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SC WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT – NOVEMBER 2018

Report of the 11th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA)

NAFO Headquarters, Dartmouth, Canada
13 - 22 November 2018

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13-22 November 2018

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 11th meeting on 13-22 November 2018 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 roadmap, 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 roadmap priorities.

ToRs to be addressed in 2018 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 Roadmap develop research and summarize new findings on the spatial structure and organisation 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 place-holders 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.

The following ToRs were addressed at the 11th meeting of WG-ESA:

THEME 1: SPATIAL CONSIDERATIONS

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

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

1.1. Update on VME indicator species data and distribution

ToR 1.1 *Update on VME indicator species data and VME indicator species distribution from EU and EU-Spain Groundfish Surveys in 2018*

New preliminary data on VME encounters in NAFO Regulatory Area (Divs. 3LMNO) from EU and EU-Spain Groundfish Surveys (2018).

During the 11th NAFO Working Group on Ecosystem Science and Assessment (WGESA) meeting new preliminary data on deep-water corals and sponges were presented from the 2018 EU and EU-Spain bottom trawl groundfish surveys. The data was made available to the NAFO WG-ESA to improve mapping of Vulnerable Marine Ecosystem (VME) species in the NAFO Regulatory Area (Divs. 3LMNO).

During the 6th meeting of the NAFO Scientific Council WG-ESA, new quantitative spatial analyses were applied for corals and sponges for all the available data within the NAFO Regulatory Area (SCS Doc. 13-24). Outcomes from the analyses produced the following thresholds for VME species groups: 75 kg per tow for sponges, 0.6 kg per tow for large gorgonians, 0.15 kg per tow for small gorgonians, and 1.4 kg per tow for sea pens. Based on these thresholds deep-water coral and sponge data were identified and mapped, overlaid with the current closed areas, polygons for kernel density of sea pens and modified kernel density polygons for sponge grounds and large gorgonian VMEs.

Data used in this study were collected from four surveys:

1. The EU-Spain 3NO groundfish survey, conducted by the Instituto Español de Oceanografía (IEO), sampled the Grand Banks of Newfoundland (NAFO Divs. 3NO) between 47 - 1380 m depth with a total of 118 tows.

2. The EU-Spain and Portugal Flemish Cap groundfish survey, conducted by the IEO together with the Instituto de Investigaciones Marinas (IIM) and Instituto Português do Mar e da Atmosfera (IPMA), sampled the Flemish Cap (NAFO Div. 3M) between 129 -1440 m, with a total of 184 tows.

3. The EU-Spain Fletán Negro-3L groundfish survey, conducted by the IEO, sampled northeast Grand Banks of Newfoundland (NAFO Div. 3L) between 116 - 1442 m depth, with a total of 101 tows.

There were 403 bottom trawl tows (397 valid) carried out during 2018 EU-Spain groundfish in the NRA for this report (Figure 1.1).

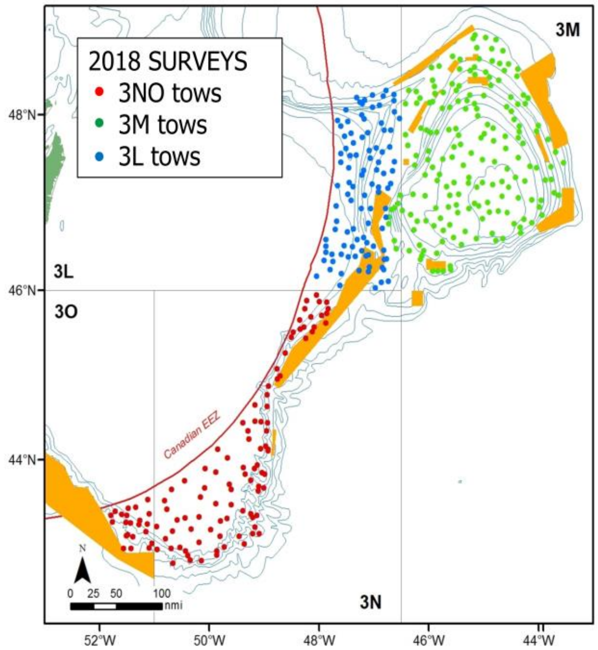

Figure 1.1. Distribution of sets (start positions) from 2018 EU-Spain groundfish surveys (NAFO Divs. 3LMNO).

Following previous methodologies used by WGESA, deep water corals were grouped by VME species groups and include; large gorgonians (Order: Alcyonacea), small gorgonians (Order: Alcyonacea), sea pens (Order: Pennatulacea), and sponges (Phylum: Porifera).

Distribution maps of presence (non-significant and significant catches) for large gorgonians, small gorgonians, sea pens, and sponges are presented below (Figures 1.2-1.5). Locations of each coral and sponge records were assigned by start position of each tow for 2018 EU-Spain groundfish surveys. Coordinates and weights of the significant catches are provided in Table 1.1.

Table 1.1. Significant catches of corals and sponges in the NRA (Divs. 3LMNO) with their corresponding depth and weight. Note that tow positions are in decimal degrees.

			Start position			
VME Indicator Species	**Year**	**Survey**	**Lat (N)**	**Lon (W)**	**Depth (m)**	**Weight (kg)**
SPONGES >= 75 kg	2018	3NO	44.97	-48.76	1380	78.65
	2018	3NO	45.52	-48.12	1312	105.99
	2018	3NO	45.62	-47.87	1283	385.35
SMALL GORGONIANS >= 0.15 kg	2018	3L	47.23	-46.69	1152	0.24
	2018	3M	47.81	-44.03	648	0.17
SEAPENS >=1.4 kg	2018	3L	47.23	-46.69	1152	2.67
	2018	3M	48.42	-44.89	723	1.51

<u>Sponges</u>

EU-Spain 2018 Data: Sponges were recorded in 129 of the 397 valid tows (31.7% of the total tows analyzed), with depths ranging between 77 - 1442 m (Figure 1.2).

Significant catches of sponge (≥ 75 kg/tow) were found in three tows (see Table 1.1 and Figure 1.2). These catches were located in Flemish Pass area inside the KDE sponge polygon. Sponge catches for these tows ranged between 78.65 - 385.35 kg.

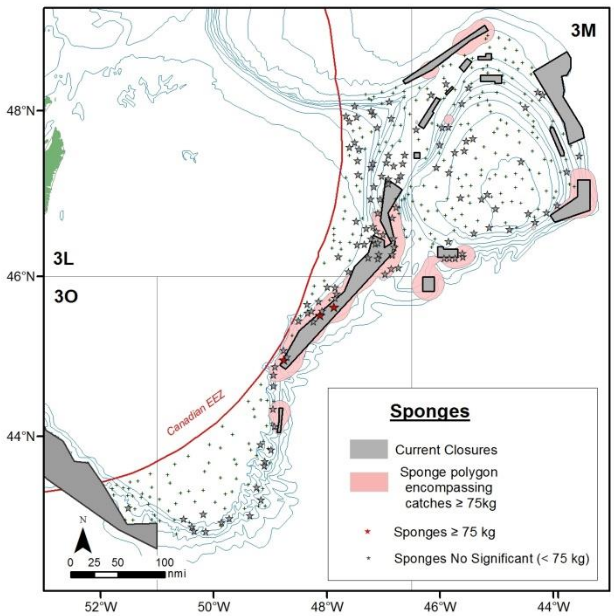

Figure 1.2. Distribution of significant and non-significant catches of sponges in the study area from 2018 EU-Spain surveys (NAFO Divs. 3LMNO). Black crosses represent tows with no sponge bycatch recorded.

<u>Large Gorgonians</u>

EU-Spain 2018 Data: Large gorgonians were recorded in 9 of the 397 valid tows (2.3% of total tows analyzed), with depths ranging between 110 - 1347 m (Figure 1.3). None of the tows have significant catches of large gorgonians (≥ 0.6 kg/tow).

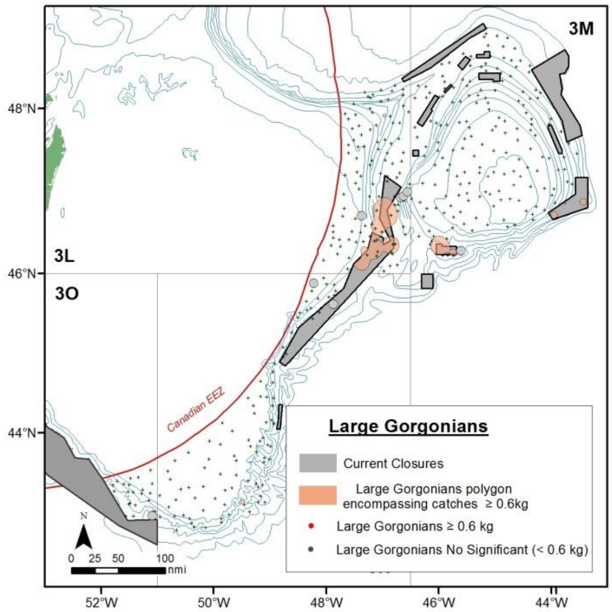

Figure 1.3. Distribution of significant and non-significant catches of large gorgonians in the study area from EU-Spain 2018 surveys (NAFO Divs. 3LMNO). Black crosses represent tows with no large gorgonians bycatch recorded.

Small Gorgonians

EU-Spain 2018 Data: Small gorgonians were recorded in 44 tows (10.5 % of total tows analyzed), with depths ranging between 331 - 1364 m (Figure 1.4).

Significant catches (≥ 0.15 kg/tow) were recorded in two tows (0.5% of the total tows) located at the top of closed area 2 in the Flemish Pass and closed area 14 in the eastern part of Flemish Cap, outside of the actual closed areas with depths of 648 and 1152 m (Table 1.1).

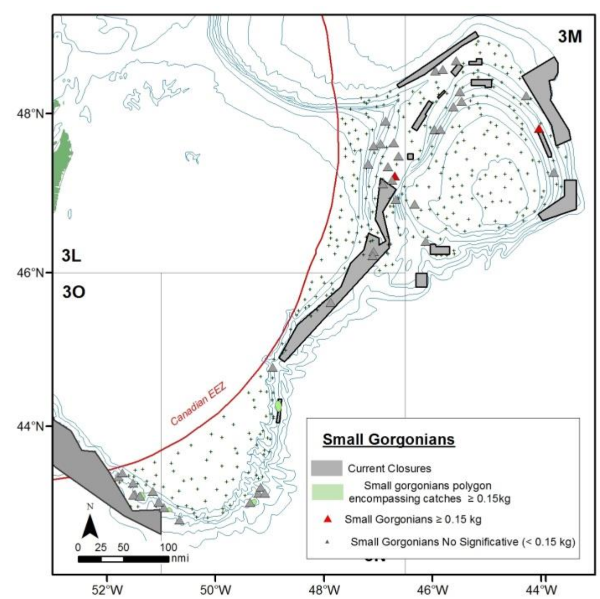

Figure 1.4. Distribution of significant and non-significant catches of small gorgonians in the study area from EU-Spain 2018 surveys (NAFO Divs. 3LMNO). Black crosses represent tows with no small gorgonian bycatch recorded.

<u>Sea Pens</u>

EU-Spain 2018 Data: Sea pens were recorded in 137 tows (34% of total tows analyzed), with depths ranging between 136 - 1442 m (Figure 1.5).

Significant catches (≥ 1.4 kg/tow) were recorded in two tows (1.5- 2.6 kg), one located at north of Flemish Cap (723 m - 1.5 kg) and the other located in the southwest part of Flemish Cap (1152 m - 2.6 kg), both of them inside the corresponding VME KDE polygon (Table 1.1).

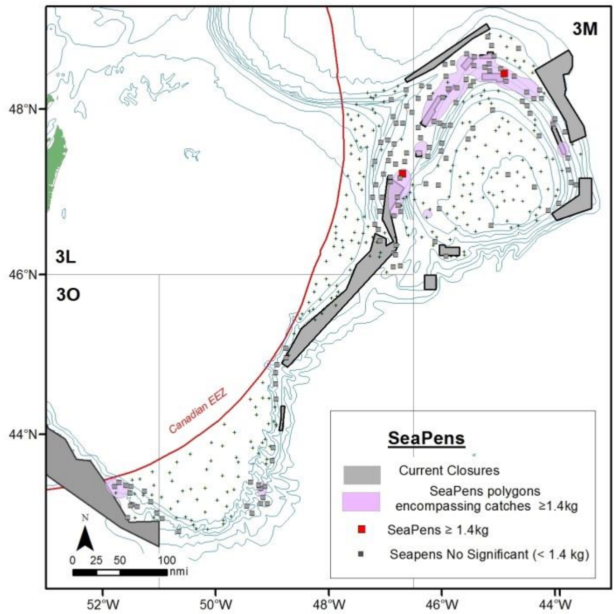

Figure 1.5. Distribution of significant and non-significant catches of sea pens in the study area from EU-Spain 2018 surveys (NAFO Divs. 3LMNO). Black crosses represent tows with no sea pen bycatch recorded.

Table 1.2. Summary of deep-water corals and sponges records for the NRA from EU-Spain 2018 survey data.

EU-Spain data 2018	Presence Significant and Non-Significant (# of tows)	Total Tows (% of tows)	Significant Concentrations (# of tows)	Significant Concentrations (% of tows)	Significant Concentrations inside KDE corresponding polygon
Sponges	129	31.7%	3	0.8%	3
Large Gorgonians	9	2.3%	0	0%	0
Small Gorgonians	44	10.5%	2	0.5%	2
Sea Pens	137	34%	2	0.5%	2

1.2. Progress on implementation of workplan for reassessment of VME fishery closures.

ToR 1.2. *Progress on implementation of workplan and timetable for reassessment of VME fishery closures including seamount closures for 2020 assessment.* (COM Request # 11).

The workplan of tasks required for the re-assessment of VME closures in 2020 was discussed and the following actions agreed and assigned to lead individuals:

1. An update of the KDE analysis from 2014 – to include all additional VME indicator species data from trawl surveys, up-to and including the 2019 survey data. The up-dated survey data should be provided by 1st October 2019 in order to allow sufficient time to progress the analysis (EU data – Mar; Canada data - Vonda). Up-dated KDE analysis and maps will be produced for; i. sea pens (assemblage), ii. sponges (*geodia*), iii. large gorgonians (assemblage), iv. small gorgonians (assemblage), v. bryozoans (assemblage), and vi. stalked tunicates (*boltenia sp*). Data on glass sponges will also be compiled and provisionally analysed (BIO-Ellen/Cam). In the event that the updated data is not available by the deadline above, it was agreed that the analyses would proceed with the data provided as of that date.
2. An update on SDM (habitat) models incorporating the individual species of sea pen SDMs developed under the ATLAS R&D project (e.g. *Pennatula sp*., *Halipteris finmarchica*, and *H. christii*), in addition to the existing sea pen species already modelled will be included in the VME assessment (IEO - Mar). An SDM for small gorgonians will also be considered, if the data is good enough. Otherwise previous SDMs will be used to underlay the KDE polygons and closed areas.
3. For the bryozoan turf (assemblage), and stalked tunicates (*Boltenia sp*) additional seabed physical data (where available) derived from Roxanne (sea bed sediment discrimination) will be used to refine the KDE polygons for these two VME indicator groups. In addition, 75 metre resolution data on substrate type may be included to refine the boundaries of the VME (BIO - Javier and others)
4. Consideration of the connectivity of VMEs through links between propagule/larval transportation and VME distribution/location, as investigated by Kenchington *et al*. should be included. This will highlight the importance of certain VME closed areas in supporting larval dispersal and recruitment between other VME closed areas of the same type (BIO - Ellen)
5. Consideration of the biodiversity of the closed areas as measured by species density (the number of species per survey trawl) will be included in the review (BIO-Ellen/Javier).
6. It was noted that the Corner Rise and New England Seamounts were originally discussed together; however, only revisions to the New England Seamounts have been progressed to date. To ensure consistency in approach other seamount closures, in particular the Corner Rise seamount should be progressed in preparation for the VME fishery closure review in 2020. To be done at the WG-ESA meeting 2019. To include any up-dates on known VME presence. (including new data on Orpan Knoll transects in 2010, and Kelvin seamount data in 2016).
7. Observed differences in VME species diversity and VME functions (being progressed under ToR 2.3) should be highlighted.

1.3. Discussion on updating Kernel Density Analysis and SDM's

ToR 1.3 *Discussion on up-dating Kernel Density Analysis and SDM's for VME indicator species in preparation for VME fishery closure review in 2020. COM Request # 11.*

The outcomes of discussion relating to this ToR are captured under ToR 1.2 above.

1.4. Update on the Research Activities related to EU-funded Horizon 2020 ATLAS Project

ToR 1.4 *Update on the Research Activities related to EU-funded Horizon 2020 ATLAS Project, Flemish Cap Case Study: Species Distribution models for two deep-water pennatulacean coral.* (COM Request # 11).

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 11th NAFO WGESA meeting, the EU ATLAS project (in collaboration with iSEAS project) was presented giving updated information regarding Species Distribution Models (SDMs) for the *Anthoptilum grandiflorum* and *Funiculina quadrangularis* deep-water pennatulacean coral for Flemish Cap Case Study (Flemish Cap and Flemish Pass areas).

ATLAS 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 1.6) 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.

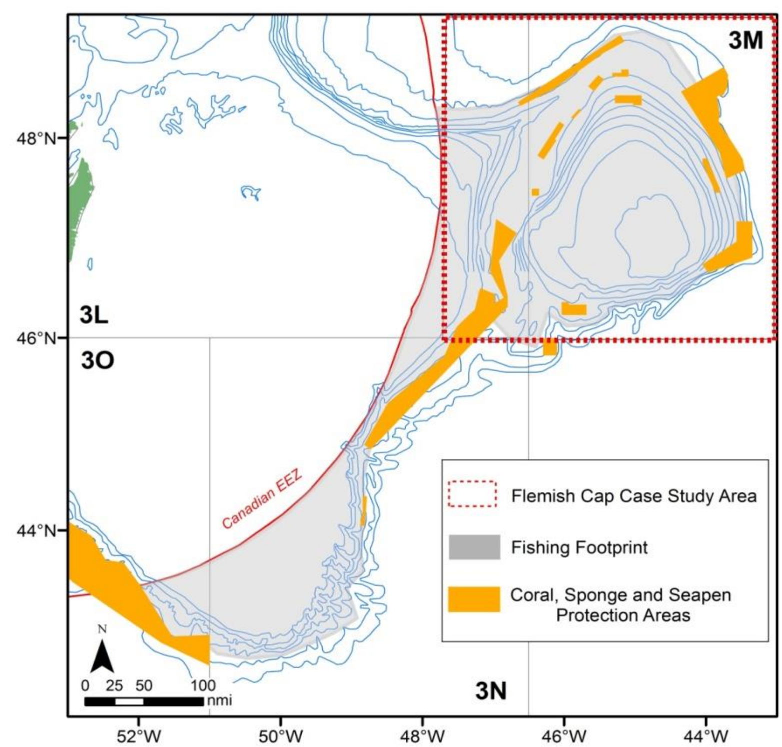

Figure 1.6. Flemish Cap Case Study spatial extent (red dashed line)

In terms of SDMs, different modeling algorithms were presented to classify the probability of habitat suitability for *Anthoptilum grandiflorum* and *Funiculina quadrangularis* 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:

1. Oceanographic variables: Sea Bottom Temperature (CTD); Sea Bottom Salinity (CTD); Mixed layer depth and Bottom Current Speed (VIKING20 model).
2. Bathymetric features: bathymetry, slope and orientation of the seabed (retrieved from NEREIDA project and MARSPEC database), sediment texture and gravel (Murillo, 2016).
3. In addition, and following the suggestions made during the 2018 Scientific Council June meeting (p. 121, SCS Doc. 18-19), fishing effort layer was included as a new predictor variable. The updated results were presented during the 11th WGESA meeting.

Three different modelling techniques were implemented: Generalised Additive Models (GAM), Random Forest (RF), and MAXENT (Maximum Entropy model) 3.4.1 (MAXENT, 2017). Models were built in the open source spatial statistical computing software R (R development Core Team, 2016) using the necessary packages for each case. 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 *Anthoptilum grandiflorum* and *Funiculina quadrangularis* deep-water pennatulacean in unsampled locations of the Case Study area.

Maps showing the probability of habitat suitability for *A. grandiflorum* (Figure 1.7) and *F. quadrangularis* (Figure 1.8) 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 effort layer.

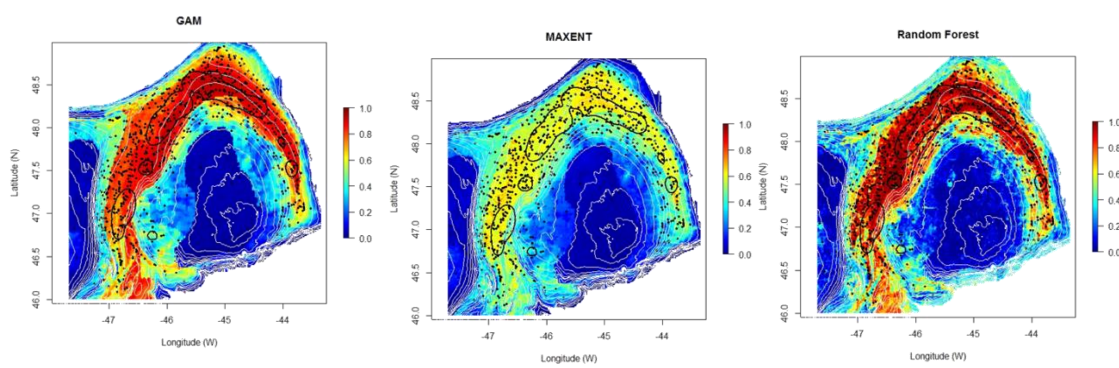

Figure 1.7. Probability of habitat suitability for *A. grandiflorum* for GAM, MAXENT and Random Forest models. Presence records (black dots) and KDE sea pens polygons are also illustrated.

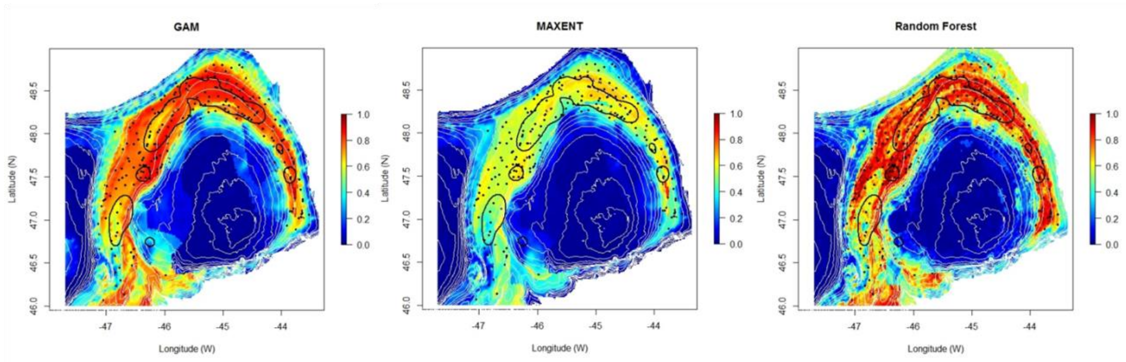

Figure 1.8. Probability of habitat suitability for *F. quadrangularis* for GAM, MAXENT and Random Forest models. Presence records (black dots) and KDE sea pens polygons are also illustrated.

Tables 1.3 and 1.4 below shows the model prediction performance statistics of the different models in order to assess the accuracy of the different SDM implemented (values with * correspond to statistics without fishing effort predictor).

Table 1.3. Model prediction performance statistics for *Anthoptilum grandiflorum.*

	AUC	Sensitivity (%True+)	Specificity (%True-)	TSS	cor
MAXENT	0.77/0.78*	0.94/0.91*	0.60/0.58*	0.54/0.49*	-
GAM	0.86/0.86*	0.67/0.67*	0.69/0.69*	0.36/0.36*	0.61/0.62*
Random Forest	0.85/0.86*	0.67/0.67*	0.68/0.68*	0.35/0.35*	0.62/0.63*

Table 1.4. Model prediction performance statistics for *Funiculina quadrangularis.*

	AUC	Sensitivity (%True+)	Specificity (%True-)	TSS	cor
MAXENT	0.79/0.79*	0.97/0.97*	0.60/0.58*	0.58/0.54*	-
GAM	0.85/0.85*	0.67/0.67*	0.66/0.66*	0.34/0.34*	0.59/0.59*
Random Forest	0.82/0.83*	0.66/0.66*	0.65/0.66*	0.32/0.32*	0.58/0.61*

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.
- 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. *A. grandiflorum* and *F. quadrangularis* exhibit specific habitat preferences and spatial patterns in response to environmental variables (mainly bathymetry, sediment texture and current speed).
4. Understanding of sea pen distribution is crucial to delineate VME protection areas, contributing to the mitigation of by-catch of vulnerable benthic invertebrates.
5. According to the prediction performance statistics, inclusion of Fishing Effort as a new predictor variable did not imply a substantial improvement in the prediction for the three different models.

This work is the updated version of the work presented during the 2018 June Scientific Council meeting (1-14 June 2018) and should be considered as an approach for the creation of sea pen VME species distribution maps and habitat distribution models (SDMs and HSMs), used to improve our understanding of their biodiversity in the Flemish Cap and Flemish Pass areas.

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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1.5. Non-sponge and non-coral VMEs (e.g. bryozoan and sea squirts).

ToR 1.5 *Continue work on non-sponge and coral VMEs (for example bryozoan and sea squirts) to prepare for the next reassessment of bottom fisheries..* (COM Request # 9)

Last year, the WG-ESA (SCS Doc. 17-021) overlaid the available RoxAnn data (period: 1994-2005) on the records of bryozoans and sea squirts (*Boltenia ovifera*). Patches of hard substrate (small rocks and rocks) were observed in areas with significance catches of *Boltenia ovifera*. Additionally, the presence of shells inside the Bryozoa KDE polygon was indicated by such data. (Shells are commonly found attached to *Eucratea loricata*, which is the main species constituting the significant bryozoan catches). Based on these observations, the WG-ESA deliberated that additional information on other habitat data, such as surficial geology layers, should be examined to support adoption of the KDE-derived significant concentrations as VME in 2020.

Following this recommendation, the WG-ESA contacted Emilie Novaczek (DFO, St. John's) who is mapping marine substrate for Newfoundland and Labrador waters as one of her PhD chapters. She is modelling substrate based on depth, shape of the seafloor (slope, position index, curvature, etc.), current speed, and distance from shore (as a proxy for terrestrial sediment inputs). She has been using RoxAnn data as well as sediment samples, imagery, and sidescan interpretation from the Geological Survey of Canada to train the substrate models. It is expected that during 2019 she will publish a spatially continuous 75m grid layer with a substrate prediction for each cell that includes the Tail of the Grand Bank area where the significant concentrations of non-sponge and coral VMEs are found. This substrate layer if available will be included in the compilation of additional information to support these non-coral and sponge VME prior to the reassessment of the VME fishery closures in 2020.

1.6. Ecological diversity mapping and interactions with fishing on the Flemish Cap

The conservation of biological diversity beyond areas of national jurisdiction ("BBNJ") has become a high-profile international issue, and the NAFO Convention on Cooperation in the Northwest Atlantic Fisheries includes commitments to the need to preserve marine biodiversity within its jurisdiction (NAFO, 2017). Species density (SpD), the exponential Shannon diversity index ($e^{H'}$) and Heip's index of evenness ($\tilde{E}'$) were mapped on the Flemish Cap based on the trawl-caught benthic invertebrates from the 2007 EU survey (Murillo et al., Submitted). Continuous surfaces of each metric were created to 2000 m depth using predictive distribution models based on random forest (RF) algorithms. Not enough samples were collected to determine asymptotic values of species richness at the community level (as identified by Murillo et al. 2016). When fishing effort was included as a predictor in the RF models, it was the most important predictor of sample SpD but the prediction surfaces and model performance differed little. However, it was unimportant in predicting $e^{H'}$ and only a minor predictor of $\tilde{E}'$.

In the absence of a historical baseline, the spatial impacts of fishing activities on diversity were evaluated using a novel approach by simulating and comparing spatial SpD prediction surfaces from response data with different levels of fishing effort. Although it is not possible to fully evaluate the precise nature of the impact of fishing on the ecological diversity, the prediction surfaces identified Sackville Spur, Flemish Pass and south of Flemish Cap as the areas of greatest impact. Combining biomass of sponges and small gorgonian corals, depth, and fishing effort resulted in the best performing generalized additive model, explaining 71% of the total variance in SpD.

Although current closures to protect VMEs from the adverse impacts of bottom fishing activities protect around 60% of the ecological diversity associated with the deeper communities, unique and representative habitats on top of the Flemish Cap remain unprotected. Future monitoring of benthic diversity should focus on SpD (the number of species in a standard research trawl) and the working group recommended monitoring this value in future and to include an assessment of diversity in the review of closed areas to be undertaken at the November 2019 meeting.

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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.

Murillo, F.J., E. Kenchington, M. Koen-Alonso, J. Guijarro, T.J. Kenchington, M. Sacau, L. Beazley & H.T. Rapp. Mapping ecological diversity and interactions with bottom-contact fishing on the Flemish Cap (northwest Atlantic). Ecological Indicators (submitted November 2018).

NAFO. 2017. Convention on Cooperation in the Northwest Atlantic Fisheries. NAFO, Dartmouth, Nova Scotia, Canada. viii+38 pp. ISBN 978-0-9959516-0-0.

1.7 Sponge removal by bottom trawling in the Flemish Cap area: implications for ecosystem functioning

Sponge aggregations in the deep sea play a key role in the functioning of marine ecosystems (Maldonado et al., 2016). On Flemish Cap and in Flemish Pass, sponge grounds locally enhance biodiversity (Beazley et al., 2013; Beazley et al., 2015) and are considered structure-forming habitats. In addition, the huge filter-feeding capacity of sponges and their large consumption of particulate organic carbon (POC) and dissolved organic matter (DOM) has an impact on benthic pelagic-coupling. Sponges may also have a significant role in the cycling of inorganic nutrients, such as silicate, nitrate, nitrite, ammonium and phosphate (reviewed in Maldonado et al. 2012). Pham et al. (2018) quantified the biomass of sponges removed by the bottom trawling fleet operating on the Flemish Cap Area (northwest Atlantic) in order to assess the consequences for ecosystem function in terms of significant adverse impacts on sponges.

Data from bottom trawl research surveys (between 2006 and 2010) were used to estimate total sponge biomass present on the Flemish Cap, Flemish Pass and Tail of the Grand Bank. These biomass layers were created using different approaches (focal statistics and random forest modelling). Total sponge biomass within the NAFO fishing footprint was estimated to range between 80 to 100 thousand tonnes. Preliminary estimates suggest that a large portion of sponge biomass is located inside the NAFO closures. These biomass estimates were overlaid with data on the spatial distribution of fishing effort (based on Vessel Monitoring System, VMS) to estimate total removal of sponge biomass between 2010 and 2013. The total non-overlapping footprint of the trawling fleet (all sponges were assumed to be removed by a single trawl pass) was 9600 km^2, which was estimated to have removed 220-1500 tonnes of sponges.

Information on the ecological functions of sponges were compiled from the literature for filtration rate (litres x 10^6 day^{-1}), respiration (mol O_2 day^{-1}), carbon consumption (tC day^{-1}), ammonium consumption (mol NH_4^+ day^{-1}), nitrite consumption (NO_2^- day^{-1}) and nitrate release (NO_3^- day^{-1}). Preliminary results suggest that sponge communities in the Flemish Cap area are filtering water at a rate of 70 million m^3 day^{-1} with significant consequences for nutrient cycling. Currently, the protections offered by the NAFO closures are safeguarding a significant portion of carbon and nutrient cycling function of sponges. These values will be used to complement the biological traits work undertaken by the working group and provide a contextual basis for the relative removals vs. protection of sponge ecosystem functioning in this area. The working group suggested the more years of VMS be evaluated than the current 4 years and that an update on the work be presented at the November 2019 meeting. It was noted that this work was undertaken by the EU Horizon2020 project SponGES.

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1.8 Predicted distribution and biodiversity associated with the *Vazella pourtalesi* glass sponge grounds off Nova Scotia, Canada

The glass sponge *V. pourtalesi* forms a large monospecific aggregation on the Scotian Shelf off Nova Scotia, Canada. The shear density of *V. pourtalesi* and its large size compared to other areas of its distribution (i.e. Florida and the Azores) renders the population off Nova Scotia globally unique (Beazley et al. 2018). While this species was cited as being indicative of a vulnerable marine ecosystem (see Fuller et al. 2008), it has not yet been reported in the NAFO Regulatory Area (NRA). However, information on its distribution, life history, and ecosystem function is still relevant to WG-ESA and may provide further support to the protection of the NRA sponge grounds.

In collaboration with the EU-funded SponGES project, a study was recently conducted to predict the distribution of this species across the Scotian Shelf using random forest modelling and identify the environmental variables important for its distribution (Beazley et al. 2018). The results of random forest were interpreted in light of both the current and historical hydrographic conditions in order to deduce the variability in conditions experienced by this long-lived population, which was first documented off Nova Scotia in 1889. With a high degree of accuracy random forest predicted the highest probability of occurrence of *V. pourtalesi* in the inner basins on the Scotian Shelf (Emerald and LaHave Basins). Minimum bottom temperature was the most important determinant of its distribution, and examination of the hydrographic conditions in the area revealed that *V. pourtalesi* is associated with a warm, saline water mass that infiltrates the inner basins on the Scotian Shelf. This water mass was identified as Warm Slope Water, originating from the Gulf Stream. Infiltration of Warm Slope Water into the region creates bottom temperatures ranging on average between 8 and 10˚C over the location of the sponge grounds. Examination of reconstructed temperature and salinity to 1870 from the Simple Ocean Data Assimilation (SODA) revealed that the *V. pourtalesi* sponge grounds have been subjected to strong multi-decadal variability in water mass characteristics, with bottom temperatures varying by 8˚C over the time period. Cold periods were indicated in both the 1960s and 1920s, where bottom temperatures over the sponge grounds dipped down to ~3˚C. This multi-decadal variability is consistent with the influence of the Atlantic Multi-Decadal Oscillation, or AMO. These results suggest that the population of *V. pourtalesi* on the Scotian Shelf has persisted in the face of this climatic variability. Furthermore, it suggests that caution should be taken when using species distribution models based on current climatic conditions to define environmental envelopes and niches. Future work will be conducted to model the distribution of this species under various climate scenarios and determine whether its range expands or contracts with increasing temperature.

Additionally, work conducted under the SponGES project to examine the biodiversity of epibenthic megafauna associated with the *V. pourtalesi* sponge grounds was recently undertaken (Hawkes et al. under review in MEPS) to further inform the role that sponge grounds play in the provision of habitat. Despite biodiversity conservation being one of the rationale for the call to protect sponge grounds (UNGA, 2006), very few studies have examined the impact these ecosystems have on the surrounding megafaunal community. In the NRA however, similar studies were undertaken in the mixed-species sponge grounds of the Flemish Pass (Beazley et al. 2013) and Sackville Spur (Beazley et al. 2015), allowing for the first time a direct comparison of the diversity associated with mixed-species versus monospecific sponge grounds.

Five photographic transects were collected in Emerald Basin on the Scotian Shelf by Fisheries and Oceans Canada (DFO) in 2011 using the drop camera CAMPOD. These transects were analyzed for the abundance of epibenthic megafauna, defined as those motile and sessile fauna greater than 1 cm (see Beazley and Kenchington, 2015). Unlike the tetractinellid sponge grounds of the NRA, *V. pourtalesi* settles on hard substrate. Thus further analyses were conducted to tease apart the effects of the sponge versus the presence of hard substrate on the diversity of associated fauna. Generalized linear models were used to examine the impact of *Vazella* presence/absence per photo, location (transect) in Emerald Basin, and the percentage cover of hard substrate on species density (i.e. the number of taxa per photo) and abundance. The presence of *Vazella* accounted for the greatest amount of deviance in the species density and abundance data, with higher metrics found in photos with *V. pourtalesi* present compared to absent, across all transects examined. However there was a strong association between the presence of *V. pourtalesi* and hard substrate, which also contributed to the diversity within the sponge grounds. When compared to the tetractinellid mixed-species sponge grounds, the monospecific sponge grounds formed by *V. pourtalesi* had a lower diversity and abundance of epibenthos. This phenomenon could possibly be due to differences in the provision of habitat by the different taxa. For example, the tetractinellid sponges of the NRA often acted as settlement substrate themselves, with attached soft corals, tunicates, and other sponges observed (Beazley et al. 2015). However, very few epifauna were observed on the surface of *V. pourtalesi*. In contrast, the barrel shape of *V. pourtalesi* allowed larger, motile fauna to 'hide' inside the sponge, a feature not observed in the sponge grounds of the NRA, which were comprised mostly of massive or globular morphologies.

Similar to the findings of Beazley et al. (2013, 2015), the *V. pourtalesi* sponge grounds are areas of enhanced diversity and abundance of epibenthic megafauna compared to the surrounding habitat, providing further evidence of the functional significance of sponge grounds in the deep ocean ecosystems of the northwest Atlantic.

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1.9 Assessment of connectivity among closed areas in the fishing footprint of the NRA

Knowledge of population- and landscape-connectivity in marine systems is an important foundation for evaluating the effectiveness of closed areas (White *et al.*, 2014; Andrello *et al.*, 2017). Kenchington *et al.* (2018) have evaluated the potential for connectivity among the 14 areas closed by NAFO to protect VME (excluding the 3O coral closure with Canada), with emphasis on connections between areas closed to protect the same taxa. Given the poor knowledge of the reproductive and larval biology of the VME species in the fishing footprint of the NRA, they used a scenario-testing approach to run particle-tracking models using a range of realistic parameters to evaluate potential dispersal kernels. There are a number of passive-particle tracking models available, many of which use flow fields from a particular ocean model, coupled with a tracking algorithm. Kenchington *et al.* (2018) used the Webdrogue Drift Prediction Model v.0.7, together with the "Southern Labrador, Newfoundland Shelf" data set (http://www.bio.gc.ca/science/researchrecherche/ocean/webdrogue/slns-tnls-en.php accessed 23 May 2018). This model draws on regional historical observations and primitive-equation numerical models with forcing by tides, wind stress, and baroclinic and barotropic pressure gradients and was developed as an offline tool by Fisheries and Oceans, Canada. The resolution of the model is high on the Flemish Cap and on the shelf break with a typical nodal spacing of ~5 km. Passive-particle dispersal was assessed using seasonal-modelled drift trajectories at two depths (surface and 100 m). To independently validate the passive-particle drift trajectories and importantly, to extend those results to the sea floor, currents at depth from an eddy-resolving model (NEMO) were investigated (the surface, 100 m, 1000 m and "on-bottom" depths). The realism of the modelled surface currents was evaluated through comparison with the observed surface currents from drifter data and found to be highly comparable.

