Northwest Atlantic Fisheries Organization

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SC WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT – NOVEMBER 2021

Report of the 14th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA)

By WebEx
16-25 November 2021

Contents

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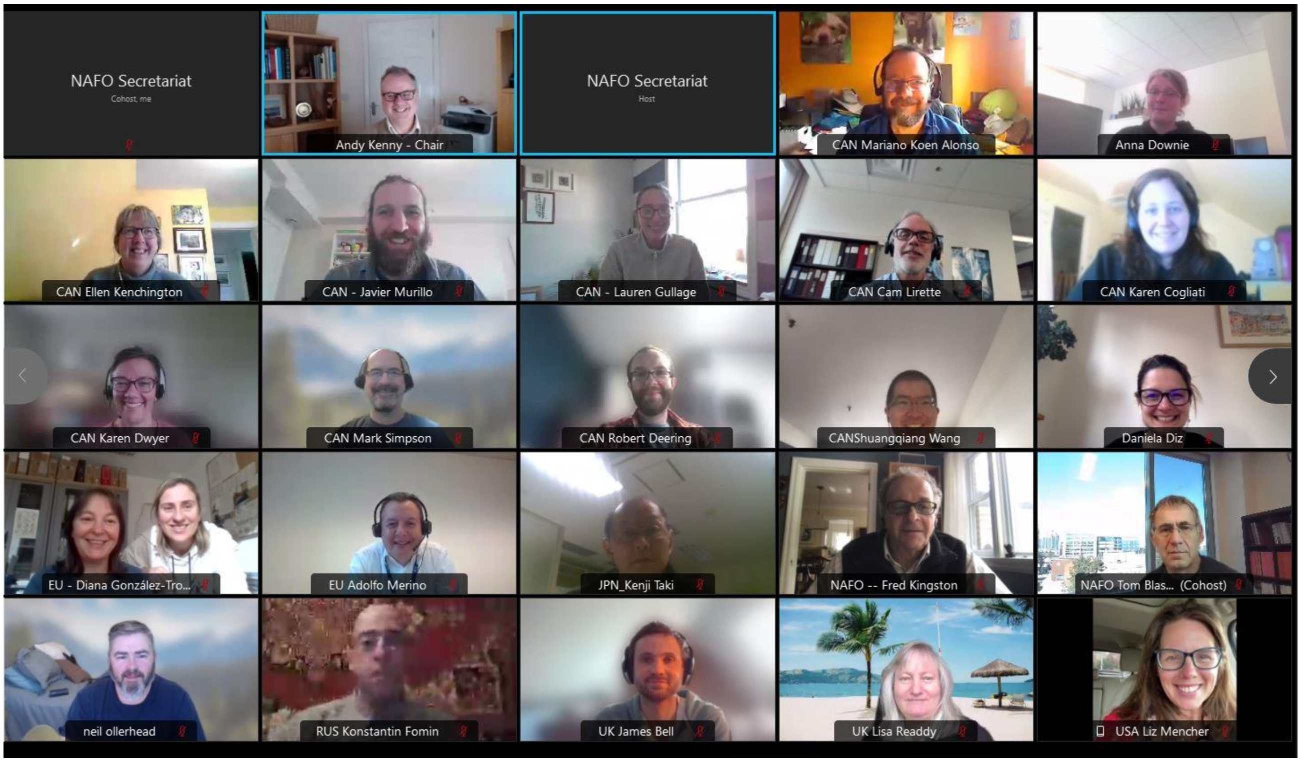

WG-ESA Meeting Participants
16-25 November 2021

From left to right:
First row: NAFO Secretariat, Andrew Kenny (Chair), NAFO Secretariat, Mariano Koen-Alonso, Anna Downie
Second row: Ellen Kenchington, F. Javier Murillo Perez, Lauren Gullage, Camille Lirette, Karen Cogliati
Third row: Karen Dwyer, Mark Simpson, Robert Deering, Shuangqiang Wang, Daniela Diz
Fourth row: Diana González-Troncoso, Mar Sacau-Cuadrado, Adolfo Merino, Kenji Taki, Fred Kingston, Tom Blasdale
Fifth row: Neil Ollerhead, Konstantin Fomin, James Bell, Lisa Readdy, Elizabethann Mencher.
Missing from photo: Deborah Austin, Andrew Cuff, Lauren Gullage, Ellen Kenchington, Camille Lirette, Barbara Neves, Paul Regular, Garry Stenson, Vonda Wareham-Hayes, Ricardo Alpoim, Pablo Durán Muñoz, Irene Garrido, Fernando González-Costas, Natalya Petukhova, Temur Tairov, Katherine Sosebee, Aaron Adamack, Krista Baker, Kasey Cantwell, Karen Cogliati, Daniela Diz, Susanna Fuller, Kimberly Galvez, Fonya Irvine, Kyle Krumsick, Keith Lewis, Valentin Lucet, Darrell Mullowney, Hannah Munro, Eric Pederson, Alfonso Perez-Rodriguez, Matthew Robertson, Tyler Eddy, Rhian Waller.

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

16-25 November 2021

1. Opening by the co-Chair

meeting was opened at 09:00 (Halifax Time) on 17 November 2021. The Chair, Andrew Kenny (UK) welcomed participants.

The Chair presented the detailed agenda and outlined the work plan for the meeting as well as the terms of reference and the Commission requests relevant to the working group. ToR and commission requests are presented in the Agenda in Annexes 1. A list of participants is presented in Appendix 2.

2. Appointment of Rapporteur

The Scientific Council Coordinator was appointed as rapporteur.

3. Adoption of Agenda

The agenda and detailed agenda were adopted as circulated (see Appendix 1).

THEME 1: SPATIAL CONSIDERATIONS

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

a) ToR 1.1. Update on VME indicator species distribution from EU; EU- Spain Groundfish Surveys (2021) and Canadian surveys (2020 Fall).

i) EU and EU- Spain Groundfish Surveys (2021)

Due to the pandemic situation during 2021, R/V Vizconde de Eza only carried out two surveys, one in Division 3M (Flemish Cap) sampling between 130-1416 m (183 tows) and other in Divisions 3NO (Grand Banks of Newfoundland) sampling between 42-1358 m (117 tows). In total there were 300 bottom trawl tows, six of them considered invalid due to technical problems during the fishing operation. 122 hauls out of 300 have shown cero catches of VME species groups. This represents the 41.5% of the total valid hauls. Sponges were recorded, with non-significant concentrations, in 85 of the 294 valid tows (28.9% of the valid tows analyzed), with depths ranging between 61 - 1345 m. Two Significant catches of sponges (≥ 100 kg/tow) were found. Large gorgonians were recorded, with non-significant concentrations, in 8 of the 294 valid tows (2.7% of valid tows analyzed), with depths ranging between 352- 1161 m. One of the tows had significant catches of large gorgonians (≥ 0.6 kg/tow). Small gorgonians were recorded, with non-significant concentrations, in 40 of the 294 valid tows (13.6% of valid tows analyzed), with depths ranging between 102- 1416 m. None of the valid tows had significant catches of small gorgonians (≥ 0.2 kg/tow). Sea pens were recorded, with non-significant concentrations, in 92 tows (31.3% of valid tows analyzed), with depths ranging between 61 - 1416 m. One significant catch (> 1.3 kg/tow) was recorded. Black corals were recorded, with non-significant concentrations, in 9 tows (3% of valid tows analyzed), with depths ranging between 401 - 1221 m. No significant catches (> 0.4 kg/tow) were recorded. Boltenia ovifera was recorded, with non-significant concentrations, in 11tows (3.7% of valid tows analyzed), with depths ranging between 50 – 315 m. Four significant catches (> 0.35 kg/tow) were recorded. Bryozoans were recorded, with non-significant concentrations, in 7 tows (2.4% of valid tows analyzed), with depths ranging between 54 - 681 m. No significant catches (> 0.2 kg/tow) were recorded.

ii) Canadian Surveys (Fall 2020)

In the Fall of 2020, the Canadian Multispecies Surveys, conducted by Fisheries and Oceans Canada (McCallum and Walsh, 1996), sampled the Grand Banks of Newfoundland (NAFO Divs. 3LNO) between mean depths of 46 – 670 m, with a total of 63 tows valid tows (68 total tows, five considered invalid). Sponges, large gorgonians, small gorgonians, sea pens, and sea squirts were all reported, with black corals being the only unreported coral group. Sponges were recorded at the widest mean depth ranges (52 - 629 m), followed by Boltenia ovifera (56 - 428 m), and sea pens (222 - 610 m). Large gorgonians were recorded at only two tows (211 and 327 m), and small gorgonians at a single tow (609 m). Presence in tows ranged between 1.58% (small gorgonians) and 30% of valid tows (sponges). Large gorgonians, sea pens, and sea squirts were present in 3.17%, 9.52%, and 11.1% of the valid tows, respectively. Among these, only Boltenia ovifera were reported in significant concentrations, at three tows (4.76%), all of them inside the Boltenia KDE polygon. These significant catches were: 0.352, 1.025, and 4.68 kg. No bryozoans were recorded during the DFO 2020 Fall surveys.

Above information, including distribution maps of VME species groups, is further detailed in SCR Doc. 21/050

Acknowledgements

The collection of the EU; EU-Spain and Portugal Groundfish Surveys used in this paper have been funded by the EU through the European Maritime and Fisheries Fund (EMFF) within the National Program of collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy. This output reflects only the author’s view (MS & PDM) and the European Union cannot be held responsible for any use that may be made of the information contained therein. BMN and VWH acknowledge DFO-NL personnel and Canadian Coast Guard captain and crew for DFO data collection.

References

Sacau, M., Neves, B.M., Wareham Hayes, V., and Durán-Muñoz, P. 2021. New preliminary data on VME encounters in NAFO Regulatory Area (Divs. 3MNO) from EU; EU-Spain and Portugal Groundfish Surveys (2021) and Canadian surveys (2020 Fall). NAFO SCR Doc. 21/050 Serial No. N7253.

b) ToR 1.2. Update on VME indicator presence on NAFO seamounts from the 2021 Okeanos Explorer “2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts” expedition.

From June 30 through July 29, 2021, NOAA Ocean Exploration and partners conducted the “2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts” expedition, a telepresence-enabled ocean exploration expedition aboard the NOAA Ship Okeanos Explorer. The mission objectives were to collect critical baseline information about unknown and poorly understood deep-water areas off the eastern U.S. coast and high seas through mapping and remotely operated vehicle (ROV) operations. The expedition completed 20 ROV dives (Figure 4.1) ranging in depth from 300 to 4,2187 m.

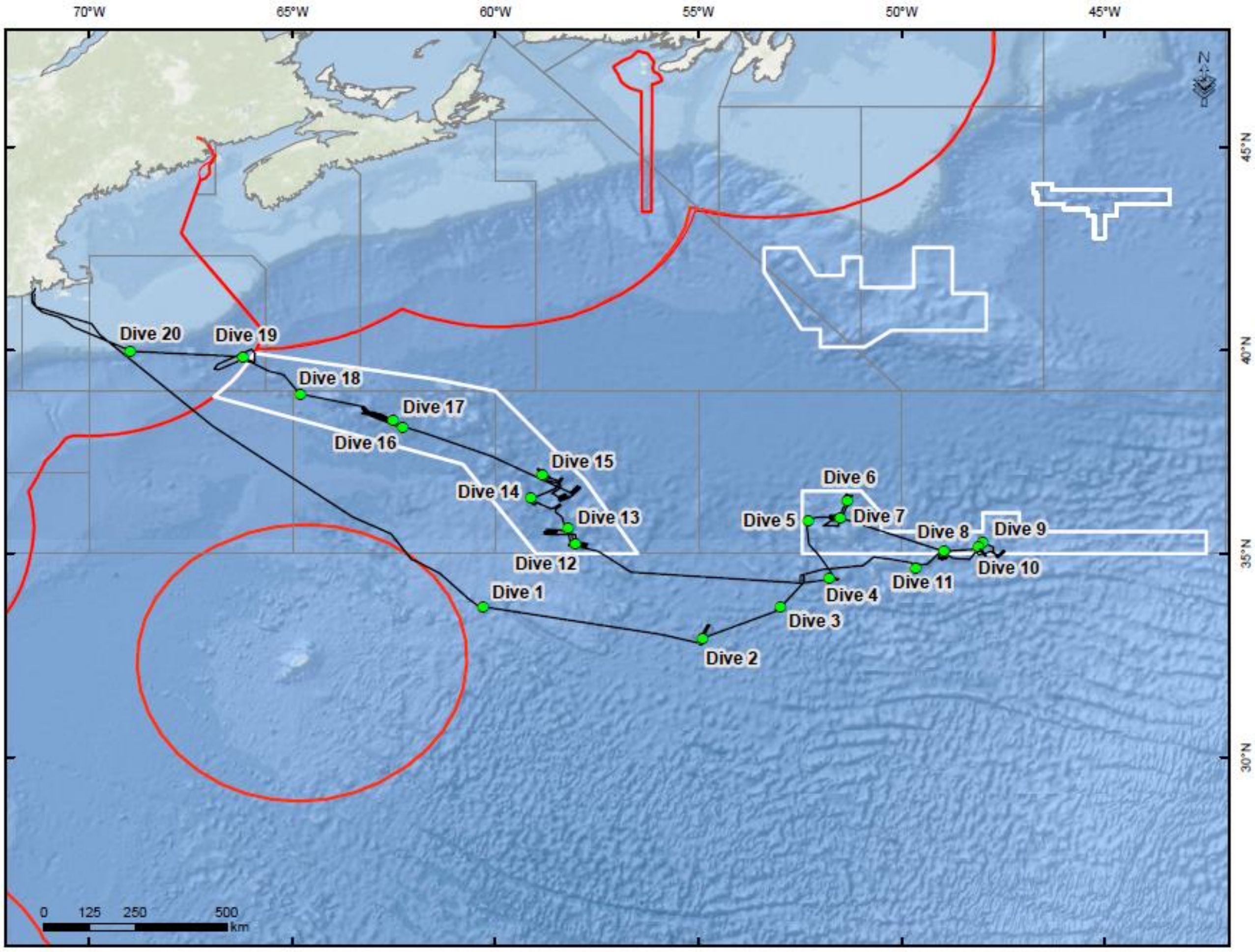

Figure 4.1. 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition map with dive sites. White lines: areas currently closed or closed effective January 1, 2022 by NAFO to protect VMEs; red lines: Exclusive Economic Zones of Canada, USA, Bermuda and France with respect to St. Pierre and Miquelon; black lines: cruise track. ROV dive sites are represented as green dots. NAFO Divisions are outlined in grey.

Thirteen of these ROV dives occurred in the NAFO areas closed to protect vulnerable marine ecosystems (VMEs) on seamounts (Figures 4.2, 4.3), including in areas that will be closed effective January 1, 2022 (Figure 4.2). The thirteen ROV dives conducted in the NAFO area surveyed 6 seamounts in the Corner Rise (Figure 4.2) and 7 seamounts in the New England (Figure 4.3) Seamount Chains. These areas are also considered Ecologically or Biologically Significant Areas (EBSAs) by the Convention on Biological Diversity (CBD) (https://chm.cbd.int/database/record?documentID=204106). NAFO VME Indicator taxa identified on the dives were Deep-sea Sponges, Stalked Crinoids, Small and Large Gorgonian Corals, Black Coral, Stony Coral, Sea Pens, Xenophyophores, Stalked Crinoids and Cerianthid Anemones, with only the Stalked Tunicates and Bryozoans not being specifically identified to date (note that they may be present but not yet confirmed) (Table 4.1). In particular, the rock pen, a rare type of sea pen that is able to attach to rock, was observed (Figure 4.4) and it is likely that several species of sponge and coral are new to science (samples have been taken of some for future determination, and are now available for public access through the Smithsonian National Museum of Natural History). VME Indicators formed extensive habitats representing VMEs on MacGregor Seamount (Dive 08) where deep sea sponge grounds were identified (Figure 4.5). Even the deepest dives at ~4,000 m observed VME indicator taxa (Table 4.1). More details of each dive with links to the video can be found in Waller et al. (2021) and Galvez et al. (2021).

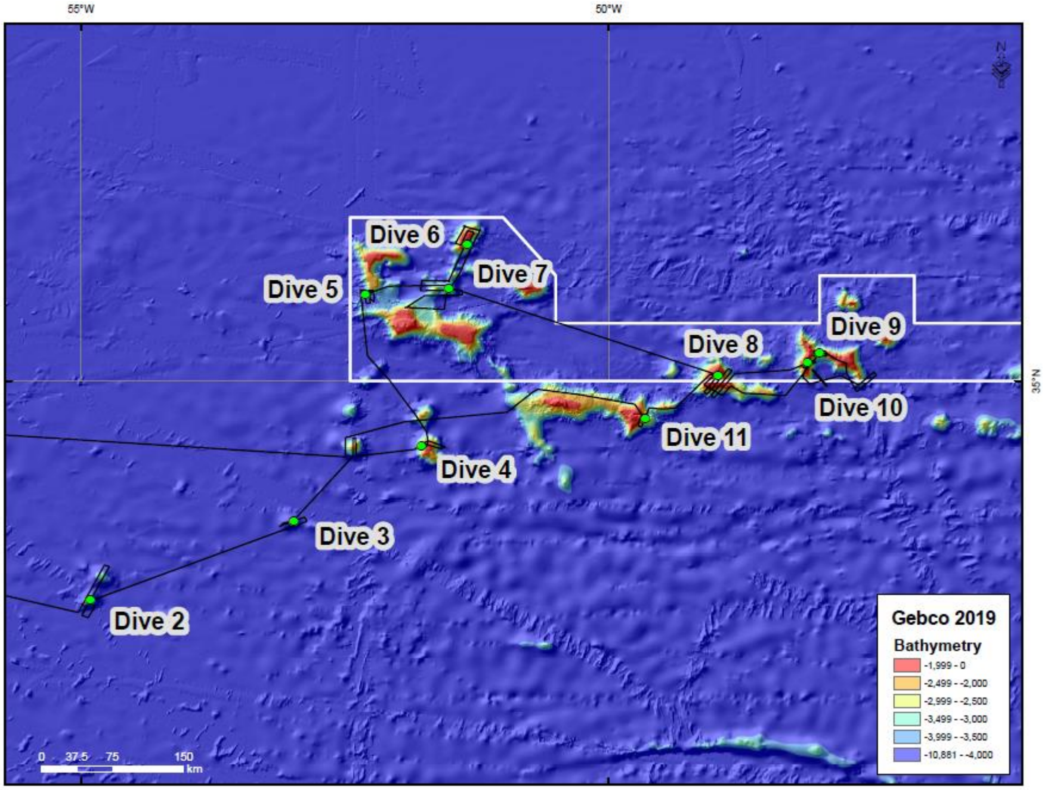

Figure 4.2. Location of the six seamounts surveyed during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition. Dives 5, 6, 7, 8, 9 and 10 are inside the NAFO Corner Rise Seamount Closure (white line) effective January 1, 2022. Cruise track is represented as a black line, and ROV dives are represented as green dots. NAFO Divisions are outlined in grey.

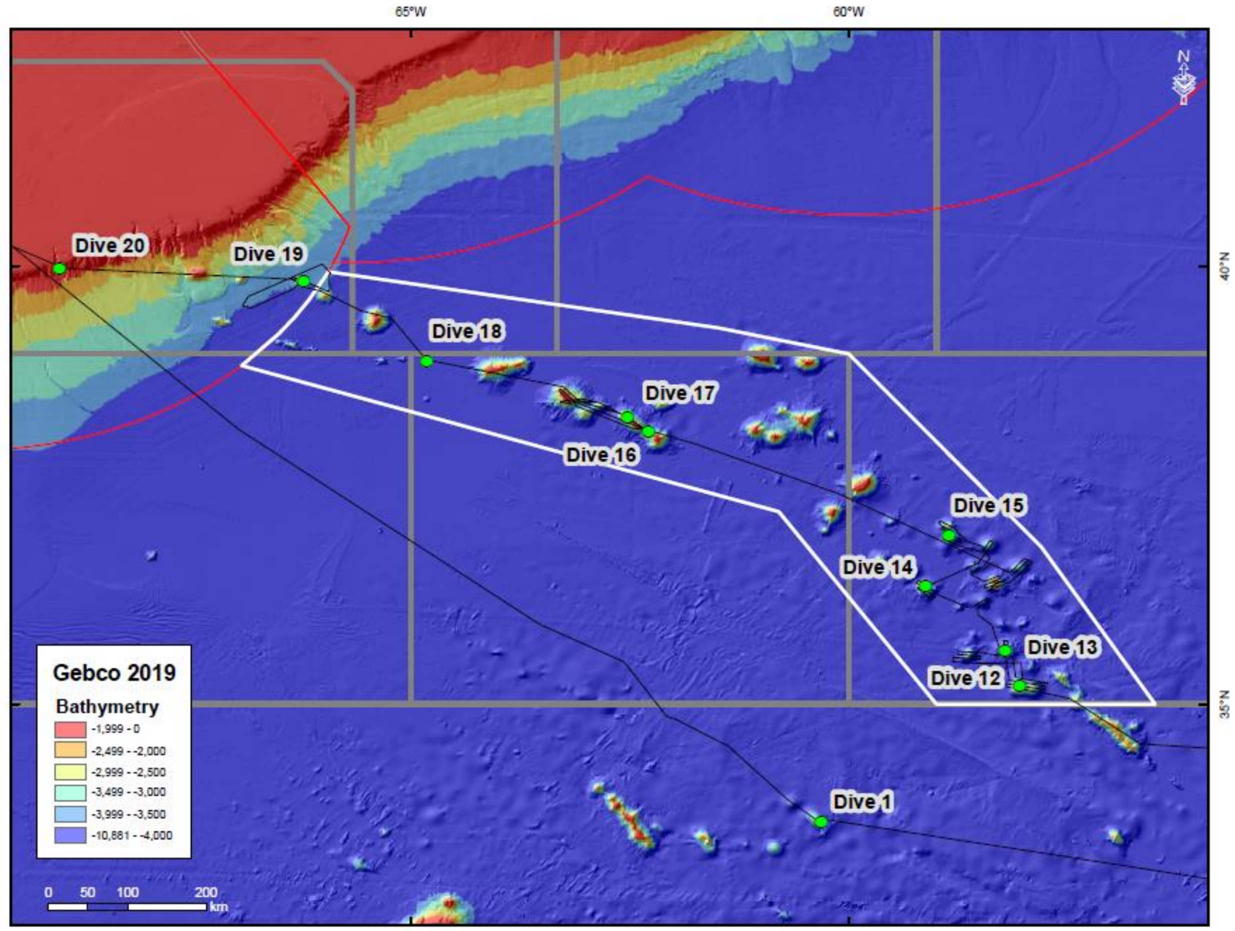

Figure 4.3. Location of the seven seamounts surveyed during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition. Dives 12, 13, 14, 15, 16, 17 and 18 are inside the NAFO New England Seamount Closure (white line). Cruise track is represented as a black line, and ROV dives are represented as green dots. NAFO Divisions are outlined in grey and the EEZs of United States and Canada are outlined in red.

Table 4.1. Summary of 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts expedition remotely operated vehicle dives on seamounts within the NAFO Closed Areas with a list of VME Indicator taxa observed. *Dives located in the new Corner Rise Seamount Protection Area that goes into effect January 1, 2022.

Dive	Date	Latitude	Longitude	Shallowest Depth (m)	Deepest Depth (m)	VME indicators observed
Corner Rise Seamount Chain NAFO area						
Dive 05: Rockaway Seamount*	July 8, 2021	35.819207°	-52.305386°	4,096	4,187	Deep-sea sponges, Stalked crinoids, Large gorgonian corals, Cerianthid anemones
Dive 06: Castle Rock Seamount*	July 9, 2021	36.300876°	-51.347289°	2,082	2,331	Deep-sea sponges, Stalked crinoids, Small gorgonian corals, Black coral
Dive 07: "Corner Rise 1" Seamount	July 10, 2021	35.890163°	-51.523687°	2,422	2,594	Small and Large gorgonian corals, Black coral, Deep-sea sponges
Dive 08: MacGregor Seamount	July 11, 2021	35.051091°	-48.969953°	939	1,272	Small and Large gorgonian corals, Black coral, Deep-sea sponge grounds
Dive 09: Yakutat Seamount – Shallow*	July 12, 2021	35.177792°	-48.116706°	1,192	1,366	Small and Large gorgonian corals, Black coral, Deep-sea sponges
Dive 10: Yakutat Seamount – Deep	July 13, 2021	35.265366°	-48.002336°	1,697	1,983	Stony corals, Small and Large gorgonian corals, Black coral, Deep-sea sponges
New England Seamount Chain NAFO area						
Dive 12: "Y" Seamount	July 17, 2021	35.222450°	-58.032272°	2,580	2,807	Large gorgonian corals, Black corals, Deep-sea sponges
Dive 13: "Near Hodgsen" Seamount	July 18, 2021	35.611445°	-58.206409°	2,359	2,531	Small and Large gorgonian corals, Black coral, Deep-sea sponges, Xenophyophores
Dive 14: "Seven" Seamount	July 19, 2021	36.348062°	-59.118589°	1,993	2,144	Small and Large gorgonian corals, Black coral, Deep-sea sponges
Dive 15: Allegheny Seamount	July 20, 2021	36.930406°	-58.858593°	3,336	3,447	Cerianthid anemones, Small and Large gorgonian corals, Black coral, Deep-sea sponges
Dive 16: Gosnold Seamount	July 23, 2021	38.134593°	-62.304282°	3,177	3,238	Small and Large gorgonian corals, Deep-sea sponges
Dive 17: Gosnold Seamount (Shallow)	July 24, 2021	38.293979°	-62.533148°	1,714	1,783	Small and Large gorgonian corals, Black corals, Stony corals, Deep-sea sponges, Stalked crinoids
Dive 18: Asterina Seamount	July 25, 2021	38.926941°	-64.820437°	3,784	3,792	Small and Large gorgonian corals, Sea pens, Black corals, Stony corals, Deep-sea sponges

Figure 4.4. Photo of a rare rock pen observed on Asterina Seamount (Dive 18) in the New England Seamount Chain. These are a type of sea pen that can attach to hard substrate as opposed to burying their rachis in the soft sediment to anchor the organism.

Figure 4.5. Deep-sea sponge grounds observed on MacGregor Seamount (Dive 8) in the New England Seamount Chain between 939 and 1272 m depth.

Additional summary information from the expedition can be found in the Expedition Summary (https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/features/summary/media/ex2104-summary.pdf). All data and products from the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts are free and publicly accessible available through the NOAA Archives using the expedition number “EX2104”. To access a summary and inventory of data available, please visit: https://www.ncei.noaa.gov/maps/oer-digital-atlas/mapsOE.htm?cruiseNum=EX2104 .

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Galvez, K., Cantwell, K., Hoy, S., Waller, R., Chaytor, J., Mizell, K. (2021). Expedition Report: EX-21-04, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (ROV and

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Waller, R., Cantwell, K., Lirette, C., Murillo, F.J. and Kenchington, E. (2021). Summary of the Vulnerable Marine Ecosystem Indicators Observed in the NAFO Closed Areas on the Okeanos Explorer Expedition "2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts". NAFO SCR Doc. 21/xx

THEME 2: STATUS, FUNCTIONING AND DYNAMICS OF NAFO MARINE ECOSYSTEMS

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

a) ToR 2.1. re-assessment of previously recommended closures of 7a, 11a, 14a and 14b (Commission Request #6a).

Conduct a re-assessment of its previously recommended closures of 7a, 11a, 14a and 14b, incorporating catch and effort data for fisheries of shrimp from 2020 and 2021 into the fishing impact assessments. This work is to be completed by the 2023 Scientific Council meeting.

i) Shrimp fishery update for reassessment of closures

The Commission has requested information about the effects that closures proposed by SC in 2021 would have on the shrimp fishery. For this purpose WG-ESA will produce two complimentary datasets in preparation for the upcoming reassessment of closures:

1. Yearly / Average effort (km/km2/year) for longlines, groundfish trawls and shrimp trawls from all VMS tracks 2010-2021 (split based on vessel information and reported catch)
2. Distribution of catch (unit to be determined) by fish species (including shrimp) from logbook-VMS combination derived trawl tracks starting from 2019 onwards, which have been linked to haul-by-haul catches in the logbook data.

The logbook-VMS data product has issues covered under 'Standard data products' and it must be interpreted with those gaps in mind.

ii) Data subgroup outcomes

Over the years WG-ESA has produced numerous summarised data products and GIS layers, both as results of analysis and for use in further analysis steps. Many of these data sets and layers are used by several members of the Working Group in regular assessments and need to be updated or reproduced for new analyses. The appropriate documentation of data collation and production steps, versioning and sharing within the Working Group has been identified as a priority area for development to ensure comparability and continuity in data products. Specifically, a subgroup was convened at the 2021 WG-ESA meeting to:

1. discuss and provide recommendations for a list of standard GIS data products and draft procedures for associated documentation including metadata;
2. review lessons learnt concerning inconsistencies in data used in analyses across the working group;
3. discuss possible solutions to data continuity through developing and maintaining a NAFO geodatabase; and
4. *plan how to prepare new fishing effort and integrated fishing effort/ log-book* data incorporating shrimp fishery data for the reassessment of VME closures by 2023.

The main two data sources used in analyses at WG-ESA are the scientific trawl catch data from EU and Canadian annual/seasonal surveys in the NRA and the Vessel Monitoring System (VMS) data collected by NAFO contracting parties and compiled by the NAFO secretariat. Both data are further processed to various data products through filtering, truncation and analysis. Currently there is no central repository for these data products, and they are shared between WG-ESA members on an ad-hoc basis. The data subgroup recommends that the data products listed below are assigned as standard WG-ESA data products with detailed descriptions of their source data, lineage and versioning and will be produced and updated through a data request and compilation by NAFO or a nominated member institute to be shared via an online platform.

Standard data products

Scientific trawl data has been used in many forms, from full trawl data with biomasses of fish and invertebrates identified to the highest level possible to total biomasses of taxa indicative of a VME type. The procedures behind preparation of this data are documented in the working group reports and some in SCR documents, but there is no agreed standard for preparation and presentation of such data sets. WG-ESA **recommends** that *trawl data products for at least 1) full fish and invertebrate trawl data, 2) VME biomass data and 3) functional group biomass data by trawl are compiled as documented and annually updated entries in a spatial database.*

By far the most well documented of all currently used data products are the VME polygons, polygons delineating functions (Bioturbation, Nutrient cycling, Habitat provision and Functional diversity), both derived from Kernel Density Estimation (KDE) analysis and 5 km and 1 km grids estimating VME biomass (kg/km2), which are all documented with detailed SCRs (NAFO SCR Doc. 19/058, NAFO SRC Doc. 20/071, NAFO SCR Doc. 20/072) and are available in a geodatabase. The VME polygons and biomass grids were last updated in 2019, whilst the functions polygons were first produced in 2020. WG-ESA **recommends** that *as a first step, the procedure demonstrated for the above products is followed for other data products and the geodatabases or map packages are made available via NAFO. A regular time interval, suited to the assessments the group is asked to do, should also be agreed for the update of the polygon and biomass grid products.*

Raw VMS data are compiled, filtered by speed to only include what can be expected to be fishing and assigned to enforcement, longline fishing and trawl fishing before being exported as point and line GIS features by the NAFO Secretariat. These data can be produced in a compatible format from 2010 onwards and the current protocol used to prepare them is described in detail in the WG-ESA 2019 Meeting Report (NAFO SCS Doc. 19/25). The group discussed further development of the filtered data and recommends that development of a further depth range filter for the VMS track data is explored. This analysis would calculate the range of depths observed for each track to identify any potentially spurious records. Fishing typically occurs along bathymetric contours and thus the expected range of depths is small. Larger observed depth ranges could be used to identify those tracks that do not depict real fishing activity. The analysis would examine the frequency distribution of all the VMS track depth ranges to determine a threshold to flag suspect tracks for removal.

A second data product from VMS data, under development by the NAFO Secretariat and IEO, combines the start and end coordinates of each commercial fishing haul, derived from vessel logbooks with the intervening VMS pings. This data product can be provided as points and lines per haul. However, inconsistencies in the way hauls are recorded in logbooks (e.g., some start and end coordinates appear to include multiple hauls) mean the data is currently not a straightforward haul by haul representation of fishing activity and needs more development. The groups recommends that the importance of accurate logbook recording is communicated to the fishing industry and that additional filtering protocols are determined, documented in an SCR and applied for the logbook-VMS combination datasets.

The VMS line data has been used to produce 1 km resolution raster layers representing fishing effort as estimated distance of trawl bottom contact (km/km2/year) by individual years and a multi-year average since 2010. The methodology for producing these layers is documented in the WG-ESA 2019 and 2020 Meeting Reports. The logbook-VMS point and line data can also be associated with the and haul by haul catches of selected fish species. Preliminary 1 km resolution raster layers of fish catch distribution in 2019 were produced for a small number of fish in 2020. These layers can be produced annually from 2019 onwards. There is also a need to produce similar layers for other target fisheries, including the shrimp fishery, for future assessments. WG-ESA **recommends** that *an SCR document is supplied to record the methodology for production of 1) VMS only fishing effort layers covering annual and mean effort from 2010 onwards; 2) Fishing effort layers based on logbook-VMS combination data covering annual and mean effort from 2019 onwards, and 3) distribution of annual catches of commercially caught fish species from 2019 onwards, and that these layers are made available through a geodatabase.*

Data documentation, storage and access

The group discussed how to improve on documentation of raw data and data products to ensure data are used appropriately and that references, which record methodology in sufficient detail, are provided to allow updating of data products using consistent methodology ensuring future reproducibility. Each data product or group of data products used in WG-ESA should include with it information about its source data, lineage and any potential amendments (version control), including the reference with detailed description of methodology. It is important that for each data product or data product group specific SCR documents are produced and kept updated along with the data. In addition, it is important that GIS metadata standards are investigated, and a suitable standard agreed upon for use by WG-ESA.

Currently all data products are shared with other members of the group on an ad-hoc basis, individually on request. WG-ESA **recommends** that *NAFO explore the feasibility of using ArcGIS Online/ ArcGIS Enterprise, or another spatial data portal, as a means to manage, visualize and share the core ecosystem data layers and derived products used by SC.*

Having a single point of access to an authoritative set of data layers would ensure that all members of WG-ESA are working with the same datasets in any analyses being conducted. Additionally, a QA/QC protocol would be established for datasets being submitted to the portal, whereby they would be reviewed by an appropriate WG member prior to being uploaded. A complete metadata record would be required for each dataset in the portal. At a minimum, it would include a data abstract, contact information for the individual who created the dataset, the planned update interval, and ideally, a link to an SCR or other reference material describing how the layers were generated. The exact metadata specification will require further discussion among the WG-ESA data sub-group members.

Lessons learned from data inconsistencies

In the recent years working with raster and polygon files, the different approaches of rasterising polygons and polygonising rasters and mixed analysis have led to differences in the resulting calculations. The group acknowledged that mostly these differences are minor but they need to be quantified and accounted for in future analyses and how they are reported.

Raster analysis works well with data that is stored in grids, and does not have distinct line boundaries, like the biomass and fishing effort data. It is quick and simple to use for scripted calculations including multiple variables and loops, which makes it more easily programmable and repeatable.

Some data have detailed boundaries, e.g. the VME polygons and especially the closed areas, where rasterization, especially at a lower spatial resolution loses boundary detail and makes calculations, especially those of area less precise. When comparing area derived from a polygon intersection analysis with polygons to that with a raster, discrepancies are inevitable. At a 1 km raster cell size over the NRA the differences are mostly minimal, and we can accept and caveat variability less than 1% of the total and deal with the discrepancy by rounding values up to set number of significant figures, where the difference disappears, when reporting numbers.

WG-ESA **recommends** that *in also recognises the future a decision is made on what importance of ensuring data spatial analysis method is most suitable to the data being used, and the same methods are consistently applied without change in approach used each time.(including rounding errors) unless otherwise agreed by the whole group.* Where the appropriate method differs between and agreed methods applied by two analysesindependent analysts generate substantial differences (beyond rounding errors) these will be further investigated before agreeing which nevertheless both produce area estimates that must be comparable, a decision should be taken on the precision of numbers reported to avoid discrepanciesdata product to use.

b) ToR 2.2. Review the VME biomass data provided to SC for inconsistencies in the impact assessment calculations.

This ToR was addressed within ToR 2.1

c) ToR 2.3. Up-date on analysis to improve methods for determining the area of impact for SAI.

Introduction

The Northwest Atlantic Fisheries Organisation (NAFO) is responsible for the management of fisheries in its regulatory area, principally the areas of the Grand Banks, and the Flemish Cap and Pass seaward of the Canadian and US EEZs. These areas are inhabited by a number of species considered indicative of the presence of Vulnerable Marine Ecosystems (VME), the conservation of which is due special consideration under several UN General Assembly agreements (e.g., UNGA 61/105, the FAO Fish

Stocks Agreement). In the NAFO Regulatory Area (NRA) there are seven groups of taxa that are considered VME indicator species (Table 5.1).

Table 5.1. List of VME indicator species/ taxa as listed in NAFO Conservation and Enforcement Measures 2020 (Annex 1 E VI) and considered here. Abbreviated genus names follow most recent full name. Number of taxa given in (). Where there are relatively many listed, most taxa are rare and those comprising >5 % of total group biomass from surveys are given in bold, if known.

Taxa	Taxonomy	Species included	
Black Corals (4)	Cnidaria – Antipatharia Families: Leiopathidae, Schizopathidae, Antipathidae	Leiopathes sp. Stichopathes spp.	Stauropathes arctica Antipatharia spp.
Boltenia (1)	Tunicata – Ascidiacea Family: Eucrateidae	Boltenia ovifera	
Bryozoa (1)	Bryozoa Family: Pyuridae	Eucratea loricata	
Large Gorgonians (17)	Cnidaria – Alcyonacea Families: Acanthogorgiidae, Corallidae, Chrysogrogiidae, Primnoidae, Paragorgiidae, Plexauridae	Acanthogorgia armata Calyptrophora sp. Corallium bathyrubrum C. bayeri Iridogorgia sp. Keratoisis siemensii K. grayi Lepidisis sp. Paragorgia arborea P. johnsoni	Paramuricea spp. P. grandis P. placomus Parastenella atlantica Placogrogia sp. P. Terceira Thouarella grasshoffi
Sea Pens (13)	Cnidaria – Pennatulacea Families: Anthoptilidae, Protoptilidae, Funiculinidae, Halipteridae, Kophobelemnidae, Pennatulidae, Umbellulidae, Vrigulariidae)	Anthoptilum grandiflorum Distichoptilum gracile Funiculina quadrangularis Halipetris sp. H. christii H. finmarchia Kophobelemnon stelliferum	Pennatula sp. P. aculeata P. grandis Protoptilum carpenter Umbellula lindahli Virgularia mirabilis
Small Gorgonians (6)	Cnidaria – Alcyonacea Families: Isisidiae, Anthothelidae, Chrysogrogiidae, Primnoidae, Plexauridae	Acanella arbuscula Anthothela grandiflora Chrysogorgia sp.	Metallogorgia melanotrichos Narella laxa Swiftia sp.
Sponges (28)	Porifera – Hexactinellida/ Demospongiae Families: Rosellidae, Aphrocallistidae, Cladorhizidae, Axinellidae, Tetillidae, Euplectellidae, Esperiopsidae, Coelosphaeridae, Geodiidae, Chalinidae, Acarnidae, Isodictyidae, Mycalidae, Polymastiidae, Ancorinidae, Pachastrellidae	Asconema foliate Aphrocallistes Beatrix Asbestopluma ruetzleri Axinella sp. Chondrocladia grandis Cladorhiza abyssicola C. kenchingtonae Craniella spp. Dictyaulus romani Esperiopsis villosa Focepia spp. Geodia barretti G. macandrewii G. parva G. phlegraei	Haliclona sp. Iophon piceum Isodictya palmata Lissodenoryx complicate Mycale lingua M. loveni Phakellia sp. Polymastia sp. Stelletta tuberosa Stryphnus fortis Thenea muricata T. valdiviae Weberella bursa

Kernel Density Estimates (KDEs) have been created that encompass significant aggregations of each of these species groups in the NRA (SCS Doc. 14-23; SCR Doc. 19-58). As part of NAFO's ongoing commitment to adopting an ecosystem approach to fisheries, this information has been paired with estimates of fishing intensity in previous analyses (SCS Doc. 14-23; 20-23) to inform status in terms of the areal extent of each VME indicator species group that is considered to have been subject to Significant Adverse Impacts (SAI).

Methods

VME species biomass is lower in areas that are subject to increased trawl fishing intensity. However, it remains a point of contention whether this relationship is causal or coincidental, the latter being perhaps because vessel operators deliberately avoid areas where VME species are more concentrated, to avoid gear fouling or damage. Therefore, the second aim of the present work is to determine if fishing pressure has a genuine effect of removing VME species biomass. The previous analysis (SCS Doc. 20-23) was modified such rather than fitting biomass accumulation against ranked, cumulative fishing intensity, fishing intensity was instead randomised. The median and confidence intervals from 1000 randomisations was then compared with the previous values calculated from the ranked curves. This approach tests the following specific null hypothesis: Fishing intensity is not a significant driver of trends in VME species biomass and there will be no difference between VME species biomass accumulation curves against ranked or randomised fishing intensity.

To determine the level of fishing intensity that is considered to have impacted each VME group, the previous analysis (SCS Doc. 20-23) compared cumulative biomass (from trawl survey series) against ranked, cumulative fishing intensity (measured as km of trawl track, per square kilometre, per year – mean of the 2010-19 period). Survey trawls in areas with low values of fishing intensity tended to be those with the greatest biomass of VME species and these curves generally assumed a steep initial phase of accumulation that sharply slowed towards the asymptote (100%), but the specific shape of the function was specific to taxa. These curves were then used to calculate the fishing intensity value that equated to 95% of biomass removed (i.e., 5% of VME species biomass remaining, and SAI considered to have occurred). This value of fishing intensity (2010-19 data, 1km^2 resolution) was then used within each of the KDE polygons to determine the area of each VME that was either impacted (i.e., above the 95% cut-off), not impacted, or protected to fishing.

There were however queries regarding the use of 95% as the cut-off, given that this represents a near total removal of VME indicator species biomass and expected commensurate reductions in ecosystem function and provision of ecosystem services. The present work in part aims to determine if there are any emergent relationships in the species response curves that support the use of alternative biomass accumulation percentages. The previous analysis considered three categories: 'Protected/ Outside Fishing Footprint' (i.e., no fishing); 'Impacted' (i.e., areas above fishing intensity at 95% biomass loss cut-off); and 'At Risk' (i.e., fishing occurred but below the intensity cut-off). Here however, these categories have been altered for further clarity, such that:

- 'Protected/ Outside Fishing Footprint (FF)' means any area where fishing is not permitted (as in the previous analysis).
- 'At Risk' now means any area where fishing is permitted but did not occur in 2010-19.
- 'Impacted' is now split into two categories, recognising that VME species in areas where fishing has occurred to a level less than the given cut-off will likely be impacted to some degree, albeit not to the extent of being considered SAI:
- 'Above cut-off '; and
- 'Below cut-off',

We re-estimated the number of cells within each of the VME KDE polygon groups that would be considered as belonging to each of these categories using cut-off values between 0 – 100% in increments of 5%. The number that are protected or at risk does not vary, so the effect of doing so is that the ratio between 'Impacted (above cut-off)' and 'Impacted (below cut-off)' varies, the proportion of the latter increasing non-linearly with the cut-off value.

Results and Discussion.

Does trawl fishing intensity significantly reduce VME species biomass?

Excepting bryozoans and black corals, all VME species groups had a significantly larger value of fishing intensity that equated to 95% biomass loss (Figure 5.1; 5.2). This further demonstrates that VME species biomass is higher in areas of lower trawl fishing intensity, and strongly implicates fishing intensity as an important driver of patterns in VME species biomass. Conclusions regarding black coral are limited by the small range of fishing intensity values over which survey biomass data are available. Black corals are absent in survey data from all areas where trawl fishing intensity exceeds 1.040 km/km^2/yr (equating to 16.8% of the total area of black coral KDE polygons[1]).

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[1] In total, 56.2% of the area within the black coral KDE polygons is estimated to be exposed to some level of trawl fishing (Table 5.3)

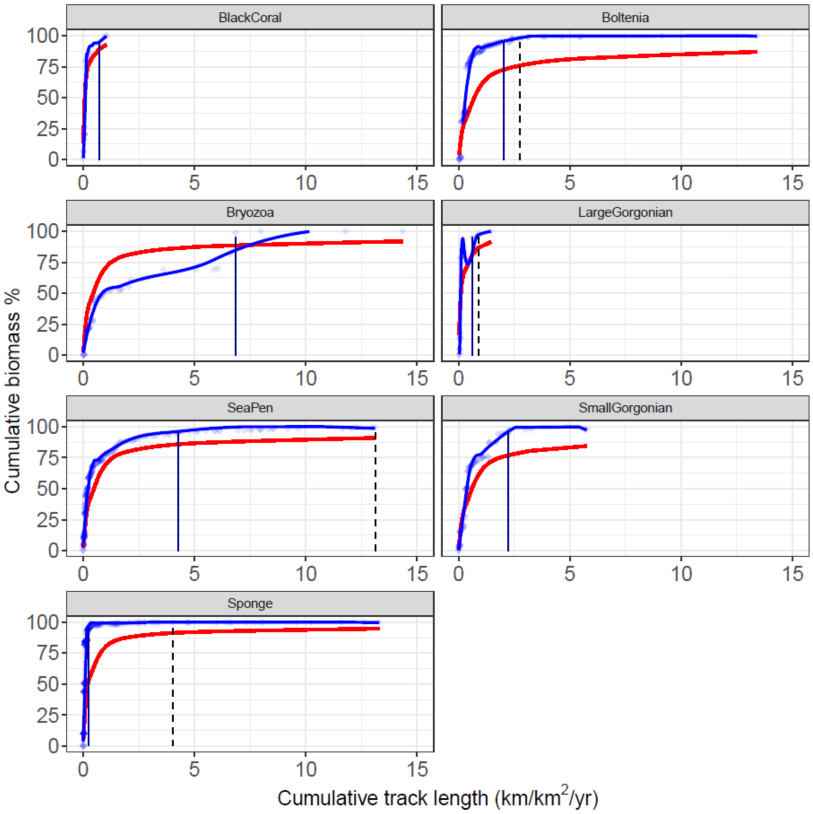


Figure 5.1. Biomass accumulation curves against ranked (blue) and randomised (red) fishing intensity. The red line represents a logistic GAM fit of the 1000 individual, randomised curves. The solid intersect = the 95% cut-off for ranked curves and the dashed intersect = median 95% cut-off for randomised curves. Dashed intersect not shown for Small Gorgonians (33.74 km/km^2/yr). Dashed and solid intersects overlap for Black Corals and Bryozoans (see Figure 5.2).

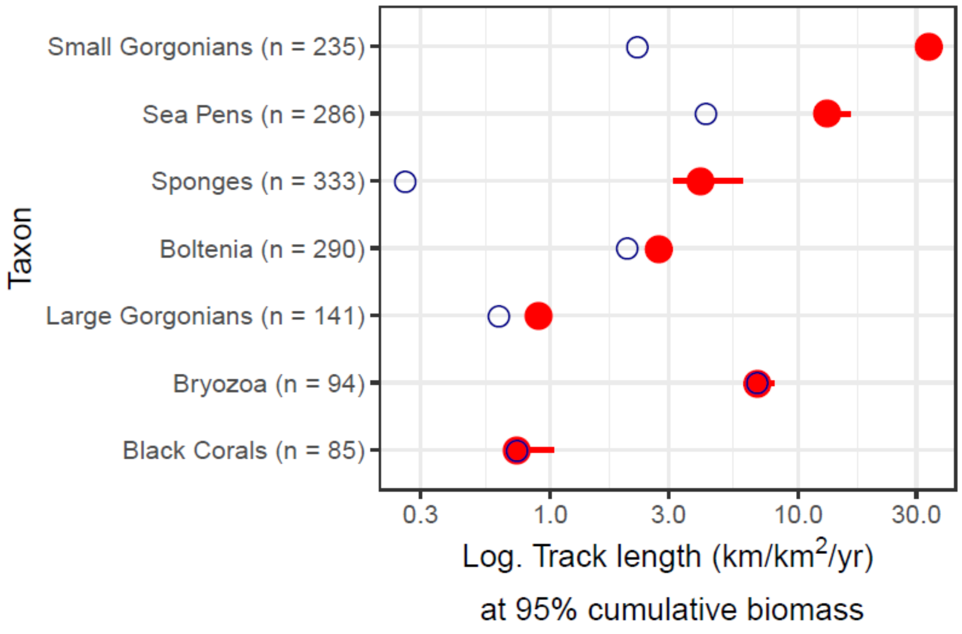


Figure 5.2 Comparison of trawl fishing intensity cut-off values at 95% biomass accumulation for ranked (hollow blue circles) and randomised (solid red circles +/- 95% confidence intervals). Y-axis ordered by effect size.

Sample sizes varied widely between taxa, with those taxa that had the fewest data also having the smallest effect size (namely, bryozoans, black corals, and large gorgonians; Figure 5.2). There was a weak correlation (0.29) between the difference in the absolute ranked and randomised trawl fishing intensity cut-off values and the number of replicates, and a strong correlation (0.78) between relative (i.e., %) difference and sample size (Table5.2). This suggested that the effect size may have been overestimated for sponges, sea pens and small gorgonians, and similarly underestimated for large gorgonians and black corals.

Table 5.2. Summary of data presented in Figure 2, and summary statistics.

Taxon	Sample size	Cut-off of fishing intensity that equated to 95% VME biomass loss (km/km²/yr)		Difference	
		Ranked	Randomised (Median + C.I. range)	Absolute (km/km²/yr)	Relative (ranked as % of median)
Black Corals	85	0.734	0.734 (0.734-1.029)	0.00	100.00
Boltenia	290	2.046	2.746 (2.643-2.861)	0.70	74.51
Bryozoa	94	6.845	6.845 (6.845-7.980)	0.00	100.00
Large Gorgonians	141	0.620	0.896 (0.871-0.896)	0.28	69.22
Sea Pens	286	4.253	13.114 (12.979-16.225)	8.86	32.43
Small Gorgonians	235	2.248	33.744 (32.452-34.058)	31.50	6.66
Sponges	333	0.260	4.037 (3.145-5.978)	3.78	6.45

No difference between ranked and randomised response curves was observed for bryozoans, but this taxon also demonstrated a different functional response across the spread of biomass accumulation cut-offs considered here (Figure 5.3). Aside from bryozoans, the relationship between biomass accumulation cut-off (%) and trawl fishing intensity assumed a similar three-phase shape with comparatively steep gradients generally between 0-20% and 80-100%, separated by a much more gradual increase in between (Figure 5.3). For instance, the difference in fishing intensity that represented 25% and 75% of biomass loss among black corals or large gorgonians equated an increase in the trawl fishing intensity cut-off of just 0.024 or 0.014 km/km^2/yr respectively, meaning that a very modest reduction in areas actively used by the fishing industry could, in the right situation, represent a substantial difference in the status assessment of some VMEs. Other taxa, such as sea pens or small gorgonians, still assumed the same three-phase relationship but with the middle section being notably steeper.

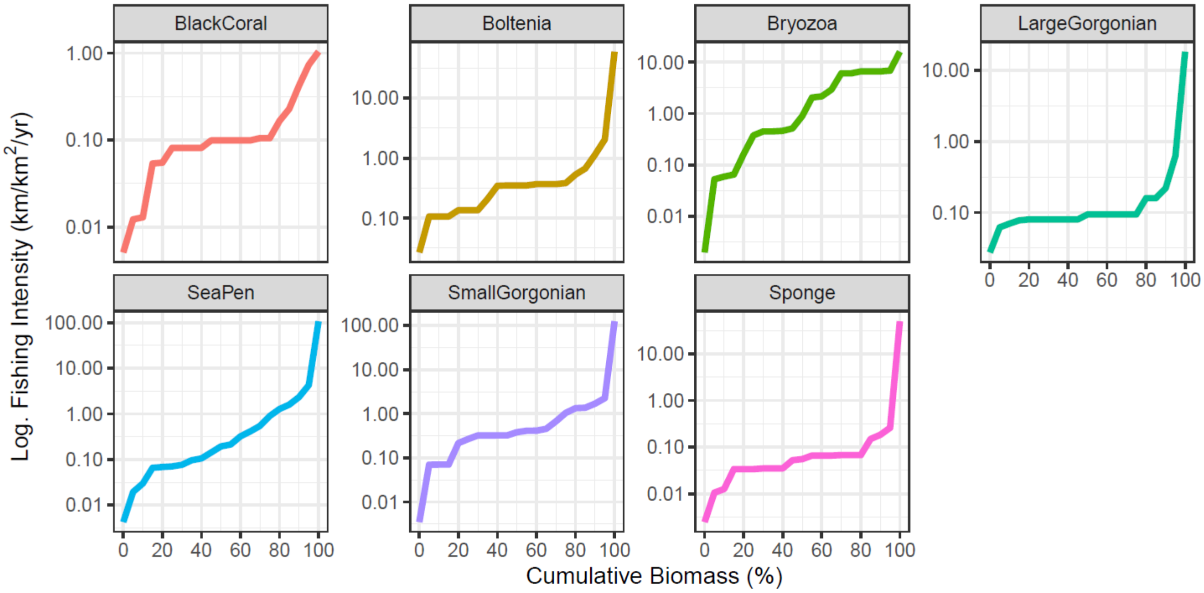


Figure 5.3. Fishing intensity equivalent per cumulative biomass cut-off per taxa.

In addition to the limitations of this analysis that relate to sample size, particularly for large gorgonians and black corals but also potentially for those taxa with larger sample sizes, there are some caveats to note.

Firstly, in the trawl survey database, the distributions of both the VME species biomass and commercial fishing intensity are abnormally distributed and are heavily weighted towards low values (zeroes excluded) interspersed with few records that comprise a large proportion of the total of each. Whilst the distribution effects are to an extent accounted for in the design of the GAM, through the specified model distribution, the randomisation does not alter the underlying data and so, for some VME species, much of the biomass accumulation is influenced by where these large values happen to occur. This creates a series of curves whose shape assumes a step-wise increase, which is most evident in the Boltenia and sponge curves (Appendix 1). This is also the reason that the median 95 % cut-off in the Boltenia panel (dashed line; Figure 5.1) appears to be lower than might be predicted by the GAM fit (red line; Figure 5.1).

Secondly, each of the VME groups actually accounts for several species and so, particularly for sponges, large and small gorgonians and sea pens, the response curve is potentially an amalgamation of the response curves of each individual species (Table 5.1). In sponges, this amalgamation effect is likely only quite small, since the vast majority (>90%) of the biomass is driven by *Geodia* spp. and so any between-species effects are mostly confined to a single genus. Large gorgonians and sea pens however are a combination of species from several families, each of which have different physiologies and habitat preferences and, potentially, different susceptibilities to trawl fishing disturbance.

Evaluating alternatives to the previous biomass accumulation cut-off

We compared the count and proportions of cells ($1km^2$ grid) that belonged to each of the four classes for each of the VME taxa and cut-off values considered (Figure 5.4). The proportion of cells within KDE polygons that is either 'protected' or 'at risk' does not vary according to cut-off but does underline some important differences between VMEs namely that some are afforded far more protection than others, and that closure of areas that are never or minimally used by the fishing industry (2010-19 data) could offer substantive gains in protection status. For instance, small gorgonians presently have around 1.8% of their KDE polygon area that is closed to fishing, but by extending that to areas that were never fished in 2010-19, this would increase to around 17.4%. Further including areas that have likely only been fished 2-4x in the entire 2010-19 period (equating to a fishing intensity of around 0.2 $km/km^2/yr$, or 20% loss of small gorgonian biomass), would increase the proportion of protected small gorgonian habitat to 37.3%.

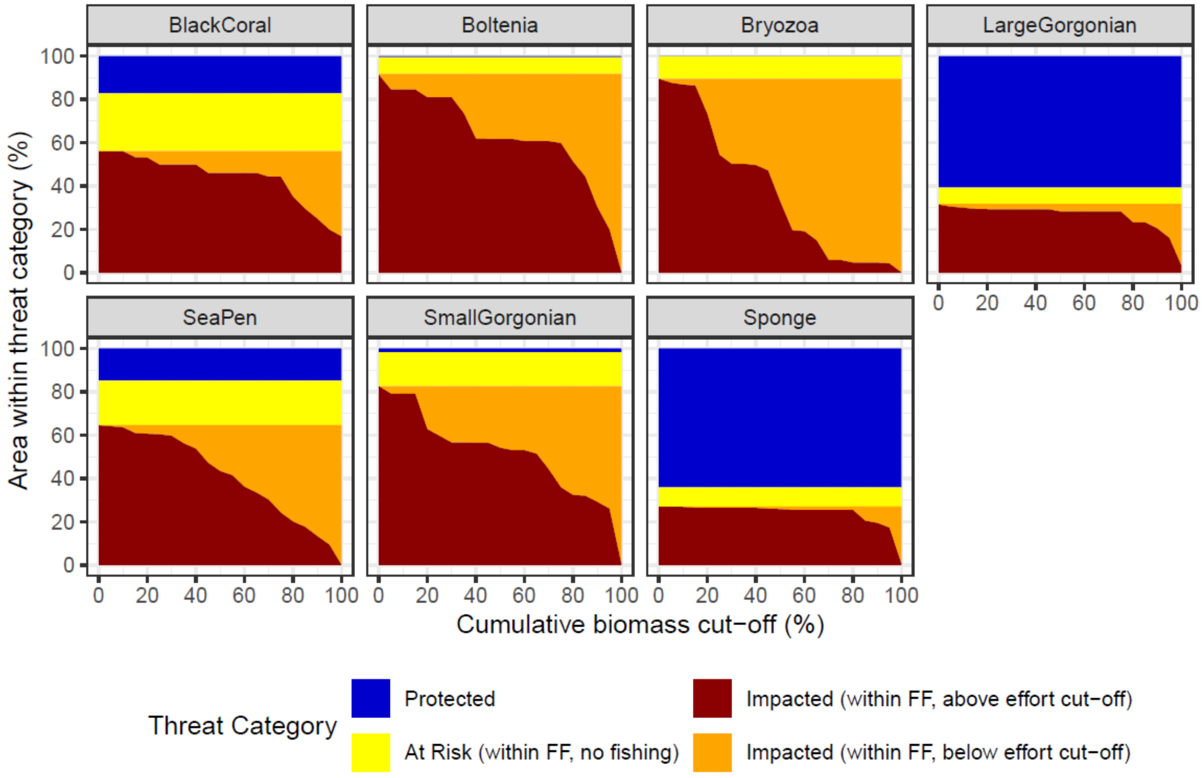


Figure 5.4. Relationship between cut-off value and the percent of cells within respective KDE polygons belonging to each impact class. These calculations do not include the extensions and additions to the closed area network that were adopted by the NAFO Commission in 2021. FF = NAFO Fishing Footprint.

Each VME species group showed somewhat distinct shifts between the impacted above- and below-cut-off categories with increasing cut-off values. The specific shape of these relationships depends in large part upon the spatial distribution of biomass and fishing effort within each of the KDE polygons, which both exhibit strong spatial autocorrelation. That said, sponges, large gorgonians, black corals and Boltenia all demonstrated sharp increases in the rate of biomass loss above cut-off values in the range 75-80% (see Figure 5.3 for non-spatially explicit equivalent). For small gorgonians, this inflection point occurred at around 65%. Similar breaks in the response curves were absent from both the sea pen and bryozoan data.

Table 5.3. Summary of estimated SAI biomass accumulation reference points (biomass cut-off %) and associated trawl fishing intensity values and summary of areas within each category at given level. Full data available in Appendix 2. Sea pens and bryozoans not reported (given as '-') since no clear inflection point was observed; figures for impacted areas given as combined.

Taxon	Proposed SAI reference point (%)	Equivalent trawl fishing intensity cut-off (km/km^2/yr)	Area within each category at proposed cut-off (% & km^2)			
			Protected/ Outside FF	At Risk	Impacted (above proposed cut-off)	Impacted (below proposed cut-off)
Black Corals	75	0.105	17.2% 453 km^2	26.6% 701 km^2	44.3% 1166 km^2	11.9% 313 km^2
Boltenia	80	0.533	0.6% 26 km^2	7.6% 312 km^2	51.3% 2098 km^2	40.4% 1654 km^2
Bryozoa	-	-	0.1% 5 km^2	10.3% 361 km^2	89.5% 3132 km^2	
Large Gorgonians	75	0.094	60.7% 3060 km^2	7.6% 381 km^2	28.3% 1425 km^2	3.5% 177 km^2
Sea Pens	-	-	15.0% 1271 km^2	20.5% 1740 km^2	64.5% 5487 km^2	
Small Gorgonians	65	0.455	1.8% 82 km^2	15.6% 709 km^2	51.4% 2333 km^2	31.2% 1418 km^2
Sponges	80	0.068	64.2% 15871 km^2	8.8% 2177 km^2	25.4% 6281 km^2	1.6% 385 km^2

It is not possible to say, purely from VME indicator species biomasses to what extent selecting a value in this range as the definition of SAI, as opposed to the previous value of 5%, might improve the realism of broader conclusions regarding the preservation of ecosystem function. However, the emergent properties of this analysis are useful for the purposes of selecting a more ecologically justified reference point for determining areas where SAI are thought to have occurred, at least some species (Table 5.3). For sponges, black corals and large gorgonians, these cut-offs equate to areas only rarely used by the trawl fleets. For sponges, black corals and large gorgonians, these cut-off values still equate to areas only rarely trawled by fisheries between 2010 - 2019.

Despite the lack of clear inflection points in either the bryozoans or sea pens, the point regarding the suitability of using a fishing intensity cut-off that equates to 95% biomass loss still stands. Sea pens are certainly susceptible to trawl fishing intensity (Figure 5.2; Table 5.2). The lack of a clear inflection point may be owing to the particular relationship between distribution of trawl fishing intensity and biomass, and the intrinsic vulnerability and recovery rates of sea pens. There is as yet no empirical case for increasing the cut-off value for sea-pens to a specific quantity, though it still may be most suitable to select SAI classifications based on similar values to those selected for other species groups (ca. 75-80%; Table 5.3), or to use 65% for all taxa in line with the precautionary approach.

Summary and conclusions

The statistical analysis presented here reveals that VME species biomass tends to be higher in areas of VME which are subject of lower trawl fishing intensity, which strongly implicates fishing intensity as an important driver of patterns in VME species biomass.

Aside from bryozoans, the relationship between biomass accumulation (%) and trawl fishing intensity assumed a similar ‘three-phased’ response, with a first phase exhibiting a comparatively steep gradient in cumulative biomass (generally occurring between 0-20%), a second phase exhibiting a much more gradual increase and finally a third phase where again there is a comparatively steep gradient in cumulative biomass (80-100%). The nature and shape of the response curves possibly reflects different underlying ecological characteristics of each of the VMEs types as described in this analysis, especially in relation to their sensitivity to bottom trawling impacts.

The emergent properties of this analysis are therefore useful for the purposes of selecting a more ecologically justified reference point for determining areas where SAIs are thought to have occurred, at least for the VME types recognised by NAFO. Accordingly, cut-off values of between 75-80% of the cumulative biomass would seem more applicable for some VMEs when conducting SAI assessments compared to the currently applied 95% value. Indeed, for small gorgonians a value nearer 65% would seem more appropriate. Therefore, given the observed VME specific differences in the response curves based upon this analysis, there may be some justification for applying VME specific cut-off values when conducting the next assessment of SAI.

