Northwest Atlantic Fisheries Organization

Serial No. N7484 **NAFO SCS Doc. 23/25**

SCIENTIFIC COUNCIL WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT – NOVEMBER 2023

Report of the 16th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA)

NAFO Headquarters, Halifax (Canada)
14-23 November 2023

Contents

Recommended Citation

NAFO, 2023. Report of the Scientific Council Working Group on Ecosystem Science and Assessment, 14 - 23 November 2023, Halifax, Nova Scotia, Canada. NAFO SCS Doc. 23/25.

WG-ESA Meeting Participants
14-23 November 2023

From left to right:
Back row: Anna Downie, Javier Murrillo-Perez, Mariano Koen-Alonso, Neil Ollerhead, Andrew Kenny, Mark Simpson, Martha Krohn, Kenji Taki, Brynn Devine
Front row: Tom Blasdale, Mar Sacau Cuadrado, Diana González-Troncoso, Brynhildur Benediktsdóttir

From left to right:
Top row: Meeting room, Stephan Hamisch, Irene Garrido
Middle row: James Bell, Miguel Caetano, Lauren Gullage
Bottom row: Bárbara Neves, Patricia Gonçalves, Cam Lirette

Missing from photo: Rylan Command, Robert Deering, Ellen Kenchington, Hannah Munro, Sara Abalo, Pablo Durán Muñoz, Adolfo Merino Buisac, Daniela Diz, Lisa Hendrickson, Elizabethann Mencher, Katherine Sosebee, Tony Thompson, Susanna Fuller

REPORT OF THE SC WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT (WG-ESA)

14-23 November 2023

1. Opening by the co-Chairs

The NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA) met during 14-23 November 2023 to address matters referred to it by the Scientific Council relating to various Commission requests, as well as its wider terms of reference.

The meeting was opened at 09:00 (Halifax Time) on 14 November 2023 by the co-Chair, Mar Sacau Cuadrado (EU) and acting co-Chair, Diana González-Troncoso (EU).

The co-Chairs 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. ToRs and Commission requests are presented in the Agenda in Appendix 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 data and VME indicator species distribution from EU, EU-Spain Groundfish Surveys (2023) and Canadian Surveys (2022 Fall/ 2023 Spring)

i) EU-Spain and Portugal and EU- Spain Groundfish Surveys (2023)

During 2023, R/V Vizconde de Eza carried out three surveys: 1) In Division 3L (Flemish Pass) sampling between 129 - 1481 meters depth, with a total of 100 tows (95 valid; 5 no valid); 2) in Division 3M (Flemish Cap) sampling between 137 - 1455 m depth, with a total of 184 tows (181 valid; 3 no valid); and 3) in Divisions 3NO (Grand Banks of Newfoundland) sampling between 43 - 1430 m depth with a total of 106 tows (103 valid; 3 no valid). In total there were 390 bottom trawl tows, eleven of them considered invalid due to technical problems during the fishing operation. 166 hauls out of 379 valid tows have shown zero catches (i.e. no presence) of VME indicator species groups. This represents the 43.8% of the total valid hauls. A brief description of the survey methodology can be found in Durán Muñoz et al. (2020). Sponges were recorded in 111 of the 379 valid tows (29.3% of the valid tows analyzed), with depths ranging between 51 - 1481 m. There were two significant catches of sponges (≥ 100 kg/tow) in these tows, both of which fell within the VME polygons for sponges. Large gorgonians were recorded in 9 of the 379 valid tows (2.4% of valid tows analyzed), at mean depths between 463 and 959 m. There was one significant catch of large gorgonians (≥ 0.6 kg/tow) in these tows, which fell outside the VME polygons for large gorgonians. Small gorgonians were recorded in 42 of the 379 valid tows (11.08% of valid tows analyzed), at mean depths between 227 and 1481 m. There were no significant catches of small gorgonians (≥ 0.2 kg/tow) in these tows. Sea pens were recorded in 133 of the 379 valid tows (35.1% of valid tows analyzed), at mean depths between 63 and 1444 m. There was one significant catch of sea pens (≥ 1.3 kg/tow) in these tows, which fell within the VME polygons for sea pens. Black corals were recorded in 15 of the 379 valid tows (4% of valid tows analyzed), at mean depths between 468 and 1187 m. There were two significant catches of black corals (≥ 0.4 kg/tow) in these tows, both of which fell outside the VME polygons for black corals. Sea squirts were recorded in 7 of the 379 valid tows (1.85% of valid tows analyzed), at mean depths between 43 and 228 m. There was one significant catch of sea squirts (Boltenia ovifera) (≥ 0.35 kg/tow) in these tows, which fell within the VME polygons for sea squirts. Bryozoans were recorded in 31 of the 379 valid tows (8.18% of valid tows analyzed), at mean depths between 43 and 1225 m. There were no significant catches of bryozoans (≥ 0.2 kg/tow) in these tows.

ii) Canadian Surveys (2022 Fall / 2023 Spring)

In the Fall of 2022 and Spring of 2023 the Canadian Multispecies Surveys, conducted by Fisheries and Oceans Canada, DFO (McCallum and Walsh, 1996), sampled the Grand Bank of Newfoundland (NAFO Divs. 3LNO) between mean depths of 36 - 711 m, with a total of 129 tows (122 valid; 7 invalid). The Fall 2022 sets that fell within the NRA were conducted using the CCGS Needler (32% of all sets, with one unsuccessful set) and the CCGS Cabot (68% of all sets, with one unsuccessful set). The Spring 2023 sets that fell within the NRA were conducted using the CCGS Teleost (57% of all spring sets, with two unsuccessful sets) and the CCGS Cabot (43% of all spring sets, with three unsuccessful sets). DFO is transitioning from the CCGS Teleost and CCGS Alfred Needler to new vessels, the CCGS Capt Jacques Cartier and CCGS John Cabot for its annual spring (Div. 3LNOPs) and fall (Div. 2HJ3KLNO) multispecies surveys. The new vessels use the same fishing protocols as previous (Needler and Teleost), but minor modifications have been made to the trawl (Wheeland et al., 2023).

Comparative fishing data on corals, bryozoans and *Boltenia* sp. were insufficient for the development of conversion factors across these surveys. Given that we are unable to inform on the relative catchability of these taxa between the previous vessels and the new vessels using the modified survey trawl, caution should be taken when interpreting the data presented here based on the new vessels. For the CCGS Teleost-Cartier/Cabot comparison (Fall 2021-2022, 2HJ3KL) and CCGS Needler-Cabot comparison (Fall 2021-2022, Fall 3KL), analysis indicated that no significant difference in catchability of sponges, and conversion factors do not need to be applied for this taxa (DFO, in press). Results of the 2022 and 2023 combined data (and vessels) showed that sponges were recorded in 66 of the 122 valid tows (54.1%), with mean depths ranging between 44 - 695 m. There were no significant catches of sponges (≥ 100 kg/tow) in these tows. No large gorgonians were recorded during the DFO 2022 Fall and 2023 Spring surveys. Small gorgonians were recorded in four of the 122 valid tows (3.28%), with mean depths ranging between 184 - 603 m. There were two significant catches of small gorgonians (≥ 0.2 kg/tow) in these tows, with *Acanella arbuscula* being the small gorgonian species identified in two of these sets, including one of the significant catches. Sea pens were recorded in 16 of the 122 valid tows (13% of total tows analysed), with mean depths ranging between 63 - 1444 m. No tows had significant catches of sea pens (≥ 1.3 kg/tow). No black corals were recorded during the DFO 2022 Fall and 2023 Spring surveys. Sea squirts (*Boltenia ovifera*) were recorded in three of the 122 valid tows (2.5% of total tows analysed), with mean depths ranging between 59 – 236 m. No tows had significant catches of sea squirts (≥ 0.35 kg/tow). Bryozoans were recorded in 11 of the 122 valid tows (9% of total tows analysed), with mean depths ranging between 44 – 427 m. No tows had significant catches of bryozoans (≥ 0.2 kg/tow).

Above information of EU, EU-Spain and Canadian surveys, including distribution maps of VME species groups, is further detailed in SCR Doc. 23/055.

Following the presentation, WG-ESA participants provided suggestions pertaining to the VME encounters SCR (SCR Doc. 23/055). One of the suggestions was to include the number of captures (non-significant and significant) that fell inside closed areas for VME protection, in order to illustrate the accomplishment of the SC recommendation “minimize impacts of the sampling and maximize the collection of data in the hauls made in those vulnerable areas” (NAFO, 2023). It was also suggested to include the species composition of VME taxa for significant catches. Finally, it was suggested to investigate temporal trends for significant catches during WG-ESA’s annual update on VME indicator species distribution in the NRA. The first two suggestions were incorporated to the 2023 SCR. The recommendation regarding assessing temporal trends has been considered, and the data are expected to be presented during the 2024 WG-ESA meeting.

iii) Acknowledgements

The collection of the EU-Spain and Portugal and EU-Spain Groundfish Surveys used in this paper has 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. The study was funded by the European Union NextGenerationEU within the framework of the Agreement between the Ministry of Agriculture, Fisheries and Food and the State Agency of the Spanish National Research Council, M.P. -through the Spanish Institute of Oceanography- to promote fisheries research as a basis for sustainable fisheries management, of the Recovery, Transformation and Resilience Plan of the Government of Spain. This output reflects only the author’s view (SAM; MS & PDM) and the European Union cannot be held responsible for any use that may be made of the information contained therein. BMN, VWH, and RC acknowledge DFO-NL personnel and Canadian Coast Guard captain and crew for Canadian data collection.

References:

DFO. In press. Newfoundland & Labrador Comparative Fishing Analysis – Part 1. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.

Durán Muñoz, P., Sacau, M., García-Alegre, A., Román, E. (2020) Cold-water corals and deep-sea sponges by-catch mitigation: Dealing with groundfish survey data in the management of the northwest Atlantic Ocean high seas fisheries. Marine Policy, 116, 103712. https://doi.org/10.1016/j.marpol.2019.103712

NAFO (2023) Report of the Scientific Council, 02 -15 June 2022, Halifax, Canada. NAFO SCS Doc. 23/18.

Abalo-Morla, S., Neves, B.M., Wareham Hayes, V., Sacau, M. and Durán-Muñoz, P. 2023. New preliminary data on VME encounters in NAFO Regulatory Area (Divs. 3LMNO) from EU, EU-Spain and Portugal Groundfish Surveys (2023) and Canadian surveys (Fall 2022 & Spring 2023). NAFO SCR Doc. 23/055 Serial No. N7485.

Wheeland, L., Trueman, S., Rideout, R. 2023. Coverage of the 2022 Canadian (Newfoundland And Labrador Region) Multi-Species RV Bottom Trawl Survey with notes on Comparative Fishing. NAFO SCR Doc. 23/042.

b) ToR 1.2. Workplan for VMS data filtering

Vessel monitoring system (VMS) data are used to generate tracks of fishing activity, supporting the development of effort and biomass layers used in various WG-ESA analyses. Currently, VMS data are filtered based on speed to retain points where vessels are travelling at fishing speeds (between 0.5 and 5 knots). The speed-filtered VMS data are used to generate tracks, which are subsequently clipped to the fishing footprint within the NRA. To address concerns surrounding how accurately the speed-filtered tracks represent fishing effort by trawls, additional filtering approaches were explored. This work was originally presented to WG-ESA in 2022 (NAFO, 2022), and again in 2023 for further consideration and work planning.

i) Summary of previous work

In 2022, filters were developed for the track data utilizing knowledge of normal trawl fleet behaviour. These filters evaluated tracks based on maximum fishing depth, track length, trawl duration and depth range. Summaries of these approaches are presented below, and detailed descriptions may be found in the 2022 WG-ESA report.

ii) Maximum Fishing Depth Filter

Based on data collected by Scientific Observers from the Spanish commercial trawl fishery data (1992-2020) a maximum trawl depth of 1500 m was identified. To account for this, a maximum depth filter was applied to exclude tracks in areas where depths were greater than 1500m.

iii) Turn Analysis and Track Length Filtering

A maximum expected trawl length of approximately 75 km was estimated using observer data from the Spanish commercial trawl fishery. An analysis of the existing speed-filtered tracks found that 36% of the total kilometres of effort were associated with tracks exceeding 75 km in length, with some tracks as long as 850 km. Assessment of the longer tracks found that they frequently followed an alternating pattern consisting of a series of long parallel segments following a bathymetric contour, punctuated by abrupt, short turn segments often running perpendicular to bathymetric contours (Figure 4.1). Because the speed of these vessels fell within the threshold used to describe fishing activities (0.5 - 5 knots), the entire track was treated as a single fishing event and subject to removal based on length and range filters in subsequent analyses.

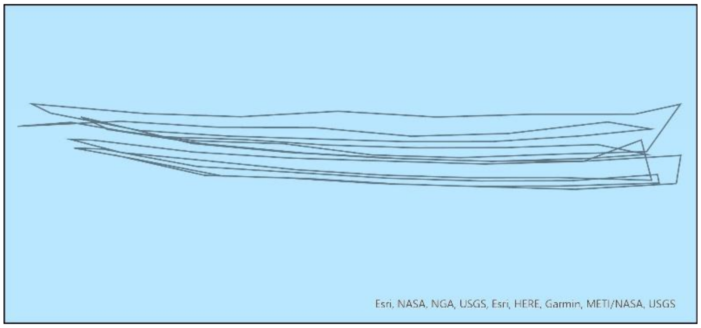

Figure 4.1. Sample long track demonstrating alternating long and short segments.

To address this, an analysis was conducted to calculate the change in bearing between consecutive track segments (Figure 4.2). Tracks were then split at any point where the change in the bearing was greater than 45° to the left or right from the previous segment. This reduced the length of individual tracks and ensured the retention of fishing effort that would have otherwise been excluded by length filters.

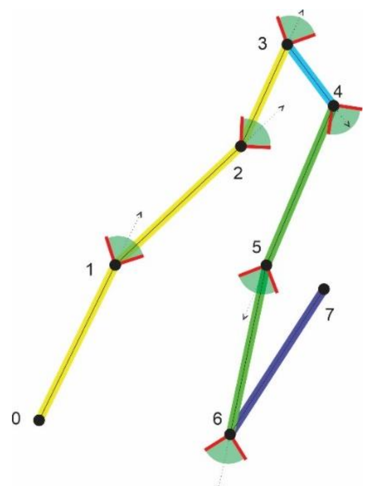

Figure 4.2. The track was constructed from 8 VMS pings and comprises seven segments. The green zone indicates the region 45° to the left and right of the bearing of each segment. A turn is identified, and the track is split anywhere the second segment of each pair falls outside this region. In this example, the original track will be split into four segments: 1-3, 3-4, 4-6, and 6-7.

Once the tracks had been processed using the turn analysis, length filtering was applied to remove all tracks exceeding 75 km in length (the maximum expected length of a trawl).

iv) Depth Range Filtering

The resulting tracks were then filtered by depth range. Observer data from Spanish commercial trawl fisheries indicated the expected depth range between the start and end of a tow was likely to be at most 250 m. The start and end of tow depths for the tracks were determined using the GEBCO bathymetric dataset (2022), differences were calculated, and all trawl tracks that exceeded the 250 m threshold were removed.

v) Neighborhood Bearing Analysis

In 2023, a neighborhood-bearing filtering analysis was presented as another approach to identify spurious tracks. This analysis involves dividing the tracks into 5km x 5km grid cells and analyzing the distribution of the bearings of the tracks in that cell. Figure 4.3a shows a set of tracks from a single grid cell, and Figure 4.3b shows the distribution of the bearings in that cell. Analyzing the frequency distribution enables us to identify those bearings that represent the predominant track orientation and those that run counter to it. Figure 4.4 illustrates the spatial representation of those tracks that fall within ± 1 standard deviation of the mean, shown in green, and those outside, in red.

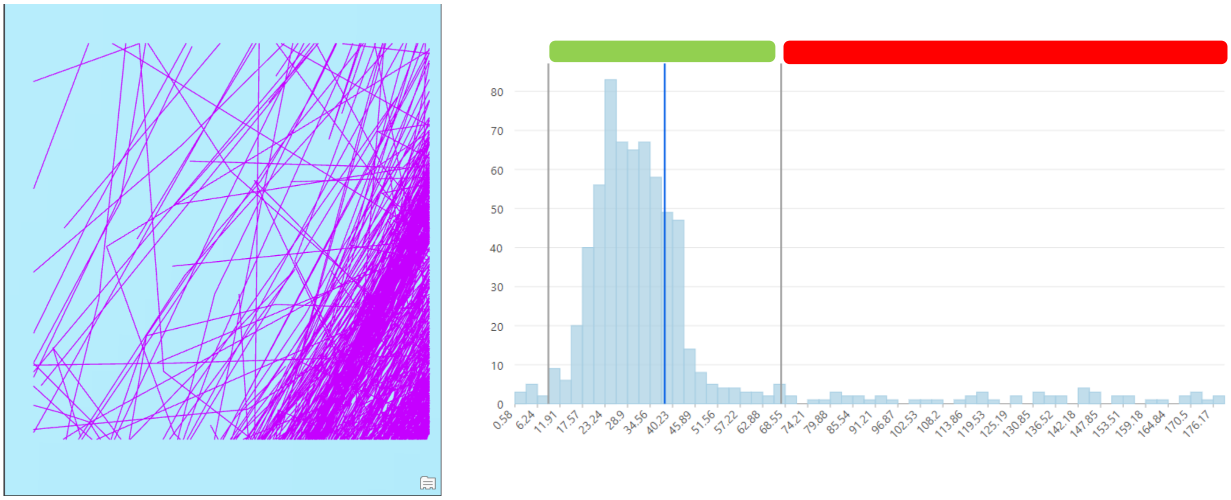

Figure 4.3. *Left:* sample set of trawl tracks in a 5km x 5km grid cell, and *right:* the frequency distribution of the bearings of the tracks in that cell. The vertical blue and grey lines indicate the mean and mean + 1 standard deviation of the distribution, respectively.

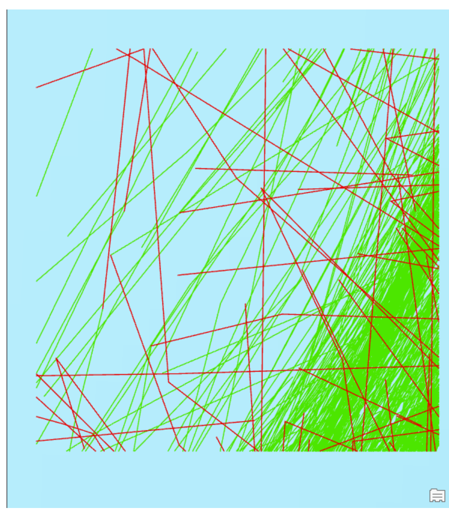

Figure 4.4. Spatial representation of the tracks symbolized to show those that comprise the predominant track orientation in green and those beyond ± 1SD from the distribution mean in red.

vi) Work planning

Discussions around these analyses provided work planning direction for the coming year. Key takeaways included stratifying the data by depth for analysis, refining filtering techniques and validating these approaches. Additionally, a suggestion was made to test the application of these filtering techniques on the logbook-filtered VMS tracks presented under ToR 2.6. Preliminary analysis of the methodology to study the bottom fishing footprint in the NRA (NEREIDA project).

Currently, the analysis applies single filtering thresholds for length and depth range to all tracks within the dataset. It was suggested that before these filters are applied, the tracks be divided into depth categories to account for variations in the catches and species observed at different depths. The proposed categories were: shallower than 200 m, 200 m – 600 m, and greater than 600 m.

Additional work was proposed to continue developing and validating the turn and neighborhood bearing analyses to determine how they might improve the representation of the fishing effort. It was suggested that improvement of the turn analysis may be achieved by using the bearing work to inform the choice of the turn angle threshold for each depth stratum.

Validation of the filtering approaches will be a major focus as this work progresses. Primarily, this will involve a comparison of the logbook-filtered VMS tracks. After the validation, the filters would be applied to the speed-filtered tracks from 2010 to 2016, before the logbooks were implemented. The potential incorporation of observer data as an additional validation dataset will also be explored. An evaluation of the possible inclusion of Automatic Identification System (AIS) data for use in these analyses will also be conducted as a supplementary source of positional information.

References

NAFO, 2022. Report of the Scientific Council Working Group on Ecosystem Science and Assessment, 15 - 24 November 2022, Dartmouth, Nova Scotia, Canada. NAFO SCS Doc. 22/25.

c) ToR 1.3. Developing a centralized data repository using ArcGIS online (COM Request #5a)

COM Request #5a: *Support the Secretariat in developing a centralized data repository using ArcGIS online to host the data and data-products for scientific advice*

WG-ESA has produced numerous summarized data products and GIS layers, both as results of analyses and for use in further analytical 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. Other data and layers are compiled for the provision of recurrent advice in relation to the habitat impact assessment component of the Roadmap (VME and SAI analyses). At its 15th meeting in November 2022, the WG-ESA Data Subgroup recommended using ArcGIS Online as a secure and centralized repository for standardized data layers and products (NAFO, 2022). During intersession the Secretariat implemented that recommendation, setting up a NAFO-hosted ArcGIS Online portal, allowing the Data Subgroup to advance data management plans for WG-ESA at its 16th meeting in November 2023. The Data Subgroup focused on addressing 4 main agenda items:

1. Standard Data Layers: build upon the existing list of standard data layers for inclusion on a NAFO-hosted ArcGIS Online portal.
2. Data Management: develop workflow for data management within ArcGIS Online (metadata, file organization, naming protocol, workflow itself, roles and responsibilities).
3. ArcGIS Online Testing: configuring and testing NAFO-hosted ArcGIS Online platform.
4. Advancing Data Management: extend data management strategies to include analysis and reporting tools.

The Data Subgroup met in break-out sessions on several occasions to address agenda items, and proposed the following recommendations to WG-ESA members in plenary:

Standard Data Layers

Datasets, intermediate layers or products that are frequently required to complete analyses in support of WG-ESA should be included in the NAFO-hosted ArcGIS Online portal. The list of standard GIS data products identified were:

- NAFO Regulatory Area (NRA)
- NAFO Divisions
- NAFO Footprint
- NAFO Closures
  - VME
  - Seamount
- Economic Exclusive Zone (EEZ)
- Sargasso Sea Area of Collaboration
- Other Effective Conservation Measures (OECMs)
- Ecosystem Production Units (EPUs)
- RV Trawl Data
  - VME Biomass
  - Functional Group Biomass
- Gridded Biomass
- KDE Rasters (VME & Functional)
- KDE Polygons (VME & Functional)
- Species Distribution Models (SDM)
- VME Polygons
- Significant Benthic Areas (SiBAs)
- VMS Tracks (Speed Filtered & Logbook Filtered)
- Fishing Effort (Speed Filtered & Logbook Filtered)
  - Fished Area
  - # of years fished
- Fishing Catch (Logbook Filtered)
- Oil & Gas
  - Lease Sites
  - Regulatory Sites
- Bathymetry
  - GEBCO
  - NEREIDA
  - NEREIDA/GEBCO Combo
  - Bathymetric Derivatives
- Currents
- Temperature
- Salinity
- Oxygen
- Geology
- Sediment Fractions
- Surficial Mapping
- Primary Productivity
- Polygon Grids (1 km & 5 km)
- Raster Grid (1 km)

This list does not represent all the data layers used/produced by WG-ESA, and additional layers will be included following consultation with WG-ESA members as the Data Subgroup advances this work. When uploading layers to the NAFO-hosted ArcGIS Online portal, priority will be given to data layers, which will directly support the upcoming assessment of VMEs and SAI.