Three biological traits of the VME indicators were considered in the models: spawning season(s), position of gametes and larvae in the water column, and duration of larvae in the water column (planktonic larval duration, PLD), although Young *et al*. (2012) have modelled deep-sea larval dispersal using only PLD. These traits were used to evaluate the trajectories as bio-physical models for matching scenarios, while species distribution models identified potential source populations from hindcast projections. Five of the 14 areas, including the three largest closures (Areas 2, 4, 5), showed particle retention, with three others showing retention within 10 km of their boundaries (Table 1.5.) – a distance considered so as to recognize the resolution of the models. Tendency for retention is expected to increase with depths below 100 m (Table 1.5.) where modeled bottom currents show decreased velocities. The number of overlying water masses also increase with depth and present potential barriers to vertical larval migration (Crooks and Sanjayan, 2006). The regional pattern of currents and their extreme topographic forcing emerged as a strong structuring agent in this region. A system of weakly-connected closed areas to protect sea pen VMEs on Flemish Cap was identified (Table 1.5.), confirming suspicions noted by the working group previously where recognition of a "system" of closed areas to protect sea pens in the shallower waters of Flemish Cap was inferred from their distributions (NAFO, 2013). The conducted approach illustrates the added value of assessing/modelling networking properties when designing MPAs and the working group recommended including forecast trajectories in the evaluation of the closed areas to take place at the 2019 WGESA meeting. It was noted that this work was undertaken by the EU Horizon2020 project SponGES.

Table 1.5. Summary of structural connectivity and retention for each of the closed areas linking areas with the same conservation targets (from Kenchington et al., 2018). Bracketed connections end within 10 km of the named closed areas. Conservation targets: S=Sponge grounds, SGC= Small gorgonian corals, LGC=Large gorgonian corals, SP=Sea pens.

Closed Area	Max. Depth (m)	Closed Area Description	Conservation Target(s)	Connectivity with Drift Depth of 100 m	Retention with Drift Depth of 100 m
Area 1	1917	Tail of the Bank	S, SGC	—	—
Area 2	2211	Flemish Pass / Eastern Canyons	S, LGC, SP	Area 1	Yes
Area 3	2598	Beothuk Knoll	S	—	Yes
Area 4	2754	Eastern FC	S, LGC	—	Yes
Area 5	2688	Northeast FC	S, LGC	—	Yes
Area 6	1952	Sackville Spur	S	—	—
Area 7	718	Northern FC	SP	(Area 8)	—
Area 8	1088	Northern FC	SP	(Area 14)	—
Area 9	1120	Northern FC	SP	Area 8 (Area 10, Area 14)	(Yes)
Area 10	1177	Northwest FC	SP	(Area 14)	—
Area 11	1132	Northwest FC	SP	—	(Yes)
Area 12	1003	Northwest FC	SP	Area 7, (Area 10)	—
Area 13	924	Beothuk Knoll	LGC	—	Yes
Area 14	688	Eastern FC	SP	(Area 9)	(Yes)

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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.*

2.1. Progress of analysis undertaken by EU NEREIDA research

ToR 2.1. *Progress of analysis undertaken by EU NEREIDA research – VME sea pen resilience and mapping fishing effort* (COM Request #9)

i) Mapping fishing effort.

Highlights:

1. 2017 Haul-by-haul logbook data was merged with the 2017 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. WG-ESA **recommends** to SC that *additional information be recorded in the haul-by-haul data as follows (1) an appropriate measure of gear dimensions to facilitate future work on developing estimates of the area being swept by the trawl and (2) target species.*

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 2017 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 2.1 illustrates the flowchart with the main steps involved on the procedure of linking VMS with logbook data.

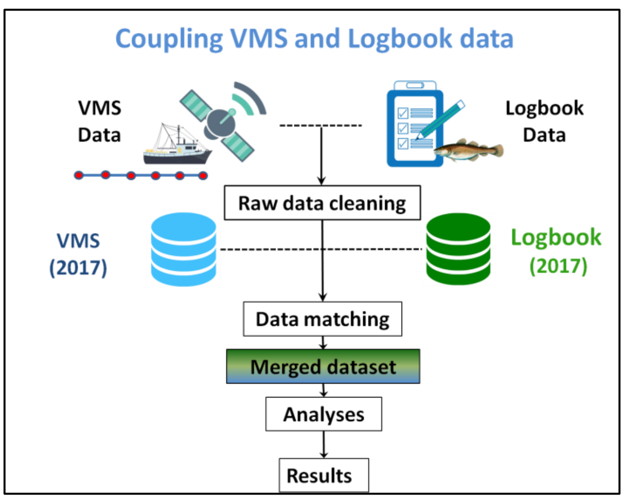

Figure 2.1. Flowchart with the main steps involved on the procedure of coupling VMS and logbook data.

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 2.2). 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.

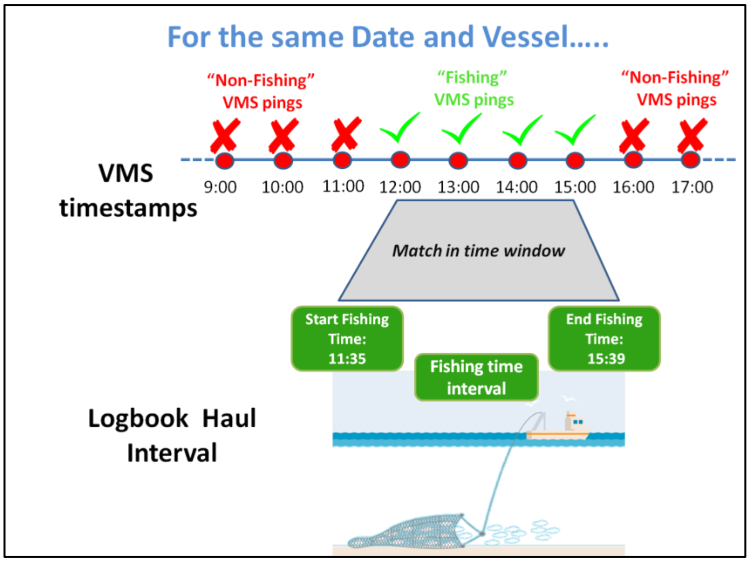

Figure 2.2. Match in time window procedure.

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 2017.

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 the main species 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 SCS Doc. 15-019. 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 2.3). 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”.

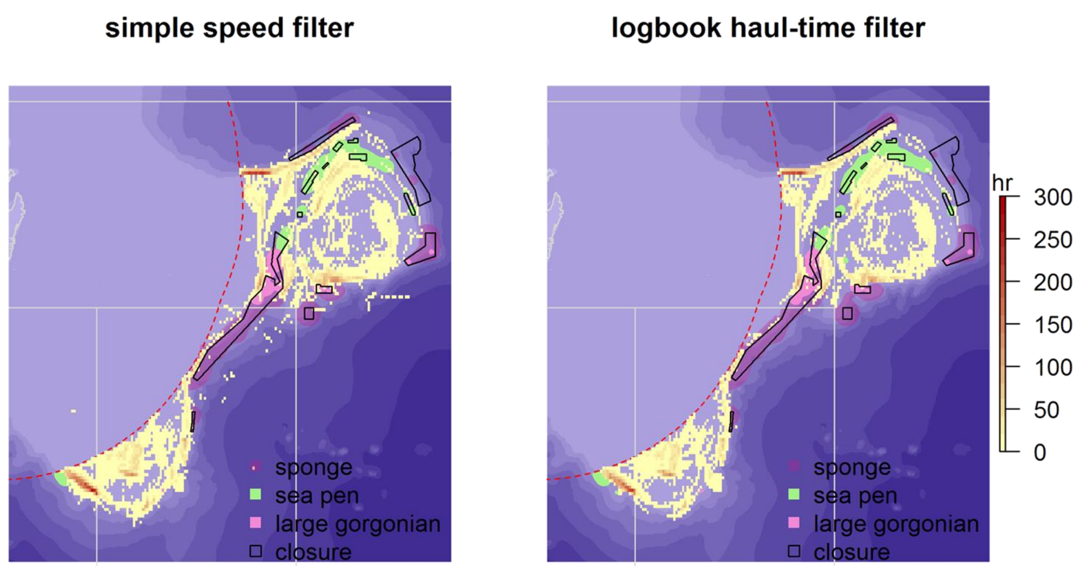

Figure 2.3. Cumulative fishing effort maps (hours fished per cell) from 2017 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

Key fishing effort layers and comparison Figures are shown below.

Fishing activities for Greenland halibut appeared to have fewer spurious cells (individual cells) as part of the fishing footprint when using the logbook haul-time filter (Figure 2.4), 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). This example also highlights how the use of haul-by-haul data to assign to a particular fishery can change in comparison with the daily catch records. In the right panel of Figure 2.4 there is a string of cells on the east side of the Flemish Cap, slightly over top of the sea pen vulnerable marine ecosystem (VME) polygon. That string of points is not represented in the corresponding left panel, but it appears in the cod bottom otter trawl effort in the right panel (Figure 2.5). Figures are shown for redfish bottom otter trawl in 3M (Figure 2.6); redfish bottom otter trawl in 3LNO (Figure 2.7); Atlantic halibut longline (Figure 2.8); Silver Hake (Figure 2.9); Skates (Figure 2.10); Witch flounder (Figure 2.11) and Yellowtail flounder (Figure 2.12).

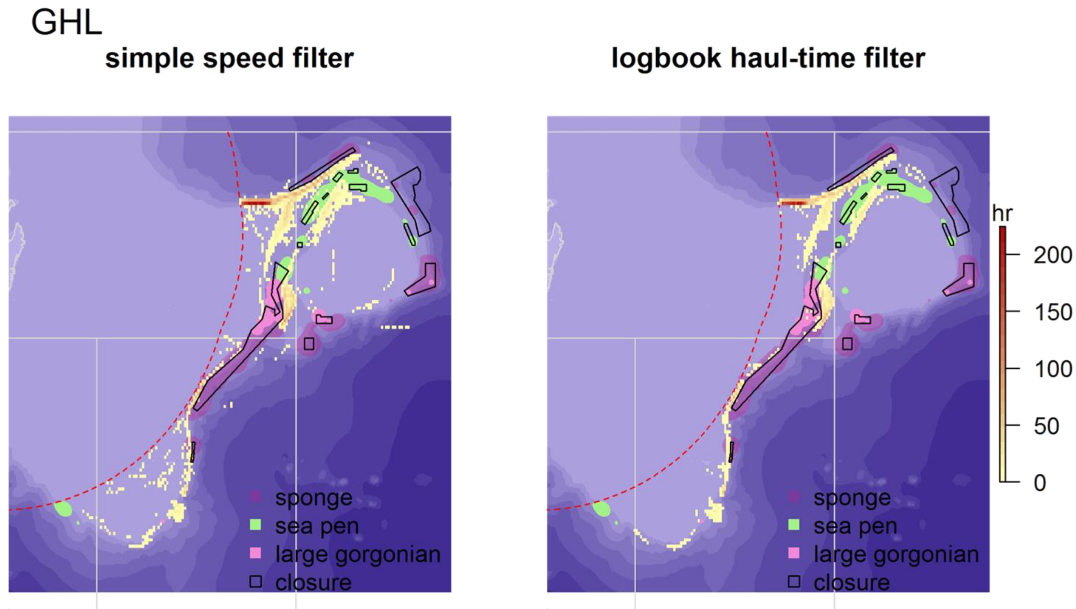

Figure 2.4. Greenland halibut fishing effort maps (hours fished per cell) from 2017 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

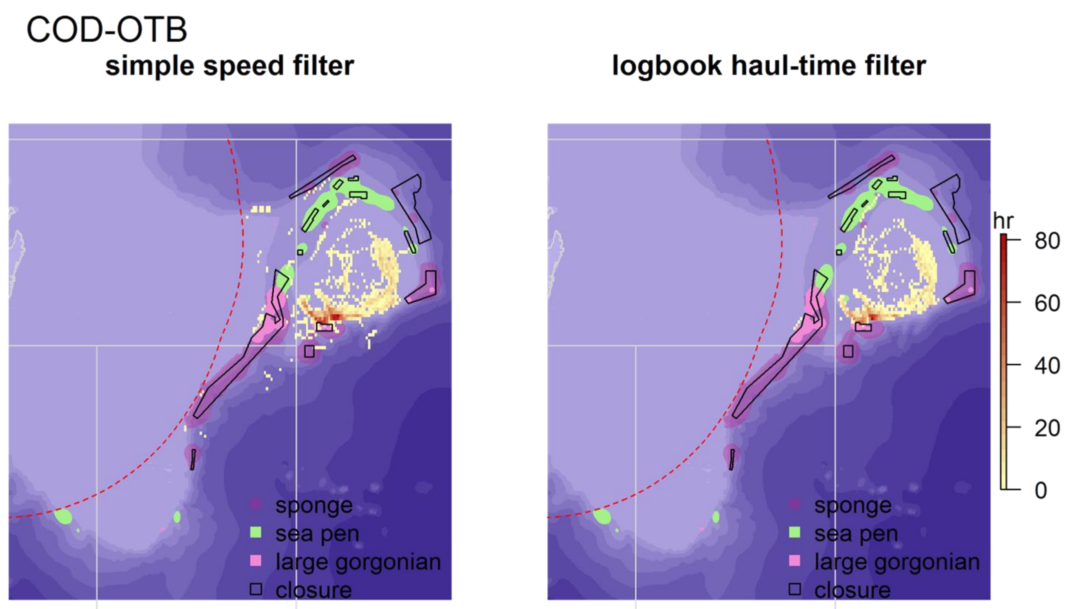

Figure 2.5. Cod bottom otter trawl fishing effort maps (hours fished per cell) from 2017 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

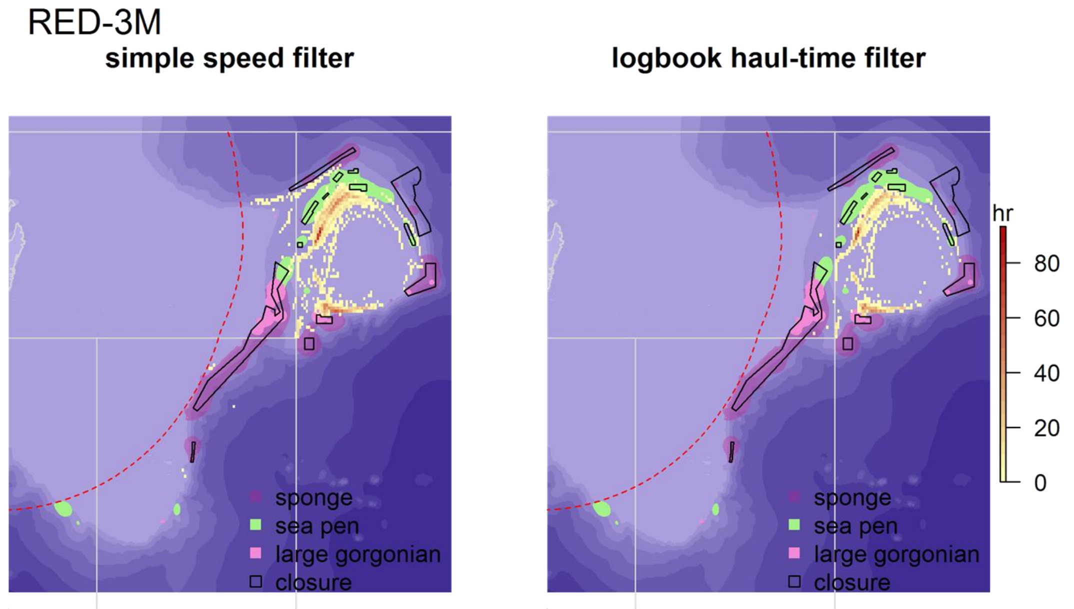

Figure 2.6. Redfish 3M bottom trawl fishing effort maps (hours fished per cell) from 2017 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

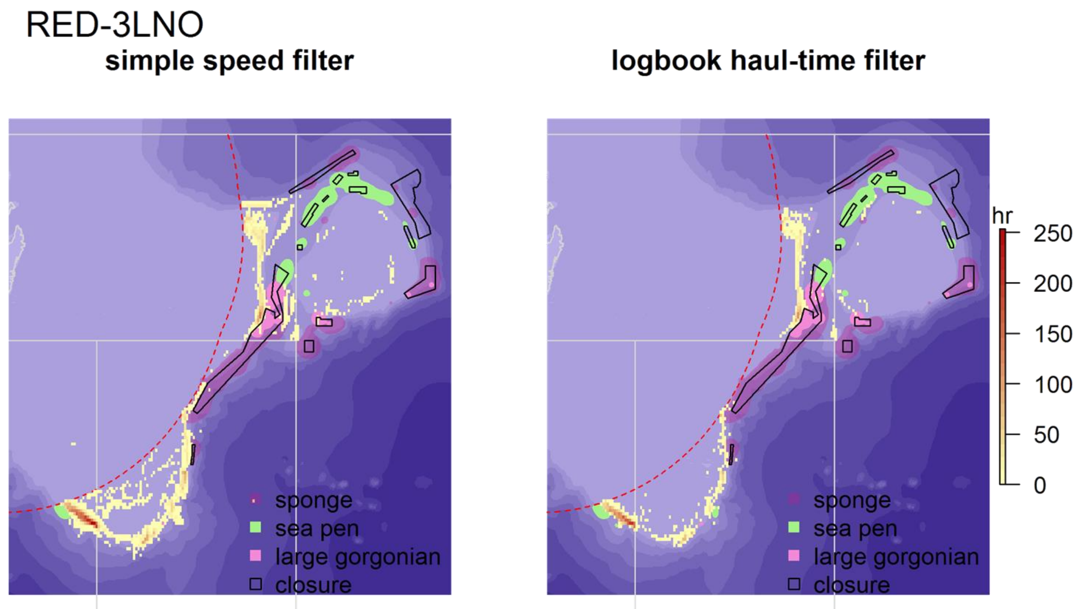

Figure 2.7. Redfish 3LNO bottom trawl fishing effort maps (hours fished per cell) from 2017 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

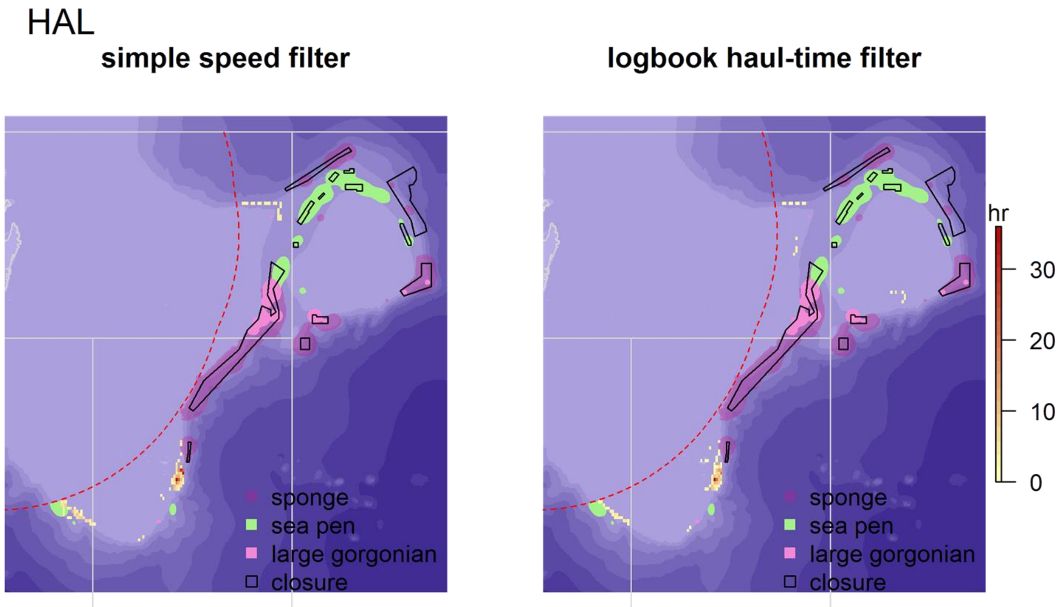

Figure 2.8. Atlantic halibut longline fishing effort maps (hours fished per cell) from 2017 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

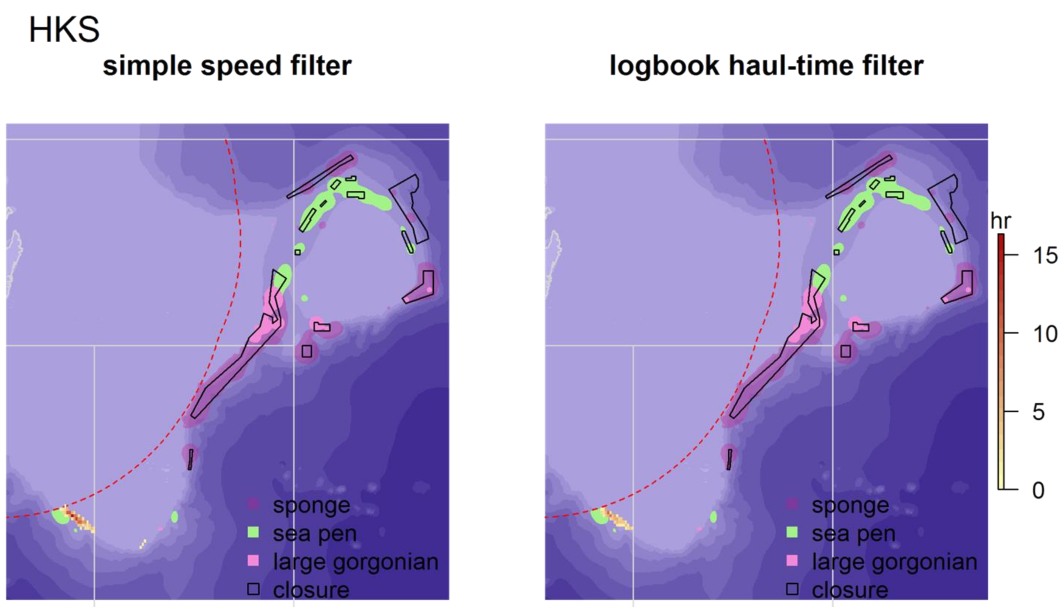

Figure 2.9. Silver Hake bottom trawl fishing effort maps (hours fished per cell) from 2017 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

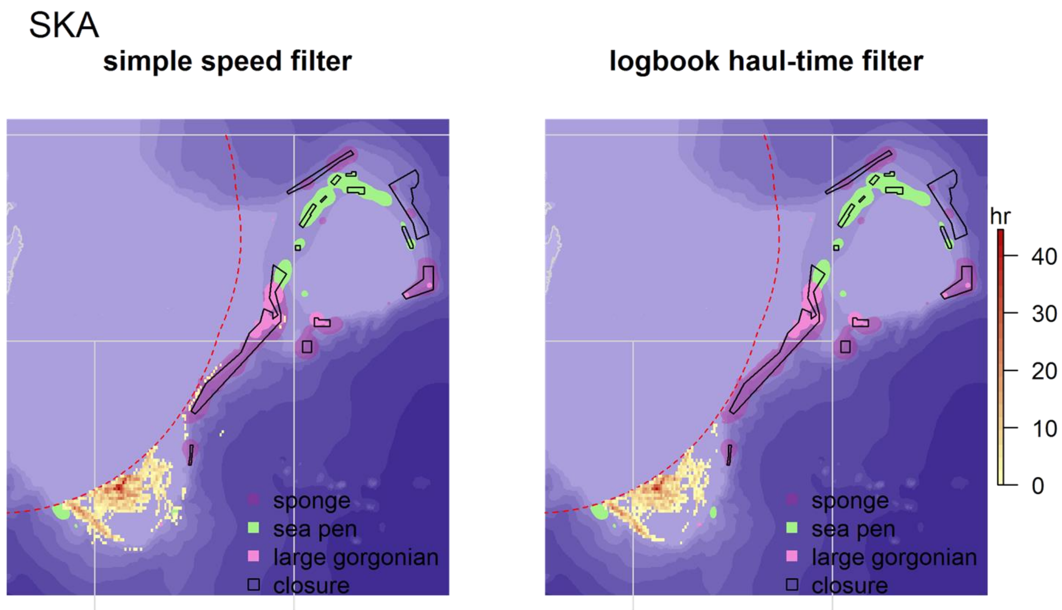

Figure 2.10 Skate bottom trawl fishing effort maps (hours fished per cell) from 2017 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

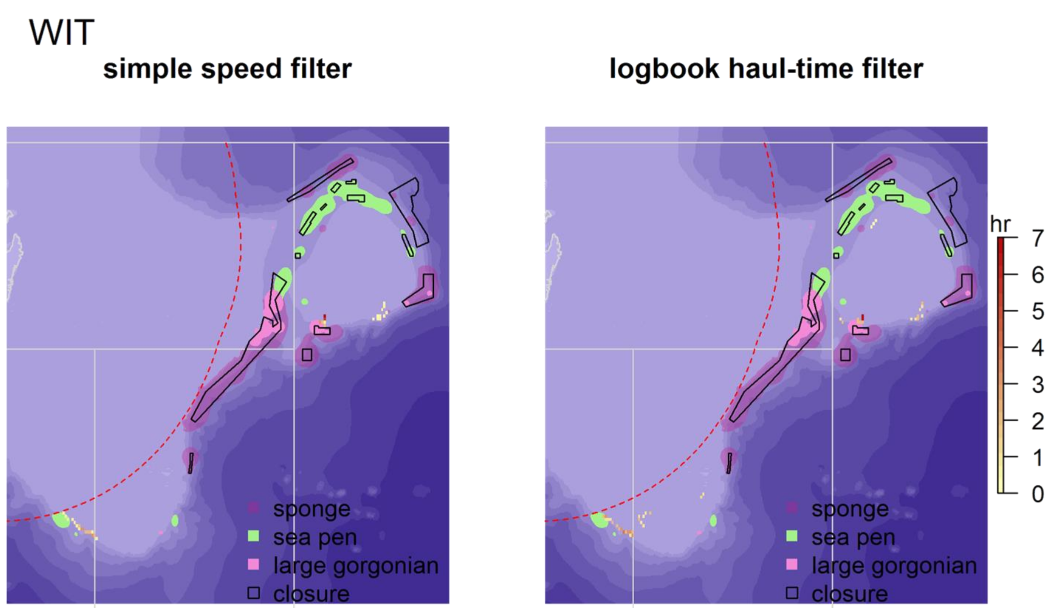

Figure 2.11 Witch flounder bottom trawl fishing effort maps (hours fished per cell) from 2017 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

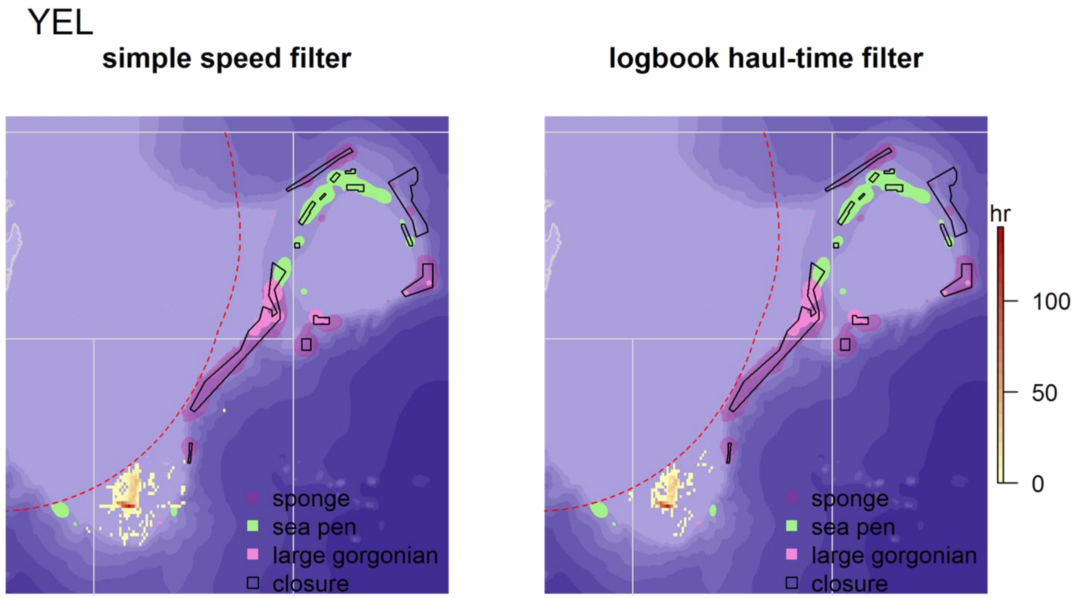

Figure 2.12. Yellowtail flounder bottom trawl fishing effort maps (hours fished per cell) from 2017 VMS and logbook data produced by two different methods. Left: VMS data was filtered for speeds within 1-5 knots, right: VMS was filtered if it was within the reported fishing time interval in the logbook.

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 nautical miles 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 13). This is not unexpected given the method of deployment for these fixed gears

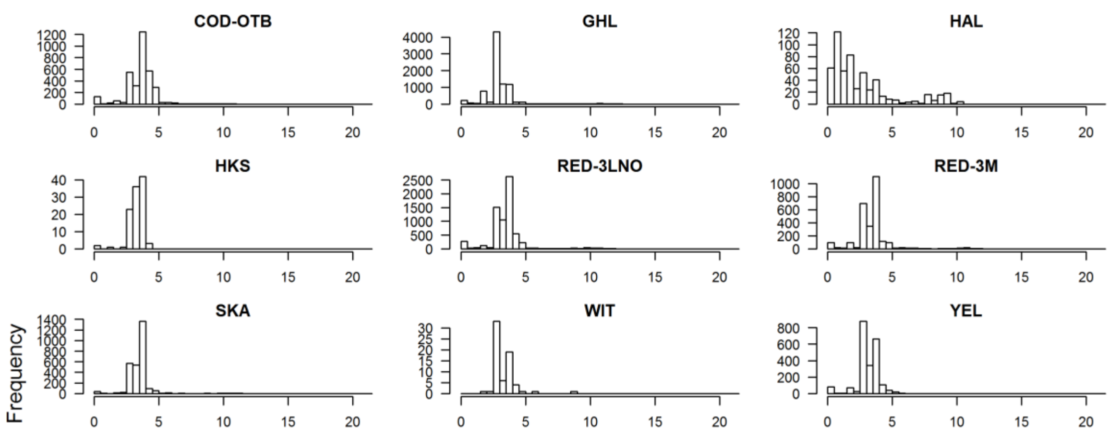

Figure 2.13. Fishery-specific speed histograms from VMS points within haul-time intervals. COD-OTB = cod bottom otter trawl, GHL = Greenland halibut, HAL = Atlantic halibut, HKS = silver hake, RED = redfish, SKA = skates, WIT = witch, YEL = yellowtail flounder.

We conducted a simple overlay analysis to estimate the area of VME polygons that is overlapped by the 2017 cumulative fishing footprint and fisheries-specific footprints (Figure. 2.14). The fishing effort layers used were based on logbook haul-time filtering. Overall, we found that 19.3% of the total VME area had some degree of fishing in 2017, with fishing activities occurring in each of the three VME taxa polygons. Large gorgonian, Sea pens, and sponge VMEs respectively had 24.6%, 22.7% and 17.2% of their area within the 2017 fishing footprint.

The Greenland halibut fishery had the greatest areal overlap with the VME polygons, for each of the VME taxa (sea pen: 17.4%; sponge: 15.8% and large gorgonian: 12.5%). 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 2017 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.

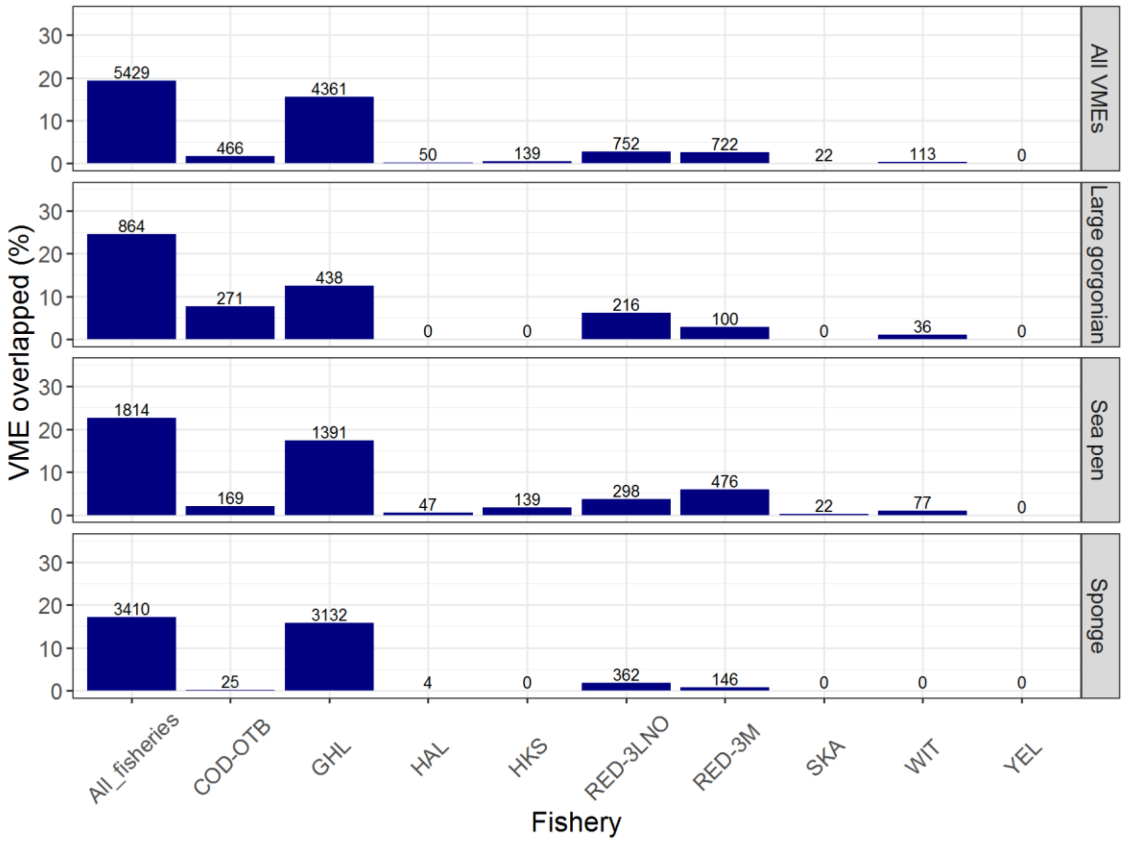

Figure 2.14. The percent of VME polygon overlapped by cumulative fisheries (far-left bars) and fisheries-specific footprints using the haul-by-haul time filtering of 2017 VMS records. The top panel represents the area of all VMEs combined, and the bottom three panels represent the specific VME polygons by taxa. The number on top of each bar represents the absolute area of VME (km2) 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. 2.13.

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.

ii) Modelling seapen resilience

Background

This analysis builds upon and develops the work previously undertaken to assess SAI on VME as part of the NAFO review of bottom fisheries in 2016 (NAFO, 2016a) and the following work on estimating the resilience of sea pens to fishing impacts, specifically the time it takes for sea pen VME biomass to recover to a certain level post fishing impact (NAFO,2016b). The 2016 study on resilience simulated the rate of accumulation of swept area from repeated passes of a bottom trawl though an area of seabed using a slightly aggregating random placement of lines across a set area. Lines representing trawl passes across a 1 x 1 km polygon (Step 1) were created by randomly drawing start and end points for lines placed in a north-sour orientation from a normal distribution around the previous line. The lines were buffered to the width of the expected ground impact of fishing gear used in the study area (150 metres), and the increase in area covered was calculated for each added line (Step 2). The buffered lines were also overlaid to estimate the percentage of the square with various number of accumulating passes (Step 3). The time, in years, taken to cover 99% of the square was calculated for the different levels of fishing effort (hrs*km^{-2}*yr^{-1}), based on the total length of tow required and an estimated fishing speed of four knots (Step 4). The time (t) it takes to impact 99% of the seabed area (or sea pen biomass) for a given level of fishing effort, and the proportion of seabed area impacted once (f1), twice(f2) etc, was then used to estimate the recovery time to sustain a given level of sea pen biomass (Step 5) by applying the following equation:

$$\text{Eq.1 } (tf1+ tf2+tf3.....tfnn)/(f1+ f2+f3....fn)=Ave.trecovery$$

A detailed description of methodology is given in NAFO (2016b).

Testing the assumptions

The first four steps in the 2016 analysis relied on assumptions surrounding the following terms:

- the pattern of accumulation of consecutive passes of fishing gear across the 1 x 1 km area;
- the width of impact of the fishing gear on the ground;
- the even distribution of sea pen biomass; and
- the speed vessels are travelling at whilst fishing.

This study addresses the uncertainty around the resilience estimates arising from the above assumptions, by calculating recovery times based on a range of values around those used in 2016 (Table 2.1). Each analysis step was evaluated separately by varying one term at a time, keeping others at the default value used in the 2016 study. The simulation was repeated 100 times for each variant of each term.

The levels of fishing effort (hrs*km^{-2}*yr^{-1}) corresponding to 5 – 95% biomass remaining used in Step 4, are derived from those calculated from biomass accumulation curves in the 2016 study and remain the same through all iterations.

Table 2.1. Variants of the terms used to test the assumptions in the model.

Analysis term	Variant
Spatial distribution of fishing effort (Step 1)	Random **Drawn from a wide normal distribution** Drawn from a narrow normal distribution
Width of impact from fishing gear (Step 2)	75 m 100 m 125 m **150 m** 175 m
Spatial distribution of biomass (Step 2)	**Even spatial distribution**, Moderately spatially aggregated Highly spatially aggregated
Speed of vessel (Step 3)	2 knots 3 knots **4 knots** 5 knots 6 knots

Step 1: Spatial aggregation of fishing effort

In a fishery that follows bathymetric contours, the placement of fishing tows is unlikely to be random. Three levels of increasing spatial aggregation of the fishing effort within the 1 x 1 km square were tested (2.15). The 2016 study used moderate spatial aggregation, simulated by generating start-of-line x-coordinates for new lines by sampling a normal distribution with a standard deviation (s.d.) of 500 m centred around the start-of line x-coordinate of the current line. The end of line coordinate was sampled from a normal distribution with a s.d. of 250 m centred around the start-of-line x-coordinate. The alternative scenarios were: 1) fully randomised selection of the start-of-line and end-of-line x-coordinates and 2) start-of-line and end-of-line x-coordinates sampled from narrower normal distributions (100 m and 50 m, respectively). Lines with start or end x-coordinates falling outside of the 1 km square were excluded, and where the start coordinate fell more than 1000 m outside of the square coordinates, a new random start was initiated inside the box (Figure 2.1).

