of environmental variables.

Species data were collected during two bottom-trawl groundfish surveys carried out by the Instituto Español de Oceanografía (IEO) jointly with the European Union (EU): i) the EU Flemish Cap survey sampled all the Flemish Cap (NAFO Division 3M) and ii) the Spanish 3L survey sampled the "Nose" of the Grand Banks of Newfoundland and the Flemish Pass (NAFO Division 3L)

For modeling, both oceanographic variables and bathymetric features were used as predictors of species habitat suitability:

I. Oceanographic variables: Sea Bottom Temperature (CTD); Sea Bottom Salinity (CTD); Mixed layer depth and Bottom Current Speed (VIKING20 model).

II. Bathymetric features: bathymetry, slope and orientation of the seabed (retrieved from NEREIDA project and MARSPEC database), sediment texture and gravel (Murillo, 2016).

III. In addition, and following the suggestions made during the 2018 Scientific Council June meeting (p. 121, NAFO SCS Doc. 18-19. Serial No. N6849), fishing effort layer was included as a new predictor variable. The updated results were presented during the 12th WGESA meeting.

Three different modelling techniques were implemented: Generalised Additive Models (GAM), Random Forest (RF), and MAXENT (Maximum Entropy model). Models were built in the free spatial statistical computing software R (R development Core Team, 2016) using the necessary packages for each case. Only for the Maximum Entropy method, freely available software was used: MAXENT 3.4.1 (MAXENT, 2017). We also estimated species probability of occurrence based on an ensemble of all models, as such predictions are often more robust than predictions derived from a single model. Ensemble predictions were calculated as averages of single-model predictions.

The objective was to identify potentially complex linear and non-linear relationships in multi-dimensional environmental space and to predict the distribution of *Pennatula aculeata* and *Acanella arbuscula* deep-water corals in unsampled locations of the Case Study area.

Maps showing the probability of habitat suitability for *P. aculeata* (Figure 14.2) and *A. arbuscula* (Figure 14.3) in the Flemish Cap and Flemish Pass were presented together with model prediction performance statistics (AUC; Specificity; Sensitivity, TSS and correlation of the different models) in order to assess the accuracy of the different SDMs implemented. Statistics were presented for models with and without inclusion of a fishing effort layer.

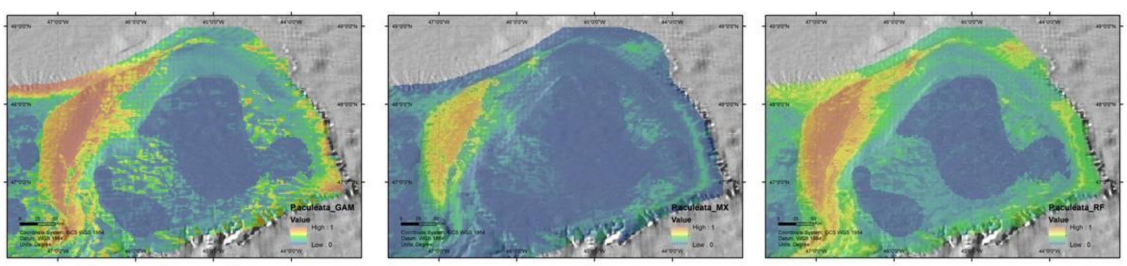

Figure 14.2. Probability of habitat suitability for *P. aculeata* for GAM, MAXENT and Random Forest models.

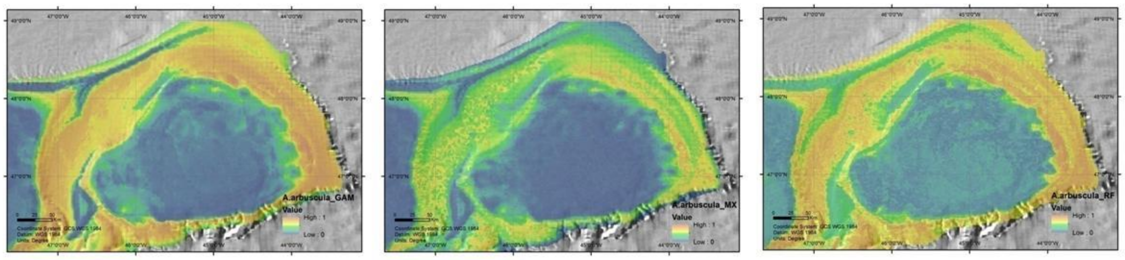

Figure 14.3. Probability of habitat suitability for *A. arbuscula* for GAM, MAXENT and Random Forest models.

Response curves for both species were presented during the 12th NAFO WGESA (Figures 14.4 and 14.5).

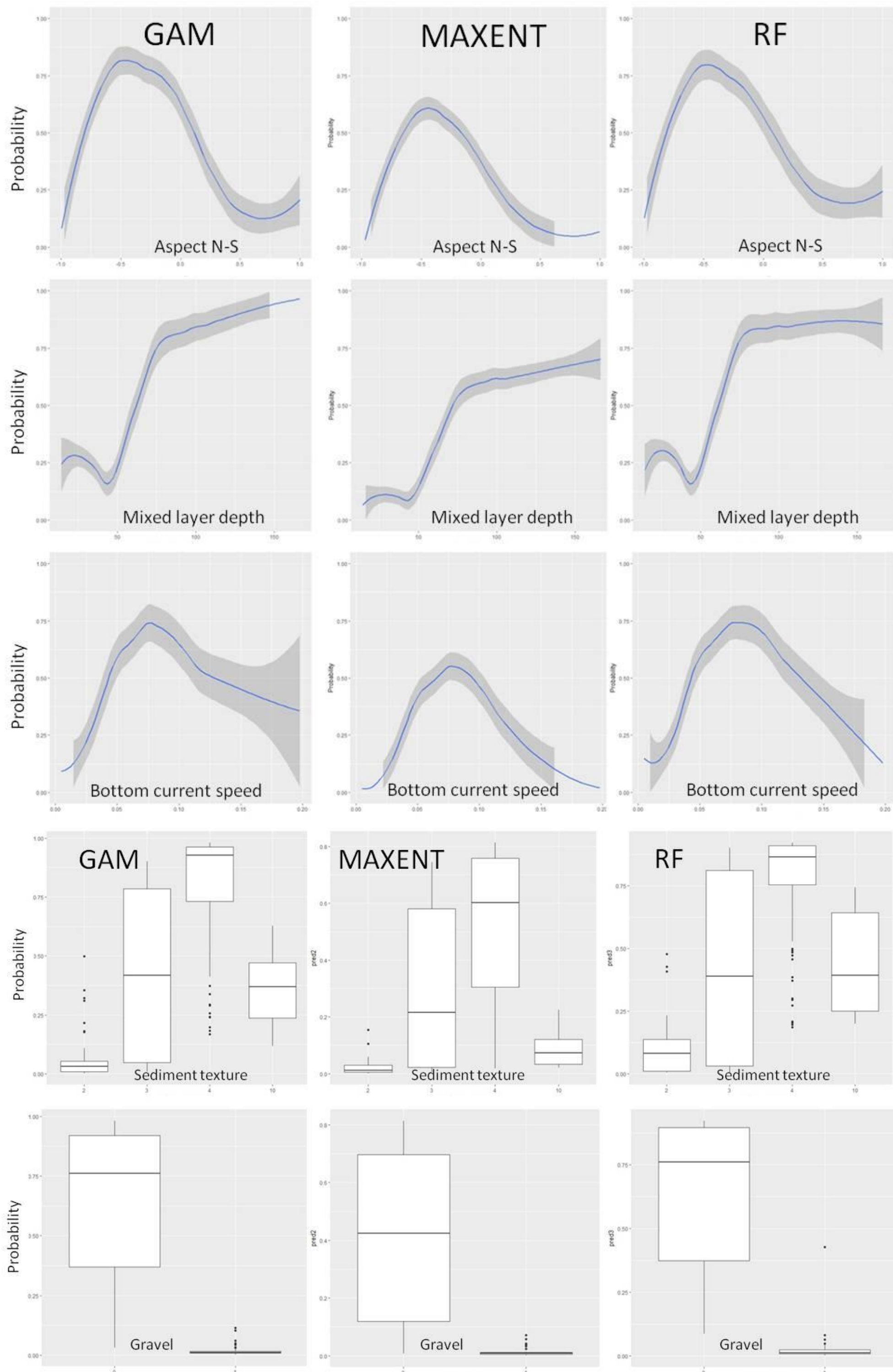

Figure 14.4. Partial GAM, Maxent and Random Forest (left, middle and right plots) for the selected continuous and categorical variables for *Pennatula aculeata* (From top to bottom: Aspect component N-S, Mixed layer depth, Bottom current speed, Sediment texture and Gravel). Each plot represents the response variable shape, independent of the other variables, in relation to the probability of the species occurrence. Confidence intervals (95%) around the response curve are shaded in grey.

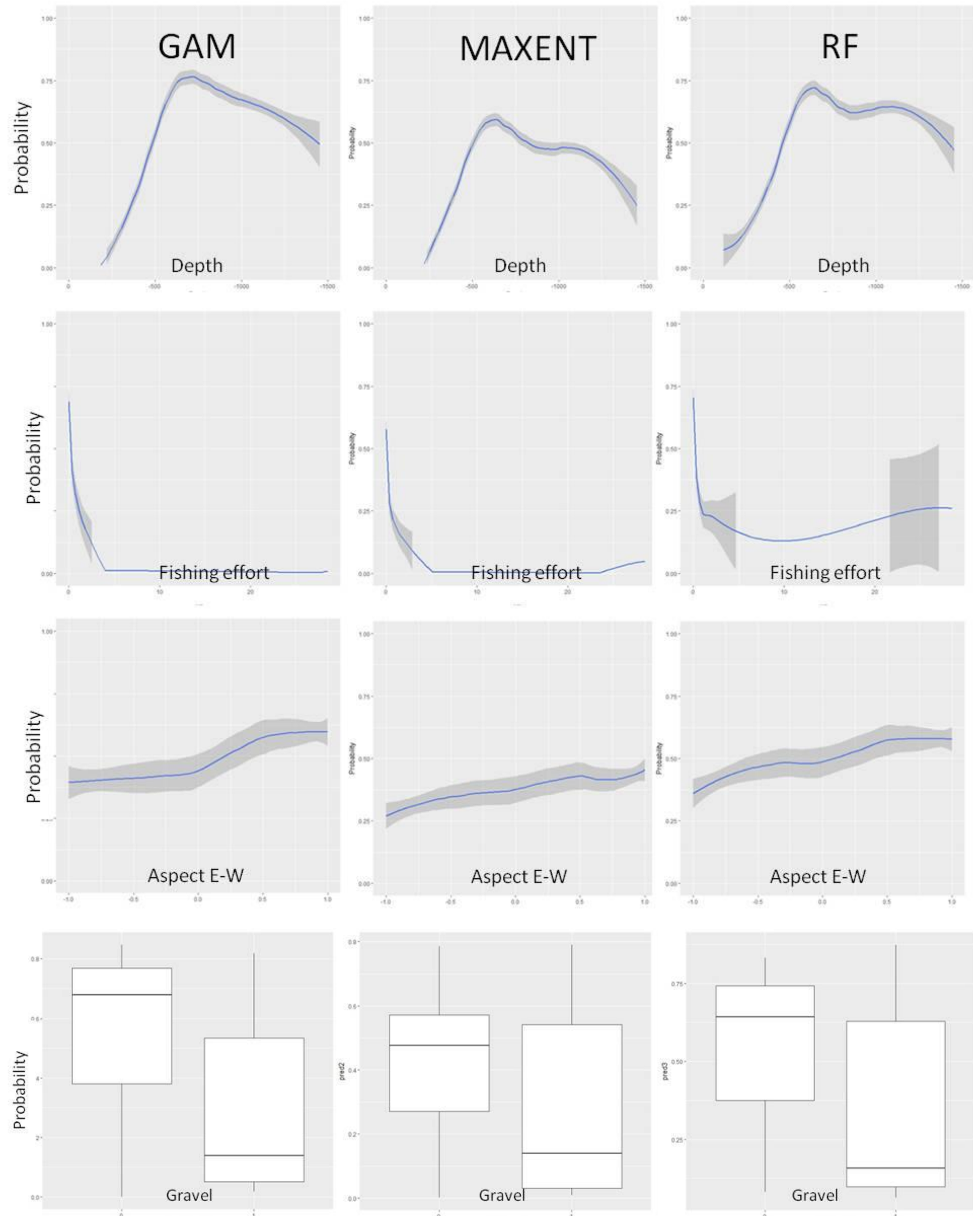

Figure 14.5. Partial GAM, Maxent and Random Forest (left, middle and right plots) for the selected continuous and categorical variables for *Acanella arbuscula* (From top to bottom: Depth, Fishing effort, Aspect component E-W and Gravel). Each plot represents the response variable shape, independent of the other variables, in relation to the probability of the species occurrence. Confidence intervals (95%) around the response curve are shaded in grey.

Table14.1 shows the model prediction performance statistics of the different models in order to assess the accuracy of the different SDM implemented.

Table14.1. Model prediction performance statistics of the different models assessed the two species. The statistics include the receiver-operating characteristic curve (AUC), specificity (TPR) and sensibility (TNR) proportion, the True Skill Statistic (TSS) and the Pearson's correlation r.

Pennatula aculeata					
	AUC	**TPR**	**TNR**	**TSS**	***r***
GAM	0.95	0.72	0.69	0.41	0.73
MAXENT	0.92	0.79	1.00	0.79	0.81
Random Forest	0.95	0.74	0.70	0.44	0.80
Acanella arbuscula					
GAM	0.86	0.69	0.66	0.36	0.51
MAXENT	0.80	0.90	0.60	0.50	0.61
Random Forest	0.83	0.67	0.65	0.33	0.58

where:

- AUC measures the ability of a model to discriminate between those sites where a species is present and those where it is absent, and has been widely used in the species distribution modeling literature (Elith *et al*., 2006). AUC ranges from 0 to 1, with values below 0.6 indicating a performance no better than random, values between 0.7 and 0.9 considered as useful, and values >0.9 as excellent.

- Specificity is the proportion of True Negatives correctly predicted and reflects a model's ability to predict an absence given that a species in fact does not occur at a location.

- Sensitivity is the proportion of True Positives correctly predicted and reflects a model's ability to predict a presence given that a species in fact occurs at a location.

- The TSS measures the accuracy of the model (Allouche *et al*., 2006) and is calculated as sensitivity + specificity – 1 and ranges from -1 to +1, where +1 indicates perfect agreement and values of zero or less indicate a performance no better than random.