Data Management

The upload and management of data layers should be enforced clearly and systematically to ensure the NAFO-hosted ArcGIS Online portal remains organized and easy for users to navigate. To support this, the Data Subgroup developed the following recommendations[1]:

Metadata

To ensure users can easily access information about layers and how they were developed, metadata should be required for layers uploaded to the NAFO-hosted ArcGIS Online portal. An easy-to-use template should be developed to assist with the compilation of metadata. Metadata should meet ISO 19115 (Geographic information — Metadata) and ISO 19139 (Geographic information — Metadata — XML schema implementation) standards, as endorsed for use by the Data Subgroup in 2022 (NAFO, 2022).

Projections

With the exception of point data, which should be uploaded to the NAFO-hosted ArcGIS Online portal in WGS84 (EPSG 4326), data layers should be projected into NAD83 UTM Zone 23N (EPSG 26923). If specific

[1] The recommendations outlined below are subject to modification as the Data Subgroup moves through the preliminary stage of testing the NAFO-hosted ArcGIS Online portal and data management strategies outlined here.

data layers/analyses are better suited to alternative projected or geographic coordinate systems, rationale should be provided prior to being submitted for upload.

File organization

Within the NAFO-hosted ArcGIS Online portal, data layers should be organized by theme, as illustrated in Figure 4.5.

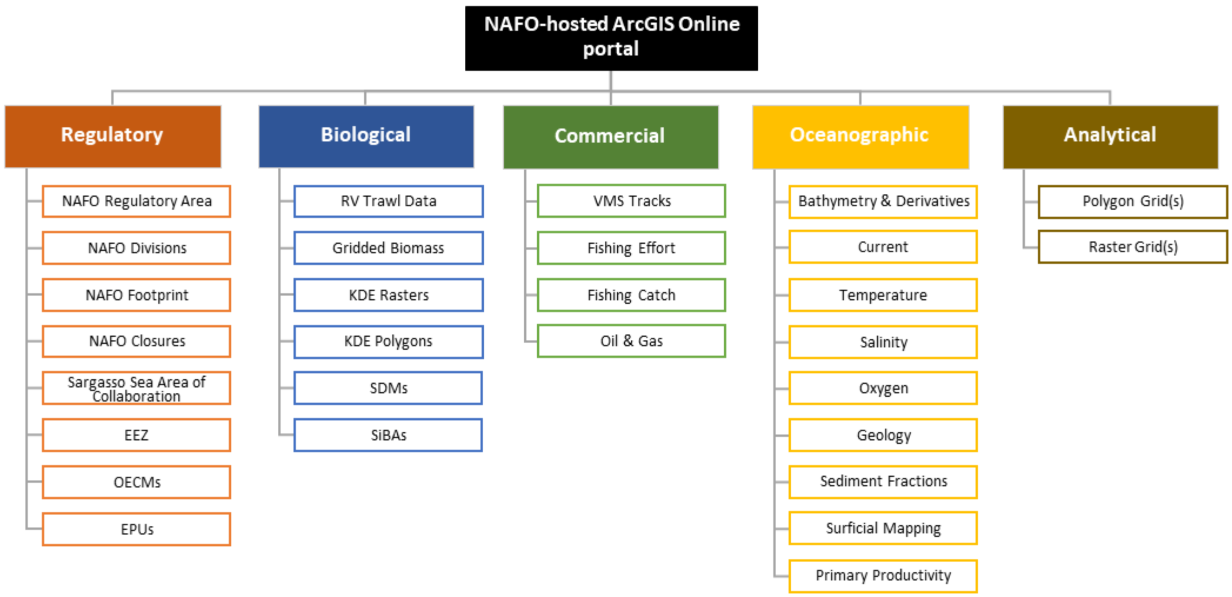

Figure 4.5. Proposed organization structure for data uploaded to NAFO-hosted ArcGIS Online portal.

Naming System

A system should be implemented to ensure that filenames are generated in a consistent manner and supports the organization of files within the NAFO-hosted ArcGIS Online portal. The naming system proposed by the Data Subgroup is illustrated in Figure 4.6.

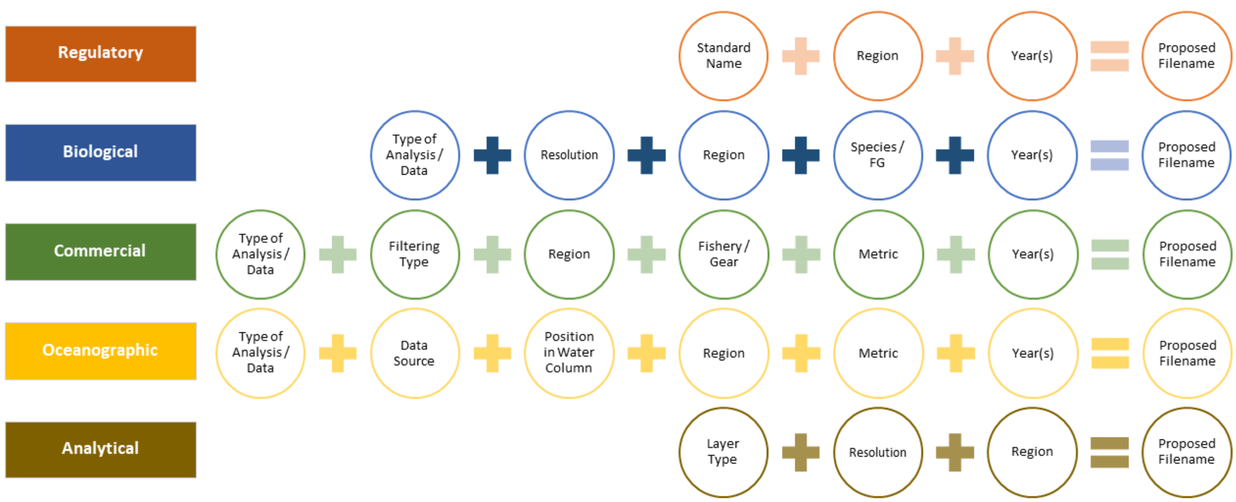

Figure 4.6. Preliminary naming system to be tested for suitability when uploading data layers to NAFO-hosted ArcGIS Online portal.

Workflow

A workflow should be implemented to outline the steps and requirements to follow when uploading data layers. A proposed workflow was developed by the Data Subgroup and presented to WG-ESA members (Figure 4.7).

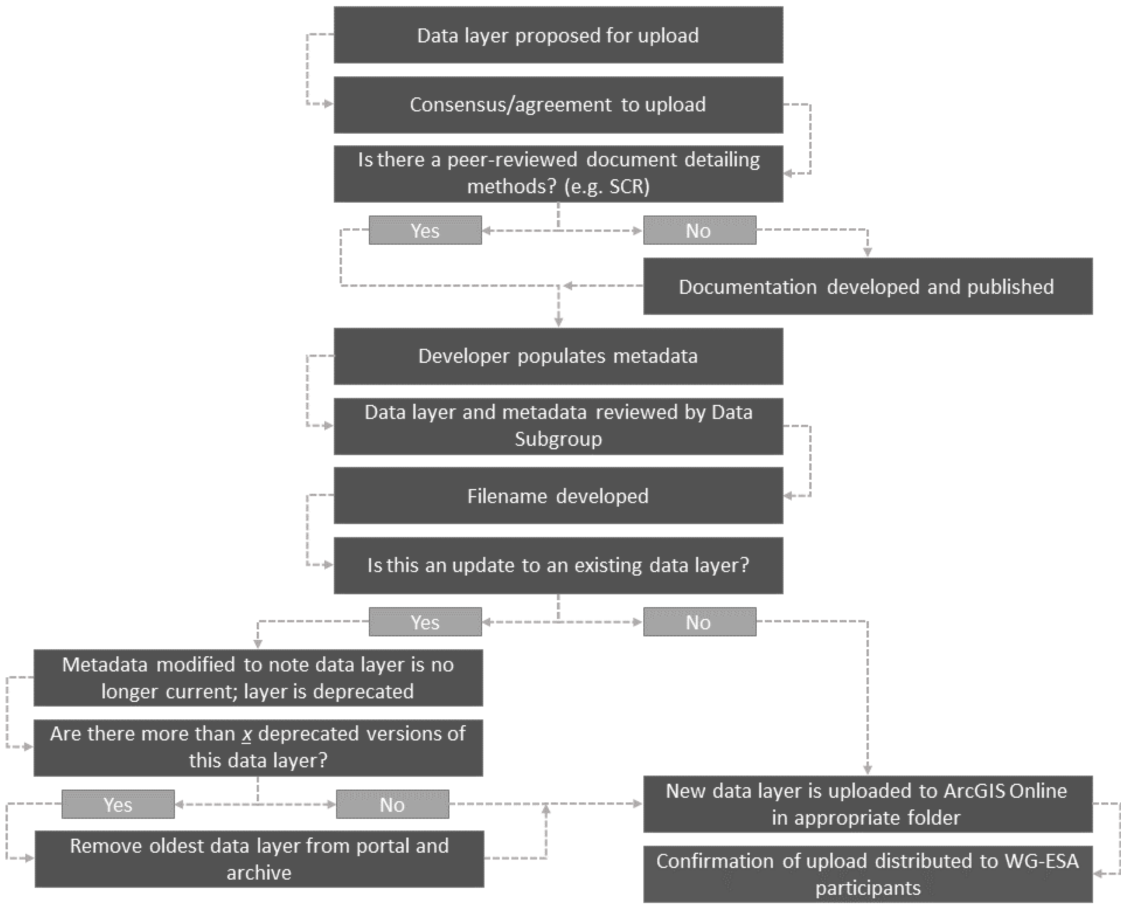

Figure 4.7. Recommended workflow for uploading data layers to the NAFO-hosted ArcGIS Online portal.

Roles & Responsibilities

WG-ESA members, the Data Subgroup and the NAFO Secretariat should be made aware of their roles and responsibilities associated with the preparation, maintenance and upload of data layers to the NAFO-hosted ArcGIS Online portal. Based on the proposed workflow presented in Figure 4.7, WG-ESA members developing layers for upload would ensure that peer-reviewed documentation is associated with the layers and that all metadata is compiled to meet recommended standards. The Data Subgroup would review data layers and associated metadata provided by developers to ensure they are ready for upload, develop appropriate filenames for data layers, and edit the metadata of layers being deprecated as a result of the upload (if needed). The NAFO Secretariat, or a designate, would upload and/or archive layers on the NAFO-hosted ArcGIS Online portal based on feedback from the Data Subgroup, and also provide formal confirmation of the changes to WG-ESA members when complete. The Data Subgroup recommends that summaries be presented annually to WG-ESA detailing changes made to the portal (e.g. number of layers added) and/or associated workflows.

Data Privacy

Administrative controls assigned by the NAFO Secretariat should ensure that access to the NAFO-hosted ArcGIS Online portal is restricted to WG-ESA members. As the Data Subgroup advances this work, additional details surrounding the privacy of individual data layers should be developed and provided to WG-ESA members.

ArcGIS Online Testing

An ESRI editor or creator license(s) should be made available to the Data Subgroup to test the NAFO-hosted ArcGIS Online portal for compatibility with the above recommendations. An assessment should be conducted to determine the type and number of licenses required to facilitate the proposed data management workflows.

Advancing Data Management

The Data Subgroup discussed the potential of setting up an online repository (e.g. GitHub) for the management of scripts, toolboxes and dashboards associated with standard analyses and reporting conducted in support of WG-ESA. This would ensure that all aspects of WG-ESA work would be well documented, accessible and reproducible. It is recommended that these discussions be revisited and advanced by the Data Subgroup in future WG-ESA meetings to allow for the incorporation of lessons-learned when managing data in the NAFO-hosted ArcGIS Online portal.

Intersessional Work

During breakout sessions, the Data Subgroup identified some items that could not be addressed at the time of the meeting. Where possible, it is proposed that these be addressed as layers begin to be uploaded to the NAFO-hosted ArcGIS Online portal.

Timelines

To streamline the data management process and provide additional steps to standardize the data management workflow, it is recommended that timelines relating to data uploads and annual maintenance of data layers be developed.

Financial Forecasting

As data layers are uploaded, periodic audits should be conducted to estimate the projected cost managing data using the NAFO-hosted ArcGIS Online portal. This will ensure that the work stays within the prescribed budget and help the Data Subgroup assign priorities when uploading data layers and defining suitable thresholds for archiving data. Work will also need to be done to determine the costs associated with licenses for WG-ESA members to use the NAFO-hosted ArcGIS Online portal after it is fully implemented.

RV Trawl Data

Many WG-ESA members rely on access to RV trawl data from Canada and the EU to complete their analyses. Different versions of the data are required depending on the work that is being conducted, with data providers often fielding multiple requests in a single year. Feedback provided to the Data Subgroup suggests there is interest among WG-ESA members to identify approaches to streamline these requests. It is recommended that a data management plan for RV trawl data, as well as a standard template for storing RV trawl data in the NAFO-hosted ArcGIS Online portal, be explored in collaboration with data providers and users.

References

NAFO, 2022. Report of the Scientific Council Working Group on Ecosystem Science and Assessment, 15 - 24 November 2022, Dartmouth, Nova Scotia, Canada. NAFO SCS Doc. 22/25.

d) ToR 1.4. Impact of Cerianthids on benthic biodiversity and ecosystem functioning in a sub-arctic fjord

During the 2023 NAFO WG-ESA meeting, an update on a study investigating the potential role of cerianthids on benthic biodiversity and ecosystem functioning was presented by Stephan Hamisch (Memorial University). Cerianthids (Cnidaria: Anthozoa) are Vulnerable Marine Ecosystem (VME) indicators. A few studies have evaluated epifauna (Shepard *et al.,* 1986) and fauna associated with cerianthid tubes (Ceriello, H. *et al.,* 2020); however, their effect on macroinfauna in soft-sediment ecosystems remains largely unknown. This research project examines the relationship between cerianthids and macrofaunal diversity, nutrient fluxes and pigment distribution in Hebron Fjord (Labrador, Northwest Atlantic). Sediment samples were collected via ROV push-coring (remotely operated vehicle ASTRID aboard CCGS *Amundsen*, September 2022) at sites with high cerianthid[2] densities (3-62 ind m^{-2}) (Kokarev *et al.,* 2021)

[2] Potentially *Pachycerianthus borealis*, but species is not yet confirmed.

and sites without ceriathids, located ~ 800 m apart, at ~ 250 m depth. Given the proximity of the sites, and the homogenic nature of isolated deepwater fjord ecosystems (Kokarev *et al.,* 2021), it was assumed cerianthid presence represented the dominant environmental difference between the two sites. Other possible disturbance regimes such as underwater landslides were not detected in the study area (pers. comm. A. Normandeau, Geological Survey of Canada).

A total of 16 cores were collected, eight inside and eight outside cerianthid fields. Three cores of each site were incubated to evaluate nutrient fluxes (NH_3, NO_2^-, NO_3^-, PO_4^{3-} and SiO_4^{4-}), and all cores were sampled for macrofauna analysis. Macrofaunal sediment samples were sliced at 0 - 2 cm, 2 - 5 cm and 5 - 10 cm deep in the core and preserved in 10% buffered formalin until subsequent sieving over 300 µm mesh sieves, sorting and identification to family level. Sediment samples taken at 0 cm, 2 cm and 5 cm depth were analysed for chlorophyll a (Chla) and phaeopigment (Phaeo) concentrations.

Overall, 35 families were identified, with 15 occurring in both sites. Findings suggest a significant impact of cerianthids on infaunal density, diversity and community composition. Inside cerianthid fields, opportunistic carnivores (*Dorvilleidae*) and selective deposit feeders (*Cirratulidae*, *Cossuridae*) dominated faunal assemblages, in contrast to strong influence of filter-feeding bivalves (*Nuculidae*) in sites outside of cerianthid fields (Figure 4.8). Additionally, sites inside cerianthid fields supported a greater number of rare species, which are important in habitat-based conservation approaches because they often contribute significantly to ecosystem resilience and functional diversity (Ellingsen *et al.*, 2007).

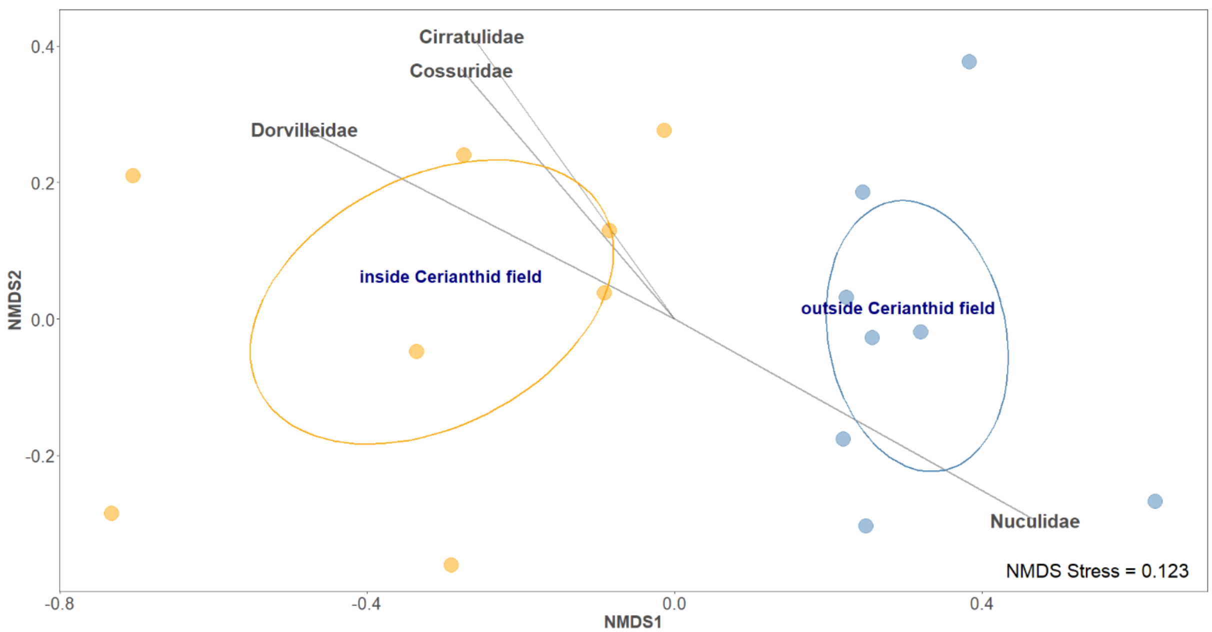

Figure 4.8. NMDS of community composition inside (orange) and outside (blue) cerianthid fields. Ellipses denote 95% confidence intervals. Vectors represent families strongly associated with site identity (mvabund, univariate tests, α-level 0.05).

Comparing communities in the three depth layers between the sites, it was found that cerianthids impact faunal composition deep into the sediment, suggesting differences in food availability that are not limited to the sediment surface.

Cerianthid presence did not significantly alter nutrient fluxes. However, the polychaete family *Dorvilleidae*, highly mobile biodiffusors that only occurred inside cerianthid fields, explained significant variations in nutrient fluxes. Thus, cerianthids could indirectly affect fluxes through impacts on infaunal community composition.

Pigment distributions suggest stronger surficial grazing, as well as higher bioturbation rates inside than outside cerianthid fields. Cerianthid presence, as well as abundance of *Cirratulidae*, *Nuculidae* and *Pectinariidae*, explained significant variation in pigment distributions across depth. The former two families are surficial modifiers and were dominant taxa within both sites, and *Pectinariidae* are important bioturbators in many soft bottom ecosystems (Queirós *et al.*, 2015). The differences in pigment distribution between the two sites were discussed with members of the working group. Similar patterns of pigment distribution such as those observed inside cerianthid fields typically result from a strong influence by deposit feeders (Josefson *et al.*, 2002). Noting the strong association of deposit feeders (*Cirratulidae*, *Cossuridae*) with cerianthid fields, It is suspected a significant impact of cerianthid presence on Organic Matter (OM) burial.

This study revealed significant impacts of cerianthids on ecosystem functioning and benthic biodiversity. Cerianthids increase diversity and abundance, and impact composition of infaunal macrobenthos. These differences in taxonomic identities translate to differing ecological traits, and impact ecosystem functioning such as nutrient remineralization and OM burial. It was therefore concluded that cerianthids represent important ecosystem engineers in deep-water ecosystems of the North Atlantic. Protection measures that limit anthropogenic impacts such as those associated with intensive bottom contact fishing (Vigo *et al.*, 2023) will help to sustain ecosystem traits provided and reliant on cerianthids, and will strengthen ecosystem resilience against environmental stressors and global climate change.

References

Shepard, A., Theroux, R., Cooper, R. & Uzmann, J. (1986). Ecology of ceriantharia (coelenterata, anthozoa) of the northwest Atlantic from Cape Hatteras to Nova Scotia. Fish BullUnited States 84.

Ceriello, H., Lopes, C.S.S., Reimer, J.D., Bakken, T., Fukuda, Magenta Cunha, C., Stampar, S.N. (2020). Knock knock, who's there?: marine invertebrates in tubes of Ceriantharia (Cnidaria: Anthozoa). Biodivers. Data J. 8.

Kokarev, V., Tachon, M., Austad, M., McGovern, M. & Reiss, H. (2021). Strong macrobenthic community differentiation among sub-Arctic deep fjords on small spatial scales. Estuar. Coast. Shelf Sci. 252, 107271.

Ellingsen, K. E., Hewitt, J. E. & Thrush, S. F. (2007). Rare species, habitat diversity and functional redundancy in marine benthos. J. Sea Res. 58, 291–301.

Queirós, A. M., Stephens, N., Cook, R., Ravaglioli, C., Nunes, J., Dashfield, S., Harris, C., Tilstone, G.H., Fishwick, J., Braeckman, U., Somerfield, P.J., Widdicombe, S. (2015). Can benthic community structure be used to predict the process of bioturbation in real ecosystems? *Prog. Oceanogr.* 137, 559–569.

Josefson, A. B., Forbes, T. L. & Rosenberg R. (2002). Fate of phytodetritus in marine sediments: functional importance of macrofaunal community. Mar. Ecol. Prog. Ser. 230, 71–85 (2002).

Vigo, M., Navarro, J., Aguzzi, J., Bahamón, N., García, J.A., Rotllant, G., Recasens, L., Company, J.B.