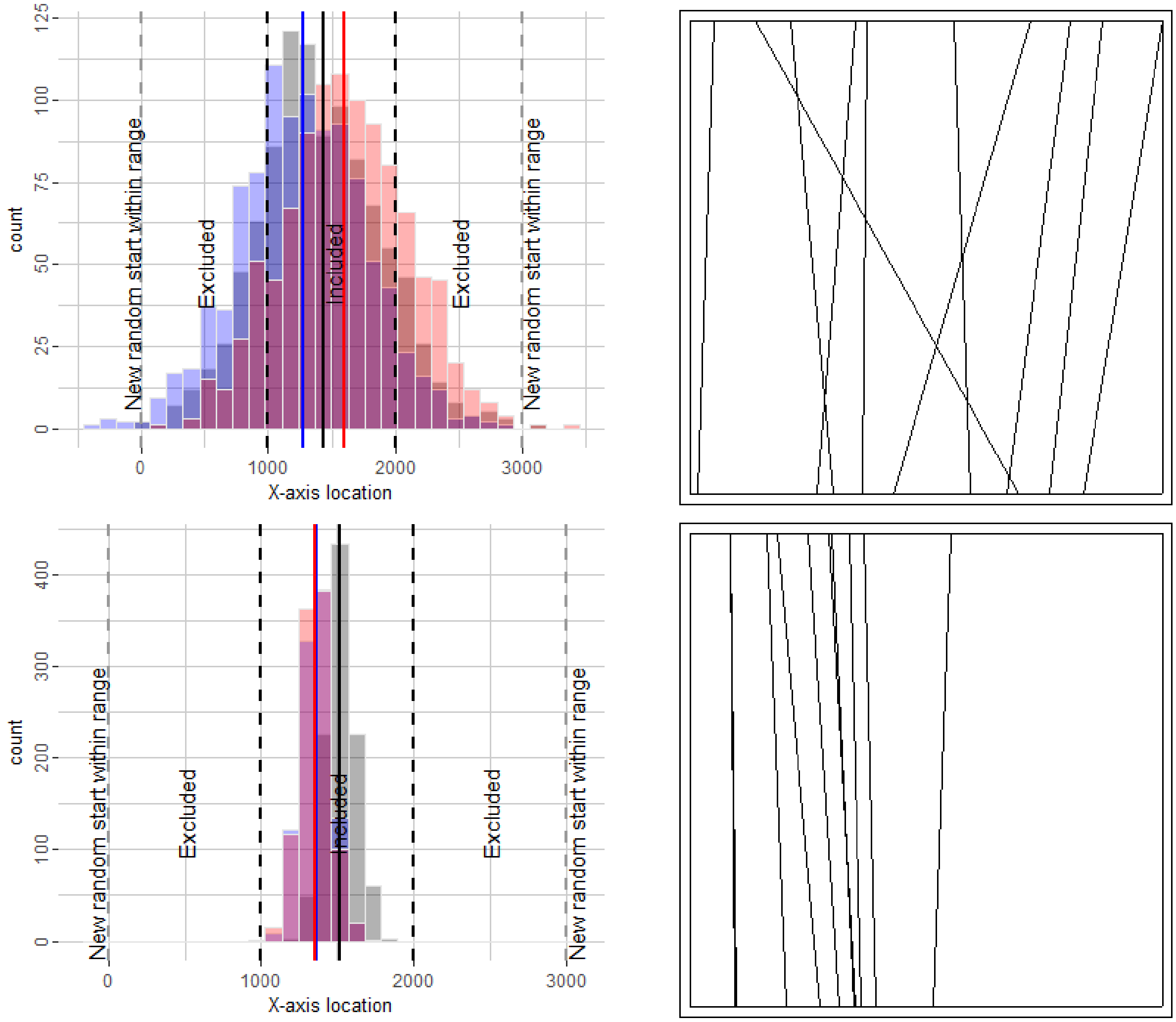

Figure 2.15. Sampling of simulated fishing tows across the wide (a) and narrow (b) normal distributions, with the respective spatial distribution of lines (c and d).

Step 2: Width of impact from fishing gear

The actual impact on the sea floor may not directly correspond to the full width of the fishing gear. Whilst the doors and net certainly impact the benthos, the full width between the doors includes lines and warps not directly in contact with the seabed. The unnetted parts of the fishing gear can still potentially impact benthic fauna that stands erect off the seabed (Eigaard et al., 2016, Buhl-Mortenson et al., 2013), such as the sea pens commonly encountered off the Flemish Cap *Halipteris* sp. (sea whip). In the 2016 study, gear width (150 m) was set midway between the full width of the two most commonly used types of fishing gear used in the area (Table 2). For the purpose of testing the effect of the gear width assumption, four additional impact widths (75 m, 100 m, 125 m and 175 m) were used in simulation runs.

Table 2.2. Dimensions of the two types of fishing gear most commonly used in the study area.

Redfish and Cod fisheries	**Gear Dimensions**
Net horizontal opening	59 metres
Net vertical opening	5 metres
Door opening (between otter boards)	140 metres
Greenland halibut fishery	**Gear Dimensions**
Net horizontal opening	63 metres
Net vertical opening	6 metres
Door opening (between otter boards)	165 metres

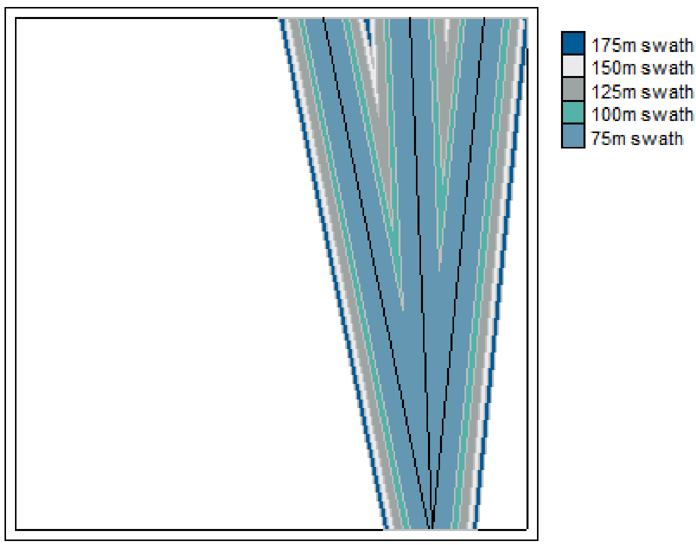

Figure 2.16. Range of impact width values included in the simulations.

Step 2: Spatial distribution of biomass

The 2016 analysis assumes that the cumulative percent of area covered by consecutive passes of the fishing gear is equivalent to the percent of sea pen biomass impacted. For this assumption to be true, biomass would need to be evenly distributed, or at least sampled with equal likelihood, across the square. In nature an even distribution is unlikely. Consequently, the alternative scenarios for biomass spatial distribution estimated two increasing levels of spatial aggregation. The spatial pattern of aggregation was simulated using a spatially correlated neutral landscape model (Kéry and Royle, 2016). Each landscape model iteration was a 1 x 1 km raster with a 1 m cell size produced using the *nlm_gaussianfield* function in the 'NMLR' package (Sciaini *et al.*, 2018) in R-3.4.3 (R Core Team, 2017). Both spatial aggregation variants used a magnitude of variation of 100 and a mean of 50. The variant with moderate spatial aggregation was created using a 500m autocorrelation distance and high spatial aggregation with a 100m autocorrelation distance.

The gaussian field landscape model creates a normal distribution of values. In reality, the biomass is more likely to follow a gamma distribution. To approximate a more skewed distribution of biomass, with a wider range, the raster cell values were replaced by values drawn from a Gamma probability distribution. Replacement values for the moderate spatial aggregation followed a gamma distribution with a shape and rate of 5, producing values between 0 – 4.7. For the moderate spatial aggregation shape and rate were set at 1, producing values between 0 – 16.9 (Figure 2.17.). For all three distributions the mean was 1. The combination of spatial autocorrelation and gamma distribution resulted in most of the square covered by very low values with a small area of very large values for the higher spatial aggregation.

The biomass rasters were standardised by converting all values to percent of the total biomass in the 1 x 1 km square. Instead of percent of the area of the square covered with each added line and buffer, the percent biomass covered by the buffer was added to the cumulative coverage. In all spatial biomass distribution variants, 100% of the square area must be covered before 100% of the biomass has been accumulated, but the rate of accumulation between 0 – 100% varies.

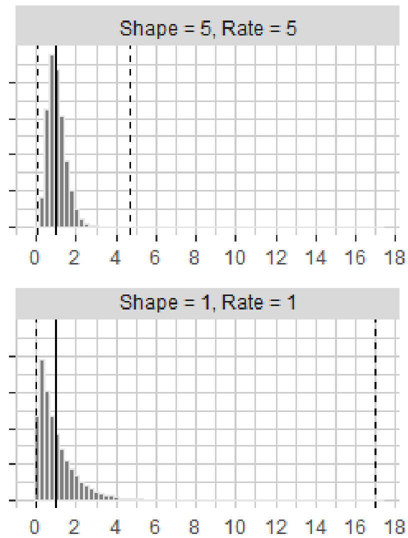

Figure 2.17. Spread of biomass values assigned to raster cells under the moderate spatial aggregation (a) and high spatial aggregation (b) scenarios. The mean is shown as a solid vertical line, and minimum and maximum values are indicated by dashed lines.

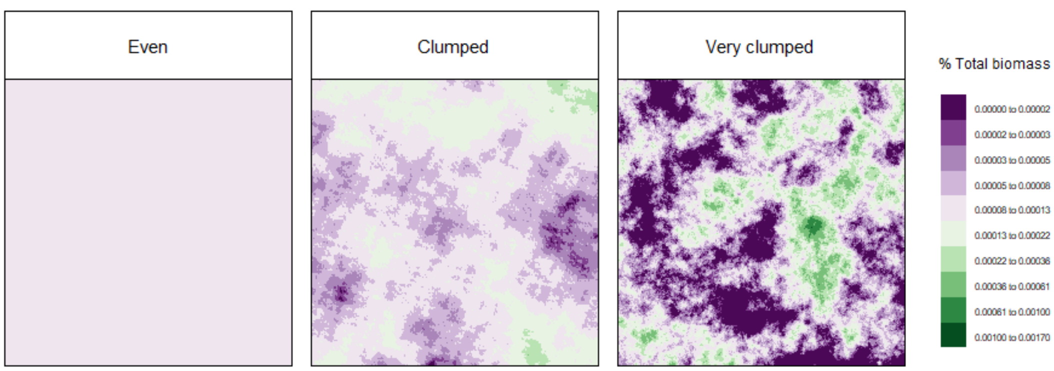

Figure 2.18. Spatial distribution of sea pen biomass under the three scenarios used in simulation runs. Values shown are the percentage of total biomass over the 1 x 1 km square.

Step 3: Speed of vessel

The speed of the vessel whilst trawling influences the time it takes to travel the distance needed to cover the whole square. With fishing effort estimated as hrs*km-2*yr-1, the distance travelled in a set time affects the number of years taken to fully cover the area. The 2016 analysis assumed an average speed of 4 knots, which is the mean of the range of empirically observed speeds of vessels whilst fishing. Four other speeds (2, 3, 5 and 6 knots) were used in the alternative simulations to estimate the effect of speed on the results.

Simulation results

The largest source of variability across the simulation runs was the stochasticity in the placement of lines during each run, irrespective of the term being tested. Variability between runs increased with restrictions on the line placement and the 'narrow normal' line generation pattern showed the greatest variability (Figure 2.19

a). Forcing the new lines to occur close to existing ones creates a pattern where some areas of the square are likely to encounter a high number of passes, before lines cover the whole area (Figure 2.19 b).

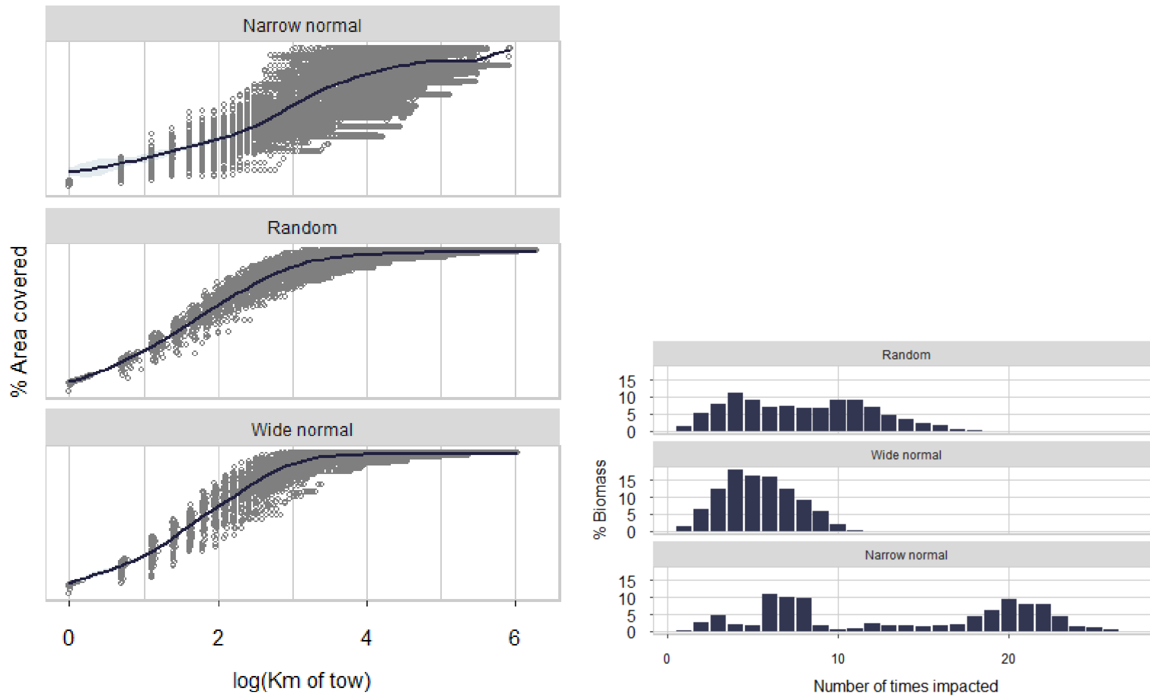

Figure 2.19. (a) Biomass (area) covered against the log of tow length from all 100 simulation runs, and (b) an example of the percent of area impacted different times for the random, wide normal distribution and narrow normal distribution variants of spatial aggregation in line generation.

The 'narrow normal' line generation pattern also differs the most from the other variants across all terms, showing on average a much longer time of recovery when comparing the central trend for all runs (Figure 2.20). Speed of vessel and to a lesser extent the gear width also show a notable range in the central trend, indicating that the decision of what speed and gear width are used to calculate the time taken to cover the square have a substantial effect on the recovery time estimates. The most accurate estimates would be derived using an average speed derived from an analysis of empirical data of fishing speeds and a realistic approximation of the catch efficiency of different parts of the gears used. Biomass distribution had very little impact on the recovery estimates. Although individual trawl passes encounter different percentages of the total biomass, overall the removal rate is averaged to be relatively similar for each spatial aggregation variant.

Table 2.3. Years for biomass to recover to a specified percentage of pre-impact biomass for each variant of each term in the simulations. Variants in **bold** are the values used in the 2016 analysis.

		Years to recover		
Term	**Variant**	3.7 ± 1.7	**50%**	**90%**
Line distribution	Random	9.8 ± 3.1	5.9 ± 3.2	30.9 ± 17.9
	Wide normal	2.8 ± 1.2	16.5 ± 6	83.3 ± 33.5
	Narrow normal	4.6 ± 1.9	5 ± 2.4	27.9 ± 13.6
Gear width	75 m	3.8 ± 1.8	7.7 ± 3.5	41.2 ± 19.2
	100 m	4.9 ± 1.5	6.4 ± 3.2	34.5 ± 17.8
	125 m	3.3 ± 1.5	9.2 ± 2.9	55 ± 17.6
	150 m	2.9 ± 1.2	5.8 ± 2.8	31.9 ± 15.8
	175 m	3.3 ± 1.5	5.1 ± 2.4	28.5 ± 13.9
Biomass distribution	**Even spatial distribution**	2.6 ± 1.2	5.8 ± 2.8	31.9 ± 15.8
	Moderately spatially aggregated	2.9 ± 1.3	4.6 ± 2.4	25.5 ± 13.4
	Highly spatially aggregated	6.7 ± 2.9	5.1 ± 2.6	28.4 ± 14.7
Vessel speed	2 knots	4.5 ± 1.9	11.6 ± 5.5	63.8 ± 31.6
	3 knots	3.3 ± 1.5	7.7 ± 3.7	42.5 ± 21.1
	4 knots	2.7 ± 1.2	5.8 ± 2.8	31.9 ± 15.8
	5 knots	2.2 ± 1	4.6 ± 2.2	25.5 ± 12.6
	6 knots	3.7 ± 1.7	3.9 ± 1.8	21.3 ± 10.5

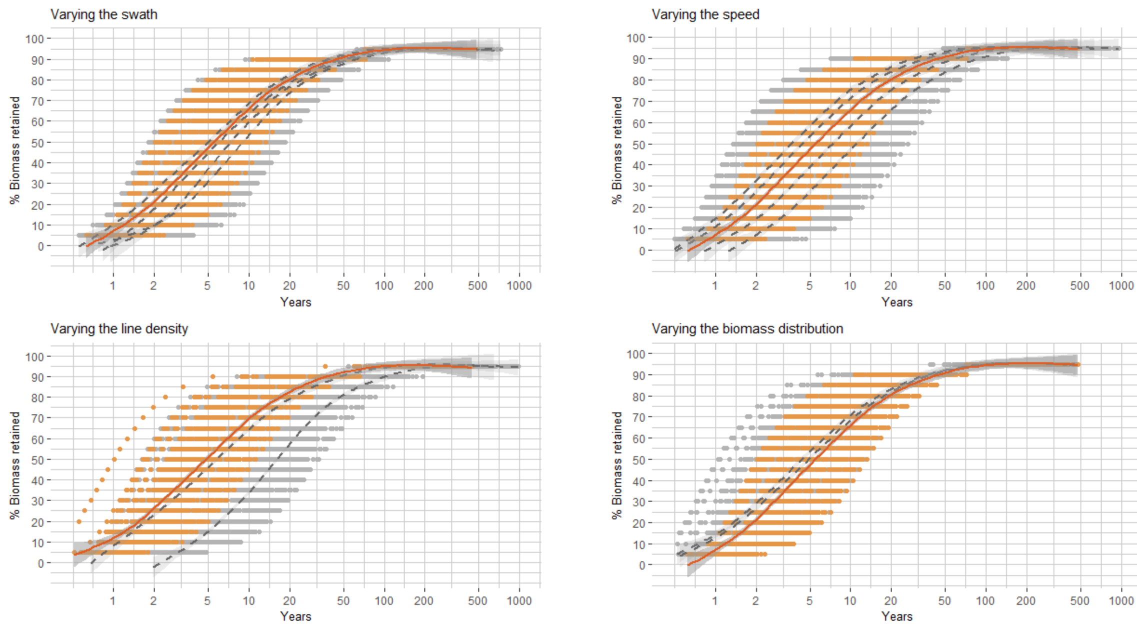

Figure 2.20. Years for biomass to recover to a percentage of total biomass for each variant of each term. The point clouds represent values from each simulation run and trend lines are provided for each variant. The values and trend line corresponding to the default variant for each term is shown in orange.

Future improvements to methodology

An accurate representation of the spatial accumulation of fishing effort (lines) is critical to obtaining reliable estimates of resilience. The most realistic approximation of the spatial placement of lines can be derived from VMS data that has been filtered to represent fishing activity and vectorised to lines representing tows. Buffering and aggregating the individual tow lines across a grid of 1 x 1 km squares in real geographical space will allow calculation of the average number of lines and time in years it takes to fully cover a square.

A review of information on removal rates of different parts of the fishing gear would further narrow the error introduced by using the full gear width with an expectation of 100% removal of biomass on first pass.

Empirical data combining VMS and fisheries log book data would also yield the most accurate estimate of the average speed of vessels whilst fishing.

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2.2. Update on VME modelling

ToR 2.2. *Up-date on VME modelling* (COM Request # 9).

i) Predicting sea pen settlement probability across space

Agent Based Model overview

An Agent-based Model (ABM) was developed to simulate the population dynamics of a generalized sea pen in the Newfoundland and Labrador and Flemish Cap bioregions. The simulated sea pen distribution can be subjected to various perturbation scenarios to provide insight into outcomes for management options. While the ABM simulates many life history traits and physical processes, the work presented here focuses on a single component – the sea pen settlement probability spatial layer.

The settlement layer is a critical component of the ABM because it determines where recruitment and colonization will occur. Sea pen distributions are partly driven by the suitability of locations where free-floating larvae settle into sediments and metamorphose into juveniles. The settlement layer provides a cell-wise probability of sea pen larval settlement across the study area.

Methods overview

A preliminary layer was constructed using a generalized linear model for the purpose of ABM development. This initial version was constrained to Canadian research vessel data (517 presences and 4708 absences, years 2005-2015) and Canadian fishing effort (mean annual effort 2005-2016). Both Canadian research vessel surveys and Canadian fishing effort is limited in the NAFO regulatory area, but the model was still used to predict in the NAFO Regulatory Area (Figure 2.21).

The work presented here focuses on a revised version of the settlement layer developed to improve predictions outside of Canadian waters beyond the 200-mile limit. The basic structure of the analysis is similar for the two versions of the settlement layer, however, the revised version has the following differences: it incorporates data from European Union/Spanish research vessel surveys, it considers both Canadian and international fishing effort, it incorporates the stratum data grouping as a random effect in a generalized linear mixed effects model (GLMM) framework, and it includes an environmental predictor of $depth^2$.

Adult sea pen catches were used as a proxy for locations of larval settlement due to settlers' lack of movement. A binary presence-absence of adults in research vessel tows was assumed to reflect the presence-absence of settlement in a given location. We combined data from 2005-2015 Canadian research vessel surveys (all sea pen species caught) and 2007-2017 EU/Spanish data for *Penatula aculeata* and *Funiculina quadrangularis* species only.

Response data were assigned to cells on 3 x 3 nm grid, keeping only one observation per cell (presence was kept if both presence and absence occurred in a cell). In order to develop a presence probability layer that was independent of fishing effort points that were located in cells with greater than 10 min of fishing km^{-2} $year^{-1}$ on a combined Canada-NAFO fishing effort layer were excluded (Figure 2.22). This fishing effort layer summed 2005-2016 annual mean fishing effort from Canadian vessels (produced according to methods in Koen-Alonso et al. 2018) and 2012-2015 annual mean fishing effort in the NAFO Regulatory area (produced according to methods in NAFO 2015). The final dataset contained 8379 Canadian data points and 2200 EU/Spanish data points which were divided into 1158 presences and 9421 absences.

Environmental covariate layers were resampled to the 3 x 3nm grid and values were extracted for each cell. The environmental predictors used in the GLMM are known to influence settlement: grain size (log10; Chia and Crawford 1973), bottom current velocity (Baillon et al. 2014, Baillon et al. 2015), bottom current direction (8 bins representing the cardinal and intercardinal compass directions; Baillon et al. 2014, Baillon et al. 2015), slope (Malecha and Stone 2009), depth (Murillo et al. 2011), $depth^2$ (Veazey et al. 2016), relative topographic index (supplement to grain size), eastness and northness (Lauria et al. 2017, De Clippele et al. 2018), and the interactions latitude:longitude, latitude:depth and longitude:depth. Oceanographic data (current velocity and bearing were obtained by taking the average and mode (respectively) over April – August 2000-2015) from GLORYS 2V4 (Mercator Ocean 2018) and bathymetric data was derived from GEBCO 2014 (GEBCO 2014). A random set of 25% of data per strata was reserved for testing the predictive ability of the model.

Prediction and model assessment

All analyses and data manipulation were performed with R version 3.5 (R Core Team 2018). The model was used to predict over the whole study area (Canadian waters and NAFO Regulatory Area), including strata where there was no RV data recorded (Figure 2.23). Therefore, only the fixed effects portion of the model was used in prediction.

Model predictive ability was assessed by calculating the area-under-curve statistic from the receiver operator curve; this rendered a value of 0.95 indicating good fit. Also, 1000 simulated datasets were created using the binomial probability of success fitted by the model. Then the mean true positive rate over simulated data (0.56) and the mean true negative rate (0.95) were calculated. Examinations of semivariograms and plots of residuals over space showed a very small but still significant amount of positive spatial autocorrelation remaining in the data (Moran's I statistic = 0.009, p = 1 x 10^{-5}).

Further work

WGESA members provided the following feedback on the settlement layer model:

1. Filtering cells to keep those with low or non-existent fishing effort may not necessarily be helpful, especially since the collection of our sea pen response variable is conducted through fishing itself. Further work will formally compare models with fishing-filters to models with all data included (no filter for low-intensity fishing points).
2. GLORYS2V4 oceanographic data may be too coarse for modelling in this specific region:, recommendations were to explore the use of Zeilang Wang and David Brickman's oceanographic model and compare results.
3. Rather than solely relying on presence/absence of sea pen catches, the use of sea pen biomass could be explored as a response variable to add further information on the quality of the potential habitat for settlement.
4. As NAFO releases data, instead of the 2012-2015 period, a more encompassing set of years could be used for creating an annual fishing footprint.

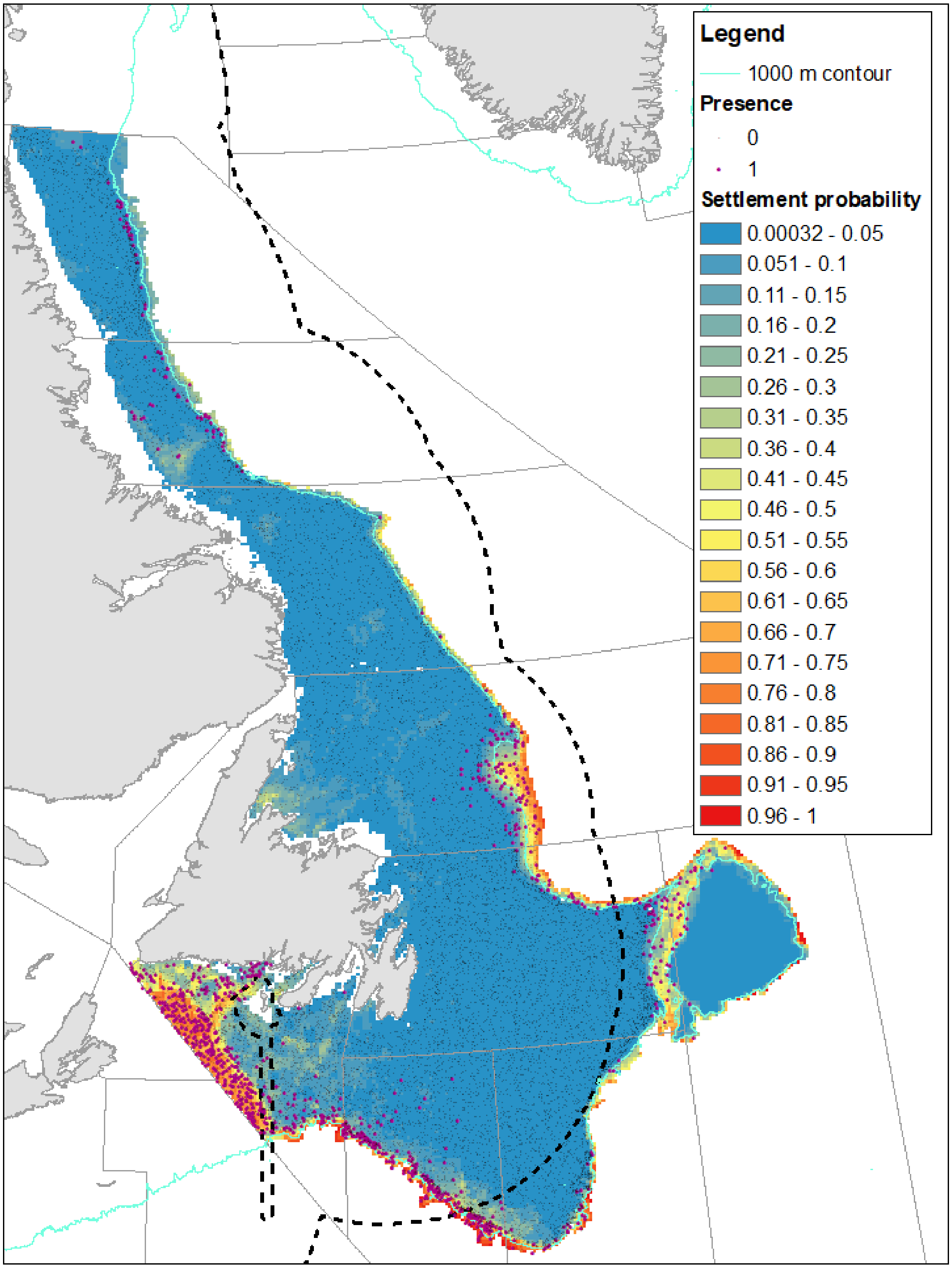

Figure 2.21. Preliminary settlement layer used in ABM, with Canada RV catches overlaid.

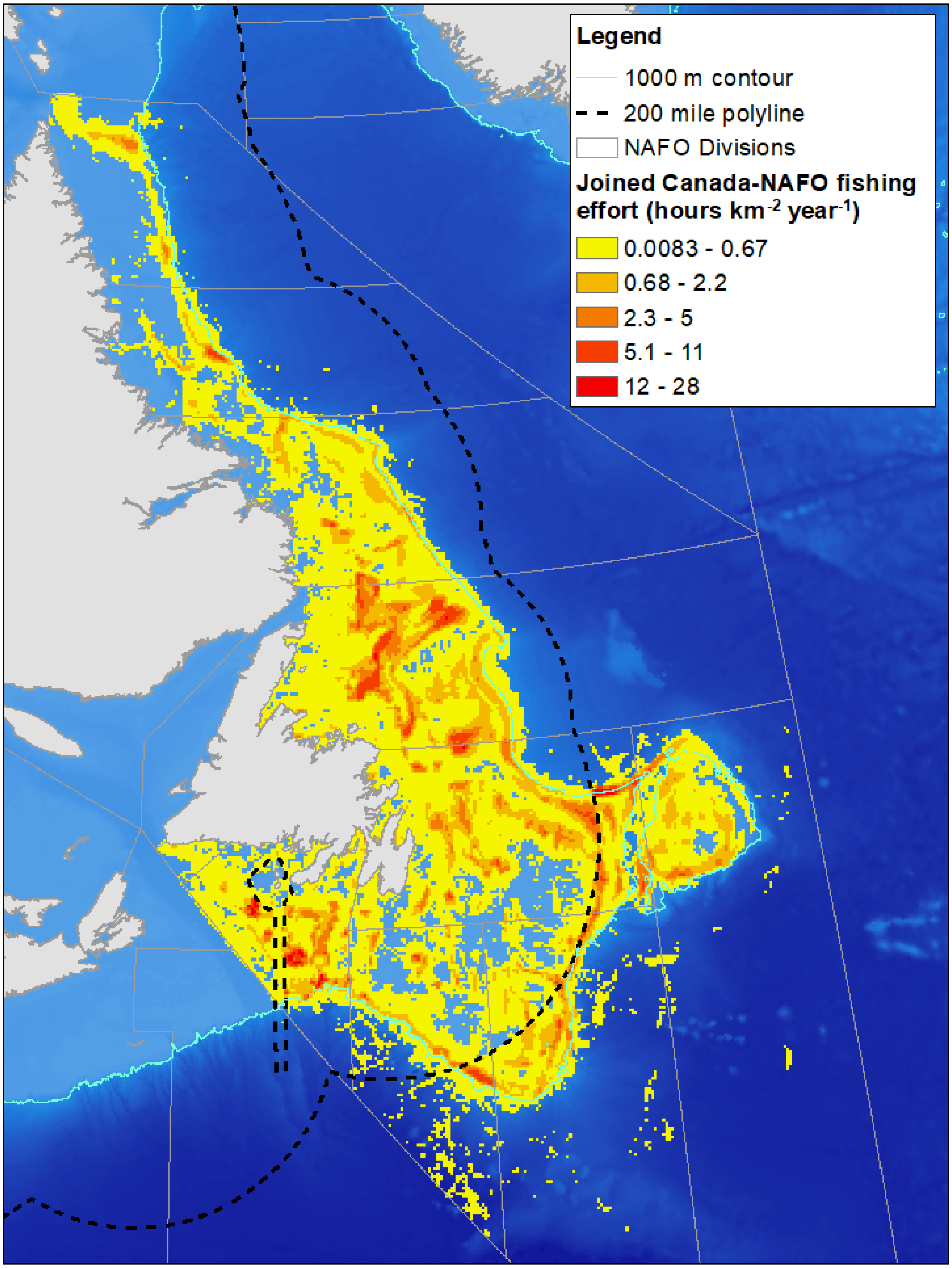

Figure 2.22. Combined fishing effort (all fisheries) from Canadian and NAFO vessel monitoring system-based layers.

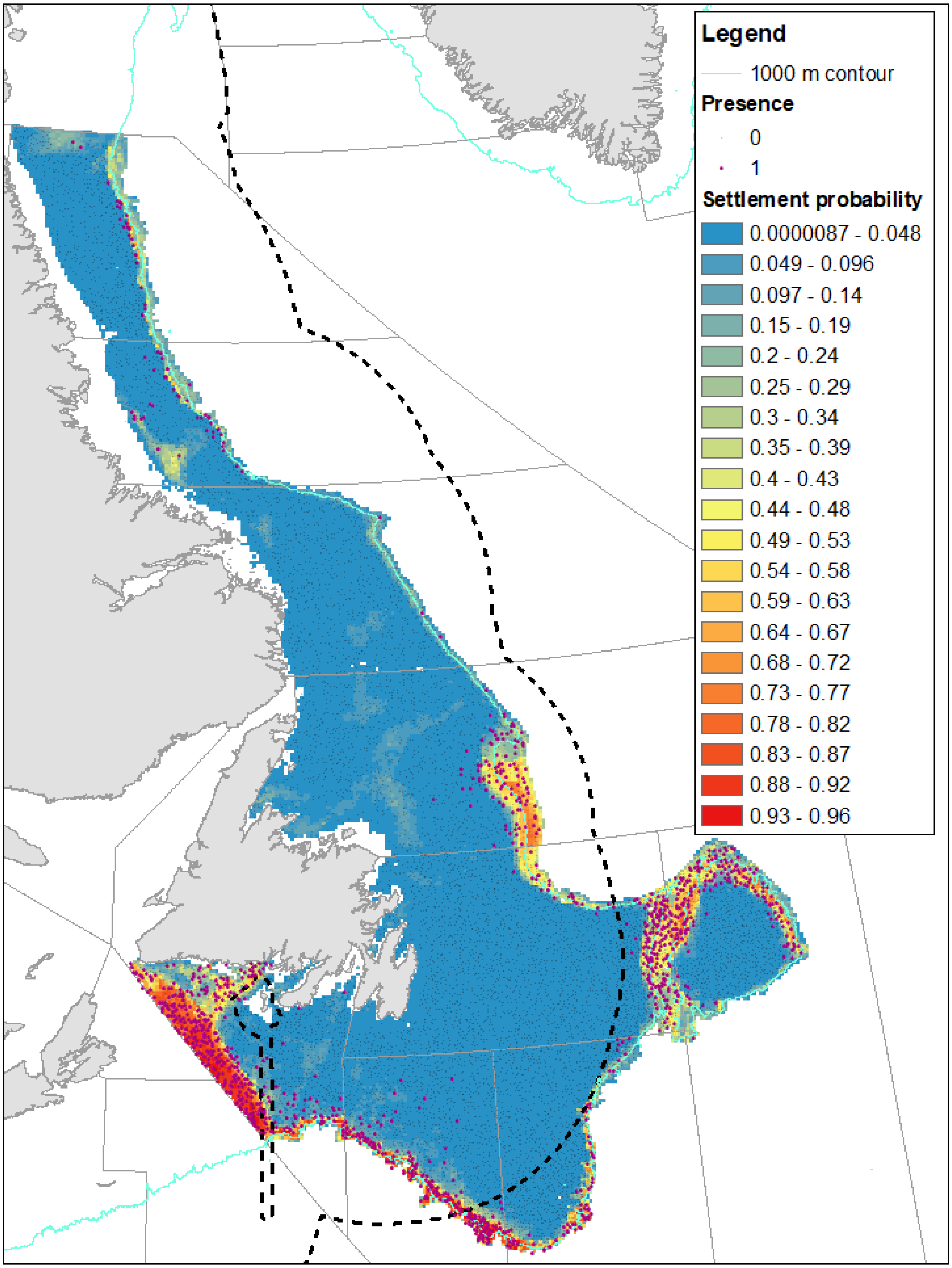

Figure 2.23. Sea pen settlement probability, with Canadian and EU/Spanish sea pen catches overlaid.

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ii) Agent-based Sea Pen model implementation

Context

VME species are typically long-lived and slow growing and thus their population dynamics are expected to playout at larger temporal scales than typical commercial species (e.g. fishes). Given the longer time scales at play, fishing impacts and recovery of these species at the population scale are difficult to assess; the current status of their populations would be expected to still show the effects of the impact of past fishing activities.

Given the sessile and/or sedentary nature of adult VME organisms, their dynamics is highly linked to habitat characteristics. On the other hand, colonization of new areas relies on larval dispersal, which is dependent on oceanographic features (transport by currents).

Protection of VME species, and the habitats they generate, requires not just understanding their dynamics and responses to perturbations over time; it also requires understanding the level of connectivity and dependence among the distinct aggregations that exist on the seascape.

In this context, the goals of this work were to a) develop a spatio-temporal model that describes the population dynamics of a generalized sea pen species in the Newfoundland-Labrador and Flemish Cap Bioregion, and b) explore the time scales for colonization, responses to perturbations, and preliminary explore the effectiveness of closures as a mechanism to promote recovery.

Modelling Approach

This model was implemented using an agent-based model (ABM) architecture that simulates the actions and interactions of autonomous agents within a system with a view to evaluating the system as a whole. The agents in this model represent collectives of sea pens where at each time-step the agents follow specific rules that simulate life-history processes. The agents operate within a 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.

This model was developed and implemented using Agent Analyst (Collier et al, 2013) within ArcGIS. Agent Analyst provides a software framework and tools to describe the agents, implement the processes that allow the agents to interact, and the scheduling of these processes. The implementation of this model expresses the sea pen dynamics in terms of number of individuals. It is important to note that it does not consider vertical movement of larvae in the water column.