It is noteworthy that relatively small changes in cut-off values for SAI can have a large effect on the proportion of VME biomass both impacted and potentially protected. For example, protecting areas of small gorgonian VME that have likely only been fished approximately 2 – 4 times between 2010 - 19 (equating to a fishing intensity of around 0.2 km/ km^2/yr, or 20% loss of small gorgonian biomass), would increase the proportion of small gorgonian VME protected from its current value of 1.8% to 37.3%.

References

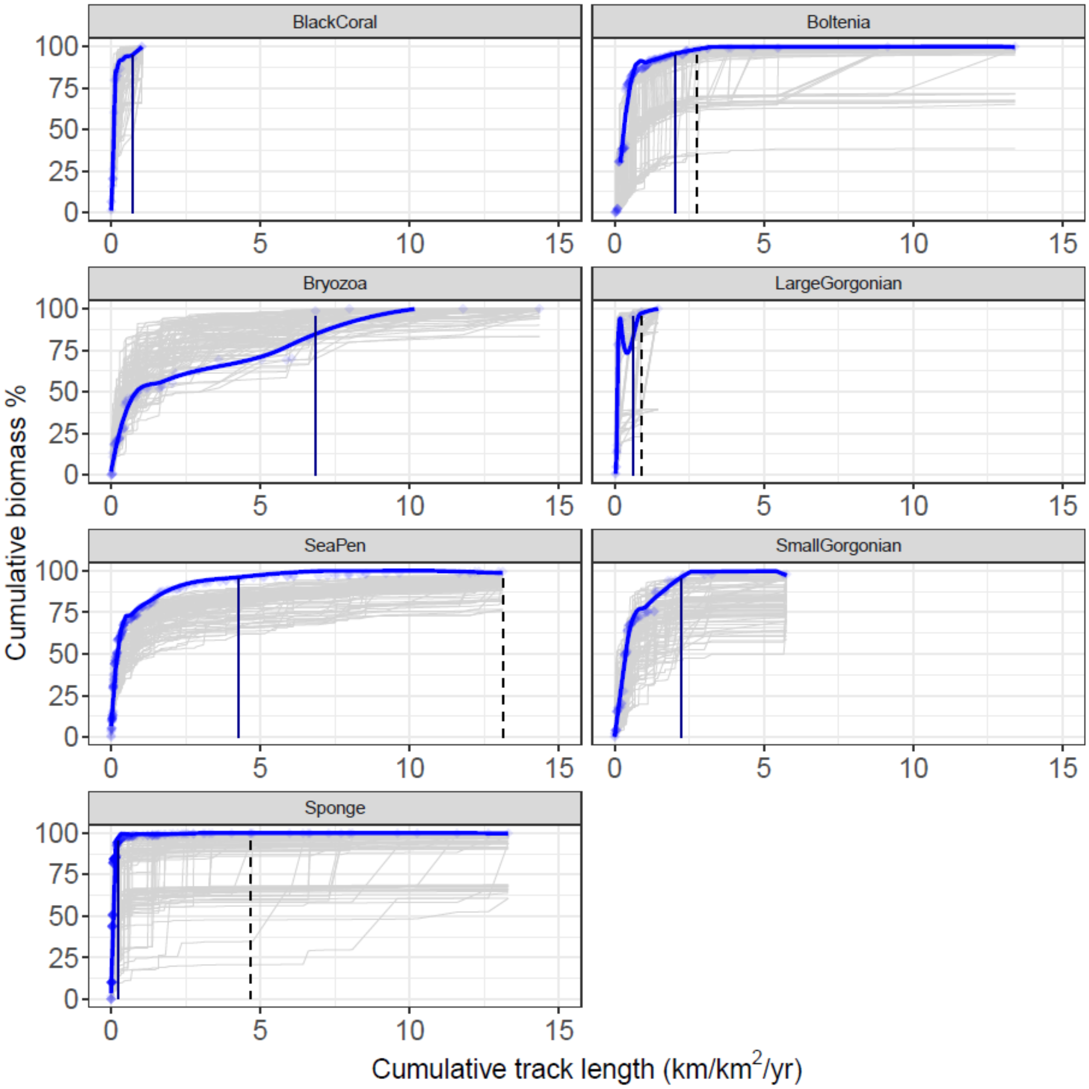
NAFO SCS 14-23 – NAFO Scientific Council Working Group on Ecosystem Science and Assessment – November 2014. Report of the 7th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO, Dartmouth, NS, Canada. 126 pp.

NAFO SCS 15-19 – NAFO Scientific Council Working Group on Ecosystem Science and Assessment – November 2015. Report of the 8th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO, Dartmouth, NS, Canada. 176 pp.

NAFO SCS 20-23 – NAFO Scientific Council Working Group on Ecosystem Science and Assessment – November 2015. Report of the 13th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO, Dartmouth, NS, Canada. 270 pp.

NAFO CEM 2020 – NAFO Conservation and Enforcement Measures 2020. 192 pp.

Appendices



Appendix 5.1. Equivalent of Figure 5.1 but with individual response curves (grey lines) instead of the fitted GAM. The solid intersect = the 95% cut-off for ranked curves and the dashed intersect = median 95% cut-off for randomised curves. Dashed intersect not shown for Small Gorgonians (33.74 km/ km2/yr). Dashed and solid intersects overlap for Black Corals and Bryozoans (see Figure 5.2).

Appendix 5.2. Trawl fishing intensity values that equate to different cut-off levels of biomass loss, per VME taxa. Data represented in Figure 5.3.

Taxon	Biomass cut-off (%)	Trawl fishing intensity (km/km²/yr)	Taxon	Biomass cut-off (%)	Trawl fishing intensity (km/km²/yr)
Black Corals	0	0.0051	Sea Pens	0	0.0042
	5	0.0122		5	0.0194
	10	0.0129		10	0.0297
	15	0.0538		15	0.0656
	20	0.0550		20	0.0683
	25	0.0813		25	0.0705
	30	0.0813		30	0.0762
	35	0.0813		35	0.0960
	40	0.0813		40	0.1052
	45	0.0991		45	0.1421
	50	0.0991		50	0.1929
	55	0.0991		55	0.2126
	60	0.0991		60	0.3208
	65	0.0991		65	0.4108
	70	0.1052		70	0.5429
	75	0.1052		75	0.8963
	80	0.1660		80	1.2730
	85	0.2286		85	1.5895
	90	0.4228		90	2.3222
	95	0.7339		95	4.2527
	100	1.0400		100	106.8670
Boltenia (Boltenia ovifera)	0	0.0268	Small Gorgonians	0	0.0035
	5	0.1065		5	0.0699
	10	0.1065		10	0.0705
	15	0.1065		15	0.0705
	20	0.1360		20	0.2158
	25	0.1360		25	0.2666
	30	0.1360		30	0.3219
	35	0.2100		35	0.3219
	40	0.3462		40	0.3226
	45	0.3511		45	0.3226
	50	0.3511		50	0.3809
	55	0.3511		55	0.4108
	60	0.3692		60	0.4129
	65	0.3692		65	0.4545
	70	0.3692		70	0.6733
	75	0.3841		75	1.0438
	80	0.5328		80	1.3342
	85	0.6717		85	1.3664
	90	1.1445		90	1.6912
	95	2.0457		95	2.2483
	100	59.5314		100	124.5050
Bryozoans (Eucratea loricata)	0	0.0020	Sponges	0	0.0025
	5	0.0526		5	0.0105
	10	0.0593		10	0.0126
	15	0.0651		15	0.0338

	20	0.1631		20	0.0338
	25	0.3764		25	0.0338
	30	0.4490		30	0.0349
	35	0.4490		35	0.0349
	40	0.4616		40	0.0349
	45	0.5135		45	0.0524
	50	0.8927		50	0.0553
	55	2.0504		55	0.0659
	60	2.1620		60	0.0659
	65	2.9363		65	0.0659
	70	6.0514		70	0.0675
	75	6.0514		75	0.0675
	80	6.6153		80	0.0675
	85	6.6153		85	0.1494
	90	6.6153		90	0.1841
	95	6.8448		95	0.2602
	100	16.0137		100	50.4885
Large Gorgonians	0	0.0274			
	5	0.0618			
	10	0.0697			
	15	0.0775			
	20	0.0799			
	25	0.0799			
	30	0.0799			
	35	0.0799			
	40	0.0799			
	45	0.0799			
	50	0.0939			
	55	0.0939			
	60	0.0939			
	65	0.0939			
	70	0.0939			
	75	0.0939			
	80	0.1591			
	85	0.1591			
	90	0.2194			
	95	0.6204			
	100	18.2080			

d) ToR 2.4. Up-date on analysis to better understand the functional significance of VME for fish.

Background

Understanding of the associations between demersal fishes and shellfishes and VMEs is important to further the development of ecosystem-based approaches to fisheries management. The work presented here builds on the results of multivariate analysis of fish and invertebrate communities described in the WGESA 2020 report (NAFO 2021), where six distinct fish/invertebrate clusters were identified within the NAFO regulatory area (NRA) in 2020. The assemblage cluster groups were found to be strongly structured by depth and geographical area (Figure 5.5a and b). A deep-water group (~500-1500 m) around the Flemish Cap and along the slope of the Grand Bank separates two shallower water groups (~150-300 m and ~300-500 m) on the top and edge of the Flemish Cap from three other shallow water groups on top of the Grand Bank (~45-90 m and ~90-200 m) and along Sackville Spur and on the tail of the Grand Bank (200-500 m).

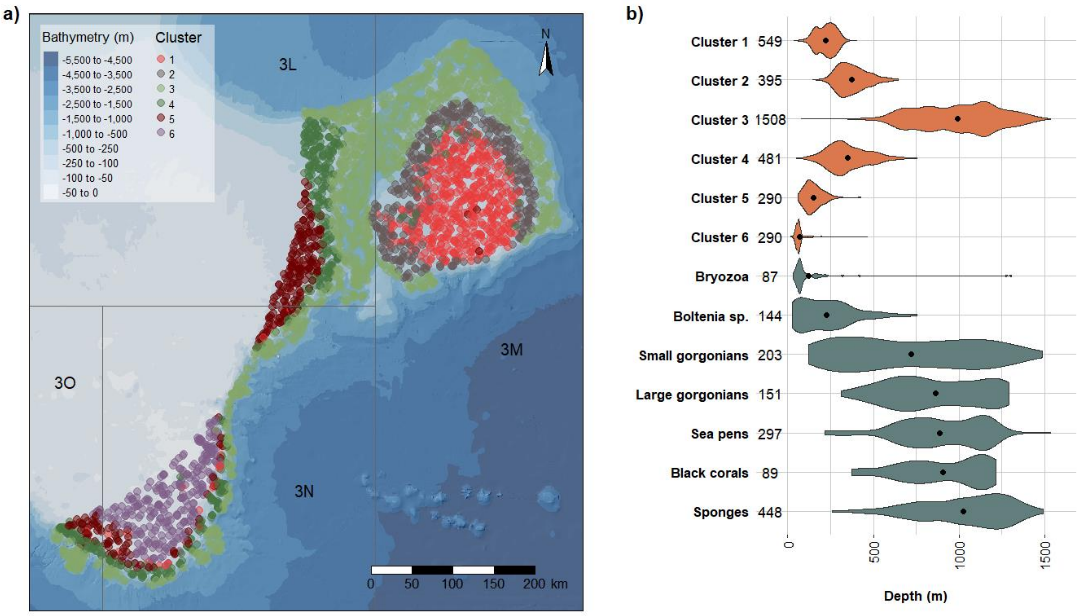


Figure 5.5. Map showing the spatial distribution of fish / invertebrate assemblage groups from cluster analysis in 2020 (a) and the depth ranges of the six cluster groups as well as the VME categories (based on 2019 KDE polygons; Kenchington et al. 2019) (b). Each violin plot has equal area. Number of samples in each cluster / VME is shown to the left of the plot. Points inside violins indicate the mean depth.

Most VME (black corals, large and small gorgonians, sea pens and geodid sponges) were found to belong to the deep-water assemblage (group 3). *Asconema* spp. sponges were associated with assemblage group 4 and smaller assorted sponges, not identified beyond Phylum were found associated with groups 1 – 5. *Boltenia* spp. and other ascidians were associated mainly with group 4, but also to a lesser extent with groups 5 and 6, whilst bryozoans were associated with groups 5 and 6 (Table 5.4). The depth ranges of the VMEs, however, do not completely coincide with the depth ranges of the fish/ invertebrate assemblage groups (Figure 5.5b). The concentration of most VME in one group and simultaneous spanning on multiple groups by some VMEs prompted additional questions about the nature of the fish interactions with specific VMEs.

Table 5.4. Main fish taxa and VME associated with each of the six assemblage groups resulting from cluster analysis done in 2020 (NAFO 2021).

	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Fish	Blue hake (Antimora rostrata) Grenadiers (*Coryphaenoides* sp.) Cutthroat eel (*Synaphobranchus* sp.) Black dogfish (Centroscyllium fabricii) Greenland halibut (Reinhardtius hippoglossoides) Rattails (*Nezumia* sp.) Roughhead grenadier (*Macrourus berglax*)	Rockfish (Sebastes sp.) Silver hake (Merluccius bilinearis)	Capelin (Mallotus villosus) American plaice (Hippoglossoides platessoides) Thorny skate (Amblyraja radiata) Eelpout (*Lycodes* sp.)	Yellowtail flounder (*Limanda ferruginea*) Northern sand lance (*Ammodytes dubius*)
VME	Black corals Large gorgonians Small gorgonians Sea pens Sponges (mainly *Geodia* spp.)	Boltenia sp. Sponges (*Asconema* sp.)	Boltenia sp. Bryozoans	Boltenia sp. Bryozoans

The strong geographical separation of groups further raised questions on the comparability of communities derived from the three fisheries surveys targeting different NAFO divisions (3M around the Flemish Cap, 3L along Sackville Spur and the edge of the Grand Banks and 3NO on the tail of the Grand Banks). The three surveys are spread over Spring and Summer and use different trawl gears (Campelen and Lofoten trawls) and mesh sizes.

The aim of the analysis presented here was to examine the links between VMEs and the distribution of fish assemblages in the NAFO management area, beyond the established community groupings suggested by the multivariate analysis. This analysis looks at the strength of association between the biomass of individual demersal fish and the NAFO VMEs, whilst accounting for the effects of depth and the different seasons and gears used in the surveys.

Data and methods

Data on the biomass of fish and invertebrates were obtained from survey trawls acquired during annual fishery surveys conducted by Instituto Español de Oceanografia (IEO, Spain) on R/V Vizconde de Eza on behalf of the European Union between 2011 and 2019. Three stratified random surveys were conducted during spring and summer (June - August) each covering one of the NAFO divisions 3L, 3M and 3NO. All survey trawls are of 30 minutes duration with a vessel speed of 3 knots, corresponding to approximately 2 km in length. The 3L and 3NO surveys use a Campelen trawl with a 20 mm mesh size and an average wingspread varying from 24.2 to 31.9 m. The 3M survey uses a Lofoten trawl with a 35 mm mesh size and an average wingspread of 13.9 m. The study area, delineated by the extent of the NAFO regulatory fishing footprint in 3LMN, contained 3 515 survey trawls.

To compare fish biomass inside and outside of each VME polygon (Kenchington et al., 2013), the scientific trawl sets were classified into three categories. Those trawls with high catches of VME indicator taxa were categorised as ‘VME trawls’. The catch thresholds for each VME were derived from the 2019 updated Kernel Density Estimate (KDE) analyses (Kenchington et al., 2019) and are shown in able 5.5. Those trawls which did not exceed the VME thresholds but where the start of the trawl fell inside the KDE polygons were categorised as ‘wider VME area’ samples. The remaining trawls were categorised as ‘Not VME’. Figure 5.6 shows the distribution of trawl data, highlighting those trawls that exceed the catch threshold for at least one VME, as well as the combined extent of the VME polygons.

Table 5.5. Catch thresholds used to classify a scientific trawl as VME.

VME	Threshold (kg)
Sponges	100
Sea pens	1.3
Large gorgonians	0.6
Small gorgonians	0.2
Black coral	0.4
Boltenia	0.35
Bryozoa	0.2

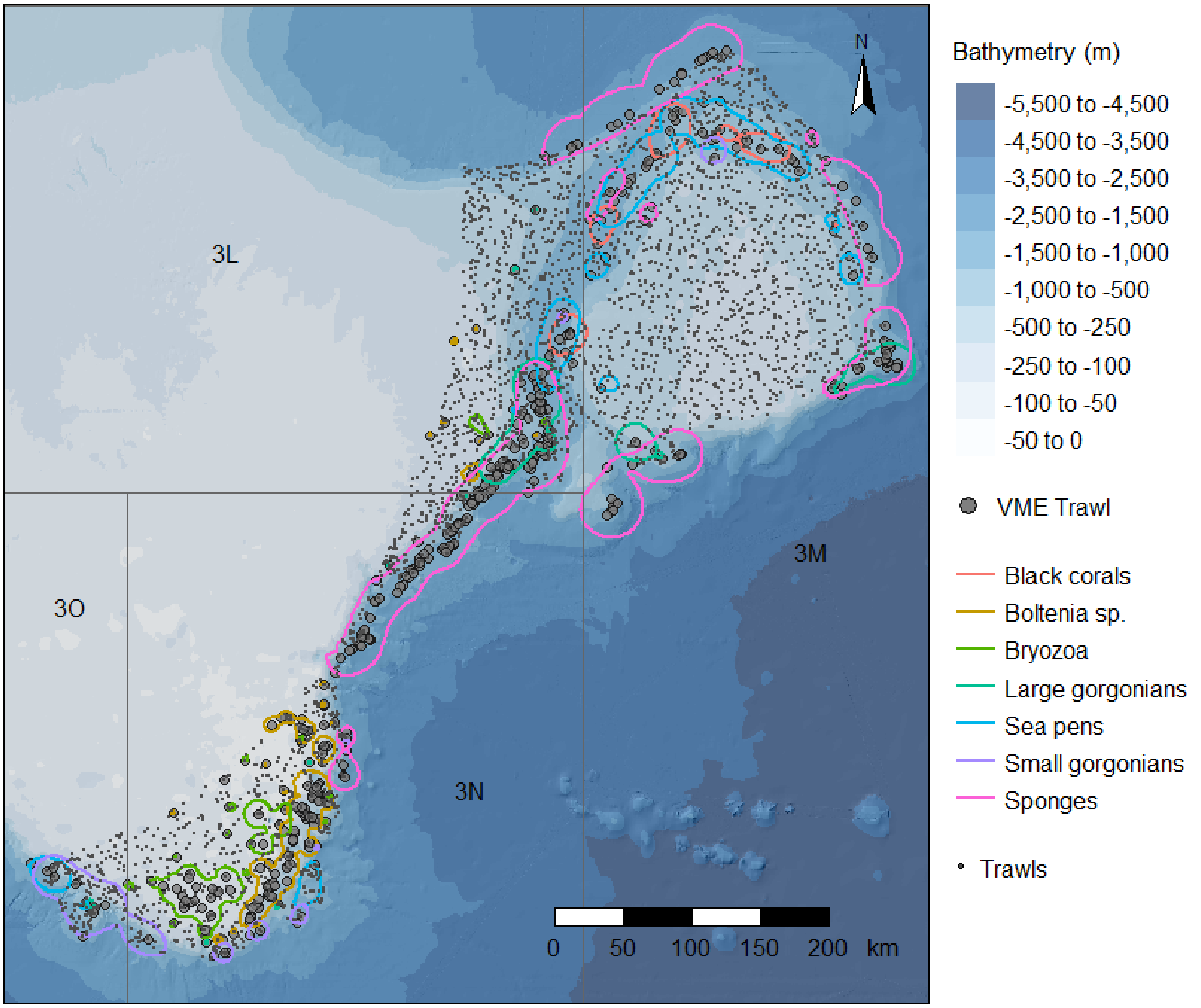


Figure 5.6. Extent of all combined VME polygons and scientific trawls exceeding the catch threshold of at least one VME (orange) with trawls below VME threshold shown in black.

Additional information was related to each trawl to control for the known and suspected effects of depth, spatial autocorrelation, the time of year and the sampling gear used. Depth is known to be an important driver of the distribution of both VME and fish taxa in the NRA (Knudby 2013a, Knudby 2013b, NAFO 2020, NAFO 2021). The mean depth along the track was added for each trawl. Similarly, as sampling locations closer to each other tend to be more similar than locations further away, the start coordinates were included for checking for spatial autocorrelation in the data. Biomass data (kg /trawl) does not account for the difference in wingspread, footrope and mesh size of the two trawl gears. Whilst previous studies have established that there were no significant differences between the trawl gears in catches of VME indicator taxa at the high biomasses forming VME aggregations, there are differences in the catchability of fish, which cannot be readily corrected. The catches of VME indicator taxa are drawn from a very patchy, aggregated spatial distribution resulting in highly skewed data distribution with many small and a few large catches. Statistical comparison of catches by the trawl gears used in these surveys by Kenchington et al. (2014) showed no significant differences between the gears for catches of sponges at >0.5 kg, sea pens >0.2 kg, small gorgonian corals >0.1 kg or large gorgonian corals >0.1 kg, all below their respective VME thresholds. Vásquez (2002), on the other hand, found that the Campelen trawl is more efficient for small fish with a wider pelagic distribution and the Lofoten trawl is more efficient for fish >~25 cm in length. Consequently, whilst catch ratios were determined for some fish, many were length dependent within species with a strong declining ratio with length for some fish. The different surveys also run over Spring and Summer. The survey series (3M, 3L, 3NO) was added as a factor variable to cover the differences between the trawl gears and seasons.

Analysis was structured to investigate fish associated with each VME. Consequently, fish biomass data was determined for the depth range covered by each VME. The proportion of scientific trawls where a fish species was present was enumerated for each separate VME/ Survey/ Fish combinations, and only those combinations with a prevalence of more than 1%, were included in the model analysis. Figure 5.7 shows the number of trawls per VME/ Fish /Survey combination that were included in analysis.

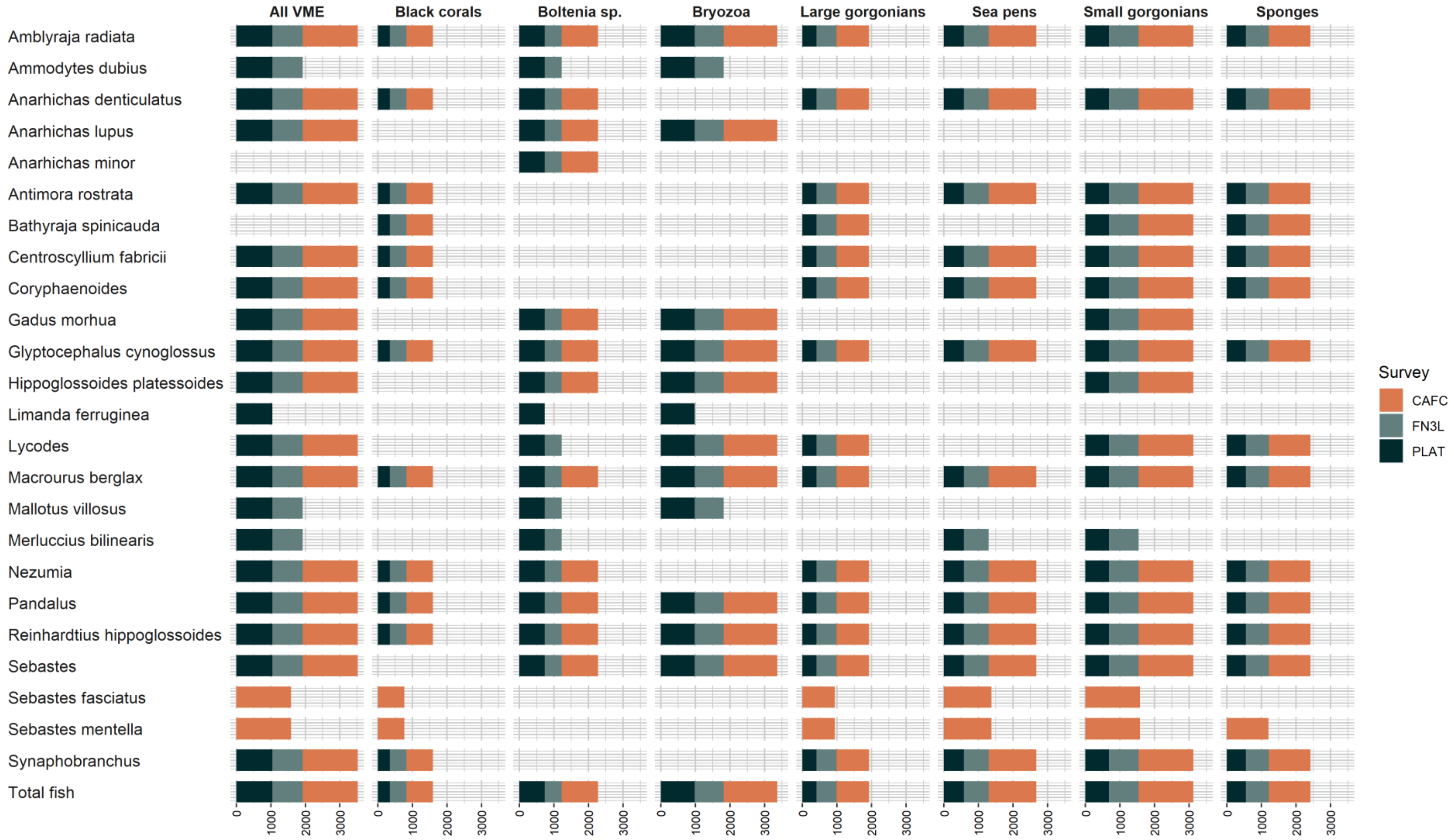


Figure 5.7. Number of scientific trawls overlapping the depth range of each VME by fish species and survey series.

The effect of the VME category (referred to here as VME Trawl, VME Polygon and Not VME) was investigated using Generalised Linear Mixed Models (GLMM, Bolker et al. 2009). The response variable used was square-root transformed fish biomass. Whilst the total biomass follows a log-normal distribution, the individual fish datasets contained a high proportion of zeros even within the restricted depth zones. Standard continuous probability distributions such as the normal, gamma or log-normal are often inappropriate for the analysis of zero-inflated biomass data. The first step in analysis was to determine the data distribution of the dependent variable, to support the selection of an appropriate error distribution family for the GLMM. Each dataset was evaluated using the 'check_distribution' function in the 'performance' R package (Lüdecke et al., 2021), which tests the fit of a range of data distributions (listed in Table 5.6) using an internal random forest model to classify the distribution, giving as output the probability of the data belonging to each model-family. It was found that the best fit for all data sets was a Tweedie distribution, with a higher than 50% probability of being drawn from that distribution (Figure 5.8).

Table 5.6. List of statistical distributions included in the 'check_distribution' function in the performance R package (Lüdecke et al., 2021)

Statistical distributions tested by the 'check_distribution' function
Bernoulli
Beta
beta-binomial
Binomial
Chi
exponential
F
Gamma
Lognormal
Normal
negative binomial
negative binomial (zero-inflated)
Pareto
Poisson
poisson (zero-inflated)
Uniform
Weibull

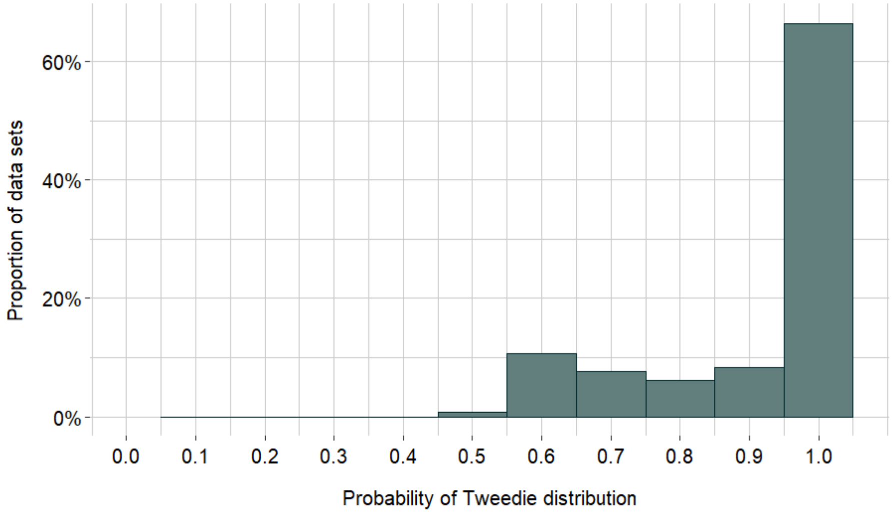


Figure 5.8. Proportion of the individual fish square-root transformed biomass datasets with probabilities of 0-1 of belonging to the Tweedie data distribution.

The Tweedie distribution (Jørgensen, 1987; Dunn and Smyth, 2005, 2008) handles zero-inflated data as an otherwise continuous distribution, but with a positive mass at zero. Peel et al (2012) point out the aptness of its theoretical interpretation into trawl sampling, where each haul encounters a random number of schools with a high likelihood of zero, and where fish are encountered, they are caught in random positive amounts from each haul. In past studies using trawl biomass data, the Tweedie model and its variants have also been found to fit fisheries biomass and abundance data well (Candy, 2004; Shono, 2008; Foster & Bravington, 2012; Lecomte et al., 2013, Leavitt et al., 2018; Siemann et al., 2018, Torre et al., 2019) and have shown good performance in cross-validation compared to other more familiar approaches for data with a high proportion of zeros (Shono, 2008).

GLMM models were built for each VME/ Fish combination with the VME category (VME trawl, VME Polygon and Not VME) and log-transformed depth as covariates and the survey series as a random effect. Models were run using the 'glmmTMB' package in R (Brooks et al., 2017), which includes the Dunn and Smyth (2005, 2008) implementation of the Tweedie distribution implemented in the 'tweedie' R package (Dunn, 2015). Total fish biomass was modelled using a log-normal distribution. The residuals of each model were checked for autocorrelation and had Moran's I values below 0.4 in all cases. All models were accepted without the need to include spatial terms.

Neither likelihood ratio tests nor F-tests are applicable with the data distribution (Bolker et al., 2009). The results of GLMM models for the VME class were therefore summarised in ANOVA-style tables using Wald $\chi 2$ statistics for comparisons on the conditional fixed effects, implemented using the 'car' package 'Anova' function in R (Fox and Weisberg, 2019). Post-Hoc Tukey comparisons were done between all VME groups using the 'glht' function in the 'multcomp' package (Hothorn et al., 2008). VME category conditional means with standard error (SE) were plotted using the 'estimate_means' function in the 'modelbased' package (Makovski et al., 2020), specifying depth to be held fixed at its mean.

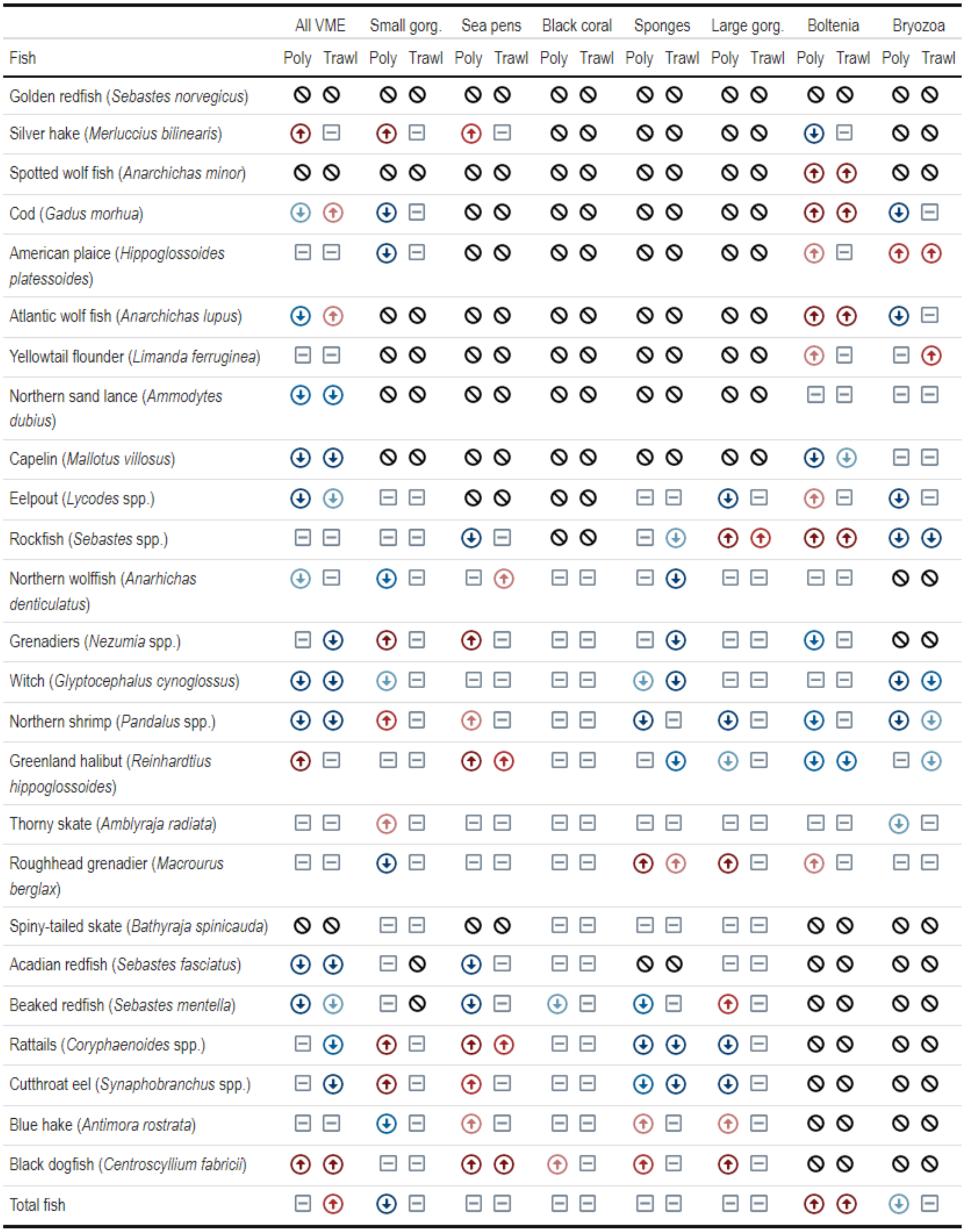
Results

Overview of significant effects

Log-transformed depth was a highly significant term in all models, confirming the importance of its inclusion as a covariate. Table 5.7 summarises the model results showing which VME/ Fish combinations were modelled, if the model showed a significant effect of either the VME Trawl or VME Polygon categories on fish biomass, and whether the effect was positive or negative.

Sea pens showed significant positive associations with the highest number of fish (9) followed by *Boltenia* spp. (8). The latter also had a highly significant ($p < 0.001$) positive effect on total fish biomass. The lowest number was observed for black coral (1). All other VMEs fall in a range from 2 to 6. Unsurprisingly, VMEs with overlapping spatial distributions and common physical habitat types share similarities in the fish they are positively associated with. Sea pens and small gorgonians have very similar positive associations with fish, albeit only in the VME Polygon category. Small gorgonians, primarily bamboo corals in the genus *Acanella*, mainly occur on the tail of the Grand Bank together with *Anthoptilum* sp. and *Halipteris* sp. sea pens. Sponges and large gorgonians similarly share part of their distribution in the Flemish Pass and around the Flemish Cap and have associations in common for the VME Polygon category. *Boltenia* spp. shares associations with both large gorgonians and Bryozoa. Large gorgonians and *Boltenia* spp., which whilst not overlapping in their distribution are both found on hard substrata on the edge and slope of the Grand Bank, each have strong positive effects on the biomass of rockfish, both in the VME Polygon and VME Trawl categories. The similarity of fish associations between *Boltenia* spp. and Bryozoa is more tenuous. Both VMEs occur in the relatively shallow waters on the top of the Grand Bank, where the VME Polygon category of *Boltenia* spp. has a positive association with flatfish that is more strongly associated with Bryozoa (in the VME Trawl category).

Table 5.7. Summary of the conditional effects of the VME category term in each GLMM (Poly = VME polygon, Trawl = VME Trawl). ⊘ = No comparison; ⊟ = No significant effect; ⬇ = Strong negative association (p<0.001); ↓ = Negative association (p<0.05); ⬆ = Strong positive association (p<0.001); ↑ = Positive association (p<0.05)



	All VME		Small gorg.		Sea pens		Black coral		Sponges		Large gorg.		Boltenia		Bryozoa	
Fish	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl
Golden redfish (*Sebastes norvegicus*)	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Silver hake (*Merluccius bilinearis*)	⬆	⊟	⬆	⊟	⬆	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⬇	⊟	⊘	⊘
Spotted wolf fish (*Anarchichas minor*)	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬆	⬆	⊘	⊘
Cod (*Gadus morhua*)	↓	↑	⬇	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬆	⬆	⬇	⊟
American plaice (*Hippoglossoides platessoides*)	⊟	⊟	⬇	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	↑	⊟	⬆	⬆
Atlantic wolf fish (*Anarchichas lupus*)	⬇	↑	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬆	⬆	⬇	⊟
Yellowtail flounder (*Limanda ferruginea*)	⊟	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	↑	⊟	⊟	⬆
Northern sand lance (*Ammodytes dubius*)	⬇	⬇	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	⊟	⊟
Capelin (*Mallotus villosus*)	⬇	⬇	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬇	↓	⊟	⊟
Eelpout (*Lycodes* spp.)	⬇	↓	⊟	⊟	⊘	⊘	⊘	⊘	⊟	⊟	⬇	⊟	↑	⊟	⬇	⊟
Rockfish (*Sebastes* spp.)	⊟	⊟	⊟	⊟	⬇	⊟	⊘	⊘	⊟	↓	⬆	⬆	⬆	⬆	⬇	⬇
Northern wolffish (*Anarhichas denticulatus*)	↓	⊟	⬇	⊟	⊟	↑	⊟	⊟	⊟	⬇	⊟	⊟	⊟	⊟	⊘	⊘
Grenadiers (*Nezumia* spp.)	⊟	⬇	⬆	⊟	⬆	⊟	⊟	⊟	⊟	⬇	⊟	⊟	⬇	⊟	⊘	⊘
Witch (*Glyptocephalus cynoglossus*)	⬇	⬇	↓	⊟	⊟	⊟	⊟	⊟	↓	⬇	⊟	⊟	⊟	⊟	⬇	⬇
Northern shrimp (*Pandalus* spp.)	⬇	⬇	⬆	⊟	↑	⊟	⊟	⊟	⬇	⊟	⬇	⊟	⬇	⊟	⬇	↓
Greenland halibut (*Reinhardtius hippoglossoides*)	⬆	⊟	⊟	⊟	⬆	⬆	⊟	⊟	⊟	⬇	↓	⊟	⬇	⬇	⊟	↓
Thorny skate (*Amblyraja radiata*)	⊟	⊟	↑	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⊟	↓	⊟
Roughhead grenadier (*Macrourus berglax*)	⊟	⊟	⬇	⊟	⊟	⊟	⊟	⊟	⬆	↑	⬆	⊟	↑	⊟	⊟	⊟
Spiny-tailed skate (*Bathyraja spinicauda*)	⊘	⊘	⊟	⊟	⊘	⊘	⊟	⊟	⊟	⊟	⊟	⊟	⊘	⊘	⊘	⊘
Acadian redfish (*Sebastes fasciatus*)	⬇	⬇	⊟	⊘	⬇	⊟	⊟	⊟	⊘	⊘	⊟	⊟	⊘	⊘	⊘	⊘
Beaked redfish (*Sebastes mentella*)	⬇	↓	⊟	⊘	⬇	⊟	↓	⊟	⬇	⊟	⬆	⊟	⊘	⊘	⊘	⊘
Rattails (*Coryphaenoides* spp.)	⊟	⬇	⬆	⊟	⬆	⬆	⊟	⊟	⬇	⬇	⬇	⊟	⊘	⊘	⊘	⊘
Cutthroat eel (*Synaphobranchus* spp.)	⊟	⬇	⬆	⊟	⬆	⊟	⊟	⊟	⬇	⬇	⬇	⊟	⊘	⊘	⊘	⊘
Blue hake (*Antimora rostrata*)	⊟	⊟	⬇	⊟	↑	⊟	⊟	⊟	↑	⊟	↑	⊟	⊘	⊘	⊘	⊘
Black dogfish (*Centroscyllium fabricii*)	⬆	⬆	⊟	⊟	⬆	⬆	↑	⊟	⬆	⊟	⬆	⊟	⊘	⊘	⊘	⊘
Total fish	⊟	⬆	⬇	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⬆	⬆	↓	⊟

Sea pens and small gorgonians

Sea pens and small gorgonians, both associated with community group 3, inhabit soft sediment habitats in depths ranging from 217-1533 m and 124-1487 m, respectively. Whilst the distributions overlap, the main sea pen VME is located around the Flemish Cap and the main small gorgonian VME on the tail of the Grand Bank (Figure 5.9). Small gorgonians and sea pens share many of the same associations with fish, so both are discussed together.

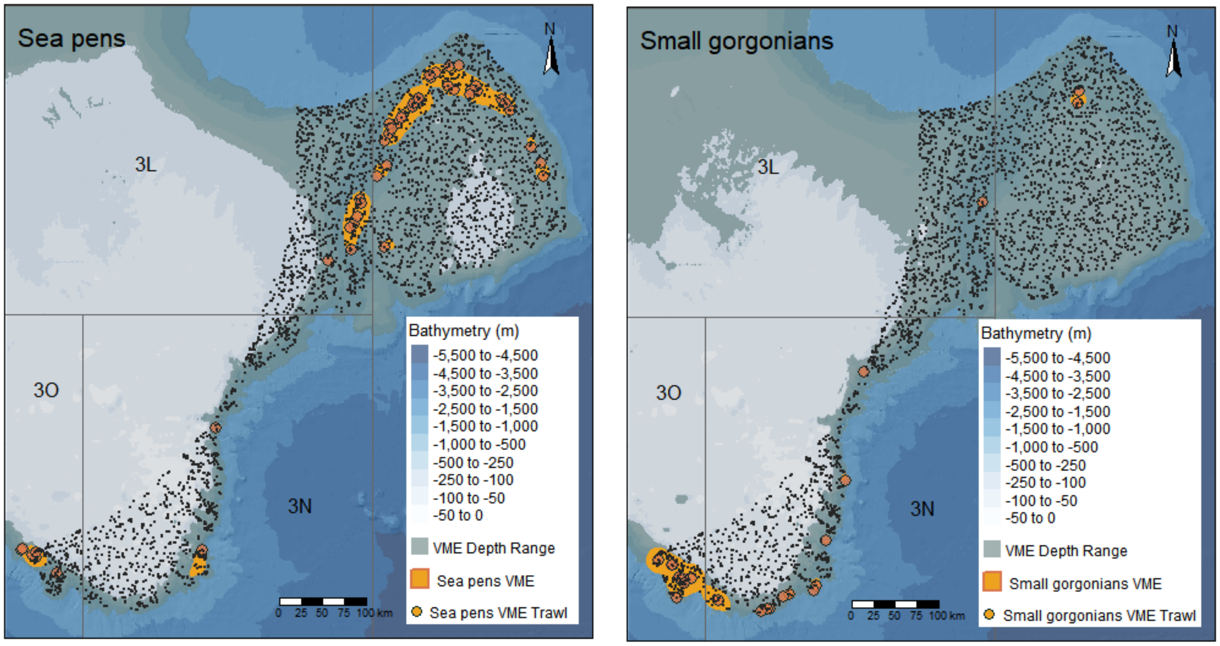
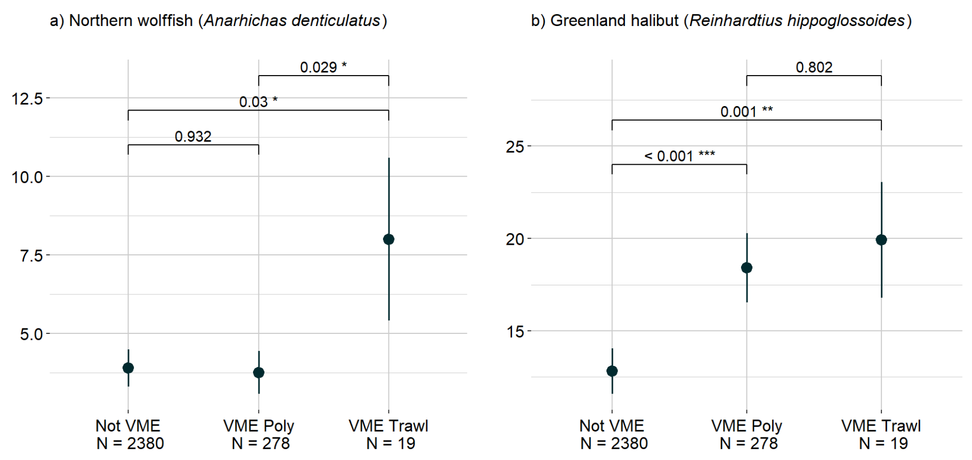


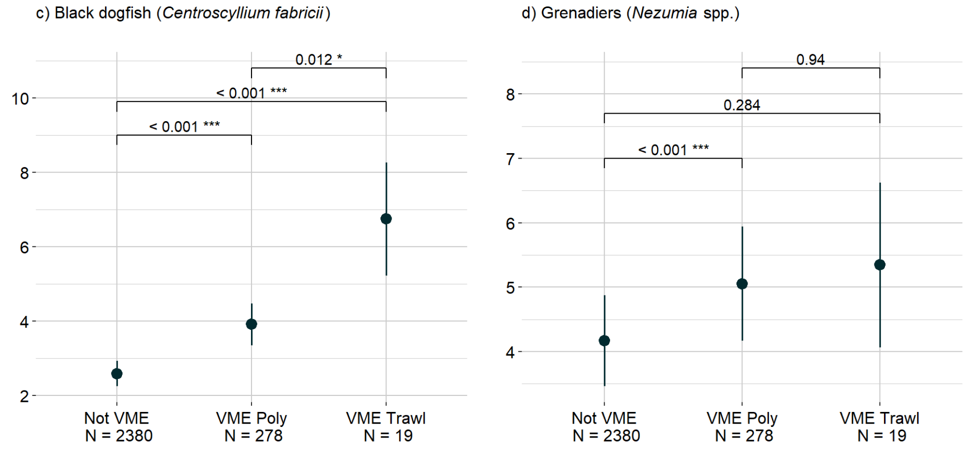
Figure 5.9. Depth ranges, extent of VME polygons and location of trawls exceeding VME threshold for sea pens (left) and small gorgonians (right) All other survey trawls are shown as black dots.

Two fish species, northern wolffish (*Anarhichas denticulatus*) and Greenland halibut (*Reinhardtius hippoglossoides*) are only positively associated with the sea pen VME. Northern wolffish biomass in trawls with sea pens exceeding VME threshold is significantly higher than in both non-VME trawls and trawls within the VME polygon (Figure 5.10). Greenland halibut biomass is significantly higher in both sea pen VME trawls and polygon than outside the VME (Figure 5.10b). Black dogfish (*Centroscyllium fabricii*), similarly has a strong positive association with sea pens. Black dogfish biomass shows a significant increasing trend from outside the VME to inside the VME polygon and is the in VME trawls (Figure 5.10c). Black dogfish is abundant in the deeper waters around the Flemish Cap, and its distribution also overlaps with the other deeper water VMEs (black coral, sponge, and small and large gorgonians, Figure 5.11). It is significantly positively associated with the VME polygons of black coral, sponge, and large gorgonians, but not the VME Trawls, suggesting higher black dogfish biomasses in the vicinity of the other VME but not overlapping with the patches of high VME biomass inside the polygons (unlike the sea pen VME).



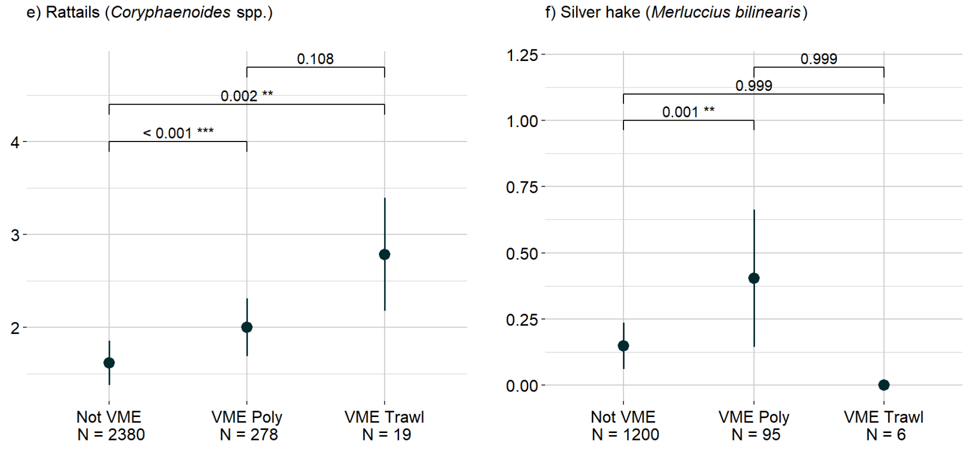
a) Northern wolffish (*Anarhichas denticulatus*)

b) Greenland halibut (*Reinhardtius hippoglossoides*)



c) Black dogfish (*Centroscyllium fabricii*)

d) Grenadiers (*Nezumia* spp.)



e) Rattails (*Coryphaenoides* spp.)

f) Silver hake (*Merluccius bilinearis*)

Figure 5.10. Mean biomass per scientific trawl in relation to Sea pen VME for Northern wolffish, Greenland halibut, Black dogfish, Grenadiers, Rattails and Silver hake. P-values for Tukey Post Hoc comparison between the three categories: outside of VME (Not VME), inside the VME KDE polygon (VME Poly) and in trawls exceeding the VME threshold (VME Trawl) are shown for each pair of means

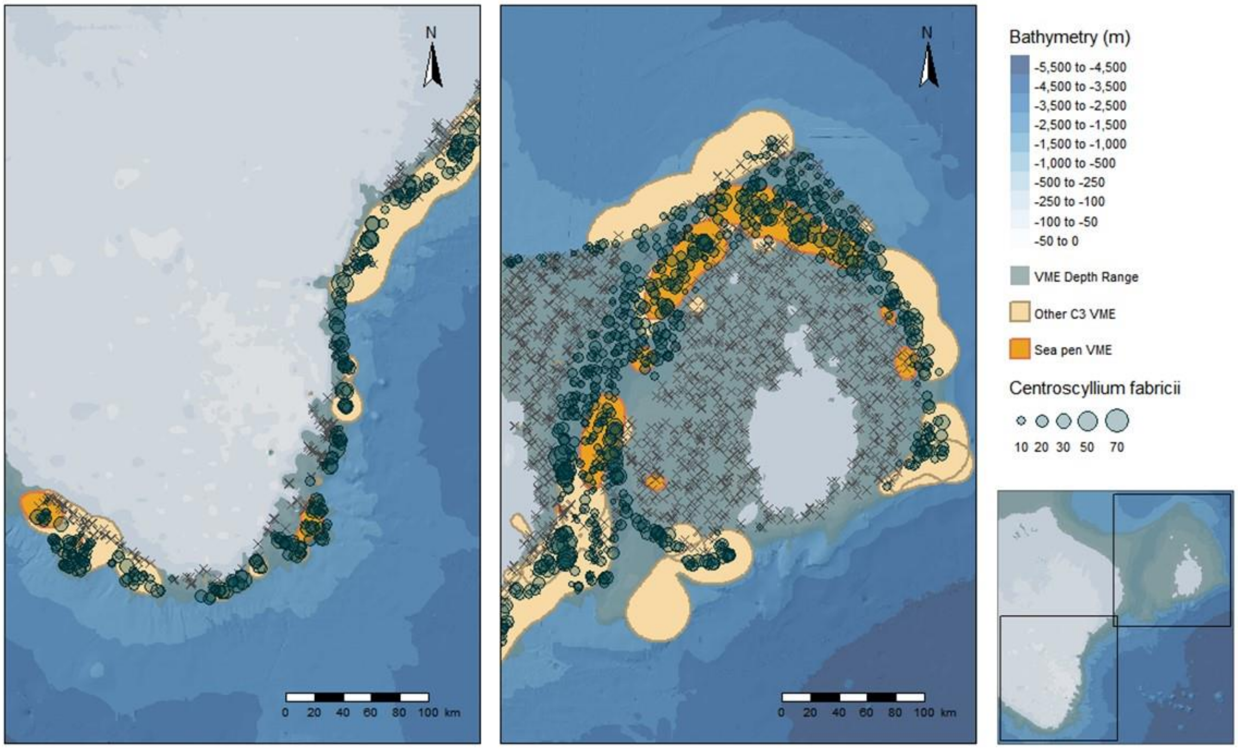


Figure 5.11. Distribution of black dogfish (*Centrocyllium fabricii*) biomass in relation to sea pen VME, and the other VMEs associated with community cluster group 3 (other C3 VME, sponges, large and small gorgonians and black corals).

Sea pens and small gorgonians were both significantly positively associated with grenadiers/ rattails (*Nezumia* and *Coryphaenoides* spp.), and cutthroat eel (*Synaphobranchus* spp.). Rattails showed significantly higher biomass in both VME polygon and trawl classes for sea pens (Figure 5.10e). Although the increasing trend from outside VME through polygon to trawl classes is the same for small gorgonians, only the VME polygon class is significant. The same is seen for grenadiers for both sea pens (Figure 5.10d) and small gorgonians and for thorny skate (*Amblyraja radiata*) for small gorgonians.

For all the above-mentioned fish, the trend in mean biomass from outside the VME, through VME Polygon to VME Trawl is seen to increase. Silver hake (*Merluccius bilinearis*), on the other hand has significantly higher biomass in the VME polygon category, than either outside VME or in VME trawls. The same pattern is seen for both sea pens (Figure 5.10f) and small gorgonians. Figure 5.12 shows the distribution of silver hake in relation to the sea pen and small gorgonian VME. Whilst silver hake clearly occurs mainly inside the VME polygons, it is limited to the shallowest depths within the VME and is not found in the high VME biomass trawls which occur in deeper water, suggesting the association may be due to an overlap of the edges of their distributions.

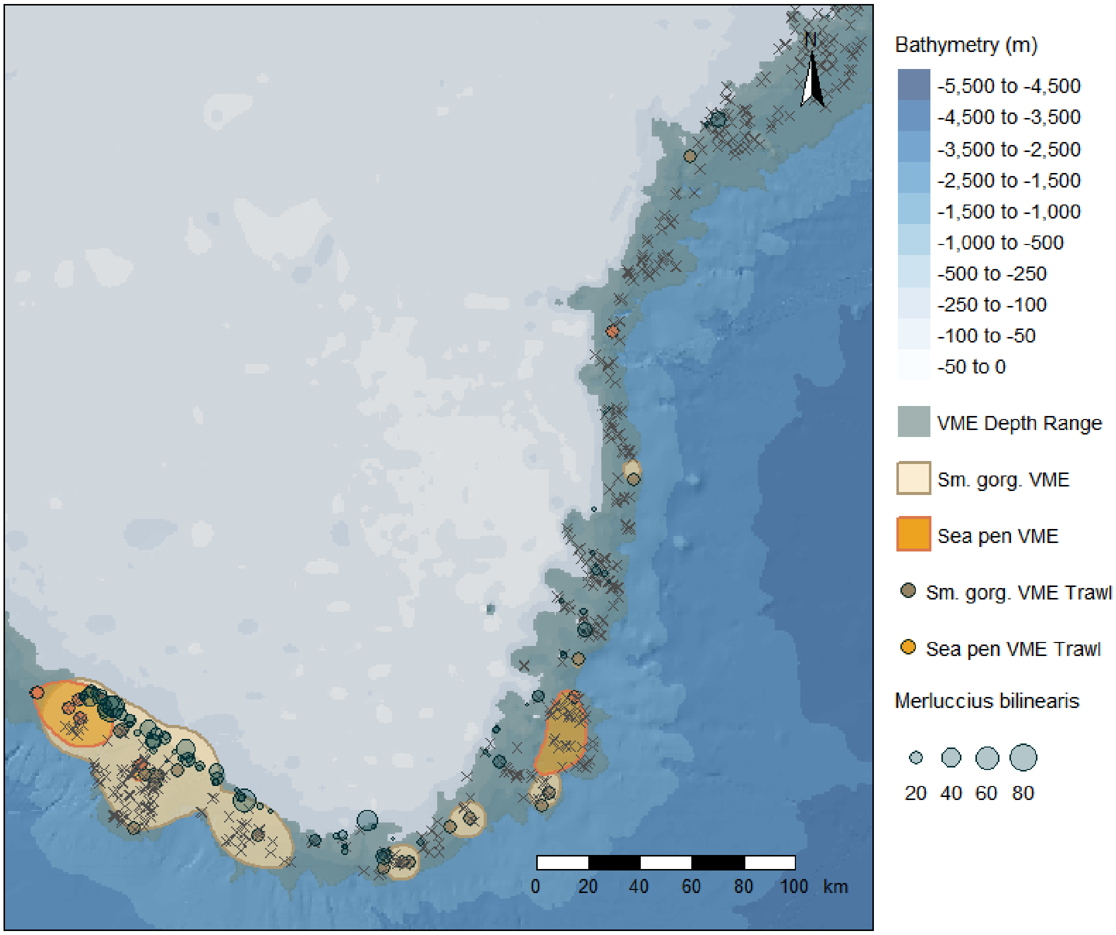


Figure 5.12. Distribution of Silver hake (Merluccius bilinearis) biomass in relation to sea pen (red) and small gorgonian (orange) VME on the tail of the Grand Bank.

Sponges

Sponge VMEs range in depth from 260 to 1488 m (Figure 5.13). In the community analysis sponges were mainly associated with the deep-water group (group 3), but the hexactinellid *Asconema* spp. was linked to group 4 and other unidentified sponges across all groups and depths. Sponges inhabit a wide variety of habitats across a range of substrata from soft to hard types. Most of the sponge VME in the NRA, however, consists of *Geodia* grounds which are mainly found on mixed sediments in deep water. The hexactinellid *Asconema* spp. sponges, which were found to be associated with the shallower community group 4, on the other hand, live on hard substrata.

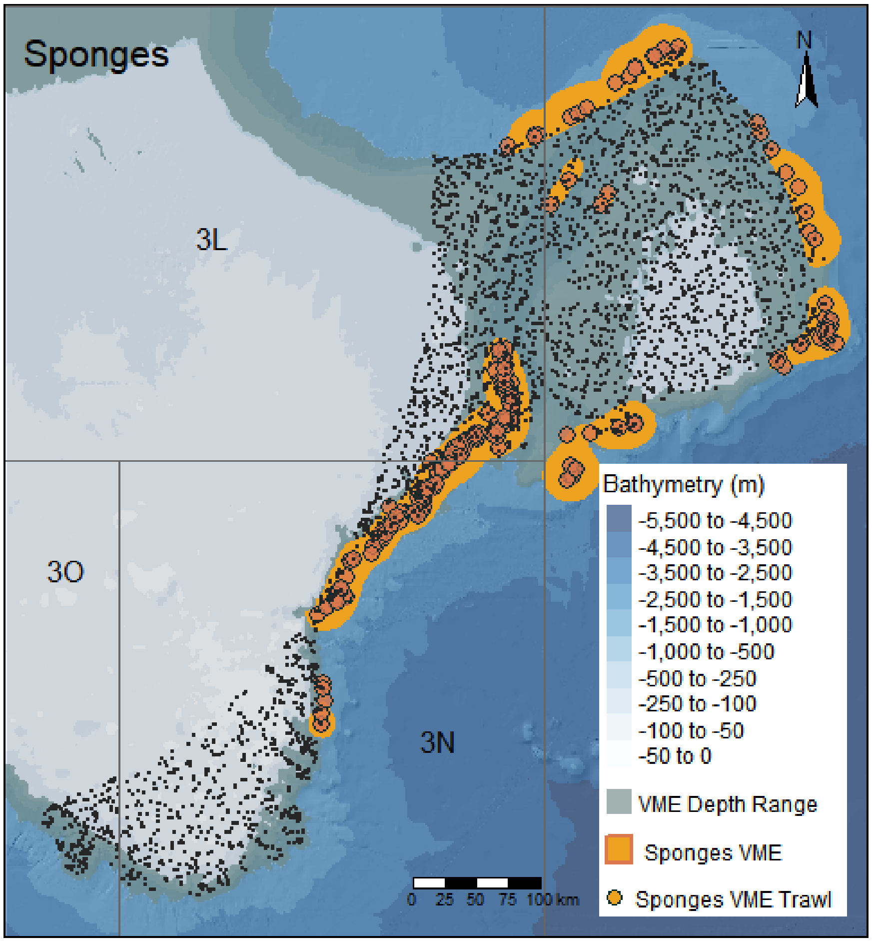
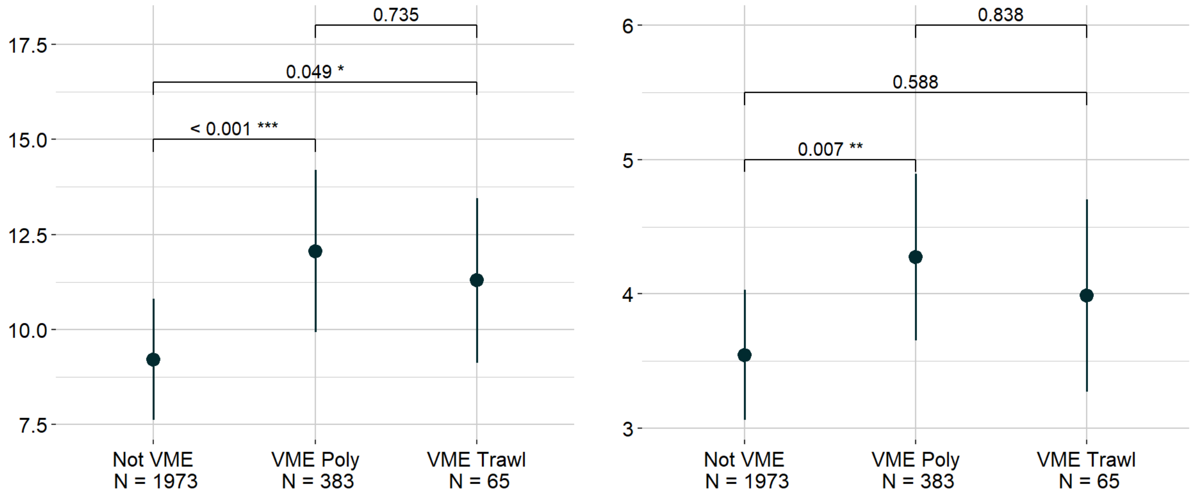


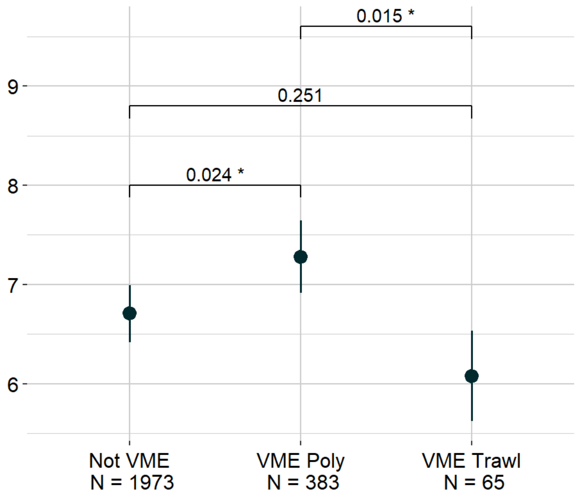
Figure 5.13. Depth range, extent of VME polygons and location of trawls exceeding VME threshold for sponges.