Main conclusions achieved with this work are:

1. Numerous SDMs methods exist, each one with different data requirements and mathematical algorithms. They can produce clearly different geographic predictions and therefore resultant conservation strategies, even when using the same data. For these reasons we have applied three SDMs algorithms and compared their results.

2. In general, all models have achieved AUC values greater than 0.80 -> good degree of discrimination between locations where sea pens are present and locations where sea pens are absent.

3. *P. aculeata and A. arbuscula* exhibit specific habitat preferences and spatial patterns in response to environmental variables (mainly bathymetry, mixed layer depth and sediment texture). For *A. arbuscula* fishing activity demonstrated to be an important variable.

4. Understanding of sea pen distribution is crucial to delineate VME protection areas, contributing to the mitigation of by-catch of vulnerable benthic invertebrates.

References

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Elith, J., Graham, C.H., Anderson, R.P., Dudık, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., et al., 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29, 129-151

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Murillo, F.J., A. Serrano, E. Kenchington, J. Mora. 2016. Epibenthic assemblages of the Tail of the Grand Bank and Flemish Cap (northwest Atlantic) in relation to environmental parameters and trawling intensity. Deep-Sea Res. I 109: 99–122.

R Core Team (2016) R: A Language and Environment for Statistical Computing. https://www.R-project.org/

15. Ecosystem Summary Sheet

Request [12] and **ToR 3.2***. Finalise the preparation of the Ecosystem Summary Sheet (ESS) for 3LNO for presentation to the Commission at the 2020 Annual Meeting*

The NAFO convention commits the organization to apply an ecosystem approach to fisheries management in the Northwest Atlantic that includes safeguarding the marine environment, conserving its marine biodiversity, minimizing the risk of long term or irreversible adverse effects of fishing activities, and taking account of the relationship between all components of the ecosystem. To fulfill this commitment, NAFO is implementing its Roadmap for an Ecosystem Approach to Fisheries (EAF).

The NAFO Roadmap requires integrating information beyond single-species, providing managers with an integrative perspective at the ecosystem level, as well as how the suite of management measures are performing at that scale. The development of Ecosystem Summary Sheets (ESSs) are one part of this process. Analogous to current Stock Summary Sheets, which provide a synoptic view of the status, trends and management processes for individual target stocks, ESSs are intended to provide a synoptic perspective on the state of NAFO ecosystems and their management regime. ESSs are tentatively scheduled to be updated every 3-5 years, constituting a tool for strategic assessment, advice, and planning. The structure of ESSs distinguishes between ecological features and management measures, aligning the summary information with the general principles adopted by NAFO in chapter III of its convention. The current structure of ESSs is the result of input from SC and WGEAFFM. The assessment considers average state over the last 5 years (S – Status) and the trend during that period (T – Trend) (Table 15.1).

To address the request from the Commission, the ESS for the 3LNO Ecosystem Production Unit (EPU) has been completed based on a material from Bélanger et al. (2019), Cyr et al. (2019), Koen-Alonso and Cuff (2018), elements from this report (status of non-commercial species, VME indicators, discard levels, incidental catches of depleted and protected species, and human activities other than fishing) as well as publications from NAFO and the Canadian Scientific Advisory Secretariat.

A number of indicators identified previously could were not available. The WG is still developing methodologies to assess the frequency and magnitude of observations of VME-defining taxa and benthic communities within the VME habitat outside defined VME protection zones. Trends in key benthic species and communities from regular surveys will be available in the future for a limited period (2010 onward) but the data are currently being curated. Trends in marine mammal abundance could not be evaluated because the status of most species are not assessed. No quantitative data on seabird abundance was available to the working group.

Discard levels across fisheries were only available for the most recent period (year) and development of a time series is being investigated for reporting at a later date.

Entries were added to the section on human activities other than fishing based on the preliminary report from the ATLAS project and synthesis of material from the Canada-Newfoundland Labrador Offshore Petroleum Board (C-NLOPB) website (www.cnlopb.ca) that appear in other parts of this report.

Metrics to assess non-NAFO Fisheries and non-NAFO VME protection are currently being developed and will be reported in future assessments. It may be appropriate for the NAFO Secretariat to request the information (i.e. percentage of non-NAFO managed stocks that are in condition of supporting fisheries; trends in abundance of stocks under moratoria; fraction of VME biomass/area under protection; level of fishing effort exerted within unprotected VME habitats; tonnage of discards in each and across fisheries) from Canada and ICCAT (International Commission for the Conservation of Atlantic Tunas) for stocks in or migrating through the 3LNO EPU.

Table 15.1. Colour scheme for ecosystem summary sheet and the corresponding criteria for assignment to each category for the status and trends. For ecological features, contributing elements time series should be standardized to zero mean and unit standard deviation relative to an appropriate reference period.

	Ecological Features		**Management Measures**	
	Status	**Trend**	**Status**	**Trend**
Green	The state over the last 5 years is consistent with conditions observed/estimated during high productivity/high resilience periods (mean > 0.5 SD)	The trend over the last 5 years indicates consistent improving of the state/condition (trend > 1 SD/5 y or >20% increase in state)	Good. Current management measures are delivering the desired results.	Good. Management measures over the last 5 years are improving conditions; moving towards/maintaining the desired results.
Yellow	The state over the last 5 years is consistent with conditions observed/estimated during average productivity/average resilience periods	The trend over the last 5 years does not indicate any consistent change of the state/condition	Uncertain. Current management measures appear to have limited ability to deliver the desired results.	Uncertain. Management measures over the last 5 years are not improving conditions; no clear movement towards achieving the desired results.
Red	The state over the last 5 years is consistent with conditions observed/estimated during low productivity/low resilience periods (mean < -0.5 SD)	The trend over the last 5 years indicates consistent deterioration of the state/condition (trend < -1 SD/5 y or >-20% decline in state)	Poor. Current management measures appear insufficient to deliver the expected results or no management measure is in place.	Poor. Management measures over the last 5 years are not effective or no management measure is in place; conditions are moving away/deteriorating from the desired results.
Grey	Unknown - insufficient data to assess or assessment pending	Unknown - insufficient data to assess or assessment pending	Unknown - insufficient data to assess or assessment pending	Unknown - insufficient data to assess or assessment pending

3LNO Ecosystem Status Summary Sheet

> *Recommendation*: The Grand Bank (3LNO) EPU is currently experiencing low productivity conditions and biomass declines in the fish community. Current reduced productivity of fish may have been driven partly by bottom-up processes. Current aggregate catches for piscivores and suspension feeders exceed the guideline level for ecosystem sustainability.

Italicized elements have not been completed but are under development.

Elements which had been proposed but for which data are not currently available or estimable are *italicized* and ~~struck out~~.

Elements that are underlined are additions from earlier reports.

ECOLOGICAL FEATURES					
Convention Principle					**Comment**
A	**Ecosystem status and trends (long-term sustainability)**		**S**	**T**	**Summary of multiple trends/state**
	1	Physical Environment			Near or slightly above normal over the last 5 years but no clear trend over the last 5-yr
	2	Primary Productivity			Nutrient indices are near normal, phytoplankton standing stocks has recovered from a prolonged below normal state and now above normal. All indices are dominated by cyclic changes with no clear trend.
	3	Secondary Productivity			Zooplankton biomass is now above normal following a prolonged period below normal state. The abundance of large zooplankton taxa has been below normal since 2013.
	4	Fish productivity			Total finfish and shellfish biomass has been declining since 2013-14. Overall biomass is below pre-collapse levels. Average weight of individuals in the survey has declined since the early 2000s.
	5	Community composition			Shellfish has declined in dominance, but piscivores have yet to regain their pre-collapse dominance.
B	**Ecosystem productivity level and functioning**		**S**	**T**	**Summary of multiple trends/state**
	1	Current Fisheries Production Potential			Total biomass declined from 50% to ~30% of the estimated pre-collapse level.
	2	Status of key forage components			Reduced levels of capelin, sandlance, and shrimp.
	3	Signals of food web disruption			Diet variable, declining trend in stomach content weights.

E	State of biological diversity		S	T	Summary of multiple trends/state
	1	Status of VMEs			There has been a general increase in both area and biomass of VMEs between 2013 and 2019. However, the change is largely the result of improved delineation of the areas of high concentration. *VME state and change of state in recent period will be initially monitored using* *the frequency and magnitude of observations of VME-defining taxa and benthic communities within the VME habitat outside defined VME protection zones.*
	2	Status of non-commercial species			Based on 22 species selected from the multispecies surveys 40% of the species are below 20% of their historical maximum. This has declined from 70% in 2015. *1) Trends in key benthic species and/or communities from regular surveys, (data not yet available – will only go back to 2010)* *~~2) Tends in marine mammals.~~ (no data on trends)* *~~3) Trends in sea birds.~~ (no data on trends)*
MANAGEMENT MEASURES					
Convention Principle					**Comment**
C/D	**Apply Precautionary Principle**		**S**	**T**	**Summary of metrics on level of management action**
	1	Total Catch Indices (TCI) and catches			Piscivores catches have exceeded their TCI since 2015; suspension feeding benthos exceed it in 2018.
	2	Multispecies and/or environmental interactions			No explicitly consideration of species interactions and/or environmental drivers.
	3	Production potential of single species			Only 60% of NAFO managed stocks are in condition of supporting fisheries; some stocks have declining trends.
D/E	**Minimize harmful impacts of fishing on ecosystems**		**S**	**T**	**Summary of metrics on level of management action**
	1	Level of protection of VMEs			Some VMEs without protection. Protection has improved. Fishing with bottom contacting gears does not intrude in closed areas. Biomass of VMEs has increased between 2013 and 2019 but the fraction under protection has declined and is generally low.

			S	T	
					The level of risk to VMEs by fisheries outside closed areas needs to be assessed.
	2	Level of protection of exploited species			Total Catch Index guidelines have been developed. LRPs or HCRs are available for 70% of managed stocks but some stocks only have survey-based LRPs. No multispecies assessments are in place.
D/F	**Assess significance of incidental mortality in fishing operations**		**S**	**T**	**Summary of metrics on level of management action**
	1	Discard level across fisheries			Total discards increased during 2014-2018, with the greatest tonnage occurring in the Greenland halibut fishery. In terms of percentage of total catch from a fishery, discards were generally greater than 40% in the Atlantic halibut fishery. For each stock, the percentage of discards reported as discards relative to total catch for that stock was generally less than 8%. ~~*4) The Amount/fraction of discard related to undersize fish could not be determined.*~~
	2	Incidental catch of depleted and protected species			Generally the incidental catch of wolffish in 3LNO fisheries is very low (less than 0.01% of survey biomass) but highly variable.
OTHER CONSIDERATIONS (outside mandate of NAFO Convention)					
Human Activities other than fisheries			**S**	**T**	**Comment**
	1	Oil and gas activities			As of 2019, there are four offshore production fields on the Grand Bank and intense exploration activities along the eastern shelf break and Flemish Pass. The total area of licenses[4] has increased 8.3-fold from 2014 to 2019. There have been ten reported incidents between 2015 and 2019, with a major oil spill in 2018, and one in 2019 that extended into the NRA. A proposed development project in the Flemish Pass overlaps with fishing grounds. It is expected, based on current exploration leases and development projections that oil and gas exploration activities may increase in the NRA until at least 2030.
	2	Pollution			There is low occurrence and density of litter in 3L and fisheries are the primary source from both NAFO-managed and non-NAFO managed fisheries. Data for 3NO are not currently available. Standardized protocols for litter data collection have been developed and await approval and implementation during EU surveys.

[4] License types: Exploration, Significant Discovery and Production

Fisheries not managed by NAFO			**S**	**T**	**Comment**
		Non-NAFO fisheries *(coastal states and other RFMOs)*			*To the extent possible compile the description, indicators and/or reporting level to be developed in collaboration with coastal states and/or other RFMOs*
		Level of protection of VMEs (coastal states and other RFMOs)			*To the extent possible compile the description, indicators and/or reporting level to be developed in collaboration with coastal states and/or other RFMOs*

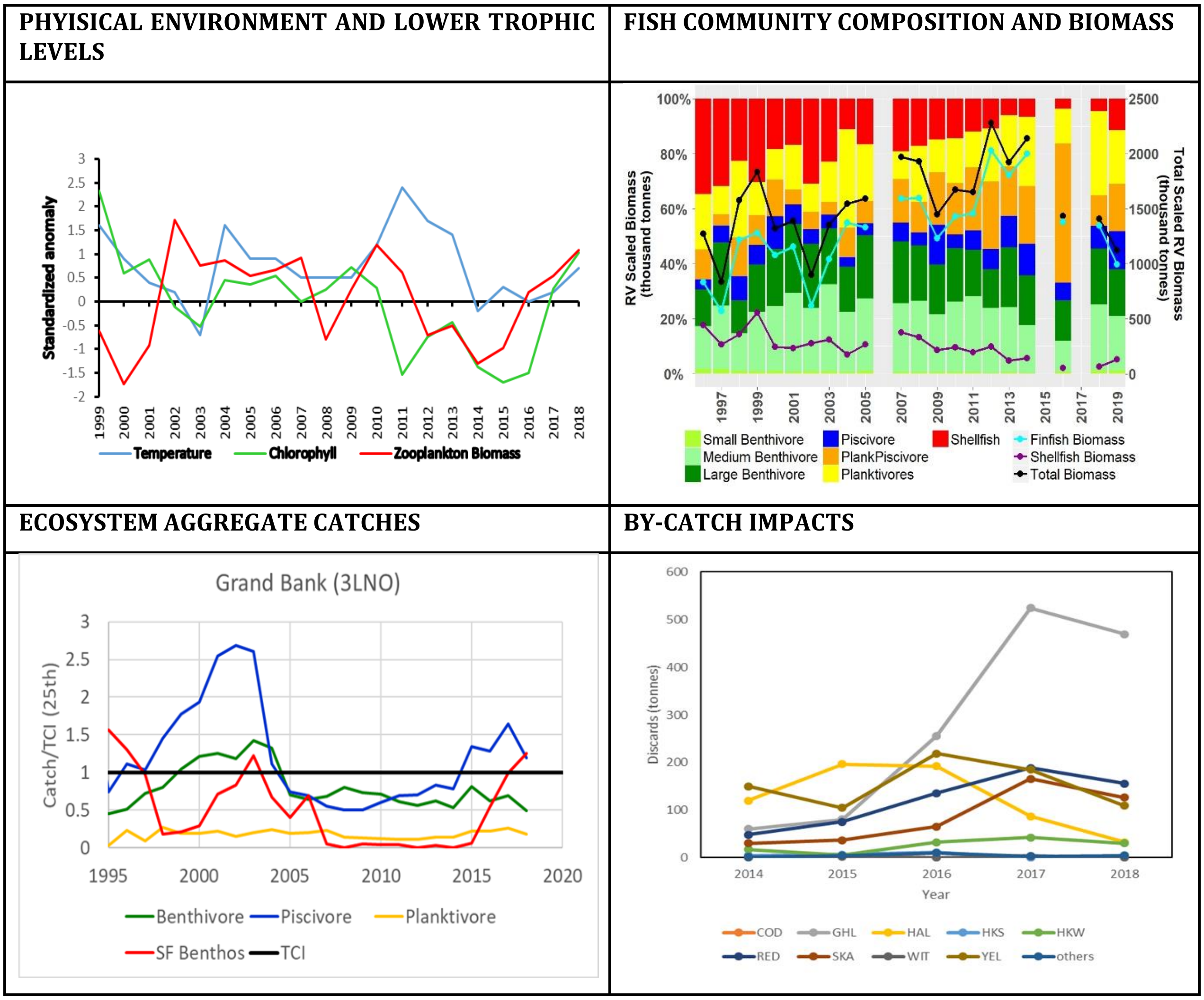

Figure 15.1 Upper left-hand panel shows anomalies of the 3LNO bottom temperature (blue), and Newfoundland and Labrador composite index of chlorophyll a abundance (green) and composite index of zooplankton biomass (red). Upper-right panel shows the relative composition of the fish and shellfish community functional feeding groups derived from research vessel trawl surveys (colour bars – referenced to the left axis with the legend at the bottom) and the total, finfish and shellfish biomass. Lower left-hand panel shows the nominal total catch of functional groups (estimated from STATLANT21A data) scaled relative to the Ecosystem Production Potential model-derived estimates Total Catch Indices disaggregated for each functional groups. The lower-right panel shows the tonnage of discards (total weight of all species) in each fishery from NAFO daily catch reports and therefore include catches in the NRA only. Fisheries are defined by the “target” species, which is the most abundant species caught on any given fishing day. The equivalent data for Canadian waters were not available.