Life history processes represented in the sea pen ABM

The model simulates the life history stages/processes of a generalized sea pen in both the egg/larvae as well as the settled state. Details on the how each step/process was modeled and parameterized are given in Table 2.4

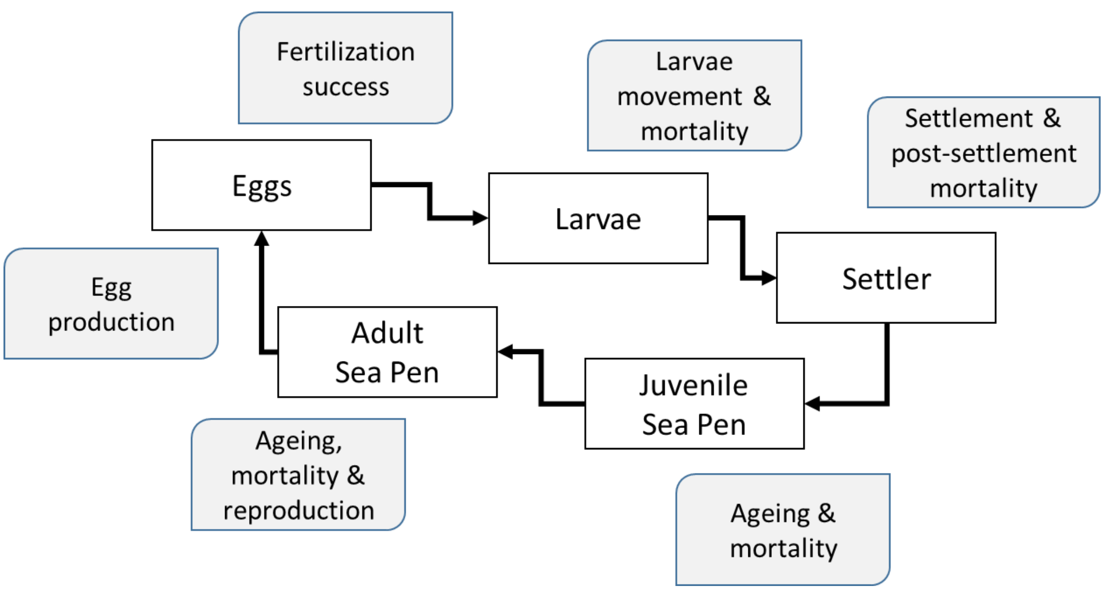


Figure 2.24 Schematic description of the life history stages/processes incorporated in the sea pen ABM.

Table 2.3. Summary description on how life history stages/process in the sea pen ABM were modeled and parameterized.

Model Parameter/Process	Details
Number of eggs produced	• Uniform distribution between 600 and 6300 per adult female (Ballion et al 2015). • Sex ratio assumed 1:1.
Number of eggs fertilized	• Fertilization rate: Beta distribution, mean=0.15, sd=0.17 (Coma and Lasker, 1997). • Fertilized eggs: Binomial distribution using the number of eggs in the cell and the probability of fertilization drawn from the above Beta distribution.
Larval movement and mortality	• Larval life span: 15 days where the larvae either settle or move/die. • Larvae can only move one cell per day. • Spawning is assumed to be a Spring-Summer process. • The season/period for these layers is April-August, 2000-2015 derived from Glorys 4 extracted from DFO's Ocean Navigator.
Larval movement: Direction	• Heading is defined as 8 bearing quadrants (N, NE, E, SE, S, SW, W, NW) • Direction of movement is randomly drawn from a normal distribution centered on the dominant bearing. This allows for counter-current movement.
Larval movement: Amount	• Number of larvae to move. • Binomial distribution using the number of larvae in cell and the probability of moving. • Probability of moving represents the fraction of the larvae to be moved is based on the bottom speed in the cell. • Logistic form with 50% probability of moving when speed in cell is equal to velocity required to travel to a neighboring cell.
Larval mortality	• The number of larvae in the water column that dies each day follows a Binomial distribution assuming a mortality rate of (0.90). • Sensitivity runs made with daily mortalities of 0.75-0.95.
Larval settlement	• Beta distribution with mean extracted from the settlement probability layer (see Settlement Probability Section in this Report) at the cell center and the sd of the entire layer (sd=0.065) • The number settled follows a binomial distribution using the amount of larvae in the cell and the probability of settlement derived from the above Beta distribution.
Post settlement larval mortality	• The amount of larvae that survives settlement to become Age 0s. • Binomial distribution using the number of settled larvae in cell and the probability of surviving settlement (1-post-settlement mortality). • Base post-settlement mortality is 90%, but asymptotically approaches 100% when density in the cell increases at approximately 20-30k settled individuals • This represents a sea pen patch (or patches) within the cell.
Juvenile and adult sea pens	• The amount of individuals that survive to become one year older follows a binomial distribution using the number of individuals at age and a survival probability of 0.90 • Maximum lifespan is 20 years. • Age at maturity is 4 years old.

Model implementation and results

Model implementation and parameterization is reasonably complete, but some details remain to be fine-tuned and explored. Therefore, while current results are not expected to change drastically from this stage to the final model configuration, they still need to be considered preliminary for the time being. Nonetheless, results are considered good enough to provide a reasonable proxy for where the final results will land, and hence, a sensible starting point for discussing management implications and potential options.

Larval mortality: sensitivity analysis

The base daily larval mortality during the larval dispersal stage was set at 90%. In order to assess the impact of this selection, runs were implemented assuming larval mortalities of 75% and 95%. The results of these alternative formulations in comparison with the base model are presented in Figure 2.25.

The overall sea pen distributions were generally similar across all larval mortality scenarios, highlighting the shelf break area in general, and the Flemish Pass, the horseshoe region joining the east, north, and west sides of the Flemish Cap, and the Laurentian Channel as core sea pen habitat. Lower levels of mortality made regions on the Newfoundland-Labrador shelf more suitable as sea pen habitats, specially southern Newfoundland (3Ps), nearshore areas off the northern coast of Newfoundland, and the shelf area off central Labrador (Fig. 2.24). The higher mortality rate resulted in an absence of sea pens along the shelf break in the northern sections of the bioregion as well as on the bank, and off the northeast coast of Newfoundland that were observed with the lower mortality rate scenarios. Given the general similarities across scenarios, the base case with 90% larval mortality was considered adequate for subsequent explorations.

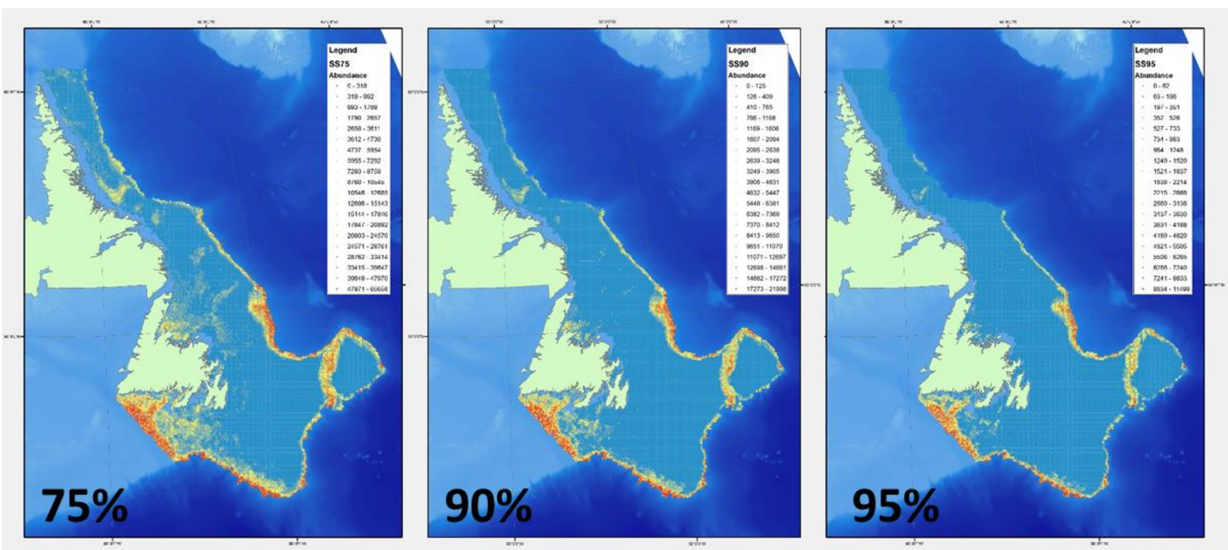


Figure 2.25. Comparison of stable sea pen distribution under the base larval mortality of 90%, and two alternative scenarios assuming 75% and 95% larval mortality.

Dynamics: Time scales and colonization

While the maximum lifespan of a single sea pen is assumed to be 20 years, the ability of the sea pen population to grow and colonize the entire NL and Flemish Cap bioregions can take a significantly longer period of time.

We implemented multiple colonization experiments within the model domain, seeding different regions with uniform distributions of sea pens, and running the model forward in time until the full region was colonized and presented a stable sea pen distribution. An example of a starting seeding scenario and a final stable sea pen distribution are illustrated in Figure 2.26.

Given the random nature of many of the processes in the sea pen ABM, and the comparatively low number of scenarios and runs explored, no average values for colonization have been computed. However, some of the emergent patterns observed were clearly consistent and the associated conclusions can be considered fairly robust.

It is very clear that from starting scenarios like the one depicted in Figure 2.26, it takes thousands of years to achieve full colonization of the two bioregions considered (NL and Flemish Cap). While the amount of time required will vary with the location and extent of the seeding area, the timelines for colonization had to be measured in hundreds and thousands of years as opposed to decades.

The colonization speed is variable, with relatively fast expansions observed in areas with fast currents and suitable habitat. Some regions, given their combinations of habitat suitability and current patterns, seem to act as natural barriers to expansion/colonization. When the sea pen distribution hits one of these areas, the overall distribution may remain stable for hundreds of years before the right conditions for overcoming these boundaries are met. These patterns of behavior create a perception of false distributional stability, with periods of "fast" expansion, bearing in mind that "fast" is in the context of the thousands year time horizons of the simulations. The 2H-2J boundary line is a good example of one of these natural barrier areas.

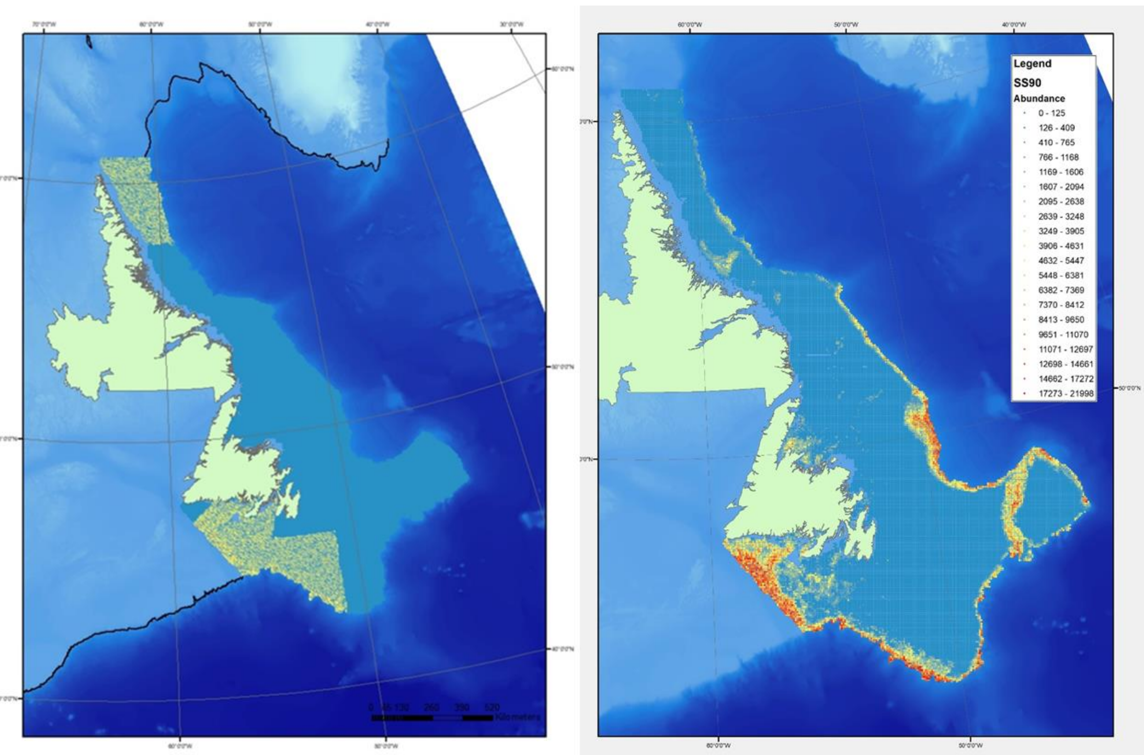


Figure 2.26. Comparison between one initial seeding scenario and the final stable sea pen distribution under the base larval mortality of 90%.

Sea pen recovery capacity: perturbation experiments

The recovery capacity of sea pens was preliminary explored using a series perturbation experiments.

Simulations were randomly 'seeded' over the entire study area and allowed to run until they arrived at a dynamic stable state where the total abundance of the system remained relatively constant. The stable state of the system was then used as the starting point to conduct the perturbation experiments to examine simulated recovery rates under different impact scenarios.

Two different types of perturbation experiments were implemented, single perturbations and recurrent perturbations under varying levels of impact. These experiments also involved broad scale as well as local perturbations. These experiments were implemented by defining a series of regions within the model domain that were used to quantify localized responses to the different perturbation scenarios (Figure 2.27). Local scale perturbations involved removals of sea pens within the defined boxes, while broad scale perturbations involved removals outside the boxes, and with the boxes acting as sea pen refuges.

Boxes were numbered from 1 to 9, with the area outside them was labelled as 0 (zero). Most areas were defined within the core distribution area of sea pens, with only one box (box # 6) placed in a low density, relatively isolated area. Regions 7 and 9 were created to evaluate upstream and downstream colonization rates and refuge connectivity under the different perturbation experiments. The spatial distribution of these boxes was intended to provide a fairly comprehensive coverage of the overall distribution (i.e. mimicking a potential network of refuges).

The recovery times were evaluated by tracking the rebuilding of the abundance within the perturbed area, expressing this abundance as the fraction of the pre-perturbation abundance. Expressing recovery in relative terms allows easy comparisons between areas that contain a range of abundance levels.

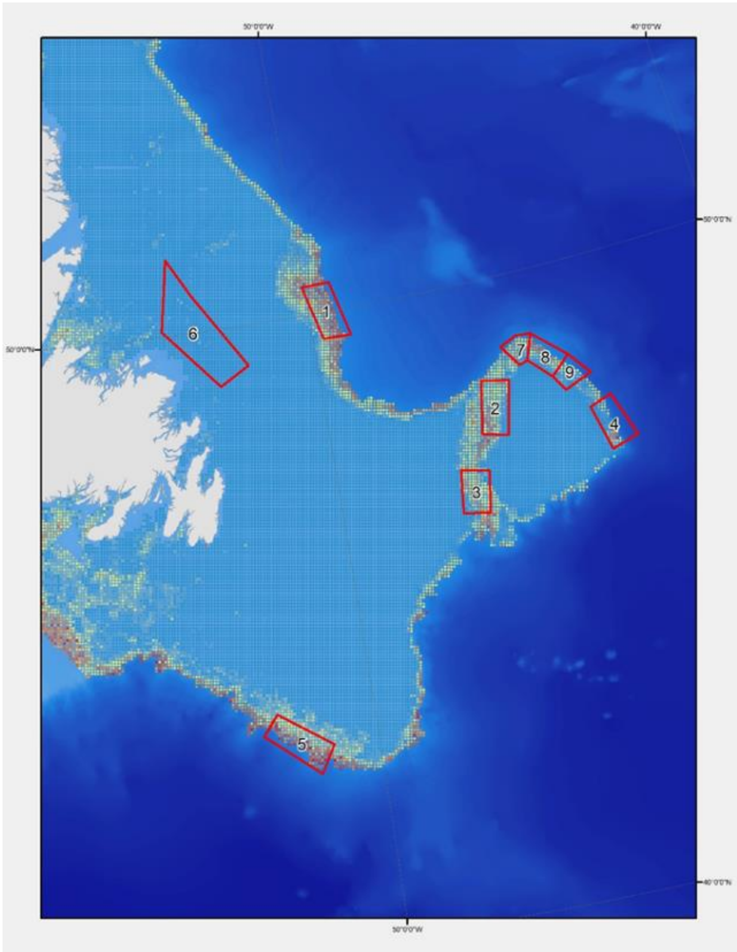


Figure 2.27. Boxes within the sea pen ABM used for perturbation experiments. Boxes were numbered from 1 to 9, with the area outside them was labelled as 0 (zero).

Broad scale single perturbation

This perturbation experiment involved the removal of 99% of the sea pen abundance outside the refuges (boxes), as well as within boxes 7 and 9, and allowing the system to recover after the single perturbation. The refuges contained approximately 14-15% of the total pre-perturbation abundance.

The abundance outside the refuges (r0) reached 95% of its pre-perturbation level in approximately 92 years (Figure2.28). Partial recoveries of 50% and 80% of pre-perturbation levels were reached at 24 and 40 years respectively (Figure 2.28).

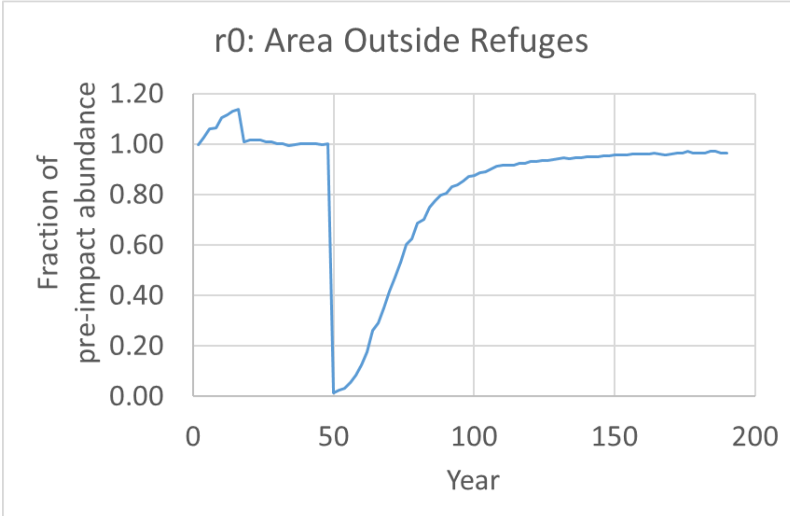


Figure 2.28. Recovery trajectory of the sea pen abundance outside the refuges (r0) after a single perturbation removing 99% of sea pens in the impacted areas (r0, r7, r9).

When the recoveries of the area outside refuges is compared with the recovery trajectories of boxes 7 and 9, box 7 shows a similar pattern as the broader area, while area 9 seems to recover faster, indicating that the local and neighboring conditions have detectable effects on recovery rates (Figure 2.29). Interestingly, the box 6, an area that was not perturbed but which is characterized by a low sea pen density showed a declining trend after the perturbation (Figure 2.29).

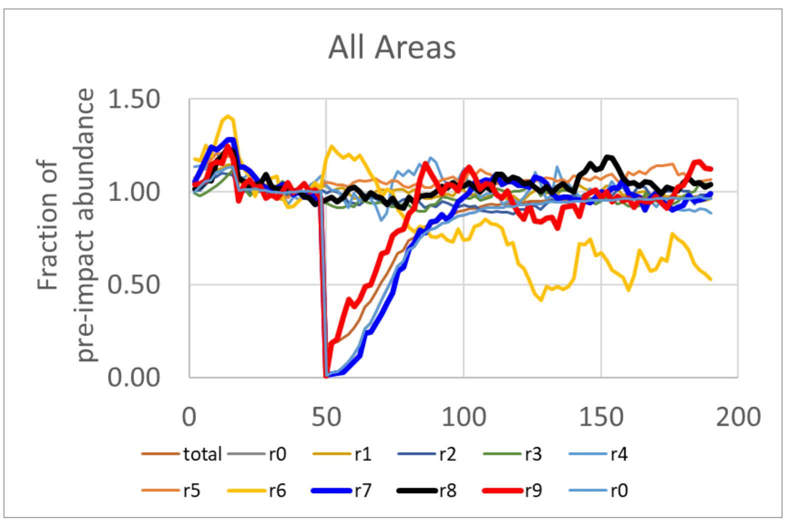


Figure 2.29. Comparison of sea pen abundance trajectories after a single perturbation removing 99% of sea pens in the impacted areas (r0, r7, r9).

Refuge effect and connectivity

To evaluate the contribution of refuges to recovery, three different single perturbation experiments were compared for two boxes adjacent to a refuge area (Figure 2.30). In these explorations, the box #8 was the refuge, while the adjacent areas #7 and #9 were perturbed. These areas were selected because area #9 is downstream of the refuge (#8) while area #7 is upstream (Figure 2.30).

The three scenarios considered were a) 100% removal of sea pens outside the refuge (area #8), b) 99% sea pen removal outside the refuge (area #8), and c) 99% removal everywhere (i.e. no refuge). The scenario with 100% removal allows for assessing recolonization from a neighboring area, while scenarios with 99% removal allow recovery from both, recolonization from a neighboring area and local self-recruitment.

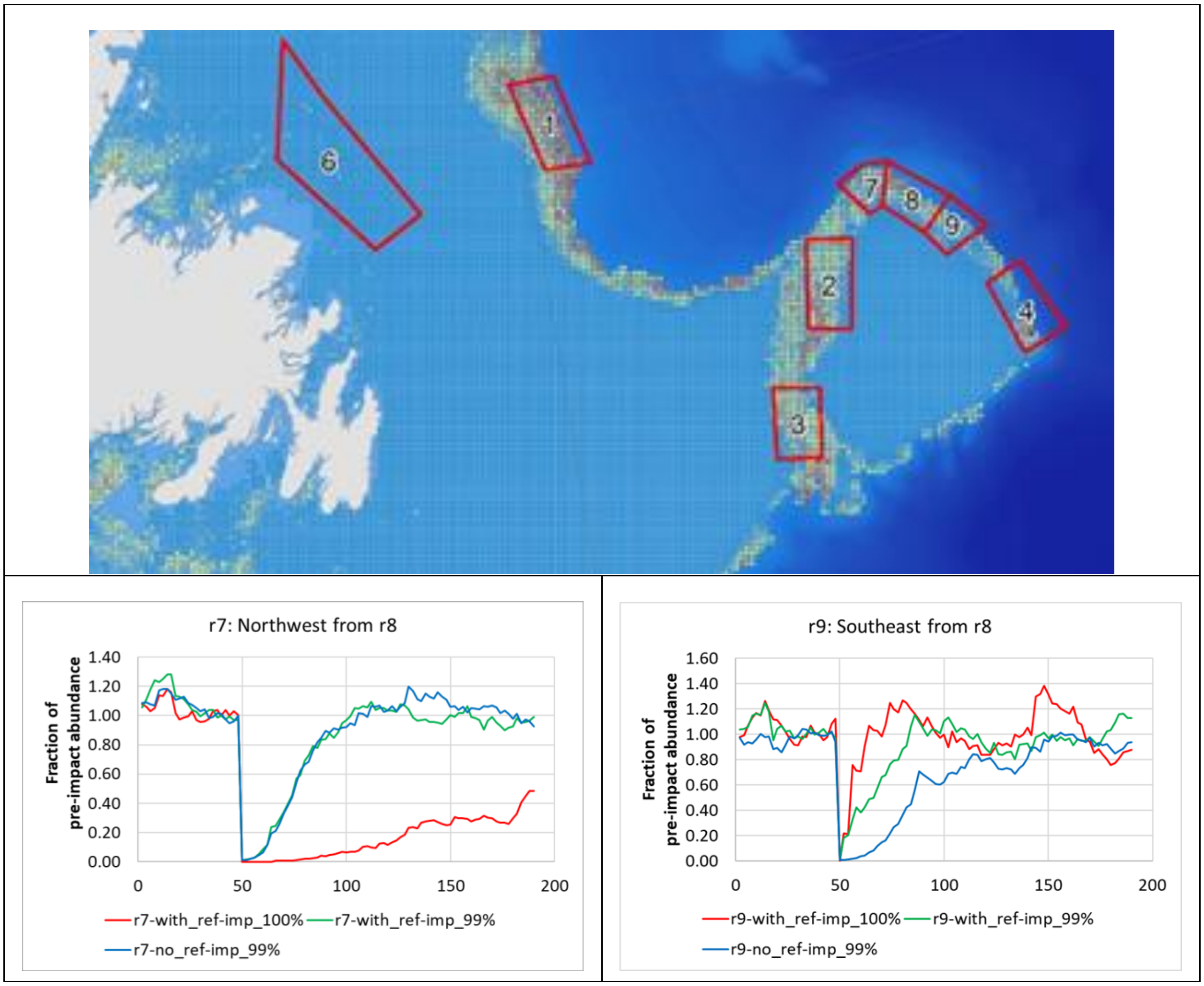


Figure 2.30. Refuge effect and connectivity perturbation experiments. Top: Map showing the spatial configuration of the boxes in the general region used for experiment. Box #8 was the refuge, while the adjacent boxes #7 and #9 were perturbed and their recovery monitored. Bottom right: Recovery trajectories of box # 7 (r7) after 100% removal and with r8 as refuge, 99% removal with r8 as refuge, and 99% removal without refuge. Bottom left: Recovery trajectories of box # 9 (r9) after 100% removal and with r8 as refuge, 99% removal with r8 as refuge, and 99% removal without refuge.

The results indicate that a refuge in box # 8 significantly accelerates recovery downstream (box # 9), approximately reducing recovery time by half. A refuge in box # 8 does not affect recovery rate upstream, but still allow long-term recolonization (Figure 2.30). These results highlights that the effectiveness of a refuge is dependent on its location and the topology of the connectivity network.

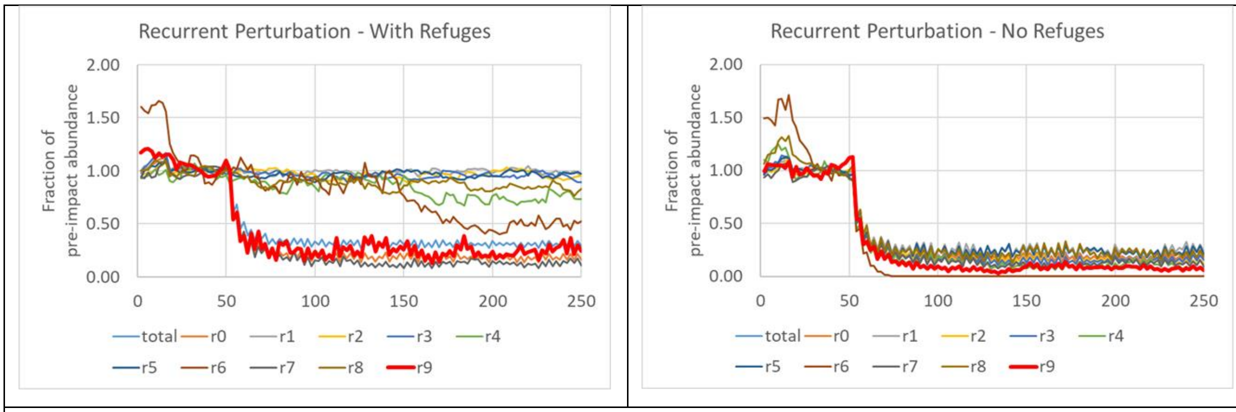
Recurrent perturbations

All above explorations were focused on recovery trajectories after a single perturbation. However, effects of fishing are recurrent; perturbations on a given location are repeated with some frequency. Here the effect of recurrent impacts was studied by applying broad scale removal outside boxes # 1-6 and # 8 (i.e. these boxes mimicked a network of refuges), using the region outside refuges (r0) and boxes #7 (r7) and #9 (r9) to monitor recovery after impact. The effectiveness of this network of refuges was evaluated by comparing results between experiments with and without refuges.

All experiments were conducted assuming a recurrence of impact of 4 years (i.e. a given location is only impacted every 4 years, allowing for colonization and growth in the intervening time), and at two different levels of impact, a 50% and a 90% sea pen removal at each impact event.

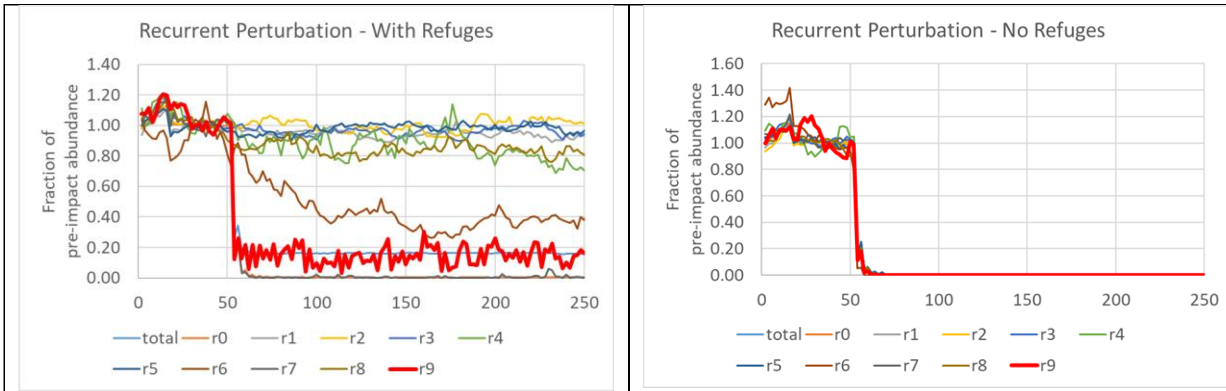
The results indicated that with and without refuges, recurrent perturbations drastically reduce the abundance levels of sea pens in the entire model domain (Figure 2.31-32). However, when the local scales are examined, it is clear that the presence of refuges has positive effects in downstream areas (Figure 2.31-32). The absence of refuges in the high impact scenario (90% removal) leads to the extirpation of sea pens in the study domain(Figure 2.32).

These results highlight that, even with refuges, the sea pen abundance in the study domain can be rapidly depleted by recurrent perturbations, reaching a dynamic stable state at a level much lower than the pre-perturbation one (Figure 2.31-32). This severe reduction in sea pen density would be expected to have important consequences in the functionality of the sea pen habitats. Still, the simulated refuge network only protects 14-15% of the total pre-perturbation abundance; higher coverage levels by the refuge network would be expected to provide better protection against recurrent perturbations.



Fraction Remaining (average of 100-250yr)		
Area	**With Refuges**	**Without Refuges**
Total	**0.31**	**0.18**
r0	**0.18**	**0.18**
r1	0.99	0.25
r2	0.96	0.15
r3	0.95	0.15
r4	0.81	0.11
r5	0.96	0.23
r6	0.65	0.00
r7	**0.13**	**0.12**
r8	0.86	0.22
r9	**0.24**	**0.08**

Figure 2.31. Recurrent perturbation experiments with 50% sea pen removal every 4 years. Top left: Recovery trajectories with refuges. Top right: Recovery trajectories without refuges. Bottom: Comparative fractions of remaining sea pen abundance with and without refuges for the different areas considered, indicating in red the areas that were perturbed in both scenarios.



Fraction Remaining (average of 100-250yr)		
Area	**With Refuges**	**Without Refuges**
Total	**0.162**	**0.000**
r0	**0.004**	**0.000**
r1	0.939	0.000
r2	0.991	0.000
r3	0.962	0.000
r4	0.850	0.000
r5	0.989	0.000
r6	0.374	0.000
r7	**0.005**	**0.000**
r8	0.835	0.000
r9	**0.142**	**0.000**

Figure 2.32. Recurrent perturbation experiments with 90% sea pen removal every 4 years. Top left: Recovery trajectories with refuges. Top right: Recovery trajectories without refuges. Bottom: Comparative fractions of remaining sea pen abundance with and without refuges for the different areas considered, indicating in red the areas that were perturbed in both scenarios.

Conclusions

The model representation of the spatio-temporal dynamics of a generalized sea pen appears reasonable. These results indicate that there is important connectivity within the model domain, but the magnitude of the connectivity varies. Some locations emerged as natural barriers.

Self-recruitment within an area is an important source of local growth, but overall growth also depends on connectivity between areas. Recovery times after a significant single perturbation is in the order of decades (20+ years). In the context of the FAO Guidelines (FAO 2009), these impacts on sea pens go beyond temporary impacts.

Refuges provide a buffer to perturbation and effectively accelerate recovery. Size and placement of refuges is key to their effectiveness. Refuge placement has to consider connectivity to be effective.

Broad scale recurrent perturbations of somewhat moderate level (50% removal every 4 years) can drive the sea pen status to very low level (e.g. 20% of pre-impact), likely impacting the ecological functions provided by sea pen habitats. Sea pens cannot tolerate high intensity broad scale recurrent perturbations. Refuges can buffer high impacts, but local extinctions would be expected in medium-low suitability areas.

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2.3. Up-date on VME biological traits analysis and the assessment of VME functions.

ToR 2.3 Up-date on VME biological traits analysis and the assessment of VME functions. (COM Request #9)

i) Revised workplan for Biological Traits Analysis

Following from the plan agreed at WG-ESA in 2017, WG-ESA has refined its plan of activities to be progressed over the next 2 years in support of the re-assessment of bottom fisheries to be conducted in 2021. A first step in these preparations is defining a list of biological traits which best describe the VMEs in the NRA. Such a list was discussed and agreed during the present meeting (see Table 2.5). Table 2.5 will be used to create a sample traits matrix from species sample data (trawl survey data) using a pre-prepared species traits matrix. The objective of this analysis is to allow a more robust assessment of SAI through the inclusion of additional functional assessment criteria in the overall assessment of SAI.

It was agreed the analysis of biological traits data should be progressed over the next two years (2019 and 2020), by undertaking the following tasks:

1. Creation of trawl sample traits matrix (based the VME indicator species from the list in the NCEM) for trawl survey 2008 – 2016 biomass data, and if time allows presence/absence data, should be performed. BIO to lead on this task that will be progressed by seeking support for DFO funding by December 2018, to include the possibility of additional high-resolution fish stomach sampling in the vicinity of VMEs (to be conducted on the 2019 surveys).
2. Creation of specific trait-based VME maps (using multivariate analysis e.g. cluster analysis)
3. Reassessment of trait-based VMEs at risk of impact and/or impacted, by assessing the trait data in relation to maps of fishing effort.
4. Bi-variate trait response curves to fishing effort.
5. Determine Trait Diversity Indices for each of the VME types.
6. Determine the relationship between Species density and VME traits.
7. Determine the overlap of fish distributions with habitats and VMEs/Traits using SDMs (to include any relevant stomach data which may be available, e.g. Flemish Cap data, and additional possible new data from 2019)
8. Evaluate available risk assessment frameworks which may be appropriate for assessing the specific VME types in the NRA.

Table 2.5. Sponge and coral VME biological traits

Trait	Modalities	Functional Links	Impact of Fishing Hypotheses	Reference
Maximum adult size	Very small <100mm small 100 - 300 mm medium 301–500 mm large >500 mm	Productivity, Biodiversity Provision, Filtration capacity, Carbon sequestration	Larger sponges are expected to be more vulnerable to bottom contact fishing gears	Sainsbury et al. (1992)
Morphology	Massive-globose Massive-irregular Tubular/Vase/cylindrical Flabellate Arborescent/Branching Cushion/Papillate Thin sheet Stalked Filiform (whip)	Productivity, Biodiversity Provision, Filtration capacity, Carbon sequestration	We expect morphology and size to interact with catchability. For example 100% of branched sponges less than 300 mm, and 80% of branched sponges between 301 and 500 mm in height, passed under the net.	Wassenberg et al. (2002)
Degree of Contagion	Highly Aggregated (Habitat forming) Small patches Solitary	Biodiversity Provision Bio-engineering habitat (e.g. sediment stability), local bottom current changes	We expect species forming aggregations will be more vulnerable to fishing than solitary species based on probability of encounter	
Feeding Mode	Filter feeder Carnivore Suspension feeder	Energy transfer (Trophic Position)	We expect filter feeding sponges to be more susceptible to impacts of sedimentation caused by fishing than carnivorous sponges.	
Preferred substrate inhabiting	Hard (rock) Gravel/Pebbles Soft (mud/sand) Epizoic (on other fauna)	Bio-engineering habitat (e.g. sediment stability), local bottom current changes	We expect sponges living on soft sediment to be more susceptible to impacts of sedimentation caused by fishing than sponges living on hard bottoms.	
Rig\ idity	Rigid Flexible	Provides stable structure and substrate for other organisms to attach to.	More rigid is more sensitive to bottom contact fishing disturbance	
Adult mobility	Sessile Sedentary	Bioturbation	Sessile if more susceptible to the effects of bottom contact fishing disturbance.	

References

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ii) Biological traits: deep sea corals

A study on trait-based approach on deep-sea corals of the Flemish Cap and Flemish Pass (NAFO Regulatory Area) is being developed by IEO in close collaboration with BIO, under ATLAS project. First results of this work were presented during the 4th World Conference on Marine Biodiversity (Montreal, 13-16 May, 2018) (García-Alegre et al., 2018). This study analyzes which biological traits are useful to classify corals in study area, prioritizing traits where information is available and that capture variation for a range of biological or ecological processes. Data used for this work was collected from EU/Spain bottom trawl surveys (2007-2017) and NEREIDA rock dredge samples (2009-2010).

This ongoing work represents a baseline revision on biological traits for further studies on deep-sea corals in this area. 24 taxa were selected as suitable for Fuzzy Correspondence Analysis (FCA) and 19 traits were found appropriate to classify deep-sea corals. Categories for each trait were defined and scored by each taxa. FCA is in progress and it is expected to be completed in a next future.

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iii) Using joint species distribution modelling to measure and predict the influence of traits on the assembly processes of benthic communities of the Flemish Cap

An essential purpose in community ecology is to understand how biotic and abiotic factors shape local species pools at different spatiotemporal scales (Ovaskainen et al., 2017, represented in Figure 2.33). The responses of the species to changes in environmental factors such as resources and disturbances vary depending on species-specific characteristics known as response traits (Lavorel and Garnier, 2002). During the last decade, ecologists have increasingly studied species' traits as a way to connect niche-based mechanisms to community patterns, although their use has been largely descriptive (Cadotte et al., 2015). Recent advances in community-level models (Warton et al., 2015; Ovaskainen et al., 2017) has allowed the incorporation of species traits in a modelling framework useful to identify response-traits that can provide functional, mechanistic and predictive perspectives on processes shaping the assembly and dynamics of ecological communities (Cadotte et al., 2015). Hierarchical Modeling of Species Communities (Ovaskainen et al., 2017), a class of joint species distribution models (JSDM; Warton et al., 2015), presents a useful framework for management and conservation. A JSDM approach was applied to presence-absence data from a subset of 105 benthic species from the 2007 EU Survey on Flemish Cap using a suite of 6 predictors (including fishing effort) and 4 biological traits (maximum body size, reproductive method, mobility, and feeding type). Preliminary results allowed characterizing the biological traits of the benthic communities previously identified on Flemish Cap (Murillo et al. 2016). Additional results will be presented next year at the 2019 WG-ESA.