(2023). ROV-based monitoring of passive ecological recovery in a deep-sea no-take fishery reserve. *Science of the Total Environment*. 883, 163339.

e) ToR 1.5. Update on the Newfoundland and Labrador Comparative Fishing Program.

Comparative Fishing (CF) has been ongoing in the Newfoundland & Labrador Region since 2021 as Fisheries and Oceans Canada (DFO) transition from the CCGS *Teleost* and CCGS *Alfred Needler* to new vessels, the CCGS *Capt Jacques Cartier* and CCGS *John Cabot*, for its annual spring (Divs. 3LNOPs) and fall (Divs. 2HJ3KLNO) multispecies surveys. In addition to the change in vessels, minor modifications have been made to the *Campelen* survey trawl for use going forward (Wheeland *et al*., 2023). Changing vessels, equipment or processes can affect how fish are caught, which changes how the data are interpreted. We need to measure these differences and do that through comparative fishing. This comparative fishing program involves side-by-side survey trawling ("paired tows") between the old and new vessels, collecting the data necessary to make adjustments that account for differences in how the vessels fish so that we can continue to maintain the existing survey time series.

Community-level comparisons of catches between paired tows indicate that there is not a widespread issue with species detectability between the old and new vessels at the taxonomic level that current species are being identified to on the vessels. This analysis removed extremely rare species (less than 7 observation over 533 sets), so there may be differences that were not detected for extremely rare species, or species that are currently being grouped at a higher taxonomic level (e.g. corals). Differences in diversity and evenness were small, but significant, and are being driven by different catch weights for some species, supporting the need for conversion factors.

The community being sampled by the new and old vessels is very similar. However, there are subtle differences that may or may not be resolved with the application of conversion factors. This will need to be considered when analyzing data that span the transition between vessels.

Analysis of paired tow data yields estimated conversion factors – the quantitative measure of relative catch efficiency (rho) between the old and new vessels (DFO *in press*). Conversion factors are intended to be applied to the vessel, season and area for which they are derived. Taxa-specific size-disaggregated conversion factors are determined from a suite of 13 binomial and beta-binomial models with various assumptions for length and station (i.e., set location) effects to estimate rho based on ratios of catch numbers at length in paired tows (Yin and Benoît, 2022). Catch aggregated conversions are also estimated by species, or for groups of taxa where identification or data availability do not allow lower taxonomic discrimination. Conversion factors could not be calculated for all species or taxonomic groups when sample sizes were too low or data was insufficient.

Notably, there is no evidence for a significant difference in catch weights of sponge between old and new vessels. No conversion is required for sponge, and data collected going forward can be used as a direct continuation of the previous series.

Data were insufficient to determine if conversion factors were appropriate for corals, bryozoans or *Boltenia* sp. for the CCGS *Alfred Needler*. Data were also insufficient for these groups for the CCGS *Teleost* series, however further comparative fishing is planned with this vessel in Fall 2023 and these groups will be revisited following the collection of these additional data.

Analyses are ongoing and further details will be published in the Canadian Science Advisory Secretariat Research Document series as they become available.

References

DFO. *In press*. Newfoundland & Labrador Comparative Fishing Analysis – Part 1. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.

Wheeland, L., Trueman, S., Rideout, R. (2023). Coverage of the 2022 Canadian (Newfoundland And Labrador Region) Multi-Species RV Bottom Trawl Survey with notes on Comparative Fishing. NAFO SCR Doc. 23/042

Yin, Y., and Benoît, H.P. (2022). A Comprehensive Simulation Study of A Class of Analysis Methods for Paired-Tow Comparative Fishing Experiments. Can. Tech. Rep. Fish. Aquat. Sci. 3466: vi + 99 p.

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. Connectivity Amongst VMEs in the NRA (COM Request #5c)

Connectivity issues were first raised by WG-ESA at the 2012 meeting in the context of Significant Adverse Impacts (SAI) on VMEs, where it was stated that connectivity amongst the sponge grounds will influence recovery dynamics (NAFO, 2012). The following year, NAFO evoked connectivity issues in its response to a Fisheries Commission request regarding sea pens closures on Flemish Cap. The sea pen VMEs were described as "a system of sea pen VME", and it was noted that "the lack of protection for the entire eastern part of their distribution [was] of concern for the long term sustainability of these VME given the lack of knowledge of recruitment processes and connectivity" (NAFO, 2013). By 2015, NAFO had incorporated aspects of habitat configuration (arrangement of the VMEs in space), as part of its assessment of SAI, in an "Index of Risk of VME fragmentation" defined as the "Proportion of discrete VME without protection" (NAFO, 2015). Recognizing the importance of connectivity to the structure and functioning of marine ecosystems, the following year WG-ESA revised and updated its long-term ToRs to incorporate connectivity issues, with the expectation that they would be implemented at its 2017 meeting and thereafter, accordingly:

> *ToR 1. Update on identification and mapping of sensitive species and habitats in the NAFO area. In support of the Roadmap develop research and summarize new findings on the spatial structure and organisation of marine ecosystems with an emphasis on connectivity, exchanges and flows among ecosystem units in the NAFO Convention Area (NAFO, 2016).*

This change to the WG-ESA ToRs stimulated research on connectivity, and in 2017 work was presented in the WG-ESA report, detailing an agent-based modelling (ABM) approach that was being explored as a means to study the impacts of commercial fishing on selected VME indicator taxa (NAFO, 2017). The model, run in ArcGIS, simulates the life-history stages/processes of a generalized sea pen in both the pelagic gametic/larval state, as well as the settled state. Basic questions that the model aimed to explore included how long it could take for VMEs to recover from specific patterns of perturbations from fishing operations, and how interconnected different VME habitat units may be. A spatially-explicit agent-based model for sea pens was ultimately constructed the following year (NAFO, 2018), and demonstrated that recovery time after a significant single perturbation is on the order of decades (20+ years), and that connectivity is important for sustaining populations. The following year, the relationship between fishing effort and sea pen mortality was implemented in the sea pen ABM. This showed that historical fishing effort has likely shaped the present-day distribution of sea pens, potentially reducing abundance to 50% of pristine levels (NAFO, 2019). Examination of the effect of the closed areas suggested that the system of closures (NAFO + Canada) in place in 2018, only provided a very limited recovery capacity at the population scale (NAFO, 2019). On average, the NAFO closures were located in areas estimated to have experienced reductions in sea pen abundance of around 60% and would be expected to rebuild in 50 years in the absence of fishing (NAFO, 2019). While the sea pen ABM reasonably captured the spatio-temporal dynamics of a generalized sea pen, its representation of the distribution in some shallow areas needed improvement. This issue was to be revisited for the final version of the sea pen ABM before use for the re-assessment of SAIs on VMEs, and the following year a final model was presented (NAFO, 2020). The 2020 ABM was used to compare and contrast closed area scenarios for sea pens (NAFO, 2021).

Concurrently with the sea pen ABM work, WG-ESA also proposed and tested methods to evaluate the spatial relationship among all of the VMEs by means of nearest neighbour and other statistics capturing information on the relative position of the VMEs within the NRA. An index of habitat configuration that incorporates habitat area and nearest neighbour distances (PX; Gustafson and Parker, 1994) was applied to the distributions of each of seven VMEs (large and small gorgonian corals, black corals, sea pens, sponges, bryozoans and tunicates) and to the configuration of the spatial closures. Lagrangian particle tracking (LPT) models were used to estimate connection distances among VMEs and among closed areas, replacing Euclidean nearest-neighbour distances. Initially those models were 2-D, that is, only allowing horizontal movement (NAFO, 2018). By 2021, more realistic connections among the closed areas and among the VME habitats were evaluated based on connectivity modeling using 3-D Lagrangian particle tracking models (Wang *et al*., 2021; NAFO, 2021). Based on this body of work, different ways of capturing the information on the network design were presented in the form of connectivity indices (NAFO, 2020). Connectivity and habitat configuration were subsequently incorporated into the assessment and recommendations for closed area protection of the VMEs (NAFO, 2021).

Aside from the black corals, with their short larval durations resulting in multiple isolated VMEs, the connectivity networks for each VME taxon all averaged more than one connection per VME, indicating a degree of redundancy in their networks, which is seen as a positive attribute. Across the taxon groups, the majority of VMEs, 67 of 84, were sources supporting other, downstream VMEs – and, in the sea pens and tunicates especially, multiple other VMEs. Conversely, a few VMEs (and none amongst the sea pens or tunicates) had no downstream connections and were identified as potential 'sink' patches. Nine of the 84 patches, including members of the large gorgonian coral, bryozoan, tunicate and black coral networks, were completely isolated (NAFO, 2022).

Simulated removal of single patches found very considerable differences in their effects on network configuration, as measured by change in PX, an index of habitat configuration that incorporates habitat area and nearest neighbour distances (Gustafson and Parker, 1994, NAFO, 2022). Removal of many VMEs, 28 of the 84, had little effect on PX (declines of < 0.05%) but, in every taxon group, there was at least one VME that, when removed, reduced the index by more than 45% and, in some cases, by more than 85% (NAFO, 2022). While PX cannot capture every important aspect of network configuration, it is clear that some VMEs are much more important to achievement of overall conservation goals than are others.

In preparing for the 2026 NAFO review of the closed areas to protect VMEs, WG-ESA agreed to consider the work done on connectivity since the last review, and to consider the best way to incorporate those results into the assessment of SAI (see SCS Doc. 24/01, COM Request #5c). It was noted that there are 84 VMEs identified from the KDE analyses (NAFO, 2019), of which only 27 are partially or fully protected by area closures. The unprotected patches could be important sources of recruitment to the patches in closed areas, and loss or diminishment of those patches could undermine the protection efforts of the VME closed areas.

References

Gustafson, E.J., and Parker, G.R. 1994. Using an index of habitat patch proximity for landscape design. Landscape and Urban Planning 29: 117–130.

NAFO. 2012. Report of the 5th Meeting of the NAFO Scientific Council Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM). NAFO Scientific Council Studies Document 12/26, Serial No. N6137, 130 pp.

NAFO. 2013. Report of the 6th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA) [Formerly SC WGEAFM]. NAFO Scientific Council Studies Document 13/024, Serial No. N6277, 209 pp.

NAFO. 2015. Report of the 8th Meeting of the NAFO Scientific Council (SC) Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO Scientific Council Studies Document 16/21, Serial No. N6655, 105 pp.

NAFO. 2016. Report of the 9th Meeting of the NAFO Scientific Council (SC) Working Group on Ecosystem Science and Assessment (WG-ESA) [Formerly SC WGEAFM]. NAFO Scientific Council Studies Document 15/29, Serial No. N6549, 176 pp.

NAFO. 2017. Report of the 10th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO Scientific Council Studies Document 17/21, Serial No. N6774, 166 pp.

NAFO. 2018. Report of the 11th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO Scientific Council Studies Document 18/23, Serial No. N6900, 112 pp.

NAFO. 2019. Report of the 12th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO Scientific Council Studies Document 19/25, Serial No. N7027, 135 pp.

NAFO. 2020. Report of the 13th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO Scientific Council Studies Document 20/23, Serial No. 7148, 270 pp.

NAFO. 2021. Report of the 14th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO Scientific Council Studies Document 21/21, Serial No. N7256, 181 pp.

NAFO. 2022. Report of the 15th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO Scientific Council Studies Document 22/25, Serial No. N7367, 90 pp.

Wang, S., Kenchington, E., Murillo, F.J., Lirette, C., Koen-Alonso, M., and Sacau, M. 2021. Advances in the Assessment of Habitat Fragmentation and Protection in the NAFO Regulatory Area. NAFO SCS Doc. 21/049, Serial No. N7252, 50 pp.

b) Tor 2.2. Role of Astrophorina sponges in food-web interactions at the Flemish Cap

Previously, twelve different faunal assemblages were identified at the Flemish Cap (NAFO Division 3M) by Murillo *et al*. (2016). We selected four of these assemblages (deep-sea coral assemblage, lower slope assemblage 1, lower slope assemblage 2, deep-sea sponge assemblage) to (1) identify the taxa in the faunal assemblages with most trophic and non-trophic interactions, to (2) investigate the importance of representative species of faunal assemblages for trophic and non-trophic interactions, and to (3) identify the highest impact taxa. The highest impact taxon is defined as the taxon whose removal results in the largest changes in food-web properties, such as number of species or interaction-web links.

To address these study aims, we developed trophic and non-trophic interaction webs using presence/ absence data of taxa collected via bottom trawls (fish, invertebrate epifauna), rock dredge/scallop gear (invertebrate epifauna), and mega box cores (macrobenthic and meiobenthic infauna). Information about trophic interactions, such as feeding strategies and diet preferences, were based on published literature about stomach contents, *in-situ* observations with remotely operated vehicles, and stable isotope analyses. Information about non-trophic interactions were based on observations and published literature.

The interaction webs consisted of 225 (lower slope assemblage 1) to 266 (deep-sea coral assemblage) compartments that were dominated by the feeding types carnivores, deposit feeders, filter- and suspension feeders, and omnivores. The dominant phyla were Annelida, Arthropoda, Chordata, Cnidaria, Echinodermata and Mollusca. The interaction-web compartments were linked with 4488 (lower slope assemblage 1) to 9939 (deep-sea coral assemblage) trophic interactions and 212 (lower slope assemblage 2) to 312 (deep-sea sponge assemblage) non-trophic interactions. The link density ranged from 20 (lower slope assemblage 1) to 38 (deep-sea sponge assemblage) and the connectance, i.e., the fraction of all existing links compared to all possible links, was between 0.083 (lower slope assemblage 2) and 0.16 (deep-sea slope assemblage). The predators with most trophic interactions varied among the faunal assemblages (i.e., *Amblyraja radiata*, *Anarhichas denticulatus*, *Todarodes sagittatus*, members of the Arthropoda family Oedicerotidae), whereas two prey types had most trophic interactions, namely Copepoda and members of the Arthropoda order

Euphausiacea. Members of the Polychaeta family Polynoidae had most non-trophic interactions in all faunal assemblages.

To study the importance of the representative taxa of the faunal assemblages for interaction-web integrity, we assessed the impacts of removing these species. Removing representative species of the deep-water coral assemblage (i.e., *Stauropathes arctica*, *Flabellum* (*Ulocyathus*) *alabastrum*, *Funiculina quadrangularis*, *Heteropolypus sol*, *Acanella arbuscula*) reduced the number of network links by only 2.47% which was less than one might expect. However, deep-sea coral assemblages on soft sediments are less species-rich than on hard substrates and the Cnidaria with most interactions were not representative taxa of the deep-water coral assemblage, but two sea pen species (*Anthoptilum grandiflorum*, *Balticina finmarchica*). Their removal led to a second order extinction cascade. Hence, sea pens and Astrophorina sponges, whose removal caused a drop of 45.0% in number of links and of 24.3% in link density, are foundation species and structural species or habitat formers. In fact, sea pens are likely more important than Astrophorina sponges because the latter is less abundant and the first provides nursery grounds for fish and crustacean larvae.

Removing representative taxa of the lower slope assemblages (i.e., *Phormosoma placenta, Bathybiaster vexillifer, Zoroaster fulgens, Funiculina quadrangularis, Anthoptilum grandiflorum, Balticina finmarchica, Pennatula aculeata*) from the lower slope assemblages 1 and 2 resulted in a loss of 9.66% to 11.3% of all network links, and a loss of 5.00% to 9.52% of link density. This might seem low when compared to the effect that removing Astrophorina sponges from the lower slope assemblage has on network integrity. However, sea stars of the families Echinasteridae and Pterasteridae, which are representative taxa of the lower slope assemblages, are spongivores predating upon Astrophorina sponges. They had no further trophic or non-trophic interactions with other compartments and therefore did not trigger further taxa losses. Sea pens, the other group of representative taxa, are biogenic habitat providers in soft-sediment habitats and serve as nurseries for crustacean larvae and larvae of *Sebastes fasciatus*. Though sea pens in the lower slope assemblages did have trophic and facultative non-trophic interactions, Astrophorina sponges had a higher number of facultative non-trophic interactions with Annelida, Cnidaria, Arthropoda, Echinodermata and fish.

The impact of Astrophorina sponge removal on the deep-sea sponge assemblage was extremely high, including a loss of 43.2% of all compartments, a reduction in 59.6% of all links, a drop of 28.9% of link density, and an increase of 25.0% in link density. This effect was even higher than the effect of removing Astrophorina sponges from any other faunal assemblages, mainly because Astrophorina sponges had more trophic and non-trophic links in the deep-sea sponge assemblage than in any other assemblage. This implies that Astrophorina sponges are key species, ecosystem engineers, structural species or habitat formers, and foundation species.

In conclusion, our study showed that Astrophorina sponges are the highest impact taxa in the deep-sea coral assemblage, the lower slope assemblage, and the deep-sea sponge assemblage. Even less abundant and/ or non-representative indicator species can be important for trophic and non-trophic interactions. Hence, when identifying impacts of fishing on vulnerable marine ecosystems, both, trophic and non-trophic, interactions should be examined as the effects might be more severe than originally thought when only trophic interactions were considered.

For further information, please refer to Stratmann *et al*., 2024.

References

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

Stratmann T, Murillo FJ, Sacau, M, Alonso MK, Kenchington E (2024) Role of Astrophorina sponges (Demospongiae) in food-web interactions at the Flemish Cap (NW Atlantic). Mar Ecol Prog Ser 729:99-116. https://doi.org/10.3354/meps14514

c) ToR 2.3. Up-date on the analysis on the functional significance of VME in relation to fish (COM Request #5c)

Background

The work presented here provides an addition to previous work undertaken to improve our understanding of the associations between demersal fishes and shellfishes and VMEs in the NRA. The results of multivariate analysis of fish and invertebrate communities described in the WG-ESA 2020 and 2021 reports (NAFO, 2020, 2021), indicated six distinct fish/invertebrate clusters strongly structured by depth and geographical area (Figure 5.1a and b). Most VME (black corals, large and small gorgonians, sea pens and geodid sponges) were found to belong to a deep-water assemblage (~500-1500 m) around the Flemish Cap and along the slope of the Grand Bank. *Boltenia* spp. and other ascidians and bryozoans in turn were associated mainly with three 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). Two other shallower water groups (~150-300 m and ~300-500 m) on the top and edge of the Flemish Cap had no associated VME indicator taxa.

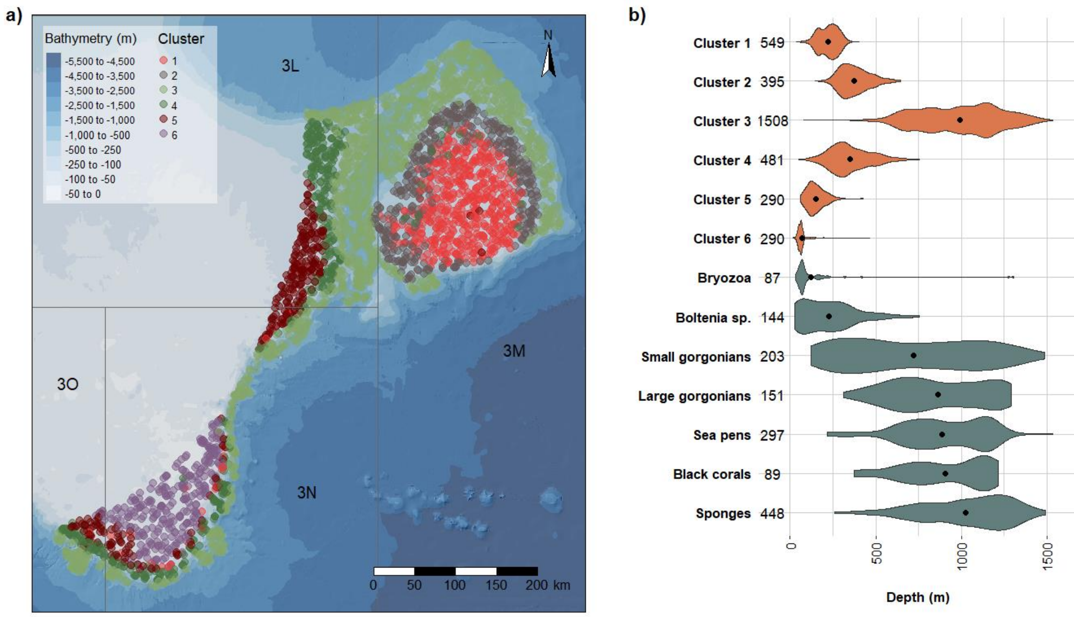

Figure 5.1. Map showing the spatial distribution of fish / invertebrate assemblage groups from cluster analysis in 2020 (a) and the depth ranges of the six cluster groups as well as the VME categories (based on 2019 KDE polygons; Kenchington *et al.*, 2019) (b). Each violin plot has equal area. Number of samples in each cluster / VME is shown to the left of the plot. Points inside violins indicate the mean depth.

The depth ranges of the VMEs, however, do not completely coincide with the depth ranges of the assemblage groups (Figure 5.1b). The concentration of most VMEs in one group and simultaneous spanning of multiple groups by some VMEs prompted additional questions about the nature of the fish interactions with specific VMEs. 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). Consequently, further analysis was done in 2021 (NAFO, 2022) 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. The 2021 analysis investigated associations between the biomass of individual demersal fish species and VMEs (sea pens, small gorgonians, large gorgonians, black corals, sponges, *Boltenia* spp. and bryozoans), which are amalgamations of the species in those groups. The analysis for each VME / fish combination was restricted to trawls within the depth range of the relevant VME. The analysis also accounted for the fish and VME's dependence on depth by its inclusion as a covariate and the differences between the trawl surveys that yielded the data through their inclusion as random variables, 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. The depth range for each VME / fish analysis in 2021 was selected based on the depth ranges of the VME types. The rationale behind this approach was to investigate the difference of fish biomass inside and outside a specific VME. The work presented here repeats the analysis from 2021 using an alternate approach looking at interactions with VME from the viewpoint of the fish, investigating the effects of VME presence in the preferred depth range of the fish (Figure 5.2).