The strongest significant positive association sponges had was with roughhead grenadier (*Macrourus berglax*), with significantly higher mean biomass in both the sponge VME polygon and VME trawls exceeding the sponge VME threshold (Figure 5.14a). Figure 5.15 illustrates the distribution of roughhead grenadier biomass in relation to the sponge VME. Roughhead grenadier is also associated with the polygons of large gorgonians and *Boltenia* spp. but has no significant positive association with them in above threshold trawls. Other species positively associated with sponges were black dogfish (*Centroscyllium fabricii*) and blue hake (*Antimora rostrata*). Black dogfish has higher biomass in polygons and trawls, although only the effect on polygons is significant (Figure 5.14b). Blue hake on the other hand has a significantly higher biomass in the VME polygon than either outside the polygon (Not VME category) or in trawls (VME trawl category) (Figure 5.14c).



a) Roughhead grenadier (*Macrourus berglax*)

b) Black dogfish (*Centroscyllium fabricii*)



c) Blue hake (*Antimora rostrata*)

Figure 5.14. Mean biomass per scientific trawl in relation to Sponge VME for the roughhead grenadier, black dogfish and blue hake. P-values for Tukey Post Hoc comparison between the three categories: outside of VME (Not VME), inside the VME KDE polygon (VME Poly) and in any trawls exceeding the VME threshold (VME Trawl) are shown for each pair of means.

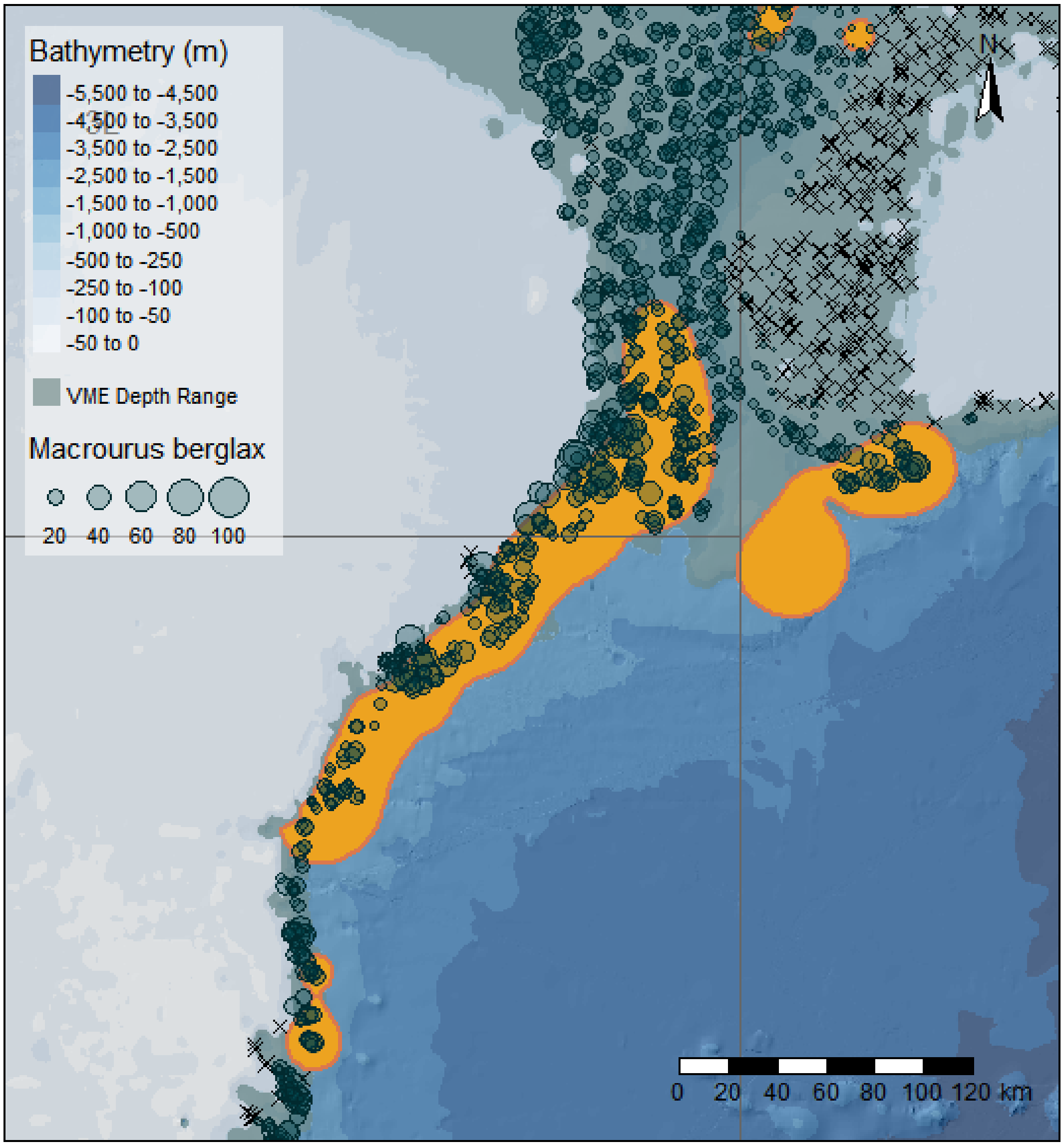


Figure 5.15. Distribution of roughhead grenadier (Macrourus berglax) biomass in relation to the sponge VME polygons on the nose of the Grand Bank.

Large gorgonians

Large gorgonian VMEs range in depth from 312 to 1289 m (Figure 5.16) and large gorgonian taxa were associated with the deep-water group (group 3) in the community analysis. They require hard substrata and are found on rock, coarse and mixed sediments with large cobbles and boulders.

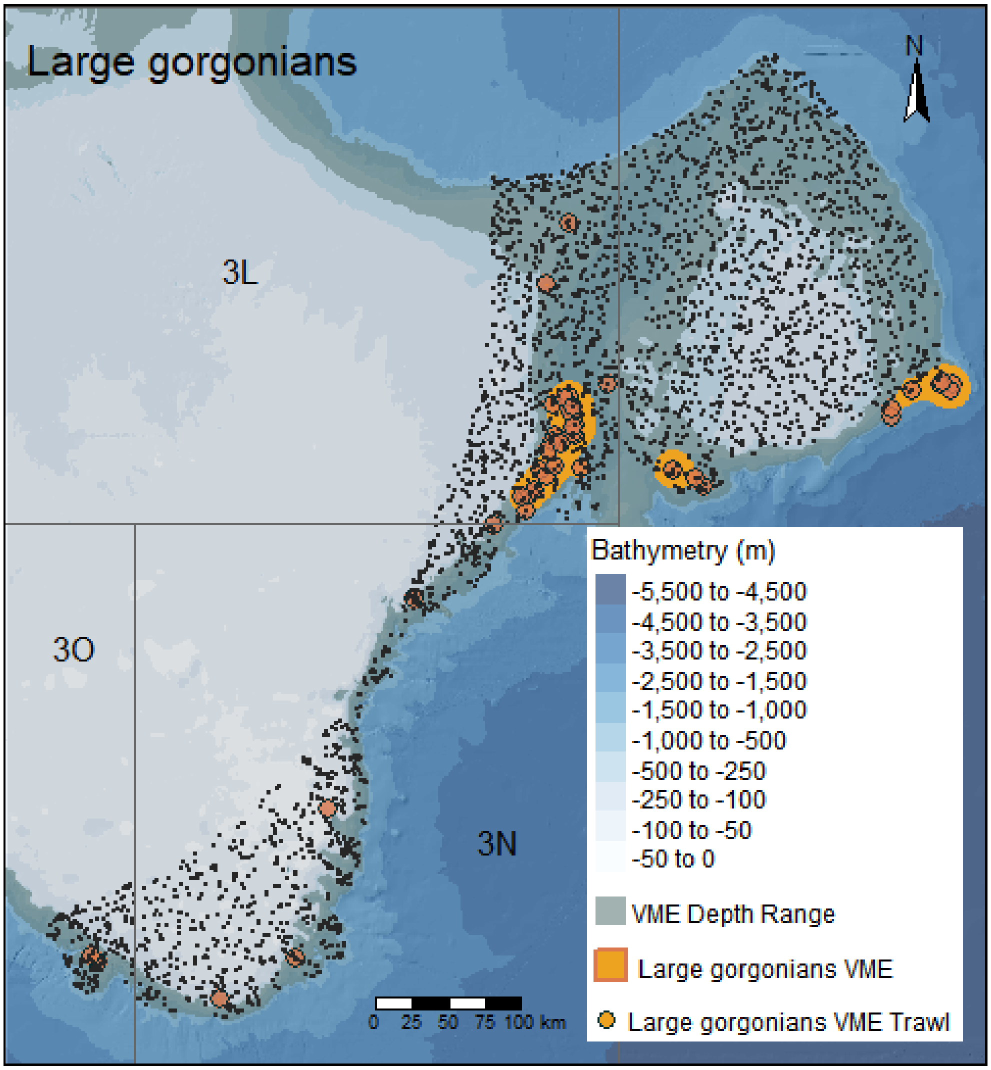


Figure 5.16. Depth range, extent of VME polygons and location of trawls exceeding VME threshold for large gorgonians.

Large gorgonians share similar associations to Roughhead grenadier (*Macrourus berglax*), Black dogfish (*Centroscyllium fabricii*) and blue hake (*Antimora rostrata*) in the VME Polygon category as sponges. The strongest association between large gorgonians and fish is, however, observed for rock fish in general (*Sebastes* spp.), which have significantly higher biomass in both VME polygons and VME trawls categories, than outside VME (Figure 5.17a). There is a similar trend seen between large gorgonians and *Sebastes mentella*, but only the VME Polygon category is significant (Figure 5.17b). Whilst an association with rock fish in general is ecologically meaningful for taxa associated with hard substrata, the association observed specifically with *Sebastes mentella* is very dependent on the mean depth used for the conditional mean. Rockfish are only identified to species in the Flemish Cap (3M) data. In this area, *Sebastes mentella* ovelap with one large gorgonian VME polygon with catches at the mean depth, whilst no catches are seen at the same depth outside the single large VME polygon (Figure 5.18)

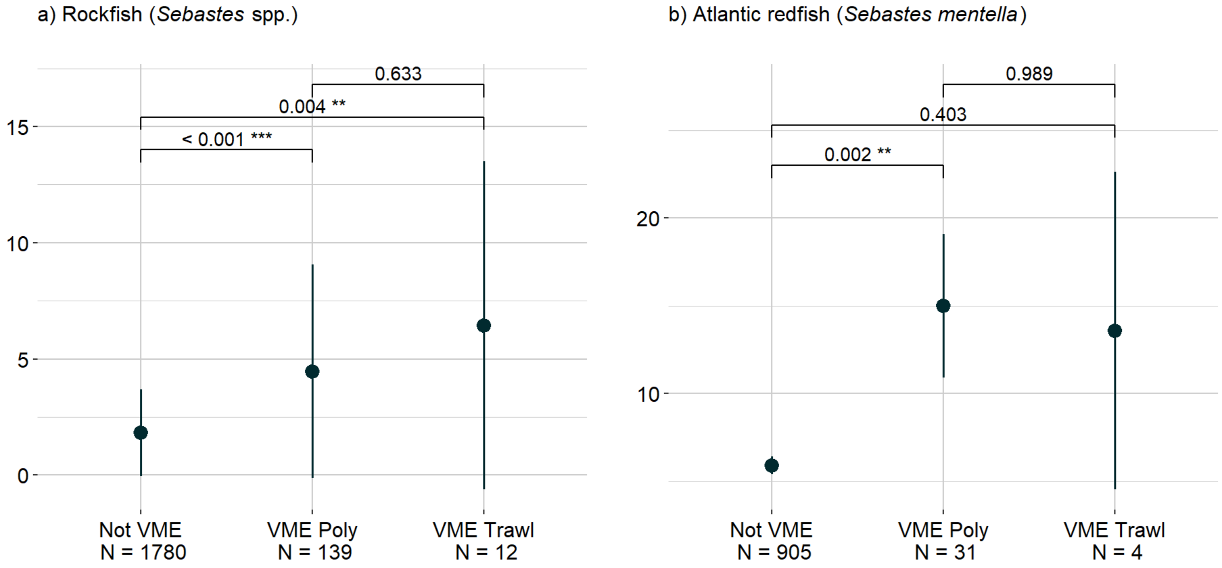


Figure 5.17. Mean biomass per scientific trawl in relation to Large gorgonian VME for undetermined Rockfish species and the beaked redfish (*Sebastes Mentella*). P-values for Tukey Post Hoc comparison between the three categories: outside of VME (Not VME), inside the VME KDE polygon (VME Poly) and in trawls exceeding the VME threshold (VME Trawl) are shown for each pair of means.

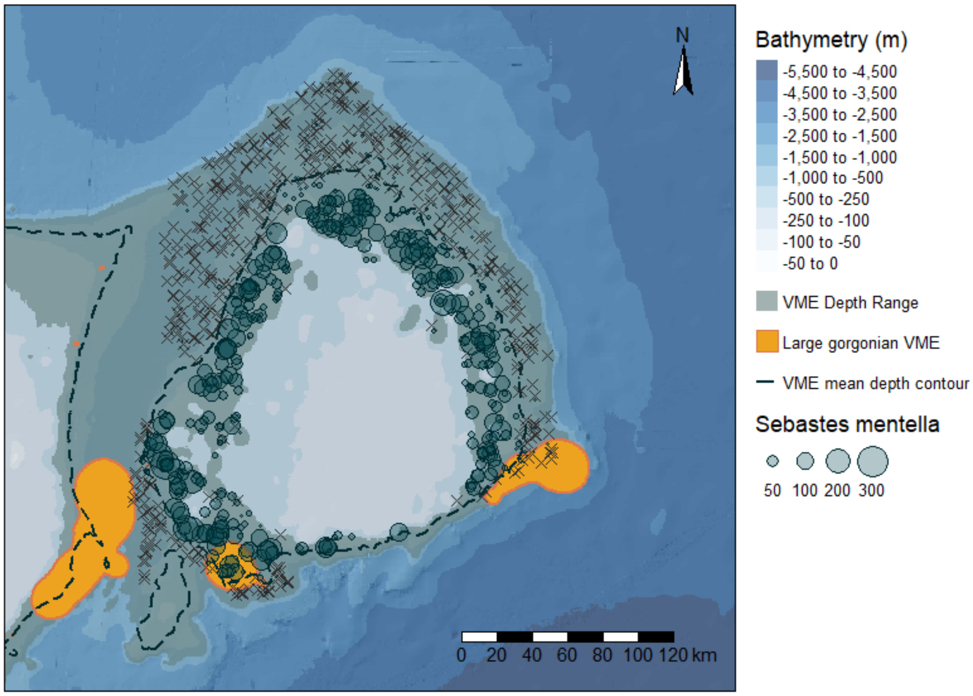


Figure 5.18. Beaked redfish (*Sebastes mentella*) biomass in scientific trawls in the Flemish Cap (3M) survey series overlapping the depth range of the Large gorgonian VME in relation to the VME polygons. A depth contour is shown for the mean depth in the dataset, used for conditional means

Boltenia spp.

The *Boltenia* spp. VME is present on mixed and hard substrata at depths from 28 to 753 m, on the shelf edge and slope of the Grand Bank. The main distribution of the VME is on the tail of the Grand Bank, a smaller area and scattered trawls exceeding the VME threshold are also present further north (Figure 5.19), overlapping with all three of the community groups identified on the edge of the Grand Bank (groups 4, 5 and 6). This is also reflected in the species associations observed in the present analysis, which includes positive effects on the biomass of fish species from all three community groups.

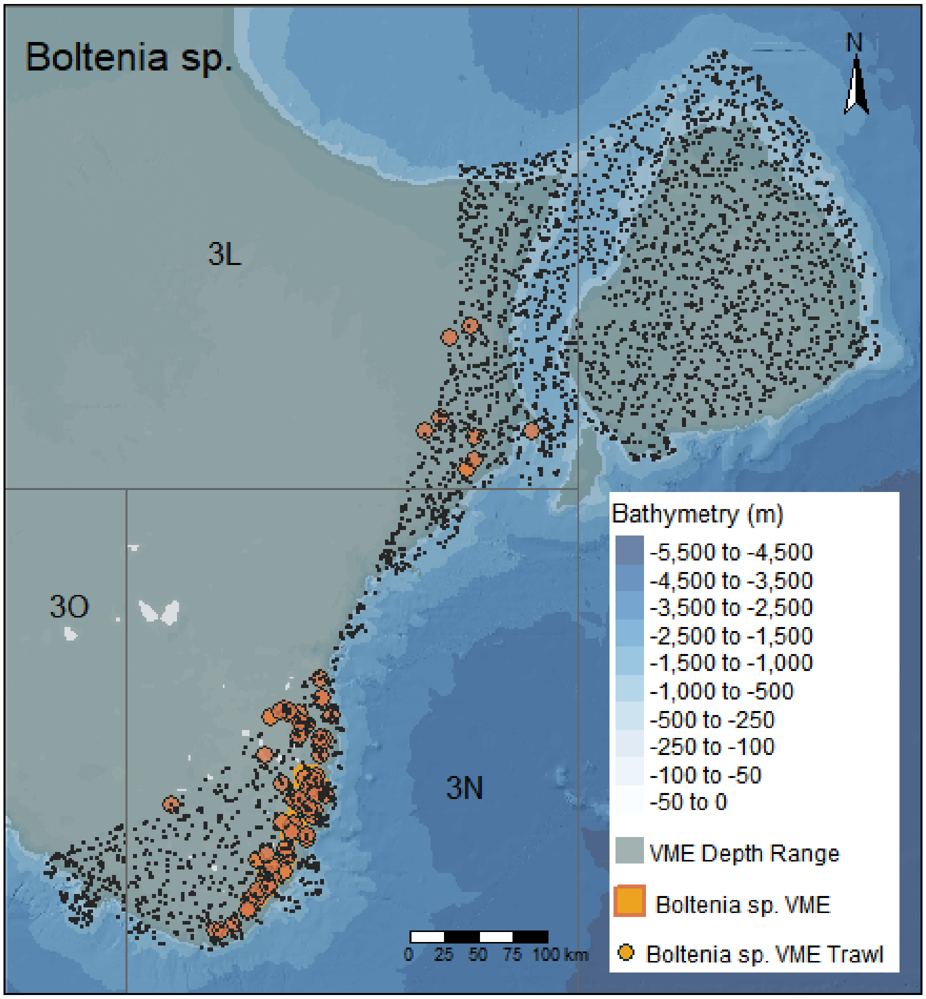


Figure 5.19. Depth range, extent of VME polygons and location of trawls exceeding VME threshold for *Boltenia* spp.

The *Boltenia* spp. VME has highly significant positive associations with rock fish (*Sebastes* spp.), as well as Atlantic ad spotted wolf fish (*Anarhichas lupus* and *Anarhichas minor*) and cod (Gadus morhua). In all the above cases both the VME Polygon and VME Trawl categories have a highly significant ($p<0.001$) positive effect on the fish biomass (Figure 5.20). All of these species distributed along the edge of the Grand Bank. Figure 5.21 shows the spatial overlap of the distribution of cod biomass in relation to the *Boltenia* spp. VME as an example. A weaker association is also observed between the *Boltenia* spp. VME Polygon category and eelpout (*Lycodes* spp.) and roughhead grenadier (*Macrourus berglax*) as well as the flatfish American plaice (*Hippoglossoides platessoides*) and Yellowtail flounder (*Limanda ferruginea*), which are found on top of the Grand Bank and have a more significant association with the Bryozoan VME.

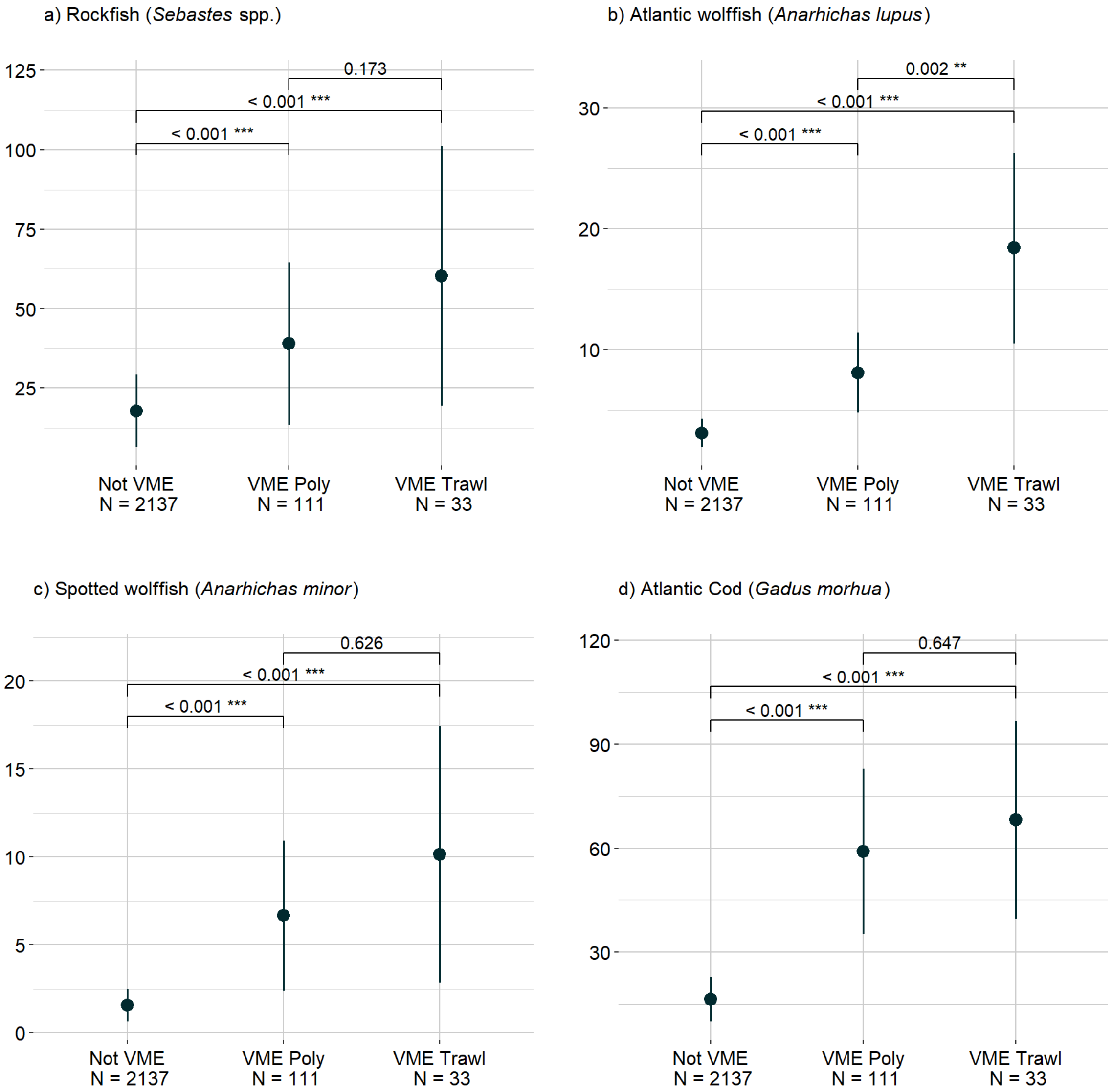


Figure 5.20. Mean biomass per scientific trawl in relation to *Boltenia* VME for undetermined Rockfish species, the Atlantic wolffish, Spotted wolffish and Atlantic cod. P-values for Tukey Post Hoc comparison between the three categories: outside of VME (Not VME), inside the VME KDE polygon (VME Poly) and in all trawls exceeding the VME threshold (VME Trawl) are shown for each pair of means.

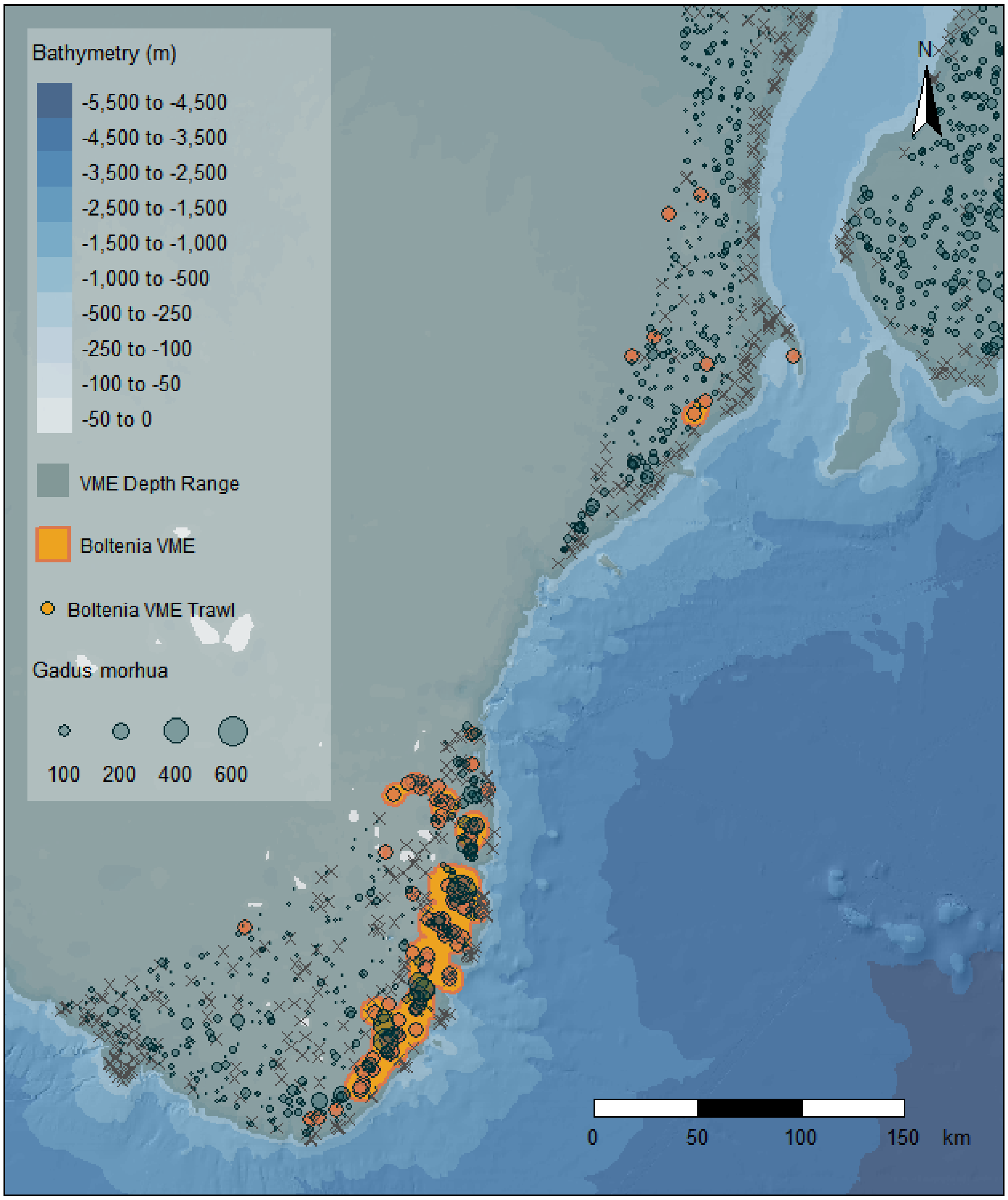


Figure 5.21. Distribution of cod (Gadus morhua) biomass in relation to the *Boltenia* spp. VME on the Grand Bank.

Bryozoans

The bryozoan VME is mainly located on the top of the Grand Bank, but individual trawls exceeding the VME threshold are found in deeper water and as a consequence, the depth range covers 33-1304 m (Figure 5.22). Bryozoans are associated with the two shallowest community groups on the Grand Bank (groups 5 and 6, ~90-200 m and ~45-90 m, respectively) and show a significant positive effect on a fish species in each group.

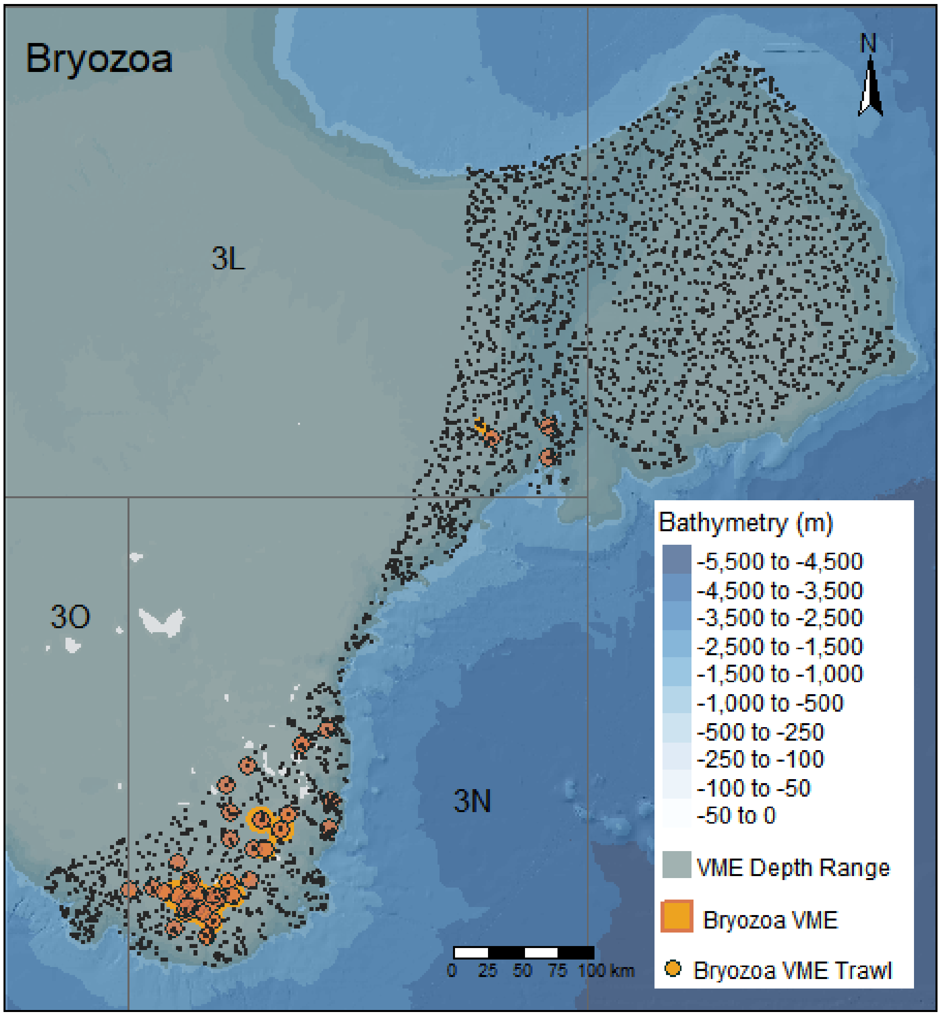


Figure 5.22. Depth range, extent of VME polygons and location of trawls exceeding VME threshold for bryozoa.

American plaice (*Hippoglossoides platessoides*) shows a trend of increasing biomass from outside of the VME, through the VME Polygon to the VME Trawl category with significantly higher biomass in both Polygon and Trawl categories than outside the VME (Figure 5.23a). Yellowtail flounder (*Limanda ferruginea*) shows a similar trend, but only the VME Trawl category is significant (Figure 5.23b). Figure 5.24 shows the spatial overall of American plaice biomass with the extent of the bryozoan VME.

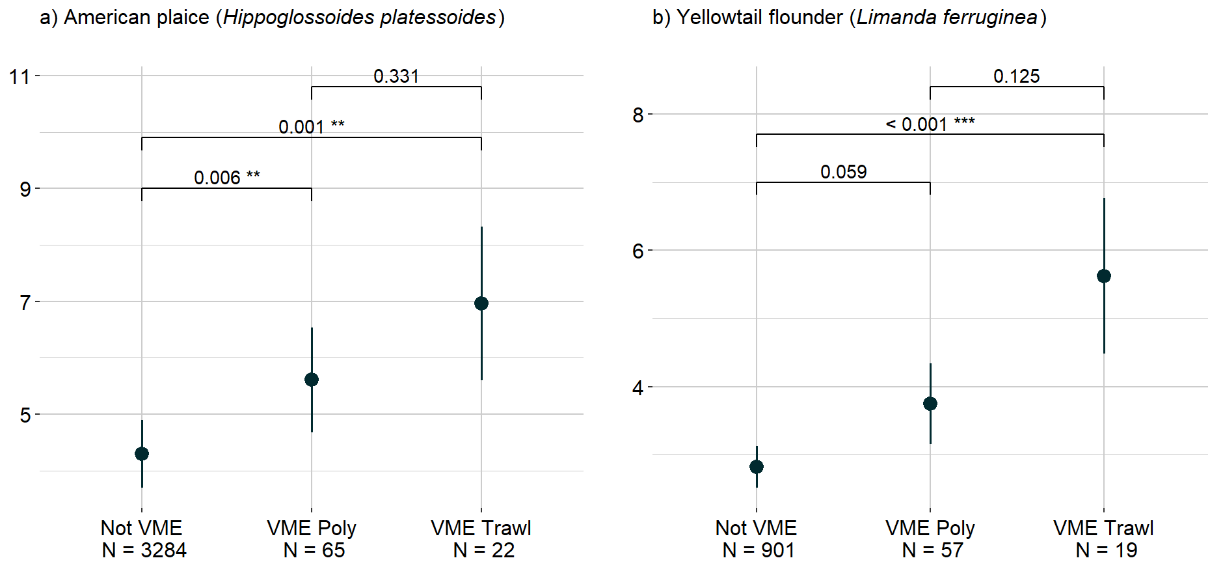


Figure 5.23. Mean biomass per scientific trawl in relation to Bryozoan VME for American plaice and Yellowtail flounder. P-values for Tukey Post Hoc comparison between the three categories: outside of VME (Not VME), inside the VME KDE polygon (VME Poly) and in trawls exceeding the VME threshold (VME Trawl) are shown for each pair of means.

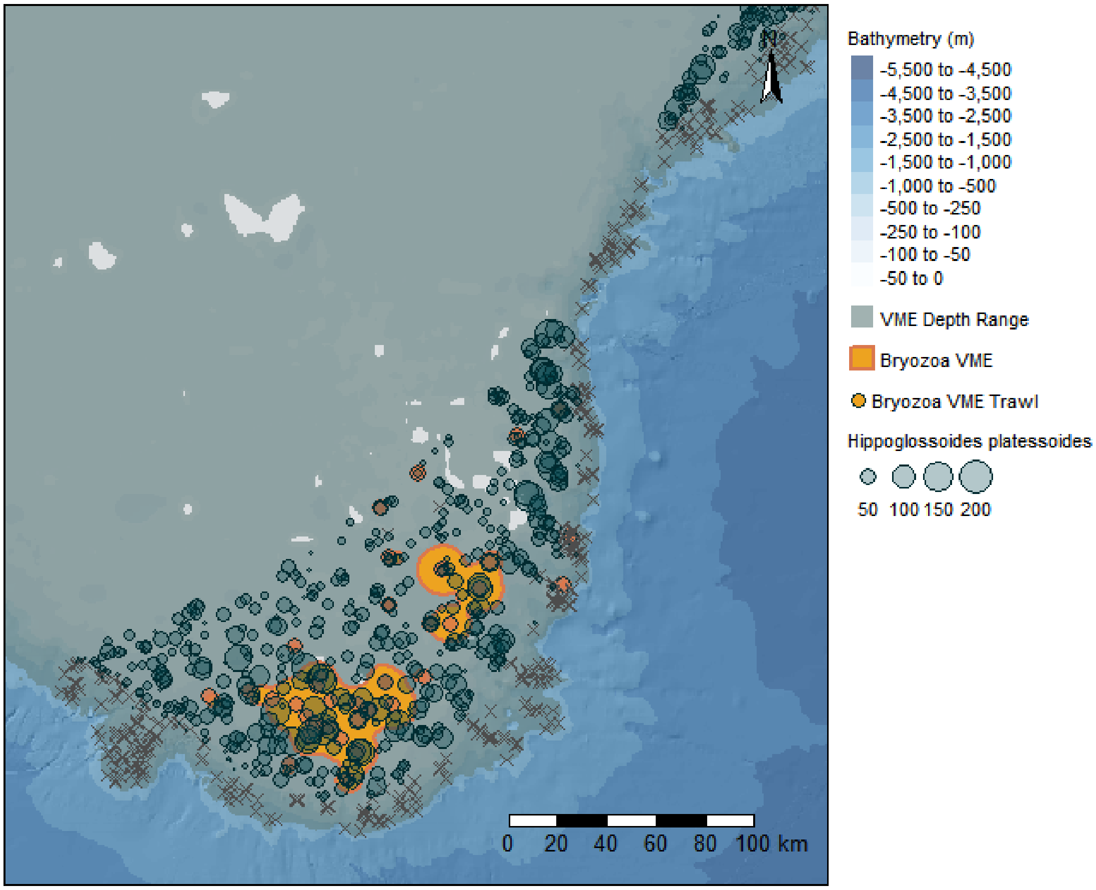


Figure 5.24. Distribution of American plaice (Hippoglossoides platessoides) biomass in relation to the bryozoan VME polygons on the tail of the Grand Bank

Black corals

The black coral VME is concentrated in deep water around the Flemish Cap ranging from 373 to 1215 m (Figure 5.25). It is one of the VMEs associated with the deep-water community group (group 3), overlapping in many places with the sea pen VME. The only positive association black corals have is with black dogfish (*Centroscyllium fabricii*), which is significantly associated with the VME Polygon category (Figure 5.26; see also Figure 5.11).

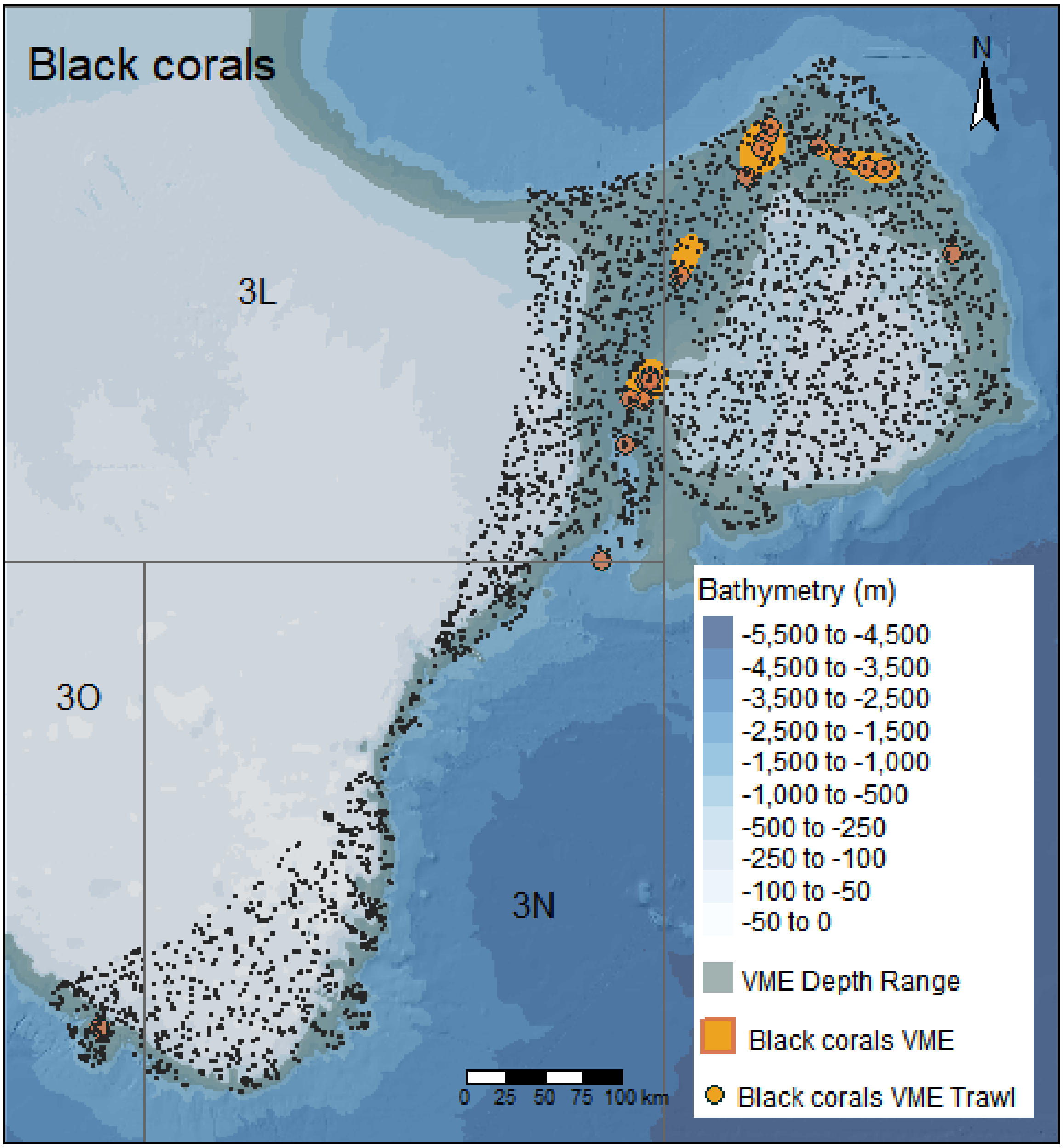


Figure 5.25. Depth range, extent of VME polygons and location of trawls exceeding VME threshold for black corals.

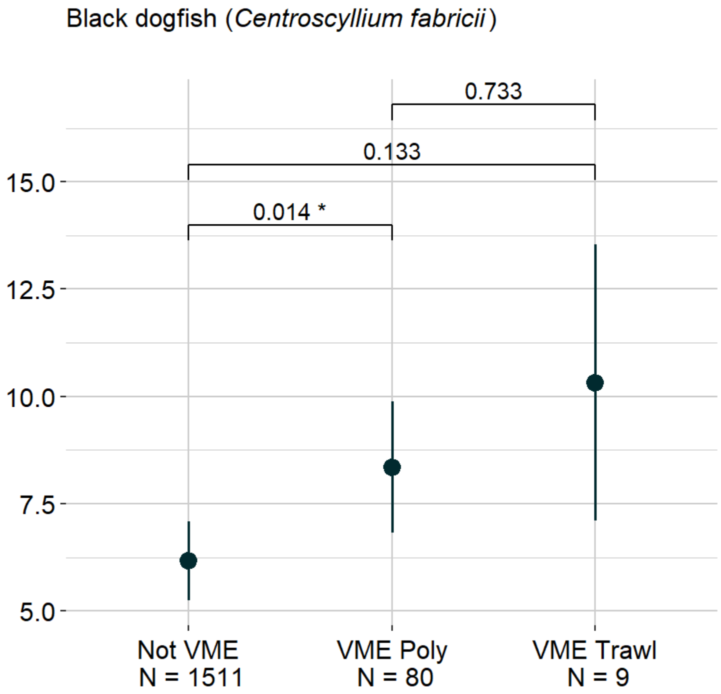


Figure 5.26. Mean biomass per scientific trawl in relation to Black coral VME for Black dogfish. P-values for Tukey Post Hoc comparison between the three categories: outside of VME (Not VME), inside the VME KDE polygon (VME Poly) and in trawls exceeding the VME threshold (VME Trawl) are shown for each pair of means.

Summary and conclusions

The present analysis took the approach of investigating associations between individual fish and VMEs, rather than the communities investigated in 2020, where most of the VMEs (small and large gorgonians, sea pens and sponges) were grouped in one community cluster (the deep-water group 3), whilst *Boltenia* spp. and bryozoans spanned the shallower groups found on the Grand Bank (groups 4-6). Whilst the fish were dealt with as individual species, VMEs were represented by the NAFO VME types (sea pens, small gorgonians, large gorgonians, black corals, sponges, *Boltenia* spp. and bryozoans) which are an amalgamation of the species in those groups. The analysis also accounted for the fish and VME's dependence on depth and the differences between the trawl surveys which yielded the data used to investigate links outside the depth and geographical commonalities.

The depth-limited approach helped to break down the large groups present in the cluster analysis, where certain fish and VMEs are present in narrower depth bands. On the other hand, similar associations were observed for VMEs with overlapping distributions and similar seabed habitats, such as sea pens and small gorgonians. Likewise, VMEs that, whilst not overlapping, provide similar structural habitat in a consistent depth range, such as sea pens, sponges, large gorgonians and black corals or large gorgonians and *Boltenia* spp., show similarities in their associations. Black dogfish especially has an association with many of the VMEs in the deep-water community group. Table 5.8

summarises the fish species with strong (significant positive effect of VME polygon and/or trawl) and moderate (significant positive effect of VME polygon only) associations with VME.

Table 5.8. Strongly and moderately associated fish by VME. Strong association includes fish with a significant positive association with polygons and trawls or trawls only (these indicated). Moderate association includes fish with a significant positive association with the VME polygon only.

VME	Strongly associated fish (polygons and/or trawls)	Moderately associated fish (polygons only)
Black corals		Black dogfish
Boltenia sp.	Rockfish Spotted wolf fish Atlantic wolf fish Cod Total fish	American plaice Yellowtail flounder Eelpout Roughhead grenadier
Bryozoa	American plaice Yellowtail flounder (Trawls)	
Large gorgonians	Rockfish	Beaked redfish Blue hake Black dogfish
Sea pens	Greenland halibut Rattails Black dogfish Northern wolffish (Trawls)	Blue hake Silver hake Grenadiers Cutthroat eel
Small gorgonians		Silver hake Grenadiers Cutthroat eel Rattails Thorny skate
Sponges	Roughhead grenadier	Blue hake Black dogfish

The depth range for each VME/ fish analysis was selected based on the depth range of VME polygon type. The rationale behind this approach was to investigate the difference of fish biomass inside and outside a specific VME. An alternate approach from the viewpoint of investigating the effects of VME presence in the preferred depth range of the fish could further elucidate connections, whilst including the whole depth distribution of the fish populations. Similarly, a comparison of the trends observed with those that would be seen for the abundance of fish would consolidate any findings based on the current analysis.

In future analysis, a combination of approaches looking at VMEs that occur in the fishes preferred environment, whilst combining VME indicator taxa with similar habitat-specific functions together across the VME boundaries could shine more light on the functional links between fish and VME. Furthermore, the analysis should include more variables related to their habitat requirements along with the depth range, such as temperature, current and bottom type where possible. Comparison of analysis results with in-situ observations, where these exist, would further help to investigate habitat use for those species with strong associations considering their ecology and environmental requirements.

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e) ToR 2.5. Up-date on connectivity analysis to assess habitat fragmentation in VME.

i) Evaluating the impacts on sea pen connectivity of alternative VME closures networks in the Newfoundland-Labrador and Flemish Cap bioregions using an Agent-based Modelling analysis

Since 2017 WGESA has been developing an Agent-based Model (ABM) for sea pens in the Newfoundland-Labrador (NL) and Flemish Cap (FC) bioregions. The sea pen ABM simulates the spatio-temporal dynamics of a generalized sea pen species within the domain defined by the NL and FC bioregions, and allows exploring time scales for colonization, responses to perturbations, and the effectiveness of closures as a mechanism to promote recovery (NAFO, 2017; NAFO, 2018; NAFO, 2019; NAFO, 2020).

The most recent update of the sea pen ABM model (NAFO, 2020) allowed determining that a realistic representation of fishing has significant impacts in both sea pen population level and distribution. Total sea pen abundance drops rapidly to around 55% of the pre-perturbation state, and reaches a "perturbed stable state". Given this type of response, all existing field data is expected to be reflective of this "perturbed stable state". This analysis also indicated that the system of closures (NAFO+Canada) existing in 2020 does not promote recovery at the total population level, but prevents fishing from expanding into remnant high density areas. However, fishing increases the variability in the sea pen dynamics at the population level, and the establishment of closures appears to provide some dampening to this variability. This is a potentially important emergent feature of the system of closures because increased variability can exacerbate patchiness, in addition to the spatial fragmentation driven by fishing. Removal of all fishing allows recovery within time scales of 50-100 years, where the recovery to ~75% requires ~25-30 years.

In 2021, the NAFO Commission (COM) considered a series of modifications to the existing VME closures in the NAFO Regulatory Area (NRA). These modifications were based on the options provided by Scientific Council (SC) as requested by COM (NAFO, 2021). In practice, the VME closure scenarios considered by COM can be described as:

a) Original closures. System of VME closures in the NRA in place in 2021.
b) Accepted closures. System of VME closures in the NRA that will be implemented in 2022. These consist of a subset of the VME closures proposed by SC (NAFO, 2021).
c) Proposed closures. System of VME closures as proposed by SC in 2021 (NAFO, 2021).

In order to evaluate the potential differences of these alternative closure scenarios on sea pens, especially in terms of connectivity, WGESA conducted a series simulation experiments using the most recent configuration of the sea pen ABM (SCS Doc. 20-23).

Simulation experiments

All simulation experiments consisted in applying realistic fishing scenarios without closures on a pristine sea pen population, letting fishing to operate for 100 years, and then applying a management scenario. The management scenarios included the three VME closures systems indicated above while allowing fishing outside the closures, plus a fourth scenario where fishing was completely stopped after the initial 100 years of fishing. In all scenarios the Canadian closures in the NL bioregion were implemented as they existed in 2021.

In all experiments, the model was initialized at a stable state without fishing and allowed to run for 100 years as a "burning period" before starting the initial fishing period (i.e. fishing without closures for 100 years). Average abundances in years 79-99 were used as baseline values to express changes as proportions of the pristine state.

Given the stochastic nature of the dynamics simulated by the sea pen ABM, 10 replicate runs of each experiment were done, and the results from each experiment summarized as the average of those 10 runs. These replicates were also used to characterize the variability in the dynamics at different stages of each simulation experiment.

The abundance of sea pens during these simulation experiments was monitored at multiple spatial scales (e.g. the entire model domain, inside closures, etc). In order to evaluate the effect of the system of closures in areas exposed to fishing (i.e. outside closures), a series of "monitoring boxes" were also implemented. These monitoring boxes provide a common and consistent area to evaluate the potential impacts on connectivity across closure scenarios; those system of closures that improve connectivity would be expected to allow for higher abundances outside closures. The location of NAFO VME closures, Canadian closures, and monitoring boxes within the model domain are shown in Figure 5.27.

Since the effect of closures on connectivity is often more local in nature (SCS Doc. 19-25; 20-23), and to focus the analysis on the different closure scenarios under NAFO regulatory purview, only the monitoring boxes within the NRA were used to evaluate impacts on connectivity (Figure 5.27)

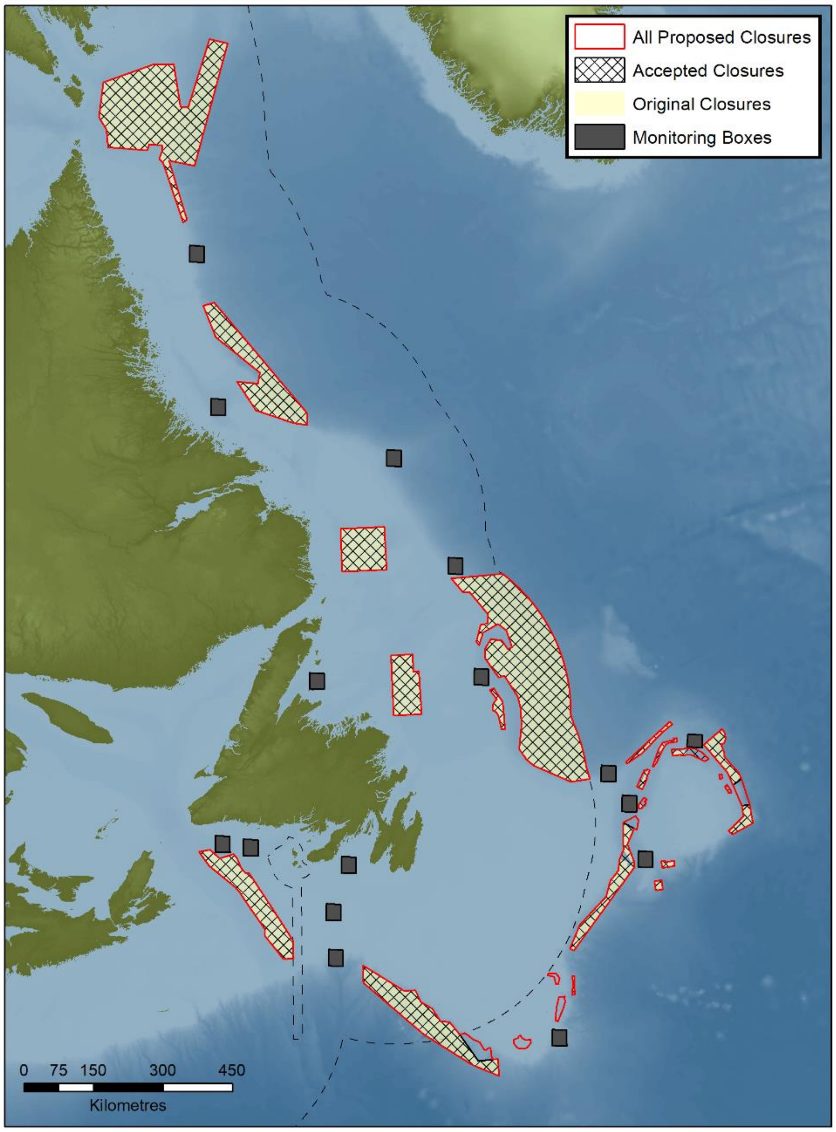

Figure 5.27. Systems of closures in the NL and Flemish Cap Bioregions, with indication of the location of the monitoring boxes.

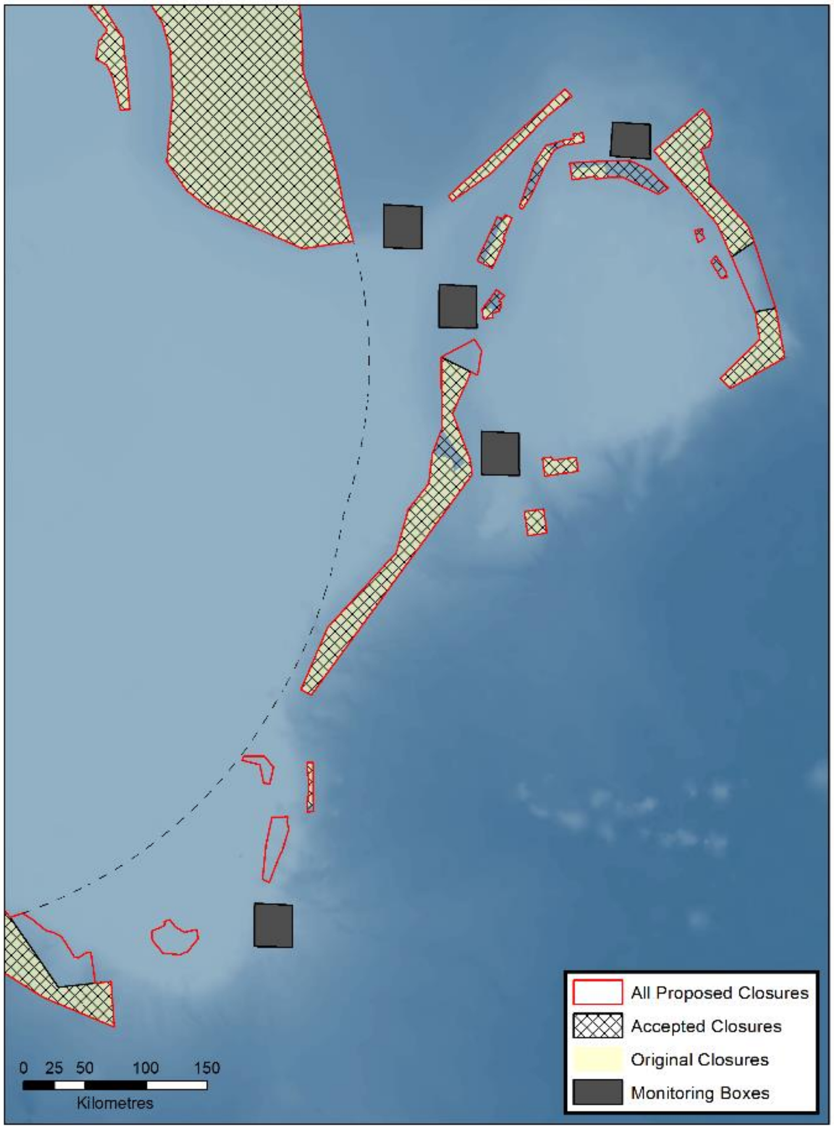

Figure 5.28. Systems of closures in the NRA and neighboring area. Only the monitoring boxes within the NRA were used to evaluate impacts on connectivity.

The basic metrics considered for this analysis were the proportion of sea pen abundance at the model domain scale (population scale abundance), the coefficient of variation of these proportions (variability in dynamics at the population scale), and the proportion of sea pen abundance within all NRA monitoring boxes (abundance outside closures within the NRA to assess impacts on connectivity).

Differences between management scenarios were evaluated using one-way ANOVA, and post hoc pairwise comparison tests (Holm, 1979) when the ANOVAs were significant. The treatments for the ANOVA were the three closure scenarios, and the fishing period without closures, which served as control. Since the data is expressed as proportions of the pristine baseline, they were transformed using the logit transformation before the analysis.

The data for the "control" treatment was pooled from the initial fishing period from all experimental runs (i.e. years 100 – 199, with fishing but before any management scenario is implemented), while the data for each experimental treatment corresponded to the data from each scenario when the management measures were in place. Since All experiments ran for 500 years with the model recording abundance every other year, it rended a total of 200 data points for the control treatment and 150 for each experiment.

Results

As expected from prior analyses with this model, the onset of fishing produces a rapid decline in total sea pen abundance, which reaches a "perturbed stable state" at around 53% of the pristine level. All closures scenarios allow a modest recovery in abundance of ~2%, bringing the total abundance to ~55% when closures are implemented (Figure 5.29). The differences among all scenarios were small, but still statistically significant (ANOVA, p-value<0.0001, all pairwise contrasts p-values <0.01), with proportions of total abundance of 53.3%, 54.5%, 54.9%, and 55.6% for the fishing without closures, original closures, accepted closures, and SC proposed closures respectively (Figure 5.30). Despite their statistical significance, the differences among the three closure scenarios evaluated are small, and unlikely to be particularly meaningful from an ecological functioning perspective.

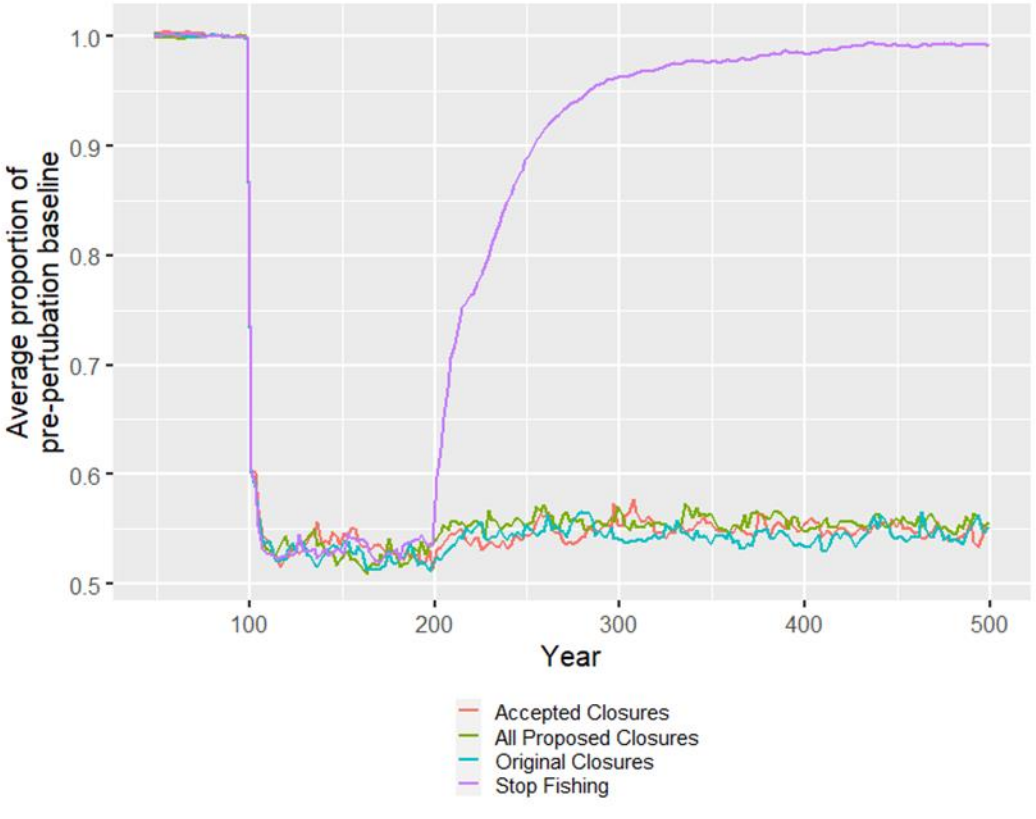

Figure 5.29. Changes in total sea pen abundance (model domain spatial scale) for all simulation experiments, expressed as proportion of the pre-perturbation level. Fishing drives total abundance to around 53% of the pristine state, and all systems of closures considered here provided only modest recovery from that reduced level.

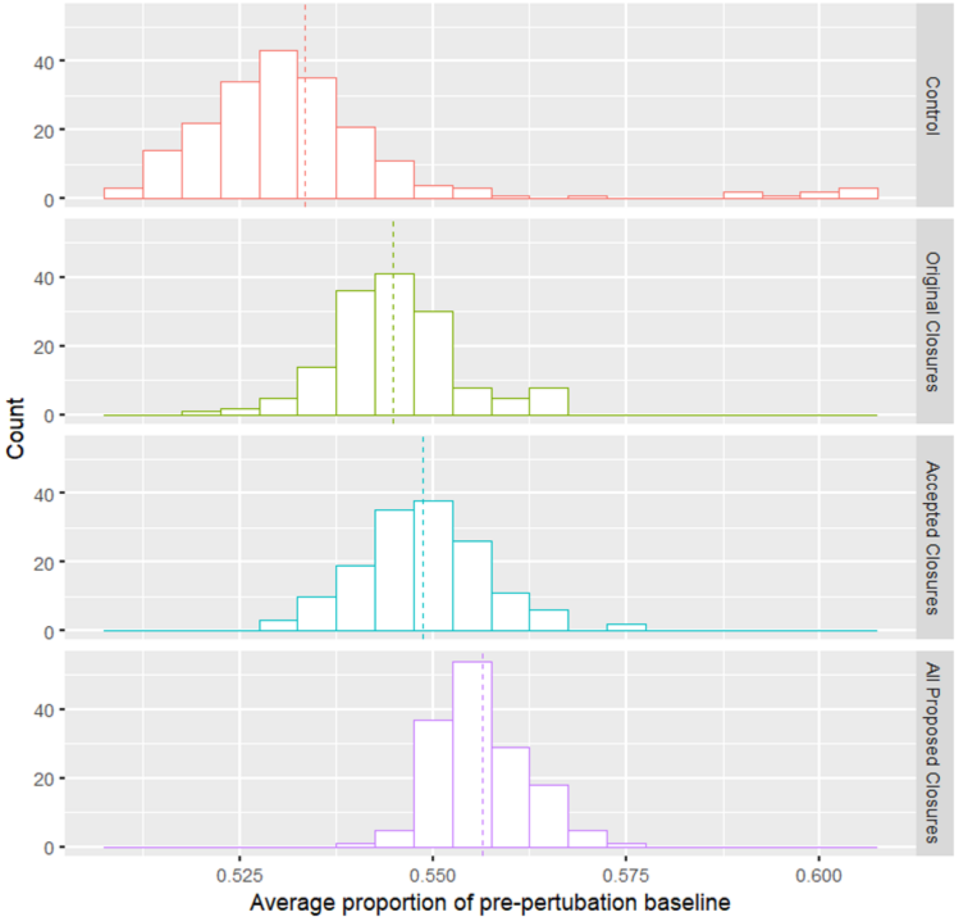

Figure 5.30. Frequency distribution of the proportion of total abundance at the model domain scale for the treatments considered in the ANOVA analysis, with indication of the mean for each distribution (dotted vertical lines). The control treatment correspond to fishing without any closure.