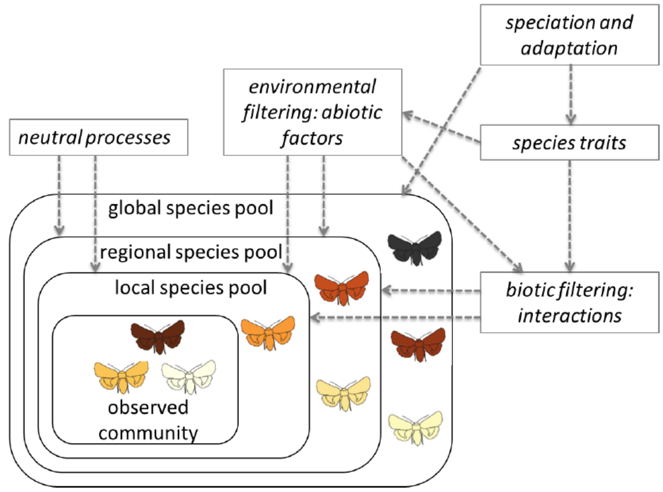

Figure 2.33. Conceptual diagram of the assembly processes influencing ecological communities at different spatiotemporal scales and influence of the species traits (Ovaskainen et al. 2017).

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iv) Soft corals as nurseries for basket stars (Gorgonocephalus sp.).

Soft corals in the family Nephtheidae have been the subject of a study on the association with basket stars in the genus *Gorgonocephalus* Leach, 1815. Bycatch samples, *in situ* imagery, and the literature indicate an association between soft corals and basket stars (Echinodermata: Ophiuroidea; Fedotov 1923, Patent 1970, Haedrich and Maunder 1984, Buhl-Mortensen and Mortensen 2005, Buhl-Mortensen et al. 2017). *Gorgonocephalus* has a wide geographic distribution, being found from the Arctic to the Antarctic, from the shallow subtidal to the deep sea (Rosenberg et al. 2005). These basket stars have branching arms coming from a central disk, which can be up to 10 cm in adult specimens (Mortensen 1927). They are conspicuous components of benthic communities in the North Atlantic and Arctic. DFO-NL RV trawl data (2011-2017) indicate bycatch biomasses of up to 240 kg of basket stars in one set (NAFO 3L), and additional sets of >100 kg basket stars/set.

We have examined over 2000 soft coral colonies from two species (*Duva florida* and *Drifa glomerata*) to investigate this association (Neves et al. 2018). Samples include DFO RV trawl soft coral colonies collected in the past 10 years, from the Newfoundland and Labrador, and Baffin Bay regions, from depths ranging between 53-1317 m.

Basket star occurrence was higher in *Duva* than in *Drifa*, with 11% and 33% of the examined colonies having associated basket stars. Maximum number of basket stars per colony was 27 for *Duva* and 111 for *Drifa*. Most basket stars were between 1-5 mm in disk diameter, but size range in a single colony was variable. Basket stars were mainly found on the upper half of the colony, which might favour protection against predation and food capture (Buhl-Mortensen et al. 2017). Data on $\delta^{13}C$ and $\delta^{15}N$ stable isotopes of basket stars and host *Duva* colonies indicate that they are feeding on the same sources (Neves et al. in prep).

Preliminary analyses of DFO-NL RV trawl data (2011-2017) indicate that basket stars are present in >50% of the sets in NAFO div 2H, 2J, 3L and 3P, and >20% of the sets for NAFO div 3K, 3N, and 3O. Among sets with basket stars, >50% of the sets also had corals in NAFO div 2H, 2J, 3K, and 3N, most of which are Nephtheidae soft corals.

The results of this study (Neves et al. 2018, Neves et al. in prep) show that Nephtheidae soft corals host juveniles of *Gorgonocephalus* sp., indicating that they are important in the life cycle of this basket star in this region. Further studies are needed in order to address the question of how exclusive this relationship might be and on how dependable basket stars are on soft corals. *Gorgonocephalus* sp. is considered vulnerable to trawling in the Barents Sea (Jørgensen et al. 2015), and it has been found as a prey item in stomach contents of Northern Wolffish (Simpson et al. 2013) and Greenland sharks (McMeans et al. 2012).

Ongoing analyses by DFO-NL include assessing effects of latitude, bathymetry, and season on this association.

Additional ongoing studies by the DFO-NL coral group on soft corals include assessing their role in sediment bioturbation and sediment cycling, their trophic ecology (Neves et al. 2017, in prep), and their potential to hold $CaCO_3$ (Neves et al. in prep) including potential variations in latitude, depth, and season.

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2.4. Assessment of NAFO bottom fisheries

ToR 2.4. *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).* COM Request # 9.

This request is largely being being addressed by the work reported against ToR 2.1, 2.2, and 2.3 (see above).

2.5. Up-date on fishery modelling activities

ToR 2.5. *Up-date on fishery modelling activities and develop 5-year plan for development and expansion of single species, multispecies and ecosystem production potential modelling*. (COM Request #14).

i) US Modelling and Statex of Ecosystem Reports

CIE Review for EBFM Management Procedure

The Northeast Fisheries Science Center conducted a Center for Independent Experts (CIE) review from April 30th to May 3rd, 2018. A management procedure framework was presented, including the following items: ecological production units, ecosystem level ceilings, fishery functional groups, strawman objectives, ecosystem level reference points, aggregate catch advice, tradeoff analysis, and species floors (Figure 2.34).

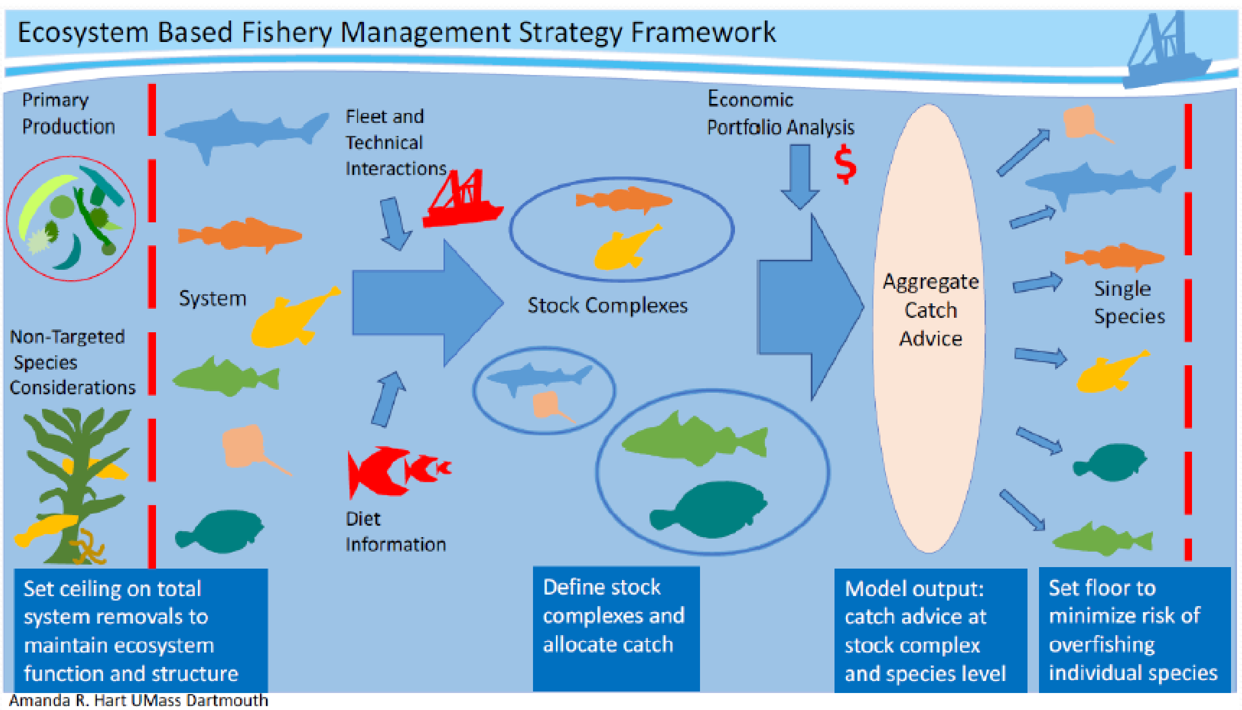

Figure 2.34. Framework for Ecosystem Based Fishery Management, proposed to address the request of the New England Fishery Management Council.

The general conclusions reached by the reviewers for the management procedure proposed, more detail of which can be found in their reports (https://www.nefsc.noaa.gov/program_review/reports2018.html), was that the overall procedure was theoretically sound, but that most elements required changes or expansion to be useful. Some of the recommendations were:

- More realistic fleets in the modeling work to take into account the nature of the mixed fleet fisheries in the region
- Using the same analyses for all models intended to be used
- Ramped fishery control rules rather than step functions
- Continued use of multiple models to examine tradeoffs and likely outcomes
- Further iteration with management to determine more specific objectives

The Fishery Production Potential analysis is worth going into in more detail. This analysis (Figure 2.35) was proposed as a way to develop the ecosystem level ceiling was considered to have been implemented in a scientifically rigorous fashion by the reviewers.

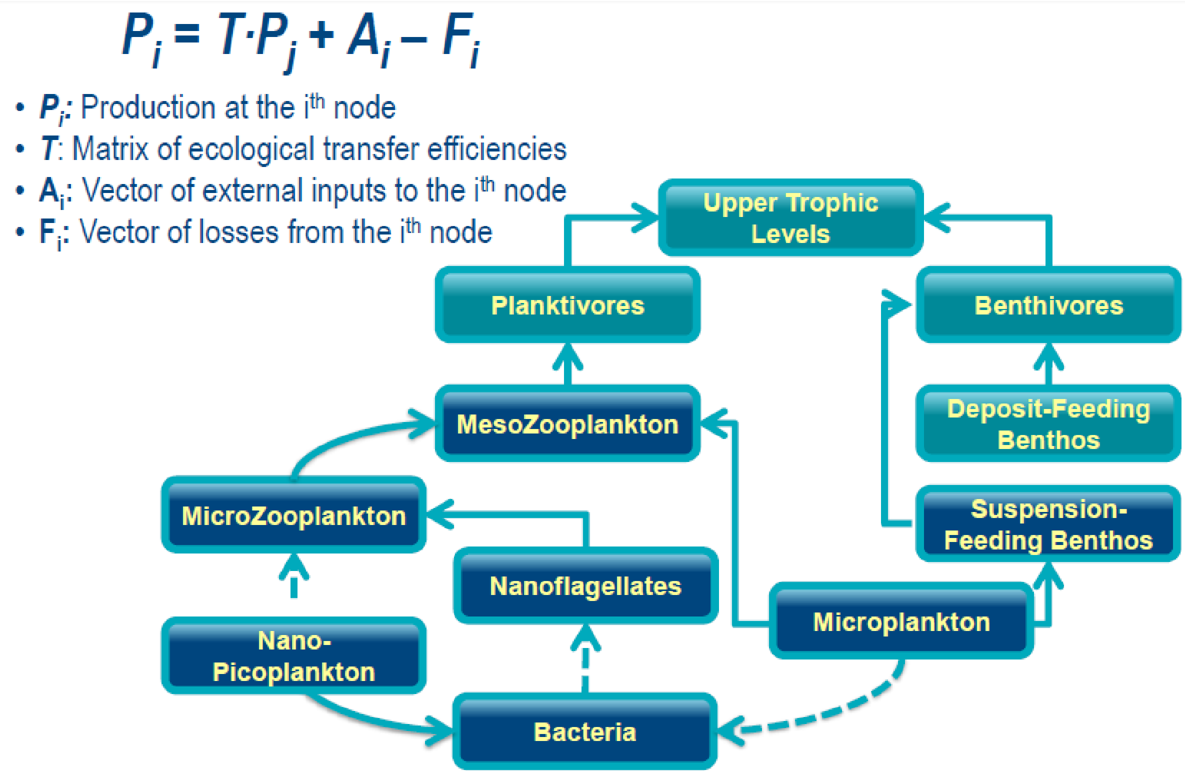

Figure 2.35. The Fishery Production Potential model used.

The results were similar to previous estimates although higher, which was considered by the review panel to be reasonable because primary production appears to have increased on Georges Bank over time. They were, however, concerned regarding the levels of uncertainty in the estimates, and how those might be interpreted by managers in determining the ecosystem level cap. Accordingly they suggested avenues of research to explore before an ecosystem level cap is implemented using this technique. One avenue of research suggested is to explore alternative methods (e.g. food web models, etc) to calculate the ecosystem level ceiling and compare them to the FPP results. The reviewers also recommended that uncertainty should be included with any estimate provided as management advice.

State of the Ecosystem Reports

Georges Bank and Gulf of Maine SoE Report

Mid-Atlantic SoE Report

The NEFSC produced two reports, one for each management council (NEFMC and MAFMC) last year and is in the process of producing those reports for 2019. The procedure has been greatly streamlined through the use of RMarkdown and github, such that more energy can be focused on determining which new indicators are useful, which indicators should be removed, and creating holistic information for managers. Each report is tailored to the corresponding management council's requests. One change that was made in the 2018 report which was well received was to start the reports with an overall executive summary and conceptual model of the system and then continue with the human elements before going to the biological and climate related portions of the ecosystem. It was found that managers appreciated getting the big picture before seeing the details.

A technical description of the methods and code used to generate the reports has also been completed.

(https://noaa-edab.github.io/tech-memo/)

MAFMC EAFM Risk Assessment Report

The MAFMC asked for a prototype Risk Assessment report derived from the State of the Ecosystem report. The report incorporated many elements of the State of the Ecosystem report and so was efficiently produced and well received. The MAFMC mainly used this as guidance to determine next steps and research suggestions, and recommended that this EAFM Risk Assessment document be added as a council deliverable to the annual Implementation Plan to reflect the most recent information available. They requested an Ecosystem Considerations for Stock Assessment of summer flounder report be created since Summer Flounder showed the highest levels of risk in the most categories of any species in their management region.

Ecosystem Considerations for Stock Assessment (ECSA) of Summer Flounder

https://noaa-edab.github.io/ECSA/

As a preliminary product, effort was placed in creating a flexible and easily changeable framework in Rmarkdown for the ECSA reports. The report itself utilized the most rapidly changing indices in the region (e.g. temperature, salinity, zooplankton composition, etc) and noted how they may affect different life history elements of summer flounder. Additionally, habitat occupancy models using the random forest technique were created, which indicate that habitat for summer flounder has had an increasing trend in recent years.

ii) EU SC05 project: "Multispecies Fisheries Assessment for NAFO"

Due to the limitations imposed in the use of the data needed for the development of the project SC05 "Multispecies Assessment for NAFO" no results were presented to the WGESA, with the exception of the contribution of the SC05 project to the task 2 of the EU SC03 project *"Support to a robust model assessment, benchmark and development of a management strategy evaluation for cod in NAFO division 3M"*. Instead, a very shallow presentation of the work done along this year within the project SC05 was done.

The tasks of the SC05 project are:

- **Task 1:** Setting the context
  - A general overview of the multispecies approach worldwide
  - Description of the biological, ecological, fishery and scientific features of the Flemish Cap.
- **Task 2:** Updating GadCap
  - An updated version of the multispecies model GadCap: a gadget cod, redfish an shrimp multispecies model in the Flemish Cap.
- **Task 3:** First approach to implement multispecies assessment
  - Explore the provision of scientific advice for a multispecies approach in the Flemish Cap
    - Use of multispecies natural mortality estimates in stock assessment
    - Multispecies MSE framework and potential new multispecies HCRs.
- **Task 4:** Economy trade-offs
  - First analysis of the socio/economic implications
  - Available techniques and models needed to assess the trade-offs

- **Task 5:** Dissemination to scientists and stakeholders
  - Discussion and interaction between scientists and other stakeholders: workshop.
  - Presentation and integration of results in the NAFO-WGESA and NAFO Scientific Council meetings
- **Task 6:** Further research
  - Identify future necessary steps and research activities

Currently, tasks 1 to 4 have already been covered and finished. In task 2, the multispecies model GadCap (Pérez-Rodríguez et al. 2017) was extended to cover and assess the dynamic of cod, redfish and shrimp over the period 1988-2016. For this, all the survey and commercial databases were updated and revised, in order to ensure that the data used in GadCap was, as much as possible, the same data used in the single species stock assessment of these stocks. Length and age distribution of survey and commercial catches, total biomass index by species, total annual commercial catches, distribution by season, biomass of the different prey species, diet composition databases, etc. All the data sources supporting the different likelihood components were reviewed and updated. In addition to the databases, some very important sub-models defining the productivity and interactions between the three stocks were reviewed and improved. On this regard, the growth model parameters were re-estimated and re-grouped by years; the sub-models of maturation and sex-change as a function of size were reviewed, the sub-models defining the prey-predator length relation as well as the suitability parameters defining the trophic interactions were refined. In relation to the natural mortality, different approaches were used to estimate the residual natural mortality (M1), that together with the predation mortality (M2) estimated within GadCap would produce values of total natural mortality (M=M1+M2) at age every year (Pérez-Rodríguez and González-Costas 2018). This matrix of natural mortalities were used (as part of the task 3) as an alternative estimate of natural mortality during the 3M cod benchmark exercise in the EU SC03 project "*Support to a robust model assessment, benchmark and development of a management strategy evaluation for cod in NAFO division 3M*" (González Troncoso et al. 2018). In addition, different model configurations were tried: model with annual instead of seasonal time steps, model with beaked and golden redfish species separated, model with different configurations in the functional response relating prey-predator consumption. This new model structures did not produced results that may be considered appropriate for long term simulations, however entailed a step forward in these lines of work. In long term simulations a "carrying capacity component was introduced".

In the development of the task 3, a multispecies MSE framework was developed taking the a4a-FLR MSE framework developed by the EU Joint Research Centre of Ispra (Italy). This multispecies MSE framework (Figure 2.36) included the updated multispecies model GadCap as an operating model, that provided information about the commercial fishery, survey and the stock to three different management procedures (one for each of the three stocks), where two possible options for the stock assessment were available (shortcut and an a4a SCAA stock assessment model). The data provided for the stock assessment passed through an observation model, with the possibility of introducing error in the data simulating the assessment error, or the commercial and survey data noise, depending if the shortcut or the a4a SCAA option was used as assessment method respectively. Once the assessment is performed, a short term projection takes places within the management procedure for each stock, which, in conjunction with the HCR is used to define the catch advice and the TAC. This TAC goes through an implementation model, which will determine the final catch that is finally sent to the operating model (GadCap), that will run forward one year, implementing the catch, introducing new recruited individuals (determined with a SSB-Recruitment considering uncertainty or not) and simulating all the biological and ecological processes occurring within the modelled system in GadCap (and very importantly the trophic interactions).

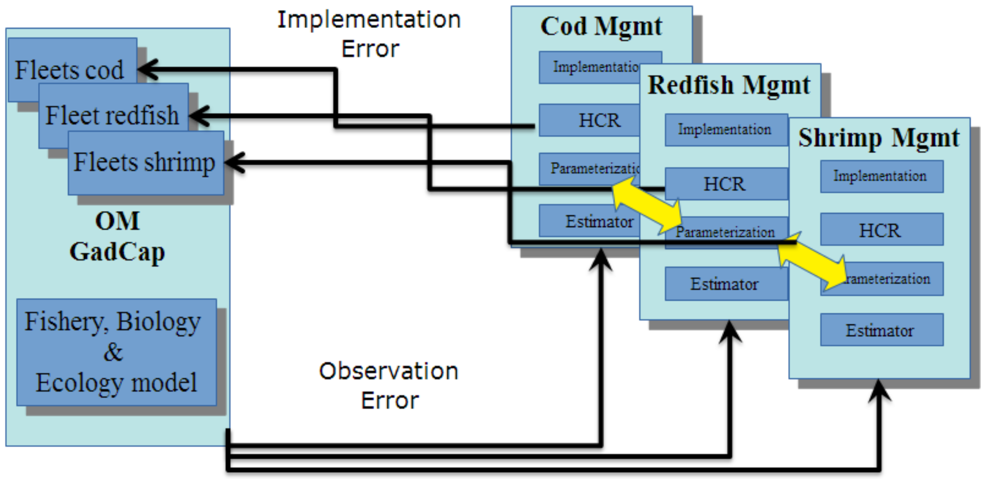

Figure 2.36. Multispecies MSE framework developed within the Task 3 of the project SC05 in conjunction with Iago Mosqueira and Ernesto Jardim from the EU Joint Research Centre in Ispra (Italy), and taking the work developed within the project REDUS by Daniel Howell and Ibrahim Umar from the Institute of Marine Research of Bergen (Norway).

As part of the task 3 of the SC05 project different management strategies were tested. Different HCRs were designed by defining the precautionary reference points (B_{lim} and $B_{trigger}$) and F reference points defined with single and multispecies considerations. In addition, two stages hockey stick HCRs were tested to assess if this HCRs would allow a reduction of an excessive predation mortality from cod. Finally, this multispecies MSE framework was used to assess the effect that an assessment considering constant M for all ages over time, a vector of M variable by age but constant over time, and a matrix of M variable at age and year (output from the OM GadCap) would have had on each of the three stocks assessed. As part of the task 4, the ecological and economic trade-offs result of the implementation of a number of different HCRs with single and multispecies foundations were assessed.

iii) An Economics Lens to Understanding NAFO Fishing towards Implementing Ecosystems-based Fisheries Management (EBFM)

Integrated Ecosystem Based Fisheries Management (EBFM) is a goal of the Northwest Atlantic Fisheries Organization (NAFO), and thoughtful implementation of EBFM could result in changes to status quo fishing behaviors within the NAFO regulatory area. Therefore, modelling such impacts is an important consideration in determining possible trade-off within the bio-economic system. Towards this end, exploratory research linking key economic and ecological considerations in a stylized conceptual model of the fishing industry operating on the Grand Bank off the coast of Newfoundland – specifically NAFO areas 3LNO- was conducted. The ecosystem model is reverse engineered in that starts with economic considerations of the management system (the fishery) and then proceeds to add the accompanying ecological components that are integral to the ecology and also support the economic system. The model development approach builds on the work of the International Council for the Exploration of the Sea (ICES) Working Group on the Northwest Atlantic Regional Sea (WGNARS) which since 2009 has been focused on building capacity to support Integrated Ecosystem Assessment for the Northeastern US and Atlantic Canada. A key objective of ICES WGNARS has been to draw on a broad base of expertise including physical and social scientists. The 3LNO conceptual model combines a dual economic and ecological lens to contemplate answers to such questions as; how do changes in key ecosystem parameter values (e.g. harvest levels, ecosystem pressures) concurrently impact human use and ecosystem components, while allowing examining questions regarding the perceived value in extending the model to include specifics of fishing activities in the NAFO regulatory area; how that analysis might proceed including unit of analysis, possible data limitations and potential solutions; initial metrics (analytical approaches) for quantifying trade-offs – specifically the treatment of landed value information in the model. The concept of commodity (fish) value chains were explored as well as methods and sources of data for landed price (value) for NAFO fleets catches which included the specification of an ordinal ranking approach for value information using a Species Value Factor concept. Next steps include investigating suitable data sources to capture fishing related variable for NAFO fleets including landed values by species/country and employment indicators (individuals and fishing hours). Given data limitations, proxy values may have to be considered (short term) to specify the model while more reliable values are explored. Ultimately, the Conceptual Model should be presented to NAFO managers to seek input and gauge support.

Conceptual model development and implementation

Most ecosystem-level bio-economic models evolve from purely ecological models where economic elements are built as add-ons. While this classical approach can render useful results from an ecological research perspective, they not always represent the reality of managers in a way that the managers themselves can relate to. Furthermore, ecological models can be seen by managers as overwhelming given their ecological complexity, preventing them from fully understanding how the model is working. These models often become a black box for most managers.

If EBFM is to become a practical approach, working level managers need to see their everyday work reflected in the tools used for EBFM, and have the capacity of understanding how those tools are working in a way that promotes trust in the outcomes. While EBFM represent a different way of approaching resource management, the transition to EBFM needs tools that can reflect today's management reality while allowing for, ideally, a seamless integration of the EBFM principles into that reality.

While the ecosystem bio-economic model being developed for the Grand Bank (3LNO) is conceptual in nature, it was nonetheless constructed under the premise of capturing the manager's point of view, aiming at delivering a conceptual tool that managers can engage with. This implied two fundamental elements: a) the focal component had to be those that managers deal with in their everyday work, and b) the implementation tool had to be one that the managers can use without a steep learning curve, and which would allow them to "look under the hood" and fully understand how the tool is working.

Based on these ideas, the model was constructed using a reverse-engineering approach from the manager's view of the ecosystem (Figure 2.37). Paradoxically, while standard single-species approaches evaluate the status of the stock and set quotas at the individual stock level and in isolation from other target stocks, managers often consider the viability of the enterprises involved (e.g. fleet sectors) when designing and assessing alternative management actions. In these viability analyses, economic factors like enterprise revenue and employment level play a key role in defining management options.

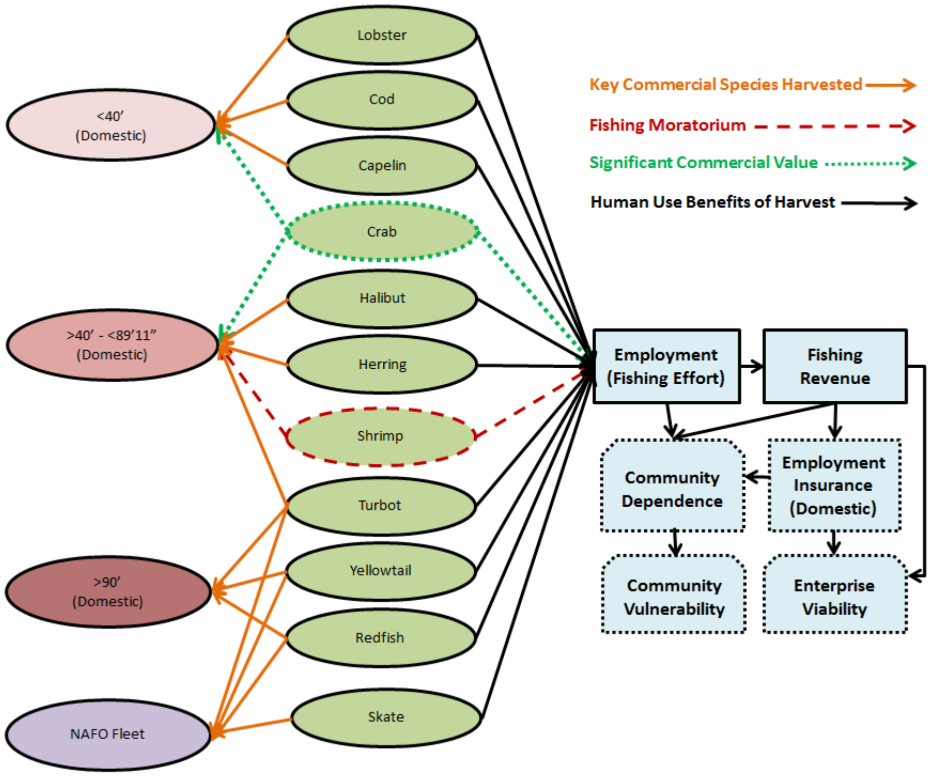

Figure 2.37. Schematic representation of the Grand Bank (3LNO) bioeconomic ecosystem, including economic units (fleets), commercial species, and socio-economic factors (e.g. employment, revenue). The current implementation of the conceptual model only includes employment and revenue as economic factors; inclusion of other factors is in development.

The manager's ecosystem point of view was used to identify the key species that needed to be included in a minimum conceptual model of the Grand Bank. However, a model only composed by these species cannot capture the basic ecosystem interactions that would make it a minimally operational representation of the Grand Bank food web. A key forage fish species in this ecosystem would be missing (sandlance), as well as key bottom-up drivers and regulators of ecosystem productivity (e.g. temperature, sea ice, coastal nursery habitats like eelgrass beds, phytoplankton, zooplankton). Adding these elements, and the basic links among them, allowed constructing a minimal ecosystem interaction web for the conceptual model (Figure 2.38). It is important to emphasize that despite their similarities, an interaction web is not equivalent to a food web. A food web represents predator-prey connections, while an interaction web represents the effect that one node has on another, allowing to represent within the web, for example, the impacts of environmental components on biological ones. Equally important, a given predator-prey link may be absent from an interaction web if the magnitude of the effect is negligible in comparison with dominant interactions.

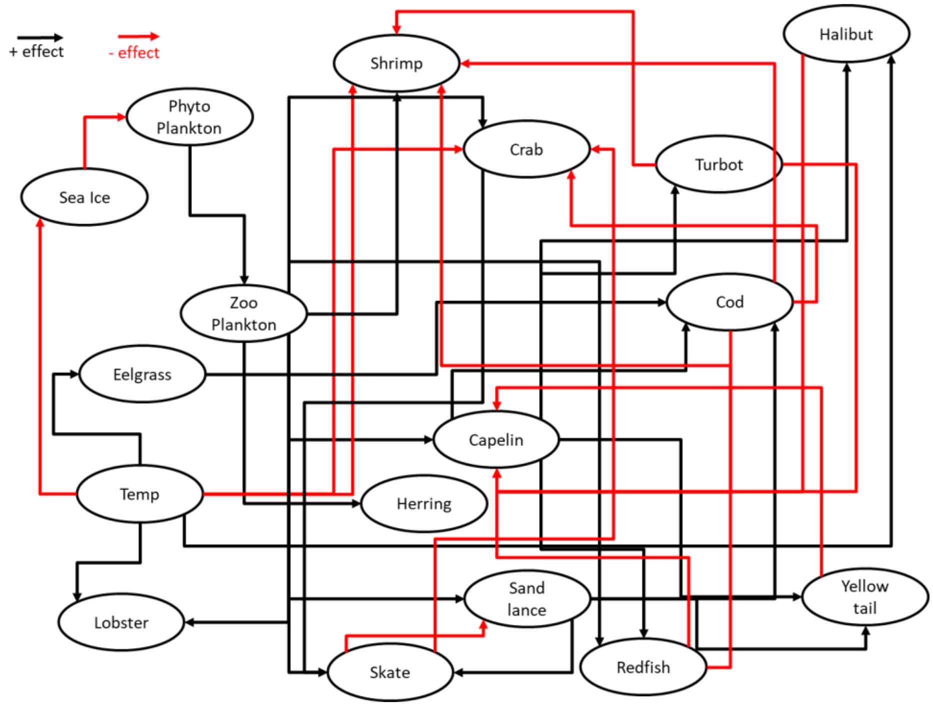

Figure 2.38. Interaction web of the ecological components included in the conceptual model of the Grand Bank (3LNO). The colored arrows represent positive and negative interactions; while most of these interactions are driven by predator-prey relationships, they represent a more general/dominant interaction effect (e.g. the negative effect of temperature on sea ice).

The integration between the ecosystem interaction web and the manager's view of the ecosystem was implemented by adding catches to the ecosystem interaction web, where those catches were resolved to the fleet-target species level. The ecosystem interaction web was composed by 17 nodes; adding the fleet-target nodes implied adding 19 additional nodes to create an integrated interaction web. While these numbers in themselves are not particularly relevant, the ratio between them is a potentially interesting indicator. A minimal conceptual representation of this bio-economic system that can represent the manager's perspective of the ecosystem required as many economic nodes (represented here by fleet-target nodes) as it needed environmental/ecosystem ones in the basic integrated interaction web.

This interaction web can be mathematically represented with a square transition matrix **T**, where each element in that matrix corresponds to the effect of one node on another (a_{ij} denotes the effect of node *j* on node *i*). If we consider a vector $\mathbf{X_t}$ representing the state of all nodes at time *t* (x_i indicates the state of node *i*), then the matrix multiplication of $\mathbf{T}\text{x}\mathbf{X_t}$ allows to estimate the state of all nodes at *t+1* ($\mathbf{X_{t+1}}=\mathbf{T}\text{x}\mathbf{X_t}$). This basic algebraic representation allows projecting the state of the system over time. While these projections represent the trajectories of the state variables, the full representation of socio-economic impacts/outputs needs scaling the catches per target species and fleet to dollars and labor hours. This scaling was implemented outside the transition matrix by considering the average price and work hours per tonne of catch for each specific fleet-target node, and required 38 additional parameters.

This model structure represents the bio-economic system as a set of linear equations. This type of architecture is common in conceptual models, but here instead of considering the model as purely topological (i.e. a signed graph), the transition matrix and biological state variables were parameterized using available information on biomass level from research surveys, diet compositions, available estimates of primary and secondary production from Ecosystem Production Potential models, and existing knowledge on the influence of environmental drivers and habitat on fish production, while the environmental state variables were represented with nominal index values (e.g. arbitrary value of 100 at equilibrium). Socio-economic state variables and parameters were compiled from a diversity of sources, including catch statistics, government databases and available economic analyses and summaries. This approach to parameterization brings the conceptual model closer to steady state ecosystem modelling (i.e. mass balance under equilibrium assumption) and allows representing most state variables with numerical values which are consistent with real world values for these variables. To allow for exploration of uncertainty in model outcomes, the option of drawing parameters for the transition matrix from triangular distributions centered on the deterministic values of these parameters was implemented.

Even though the conceptual model is not intended to be an accurate representation of the real world, by rendering results that approximate actual magnitudes, the potential consequences of alternative management option can be more directly interpreted and assessed by managers. The hope is that by providing sufficient resemblance to reality, managers would consider the conceptual model good enough to meaningfully engage in the EAF conversation and way of thinking.

The other important element in the development of this conceptual model is the ability for managers to use it without a steep learning curve or specialized training. This was accomplished by developing the model in the broadly used spreadsheet software Microsoft Excel (Figures. 2.39-2.41). Most managers are not familiar with the tools typically used by scientists (e.g. R software), but do most of their quantitative analyses using Excel, and they are fully familiar and proficient with this software tool. Implementing this conceptual model in a tool familiar to managers facilitates its adoption, and promotes trust by removing concerns about "black box" approaches.

The developing of this conceptual model is still work in progress. Next steps include refinements in the parameterization, and the inclusion of some of the additional socio-economic dimensions displayed in Figure 2.37. In terms of functionality, some pending work include improvements in the user interface (i.e. make it easier to modify parameters to explore management options), and adding the capacity to generate statistical summaries of multiple random runs. Beyond the modelling aspects, and the exploration of alternative management options in a conceptual way, a workshop to engage with managers, present the tool, and get their feedback is also intended.

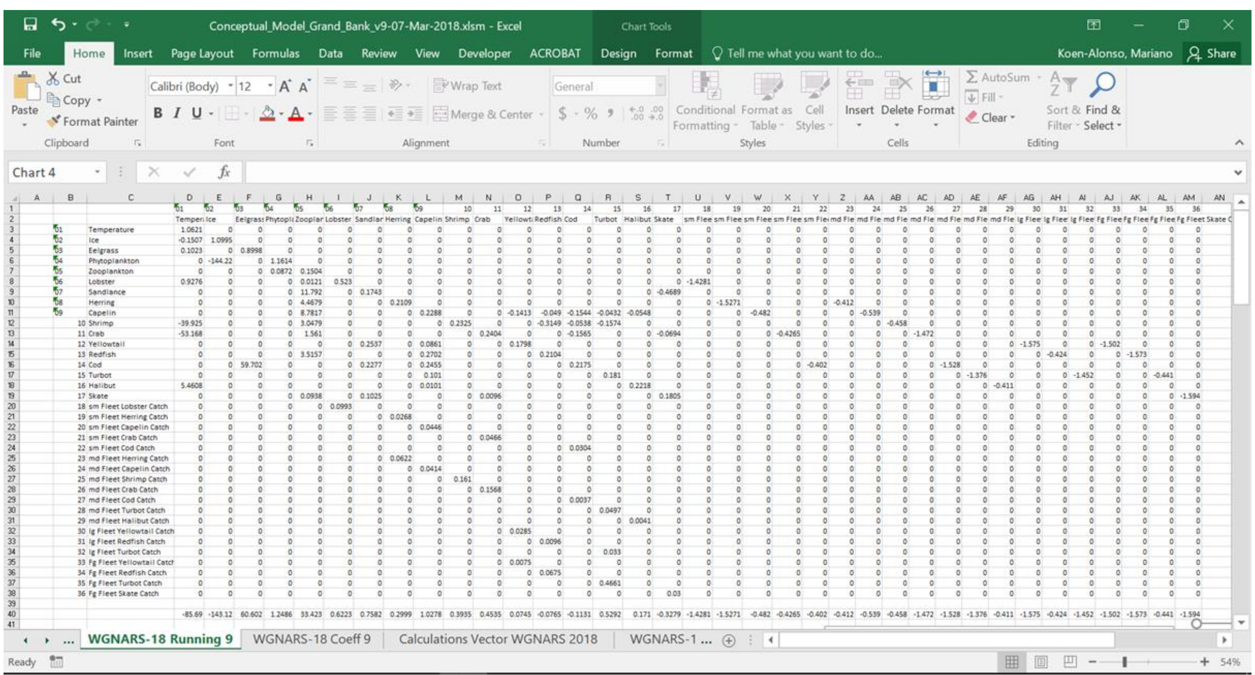

Figure 2.39. Screen shot of the conceptual model for the Grand Bank (3LNO) implemented in Microsoft Excel. Details of the transition matrix.

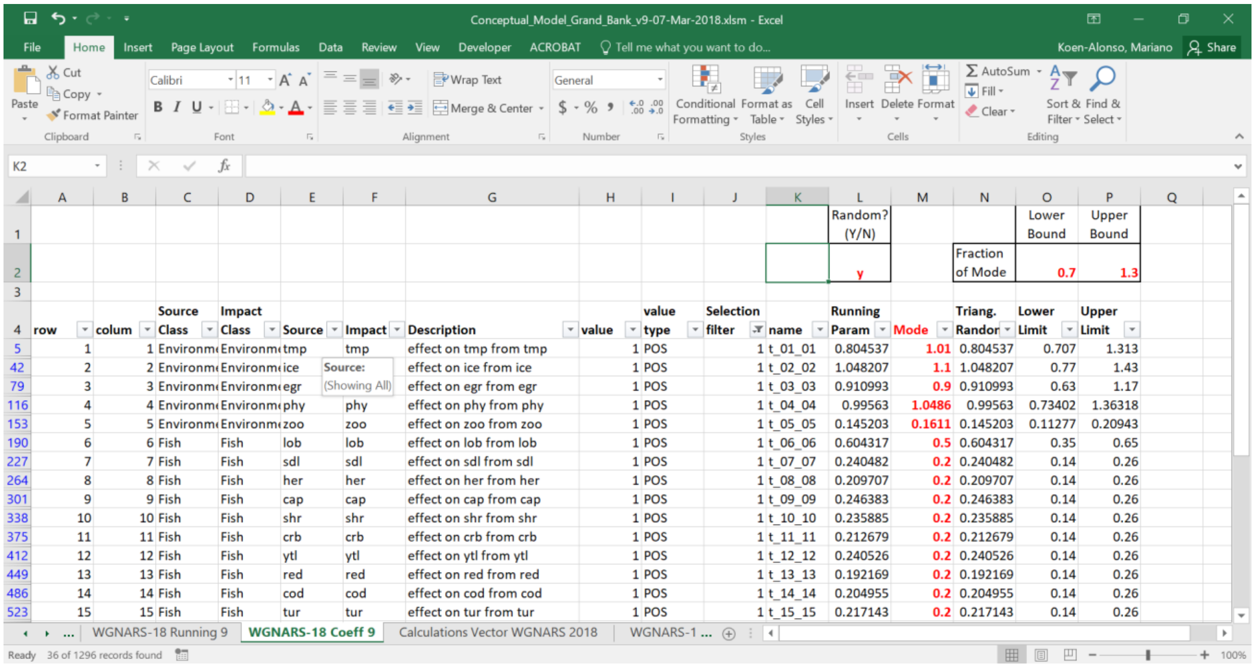

Figure 2.40. Screen shot of the conceptual model for the Grand Bank (3LNO) implemented in Microsoft Excel. Details of the table of parameters used to populate the transition matrix; notice cell 2L which allows setting on/off the use of random triangular distributions for the parameters in the transition matrix.