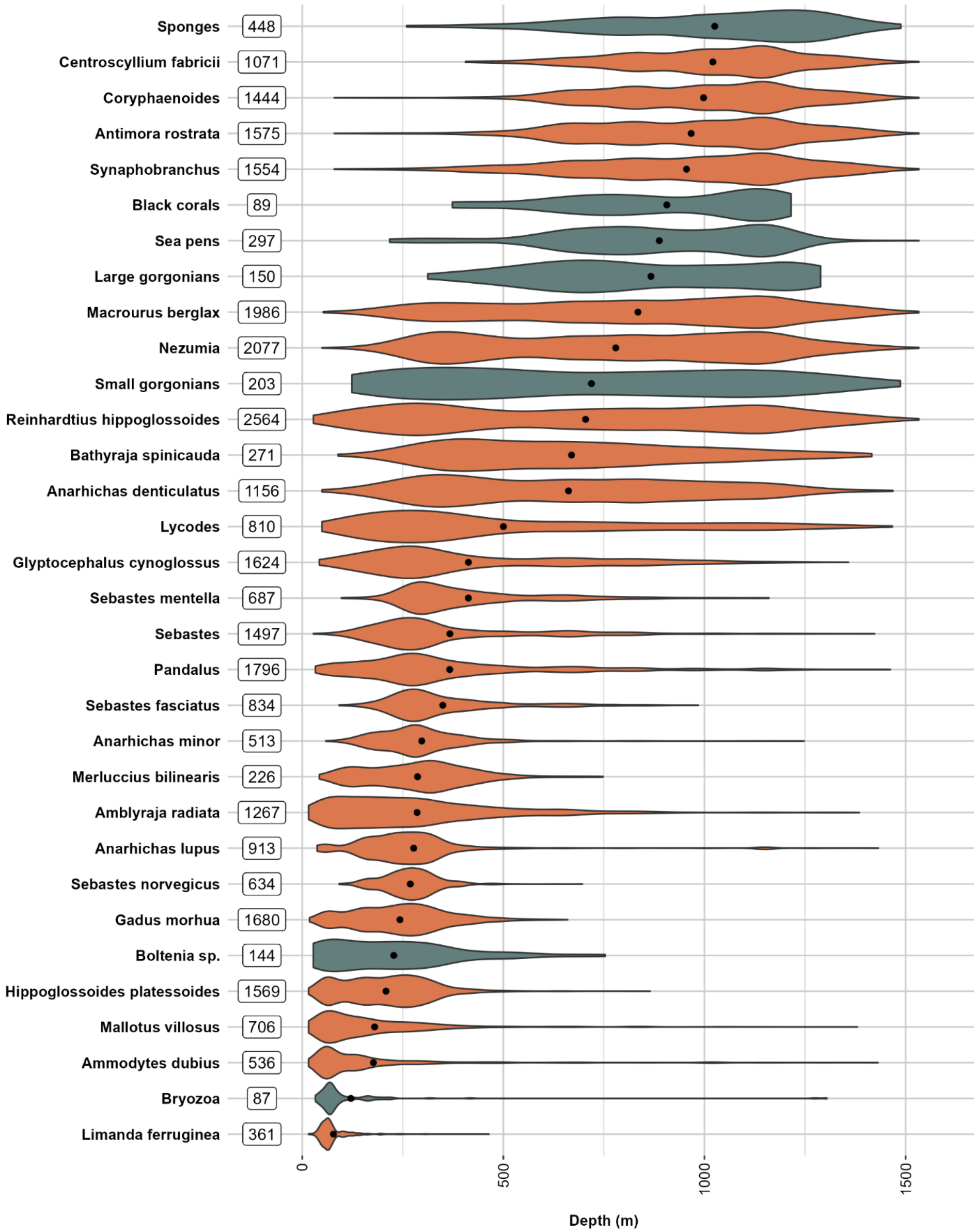

Figure 5.2. Depth ranges of individual fish species (in orange) and VMEs (in green).

Data and methods

The current analysis used the same study area, delineated by the extent of the NAFO regulatory fishing footprint in 3LMN, and data on the biomass of fish and invertebrates from 3515 survey trawls as used in the 2021 analysis. Comparison of fish biomass inside and outside of each VME polygon (Kenchington *et al.*, 2019), was also done using the same three categories: 'VME trawls' (trawls with catches of VME indicator taxa above the VME threshold), 'wider VME area' (trawls which did not exceed the VME thresholds but where the start of the trawl fell inside the VME polygon), and 'Not VME'. The data and categorisation of trawls is described in detail in the Report of the 2021 WG-ESA Meeting (NAFO, 2021).

The analysis also followed the same methodology used in 2021, with only two changes. In 2021 the analysis was structured to investigate fish associated with each individual VME. Consequently, fish biomass data was restricted to the depth range covered by each VME. The current analysis was instead structured by individual fish species, investigating the effects of VME presence on fish biomass within the fish's depth range. As in 2021, sufficient numbers of samples with non-zero fish biomass in each VME category is needed to allow successful comparison between the categories, so only those VME / Fish / Survey combinations with a prevalence of more than 1% were included in the model analysis. In the current analysis, using the fish-specific depth range, an additional requirement was added to ensure at least 5 occurrences of each VME category for analysis to proceed. Figure 5.3. shows the numbers of trawls per VME / Fish / Survey combination that were included in analysis.

In line with the 2021 analysis methodology, the effect of the VME was investigated using Generalised Linear Mixed Models (GLMM, Bolker *et al.*, 2009) built for each VME / Fish combination. The response variable used was square-root transformed fish biomass. Model terms included the VME category (VME trawl, VME Polygon and Not VME), log-transformed depth as covariates and the survey series as a random effect. Models for individual species used the Tweedie distribution and total fish biomass 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. The effect of VME class was summarised in ANOVA-style tables using Wald χ^2 statistics for comparisons on the conditional fixed effects and Post-Hoc Tukey comparisons were done between all VME groups. For more detail see NAFO (2022).

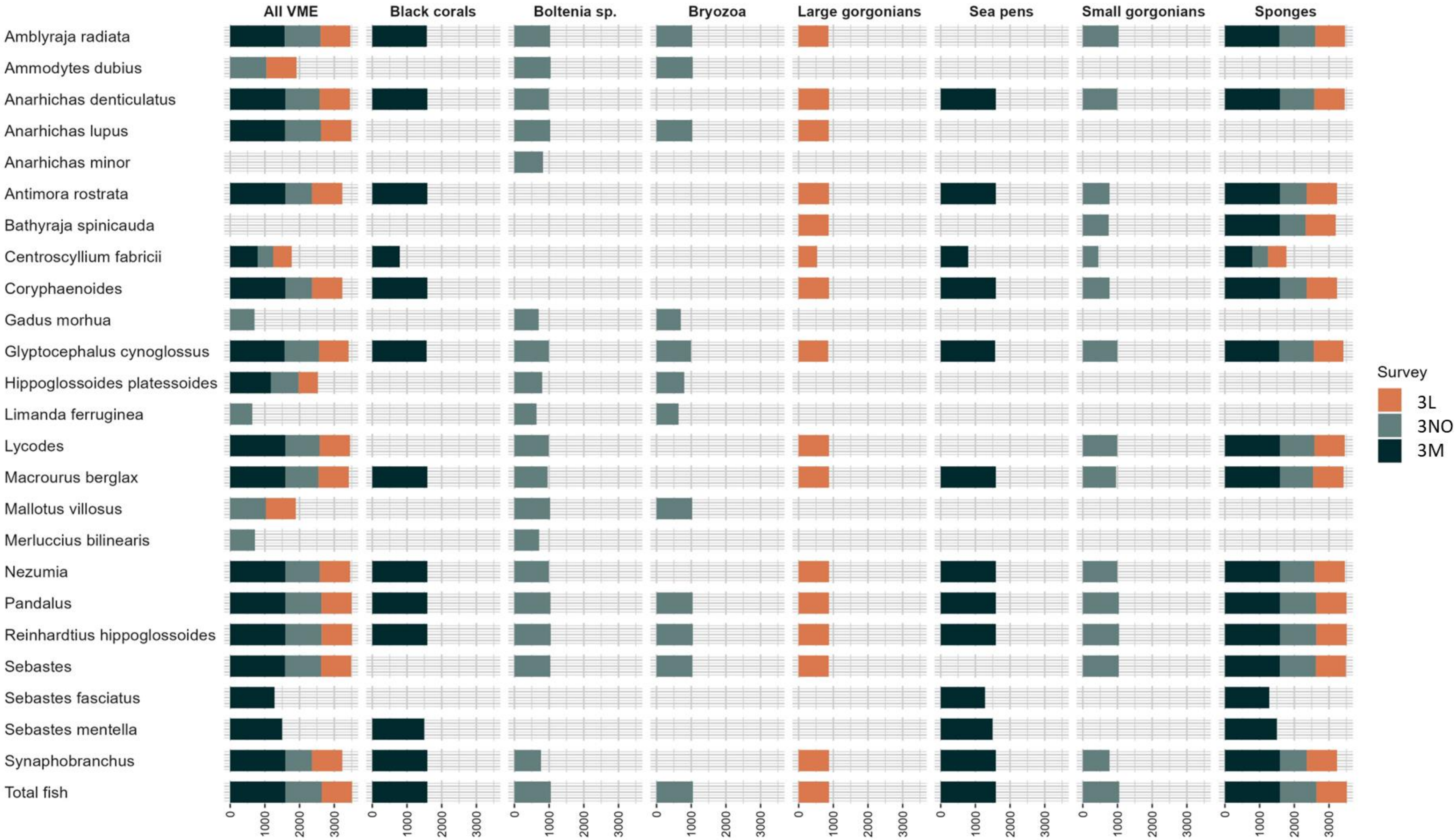

Figure 5.3. Number of scientific trawls overlapping the depth range of each VME by fish species and survey series.

Results

Overview of significant effects

Log-transformed depth was again a highly significant term in all models, confirming the importance of its inclusion as a covariate. Table 5.1**Error! Reference source not found.** summarises the model results showing which VME / Fish combinations were modelled and if the model included a significant positive or negative effect of either the VME Trawl or VME Polygon categories on the biomass of the fish modelled. Of the VME, *Boltenia* sp. showed most significant positive associations with the highest number of fish (7) followed by sea pens (6). The lowest number of significant positive associations was observed for black coral and bryozoans (3).

Table 5.1. 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		Black coral		Sea pens		Sponges		Large gorg.		Small gorg.		Bryozoa		Boltenia	
Fish	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl
Golden redfish (*Sebastes norvegicus*)	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Spiny-tailed skate (*Bathyraja spinicauda*)	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	⊟	⊟	⊟	⊟	⊘	⊘	⊘	⊘
Eelpout (*Lycodes* spp.)	⬇	↓	⊘	⊘	⊘	⊘	⬇	⬇	⬇	⊟	⊟	⊟	⊘	⊘	⬆	⬆
Rockfish (*Sebastes* spp.)	⊟	⊟	⊘	⊘	⊘	⊘	⬇	⬇	↑	⊟	⊟	⊟	⬇	⬇	⬆	⬆
Thorny skate (*Amblyraja radiata*)	⊟	⊟	⊟	⊟	⊘	⊘	⬇	⬇	⊟	⊟	↑	⊟	⊟	⊟	⊟	↑
Greenland halibut (*Reinhardtius hippoglossoides*)	⬆	⊟	⬆	⊟	⬆	⬆	⊟	⬇	↓	⊟	⊟	⊟	⬇	↓	⬇	⬇
Witch (*Glyptocephalus cynoglossus*)	⬇	⬇	⊟	⊟	⊟	⊟	⬇	⬇	⊟	⊟	↓	⊟	⊟	⊟	⊟	⊟
Northern shrimp (*Pandalus* spp.)	⬇	⬇	⊟	⊟	⊟	⊟	⬇	⬇	⬇	↓	⬆	⊟	⬇	⊟	⊟	⊟
Rattails (*Coryphaenoides* spp.)	⊟	⬇	⬆	↑	⬆	⬆	⬇	⬇	⊟	⊟	⬆	↑	⊘	⊘	⊘	⊘
Blue hake (*Antimora rostrata*)	⊟	⊟	⊟	⊟	⬆	⊟	↑	⊟	↑	⊟	⬇	⊟	⊘	⊘	⊘	⊘
Black dogfish (*Centroscyllium fabricii*)	⬆	⬆	⬆	⬆	⬆	⬆	⬆	⊟	⬆	↑	⊟	⊟	⊘	⊘	⊘	⊘
Grenadiers (*Nezumia* spp.)	⊟	⬇	⊟	⊟	⬆	⊟	⬇	⬇	⊟	⊟	⬆	⊟	⊘	⊘	⊟	↓
Cutthroat eel (*Synaphobranchus* spp.)	⊟	⬇	⊟	⊟	⬆	⊟	⬇	⬇	⬇	⊟	⬆	⊟	⊘	⊘	⬇	⊟
Northern wolffish (*Anarhichas denticulatus*)	↓	⊟	⊟	⊟	⊟	⊟	⊟	⬇	⊟	⊟	⬇	⊟	⊘	⊘	⊟	⊟
Roughhead grenadier (*Macrourus berglax*)	⊟	⊟	⊟	⊟	⊟	⊟	⬆	⊟	⬆	⊟	⬇	⊟	⊘	⊘	↑	⊟
Acadian redfish (*Sebastes fasciatus*)	⬇	⬇	⊘	⊘	⬇	↓	⬇	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Beaked redfish (*Sebastes mentella*)	⬇	⬇	⊟	⊟	⬇	⊟	⬇	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Spotted wolf fish (*Anarchichas minor*)	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬆	⬆
Silver hake (*Merluccius bilinearis*)	⬆	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬇	⊟
Atlantic wolf fish (*Anarchichas lupus*)	⬇	↑	⊘	⊘	⊘	⊘	⊘	⊘	⬇	⊟	⊘	⊘	⊟	⊟	⬆	⬆
Northern sand lance (*Ammodytes dubius*)	⬇	⬇	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	⊟	⊟
Capelin (*Mallotus villosus*)	⬇	⬇	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	⬇	⊟
Cod (*Gadus morhua*)	⬆	⬆	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	⬆	⬆
American plaice (*Hippoglossoides platessoides*)	⊟	⬆	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬆	⬆	⊟	⊟
Yellowtail flounder (*Limanda ferruginea*)	↑	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	↑	⬆	⊟	⊟
Total fish	↓	⊟	⊟	⊟	↓	⊟	⊟	⊟	↑	⊟	⊟	⊟	⊟	⬆	⊟	⊟

Comparison to 2021 Analysis

In cluster groups 1 and 2, two combinations of fish and VME that had previously been analysed, namely cod (*Gadus morhua*) in combination with small gorgonians and beaked redfish (*Sebastes mentella*) with large gorgonians, lacked sufficient numbers of observations in each VME category within the fish-specific depth ranges to complete the analysis (Table 5.2). Of the VME/Fish combinations analysed, changes to associations were seen with cod and witch (*Glyptocephalus cygnoglossus*) no longer showing a significant negative association with the bryozoa VME polygons, as well as the reduction of the negative association of northern shrimp (*Pandalus* spp.) with bryozoa from both polygon and trawls, to just showing a significant effect of the VME polygons. The positive effect observed between northern shrimp and sea pens in the sea pen VME depth range was also not significant when investigated in the depth range of northern shrimp. The negative association between northern shrimp and the sponge and large gorgonian VMEs became significant in the VME trawls category as well as the VME polygon category as found in the previous analysis. A similar change was seen in Acadian redfish (*Sebastes fasciatus*) and sea pens. A new negative association was found between Acadian redfish and the sponge VME polygons.

Table 5.2. Summary of the conditional effects of the VME category term in GLMMs for fish in Clusters 1 and 2. (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		Black coral		Sea pens		Sponges		Large gorg.		Small gorg.		Bryozoa		Boltenia	
Cluster	Fish	Depth range	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl
Cluster 1	Cod (*Gadus morhua*)	Fish	⬆	⬆	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	⬆	⬆
		VMEs	↓	↑	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬇	⊟	⬇	⊟	⬆	⬆
	Witch (*Glyptocephalus cynoglossus*)	Fish	⬇	⬇	⊟	⊟	⊟	⊟	⬇	⬇	⊟	⊟	↓	⊟	⊟	⊟	⊟	⊟
		VMEs	⬇	⬇	⊟	⊟	⊟	⊟	↓	⬇	⊟	⊟	↓	⊟	⬇	⬇	⊟	⊟
	Golden redfish (*Sebastes norvegicus*)	Fish	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
		VMEs	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Cluster 2	Northern shrimp (*Pandalus* spp.)	Fish	⬇	⬇	⊟	⊟	⊟	⊟	⬇	⬇	⬇	↓	⬆	⊟	⬇	⊟	⊟	⊟
		VMEs	⬇	⬇	⊟	⊟	↑	⊟	⬇	⊟	⬇	⊟	⬆	⊟	⬇	↓	⬇	⊟
	Acadian redfish (*Sebastes fasciatus*)	Fish	⬇	⬇	⊘	⊘	⬇	↓	⬇	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
		VMEs	⬇	⬇	⊟	⊟	⬇	⊟	⊘	⊘	⊟	⊟	⊟	⊘	⊘	⊘	⊘	⊘
	Beaked redfish (*Sebastes mentella*)	Fish	⬇	⬇	⊟	⊟	⬇	⊟	⬇	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
		VMEs	⬇	↓	↓	⊟	⬇	⊟	⬇	⊟	⬆	⊟	⊟	⊘	⊘	⊘	⊘	⊘

Fish species included in cluster group 3, namely blue hake (*Antimora rostrata*), rattails (*Coryphaenoides* sp.), cutthroat eel (*Synaphobranchus* sp.), black dogfish (*Centroscyllium fabricii*), Greenland halibut (*Reinhardtius hippoglossoides*), grenadiers (*Nezumia* sp.) and roughhead grenadier (*Macrourus berglax*), showed mostly similar associations with VME in the current analysis using the depth ranges of fish as in the previous analysis done using VME depth ranges (Table 5.3). All cluster 3 fish bar roughhead grenadiers show some positive association with sea pens, with no changes from previous analysis.

In the analysis based on VME depth ranges black coral VME, with a distribution concentrated in the deep water around the Flemish Cap, only showed a positive association with black dogfish, which was found to be significantly associated with the VME Polygon category. Using the depth range of black dogfish, the VME trawl category for black coral also shows a positive association. Rattails in their depth range have a positive association with both the clack coral VME polygon and trawl categories and Greenland halibut also gains a positive association with the black coral VME polygon. The previously observed positive associations between black dogfish and large gorgonian VME polygons, along with those of rattails with small gorgonian VME polygons, were extended to include the VME trawls category.

The strongest significant positive association sponges had in the previous analysis was with roughhead grenadier, with significantly higher mean biomass in both the sponge VME polygon and trawls exceeding the sponge VME threshold. In the current analysis, using the depth range of roughhead grenadiers, only the association with the VME polygon remains. The other observed associations of roughhead grenadier with the VME polygons of large gorgonians and *Boltenia* spp. remain unchanged.

Table 5.3. Summary of the conditional effects of the VME category term in GLMMs for fish in Cluster 3. (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).

Cluster	Fish	Depth range	All VME Poly	All VME Trawl	Black coral Poly	Black coral Trawl	Sea pens Poly	Sea pens Trawl	Sponges Poly	Sponges Trawl	Large gorg. Poly	Large gorg. Trawl	Small gorg. Poly	Small gorg. Trawl	Bryozoa Poly	Bryozoa Trawl	Boltenia Poly	Boltenia Trawl
Cluster 3	Blue hake (*Antimora rostrata*)	Fish	⊟	⊟	⊟	⊟	↑↑	⊟	↑	⊟	↑	⊟	↓↓	⊟	⊘	⊘	⊘	⊘
		VMEs	⊟	⊟	⊟	⊟	↑	⊟	↑	⊟	↑	⊟	↓↓	⊟	⊘	⊘	⊘	⊘
	Black dogfish (*Centroscyllium fabricii*)	Fish	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	⊟	↑↑	↑	⊟	⊟	⊘	⊘	⊘	⊘
		VMEs	↑↑	↑↑	↑	⊟	↑↑	↑↑	↑↑	⊟	↑↑	⊟	⊟	⊟	⊘	⊘	⊘	⊘
	Rattails (*Coryphaenoides* spp.)	Fish	⊟	↓↓	↑↑	↑	↑↑	↑↑	↓↓	↓↓	⊟	⊟	↑↑	↑	⊘	⊘	⊘	⊘
		VMEs	⊟	↓↓	⊟	⊟	↑↑	↑↑	↓↓	↓↓	↓↓	⊟	↑↑	⊟	⊘	⊘	⊘	⊘
	Roughhead grenadier (*Macrourus berglax*)	Fish	⊟	⊟	⊟	⊟	⊟	⊟	↑↑	⊟	↑↑	⊟	↓↓	⊟	⊘	⊘	↑	⊟
		VMEs	⊟	⊟	⊟	⊟	⊟	⊟	↑↑	↑	↑↑	⊟	↓↓	⊟	⊟	⊟	↑	⊟
	Grenadiers (*Nezumia* spp.)	Fish	⊟	↓↓	⊟	⊟	↑↑	⊟	↓↓	↓↓	⊟	⊟	↑↑	⊟	⊘	⊘	⊟	↓
		VMEs	⊟	↓↓	⊟	⊟	↑↑	⊟	⊟	↓↓	⊟	⊟	↑↑	⊟	⊘	⊘	↓↓	⊟
	Greenland halibut (*Reinhardtius hippoglossoides*)	Fish	↑↑	⊟	↑↑	⊟	↑↑	↑↑	⊟	↓↓	↓	⊟	⊟	⊟	↓↓	↓	↓↓	↓↓
		VMEs	↑↑	⊟	⊟	⊟	↑↑	↑↑	⊟	↓↓	↓	⊟	⊟	⊟	⊟	↓	↓↓	↓↓
	Cutthroat eel (*Synaphobranchus* spp.)	Fish	⊟	↓↓	⊟	⊟	↑↑	⊟	↓↓	↓↓	↓↓	⊟	↑↑	⊟	⊘	⊘	↓↓	⊟
		VMEs	⊟	↓↓	⊟	⊟	↑↑	⊟	↓↓	↓↓	↓↓	⊟	↑↑	⊟	⊘	⊘	⊘	⊘

Fish in cluster groups 4, 5 and 6 also did not show much change to the previous analysis (Table 5.4). Again, not all combinations of fish and VME class that had previously been analysed had sufficient number of observations within the fish specific depth ranges. These included silver hake (*Merluccius bilinearis*) in combination with sea pens and small gorgonians, rockfish (*Sebastes* spp.) with sea pens, American plaice (*Hippoglossoides platessoides*) with small gorgonians and eelpout (*Lycodes* spp.) with bryozoans.

The strongest association between large gorgonians and fish in the previous analysis was observed for rockfish, which were found to have significantly higher biomass in both VME polygons and VME trawls categories than outside in the depth range of the large gorgonians. In the current analysis, using the depth range of the rockfish, this association was reduced to the VME polygon only.

Bryozoans continue to be associated with the two shallowest community groups on the Grand Bank (cluster groups 5 and 6). The positive association of yellowtail flounder (*Limanda ferruginea*) with bryozoans extended from the VME trawls only to also cover the VME polygon category. The negative association between Thorny skate (*Amblyraja radiata*) and bryozoan VME found in the previous analysis, on the other hand, is not significant in the depth range of the fish.

Eelpout shows a strong negative association with both the sponge VME polygons and trawls within its depth range where no significant association was observed using the sponge VME depth range. The positive association between eelpout and the *Boltenia* sp. VME is, however, extended from the VME polygon category only to include the VME trawls category. American plaice conversely does not have the significant positive association with the *Boltenia* sp. VME Polygon found in the *Boltenia* sp. depth range.