In terms of variability, the results are clear with regards to fishing increasing the variability in abundance, but are less clear in terms of the potential effectiveness of the closures scenarios in dampening that variability (Figure 5.31). While the ANOVA results indicate highly significant statistical differences between treatments (ANOVA, p-value<0.0001), the pairwise comparisons showed somewhat inconsistent results. The coefficients of variation of the proportion of total abundance where lower for all closures scenarios in comparison with the control (i.e. fishing without closures), which gives credence to the contention that closures somewhat dampened the demographic variability generate by fishing (Figure 5.32). However, the pairwise comparisons indicated that the only statistical differences between the control (i.e. fishing without closures) and a closure scenario were those with the original closures (p-value=0.004), and with the SC closures proposal (p-value=0.0001); the comparison between the control and the accepted closures scenario was not significant (p-value=0.14). Since the accepted closures scenario is an intermediate one between the original closures and the SC closures proposal, this suggests that the stochasticity in the dynamics may be overriding the underlying average response signal. Considering that the original and SC proposal closure scenarios rendered statistical differences with the control, and the direction and distributions of all differences are consistent with a dampening effects of closures (Figure. 5.32), the current evidence appears to support the existence of such effect, but additional replicate runs may be required to either consolidate or disprove its existence.

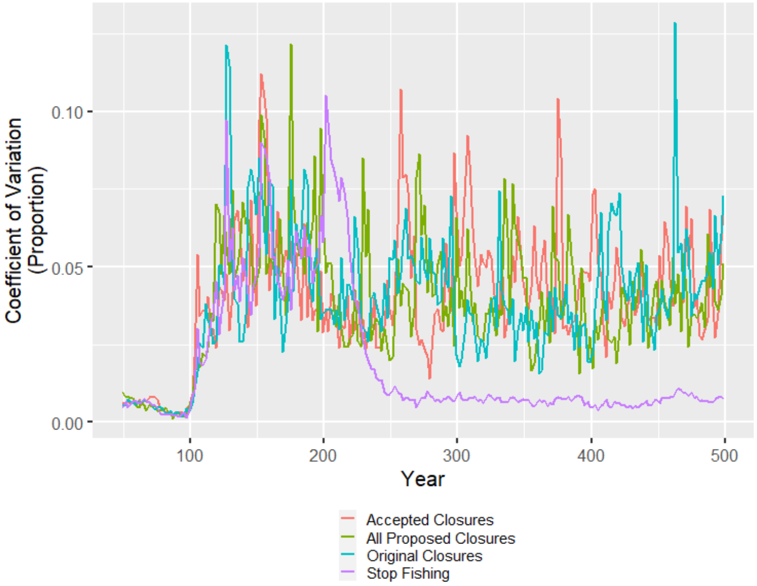

Figure 5.31. Changes in the coefficient of variation of the proportion of total sea pen abundance (model domain spatial scale) for all simulation experiments. Fishing clearly increases the demographic stochasticity of the sea pen dynamics.

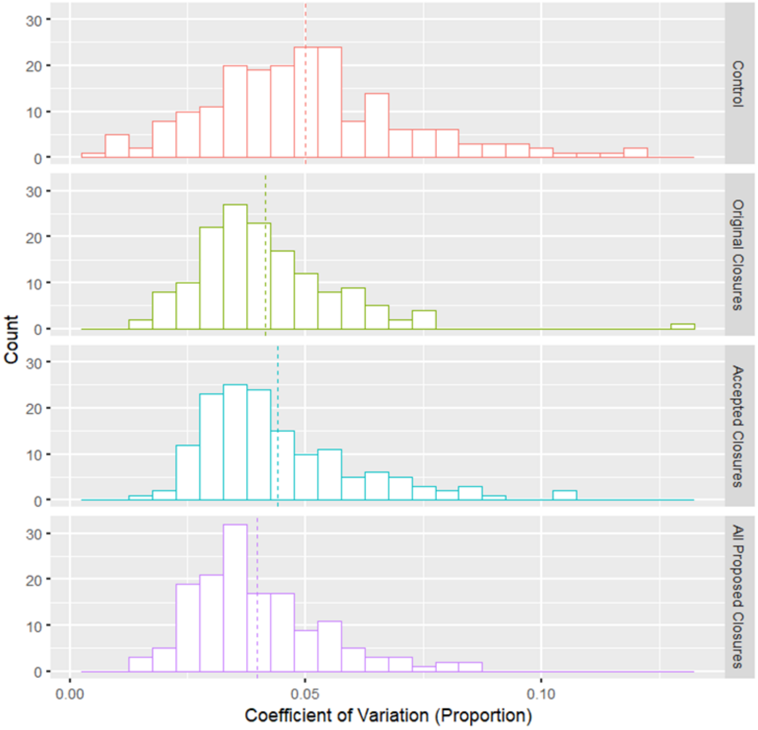

Figure 5.32. Frequency distribution of the coefficient of variation of the proportion of total abundance at the model domain scale for the treatments considered in the ANOVA analysis, with indication of the mean for each distribution (dotted vertical lines). The control treatment correspond to fishing without any closure.

The examination of sea pen abundance outside closures within the NRA using the monitoring boxes indicated that fishing impacted sea pen abundance to a larger degree than at the overall population scale, reducing the abundance to 41.5% of the pristine state (Figure 5.33). While the elimination of fishing allowed these areas to recover, the recovery time to pre-perturbation levels was 100 years, but recovery up to 75-85% took around 30-50 years. The implementation of closure scenarios did not provide an obvious improvement in abundance within these areas exposed to fishing (Figure 5.33), with the exception of the SC closures proposal scenario which rendered a more evident increase in the average proportion, as well as in its overall distribution (Fig. 5.34). The statistical analyses confirmed these observations; the ANOVA indicated statistically significant differences among treatments (ANOVA, p-value<0.0001), while the pairwise comparisons indicated that only the SC closure proposal scenario was statistically different from all other treatments (all pairwise p-values <0.001); the pairwise comparison between all other treatments (control, original closures, and accepted closures) were non-significant (all p-values >0.2).

The implications from this last analysis on connectivity are important. The implementation of the original and accepted closure scenarios allow for sea pen rebuilding within closures, but do not appear to provide any detectable improvement in connectivity from a perturbed stable state without any closures. Only the SC closure proposal scenario appears to provide some improvement in connectivity, even if this improvement is rather small.

Overall, all closure scenarios under consideration only provide a very limited rebuilding potential, but they are effective at preventing further declines by preventing fishing from expanding into previously unfished areas where high sea pen abundances still remain. The evidence from the analysis of the NRA monitoring boxes suggests that even modest changes within the scope of closures networks like the ones being examined here can actually start providing some marginal improvements in connectivity, allowing for modest improvements in abundance outside closed areas. However, the accepted closure scenario, which is the one to be implemented in 2022, still falls short at providing these improvements.

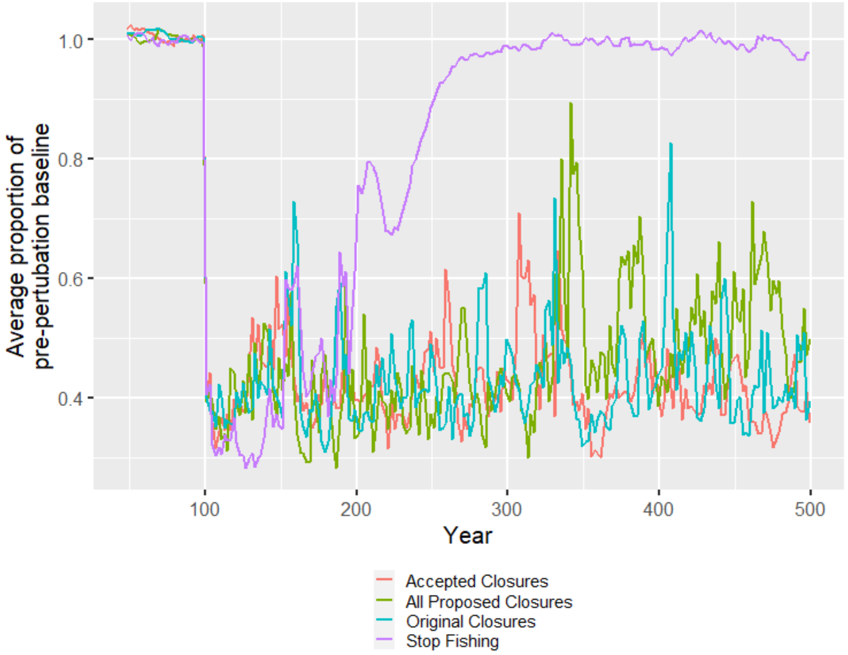

Figure 5.33. Changes in the proportion of sea pen abundance within the NRA monitoring boxes for all simulation experiments.

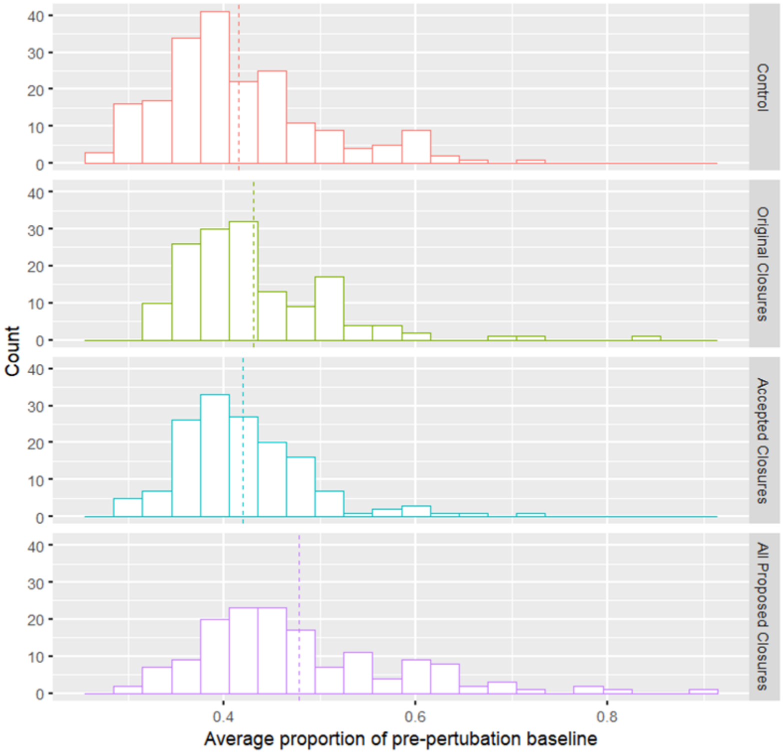

Figure 5.34. Frequency distribution of the proportion of sea pen abundance within the NRA monitoring boxes for the treatments considered in the ANOVA analysis, with indication of the mean for each distribution (dotted vertical lines). The control treatment correspond to fishing without any closure.

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ii) Advances in the Assessment of Habitat Fragmentation and Protection

NAFO has used kernel density analyses to identify VMEs dominated by large-sized sponges, sea pens, small and large gorgonian corals, erect bryozoans, sea squirts (Boltenia ovifera), and black corals. That analysis (Kenchington et al. 2014) generates polygons of significant concentrations of biomass for each VME indicator which are spread across the spatial domain of the NAFO fishing footprint. There is potential for bottom contact fishing to induce changes in both the amount and configuration of habitat (e.g., decreased polygon size, increased polygon isolation, and increased edge area) through direct and indirect impacts, and it is unknown to what degree such changes may already have taken place given the long fishing history of the area. Habitat fragmentation is defined as the division of habitat into smaller and more isolated fragments (Haddad et al. 2015), and can arise through both natural and anthropogenic activities (Haddad et al. 2015, Wilson et al. 2016). In the Report of the 13th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WGE-ESA), preliminary work on assessing and monitoring habitat fragmentation was presented (SCS. Doc. 20-23).

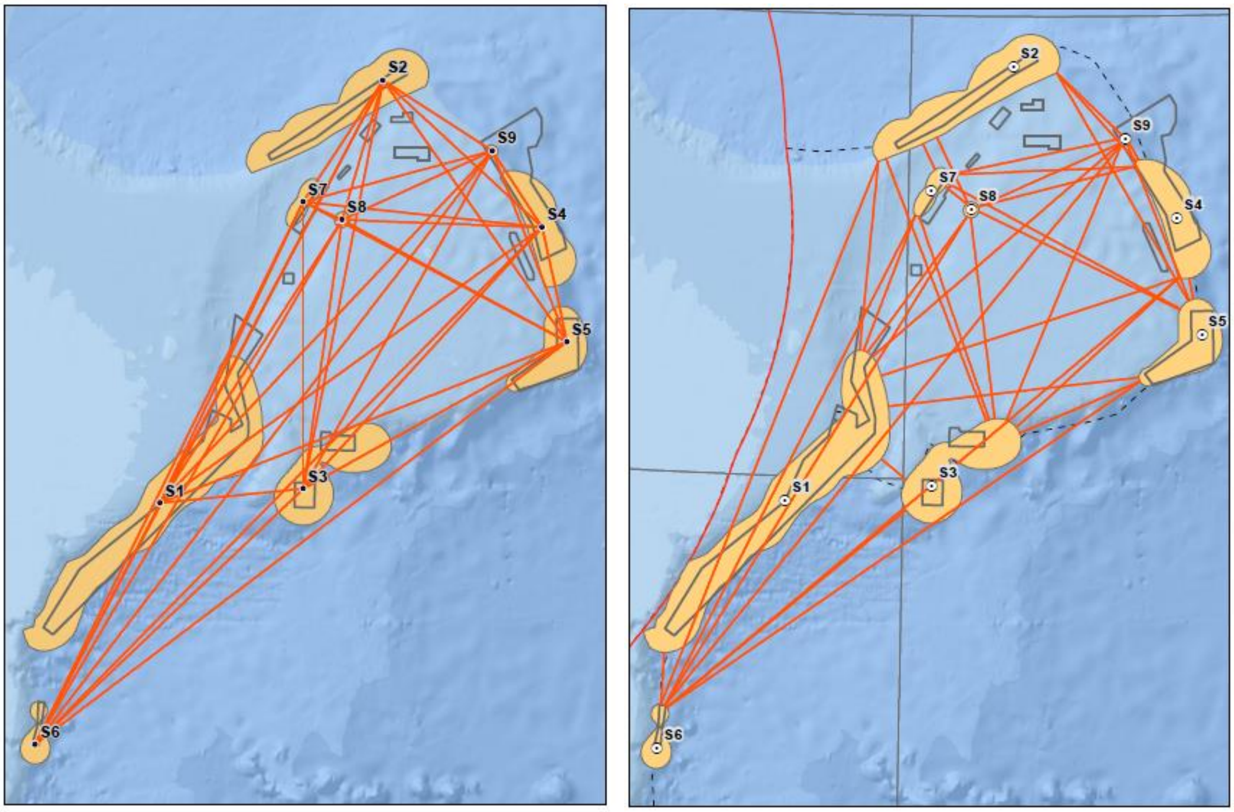


Figure 5.35. Nearest neighbour distance lines between large-sized sponge VME polygons in the NRA calculated from centroid to centroid (Left panel) and from the nearest edge (Right panel). NAFO closed areas for the protection of corals and sponges are indicated in grey. [from SCS. 20-23]. Projection: NAD83 UTM 23.

Two methods were used to calculate nearest neighbour distances between polygons (NAFO, 2020): centroid to centroid, and edge to edge (Figure 5.34, Table 5.9). In addition, the average nearest neighbour ratio and a proximity index (PX) as described by Gustafson and Parker (1994), were calculated. The former could only be applied to symmetrical distributions (across all closed areas for example) while the later can only be applied to the edge-edge distances. The distance matrices used in those assessments included connections between VME polygons and between Closed Areas that may not occur (e.g., Figure 5.35, Table 5.9). Removal of connections that are unlikely to occur due to the prevailing oceanographic currents, and recalculation of the indices was proposed for the next phase of development of this index. This needs to be been done both for the VME polygons and the new Closed Areas. Here we present the results for Large-sized Sponge VMES and for the new Closed Areas with other VMEs to be assessed once the methodology is agreed upon.

Table 5.9. Nearest neighbour distances (km) calculated from centroid to centroid (below diagonal, shaded) and from nearest edges (above diagonal) for the sponge VME polygons in the NAFO Regulatory Area (numbered as in Figure 5.35). The mean nearest-neighbour distance for each polygon, as a measure of relative isolation, is shown below the rows for the centroid to centroid distances and to the right of columns for the nearest edges distances. Polygons are numbered according to decreasing area. [from NAFO 2020]. Projection: NAD83 UTM 23.

	Polygon Area km^2	S1	S2	S3	S4	S5	S6	S7	S8	S9	Mean Nearest-Neighbour Distance (Edge-Edge)
S1	9687.0	---	148	25	244	197	40	113	131	256	144
S2	4596.9	382	---	219	93	205	455	22	56	69	158
S3	3695.9	115	333	---	172	102	242	168	157	234	165
S4	2571.5	377	173	283	---	17	521	144	125	14	166
S5	2255.1	350	256	242	94	---	448	206	175	131	185
S6	711.9	217	600	296	579	534	---	429	448	565	394
S7	516.2	267	116	230	192	239	484	---	21	136	155
S8	119.8	269	116	217	160	205	486	34	---	122	154
S9	63.5	387	104	310	73	164	599	157	132	---	191
Mean Nearest-Neighbour Distance (Centroid-Centroid)		296	260	253	241	261	474	215	202	241	

Large-sized Sponge VMEs

Connectivity Assessment

Lagrangian particle tracking (LPT) models are considered an important tool for assessing structural connectivity in the deep sea (e.g., Xu et al., 2018; Bracco et al., 2019; Kenchington et al., 2019; Zeng et al., 2019, Wang et al., 2020; Wang et al., 2021b) and can provide strong support for the evaluation of species distribution models (Kenchington et al., 2019; Wang et al., 2021b). In LPT models, virtual particles are advected by the flow fields from numerical ocean models (Lange and van Sebille, 2017). Virtual behavior, if known, can also be added to the particles so that they can act as active drifters, i.e., swimming larvae, and enable predictions of functional connectivity (sensu Tischendorf and Fahrig, 2000). Here, the Parcels framework version 2.2.2 (Lange and van Sebille, 2017; Delandmeter and van Sebille, 2019) was used to perform three-dimensional (3-D) passive particle tracking experiments in the NAFO Regulatory Area of the northwest Atlantic. The Bedford Institute of Oceanography North Atlantic Model (BNAM) (Wang et al., 2018, 2019) was used to generate the current data used in the particle tracking models (Wang et al., 2020). Climatological monthly-averaged currents were obtained from the BNAM ocean model over the 1990-2015 period. A horizontal diffusivity constant, Kh = 100 m s-1 was applied (Wang et al. 2020) to compensate in part for the variation lost in averaging. The proportion of particles passing over or terminating in another sponge VME polygon (Goldsmit et al., 2019) was presented as a connectivity matrix among sponge VME polygons for each model run.

Particles were seeded uniformly inside the sponge VME polygons (Figure 5.35) as in Figure 5.36. Rectangles encapsulating each of the sponge VME polygons were constructed (Figure 5.36A) and a 1-km grid was overlain in each (Figure 5.36B). The projection NAD83 UTM 23 was used to construct all grids. The grid points falling within the sponge VME polygon were retained and used to seed particles for the LPT analyses (Figure 5.36B). A minimum of 50 particles per area was established and additional particles were randomly placed in small sponge VME polygons.

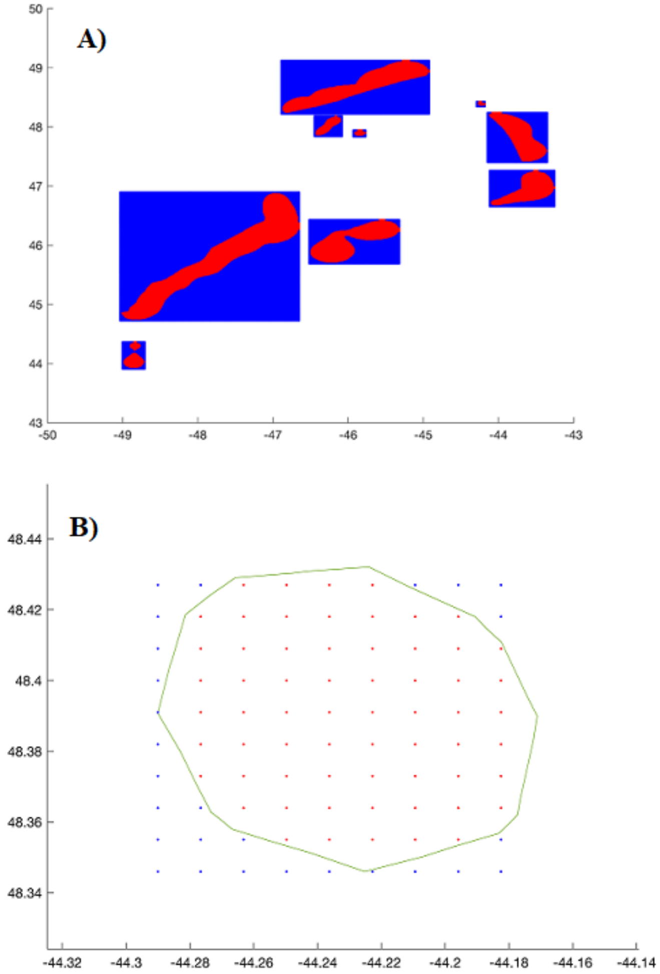


Figure 5.36. Steps showing the construction of grid cells for the particle seeding for the LPT analyses among large-size sponge VMEs. A) rectangles (red and blue) were placed over each sponge VME polygon (red) within which B) a uniform grid with 1-km spacing was overlain and grid points falling within the sponge VME polygons were used to position particles to seed the analyses. Projection: NAD83 UTM 23.

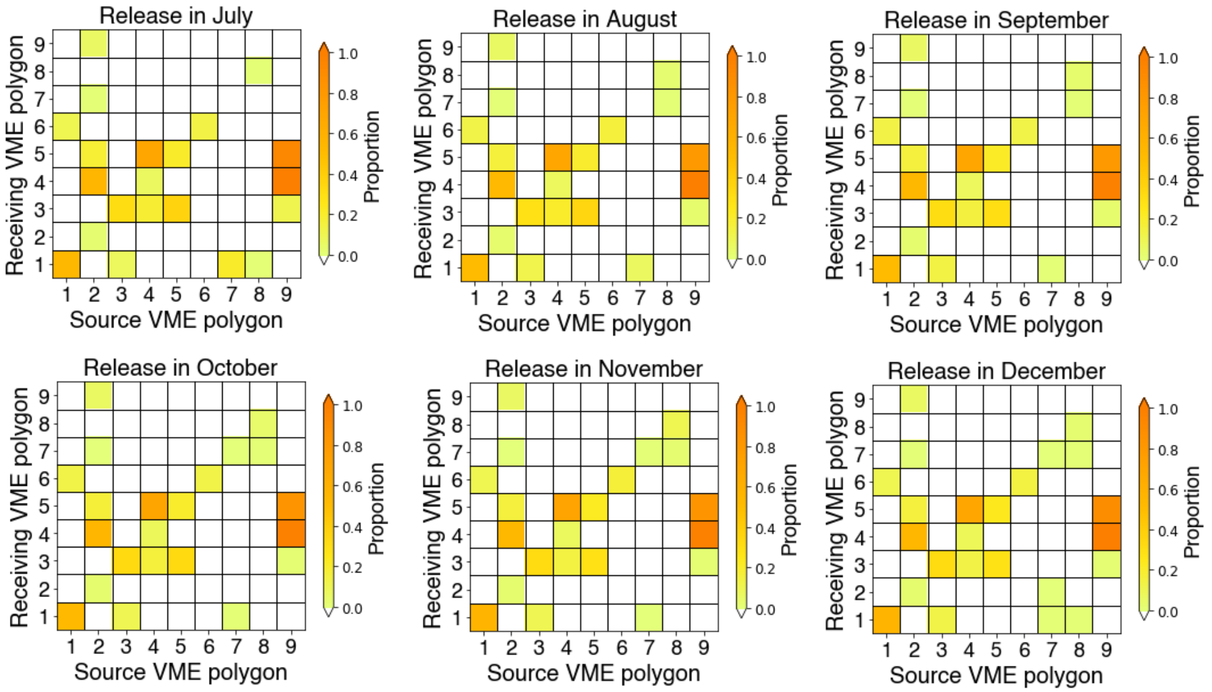


Figure 5.37. Connectivity matrices between sponge VME polygons for particles released in each month from July to December (Summer and Fall) as evaluated in Wang et al. (2020). The diagonal represents particle retention. Polygon numbers are shown in Figure 5.35.

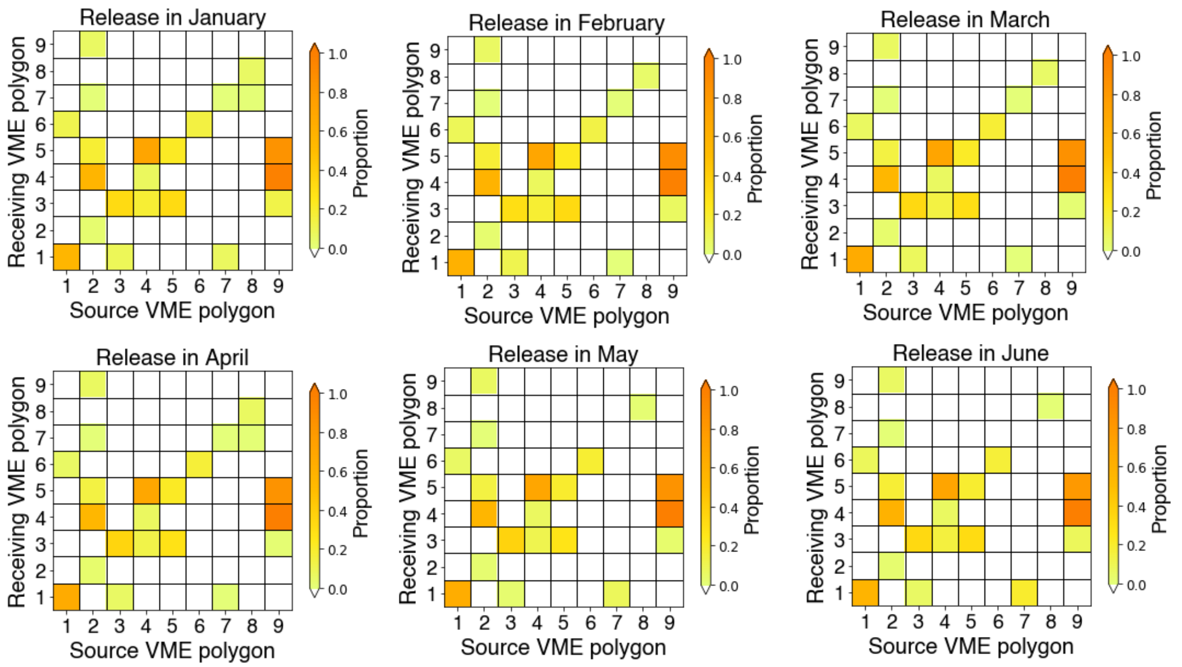


Figure 5.38. Connectivity matrices between sponge VME polygons for particles released in each month from January to June (Winter and Spring). The diagonal represents particle retention. Polygon numbers are shown in Figure 5.35.

Wang et al. (2020) used Summer and Fall to release particles, as these are the most likely spawning season for the sponges (Kenchington et al., 2019). Here, monthly averaged currents were extracted from BNAM for each season (Winter, Spring, Summer, Fall) to confirm that no new connections were made at other times. Particles were released from the sea bed and allowed to advect for two weeks, a maximal estimate for pelagic larval duration for all sponges (Kenchington et al., 2019). The connectivity matrices for each month are shown in Figures 5.37 and 5.38. No additional connections were made in the Winter and Spring (over Summer and Fall) as observed by Wang et al. (2020).

The nearest-neighbour distances in kilometres, calculated from centroid to centroid (Table 5.10) and from edge to edge (Table 5.11) for polygons that have a strong likelihood of connecting with one another, as indicated by the LPT analyses are provided. As connections are only unidirectional the results are presented as a square matrix. Only 16 of the 81 possible connections were considered likely. Mean nearest-neighbour distances ranged from 0-217 km (centroid to centroid) and 0-126 km (edge to edge). The Proximity Index, PX, was smaller than when all connections were considered (Table 5.12) being 1111.8 previously (SCS Doc. 20-23).

Table 5.10. Unidirectional (source to sink) nearest neighbour distances (km) calculated from centroid to centroid for the sponge VME polygons in the NAFO Regulatory Area (numbered as in Figure 5.35) which showed connectivity (Figures 5.37, 5.38, 5.39). The mean nearest-neighbour distance for each polygon is shown.

			Source Sponge VME Polygon								
		Polygon Area km2	S1	S2	S3	S4	S5	S6	S7	S8	S9
Sink Sponge VME Polygon	S1	9687.0	---		115				267	269	
	S2	4596.9		---					116		
	S3	3695.9			---	283	242				310
	S4	2571.5		173		---					73
	S5	2255.1		256		94	---				164
	S6	711.9	217					---			
	S7	516.2		116					---	34	
	S8	119.8								---	
	S9	63.5		104							---
	Mean Nearest-Neighbour Distance (Centroid-Centroid)		217	162	115	188	242	0	192	152	182

Following NAFO (2020) we undertook a t-test, assuming unequal variances, between the mean nearest-neighbour distances using the centroid to centroid (Table 5.10) and separately, the edge to edge averages (Table 5.11), comparing distances between VME polygons and the closed areas in place in 2021 (NAFO, 2020). The p-value of the t-test for differences between the means is considered to be a Consistency Index (NAFO, 2020). For the sponge VMEs the p-values were 0.0090 (t-ratio -2.882, df 20.648) and 0.0002 (t-ratio -4.661, df 17.041) respectively. Both values are much lower than reported previously when the connectivity was not considered and all possible connections were included. These values are directly comparable to those produced in the Consistency Index for the 2020 Assessment with only the connectivity among sponge VMEs being altered.

Table 5.11. Unidirectional (source to sink) nearest neighbour distances (km) calculated from edge to edge for the sponge VME polygons in the NAFO Regulatory Area (numbered as in Figure 5.35) which showed connectivity (Figures 5.37, 5.38, 5.39). The mean nearest-neighbour distance for each polygon is shown.

			Source Sponge VME Polygon								
		Polygon Area km2	S1	S2	S3	S4	S5	S6	S7	S8	S9
Sink Sponge VME Polygon	S1	9687.0	---		25				113	131	
	S2	4596.9		---					22		
	S3	3695.9			---	172	102				234
	S4	2571.5		93		---					14
	S5	2255.1		205		17	---				131
	S6	711.9	40					---			
	S7	516.2		22					---	21	
	S8	119.8								---	
	S9	63.5		69							---
	Mean Nearest-Neighbour Distance (Edge to Edge)		40	97	25	95	102	0	68	76	126

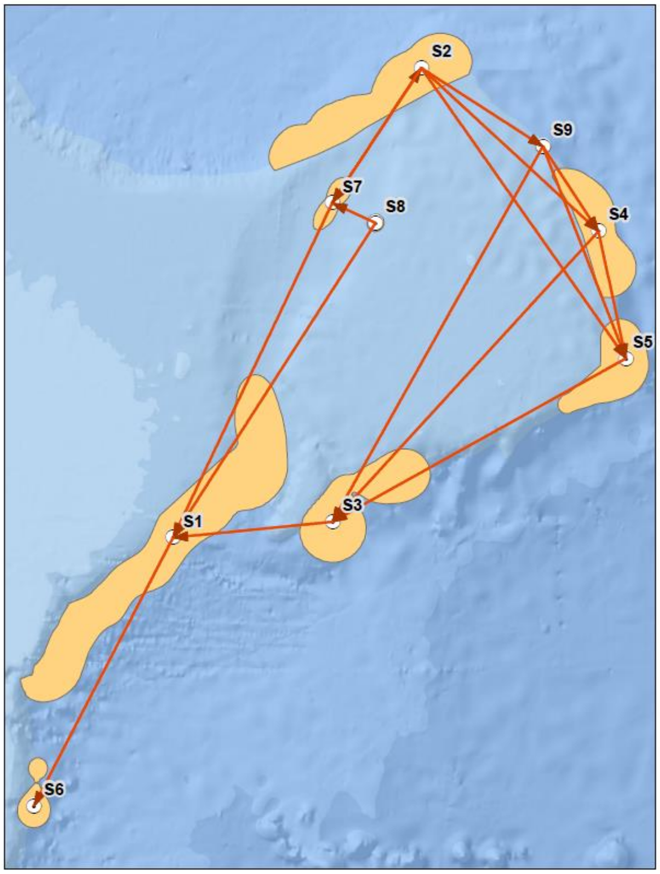


Figure 5.39. Unidirectional (source to sink) connectivity for the sponge VME polygons in the NAFO Regulatory Area (numbered as in Figure 5.35) which showed connectivity (Figures 5.37, 5.38)

Table 5.12. Isolation/Proximity indices for the large-sized sponge VME polygons in the NAFO Regulatory Area calculated using only the connections that were shown to be possible through the LPT modeling (Figures 5.37, 5.38, 5.39).

Distance Measurement Method	Mean Nearest-Neighbour Distance Over All Polygons Pairs	Proximity Index (PX)
Centroid-Centroid	161	
Edge-Edge	70	806.04

Application to the New Closed Areas in the NAFO Regulatory Area (Effective 1 January 2022)

The results of the analyses applied to the new NAFO closed areas approved at the 2021 Annual General Meeting are shown in Tables 5 and 6. The distances between the closed areas (Figure 5.40) ranged from 31 to 842 km centroid to centroid, and 11 to 775 km edge to edge (Table 5.13). Using the distances from centroid to centroid, shown in the lower diagonal of Table 5.13, the values for the mean nearest-neighbour distance over all polygons and the average nearest neighbor ratio are provided in Table 5.14. The values for the mean nearest-neighbour distance over all polygons (Table 5.13) and PX are provided for the edge-edge distances (Table 5.14). The establishment of the new closures did not change the edge-edge distance range or mean and only slightly changed the centroid-

centroid distance, however PX was increased from 452 to 783. PX is larger when the polygons are surrounded by larger and/or closer polygons and decreases as polygons become smaller and/or sparser (Gustafson and Parker, 1994). The increase here is likely due to the increase in size of the closed areas which combine some of the smaller previous closures. In the sponge analysis the VME polygons did not change, only the number of connections, so in that case the change in values was just reflective of the data and not due to a change in configuration as is the case here.

Table 5.13. Nearest neighbour distances (km) calculated from centroid to centroid (below diagonal, shaded) and from nearest edges (above diagonal) for the closed areas in the NAFO Regulatory Area (numbered as in Figure 5.40). The mean nearest-neighbour distance for each closed area, as a measure of relative isolation, is shown below the rows for the centroid to centroid distances and to the right of columns for the nearest edges distances. Closed areas are numbered according to the NAFO Conservation and Enforcement Measures. All calculations were performed using NAD83 UTM 23 projection.

Area No.	**Description**	**Polygon Area km²**	**Area 1**	**Area 2**	**Area 3**	**Area 4**	**Area 5**	**Area 6**	**Area 7**	**Area 10**	**Area 11**	**Area 12**	**Area 13**	**Area 14a**	**Area 14b**	**3O**	**Mean Nearest-Neighbour Distance (Edge-Edge)**
Area 1	Tail of the Bank	172	---	55	254	454	532	470	518	427	386	480	299	525	514	211	394
Area 2	Flemish Pass	5,771	263	---	52	202	230	127	176	83	43	137	58	212	214	284	144
Area 3	Beothuk Knoll	308	286	85	---	178	254	259	268	199	159	244	27	250	236	497	221
Area 4	E Flemish Cap	1,358	510	287	228	---	48	229	122	205	187	195	133	72	36	697	212
Area 5	NE Flemish Cap	2,879	594	335	316	169	---	80	11	127	169	57	205	12	10	775	193
Area 6	Sackville Spur	987	549	288	305	261	136	---	40	32	81	16	221	147	174	686	197
Area 7	N Flemish Cap	1,053	564	302	294	186	48	90	---	58	108	15	223	40	67	753	184
Area 10	NW Flemish Cap	527	472	210	230	231	162	78	116	---	18	11	159	148	165	657	176
Area 11	NW Flemish Cap	220	423	160	179	219	191	130	150	52	---	69	121	163	169	619	176
Area 12	NW Flemish Cap	511	555	292	301	234	104	32	58	85	132	---	202	114	141	712	184
Area 13	Beothuk Knoll	338	333	104	49	186	267	262	245	189	141	255	---	200	186	542	198
Area 14a	NE Flemish Cap	50	551	300	268	105	65	170	85	166	177	140	219	---	17	768	205
Area 14b	NE Flemish Cap	104	539	294	254	74	95	196	114	183	186	167	206	31	---	757	207
3O	3O Coral Closure	3,694	269	508	548	775	842	774	807	702	658	787	593	806	798	---	612
Mean Nearest-Neighbour Distance (Centroid-Centroid)			455	264	257	267	256	252	235	221	215	242	235	237	241	682	

Table 5.14. Isolation/Proximity indices for the VME closures in the NAFO Regulatory Area.

Distance Measurement Method	Mean Nearest-Neighbour Distance Over All Polygons Pairs	Nearest Neighbour Ratio	Proximity Index (PX)
Centroid-Centroid	290	1.287498 p-value: 0.040	
Edge-Edge	236		782.96

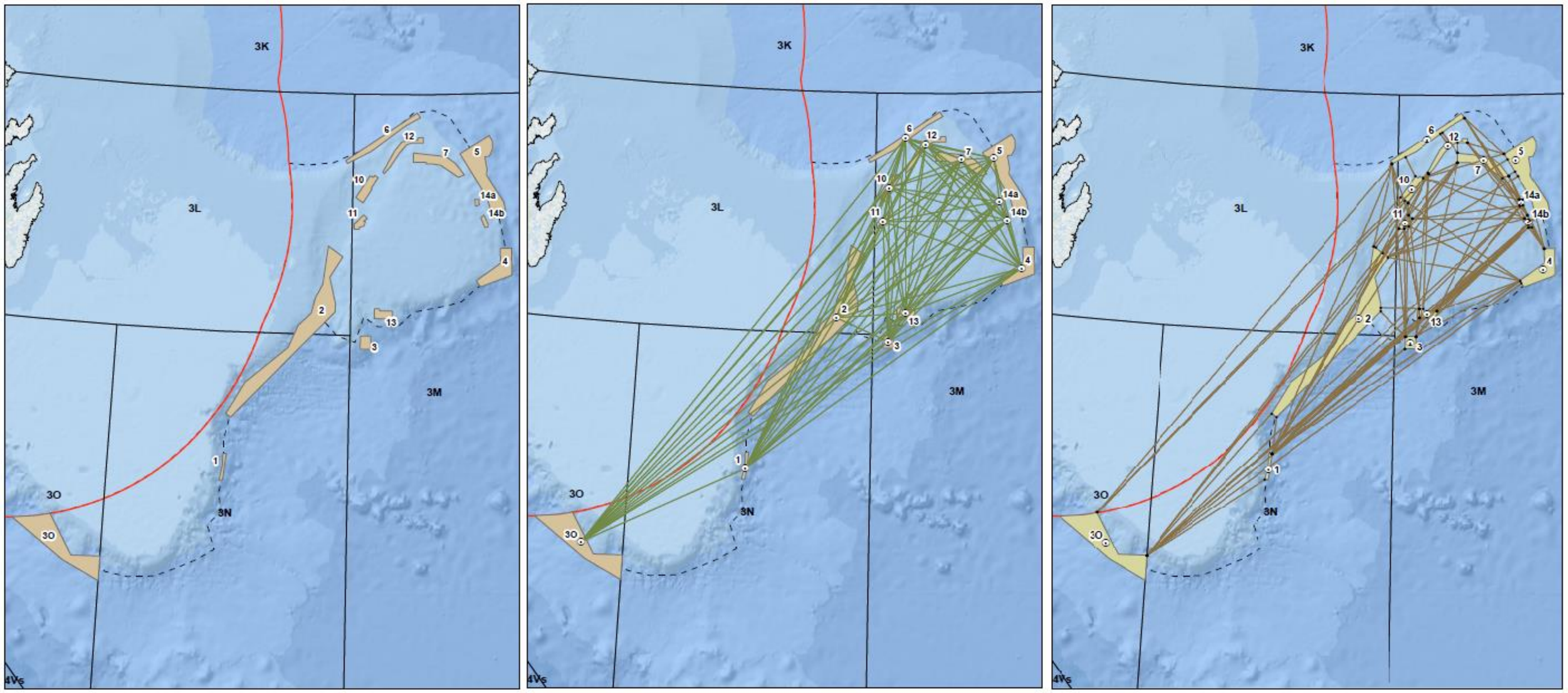


Figure 5.40. Nearest neighbour distance lines between areas closed to protect coral and sponge in the NRA (Left panel) calculated from centroid to centroid (Middle panel) and from the nearest edge (Right panel). NAD83 UTM 23 projection.

iii) Modifications to Connections Among the New Closed Areas Based on Particle Tracking Modeling

Connectivity among the new closed areas was applied as for the Sponge VME polygon example above. We assessed connectivity among the new closed areas using average monthly currents for the summer and fall (summer refers to monthly averaged currents for July, Aug, Sep; fall refers to monthly averaged currents for Oct, Nov, Dec). The currents were averaged over the long term time period of the data for each month, 1995-2015. The 3-D LPT models were seeded on the bottom and applied the diffusivity constant Kh=100 m s-1 (Wang et al., 2020). Models were run for 2 weeks, 1 month and 3 months given the uncertainty in the reproductive biology of all of the VME Indicators present (Table 5.15). Seeding of particles was the same as for the sponge VME polygons and is illustrated in Figure 5.41. The results are shown in Figure 5.42. As expected there are more connections made with the longer model runs (3 months) but given the uncertainties surrounding the reproductive biology and larval ecology of these VME Indicators we have used a conservative approach and accepted all connections made under all of the model simulations (Figures 5.42, 5.43). Tables 5.16, 5.17, and 5.18 provide the modifications to the distances shown in Tables 5.13 and 5.14 through removal of unlikely connections.

Removal of unlikely connections resulted in a similar average distance edge-edge and a reduced average centroid-centroid distance. PX as much reduced from 783 when all connections are considered (Table 5.14) to 190 when unlikely connections are removed (Table 5.18).

Table 5.15. Description of the new NAFO Closed Areas with the VME taxa under protection.

Description of Area	Closed Area Number	VME Type
Tail of the Bank	1	Sponge
Flemish Pass / Eastern Canyon	2	Sponge, Sea pen, Large and Small Gorgonian Corals, Boltenia, Black Coral
Beothuk Knoll	3	Sponge
Eastern Flemish Cap	4	Sponge, Large Gorgonian Corals
Northeast Flemish Cap	5	Sponge, Large Gorgonian Corals
Sackville Spur	6	Sponge
Northern Flemish Cap	7	Sea pen, Black Coral, Small Gorgonian Coral
Northwest Flemish Cap	10	Sea pen, Asconema Sponge
Northwest Flemish Cap	11	Sea pen
Northwest Flemish Cap	12	Sea pen, Black Corals
Beothuk Knoll	13	Large Gorgonian Corals
Northeast Flemish Cap	14a	Sea pen, Black Coral
Northeast Flemish Cap	14b	Sea pen
3O Coral Closure	3O	?

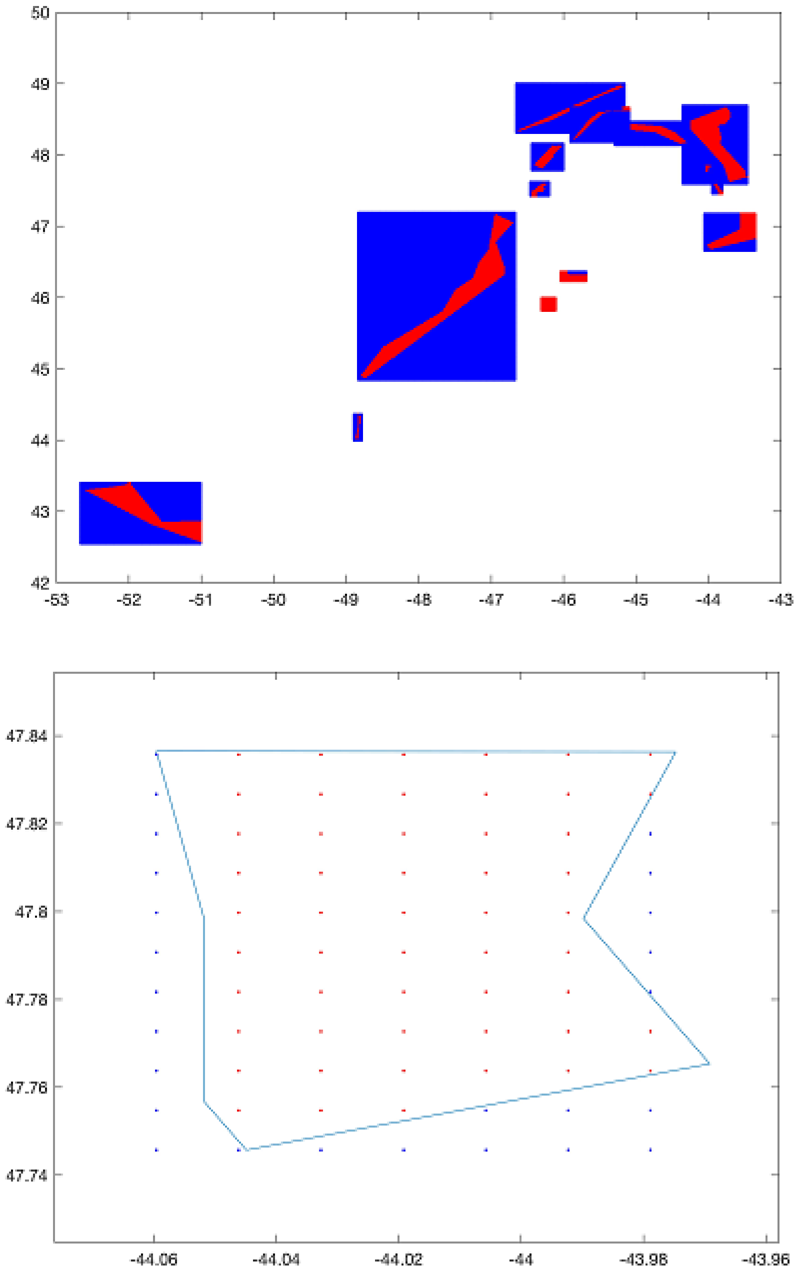


Figure 5.41 Steps showing the construction of grid cells for the particle seeding for the LPT analyses among the new NAFO Closed Areas which come into effect 1 January 2022. A) rectangles (red and blue) were placed over each closed area (red) within which B) a uniform grid with 1-km spacing was overlain and grid points falling within the sponge VME polygons were used to position particles to seed the analyses. Projection: NAD83 UTM 23.

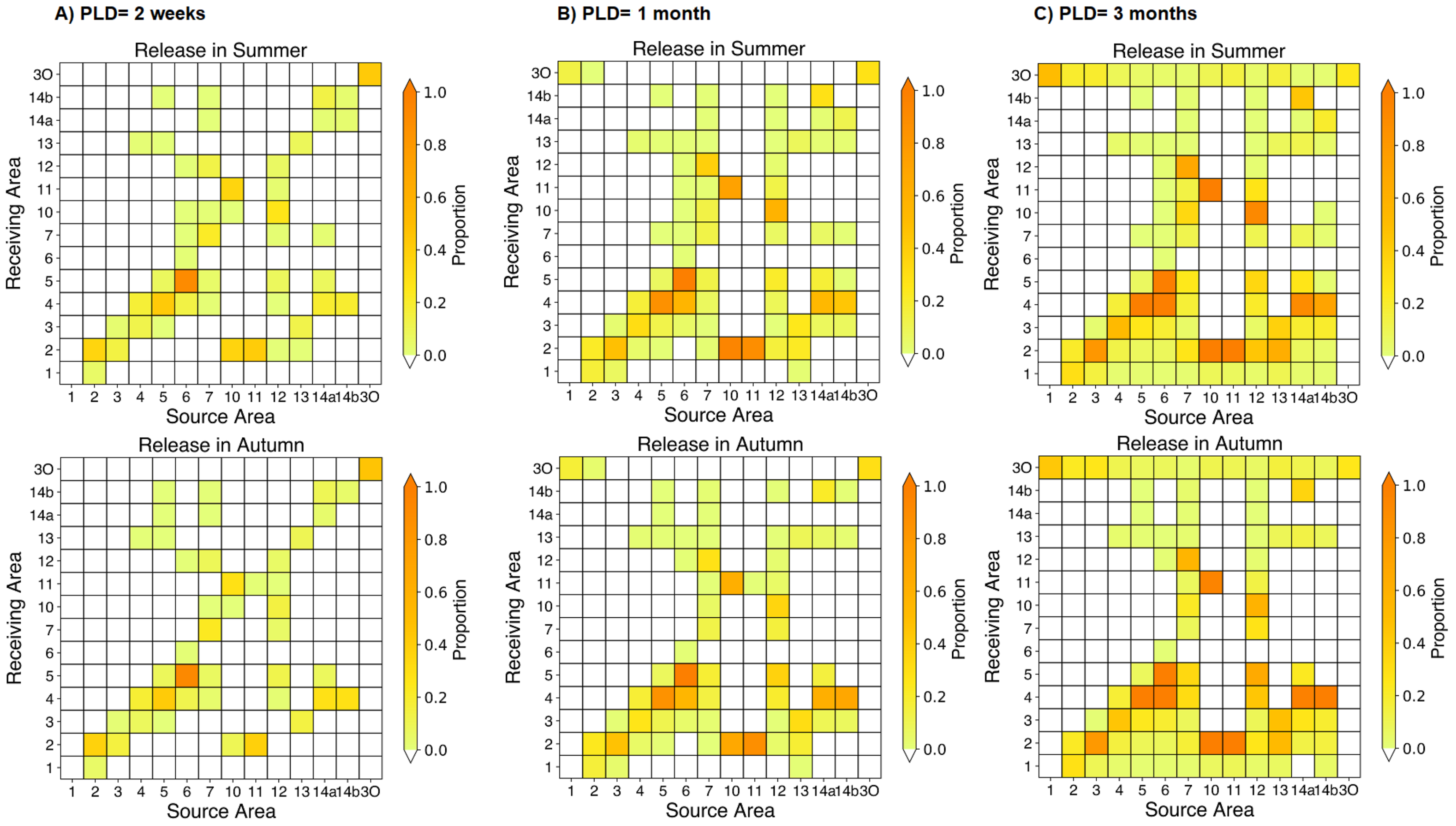
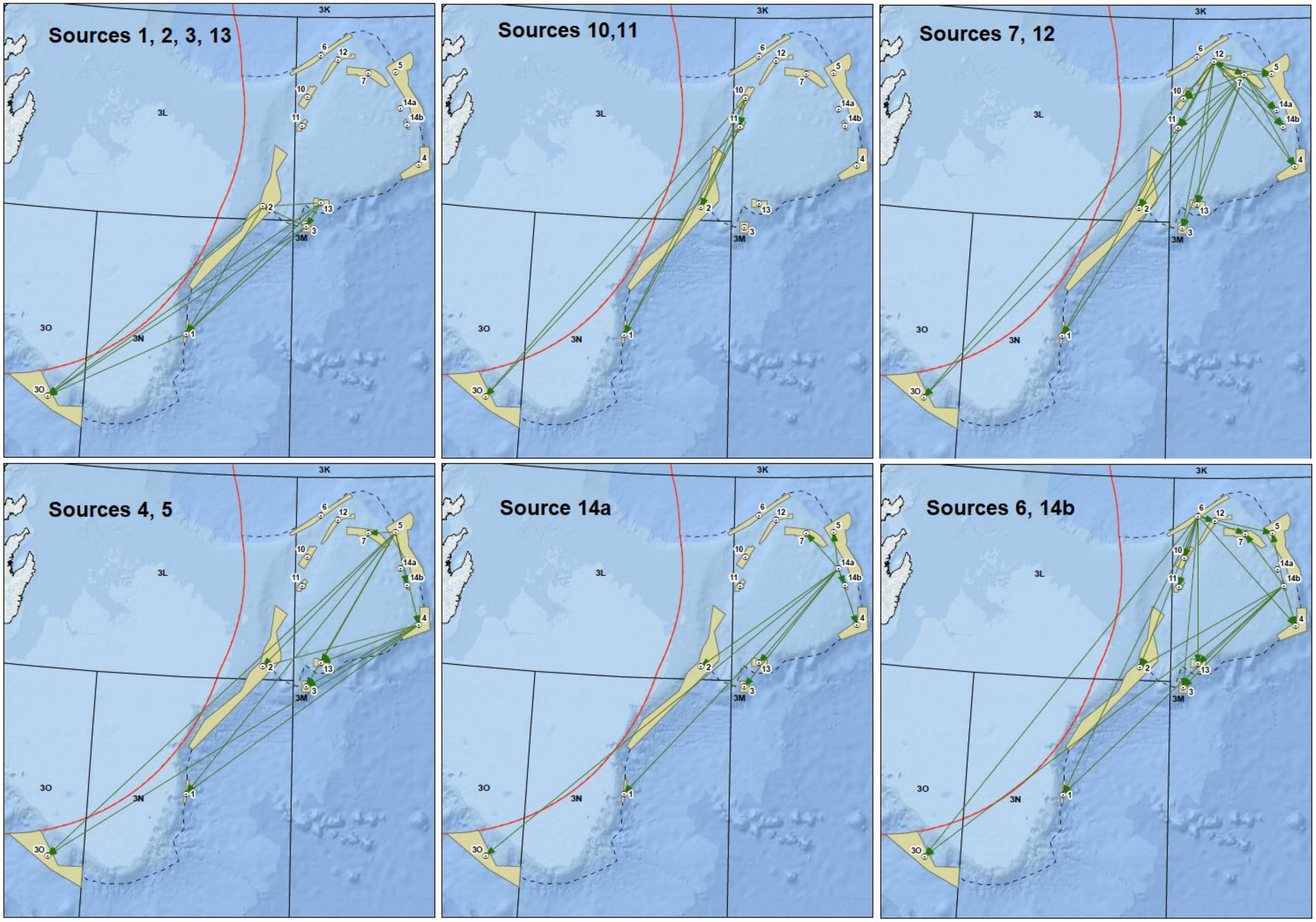


Figure 5.42. Connectivity matrices between NAFO Closed Areas in the Summer and Autumn for each of the pelagic larval durations (PLD) simulated in Wang et al. (2020) to reflect VME larval time in the water column. The diagonal represents particle retention. Closed Area numbers are shown in Figure 5.35.


Sources 1, 2, 3, 13

Sources 10,11

Sources 7, 12

Sources 4, 5

Source 14a

Sources 6, 14b

Figure 5.43. Unidirectional (source to sink) connectivity for the NAFO Closed Areas in the NAFO Regulatory Area (numbered as in Figure 5.35) which showed connectivity (Figure 5.37). Each panel shows connections for different source areas to avoid congestion.

Table 5.16. Nearest neighbour distances (km) calculated from centroid to centroid for the closed areas in the NAFO Regulatory Area (numbered as in Figure 5.35) with connections not found in the Lagrangian Particle Tracking (LPT) simulations removed. The mean nearest-neighbour distance for each closed area, as a measure of relative isolation, is shown below the rows. Closed areas are numbered according to the NAFO Conservation and Enforcement Measures. All calculations were performed using NAD83 UTM 23 projection. Area 6 is the upstream closure so no other areas can connect with it. Similarly 3O is the downstream closure so it can't connect with any other areas.

				Source Particle Release Areas													
	Area No.	Description	Polygon Area km^2	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6*	Area 7	Area 10	Area 11	Area 12	Area 13	Area 14a	Area 14b	3O*
Sink Closed Areas	Area 1	Tail of the Bank	172	---	263	286	510	594	549	564	472	423	555	333	551	539	269
	Area 2	Flemish Pass	5,771		---	85	287	335	288	302	210	160	292	104	300	294	
	Area 3	Beothuk Knoll	308			---	228	316	305	294			301	49	268	254	
	Area 4	E Flemish Cap	1,358				---	169	261	186			234		105	74	
	Area 5	NE Flemish Cap	2,879					---	136	48			104		65	95	
	Area 6	Sackville Spur	987						---								
	Area 7	N Flemish Cap	1,053					48	90	---			58		85	114	
	Area 10	NW Flemish Cap	527						78	116	---		85				
	Area 11	NW Flemish Cap	220						130	150	52	---	132				
	Area 12	NW Flemish Cap	511						32	58			---				
	Area 13	Beothuk Knoll	338				186	267	262	245			255	---	219	206	
	Area 14a	NE Flemish Cap	50							85			140		---		
	Area 14b	NE Flemish Cap	104					95		114			167		31	---	
	3O	3O Coral Closure	3,694	269	508	548	775	842	774	807	702	658	787	593	806	798	---
	Mean Nearest-Neighbour Distance (Centroid-Centroid)			269	264	257	267	256	252	235	221	215	242	235	237	241	269

Table 5.17. Nearest neighbour distances (km) calculated from the nearest edges for the closed areas in the NAFO Regulatory Area (numbered as in Figure 5.35) with connections not found in the Lagrangian Particle Tracking (LPT) simulations removed. The mean nearest-neighbour distance for each closed area, as a measure of relative isolation, is shown below the rows. Closed areas are numbered according to the NAFO Conservation and Enforcement Measures. All calculations were performed using NAD83 UTM 23 projection.

				Source Particle Release Areas													
	Area No.	Description	Polygon Area km2	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 10	Area 11	Area 12	Area 13	Area 14a	Area 14b	3O
Sink Closed Areas	Area 1	Tail of the Bank	172	---	55	254	454	532	470	518	427	386	480	299	525	514	211
	Area 2	Flemish Pass	5,771		---	52	202	230	127	176	83	43	137	58	212	214	
	Area 3	Beothuk Knoll	308			---	178	254	259	268			244	27	250	236	
	Area 4	E Flemish Cap	1,358				---	48	229	122			195		72	36	
	Area 5	NE Flemish Cap	2,879					---	80	11			57		12	10	
	Area 6	Sackville Spur	987						---								
	Area 7	N Flemish Cap	1,053					11	40	---			15		40	67	
	Area 10	NW Flemish Cap	527						32	58	---		11				
	Area 11	NW Flemish Cap	220						81	108	18	---	69				
	Area 12	NW Flemish Cap	511						16	15			---				
	Area 13	Beothuk Knoll	338				133	205	221	223			202	---	200	186	
	Area 14a	NE Flemish Cap	50							40			114		---		
	Area 14b	NE Flemish Cap	104					10		67			141		17	---	
	3O	3O Coral Closure	3,694	211	284	497	697	775	686	753	657	619	712	542	768	757	---
	Mean Nearest-Neighbour Distance (Edge-Edge)			211	170	268	333	258	204	197	296	349	198	232	233	253	211

Table 5.18. Revised Isolation/Proximity indices for the VME closures in the NAFO Regulatory Area after removal of unlikely connection links.

Distance Measurement Method	Mean Nearest-Neighbour Distance Over All Polygons Pairs	Proximity Index (PX)
Centroid-Centroid	247	
Edge-Edge	244	190.24

As part of the most recent assessment of Significant Adverse Impacts (SAIs) on VMEs, WGESA evaluated the adequacy of the spatial configuration of the NAFO Closed Areas for each VME type by a) visually comparing the relative cumulative distribution of distances between the VME polygons and the Closed Areas that overlapped with the VME type, and b) statistically comparing the average edge-to-edge distances between the VME polygons and Closed Areas using t-tests, where the p-value from the test was used as a ***consistency indicator*** in the sense that the less significant the difference between the average distances from VME polygons and Closed Areas is, the more consistent the distributions of VMEs and closures are (NAFO, 2020).

This initial analysis considered the overall spatial configuration of the VME and closed areas systems, but did not considered the directionality of the source-sink connections. As showed earlier in this section, this functional aspect of connectivity can have an important impact on the adequacy of the system of closures.

As a complement to the particle tracking analyses, we updated the cumulative distribution and consistency indicator for the Sponge VME considering a) the new closures to be implemented in 2022, and b) including all connections (Figure 5.35) or only those that emerge as likely from the source-sink analysis (Figure 5.39).

The results indicate that the cumulative distributions of distances for Sponge VME and NAFO Closed Areas are generally well aligned irrespective if all or only directional connections are considered (Figure 5.44). However, while the consistency indicator remains non-significant in both scenarios (all connections: p-value=0.4, directional connections: p-value=0.2), there is a clear reduction in consistency when the directionality of the connections is taken into account. When all connections are considered, the average edge-to edge distance between VMEs and Close Areas is very similar (VME: 190km, Closed Areas:200km), but when directionality of the connectivity is considered, not only the average distances are much smaller (VME: 88km, Closed Areas:110km), but the discrepancy between VMEs and Closed Areas doubles. This suggests that, while sponges are the best covered VMEs (NAFO 2022) the 2022 Closed Areas could still be too far apart to match the spatial structure that emerges from consider some basic dynamic attributes of sponge connectivity.