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D. Bélanger, P. Pepin, G. Maillet, C. Johnson, E. Devred, B. Casault, C. Caverhill, S. Plourde, M. Blais. 2019. Biogeochemical oceanographic conditions in the Northwest Atlantic during 2018. SCR Doc. 19/010. 26p.

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3LNO EXAMPLE Ecosystem Status Narrative

ECOLOGICAL FEATURES

Ecosystem Status and Trends

The last 5 years there have been characterized by increased levels of nutrients and phytoplankton indices, as well as total zooplankton biomass. Small-sized taxa have significantly increased in abundance but the larger, lipid-rich taxa that are the preferred prey of forage fish have been below normal since 2013. Since 2013, total fish biomass has lost the gains built-up since the mid-1990s. Fishes have increased their dominance in the community at the expense of shellfish, but the piscivore functional group has not regained its pre-collapse dominance.

Ecosystem productivity level and functioning

The Grand Bank is experiencing low productivity conditions. After the regime shift in the late 1980 and early 1990, this ecosystem never regained its pre-collapse biomass level based on multi-species surveys. Improved conditions between the mid-2000s and early 2010s allowed a build-up of total biomass up to ~50% the pre-collapse level. This productivity was associated to good environmental conditions for groundfish, and modest increases in forage species, principally capelin. Since 2013, forage species have declined, and a reduction in total multispecies biomass to ~30-40% of pre-collapse levels has occurred across all fish functional groups. Although variable, diet composition of cod suggests reduced contributions of forage species, and average stomach content weights of cod and Greenland halibut have shown declines, suggesting poor foraging conditions.

State of biological diversity

Biological diversity is a multi-faceted concept. Out of its many dimensions, assessment of its state is being limited to Vulnerable Marine Ecosystems (VMEs) and the number of non-commercial fish species considered depleted owing to availability of appropriate analyses. Although identification and delineation of VMEs is being done, it is difficult to assess their status given the absence of a defined baseline and the unquantified impacts from historical fishing activities. The status of non-commercial species indicates that 40% of 22 taxa have biomasses that are below 20% of the 95th percentile of their historical biomass for the period 1981-2018.

MANAGEMENT MEASURES

Precautionary Principles

The NAFO Roadmap addresses sustainability of fishing at three nested levels of ecosystem organization: ecosystem, multispecies and stock levels. Catches of piscivore species have been above their Total Catch Index (TCI) in the past, are currently increasing, and since 2015 are once again above the estimated TCI. Catches for suspension feeding benthos are currently above their TCI. Only 60% of the NAFO managed stocks in the Grand Bank are in conditions of supporting fishing, and some of the stocks not supporting fisheries are showing declining trends in abundance indices. Impacts of either species interactions or environmental drivers are not currently being considered in the provision of advice or management.

Minimize harmful impacts of fishing on ecosystems

Minimization of harmful impacts of fishing on benthic communities has been focused on the protection of VMEs. Many coral and sponge VMEs in the Grand Bank are currently protected with dedicated closures, but the 3O coral closure does not provide protection for the identified VMEs in that area. Closures protect 59% of the large-sized sponge VME, 22% of sea pen VME and 56% of large gorgonian coral VME in 3LNO. Non-coral and non-sponge VMEs have been identified and areas of high concentration have been delineated on the tail of the Grand Bank during the 2019 meeting of WGESA but only 18% of black coral are currently protected by closures for other taxa and 1% or loss of small gorgonian corals, sea squirts and erect bryozoans are protected.

At the ecosystem level, Total Catch Indices for this ecosystem have been developed, while at the stock level and 70% of managed stocks have LRPs or HCRs, although some LRPs are based on survey indices. At this time, there are no multispecies assessments to inform on trade-offs among fisheries, and no stock-assessment explicitly considers either species interactions or environmental factors as drivers.

Assess significance of incidental mortality in fishing operations

Total discards demonstrated a general increase during the period 2014-2018, peaking at ~1200 tonnes in 2017. Total discards were greatest in the fishery for Greenland halibut. As a fraction of total catches, discards were most important in the fisheries for Atlantic halibut and white hake. As a fraction of the total catch for each stock, discards were generally below 8% of the total catch.

Generally the incidental catch of wolffish in 3LNO fisheries is very low (less than 0.01% of survey biomass) but highly variable. While wolffish are caught in many different gear types, historically landings were greater in bottom trawl gear than in gillnet or longline gears. In addition, while catches of Northern and Spotted Wolffish dominate the catches in NAFO division 3L, Atlantic Wolffish are the dominant species in NAFO divisions 3NO.

OTHER CONSIDERATIONS

Human activities other than fishing

As of 2019, there are four offshore production fields on the Grand Bank and intense exploration activities along the eastern shelf break and Flemish Pass. The total area of licenses[5] has increased N-fold from 2014 to 2019. Three spills from production fields were reported during the summer of 2019, with one extending into the NRA. It is expected, based on current exploration leases and development projections that oil and gas exploration activities will increase until at least 2030.

There is low occurrence and density of litter in 3L and fisheries are the primary source. Data for 3NO are not currently available. Standardized protocols for litter data collection have been developed and await approval and implementation during EU surveys.

Supporting evidence

Non-commercial species indicator

The indicator selected to monitor the status of non-commercial species was the fraction of species that are below 20% of their maximum observed biomass. Even in a fully functional ecosystem, it would be expected that, due to natural variability and cycles, some fraction of species would always be found below 20% of their maximum biomass.

Even though the precise value of this index that indicates a fully functional ecosystem is unknown, large values for this indicator would correlate with ecosystems under stress. Under natural/healthy ecosystem conditions, it cannot be expected that many species would be below 20% of their maximum, especially if they are not harvested.

From a simple theoretical perspective, and assuming that the maximum observed biomass actually corresponds to the carrying capacity of the stock, a simple stock-production (logistic) model would indicate that 20% of the maximum corresponds to 40% of the biomass at which the stock produces the Maximum Sustainable Yield (B_{msy}). Furthermore, 20% of the maximum observed survey biomass was one of the metrics proposed by Serchuk et al. (1997) as a possible value for a biomass limit reference point (B_{lim}) in the context of the NAFO Precautionary Approach framework.

The above observations would indicate that any stock below 20% of its maximum can be considered under stress, and hence, if the fraction of non-commercial species below this threshold is high, the appropriate conclusion is that the fraction of the community represented by non-commercial species is under stress. Non-commercial fish species have, for the most part, lower biomasses than commercial ones, but they are important contributors to the overall biodiversity. Therefore, a high value for this indicator implies a poor biodiversity status.

Data from DFO RV Spring and Fall surveys in the Grand Bank (3LNO) Ecosystem Production Unit (EPU) were used for the calculation of average biomass per tow as a measure of this indicator. Since these surveys changed

[5] License types: Exploration, Significant Discovery and Production. Exploration licences represent the greatest contributors to total area of oil and gas activities.

the sampling gear in 1994-1995 (the Engel gear was replaced by the Campelen gear), coarse scaling factors applied at the fish functional group level were used to generate comparable order of magnitude estimates of biomass between the Engel and Campelen series. A total of 22 non-commercial fish species were selected for the calculation of this indicator (Table 15.2). Species were included on the basis that a) they have a consistent time series record (i.e. they were absent in no more than 3 years in the time series), and b) the examination of the time series did not show any obviously anomalous jump between the Engels and Campelen time series. Some of the species selected actually correspond to higher order taxonomic level aggregates for those groups where consistent and systematic identification to the species level in the survey is not available.

Table 15.2. Fish species selected for the calculation of the non-commercial species indicator

Common name	Scientific name
Arctic cod	Boreogadus saida
Arctic eelpout	Lycodes reticulatus
Barracudinas	Paralepididae
Broadhead wolffish	Anarhichas denticulatus
Common grenadier	Nezumia bairdi
Polar deepsea sculpin	Cottunculus microps
Dragonfish	Stomias boa ferox
Esmark's eelpout	Lycodes esmarki
Longhorn sculpin	Myoxocephalus octodecemspinosus
Lumpfish	Eumicrotremus sp.
Common ocean pout	Macrozoarces americanus
Roughead grenadier	Macrourus berglax
Sea raven	Hemitripterus americanus
Seasnail	Liparidae
Shorthorn sculpin	Myoxocephalus scorpius
Round deepwater skate	Raja fyllae
Smooth skate	Raja senta
Spinytail skate	Raja (bathyraja) spinicauda
Atlantic snipe eel	Nemichthys scolopaceus
Spotted wolffish	Anarhichas minor
Striped wolffish	Anarhichas lupus
Vahl's eelpout	Lycodes vahlii

The results indicate that, despite the interannual variability of the indicator, there is a clear trend over time (Figure 15.2). The fraction of non-commercial species below 20% of their maximum increased since the mid-1980s to the mid-1990s, where it peaks around 60-70%. This trend is consistent with the period leading and during the regime shift experienced by the EPUs in the Newfoundland and Labrador bioregion, when the groundfish community declined. This result, focused on non-commercial species, further highlights that the collapse involved commercial and non-commercial species alike.

The non-commercial species recovered during the late 1990s and 2000s, with the fraction of non-commercial species below 20% falling to around 30%. This also reflects the trends in the fish community, which experience a rebuilding trend since the mid-2000s until the early 2020s. Also coinciding with the decline in total biomass observed in the Grand Bank after 2014, the fraction of non-commercial species below 20% of their maximum shows another increase in the late 2010s, with some improvement in 2018-2019. Still, the level of the index sits around 40%, which is higher than where it was in the 2000s. This fraction of non-commercial species below

20% of their maximum is also consistent with the fraction of commercial species managed by NAFO which are currently close to fishing.

These results indicate that the current status of biodiversity, as measured by this indicator is still concerning, but the trend over the last couple of years suggest the conditions could be improving.

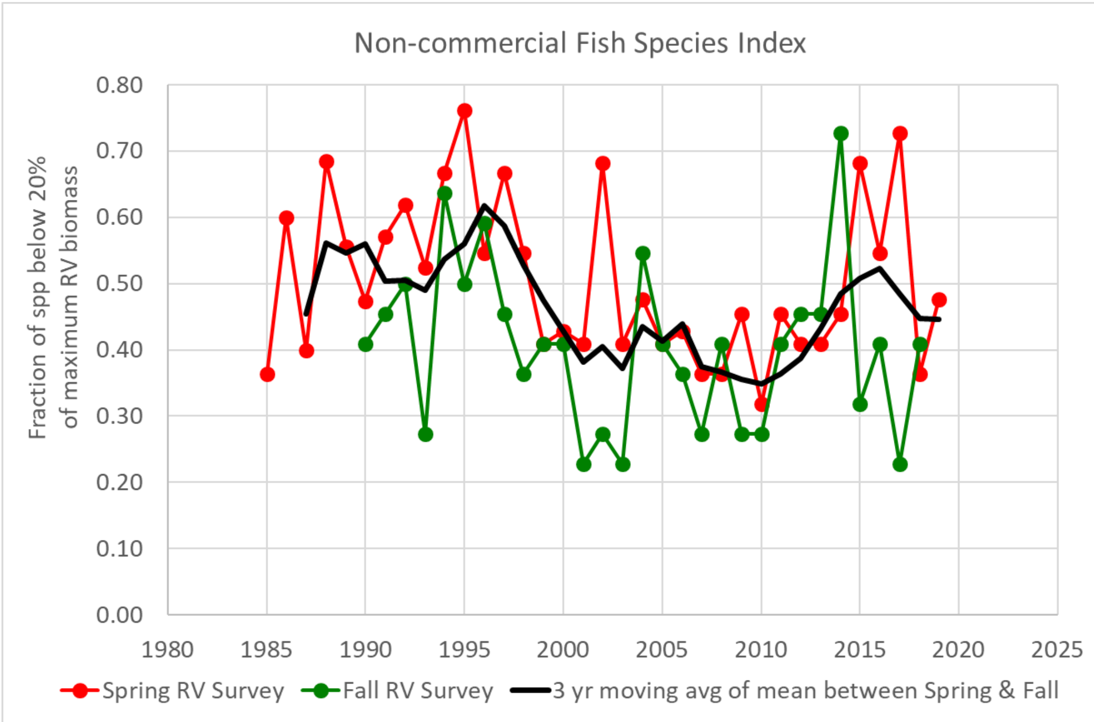

Figure 15.2. Non-commercial fish species index for the Grand Bank (3LNO EPU) based on 22 selected taxa. Fraction of species below the 20% of the observed RV biomass from the Spring (red) and Fall (green) DFO RV surveys. The black line indicates the 3 year moving average of the average between the fall and spring series; it is simply intended to provide a visual summary of the general trend in the indicator.

References

Serchuk, F., D. Rivard, J. Casey and R. Mayo (1997). "Report of the Ad hoc Working Group of the NAFO Scientific Council on the Precautionary Approach." NAFO SCS Document 97(12).