Table 5.4. Summary of the conditional effects of the VME category term in GLMMs for fish in Clusters 4, 5 and 6. (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		Black coral		Sea pens		Sponges		Large gorg.		Small gorg.		Bryozoa		Boltenia	
Cluster	Fish	Depth range	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl	Poly	Trawl
Cluster 4	Silver hake (*Merluccius bilinearis*)	Fish	↑↑	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	↓↓	⊟
		VMEs	↑↑	⊟	⊘	⊘	↑↑	⊟	⊘	⊘	⊘	⊘	↑↑	⊟	⊘	⊘	↓↓	⊟
	Rockfish (*Sebastes* spp.)	Fish	⊟	⊟	⊘	⊘	⊘	⊘	↓↓	↓↓	↑	⊟	⊟	⊟	↓↓	↓↓	↑↑	↑↑
		VMEs	⊟	⊟	⊘	⊘	↓↓	⊟	⊟	↓	↑↑	↑↑	⊟	⊟	↓↓	↓↓	↑↑	↑↑
Cluster 5	Thorny skate (*Amblyraja radiata*)	Fish	⊟	⊟	⊟	⊟	⊘	⊘	↓↓	↓↓	⊟	⊟	↑	⊟	⊟	⊟	⊟	↑
		VMEs	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⊟	↑	⊟	↓	⊟	⊟	⊟
	American plaice (*Hippoglossoides platessoides*)	Fish	⊟	↑↑	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	↑↑	↑↑	⊟	⊟
		VMEs	⊟	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	↓↓	⊟	↑↑	↑↑	↑	⊟
	Eelpout (*Lycodes* spp.)	Fish	↓↓	↓	⊘	⊘	⊘	⊘	↓↓	↓↓	↓↓	⊟	⊟	⊟	⊘	⊘	↑↑	↑↑
		VMEs	↓↓	↓	⊘	⊘	⊘	⊘	⊟	⊟	↓↓	⊟	⊟	⊟	↓↓	⊟	↑	⊟
	Capelin (*Mallotus villosus*)	Fish	↓↓	↓↓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	↓↓	⊟
		VMEs	↓↓	↓↓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	↓↓	↓
Cluster 6	Northern sand lance (*Ammodytes dubius*)	Fish	↓↓	↓↓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	⊟	⊟
		VMEs	↓↓	↓↓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	⊟	⊟
	Yellowtail flounder (*Limanda ferruginea*)	Fish	↑	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	↑	↑↑	⊟	⊟
		VMEs	⊟	⊟	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊟	↑↑	↑	⊟

The Atlantic, spotted and northern wolffish (*Anarhichas lupus*, *Anarhichas minor* and *Anarhichas denticulatus*) and spiny-tailed skate (*Bathyraja spinicauda*) are not strongly associated with any of the clusters. Both Atlantic and spotted wolffish remain positively associated with both the *Boltenia* spp. VME polygons and trawls (Table 5.5). The northern wolffish, on the other hand, is not significantly positively associated with sea pens in its depth range unlike in the sea pen depth range. The Atlantic wolffish, in its depth range, shows a negative association with large gorgonians, where data was not sufficient for this comparison in the depth range of the large gorgonian VME. The negative association of Atlantic wolffish with bryozoans in the bryozoan VME depth range is not significant in the Atlantic wolffish depth range.

Total fish biomass associations with VMEs change in most cases. In the full depth range encompassing all fish there is a significant negative association with sea pen VME polygons, which is not present in the sea pen VME depth range. Conversely, the negative associations with small gorgonian and bryozoan VME polygons present in their respective depth ranges are not significant in the full observation depth range. The highly significant positive association with both polygons and trawls of the *Boltenia* sp. VME present in the VME depth range is also absent in the full depth range. New positive associations between total fish biomass are observed with large gorgonian VME polygons and bryozoan VME trawls.

Table 5.5. Summary of the conditional effects of the VME category term in GLMMs for fish Not strongly associated with a cluster and total fish biomass. (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).

Cluster	Fish	Depth range	All VME Poly	All VME Trawl	Black coral Poly	Black coral Trawl	Sea pens Poly	Sea pens Trawl	Sponges Poly	Sponges Trawl	Large gorg. Poly	Large gorg. Trawl	Small gorg. Poly	Small gorg. Trawl	Bryozoa Poly	Bryozoa Trawl	Boltenia Poly	Boltenia Trawl
No Cluster	Northern wolffish (*Anarhichas denticulatus*)	Fish	↓	⊟	⊟	⊟	⊟	⊟	⊟	⬇	⊟	⊟	⬇	⊟	⊘	⊘	⊟	⊟
		VMEs	↓	⊟	⊟	⊟	⊟	↑	⊟	⬇	⊟	⊟	⬇	⊟	⊘	⊘	⊟	⊟
	Atlantic wolf fish (*Anarchichas lupus*)	Fish	⬇	↑	⊘	⊘	⊘	⊘	⊘	⊘	⬇	⊟	⊘	⊘	⊟	⊟	⬆	⬆
		VMEs	⬇	↑	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬇	⊟	⬆	⬆
	Spotted wolf fish (*Anarchichas minor*)	Fish	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬆	⬆
		VMEs	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⬆	⬆
	Spiny-tailed skate (*Bathyraja spinicauda*)	Fish	⊘	⊘	⊘	⊘	⊘	⊘	⊟	⊟	⊟	⊟	⊟	⊟	⊘	⊘	⊘	⊘
		VMEs	⊘	⊘	⊟	⊟	⊘	⊘	⊟	⊟	⊟	⊟	⊟	⊟	⊘	⊘	⊘	⊘
	Total fish	Fish	↓	⊟	⊟	⊟	↓	⊟	⊟	⊟	↑	⊟	⊟	⊟	⊟	⬆	⊟	⊟
		VMEs	⊟	⬆	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⊟	⬇	⊟	↓	⊟	⬆	⬆

Summary and conclusions

The current analysis repeated the investigation of associations between the biomass of individual demersal fish species and VME types (sea pens, small gorgonians, large gorgonians, black corals, sponges, *Boltenia* spp. and bryozoans) carried out in 2021, with the distinction that, whereas the trawls included in the analysis for each VME / Fish combination in the 2021 analysis were restricted to those within the depth range of the relevant VME, in the current analysis the depth range of each fish was used instead. The change in approach was made to determine if there was an effect, independent of depth, of VME presence on fish biomass across the fish's natural distribution. Conversely, the 2021 analysis was structured to investigate fish biomass inside and outside of VME, within the suitable depths for the VME.

Table 5.6 summarises the positive associations between fish and VME in the current analysis and the 2021 analysis. There was no change in most of the strong associations, where there is a solid overlap in the depth ranges of the fish and VME analysed. Some associations, especially where the fish and VME depth distributions only partially overlap, were not significant when analysed in the fish's full distribution depth range. In some cases, associations changed from significantly positive to negative and vice versa. This indicates that the choice of depth interval for the analysis has an effect on the outcome and results should be treated with caution. Whilst the analysis presented here has confirmed many positive associations between fish and VME in the wider picture, future analysis should be targeted more towards study of individual combinations of fish and VME which share habitat requirements, such as temperature, current and bottom type preferences. A more detailed investigation of relationships in the biomass and abundance of fish and the biomass and density of structure building VME indicator taxa is likely to give more useful insight. Combining VME indicator taxa with similar habitat-specific functions together across the VME boundaries is also likely to be more relevant to the links between fish and VME.

Table 5.6. Strongly and moderately associated fish by VME in the 2021 and 2023 analyses. 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. New significant associations in either category (or where a fish has moved from one category to another) in 2023 are highlighted in bold.

VME	Strongly associated fish (polygons and/or trawls)		Moderately associated fish (polygons only)	
	2023	**2021**	**2023**	**2021**
Black corals	**Black dogfish**			Black dogfish
***Boltenia* sp.**	Rockfish Spotted wolffish Atlantic wolffish Cod **Eelpout** Thorny skate (Trawls)	Rockfish Spotted wolffish Atlantic wolffish Cod Thorny skate (Trawls) Total fish	Roughhead grenadier	American plaice Yellowtail flounder Eelpout
Bryozoa	American plaice Yellowtail flounder **Total fish (Trawls)**	American plaice Yellowtail flounder (Trawls)		
Large gorgonians	**Black dogfish**	Rockfish	Blue hake **Rockfish** **Total fish**	Beaked redfish Blue hake Black dogfish
Sea pens	Greenland halibut Rattails Black dogfish	Greenland halibut Rattails Black dogfish Northern wolffish (Trawls)	Blue hake Grenadiers Cutthroat eel	Blue hake Silver hake Grenadiers Cutthroat eel
Small gorgonians	**Rattails**		Grenadiers Cutthroat eel Thorny skate	Silver hake Grenadiers Cutthroat eel Rattails Thorny skate
Sponges		Roughhead grenadier	Blue hake Black dogfish **Roughhead grenadier**	Blue hake Black dogfish

References

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. H., and White, J. S. S. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology & Evolution, 24: 127–135. Elsevier. http://www.cell.com/article/S0169534709000196/fulltext

Kenchington, E., Lirette, C., Murillo, F.J., Beazley, L. and Downie, A.L. 2019. Vulnerable Marine Ecosystems in the NAFO Regulatory Area: Updated Kernel Density Analyses of Vulnerable Marine Ecosystem Indicators. NAFO Scientific Council Research Documents 19/058, Serial No. N7030. 68 pp. https://www.nafo.int/Portals/0/PDFs/sc/2019/scr19-058.pdf

NAFO. 2021. Report of the 14th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). Serial No. 7256. NAFO Scientific Council Studies Document 21/21.

NAFO. 2020. Report of the Scientific Council Working Group on Ecosystem Science and Assessment, 17 - 26 November 2020, Dartmouth, Nova Scotia, Canada. NAFO SCS Doc. 19/23.

NAFO. 2022. Report of the Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). Serial No. 7367. NAFO Scientific Council Studies Document 22/25.

d) ToR 2.4. Update on the analysis of significant adverse impact cut-offs based on cumulative response curves (COM Request #5c)

Intersessionally, there have been two distinct pieces of work conducted to update the cumulative biomass curve method, with some further amendments having been completed during the meeting:

1. Conduct a sensitivity analysis to determine the influence of patch size upon SAI cut-off value estimation.
2. Refinements to the biomass accumulation curve methodology, based upon reviewer comments to submission to Global Ecology and Conservation (received August 2023) and following discussions at 2023 WG-ESA.

Terminology

- Cut-off — Percentage loss of VME, based on the biomass accumulation curves
- KDE — Kernel Density Estimation
- Reference point — Fishing intensity equivalent (km/km^{-2}/yr^{-1}) of a given biomass cut-off value
- SAI — Significant Adverse Impacts
- VME — Vulnerable Marine Ecosystems[3]

i) Influence of patch size

Presently the spatial component of the accumulation curve method is confined to the VME 'significant extent' polygons, defined previously by kernel density estimation (KDE) in Kenchington *et al*. (2014) and variously at WG-ESA (e.g., 2019). These polygons serve to constrain to the habitat suitability models (idealised environmental niche) to the areas of the NRA where a given VME type has been most commonly observed (realised environmental niche). This reduces spurious inferences of the effect of fishing by substantially reducing the chance that the absence of a given VME from a particular area is not a result of naturally occurring patterns in distribution rather than having been removed through fisheries bycatch.

However, the size of these patches has the potential to influence how WG-ESA is currently estimating VME loss rates, as larger patches increasingly include areas outside of the 'core' habitat where the VME indicator species are most abundant. Hence, larger patches progressively lower the mean biomass density of the patch and so

[3] usually one of the seven groups recognised in NAFO, but in the first part of this section on patch size, generally referring specifically to sea pens

affect the likelihood that a given haul (scientific or commercial trawls) will encounter VME and the slope of the accumulation curve used to estimate the VME loss component of the five-yearly SAI assessment.

Previously, significant extent thresholds were delimited based on spatial trends in abundance designed to discriminate naturally occurring ‘breaks’ between core habitats, where the majority of extant biomass is expected to be found, vs. areas where a given VME is either absent or at least relatively sparse. For sea pens, the significant extent polygon equates to areas where bycatch in scientific hauls is expected to be more than 1.4 kg per haul.

To examine the potential influence of the delimitation of significant extents, we created several new polygons based on different KDE thresholds and repeated the biomass accumulation curve analysis using data from within each polygon. In this instance, we used sea pens as a test case and did not examine other more data-limited VME types.

Key findings are as follows:

- For a given percentage accumulation (which itself remains a subject of ongoing research), larger polygons led to higher estimates of the reference point (fishing intensity equivalent) (Figure 5.4).
- The polygons for a given threshold are typically a set of discrete polygons of variable size, rather than being a single unit. Cut-off value estimation was however independent of whether data was used from all polygons in the set or only the largest polygon.

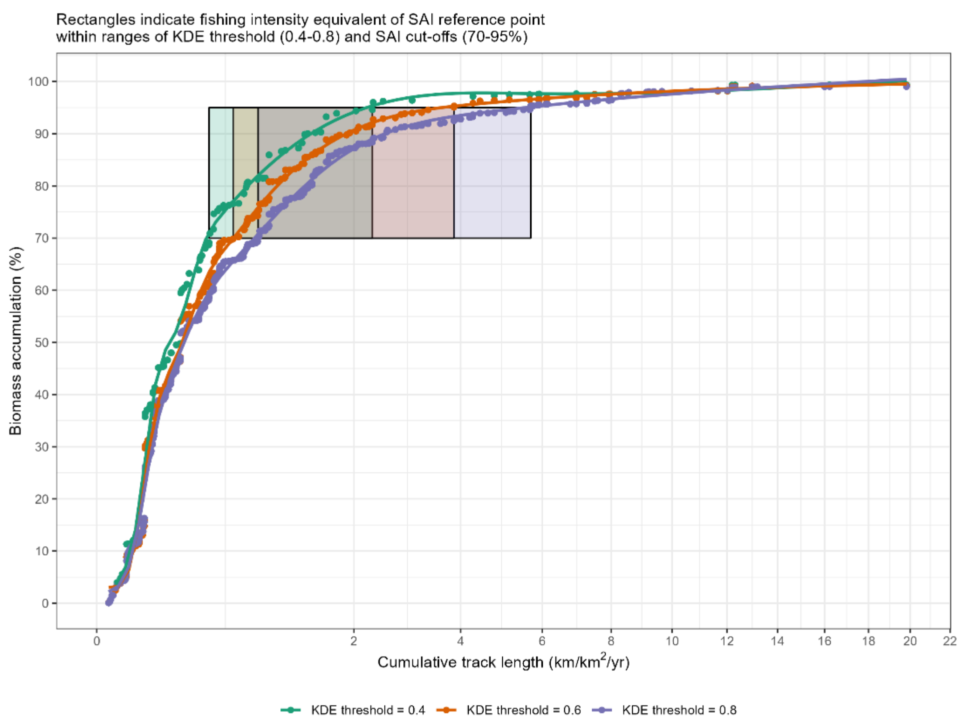

Figure 5.4. Biomass accumulation curves of seapens using data subsetted to one of three polygon sets.

We have shown that the biomass accumulation method is to some degree sensitive to the size of the significant extent polygons, and the influence of patch size suggests that the estimation of cut-off values is to some degree density dependent. To avoid any introduction of arbitrary selections, the choice of KDE threshold should be, as previously (Kenchington *et al*., 2014), made independently of any subsequent biomass accumulation method and based upon agreed statistical and ecological reasoning, rather than with consideration to implications for any subsequent SAI assessment.

ii) Biomass accumulation method

Responses to reviews of GEcCo submission

One of the comments received from the anonymous reviewers highlighted a concern that our conclusions regarding biomass loss percentages were unduly skewed by a bias towards number observations at lower levels of fishing intensity. Although this would be expected to some degree (and as we have previously demonstrated empirically, see Figures 5.1 and 5.2 in WG-ESA 2021), since the chance of VME indicator species occurring in scientific trawl catches decreases with increasing fishing intensity, we acknowledge the reviewers' point that this does affect how reference points should be calculated for assessing the extent of SAIs.

The reviewers were correct in supposing that such a bias exists and, to address this issue, we trialled four methods (for all VME types):

1. Quantile filtering
    a. We noted that for some of the taxa, most particularly sponges, a very large proportion of the total biomass consists of a small number of records and that this had a significant controlling influence upon biomass accumulation rates. 3 of 249 sponge records comprised 77% of the total observed scientific catch weight, and for which the estimates of commercial fishing effort were considered uncertain either because the associated track(s) ran perpendicular to seafloor contours or because of proximity to a closed area. An upper 99% quantile filter was applied to scientific survey catch weights for methods 2-4 below.
2. Binned median
    a. To estimate biomass accumulation curves independently of bias towards any level of fishing intensity, we created equal-sized bins of fishing intensity (both for natural and $\log_{10}$-transformed fishing intensity data) and used the median biomass per bin to re-estimate accumulation curves using approximately 15-30 points per VME, following the cut-off curve method established previous.
    b. Since these curves are based on far fewer observations for most taxa, there is a significant associated increase in uncertainty for the estimation of any reference points.
    c. A small amount of residual bias exists, in that some medians were calculated from relatively few values, and so accumulation curves generally became less certain with increasing fishing intensity.
3. Binned median with inferred cut-off
    a. As per (2) but using a generalised linear model to estimate the fishing intensity equivalent reference point for a given cut-off value.
4. Resampling
    a. Following the binned method as per (2) but basing accumulation curves on a small number of random draws from each bin, instead of median values, and repeating for 5k iterations. Reference points were then estimated as the median value against a given cut-off value.
    b. Owing to data limitations (similar to those described in 2b), this method was not possible for either black corals or large gorgonians, that typically only had one or two values per bin, meaning that the resultant 'random draws' served only to recreate virtually the same accumulation curve in every iteration.

Table 5.7. Summary of different fishing intensity equivalent threshold values.

Taxa	Fishing intensity (Km fished per Km² per year) at 95 % biomass accumulation estimates (+/- % difference to original estimate)						
	Original method		Bias correction methods				
			Median-per-bin w/ 99 % quantile filter		Resampled (5k iterations w/ 99 % quantile filter)		
	All data	99 % quantile filter	Directly measured	GLM inferred	Mean	Lower 95 % CI	Upper 95 % CI
Boltenia	2.046	2.746 (+ 34.2 %)	9.142 (+ 346.2 %)	11.705 (+ 472.2 %)	6.694 (+ 227.2 %)	1.429	11.960
Sea Pens	4.253	5.141 (+ 20.9 %)	5.906 (+ 38.9 %)	11.941 (180.8 %)	5.842 (+ 37.4 %)	4.950	6.735
Sponges	0.260	0.872 (+ 335.0 %)	0.181 (- 30.5 %)	0.583 (+ 124.0 %)	3.756 (+ 1343.4 %)	2.527	4.985
Bryozoans	6.845	6.615 (- 3.4 %)	6.051 (- 11.6 %)	5.003 (- 26.9 %)	5.437 (-20.6 %)	3.985	6.889
Small Gorgonians	2.248	2.289 (+ 1.8 %)	34.478 (+ 1433.5 %)	24.533 (+ 991.2 %)	13.052 (+ 480.5 %)	4.115	21.990
Black Corals	0.734	1.029 (+ 40.2 %)	0.734 (+/- 0.0 %)	0.472 (- 35.6 %)	Method rejected – insufficient records for approach		
Large Gorgonians	0.620	0.896 (+ 44.5 %)	0.884 (+ 42.4 %)	0.726 (+ 17.0 %)			

The estimation methods differed above and below the original estimate (Table 5.7), with the largest relative changes being for sponges owing to the originally very low estimate. The three estimation methods trialled are subject to the following caveats:

- Both the median-per-bin and resampling method base their estimates of biomass accumulation rates upon a small number of data points (one median value from each of 10 – 25 bins, depending on the range of fishing intensity values sampled) and so are individually much more uncertain than the 'original' method.
- Both methods are still somewhat biased in the sense that the medians or resamples are drawn from a varying number of individual records and so uncertainty or repeat usage of the same values is higher towards the extremities of the distribution of catch data against fishing intensity. There are also more empty bins at higher fishing intensities, so some degree of bias still remains in whichever case.
- The original method with the newly applied quantile filter is subject to similar weighting towards lower fishing intensity values, but less sensitive to upper extreme catch rates.

iii) Further work conducted at 2023 WG-ESA meeting

During the 2023 WG-ESA meeting, it was agreed that the data used to construct the accumulation curves should be further filtered to allow only records that occurred within their respective VME polygons. This sub-setting further compromised the viability of the methods (described above) for some taxa and for some, most especially large gorgonians and black corals, the attempts to adjust for sampling bias are made highly uncertain or impossible by the lack of data (Table 5.8).

Table 5.8. Summary of new filtered data and cut-off value, calculated using data with the same filters applied in each case.

Taxa	Number of records after all filters applied	Old cut-off value (95% accumulation)	New cut-off value (curve subtraction)	Estimated biomass loss
		Km fished per Km^2 per year		%
Black Corals	15	0.423	0.321	88.6
Boltenia	63	2.861	5.489	96.3
Bryozoans	41	6.615	2.638	74.5
Large Gorgonians	8	0.219	N/A	N/A
Sea Pens	177	5.141	5.501	95.5
Small Gorgonians	78	2.289	5.761	96.0
Sponges	182	0.718	2.228	99.1

However, upon comparison of trends in cumulative biomass and cumulative fishing effort (as %) along a gradient of cumulative fishing intensity, it became apparent that trends in VME catch and fishing effort were divergent in a way that potentially allowed the discrimination of a cut-off value for SAI without the need to specify an arbitrary level of VME biomass loss. This was calculated by subtracting the fishing accumulation curve from the biomass accumulation curve and then taking the maximum 'offset' value as the point at which biomass accumulation starts to slow relative to fishing intensity. In this way, we can derive cut-off values for SAI in a manner that takes account of the bias towards sampling at lower fishing intensities (Figure 5.5). This method will undergo further development after the conclusion of 2023 WG-ESA and submitted for peer review in due course. The major outstanding issues are to understand why bryozoans have a cut-off value at such a relatively low effective biomass loss rate (56.7%, compared with > 80 % for other taxa, and the most markedly changed against the previous method; Table 5.8), and how (or whether) to include large gorgonians in the analysis, which now have very few qualifying records.