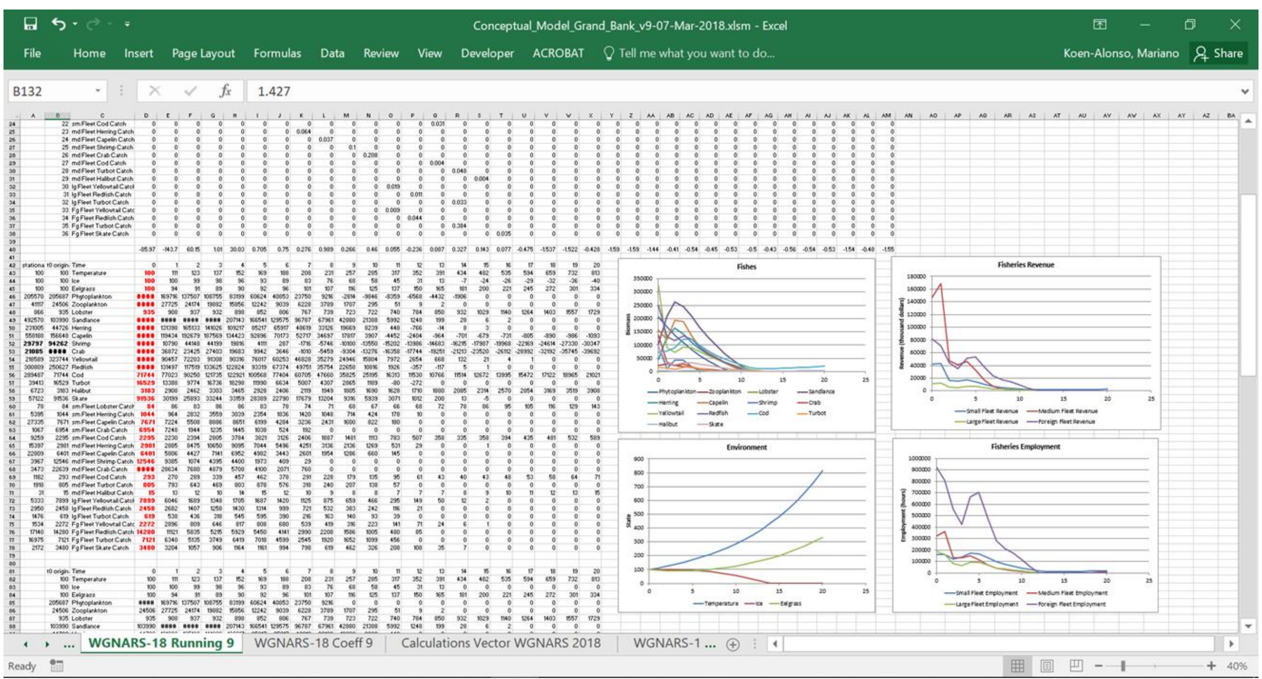

Figure 2.41. Screen shot of the conceptual model for the Grand Bank (3LNO) implemented in Microsoft Excel. Details of the vectors of state variables over time, and plots summarizing the biological and environmental trends, as well as the trends in fisheries revenues and employments by fleet. This specific screen-shot corresponds to a run with increasing temperature over time (i.e. mimicking climate change) and random triangular noise in the parameters of the transition matrix. These results correspond to a single random draw.

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iv) Modelling dynamics of key components of the Newfoundland and Labrador marine community in a ecosystem context: The case of Northern cod (NAFO Divs 2J3KL)

Introduction

Considering ecosystem drivers in modelling stock dynamics is one of the cornerstone elements in implementing ecosystem-informed stock-assessments and advice. In 2017 WGESA explored the dynamics of Northern cod (NAFO Divs 2J3KL) using an Empirical Dynamic Modelling (EDM) approach (NAFO 2017). EDM is an equation-free approach that allows reconstructing a multidimensional attractor using lagged coordinates embedding of empirical time series data (Sugihara and May 1990, Deyle and Sugihara 2011). Current developments of this technique allow using multiple time series to better map the underlying attractor for short term forecasting (Ye et al. 2015), as well as to explore causality between pair of variables using convergent cross-mapping (CCM) (Sugihara et al. 2012).

The WGESA 2017 EDM analysis considered RV cod biomass and catches, the cumulative Composite Environmental Index (CEI), and the capelin acoustic and RV capelin biomass indices into the EDM, predicted a stable or reduced Northern cod level for 2017, in contrast with the accepted assessment model which predicted an increase (NAFO 2017). The 2017 RV Fall survey showed a decline in Northern cod.

The agreement between EDM predictions and RV observations prompted a further exploration of how to incorporate ecosystem drivers in modelling Northern cod dynamics. These explorations included an updated EDM analysis and the implementation of a bioenergetic-allometric model for Northern cod based on the work of Buren et al (2014).

Northern cod EDM update

The EDM approach to Northern cod involves running an assemble of models, each of them with different subsets of drivers, and comparing outputs to generate an envelope of possible trajectories. In the current update, a series of eight models were implemented (Table 2.6). These model configurations ranged from single species (model s, only cod biomass in the model), cod and fisheries catches (m4, cod biomass and cod catches), cod and environmental variables only (m1, cod biomass and cumulative CEI), cod and prey only (m2, m3, and m5, with cod biomass and the capelin acoustic biomass index, the RV shrimp biomass index, and the RV capelin biomass index respectively), and two multifactor models (m6 and m7) which combined cod biomass and fisheries catches with environmental and prey drivers (Table 2.6).

All EDM configurations where fitted to a common time series for comparison across configurations. All models showed good fits to the cod time series (Table 2.6, Figure 2.42), and were used to explore 1-3 year forecasts for the stock (Figure 2.43).

The forecast results indicate that while some of the models in the one year forecast predict increases from the 2017 levels, all three year forecasts indicate a more consistent picture of stable or decline trends from the 2017 level. These results suggests that continued significant rebuilding of the Northern cod stock within the next 1-3 years seems unlikely.

Table 2.6. Northern cod EDM configurations and associated fits. Rho: correlation coefficient, MAE: Mean Absolute Error, RMSE: Root Mean Square Error. The modifiers t1 and t2 indicated the temporal lag of the variable. The first variable indicated corresponds to the dependent variable being predicted (cod)

Abbr	Model	Variables	Number of predictions	Rho	MAE	RMSE	p-value
s	Cod	(cod, cod_t1, cod_t2)	21	0.905	0.069	0.094	1.08E-10
m1	Cod+Env	(cod, cod_t1, cumCEI)	21	0.940	0.047	0.073	7.22E-14
m2	Cod+CapeAc	(cod, cod_t1, CapeAc)	21	0.919	0.060	0.084	1.01E-11
m3	Cod+Shrimp	(cod, cod_t1, Shrimp)	21	0.863	0.081	0.108	1.54E-08
m4	Cod+Catch	(cod, cod_t1, CodCatch)	21	0.927	0.059	0.083	1.81E-12
m5	Cod+Capelin	(cod, cod_t1, Capelin_t1)	21	0.875	0.077	0.116	4.59E-09
m6	Multi-factor 1	(cod, cod_t1, CodCatch, cumCEI, Capelin_t1)	21	0.917	0.051	0.086	1.32E-11
m7	Multi-factor 2	(cod, cod_t1, CodCatch, cumCEI,CapeAc)	21	0.933	0.048	0.076	4.85E-13

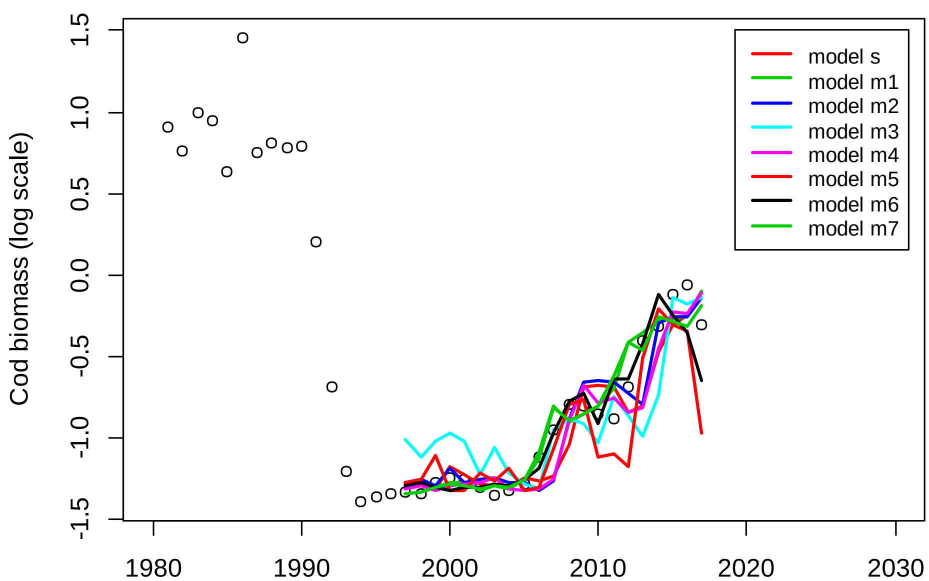
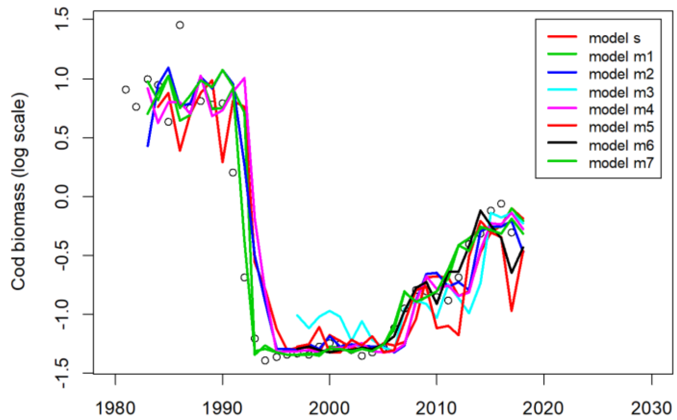
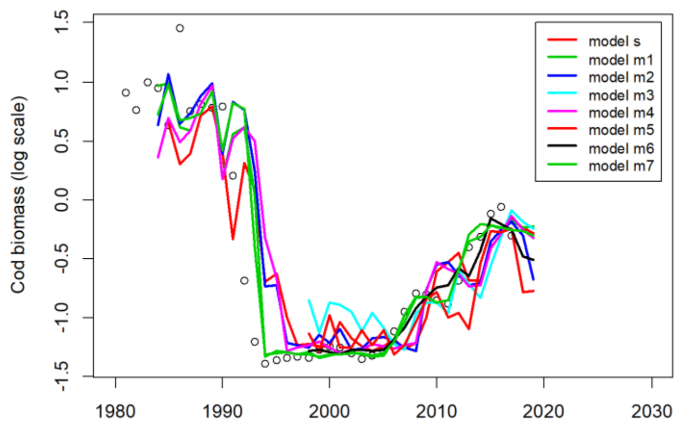


Figure 2.42. Northern cod EDM fits for the eight model configurations explored. Each model description is given in Table 2.6.

1 year forecast



2 year forecast



3 year forecast

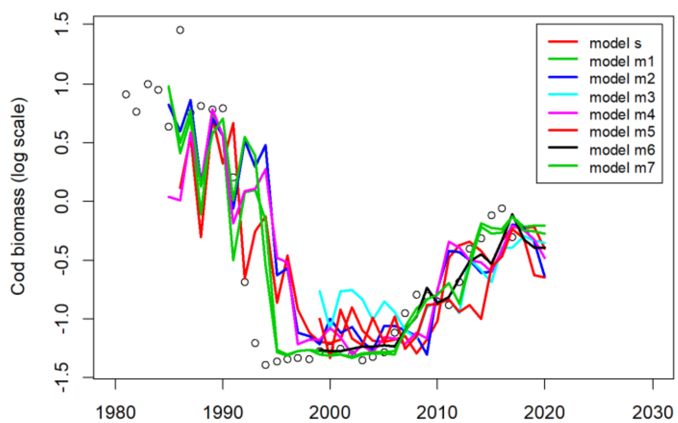


Figure 2.43. Assemble of Northern cod EDM 1-3 year forecasts. Each model description is given in Table 2.7.

Capcod: A simple bioenergetics-allometric model for Northern cod

Bioenergetic-allometric modelling (Yodzis and Innes, 1992) has been used to investigate the relative roles of fishing, food availability (i.e. capelin) and harp seal predation in the trajectory of Northern cod (Buren et al., 2014). This study concluded that both fishing and capelin availability were significant drivers of Northern cod dynamics, while predation by harp seals was not (Buren et al., 2014).

Based on these earlier results, a new bioenergetics-allometric model was developed. This new model, capcod, differed from the earlier implementation on several ways. These included: a) capcod uses discrete equations (as opposed to differential equations), b) the effect of harp seal predation was not included, c) the functional response was configured differently, assuming a fixed Type 3 form and including an other prey component, d) the model assumes process error only.

The basic capcod engine is described by the following equation:

$$B_{t+1}^{p} = B_t^o + B_t^o \left(-T + \boldsymbol{e} J_{max} \left(\frac{\boldsymbol{a}(C_{t+1} + \boldsymbol{cpr})^2}{J_{max} + \boldsymbol{a}(C_{t+1} + \boldsymbol{cpr})^2} \right) \right) - \boldsymbol{m}(B_t^o)^2 - H_{t+1}$$

where **Blue** indicates data, **Black** indicates fixed parameters, **Red** indicates estimated parameter, and with the predicted biomasses constrained to be positive. Beyond the parameters in the above equation, there is an additional estimated parameter $\boldsymbol{B_0}$ for the initial cod biomass. B_{t+1}^{p} in the equation indicates the predicted cod biomass.

The parameters in the capcod model are:

T: mass-specific respiration rate for the population; derived from allometric equations (Yodzis and Innes 1992) and assumed average individual cod body mass of 1 kg.

$\boldsymbol{J_{max}}$: maximum mass-specific ingestion rate for the population; derived from allometric equations (Yodzis and Innes 1992) and assumed average individual cod body mass of 1 kg.

e: fraction of the ingested energy/biomass available at the metabolizable level.

a: functional response coefficient ("attack rate")

cpr: "*capelin prey replacement*"; it represent a constant baseline of food available to cod in the absence of capelin.

m: density-dependent mortality rate.

$\boldsymbol{B_0}$: initial cod biomass.

The data used to fit this model were the RV 2J3KL Fall cod biomass index, the RV 3L Spring Acoustic biomass index for capelin, and estimated fisheries catches for 2J3KL from commercial and recreational fisheries. The model was fitted using a maximum likelihood approach, assuming a lognormal process error.

The capcod model provided a good fit to the data (Figure 2.44). The examination of residuals and exploration of retrospective patterns indicated that the estimated parameters were notably stable and robust, but with some indications that environmental signals (e.g. weak but still significant rank correlations between capcod residuals and CEI and cumulative CEI) may need to be included into this modelling framework in the future.

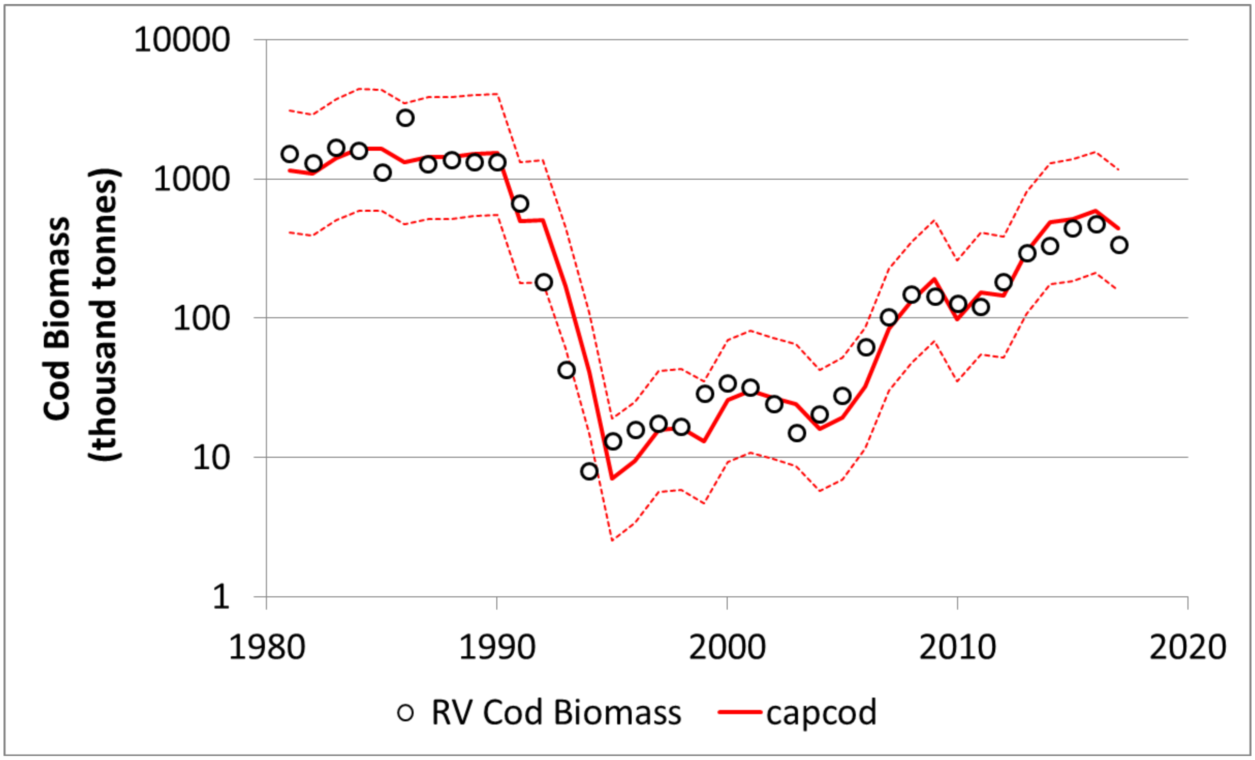


Figure 2.44. Capcod model fit.

The capcod model was used to generate decision tables conditional to capelin levels (Table 2.7). Given the process error structure of the model, projections were implemented by adding process error components randomly generated from the estimated process error distribution assuming fix levels of capelin and harvest (derived as multipliers of the observed catch in 2017).

Table 2.7. Capcod-based probabilities of RV Northern cod biomass in 2018, 2020, and 2022 to be larger than the one observed in 2017, conditional to specific catch and capelin levels.

$Pr(B_t > B_{2017})$		Catch Level											
		status quo (2017)			No Catch			50% status quo			200% status quo		
		2018	2020	2022	2018	2020	2022	2018	2020	2022	2018	2020	2022
Capelin level	SQ (2017)	0.48	0.42	0.37	0.49	0.47	0.47	0.49	0.45	0.41	0.46	0.32	0.25
	100	0.31	0.21	0.13	0.35	0.26	0.21	0.37	0.24	0.19	0.33	0.15	0.08
	300	0.64	0.71	0.75	0.67	0.73	0.77	0.64	0.73	0.77	0.62	0.65	0.67
	500	0.72	0.86	0.86	0.77	0.88	0.90	0.77	0.86	0.88	0.71	0.84	0.85
	1000	0.80	0.92	0.93	0.84	0.94	0.92	0.81	0.93	0.92	0.82	0.92	0.92

The results from this modelling exploration indicates that taking into account capelin levels in setting catch quotas can improve the odds for stock rebuilding. Short-term prospects for the stock are not good; under current capelin levels the stock is more likely to decline, or at best remain stable. Rebuilding to pre-collapse levels within the next 5 years appear highly unlikely.

Conclusions

Capelin and environmental/ecosystem conditions, together with fishing, are important drivers of the Northern cod stock. Considering these factors in defining harvest control rules for the stock can improve the odds for stock rebuilding.

In line with the overall ecosystem trends and conditions, stock rebuilding has stalled. Short-term (3-5yr) explorations suggest that the stock is likely to decline, or at best remain at its general current level.

Beyond Northern Cod as an example, these analyses indicate that: a) ecosystem signals can be effectively incorporated into stock-level models without the need of extremely complex models, b) these models can provide outputs which are complementary, and operationally equivalent to traditional stock-assessment models, and c) these models can be more sensitive/responsive than traditional stock-assessment models.

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2.6. Review of oceanographic and ecosystem status conditions in the NRA

ToR 2.6. *Review of oceanographic and ecosystem status conditions in the NRA*

i) Environmental Trends

The information concerning physical, chemical and biological oceanographic conditions in NAFO areas 2 and 3 were extracted from Colbourne et al. (2018a, b) and Bélanger et al. (2018). Figures were excluded for brevity.

A standardized composite climate index for the Northwest Atlantic (NAFO areas 2GHJ3KLNO) derived from 28 time series of meteorological, ice, water mass areas and ocean temperature and salinity conditions since 1950 reached a record low (cold) value in 1991. Since then it shows a warming trend that reached a peak in 2010 and thereafter decreased to mostly below normal conditions (cold/fresh) during the past 4 years. The 2015 value was the 7th lowest in 68 years of observations and the lowest value since 1993, while the 2017 value was the 15th lowest. A composite climate index derived from several metrics based on the EU summer survey (NAFO area 3M) show a cooling trend since 2012 that reached a record low in 2015 but has since moderated with 2016 and 2017 returning to near-normal conditions over most of the water column. In general, data from four surveys in NAFO division 3M on the Flemish Cap during the past several years captured a significant event highlighted by an unprecedented cold-fresh water mass over the Flemish Cap that peaked in 2015.

The shallow (0-50 m) nitrate inventories for 2017 were near the climatological mean throughout the NW Atlantic with the exception of large positive anomalies for the SE Grand Banks section (3LNO). This represents a general increase from 2016 especially on the Grand Banks. The deep (50-150 m) nitrate inventories were near or below climatology across the NW Atlantic and represents a decrease in deep nitrate inventories for most of NAFO Subarea compared to 2016. The chlorophyll (Chl) a inventories inferred from the seasonal oceanographic surveys, which provides an index of phytoplankton biomass throughout the water column, were generally near normal (anomalies within 1 SD) across the NW Atlantic. Anomalies were negative on the Flemish Cap and the Grand Banks (3LMNO). The composite anomaly time series showed an overall negative trend form the start of the series until a record-low observed in 2011, punctuated by a brief record-high in 2007. Since 2010, Chl a biomass remained near or below climatology. Trends in composite anomalies for both shallow and deep nitrate inventories generally tracked each other, as well as the trend in chlorophyll biomass, across Subareas 2-4.

The magnitude of the spring phytoplankton bloom (total phytoplankton production) was either near or below normal across all subregions except for one exceptionally large bloom observed at the Bravo sub-region in the Labrador Sea. Spring bloom peak production timing in 2017 were later for the Labrador Sea (1F2GH), the Newfoundland Shelf and the Grand Banks (including the Flemish Cap) (3KLMNOPs) and earlier on the Greenland Shelf (1F) and the Labrador Shelf (2HJ). Time series of composite standardized anomalies were constructed for each ocean colour index extending back to the start of SeaWiFS in 1998. Overall, the magnitude of the spring bloom showed small changes from 1998 until 2005 followed by an increasing trend from 2006 until a record-high in 2011 and a subsequent decline through 2017. Peak timing of the spring bloom shifted between periods of early-late blooms throughout the 20-year time series and have stayed above normal (late blooms) since 2013.

Pseudocalanus spp. is a dominant small epipelagic copepod and an important preferred prey for many early life stages of fish. In 2017, *Pseudocalanus* spp. abundances were near to above normal on the NL Shelf and the GB (2J3KLNO). The abundance of the large grazing copepod, *Calanus finmarchicus*, another dominant species and important prey item to higher trophic levels, remained below or near normal across the entire survey area in 2017. Observations from 2016 and 2017 showed similar spatial pattern of C. finmarchicus abundance throughout the Northwest Atlantic. Copepod abundances were generally within 1 SD from climatology, with larger positive and negative anomalies observed for the SE Grand Banks section (3LNO). This represents a general decline in copepod abundance from the previous year when abundances were either near or above normal across the entire survey area. The non-copepod taxa (mostly larval stages of benthic invertebrates, gelatinous and carnivorous zooplankton) remained above normal throughout most of the study area in 2017. Zooplankton biomass increased from the beginning of the time series to a record high in 2003, followed by a general declining trend until 2012-2014. This was followed by an abrupt decrease in biomass to a record low in 2015 after which biomass has remained well below the climatological average throughout the NW Atlantic.

Nitrate concentration in the upper portion of the water column is a good indicator of the ongoing phytoplankton production, whereas nitrate concentration in the deeper layer of the ocean is normally related to the primary production of the following year, when deep nitrate becomes available to primary producers after being transported near the surface by vertical mixing. Chl *a* anomalies were correlated to deep nitrate (p=0.02, r^2=0.31) on the Newfoundland Shelf. Spring bloom magnitude (p<0.01, r^2=0.45), amplitude (p=0.02, r^2=0.27) and peak timing (p<0.01, r^2=0.56) were correlated with the composite climate index and showed an association between warmer climatic conditions and early, important spring blooms, highlighting the potential cascading effects of climate on regional oceanic productivity. The negative correlation between spring bloom peak timing and magnitude observed both regionally (p=0.03, r^2=0.25) and zonally (p=0.03, r^2=0.25) likely reflected similar trade-offs across the NW Atlantic between phytoplankton production and zooplankton grazing, i.e., mismatch between early bloom and zooplankton propagation allows phytoplankton biomass to further develop. The composite climatic index for NAFO areas 2-3 was positively correlated (p=<0.01, r^2=0.38) with *C. finmarchicus* abundance and negatively correlated (p=<0.01, r^2=0.38) with *Pseudocalanus* spp. abundance indicating higher *C. finmarchicus* abundance during warmer period and higher Pseudocalanus abundance during colder climatic episodes. Moreover, high *Pseudocalanus* spp. abundances were associated with later spring blooms (positive correlation with peak timing) on the Newfoundland Shelf (p=0.01, r^2=0.39).

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ii) *Update on the status and trends of the fish community in the Newfoundland-Labrador and Flemish Cap Bioregions*

The fish communities of the Newfoundland-Labrador and Flemish Cap bioregions have undergone important changes in its structure over the last 30 years. WGESA examined and summarized these changes focusing the analyses at the functional ecosystem level represented by the Ecosystem Production Units (EPUs). Status and trends updates were provided for the following EPUs: the Newfoundland Shelf (2J3K), the Grand Bank (3LNO), southern Newfoundland (3Ps), and Flemish Cap. Trends were summarized by fish functional groups defined in terms of general fish size and feeding habits: small, medium, and large benthivores, piscivores, plank-piscivores, planktivores, and shellfish. This last functional group was discriminated into shellfish, which encompass only commercial species (*Pandalus* shrimp and snow crab), and shellfish2, which aggregated all other shellfish species.

These analyses were based on DFO Fall and Spring Research Vessel (RV) surveys for the NL EPUs, and the EU Summer RV survey for the Flemish Cap EPU. In the case of the Canadian surveys, shellfish were only reliably recorded since the switch to the Campelen trawl in the mid 1990s; the reporting here is focused on this period. The EU survey switch vessels but not gear in the early 2000s; conversion factors were applied to account for vessel differences (Pérez-Rodriguez and Koen-Alonso 2010).

All these ecosystems experienced collapses in their groundfish communities in the late 1980s and early 1990s undergoing important structural changes which included, among others, the increase in dominance of shellfish. This shellfish dominance was more significant in the northern EPUs (2J3K), and less so in Southern Newfoundland (3Ps), with the Grand Bank (3LNO) and Flemish Cap (3M) showing in between levels of dominance (Figure 2.45). In recent years most of these EPUs have seen some degree of rebuilding in their groundfish communities, with the biomass of shellfish declining across the EPUs during these groundfish buildups (Figure 2.45).

Most NL EPUs experienced significant declines in total biomass during the collapse of their fish communities. After the collapse, total biomass in the Newfoundland Shelf (2J3K) and the Grand Bank (3LNO) remained stable at a low level until the mid-late 2000s, when groundfishes started to show clear positive signals. These buildups in total biomass stalled in the early-mid 2010s, even though some specific stocks (e.g. Atlantic cod) may have continue growing, and have shown clear signal of decline since the mid 2010s, showing reductions of around 30-40% in total biomass from the mid-2010 levels.

Unlike most NL EPUs, the Flemish Cap (3M) did not show a decline in total biomass during the groundfish collapse, and actually experienced a temporary increase in total biomass during the mid-late 2000s associated to buildups of plankpiscivores (redfishes, Figure 2.45). While the current structure of the Flemish Cap community shows levels of dominance of piscivores (e.g. cod) similar to the pre-collapse period, plankpiscivores appear more dominant, while large benthivores remained at comparatively lower levels.

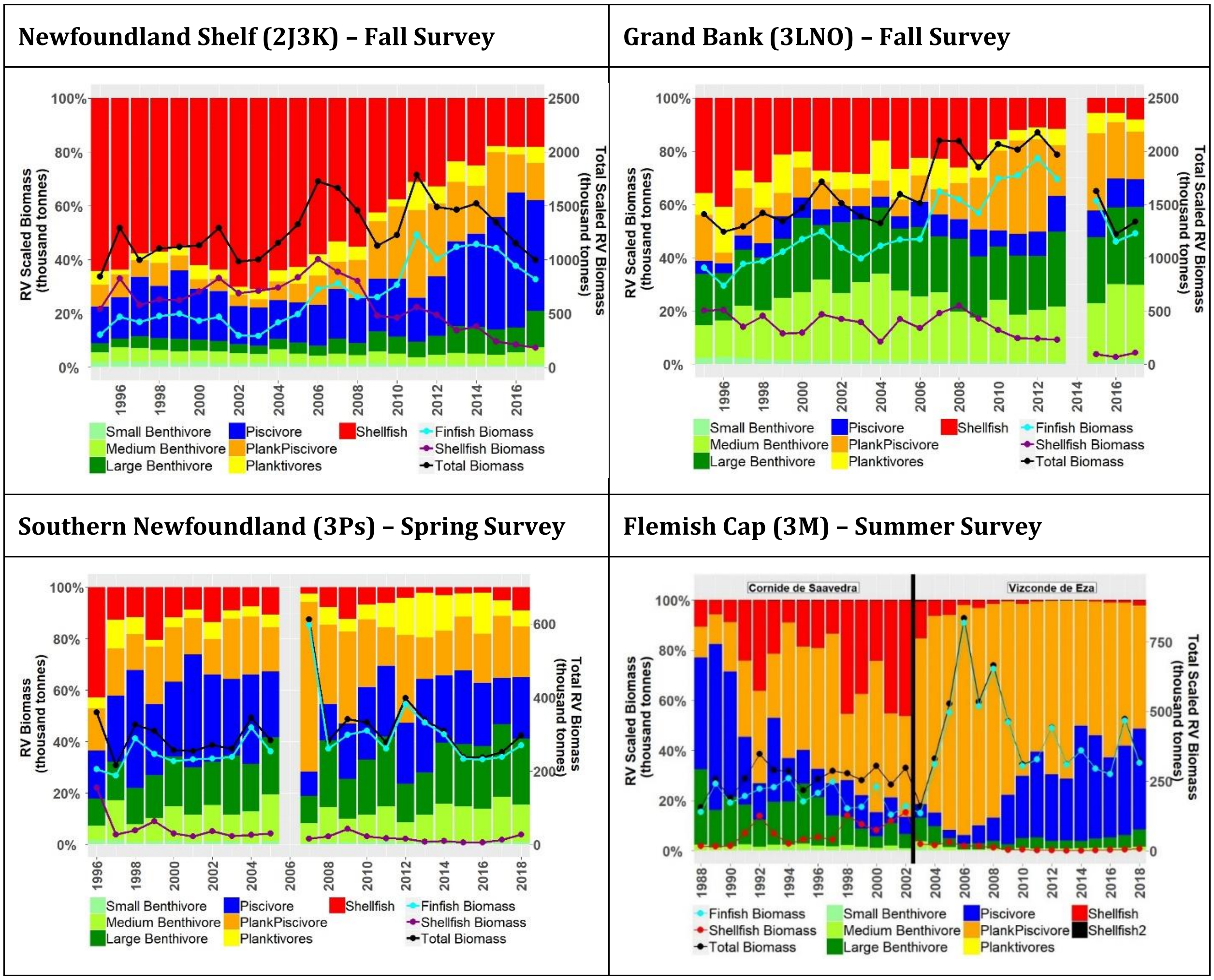

Figure 2.45. Synoptic comparison of the structure and trends in the fish communities during 1995-2017 among three NL Bioregion EPUs: the Newfoundland Shelf (2J3K), the Grand Bank (3LNO) and Southern Newfoundland (3Ps).

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iii) Application of neural networks to model changes in fish community biomass in relation to pressure indicators and comparison with a linear approach

Disentangling the impacts of multiple pressures on the fish community is challenged by the complex nature of marine ecosystems. The objective of this research was to address these challenges using an artificial neural network (NN), which is a non-linear, multivariate statistical model, to identify key pressures on the fish community of the Grand Bank over the past three decades. Nine fishing and environmental pressures were used to simultaneously model the biomass indices of six fish functional groups before and after the collapse of fish biomass in the region, and over the full data series. The analysis was repeated with time delays of different lengths (0–10 years) and types (moving average vs. lags) imposed on the pressures. The most influential pressures were identified, and the fit and predictive power evaluated for each period. Results were compared to a similar analysis applying a multivariate linear regression (MLR) approach. In contrast to the MLR approach, the delay type and length of the pressures had negligible impacts on the NN fit, which illustrates the powerful ability of even simple NN to extract patterns from data. However, MLR generally had better fit than the 1-hidden node NN models. Both approaches showed that the most influential pressures shifted after the collapse, and that a combination of current and past pressures, as well as both top-down and bottom-up forcing, have influenced the Grand Bank fish community over the past several decades. A preliminary assessment of NN predictive power showed that NN may have useful forecast ability, although the quality of the forecast differs among functional groups. Future work is required to improve the forecasts before they can be directly used to inform management. A similar comparison of the MLR and NN approaches for the Georges Bank fish community also demonstrated that MLR have better fit than NN. Additionally, MLR models were more straightforward to fit and interpret than the NN models. These advantages suggest MLR may prove more useful for this application, although NN may be able to provide complementary information through forecasts.

Based on: Dempsey, D.P., Pepin, P., Koen-Alonso, M., and Gentleman, W.C. (in review). Application of neural networks to model changes in fish community biomass in relation to pressure indicators and comparison with a linear approach. Submitted to the Canadian Journal of Fisheries and Aquatic Sciences in October 2018.

iv) Ecopath with Ecosim models of the Grand Banks, NL shelves bioregion

The work from this presentation is part of the CoArc project (A transatlantic innovation arena for sustainable development in the Arctic). This project is funded by the Ministry of Foreign Affairs and part of this project aims to compare ecosystem analyses between the Grand Banks and Barents Sea ecosystems. The goal is to develop management tools to explore sub-arctic and arctic marine ecosystems.

The ecosystem models built for this project use Ecopath with Ecosim and Ecospace (EwE; Pauly et al. 2000; Christensen and Walters 2004) which is a software used to develop mass balance models (Ecopath) of energy flows in the ecosystem that links functional groups through parameterization of biomass, production, consumption, mortality, diet and biomass accumulation. Ecosim can then be used to explore time dynamic scenarios, while Ecospace allows for the consideration of spatial management.

The location selection for the Canadian side of this project is the NAFO 2J3KLNO divisions. This decision was based on a previous EwE model developed by Bundy et al. (2000) where they produced a mass balance model for the NAFO 2J3KLNO region for the 1985 to 1987 period. This model was updated to reflect different functional groups and to make the EwE model structure comparable to the Barents Sea.

The EwE model time periods were selected from previous work by Mariano Koen-Alonso in the 2J3KLNO region that reflect periods of stability within the ecosystem of the area in terms of major fish functional groups based on diet (piscivorous fish, plank-pisc fish, large benthivorous fish, medium benthivorous fish, small benthivorous fish, planktiviorous fish and shellfish). The time periods selected for EwE models are 1985-1987 which represents the period prior to the groundfish collapse (in the early 1990s) and 2013-2015 which represents a period of high shellfish resources (e.g. shrimp and snowcrab) that make up the current fisheries in the region. These time periods align with important time periods for the Barents Sea where they experienced lower groundfish biomasses in the 1985 period and an increase in groundfish in 2013.

The current status of the Grand Banks 1985-1987 and 2013-2015 model are that they are built and in the process of being “tuned”. The tuning process for EwE models involves examining the model validity and sensitivity through a series of diagnostics and fitting routines. PREBAL diagnostics (Heymans et al. 2016) and time series fitting (Scott et al. 2015) are currently being explored to help tune the model.

There are a number of avenues to support the NAFO Roadmap with the Grand Banks EwE models. To address Tier 1 (Ecosystem-level) issues, general statistics of the model can be generated that calculate estimates of net primary productivity within the ecosystem and net system production. To address Tier 2 (multispecies-level) issues, EwE can estimate Maximum Sustainable Yield (MSY) of specific fleet groupings or of specific functional groups (or single species) using a Stationary system assessment or Full compensation assessment. The Stationary system assessment of MSY is obtained by running the Ecosim model to equilibrium for a range of fishing mortality values while holding the biomasses of the other groups constant. This gives an estimate of MSY that is analogous to single species assessments. The Full compensation assessment calculates MSY for a given group, but allows for ecosystem interactions (trophic interactions). These calculations for MSY can help to estimate the level of overall biomass that can be removed from the system or group while minimizing the risk of an ecosystem shift. Other methodologies presented in (Tam et al. 2017) outline other empirical methods to calculate ecosystem-level reference points for ecosystem-level harvest control rules that could also be used to corroborate the findings from EwE.