VME indicators

The status and trends in the VMEs within NAFO Divisions 3LNO were evaluated by comparing changes in the area and biomass of the VME polygons delineated in both 2019 and 2013 through kernel density estimation (KDE) and species distribution modelling techniques. A detailed description of how the area and biomass of the VME polygons was calculated (for the full NRA) can be found in SCR Doc 19-058. We note that the biomass used here is drawn from the KDE biomass surface and is not a true biomass (see SCR Doc 19-058 For the Ecosystem Summary Sheets, the portion of VMEs that extended into NAFO Division 3M were removed, restricting the analyses to Divisions 3LNO only.

With the exception of sponges and erect bryozoans, the area occupied by the VME polygons has generally increased between 2013 and 2019 (Table 15.3). Small gorgonian corals showed the largest increase (1292%), which can likely be attributed to the increase in default search radius (22.1 km versus 12.5 km in 2013) resulting from the greater extent of the data used in the 2019 assessment, and the amalgamation of the 2013 VME polygons adjacent to the 3O closure into one large polygon (see Figure 17 of SCR Doc 19-058). Sponges showed a marginal decrease (5%) in area between 2013 and 2019, possibly explained by a combination of the distribution of additional data as well as the increase in threshold from 75 to 100 kg, which would result in fewer catches and thus area of habitat encompassed by the VME polygons. Despite no change in threshold between 2013 and 2019, the erect bryozoans showed a decrease in area of 47%. This is likely the result of the smaller default search radius in the 2019 assessment (12.4 km versus 25 km in 2013), resulting in the separation of two bryozoan concentrations on the Tail of Grand Bank that were joined in 2013 (see Figure 27 of SCR Doc 19-058). Note that caution must be taken when comparing such metrics between the 2019 and 2013 assessments, as any changes are likely the result of data-driven processes such as the addition of data or changes in biomass distribution between years, rather than actual expansion or contraction of habitat.

The KDE biomass of all VME indicator taxa showed an increase from 2013 to 2019 (Table 15.1). As the threshold for most indicator groups has either not changed or changed only marginally, this increase is likely due to the additional data collected between 2013 and 2019 and its density distribution.

In order to assess the effectiveness of the closed areas in 3LNO, the area and biomass of the VME considered protected, i.e., inside the closures, and unprotected, i.e., outside the closures, was calculated for all VME indicator groups. Detailed methods on how the area and biomass were extracted from the VME are outlined in SCR Doc 19-058. Unlike the analyses conducted in SCR Doc 19-058 for the full NRA, the area of protected and unprotected VME were designated irrespective of the fishing footprint. Thus the area considered 'Protected' in this analysis is equivalent to the 'Closure Protected' (i.e., inside closure) area illustrated in Figure 42 of SCR Doc 19-058, while the 'Unprotected' area is equivalent to the sum of the 'Unprotected' (i.e., outside closure, inside fishing footprint) and 'Conditionally Protected' (i.e., outside closure, outside fishing footprint) areas of SCR Doc 19-058.

Tables 15.4 and 15.5 show the area of VME protected versus unprotected for those VME delineated in 2013 and 2019, respectively. Overall the level of protection is similar between the 2013 and 2019 VMEs with the exception of small gorgonians, where the level of protection decreased from 18% to 3%. This is likely due to the large VME delineated adjacent to the 3O closure in the 2019 assessment. Overall, the level of protection of the VME delineated in 2019 (Table 15.5) is at most incomplete (refer to rating guide table in this report). Sea squirts have no protection, while erect bryozoans have less than 1% protection. While the KDE biomass encompassed by the VME has increased from 2013 to 2019 in 3LNO (see Tables 15.6 and 15.7), its protection has decreased and is low overall for all indicator groups. Sea squirts and erect bryozoans have little to no protection.

Table 15.3. Change in significant concentration threshold (kg), total area (km^2), and total KDE biomass (kg) of VME polygons in NAFO divisions 3LNO delineated in 2019 and 2013 from kernel density estimation and species distribution modelling techniques. Also shown is the percentage change in polygon area and KDE biomass between 2019 and 2013. Note that kernel density analyses were not applied to black corals in 2013.

Common Name	Threshold (kg)		Area of VME in 3LNO (km^2)		Percentage (%) Change in Area Between 2019 & 2013	KDE Biomass of VME in 3LNO (kg)		Percentage (%) Change in KDE Biomass Between 2019 & 2013
	2019	2013	2019	2013		2019	2013	
Large-sized sponges	100	75	11,112	11,750	-5	120,538	96,036	26
Sea pens	1.3	1.4	2734	1268	116	52	29	80
Small gorgonian corals	0.2	0.15	4278	307	1292	15	3	497
Large gorgonian corals	0.6	0.6	3028	2754	10	266	200	33
Sea squirts	0.35	0.3	4077	2193	86	396	41	876
Erect bryozoans	0.2	0.2	3491	6587	-47	122	103	18
Black corals	0.4	-	604	-	-	6	-	-

Table 15.4. Total area (km^2) of VME polygons generated in 2013 that are protected (inside closures) versus unprotected (outside closures) in NAFO Divisions 3LNO. The percentage (%) of total area protected versus unprotected is also shown.

Common Name	Total Area of 2013 VME in 3LNO (km^2)	Protected		Unprotected	
		Area (km^2)	Percentage of Total (%)	Area (km^2)	Percentage of Total (%)
Large-sized sponges	11,750	5200	44	6550	56
Sea pens	1268	338	27	930	73
Small gorgonian corals	307	56	18	252	82
Large gorgonian corals	2754	1568	57	1185	43
Sea squirts	2193	0	0	2193	100
Erect bryozoans	6587	0	0	6587	100

Table 15.5. Total area (km²) of VME polygons generated in 2019 that are protected (inside closures) versus unprotected (outside closures) in NAFO Divisions 3LNO. The percentage (%) of total area protected versus unprotected is also shown.

Common Name	Total Area of 2019 VME in 3LNO (km²)	Protected		Unprotected	
		Area (km²)	Percentage of Total (%)	Area (km²)	Percentage of Total (%)
Large-sized sponges	11,112	4962	45	6149	55
Sea pens	2734	530	19	2204	81
Small gorgonian corals	4278	128	3	4150	97
Large gorgonian corals	3028	1605	53	1423	47
Sea squirts	4077	0	0	4077	100
Erect bryozoans	3491	5	0.14	3486	99.86
Black corals	604	124	21	479	79

Table 15.6. Total KDE biomass (kg) VME indicator taxa inside the 2013 VME polygons derived from KDE density surfaces that are protected (inside closures) versus unprotected (outside closures) in NAFO Divisions 3LNO. The percentage (%) of total KDE biomass protected versus unprotected is also shown.

Common Name	Total KDE Biomass of 2013 VME in 3LNO (kg)	Protected		Unprotected	
		KDE Biomass (kg)	Percentage of Total (%)	KDE Biomass (kg)	Percentage of Total (%)
Large-sized sponges	96,036	62,287	65	33,749	35
Sea pens	29	8	26	22	74
Small gorgonian corals	3	0.09	4	2	96
Large gorgonian corals	200	124	62	76	38
Sea squirts	41	0	0	41	100
Erect bryozoans	103	0	0	103	100

Table 15.7. Total KDE biomass (kg) VME indicator taxa inside the 2019 VME polygons derived from KDE density surfaces that are protected (inside closures) versus unprotected (outside closures) in NAFO Divisions 3LNO. The percentage (%) of total KDE biomass protected versus unprotected is also shown.

Common Name	Total KDE Biomass of 2019 VME in 3LNO (kg)	Protected		Unprotected	
		KDE Biomass (kg)	Percentage of Total (%)	KDE Biomass (kg)	Percentage of Total (%)
Large-sized sponges	120,538	71,533	59	49,004	41
Sea pens	52	12	22	41	78
Small gorgonian corals	15	0	1	15	99
Large gorgonian corals	266	150	56	116	44
Sea squirts	396	0	0	396	100
Erect bryozoans	122	0	0.01	122	99.99
Black corals	6	1	18	5	82

Changes in the proportion of VME indicator presences and absences as indicators of VME status

During the 12th WG-ESA meeting, the working group deliberated that the proportion of research vessel catches with and without the presence of VME indicator taxa inside their respective VME but outside the closures (Figure 15.3) may be an useful indicator of the status of unprotected (i.e., outside closures) VMEs over time. However, in order to conduct these analyses, information on null catches from the EU-Spain and Canadian RV trawl surveys is required, which was not available for all functional groups prior to the meeting. The working group proposed analyses examining the proportion of null and positive catches be conducted at next year's meeting. An example of how such analyses could be conducted is shown below for erect bryozoans, where information on presences and null catches over time were available. In Figure 15.3, catches of erect bryozoans (presences) and nulls (absences) collected in 2016 from the EU-Spain and Canadian RV surveys inside the 2019 erect bryozoan VME polygons are shown. Changes in the proportion of presences and absences over time (stacked bar chart in Figure 15.3) inside the VME but outside the closure areas may be useful indicators of the effects of fishing on these habitats. Requests for the data required to create nulls have been made and will be reiterated in advance of the 13th WG-ESA meeting.

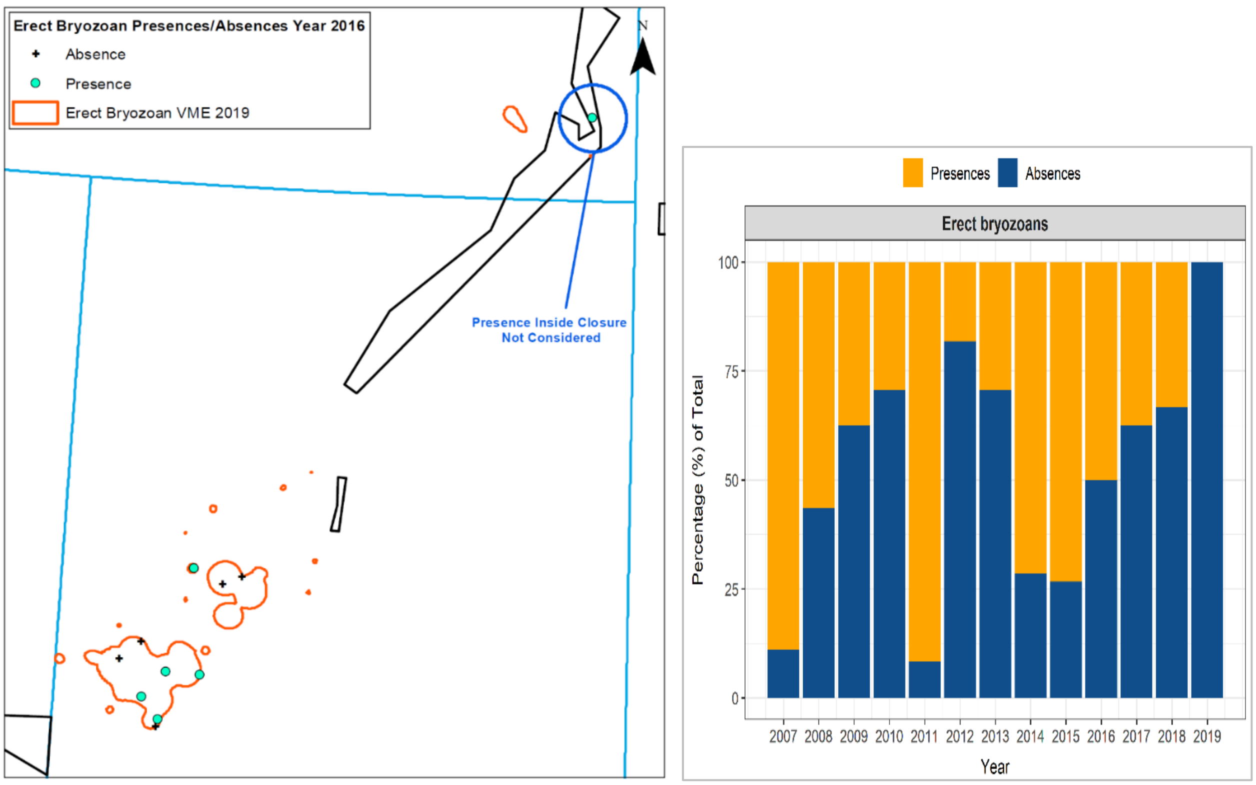

Figure 15.3. Depiction of erect bryozoan presences (aqua circles) and nulls (black crosses) collected in 2016 from the EU-Spain and Canadian research vessel trawl surveys. The proportion of presences versus absences inside the 2019 VME but outside the closures as an indicator of the status of VMEs will be reviewed during the WG-ESA meeting in 2020.

References

Kenchington, E., C. Lirette, F.J. Murillo, L. Beazley, A.-L. Downie. 2019. Vulnerable Marine Ecosystems in the NAFO Regulatory Area: Updated Kernel Density Analyses of Vulnerable Marine Ecosystem Indicators. NAFO SCR Doc. 19/058.

Discard levels

Discards data for 3LNO from NAFO daily catch reports and thus only cover vessels in the NRA. The equivalent data were not available for Canadian waters.

1) Tonnage of discards in each and across fisheries,

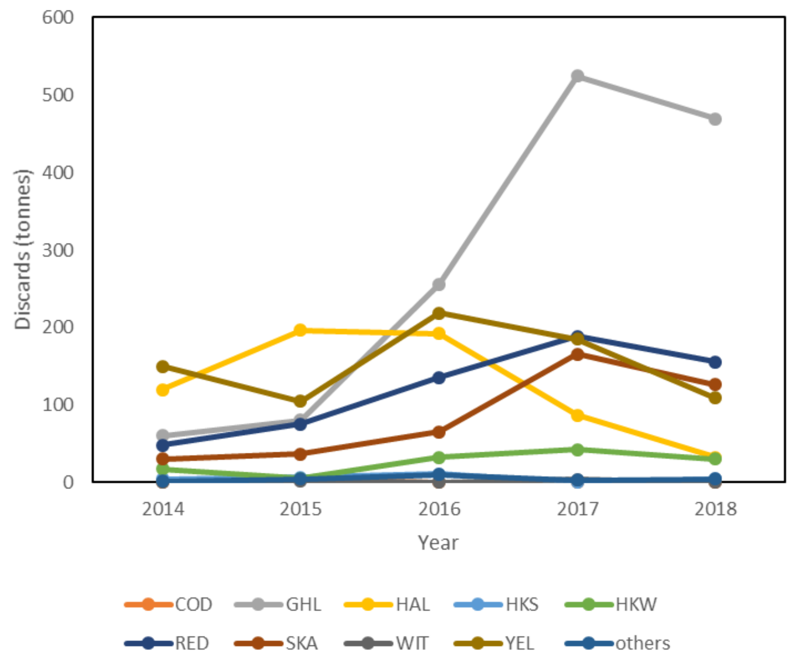

Figure 15.4. Tonnage of discards (total weight of all species) in each fishery. Data are from NAFO daily catch reports and therefore include catches in the NRA only. Fisheries are defined by the "target" species, which is the most abundant species caught on any given fishing day.