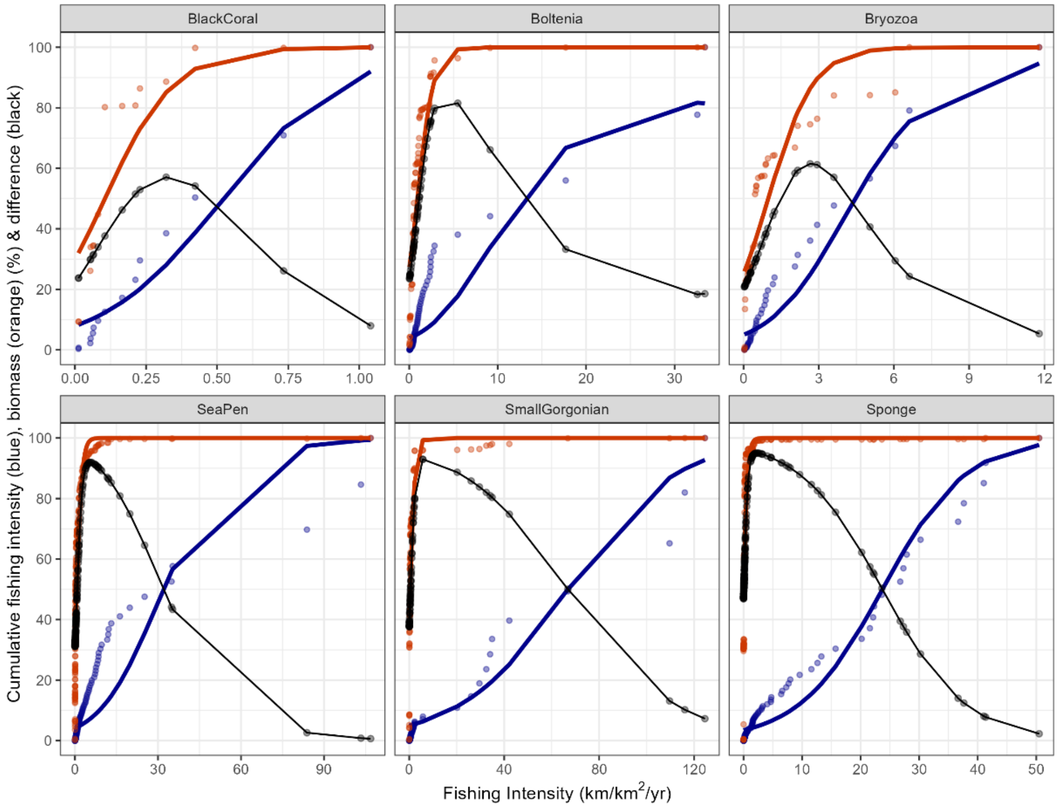

Figure 5.5. Cumulative fishing intensity (blue), cumulative biomass (orange) and the offset between the two (black).

References

Kenchington, E. L., Murillo, F. J., Lirette, C., Sacau, M., Koen-Alonso, M., Kenny, A., Ollerhead, N., Wareham, V., Beazley, L., 2014. Kernel Density Surface Modelling as a means to Identify Significant Concentrations of Vulnerable Marine Ecosystem Indicators. PLoS ONE 9(10) e109365

NAFO WG-ESA. 2019. Vulnerable Marine Ecosystems in the NAFO Regulatory Area: Updated Kernel Density Analyses of Vulnerable Marine Ecosystem Indicators. NAFO SCR Doc 19/058

NAFO WG-ESA. 2021. SC Working Group on Ecosystem Science and Assessment – November 2021: Report on the 14th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA) NAFO SCS Doc 21/21

e) ToR 2.5. Work towards the reassessment of VMEs and the impact of bottom fisheries on VMEs for 2026 (COM Request #5c)

COM Request #5. *In relation to the habitat impact assessment component of the Roadmap (VME and SAI analyses), the Commission requests that Scientific Council to:*

c) *Work towards the reassessment of VMEs and the impact of bottom fisheries on VMEs for 2026.*

WG-ESA noted the review of VMEs and the reassessment of bottom fisheries are both now required in 2026. In previous years the timetable for these assessments were staggered by 1 year and reported separately to SC, WG-EAFFM and the Commission. However, given the need to inform management options to mitigate SAIs, it is now necessary to integrate the results of the review of VME with the assessment of SAI, as was requested by WG-EAFFM and the Commission in 2020. We are expected to provide a single assessment of the management options to mitigate SAI, comprising a review of the VMEs and a reassessment of bottom fisheries, to be presented to SC, WG-EAFFM and the Commission in 2026. However, in order to manage the workload, WG-ESA agreed to conduct and complete a review of the VMEs using 2024 survey data ahead of undertaking the SAI and the assessment of the management options to be conducted by WG-ESA in 2025.

Specific tasks, in chronological order, for the review of NAFO VMEs will broadly follow the structure of the review undertaken in 2019 (NAFO 2019), and are highlighted in Table 5.9 below.

Table 5.9. Specific tasks, in chronological order, for the review of NAFO VMEs

Task	Sections	Lead	When
1	Description of new data collected in bottom trawl surveys (table of data sources) since last review	Ellen/Cam	WG-ESA 2024
2	Section on up-dated VME indicators	Javi	WG-ESA 2024
3	Section on up-dated species taxonomy	Javi/ Barbara	WG-ESA 2024
4	New SDMs (divide up tasks and produce maps in order to clip KDEs -see detailed SDM tasks for 2024 in section 5e)	Ellen/Cam/Anna/Javi	WG-ESA 2024
5	New KDE VME analysis (to include 2024 survey data)	Ellen/Cam/Javi	Feb 2025 WG-ESA ICG
6	Table of VME polygon areas & biomass changes – 2013, 2019 & 2025	Ellen/Cam	Feb 2025 WG-ESA ICG
7	Table of assessment categories (does not change from the last assessment)	All to check/ review	WG-ESA 2024
8	Maps showing VME polygon differences between 2013/ 2019, 2019/ 2024, and 2013/ 2024 (compare two sets of polygons per map)	Ellen/ Cam	Feb 2025 WG-ESA ICG

Specific tasks for the assessment of SAI and the reassessment of bottom fisheries will be specified during WG-ESA in 2024, but in general the tasks will follow the structure and the methods presented in the previous assessment undertaken in 2020 (NAFO 2020).

Provisional tasks, broadly in chronological order, for the assessment of SAI and the reassessment of bottom fisheries impacts are shown in Table 5.10 below, noting that the leads and timing for completion of the tasks will be specified at WG-ESA 2024.

Table 5.10. Provisional tasks for the assessment of SAI and the reassessment of bottom fisheries impacts.

Task	Sections	Lead
1	**Introduction**	**??**
1.1	Policy background (incl. BBNJ developments)	Dani
1.2	Oceanographic conditions	Miguel
1.3	Ecosystems	
1.4	Habitats	
1.5	Communities – fish, epibenthos, infauna	Javi/ Fernando
1.6	Description of EPUs	Mariano
2	**VMEs**	**Ellen**
2.1	Defining, identifying and mapping VMEs (from review of VMEs)	
2.2	VME polygon boundaries (from review of VMEs)	
2.3	VME and functional biomass (grids)	Cam
2.4	Benthic functional polygon boundaries	Javi/ Cam
2.5	VME closure connectivity index	Ellen
3	**ASSESSMENT OF FISHERIES**	**Mar**
3.1	Description of fisheries in the NRA	Mar/ Irene/ Patricia & others?
3.2	VMS filtered data (2011 – 2024)	Neil/ Tom
3.3	Integrated VMS and logbook data (2016 – 2024)	Irene/ Mar/ Neil
3.4	Demersal fisheries (maps/tables)	Mar
3.5	Overlap of demersal fisheries with VMEs	Mar
4	**ASSESSMENT OF SAI**	**Andy**
4.1	Background to the assessment of SAI	Andy
4.2	VME impacts, resilience and recovery (review up-date)	Barbara
4.3	VME SAI impact assessment categories (cut-off values) for both VMEs and VME functions (including the relationship to FAO criteria and weighting rationale), See previous assessment text.	James
4.4	Other SAI assessment metrics	
(i)	- fishing stability index	Neil/ Anna
(ii)	- overlapping VME index	Cam/ Anna
(iii)	- overlapping functions index	Cam/ Anna
(iv)	- VME fragmentation index	Ellen

(v)	- VME closure adequacy 'consistency' index	Ellen
(vi)	- Index of VME sensitivity	Andy/ James
4.5	Overall assessment of SAI (core SAI assessment metrics)	Andy/ James
5	**VME MANAGEMENT (SAI mitigation) OPTIONS**	**??**
5.1	Introduction	
5.2	Contributing elements (catch, VME data, VME polygons, VME closures)	
5.3	Fishery/ VME trade-offs	
5.4	Management options	
5.5	Summary of management options (SAI mitigation)	

f) ToR 2.6. Preliminary analysis of the methodology to study the bottom fishing footprint in the NRA (NEREIDA project) [COM Request #5c].

COM Request #5. *In relation to the habitat impact assessment component of the roadmap (VME and SAI analyses), the Commission requests that Scientific Council to:*

c) *Work towards the reassessment of VMEs and the impact of bottom fisheries on VMEs for 2026.*

Integrating VMS and Logbook data

During the 2018 WG-ESA meeting the original methodology of "coupling VMS with Logbook data" (NAFO, 2017) was presented. The purpose was to establish a connection between these elements for characterizing the distribution and intensity of fishing effort from the year 2016 onwards. The applicability of this methodology was made feasible starting in 2016 due to the implementation of a new logbook data format implemented at the beginning of that year. This revised format facilitated an improved interpretation of the logbook data by incorporating fishing timestamps, geographic coordinates for gear deployment and retrieval, as well as the catch and discard weight for each species caught by trawl.

In 2020, through supplementary studies on fishing effort (Garrido *et al.*, 2020), certain technical challenges with the original methodology came to light. Subsequent analysis conducted this year arose some other issues, which will be described in the following section. That section will also delve into the quality assessment of the two primary data sources that have been used to study the distribution and intensity of fishing effort during the period 2016-2022 in the NRA: a) Vessel Monitoring System (VMS) and b) logbook information data.

Vessel Monitoring System (VMS)

The NAFO Vessel Monitoring System (VMS) is a satellite-based monitoring system that provides data on the location, heading and speed of licensed fishing vessels. The transmission of such data, called a "ping", occurs approximately every hour, providing high resolution positions recorded at higher frequencies when compared to logbook reporting.

VMS data used in this study were obtained from NAFO Secretariat who has the responsibility for collecting and maintaining VMS data from fishing vessels in the NAFO Regulatory Area (NRA). In addition to be an integral part of NAFO´s Monitoring, Control and Surveillance (MCS) scheme, the VMS data are also used for scientific purposes, e.g., for the assessment of SAIs on VMEs.

VMS data include the following information: NAFO Vessel Identification; Flag State; Radio (vessel call sign); UTC Date and Time of the vessel position; vessel position by latitude and longitude; speed and heading (Annex II.E, NAFO, 2023).

Haul-by-haul catch data (logbook data)

Haul-by-haul catch data are collected in the logbook during every fishing vessel activity. Specifically, timestamps and geographic coordinates for gear deployment and retrieval are recorded, as well as the catch and discard weight for each species caught by haul (Annex II.A, NAFO, 2023). This data format was implemented in 2016 as an improvement over 2015 when the data were recorded only for the top three species by weight and did not include fishing timestamps.

Haul-by-haul logbook data used for this study were also provided by NAFO Secretariat. They provide details for each vessel on catch and discard characteristics, date, type of gear used and geographic position collected during fishing vessel activities. The collection of these data is the responsibility of the skipper of each vessel.

VMS/logbook data quality

A key step when studying the environmental impact of fishing activity is to assess the fished area. There are two methodologies to study the fishing effort and fished area in the NRA. The first one uses a simple speed filter to select the VMS pings most likely to be associated with fishing activity. The second one involves filtering VMS pings that align with the haul fishing time intervals recorded by skippers in the logbook.

Two comprehensive analyses conducted by Garrido *et al.* (2020) and Sacau *et al.* (2020) have focused on assessing the quality and coverage of VMS and logbook data. Similar results were obtained this year, both in terms of quality and coverage of these data, compared to those from Garrido *et al.* (2020). Notably, both VMS and logbook data contain inaccurate entries, namely: points with incomplete timestamps; erroneous vessel positions; duplicated records; headings outside the compass range, etc. These inaccuracies are often attributed to submission issues and human errors in logbooks, while in VMS they are usually due to technical problems.

The quality of the information, both in the VMS system and in the logbooks, should be of concern to NAFO. Enhancing the quality of these data is crucial for better studying the effort distribution and the tasks related to this effort (SAI, fished area, fishing overlap with VME, assessments, etc.).

"Coupling VMS with Logbook" methodology

Logbook data and VMS are complementary and the coupling of both datasets has already proven powerful for delineating the spatial distribution of fishing activity at a much finer resolution (NAFO, 2017).

The first important step is "Raw Data Cleaning". Once this meticulous cleaning process is completed, both datasets are ready for the "Data Matching" by using the NAFO Vessel ID and Date as common fields to establish a connection between both. The success of this linking step is particularly important, as all subsequent analyses depend on this accuracy. Subsequently, from the resulting "Merged dataset" we can start to do the comprehensive "Analyses" and get the final "Results".

The utilization of haul-by-haul data allows for the categorization of VMS pings into "fishing" or "non-fishing" classification, based on whether or not they align with the reported fishing time intervals documented in the haul-by-haul catch data. In essence, the start and end of fishing timestamps of fishing activities recorded in the logbooks are used to extract relevant VMS points. These points, when spatially mapped, effectively depict the extent of fishing effort. When these VMS points are directly within the reported fishing times interval, they are considered to be associated with fishing activity.

Comparison of the fishing effort

Beyond the quality analyses of the databases, the resulting effort using both methods were analysed. The information gathered by the Spanish Observers Program, on board the Spanish fleet in NAFO, was used to check how accurate these two methods for the characterization of the fished area are to represent the real effort exerted by the Spanish fleet.

The outcomes of this analysis underscore the accuracy of the coupling method in delineating fishing effort, even in the presence of erroneous or incomplete information within the datasets. The effort determined through this method represents every year, on average, 90% of the real effort exerted by the Spanish fleet. In contrast, the simple speed filter exhibits a notable tendency to overestimate effort, given that the resulting effort is around 3 to 4 times, on average, the effort recorded by the observers.

Further analyses have been proposed to try to fine-tune the analysis of the fishing effort before 2016, when logbook data is unavailable.

Conclusions

The "coupling VMS with Logbook" methodology has been demonstrated to improve the identification of "fishing VMS pings". Despite concerns regarding data quality, this methodology has demonstrated its accuracy in characterizing fishing effort. Consequently, addressing misreporting and errors identified in both VMS and Logbook data is crucial for ensuring data integrity. To this end, additional analyses have been suggested to refine the examination of fishing efforts pre-2016, a period where logbook data are unavailable.

Acknowledgements

This work was conducted as part of the NEREIDA project funded by the European Commission under Grant Agreements SI2.770786; SI2.793318; SI2.827558 and Grant Agreement Project 101074766 — NAFO NEREIDA 2022.

References

Garrido Irene, Fernando González-Costas and Diana González-Troncoso. 2020. Analysis of the NAFO VMS and logbook data. NAFO SCR Doc. 20/068REV, Serial No. N7144.

NAFO 2017. Report of the 10th Meeting of the NAFO Scientific Council (SC) Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO SCS Doc. 17/21, Serial No N6774.

NAFO 2023. Northwest Atlantic Fisheries Organization Conservation and Enforcement Measures 2023. NAFO/COM Doc. 23-01, Serial No. N7368.

Sacau, Mar, Pablo Durán-Muñoz, Irene Garrido and Francisco Baldó. 2020. Improvements in the methodology to study the bottom fishing footprint in the NRA using VMS and logbook data. NAFO SCR Doc. 20/069, Serial No. N7145.

g) ToR 2.7. Addressing the Impacts of Climate Change on NAFO Fisheries and Ecosystems (COM Request #10)

i) Introduction

In its 2023 Annual Meeting, NAFO adopted a resolution on "Addressing the Impact of Climate Change on NAFO Fisheries" (NAFO/COM Doc. 23-13). In this resolution, NAFO committed to "*developing effective management strategies and approaches in NAFO to adapt to ongoing broad-scale changes in environmental conditions that have been documented in the Northwest Atlantic Ocean, including supporting the resilience of NAFO stocks and related ecosystems, as well as of fishing communities, in the face of climate change*". In following with this commitment, NAFO resolved to:

1. Consider the current and future impacts of climate change on NAFO managed stocks, non-target species and associated ecosystems in the Convention Area, including, inter alia, as appropriate, in its decision making, and through its work in the Ecosystem Roadmap.
2. To that end, take into account the best scientific advice available on the current and future impacts of climate change on NAFO-managed stocks, non-target species and associated ecosystems, when developing conservation and management measures, with a view to address the effects of such impacts.
3. Further, evaluate how the management of target and non-target NAFO-managed stocks and associated ecosystems, as well as fishing activities, may be affected by climate change and examine if there are actions that could be taken to reduce or mitigate such impacts, including, as appropriate, consideration of adapting NAFO management approaches.
4. To inform the work in paragraphs one through three, and while recognizing the capacity challenges of the Scientific Council, request that the Scientific Council at its 2024 meeting summarize the information it currently has available regarding the current and future impacts of climate change on NAFO-managed stocks, non-target species and associated ecosystems. The Scientific Council should

further identify any consequential data gaps, research needs and opportunities for productive research.

5. Based on that information, the Commission should at the 2024 Annual Meeting consider appropriate next steps to advance NAFO's work on this important issue.

In line with addressing item 4) above, the NAFO Commission requested Scientific Council to:

COM Request 10. The Commission requests that the Scientific Council at its 2024 meeting: summarize the information it currently has available regarding the current and future impacts of climate change on NAFO-managed stocks, non-target species and associated ecosystems; and identify any consequential data gaps, research needs and opportunities for productive research.

ii) Environmental variability and climate change in the context of NAFO Scientific Council (SC) work

Anthropogenic climate change, driven by the emission of greenhouse gasses, is not only an undeniable fact, but its impacts at regional and global scales are already being felt in significant ways today. Fisheries, and the ecosystems they rely upon, are no exception, and fisheries management systems need to be prepared for responding to these impacts by incorporating climate change into their planning and decision-making processes.

The importance of environmental conditions in driving biological and ecological processes has been long acknowledged by SC. In 1995 the Environmental Subcommittee of the Standing Committee on Fisheries Science (STACFIS) became an SC Standing Committee in its own right. The Standing Committee on Fisheries Environment (STACFEN) has been monitoring environmental conditions in the Northwest Atlantic and providing advice on how changes in these environmental conditions may influence NAFO fish stocks and ecosystems since. Further, the SC Working Group on Ecosystem Science and Assessment (WG-ESA), which has been leading the SC work on developing ecosystem approaches since 2008, explicitly included climate change as part of the design of the Roadmap for an Ecosystem Approach to Fisheries (hereafter referred to as Roadmap), which is the framework that NAFO as a whole is now following for the implementation of an ecosystem approach (Koen-Alonso *et al*., 2019).

While SC has been considering the impacts of environmental conditions and drivers as part of its regular scientific and advisory work, and has been fully aware of the increasing risks associated with climate change, targeted work to explicitly address climate change effects and how to integrate them into science advice and fisheries management has so far only been acknowledged as one of the elements to consider within the Roadmap, but has yet to be made a top SC priority. This is a consequence of the combination of Commission stated priorities, which so far have not been focused on climate change, and the limited SC capacity and resources to do its work. The COM Request 10, and the COM Resolution that triggered it (NAFO/COM Doc. 23-13), indicate that Commission is now raising the urgency and priority of addressing climate change impacts.

From a science perspective, the impacts of climate change on fish stocks and ecosystem components can be schematically conceptualized as direct (those caused by changes in the physical environmental that directly influence stock traits like metabolism, behaviour/activity level, thermal range) and indirect (those mediated through the effects of climate change on other stocks/ecosystem components like changes in predator/prey fields, community composition and interactions, habitats) (Figure 5.6). Furthermore, this conceptualization also helps visualizing that climate change as a forcing signal on the climate system, and hence, understanding the role of environmental drivers on stocks and ecosystems is indeed the avenue to uncover the mechanisms behind climate change impacts.

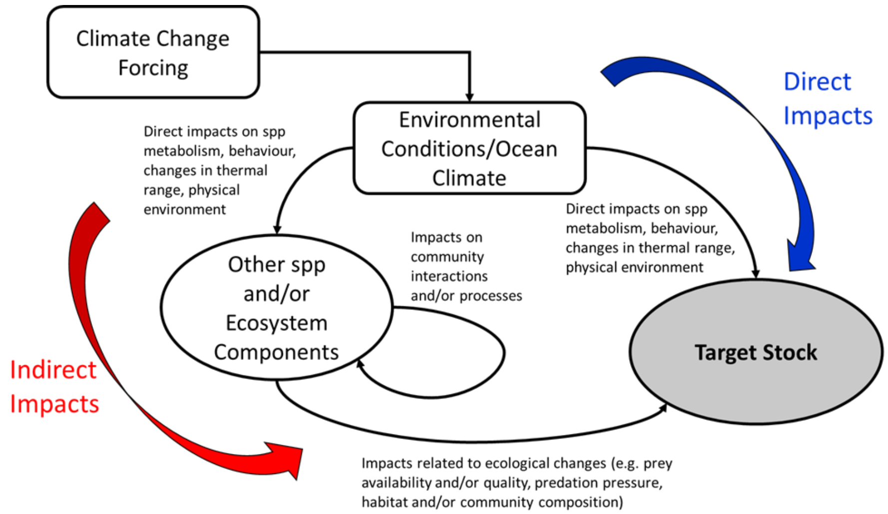

Figure 5.6. Schematic representation of the pathways of effects of climate change impacts on a target stock (or ecosystem component).

In practical terms, fisheries organizations around the world are all trying to grapple with the implication of climate change for their activities and ways of operation. For example, some general issues that Regional Fisheries Management Organizations (RFMOs) are contending with include:

1. How to adapt management references points to take account of climate change (e.g. stock productivity may change over time beyond current natural ranges, and related reference points may need to be adapted as a result)?

2. How to deal with distributional shifts across national boundaries (zonal attachment) but also to areas beyond national or RFMO jurisdiction?

3. Whether to consider just climate change impacts on fish populations, habitats and ecosystems, or also address the resulting consequences for fishing fleets and fisheries (e.g. revision of quota allocation in relation to changes in fish distribution)?

4. How can RFMOs work with climate change causes and mitigation (e.g. reducing emissions from fishing vessels, protecting seabed carbon stores)?

Many of these challenges are entirely new to SC and Commission, and their impacts on NAFO operations, or the degree they may fall under NAFO jurisdiction and regulatory scope, also needs focus and careful attention.

iii) A path for addressing COM Request #10

Conversations at the 2023 Annual Meeting between SC and the FAO Deep-Sea Fisheries (DSF) Project led to the possibility that this FAO project could work with its NAFO partner on climate change in the Northwest Atlantic through a consultancy. To this effect, SC established a Steering Group on Climate Change which included representation from STACFEN, WG-ESA and SC at large (Diana González-Troncoso, Miguel Caetano, Mar Sacau, Mariano Koen-Alonso, Lisa Readdy, Irene Garrido, Laura Wheeland, Frederic Cyr, Lisa Hendrickson and Patricia Gonçalves). This Steering group is expected to support the initial SC work on climate change, including the collaboration with the DSF Project on this topic.

The discussion around the expectations for the consultancy concluded that the required work has to be focused on reviewing/summarizing facts and findings, not on development of proposals, strategies, or management plans. Furthermore, it has to cover a range of topics that would position SC not only to answer the COM Request 10 *per se*, but to inform the SC discussion and planning on effective and practical ways of incorporating climate change impacts in the medium and long term.