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2.7. Effects of multiple environmental drivers on sponges in the deep-sea

Sponges (phylum Porifera) play a pivotal role for the marine ecosystems they inhabit. Filtering and processing large volumes of seawater they are key-players in benthic-pelagic coupling and biochemical processing. Sponges are highly abundant throughout the deep North Atlantic Ocean with hotspots of biomass, abundance and diversity. Dense sponge aggregations often overlap or abut with intense fishing efforts utilizing bottom-trawl gear. In addition to direct effects such as removal or burying, bottom trawling has the potential to impact filter-feeding sponges indirectly by re-suspending bottom sediments. Concentrations up to 500mg/L can be reached in the vicinity of a deployed trawl net. Suspended particles with a size of 2µm have the potential to stay suspended for up to 87 days and get dispersed with oceanic currents over vast distances (Bradshaw et al., 2012; Mengual et al., 2016; Oberle et al., 2016). In this way bottom-trawling can impact sponge dominated ecosystems hundreds of kilometres from the fishing site.

Sediment plumes are also created by other anthropogenic activities. With increasing costs for resources deep-sea mining is becoming economically feasible. Companies are planning to mine seafloor massive sulphide (SMS) deposits that are a common geological feature throughout the North Atlantic Ocean. Mining activities potentially create plumes of crushed SMS deposits impacting benthic fauna hundreds of kilometres from the impact site. Studies have shown, that cold water adapted hexactenellid sponges respond to the presence of suspended particles by arresting their pumping and feeding activity (Tompkins-MacDonald and Leys, 2008). Deep-water sponges from the Barents Sea rapidly respond to suspended particles with decreased respiration rates (Tjensvoll et al., 2013). It is yet unknown how these responses affect overall animal performances and consequently the ecological functioning and productivity of sponge dominated habitats.

For the first time, the response of cold-water sponges to a combination of stressors was evaluated in the EU Horizon2020 project SponGES (Wurz et al., 2018). The species *Geodia barretti* was used as a model species to assess the impact of future ocean conditions (decreasing pH, increasing temperature) in combination with the exposure to natural bottom sediments and mining sediments. Sponges that were acclimatized to climate change conditions over a 10 month period were exposed to 50 mg/L of bottom and mining sediments. Preliminary results indicated a decrease in feeding efficiency of 50% in *Geodia barretti* after exposure to natural sediments.

The combined effects of climate change and exposure to sediment led to a 100% reduction in feeding under experimental conditions. In contrast to these findings, the hexactenellid sponge *Vazella pourtalesi* was able to maintain comparable respirations rates throughout a three-week exposure to elevated concentrations of natural sediment. Further sample processing will show if sediment exposure affected feeding efficiency in this species. Experiments with SMS deposit sediments show strong effects on sponge-associated fauna. As of November 2018 these experiments are still ongoing, but sampling of individuals over time show that sponges directly take up particles and tissues change in colour with accumulation of SMS deposits within the sponge tissue. The working group found this work highly relevant to both the assessment of SAI of bottom contact fishing gears on sponges and to potential other anthropogenic stressors such as oil and gas and deep-sea mining activities. An update on these experiments was requested for the next meeting by which time the data should be further analyzed.

Based on the information presented on the effects of sedimentation on sponges, the working group deliberated that information on the distance and magnitude of fishing adjacent to the VME closure areas could help inform the status of a VME and their SAI. Frequent and intense trawling directly adjacent to a closure may have a negative impact on the VME inside the closure due to the plumes caused by the trawl gear. It was noted that more information is required on residence times, distance travelled by the plume, and other features of this disturbance prior to incorporation of the concept into the ecosystem summary sheets and SAI work.

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THEME 3: PRACTICAL APPLICATION OF EAFM

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

3.1. Development and application of the EAF Roadmap

ToR 3.1. *Refine work to progress the EAFM roadmap by testing the reliability of the ecosystem production potential model and other related models, and to report on these results to the WG-EAFFM and WG-RBMS to further develop how it may apply to management decisions.* (COM Request #8)

Ecosystem Summary Potential Research Needs

Ecosystem production potential (EPP) is determined by total annual phytoplankton primary production (NAFO Roadmap Tier 1). The basic principle is that biomass is transferred through a series of consumers (trophic levels) from phytoplankton to fish and higher trophic levels. Consumption by one trophic level cannot exceed production of the trophic level(s) being consumed (i.e. prey-predator balance is in steady state – no net depletion). The overall concept is based on the principle that you should not extract more biomass than is produced annually: exceeding total annual production can cause the system to deteriorate or collapse.

Most of the energy consumed by an organism goes to maintenance (respiration, excretion, reproduction) and the net transfer efficiency between trophic levels is ~10-15%. Total Production consists of regenerated (metabolized) and new (fresh) production (i.e. mixed into the surface layer during fall and winter overturning from deep nutrient inventories). New production is the exploitable portion of the energy produced in ecosystems and corresponds to ~ 20% of the biomass of upper trophic levels (f-ratio; Rosenberg et al. 2014). The food web is not linear: there is more than one path for the flow of energy from phytoplankton to upper trophic levels. Energy from large phytoplankton is principally eaten by zooplankton while energy from small phytoplankton feeds the microbial loop, with some energy sinking to the bottom (benthos).

The EPP is calculated knowing there is variability (uncertainty) in [1] total annual phytoplankton production, [2] the proportion of primary production that stays in the water column or goes through the microbial loop or sinks to the bottom, and [3] the transfer efficiency from prey to predator between each component of the food web. Taking these sources of variability into consideration yields a range of potential values of Fishery Production Potential (FPP), the biomass that can be extracted from each exploitable component of the ecosystem. FPP provides guidelines for the Total Catch Indices (TCIs) [or Sustainable Ecosystem Catches – SEC] appropriate for each Ecosystem Production Unit (EPU), and which takes into account the capacity (or lack thereof) of the system to produce at maximum capacity. Ecosystems and communities that are depleted will not be able to allow the full transfer of energy from lower to upper trophic. TCI/SEC values represent the 25th percentile of the distribution of biomass for each functional guild estimated from model runs using the inherent variability in the flow of energy. The choice of the 25th percentile is slightly less conservative than the 20% example level used in the NAFO Precautionary Approach (NAFO, FC Doc. 04-018), which states that there should be a low risk of exceeding a limit reference point. The 50th percentile of the distribution of TCIs/SECs represent the critical point for which exploitation is highly likely to exceed ecosystem productivity.

SC and WG-EAFFM raised concerns about the underlying reliability of the model and the rationale and robustness of the 25th percentile of the distribution as a limit TCI/SEC. It was unclear to WGESA whether there were any specific structural concerns with the model and its parameterization. It appears there is a lack of understanding about whether model predictions are reasonable, and should be compared with other models of ecosystem processes (i.e., not necessarily foodweb models but approaches that quantify the major flow of biomass through the system). It was noted that earlier WGESA reports had contrasted the EPP model predictions with two types of data from the Newfoundland Shelf to determine their similarity. Along these lines, other sources of contrast were also discussed by WGESA, including contrasting recommendations using the f-ratio with values derived using F_{MSY} for individual stocks. Consolidating previous analyses, and adding to them using more extensive reviews of the predictions from similar types of models should improve the foundation on which FPP estimates of TCIs can rest. It is also important to clearly outline underlying assumptions of the FPP 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 annual primary production and nutrient inventories.

Other research needs include:

1. Assess whether the 25th percentile of the TCI/SEC estimates is the correct precautionary metric to define Ecosystem-level Limit Reference Point (i.e. fishery carrying capacity).
2. Make model dynamic to develop projections and assess 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. 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.

6. Estimate the risks associated with changes in environmental conditions and ecosystem status
7. Eventually perform Ecosystem-level MSE to evaluate alternate sustainable exploitation allocations among functional feeding groups once model is accepted by SC.

Further insight was gained from the US efforts to advocate for the application of FPP approaches in the provision of advice and in setting ecosystem level limitations on total catches (United States Northeast Fisheries Science Centre of the National Oceanic and Atmospheric Administration). In a peer review assessment by the Center for Independent Experts (CIE) of Ecosystem Based Fisheries Management procedures and models, Term of Reference 2 requested the panel to “evaluate methods for estimating ecosystem productivity on Georges Bank EPU and advise on the suitability of these methods for defining limits on ecosystem removals as part of management procedures” (https://www.nefsc.noaa.gov/program_review/). The review Panel found that the FPP approach was scientifically rigorous, straight forward and grounded in the scientific literature and can be well supported by information on lower trophic levels. The Panel also suggested that the approach is useful for tracking changes in primary production, understanding how this may impact production at lower trophic levels, and that it may serve as a warning sign of changes in the ecosystem. Overall, the Panel felt that the estimates of production were consistent with previous findings. However, although the approach provided an approximation of fishery production, the Panel was concerned that the uncertainty in model predictions be properly communicated, particularly in instances where the use of FPP estimates is being proposed as ecosystem-level reference points. Also, because the approach is based on a bottom-up approach, and does not consider information on upper trophic levels, it is important to note that fishery production consist of both exploited and non-targeted species in each functional feeding guild. The panel also expressed concern regarding the application of FPP estimates as limit reference points for fishery removals. Finally, FPP should be contrasted with other approaches to estimating fishery production (e.g. multispecies surplus production models, Ecopath) and represents a highly important step to determine which may be the best approach. The Panel also recommended the examination of how ceilings can be applied in real-world applications (e.g. what actions could be taken when an ecosystem or fishery functional group ceiling is breached). Overall, the findings and recommendations from the peer review of the US efforts around the use of FPP models in management procedures are consistent with the research needs identified in the discussions of the Working Group.

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3.2 Development of draft summary sheets at ecosystem level

ToR 3.2 *Consider the terminology used in ecosystem summary sheets in order to avoid potential confusion with standard terminology in fisheries management, review their structure to address concerns raised by WG-EAFFM, as well as considering their potential to inform management decisions and responses.* (WG-EAFFM recommendation 2019)

i) SC Commission Dialogue on Ecosystem Objectives

The Convention on Cooperation in the Northwest Atlantic Fisheries (hereafter the “Convention”) states that NAFO is committed 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. Furthermore, the 2018 NAFO Performance Review Panel recommends “the Commission, within a defined timeline, sets objectives and determines acceptable risks as outlined in the Ecosystem Approach to Fisheries Roadmap to ensure its implementation”. In response to request 8 in the 2019 Commission Requests to SC, to refine work under the Ecosystem Approach Roadmap, and engage in continue dialogue with COM-SC WG-EAFFM, a breakout group (BG) aimed to [1] Propose ecosystem-level conservation objectives (long-term and interim) appropriate for NAFO management actions, and [2] Identify options by which ecosystem considerations (e.g. as could be identified in ecosystem summary sheets) can be operationally integrated into decision-making.

The NAFO Roadmap identifies a three-tiered approach to implementation of sustainable exploitation levels within an Ecosystem Approach to Fishery Management. Tier 1 outlines the need to provide guidelines for limits to total fisheries exploitation (Total Catch Ceilings – TCCs) based on the overall amount of primary production of the ecosystems being fished. Failure to recognize and govern exploitation of renewable marine resources based on such principles is inconsistent with the Precautionary Approach and could to lead to removals that have a high risk of damaging the ecosystem's productive capacity. Furthermore, in areas recovering from earlier collapses, ecosystem over-exploitation could result in a return to low biomass levels and impede a future recovery. However, the report of WG-EAFFM raised concerns about the appropriateness of TCCs as a management measure which were perceived as a potential restrictive principle that could interfere with other factors important to the decision-making process. Part of the concerns raised WG-EAFFM dealt with some terminology used in the advice, to which WG-ESA responded that can be relabelled as Total Catch Indices (TCIs) [or Sustainable Ecosystem Catches (SECs)] , the effective applicability of the concept and the corresponding responses from the Commission requires more elaboration and dialogue. A fundamental element of this process lies in understanding that this kind of aggregated catch indices represent a *Strategic Approach to ecosystem-sustainability*. Aggregated catches have been explicitly presented as guidelines aimed at making the concept of ecosystem-level sustainability operational based on long-term and interim objectives. They do not constitute hard tactical limits, but provide a mechanism to synoptically assess the sustainability of the overall level of fisheries extraction, allowing for strategic planning. These estimates should be reviewed every 3-5 years for each Ecosystem Production Unit (EPU). Examples of potentially appropriate goals are:

- Ecosystem-level long-term objective: Achieve and maintain the biomass and relative proportions of functional guilds at historical levels for each Ecosystem Production Unit (EPU) in which NAFO manages or co-manages fishing activity. Historical levels are based on time intervals when ecosystem state (combined biomass from trawl surveys) was considered consistent with a fully functional/high productivity ecosystem state (as defined in Ecosystem Summary Sheets).
- Ecosystem-level interim milestone: As an interim milestone, ensure that the biomass of functional guilds is allowed to remain at or increase toward levels consistent with a fully functional/high productivity state (as defined in Ecosystem Summary Sheets) through adjustment of TACs and by-catch levels.

Conservation actions would depend on catches relative to TCIs/SECs and ecosystem state as described in the Ecosystem Summary Sheets (ESS).

The discussion focussed initially on how to define some of the terms what appeared in the mock goals. "Historical" levels/conditions require definition and it was unclear whether these represent a fully functional/high productivity state for each EPU. Concerns were also raised about how NAFO would, or could, deal with non-managed elements of the ecosystem because goals would have to deal with fishery management issues in the context of a changing environment which could, in turn, influence the long-term or interim objectives because of a shifting baseline. Furthermore, considerations would have to be developed to accommodate the need for multiyear planning by industry. Both these constraints require opportunities and appropriate timeframes for adjustment and flexibility of management measures. Discussions then attempted to formulate Ecosystem Objectives based on the General Principles of the Convention (Article III). All outcomes lacked the specificity that can be considered appropriate in any future accountability audit of the effectiveness of NAFO management actions in achieving Ecosystem Objectives.

The group then considered a case of reverse-engineering WG-ESA's work to ultimately create objectives linked with the Ecosystem's Fishery Production Potential (TCIs/SECs) and how they may be changing over time. The work would involve a review of the potential versus realized productivity of stocks, and unregulated elements, that could potentially serve to define an ecosystem-level goal in terms of the realized goal we want to achieve (analysis of state and trends from ESS and relation to TCIs/SECs). The exercise consists of providing aggregate advice based on SC's single species stock assessments, contrast with expectations from TCI/SEC estimates, and compare advice with the actions taken by the Commission and the resulting changes in ecosystem state. WG-ESA would review stock assessment advice and Commission actions during 2005-2015 to remove this analysis from the objectives for current management decisions. The work would be carried out on the 3LNO EPU where the more comprehensive information on ecosystem state is available. The analysis could consider analyses of patterns in recruitment, recruit-per-spawner, and biomass growth (with and without the effect of the harvest). Doing the analyses retrospectively in an aggregated manner may also identify questions that need to be addressed in terms of potential multispecies interactions. Multispecies surveys can serve as a source of information for the elements for which assessments are unavailable to insure non-managed elements are included in the discussions. This retrospective analysis aims to provide the basis for dialogue with WG-EAFFM through the illustration of the underlying principles on which the elements of Tier-1 are based, and its link with single species stock assessments (Tier-3 of the Roadmap).

WG-EAFFM also raised concerns about the term overfishing in the ESS, because they would trigger immediate management actions that could interfere with other factors important to the decision-making process. Details were debated under the review of the Ecosystem Summary Sheets. WG-EAFFM concerns about the reliability and robustness of FPP estimates of total catch ceilings are address under ToR 3.2. WG-ESA also noted that the ecosystem-level limits to aggregate catches have been found effective as a fisheries management tool in other jurisdictions (Link, 2017).

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ii) Ecosystem Summary Sheets (ESSs): Context, terminology updates, and proposed revisions

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 piece 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 the chapter III of its convention. These principles are:

(a) promote the optimum utilization and long-term sustainability of fishery resources;

(b) adopt measures based on the best scientific advice available to ensure that fishery resources are maintained at or restored to levels capable of producing maximum sustainable yield;

(c) apply the precautionary approach in accordance with Article 6 of the 1995 Agreement;

(d) take due account of the impact of fishing activities on other species and marine ecosystems and in doing so, adopt measures to minimize harmful impact on living resources and marine ecosystems;

(e) take due account of the need to preserve marine biological diversity;

(f) prevent or eliminate overfishing and excess fishing capacity, and ensure that levels of fishing effort do not exceed those commensurate with the sustainable use of the fishery resources;

(g) ensure that complete and accurate data concerning fishing activities within the Convention Area are collected and shared among them in a timely manner;

(h) ensure effective compliance with management measures and that sanctions for any infringements are adequate in severity; and

(i) take due account of the need to minimize pollution and waste originating from fishing vessels as well as minimize discards, catch by lost or abandoned gear, catch of species not subject to a directed fishery and impacts on associated or dependent species, in particular endangered species.

The initial draft example for an ESS was developed by WGESA during its 10th meeting (November 2017) and through intersessional work between November 2017 and June 2018. This draft was further developed by NAFO Scientific Council (SC) at its June 2018 meeting, and formally presented by SC to the joint Commission (COM)-SC Working Group on the Ecosystem Approach Framework to Fisheries Management (COM-SC WGEAFFM) in August 2018, and COM during the NAFO Annual Meeting in September 2018. During these presentations, and the discussions that ensued, managers raised a number of concerns about the structure, content, and terminology used in the ESS draft example (COM-SC WGEAFFM Report 2018).

Some of these concerns began to be addressed at an intersessional WGEAFFM meeting (via WebEx) in October 2018, and the results of all these discussions tabled at WGESA for consideration at the meeting reported here. Based on the feedback received, WGESA reviewed and updated the context and terminology used in the draft ESS example.

The key concerns and issues addressed by WGESA were:

a) Use of terminology that can be confused with existing concepts in a single-species context and that can have prescribed legal ramifications (e.g. overfishing).
b) The potentially restrictive interpretation of the term “Total Catch Ceiling” in the context of implementing the Tier 1 of the Roadmap.
c) Further development of content and context for items that were not fully fleshed-out in the original draft (e.g. indicators of status and management measures for Vulnerable Marine Ecosystems –VMEs-, biodiversity, non-target species, incidental catches).
d) Expansion of the topics included as “other considerations” among management measures, to allow for a more comprehensive representation of management actions taken by organizations other than NAFO within the focal ecosystem of the ESS.

These elements were addressed as follows:

a) Potentially confusing terminology
WGESA acknowledge that terms like “overfishing” can have a specific technical meaning in a single-species stock assessment context, as well as prescribed legal and management procedures being triggered by its use. This term was employed in the original ESS draft in the context of ecosystem-level exploitation, indicating that catches have exceeded the level estimated as sustainable from an ecosystem productivity point of view. While this usage of overfishing is consistent with some of the concepts being discussed to define ecosystem overfishing, WGESA also acknowledged that there is no formal definition of ecosystem overfishing broadly adopted by the scientific community, nor a legal/management framework that can formally trigger actions if a case of ecosystem overfishing is identified. Therefore, and until a formalized framework including both, scientific definitions for

ecosystem overfishing and legal/management procedures to trigger specific actions is developed, WGESA will refer to cases like the one detailed here as catches "exceeding" or "above" indicator values representing the estimated current level of fisheries production that can be extracted sustainably.

b) Renaming the Total Catch Ceiling reference value

The term "Total Catch Ceiling" was coined to refer to the estimated level of catches considered to be sustainable from an ecosystem productivity perspective. The estimation of this level is based on the output from an Ecosystem Production Potential Model (Coll et al., 2008; Murawski, 2000) (REFS), which generates estimates of Fisheries Production Potential (FPP), plus the incorporation of elements from the NAFO Precautionary Approach (i.e. there has to be a low probability of exceeding a limit reference point, NAFO FC Doc. 04/18), and a re-scaling procedure (i.e. penalty factor) to adjust the estimated FPP (which assumes a fully functional and productive ecosystem) to the current productivity level of the ecosystem. While estimates for these reference values have always been provided as guidelines, not as hard limits, WGESA acknowledges that some contracting parties and stakeholders may interpret the current terminology as a strict boundary. This should not be case, at least not until these concepts are fully tested and their reliability verified, and associated appropriate management procedures are formally adopted by NAFO.

In further developing and testing the reference values for sustainable for total catches at the ecosystem level, WGESA will provide some additional interpretation for the concepts and how they should be seen in the context of science advice and decision making, with the goal of preventing any potential misinterpretation of the intent of the advice. As part of this process, and in response to management concerns, the concept formerly known as "Total Catch Ceilings" will be renamed as "Sustainable Ecosystem Catch" (SEC).

c) Additional details and content for specific items

The initial ESS draft example left several items to be completed at a later date. These elements included a revision of indicators for "State of biological diversity" under "Ecological features", as well as a revision of items in the "Minimize harmful impacts of fishing on ecosystems" and "Assess significance of incidental mortality in fishing operations" sections, under "Management measures".

The topic "State of biological diversity" summarizes ecological information under two line items the "Status of VMEs", and the "Status of non-target species and protected species (or in need of protection)". Regarding the status of VMEs, there was a need to identify metrics that would allow tracking the status and trends of VME habitats. WGESA considered that the area of the VME habitats (as estimated through KDE polygons), as well as the biomass value emerging from KDE analyses that identifies the boundary for a high concentration of a VME-defining species were suitable indicators to monitor the state of VME habitats. These metrics can also track trends, but given the slow population dynamics of VME species, these trends would only be expected to become evident after many cycles of ESSs updates.

VMEs constitute biogenic habitats, and hence, they also have characteristic communities in addition to the VME-defining species that creates them. Because only a portion of the VMEs is under protection, the status of these habitats can also be monitored by tracking the frequency and magnitude of VME and benthic taxa observations outside any existing closures. Regular bottom trawl surveys within defined VME habitat, but outside fisheries closures, can continue providing the type of data required for these calculations. While the proposed indicators can be estimated with current data, WGESA expects that ongoing work towards assessing Significant Adverse Impacts (SAIs) on VMEs, as well as any future non-destructive surveys for VMEs that may be put in place, will provide additional sources of information that can be integrated to the reporting on the status of VMEs in the ESSs.

Regarding the line item "Status of non-target species and protected species (or in need of protection)", WGESA made significant revisions. This item was originally labelled "Species depletion", but based on the feedback received, it became clear that the original focus was too narrow. Since this topic is contributing to the overall reporting on the topic "status of biological diversity", WGESA renamed the item to allow for a broader consideration of non-targeted species and communities. While the focus of this item continues to be the detection of potential negative trends in non-target taxa, especially those under protection or in need of protection, WGESA also includes under this topic, the monitoring of benthic communities, marine mammals, and seabirds, which will require involvement of scientist with additional expertise to that currently available in WGESA membership. The basic proposed metric was kept as the proportion of taxa below 20% of maximum historical biomass/abundance based on survey indices in following with the NAFO Precautionary Approach B_{lim} proxy (NAFO SCS Doc. 97/12), but WGESA proposes to also include monitoring the trends of key benthic species/communities from bottom trawl surveys (e.g. species density of benthic taxa as described in ToR 2.3 in this report). The metrics and data sources for monitoring marine mammals and sea birds have yet to be defined by consulting with the proper experts.

Under "Management Measures", the line item on "Protection of VMEs" within the "Minimize harmful impacts of fishing on ecosystems" topic was revised. This revision included the identification of indicators that can be used to monitor the level of protection provided to VME habitats. WGESA identified two key indicators for this task, 1) the fraction of VME biomass/area under protection, and 2) the level of fishing effort exerted within unprotected VME habitats. The data for calculating these indicators is readily available, but ongoing research on the effect of smothering by sediment plumes, like the ones generated by trawling, could be used to derived additional indicators in the future, as results become available.

The topic "Assess significance of incidental mortality in fishing operations" was substantially revised. the line item "Discard level across fisheries", originally named "By-catch level across fisheries", was refocused to make clear that the goal is to track discards, allow the integration of these data across fisheries, and assess the potential impacts of those discards. WGESA identified four candidate indicators to inform and monitor this line item: 1) the tonnage of discards in each and across fisheries, 2) the fraction of discard by fishery and across fisheries, 3) the fraction of discard with respect to stock/community size and/or productivity, and 4) the amount/fraction of discard related to undersize fish. With respect to this last indicator, undersize fish initially refers to the sizes indicated in the NAFO Enforcement and Conservation Measures (NCEM), but WGESA suggests that an analysis of these minimum sizes in relation to biological minimum sizes (e.g. 50% maturity) needs to be explored. WGESA also identified the NAFO Secretariat as a natural candidate to compile these indicators (or some of their necessary components) using the suite of sources of data compiled and/or reported to the Secretariat. These sources include tow-by-tow reporting, Observers Reports, STATLAN21A, and Port Inspection Reports, among others.

Complementing this discard monitoring, the second line item within the "Assess significance of incidental mortality in fishing operations" topic is "Incidental catch of depleted/protected/unregulated species". This line item was previously named "By-catch of depleted species", and its intent is to specifically track incidental catches of species of with conservation concerns. WGESA recognizes that while the same sources of data utilized for discards can be used to address this line item, issues may arise in relation to the level of aggregation reported in these databases. As a first step, WGESA proposes the following as candidate indicators: 1) records of frequency and amount of catches, and 2) the ratio between these catches and estimates of stock size when available, but leaves up to the Secretariat to explore options depending on the level and/or quality of the data available. At minimum, a list of depleted, protected, and/or unregulated species incidentally caught needs to be compiled.

d) Incorporation of topics under “Management Measures/Other Consideration”

Originally this section under management measures only contained references to activities other than fisheries (e.g. oil and gas, pollution). After considering that the ESSs are reporting at the ecosystem level, and in some instances, fisheries within these ecosystems are managed by organizations other than NAFO (e.g. coastal states, other RFMOs like ICCAT), this section was expanded to include fisheries not managed by NAFO. Under this topic two line items have been included to allow a general reporting on these fisheries, and the protection provided to VMEs by other jurisdictions within the same ecosystem unit. WGESA did not advance on the level of reporting and/or indicators required for these line items; these should be develop in collaboration with these other organizations and/or coastal states. However, WGESA suggests that the level or reporting being done in the ESS for NAFO managed fisheries could be a reasonable template for others to consider.

The update Ecosystem Summary Sheet (ESS) example for the Grand Bank (3LNO) Ecosystem Production Unit (EPU) is presented below. While the data and basic analyses has not been updated, the terminology and items within the ESS have been. All text in italics indicate wording, sections and places were the text have been updated. This ESS continues to be working example of how an actual ESS is expected to look like, and the level of information and terminology is expected to contain.

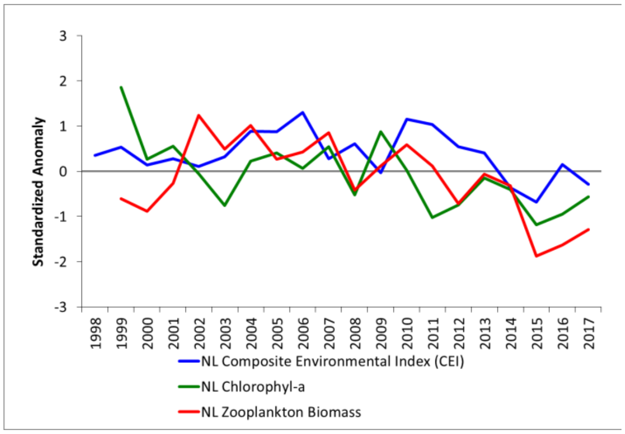
ECOSYSTEM SUMMARY SHEET: GRAND BANK (3LNO) ECOSYSTEM PRODUCTION UNIT (EPU)

The Grand Bank (3LNO) EPU is currently experiencing low productivity conditions and biomass declines across multiple trophic levels and stocks. Although reduced productivity appears to be driven by bottom-up processes, current aggregate catches for piscivore species have been increasing and exceeding the guideline level for ecosystem sustainability. Reductions in piscivore catch levels are recommended.

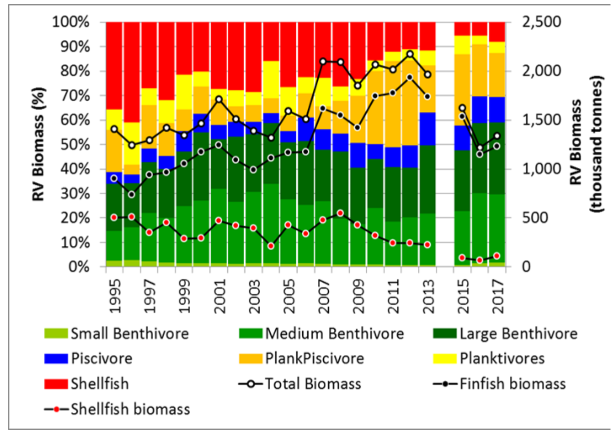
SUMMARY TABLES AND FIGURES

ECOLOGICAL FEATURES					
Convention Principle					**Comment**
a		**Ecosystem status and trends (long-term sustainability)**	**S**	**T**	**Summary of multiple trends/state**
	1	Physical Environment			No clear 5-yr trend but 10-yr declining trend
	2	Primary Productivity			Reduced nutrients, phytoplankton standing stocks and productivity.
	3	Secondary Productivity			Reduced total zooplankton biomass, with increased abundance of small-sized taxa.
	4	Fish productivity			Declines in total, finfish, and shellfish biomass since 2013-14. Overall biomass below pre-collapse levels.
	5	Community composition			Shellfish has declined in dominance, but piscivores have yet to regain their pre-collapse dominance.
b		**Ecosystem productivity level and functioning**			**Summary of multiple trends/state**
	1	Current Fisheries Production Potential			Total biomass further declined from 50% to ~30% of the estimated pre-collapse level.
	2	Status of key forage components			Reduced levels of capelin, sandlance, arctic cod, and shrimp.
	3	Signals of food web disruption			Diet variable, declining trend in stomach content weights.
e		**State of biological diversity**			**Summary of multiple indicators**
	1	Status of VMEs			*VME state and change of state in recent period will be initially monitored using 1) the area of the VME habitat (i.e. KDE polygon), 2) the level of biomass that indicates a high concentration of VME-defining taxa, and 3) 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-target species and protected species (or in need of protection)*			*The status of non-target species will be monitored through 1) the proportion of taxa below 20% of maximum historical biomass/abundance based on survey indices for fish species, 2) trends in key benthic species/communities for regular surveys, 3) trends in marine mammals, and 4) trends in sea birds.*

PHYISICAL ENVIRONMENT AND LOWER TROPHIC LEVEL TRENDS



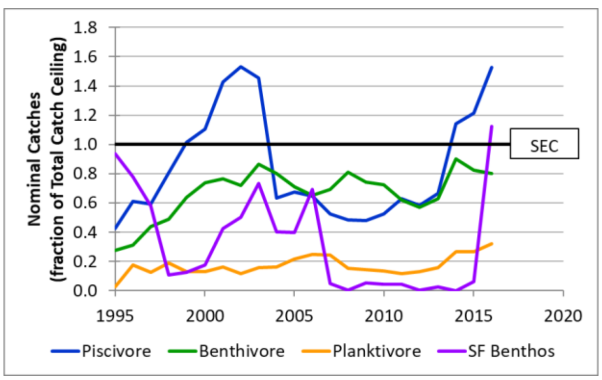
FISH COMMUNITY COMPOSITION AND TREND



MANAGEMENT MEASURES					
Convention Principle					**Comment**
c/d	**Apply Precautionary *Principle***		**S**	**T**	**Summary of metrics on level of management action**
	1	*Sustainable Ecosystem Catch (SEC) and catches*			*Piscivores catches have been exceeding their SEC; suspension feeding benthos exceed it in 2016.*
	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 are in conditions of supporting fisheries; some stocks have declining trends.
d/e	**Minimize harmful impacts of fishing on ecosystems**				**Summary of metrics on level of management action**
	1	Level of protection of VMEs			*Some VMEs without protection. Protection has improved. Fishing does not intrude in closed areas. The level of risk to VMEs by fisheries outside closed areas needs to de assessed. Level of protection to VMEs will be monitored using 1) the fraction of VME biomass/area under protection, and 2) the level of fishing effort exerted within unprotected VME habitats.*
	2	Level of protection of exploited species			*Sustainable Ecosystem Catch guidelines have been developed. 70% of managed stocks have LRPs or HCRs, but some stocks only have survey-based LRPs. No multispecies assessment in place.*
d/f	**Assess significance of incidental mortality in fishing operations**				**Summary of metrics on level of management action**
	1	*Discard level across fisheries*			*Integrative indicators need to be compiled. These indicators include: 1) the tonnage of discards in each and across fisheries, 2) the fraction of discard by fishery and across fisheries, 3) the fraction of discard with respect to stock/community size and/or productivity, and 4) the amount/fraction of discard related to undersize fish.*
	2	*Incidental catch of depleted/protected/unregulated species*			*Integrative indicators need to be compiled. These indicators include: 1) records of frequency and amount of catches, and 2) the ratio between these catches and*

					estimates of stock size when available At minimum, a list of these species incidentally caught needs to be compiled.
OTHER CONSIDERATIONS (outside mandate of NAFO Convention)					
Human Activities other than fisheries					**Comment**
	1	Oil and gas activities			There are four offshore production fields on the Grand Bank and intense exploration activities along the eastern shelf break and Flemish Pass.
	2	Pollution			…
Fisheries not managed by NAFO					***Comment***
		Non-NAFO fisheries (coastal states and other RFMOs)			*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)			*Description, indicators and/or reporting level to be developed in collaboration with coastal states and/or other RFMOs*

ECOSYSTEM SUSTAINABILITY OF AGGREGATE CATCHES



BY-CATCH IMPACTS

To be defined

SUMMARY NARRATIVE

ECOLOGICAL FEATURES

Ecosystem Status and Trends

The last 5 years there have been characterized by reduced levels of nutrients, phytoplankton standing stock and primary production, and total zooplankton biomass. Reduction in zooplankton biomass has been accompanied with changes in the composition of the zooplankton community, with small-sized taxa have significantly increased in abundance while the larger, lipid-rich taxa have declined. Since 2013, total fish biomass has lost the gains built-up since the mid-1990s. Fishes have increased their dominance in the community to 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 level. Improved conditions between the mid 2000s and early 2010s allowed built-up of total biomass up to ~50% the pre-collapse level. This productivity was associated to good environmental conditions for groundfishes, and modest increases in forage species (capelin). Since 2013, forage species have declined, and a reduction in total biomass to ~30% of pre-collapse levels has occurred. 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 fish species considered depleted. 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. Work on metrics to assess VME state and the evaluation of depleted species is ongoing, but results are not yet available.

MANAGEMENT MEASURES

Apply Precautionary Approach

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 *Sustainable Ecosystem Catch (SEC)* in the past, are currently increasing, and since 2014 are once again above their *SEC*, indicating overfishing at the ecosystem level. Catches for suspension feeding benthos were also above their *SEC* in 2016. Only 60% of the NAFO managed stocks in the Grand Bank are in conditions of supporting fishing, and some of these stocks are showing declining trends. Impacts of species interactions and/or environmental drivers are not currently being considered in 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. Other non-coral/sponge VMEs have been identified in the tail of the Grand Bank, but remain unprotected due to difficulties in delineation at appropriate spatial scales.

At the ecosystem level, *Sustainable Ecosystem Catches* 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 the present time there are no multispecies assessments to inform on trade-offs among fisheries, and no stock-assessment explicitly considers species interactions and/or environmental factors as drivers, but there is ongoing work on these issues.

Assess significance of incidental mortality in fishing operations

By-catch limits and move-on measures are in place for some fisheries, but there is no integrative assessment of by-catch in fisheries operations and their potential impact at the ecosystem scale. There are n dedicated measures to quantify and manage by-catch of listed species. Additional work on these areas is required.

COLOR KEY FOR ECOSYSTEM SUMMARY TABLES

	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	The trend over the last 5 years indicates consistent improving of the state/condition	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	The trend over the last 5 years indicates consistent deterioration of the state/condition	Bad. Current management measures appear insufficient to deliver the expected results or no management measure is in place.	Bad. 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

3.3 Impact of removal of survey stations from VME closed areas on stock assessment metrics.

ToR 3.3 *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.* (COM Request #5).

Work to complete this task was planned by WG-ESA in 2017 with the intention of finalising the analysis ahead of the SC meeting in June 2018. However, work commitments of 'key' staff prevented the required assessment of the length and age-disaggregated indices from the EU Flemish Cap surveys remains to be completed in 2018.

3.4 Options for the non-destructive regular monitoring of VMEs

Tor 3.4 *Consider possible options for the non-destructive regular monitoring within closed areas, develop preliminary plans for evaluation of new approaches and potential survey design, bearing in mind the cost implications and the utility of data collected for the provision of advice.*

It was noted that plans have been developed on how to monitor Arctic marine ecosystems by six Arctic coastal nations and a great number of national, regional, Indigenous and academic organizations and agencies across the region. Specifically, the plan (https://www.caff.is/marine/marine-monitoring-publications/3-arctic-marine-biodiversity-monitoring-plan) identifies agreement on; **i.** a suite of common biological parameters and indicators to monitor and report on change across Arctic marine ecosystems, **ii.** key abiotic parameters, relevant to marine biodiversity, which should be monitored; **iii.** optimal sampling schemes (e.g., where, when and how the suite of parameters should be measured and by whom); and, **iv.** Arctic Marine Assessment Areas, by which monitoring results will be organized and reported.

In the context of NAFO, recognising the different steps outlined above, in addition to several NAFO specific issues (e.g. the likely removal of survey trawls from VME closed areas), provides a basis for developing a possible fixed station VME monitoring plan for NAFO:

1. Identifying important VME processes linked to critical ecosystem functions which can be quantified, e.g, increased habitat structural complexity, bioturbation, filtration, which facilitates increased benthic secondary production. These must be explicitly related to the criteria which underpin the assessment of SAI.
2. Identifying 'key' indicators which are both sensitive and reliable measures of VME structure and function related to the processes and functions defined above, e.g. VME species density, population and community size structure.
3. Designing an optimal sampling scheme in time and space to acquire data to determine the status of the 'key' indicators. Such a plan is likely to be conducted periodically (e.g. every 5 years) and at relatively few 'key' sites within VMEs.
4. Enable the integration of existing trawl survey data to ensure long-term trends in the status of VME biomass can be maintained both inside and outside closed areas.

The work undertaken during the NEREIDA project provided good baseline data for *in situ* observations in 6 of the 14 areas closed to protect VME in the fishing footprint, in the Orphan Knoll and to a lesser extent the Fogo seamount closures. Box core samples, multibeam bathymetry and surficial geological data further position adoption of the Circumpolar Marine Biodiversity Monitoring Plan noted above. The working group will continue to work on developing a monitoring plan for evaluating the effectiveness of the area closures, with an emphasis on the area within the fishing footprint, once the work on evaluating SAI is advanced.