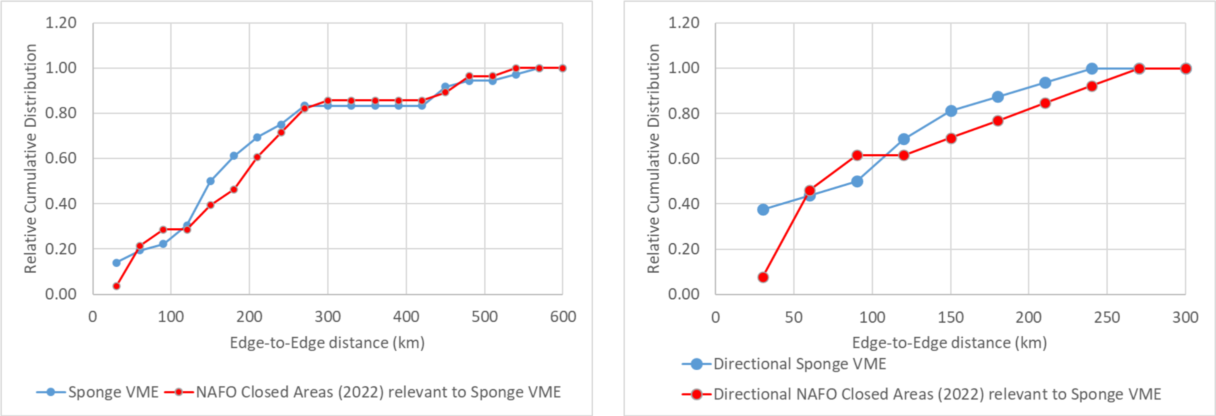


Figure 5.44. Relative cumulative distributions of edge-to-edge distances for the Sponge VME polygons, and the 2022 NAFO Closed Areas that overlap with Sponge VME. Left: All connections among areas are considered. Right: Only directional connections, as they emerge from the source-sink analysis, are considered.

Conclusions

The results of our analyses are presented in Table 5.19 in comparison with those completed last year (NAFO, 2020). In both the case of the large-sized sponge VME polygons and the new closed areas that will come into effect in 2022, there was a decrease in the mean nearest-neighbour distance over all polygons calculated centroid to centroid when only connections confirmed through the LPT simulations were considered. This is a straightforward recalculation and has nothing to do with fragmentation. However the comparison of the current (NAFO, 2020) and the new closures showed little change in the mean nearest-neighbour distance over all polygons but shows a large increase in PX. This indicates that PX is sensitive to the change of configuration within the spatial extent. The new closures have fewer larger closures on Flemish Cap and the result is picked up by PX. As a result we expect PX to respond to changes in the configuration of the VME polygons which we plan to simulate in the next phase of this work.

Table 5.19. Summary of Isolation/Proximity Indices for large-sized sponge VMEs and the NAFO Closed Areas with and without removal of unlikely connections established by Lagrangian particle tracking analyses.

Isolation/Proximity Index	Sponge VME All Connections (NAFO, 2020)	Sponge VME Likely Connections Only	2020 Closures (NAFO, 2020)	New 2022 Closures All Connections	New 2022 Closures Likely Connections Only
Mean Nearest-Neighbour Distance Over All Polygons Pairs Centroid-Centroid	271	161	282	290	247
Mean Nearest-Neighbour Distance Over All Polygons Pairs Edge-Edge	190	70	236	236	244
Proximity Index (PX)	1111.80	806.04	452.00	782.96	190.24

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f) ToR 2.6. Work plans for the next review of VME and re-assessment of bottom fisheries

Research in support of the next review of VMEs and re-assessment of bottom fisheries

WG-ESA undertakes and develops research in support of all elements of the NAFO roadmap linked to scientific advice requests, but especially in relation to i. the understanding, identification, quantification and mapping VMEs, ii. the assessment of Significant Adverse Impacts, and iii. the development of Tier 1 and 2 models. Having completed a review of VMEs and bottom fisheries in the NRA in 2021, new assessments are not required now until 2026. However, to further develop and improve the next re-assessments the following research areas have been identified as being worthy of attention:

In relation to VMEs

- Functional biomass data will be assessed to answer the following questions, a) which functions are highly associated with VMEs, and b) how much function do we lose when the

VME biomass is impacted? To achieve this separate analysis will be undertaken on the EU and Canadian surveys, as the data from the different surveys is not directly comparable. A follow-up discussion on the use of the functional biomass data to address these questions will be undertaken between Anna, Cam, Ellen, Javi, James and Mar and initial thoughts and plans for analysis presented at the next WG-ESA meeting.

- An up-date of the KDE analysis – including potential developments? A full review of VMEs will be undertaken closer to the date for the re-evaluation of VMEs in 5 years (e.g. in 2026). However, a question of spatial scope for the KDE analysis was raised, essentially to understand if including VMEs outside the fishing footprint would have any influence on the present VME KDE distribution inside the NRA fishing footprint. To explore this question, it was agreed that one of the VMEs (e.g. sponge), would be up-dated to include data (where available) for all three of the EPUs (3M, 3LNO, 2J3K) in the NRA. It was agreed that this analysis would be undertaken in preparation for the next WG-ESA meeting so the results could be discussed, and a decision made about the spatial extent of the analysis for the next VME review.
- VME and VME closure connectivity analysis will continue with the aim of understanding the optimal design for the VME closure network. Initial analysis will include modifying VME boundaries (extent and location) to see what impact this has on the VME connectivity index used in the assessment of SAI.
- It was agreed that in order to support the ICES VME benchmark process it would be useful to provide ICES the NAFO VMS data (2010 – 2019) in order to create C-Square swept area ratios to be used alongside the existing VME biomass data.

In relation to SAI

- Refine fishing impact cut-off values – explore a deeper understanding of VME response curves and consider providing a range of cut-off values where there is some uncertainty in assigned values for some of the VMEs. Develop response curves using functional biomass data and determine impact, at risk and protected area/biomass assessment categories for SAI. There is also a need to better understand the relationship between VME and functions in general – are there some important functions we are missing.
- Functional links between fisheries, fish and VMEs – analysis to consider using the depth range of fish in addition to VME depth range. Also review literature on how the fish use habitat, also identify which species of VME are particularly important.
- Fishing/VME trade-off analysis A need to up-date the analysis for the VME closure next year in the same way we did this year (in 2021). This is a priority and is needed to address Com. Request #7a, the reassessment of VME closures in 2023.
- VMS data – improve historic track definition using improved data filters, utilising log-book data (from 2016).
- Improved spatial resolution linking fishery and survey trawl data, e.g. to better quantify the trawling impacts on VME associated with complex hard ground types e.g. Boltenia. May be

useful to look at the multibeam and backscatter data. We are probably at the resolution limit of the current data at 1km.

- How different is historical distribution of fishing effort compared to present day? Does the long-term pattern of fishing match long-term changes in distribution of VME?

In relation to Tier 1 and Tier 2 elements of the Roadmap

- Should/could we include an economic analysis? The economic (or benefits/values) analysis will vary greatly between CPs – it is a complex question, first step would be to ask each CP how important (economically, culturally etc) the fisheries are.
- Complete Tier 1 review and further develop Tier 1 models as required.
- Tier 2 model development – GAGET model of Flemish Cap. Limited capacity and resources to take forward. Models need to be kept alive with new data.
- ESS need further analysis – 3M ESS being developed for next year by IEO
- Develop a table identifying assigned task leads coordinators for the above research items.

THEME 3: PRACTICAL APPLICATION OF ECOSYSTEM KNOWLEDGE TO FISHERIES MANAGEMENT

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

a) ToR 3.1. Review of NAFO CEM, Chapter 2 (Com. Request #6b)

Review the effectiveness of NAFO CEM, Chapter 2 from a scientific and technical perspective and report back to the WG-EAFFM. WG-EAFFM would subsequently in 2022 consider whether any modifications to this Chapter should be recommended.

WG-ESA reviewed the text in plenary to highlight potential inconsistencies and to make suggestions to up-date specific paragraphs and wording in light of recent scientific developments in NAFO.

Accordingly, the following text is copied from Annex 2 of the latest CEM document to which comments and edits have been made for further consideration at SC in June 2022. It includes suggested specific changes to the text, along with more general comments which are highlighted in bold and in square-brackets.

Article 15 –Definitions

Definitions

In addition to the definitions listed in Article 1, the following definitions apply to this Chapter.

1. The term "Encounter" means catch of a VME indicator species above threshold levels as set out in Article 22.1. Any encounter with a VME indicator species or merely detecting its presence is not sufficient to identify a VME. That identification should be made on a case-by-case basis through assessment by relevant bodies;
    a. “Exploratory bottom fishing activities" means bottom fishing activities conducted outside the footprint, or within the footprint with significant changes to the conduct or in the technology used in the fishery;
    b. “Footprint”, otherwise known as “Existing bottom fishing areas”, means that portion of the Regulatory Area where bottom fishing has historically occurred, and is defined by the coordinates shown in Table 4 and illustrated in Figure 2;
    c. "Significant adverse impacts" refers to paragraphs 17 to 20 of the FAO International Guidelines for the Management of Deep Sea Fisheries in the High Seas;
    d. "Vulnerable marine ecosystems (VMEs)" refers to paragraphs 42 and 43 of the FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas **[WG-ESA suggests the insersion; *and as further defined by NAFO on page 39 of SCS 14-17*]**;
    e. "VME indicator element" refers to topographical, hydrophysical or geological features which potentially support VMEs, as specified in Part VII of Annex I.E;
    f. "VME indicator species" refers to species that [**WG-ESA suggests the insersion; *may***] signal the occurrence of vulnerable marine ecosystems, as specified in Part VI of Annex I.E.

Article 16 - Map of Footprint (Existing Bottom Fishing Areas)

[**WG-ESA suggests that this section should be revised to reflect the actual years used to define the existing footprint. It should also be noted that there has been no revision of the footprint since it was originally defined despite the text indicating it should be up-dated regularly**].

The map of existing bottom fishing areas in the NAFO Regulatory Area illustrated in Figure 2 is delimited on the western side by the Canadian EEZ boundary and the eastern side by the coordinates shown in Table 4. The map shall be revised regularly to incorporate any new relevant information. Contracting Parties may propose revising the map on the basis of any information available, in particular on the haul by haul catch data.

Table 4. Boundary Points Delineating the Eastern Side of the Footprint.

Coordinate No.	Latitude	Longitude	Coordinate No.	Latitude	Longitude
1	48°17'39''N	EEZ boundary[1]	26	46°26'32''N	46°58'53''W
2	48°16'51''N	47°25'37''W	27	46°27'40''N	47°12'01''W
3	48°19'15''N	46°53'48''W	28	46°04'15''N	47°09'10''W
4	48°29'21''N	46°21'17''W	29	46°04'53''N	47°31'01''W
5	48°32'43''N	46°08'04''W	30	45°48'17''N	47°37'16''W
6	48°48'10''N	45°37'59''W	31	45°33'14''N	47°52'41''W
7	48°59'54''N	45°17'46''W	32	45°27'14''N	48°10'15''W
8	49°02'20''N	44°53'17''W	33	45°16'17''N	48°26'50''W
9	48°56'46''N	44°33'18''W	34	44°54'01''N	48°43'58''W
10	48°33'53''N	44°10'25''W	35	44°33'10''N	48°50'25''W
11	48°08'29''N	43°57'28''W	36	44°09'57''N	48°48'49''W
12	47°42'00''N	43°36'44''W	37	43°50'44''N	48°52'49''W
13	47°12'44''N	43°28'36''W	38	43°34'34''N	48°50'12''W
14	46°57'14''N	43°26'15''W	39	43°23'13''N	49°03'57''W
15	46°46'02''N	43°45'27''W	40	43°03'48''N	48°55'23''W
16	46°38'10''N	44°03'37''W	41	42°54'42''N	49°14'26''W
17	46°27'43''N	44°20'38''W	42	42°48'18''N	49°32'51''W
18	46°24'41''N	44°36'01''W	43	42°39'49''N	49°58'46''W
19	46°19'28''N	45°16'34''W	44	42°37'54''N	50°28'04''W
20	46°08'16''N	45°33'27''W	45	42°40'57''N	50°53'36''W
21	46°07'13''N	45°57'44''W	46	42°51'48''N	51°10'09''W
22	46°15'06''N	46°14'21''W	47	42°45'59''N	51°31'58''W
23	45°54'33''N	46°24'03''W	48	42°51'06''N	51°41'50''W
24	45°59'36''N	46°45'33''W	49	43°03'56''N	51°48'21''W
25	46°09'58''N	46°58'53''W	50	43°22'12''N	EEZ boundary[2]

[1] approximately 47°47'45"W

[2] approximately 52°09'46"W

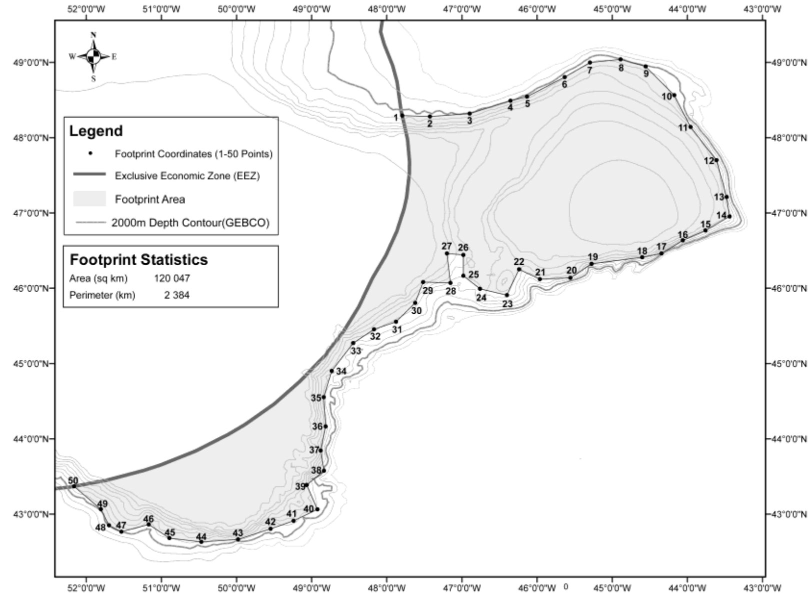

Figure 2. NAFO Regulatory Area footprint map (shaded).

Article 17 – Area Restrictions for Bottom Fishing Activities

Seamount Closures

1. Until 31 December 2021, no vessel shall engage in bottom fishing activities in any of the areas illustrated in Figure 3 and defined by connecting the following coordinates specified in Table 5 in numerical order and back to coordinate 1.

Table 5. Boundary Points Delineating the Seamount Closures in the NAFO Regulatory Area Referenced in Article 17.1

Description	**Coordinate No.**	**Latitude**	**Longitude**
Fogo Seamounts 1	1	42°31’33”N	53°23’17”W
	2	42°31’33”N	52°33’37”W
	3	41°55’48”N	53°23’17”W
	4	41°55’48”N	52°33’37”W
Fogo Seamounts 2	1	41°07’22”N	52°27’49”W
	2	41°07’22”N	51°38’10”W
	3	40°31’37”N	52°27’49”W
	4	40°31’37”N	51°38’10”W
Orphan Knoll	1	50°00’30”N	45°00’30”W
	2	51°00’30”N	45°00’30”W
	3	51°00’30”N	47°00’30”W
	4	50°00’30”N	47°00’30”W
Corner Rise Seamounts	1	35°00’00”N	48°00’00”W
	2	36°00’00”N	48°00’00”W
	3	36°00’00”N	52°00’00”W
	4	35°00’00”N	52°00’00”W
Newfoundland Seamounts	1	43°29’00”N	43°20’00”W
	2	44°00’00”N	43°20’00”W
	3	44°00’00”N	46°40’00”W
	4	43°29’00”N	46°40’00”W
New England Seamounts*	1	38°51'54.000” N	66°55'51.600” W
	2	37°12'0.000” N	60°48'0.000” W
	3	35°00'0.000” N	59°00'0.000” W
	4	35°00'0.000” N	56°30'0.000” W
	5	36°48'0.000” N	57°48'0.000” W
	6	39°00'0.000” N	60°00'0.000” W
	7	39°18'0.000” N	61°30'0.000” W
	8	39°56'20.400” N	65°56'34.800” W

*From point 8 back to point 1, following the outer boundary of the US EEZ.

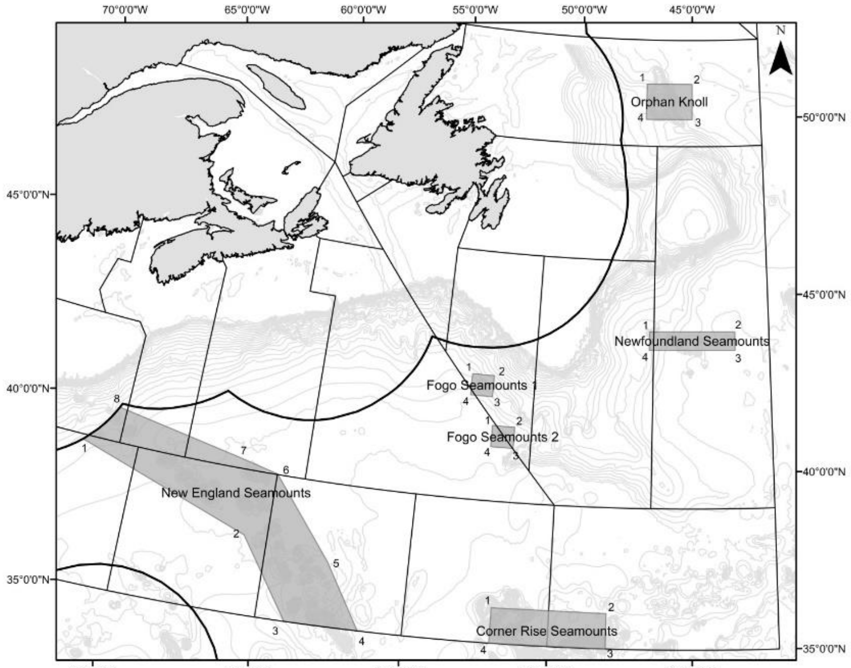

Figure 3. Polygons Delineating Seamount Closures Referenced in Article 17.1.

3O Coral Area Closure [**WG-ESA suggests removing the word 'coral' since we have no firm evidence of the presence of coral in this area**]

2. Until 31 December 2021, no vessel shall engage in bottom fishing activities in the area of Division 3O illustrated in Figure 4 and defined by connecting the coordinates specified in Table 6 in numerical order and back to coordinate 1.

Table 6. Boundary Points Delineating the 3O Coral Area Closure in the NAFO Regulatory Area Referenced in Article 17.2. [**WG-ESA suggests removal of the word 'coral' as above**]

Coordinate No.	Latitude	Longitude
1	42° 53' 00" N	51° 00' 00" W
2	42° 52' 04" N	51° 31' 44" W
3	43° 24' 13" N	51° 58' 12" W
4	43° 24' 20" N	51° 58' 18" W
5	43° 39' 38" N	52° 13' 10" W
6	43° 40' 59" N	52° 27' 52" W
7	43° 56' 19" N	52° 39' 48" W
8	44° 04' 53" N	52° 58' 12" W
9	44° 18' 38" N	53° 06' 00" W
10	44° 18' 36" N	53° 24' 07" W
11	44° 49' 59" N	54° 30' 00" W
12	44° 29' 55" N	54° 30' 00" W
13	43° 26' 59" N	52° 55' 59" W
14	42° 48' 00" N	51° 41' 06" W
15	42° 33' 02" N	51° 00' 00" W

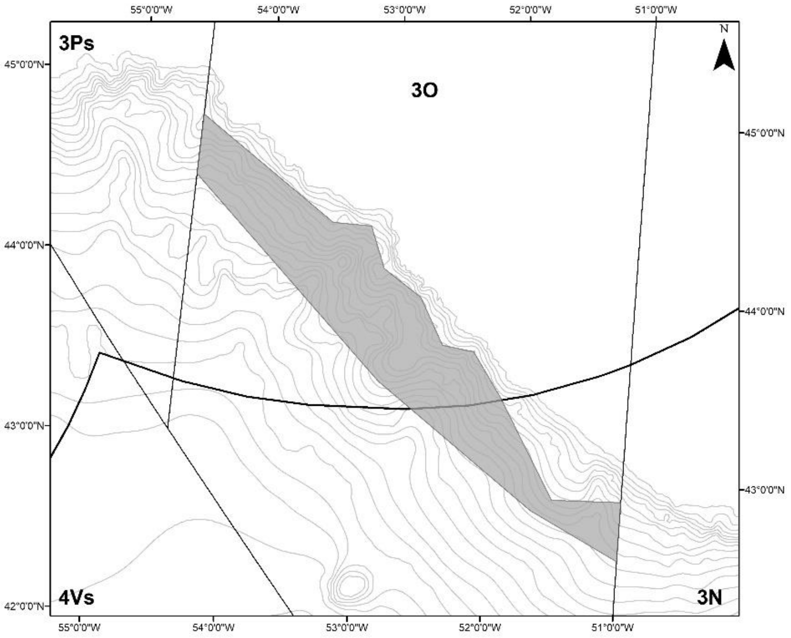

Figure 4. Polygon Delineating Area of 3O Coral Closure Referenced in Article 17.2. [**WG-ESA suggests removal of the word 'coral' as above**]

High Sponge and Coral Concentration Area Closures [**WG-ESA suggests removing 'high sponge and coral concentration' and replace with 'VME area closures'**]

3. Until 31 December 2021, no vessel shall engage in bottom fishing activities in areas 1-13 illustrated in Figure 5 and defined by connecting the coordinates specified in Table 7 in numerical order and back to coordinate 1.

Table 7. Boundary Points Delineating the High Sponge and Coral Concentration Area Closures in the NAFO Regulatory Area Referenced in Article 17.3. [**WG-ESA suggests removing ‘high sponge and coral concentration’ and replace with ‘VME’**]

Area	Description	Coordinate No.	Latitude	Longitude
1	Tail of the Bank	1.1	44° 02' 53.88" N	48° 49' 9.48" W
		1.2	44° 21' 31.32" N	48° 46' 48" W
		1.3	44° 21' 34.56" N	48° 50' 32.64" W
		1.4	44° 11' 48.12" N	48° 50' 32.64" W
		1.5	44° 02' 54.6" N	48° 52' 52.32" W
2	Flemish Pass/ Eastern Canyon	2.1	44° 50' 56.4" N	48° 43' 45.48" W
		2.2	46° 18' 54.72" N	46° 47' 51.72" W
		2.3	46° 25' 28.56" N	46° 47' 51.72" W
		2.4	46° 46' 32.16" N	46° 55' 14.52" W
		2.5	47° 03' 29.16" N	46° 40' 4.44" W
		2.6	47° 11' 47.04" N	46° 57' 38.16" W
		2.7	46° 40' 40.8" N	47° 03' 4.68" W
		2.8	46° 24' 24.12" N	46° 51' 23.04" W
		2.9	46° 21' 4.78" N	46° 58' 53" W
		2.10	46° 26' 32" N	46° 58' 53" W
		2.11	46° 30' 22.20" N	47° 11' 2.93" W
		2.12	46° 17' 13.30" N	47° 15' 46.64" W
		2.13	46o 07' 1.56" N	47o 30' 36.36" W
		2.14	45o 49' 6.24" N	47o 41' 17.88" W
		2.15	45o 19' 43.32" N	48o 29' 14.28" W
		2.16	44o 53' 47.4" N	48o 49' 32.52" W
3	Beothuk Knoll	3.1	45° 49' 10.2" N	46° 06' 2.52" W
		3.2	45° 59' 47.4" N	46° 06' 2.52" W
		3.3	45° 59' 47.4" N	46° 18' 8.28" W
		3.4	45° 49' 10.2" N	46° 18' 8.28" W
4	Eastern Flemish Cap	4.1	46° 44' 34.80" N	44° 03' 14.40" W
		4.2	46° 58' 19.20" N	43° 34' 16.32" W
		4.3	47° 10' 30.00" N	43° 34' 16.32" W
		4.4	47° 10' 30.00" N	43° 20' 51.72" W
		4.5	46° 48' 35.28" N	43° 20' 51.72" W
		4.6	46° 39' 36.00" N	43° 58' 8.40" W
5	Northeast Flemish Cap	5.1	47° 47' 46.00" N	43° 29' 07.00" W
		5.2	47° 40' 54.47" N	43° 27' 06.71" W
		5.3	47° 35' 57.48" N	43° 43' 9.12" W
		5.4	47° 51' 14.4" N	43° 48' 35.64" W
		5.5	48° 27' 19.44" N	44° 21' 7.92" W
		5.6	48° 41' 37.32" N	43° 45' 08.08" W
		5.7	48° 37' 13.00" N	43° 41' 24.00" W
		5.8	48° 30' 15.00" N	43° 41' 32.00" W
		5.9	48° 25' 08.00" N	43° 45' 20.00" W
		5.10	48° 24' 29.00" N	43° 50' 50.00" W
		5.11	48° 14' 20.00" N	43° 48' 19.00" W
		5.12	48° 09' 53.00" N	43° 49' 24.00" W
6	Sackville Spur	6.1	48° 18' 51.12" N	46° 37' 13.44" W
		6.2	48° 28' 51.24" N	46° 08' 33.72" W
		6.3	48° 49' 37.2" N	45° 27' 20.52" W
		6.4	48° 56' 30.12" N	45° 08' 59.99" W

Area	Description	Coordinate No.	Latitude	Longitude
		6.5	49° 00' 9.72" N	45° 12' 44.64" W
		6.6	48° 21' 12.24" N	46° 39' 11.16" W
7	Northern Flemish Cap	7.1	48° 25' 02.28" N	45° 17' 16.44" W
		7.2	48° 25' 02.28" N	44° 54' 38.16" W
		7.3	48° 19' 08.76" N	44° 54' 38.16" W
		7.4	48° 19' 08.76" N	45° 01' 58.56" W
		7.5	48o 20' 29.76" N	45o 01' 58.56" W
		7.6	48o 20' 29.76"N	45o17' 16.44" W
8	Northern Flemish Cap	8.1	48° 38' 07.95" N	45° 19' 31.92" W
		8.2	48° 38' 07.95" N	45° 11' 44.36" W
		8.3	48° 40' 9.84" N	45° 11' 44.88" W
		8.4	48° 40' 9.84" N	45° 05' 35.52" W
		8.5	48o 35' 56.4" N	45o 05' 35.52" W
		8.6	48° 35' 56.4" N	45o 19' 31.92 W"
9	Northern Flemish Cap	9.1	48° 34' 23.52" N	45° 26' 18.96" W
		9.2	48° 36' 55.08" N	45° 31' 15.96" W
		9.3	48° 30' 18.36" N	45° 39' 42.48" W
		9.4	48° 27' 30.6" N	45° 34' 40.44" W
10	Northwest Flemish Cap	10.1	47° 49' 41.51" N	46° 22' 48.18" W
		10.2	47° 47' 17.14" N	46° 17' 27.91" W
		10.3	47° 58' 42.28" N	46° 6' 43.74" W
		10.4	47° 59' 15.77" N	46° 7' 57.76" W
		10.5	48o 7' 48.97" N	45o 59' 58.46" W
		10.6	48o 9' 34.66" N	46o 4' 8.54" W
11	Northwest Flemish Cap	11.1	47° 25' 48" N	46° 21' 23.76" W
		11.2	47° 30' 1.44" N	46° 21' 23.76" W
		11.3	47° 30' 1.44" N	46° 27' 33.12" W
		11.4	47° 25' 48" N	46° 27' 33.12" W
12	Northwest Flemish Cap	12.1	48o 12' 6.60" N	45o 54' 12.94" W
		12.2	48o 17' 11.82" N	45o 47' 25.36" W
		12.3	48o 16' 7.06" N	45o 45' 48.19" W
		12.4	48o 11' 3.32" N	45o 52' 40.63" W
13	Beothuk Knoll	13.1	46° 13' 58.80" N	45° 41' 13.20" W
		13.2	46° 13' 58.80" N	46° 02' 24.00" W
		13.3	46° 21' 50.40" N	46° 02' 24.00" W
		13.4	46° 21' 50.40" N	45° 56' 48.12" W
		13.5	46° 20' 14.32" N	45° 55' 43.93" W
		13.6	46° 20' 14.32" N	45° 41' 13.20" W

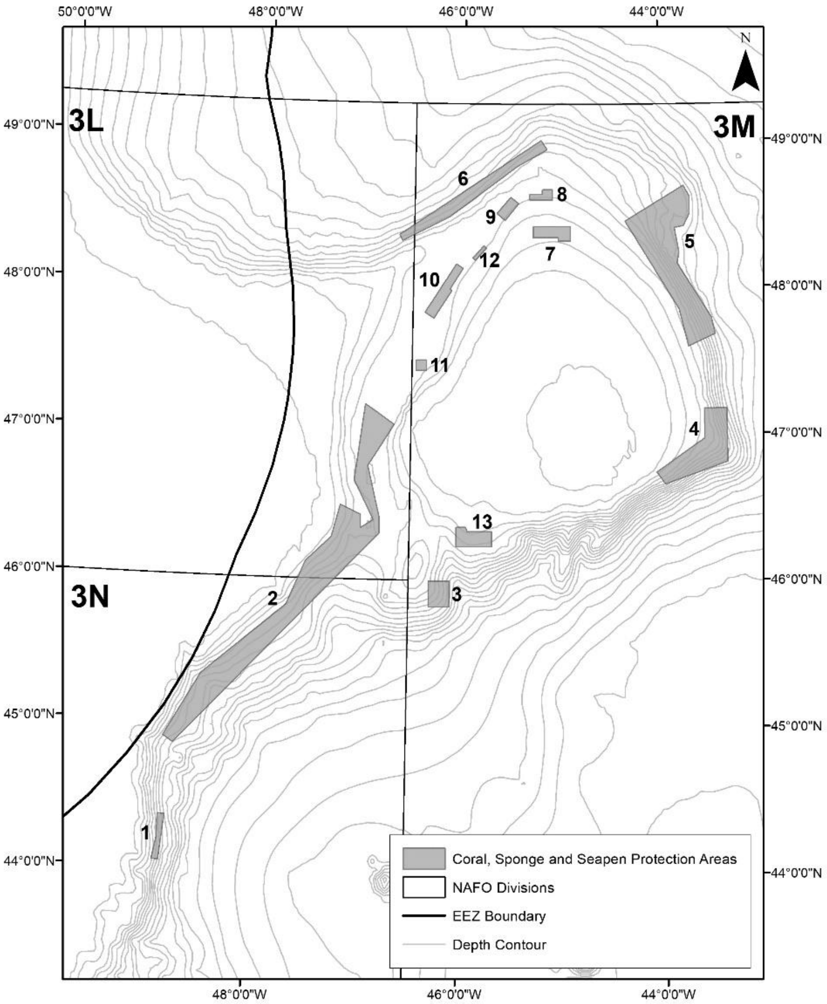

Figure 5. Polygons Delineating Areas of High Sponge and Coral Concentrations Referenced in Article 17.3.

4. Contracting Parties are encouraged to the extent possible to record all coral and sponge catch [**WG-ESA suggests removing 'coral and sponge catch' and replacing with 'all VME indicator species'**] in their annual government and/or industry research programs and to consider non-destructive means for the long-term monitoring of coral and sponged [**WG-ESA suggests removing 'coral and sponged' and replacing with 'VME**'] in the closed areas.

Article 18 – Exploratory Bottom [WG-ESA suggests insersion of "Contacting" to be consistent with the language used in the UN Resolution] Fishing Activities

1. Exploratory bottom fishing activities shall be subject to a prior exploration conducted in accordance with the exploratory protocol set out in Annex I.E.
2. Contracting Parties whose vessels wish to engage in exploratory bottom fishing activities shall, for the purpose of the evaluation referred to in Article 20:
   (a) communicate to the Executive Secretary the 'Notice of Intent to Undertake Exploratory Bottom Fishing' in accordance with Annex I.E together with the assessment required under Article 19.1;
   (b) require vessels entitled to fly their flag to start exploratory bottom fishing activities only after they have been authorized in accordance with Article 20;
   (c) have an observer [**WG-ESA suggests alteration to "observer(s)" to reflect that it could be more than one observer**] with sufficient scientific expertise on board for the duration of the exploratory bottom fishing activity; and
   (d) provide to the Executive Secretary an "Exploratory Bottom Fishing Trip Report" in accordance with Annex I.E. within 3 months of the completion of the exploratory bottom fishing activities.

Duties of the Executive Secretary

3. The Executive Secretary:
   (a) promptly forward the documents referred to in paragraph 2(a) of this Article to the Scientific Council and to the Commission; and
   (b) circulates the "Exploratory Bottom Fishing Trip Reports" to the Scientific Council and to all Contracting Parties [**WG-ESA suggests that a specific time-frame should be considered**].

Article 19 – Preliminary Assessment of Proposed Exploratory Bottom *[insertion of 'Contacting']* Fishing Activities

1. Any Contracting Party proposing to participate in exploratory bottom fishing activities shall submit, in support of their proposal, a preliminary assessment of the known and anticipated impacts of the bottom fishing activity, which will be exercised by the vessels entitled to fly its flag, on VMEs.
2. The preliminary assessment referred to in paragraph 1 of this Article shall:
   (a) be sent to the Executive Secretary no less than two weeks in advance of the opening of the June meeting of the Scientific Council;
   (b) be in accordance with guidance developed by the Scientific Council, or, in the absence of such guidance, to the best ability of the Contracting Party; and
   (c) address the elements in accordance with Annex I.E.
3. The Commission will request the Scientific Council to: [WG-ESA suggests that this should also include a request to develop new encounter thresholds for VME indicator species as required]
   (a) undertake an analysis of the preliminary assessment submitted in accordance with Article 19.1 at its meeting immediately following the submission by the Contracting Parties,

according to procedures and standards it develops, and taking into account the risks of significant adverse impacts on VMEs;
   (b) consider any available additional information, including information from other fisheries in the region or similar fisheries elsewhere; and
   (c) in line with the precautionary approach, provide advice to the Commission on possible adverse impacts on VMEs and on the mitigation measures to prevent them.

4. The Joint Commission-Scientific Council Working Group on Ecosystem Approach Framework to Fisheries Management shall:
   (a) examine the advice of the Scientific Council delivered in accordance with Article 19.3; and
   (b) make recommendations to the Commission in accordance with its mandate.

Article 20 – Management of Exploratory Bottom *[insertion of 'Contacting']* Fishing Activities

1. The Commission shall adopt conservation and management measures to prevent significant adverse impacts of the exploratory fishing activities on VMEs, taking account of advice and recommendations provided by the Scientific Council and the Joint Commission-Scientific Council Working Group on Ecosystem Approach Framework to Fisheries Management, including data and information arising from reports pursuant to Article 22. These measures may include:

(a) allowing, prohibiting or restricting bottom **[WG-ESA suggests insersion of "Contacting"]** fishing activities;
(b) requiring specific mitigation measures for bottom **[WG-ESA suggests insersion of "Contacting"]** fishing activities;
(c) allowing, prohibiting or restricting bottom **[WG-ESA suggests insersion of "Contacting"]** fishing with certain gear types, or changes in gear design and/or deployment; an
(d) any other relevant requirements or restrictions to prevent significant adverse impacts to vulnerable marine ecosystems.

Article 21 – Evaluation of Exploratory Bottom *[insertion of 'Contacting']* Fishing Activities

1. The Commission will request the Scientific Council to:
   (a) evaluate the exploratory bottom fishing activities at its meeting immediately following the reception of the "Exploratory Bottom Fishing Trip Report" circulated in accordance with Article 18.2; and
   (b) in line with the precautionary approach, provide advice to the Commission on the decision to be taken in accordance with Article 21.3, taking account the risks of significant adverse impacts on VMEs.
2. The Joint Commission-Scientific Council Working Group on Ecosystem Approach Framework to Fisheries Management shall examine the advice of the Scientific Council delivered in accordance with Article 21.1 and shall make recommendations to the Commission in accordance with its mandate.
3. The Commission shall, taking account of advice and recommendations provided by the Scientific Council and the Joint Commission-Scientific Council Working Group on Ecosystem Approach Framework to Fisheries Management either to:
   (a) authorize the bottom [**WG-ESA suggests insersion of "Contacting"**] fishing activity for part or all of the area in which exploratory bottom fishing was carried out and include this area in the footprint, or [**WG-ESA suggests that this should invoke the provision for re-**

evaluating the footprint (as defined in Art. 16) rather than automatically including the exploratory area in the footprint. In addition, new encounter protocols will need to be developed for VME indicators in any newly authorized areas].

(b) discontinue the exploratory bottom fishing activity and, if necessary, close part or all of the area where which exploratory bottom fishing was carried out, or

(c) authorize the continued conduct of exploratory bottom fishing activity, in line with Article 18 with a view to gather more information.

Article 22 – Provisions in Case of *[insertion of 'VME']* Encounter

Encounter Threshold

1. An encounter with VME indicator species is defined as catch per set (e.g. trawl tow, longline set, or gill net set) of more than 7 kg of sea pens and/or 60 kg of other live coral and/or 300 kg of sponges. [**this only applies within the NAFO fishing footprint. These thresholds were developed for VMEs that have been studied within the footprint and may not be applicable in areas outside the footprint. If fishing is authorized outside the current footprint, new thresholds would have to be developed for those areas or the use of existing thresholds deemed to be appropriate. WG-ESA suggests that additional provisions should be added to Art. 19 to 21 to cover encounters in experimental fisheries outside the footprint**]

Duties of the Master

2. Each Contracting Party shall

(a) require that masters of vessels entitled to fly its flag and conducting bottom fishing activities in the NAFO Regulatory Area abide by the following rules, where evidence of VME indicator species, in accordance with Annex I.E, are encountered during the course of fishing operations:

(1) quantify the catch of VME indicator species; and

(2) if the quantity of VME indicator species caught in a fishing operation (such as trawl tow or set of a gill net or longline) is beyond the threshold defined in paragraph 1 of this Article:

(i) report the encounter without delay to the flag State Contracting Party including the position that is provided by the vessel, either the end point of the tow or set or another position that is closest to the exact encounter location, the VME indicator species encountered, the quantity (kg) of VME indicator species encountered; and

(ii) cease fishing and move away at least 2 nautical miles from the ***endpoint of the tow/set in the direction least likely to result in further*** encounters. The captain shall use his best judgment based on all available sources of information.

Duties of the observer

(b) require that an observer with sufficient scientific expertise deployed in accordance with Article 18.2(c) for the areas outside the footprint:

(1) identifies corals, sponges and other organisms [**WG-ESA suggests removing 'coral, sponges and other organisms' and replacing it with 'VME taxa'**] to the lowest possible taxonomical level, using the "Exploratory Fishery Data Collection Form" in accordance with Annex I.E (templates); and

(2) delivers the results of such identification to the master of the vessel to facilitate quantification referenced in paragraph 2(a)(1) of this Article;

Duties of the Contracting Party

(c) forward, without delay, the encounter information reported by the master to the Executive Secretary if the quantity of the VME indicator species caught in a fishing operation (such as trawl, tow, set, of a gill net or longline) is beyond the threshold defined in paragraph 1 of this Article. The Contracting Party may allow the master of their vessels to also report the encounter directly to the Executive Secretary;

(d) issue an immediate alert of the encounter to all fishing vessels entitled to fly its flag; and

(e) consider [**WG-ESA suggests removing the word 'consider' to clearly affirm the establishment of a temporary closure. This should also be consistent with the comments provided in respect to Art 22.1 concerning encounter thresholds in exploratory areas outside of the NAFO fishing footprint]** temporarily closing a two-mile radius around any reported VME encounter location outside of footprint upon notification by the Executive Secretary in accordance with Article 22.3(c). Contracting Parties may reopen temporarily closed areas upon notification from the Executive Secretary in accordance with Article 22.3(e).

Duties of the Executive Secretary

3. The Executive Secretary:

(a) archives the information on incident information reported by masters and without delay transmits it to all Contracting Parties;

(b) makes an annual report to the Scientific Council on single and multiple encounters in discrete areas within the footprint. This report should also include reports from the exploratory bottom fishing activities conducted in the last year;

(c) requests all Contracting Parties to implement a temporary closure of a two mile radius around the reporting position of an encounter with VME indicator species outside the footprint, as identified in accordance with paragraph 2(c) of this Article. The reporting position is that provided by the master;

(d) requests Contracting Parties to maintain the temporary closure until such time that the Commission has adopted conservation and management measures in accordance with paragraph 5 of this Article if the Scientific Council concludes that the area covered by a temporary closure consists of a VME;

(e) informs the Contracting Parties that they may reopen the area to their vessels if the Scientific Council does not conclude that the area covered by a temporary closure consists of a VME; and

(f) makes an annual report to the Scientific Council on archived reports from encounters in areas outside the footprint. This report shall also include reports from the exploratory bottom fishing activities that were conducted in the last year.

Duties of the Scientific Council

4. The Scientific Council will be requested by the Commission to:
   (a) analyze the information received from the Executive Secretary pursuant to paragraph 3(b) and (f) of this Article;
   (b) examine any temporary closures implemented in accordance with paragraph 3(c) of this Article at the meeting immediately following the implementation of such closures; and
   (c) provide advice to the Commission on whether a VME exists following encounters with VME indicator species on a case-by-case basis and on the appropriateness of the temporary closures or other measures. The advice shall be based on annually updated assessments of the accumulated information on encounters as well as other scientific information. The Scientific Council's advice on the need for action, using FAO guidelines as a basis. In determining the appropriateness of the temporary closures or other measures, the Scientific Council should describe how these measures respond to the relevant provisions of the FAO guidelines, in particular the six criteria defining a significant adverse impact on an identified VME, consistent with the best available scientific information and the precautionary approach.

Duties of the Commission

5. The Commission shall:
   (a) consider the advice provided by the Scientific Council pursuant to paragraph 4(c) of this Article; and
   (b) adopt conservation and management measures in accordance with Article 20.

Article 23 – Reassessment of Bottom Fishing Activities [WG-ESA suggests that this heading be reworded to more accurately reflect what is being assessed, e.g. 'impact assessment of bottom contacting fishing activities on VMEs']

1. The Commission will request the Scientific Council to: [WG-ESA suggests that this should also include 'an assessment of Significant Adverse Impacts (SAI) as defined by the FAO guidelines for deep-sea fisheries].
   (a) identify VMEs, on the basis of best available scientific information and with the co-operation of Contracting Parties;
   (b) map sites where these VMEs are known to occur or likely to occur; and
   (c) provide such data and information to the Executive Secretary for circulation to all Contracting Parties.
2. The Commission shall:
   (a) conduct **[In practice this is done by SC, so WG-ESA suggests that this whole paragraph should read "request SC to conduct an impact assessment of bottom contacting fishing activities in 2021 in accordance with the NAFO roadmap every and every 5 years thereafter, or when there is new scientific information indicating a VME in a given area, other new scientific information becomes available, or there is significant change in the fishery" – this could also be moved into Article 23.1]** a reassessment of bottom fishing activities in 2021 and every 5 years thereafter, or when there is new scientific information

indicating a VME in a given area, other new scientific information becomes available, or there is significant change in the fishery, in collaboration with the Scientific Council and the Joint Commission-Scientific Council Working Group on Ecosystem Approach Framework to Fisheries Management; and

[**WG-ESA suggests to include a new item, "conduct a risk assessment based on the outcome of Article 23.1 assessments"**]

(b) take the necessary actions to protect VMEs, including potential adjustment of closed areas, following the reassessment specified in paragraph 2(a) of this Article.

Article 24 - Review

The provisions of this Chapter shall be reviewed by the Commission at its Annual Meeting no later than 2022

b) ToR 3.2. continued work on the sustainability of catches aspect of the Ecosystem Roadmap (Commission Request #5).

i) Independent review of the NAFO roadmap

The Commission requests that Scientific Council continue work on the sustainability of catches aspect of the Ecosystem Roadmap, including:

a) In consultation with WG-EAFFM via co-Chairs, convene independent experts to do a scientific review of; a) the estimation of fisheries production potential and total catch indices, and b) the adequacy of this analysis for their proposed use within the NAFO roadmap (Tier 1), while considering how species interactions are expected to be addressed in the future (Tier 2) within the overall Roadmap structure. The outcomes of this review would need to be tabled in June at Scientific Council to be available in advance of the planned workshop in 2022.

An important consideration in organising the independent expert review of Tier 1 and Tier 2 elements of the roadmap is defining the timeline of specific actions required by SC in consultation with WG-EAFFM to meet the tight deadline of having the results of the review available for the planned WG-EAFFM workshop in 2022 (see ToR 3.2, Com. Request #6b). The following plan sets out such a timeline of activities:

Plan/timeline of review milestones

i) Selection of 3 experts to be concluded by the end of November 2021 – the list of experts is currently with WG-EAFFM awaiting their approval and endorsement of the SC selected experts.

ii) Initial invitations to be sent (by SC) this year before the holidays (to confirm expert availability and willingness to participate) – what detail is required in the letter of invitation?

We need to provide some background/context for the review and could refer to the Roadmap paper if needs be, but this will depend on how much familiarity the reviewers have of NAFO. The invitation should be short and to the point - they need to know what is expected. e.g. need to state that, i. we are expecting essentially a paper level review (to check on the science), ii. an opinion on the suitability of the science in terms of the roadmap application/implementation. Essentially we are looking for the reviewers to endorse (or otherwise) the approach and the science SC has developed in response to Tier 1 and 2 of the roadmap.

iii) *Material for review is prepared between now and mid-March 2022*

This will consist of an SCR detailing the EPP model and TCI, which will be first circulated to WG-ESA/SC members for internal review.

In addition, relevant supporting/background material such other SCRs and WG-ESA selected sections from previous WG-ESA report will be compiled.

iv) *Confirmed experts receive material to review with guidance – by mid-April 2022.*

v) *Virtual meeting between reviewers' and WG-ESA to be convened by mid-May 2022.*

This will allow any specific questions raised by the reviewers to be addressed by WG-ESA.

vi) *Deadline for completing the review end of May, upon which it will be submitted to SC.*

vii) *Virtual presentation to SC by reviewers in June 2022.*

viii) *SC prepares response to COM Request (June)*

ix) *WG-EAFFM considers SC response in August 2022*

x) *Conclusions of the review presented at EAFFM ecosystem workshop (in person) August 2022.*

ii) Up-date on TCI modelling work

In its 2019 meeting WGESA reviewed and summarized its work on Ecosystem Production Potential (EPP) models and their use to derive Total Catch Indices (TCIs) (SCS Doc. 19-25). A key result from those analyses was the integration of trends for those EPP functional feeding guilds with a consistent history of fishing within NAFO (piscivore and benthivore functional guilds) with their corresponding smoothed Catch/TCI ratio (Figure 6.1) (SCS Doc. 19-25). This analysis shows that catches above TCI are more consistently associated with negative trends in the functional guilds, than catches below TCI. The even distribution of positive and negative trends when fishing below TCI is also consistent with the premise that, if fishing is sustainable, other factors would control functional guild trajectories. The average functional guild trend for catch levels above TCI was -0.457, while the average trend for catch levels below TCI was 0.041. Trends above the boundary defined by TCI were significantly smaller than those below this boundary (Mann-Whitney test, p-value < 0.006).

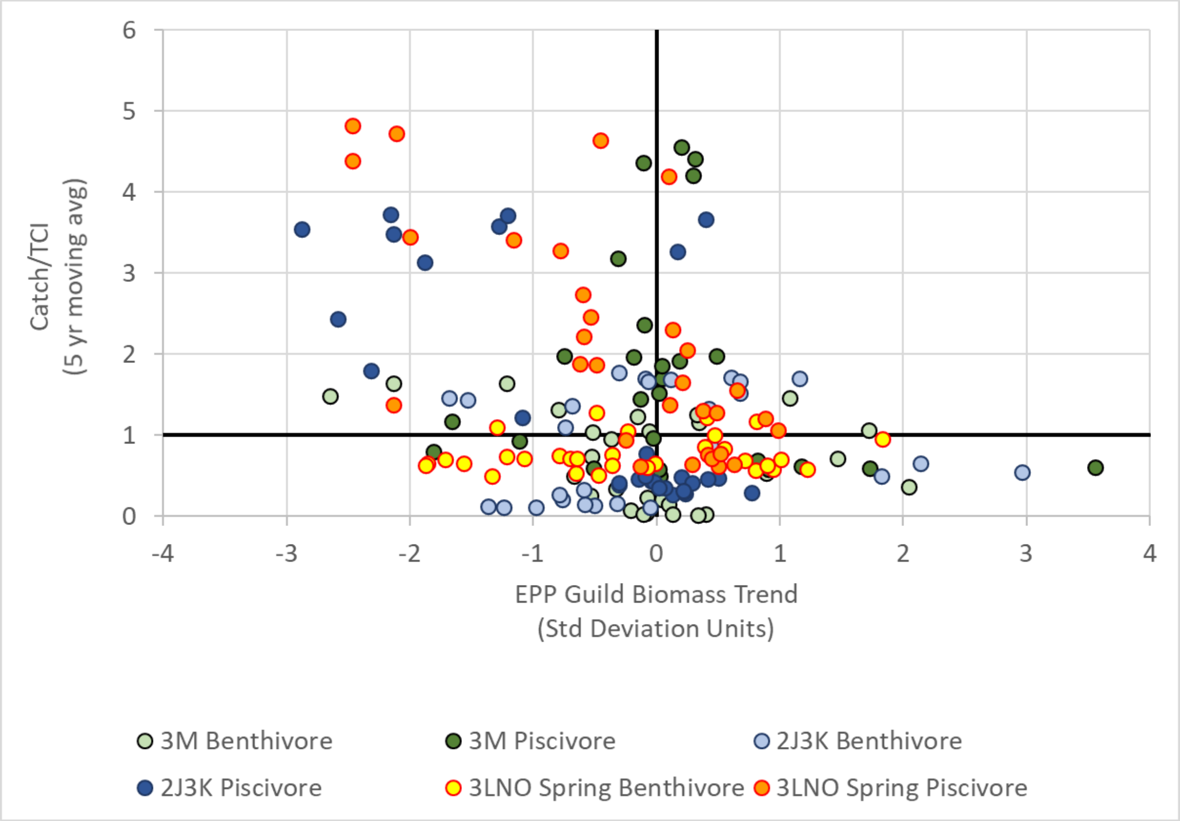

Figure 6.1. Relationship between functional guild biomass trends and catch level expressed as a fraction of the corresponding Total Catch Index (TCI) for the piscivore and benthivore guilds in the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Flemish Cap (3M) EPUs. Catch levels below 1 indicate sustainable exploitation levels from the perspective of TCI.

On the basis of these results, Scientific Council (SC) formulated its advice (SCS Doc. 20-14) for the initial implementation of the Tier 1 assessment within the Roadmap for an Ecosystem Approach to Fisheries in NAFO (Koen-Alonso et al., 2019). In this advice SC recommended the interim implementation of TCIs as a strategic measure to guide management actions in response to levels of aggregated catch that have the potential for eroding ecosystem functioning (i.e. ecosystem overfishing) (SCS Doc. 20-14). This recommended implementation effectively represents a traffic light approach, where aggregated catches above 2*TCI trigger the explicit consideration by the Commission (COM) of the risk of ecosystem-level impacts when making decisions on stock catch levels (red light, high risk of ecosystem impacts), catches between TCI and 2*TCI triggered enhanced ecosystem monitoring and reporting but no explicit consideration of aggregated catches by COM in their decisions (yellow light, increased risk of ecosystem impacts), and catches below TCI require no additional ecosystem monitoring and reporting (green light, low risk of ecosystem impacts).

One way of presenting this approach in terms of risk is by using the data from Figure 6.1 to construct empirical cumulative distributions of the probability of negative ecosystem outputs (i.e. a negative biomass trend at the functional guild level) for the different Catch/TCI levels. This representation of the results (6.2) clearly shows that the risk of negative outcomes increases as the Catch/TCI ratio increases, and indicates that TCI maps the boundary of sustainable catches in an effective way since it renders an even distribution of positive and negative growth in fish functional guilds, but with a low probability of severe declines. Catch levels between 1-2 TCI may still be considered generally sustainable given that they still show a fairly even partition between positive and negative trends, but these higher catches come with an increased probability of steeper declines and a reduced probability of important increases, and it would be up to managers to decide if these increased risks of negative outcomes are deemed acceptable or not. Catch levels above 2*TCI are clearly unsustainable with very high probability of negative outcomes.

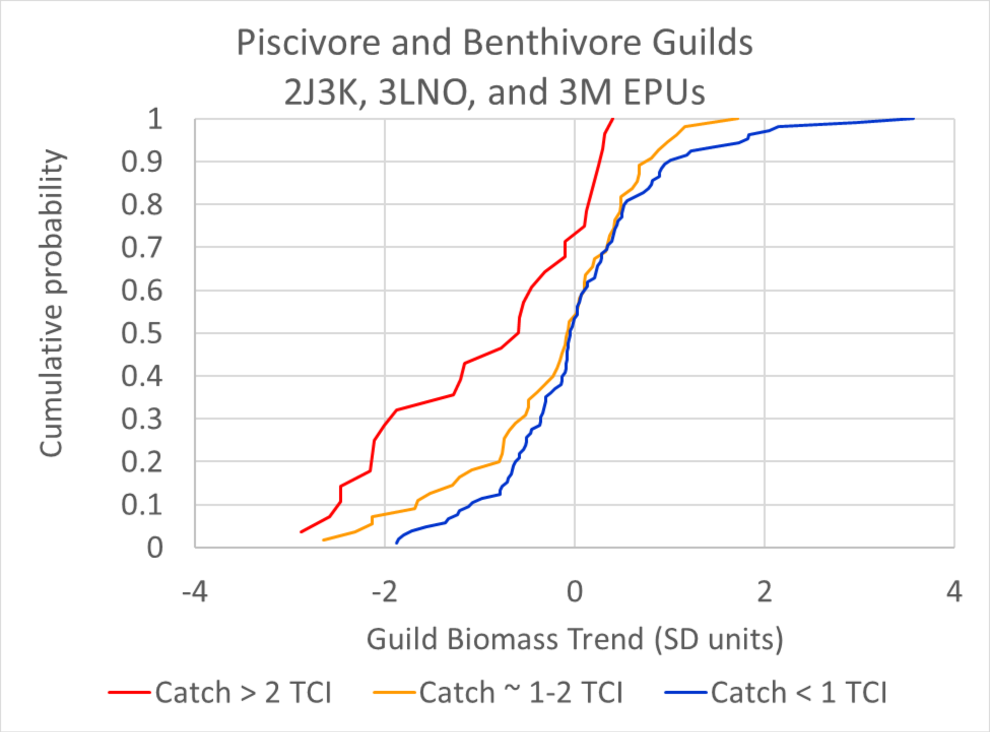

Figure 6.2. Empirical cumulative probability distributions for functional guild trends (in standard deviation -SD- units) under three catch scenarios: catch below TCI, catch between 1 and 2 times TCI, and catch above 2*TCI. The data used to build these empirical distributions is the one presented in Figure 6.1. These distributions do not discriminate by EPU nor functional guild.

While the results summarized in Figures 6.1 and 6.2 are compelling in themselves, trends in functional guilds would be expected to be affected by factors other than fishing pressure, like intrinsic ecosystem features, functional guild identity, environmental conditions, and/or other drivers that could be changing over time.

Current understanding of the marine ecosystem in the NL and Flemish Cap bioregions indicate the both fishing pressure and environmental conditions have been important drivers of the changes observed (Koen-Alonso et al., 2010; Pérez-Rodríguez et al., 2011; Dawe et al., 2012; Perez-Rodriguez et al., 2012; Buren et al., 2014b; Dempsey et al., 2017; Dempsey et al., 2018; Koen-Alonso and Cuff, 2018; Koen-Alonso et al., 2018). Furthermore, while the changes in these systems have had similarities, these changes have not been homogeneous nor perfectly synchronized across all ecosystem units. For example, the Flemish Cap did not experienced a fish community collapse like the EPUs in the NL bioregion did, even if some important stocks showed severe declines (Perez-Rodriguez et al., 2012; Koen-Alonso et al., 2018), and the increase in shellfish biomass started earlier and was more important in the Newfoundland Shelf (2J3K) than in the Grand Bank (3LNO) EPU (Dempsey et al., 2017; Dempsey et al., 2018; Koen-Alonso and Cuff, 2018). Still, despite their differences, signals linking many of these changes to fishing and environmental conditions have been detected in all ecosystem units (Koen-Alonso et al., 2010; Pérez-Rodríguez et al., 2011; Perez-Rodriguez et al., 2012; Buren et al., 2014a; Dempsey et al., 2018; Dempsey et al., 2020).

The role of these additional variables in driving functional guild trends was examined using a general linear model (glm) with identity link, where the functional guild trend was the response variable, and the independent variables were EPU and functional guild as factors, and year, the Newfoundland and Labrador (NL) Climate Index (NLCI), and the Catch/TCI ratio as continuous variables. The NLCI (Cyr and Galbraith, 2021) was used as a proxy for overall environmental conditions because it is a composite index which characterizes the large scale ocean climate state in the broad NL bioregion, and hence, it was also considered adequate to capture general environmental conditions in the Flemish Cap (3M) given its geographical proximity to the Grand Bank (3LNO). A single term deletion procedure was used to identify significant independent variables in the glm.

The results from the glm analysis were consistent with our current understanding of the factors controlling the dynamics of these ecosystems (Table 6.1). Both Catch/TCI ratio and NLCI were statistically significant drivers of functional guild trends, while functional guild, EPU, and year were not, but there is a hint in the coefficients results that the Flemish Cap (3M) EPU could have somewhat higher functional guild trends than the Newfoundland Shelf (2J3K) and Grand Bank (3LNO) EPUs (Table 6.1).

These results are also consistent with the expected directions of the impacts from the different drivers; fishing has a negative effect on guild trends while NLCI has a positive effect. The NLCI result meets expectations because NLCI is constructed using properly signed anomalies so that the resulting index increases when the ocean climate is dominated by conditions generally associated with a warmer ocean state, and decreases with conditions more associated with a colder ocean state (Cyr and Galbraith, 2021). These warmer ocean states have been found to be more favourable for some key groundfish stocks (Koen-Alonso et al., 2010). Considering that TCIs are derived from average values of primary production, the mechanisms underlying the statistical significance of NLCI would be expected to be diverse, from tracking changes of underlying physical conditions that promote primary production, to reflecting a generally more favourable environment for fish production.

It is also interesting to note that neither year nor functional guild were identified as significant drivers. Any variation over time in fish functional group trends is being explained by the variations in both fishing pressure and ocean climate conditions, while any potential difference between functional guilds was likely factored out by the standard deviation scaling applied to the trends. While EPU was also found not significant, the results hint at the possibility that the Flemish Cap (3M) EPU may have higher functional group trends than the EPUs in the NL bioregion. Such potential difference would not be surprising; the marine community in the Flemish Cap did not experience a collapse, and this ecosystem, unlike those in the NL bioregion, is considered fully functional. Even if we do not fully understand the exact nature of the processes involved in the erosion of functionality of the Newfoundland Shelf (2J3K) and Grand Bank (3LNO) ecosystem units, the hint at higher trends in the Flemish Cap (3M) would be consistent with the expected differences arising from different levels of ecosystem functionality.

Table 6.1. General Linear Model (glm) results for the model considering functional guild trend as a function of Catch/TCI Ratio, EPU, functional guild, year, and NLCI (trend~Catch_TCI+EPU+funct_guild+ year+NLCI), where EPU and Functional guild were considered as factors and the remaining as continuous variables. This model was fitted with an identity link (i.e. gaussian distribution).

Analysis of Deviance

Term	df	Deviance	Residual df	Residual Deviance	F statistic	p-value
Null model			187	187.17		
Catch/TCI Ratio	1	19.81	186	167.36	22.624	4.01E-06
EPU	2	3.35	184	164.01	1.913	0.151
Functional guild	1	1.45	183	162.56	1.654	0.200
Year	1	0.63	182	161.94	0.715	0.399
NLCI	1	3.44	181	158.50	3.925	0.049

Coefficients

Term	Estimate	Std. Error	t statistic	p-value
Intercept	2.494	18.303	0.136	0.892
Catch/TCI Ratio	-0.280	0.074	-3.781	2.12E-04
EPU (3LNO)	0.085	0.167	0.511	0.610
EPU (3M)	0.297	0.171	1.737	0.084
Funct. guild (piscivore)	0.150	0.150	0.998	0.320
Year	-0.001	0.009	-0.139	0.890
NLCI	0.261	0.132	1.981	0.049

Single term deletion analysis

Term	df	Deviance	AIC	F statistic	p-value
Full model		158.50	517.43		
Catch/TCI Ratio	1	171.02	529.72	14.293	2.12E-04
EPU	2	161.25	516.67	1.572	0.210
Functional guild	1	159.37	516.46	0.996	0.320
Year	1	158.52	515.45	0.019	0.890
NLCI	1	161.94	519.46	3.925	0.049

Based on the results of the full glm, a reduced model was constructed using solely Catch/TCI ratio and NLCI as independent variables. An examination of this model diagnostics indicates an adequate model fit, with model predictions generally well aligned with the observations, and an even distribution of the standardized residuals above and below the zero line, mostly bound between ±2 standard deviations, and without any obvious pattern (Figure 6.3). The results from this reduced model confirms the conclusions from the full glm, indicating that both fishing pressure and environmental conditions are significant drivers of functional guild trends (Table 6.2). The examination of the single term deletion analysis indicates that fishing pressure is a more significant driver of functional guild trends than environmental conditions, suggesting that fishing pressure, scaled by ecosystem productivity, has been the dominant driver of functional guild trends for piscivores and benthivores, with ocean climate playing a more modulating role.

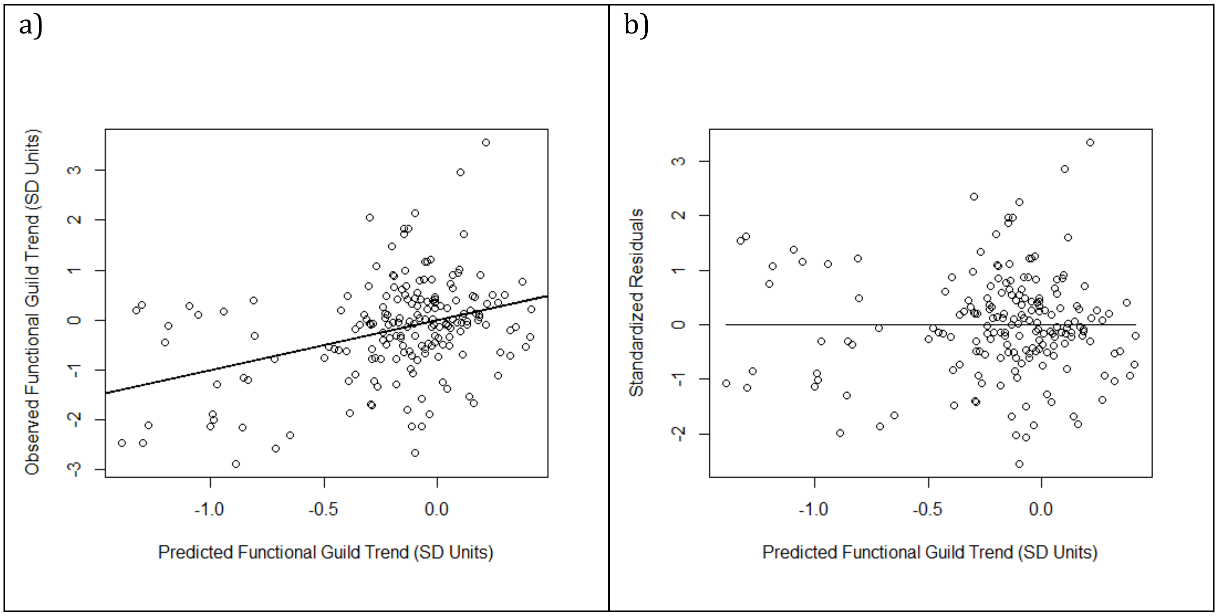

Figure 6.3. Diagnostics for the reduced general linear model considering functional guild trend as a function of Catch/TCI Ratio, and NLCI (trend~Catch_TCI+ NLCI). a) Predicted vs observed functional guilds trend values; the line indicates the 1:1 relationship. b) Standardized residuals as a function of observed functional guilds trend values, including the zero line for reference.