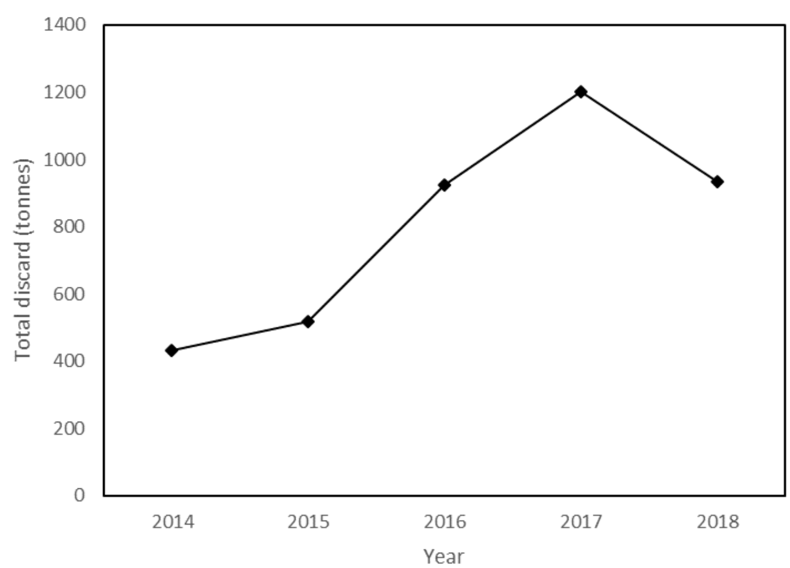

Figure 15.5. Tonnage of discards (total weight of all species) across fisheries. Data are from NAFO daily catch reports and therefore include catches in the NRA only.

2) Fraction of discard by fishery and across fisheries,

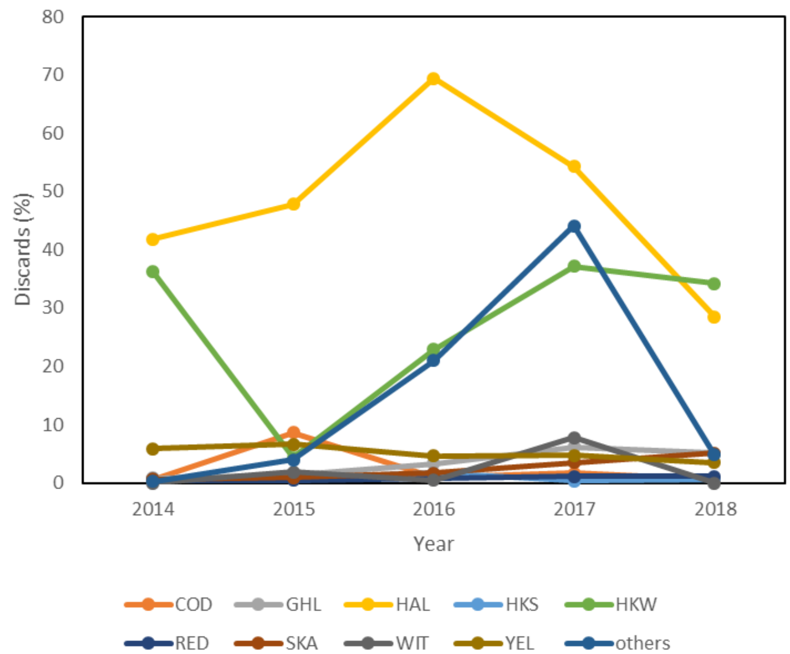

Figure 15.6. Fraction of discards (percentage by weight of total catch) in each fishery. Data are from NAFO daily catch reports and therefore include catches in the NRA only. Fisheries are defined by the "target" species, which is the most abundant species caught on any given fishing day.

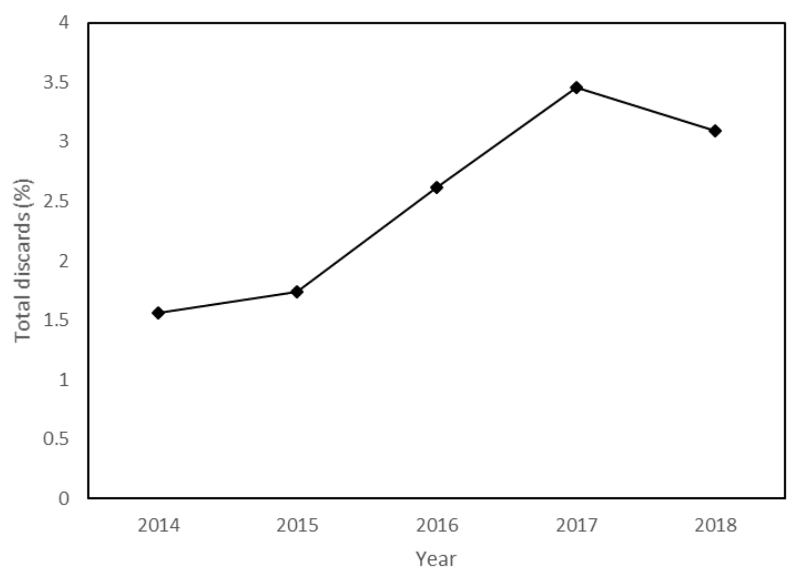

Figure 15.7. Fraction of discards (percentage by weight of total catch) across fisheries. Data are from NAFO daily catch reports and therefore include catches in the NRA only.

3) Fraction of discard with respect to stock/community size and/or productivity

Not possible to estimate relative to stock size or productivity so we report we report on the percentage of catch from each stock.

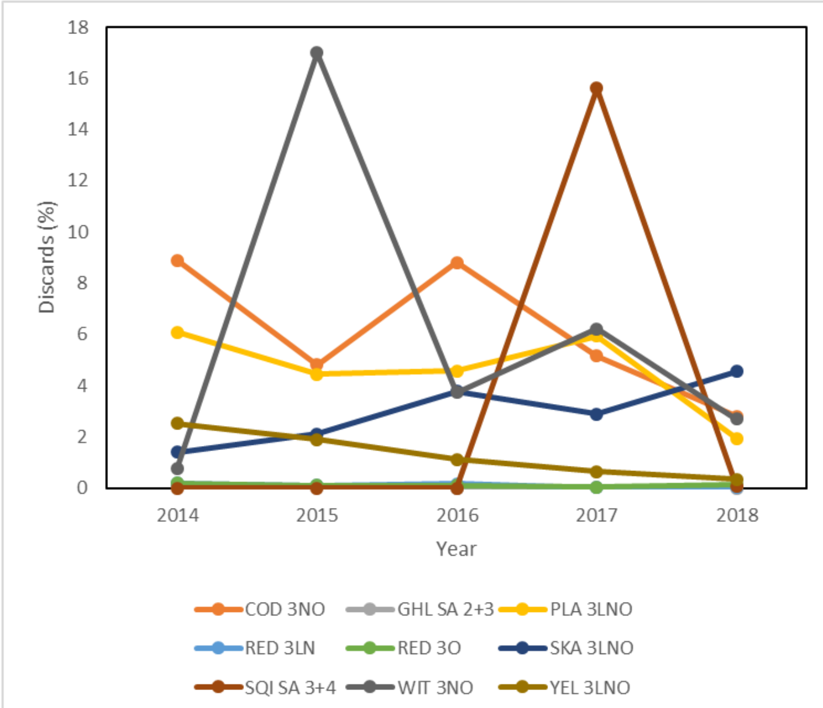

Figure 15.8. Percentage discard by stock (percentage of catches from each stock that are reported as discarded). Data are from NAFO daily catch reports and therefore include catches in the NRA only.

4) Amount/fraction of discard related to undersize fish.

No data are available to address this indicator.

Incidental catches of depleted and protected species

The NAFO convention commits the organization to safeguarding the marine environment, conserving its marine biodiversity, and minimizing the risk of long term or irreversible adverse effects of fishing activities. Part of that process is to assess the significance of incidental mortality in fishing operations and in particular the incidental catch of depleted and protect species. In the 3LNO Ecosystem, three species of wolffish, Northern Wolffish (*Anarhichas denticulatus*-Threatened), Spotted Wolffish (*Anarhichas minor*-Threatened) and Atlantic Wolffish (*Anarhichas lupus*-Special concern) are protected under the Canadian Species at Risk Act (SARA). Together these three species are often reported in landings statistics as catfish which makes the assessment of incidental catch problematic. Due to the lack of species-specific catch data on these protected species, incidental catch was estimated from an estimate of bycatch on fishing trips where an At-Sea Observer (ASO) monitored catch of the wolffish to species. Observed species-specific catch estimates were then adjusted up to the scale of the total catch in the 3LNO fisheries. The estimated incidental catch of the three wolffish species was then divided by the biomass estimate from the Canadian spring 3LNO survey to derive a Relative Fishing mortality estimate.

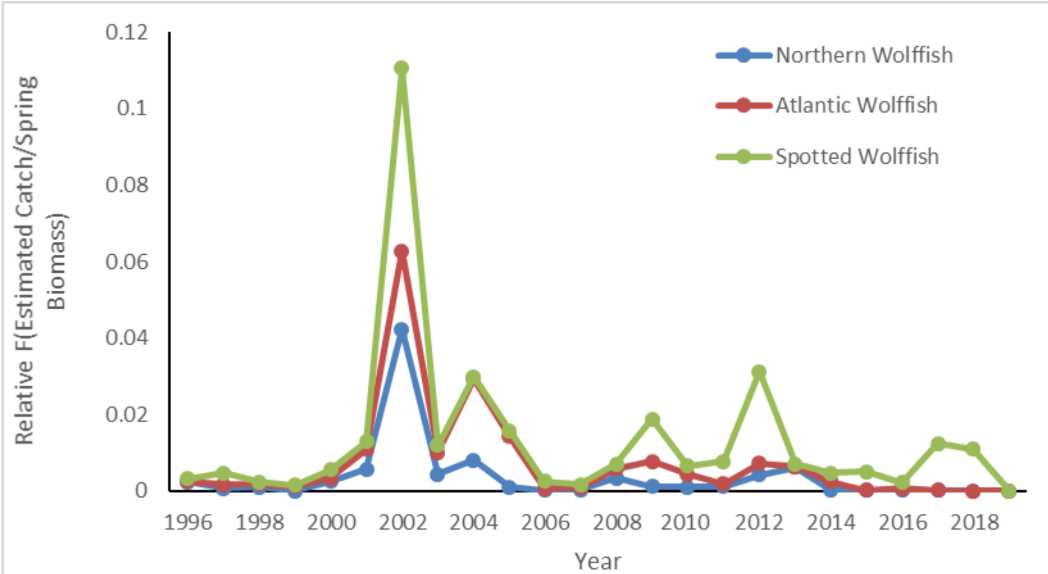

Figure 15.9. Time series of relative fishing mortality from incidental catches of wolfish based on the overall estimated catch relative to the estimate of biomass from the Canadian spring random stratified surveys.

Generally the incidental catch of wolffish in 3LNO fisheries is very low (less than 0.01% of survey biomass) but highly variable. In 2002, the survey biomass of all three species of wolffish was considerably lower which increased the impact of the catch in that year. Variability in the catch indices is also a function of the ASO coverage in any particular year and fishery. While wolffish are caught in many different gear types, historically landings were greater in bottom trawl gear than in gillnet or longline gears. In addition, while catches of Northern and Spotted Wolffish dominate the catches in NAFO division 3L, Atlantic Wolffish are the dominant species in NAFO divisions 3NO.

16. Activities Other than Fishing (ATLAS)

COM Request [16] and **ToR 3.4.** ***Continue to monitor and provide updates resulting from relevant research related to the potential impact of activities other than fishing in the Convention Area***

Seabed litter in NAFO Division 3L

Marine litter has been recognized as a worldwide problem affecting the marine environment in several ways: economic loss, degradation of habitats and impact on biota. Marine litter is distributed throughout the marine environment (coastal areas, water column and seabed). Despite an important increase in the number of studies on marine litter in recent years, there are still gaps in the knowledge, especially related to the high-seas and deep waters.

To address the concerns about seabed litter in NAFO Regulatory Area, a pilot study (García-Alegre *et al*., 2018) was conducted by the IEO-Vigo, analysing an extensive database based on EU-Spain groundfish surveys (Durán Muñoz *et al.,* 2019) in Division 3L.

A total of 1,169 trawls were analyzed for the 2006-2017 period, ranging from 104 m to 1478 m depth. Litter items retained in the bottom trawl hauls were examined and recorded using a standardized litter monitoring protocol.

Results indicate a low occurrence and density of seabed litter, for which NAFO-managed and non-NAFO managed fisheries are the primary sources (Figures 16.1 and 16.2). Presence of litter was observed in the 8.3% of the total hauls with mean densities of 1.4 ± 0.4 items/km2 and 10.6 ± 5.2 kg/km2 (Table 17.1). The highest densities of seabed litter were found in the deepest areas located in the Flemish Pass channel and down the northeastern flank of the Grand Bank. Fisheries were the principal source of marine litter; 61.9 % of the hauls with litter present were fishery related. In most cases litter consisted of small fragments of rope but in some, litter consisted of entire traps or nets. Plastics, metal and other anthropogenic litter were the next most abundant categories. Higher densities of seabed litter were found in years 2007 and 2008, with a declining trend in the following years (Table 16.1).

WG-ESA recommends to Scientific Council that standardized protocols for marine litter data collection should be implemented by all Contracting Parties as part of their groundfish surveys conducted in NAFO Regulatory Area. Implementation of such protocols would allow monitoring the spatial and temporal distribution of marine litter, contributing to improved knowledge of their characteristics in the NAFO Regulatory Area.

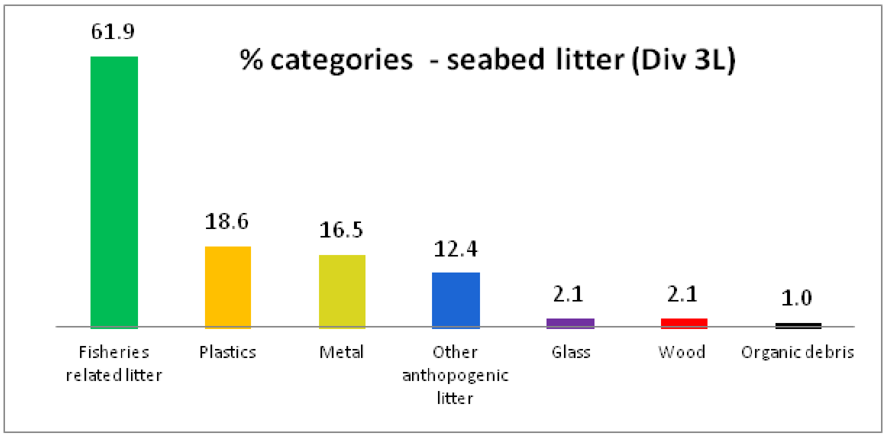

Figure 16.1. Percentage of the occurrence of the different litter categories by trawls with litter presence.