Under these general expectations, the agreed ToRs to guide the setup of the consultancy by the FAO DSF Project were:

1. Summarize the current state of knowledge on climate change projections for the Northwest Atlantic for the next 10-50 years, with emphasis on comparisons across models (e.g. type of model, resolution, level of downscaling), how the projected changes (e.g. temperature levels, heat waves, frequency of extreme events, including their level of uncertainty) may differ for different scenarios, and what are the recommended applications/standards for the use of these scenarios for ecological analyses in fisheries and marine ecology (i.e. current best practice).
2. Review the state of knowledge of the potential impacts of climate change on Northwest Atlantic fish stocks and ecosystems, discriminating the degree to which direct and indirect effects have been considered/addressed. To the extent possible, compare and rank these potential impacts in terms of a) their likely magnitude, b) their time of emergence (i.e. when they could be expected to manifest), and c) dependency of climate change scenario (i.e. how their potential impact/ranking depends on a specific scenario).
3. Review the state of knowledge on proposed approaches to incorporate climate change in stock-assessment and ecosystem-based fisheries management, with emphasis in Northwest Atlantic stocks and ecosystems. Given the results from ToRs 1 and 2, identify and rank the likely critical data and process gaps that would be required to be addressed in order to implement these approaches for NAFO stocks and ecosystems.

In addition of these ToRs, it is expected that the consultant would do this work in close consultation with the Steering Group from SC on Climate Change.

The expected outcomes from this consultancy would be a report addressing the ToRs, which should be circulated among SC members prior to the 2024 SC June meeting, and a presentation by the consultant at that meeting highlighting the key results from this work.

References

Koen-Alonso, M., Pepin, P., Fogarty, M. J., Kenny, A., and Kenchington, E. 2019. The Northwest Atlantic Fisheries Organization Roadmap for the development and implementation of an Ecosystem Approach to Fisheries: structure, state of development, and challenges. Marine Policy, 100: 342-352.

h) ToR 2.8 Climate-change refugia for the large gorgonian coral *Paragorgia arborea* in the Scotian Slope (COM Request #10)

The large, habitat-forming bubblegum coral, *Paragorgia arborea* (Figure 5.7 A), is a Vulnerable Marine Ecosystem indicator (NAFO, 2023) with an antitropical distribution. Over the last 20 years, dense aggregations of this species have been protected from bottom-contact fishing in the Scotian Shelf bioregion off Nova Scotia (e.g., Breeze and Fenton, 2007; DFO, 2019; Metaxas *et al*., 2019). Those protection areas were adopted independently, as aggregations were discovered and described. With the need to develop a network of protected areas in response to domestic (Oceans Act Section 35 (2)) and international (UN Convention on Biological Diversity, UN Sustainable Development Goals) policies, network properties such as representativity, connectivity, adequacy and viability must be considered (DFO, 2010; Garcia *et al*., 2021). Furthermore, with changing climatic conditions there is a need to consider climate resiliency in protected area network design (Brock *et al*., 2012; Simard *et al*., 2016). Recently, basin-scale habitat suitability ensemble modeling has projected an alarming loss of 99% of suitable habitat for this species across the North Atlantic by 2100 (Morato *et al*., 2020). Wang *et al*. (2022) undertook a regional reassessment of the predicted distribution of this species in the Scotian Shelf bioregion, using both machine learning (random forest) and generalized additive model (GAM) frameworks, including projection to 2046–2065. Extrapolation diagnostics using the Extrapolation Detection (ExDet) tool (Bouchet *et al*., 2020), were applied in this new study, to determine the degree to which the models projected into novel covariate space (i.e., extrapolation) in order to avoid erroneous inferences. The best predictors of the species' distribution were a suite of temporally-invariant terrain variables that identified suitable habitat along the upper continental slope. Additional predictors, projected to vary with future ocean climatologies, identified areas of the upper slope in the eastern portion of the study area that will remain within suitable ranges for *P. arborea* at least through to the mid-century. Additionally, 3-D Lagrangian particle tracking simulations indicated potential for both connectivity among known occurrence sites and existing protected areas, and for colonization of unsurveyed areas predicted to have suitable habitat, from locations of known occurrence. Results from Wang *et al*. (2022) showed that extirpation of this iconic species from the Scotian

Shelf bioregion is unlikely over the next decades. Additionally, potential climate refugia were identified (Figure 5.7 B) and results presented in the context of protected area network design properties of representativity, connectivity, adequacy, viability and resilience.

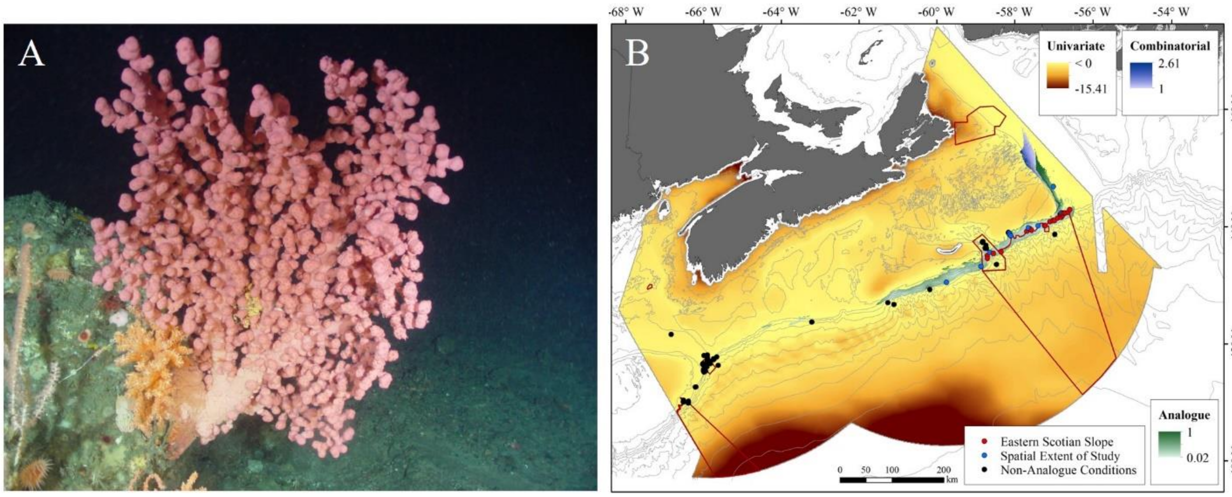

Figure 5.7. A) *In situ* image of the large gorgonian coral *Paragorgia arborea* from the Scotian Slope. B) Areas of analogous and non-analogous conditions under RCP 4.5 climate projections for 2046-2065, defined by eight input covariates, showing the locations of confirmed records of *Paragorgia arborea* coded by the projected future status of environmental conditions at those sites and existing conservation areas (in red outline). Locations of existing records that are projected to retain conditions analogous to those where the species presently occurs on the eastern Scotian Slope are shown in red. Locations which will retain, or change to, conditions analogous to those under which the species is presently found west of 60°W are shown in blue. Black dots mark records in areas projected to change to non-analogous conditions. More details in Wang *et al*. (2022).

References

Breeze, H. and Fenton, D. 2007. Designing Management Measures to Protect Cold-Water Corals Off Nova Scotia, Canada. Bull. Mar. Sci. 81, 123–133.

Bouchet, P. J., Miller, D. L., Roberts, J. J., Mannocci, L., Harris, C. M. and Thomas, L. 2020. Dsmextra: Extrapolation Assessment Tools for Density Surface Models. Methods Ecol. Evol. 11, 1464–1469. doi: 10.1111/2041-210X.13469.

Brock, R. J., Kenchington, E. and Martínez-Arroyo, A. (Eds.) 2012. Scientific Guidelines for Designing Resilient Marine Protected Area Networks in a Changing Climate (Montreal, Canada: Commission for Environmental Cooperation). Available at: http://www.cec.org/files/documents/publications/10820-scientificguidelines-designing-resilient-marine-protected-area-networks-in-changing-en.pdf.

DFO. 2010. Science Guidance on the Development of Networks of Marine Protected Areas (MPAs). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/061.

DFO. 2019. Northeast Channel Coral Conservation Area (Restricted Bottom Fisheries Zone). In: Northeast Channel Coral Conservation Area (Restricted Bottom Fisheries Zone) (dfo-mpo.gc.ca) (Accessed October 4, 2021).

Garcia, S. M., Rice, J., Charles, A. and Diz, D. 2021. OECMs in Marine Capture Fisheries: Systematic Approach to Identification, Use and Performance Assessment in Marine Capture Fisheries (Version 2) (Brussels, Belgium: Fisheries Expert Group of the IUCN Commission on Ecosystem Management, Gland, Switzerland. European Bureau of Conservation and Development). Available at: https://ebcd.org/oecms-in-marine-capture-fisheries/ (Accessed December 14, 2021).

Metaxas, A., Lacharité, M. and de Mendonça, S. N. 2019. Hydrodynamic Connectivity of Habitats of Deep-Water Corals in Corsair Canyon, Northwest Atlantic: A Case for Cross-Boundary Conservation. Front. Mar. Sci. 6. doi: 10.3389/fmars.2019.00159.

Morato, T., González-Irusta, J.-M., Dominguez-Carrió, C., Wei, C.-L., Davies, A., Sweetman, A. K., Taranto, G.H., Beazley, L., García-Alegre A., Grehan, A., Laffargue, P., Murillo, F.J., Sacau, M., Vaz, S., Kenchington, E., Arnaud-Haond, S., Callery, O., Chimienti, G., Cordes, E., Egilsdottir, H., Freiwald, A., Gasbarro, R., Gutiérrez-Zárate, C., Gianni, M., Gilkinson, K., Wareham Hayes, V.E., Hebbeln, D., Hedges, K., Henry, L., Johnson, D., Koen-Alonso, M., Lirette, C., Mastrototaro, F., Menot, L., Molodtsova, T., Durán Muñoz, P., Orejas, C., Grazia Pennino M.,, Puerta, P., Ragnarsson, S.Á., Ramiro-Sánchez, B., Rice, J., Rivera, J., Roberts, J.M., Ross, S.W., Rueda, J.L., Sampaio, I., Snelgrove, P., Stirling, D., Treble, M.A., Urra, J., Vad, J., van Oevelen, D., Watling, L., Walkusz, W., Wienberg, C., Woillez, M., Levin, L.A., Carreiro-Silva, M. 2020. Climate-Induced Changes in the Suitable Habitat of Cold-Water Corals and Commercially Important Deep-Sea Fishes in the North Atlantic. Glob. Change Biol. 26, 2181–2202. doi: 10.1111/gcb.14996.

NAFO. 2023. Northwest Atlantic Fisheries Organization Conservation and Enforcement Measures 2023. NAFO/COM Doc. 23-01 (Revised), Serial No. N7368, 204 p.

Simard, F., Laffoley, D. and J.M, B. (Eds.) 2016. Marine Protected Areas and Climate Change: Adaptation and Mitigation Synergies, Opportunities and Challenges. Full Report (Gland, Switzerland: IUCN).

Wang, S., Murillo, F.J. and Kenchington, E. 2022. Climate-Change Refugia for the Bubblegum Coral Paragorgia arborea in the Northwest Atlantic. Frontiers in Marine Science. doi: 10.3389/fmars.2022.863693.

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. Preparation of the OECM nomination template.

WG-EAFFM 2023 Recommendation 3.a: *[WG-EAFFM recommends that the Commission] requests the Secretariat, in consultation with the Scientific Council as required, to submit the seamount closure areas and the sponge VME fishery closures 1 to 6 to the CBD Secretariat and to the UN Environment Programme World Conservation Monitoring Centre (UNEP WCMC) for inclusion in the World Database on OECMs*.

Draft Other Effective Area-Based Conservation Measures (OECMs) nomination templates for sponge and seamount areas, prepared during the ICES/IUCN-CEM FEG Workshop on Testing OECM Practices and Strategies (WKTOPS), were uploaded to the WG-ESA SharePoint for review by meeting participants. Several WG-ESA members reviewed and edited the documents during the meeting, and their comments will be incorporated into the final submission by the Secretariat.

b) ToR 3.2. ICES Workshop to evaluate long-term biodiversity/ecosystem benefits of NEAFC closed and restricted areas (WKECOVME)

WKECOVME [https://www.ices.dk/community/groups/Pages/WKecovme.aspx] was formed as part of the formal ICES advisory process in response to requests from the North-East Atlantic Fisheries Commission (NEAFC) for advice on OECMs in relation to long-term biodiversity/ecosystem benefits of NEAFC's areas restricted to bottom fishing, VME closed areas and on the potential maximum depths of bottom fishing. With the aim of establishing a scientific basis for providing the advice the Workshop was requested: to evaluate the biodiversity of the areas concerned; to evaluate threats affecting or expected to affect the biodiversity attributes; to evaluate the NEAFC management measures as to whether they achieve, or are expected to achieve, positive and sustained outcomes for the in situ conservation of biodiversity; and to provide a commentary on current and potential maximum depth on the use of bottom-contacting fishing gears in the NEAFC regulatory area.

WKECOVME compiled information on biodiversity attributes present in the areas restricted to bottom fishing and in the VME closed areas and established a comprehensive list of biodiversity attributes by area. Only benthic and demersal attributes were consistently considered, given the focus on bottom-contact fishing in the

NEAFC request. In defining biodiversity attributes, WKECOVME used examples provided by Convention on Biological Diversity (CBD) it the guidance on OECMs (CBD/COP/DEC/14/8).

WKECOVME compiled information on pressures and threats in NEAFC Regulatory Area and evaluated how they affect or potentially can affect the biodiversity attributes in the area.

As a guidance to evaluate the NEAFC management measures for the VME closures and the restricted bottom fishing areas as to whether they achieve, or are expected to achieve, positive and sustained outcomes for the *in situ* conservation of biodiversity WKECOVME used the relevant criterion provide by CBD in its OECM guidance.

The information on the current and potential maximum fishing depth with bottom-contacting gears in the NEAFC Regulatory Area presented in this report is based on analyses of the bottom fishing footprint and on information on the depth distribution of deep-sea fish species (ICES, 2023).

Key messages were that biodiversity attributes meeting the CBD definitions for OECMS were identified in all of the NEAFC areas, including inside the NEAFC Regulatory Area and outside of the currently fished areas. Even though many areas are remote, when direct evidence was not available the evidence base could reasonably be inferred from other similar nearby ecosystems such that experts could determine with confidence that the attribute was likely to occur in the area. Further, the evidence available on current, historic and potential future activities indicates that fishing is the most prevalent activity occurring across NEAFC RA1, 2 and 3 (RA4 is currently ice-covered), with the greatest potential threats from associated pressures. Workshop participants saw value in highlighting biodiversity attributes outside of the NEAFC fishing footprint, as this could give enhanced protection to such areas in future that are within fishing depths, and facilitate protection from other threats in a wider BBNJ context.

References

ICES. 2023. ICES Workshop to evaluate long-term biodiversity/ecosystem benefits of NEAFC closed and restricted areas (WKECOVME). ICES Scientific Reports. 5:89. 88pp. https://doi.org/10.17895/ices.pub.24198771

c) ToRs 3.3 to 3.5. Potential impact of activities other than fishing in the Convention Area (COM Request #9)

COM Request 9: *The Commission requests the SC to monitor and provide regular updates on relevant research related to the potential impacts of activities other than fishing in the Convention Area, subject to the capacity of the Scientific Council*.

Updates on relevant research related to the potential impacts of activities other than fishing in the Convention Area

There are a number of ongoing oil and gas activities occurring in the Newfoundland and Labrador offshore region. Activities related to existing oil projects and new oil field development in the NAFO convention area are likely to occur in coming years. Conflict between the fishing industry and the oil and gas industry has been ongoing, however there is limited scientific evidence to identify what the exact impact of these activities are on commercial fishery resources or their important habitats. This is a gap in information required to adequately assess the impacts of oil and gas related activity on fisheries.

Two presentations related to oil and gas activities were provided during the 2023 WG-ESA meeting. The first presentation was titled "*Overview of the effects of seismic surveying on snow crab, and preliminary findings pertaining to groundfish, resources in the Newfoundland and Labrador offshore*". This presentation was related to COM Request #9 (activities other than fishing) for Terms of Reference 3, and its update on recent and relevant research related to the application of ecosystem knowledge for fisheries management in the NAFO area. The second presentation, on related NAFO objectives, was titled "*Emerging research on abandoned well sites in the Newfoundland and Labrador offshore*". Both presentations are described in sequence herein:

i) Overview of the effects of seismic surveying on snow crab, and preliminary findings pertaining to groundfish, resources in the Newfoundland and Labrador offshore.

Noise from human sources is increasing in the world's oceans, as a result of increased shipping, construction, seismic surveying and other activities. Understanding the impacts of underwater noise on commercial fisheries, especially catch rates, is a concern for the commercial fishing industry. Many harvesters in the Newfoundland region have complained that the noise from seismic surveying has impacted their catch rates and they are also concerned about related effects on their fishery resources. Research was funded by the Environmental Studies Research Fund to address effects of seismic surveying on both Snow Crab and groundfish resources. This research, its approach, study design, methods, results and impacts/deliverables are discussed.

Research was conducted in the field, at places where seismic surveying overlapped with commercial fishing (snow crab and groundfish). Industry-based seismic survey vessels took part in controlled experiments on fishing grounds and commercial harvesters were engaged to conduct experimental fishing and other scientific experiments. The study followed a Before-After Control-Impact (BACI) study design that was replicated over several years from 2015-2018 for snow crab, and also included both short (2D) and long (3D) periods of exposure to seismic surveying. Associated experiments were multi-facetted and investigated catch rates, movement, genomics and physiology effects. The value of multiple metrics was realized as important in order to provide a weight-of-evidence while trying to evaluate an inherently variable and difficult environment.

To conduct research in a meaningful way, useful and valued by all stakeholders, collaboration was extremely important. Collaborations were built over several years and involved consistent representation from the oil and gas industry, the fishing industry, regulators, academics and private industry. Openness and transparency were maintained by including stakeholders in the research and holding meetings with them twice each year to provide detailed updates on the progress of research. This ensured that all stakeholders were engaged, and in the end accepted the scientific results. It was critical for the scientific process to clearly define the focus of research, because not all questions could be addressed in a single study. For example, the snow crab research targeted adult male snow crab that are caught in commercial fishing and did not address important questions related to eggs, larvae, or females for which many unanswered questions still remain.

At the beginning of the research project, it was determined that the goal was publish results in openly available peer-review literature as well as communicate openly through academic, industry or government processes. This included several scientific publications (provided to NAFO), oil and gas conferences, fishing-fleet meetings, stock assessment meetings and advisory processes.

The results of the snow crab work determined that the impact of seismic surveying, when noise levels exceeded that of fishing vessel noise, was within the range of natural variability. Significant differences were observed between day and night, and at different temperatures, but differences were not owing to the effect of seismic surveying. This result was consistent among different studies, that included snow crab movements (as measured by telemetry), tank studies looking at physiology effects, and genomic studies, in addition to catch rate comparisons.

The results of research on groundfish is ongoing and is not yet published. The approach to this research is very similar to that followed for the snow crab study. However, the metrics used to measure groundfish include baited underwater video cameras, passive acoustic techniques, soundscape modelling and commercial fishery catch-rate comparisons, in addition to acoustic telemetry and eDNA. Preliminary findings are consistent with previously published literature, in that the behaviour of fish appears to change when exposed to seismic surveying noise. In our study, it seems that groundfish move deeper in the water column and move less when the noise from seismic surveying is quite high, and exceeding that of a commercial fishing vessel. Research is continuing on the impact of seismic surveying noise on groundfish.

ii) Emerging research on abandoned well sites in the Newfoundland and Labrador offshore.

The drilling and subsequent abandonment of oil wells in offshore, and onshore, environments can result in the leakage of hydrocarbons into the environment. There are several reasons for concern, primarily being the associated contamination risks. Other concerns include clean-up liabilities and greenhouse gas impacts. As a result, there is considerable interest from academic scientists, environmental and industry regulators and responsible government agencies, and the general public. Fisheries and Oceans Canada provide funding to conduct research on abandoned oil wells, in collaboration with the Canada-Newfoundland and Labrador Offshore Petroleum Board.

Unlike areas of the world that have extensive offshore drilling programs, such as the Gulf of Mexico with more than 50,000 wells or the Northern Sea with more than 11,000 wells, the Newfoundland and Labrador offshore has less than 400 oil wells. Nonetheless, some abandoned oil wells in the Gulf of Mexico and North Sea have been looked at and are known to leak hydrocarbons. Abandoned oil wells in the Newfoundland and Labrador offshore area have not been surveyed to consider possible leakage of hydrocarbons.

The purpose of this research was, in the first instance, to consider what methods might be most appropriate to assess abandoned well sites and then to conduct a survey of several old, abandoned wells distributed over a large area and range of depths. The methods applied included multibeam habitat mapping, benthic sediment samples, water samples, video of habitat and fish, and eDNA. Sampling was conducted at the well site and an adjacent control site for each well. During 2022 and 2023, a total of 25 wells were surveyed. The well sites were located on the southern Grand bank, East of the Grand Bank and to the North along the Northeast Newfoundland slope, ranging in water depths from 60 to 1200 meter depths. The wells surveyed were drilled from 1966 to 1985.

Preliminary results did not detect obvious evidence of leakage; however, laboratory analysis is not yet completed. Future research will likely consider site-specific studies, if there is any evidence of elevated hydrocarbon levels, and further examination of more recently drilled well sites. ToR 3.5. NEREIDA's planned work regarding activities other than fishing in the NRA (COM Request #9).