Table 6.2. General Linear Model (glm) results for the reduced model considering functional guild trend as a function of Catch/TCI Ratio, and NLCI (trend~Catch_TCI+ NLCI). Both independent variables were considered as continuous. This model was fitted with an identity link (i.e. gaussian distribution). df: degrees of freedom, AIC: Akaike Information Criterion

Analysis of Deviance

Term	df	Deviance	Residual df	Residual Deviance	F statistic	p-value
Null model			187	187.17		
Catch/TCI Ratio	1	19.81	186	167.36	22.615	3.97E-06
NLCI	1	5.29	185	162.07	6.040	0.015

Coefficients

Term	Estimate	Std. Error	t statistic	p-value
Intercept	0.098	0.107	0.916	0.361
Catch/TCI Ratio	-0.245	0.064	-3.816	1.85E-04
NLCI	0.285	0.116	2.458	0.015

Single term deletion analysis

Term	df	Deviance	AIC	F statistic	p-value
Full model		162.07	513.62		
Catch/TCI Ratio	1	174.82	525.86	14.559	1.85E-04
NLCI	1	167.36	517.66	6.040	0.015

Still, caution must be taken to not over-interpret these results. This analysis is a proof of concept for the utility of TCI. This index summarizes a lot of information at a high level of aggregation, and has proven useful for uncovering relationships between system-level fishing pressure and large scale responses of ecosystem components, but understanding fully the processes that ultimately drive trends in functional guilds requires more detailed analyses, likely including species interactions, more appropriate consideration of the dynamics (this is a simple linear model after all), and more nuanced characterizations of both, the impacts of fishing and environmental factors. The goal of TCIs is to inform ecosystem level assessments about the sustainability of aggregate catch levels, and within that context, it follows from these results that if a TCI-based indicator can be effective for predicting general responses in the trends of functional guilds, they can also be useful for supporting guidance on total catches in relation to the likely impacts of those catch levels on ecosystem functioning, at least as measured by the functional guild trends.

Overall, these results further validate the logic behind, and the effectiveness of TCIs as a metric for identifying the upper bound for sustainability of aggregate catches at the ecosystem level, and indicate that TCIs constitute a robust guideline reference for informing Tier 1 assessments within the Roadmap.

From Ecosystem Production Potential (EPP) to Total Catch Index (TCI): A quick summary and implications

The development of TCIs and associated guidelines for total catches at the ecosystem levels has taken multiple years and iterations, so a quick summary of the current process and its implications can be useful, especially now that this work is undergoing an independent scientific review.

When taken together, the different steps and analyses involved provide a framework to address the question of how much fish can we safely extract from the ocean based on the observed primary production? This question is answered by using the EPP model to estimate how primary production becomes Fisheries Production Potential (FPP). The upper bound for sustainability that defines FPP is justified on the fraction of primary production supported by the inventory of nitrogen, a generally limiting nutrient in the ocean, that is annually added to the system from fresh sources. This FPP is adjusted to realized productivity conditions using changes in total biomass in the ecosystem, under the premise that total biomass tracks changes in productivity. Finally, we use the 25th percentile of this adjusted FPP distribution (FPPadj) to define TCI, and indicator that allows evaluating if total catches are within the sustainability envelope while keeping a low probability of exceeding the upper bound for total catches.

As part of this process we have characterized the uncertainty in the estimates derived from the EPP model, and in doing so we showed that this simple model encapsulates features that have been identified by empirical studies as necessary to link primary production with fisheries production, as well as others emerging from theoretical studies about the structure of food webs. We also found that, despite the differences in the underlying frameworks, FPP estimates are consistent with Maximum Sustainable Yield (MSY) ones, which indicates that the FPP estimates are likely robust. We have also indicated how the available data supports the type of adjustment to realized productivity conditions implemented in the framework.

From the perspective of reliability for management applications, we have demonstrated that TCI does indeed provide an effective boundary for total catches by showing that catches exceeding TCI are consistently associated with negative trends in the exploited functional guilds. We also showed that fishing pressure, scaled by ecosystem productivity, has been a significant driver of functional guild trends, which have also been influenced by ocean climate conditions.

Perhaps more importantly, the analyses have shown that after many groundfish collapses, the management measures implemented by NAFO at the stock level were effective at significantly reducing the overall fishing pressure. However, these measures, driven by single stock considerations, where insufficient to consistently keep aggregate catches within the sustainability envelope defined by TCIs. Given this shortcoming, and the demonstrated significance of fishing pressure as a driver of negative outcomes at the scale of functional guilds, it becomes evident that additional management measures beyond single stock management are required to ensure that exploitation levels are sustainable at the ecosystem level. TCIs not only work, they -or conceptually similar approaches- appear necessary for sustainable fisheries in an ecosystem context.

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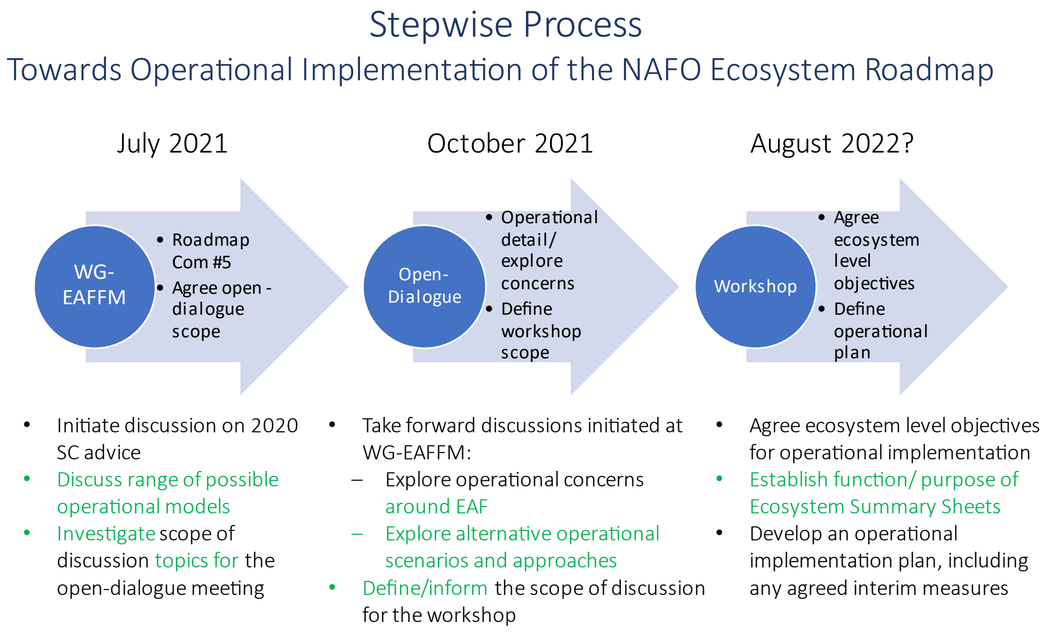
iii) Work to support the WG-EAFFM workshop in 2022 (Commission Request #5b).

> ***The Commission requests that Scientific Council continue work on the sustainability of catches aspect of the Ecosystem Roadmap, including:***
>
> ***b) Work to support the WG-EAFFM workshop in 2022, which will explore ecosystem objectives and further develop how the Roadmap may apply to management decision making.***

Preparations for a WGEAFFM workshop have been on-going since it was announced at the 41st Annual Meeting (2019) that a workshop would be organised to progress the implementation of all aspects of the NAFO Roadmap (COM SC Doc. 19-10). Specifically, it was agreed the workshop would have the following objectives: i. to advance the drafting of ecosystem level objectives, ii. identify elements for their application, iii. explore existing practice, and iv. identify information needs for future development. However, with the onset of the COVID-19 pandemic it has been necessary to push-back the timetable for the workshop. Nevertheless, WGEAFFM in the meantime organised an 'Open Dialogue' discussion between scientists and managers to maintain the momentum in moving forward with EAFM implementation in NAFO. This should be seen as part of a stepwise process, as summarised in Figure 6.4, which is leading towards the operational implementation of the NAFO Roadmap for an Ecosystem Approach to Fisheries (Koen-Alonso et al., 2019).



- Initiate discussion on 2020 SC advice
- Discuss range of possible operational models
- Investigate scope of discussion topics for the open-dialogue meeting

- Take forward discussions initiated at WG-EAFFM:
  - Explore operational concerns around EAF
  - Explore alternative operational scenarios and approaches
- Define/inform the scope of discussion for the workshop

- Agree ecosystem level objectives for operational implementation
- Establish function/ purpose of Ecosystem Summary Sheets
- Develop an operational implementation plan, including any agreed interim measures

Figure 6.4. Recent meetings between managers and scientists in preparation for the EAFFM workshop in August 2022

SC input at the workshop will be primarily from the standpoint of the application of the technical aspects (or elements) which underpin the Roadmap, specifically in relation to Tiers 1 and 2 assessment levels in general, and the Total Catch Index (TCI) and multi-species modelling work in particular. SC is also overseeing the independent expert review on the estimation of fisheries production potential, and the adequacy of this analysis for the intended application within the Roadmap (Tier 1) while taking into account how species interactions are expected to be addressed in Tier 2, which is expected to be presented to SC in June 2022.

At the 'Open Dialogue' meeting a number of questions were raised by participants concerning the implementation of the Roadmap and how it would work in practice (see below). These questions (where they relate to technical aspects of the Roadmap implementation), can provide a useful focus for further SC consideration.

Questions and options raised at the 'Open Dialogue' of a technical nature

- Managers would like to see some examples of how the TCI would work in practice.
- There was some interest in better understanding how the F_{eco} approach being developed in ICES relates to TCI.
- The inclusion of the relevant functional guild TCI scientific advice into the stock summary sheets.
- A need by managers to better understand the distinction between strategic and tactical level advice with respect to how the TCI would be used in practice.
- The role of Ecosystem Summary Sheets (ESS) in support of identifying/defining ecosystem level objectives.
- How does the Roadmap relate to the Precautionary Approach to Fisheries?

Operational application of Tier 1 scientific advice

Tier 1 of the Roadmap outlines the need to set upper limits to the total fishery catches being extracted from an ecosystem. This was previously termed the Total Catch Ceiling, and later renamed as Total Catch Index (TCI), which is based on the primary production and productivity state of the ecosystems being fished. This level of assessment allows for considering ecosystem overfishing (Murawski, 2000; Coll et al., 2008; Link and Watson, 2019), as well as to provide an avenue for eventually factoring in some of the impacts from climate change (Free et al., 2019; Tittensor et al., 2021). A failure to recognize and govern exploitation of renewable marine resources based on such principles has led (see Section 6.b.ii in this Report), and/or it is likely to lead to removals that have a high risk of damaging the ecosystem's productive capacity or to prevent its recovery in those cases where prior collapses may have already eroded it.

Applying the Total Catch Index (TCI) represents a strategic approach to ecosystem sustainability by providing a tool to prevent ecosystem overfishing. It does not constitute a hard tactical limit for any specific stock, but it does provide a mechanism to synoptically assess the sustainability of the overall level of fisheries extraction, allowing for strategic planning over a 3 to 5 year time frame.

Defining ecosystem level objectives

As it has been highlighted, there is a need to define appropriate ecosystem level objectives against which the TCI technical elements can be applied. For example, one possible long-term objective could be:

"To achieve and maintain the biomass and relative proportions of functional feeding groups 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 "healthy" (as defined in Ecosystem Summary Sheets)."

In addition, a shorter-term, more operational objective could be.:

"To 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"

The link between the fishery-based ecosystem level objectives (above) and technical elements of the TCI are made explicit within the ecosystem summary sheets.

TCI operational implementation

The TCI is intended to be used at a fish functional guild level, such that if the total aggregated catch approaches or exceeds a defined TCI boundary (see section 6.1) then there is a higher risk of overfishing at the ecosystem level (e.g. seeFigure 6.2). Under such conditions managers would be expected to consider aggregated catches in addition to the results from individual stock assessments when negotiating TACs, taking into account potential trade-offs in TACs within a functional guild.

The SC advice on the implementation of TCIs (SCS Doc. 20-14) effectively constitutes a traffic light approach:

- *Red light (High risk of ecosystem impacts due to ecosystem overfishing)*: Catches > 2TCI. This triggers explicit consideration by the Commission (COM) of the risk of ecosystem-level impacts when making decisions on stock catch levels.
- *Yellow light (Increasing risk of ecosystem impacts due to ecosystem overfishing)*: Catches are between TCI and 2TCI. This triggers enhanced ecosystem monitoring and reporting but no explicit requirement for COM to consider the likely impacts of aggregated catches in their decisions on stock catch levels. Of course, this does not impeded COM to take management measures to avoid crossing the 2TCI boundary.
- *Green light (Low risk of ecosystem impacts due to ecosystem overfishing)*: Catches are below TCI. There is no requirement for increased ecosystem monitoring and reporting; regular ecosystem monitoring is sufficient.

While there is no specific management action recommended by SC in response to the TCI advice, some operational examples associated with potential management action could be:

1. When functional group catches (ΣTACs) are approaching 2TCI during an assessment cycle, then:
   a) change the probability of exceeding the Limit Reference Points (LRPs) in single species assessment projections, to reduce the risk of exceeding 2TCI, and;
   b) apply to all stocks within a functional guild during and assessment cycle (2 – 3 yrs).
2. When exceeding 2TCI during an assessment cycle;
   a) apply a penalty (e.g. 2TCI/ ΣTACs) to all projected TACs for stocks within the corresponding functional guild, whilst;
   b) considering the historical TACs/biomass status and trends from the ecosystem summary sheets (ESS).

It is also noteworthy that since the mid 1990's, total catches have only exceeded 2TCI twice (piscivores in 3LNO, and benthivores in 2J3K), but analyses show (see section 6.b.ii) that when total catches exceed 2TCI the risk of negative ecosystem outcomes is substantial, and with catches below TCI the probability of faster rebuilding is improved. In addition to these concrete differences in ecosystem performance, the implementation of TCI also contributes to explicitly address some legal obligations embedded in the NAFO convention like the UNFSA and FAO PA requirements to consider "non-target and associated or dependent species" and "aggregated impacts" of fisheries.

Workshop organisation, planning and agenda

Whilst recognising the responsibility for the workshop belongs to WGEAFFM, WGESA did consider a number of issues related to the organisation, planning and running of the workshop, largely because both WGEAFFM co-Chairs were present for discussion of this item.

It is understood the workshop would be held as a physical meeting over two days, back-to-back with the WGEAFFM meeting in August 2022. The agenda has yet to be drafted, but given the original ToRs for the workshop and the present COM Request explicitly mention defining ecosystem level objectives and the need to consider implications for management implementation, it would seem reasonable for the meeting agenda to be split into three parts, e.g.:

1. NAFO state of play
    - To include a summary of the NAFO approach (including the most recent analytical up-date)
    - The outcome of the independent expert review.
2. Ecosystem level objectives
    - To include a summary of the discussions undertaken by SC and WGEAFFM on this topic since 2018 (see above) and to refer to the development of the ESS, the links between objectives, and the application of technical elements of TCI to measure performance.
3. Management implementation
    - To include possible interim measures, e.g. the inclusion of TCI into stock summary sheets.
    - Develop worked examples of how TCI would work in practice. **i.** this is what you do if you reach 2TCI (as suggested above), **ii**. if you did this, what would you get (to answer the what if question), and **iii.** If you implement TCI would you actually get a better outcome (TCI *vs* non-TCI management).
    - Tier 1 operational elements – to include aspects of the material presented above.
    - How to take this discussion forward?

WGESA concluded that its focus in supporting the workshop would be mainly with developing the technical elements as worked examples of how the TCI could be implemented in practice, possibly to include some evaluation of TCI *versus* non-TCI management through a process of historical analysis.

To take this forward it was agreed that WGESA would establish a sub-group, jointly led by Mariano Koen-Alonso and Karen Dwyer to explore the options for worked examples.

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iv) work to develop models that support implementation of Tier 2 of the EAFM Roadmap (Commission Request #5c).

The Commission requests that Scientific Council continue work on the sustainability of catches aspect of the Ecosystem Roadmap, including:

c) Continue its work to develop models that support implementation of Tier 2 of the EAFM Roadmap.

As part of its Request #5, the NAFO Commission (COM) requested Scientific Council (SC) to continue its work to develop models that support implementation of Tier 2 of the Roadmap. This type of work has received some attention over the years, but a consistent development of Tier 2 models requires a more focused, structured approach that can promote modelling applications which are suitable for utilization within the scope of the Roadmap.

The first step in developing such structured approach requires a clear understanding of what a Tier 2 model is, and what is required for its development and application within the Roadmap. As an initial step of this process, WGESA organized a discussion session on the topic, and invited a number of experts working on relevant modelling work to participate.

The Tier 2 discussion session was split in two parts, one focused on the role of Tier 2 models within the Roadmap, and the other on relevant ongoing work that can inform Tier 2 applications. The specific goals of each one of these discussions were:

Part 1: Opening Session (Nov 18, 2021)

- Further clarify what is expected from Tier 2 models within the Roadmap.
- Identify the type of applications/use these models are expected to support.
- If possible, provide initial considerations on how to operationalize these models for the generation of advice.

Part 2: Modelling Discussion Session (Nov 22, 2022)

- Presentation of selected examples to explore the range of alternative/complementary methods that could be used to develop Tier 2 models.
- Summary compilation of relevant work that can inform/support the Tier 2 modelling within WGESA/NAFO. This compilation will also inform the identification of useful modelling approaches/techniques.
- Generation of draft guidelines/considerations for the development/promotion of Tier 2 modelling work in ways that can support WGESA/NAFO for the full implementation of the Roadmap.

This discussion session was intended as an initial scoping exercise, and given the limited time available, the goals were explicitly recognized as ambitious. Therefore, they were advanced as much as possible within the meeting, but the expectation was that additional work in upcoming WGESA meetings would be required to fully scope the development of Tier 2 models. Still, important progress was made in terms of defining the role and features of this type of models, and what is required for their development as part of the Roadmap implementation. The following sections summarize this progress.

The role of Tier 2 models within the Roadmap

The Roadmap represents the template that NAFO is following to implement an ecosystem approach. As such, it integrates both, scientific information and analyses, as well as how that information feeds into the management process. In doing so, it implements a recursive path that allows for adaptation and reformulation of management objectives, science applications and advice, and management practices (Koen-Alonso et al., 2019).

Within the Roadmap, sustainable catches are derived from a series of nested assessments focused at different levels or ecological organization; Tier 1 corresponds to Ecosystem State Assessments, Tier 2 corresponds to Multispecies Assessments, and Tier 3 corresponds to Single Stock Assessments (Koen-Alonso et al., 2019). This implies that while models are relevant in all tiers, the tiers themselves are more than specific modelling exercises, they constitute full assessments within which models provide specific information.

The ecological foundation for the tiered structure is considering ecosystems as nested hierarchical structures that integrate biological, chemical, and physical processes operating at different temporal and spatial scales. Like Russian dolls, outer [higher] level structures would affect inner [lower] level ones, acting as constraints to the levels within. Higher tiers provide support for strategic decisions, while the lower tiers provide support for tactical decisions (Figure. 6.5).

Tier 2 assessments are focused on multispecies interactions, and intended to evaluate potential trade-offs emerging from those interactions, as well as to consider management objectives related to multispecies sustainability (e.g. ecosystem resilience under perturbations). In this context, Tier 2 models are aimed at capturing intermediate levels of ecological complexity. This tier serves as a bridge between the large-scale ecosystem features and characteristics (e.g. ecosystem-level production), and the individual stock-level status and trends. This implies that Tier 2 assessments can provide support for strategic and/or tactical decisions, depending on the specifics of the assessment and the models it relies upon.

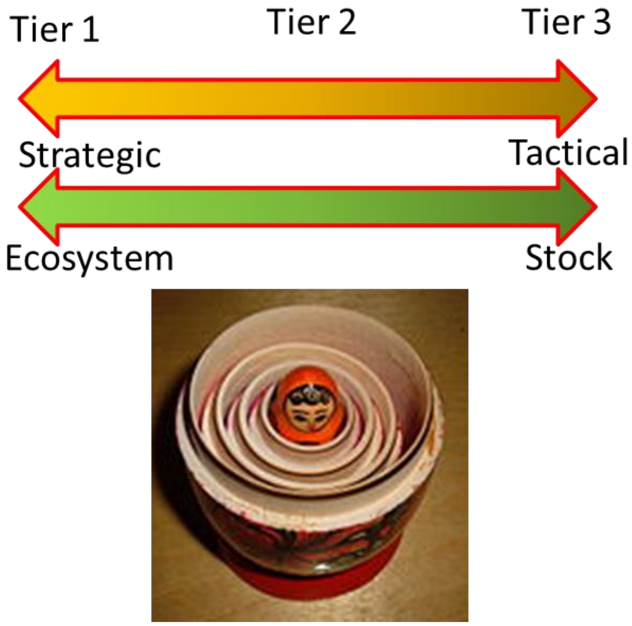

Figure 6.5. Schematic conceptualization of the Tiers used by the Roadmap to derive sustainable catch levels. Outer [higher] tiers define boundary conditions for the tiers within and provide support for strategic decisions, while the inner [lower] tiers provide support for tactical decisions. Tier 2 assessments (and models) capture intermediate levels of complexity and serve as a bridge between the large scale ecosystem features and characteristics (e.g. ecosystem-level production), and the individual stock-level status and trends.

Basic features of Tier 2 models

Tier 1 strategic advice, like the Total Catch Index (TCI) used to provide guidance on the sustainability of total catches at the level of Ecosystem Production Unit (EPU) (Koen-Alonso et al., 2019; SCS Doc. 19-25; SCS Doc. 20-14), does not necessarily have to be dynamic in nature, but has to reasonably represent the general ecosystem state during a given period of time. Tier 3 advice (i.e. traditional stock-assessment) must capture the temporal dynamics of the stock in order to provide the short-term expectations required for setting catch quotas (e.g. Total Allowable Catch –TAC–)(SCS Doc. 20-14). Since Tier 2 assessments represent a bridge between these two levels of organization and assessment, the basic features required for Tier 2 models are expected to be somewhere in between.

The focus of Tier 2 models is to capture the key interactions affecting managed stocks, so those interactions can be factored into the decisions about sustainable catch levels. While many of these key interactions are expected to be trophic-related (e.g. predation, competition, food availability/limitations), these may also involve the effect of environmental drivers on the managed stocks (e.g. temperature and/or broader ocean climate effects, climate change impacts).

Given the type of focal interactions in Tier 2 models, and the potential need for using Tier 2 models to inform (or even base) tactical advice in some cases (e.g. strong interactions among commercial stocks), these models need to minimally possess some basic features. Trying to avoid being overly prescriptive, these basic characteristics of Tier 2 models are:

1. be time-dynamic, and include fishing as a driver.
2. Only incorporate key interactions and drivers (e.g. Minimum-Realistic Models –MRM–, Models of Intermediate Complexity for Ecosystem assessments –MICE–)(Plagányi, 2007; Koen-Alonso, 2009; Plagányi et al., 2014; Collie et al., 2016).
3. Amenable to statistical model fitting evaluation, and/or robust simulation testing (depending on purpose of application).

Other features, like spatially explicit dynamics, and/or age/size structure, may be needed for some applications, but not all Tier 2 models may necessarily have to consider these levels of complexity.

What truly defines Tier 2 is the scope of the assessment, not the specific details of the model and/or analyses used to inform the assessment. The essence of Tier 2 assessments is to consider the key interactions that affect managed stocks. While the evaluation of species interactions, and/or the impact of environmental drivers on them are multispecies questions, this does not necessarily imply that Tier 2 models are bound to be multispecies models in all cases. It is the nature of the key interactions that will dictate the type and level of complexity of the model required. For example, a predator-prey system with strong feedback loops between predators and prey would be expected to require a multispecies model for the Tier 2 assessment; however, if the feedback loop between predator and prey is weak or diffuse, a single-species model where the effect of predation/food availability is represented as an external driver may be sufficient for the Tier 2 assessment.

From a modelling perspective, the boundary between a Tier 2 and a Tier 3 model is a fuzzy one. A multispecies model can eventually be used for the provision of tactical advice on a specific stock (i.e. Tier 3 assessment level), and an expanded single species model (.e.g. one that includes ecosystem/environmental indices as external drivers) can be used to inform how changes in prey and/or predators are expected to influence one or many managed stocks (i.e. Tier 2 assessment level) (Figure 6.6). Another important consideration of the gradient nature of the boundary between Tier 2 and Tier 3 models is that developing models from both perspectives along that gradient (e.g. a tactical-oriented multispecies model and an expanded single-species model) can be used to cross-validate the models and build-up confidence in the overall results.

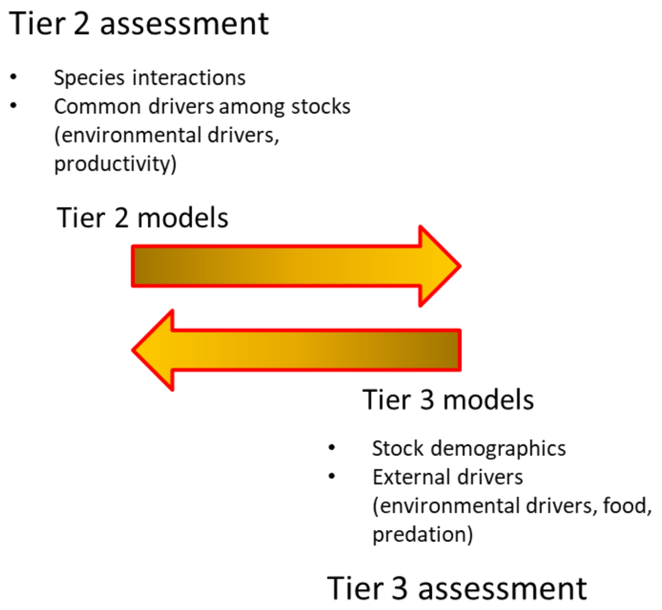

Figure 6.6. Schematic representation of the relationships between Tier 2 and 3 as assessment levels, versus the role of Tier 2 (e.g. multispecies) and Tier 3 (e.g. stock-assessment) models within these assessment levels. From a model structure perspective, the boundary between Tier 2 and Tier 3 models can be a fuzzy one; what effectively defines the Tier is the scope of the assessment being conducted.

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*". Within the context of a Tier 2 assessment, fulfilling these commitments implies that Tier 2 models can support a diversity of applications. These applications can be nominally grouped into two major areas depending on the general type of objective they are intended to support: fisheries and biodiversity advice.

Since the tiered assessment structure within the Roadmap is aimed at defining sustainable catch levels, the most evident applications of Tier 2 models are those related to fisheries advice. These include, for example, the evaluation of trade-offs between fisheries, the responses of managed stocks to external drivers (i.e. environmental and/or other stocks), informing stock-assessment models/advice (e.g. trends in natural mortality, consumption models for the estimation of predation mortality), and construction of ecosystem-informed precautionary approach frameworks (e.g. Reference Points) and/or ecosystem-informed Management Strategy Evaluation (MSE) frameworks and Harvest Control Rules (HCRs). However, Tier 2 applications can be equally relevant to address commitments related to broader biodiversity conservation objectives, like assemblage-level responses to perturbations (e.g. system resilience, long-term oscillations), detection/forecasting of changes in ecosystem regimes (e.g. regime shifts, long-term cycles, climate change), evaluation of impacts on threatened species (e.g. by-catch, but also through species interactions), and considering the role of Vulnerable Marine Ecosystems (VMEs) on stock/assemblage dynamics. Overall, Tier 2 models provide the platform for testing targeted hypotheses about ecosystem/multispecies functioning and dynamics.

On the specific issue of trade-offs between fisheries, it is critical to recognize that when managed stocks have important interactions, trade-offs are always being made, irrespectively if the management system explicitly address them or completely ignores them. Tier 2 models, among other goals, are aimed to model and simulate those trade-offs, so they can be taken into account when defining management strategies for a group of interacting commercial stocks and/or ecosystem components. Ignoring these trade-offs could potentially result on the system being unintentionally driven to a "bad scenario", where management actions on different stocks counteract each other, and prevent from achieving objectives for said stocks. Identifying these situations is only possible when trade-offs are made an explicitly component of the management system.

Making Tier 2 operational

The implementation of Tier 2 requires formalizing how Tier 2 models are going to be developed. While some models that can inform Tier 2 assessments already exist, other will need to be developed, and overall, all these models need to be examined within a formal process that can ensure that they are adequately aligned with the 3-tiered structure of assessments within the Roadmap, and that the models are fit for purpose within that structure.

In practice, the development of Tier 2 models has two distinct dimensions, one involves a science process that provides a consistent, scientifically defensible structure for model development, and which focuses on ensuring the need and adequacy of the model for the management system. The second dimension identifies the logistical requirements for the development and use of Tier 2 models within the management system.

Science dimension

Tier 2 models are expected to inform and support management decisions. As such, these models would have a specific role to play within the Tier 2 assessment, and the science advice emerging from this level of assessment. Therefore, the first step in developing a Tier 2 model is putting together an "ecological case" (analogous to a business case) to explain the need for the Tier 2 model. This ecological case needs to provide a) a rationale for the interactions to be included in the model, b) a credible expectation of relevance for the managed stocks (i.e. the modelled interactions are expected to be dynamically influential), and c) some empirical evidence supporting the rational and expectation of relevance.

Once the need for a Tier 2 model is established (i.e. the ecological case is accepted), the second step is the development of a suitable model structure that can address the needs identified in the ecological case. This includes the selection of a proper model architecture and the identification of the data required and available for model implementation. This step is expected to be an iterative process, as the initial model architecture is modified as a function of data availability/quality, and/or data collection programs are adapted to provide the data required by the model. Whenever possible, the model architecture should consider the use of existing standards on units, space, and/or time of estimates to allow for easier interoperability and connection among different models. An initial scoping for the specific intended use/application of the model is also expected as part of this step.

The third step is the actual model implementation. This includes the construction of a functioning model, model validation, evaluation of model forecasting skills, and the explicit and detailed identification of the intended use/application based on the prior scoping work.

The fourth and final step is the production of model outputs that are informative for the relevant science advice, and/or intended science application (e.g. input into a Tier 3 model).

Logistical dimension

While the science dimension provides a structured step-wise process on how to develop a Tier 2 model, the actual implementation of that process requires a series of elements, each one of them with the potential of becoming practical bottlenecks for model development. In a general sense, these elements apply to both, the initial model construction and the subsequent model updating, but there are some nuances between these two stages that are important to distinguish.

The initial model construction is effectively a one off activity; it happens only once. This type of work is typically well suited for a single project or a term initiative. The key necessary elements for its development include:

- Modelling capacity (i.e. a developing team with sufficient modelling skills and system/stocks knowledge to construct the model from scratch or from minimal pre-existing code).
- Technical infrastructure (i.e. hardware/software, but also proper support for maintaining the technical infrastructure operational).
- Reliable access to data sources (i.e. data access, but also access to data experts that can support the developing team in understanding the nuances and limitations of the data sources).
- Generation of full documentation of all aspects of model development and implementation to ensure full reproducibility, and transparency on the technical decisions made during development.
- Institutional and financial support to effectively implement/deploy the above elements.

The model updating stage is a recurrent activity; it is expected to occur with some predetermined frequency and effectively constitutes the ongoing source of information that feeds the science advice and/or applications over time. It is expected to have less overhead costs, but requires ongoing support (i.e. it is not well suited for a single project or term initiative). The key necessary elements for this stage include:

- Standard procedures to ensure the timely production and access to updated datasets.
- Modelling capacity (i.e. identified team with adequate modelling skills to run the model and validate results).
- Technical infrastructure (software/hardware, and support maintaining the technical infrastructure operational).
- Institutional and financial commitment to stabilize and maintain the elements above over time.

Other considerations

Other aspects that were identified as important to be considered for the operationalization of Tier 2, but were only briefly discussed during the discussion session included:

1. *Triage/prioritization of models for development*. In recent years WG-ESA in particular, and SC in general, have seen an increasing workload, and limited willingness by the Commission to identify and keep priority tasks. This poses a particular challenge to WGESA, which is also experiencing an ongoing erosion in its capacity to develop Tier 1 and 2 models (i.e. loss of experts). Under these circumstances, it becomes critical to define criteria that would help guide the prioritization of Tier 2 models for development. In addition to this triage procedure, another avenue that needs exploration is the creation of mechanisms that can promote Tier 2 modelling work by non-NAFO experts (e.g. university research) in ways that can link and feed this external work into the NAFO Roadmap implementation. This option is likely better suited for model construction than model updating, but even for the model construction stage, more clear and concrete mechanisms are required to effectively promote this type of research and connection to NAFO.

2. *Benchmarking process for Tier 2 models*. Like standard stock-assessment models, Tier 2 models are expected to be revised and improved over time. The formal review process of any substantive revision of a Tier 2 model is expected to take place as part of a benchmark process which should examine both the model modifications/revisions (or alternative model if the original model is to be replaced), as well as the data inputs and standard outputs to be used for advice. While the elements of a benchmark process are typically well established for stock-assessment models, there is no common standard or well established body of practice for this type of work with Tier 2-type of models. Therefore, it is necessary to develop guidance on what a Tier 2 benchmark process should entail, also including its frequency, and the triggers for a benchmark (e.g. fixed frequency, event-triggered benchmark, etc.). This guidance can be informed by the work of the ICES Working Group on Multispecies Stock Assessment (WGSAM) which has develop a series of criteria for the review of key runs from ecosystem models (ICES, 2021). Since there are no formalized Tier 2 models within NAFO at the present time, the model development process (see *Science dimension* above) is expected to cover the initial benchmark exercise, and consequently, any formal Tier 2 benchmark process would only be expected to be required in the medium-term. This implies that there is still some time for developing Tier 2 benchmark guidelines, but developing such guidelines is not a trivial exercise, and given the existing workload at WGESA and SC, starting early and pacing this work over few years would likely be a sensible way forward.

3. *Integration with other Tiers*. The three tiers within the Roadmap are targeting different levels of ecological organization, and their hierarchical structure allows for higher tiers to provide boundary conditions for the tiers within. Still, models from different tiers are not necessarily functionally interconnected (although the use of standards and common units may allow for the eventual development of interoperability, see *Science dimension* above), and it is conceivable that their results may come into conflict in some cases. Developing of mechanisms for handling these potential conflicts is another important aspect that needs consideration. At present, there is no agreed approach to deal with these kind of situations. Possible paths include the development of rules based on general/first principles that could be applied across the board to address any potential conflict, *ad hoc* solutions for each specific case, and/or the construction of a hierarchical/sequential risk framework to allow for the

propagation of risk across tiers, and into the final advice for tactical decision. Confronting this kind of conflict implies that all three tiers are sufficiently implemented for this conflict to actually arise. While this is not the case at the moment, this hypothetical situation is potentially sufficiently disruptive to the management process that warrants an early definition of the strategy to be followed if conflict emerges.

As indicated above, these topics were only briefly addressed during the discussion session, and further work to fully develop them is required as part of the operationalization of Tier 2. The ideas summarized here provide an initial scoping on which to build a more fulsome discussion, and planning to address them.

Summary compilation of relevant modelling work

The universe of models and modelling approaches that can support Tier 2 applications is diverse. As part of the discussion session at WGESA, the exploration of available options was informative for the development of the operational aspects discussed in the sections above, as well as useful as an initial catalog of ongoing work that could serve as starting point for developing Tier 2 models within NAFO. The review of relevant work was exemplified by three presentations showcasing relevant Tier 2-type modelling at different stages of development. The abstracts of these presentations are provided in the sections below.

The Northern Shrimp Spatial Surplus Production model: A Tier II model of spatiotemporal drivers of shrimp productivity (presented by Eric Pedersen)

Northern Shrimp stocks in the Newfoundland and Labrador Shelves have shown strong productivity fluctuations at decadal time scales, unlinked to significant changes in exploitation rates. This included a precipitous decline of shrimp stocks in the southern shelf in the late 2000's. To determine if this shift in stock productivity was being driven by shifting ecosystem conditions, we developed a spatially structured surplus production model (called sspm). The sspm model uses a spatially structured logistic growth model with environmental parameters for factors such as temperature and predator abundance. This model focuses on predicting stock dynamics in subpatches across the region, allowing us to predict how both shifts in average ecosystem state, but also how changes in the spatial distribution of predators or ecosystem factors, might affect shrimp productivity. Based on this model, we identified increases in shrimp predators (Altantic Cod, Greenland Halibut, and Atlantic Redfish) as a major potential ecosystem driver, as well as shifting environmental conditions (using the NAO index as a proxy). This model allows for the prediction of changes in stock, and scenario-based evaluation of how future ecosystem changes might affect the status of this stock. It further emphasizes the use of ecosystem-approaches to fisheries management when dealing with varying productivity stocks.

Grand Bank flatfish model (presented by Matthew Robertson)

Multispecies models serve as useful tools to examine species interactions and the allocation of fisheries harvest among a set of target stocks. The American plaice and yellowtail flounder populations on the Grand Bank may provide a useful case study for the creation of a multispecies model since these potentially interacting species both collapsed in the early 1990's but only yellowtail flounder has since recovered. Here, we discuss general hypothesis exploration and development strategies that I have used to begin the creation of a Model of Intermediate Complexity for Ecosystem assessment (MICE) for these two flatfish populations to understand differences in their recovery trajectories. I specifically discuss the processes involved in the identification of minimum realistic population dynamics models, development of hypotheses about how ecosystem components impact population dynamics, and tests to determine the influence of ecosystem components and multispecies interactions on population trajectories. For our case study, we expect that the two flatfish species may have been influenced by temperature, prey availability, and/or competition with each other or with a shared competitor, thorny skate. Once created these models may serve as a useful platform to assess trade-offs and multispecies reference points.

Multispecies models in the assessment of fishery resources and the development of management strategies. The Flemish Cap fishing ground and the GadCap gadget model as a case study (presented by Alfonso Pérez-Rodriguez)(Pérez-Rodríguez et al., 2017)

The European Union, through the SC05 project *"Multispecies Fisheries Assessment for NAFO"*, contributed to the development of multispecies assessments in the NAFO area using the Flemish Cap (NAFO Div. 3M) as a case study. As an initial task of this project, the multispecies model GadCap was updated by extending the model time coverage up to 2016 (Pérez-Rodríguez et al., 2017). This model includes the three main commercial stocks in the Flemish Cap: cod, redfish and shrimp, and includes the dynamics of the stocks, the EU survey, and their commercial fisheries. Some components of the model were improved, like those defining growth or maturation, trophic interactions, and fishing fleet structure. The effects of fishing, trophic interactions (including cannibalism on cod and redfish), and water temperature on the dynamics of these three major fishing resources were updated (Figure 6.7). The model results highlighted the interdependent dynamic of these stocks, and revealed strong interactions between recruitment, fishing and predation (including cannibalism). These drivers have marked changes in their relative importance by species, age, and length over time, producing a transition from a traditional redfish-cod dominated system in the early 1990s, to an intermediate shrimp-other fish species state by late 1990s, and in turn back to something close to the initial state by late 2000s. It was concluded that the dynamics of the Flemish Cap cod, redfish and shrimp stocks are strongly interconnected, with predation mortality being a main driver of changes in population size and age/length structure over time. The role of cannibalism in cod and redfish was found of major relevance when the abundance of large and old individuals is higher.

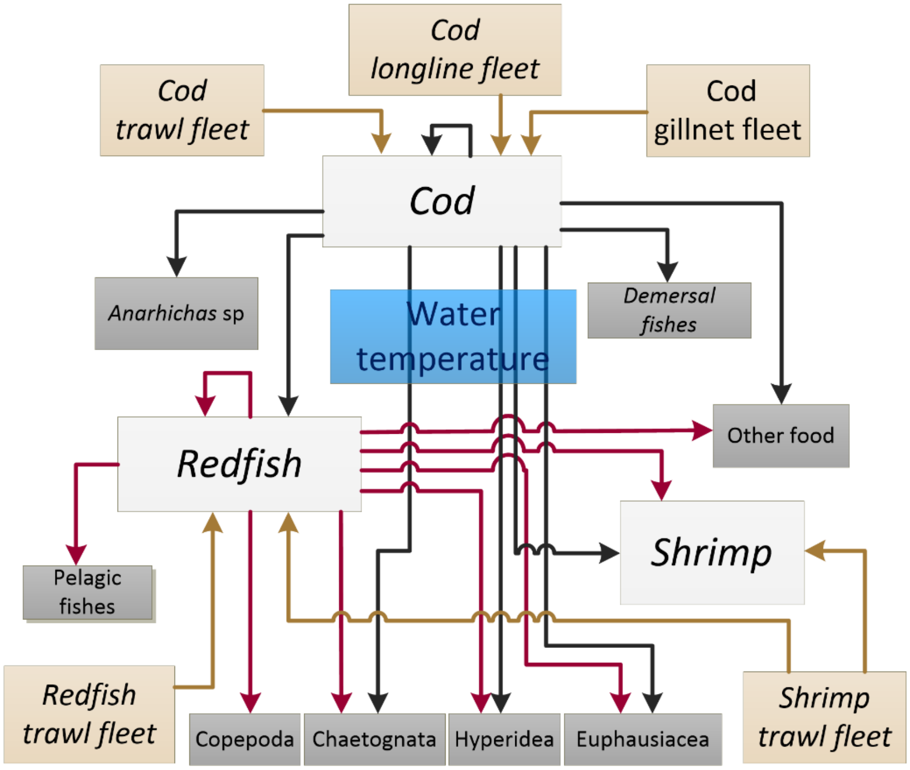

Figure 6.7. Interactions modelled in GadCap. Cod, redfish and shrimp are fully dynamically modelled, whereas species/prey groups in grey text boxes are incorporated as time series or constant values. The fleets fishing each species are also represented, as well as the effect of water temperature on total consumption. The trophic interactions for cod (black arrows) and redfish (dark red arrows) are indicated in the figure, including the cannibalism interactions.

A main goal of the SC05 project was contributing to the development of the NAFO Roadmap to EAF exploring alternatives to incorporate the multispecies considerations into the fisheries advice process. As a first for NAFO, and within the context of the EU project SC03 "Support to a robust model assessment, benchmark and development of a management strategy evaluation for cod in NAFO division 3M", estimates of natural mortality (predation plus residual natural mortality) from a multispecies model (Pérez-Rodríguez and González-Costas, 2018) were tested in a stock assessment model as part of a benchmark process. This could be considered as the first use of a Tier 2 model within a tactical management application in NAFO.

Regarding Management Strategy Evaluation (MSE) applications, the GadCap model was used for the development of a multispecies MSE framework (msMSE) integrating GadCap as operating model (OM) within an a4a-MSE framework (Jardim et al., 2017). Within the msMSE framework, GadCap provides information about the "real" stocks, survey and commercial fleets that, once modified by the observation error model, is used for stock assessment in the management procedure module. Within the framework each of the three stocks has its own independent management procedure module. The current settings allow for a shortcut assessment, with and without assessment error, but also an assessment using an a4a Statistical Catch-at-Age (SCAA) model, that can also consider errors in the observation of survey and commercial information (Figure 6.8).

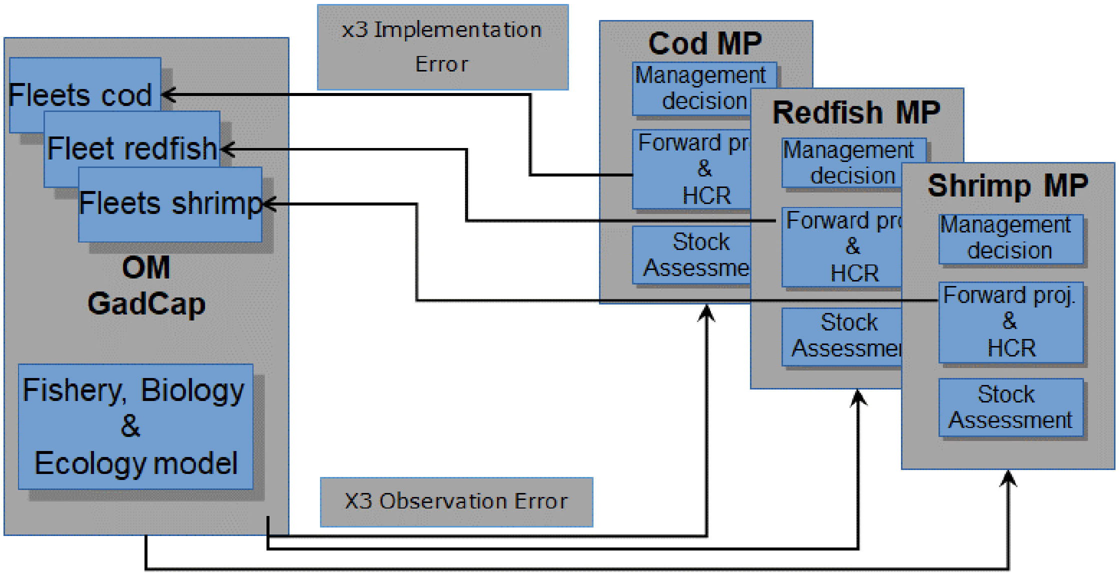

Figure 6.8. Multispecies gadget-a4a-MSE framework. The multispecies model GadCap was used as OM. Uncertainty on the knowledge of the system was simulated as SSB-Recruitment uncertainty in the OM. Uncertainty in the input data for stock assessment was possible through the observation error module. Implementation error of management decisions is also possible, although at this stage prefect implementation was simulated.

A high number of combinations of Harvest Control Rules (HCRs) for the three stocks were tested with the msMSE framework. These HCRs were defined by precautionary reference points (B_{lim} and $B_{trigger}$), estimated following the NAFO standard protocols for single species approach. The F_{target} in those HCRs were defined considering the interdependent productivity of the three stocks, i.e. from a multispecies approach. Long term simulations were run considering multiple combinations of Fs for cod, redfish and shrimp. The results showed the influence that variable fishing strategies on predators (cod and redfish) would have on the prey stocks (shrimp, redfish, but also cannibalism in cod). It was especially evident the impact that different fishing strategies on cod would have in the productivity of shrimp and redfish. In the case of shrimp, only when very high or very low fishing pressure on cod was implemented, the shrimp SSB reached values above Blim (Figure 6.9). This is due to the importance of cod as predator of redfish and shrimp, and the relevance of redfish as predator of shrimp.

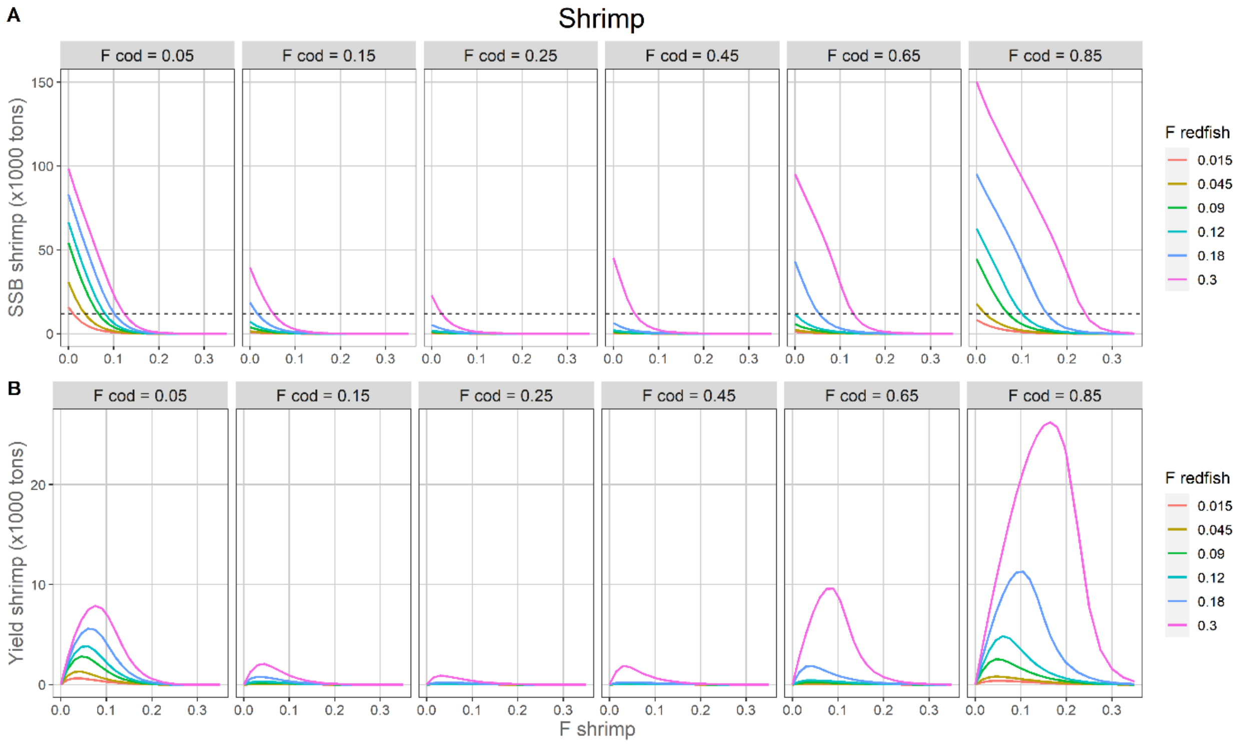

Figure 6.9. Mean SSB (upper panel) and yield (lower panel) for the shrimp stock at the end of the forecast simulation period (2035-2050). The figures show the SSB and yield values for the combination of 20 different F values of shrimp, 6 F values of cod, and 6 F values for redfish. The dashed horizontal line in the upper panels indicates the Blim.

The risk analysis of the combinations of one stage HCRs showed that due to the strong trophic interactions between the three stocks, in order to maintained shrimp above Blim, fishing pressure on cod and redfish must be at the highest. Under this high fishing pressure, the recruitment variability and the observation/assessment error entail a high risk of being bellow Blim for cod and redfish, and specially for cod. The results of the simulations indicate that there is no combination of HCRs that could maintain the SSB of the three stocks above Blim at the same time. This result indicate that multispecies HCRs must be designed disregarding one or two of the other species in the system. For example, in the case that shrimp is disregarded (i.e., the impact of a given combination of HCRs on shrimp stock is disregarded), a number of combinations of Fs (HCRs) is obtained for which the risk of being below Blim is low (below 10% probability) at the same time for cod and redfish (Figure 6.10). Additionally, as an exploratory exercise, a two-stage hockey stick HCR for cod was simulated, with the intention of testing the effect of reducing an excessive predation capacity from cod when the stock is at very high biomass levels. In these HCRs, the fishing pressure on cod was increased when the SSB was above a value considered high based in the historical data. Different combinations of F and SSB were tested. This two stage HCR clearly reduced the risk of being below Blim both for cod and redfish (Figure 6.11).

This study allowed concluding that:

- The results suggest that it is not possible having the three species above Blim
- Disregarding one stock (shrimp or another stock) may allow finding precautionary multispecies reference points for the others.
- The results suggest that the two stages HCRs for cod reduces predation and increases probability of redfish, and somehow shrimp being above Blim.

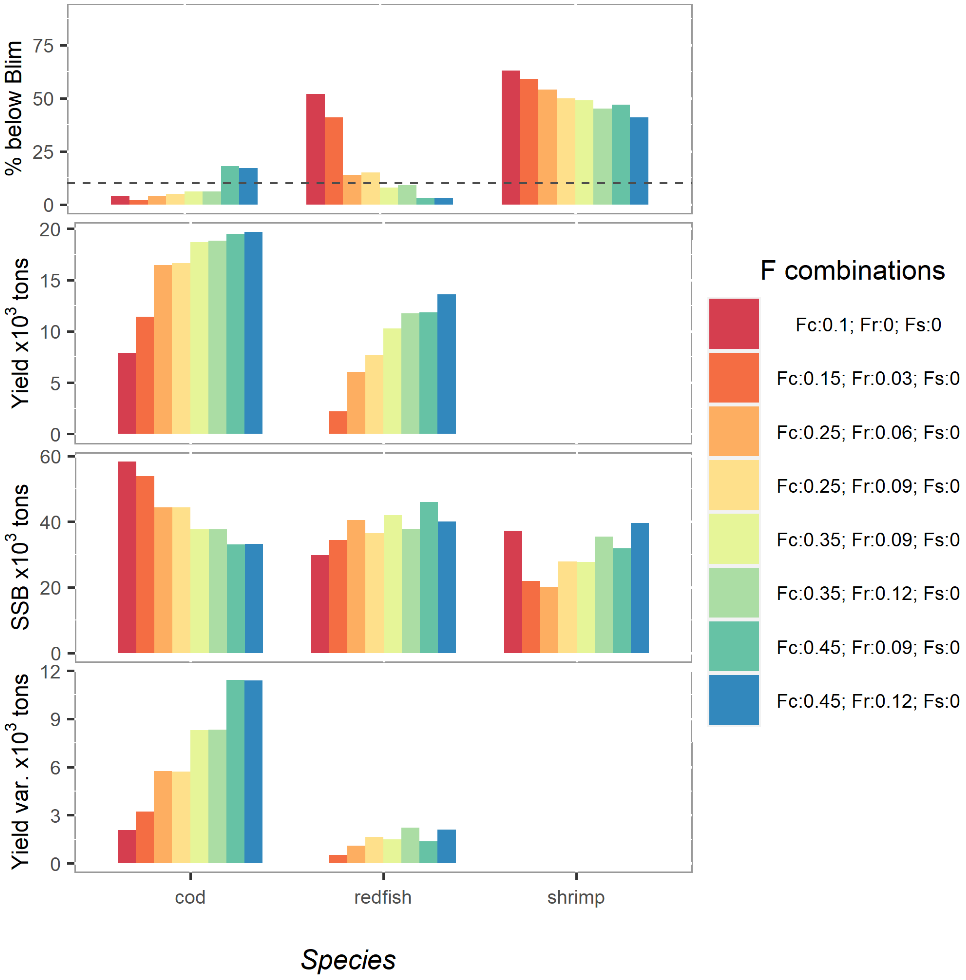

Figure 6.10. Results of the risk analysis for a subset of Ftarget combinations that maintained cod and redfish above Blim , but not shrimp, in the deterministic simulations. The assessed combinations of HCRs are defined by the Ftarget for each stock (fishing mortality on cod (Fc), redfish (Fr) and shrimp (Fs)). The maximum probability of being below Blim at least one year over the period 2030-2055 (% below Blim), the mean spawning biomass (SSB), mean annual yield (Yield) and mean interannual variability in yield (Yield var.) over the period 2030-2055 are presented. The dashed horizontal line in the upper panel represents the 10% risk of being below Blim.

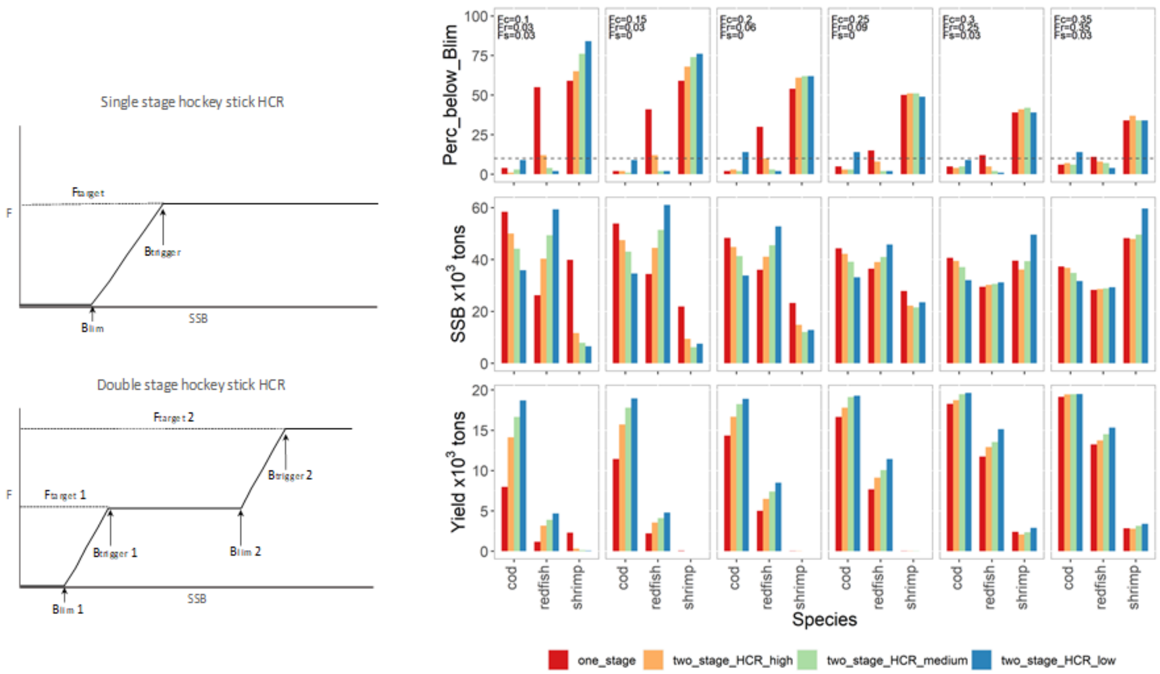

Figure 6.11. SSB, yield and risk of being below Blim over the period 2030-2055 (in percentage) for cod, redfish and shrimp, when applying one-stage versus two-stage HCRs with three different combinations of Ftarget1, Blim2 and Btrigger2.

Additional modelling work

In addition to the modelling work described above, other relevant modelling exercises were highlighted as part of the discussion. While this emergent compilation of work was not intended to be exhaustive, it provides a first look at some relevant research being conducted within NAFO ecosystem units that can be supportive of Tier 2 assessments, and/or illustrates modelling approaches for which there is expertise potentially available for collaborative work for Tier 2 model development. The additional ongoing work discussed included:

Multispecies surplus production model for Grand Bank groundfish stocks (Paul Regular). A multispecies surplus production model is in development where intrinsic growth rates are species specific however carrying capacity is based on the total biomass of all species included in the model. The concept is that the species included in the model are limited by the finite amount of energy in the system. Covariance between the species can also be estimated using the multivariate normal distribution to estimate correlation in the errors across species. If the species included in the model are affected by similar drivers, then correlations will be positive. Alternatively, negative correlations may occur if there is competition or predator-prey interactions between two species. Potential implementations of covariates are being explored.

Snow crab multi-stock model (Darrell Mullowney). Comparative work with stocks occurring both within and outside of the NAFO area could be beneficial. More specifically, a common model applied to two major stocks of snow crab occurring within Divisions 2HJ3KLNOP (NL Bioregion) and 4T

(Southern Gulf of St. Lawrence), which uses the strength of the Arctic Oscillation (AO) during pelagic stages, and winter sea ice extent during early life stages as explanatory variables was capable of explaining subsequent snow crab biomass available to the fishery 11 years later. Interestingly, the model was dynamic in being able to explain an out-of-phase relationship between the two stocks, reflecting different directional forcing of the AO across the two regions. The model was also successfully applied to the snow crab stock in the Bering Sea of Alaska. The work demonstrates the value of comparative works in isolating key focal variables for the basis of ecosystem-based models and application of similar approaches to NAFO-focused stocks could assist in development of dynamic reference points associated with varying productivity or carrying capacity in the ecosystem.

Capelin-Cod (capcod) model (Mariano Koen-Alonso) (Koen-Alonso et al., 2021). A bioenergetic-allometric model for Atlantic cod, which uses capelin availability and fisheries catches as drivers, was developed. This model was implemented for Northern cod (2J3KL) and Barents Sea cod in an integrated architecture that allowed fitting common parameters for both stocks. The results indicated that not only this model was capable of successfully fitting the drastically different trajectories of these two stocks using common drivers (capelin and fishing), but also to identify that parameters that encapsulate intrinsic vital rates were not significantly different between stocks, indicating that the differences in stock trajectories are associated with the ecosystem context in which the stocks are embedded.

NL multispecies model (Mariano Koen-Alonso). A multispecies bioenergetics-allometric model for key stocks in the NL bioregion is in development. The model architecture is focused on key managed stocks and key supporting ones only, and it can be classified as a minimum-realistic model. There is no explicit spatial structure within the model, but its construction around stock units provides an initial proxy for some potential large-scale spatial effects. The modulation of basal species productivity using large scale environmental signals is also part of this modelling exercise. This model is in the development stage.

Size-based models for the Newfoundland & Labrador Shelf and The Grand Banks (Abe Solberg & Raquel Ruiz-Díaz, respectively). Size-based biomass models using the mizer approach are in development by PhD students at the Fisheries & Marine Institute, Memorial University of Newfoundland and Labrador. Species included in the NL shelf model (2J3K) being led by Abe Solberg are: capelin, northern cod, northern shrimp, snow crab, redfish, and turbot. Species included in the Grand Banks (3LNO) model are: American plaice, northern cod, redfish, silver hake, thorny skate, turbot, witch flounder, yellowtail flounder, northern shrimp, snow crab, and sand lance.

Species distribution modelling for The Grand Banks (Raquel Ruiz-Díaz). Bayesian species distribution models based on biomass for sand lance, northern cod, snow crab, yellowtail flounder, and Greenland halibut biomass are being developed for The Grand Banks (3LNO) region. Covariates are being tested for their predictive power of spatial and temporal biomass distribution, including bottom temperature, depth, the NAO, and the AMO.

Conclusions and Next Steps

The Tier 2 discussion session consolidated the concept of Tier 2 assessment, and the role and features of Tier 2 models within this assessment tier (sections 6.b.i and ii). It also rendered a suitable template for structuring the development of Tier 2 models, and what is required for that to happen (section 6.b.iii), and provided an initial compilation of ongoing work that could potentially inform and/or support Tier 2 implementation (section 6.b.iv). Still, some important elements remain to be fully discussed and developed (section 6.b.iv *other considerations*).

Among these remaining elements, the triage procedure for identifying priorities for model development, and how to promote Tier 2 model development by non-NAFO researchers are the likely and logical next steps for any strategy aimed at a broader implementation of Tier 2. In terms of specific applications, the exploration of the use of the existing Flemish Cap model (Pérez-Rodríguez et al., 2017) for the implementation of Tier 2 in the Flemish Cap is also an obvious next step. Taken together, all these elements can generate a tangible list of Tier 2 modelling priorities, and a very concrete and relevant Tier 2 application to evaluate how a Tier 2 assessment can work in practice. These elements would need to be among the key priorities for WGESA and SC work in the upcoming years if we are to effectively promote Tier 2 implementation.

Finally, it is critical to highlight that any progress on Tier 2 development and implementation is conditional to the support provided by CPs. Current capacity within WGESA and SC is very limited, and has been dwindling in recent years due to an ongoing loss of expertise; unfortunately, this trend is likely to continue. Nowadays, there are no people available in SC to fully engage on Tier 2 development, especially given the amount of request that COM has made in the last few years, and the declining support and commitment for this type of work within CPs.

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c) ToR 3.3. Activities other than fishing (Commission Request #12)

The Commission requests the Secretariat and the Scientific Council with other international organizations, such as the FAO and ICES to inform the Scientific Council's work related to the potential impact of activities other than fishing in the Convention Area. This would be conditional on CPs providing appropriate additional expertise to Scientific Council.

i) Update on oil and gas activities

The information presented here was obtained through a literature review (Durán Muñoz and Sacau, 2021) of publicly available data sources[2], including a report (Equinor, 2020) on a development project located in the Flemish Cap ("Bay du Nord Development Project"). Some of the exploration and proposed production activities related with this project, appear to have significant spatial overlap with NAFO bottom fisheries, NAFO closures and VMEs in Division 3L, and particularly in Division 3M.