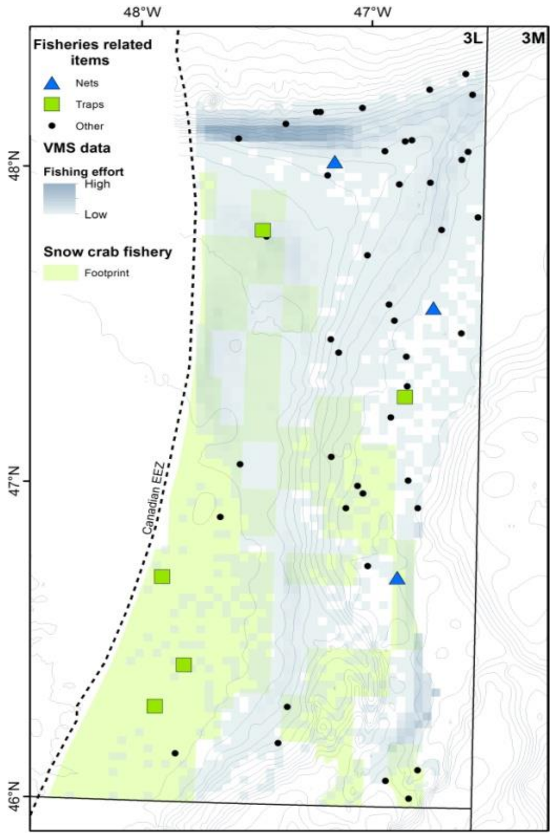

Figure 16.2. Distribution of fisheries related seabed litter items found in the Flemish Pass area (NAFO Div 3L). showing in blue scale the NAFO fishing effort (2008-2014) and in green the snow crab fishery footprint (2007-2017) (blue triangles, nets; green squares, traps; black dots, other fisheries related items).

Table 16.1. Mean values of marine litter densities estimated by weight/km² and number of items/km² by year and in the total period (N, number of valid trawls performed; %, percentage of valid trawls with litter presence).

Year	N	%	kg/km²	Item/Km²
2006	100	19.0	3.8 ± 2.1	4.1 ± 1
2007	94	17.0	97.6 ± 63.5	3.1 ± 0.9
2008	100	7.0	1.9 ± 1.1	1.4 ± 0.6
2009	98	6.1	0.4 ± 0.2	0.8 ± 0.3
2010	97	4.1	0.2 ± 0.1	0.8 ± 0.4
2011	89	3.4	0.9 ± 0.8	0.6 ± 0.3
2012	98	8.2	8.1 ±5.9	1.3 ± 0.5
2013	100	4.0	3.5 ± 2.4	0.9 ± 0.5
2014	99	5.1	6.7 ± 4.2	0.9 ± 0.5
2015	97	5.2	1.1 ± 0.6	0.6 ± 0.3
2016	98	12.2	4.5 ± 2.2	1.5 ± 0.4
2017	99	8.1	1.9 ± 1.1	1.2 ± 0.4
2006-2017	**1169**	**8.3**	**10.6 ± 5.2**	**1.4 ± 0.4**

References

Durán Muñoz, P., Sacau, M., García-Alegre, A. and Román, E. (2019) Cold-water corals and deep-sea sponges by-catch mitigation: Dealing with groundfish survey data in the management of the northwest Atlantic Ocean high seas fisheries, Marine Policy. https://doi.org/10.1016/j.marpol.2019.103712.

García-Alegre, A., Román, E., Gago, J.,González-Nuevo, G., Sacau, M. Durán Muñoz, P. (2018). Seabed litter distribution in the high-seas of the Flemish Pass (NW Atlantic). VI International Symposium on Marine Sciences. Vigo, Spain, 20-22 June 2018.

17. Marine Spatial Planning

COM Request [16] and **ToR 3.4.** ***ATLAS Project: updates on potential impact of activities other than fishing - oil and gas***

ATLAS Project: updates on potential impact of activities other than fishing - oil and gas

According to the UNESCO approach towards ecosystem-based management (Ehler *et al.*, 2009), Marine Spatial Planning (MSP) is a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that have been specified through a political process. Conflicts user-user or user-environment weaken the ability of the ocean to provide the necessary ecosystem services. Demands for goods and services from a marine area usually exceed its capacity to meet all of them simultaneously. Some public process, such as MSP, must be used to decide what mix of goods and services will be produced from the marine area.

ATLAS (www.eu-atlas.org) is a multidisciplinary international project funded by the EU Horizon 2020 program. ATLAS is testing a generic MSP framework (Stelzenmüller *et al*., 2013) developed by the EU FP7 MESMA project to assess spatially managed areas (SMAs) in all 12 of the ATLAS Case Studies. SMAs are discrete geographic regions that can be defined at different spatial scales, but where a spatial management framework (e.g. MSP) is either in place, under development, or potentially being considered. The main focus of ATLAS regarding MSP is to assess whether the existing science base is sufficient to support theoretical regional/local SMAs.

The different ATLAS Case Studies represent a wide range of biogeographic, regulatory and jurisdictional situations encountered across the Atlantic from national deep-waters to Areas Beyond National Jurisdictions (ABJN). ATLAS Case Study No11, located in ABJN, is focused on the Flemish Cap and the Flemish Pass within NAFO Regulatory Area.

ATLAS is developing a theoretical exercise of MSP, considering the scenario of a potential development of a new human activity in the Case Study No11. The *Blue Economy* - *Blue Growth* goal considered here is the provision of a framework for the sustainable use of goods and services derived from the Flemish Cap and Flemish Cap area, which can accommodate an emergent offshore hydrocarbon exploration and exploitation, preventing impacts on VMEs and existing high seas commercial fisheries. The "context setting" for MSP in the study area was identified and the works related to the collection of “existing information”, collation and mapping is ongoing. Relevant biophysical and socio-economic ecosystem components were preliminary mapped, taking into account the importance of the components and the availability of data in the SMA. All this information was organized and integrated into a GIS. At present, ATLAS is exploring methods and tools to assess the cumulative impacts of the human activities, particularly an additive spatial model (Halpern *et al.,* 2008) and an open source software tool (Stock, 2016) to implement this model with a simple user interface and GIS. Two main challenges to apply such methodology to the NAFO Regulatory Area were identified: (i) calculation of sensitivity of the ecosystem components to the stressors and (ii) availability of additional data layers.

The present MSP exercise pays special attention to the spatial overlap between emergent and existing uses of the marine space, as well as between human activities (footprints) and natural components of the ecosystem. A simple mapping of footprints (Figure 17.1) allowed us to identify potential conflicts user-user (e.g. hydrocarbon industry *vs.* deep-sea fishers) or users-sensitive ecosystems (e.g. hydrocarbon industry *vs.* VMEs), as well as potential tensions between different regulatory and jurisdictional frameworks in ABNJ (e.g. areas closed to bottom fishing by NAFO, do not apply to the oil and gas industry).

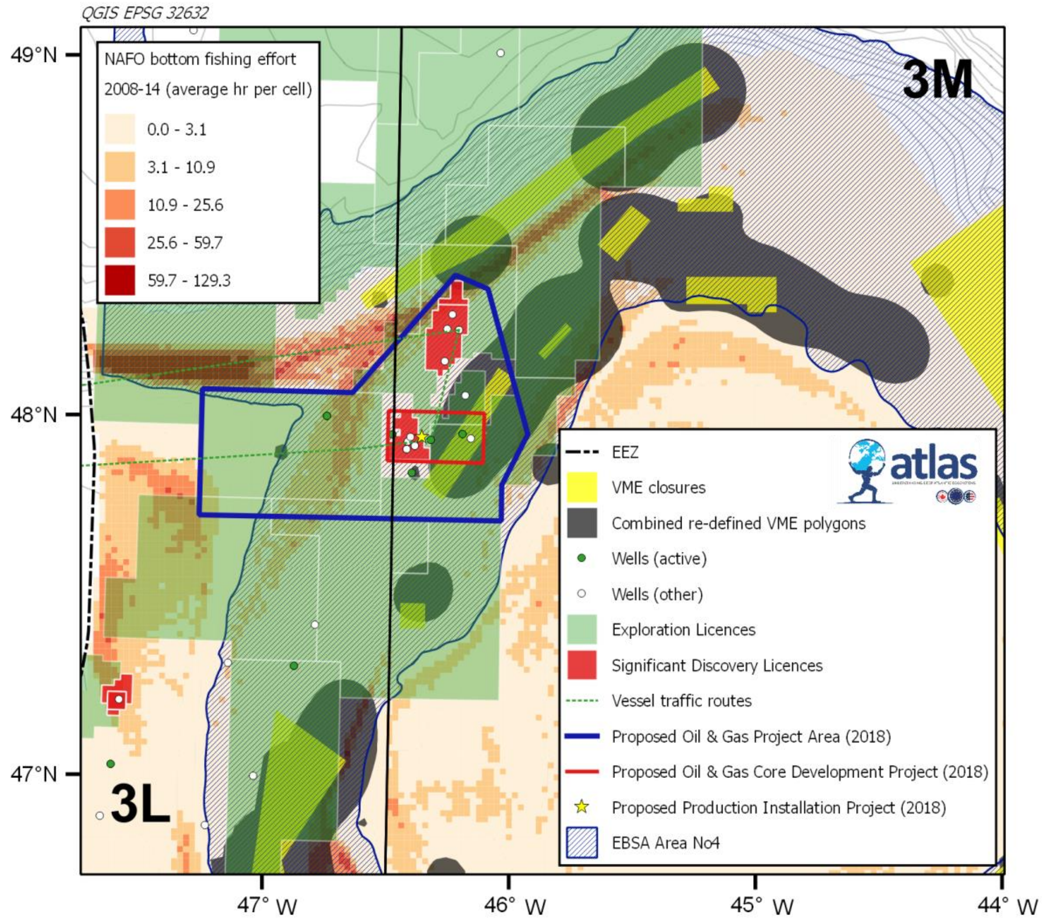

Figure 17.1. Map of the Flemish Cap-Flemish Pass area (Div. 3LM) showing the potential conflicts between different users of the marine space (e.g. oil and gas *vs.* fisheries) and between users and environment (oil and gas *vs.* VMEs). The yellow star indicates the location of the proposed production installation. Moreover, the map reveals the tensions between different regulatory and jurisdictional frameworks (e.g. areas closed to bottom fishing are currently open to oil and gas exploration and exploitation). Sources (2018): NAFO, C-NLOPB and CBD.

During the period 2015-2019 there have been ten reported incidents of different types, with a major oil spill reported in 2018 (250,000 litres), and one in 2019 that occurred in the EEZ of the coastal state but extended into the NAFO Regulatory Area[6] (Table 17.1).

[6] According to the letter from Fisheries and Oceans Canada sent to NAFO on 23 July 2019 (Ref.NAFO/19-205).

Table 17.1. List of recent offshore oil spills and other relevant incidents in the NW Atlantic in the last five years (source CLNOPB).

Date	Incident description	Observations
17/08/2019	Hibernia Oil Spill	Estimated volume of oil on the water was 2,184 L at that time
17/07/2019	Hibernia Oil Spill	Oil expressed on the water could be in the order of 12,000 L. It occurred inside Canadian EEZ, but the analysis indicated that the oil drifted outside the EEZ and into the NAFO NRA (1)
16/10/2018	White Rose Field Oil Spill	250,000 L of oil were released to the environment
27/04/2018	Unauthorized discharge of Synthetic Based Mud (SBM) (Transocean Barents platform)	28,000 L of SBM was released to the environment
29/03/2017	Near Miss - Iceberg Approaches Close to the SeaRose Floating Production, Storage and Offloading (FPSO) Vessel	A medium size iceberg came within 180 meters of the FPSO (about 340,000 barrels of crude oil on board at that time)
15/07/2016	Unauthorized discharge/Impairment of safety critical equipment (Henry Goodrich drilling)	Approximately 1,800 L of hydraulic fluid was released to the environment
15/02/2016	Unauthorized discharge of glycol (West Aquarius)	1,317 L of glycol was released to the sea
30/09/2015	Unauthorized discharge of methanol (Terra Nova field)	3,000 L of methanol was released to the sea
31/08/2015	Major hydrocarbon gas release (Southern drill center)	8,938 kg of natural gas was released to the sea
28/07/2015	Major hydrocarbon gas release (Terra Nova FPSO)	10,000 kg of gas was released

In terms of trends of hydrocarbon activities, it is expected (based on current exploration leases and development projections) that oil and gas exploration activities could increase in the NRA until at least 2030. As of 2019, there are four offshore production fields on the Grand Banks and intense exploration activities along the eastern shelf break and Flemish Pass. The total area of licenses[7] has increased from 2014 to 2019 (see section on synthesis of offshore petroleum activities in this report). Table 17.2 presents the list of oil and gas projects (different Exploration Drilling Projects and one Development Project) proposed within the NAFO Regulatory Area.

Table 17.2. List of oil and gas projects proposed within the NAFO Regulatory Area. Source: IAAC

Location	Type of offshore project	Status of the Environmental Impact Assessment	Reference in the map of Figure 17.2
Newfoundland Orphan Basin	Exploration Drilling Project	In progress	1
Newfoundland Orphan Basin	Exploration Drilling Project	In progress	2
West Flemish Pass	Exploration Drilling Project	In progress	3
Flemish Pass Basin	Exploration Drilling Project (Approved)	Completed	4
Flemish Pass Basin - Baie du Nord	Development Project	In progress	5
Flemish Pass Basin	Exploration Drilling Project	In progress	6
Jeanne d'Arc Basin and Flemish Pass Basin	Exploration Drilling Project (Approved)	Completed	7
Flemish Pass - Central Ridge Area	Exploration Drilling Project	In progress	9
Grand Banks	Exploration Drilling Project	In progress	10
Jeanne d'Arc Basin - Grand Banks	White Rose Extension Project (Approved)	Completed	11
Jeanne d'Arc Basin - Grand Banks (Tilt Cove)	Exploration Drilling Project	In progress	12
Southeastern Newfoundland (Carson Basin)	Exploration Drilling Project	In progress	13

Figure 17.2 shows the spatial extent of the Project Areas and the overlap with NAFO fisheries, VME closures and VME polygons in Div. 3LMN. Although ATLAS the MSP evaluation is focused specifically on the Flemish Cap – Flemish Pass area, the map indicated there are some other areas of interest in the NRA where the potential impact of activities other than fishing, particularly human activities linked to hydrocarbon exploration and exploitation, may be occurring.