3.5 Assessment of bottom fisheries SAI: establishing a clear ranking process.

ToR 3.5. *Review progress against establishing clearer objective ranking processes and options for objective weighting criteria for the overall assessment of SAI and risk of SAI.* (COM Request # 9).

In 2016, during the last assessment of bottom fishing activities, the criteria applied to assess significant adverse impacts were essentially equally weighted, which implies that each of the VMEs are of equal functional importance, e.g. a 10% impact of the Sea Pen VME was evaluated the same as a 10% impact of Sponge VME. To overcome this limitation, it is necessary to better understand the functional characteristics of each of the VME types. Studies have now been initiated to fill some of the gaps in our understanding of the functional properties of VME, namely an analysis of VME biological traits (described under ToR 2.3), modelling of bottom fishing impacts on VME functions (described under ToR 2.1) and studies reviewing and assessing the recovery potential of VMEs (also described under ToR 2.1). The work described under ToRs 2.3 and 2.1 will be progressed over the next two meetings of WG-ESA supported by research grants awarded by the EU and Canadian Government to be completed ahead of the next reassessment of bottom fisheries expected in 2021. Members for the EU Horizon2020 SponGES project made presentations on the functions of sponges in particular and work being done to evaluate the impact of removals on those functions. Updates on their work will be provided to the next meeting. The results will then be used to weight the SAI criteria in line with the observed quantified differences in the functional characteristics of the VMEs.

3.6. Potential impact of activities other than fishing in the Convention Area

ToR 3.6. *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.* **(**COM Request #13)**.**

ATLAS Project: Mapping pressures on the Flemish Cap and Flemish Pass

ATLAS is a multidisciplinary international project funded by the EU Horizon 2020 program. ATLAS is testing a generic Marine Spatial Planning (MSP) framework 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 ATLAS Case Studies represent the range of biogeographic, regulatory and jurisdictional situations encountered across the Atlantic from national deep-waters to Areas Beyond National Jurisdictions. IEO-Vigo is the coordinator of Case Study No11 which includes Flemish Cap and Flemish Pass (NAFO Regulatory Area).

The main focus of ATLAS regarding MSP is to assess whether the existing science base is sufficient to support theoretical regional/local SMAs. Existing available information for each Case Study SMA will be compiled, and knowledge gaps identified and addressed, so that decision support tools can be employed to test available management/policy options when faced with the hypothetical need of accommodating a new blue economy/blue growth activity.

The MESMA framework (Stelzenmüller et al., 2013) comprises seven key steps. *Step 1* requires the definition of spatial and temporal boundaries to specify the context, the boundaries and the high-level goals and operational objectives. *Step 2* comprises the collation and mapping of existing information including all ecosystem components (natural and socio-economic) relevant to the set of operational objectives. The socio-economic components (human activities) must be mapped and the (cumulative) impacts of these on natural ecosystem components assessed. *Step 3* involves the definition of indicators and related thresholds. *Step 4* comprises state assessments of the indicators and/or a risk analysis of management scenarios. *Step 5* evaluates the findings against the operational objectives. *Step 6* assesses the effectiveness of the proposed management measures. Finally, *Step 7* collates the outputs from the previous steps leading to recommendations to support adaptive management in the SMA.

The implementation of the MESMA framework in the Flemish Cap and Flemish Pass area is ongoing: *Step 1* was completed and *Step 2* is in progress (https://zenodo.org/record/1147702#.W_TPRzFRe00). It is expected that the following Steps will be developed over the coming months.

The Flemish Cap-Flemish Pass area includes several types of valuable habitats and ecosystems (e.g. sea pen fields and sponge grounds) and several types of potential blue economy/blue growth activities. Currently the main human activities in the region are deep-sea fisheries, scientific research, vulnerable marine ecosystems (VME) conservation, shipping, undersea cables, and hydrocarbon exploration. There are plans for increased hydrocarbon exploration and exploitation in the area, which could potentially come into conflict with existing activities and uses of the marine space (e.g. high seas fisheries) and natural components of the ecosystem (e.g. VMEs and fisheries resources). Bioprospecting is another potential future activity to consider. The SMA selected for the Flemish Cap-Flemish Pass Case Study corresponds to the area identified as an ecologically or biologically significant marine area (EBSA) in UNEP (2014): *EBSA Area No. 4 Slopes of the Flemish Cap and Grand Banks*. This area contains most VME habitats currently identified in the NAFO Regulatory Area, many of which are protected by NAFO through bottom fisheries closures, the NAFO fishing footprint which represents the area where regular NAFO fisheries take place, and most of the areas of interest for hydrocarbon exploration and exploitation, managed by the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB). The SMA is also relevant for shipping, marine research, and undersea cables.

A set of hypothetical management goals were defined for the Flemish Cap-Flemish Pass SMA, with the aim of exploring the potential accommodation of an emergent blue economy/blue growth activity, in this case hydrocarbon exploration and exploitation, while ensuring (i) minimum disruption to existing activities (e.g. high seas fisheries), and (ii) impacts on delivery of ecosystem goods and services (e.g. protection of VMEs and biodiversity). As part of this exercise, the main ecosystem components (socio-economic and natural) relevant to the SMA were identified (Table 3.6.1).

Table 3.6.1. Preliminary list of existing and potential socio-economic components of the ecosystem (human activities) identified in ATLAS Case Study No11 (Flemish Cap-Flemish Pass).

Sector/Driver	Subsector	Activity
Fisheries	Bottom fisheries	Pots, traps, gillnets, trawls & longlines
	Pelagic fisheries	Seines, gillnets, trawls & longlines
Exploitation and exploration of non-living resources & ocean energy	Hydrocarbon (oil & gas)	Exploration (drilling & seismic activities)
		Exploitation (significant discoveries/production)
		Pipelines
	Offshore renewables	Wind, tidal & current energy converters
		Power cables
	Mining	Seabed mining
	Carbon capture and storage	Carbon capture and storage
Transportation	Shipping (passengers and items)	Shipping (passengers and items)
Telecommunication	Undersea cables	Laying & maintain undersea cables
Science	Research & education	Fish stock assessment & ecosystem surveys
Conservation	Environmental conservation & protection	Environmental conservation & protection
Biotechnology	Bioprospecting	Search for biological compounds & genetic resources
Defence	Military activities	Dumping, sonar, training
External influences	Climate change	Climate change
	Pollution	Pollution (including long-distance pollution)

Despite that georeferenced information on ecosystem components in the high seas is often difficult to obtain, the exercise of gathering information and mapping relevant components is in progress, and many preliminary maps of natural components and human activities in the study area have been produced. Mapping pressures and impacts using GIS considering cumulative impacts of pressures is expected to be conducted in the next months. This action requires the analysis of the spatial and temporal overlap of the distribution pattern of the identified natural ecosystem components and current and future human activities. This implies the identification of existing or potential conflicts between different users, or between users and natural ecosystem components. At present, IEO-Vigo is exploring different methodologies to assess the (cumulative) impacts of the human activities in the area using GIS (e.g. Ban et al., 2010, Sharp, et al. 2018, Stelzenmüller et al., 2010).

An example of potential conflict areas between different users of the marine space (e.g. oil and gas exploration/exploitation, and high seas fisheries), or between users and natural ecosystem components (e.g. oil and gas exploration/exploitation and VMEs) is presented in Figure 3.6.1.This map shows the potential overlap between oil and gas activities, including potential marine traffic routes linked to some new projects, the NAFO fishing effort, and VME habitats, including the current fishery closures.

WGESA acknowledged the value of this exercise under the ATLAS project, and found it useful to inform SC answer to COM Request 13 regarding monitoring and provision of regular updates on activities other than fishing that could potentially impact fisheries resources and biodiversity in the NRA. While these results were very timely and certainly will support SC response, WGESA also observed that activities other than fishing taking place in the NRA are not formally nor regularly reported to SC or its working groups by contracting parties, making extremely difficult to develop any kind of reliable monitoring scheme for these activities. In addition, the expertise within WGESA in particular, and SC in general, is insufficient to fully assess long term, cumulative impacts of these activities, including potential interaction/feedback effects. In this context, while this COM request is understandable, sensible and pertinent, finding a way to address it is not a task that solely belongs to SC and its working groups. Contracting parties themselves should commit to canvass, consolidate, and reportto NAFO their activities other than fishing in the NRA, as well as properly supporting SC with the resources and expertise required to produce the summaries and assessments that COM is asking for. Without a serious commitment from contracting parties to increase SC capacity to address these issues, these type of requests can only be rudimentarily addressed at best, and hence, likely falling short of the mark that what may be needed.

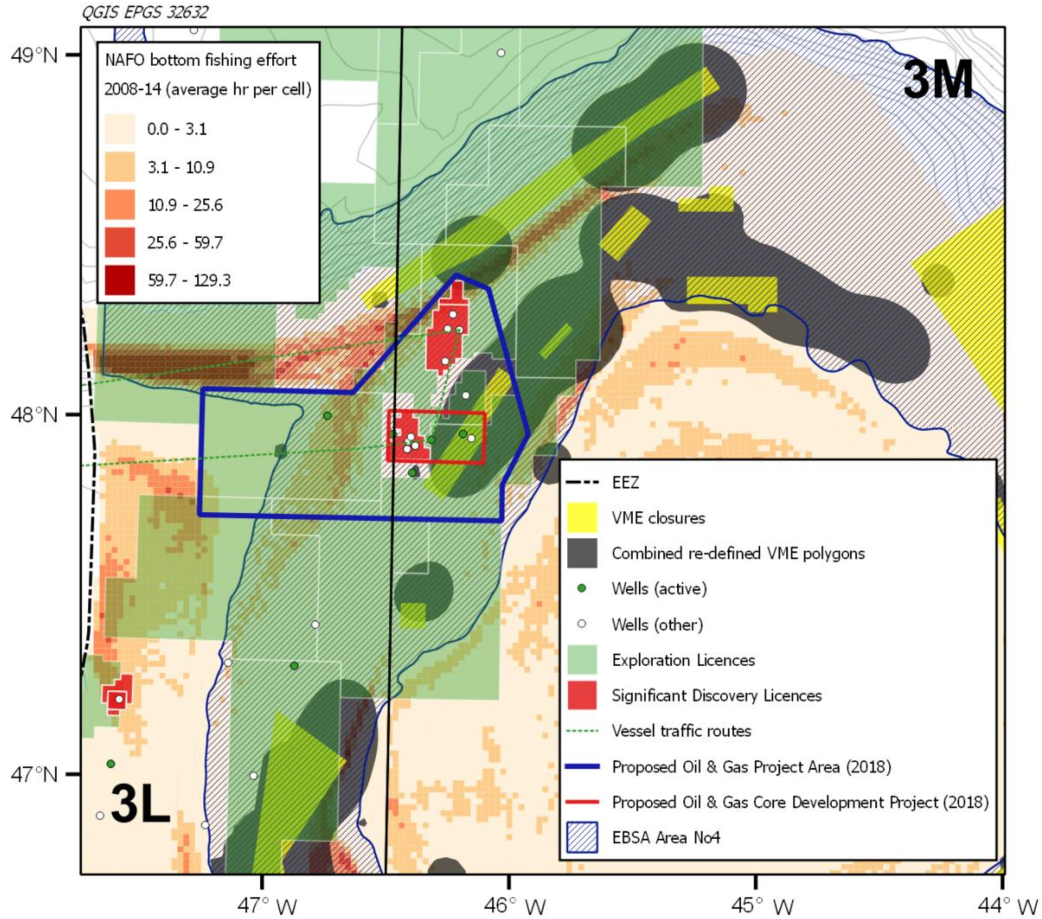


Figure 3.6.1. Preliminary map of the Flemish Cap-Flemish Pass area, showing the potential conflicts between different users of the marine space (e.g. new oil & gas exploration/exploitation and traditional high seas fisheries), or between users and natural ecosystem components (e.g. oil & gas exploration/exploitation and VMEs). Sources: WEBs from NAFO, C-NLOPB and CBD.

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3.7. Assessment of bottom fisheries SAI : overlap of NAFO fisheries with VME.

Tor 3.7 *Assess the overlap of NAFO fisheries with VME to evaluate fishery specific impacts in addition to the cumulative impacts.* (COM Request #9).

This ToR has been addressed under ToR 2.1 of the present report.

3.8. Update NAFO CEM Annex I.E, Part VI with appropriate three character (ASFIS) codes

ToR 3.8. *In relation to FAO three letter codes for VME indicator species, the existing taxa list in Annex I.E Part IV of the NCEM should be up-dated with the FAO ASFIS codes as listed in Annex 4.*

This ToR is addressed under 3.9 below.

3.9 Review consistency between NAFO CEM Annex I.E, Part VI and the *VME species guide*

ToR 3.9. *Review the proposed revisions to Annex I.E Part IV as reflected in COM-SC EAFFM-WP 18-01 and to compare the consistency of the list of taxa in that Annex to the VME species guide with a view to recommend up-dates as necessary*. (COM Request # 10).

It was recognized during the 10th meeting of the NAFO Scientific Council WG-ESA that a review of the current list of vulnerable marine ecosystem indicator species in Annex 1.E of the NAFO Conservation and Enforcement Measures (NCEM) was required in order to prepare for the reassessment of the VME fishery closures in 2020. The last assessment of VME species found in the NAFO Regulatory Area (NRA) occurred in 2011, where over 500 different taxa were reviewed and assessed against the FAO criteria. Since then additional information has become available on the presence of potential new VME indicator taxa in the NRA, and more work has been done to refine the identifications of some that were identified only to the level of genus, calling for a review of the current list found in the NAFO CEM (NAFO, 2017). At the same time the nomenclature of a few of the species on the NCEM list has been revised according to the taxonomic database WORMS (World Register of Marine Species (http://www.marinespecies.org/) and we have taken this opportunity to update the names in the NCEM to reflect those changes.

Table 3.1. shows the common name, known VME indicator taxon, and the suggested revisions to those taxon names currently listed in the NCEM, based on current scientific knowledge of the species in the NRA and nomenclature.

Table 3.1. Suggested revisions to the existing list of VME Indicator Species in Annex I.E Part VI of the NAFO CEM.

Common Name	Known Taxon	Replacement Name or Action	Reason	Reference
Large-sized sponges	*Craniella cranium*	*Craniella* spp.	Multiple species of *Craniella* present in NRA (still under revision)	Cárdenas et al. (2013)
	Stelletta sp.	*Stelletta tuberosa*	Further taxonomic identification of samples	Cárdenas and Rapp (2015)
	Stryphnus ponderosus	*Stryphnus fortis*	Reexamination of taxonomic material	Cárdenas and Rapp (2015)
	Weberella sp.	Remove from list	Only *Weberella bursa* found in the NRA	Murillo et al. (2016)
Small gorgonian corals	*Acanella eburnea*	*Acanella arbuscula*	Synonymized with *A. arbuscula*	Saucier et al. (2017)
Large gorgonian corals	*Keratoisis ornata*	*Keratoisis grayi*	Synonymized with *K. grayi*	Cordeiro et al. (2018)
	Keratoisis sp.	*Keratoisis* cf. *siemensii*	Further taxonomic identification of samples	Murillo et al. (2016)
Sea pens	*Protoptilum* sp.	*Protoptilum carpenteri*	Further taxonomic identification of samples	Murillo et al. (2016)

As work has progressed on the analysis of samples collected through the NEREIDA program, several new species of large-sized sponges have been documented within the NRA as a result (see Table 3.2.), calling for their assessment against the VME criteria. We defined 'large-sized sponges' to be those with either a height or width greater than 10 cm at maturity. Several sponge species recently documented in the NRA did not fit this criteria (e.g. *Thenea levis*; Cárdenas and Rapp 2015) and were therefore not considered further. Following Murillo et al. (2011) these 13 sponge species were assessed against the biological traits deemed relevant to the FAO guidelines on VME designation (see Table 3.3.). All sponge species were considered fragile and able to provide structure for other organisms when aggregated. However, specific information on their life-history traits, such as longevity, growth rate, and reproductive capacity, is lacking. Four new species, *Asbestopluma (Asbestopluma) ruetzleri*, *Chondrocladia grandis*, *Cladorhiza abyssicola, and C. kenchingtonae* are carnivorous sponges from the family Cladorhizidae, characterized by their ability to passively capture small invertebrates such as crustaceans using filaments or other appendages (Hestetun et al. 2017). There were therefore considered to occupy a higher trophic level in the ecosystem than filter-feeding species, but less important for carbon sequestration. The sponge *Cladorhiza kenchingtonae* may qualify as a rare species and possibly endemic to the region, as it has thus far only been described from one location on the southern slope of the Flemish Cap between closure areas 4 and 13 at ~2935 m depth. Both *C. kenchingtonae* and *A.* (*A.*) *ruetzleri* were collected from the NRA as part of the NEREIDA program, and were described as new species to science by Hestetun et al. (2017).

Based on their fragility and vulnerability, and capacity to provide structure for other organisms when aggregating, we therefore consider these sponges to meet the FAO criteria for VME designation and recommend their inclusion in the list of VME Indicator Taxa in the NAFO CEM.

Table 3.2. New large-sized sponge species found or confirmed to occur within the NRA since the last assessment of taxa against the FAO criteria for VME designation in 2011.

Common Name	Taxon	Reference for NAFO Convention Area Record
Large-sized sponges	*Aphrocallistes beatrix*	Murillo et al. (2013) ; Murillo et al. (2016)
	Asbestopluma (Asbestopluma) ruetzleri	Hestetun et al. (2017)
	Chondrocladia grandis	Hestetun et al. (2017)
	Cladorhiza abyssicola	Hestetun et al. (2017)
	Cladorhiza kenchingtonae	Hestetun et al. (2017)
	Dictyaulus romani	Murillo et al. (2013); Murillo et al. (2016)
	Forcepia spp.	Murillo et al. (2016)
	Geodia parva	Cárdenas et al. (2013)
	Haliclona sp.	Murillo et al. (2016)
	Isodictya palmata	Murillo et al. (2016)
	Lissodendoryx (Lissodendoryx) complicata	Beazley et al. (2013); Beazley et al. (2015); NAFO, 2015
	Mycale (Mycale) loveni	Murillo et al. (2016); Wareham pers. comm.
	Thenea valdiviae	Cárdenas and Rapp (2015)

Table 3.3. Biological traits for vulnerable marine ecosystem components used to evaluate new large-sized sponges known to occur in the NAFO regulatory area (NRA). Traits reflect the three pillars of the FAO Guidelines (FAO 2009): Vulnerability, Recoverability and Ecosystem Function.

Biological Traits Relevant to FAO Guidelines	**Sponge taxa**					
	Aphrocallistes beatrix	***Asbestopluma (Asbestopluma) ruetzleri***	***Chondrocladia grandis***	***Cladorhiza abyssicola***	***Cladorhiza kenchingtonae***	***Dictyaulus romani***
Fragility, Vulnerability and Recoverability						
Fragility	Yes	Yes	Yes	Yes	Yes	Yes
Height off bottom > 10 cm	Yes	Yes	Yes	Yes	Yes	Yes
Lifespan (> 20 yr)	Likely	Likely	Likely	Likely	Likely	Likely
Slow growth rates	Likely	Likely	Likely	Likely	Likely	Likely
Late age of maturity	?	?	?	?	?	?
Irregular or episodic recruitment	?	?	?	?	?	?
Poor regeneration ability (> 20 years)	?	?	?	?	?	?
Low fecundity	?	?	?	?	?	?
Significant Role in Ecosystem (Function)						
Structural engineer	X	X	X	X	X	X
Predator		X	X	X	X	
Bioturbator						
Carbon sequester	X					X
Benthic pelagic coupling	X	X	X	X	X	X
Benthic production						

Table 3.3. continued.

	***Forcepia* spp.**	***Geodia parva***	***Haliclona* sp.**	***Isodictya palmata***	***Lissodendoryx (Lissodendoryx) complicata***	***Mycale (Mycale) loveni***	***Thenea valdiviae***
Fragility, Vulnerability and Recoverability							
Fragility	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Height off bottom > 10 cm	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lifespan (> 20 yr)	Likely	Likely	Likely	Likely	Likely	Likely	Likely
Slow growth rates	Likely	Likely	Likely	Likely	Likely	Likely	Likely
Late age of maturity	?	?	?	?	?	?	?
Irregular or episodic recruitment	?	?	?	?	?	?	?
Poor regeneration ability (> 20 years)	?	?	?	?	?	?	?
Low fecundity	?	?	?	?	?	?	?
Significant Role in Ecosystem (Function)							
Structural engineer	X	X	X	X	X	X	X
Predator							
Bioturbator							
Carbon sequester	X	X	X	X	X	X	X
Benthic pelagic coupling	X	X	X	X	X	X	X
Benthic production							

Table 3.4. contains the final suggested list of VME indicator species to be included in Annex I.E of the NAFO CEM. While most taxa occur in the fishing footprint, some were documented exclusively from the seamounts. Those taxa are indicated by an asterisk in the table. This list encompasses only those species that are caught or likely to be retained in trawl gear. However, the use of camera and video systems in the NRA has revealed the presence of VME indicator species not previously observed in the trawl surveys. For instance, xenophyophores, which are considered a VME indicator by the FAO (FAO, 2009) and the South Pacific Regional Fisheries Management Organisation (Hansen et al. 2013), were recorded during a camera survey of Kelvin Seamount (NAFO, 2016) in the NAFO New England Seamount Closure. This group is unlikely to be recorded in trawl gears as their tests are fragile and easily disintegrate. However, as NAFO moves towards the use of non-destructive sampling alternatives such as camera systems for long-term monitoring, such taxa will likely be encountered more frequently and should be recorded. Thus, we declare large xenophyophores, specifically *Syringammina* sp., as a VME indicator species. This species is highlighted at the bottom of Table 3.4. as a VME indicator likely to be observed *in situ* only.

In order to facilitate reporting of catches of vulnerable marine ecosystem indicator taxa in observer and haul by haul catch reports, the NAFO Joint Commission-Scientific Council Working Group on Ecosystem Approach Framework to Fisheries Management (WG-EAFFM) recommended that the NAFO Secretariat, in conjunction with STACTIC and WG-EAFFM, develop tools to cross-reference the relevant FAO 3-alpha codes with the VME indicator species in Annex I.E of the NAFO CEM (see NAFO COM-SC EAFFM-WP 18-01).

Table 3.4 contains the available 3-alpha codes for the updated VME indicator species. Codes were commonly available for the genus level but not species; those instances are indicated by the bracketed text. The working group favoured separate codes for each taxon, recognizing that many of the taxa were unlikely to be accurately identified at sea. Blank entries in the table indicate that codes were not available and should be requested from the FAO. Similarly, 3-alpha codes were added for each common name/functional group where available in order to help facilitate recording of specimens that could only be identified to a coarse taxonomic level. Note that codes are not available for the large and small gorgonian coral groups and should be requested from FAO.

Table 3.4. Updated List of VME Indicator Species for inclusion in Annex I.E of the NAFO CEM. Also included are the FAO ASFIS 3-alpha codes. Codes for the genus level are indicated in brackets. Blank entries indicate that no code exists for that taxon. Those taxa marked with an asterisk were documented exclusively from the NAFO seamount closures.

Common Name and FAO ASFIS 3- ALPHA CODE	Taxon	Family	FAO ASFIS 3-ALPHA CODE
Large-Sized Sponges (PFR - Porifera)	*Asconema foliatum*	Rossellidae	ZBA
	Aphrocallistes beatrix	Aphrocallistidae	
	Asbestopluma (Asbestopluma) ruetzleri	Cladorhizidae	ZAB (Asbestopluma)
	Axinella sp.	Axinellidae	
	Chondrocladia grandis	Cladorhizidae	ZHD (Chondrocladia)
	Cladorhiza abyssicola	Cladorhizidae	ZCH (Cladorhiza)
	Cladorhiza kenchingtonae	Cladorhizidae	ZCH (Cladorhiza)
	Craniella spp.	Tetillidae	ZCS (Craniella spp.)

	Dictyaulus romani	Euplectellidae	ZDY (Dictyaulus)
	Esperiopsis villosa	Esperiopsidae	ZEW
	Forcepia spp.	Coelosphaeridae	ZFR
	Geodia barretti	Geodiidae	
	Geodia macandrewii	Geodiidae	
	Geodia parva	Geodiidae	
	Geodia phlegraei	Geodiidae	
	Haliclona sp.	Chalinidae	ZHL
	Iophon piceum	Acarnidae	WJP
	Isodictya palmata	Isodictyidae	
	Lissodendoryx (Lissodendoryx) complicata	Coelosphaeridae	ZDD
	Mycale (Mycale) lingua	Mycalidae	
	Mycale (Mycale) loveni	Mycalidae	
	Phakellia sp.	Axinellidae	
	Polymastia spp.	Polymastiidae	ZPY
	Stelletta normani	Ancorinidae	WSX (Stelletta)
	Stelletta tuberosa	Ancorinidae	WSX (Stelletta)
	Stryphnus fortis	Ancorinidae	WPH
	Thenea muricata	Pachastrellidae	ZTH (Thenea)
	Thenea valdiviae	Pachastrellidae	ZTH (Thenea)
	Weberella bursa	Polymastiidae	
Stony Corals (CSS - Scleractinia)	*Enallopsammia rostrata**	Dendrophylliidae	FEY
	*Lophelia pertusa**	Caryophylliidae	LWS
	*Madrepora oculata**	Oculinidae	MVI
	*Solenosmilia variabilis**	Caryophylliidae	RZT

Small Gorgonians	*Acanella arbuscula*	Isididae	KQL (Acanella)
	Anthothela grandiflora	Anthothelidae	WAG
	Chrysogorgia sp.	Chrysogorgiidae	FHX
	*Metallogorgia melanotrichos**	Chrysogorgiidae	
	Narella laxa	Primnoidae	
	Radicipes gracilis	Chrysogorgiidae	CZN
	Swiftia sp.	Plexauridae	
Large Gorgonians	*Acanthogorgia armata*	Acanthogorgiidae	AZC
	Calyptrophora sp.*	Primnoidae	
	Corallium bathyrubrum	Coralliidae	COR (Corallium)
	Corallium bayeri	Coralliidae	COR (Corallium)
	Iridogorgia sp.*	Chrysogorgiidae	
	Keratoisis cf. *siemensii*	Isididae	
	Keratoisis grayi	Isididae	
	Lepidisis sp.*	Isididae	QFX (Lepidisis)
	Paragorgia arborea	Paragorgiidae	BFU
	Paragorgia johnsoni	Paragorgiidae	BFV
	Paramuricea grandis	Plexauridae	PZL (Paramuricea)
	Paramuricea placomus	Plexauridae	PZL (Paramuricea)
	Paramuricea spp.	Plexauridae	PZL (Paramuricea)
	Parastenella atlantica	Primnoidae	
	Placogorgia sp.	Plexauridae	
	Placogorgia terceira	Plexauridae	
	Primnoa resedaeformis	Primnoidae	QOE

	*Thouarella (Euthouarella) grasshoffi**	Primnoidae	
Sea Pens (NTW – Pennatulacea)	*Anthoptilum grandiflorum*	Anthoptilidae	AJG (Anthoptilum)
	Distichoptilum gracile	Protoptilidae	WDG
	Funiculina quadrangularis	Funiculinidae	FQJ
	Halipteris cf. *christii*	Halipteridae	ZHX (Halipteris)
	Halipteris finmarchica	Halipteridae	HFM
	Halipteris sp.	Halipteridae	ZHX (Halipteris)
	Kophobelemnon stelliferum	Kophobelemnidae	KVF
	Pennatula aculeata	Pennatulidae	QAC
	Pennatula grandis	Pennatulidae	
	Pennatula sp.	Pennatulidae	
	Protoptilum carpenteri	Protoptilidae	
	Umbellula lindahli	Umbellulidae	
	Virgularia mirabilis	Virgulariidae	
Tube-Dwelling Anemones	*Pachycerianthus borealis*	Cerianthidae	WQB
Erect Bryozoans (BZN – Bryozoa)	*Eucratea loricata*	Eucrateidae	WEL
Sea Lilies (CWD – Crinoidea)	*Conocrinus lofotensis*	Bourgueticrinidae	WCF
	Gephyrocrinus grimaldii	Hyocrinidae	
	Trichometra cubensis	Antedonidae	
	Boltenia ovifera	Pyuridae	WBO

Sea Squirts (SSX – Ascidiacea)	*Halocynthia aurantium*	Pyuridae	
Unlikely to be observed in trawls; *in situ* observations only:			
Large xenophyophores	*Syringammina* sp.	Syringamminidae	

The Coral, Sponge, and Other Vulnerable Marine Ecosystem Indicator Identification Guide (Kenchington et al. 2015) contains both VME and non-VME indicator taxa that are commonly encountered within the fishing footprint. The inclusion of both VME and non-VME indicator taxa in the guide was done as a means to prevent misidentification of VME taxa from others commonly encountered in the NRA. Those taxa documented exclusively on the seamounts are not included in the guide. Rather than create one for exploratory fishing in those areas the working group felt that it might be better to wait for the bycatch identification apps being developed by the NAFO Secretariat to be completed. It was noted that the Marine Spatial Ecology and Analysis (MSEA) research group from Fisheries and Oceans Canada Science (NE Pacific) has begun using an online tool for collaborative, image-based marine species identification, sharing, and inventorying: iNaturalist.org. This free platform has proven reliability and longevity. It can be used online and interactive, to output offline data and field guides (PDFs), on computers and through iPhone or Android apps. This tool enables groups to archive and curate image-based species distribution data with the highest taxonomic accuracy and consistency possible by crowd-sourcing experts, building a large, reliable inventories of life, providing a photo-based guide and workflow that will ultimately be beneficial for research that follows. Metadata associated with each photo can be project-specific, but usually includes GPS and temporal information. The North Pacific RFMO is currently considering this app to help identify invertebrate bycatch on seamount fisheries.

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THEME 4: SPECIFIC REQUESTS

No additional requests wwere received from the Scientific Counciland hence there were no matters to report under this ToR.

AOB.

Date and place of next meeting

The next meeting will be held at the NAFO Secretariat offices, Nova Scotia, Canada from 19 to 28 November 2019.

ANNEX 1: WG-ESA 2018 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 EU-Spain Groundfish Surveys in 2018.
2. Progress on implementation of workplan and timetable for reassessment of VME fishery closures including seamount closures for 2020 assessment. **COM Doc. 18-20 Request # 11.**
3. Discussion on up-dating Kernel Density Analysis and SDM's for VME indicator species in preparation for VME fishery closure review in 2020. **COM Request # 11.**
4. Update on the Research Activities related to EU-funded Horizon 2020 ATLAS Project, Flemish Cap Case Study: Species Distribution models for two deep-water pennatulacean coral. **COM Request # 11.**
5. Continue work on non-sponge and coral VMEs (for example bryozoan and sea squirts) to prepare for the next reassessment of bottom fisheries. **COM Request # 9**

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 – VME sea pen resilience and mapping fishing effort**. COM Request # 9**
2. Up-date on VME modelling **COM Request # 9**
3. Up-date on VME biological traits analysis and the assessment of VME functions **COM Request # 9**
4. 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). **COM Request # 9.**
5. Up-date on fishery modelling activities and develop 5-year plan for development and expansion of single species, multispecies and ecosystem production potential modelling **COM Request # 16.**
6. Review of oceanographic and ecosystem status conditions in the NRA

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. Refine work to progress the EAFM roadmap by testing the reliability of the ecosystem production potential model and other related models, and to report on these results to the WG-EAFFM and WG-RBMS to further develop how it may apply to management decisions. **COM Request # 8**.
2. Consider the terminology used in ecosystem summary sheets in order to avoid potential confusion with standard terminology in fisheries management, review their structure to address concerns raised by WG-EAFFM, as well as considering their potential to inform management decisions and responses.
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. **COM Request # 5.**
4. Consider possible options for the non-destructive regular monitoring within closed areas, develop preliminary plans for evaluation of new approaches and potential survey design, bearing in mind the cost implications and the utility of data collected for the provision of advice.
5. Review progress against establishing clearer objective ranking processes and options for objective weighting criteria for the overall assessment of SAI and risk of SAI. **COM Request # 9.**
6. 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. **COM Request # 13.**

7. Assess the overlap of NAFO fisheries with VME to evaluate fishery specific impacts in addition to the cumulative impacts. **COM Request # 9.**
8. In relation to FAO three letter codes for VME indicator species, the existing taxa list in Annex I.E Part IV of the NCEM should be up-dated with the FAO ASFIS codes as listed in Annex 4.
9. Review the proposed revisions to Annex I.E Part IV as reflected in COM-SC EAFFM-WP 18-01 and to compare the consistency of the list of taxa in that Annex to the VME species guide with a view to recommend up-dates as necessary. **COM Request # 10.**

AOB.

1. Date and place of next meeting

ANNEX 2: SUMMARY OF RECOMMENDATIONS

WG-ESA made the following recommendations in 2018.

In relation to ToR 1: *Update on identification and mapping of sensitive species and habitats in the NAFO area. In support of the Roadmap develop research and summarize new findings on the spatial structure and organisation of marine ecosystems with an emphasis on connectivity, exchanges and flows among ecosystem units in the NAFO Convention Area. area.* WG-ESA recommended;

Future monitoring of benthic diversity should focus on SpD (the number of species in a standard research trawl) and the working group **recommended** *monitoring this value in future and to include an assessment of diversity in the review of closed areas to be undertaken at the November 2019 meeting.*

In relation to ToR 2.1: *Progress of analysis undertaken by EU NEREIDA research – VME sea pen resilience and mapping fishing effort (COM Request #9);*

WG-ESA **recommends** to SC that; *additional information be recorded in the haul-by-haul [logbook] data as follows (1) an appropriate measure of gear dimensions to facilitate future work on developing estimates of the area being swept by the trawl and (2) target species.*

In relation to ToR 3.9: *review of the proposed revisions to Annex I.E Part IV as reflected in COM-SC EAFFM-WP 18-01 and to compare the consistency of the list of taxa in that Annex to the VME species guide with a view to recommend up-dates as necessary (COM Request # 10);*

Based on their fragility and vulnerability, and capacity to provide structure for other organisms when aggregating, WG-ESA consider the following sponges to meet the FAO criteria for VME designation and **recommend** their *inclusion in the list of VME Indicator Taxa in the NAFO CEM:*

- *Aphrocallistes beatrix*
- *Asbestopluma (Asbestopluma) ruetzleri*
- *Chondrocladia grandis*
- *Cladorhiza abyssicola*
- *Cladorhiza kenchingtonae*
- *Dictyaulus romani*
- *Forcepia spp.*
- *Geodia parva*
- *Haliclona sp.*
- *Isodictya palmata*
- *Lissodendoryx (Lissodendoryx) complicata*
- *Mycale (Mycale) loveni*
- *Thenea valdiviae*

ANNEX 3: LIST OF PARTICIPANTS

Name	Affiliation	E-mail
CHAIRS		
Andrew Kenny (WG-ESA Co-Chair)	CEFAS, Lowestoft Laboratory, Lowestoft, UK	andrew.kenny@cefas.co.uk
Pierre Pepin (WG-ESA Co-Chair)	Fisheries and Oceans Canada, St. John's, NL	pierre.pepin@dfo-mpo.gc.ca
Brian Healey (SC Chair)	Fisheries and Oceans Canada, St. John's, NL	brian.healey@dfo-mpo.gc.ca
CANADA		
Deborah Austin	Fisheries and Oceans Canada, Ottawa, ON	deborah.austin@dfo-mpo.gc.ca
Lindsay Beazley	Fisheries and Oceans Canada, Dartmouth, NS	lindsay.beazley@dfo-mpo.gc.ca
Alida Bundy	Fisheries and Oceans Canada, St. John's, NL	alida.bundy@dfo-mpo.gc.ca
Andrew Cuff	Fisheries and Oceans Canada, St. John's, NL	andrew.cuff@dfo-mpo.gc.ca
Corinna Favaro	Fisheries and Oceans Canada, St. John's, NL	corinna.favaro@dfo-mpo.gc.ca
Ellen Kenchington	Fisheries and Oceans Canada, Dartmouth, NS	ellen.kenchington@dfo-mpo.gc.ca
Mariano Koen-Alonso	Fisheries and Oceans Canada, St. John's, NL	mariano.koen-alonso@dfo-mpo.gc.ca
Camille Lirette	Fisheries and Oceans Canada, Dartmouth, NS	camille.lirette@dfo-mpo.gc.ca
Francisco Javier Murillo-Perez	Fisheries and Oceans Canada, Dartmouth, NS	javier.murillo-perez@dfo-mpo.gc.ca
Barbara Neves	Fisheries and Oceans Canada, St. John's, NL	barbara.neves@dfo-mpo.gc.ca
Neil Ollerhead	Fisheries and Oceans Canada, St. John's, NL	neil.ollerhead@dfo-mpo.gc.ca
Fred Phelan	Fisheries and Oceans Canada, St. John's, NL	fred.phelan@dfo-mpo.gc.ca
Jamie Tam	Fisheries and Oceans Canada, Dartmouth, NS	jamiectam.phd@gmail.com
DALHOUSIE UNIVERSITY		
Danielle Dempsey	Dalhousie University, Halifax, NS, Canada	dempseydanielle@dal.ca
EUROPEAN UNION		
Ricardo Alpoim	Instituto Português do Mar e da Atmosfera, Lisbon, Portugal	ralpoim@ipma.pt
Anna Downie	CEFAS, Lowestoft Laboratory, Lowestoft, UK	anna.downie@cefas.co.uk
Pablo Durán Muñoz	Instituto Español de Oceanografía, Vigo, Spain	pablo.duran@ieo.es

Alfonso Pérez-Rodriguez	Wageningen Marine Research, Netherlands	alfonso.perezrodriguez@wur.nl
Mar Sacau	Instituto Español de Oceanografía, Vigo, Spain	mar.sacau@ ieo.es
FOOD AND AGRICULTURE ORGANIZATION (FAO)		
Hassan Moustahfid	Food and Agriculture Organization of the United Nations	hassan.moustahfid@fao.org
OCEANS NORTH		
Susanna Fuller	Oceans North, Halifax Office, Halifax, NS, Canada	susannafuller@oceansnorth.ca
RUSSIAN FEDERATION		
Temur Tairov	Representative of the Federal Agency for Fisheries of the Russian Federation in Canada, Bedford, NS, Canada	temurtairov@mail.ru
UNITED STATES OF AMERICA		
Robert Gamble	Northeast Fisheries Science Cener, Woods Hole, MA, USA	robert.gamble@noaa.gov
Elizabethann Mencher	National Marine Fisheries Service, Office of International Affairs and Seafood Inspection, NOAA, USA	elizabethann.mencher@noaa.gov
NAFO SECRETARIAT		
Fred Kingston	NAFO Secretariat, Dartmouth, NS, Canada	fkingston@nafo.int
Tom Blasdale	NAFO Secretariat, Dartmouth, NS, Canada	tblasdale@nafo.int
Dayna Bell MacCallum	NAFO Secretariat, Dartmouth, NS, Canada	dbell@nafo.int