Spatial location of oil and gas activities

The map of the geographical location of oil and gas activities in NAFO Divs. 3LNM is presented in Figure 6.12. The yellow star indicates the location of the proposed production installation within the "Bay du Nord Development Project" in the Flemish Pass (outlined in blue). This map shows the potential conflicts between oil and gas activities and NAFO fisheries (e.g. reduction of fishing opportunities), as well as between oil and gas activities and VME areas closed by NAFO (particularly, Areas 2 and 10).

Updated spatial data (licences and wells) was available this year. In comparison with the information assessed previously reported by WG-ESA (SCS Doc. 20-23), there are two new "exploration wells" in Division 3L, one of them located inside NAFO fishing grounds. The information assessed since 2018, indicates that offshore oil and gas activities in NAFO Divs. 3LNM increased in recent years.

Oil spills and other relevant incidents

At the reporting date (November 2021), according to the available information[3], no relevant environmental incidents occurred during 2021. Nevertheless, during the period 2015-2020 there have been 12 reported incidents of different nature (see NAFO, 2020), with a major oil spill in 2018

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[2] Available data was collected mainly from the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) [https://home-cnlopb.hub.arcgis.com/] and the Impact Assessment Agency of Canada (IAAC).

[3] "Incident Disclosure 2021" in https://www.cnlopb.ca/incidents

(250,000 L), and one in 2019 that occurred into the EEZ of the coastal state, but was extended outside the EEZ, and into the NAFO Regulatory Area[4]. Another type of incidents, such as the iceberg affaire (a near-miss incident) occurred in March 2017, illustrate the potential risks of deep-water offshore oil and gas activities in the NW Atlantic.

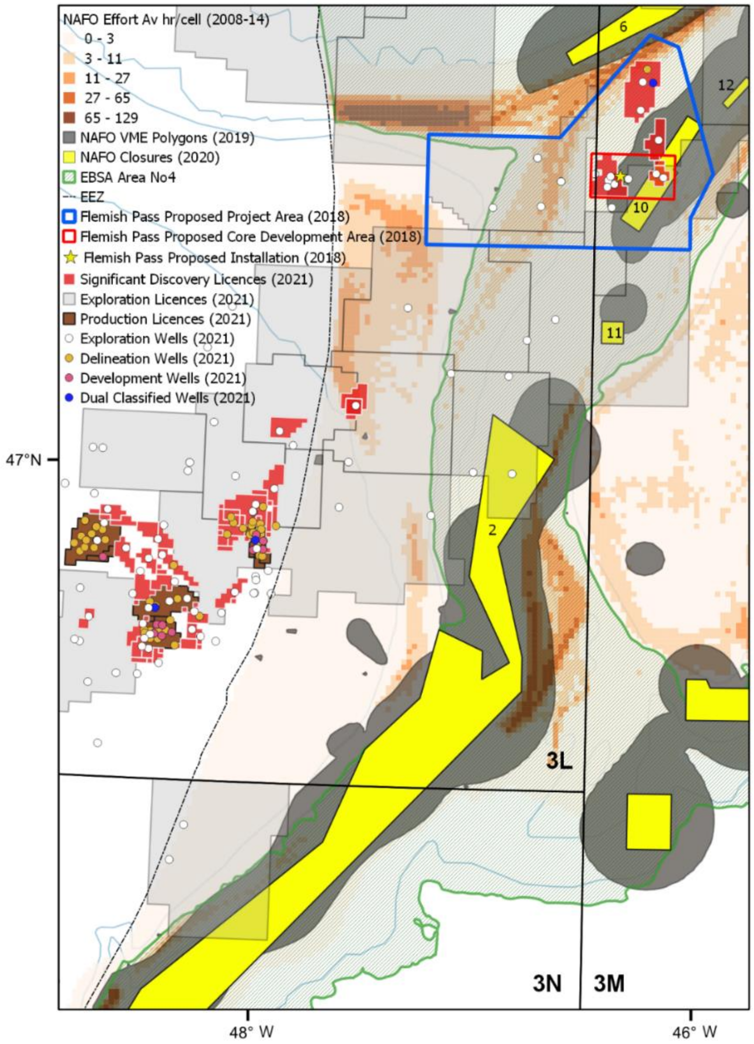

Figure 6.12. Updated map showing the geographical location of oil and gas activities in NAFO Divs. 3LNM. The map shows the potential conflicts between different users of the marine space (e.g. oil and gas vs. fisheries) and between users and marine environment (oil and gas vs. VMEs). The yellow star indicates the location of the proposed production installation within the "Bay du Nord Development Project" in the Flemish Pass (outlined in blue). Available spatial information on oil and gas activities – at the reporting date, November 2021 – is noted in brackets (2021). Sources: NAFO, C-NLOPB and CBD.

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

The issue of the routine operations

In addition to the impacts of accidental events, there is a concern about the effects of routine operations on the ecosystems. According to Cordes et al. (2016), routine oil and gas activities can have detrimental environmental effects during each of the main phases of exploration, production, and decommissioning. Figure 6.13 shows the diagram of the impacts from typical deep-sea drilling activity.

Environmental effects include impacts from routine operational activities such as drilling waste and produced water discharges (Neff et al., 2011; Neff et al., 2014), accidental discharges and spills (e.g. Cordes et al., 2016), long-term impacts on deep-sea corals (e.g., Girard and Fisher, 2018) and impacts on deep-sea sponges and their associated habitats (Vad et al., 2016).

There is a need to assess the cumulative impacts of human activities (e.g., fisheries and oil and gas exploration/exploitation) on the NAFO ecosystems. Moreover, in order to have a better understanding of the contribution of each anthropogenic activity, impacts should be assessed both inside VME polygons and VME closure areas (SCS Doc. 20-23).

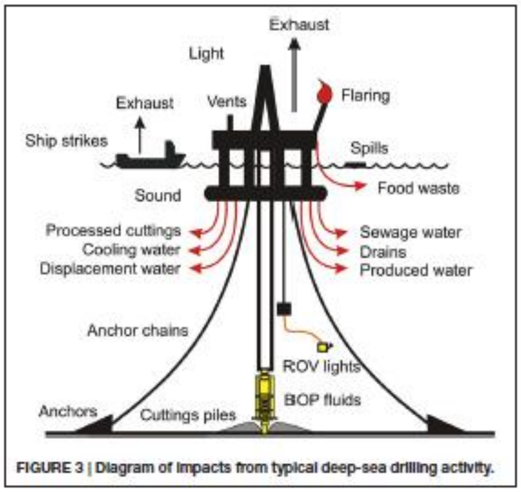

Figure 6.13. Diagram of impacts from typical deep-sea drilling activity (Source: Cordes et al., 2016)

Data availability and data gaps

In general, data on geographical location of oil and gas activities is available in websites and project reports (including location and technical details of a development project in the Flemish Pass). In contrast, information on the adverse impacts of such activities (e.g. routine operations, accidental events, unauthorized discharges, exploratory drilling on VME closed areas, etc.), as well as details on mitigation measures, is scarce, less visible or difficult to obtain from such sources.

Implications for the development of ecosystem summary sheets

Ecosystem summary sheets are intended to provide a synoptic perspective on the state of NAFO ecosystems and their management regime. In 2019, information on oil and gas activities was included for the first time in the ecosystem summary sheet for Divs. 3LNO (SCS Doc. 20-23). In 2021, the WGESA agreed that a similar exercise is needed for Division 3M, considering that, at present, most of the offshore oil and gas activities in NAFO Regulatory Area are located in Division 3M (see Figure 6.12). Some of these activities – particularly wells (Table 6.3) and Licences (Table 6.4) – overlap fishing grounds, VME polygons (e.g. sponges, sea pens and black corals) and VME closures (e.g. Areas 6, 9, 10, 11 and 12).

It is worth to note that ecosystems inside "NAFO VME closures" and outside "NAFO footprint" are currently protected against SAI from bottom fishing, but they are unprotected regarding potential threats from activities other than fishing (e.g. drilling activities inside VME closures in Divisions 3L and 3M). Moreover, in addition to the "ecosystem issues", there are other issues related with the "use of the marine space" (e.g. potential conflicts between NAFO bottom fisheries and offshore oil and gas activities).

Table 6.3. List of wells in NAFO Division 3M (source C-NLOPB) indicating their spatial location with respect to the NAFO VME closures (2020) and/or VME polygons (2019).

Well Name	Well #:	Well Classification[5]	Water Depth (m)	Observations
Baccalieu F-89	426	Exploration	1,146	Inside VME polygons (sponges and sea pens) and VME Closed Area 10
Baccalieu I-78	109	Exploration	1,092.8	Inside VME polygon (sea pens) and VME Closed Area 10
Bay de Loup M-62	425	Exploration	1,170	Inside VME polygon (sponges)
Bay de Verde F-67	404	Exploration	1,165	Inside VME polygon (sponges)
Bay du Nord C-78	391	Exploration	1,166	--
Bay du Nord L-76	415	Exploration	1,177	--
Bay du Nord P-78	412	Exploration	1,173	--
Bonaventure O-96	441	Exploration / Delineation	1,116	--
Harpoon O-85	385	Exploration	1,160	Inside VME polygons (sponges and sea pens)
Mizzen F-09	369	Delineation	1,067	--
Mizzen L-11	234	Exploration	1,153	--
Mizzen O-16	342	Exploration	1,095	--
Portugal Cove E-38	440	Exploration	1,169	Inside VME polygon (sponges)

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[5] Exploration well: A well drilled on a geological feature on which a significant discovery has not been made; Delineation well: Normally, a well drilled on a significant or commercial discovery of petroleum, drilled in order to determine the commercial value; Dual classified wells: e.g. Exploration/delineation wells.

Table 6.4. List of Licences in NAFO Division 3M (source C-NLOPB) indicating their spatial location with respect to the NAFO VME closures (2020) and/or VME polygons (2019). SDL: Significant discovery licences[6]; EL: Exploration licences.

Licence	Observations
SDL-1047	Overlap with fishing grounds
SDL-1058	Overlap with VME poligons (sponges and sea pens) and VME Closed Area 10
SDL-1057	Overlap with VME poligons (sponges and sea pens) and VME Closed Area 10
SDL-1056	Overlap with VME poligons (sponges, sea pens and black coals) and VME Closed Area 10
SDL-1055	Overlap with VME poligons (sponges and black corals)
EL-1139	--
EL-1140	--
EL-1141	Overlap with fishing grounds, VME poligon (sponges) and VME Closed Area 6
EL-1142	Overlap with fishing grounds, VME poligons (sponges, sea pens and black coals) and VME Closed Areas 6, 9 and 12
EL-1143	Overlap with fishing grounds, VME poligons (sponges, sea pens and black coals) and VME Closed Area 10
EL-1150	Overlap with fishing grounds, VME poligons (sea pens and black corals) and VME Closed Area 11
EL-1144	Overlap with VME poligons (sea pens and black corals)

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[6] Significant discovery licence: A discovery suggesting the existence of an accumulation of hydrocarbons that has potential for sustained production.

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d) ToR 3.4. development of ecosystem summary sheets for 3M and 3LNO progress toward undertaking a joint Workshop with ICES Commission Request #13

The Commission requests that Scientific Council proceed with developing the ecosystem summary sheets for 3M and 3LNO move toward undertaking a joint Workshop with ICES (International Council for the Exploration of the Sea) as part of a peer review of North Atlantic ecosystems.

i) Ecosystem Summary Sheets for 3LNO and 3M Ecosystem Production Units (EPUs)

The Commission (COM) in its Request #13 asked Scientific Council (SC) to "*proceed with developing the ecosystem summary sheets for 3M and 3LNO move toward undertaking a joint Workshop with ICES (International Council for the Exploration of the Sea) as part of a peer review of North Atlantic ecosystems*".

This request is a carryover from 2020, where it was included as the 2020 COM Request #18. In examining the request, WGESA noted that a nominally final version of the 3LNO Ecosystem Summary Sheet (ESS) has been already tabled by SC in its 2020 June Report (SCS Doc 20-14). The basic work for this ESS was produced at the 2019 WGESA meeting, and included data up to 2018-2019. While some items in this ESS version remained greyed out (e.g. sections on non-NAFO fisheries and protection of non-NAFO Vulnerable Marine Ecosystems –VMEs-), completing those sections required formal data inputs from CPs, and the NAFO Secretariat had been requested to follow-up with those CPs to complete this information. It was also during the 2019 WG-ESA meeting that the initial conversations were held with the International Council for the Exploration of the Sea (ICES) to explore opportunities for collaboration on ecosystem-related work, including ecosystem summary sheets (NAFO) and ecosystem overviews (ICES), and the path tentatively identified for those collaborations was a joint in person workshop.

Since that time, the Covid-19 pandemic, and the workload associated with the review of the VME closures and the assessment of Significant Adverse Impacts on VMEs have prevented WGESA to advance this work as originally intended (SCS Doc 20-23). These circumstances also prevented the NAFO Secretariat from following-up on some of the items identified as in need of formal CP input. In addition, during 2021 WG-ESA lost the expert that was spearheading this work, and there is a real possibility that the drain of scientific expertise on this front may continue going forward due to the lack of support for this type of work by CPs. Under these circumstances, there is a credible risk that WG-ESA will be increasingly limited in its capacity to fully deliver on this request.

This is particularly poignant in the case of the joint workshop with ICES; not only WG-ESA is losing the relevant experts that would have been expected to engage in this collaboration, but planning and pursuing this type of collaborative work requires short/medium term commitments from WG-ESA members at a time where the support by CPs for this work is dwindling. While the joint workshop with ICES is a truly valuable exercise definitely worth pursuing, explicit and concrete support for this type of ecosystem work by CPs would be a necessary pre-requisite to ensure its viability and success. Until then, only preliminary talks with ICES to maintain this dialogue open appear warranted.

In order to advance as much as possible on this request despite the difficult circumstances, WGESA developed the following action plan:

1. ***3LNO ESS***. Update as much as possible the existing 3LNO ESS, including at the very least the most updated survey information (see section below). This updated ESS will be compiled at the 2022 WGESA meeting and tabled at the 2023 SC June meeting for discussion and approval as a final version. This ESS may still contain some greyed out elements depending on the data effectively compiled by the time the 2022 WGESA meeting takes place.
2. ***3M ESS***. Compile the necessary information to populate a 3M ESS, and develop an initial 3M ESS draft. This 3M ESS draft will be produced at the 2022 WGESA meeting, and tabled for discussion at the 2023 SC June meeting. Depending on the amount of data successfully compiled, this initial draft could be sufficiently complete to be approved as final by SC; this decision will be made at the 2023 SC June meeting.
3. ***Additional data from CPs***. The NAFO Secretariat will coordinate with the WGESA Chair and relevant WGESA experts to formalize requests to CPs for any additional information required to complete the ESSs.
4. ***Ecosystem-level Designated Experts.*** Updating summary sheets going forward will require compilation and consolidation of multiple data streams, as well as integration and interpretation of the emerging ecosystem signals and trends. While the general conclusions and main points would result from the discussion among the experts in WGESA and SC, carrying out the work still requires an expert to take the lead in coordinating the work, preparing material, analyses, and generating preliminary result and conclusions for the collective peer-review and discussion. Given the workload, time-commitment, and responsibility associated with this preparatory work, the creation of an Ecosystem-level Designated Expert role appears necessary. These Ecosystem DEs would need to be designated for each Ecosystem Production Unit (EPUs) for which an ESS is produced. Their role would be analogous to those of existing stock-level DEs, and would be expected to received similar support by CPs to carry out their work. Since creating these formal positions is within the purview of SC, WGESA will table this proposal for discussion and follow-up at the 2022 SC June meeting.
5. ***Joint NAFO-ICES Workshop on Ecosystem Summaries***. The WGESA Chair will re-establish contact with ICES about the possibility and potential scope for this workshop. Since ESSs constitute an operational element of the implementation of the Roadmap, and the planned COM-SC WGEAFFM 2022 workshop on ecosystem objectives would be instrumental regarding Roadmap implementation, any joint workshop with ICES on this issue would be expected to take place in late 2022 at the earliest, but most likely during 2023. At present, this renewed contact with ICES would be intended to keep the dialogue open, but any concrete commitment about this workshop would be conditioned by the support provided by CPs for this type of ecosystem work.

As a first step towards completing this action plan, WGESA reviewed the most recent update on the status, trends, and food consumption and diets of the fish communities for three of the EPUs in the

Newfoundland and Labrador Bioregion (2J3K, 3LNO, and 3Ps). The information from the 3LNO EPU would be used for the update of the 3LNO ESS.

Ecosystem summary for the Newfoundland and Labrador Bioregion

Status and trends of the fish communities in the Newfoundland and Labrador Bioregion

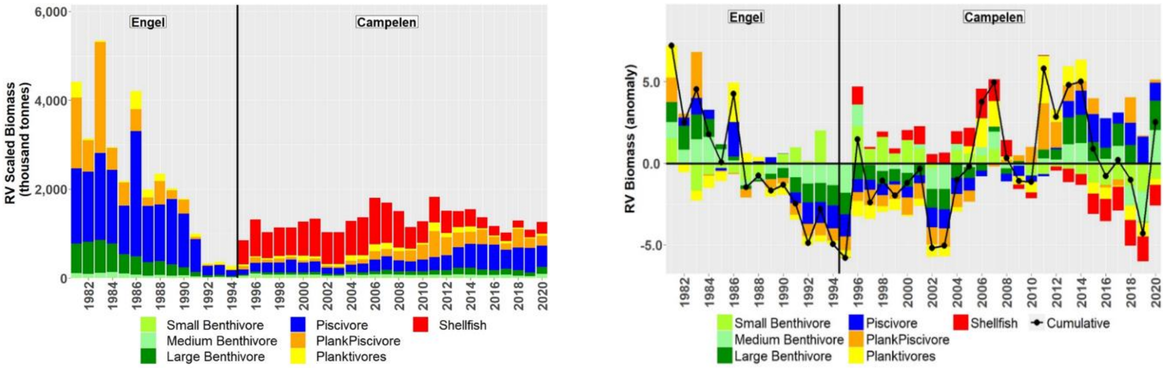
The Newfoundland and Labrador (NL) bioregion constitutes a large marine ecosystem which can be subdivided into four Ecosystem Production Units (EPUs): Labrador Shelf (2GH), Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Southern Newfoundland (3Ps). While still interconnected, these EPUs represent relatively well defined functional ecosystems, and represent the spatial scale best suited for integrated ecosystem management plans (Pepin et al., 2014; Koen-Alonso et al., 2019).

WGESA reviewed and summarized the status and trends for three of the four EPUs in the NL bioregion, the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Southern Newfoundland (3Ps), based on the most recent information from Fisheries and Oceans Canada (DFO) Spring and Fall Research Vessel (RV) surveys.

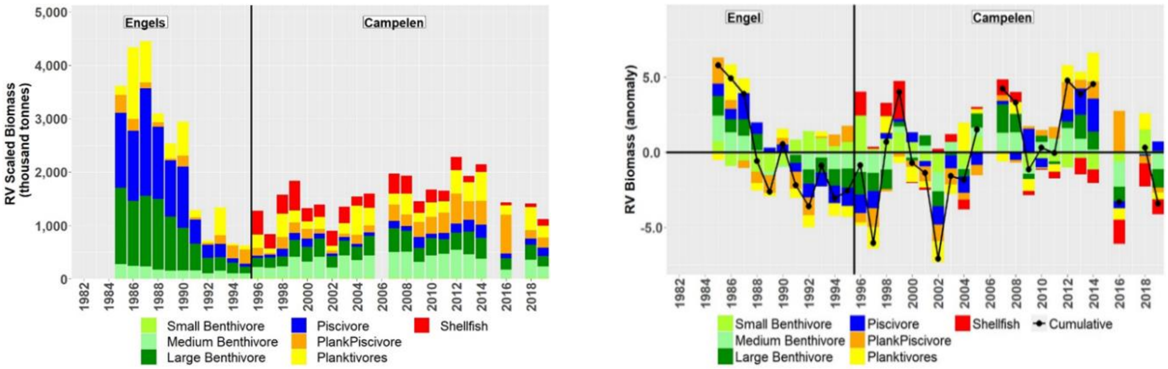
The ecosystem changes observed in the 1990s involved the collapse of the groundfish community (i.e. not just cod), a key prey like capelin (Buren et al., 2019), and the increase in shellfish (Figure 6.14). Even with the increases in shellfish, total biomass never rebuilt to pre-collapse levels. Consistent signals of rebuilding of the groundfish community appeared in the mid-late 2000s (Figures 6.14 and 6.15), and coincided with modest improvements in capelin (Buren et al., 2019; Murphy et al., 2021), and the beginning of the shellfish decline.

The finfish biomass in the 2010s in 2J3K and 3LNO was relatively stable until 2013-2014, when started to show evidence of declines. While there are signals of improvement since the lows in 2016-2017, current total biomass has not yet returned to the 2010-2015 level (Figs 6.14 and 6.15). The conditions that led to the initial rebuilding of the groundfish community in the mid-late 2000s appear to have eroded, and this may have been linked to the simultaneous reductions in capelin and shrimp availability as evidenced by the largely consistent negative biomass anomalies for shellfish and planktivores in the late 2010s (Fig. 6.14).

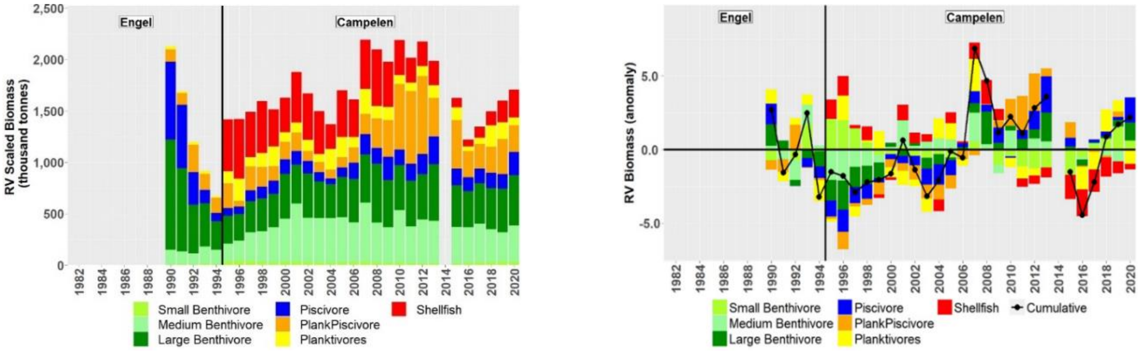
Nfld Shelf (2J3K) Fall



Grand Bank (3LNO) Spring



Grand Bank (3LNO) Fall



Southern Nfld (3Ps) Spring

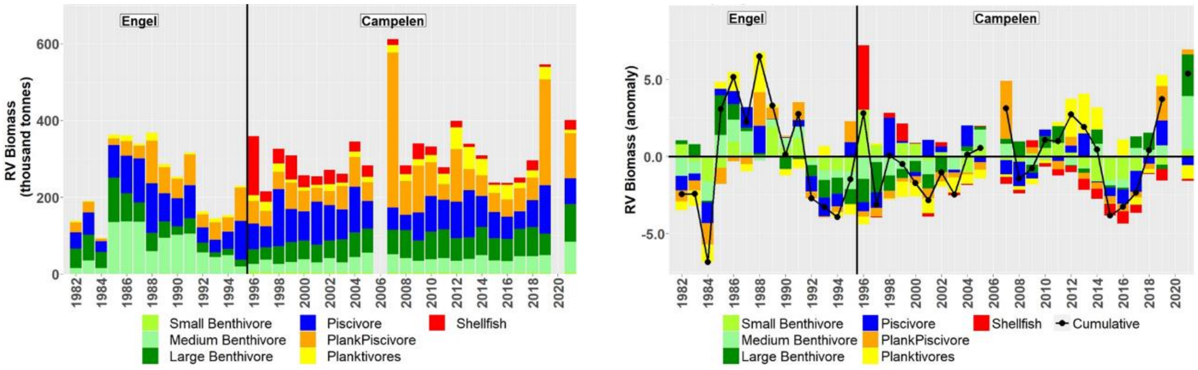


Figure 6.14. RV Biomass Index by fish functional groups (left column), and its normalized anomaly (right column) for the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Southern Newfoundland (3Ps) EPUs. Anomalies were calculated by gear series and fish functional group. RV Biomass for 2J3K and 3LNO is scaled to allow comparisons between gears, but not for 3Ps, where the suitability of existing scaling factors is still under investigation. Data for the Shellfish functional group is only available for the Campelen gear.

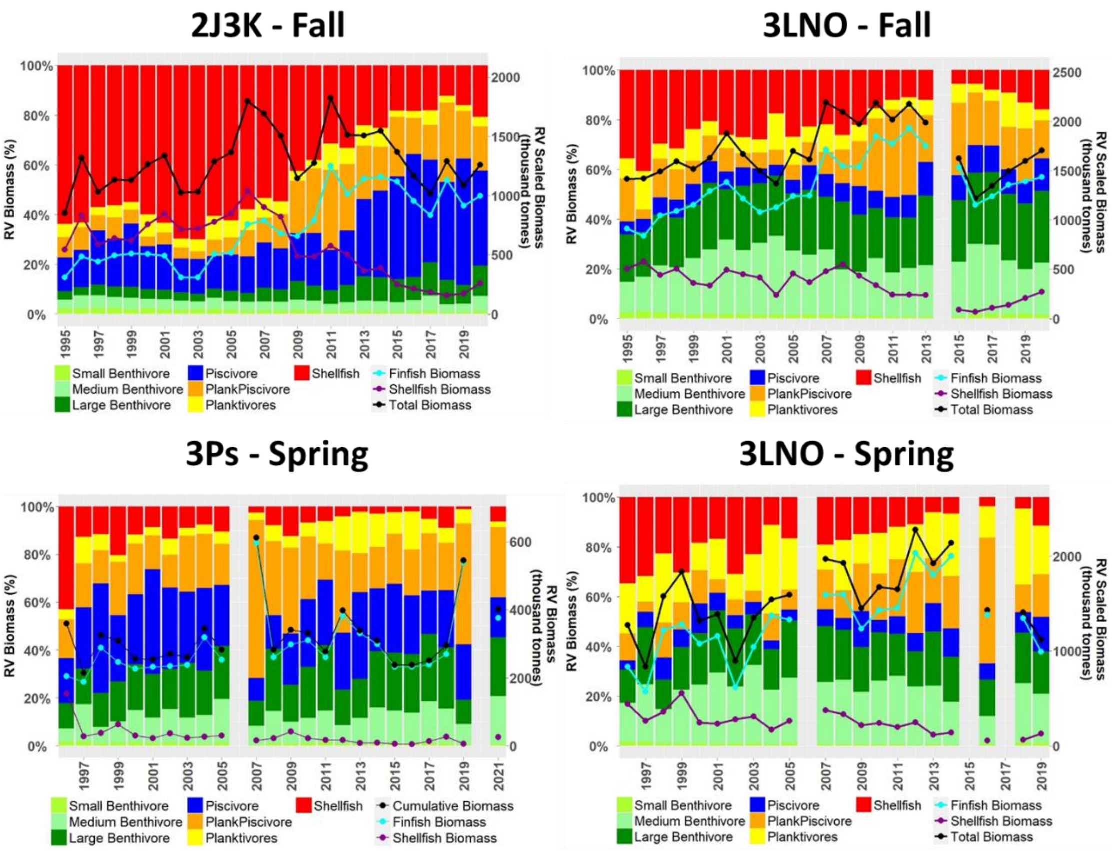


Figure 6.15. Synoptic summary of the structural changes (functional group composition) and trends in RV Biomass Index since the mid 1990's (Campelen series) for the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Southern Newfoundland (3Ps) EPUs.

In contrast with 2J3K and 3LNO, total fish biomass in 3Ps has remained fairly stable since the mid 1990s, with ephemeral increases mostly driven by outbursts of plankpiscivores (e.g. 2007,2019), although there is some evidence of reduced biomass levels in the mid-late 2010s in comparison with precedent years (Figures 6.14 and 6.15). Even with this comparatively more stable biomass level, the structure of the fish community has been changing. Among piscivores, silver hake has increased its dominance to similar levels as cod, and a large intrusion of spiny dogfish was observed in 2019 (Figure. 6.16). This ecosystem unit is at the boundary between temperate ecosystems to the south, and subarctic-boreal ecosystems to the north, and since silver hake and spiny dogfish are more warm water species, these changes may be associated with increasing warming conditions since the mid-late 1990s (DFO, 2021), and be a reflection of what to expect as climate change progresses.

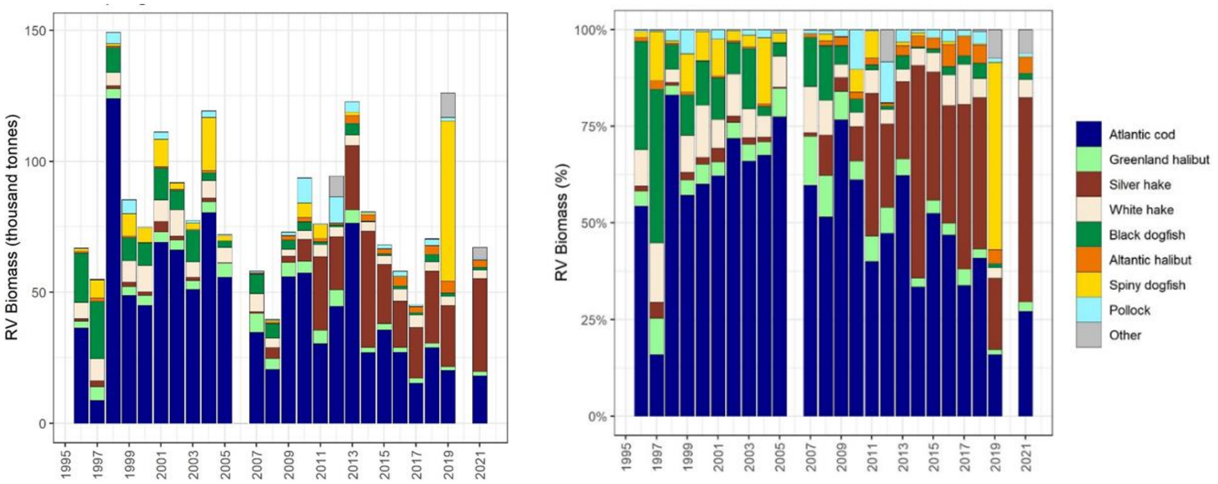


Figure 6.16. Trends in RV Biomass (left) and structure (right) of the piscivore functional group in the Southern Newfoundland (3Ps) EPUs. The increasing in dominance of silver hake, and the high intrusion of spiny dogfish in 2019, both warmer water species, may indicate community changes associated with the warming trends in this EPU.

Total productivity per unit area, as measured by the Maximum Sustainable Yield (MSY) from aggregate biomass production models, appear to be a fairly conservative ecosystem property, where variations between ecosystems tend to be linked to ecosystem size, and functional characteristics like the vertical mass flux of particulate organic matter (Bundy et al., 2012). Therefore, changes in productivity within a given ecosystem would be expected to be associated with changes in functionality. Under the assumption of a relatively stable production/biomass ratio at the ecosystem level, variations in total biomass density (weight per unit area) over time can be used as a proxy to characterize trends in ecosystem productivity. In this context, the comparison of total RV Biomass density allows inferences about productivity across EPUs. This examination indicates that all these ecosystem remain in an overall lower productivity state, but some signals of improvement have been observed in recent years (Figure. 6.17).

Even without scaled data for 3Ps during the Engel period, there are clear indications in the data that the overall biomass also declined in this EPU during the early 1990s (Figure. 6.14), and the similarities in post-collapse densities across EPUs suggest that 3Ps should have also underwent reductions in productivity of somewhat similar order of magnitude than 2J3K and 3LNO (Figure. 6.17). While trends among EPUs are generally consistent, 3Ps densities tend to be on the lower end, especially during the 2010s (Figure. 6.17), suggesting particularly limiting productivity conditions in this EPU during this period.

Signals from 2018-2020 appear to suggest that conditions could be improving (Figures 6.14 6.15, 6.16), but total biomass densities are still generally below the 2010-2013/14 levels. Few more years of data would be needed to define a clear trend.

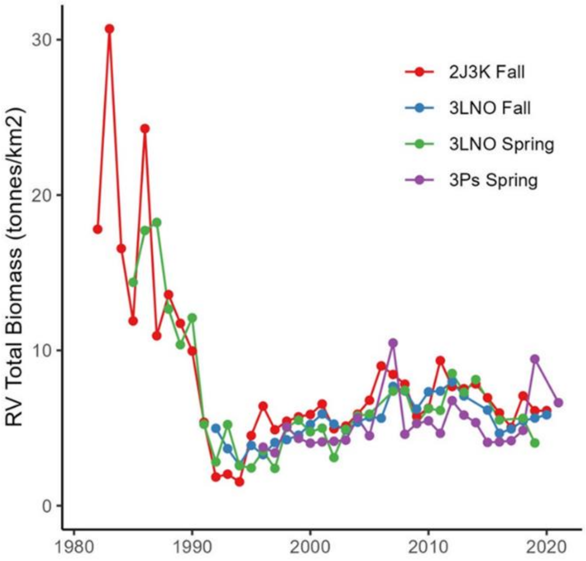


Figure 6.17. Trends in RV Biomass density by EPU based on DFO RV surveys.

Food consumption and diets for the fish communities in the Newfoundland and Labrador Bioregion

The order of magnitude of the food consumption by the fish community, and how that consumption is partitioned among different prey species are important elements for understanding the trophic dynamics of the fish community and evaluating the potential role of predation as a source of mortality for managed stocks.

WGESA reviewed and summarized estimates of total food consumption by fish functional groups in the Newfoundland Shelf (2J3K), Grand Bank (3LNO), and Southern Newfoundland (3Ps) EPUs, as well as diet composition for key species.

The total food consumption by the fish community was evaluated by defining a consumption envelope. This envelope was constructed from the range of consumption estimates derived from a suite of consumption models. All models were based on the combination of fish biomass, and consumption rates per unit of biomass.

Total biomass of fish species was approximated by the RV Biomass index from DFO RV multispecies surveys. This assumes that the sampled population reflect fish community composition, and that the RV Biomass indices are a good approximation to absolute biomass. However, as species-specific estimates were not corrected for gear catchability, they likely reflect minimal estimates of fish biomass, and hence, the constructed consumption envelope represents a minimum estimate of consumption.

Estimation of consumption rates per unit of biomass were derived using two families of approaches:

1. *Allometric methods*. Two different models were used here: a) a bioenergetic-allometric consumer-resource modelling framework, based on empirical allometric scaling

relationships (Yodzis and Innes, 1992), and b) an allometric framework derived from growth principles based on the Von Bertallanfy equation and rationale (Wiff and Roa-Ureta, 2008).

2. *Daily ration*. These estimates are based on assuming daily consumption as a percent fraction of body weight. We assumed two generic daily ration scenarios of 1% and 2% based on the typical range of values from literature reports (Macdonald and Waiwood, 1987; Adams and Breck, 1990), plus an additional scenario of 2.6% applied only to shrimp based on averaged daily rations for some shrimp species (Maynou and Cartes, 1997; Maynou and Cartes, 1998).

Considering the combinations of models and parameterizations, a total of eight different consumption sets were considered for constructing the consumption envelopes.

Strictly speaking, these approaches estimate average food requirements, not actual food consumption. The implicit assumption is that all predators achieve their food requirements. Using together these alternative estimates of consumption rates allows the development of a plausible envelope for consumption that likely contains the actual consumption rate.

The consumption envelopes for the Newfoundland Shelf (2J3K) and Grand Bank (3LNO) EPUs clearly show and increase in finfish food consumption from the mid 2000s to the 2010s, relatively stable consumption levels in the early 2010s, and declines after the mid 2010s (Figure 6.17). While this general pattern is also discernible in the total consumption (Figure 6.17), the increase is less clear in the Newfoundland Shelf (2J3K) EPU where the dominance by shellfish in the total biomass during this period ((Figure 6.15), and consequently its impact on consumption, masks the finfish trend. In the Grand Banks (3LNO) EPU the consumption by finfishes clearly dominates the overall signal over the entire period. In recent years the estimated total food consumption envelopes have been of 4-10 Mt, and 6-13 Mt per year in 2J3K and 3LNO respectively (Figure 6.17).

Unlike the other two EPUs considered, the Southern Newfoundland (3Ps) EPU shows a more stable consumption envelope (Figure 6.17), with sporadic spikes linked to plank-piscivores (i.e. redfish), and some reduced levels in the mid-late 2010s in comparison with preceding years (Figure 6.14), Like the Grand Bank (3LNO) EPU, the total consumption signal is dominated by finfish consumption. The estimated envelope for consumption in this ecosystem has generally been around 1-2Mt per year, rising up to 2-5Mt when the plank-piscivore outbursts occurred. It is interesting to note that 2021, the last year of data, has an estimated envelope of 1.5-3.0Mt without a plank-piscivore spike. This increase in consumption is driven by a general increase in fish biomass, but it is unclear if this represents the beginning of a trend, or it is simply a year effect.

These estimates of consumption also provide a useful point of comparison with the estimated fish production from the Ecosystem Production Potential (EPP) models (Koen-Alonso et al., 2013; NAFO, 2019). The EPP models estimate the fish production at the ecosystem level using an stylized food web architecture where production is estimated by functional feeding guilds. These functional guilds are more encompassing that the fish functional groups used here to described the status and trends of the fish community, and also cover a broader range of organisms and trophic levels, from phytoplankton and bacteria all the way up to top predators. This also means that the production that sustains the food sources for the consumption being estimated here is a subset of the total ecosystem production estimated by the EPP model (NAFO, 2013). More specifically, the food being consumed by the fish community as represented in the consumption analyses would largely be produced by the meso-zooplankton, planktivore, suspension and deposit-feeding benthos, benthivore, and piscivore functional guilds within the EPP model. Therefore, we can compare the production estimates for these guilds with the estimated consumption, and gauge how well the two estimates match. If the order of magnitude of the different estimates is reasonable, one would expect that the estimated consumption and production would be of a similar order of magnitude.

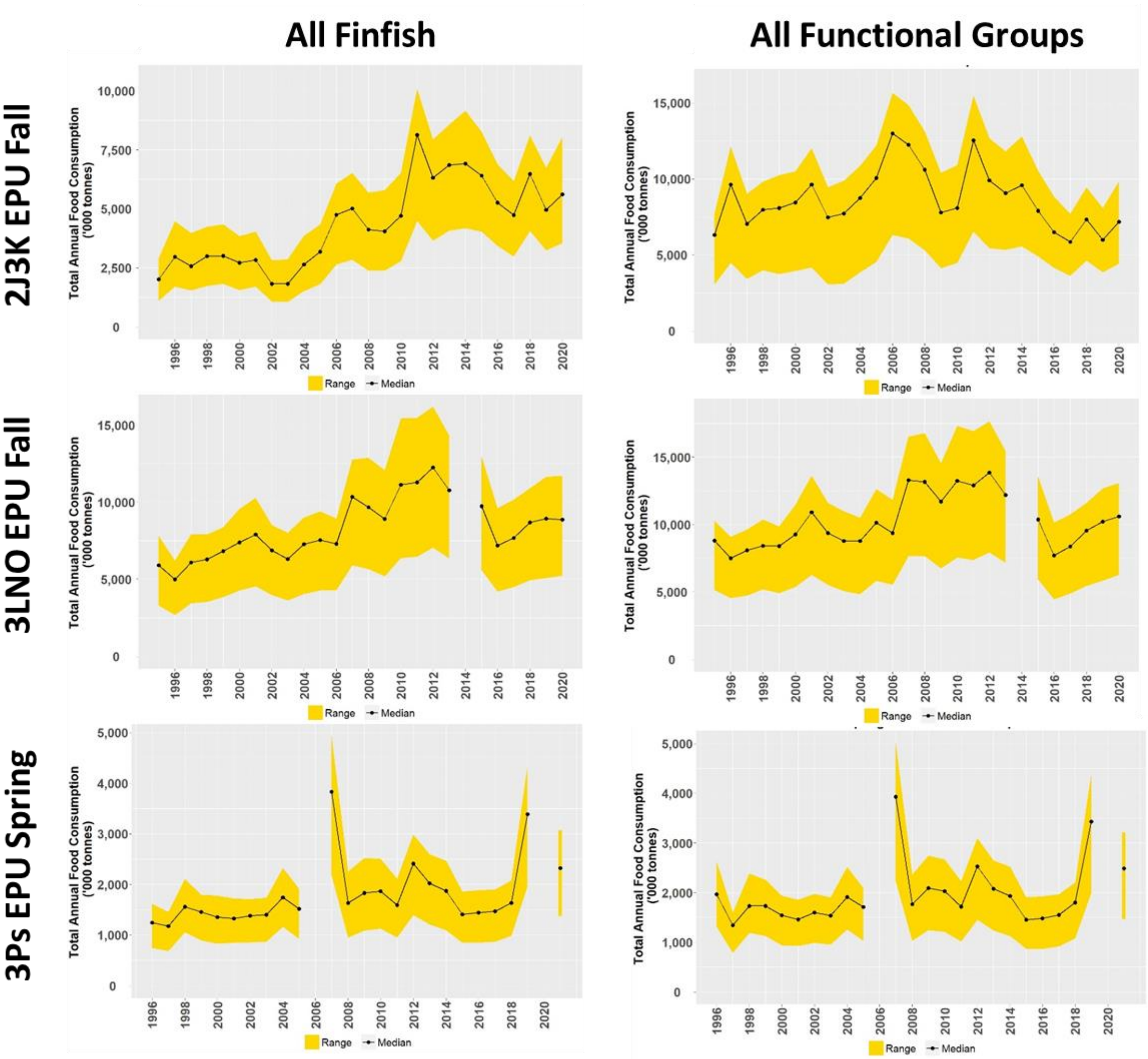


Figure 6.17. Annual food consumption envelopes (median and range) by EPU for the finfish component and total fish community as estimated by RV survey in the 1995-2021 period.

This comparison also needs some additional considerations before proceeding. On one side, the estimated consumption is for the fish community, but does not include other important ecosystem components like marine mammals and seabirds, which are also utilizing the same sources of production for their food. Doing the proposed comparison also needs to include the consumption by these components. The other important consideration is that the Newfoundland Shelf (2J3K) and Grand Bank (3LNO) EPUs are considered to have impaired productivity (NAFO, 2019), so the estimated production from the EPP model needs to be adjusted to reflect the realized productivity.

While there are no readily available integrated estimates of food consumption by all seabird species in the NL bioregion, when considered in terms of total biomass, seabirds are not expected to represent a significant fraction of the overall ecosystem biomass in comparison with fish and marine mammals, so an initial comparison without including seabird consumption would still be informative for an order of magnitude analysis at the ecosystem level. In terms of marine mammal consumption, there are estimates for the most important seal species in the NL bioregion, and coarse approximations for the consumption by cetaceans (NAFO, 2015). Since marine mammals are highly mobile, their consumption is not constrained by the EPU boundaries, so effective comparisons need to integrate both EPUs. Most of the seal consumption occurs within 2J3KL, while cetacean consumption is less understood, but expected to occur in the broader NL bioregion (NAFO, 2015).

In terms of adjusting the EPP estimates to realized productivity conditions, the ongoing work for the development of Total Catch Indices (TCIs) indicates that penalty factors scaling the EPP estimates with the changes in the total RV Biomass is an effective approach for this productivity adjustment (NAFO, 2019).

Putting all these pieces together allows for a general comparison between the estimated consumption by the marine community (fish + marine mammals) and the production estimates from the EPP model. The results from this comparison (Table 6.5) are surprisingly close given the many uncertainties, caveats, and assumptions involved in the estimations of consumption and adjusted ecosystem production, and indicate a remarkable consistency between them. This level of agreement adds credibility to both estimations procedures, and suggest that the order of magnitude of the consumption and production figures would be expected to be robust estimates. While care must be taken when considering these results given that the uncertainty around these estimates is known to be large, this does not detract from the emerging alignment in their central trend estimates.

Table 6.5. Comparison between production and consumption in the Newfoundland Shelf (2J3K) and Grand Bank (3LNO) EPUs. Production is derived from the EPP models for each EPU after applying the corresponding penalty to adjust for realized productivity conditions (NAFO, 2019), and correspond to the production of the EPP model functional guilds considered to be food sources for the fish community and marine mammals (meso-zooplankton, planktivores, deposit and suspension-feeding benthos, benthivores, and piscivores). Consumption estimates are derived from the analyses presented here (fish community), and previous

	Production (median) (Mt)		Consumption (Mt)	
Area	Amount	Comment	Amount	Comment
Newfoundland Shelf (2J3K)	11.95	Penalty factor: 0.4	7.44	Fish community (median)
Grand Bank (3LNO)	13.89	Penalty factor: 0.3	10.50	Fish community (median)
NL Bioregion (effectively 2J3KL)			3.56	Seals (harp + hooded) (means)
NL Bioregion			3.90	Cetaceans (coarse point estimate)
Total	25.84		25.40	

In terms of diet composition, food habits for key groundfish species have been examined through stomach content analyses from samples collected during DFO RV Fall and Spring surveys, Some historically important commercial groundfish species like Atlantic cod and turbot started to be studied in the late 1970s, while others only started to be examined more recently (Figures 6.18 – 6.20).

While diets have been variable across species and over time, some key prey have been important for many of the predator species. In the Newfoundland Shelf (2J3K) EPU (Figure 6.18), capelin and shrimp have been important prey for cod, turbot and American plaice, but have also been found in some of the other predators like thorny skate and redfish. Capelin was a dominant prey during the 1980s, but its importance declined with the capelin collapse in the early 1990s, and shrimp became a dominant prey. In the late 2000s and early 2010s, this situation reverses, with shrimp declining in the diets and capelin increasing, but without reaching the dominance observed in the 1980s. The most recent years have seen reductions of both prey in the diets. Other prey that is important for some predators like cod and thorny skate, especially in more recent years, is snow crab. While most predators show a mix of invertebrates and fish in their diets, witch flounder emerges as the only predator with a clear invertebrate diet, highly dominated by polychaetes, and with some amphipods.

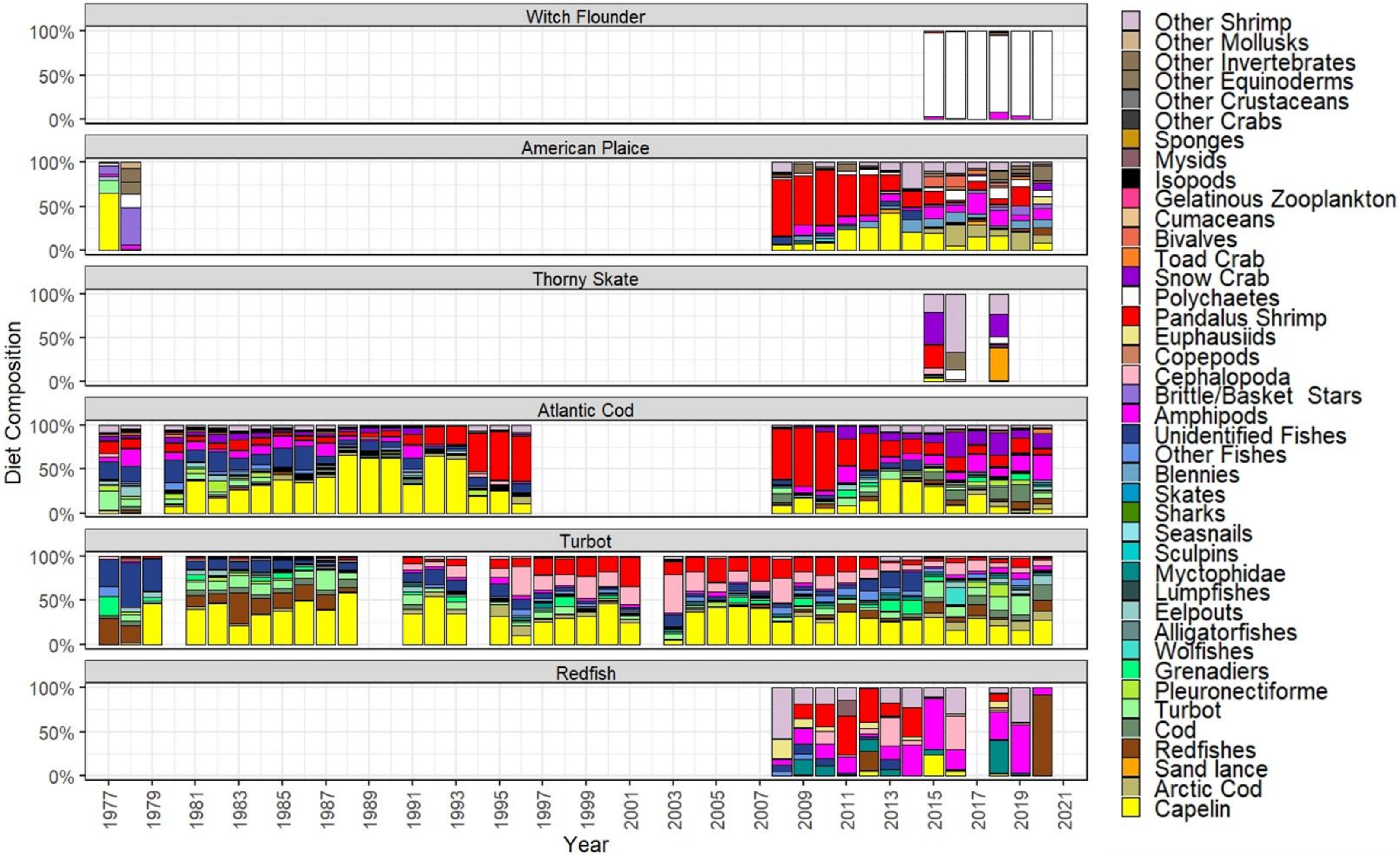


Figure 6.18. Diet composition for key species in the Newfoundland Shelf (2J3K) EPU from stomach contents collected during DFO Fall survey.

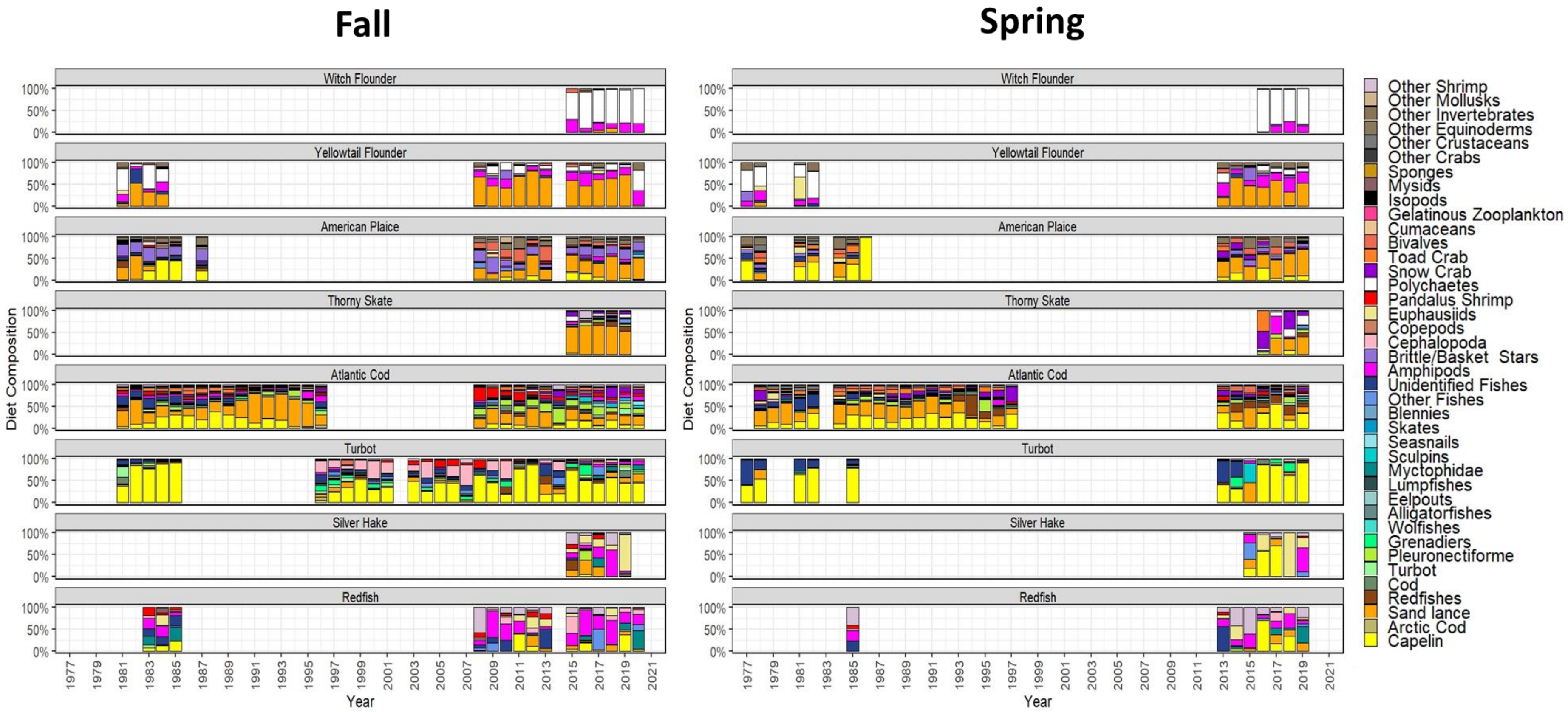


Figure 6.19. Diet composition for key species in the Grand Bank (2J3K) EPU from stomach contents collected during DFO Fall and Spring surveys.

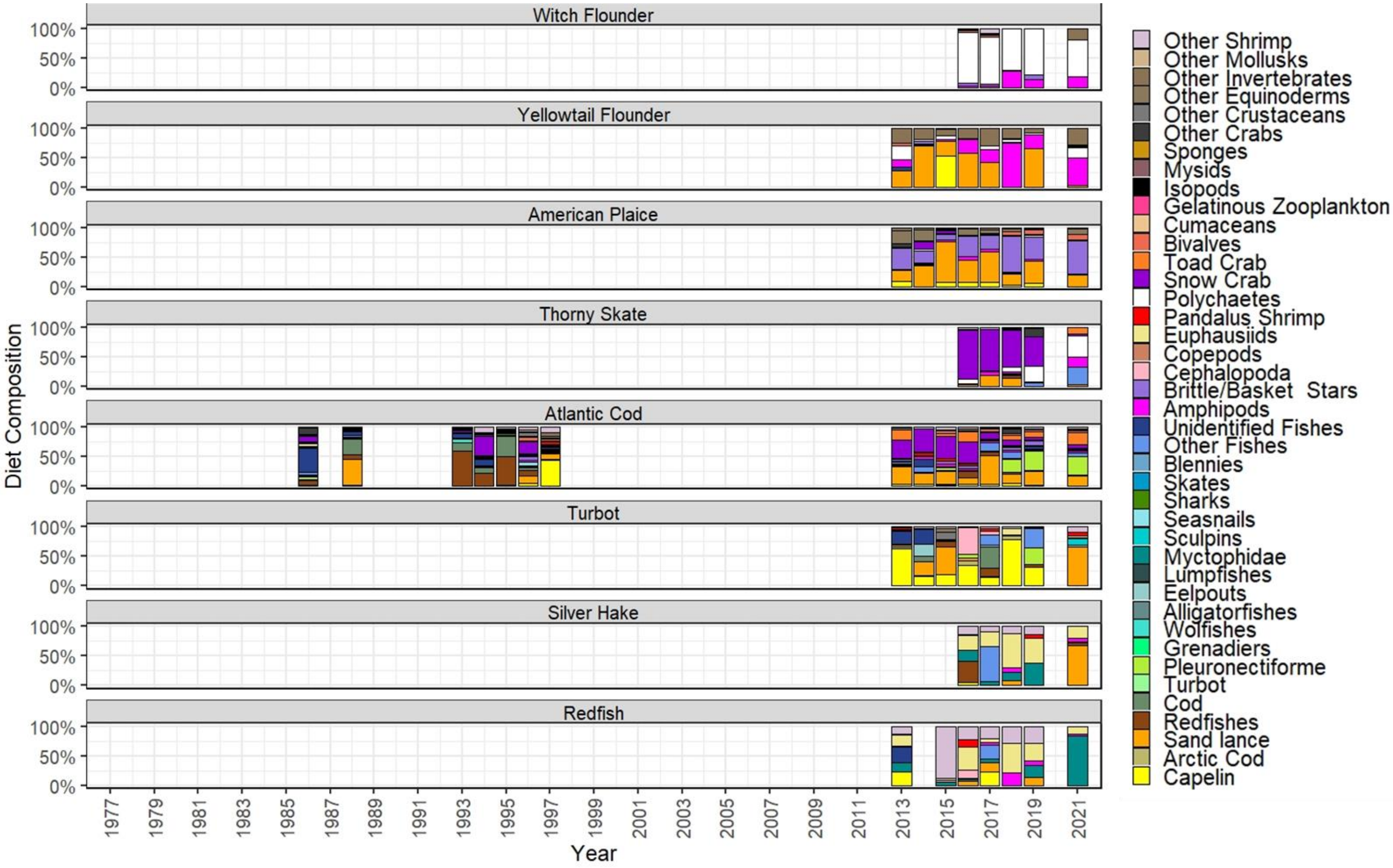


Figure 6.20. Diet composition for key species in the Southern Newfoundland (3Ps) EPU from stomach contents collected during DFO Spring survey.

The Grand Bank (3LNO) EPU is the only ecosystem unit with diet information from both fall and spring. In general terms, the important prey items remain consistent between seasons, but the dominance between them can show some changes (Figure 6.19). Overall, both capelin and sandlance are the most important prey in the Grand Bank, with capelin being consistently the more important prey for turbot, while both sandlance and capelin are important for cod, but their importance changes seasonally, with capelin being generally more important in the spring and sandlance in the fall (Fig. Figure 6.19). Sandlance is a dominant prey for yellowtail flouder, American plaice, and thorny skate, while invertebrates dominate the diet of witch flounder, with polychaetes being the most important prey, but with an increased role of amphipods in comparison with the Newfoundland Shelf (Figures 6.18 and 6.19). Redfish diet is highly variable, but sample sizes for redfish are generally low, given that most redfish evert their stomachs as they are brought to the surface, making difficult the collection of samples.

The diets in the Southern Newfoundland (3Ps) EPU) appear more diverse than in other ecosystem units. While there is less consistent signals across predators, sandlance remains an important prey for several groundfishes (Figure 6.20), but its dominance is lower in comparison with the Grand Bank. American plaice still has sandlance as an important prey, but the dominance of brittle/basket stars is increased. Yellowtail flounder also shows sandlance as an important prey, but the role of invertebrates in the diet like polychaetes and amphipods appears more important (Figure 6.20). Cod and thorny skate have snow crab as a more important prey in comparison with the other EPUs, but cod shows a clear switch from snow crab to flatfishes in 2018. The generally more diverse, and variable diets from year to year suggest that food availability may be an issue in this ecosystem, where predators cannot rely on staple, consistent prey items, and have to utilize whatever food becomes available.

This issue of food availability can be examined more generally by looking at the changes in average stomach content weight over time. On the basis of those species for which longer time series are available, and focusing the examination of stomach content weights only on those stomachs with actual content in them, and within a restricted predator size-range to control for bias associated with changes in predator size distribution, the changes in average stomach content weight over time can be an indicator for food availability in the ecosystem.

This examination was carried out for cod, turbot and American plaice across EPUs (Figure 6.21). The results generally indicate heavier stomach content weights in the 1980s, a decline in stomach content weight in the early 1990s, increased weights in the 2010s, and declines in the mid-late 2010s (Figure 6.21). While there is noise in these trends over time, the signals from 3Ps tend to be on the lower end for cod and turbot, suggesting that the observed diet variability could be associated with reduced prey availability in this ecosystem unit.

The general pattern of changes in stomach content weights over time was further examined using the cod and turbot time series. These series were normalized, plotted together, and the median of all available time series calculated (Figure 6.22). The emergent signal from this analysis, characterized by the median trajectory (Figure 6.22), shows a pattern over time that closely resembles the trajectory of the total RV Biomass from the Newfoundland Shelf (2J3K) and Grand Bank (3LNO) EPUs (Figure 6.14). This similarity indicates that food availability has likely been an important factor in driving ecosystem changes, and suggest that these ecosystems appear to be bottom-up controlled. This is consistent with recent analysis indicating that capelin availability has been an important driver for Northern cod (Buren et al., 2014; Koen-Alonso et al., 2021), and that starvation induced mortality represents an important component of Northern cod natural mortality (Regular et al., 2022).

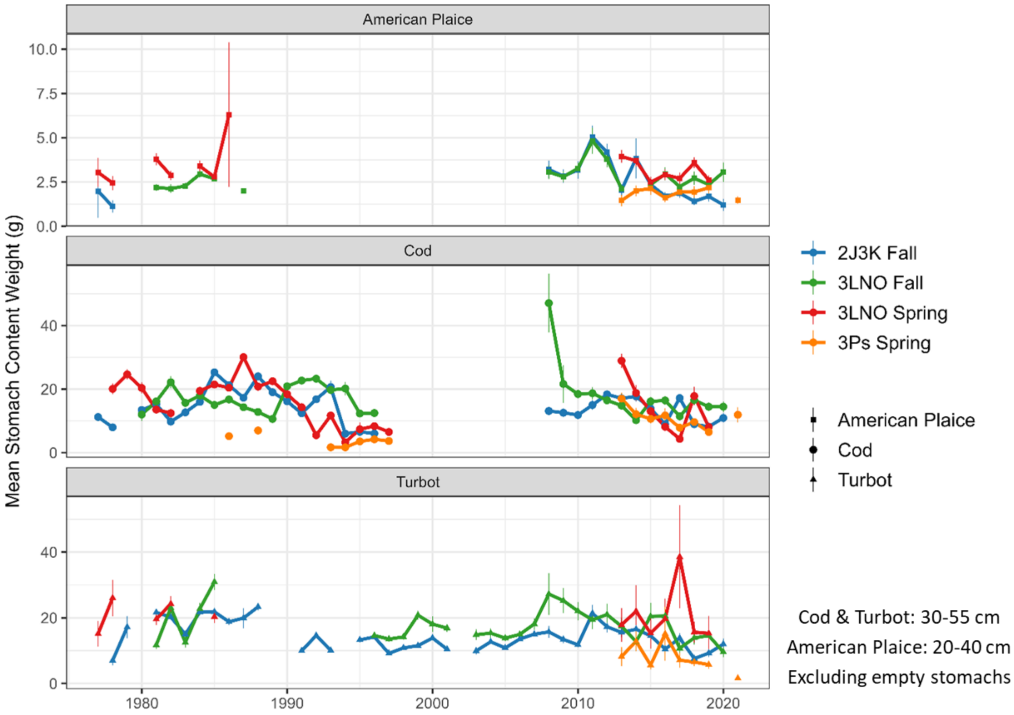
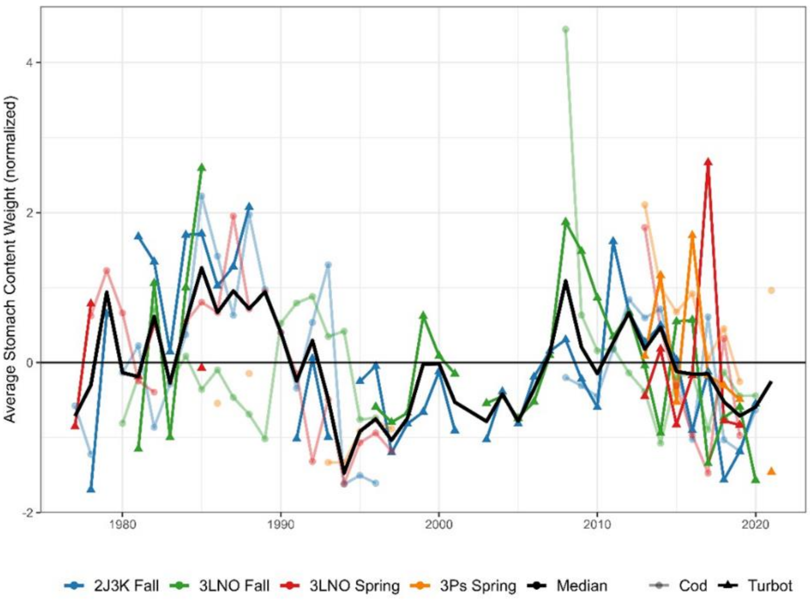


Figure 6.21. Stomach content weights for cod, turbot and American plaice across EPUs, excluding empty stomachs and considering only stomachs from restricted predator size ranges.