The expected increase in demand for oil and gas exploration and production suggests that potential transboundary conflicts in the use of high seas areas could arise in the future in the NRA. Comprehensive MSP could help to evaluate specific conflicts in the high seas, contributing to the objective of ensuring that ecosystems in ABJN continue to perform their functions (Thurber *et al.,* 2014), while providing a balance between human uses and impacts (e.g. renewable and non-renewable exploitation, litter) and marine environments (e.g. fish, habitats, VMEs) (Armstrong *et al.,* 2010).

[7] License types: Exploration, Significant Discovery and Production

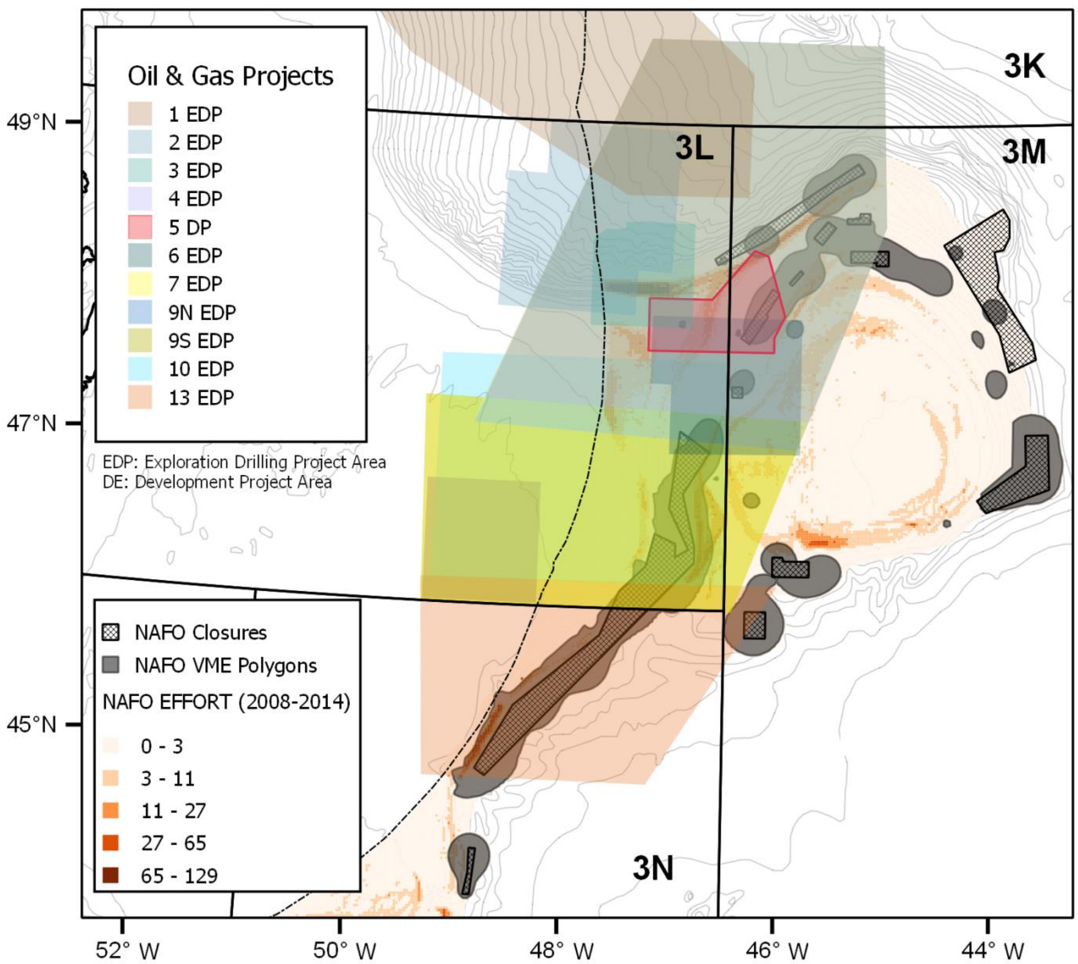

Figure 17.2. Map of the NAFO Regulatory Area (Div. 3KLNM), showing the location of the proposed Oil and Gas Project Areas listed in Table 17.2, and the overlapping with NAFO fisheries, VME closures and VME polygons (Div. 3LNM). The red polygon in Div. 3LM, indicates the location of the Flemish Pass Basin - Bay du Nord Development Project. EDP, Exploration Drilling Project Area; DP, Development Project Area. Sources (2019): NAFO and C-NLOPB website.

According to the UNESCO, one of the first tasks of MSP is the identification and establishment of the appropriate authority for MSP. Ehler *et al.* (2009) suggest that while planning without implementation is futile, implementation without planning is a recipe for failure. Therefore, MSP requires two types of authority: (i) authority to plan for MSP; and (ii) authority to implement MSP. Both are equally important. They could be combined in one organization, but in most MSP initiatives around the world, planning authority is often established for MSP, while implementation is carried out through existing authorities and institutions. One suggested way to establish a planning authority for MSP is through the creation of new legislation. Therefore, in order to develop and implement a spatial management plan integrating fishing and hydrocarbon activities in the NAFO Regulatory Area, as it is located in ABNJ, an international agreement on what type of authority is most appropriate, is necessary. This is the case for all MSP initiatives in ABNJ.

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18. Oil and gas activities

COM Request [16] and **ToR 3.4.** ***Synthesis of offshore petroleum activities in 3KLMN***

Offshore petroleum activities have been occurring in NAFO divisions 3KLMN for decades. The first drilling activities began in the 1960s, reservoirs were discovered in the 1970s and by 1997 the first oil producing platform (Hibernia) began operation. Today the most intense offshore activity is concentrated in 3L with four petroleum producing platforms assembled in the Jeanne d'Arc basin area. 3KMN is currently subject to exploration activity only with the exception of the relatively recent significant development licences in the Bay du Nord area in 3M.

Cumulative well counts and licence areas over time are presented in Figure 18.1 to illustrate the trends in exploration and development activity in 3KLMN. These data were sourced from the Canada-Newfoundland Labrador Offshore Petroleum Board (C-NLOPB) website[8]. Recent increases in offshore activity in 3KLMN is reflected by the steady rise in the number of wells starting in the early 2000s and licence areas starting in early 2010s (Figure 18.1). The spatial distribution of licences and wells in 3KLMN are displayed in Figure 19.2.

[8] The C-NLOPB was initiated in 1985 to manage resources in the Newfoundland Labrador offshore area on behalf of the Newfoundland Labrador and Canadian governments.

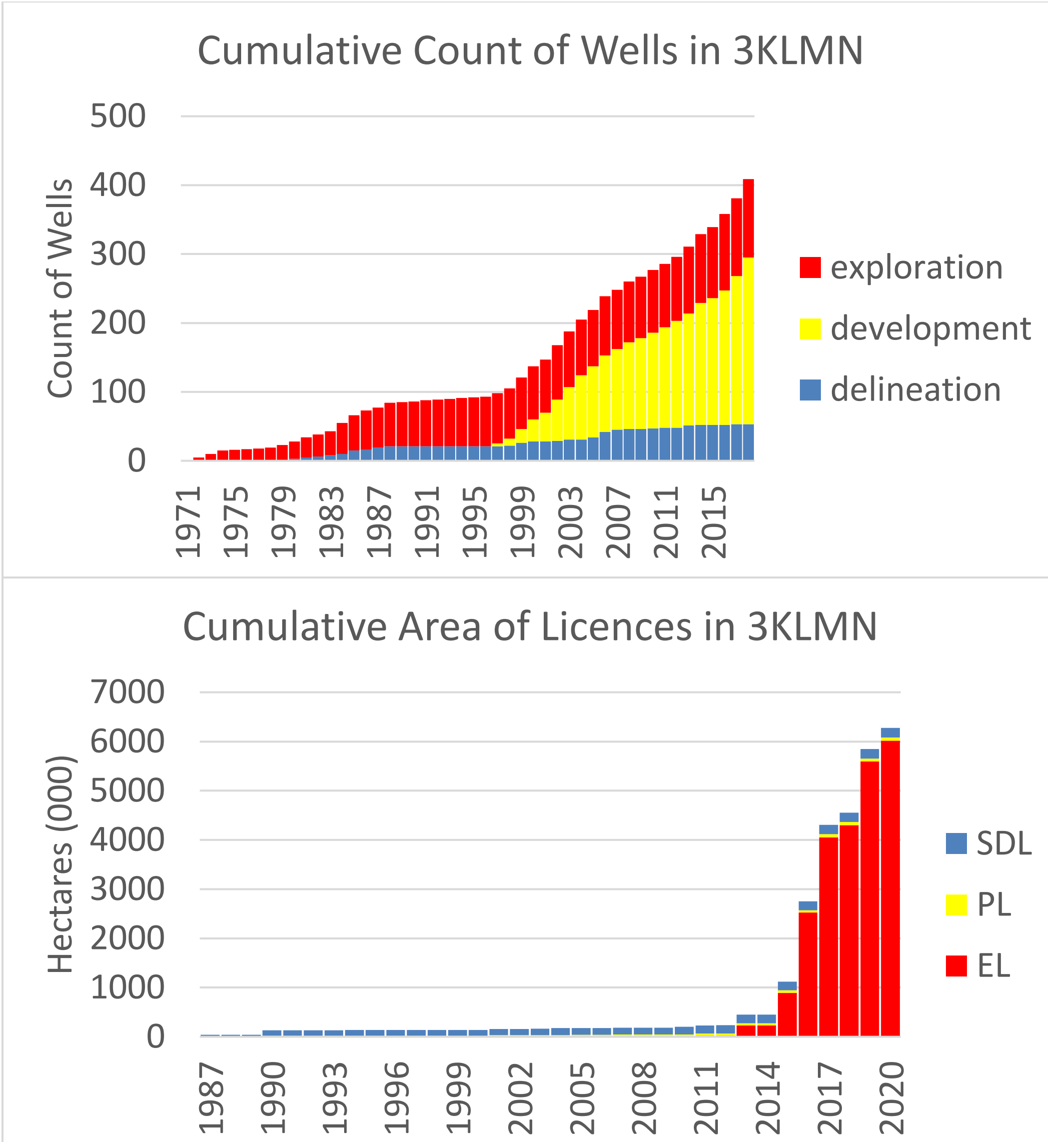

Figure 18.1. Cumulative number of offshore wells (top) and cumulative area of offshore licences (bottom) in the 3KLMN region (source: www.cnlopb.ca). EL (exploration licences), PL (production licences), SDL (significant development licences).

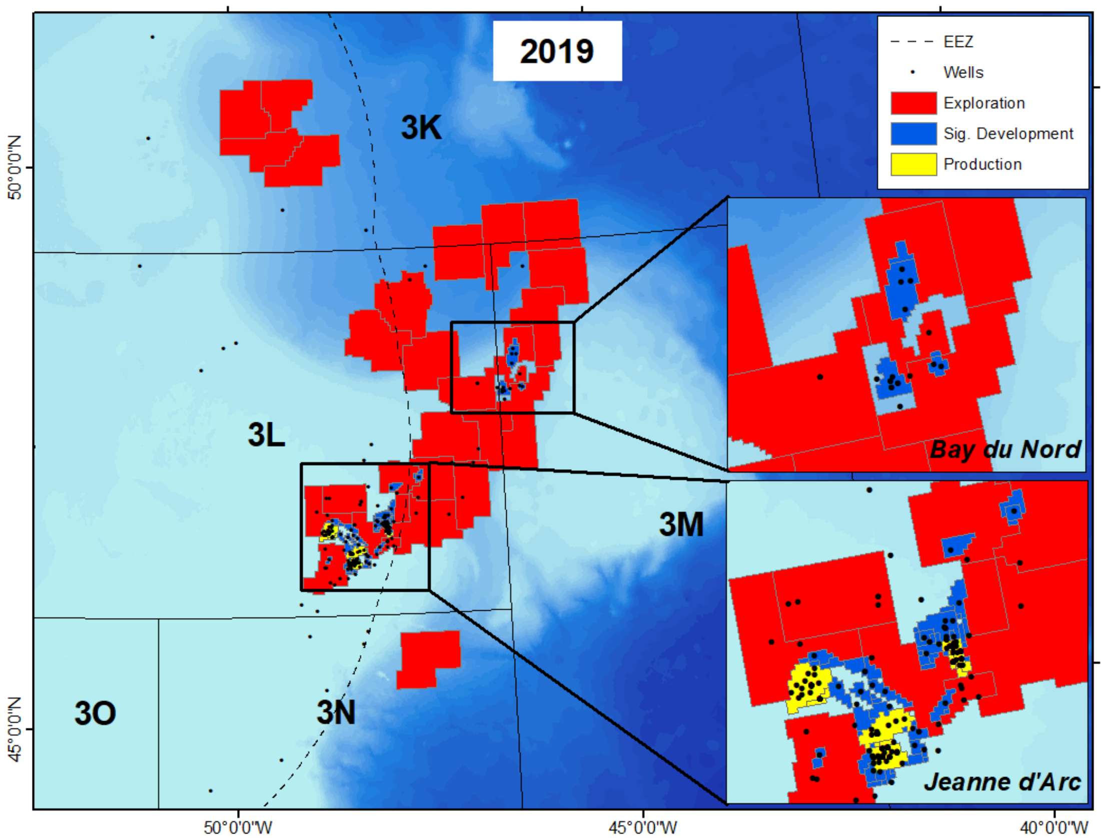

Figure 18.2. Offshore licences and wells in 3KLMN (2019)

19. Marine Mammals and Turtles

ToR 1.3, **COM Request [18]** ***Marine mammals and sea turtles in the NAFO regulatory area***

Data on the presence and abundance of marine mammals and turtles in the NAFO regulatory area are obtained from dedicated sighting surveys, opportunistic sightings, acoustic recorders and satellite telemetry studies. However, the amount of survey data available from the NRA is limited as a result of difficulties reaching the area with survey aircraft while opportunistic sightings reflect the distribution of observers rather than the distribution of animals. Marine mammal observers during the Spanish groundfish survey and on the fishing fleet have provided some information on species presence in the NRA. The deployment of acoustic recorders in offshore areas is recent and not fully analyzed. These instruments provide information on the presence or absence of individual species although preliminary analyses have indicated that identification of marine mammals present is difficult because of the high level of background noise from vessels and seismic activity.

Being highly mobile, marine mammals and turtles utilize large areas, often moving across the North Atlantic or from the Caribbean to the Arctic. Most species are seasonal migrants although some individuals may remain year-round, particularly in the warmer waters near the tail of the Grand Banks. Many of the cetaceans and turtles winter in southern waters, but summer on the Grand Banks and in the NRA while others such as harp and hooded seals summer in the Arctic and winter on the Newfoundland Shelf and Grand Banks.

The Grand Banks are a transition zone with both Arctic and temperate species occurring. As a result, approximately 25 cetacean and 7 pinniped species are present in the NAFO convention area. Of these, 5 pinnipeds (walrus, and ring, bearded, harbour, and grey seals) and 2 cetaceans (beluga and narwhal) are mainly observed in nearshore waters and so unlikely to occur in the NRA. Many of the remaining species, such as minke, humpback and killer whales, and most of the small cetaceans and harbour porpoise, are widely distributed across the continental shelf, including the NRA. They are also occasionally sighted in the deep water off the shelf edge. Sperm whales are commonly reported in NRA in both the opportunistic sightings database and by Spanish observers. Fin whales are also widely spread throughout the convention area, although a habitat suitability model identified the nose and tail of the Grand Banks, Flemish Pass and Orphan Basin areas as important habitat during the spring and summer. The southern edge of the Grand Banks was also identified as important habitat for the endangered Northwest Atlantic blue whale population.

Some species are most commonly found along the continental slope. Beaked whales (Family Ziphiidae) are a poorly understood group that inhabit offshore slope habitats and appear to be particularly sensitive to sound. The best known of this family is the Northern Bottlenose Whale which occurs along the edge of the continental shelf from Davis Strait to the Scotian shelf. A habitat suitability model indicates that the area from the nose of the Banks, Orphan Basin to Flemish Pass and Flemish Cap are particularly important for this species.

There are considerable data available on the movements of harp and hooded seals based on satellite telemetry studies. Both species feed in the NRA prior to, and after, the pupping period in March. Harp seals utilize the continental shelf, particularly the nose of the Banks, while hooded seals are common along the slope edges of the Flemish Pass and Flemish Cap. These are important feeding areas for both species.

Harp seals are the most abundant marine mammal in the North Atlantic. After two decades of being relatively stable, the NW Atlantic population is currently estimated to have increased over the past 5 years to 7.6 million. Hooded seals were last assessed in 2006 at 587,000. Less is known about abundance of cetaceans; only two large scale surveys have been carried out that covered the entirety of Canadian Atlantic waters, one in 2007 and the other in 2016. The estimates of abundance of the main species varied among surveys and could not be accounted for by population growth, suggesting a change in distribution from the earlier to the later survey. In 2016, abundance of minke whales, humpback whales and fin whales in Newfoundland and Labrador waters were estimated to be 12,000, 8,400 and 2, 200, respectively. The most abundant cetacean was white-beaked dolphins (530,500). Because of the lack of long-term data, trends in abundance of almost all of the cetacean species are unknown.

Three species of sea turtles, loggerhead, green and leatherback, have been reported in the NRA. However, only leatherback turtles occur regularly. They migrate from South America to feed on jellyfish in the NAFO convention area each year, and occur in the Northwest Atlantic primarily during the late summer and early fall when water temperatures reach a maximum. A habitat suitability model based on data from the 2016 megafauna survey did not extend to the NRA but indicated that suitable habitat for leatherback turtles extended across the Grand Banks to both the nose and tail.

Many of the species included in this summary have been reported caught in fishing gear in the NRA and the Convention Area but bycatch rates and the species involved are unknown.

20. AOB.

a) Presentation to IAAC

WGESA Presentation to Impact Assessment Agency of Canada Regional Assessment Committee

In early November 2019, the Regional Assessment Committee for Exploratory Drilling East of Newfoundland and Labrador of the Impact Assessment Agency of Canada (IAAC) contacted the Executive Secretary of NAFO to express interest in receiving information/input from NAFO on its VMEs. The Committee was conducting a Regional Assessment of the effects of existing and anticipated exploratory drilling in the eastern Newfoundland and Labrador offshore. The purpose of the regional assessment is to make it easier for future individual oil and gas exploratory drilling proposals to get their respective environmental approvals for their projects. The Committee's report is expected to recommend, *inter alia*, areas to avoid, areas in which mitigation measures should be put in place, as well as areas in which an individual environmental approval would not be necessary.

Following consultation with Contracting Parties, and because of the availability of WGESA members, the Executive Secretary arranged for an exclusive session for NAFO with the Committee to:

1. Provide a brief introduction to NAFO (Fred Kingston)

2. Present five areas NAFO wishes to raise, namely (1) Significant fishing activity beyond Canada's EEZ; (2) VMEs; (3) Annual scientific surveys to assess fishery resources and ecosystem state; (4) Scientific assessment of fish stocks; and (5) Information exchange with the Government of Canada (Fred Kingston)
3. Present the current state of knowledge of VMEs in the NAFO Area pertinent to the Regional Assessment (Pierre Pepin, Andrew Kenny, WGESA co-chairs)

Participants in the meeting included: Fred Kingston (NAFO Secretariat), Ricardo Federizon (NAFO Secretariat), Andy Kenny (WGESA co-chair), Pierre Pepin (WGESA co-chair), and members of WGESA (Mariano Koen-Alonso; Mar Sacau-Cuadrado, Pablo Durán Muñoz, Bárbara Neves, Kenji Taki).

Discussion with ICES

AOB ICES and NAFO Dialogue

As a result of consultations during the SC meeting in September 2019, WGESA approached the International Council for the Exploration of the Seas (ICES) to go over the plans and approaches for ecosystem status reports and how they link with each organization's plans for the implementation of ecosystem approaches.

A two hour consultation between WGESA members and ICES representative (Iñigo Martinez, Sebastian Valanco and Julie Kellner) occurred via WebEx. NAFO provided an overview of the Ecosystem Summary Sheets, VME assessments and the ongoing work to implement the NAFO Roadmap. ICES provided an overview of Ecosystem Overviews, Integrated Ecosystem Assessments (IEAs) and Seafloor Integrity, D6 and deep sea access regulations.

The discussions identified a number of areas of common interest. VME assessments and protection were areas where there is considerable potential for cooperation, partly because some WGESA members have been contributing to both NAFO and ICES. Development and application of ecosystem overviews in the provision of advice was also an area in which both organizations could benefit from cross-fertilization. Development and application of ecosystem level objectives through a dialogue between science and management sectors (e.g. workshop) were identified as active areas that would provide good opportunities for participation in each organization's meetings.

Date and place of next meeting

The next meeting will be held at the NAFO Secretariat offices, Nova Scotia, Canada from 17 to 26 November 2020.

ANNEX 1: WG-ESA 2019 MEETING AGENDA TERMS OF REFERENCE AND SPECIFIC TOPICS TO ADDRESS

Theme 1: Spatial considerations

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

1. *Update on VME indicator species data and VME indicator species distribution from EU and Canada Groundfish Surveys in 2019. (Mar)*
2. *Reassessment of VME fishery closures including seamount closures for 2020 assessment. (Ellen, Andy + Others).* ***COM Request [7].***
    - *Up-dated KDE analyses for all VME indicator groups for review of closed areas (Ellen)*
    - *New SDMs for bryozoans and tunicates using Bathy Position Index (BPI) to better resolve hard bottom areas spatially (Ellen & Anna).* ***COM Request [6]***
    - *Summarise connectivity research for review of closed areas using 3d tracking of ocean parcels (Ellen and Shuangqiang)*
    - *Review of VME indicator species (Lindsay/Javier and Barbara)*
    - *Update on the Research Activities related to EU-funded Horizon 2020 ATLAS Project, Flemish Cap Case Study: Species Distribution models for Pennatula aculeata (sea pen) and Acanella arbuscula (small gorgonian) (Mar).*
3. *Provide information to the Commission at its next annual meeting on sea turtles, sea birds, and marine mammals that are present in NAFO Regulatory Area based on available data. (Garry, Pablo.)* ***COM Request [18].***

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

ToR 2. Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area.

1. *Progress of analysis undertaken by EU NEREIDA research (Andy, Anna & Mar)* ***COM Request [6]****:*
    a. *Up-date on empirical analysis of trawl data and sea pen resilience modelling (Anna)*
    b. *Up-date on fish habitat modelling (Anna)*
    c. *Up-date on mapping fishery specific effort and overlap with VME (integration of VMS & log-book data) (Mar)*
    d. *Up-date on bottom fishery risk assessment frameworks (Mar/Pablo)*
2. *Up-date on VME modelling (Mariano, Neil).* ***COM Request [6 and 7].***
3. *Up-date on VME biological traits analysis and the assessment of VME functions (Javier et al.).* ***COM Request [6]***
4. *Review progress on assessment of bottom fisheries and functional traits analysis workplan, including stock take on SAI approach (Andy)*
5. *Maintain efforts to assess all six FAO criteria (Article 18 of the FAO International Guidelines for the Management of Deep Sea Fisheries in the High Seas) including the three FAO functional SAI criteria which could not be evaluated in the current assessment (recovery potential, ecosystem function alteration, and impact relative to habitat use duration of VME indicator species). (Ellen, Andy et al.).* ***COM Request [6].***
6. *Review progress against establishing clearer objective ranking processes and options for objective weighting criteria for the overall assessment of SAI and risk of SAI (All).* ***COM Request [6]****.*

Theme 3: Practical application of ecosystem knowledge to fisheries management

ToR 3. Update on recent and relevant research related to the application of ecosystem knowledge for fisheries management in the NAFO area.

1. *The Commission requests the Scientific Council to continue to refine its work under the Ecosystem Approach Road Map, and to evaluate the reliability of the ecosystem production potential model based upon the workplan developed by SC. (Pierre & Mariano.)* ***COM Request [5]****.*

2. *Finalise the preparation of the Ecosystem Summary Sheet (ESS) for 3LNO for presentation to the Commission at the 2020 Annual Meeting. (Pierre, Mariano, Andrew, Ellen, Garry)* ***COM Request [12]***
3. *The Commission requests that Scientific Council continue its evaluation of the impact of scientific trawl surveys on VME in closed areas, and the effect of excluding surveys from these areas on stock assessments (SC – June).* ***COM Request [3].***
4. *The Commission requests Scientific Council to monitor and provide regular updates on relevant research related to the potential impact of activities other than fishing in the Convention Area, such as oil exploration, shipping and recreational activities, and how they may impact the stocks and fisheries as well as biodiversity in the Regulatory Area.(Pablo).* ***COM Request [16].***
5. *Framework to revise Chapter 2 assessment needs regarding potentially integrating the requirements of the review of VMEs with the reassessment of bottom fisheries every 5 years. (All)* ***COM Request [6 and 7]***

Theme 4: Additional Requests

AOB.

ANNEX 2: SUMMARY OF RECOMMENDATIONS

In relation to Commission Request [3] *The Commission requests that Scientific Council continue its evaluation of the impact of scientific trawl surveys on VME in closed areas, and the effect of excluding surveys from these areas on stock assessments.*

WG-ESA therefore **recommends** that *Scientific Council investigates the use of non-destructive cost effective sampling techniques to monitor VMEs and the options for integrating such techniques and the data they generate into the existing scientific trawl surveys, possibly through the establishment of an ad hoc WG on non-invasive survey methods.*

In relation to Commission Request [7] T*he Commission requests Scientific Council to conduct a re-assessment of VME closures by 2020, including area #14.*

The areas requiring urgent management action are the VME areas on the Tail of Grand Bank and the sea pen closures on Flemish Cap. The former have completely unprotected VME (small gorgonian corals, sea squirts, sea pens, and erect bryozoans) while the latter have overlapping VMEs (2-4 habitats including glass sponges), and are too small to ensure protection from fishing and to enable connectivity among closures. New boundaries for seamount closures have been proposed and management action would be desirable.

A summary of the re-assessment of the NAFO closed areas and how each VME taxon is protected based on the information provided above is given in Table 12.4.

Table 12.4. Re-assessment of NAFO closed areas. Overview of recommendations and need for management action (see Table 12.2) for each of the VME taxa considering their overall protection, and regionally-specific assessments of the effectiveness of the closed areas, all ranked by need for management action.

VME Type/Closure	Recommendation	Management Action
Small Gorgonian Corals	Inadequate	Essential
Sea Squirts (*Boltenia ovifera*)	Inadequate	Essential
Erect Bryozoans	Inadequate	Essential
Black Coral	Poor	Essential
Sea Pens	Poor	Essential
Large Gorgonian Corals	Incomplete	Desirable
Large-Sized Sponges	Incomplete	Desirable
Division 3O Coral Closure and Area 1 Tail of the Bank	Inadequate	Essential
Areas 4-12 Flemish Cap and Sackville Spur Including Area 14	Inadequate	Essential
Area 2 Flemish Pass/Eastern Canyon and Areas 3, 13 Beothuk Knoll	Adequate-Poor	Desirable
Seamounts	Incomplete	Desirable

In relation to Commission Request [7] T*he Commission requests Scientific Council to conduct a re-assessment of VME closures by 2020, including area #14*

The group proposed that a review of the existing list of VME indicator species given in Annex I.E, Part VI of the NAFO CEM is conducted each year under *ToR 1.2. Review of VME Indicator Species* and that a running list of such changes to the taxonomy and nomenclature be kept until every third year, when such revisions are submitted as recommendations to SC.

Based on the new kernel density estimation (KDE) analyses of black corals conducted during the 12th WG-ESA meeting (see SCR Doc 19-058), WG-ESA recommends to SC the inclusion of black corals, and its following constituent taxa, in the list of VME Indicator Taxa of the 2021 NAFO CEM:

Table 13.2. Black coral taxa known to occur in the NAFO Regulatory Area (including seamounts).

Known Taxon	Family	Included in NAFO VME Guide
Stichopathes sp.	Antipathidae	Yes
Leiopathes cf. *expansa*	Leiopathidae	No
Leiopathes sp.	Leiopathidae	No
Plumapathes sp.	Myriopathidae	No
Bathypathes cf. *patula*	Schizopathidae	No
Parantipathes sp.	Schizopathidae	No
Stauropathes arctica	Schizopathidae	Yes
Stauropathes cf. *punctata*	Schizopathidae	No
Telopathes magnus	Schizopathidae	No

In relation to Commission Request [16]*. The Commission requests Scientific Council to continue to monitor and provide updates resulting from relevant research related to the potential impact of activities other than fishing in the Convention Area (for example via EU ATLAS project), and where possible to consider these results in the on-going modular approach concerning the development of Ecosystem Summary Sheets.*

WG-ESA recommends to Scientific Council that standardized protocols for marine litter data collection should be implemented by all Contracting Parties as part of their groundfish surveys conducted in NAFO Regulatory Area. Implementation of such protocols would allow monitoring the spatial and temporal distribution of marine litter, contributing to improved knowledge of their characteristics in the NAFO Regulatory Area.

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