Fish sizes: 30-55 cm
Excluding empty stomachs

Figure 6.22. Normalized Stomach content weights for cod, and turbot across EPUs, excluding empty stomachs and considering only stomachs from restricted predator size ranges.

Concluding remarks

The ecosystem changes observed across EPUs in the NL bioregion during the 1990s involved the collapse of the entire groundfish community, the collapse of a key forage species like capelin, and the increase in shellfish species, but the build-ups of shrimp and snow crab did not compensate for the losses in groundfish. Total biomass never rebuilt to pre-collapse levels.

Consistent signals of groundfish rebuilding appeared in the mid-late 2000s, and coincided with modest improvements in capelin, and the beginning of the shellfish decline. The finfish biomass in the 2010s was relatively stable until 2013-2014, when started to show signals of decline. While there are signals of improvement since the lows in 2016-2017, current total biomass has not yet returned to the 2010-2015 level.

The conditions that led to the initial rebuilding of the groundfish community in the mid-late 2000s appear to have eroded. This may have been linked to the simultaneous reductions in capelin and shrimp availability.

Estimated consumption levels are generally consistent with the production estimates from the EPP model under reduced productivity conditions. This provides some level of cross validation between analyses, and provides further support to the argument that these ecosystems are experiencing reduced productivity conditions.

Shrimp, capelin, and sandlance are key prey for a range of groundfish species. Shrimp and capelin dominate the diets in the Newfoundland Shelf (2J3K) EPU, while capelin and sandlance are more important in the Grand Bank (3LNO) EPU. Sandlance is the most consistent prey in the Southern Newfoundland (3Ps) EPU, but diet variability is a more prevalent feature in this ecosystem, likely associated with limited and variable food availability.

Average stomach content weights for cod and turbot track well the general trends observed in the fish community. This supports the idea that declines in total biomass observed in recent years are associated with bottom-up processes, but also indicates that food availability has been an important driver of ecosystem changes in the Newfoundland-Labrador bioregion.

The overall results indicate that Newfoundland-Labrador ecosystems remain in low overall productivity conditions likely driven by bottom-up processes, but there are modest signals suggesting that conditions could be improving.

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e) ToR 3.5. accounting for changes in the closed areas over time in SAI and VME assessments.

TOR 3.5. The results of the removal of survey trawls from closed areas is dependent on the closed areas not changing over time – how do we address this? Also how do we ensure the applicability of the current VME and SAI assessment methods without continuity of VME closed area survey data?

Several items were discussed under this point:

Impact of removing the survey trawls inside closed areas in stock assessments. This item is still open, waiting for the results of the EU surveys, but it seems that, except in a small number of species (such as Greenland halibut and roughhead grenadier), the impact of removing the hauls of the surveys inside the closed areas is minimal.

The change in the closed areas over time could be a problem with not easy solution to know the impact of removing the closed areas from the design of the surveys in the stock assessments in the future. The analysis for studying that impact is a very time-consuming task, and it is not possible to redo it every time the closed areas change. So, if the closed areas continue to increase their extension, or new closed areas are set, the impact of removing the surveys in the stock assessments could be a matter of study. In this regard and for the time being, it is really difficult to establish a clear rule that could be considered valid to present and future scenarios. The issue of developing some sort of protocols (rules of practices) to deal with this situation was raised. It was mentioned that such protocols should be flexible.

Some concerns about the bias of the data without the data inside the closed areas for the assessment of SAI were raised.

Impact of not having information from the surveys in the closed areas in the applicability of the current VME and SAI assessment methods. Once the cut-off limits are set, not having information of the VME from the surveys inside the closed areas seems not to have a big impact, as the curves are not going to be updated. The monitoring of the VMEs could be done with the data provided by the surveys outside the closed areas. A factor that cannot be monitored is how the closed areas improve the biomass of the VMEs. Another type of monitoring system is required, such as camera-based systems. But these systems are not fully designed yet, and to have a taxonomic detail of the individuals encountered would be very difficult. Further development of a camera-based survey should have done, but in the long term. In the meantime, some way to monitor the status of the VMEs is necessary. It was pointed out that Canada has a protocol for which a survey can be allowed to trawl inside a closed area if the advantages overcome the disadvantages. These could be a way of monitoring the VMEs while the camera-based survey is not implemented.

THEME 4: OTHER MATTERS

7. Other Business

a) Updates from the Executive Secretary on, i. MoU with the Sargasso Sea Commission, ii. renewal of the ABNJ Deep-Seas Fisheries Project.

i) MoU with the Sargasso Sea Commission

The Executive Secretary referred to SC Working Paper 21-016, which provided an update on developments concerning the possibility of the NAFO Secretariat entering into a Memorandum of Understanding (MOU) with the Secretariat of the Sargasso Sea Commission (SSSC). In particular the Executive Secretary said that the Commission at the 2021 Annual Meeting had expressed its support of the development of this MOU following the recommendation of the Joint Commission-Scientific Council Working Group on the Ecosystem Approach Framework to Fisheries Management (WG-EAFFM). He added that, since the operative provisions of the proposed text, namely Articles 2 and 3, would be of interest to the Scientific Council including WG-ESA, the NAFO Secretariat would appreciate input and guidance on the Working Group to improve the text of this draft. In this context, it was agreed that members of WG-ESA would contact the Secretariat directly after the meeting.

ii) Renewal of the ABNJ Deep-Seas Fisheries Project

The Executive Secretary referred to SC Working Paper 21-015, which provided an update on NAFO's participation in the proposed five-year (2022 to 2027) GEF "Deep-sea Fisheries Project" (DSF) under the Common Oceans Program. The Executive Secretary said that the Commission, at the 2021 Annual Meeting, had agreed that NAFO should become a partner and commit in-kind support of approximately US$ 3.03 million over the DSF Project's 5-year term. The details of this in-kind support is outlined in the Table appended to the Working Paper. Much of NAFO's proposed commitment focuses on Component 2 of the DSF Project, entitled "Strengthening effective management of deep-sea fisheries" and would include all the work of WG-ESA regarding NAFO's EAF Roadmap, the protection of VMEs, etc. The Executive Secretary added that since the 2021 Annual Meeting, the NAFO Secretariat confirmed its commitment to the DSF Project. He understood that the GEF is anticipated to make a decision whether to approve the DSF Project early in 2022, after which the DSF Project is expected to start. He added that under the Common Oceans Program, there are a number of other Projects, including one concerning tuna fisheries and another concerning the Sargasso Sea, part of which overlaps with the NAFO Convention Area.

Under this Agenda Item, the Executive Secretary was asked about the development of NAFO's links with the International Seabed Authority (ISA). He replied that both Secretariats had agreed to try to establish some informal mechanisms for dialogue, but the pandemic had curtailed any further developments. He added that there are no ISA-related activities envisaged in the NAFO Convention Area in the foreseeable future. Nevertheless, in November 2020, the NAFO Secretariat was invited to take part in a workshop on the development of a Regional Environmental Management Plan (REMP) for the Area of the Northern Mid-Atlantic Ridge with a focus on polymetallic sulphides (PMS) deposits and gave a presentation along with the Secretary of NEAFC on the use of area-based management tools used by fishery bodies.

b) Joint ICES/IUCN workshop on OECMs – NAFO sponge VMED case study. WGEAFFM Response and way forward for NAFO OECMs.

i) Joint ICES/IUCN-CEM FEG Workshop on Testing OECM Practices and Strategies (WKTOPS) March 2021.

In March 2021, NAFO scientists participated in a joint ICES/IUCN-CEM FEG workshop on testing OECM (Other Effective area-based Conservation Measures) practices and strategies in relation to several different types of spatial fishery management measures (e.g. VME fishery closures). Included as case studies were the NAFO large sponge VME and NAFO Corner Rise Seamount which were both positively evaluated against the OECM criteria (Publication Reports - ICES - IUCN-CEM FEG Workshop on Testing OECM)

Following the meeting of WG-EAFFM in July 2021, it was recommended that the Secretariat work with CBD to inform WG-EAFFM on the OECM process for closed area nomination by RFMOs, including what role, if any, RFMOs have had to date. It was also agreed that WG-EAFFM would form an informal group of managers and scientists with the purpose of; i. to evaluate the current NAFO VME closures and other relevant management measures against the OECM criteria, and ii. to consider the implications of presenting NAFO's VME closures and any other relevant management measures to the CBD as possible classification as OECMs. This sub-group has yet to be convened.

It was further noted by the WG-ESA Chair that a Theme Session on "spatial management, climate change and biodiversity" will be convened at the ICES Annual Science Conference in 2022 to be held in Dublin from 19th – 23rd September. The Theme Session is particularly relevant to the discussions and outcomes arising from the ICES/IUCN-CEM FEG Workshop and will be jointly chaired by Andrew Kenny (CEFAS), Catarina Frazao Santos (University of Lisbon) and Tundi Agardy (Earthlink). Oral and poster contributions that relate to the following main topics are welcome:

(a) The integration of knowledge on climate change into marine spatial plans (e.g., modelling and mapping tools, risk and vulnerability analyses, sea-use scenarios); and, ways to support dynamic and flexible ocean planning and management initiatives (e.g., dynamic ocean management, anticipatory zoning, adaptive law, adaptive governance);

(b) The identification and quantification of biodiversity benefits associated with ABFMs (e.g., closures to protect essential fish habitat, vulnerable marine ecosystems, fish spawning and nursery areas); and, pathways to support effective, equitable and sustainable ocean management and governance, particularly in the context of OECMs.

However, it is unfortunate that the Theme Session dates clash with the NAFO Annual Meeting and this will most likely limit the participation (at least in person) at the ICS ASC from those who are involved in NAFO.

c) Collaboration with ICES Working Group on Fisheries Benthic Impact and Trade-offs (WG-FBIT).

A half-day session was convened jointly by WG-ESA and ICES Working Group on Fisheries Benthic Impact and Trade-offs (WG-FBIT) to facilitate the sharing of data and assessment methods, and to coordinate on-going assessment work. Members of WG-ESA through the work undertaken in NAFO are supporting ICES in a number of ways, e.g. i. to provide scientific advice on VMEs, ii. to conduct bottom contacting fishing impact assessments and iii. to develop habitat suitability and species distribution modelling for the deep sea. The session consisted of a series of presentations made by members of WG-ESA and WG-FBIT, summarized below:

i) ICES WGFBIT Assessment of bottom trawl impacts on seabed biota – Jan Geert Hiddink

The FBIT assessment of the impact of bottom trawling depends on three key parameters that are estimated on a grid cell bases. Firstly, fishing intensity is quantified for each grid cell as the swept-area-ratio, estimating using VMS data and logbooks. Secondly, the depletion caused by a trawl pass (i.e. the fraction of biota removed by a single trawl in the trawl path) has been estimated for a range of metiers based on the penetration depth of the metiers. Thirdly, the sensitivity of the benthic community in each grid cell is estimated based on the correlation that exists between the longevity of the biota and their recovery rates. These three values feed into the assessment model that predicts the impact of bottom trawling for each grid cell. This assessment is operation for much of the sedimentary European shelves, but has not been applied to deep-sea habitats and Vulnerable Marine Ecosystems yet. Such habitats are likely to be more sensitive to trawling, but we currently do not know to what extent the existing parameter estimates are applicable to these habitats, and WGFBIT hopes that collaboration with WGESSA will work towards plugging this gap.

ii) Assessment of SAI – Andy Kenny

To assess Significant Adverse Impacts (SAI) caused by bottom trawling activities in the NAFO Regulatory Area (NRA), NAFO created a gridded layer of fishing effort (km fished/km2/yr) using VMS data (2010 – 2019) and a 1km2 gridded layer of VME biomass data derived from an extensive survey of fishery independent trawls recording VME indicator species biomass. Combining these two data sets has allowed an estimate of bottom trawling impact on deep sea VME to be determined which is similar to the benthos depletion estimates developed by WGFBIT. To determine if an impact is 'significant' a fishing effort impact cut-off value has been derived which corresponds to a level of fishing effort where 95% of the biomass has been impacted (or removed) by trawling. This cut-off value is then applied to the fishing effort layer associated with each of the VME polygons to determine the total area of VME impacted (all areas above the cut-off value) and the total area of VME at risk of impact (all areas below the cut-off value). Following the presentation made by FBIT it is apparent there would be benefit in using the NAFO deep sea VME and SAI data to plug a data gap in the FBIT approach for the assessment of deep-sea fishing impacts on VMEs. Furthermore, it would be interesting to understand and possibly apply the FBIT methodology to assess SAI in NAFO, thereby potentially unifying the assessment methods currently being applied to continental shelf and deep sea ecosystems in the North Atlantic.

iii) Applying the WKEUVME methods to NAFO data – Ellen Kenchington

Under regulation (EU) 2016/2336, the EU fleet will be banned from bottom fishing for deep-sea species in all waters, apart from within the existing fishing footprint. Within the fishing footprint, EU vessels will be prohibited from bottom fishing in any closed areas that might be introduced to protect VMEs. To meet these regulatory requirements, ICES was requested by the European Commission to provide "advice on the list of areas where VMEs are known to occur or are likely to occur and on the existing deep-sea fishing areas (ref. (EU)2016/2336)".

In 2020, an ICES workshop WKEUVME was tasked to produce the technical evidence base for producing a set of regulatory area options, building from 2019 work (Technical Service and WKREG workshop), as well as previous ICES advice (ICES 2018a) and technical services (ICES 2018b). The work drew upon the most recent fishing activity and VME data at ICES that has been quality assured following the respective annual ICES data calls for VMS/logbook (link) and VMEs (link).

Within this context, the workshop planning committee created a workflow to guide the required technical work of WKEUVME to propose a set of regulatory area options in an open and transparent way. Using the workflow, WKEUVME created a framework for systematically integrating all of the information. There are also strong links to shallower water assessment procedures developed by WGFBIT (Working Group on Fisheries Benthic Impact and Trade-offs) that have been developed for the ICES Ecosystem Overview advice in the context of Descriptor 6 seafloor integrity of the EC's marine strategy framework directive (MSFD).

WKEUVME used a data-driven approach to provide management options for this request. Two broad scenarios were provided each with a set of rules defined for producing the outcomes. The first scenario defined VME closure polygons without any modification by known fishing activity; the second scenario identified areas where the fishing footprint overlapped with Scenario 1 and then used VME biomass/fishing intensity relationships to identify a threshold for areas (C-squares) where effort was low and unlikely to have caused significant adverse impacts to the VMEs-opening those areas above the threshold. Within each scenario two options were provided based on the level of uncertainty associated with VME presence. The first option included VME habitats and areas with a high or medium VME Index score (a multi-criteria assessment method developed by the ICES WGDEC and published by Morato et al. (2018). The second included VME elements (areas where VME elements are likely to occur, e.g., seamounts, canyons etc.) and all VME presence (habitats and low, medium and high VME index values); allowing managers to choose the level of precaution they wish to apply in protecting VMEs. In order for managers to evaluate the impact that closing these areas might have on different fishing métiers, WKEUVME tabulated fisheries data summarizing the percent of the fishing activity occurring within 400-800 m depth relative to the EEZ of the relevant countries in each ecoregion. Further, WKEUVME used the percentiles of fishing effort (swept-area ratio, SAR) to map core fishing grounds both in the fishing footprint years (2009-2011) and in two 4-year periods following. Summary statistics, graphs and maps were produced for the assessments.

The established ICES VME and fishing activity data flows, and the assessment procedure presented in the respective assessment sheets form a solid foundation from which ICES can base any annual assessment as formal ICES advice to the EC (as is done for NEAFC VME advice). This assessment procedure is fully documented using ICES TAF (transparent assessment framework) principles, with the respective scripts to run the assessment made publically available on an open source platform (WKEUVME GitHub site); a first for ecosystem work within ICES. The framework has recently been peer reviewed and accepted for publication in an International science journal (van Denderen et al., in press).

Application to the NAFO Regulatory Area and Surrounds

As an initial exploration of the application of the ICES WKEUVME framework we used the data from the ICES VME database for the Northwest Atlantic Fisheries Organization (NAFO) Regulatory Area (Flemish Cap and the Tail of Grand Bank) and applied Scenario 1, Option 1 and Option 2 (in part). In order to apply Scenario 2 the following data would be required:

- bottom-contact gear fishing effort data (swept area/hours fished) at the 0.05 by 0.05 degrees C-square resolution (with mid-points of C-square ending on 25 or 75 e.g. -9.975, 48.025, -9.825).

The fishing effort threshold used for the assessment of Significant Adverse Impacts (SAI) by NAFO WG-ESA is used in Scenario 2 Option 1 to include Low VME Index C-squares if mobile bottom-contacting gear fishing pressure is also low (≤ SAI threshold value) in addition to the C-squares identified under Scenario 1 Option 1. This option prioritizes protection of VMEs where they are known or likely to occur, and includes areas where the 'likelihood' of occurrence of VME presence is lower but where fishing activity is also low and therefore any VMEs present are less likely to have been heavily damaged by trawl fishing. Scenario 2 Option 2 would close C-squares including all VME habitats, High, Medium and Low VME Index C-squares but excluding C-squares with high mobile bottom-contacting gear fishing pressure (heavily fished areas above the SAI threshold). This option prioritizes protection of VMEs where they are known or likely to occur, but excludes areas that have been heavily fished (core fishing areas) and where VMEs are therefore likely to have been heavily damaged by past trawl fishing.

Steps for Operationalizing Closure Scenario 1

Option 1 - Protection for VME Habitat and Medium and High VME Index C-squares

Select all VME Habitat, and High and Medium VME Index C-squares and create a ½ C-square buffer around them (Figure 7.1). These cells are known or likely to contain VMEs and the buffer zones account for the offset between vessel positions and the position of their gear, which can be substantial in deep water, and the effects of sediment resuspension, which can have detrimental effects on VMEs.

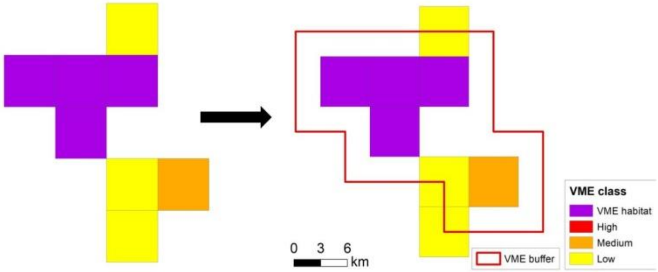

Figure 7.1. Scenario 1 Option 1, Step 1 illustrating the selection of C-squares and creation of buffer.

Where Low VME Index C-squares are adjacent and joining any C-squares in Step 1, these should be selected and a ½ C-square buffer placed around the C-square (Figure 2). These cells are considered more likely to contain VMEs than other low index cells by their proximity to higher index cells.

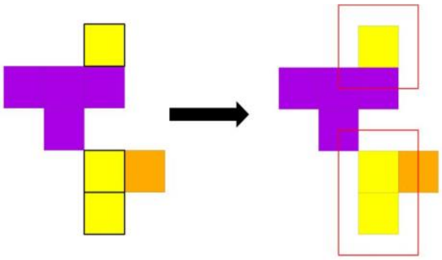

Figure 7.2. Scenario 1 Option 1, Step 2 illustrating inclusion of adjacent VME Index Low C-squares and associated buffers.

Where two or more C-squares from Steps 1 and 2 are joined by their buffers or directly joined (in any way) they will be combined into one VME closure polygon (Figure S3). This reduces the number of polygons in a data-layer but does not change the protected area.

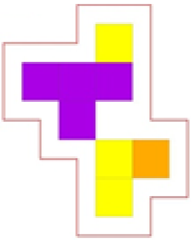

Figure 7.3. Scenario 1 Option 1, Step 3 illustrating the final VME closure polygon with buffers (red line).

All satellite VME C-squares in Step 1 above should be defined as individual VME closures with associated ½ C-square buffer (Figure 4). Many VMEs types can naturally consist of small patches of about one C-square in size or smaller.

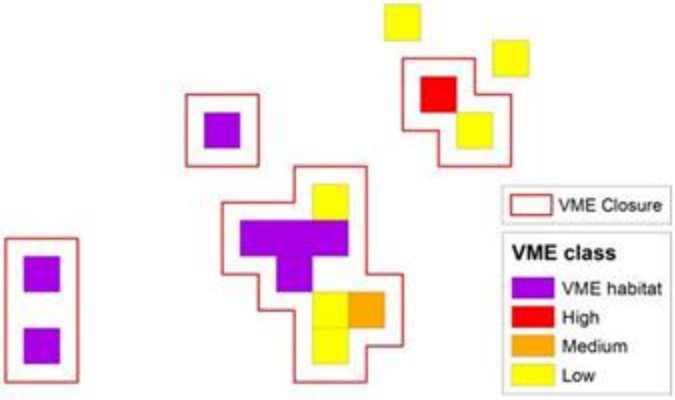

Figure 7.4. Scenario 1 Option 1, Step 4 illustrating the inclusion of isolated C-squares with buffers.

Fill all holes with 1 or 2 C-squares inside VME closures (Figure 5). Fishing vessels are unlikely to be able to fish effectively in very small areas without risking straying into closed areas. A trawler that fishes at 3.5 knots will cover 7nm in a typical 2h haul, which is equivalent to about between 2 and 3 C-squares. Open holes of less than 3 C-squares are therefore not considered practical.

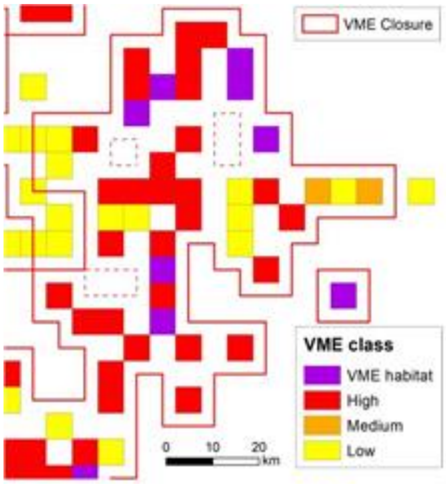

Figure 7.5. Scenario 1 Option 1, Step 5 illustrating the filling of holes (dashed lines) within the VME polygons (dark red lines) produced from Steps 1-4.

Option 2 - Protection for VME Habitat, VME Index C-squares and VME Elements

Select the VME elements with an occurrence of a VME Habitat or VME Indicator (High, Medium and Low). VME elements are selected with the VME points (using middle point position) rather than the C-squares to avoid selecting elements that intersect with the buffer of a C-square but not with a VME record per se (Figure 6). The VME elements used for Scenario 1 option 2 were limited to canyon and shoal elements. Other VME elements were excluded in this example but should be added in future. Using the point data for the VMEs ensures that the VME element is associated with the VME record.

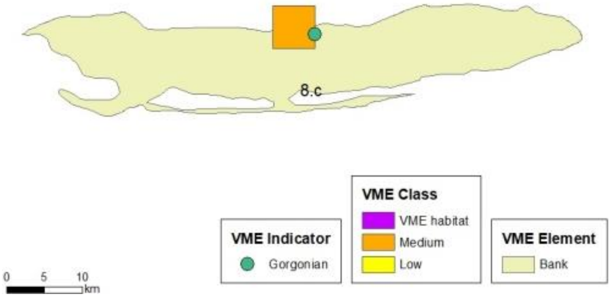

Figure 7.6. Scenario 1 Option 2, Step 1 illustrating the selection of VME element (bank) with an occurrence of a VME Indicator (Medium).

Select the C-squares overlapping with the VME elements selected in step 1 (Figure 7).

These three technical steps bring the VME elements which are most likely to contain VMEs into the closures. At the same time, VME elements for which there are no supporting evidence of VMEs are not included.

Figure 7.7. Scenario 1 Option 2, Step 2 illustrating the selection of the C-squares overlapping with the VME elements selected in step 1.

Remove the C-square buffer from Scenario 1 Option 1 that intersects with VME elements but does not overlap with the C-squares selected in Step 2 above, and include all C-squares that overlap with the VME element (Figure 8). The VME elements were not buffered. This is because the areas with VME elements are generally large and only C-squares along the periphery of the VME elements would potentially be subject to direct or indirect effects of bottom contact fishing.

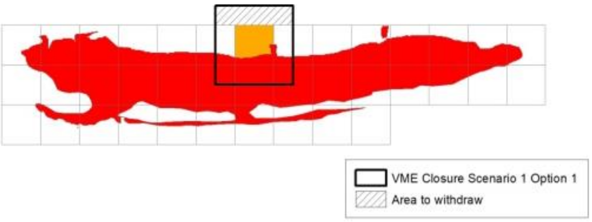

Figure 7.8. Scenario 1 Option 2, Step 3 illustrating the C-squares and its buffer from Scenario 1 Option 1 that intersect with the VME element (orange C-square with black surrounding buffer). In Step 3 the buffer (hatched area above the C-square) is removed.

Merge Step 3 above with Scenario 1 Option 1. This captures areas where VMEs are known or likely to occur (Figure 9). There may still be an under-representation of sea pen VMEs in this option.

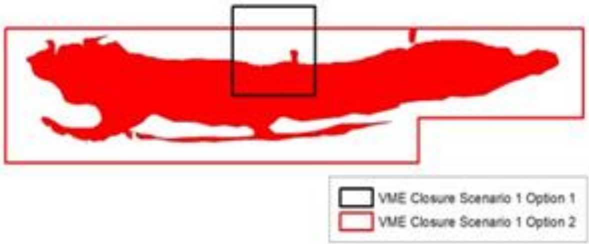

Figure 7.9. Scenario 1 Option 2, illustrating the difference between Scenario 1 Option 1 that does not include the VME element (black line) and Scenario 1 Option 2 that includes the VME element (red line).

Location of Closures in the NAFO NRA Under Scenario 1 Option 1

The VME data in the ICES VME Database for this area is comprised mostly of Low VME Index records (Figure 10A). This is not surprising as the weighting scheme typically gives lower values to trawl catch and to sea pens, both which are prevalent in the NAFO Regulatory Area and dominant in the ICES VME Database. Medium VME Index records are common also and are associated with sponge grounds (Figure 10A). Bona fide VME habitats and High VME Index records obtained by in situ observations are present in the region but are much sparser.

Application of the Steps outlined above for Scenario 1 Option 1 to the VME Index and VME habitat data present in Figure 10A produced the closures identified in Figure 10B under Scenario 1 Option 1 of the ICES WKEUVME framework (ICES, 2020). Both the index and closures are mapped on a spatial C-square grid scale (Rees, 2003) of 0.05° x 0.05°. This option identifies C-squares that contain VME habitats and VME Index Medium to High 'likelihood' of occurrence, regardless of fishing activity. C-squares with Low VME Index are only included when adjacent to VME Index Medium to High C-squares. This option prioritizes protection of VMEs where they are known to occur, regardless of fishing activity, and identifies many C-squares within the fishing footprint of <2000 m that are not currently protected by the NAFO Closed Areas (Figure 11).

Location of Closures in the NAFO NRA Under Scenario 1 Option 2

Scenario 1 option 2 uses knowledge of VME elements to fill in data gaps giving priority to protection of VMEs where they are known and where they are likely to occur, regardless of fishing activity. NAFO has identified a number of VME elements within the fishing footprint of the Regulatory Area (NRA) on Flemish Cap and the Tail of Grand Bank (Murillo et al., 2011). Here we used the elements canyons and shoals to demonstrate the application of Scenario 1 Option 2, recognizing that shelf-indenting canyons and other features were not included. The process identified candidate closure areas (Figure 12) that were more extensive than those of Scenario 1 Option 1 as would be expected. The increase includes large areas on the Tail of Grand Bank associated with the Southeast Shoal (https://www.cbd.int/doc/meetings/mar/ebsaws-2014-02/other/ebsaws-2014-02-submission-wwf-01-en.pdf).

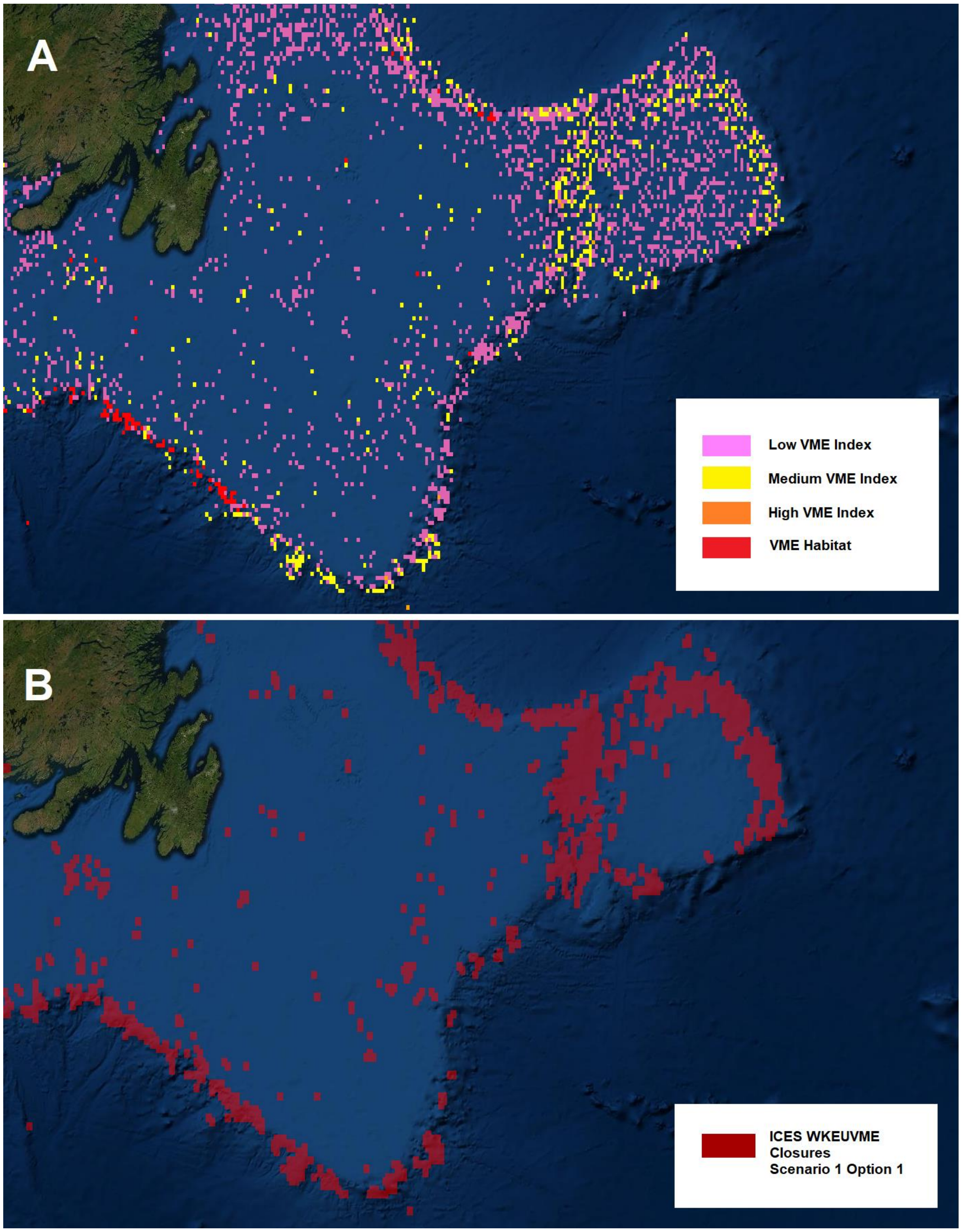

Figure 7.10. A) Location of regional VME Index and VME habitat data held in the ICES VME Database (https://vme.ices.dk/webservices.aspx Accessed 21 October 2021); B) Location of closures under Scenario 1 Option 1 of the ICES WKEUVME framework (ICES, 2020). The index and closures are mapped on a spatial C-square grid scale (Rees, 2003) of 0.05° x 0.05°.

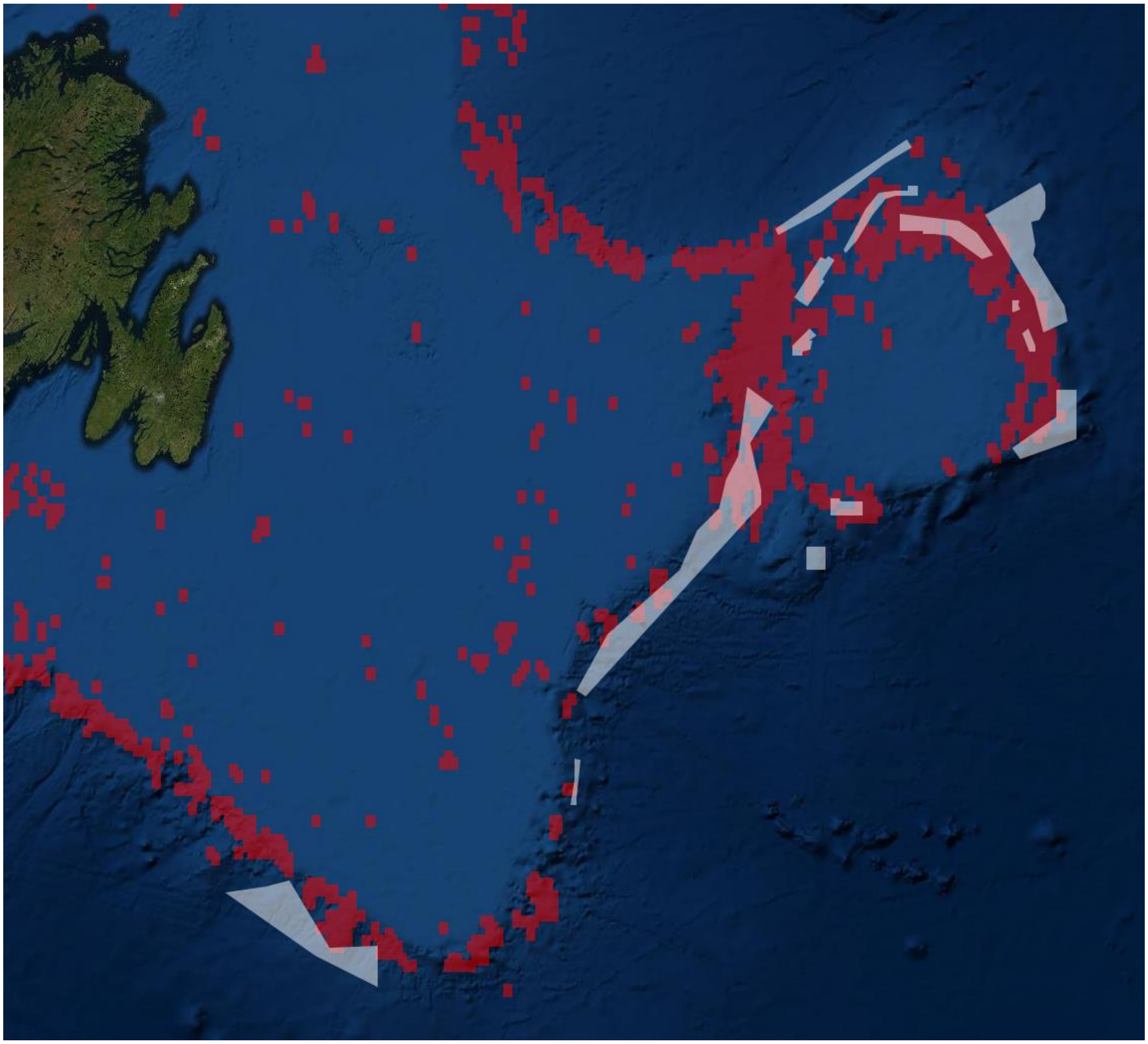

Figure 7.11. Location of closures under Scenario 1 Option 1 of the ICES WKEUVME framework (ICES, 2020) with the NAFO closed areas overlain (closure configuration as of 1 January 2022). The index and closures are mapped on a spatial C-square grid scale (Rees, 2003) of 0.05° x 0.05°.

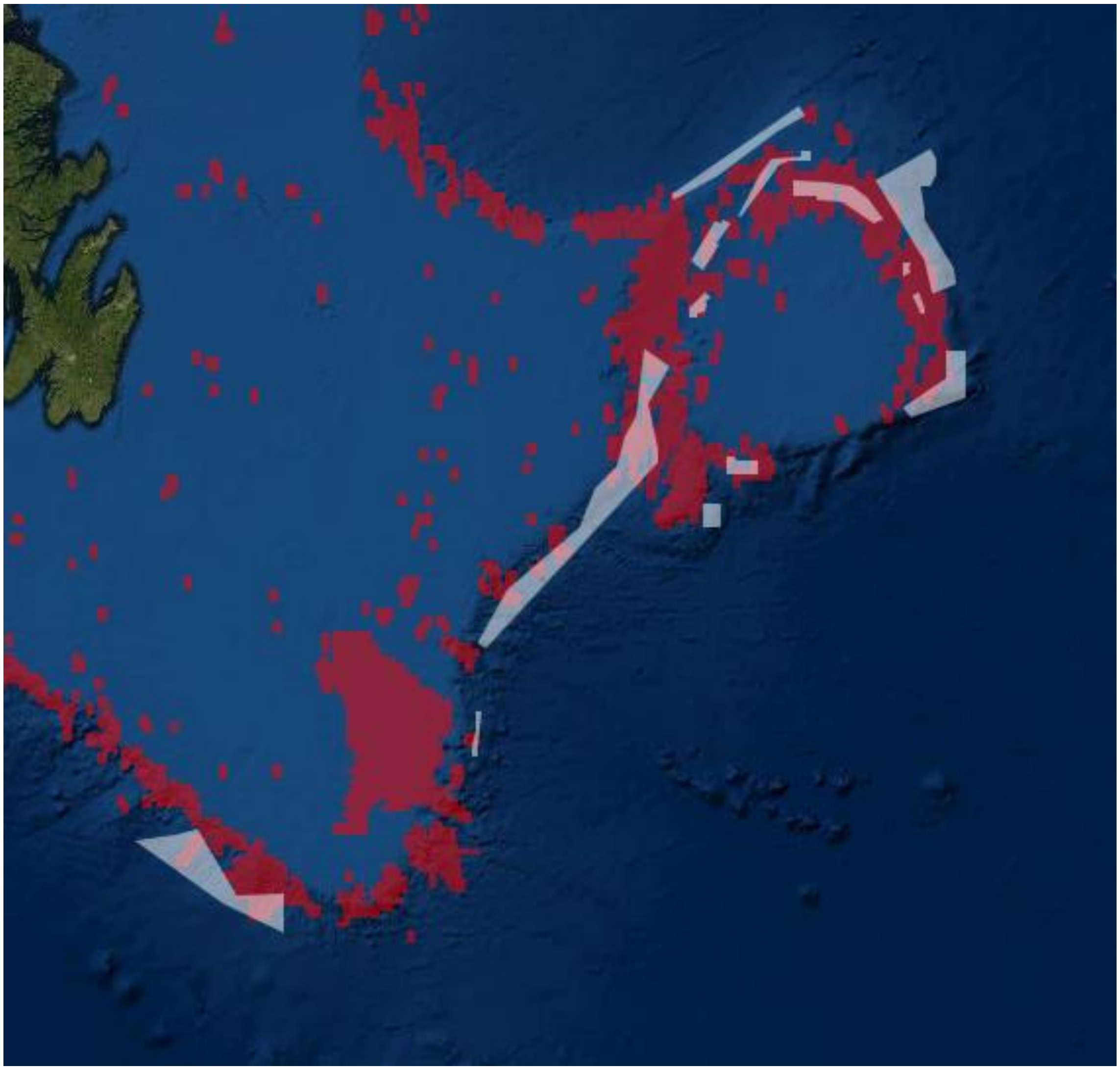

Figure 7.12. Location of closures under Scenario 1 Option 2 of the ICES WKEUVME framework (ICES, 2020) with the NAFO closed areas overlain (closure configuration as of 1 January 2022). The index and closures are mapped on a spatial C-square grid scale(Rees, 2003) of 0.05° x 0.05°.

Comparison of Closures in the NAFO NRA

The closures that are currently in place to protect VMEs in the NAFO area are much smaller in area than those identified through this analysis, whether under Scenario 1 Option 1 or Scenario 1 Option 2 (Figure 13). Many of the NAFO closures extend into deeper water where data were not available in the ICES VME database and where inclusion of slope, shelf indenting canyons and other VME elements under Scenario 1 Option 2 could extend the area in the Flemish Cap region. Nevertheless, NAFO has not closed all known VME areas and so it is not surprising that the closed areas fall short of protecting the VMEs herein identified.

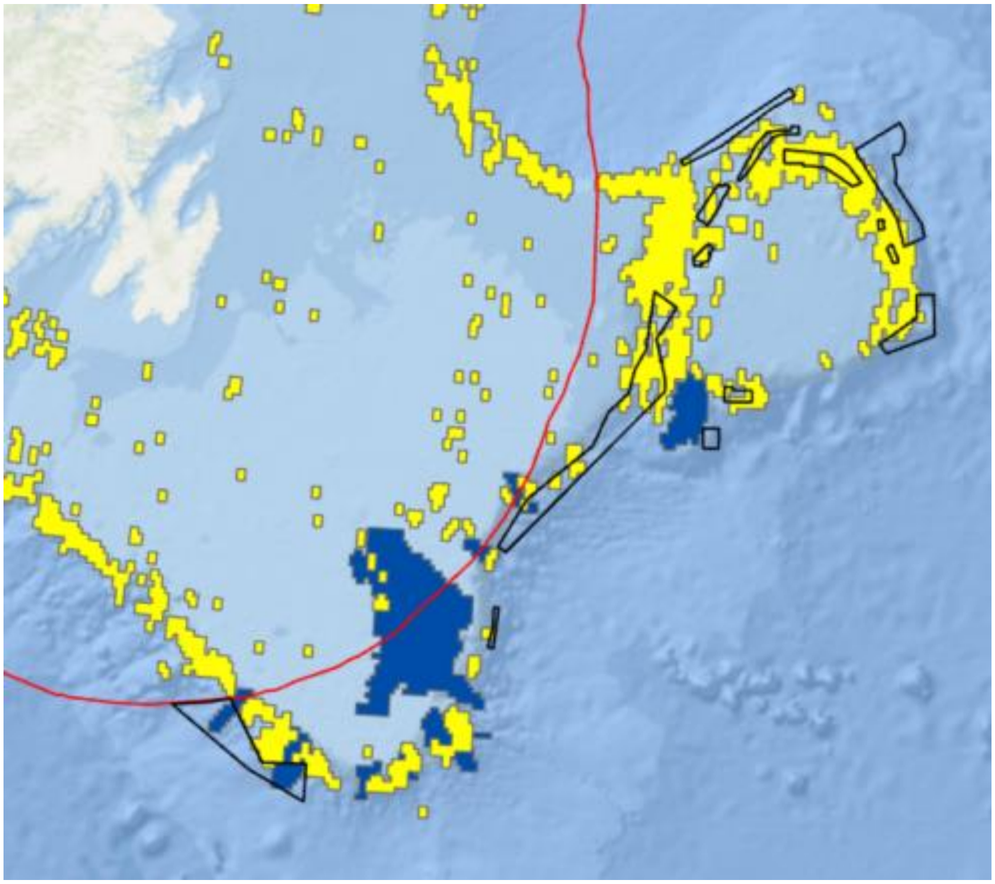

Figure 7.13. Location of closures under Scenario 1 Option 1 (yellow) overlain on locations identified under Scenario 1 Option 2 (blue) of the ICES WKEUVME framework (ICES, 2020) with the NAFO closed areas identified (closure configuration as of 1 January 2022). The index and closures are mapped on a spatial C-square grid scale (Rees, 2003) of 0.05° x 0.05°.

NAFO Approach to Identification of VMEs

NAFO undertook a review of the closed areas to protect VMEs in 2013/2014 and in 2020. At both times kernel density estimation (KDE) applied to research vessel trawl survey biomass data was used, along with an area-expansion technique (Kenchington et al., 2014), to identify significant concentrations of VME indicator taxa in the NAFO Regulatory Area (NRA). NAFO is unique amongst the RFMOs in having the data available to identify VMEs based on a combination of high biomass and discreteness.

Kernel density estimation (KDE) utilizes spatially explicit data to model the distribution of a variable of interest. It is a simple non-parametric neighbour-based smoothing function that relies on few assumptions about the structure of the observed data. It has been used in ecology to identify hotspots, that is, areas of relatively high biomass/abundance. With respect to marine benthic invertebrate species, it was first applied to the identification of significant concentrations of sponges in the NAFO Regulatory Area in 2009 (Kenchington et al., 2009) followed by an application to sea pens (Murillo et al., 2010). Since then it has been used to identify significant concentrations (VMEs) of corals, sponges and other VME indicators in both Canada (Kenchington et al., 2016) and in the NRA (NAFO, 2013; Kenchington et al., 2014; NAFO, 2020). The congruence between the KDE-generated VME polygons and areas of predicted occurrence derived from species distribution models (SDM) was examined, and were used to modify the polygons to eliminate areas where the taxon was not predicted to occur (NAFO, 2015). Many of the VME polygons were ground-truthed using ROVs and drop cameras. NAFO considers the KDE-derived polygons to be VMEs. A working group of fisheries managers and scientists propose the boundaries of closed areas based on this and other information such as fishing activity, VME elements, presence of VME indicator species and final decisions on closures are voted on by the Commission at the NAFO Annual Meeting. Therefore the major difference between the ICES WKEUVME approach and that used by NAFO lies in the analyses of VME biomass.

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iv) Conclusions from the perspective of WG-ESA arising from the joint session presentations

The framework WGFBIT is using should be applicable to VMEs, at least from a conceptual level. However, while that approach can be informative for general benthic taxa with recovery rates somewhat closer to the time horizon of fisheries management, the issue with VMEs is that the points will be mostly grouped in one region of the recovery space, e.g. that associated with “no effective recovery within management time horizons”. This means that while that framework can be useful for ongoing managing of impacts on “typical” shelf-based benthic communities that have relatively short recovery times, it may be less useful in situations (habitats) where the effective recovery is outside the time-frame of more traditional and established fishery management plans.

Some of these aspects of recovery for VME taxa could be explored by applying the WGFBIT framework to outputs from the sea pen ABM. One of the potential issues with the framework when applied to VMEs is the spatial scale at which you perform the analysis, and how the local vs global variability in the dynamics influence the outcomes (e.g. full population vs individual VME habitat patch, and how larval dispersion, connectivity, and fishing influence recovery at different spatial scales).

In terms of VME delineation, one obvious difference between the approaches taken by ICES and NAFO is the level of spatial resolution and quality/quantity of the data available. In NAFO there is comparatively far better data, so in the context of the proposed ICES VME benchmark process, the application of the ICES VME Index to NAFO VME data could be extremely informative to effectively help identify and understand where the ICES VME Index is robust, and where it isn’t.

A fundamental difference between the NAFO and ICES in identifying VME indicator species is that NAFO effectively takes as a binary classification approach, such that a species is or is not a VME taxa based on its life history characteristics and proceed from there to delineate areas of VME associated with that taxa. NAFO does not assign a higher VME “level” to any VME, all NAFO VMEs have equal status, and their differences simply arise by being composed of different species and habitats, and ecosystem services they provide. This is very different from the ICES VME index with defines a hierarchy of VME status; for example a sea pen VME is evaluated as having a lower level of VME status in comparison with, for example, large gorgonian VME. This may be appropriate when having to prioritise management action (especially if focused on vulnerability), but there remains much uncertainty with respect to understanding the functional significance of different VMEs which makes is very difficult to conclude that sea pen VME is less significant than large gorgonian VME – they are simply different VMEs. There is therefore an important conceptual difference between the VME identification methods as applied by NAFO and ICES, and it is this difference that is most likely driving the observed inconsistencies between maps of VME in the NAFO Regulatory Area derived by the ICES VME Index and NAFO approaches.

A combination of using SDMs to define VME probability surfaces, and KDE to extract polygons from those surfaces could be one way to obtain maps of VME distribution which are less sensitive to the vagaries associated with a subjective VME classification and identification Index.

It was agreed the Chair of WG-ESA would approach the organisers of the ICES VME benchmark process to offer relevant data and observations arising from the comparative analysis of VMEs (presented above) in support of the ICES VME benchmark process.

d) Appointment of co-Chair, and process for on-going appointment of WG-ESA Chairs

WG-ESA discussed the process for appointing new chairs and the appointment of a new co-chair to replace Pierre Pepin.

During discussions in SC in September 2021, it was noted that WG-ESA does not have a formal process for the appointment of Working Group chairs, or fixed terms for chairs as is the case for SC and its standing committees, and suggested that it would be beneficial to consider adopting a more formal procedure. WG-ESA agreed that it would benefit the group to have a greater turnover of chairs, rather than the current practice where one co-chair has been in post for more than 10 years, noting that working groups are, unlike standing committees, nominally temporary bodies and not intended to continue indefinitely. The possibility of WG-ESA changing status to become a standing committee of SC has been discussed in the past but was rejected at that time.

Several WG members noted that the current structure of having two co-chairs, leading on the VME/SAI work and the ecosystem modeling elements of the roadmap respectively, is very effective and should be maintained.

No nomination or volunteers for the second co-chair position came forward during the current meeting. A small committee will be set up to identify and approach possible candidates after the current meeting

It was agreed that Andy Kenny should continue as chair at least in the short term until another co-chair can be appointed, and for another one or two meetings in order to support the new co-chair.

e) Date and place of next meeting

The next WG-ESA meeting will be held in Halifax, Nova Scotia, from 15 to 24 November 2022.

2. Adjournment

The Chair thanked the participants for their hard work and cooperation, noting the particularly difficult circumstances of this year's meeting. There being no other business the meeting was adjourned at 12:30 on 25 November 2021.

APPENDIX 1: AGENDA: NAFO SCIENTIFIC COUNCIL (SC) WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT (WG-ESA)

Provisional Agenda and Terms of Reference (ToRs)

1. Opening by the Chair, Andrew Kenny (UK)
2. Appointment of Rapporteur
3. Adoption of Agenda
4. Review of Annual Meeting 2021 outcomes – SAI and VME closures, Ecosystem Roadmap
5. Commission requests for advice on management in 2023 and beyond, requiring input from WG-ESA in 2021 to be presented at the Scientific Council meeting June 2022.

- a) **COM. Request #6**. The Commission requests that Scientific Council continue work on the sustainability of catches aspect of the Ecosystem Roadmap, including:
    - i. In consultation with WG-EAFFM via co-Chairs, **convene independent experts to do a scientific review** of; a) the estimation of fisheries production potential and total catch indices, and b) the adequacy of this analysis for their proposed use within the NAFO roadmap (Tier 1), while considering how species interactions are expected to be addressed in the future (Tier 2) within the overall Roadmap structure. The outcomes of this review would need to be tabled in June at Scientific Council to be available in advance of the planned workshop in 2022.
    - ii. Work to support the WG-EAFFM workshop in 2022, which will explore ecosystem objectives and further develop how the Roadmap may apply to management decision making.
    - iii. Continue its work to develop models that support implementation of Tier 2 of the EAFM Roadmap.
- b) **COM. Request #7**. The Commission requests that Scientific Council, in relation to VME analyses:
    - i. Conduct a re-assessment of its previously recommended closures of 7a, 11a, 14a and 14b, incorporating catch and effort data for fisheries of shrimp from 2020 and 2021 into the fishing impact assessments. This work is to be completed by the 2023 Scientific Council meeting.
    - ii. Review the effectiveness of NAFO CEM, Chapter 2 from a scientific and technical perspective and report back to the WG-EAFFM . WG-EAFFM would subsequently in 2022 consider whether any modifications to this Chapter should be recommended.
- c) **COM. Request #14**. The Commission requests Secretariat and the Scientific Council with other international organizations, such as the FAO and ICES to inform the Scientific Council's work related to the potential impact of activities other than fishing in the Convention Area. This would be conditional on CPs providing appropriate additional expertise to Scientific Council.
- d) **COM. Request #15.** The Commission request that Scientific Council proceed with developing the ecosystem summary sheets for 3M and 3LNO move toward

undertaking a joint Workshop with ICES (International Council for the Exploration of the Sea) as part of a peer review of North Atlantic ecosystems.

6. Review Recommendations

7. Other Business
   a) Updates from the Executive Secretary on, **i.** MoU with the Sargasso Sea Commission, **ii.** renewal of the ABNJ Deep-Seas Fisheries Project.

   b) Joint ICES/IUCN workshop on OECMs – NAFO sponge VMED case study. WGEAFFM Response and way forward for NAFO OECMs.

   c) Appointment of co-Chair, and process for on-going appointment of WG-ESA Chairs

   d) Date and place of next meeting

8. Adjournment

ANNEX 1. WG-ESA TERMS OF REFERENCE

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.* ***Mar***
2. *Update on VME indicator presence on NAFO seamounts from the 2021 Okeanos Explorer "2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts" expedition.* ***Ellen, Javier, Cam, OE (NOAA)***

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. *Agree plan to conduct a re-assessment of closures of 7a, 11a, 14a and 14b, incorporating catch and effort data for fisheries of shrimp from 2020 and 2021 into the fishing impact assessments. This work is to be completed by the 2023 Scientific Council meeting (**COM. Request #7a**).* ***Andy, Ellen, Anna, Cam.***
2. *Review the VME biomass data provided to SC for inconsistencies in the impact assessment calculations –* ***James, Anna, Andy, Cam, Javier, Neil, Ellen, Mariano.***
3. *Up-date on analysis to improve methods for determining the area of impact for SAI -* ***James, Anna, Andy, Cam, Javier, Neil, Ellen, Mariano***
4. *Up-date on analysis to better understand the functional significance of VME for fish –* ***Anna, James, Andy***
5. *Up-date on connectivity analysis to assess habitat fragmentation in VME –* ***Ellen, Shuangqiang, Cam, Javier, Mariano, Andy, Mar***
6. *Work plans for the next review of VME and re-assessment of bottom fisheries including research to develop assessment methods ahead of the next reviews (to include discussions on SAI metrics, assessment of functions, e.g. spatial scope of the VME and SAI assessments (EPU vs. NRA), and the timing of the assessments etc.* ***ALL***

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. *Review the effectiveness of NAFO CEM, Chapter 2 from a scientific and technical perspective and report back to the WG-EAFFM. WG-EAFFM would subsequently in 2022 consider whether any modifications to this Chapter should be recommended (COM. Request #7b).*

2. *The Commission requests that Scientific Council continue work on the sustainability of catches aspect of the Ecosystem Roadmap, including (COM. Request #6): Mariano, Andy and others.*
    a. *In consultation with WG-EAFFM via co-Chairs, convene independent experts to do a scientific review of; a) the estimation of fisheries production potential and total catch indices, and b) the adequacy of this analysis for their proposed use within the NAFO roadmap (Tier 1), while considering how species interactions are expected to be addressed in the future (Tier 2) within the overall Roadmap structure. The outcomes of this review would need to be tabled in June at Scientific Council to be available in advance of the planned workshop in 2022.*
    b. *Work to support the WG-EAFFM workshop in 2022, which will explore ecosystem objectives and further develop how the Roadmap may apply to management decision making.*
    c. *Continue its work to develop models that support implementation of Tier 2 of the EAFM Roadmap.*
3. *The Commission requests the Secretariat and the Scientific Council with other international organizations, such as the FAO and ICES to inform the Scientific Council's work related to the potential impact of activities other than fishing in the Convention Area. This would be conditional on CPs providing appropriate additional expertise to Scientific Council. (COM. Request #14). Pablo and others*

4. *The Commission requests that Scientific Council proceed with developing the ecosystem summary sheets for 3M and 3LNO move toward undertaking a joint Workshop with ICES (International Council for the Exploration of the Sea) as part of a peer review of North Atlantic ecosystems. (COM. Request #15). Mariano and others.*

5. *The results of the removal of survey trawls from closed areas is dependent on the closed areas not changing over time – how do we address this? Also how do we ensure the applicability of the current VME and SAI assessment methods without continuity of VME closed area survey data? - ALL*

APPENDIX 2 LIST OF PARTICIPANTS

Name	Affiliation	E-mail
CHAIRS		
Kenny, Andrew (WG-ESA Chair)	CEFAS, Lowestoft Laboratory, Lowestoft, UK	andrew.kenny@cefas.co.uk
CANADA		
Austin, Deborah	Fisheries and Oceans Canada, Ottawa, ON	deborah.austin@dfo-mpo.gc.ca
Cuff, Andrew	Fisheries and Oceans Canada, St. John's, NL	andrew.cuff@dfo-mpo.gc.ca
Dwyer, Karen	Fisheries and Oceans Canada, St. John's, NL	karen.dwyer@dfo-mpo.gc.ca
Gullage, Lauren	Fisheries and Oceans Canada, St. John's, NL	lauren.gullage@dfo-mpo.gc.ca
Kenchington, Ellen	Fisheries and Oceans Canada, Dartmouth, NS	ellen.kenchington@dfo-mpo.gc.ca
Koen-Alonso, Mariano	Fisheries and Oceans Canada, St. John's, NL	mariano.koen-alonso@dfo-mpo.gc.ca
Lirette, Camille	Fisheries and Oceans Canada, Dartmouth, NS	camille.lirette@dfo-mpo.gc.ca
Murillo-Perez, Francisco Javier	Fisheries and Oceans Canada, Dartmouth, NS	javier.murillo-perez@dfo-mpo.gc.ca
Neves, Barbara	Fisheries and Oceans Canada, St. John's, NL	barbara.neves@dfo-mpo.gc.ca
Ollerhead, Neil	Fisheries and Oceans Canada, St. John's, NL	neil.ollerhead@dfo-mpo.gc.ca
Regular, Paul	Fisheries and Oceans Canada, St. John's, NL	Paul.Regular@dfo-mpo.gc.ca
Simpson, Mark	Fisheries and Oceans Canada, St. John's, NL	mark.simpson@dfo-mpo.gc.ca
Stenson, Garry	Fisheries and Oceans Canada, St. John's, NL	garry.stenson@dfo-mpo.gc.ca
Wang, Shaungqiang	Fisheries and Oceans Canada, Dartmouth, NS	shaungqiang.wang@dfo-mpo.gc.ca
Wareham-Hayes, Vonda	Fisheries and Oceans Canada, St. John's, NL	vonda.wareham-hayes@dfo-mpo.gc.ca
EUROPEAN UNION		
Alpoim, Ricardo	Instituto Português do Mar e da Atmosfera, Lisbon, Portugal	ralpoim@ipma.pt
Durán Muñoz, Pablo	Instituto Español de Oceanografía, Vigo, Spain	pablo.duran@ieo.es
Garrido, Irene	Instituto Español de Oceanografía, Vigo, Spain	irenegarridof@hotmail.com
González-Troncoso, Diana	Instituto Español de Oceanografía, Vigo, Spain	diana.gonzalez@ieo.es
González-Costas, Fernando	Instituto Español de Oceanografía, Vigo, Spain	fernando.gonzalez@ieo.es

Merino Buisac, Adolfo	European Commission. Directorate-General for Maritime Affairs and Fisheries. Unit C.3 – Scientific advice and data collection	adolfo.merino-buisac@ec.europa.eu
Sacau-Cuadrado, Mar	Instituto Español de Oceanografía, Vigo, Spain	mar.sacau@ ieo.es
JAPAN		
Taki, Kenji	Scientist, National Research Institute of Far Seas Fisheries, Agency, 5-7-1, Orido, Shimizu-Ward, Shizuoka-City, Shizuoka, Japan	takisan@fra.affrc.go.jp
RUSSIAN FEDERATION		
Fomin, Konstantin	Knipovich Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, Russian Federation	fomin@pinro.ru
Petukhova, Natalya	Russian Federal Research Institute of Fisheries & Oceanography, Moscow, Russian Federation	ng_petukhova@mail.ru
Tairov, Temur	Representative of the Federal Agency for Fisheries of the Russian Federation in Canada, Bedford, NS, Canada	temurtairov@mail.ru
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND		
Bell, James	CEFAS, Lowestoft Laboratory, Lowestoft, UK	james.bell@cefas.co.uk
Downie, Anna	CEFAS, Lowestoft Laboratory, Lowestoft, UK	anna.downie@cefas.co.uk
Readdy, Lisa	CEFAS, Lowestoft Laboratory, Lowestoft, UK	lisa.readdy@cefas.co.uk
UNITED STATES OF AMERICA		
Mencher, Elizabethann	National Marine Fisheries Service, Office of International Affairs and Seafood Inspection, NOAA, USA	elizabethann.mencher@noaa.gov
Sosebee, Katherine Chair of STACFIS	National Marine Fisheries Service, NEFSC, Woods Hole, Massachusetts	katherine.sosebee@noaa.gov
INVITED EXPERTS		
Adamack, Aaron		aaron.adamack@dfo-mpo.gc.ca
Baker, Krista		Krista.Baker@dfo-mpo.gc.ca
Cantwell, Kasey	NOAA Okeanos Explorer	kasey.cantwell@noaa.gov
Cogliati, Karen		karen.cogliati@dfo-mpo.gc.ca
Deering, Robert		robert.deering@dfo-mpo.gc.ca
Diz, Daniela	The Lyell Centre, Heriot-Watt University, Scotland	dizdani@gmail.com d.diz@hw.ac.uk
Eddy, Tyler		tyler.Eddy@mi.mun.ca
Fuller, Susanna	Oceans North, Halifax Office, Halifax, NS, Canada	susannafuller@oceansnorth.ca
Kimberly Galvez		Kimberly.galvez@noaa.gov

Irvine, Fonya		fonyairvine@gmail.com
Krumsick, Kyle		Kyle.Krumsick@mail.concordia.ca
Lewis, Keith		Keith.Lewis@dfo-mpo.gc.ca
Lucet, Valentin,		valentin.lucet@gmail.com
Mullowney, Darrell		darrell.mullowney@dfo-mpo.gc.ca
Munro, Hannah		hannah.munro@dfo-mpo.gc.ca
Pedersen, Eric		eric.pedersen@concordia.ca
Perez-Rodriguez, Alfonso		alfonso.perez-rodriguez@hi.no
Robertson, Matthew		matthew.robertson@mi.mun.ca
Waller, Rhian	NOAA Okeanos Explorer	rhian.waller@maine.edu
NAFO SECRETARIAT		
Blasdale, Tom	NAFO Secretariat, Halifax, NS, Canada	tblasdale@nafo.int
Federizon, Ricardo	NAFO Secretariat, Halifax, NS, Canada	rfederizon@nafo.int
Kingston, Fred	NAFO Secretariat, Halifax, NS, Canada	fkingston@nafo.int
McAllister, Fiona	NAFO Secretariat, Halifax, NS, Canada	FMcAllister@nafo.int