> **COM Request 9:** *The Commission requests the SC to monitor and provide regular updates on relevant research related to the potential impacts of activities other than fishing in the Convention Area, subject to the capacity of the Scientific Council*.

iii) Rationale for studies on activities other than fishing in the NAFO context

There are strong arguments that justify the need to conduct studies to better understand the non-fishing activities occurring in the NAFO area, as requested in the Commission Request # 9. First, United Nations General Assembly (UNGA) Resolution 71/123, adopted in 2016, reflects the international community' concern about the potential impacts of non-fishing activities. Specifically, paragraph 184[4] *notes with concern that vulnerable marine ecosystems may also be impacted by human activities other than bottom fishing, and encourages in this regard States and competent international organisations to consider taking action to address such impacts*. While Resolution 71/123 focuses on sustainable fisheries, it also addresses the need to implement conservation measures VMEs in relation to human activities other than bottom fishing. In this context, it is noteworthy that the participants of the last workshop[5] to review the implementation of UNGA resolutions (64/72, 66/68 and 71/123) on sustainable fisheries, held at UN headquarters in August 2022, *acknowledged a concern that management actions taken by RFMO/As were unable to address potential impacts resulting from other activities taking place in the same area, thereby affecting the effectiveness of ecosystem-based approaches*. In particular, NAFO's contribution[6] to the review workshop, pointed out *that there are a number of non-fishing activities occurring in the Regulatory Area that have the potential to impact fisheries resources and the ecosystem*. NAFO also expressed its concern about non-fishing activities (specifically mentioning oil and gas as an example) and confirmed that these remain on the agenda of the NAFO Commission during its annual meetings. As is known from the scientific literature, in addition to the impacts of accidental events (Fisher *et al.*, 2014), routine oil and gas activities can have detrimental environmental effects during each of the main phases of exploration, production and decommissioning (Cordes *et al.*, 2016). Environmental effects include, among others, long-term impacts on deep-sea corals (e.g. Girard and Fisher, 2018), as well as impacts on deep-sea sponges and the habitats they form (Vad *et al.*, 2016). On the other hand, lessons learned from one sector may be useful for

[4] https://www.un.org/Depts/los/reference_files/Bottom_Fishing_Workshop_2020.pdf

[5] https://digitallibrary.un.org/record/3988731?ln=es

[6] See pp.14 *In*: NAFO Input to the 2022 Workshop to discuss the implementation of UNGA resolutions (64/72, 66/68, 71/123). 16 March 2022. NAFO/22-096. 15 pp. https://www.un.org/depts/los/bfw/NAFO__2022.pdf

others. For example, Bravo *et al.* (2023) proposed how the criteria for conducting impact assessments from the FAO Guidelines for Deep-sea Fisheries (FAO, 2009) could be adapted to the oil and gas industry.

Some stakeholders are also concerned about effects of non-fishing activities. For example, the EU long distance fisheries stakeholder body (Long Distance Fleet Advisory Council, LDAC), has prioritised promoting an Ecosystem Approach to Fisheries Management through the protection and conservation of the marine environment (VMEs), while looking at other marine users (e.g., deep sea mining, oil and gas) that compete with high-sea fisheries and may have adverse effects on the marine environment and seabed (Guerin, 2019).

Knowing the geographical location of areas where other human activities overlap with VMEs, fisheries resources and fishing activity, is the starting point to better understand potential interactions and conflicts in the NRA. This can also help to understand whether such activities may affect the effectiveness of the conservation measures adopted by NAFO. In addition, a comprehensive literature review will allow us to explore the usefulness and potential application of cutting-edge research in the context of NAFO, including cross-sectoral aspects. All this knowledge is relevant to feed the NAFO Ecosystem Summary Sheets. Mapping is also essential to identify which areas are multi-sectoral, in order to further advance the process for nomination and recognizing OECMs (NAFO, 2023). According to the FAO handbook for fisheries OECMs (FAO, 2022), in the case of multi-sectoral areas, i.e. areas where many uses exist (e.g. Closed Area 10), the optimal approach is to carry out cross-sectoral identification, assessment and reporting of OECMs.

iv) NEREIDA's planned work related to activities other than fishing

The NEREIDA study is funded by the European Union through the NAFO Secretariat. The proposed activities under NEREIDA are specifically designed to address several NAFO Commission requests (namely, re-assessment of NAFO bottom fisheries, continue to monitor and provide updates resulting from relevant research related to the potential impact of activities other than fishing) and contribute directly to respond to them. It should be noted that this study is not intended to duplicate the work done by the relevant authorities in each sector (e.g. the work done through existing impact assessment processes).The ultimate goal of the NEREIDA tasks related to activities other than fishing is to understand some of these activities taking place in the NRA (namely seabed marine litter and offshore oil and gas), in relation to their potential impact on the fishery resources, the ecosystem and the fishing activity regulated by NAFO. The NEREIDA work started with a long delay due to administrative problems. The results are expected to be presented during 2024. This delay has affected the original timeline, and therefore a potential need for an extension to effectively address the NEREIDA tasks is being considered to ensure the successful completion of the project.

Seabed marine litter

a) Task: WP2 – Activities other than fishing in the NRA (Divs. 3LMNO): Monitoring the spatial and temporal distribution of marine litter, contributing to improved knowledge of their characteristics.

b) Aim of this task: To characterize the seabed marine litter, analyse its spatial and temporal distribution, and determine the main sources of seabed litter.

c) Study area: NRA, Divs. 3LMNO.

d) Data sources: EU groundfish surveys.

e) Background: Work from García-Alegre *et al*. (2020) in Div. 3L (2006-2017).

f) Brief summary of planned activities: (i) Cross-check groundfish survey data; (ii) Mapping and analysis, focused on composition, spatial distribution and sources of seabed litter; (iii) Review and update the current protocol for data collection.

Offshore oil and gas

a) Task: WP3 – Activities other than fishing in the NRA (Divs. 3LMNO), with focus on offshore oil and gas: Spatial distribution and literature review of its potential impacts, its interactions with deep-sea fisheries and criteria/methodologies for studying them.

b) Aim of this task: Update available information on the spatial distribution of oil and gas activities and relevant research.

c) Study area: NRA, Divs. 3LMNO.

d) Data sources: Public information, websites, reports, papers, etc. (desk study).

e) Background: SCR Doc. 20/022; SCR Doc. 21/051; reports from SC and WG-ESA.

f) Brief summary of planned activities: (i) Update of maps of main ecosystem components and identify potential spatial conflicts (user-environment, user-user) with special attention to oil and gas, Deep-sea fisheries and VMEs; (ii) Literature review (e.g. relevant research, impacts, interactions, cross-sectoral issues, criteria/methods for studying impacts, etc.) with special attention to the usefulness and potential application of these research in the context of NAFO; (iii) Identify gaps, needs, opportunities and challenges in the framework of NAFO (e.g. collaboration, monitoring, mitigation measures, etc.).

References

Bravo, M.E., Brandt, M.I.., van der Grient, J.M.A., Dahlgren, T.G., Esquete, P., Gollner, S., Jones, D.O.B., Levin, L.A., McClain, C.R., Narayanaswamy, B.E., Sutton, T., Victorero, L. and Cordes, .EE. 2023. Insights from the management of offshore energy resources: Toward an ecosystem-services based management approach for deep-ocean industries. Front. Mar. Sci. 9:994632. doi: 10.3389/fmars.2022.994632

Cordes, E.E., Jones, D.O.B., Schlacher, T.A., Amon, D.J., Bernardino, A.F., Brooke, S., Carney, R., DeLeo, D.M., Dunlop, K.M., Escobar-Briones, E.G., Gates, A.R., Génio, L., Gobin, J., Henry, L.-A., Herrera, S., Hoyt, S., Joye, M., Kark, S., Mestre, N.C., Metaxas, A., Pfeifer, S., Sink, K., Sweetman, A.K., Witte, U. 2016. Environmental impacts of the deep-water oil and gas industry: a review to guide management strategies. Frontiers in Environmental Science 4. 10.3389/fenvs.2016.00058.

FAO. 2022. A handbook for identifying, evaluating and reporting other effective area-based conservation measures in marine fisheries. Rome. https://doi.org/10.4060/cc3307en

FAO. 2009. International Guidelines for the Management of Deep-Sea Fisheries in the High Seas, Food and Agriculture Organization of the United Nations, Rome, 2009.

Fisher, C.R., Hsing, P.Y., Kaiser, C.L., Yoerger, D.R., Roberts, H.H., Shedd, W.W., Cordes, E.E., Shank, T.M., Berlet, S.P., Saunders, M.G., Larcom, E.A., Brooks, J.M. 2014. Footprint of Deepwater Horizon blowout impact to deep-water coral communities. Proc Natl Acad Sci U S A. 2014 Aug 12;111(32):11744-9. doi: 10.1073/pnas.1403492111.

García-Alegre A., Román-Marcote E., Gago J., González-Nuevo G., Sacau M., Durán Muñoz P. 2020. Seabed litter distribution in the high seas of the Flemish Pass area (NW Atlantic). Scientia Marina 84(1)

Girard, F. and Fisher, C. 2018. Long-term impact of the Deepwater Horizon oil spill on deep-sea corals detected after seven years of monitoring. Biological Conservation 225, 117-127. 10.1016/j.biocon.2018.06.028.

Guerin, B. 2019. Long Distance Fleet Advisory Council (LDAC) Strategic Report Nº1 Performance Review 2016-2018. https://ldac.eu/images/LDAC_web-compressed_Performance_Review.pdf

NAFO. 2023. 2023 informal group of WG-EAFFM on OECMs. 20th March 2023. COM-SC WP 23-02. 5 pp.

Vad, J., Kazanidis, G., Henry, L.A., Jones, D.O.B., Tendal, O.S., Christiansen, S., Henry, T.B. and Roberts, J.M. 2016. Potential Impacts of Offshore Oil and Gas Activities on Deep-Sea Sponges and the Habitats They Form. *In* Advances in Marine Biology 79, Elsevier, pp. 33-60. 10.1016/bs.amb.2018.01.001.

d) ToR 3.6.In relation to the habitat impact assessment component of the roadmap (VME and SAI analyses), the Commission requests that Scientific Council (COM Request #5b):

COM Request 5b: *continue working with WG-EAFFM towards developing operational objectives for the protection of VMEs and biodiversity in the NRA.*

Discussions at WG-EAFFM in 2023 endorsed the framework of terms and definitions proposed by WG-ESA in 2022 and these were further endorsed by the Commission in 2023. However, it was suggested the term "overall goal" in the framework table be replaced with the term "mission statement", in order to make clearer the distinction between the terms used in the framework.

It was noted this COM request was categorised as low priority by SC during a review of up-coming tasks at its meeting in September 2023, and as such this item is not expected to be discussed at SC in June 2024. Nevertheless, a short discussion on this topic was had at WG-ESA and the following points were highlighted:

- The starting point for discussions on operational conservation objectives, especially in relation to defining indicators and targets, is the identification and mapping of VMEs (NAFO 2019) and the assessment of SAI (NAFO 2020).
- The objectives should ideally consider the principles set out in the Convention of Biological Diversity, specifically Principle 6 which states "ecosystems must be managed within the limits of their functioning" (CBD, 2004). In part, this is addressed by the ecosystem overfishing target and TCI limit, defined under Tier 1 of the roadmap.
- It was agreed that the objectives could be widened to include the protection of ETP species such as sharks, seabirds, marine mammals, or other non-VME related bycatch species. This consideration is closely related to the discussions in WG-ESA under COM Request #4 (ToR 3.7) to develop the Ecosystem Summary Sheets (ESS) and a list of ETP species for NAFO.
- It was noted at the WG-EAFFM meeting that "representatives from WG-EAFFM (scientists and managers) will work intersessionally to develop a draft framework document for presentation at the next WG-EAFFM meeting in August 2024, reflecting the working group's discussions" (NAFO, 2023). It was not clear to members of WG-ESA what a framework document is, or what it would contain. It was suggested that such a document may articulate how the NAFO Convention objectives are aligned with the operational objectives (framework table) and other terms already approved and their relationship to the existing elements of EAFM Roadmap that are represented in the ESS.
- It was agreed that further developments of the targets and indicators by SC within the framework are, in part, dependent on developments of the methods applied to assess SAI. As such, further efforts to elaborate the list of targets and indicators against specific biodiversity and conservation objectives would benefit from the outcome of the 2026 reassessment of bottom fisheries.
- However, consideration of conservation objectives related to Endangered, Threatened and Protected (ETP) species, and the methods for their assessment (as part of defining a list of ETP species in the NRA) are amenable to further discussion at WG-EAFFM.

References

NAFO. 2019. Report of the Scientific Council Working Group on Ecosystem Science and Assessment, 18 - 29 November 2019, Dartmouth, Nova Scotia, Canada. NAFO SCS Doc. 19/25.

NAFO. 2020. Report of the Scientific Council Working Group on Ecosystem Science and Assessment, 17 - 26 November 2020, Dartmouth, Nova Scotia, Canada. NAFO SCS Doc. 19/23.

CBD, 2004. CBD, COP Decision VII/11 Ecosystem Approach (Kuala Lumpur, 9–20 and 27 February 2004).

NAFO, 2023. Report of the NAFO Joint Commission–Scientific Council Working Group on Ecosystem Approach Framework to Fisheries Management (WG-EAFFM) Meeting, 20–22 July 2023 Edinburgh, United Kingdom. NSFO COM-SC Doc. 23/04

e) ToR 3.7 Continued work on tiers 1 and 2 of the Roadmap (COM Request #4a).

COM Request 4: *The Commission requests that the Scientific Council continue to work on tiers 1 and 2 of the Roadmap, specifically to:*

a) annually provide catch information in relation to 2TCI, including recent cumulative catch levels and a scoping of expected cumulative catch levels;

b) as practicable and taking into account Scientific Council capacity constraints, develop stock summary sheets for NAFO managed stocks that are evaluated using HCR or MSE processes.

i) Introduction

The Roadmap for an Ecosystem Approach to Fisheries (hereafter Roadmap) is the framework that NAFO is implementing to deliver an ecosystem approach for the management of NAFO fisheries and ecosystems (Koen-Alonso *et al.*, 2019). As a management framework, the Roadmap integrates the impacts of a changing environment and ecosystem productivity to define sustainable exploitation levels for fish stocks, with the impacts that fishing has on stocks, ecosystems and habitats (Figure 6.1).

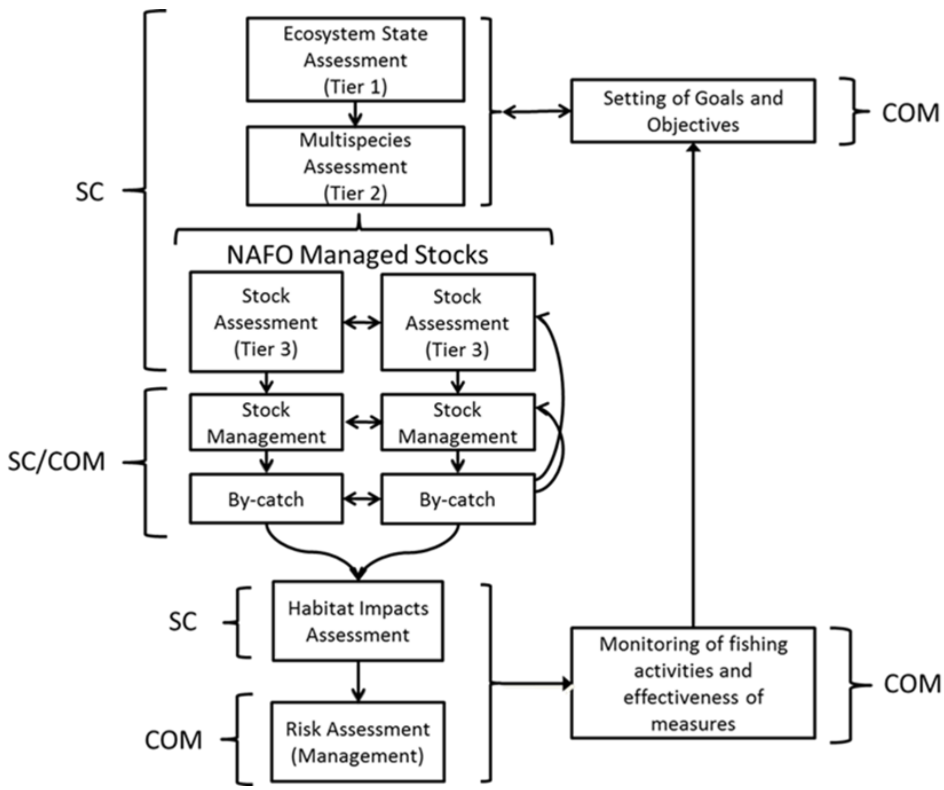

Figure 6.1. Structure of the Roadmap for an Ecosystem Approach to Fisheries, the framework that NAFO is implementing to deliver an ecosystem approach to fisheries management.

Within the Roadmap, sustainability of fisheries catches is achieved through a nested series of assessment aimed at evaluating sustainability at different levels of organization. Within these assessments, Tier 1 is focused at sustainability at the ecosystem level, Tier 2 is focused on sustainability at the multispecies level (e.g. species interactions), and Tier 3 is focused on sustainability at the stock level (i.e. traditional stock-assessment) (Figure 6.1).

At the 2023 WG-ESA meeting the work on sustainability of catches (Tiers 1-3) was focused on Tier 1 of the Roadmap. The current implementation of Tier 1 includes two distinct elements. These elements are an ecosystem reference point for aggregate catches by functional guild within an ecosystem that informs on the risk of ecosystem overfishing, and an Ecosystem Summary Sheet that provides an *at glance* view of the status and trends of multiple ecological features, as well as the general performance of management measures within the ecosystem.

ii) Additional work on Tier 1 and 2 of the Roadmap

As part of the implementation of Tier 1, NAFO has adopted a framework based on the estimation of ecosystem and fisheries production potential. Within this framework, an indicator of the upper limit for sustainability of aggregated catches by functional guild, the Total Catch Index (TCI), provides information on the risk of ecosystem overfishing. Within a functional ecosystem, aggregated functional guild catches below TCI are associated with a low risk of ecosystem overfishing, while catches exceeding 2TCI have been linked to consistent biomass declines at the functional guild level, indicating the occurrence of ecosystem overfishing (Koen-Alonso *et al*., 2022). On this basis, NAFO adopted 2TCI as an ecosystem reference point to inform on the risk of ecosystem overfishing; catches above this reference point indicate that there is a high risk that ecosystem overfishing can occur or is occurring.

Information on catches in relation to TCI is included in the Stock Summary Sheets (SSSs), in the Summary Report on Sustainability of Catches at the Ecosystem Level, and in the Ecosystem Summary Sheets (ESSs). Each one of these SC communication vehicles has a different focus and level of detail on the TCI information provided, with the Summary Report on Sustainability of Catches at the Ecosystem Level being the most comprehensive summary.

Since the adoption of the Ecosystem Production Potential and Total Catch Index (EPP-TCI) framework and the 2TCI ecosystem reference point is very recent, the content and format of the different communication vehicles for this information is still evolving based on the feedback provided by managers regarding their utility and effectiveness. This iterative process is expected to continue until the way of communicating (science) and using (managers) this new type of information becomes standard procedure within NAFO.

The presentation of TCI-related information as part of the regular science advice occurred for the first time in 2023. Based on this experience, and the feedback emerging from the discussions at the WG-EAFFM, additional work on the presentation of TCI-related information was requested by Commission through the COM Request #4. This request asks SC the following:

COM Request #4. The Commission requests that the Scientific Council continue to work on tiers 1 and 2 of the roadmap, specifically to:

a) Annually provide catch information in relation to 2TCI, including recent cumulative catch levels and a scoping of expected cumulative catch levels;
b) As practicable and taking into account Scientific Council capacity constraints, develop stock summary sheets for NAFO managed stocks that are evaluated using HCR or MSE processes.

Addressing this request requires work on scoping the impact of incoming/advised catches in relation to the 2TCI ecosystem reference point (item a), and on developing Stock Summary Sheets (SSSs) for stocks assessed with Harvest Control Rules (HCR) or Management Strategy Evaluation (MSE) (item b). Since developing SSSs is beyond the scope of WG-ESA, the working group focused its efforts solely on item (a).

The Report on Ecosystem Sustainability of Catches was first produced in 2023, and includes a summary of aggregated catches in relation to TCI (i.e. Catch/TCI Ratio), as well as detailed catch information by functional guild, indicating the TCI, 2TCI levels, and the main species that conform the bulk of the catches by functional guild.

While this summary report is comprehensive, it only provides information about the past; it shows where past catches have been in relation to TCI. COM Request #4a is asking for a forward-looking scoping of where catches might be in relation to TCI. More explicitly, this request is asking to scope where catches might be if the catch advice provided by SC were to be followed.

Unlike the catch advice from stock assessments, scoping the total catch by functional guild depends on more elements than the results from SC stock assessments. It needs to consider the catch advice provided by SC, as well as the expected catches of species for which SC does not provide advice (i.e. by-catch species, but also catches for stocks not managed by NAFO but managed by coastal states). Furthermore, this scoping also needs to consider that for those stocks for which catch advice exists, this advice is typically provided at the scale of the stock area, and these areas can include more than one Ecosystem Production Unit (EPU), which is the spatial domain used for the EPP-TCI analyses. This means that the catch advice needs to be partitioned among EPUs for the scoping exercise.

Taking into account all these elements, the proposed approach for approximating the aggregated catch by functional guild to be used for the TCI scoping exercise is as follows:

> Considerations for the compilation of catch information to be used in a scoping exercise done in year t for catch levels expected in year t+1:
>
> a. Stocks assessed by SC:
>   i. Catch: maximum catch advice recommended by SC for year t+1, noting that this catch advice needs to be done solely considering the stock assessment and without influence of TCI information.
>   ii. Stock area: if the stock area expands beyond the EPU, the catch advice should be allocated to the EPU based on the fraction of the total catch for the stock that was taken in the EPU in the year t-1 (the latest full year for which information is available).
>
> b. Stocks without assessment or catch advice:
>   i. Catch: Level observed in the EPU in year t-1 (the latest full year for which information is available).
>   ii. Stock area: not applicable.
>
> c. Stocks assessed by Coastal State:
>   i. Catch: maximum catch advice from the relevant authority for year t+1. If the catch advice is not available at the time of the scoping exercise, the level of catch observed in the EPU in year t-1 should be used instead.
>   ii. Stock area: if the stock area expands beyond the EPU, the catch advice should be allocated to the EPU based on the fraction of the total catch for the stock that was taken in the EPU in the year t-1 (the latest full year for which information is available). If the catch advice is not available at the time of the scoping exercise, the use of level of catch observed in the EPU in year t-1 makes stock area scaling unnecessary.

Based on the above considerations, the aggregate catch by functional guild at the EPU level can be approximated, and the Catch/TCI ratio computed using the TCI value corresponding to the appropriate guild and EPU. These Catch/TCI values constitute the results of the scoping exercise, and provide a coarse indication of the odds that the 2TCI ecosystem reference point could be exceeded in the year t+1. It is important to clearly report that this scoping exercise is not a formal projection nor model estimation, but a simple exploration of what the risk of ecosystem overfishing could be under the current circumstances and catch advice.

WG-ESA considered that the best vehicle to communicate the results of the scoping exercise is the Summary Report on Sustainability of Catches at the Ecosystem Level, which already contains the necessary granularity for an easy inclusion of the scoping results, and a grey box where the key highlights of the scoping exercise can be provided.

In addition to this work on scoping, WG-ESA also discussed the recommendations from WG-EAFFM to modify the text on TCI in the SSSs which is included in the section Ecosystem Sustainability of Catches, and agreed to remove references to risk level of ecosystem overfishing in those summaries as requested. References on risk of ecosystem overfishing will be kept in the Summary Report on Sustainability of Catches at the Ecosystem Level, where the distinction between a low (catch < TCI), medium (TCI ≤ catch < 2TCI) and high (catch ≥ TCI) risk of ecosystem overfishing emerging from the scientific work will be maintained, while reporting to managers will be centered in the adopted 2TCI ecosystem reference point. Related to this discussion, and in an effort to maintain consistency among the different communication vehicles, the Summary Report on Sustainability of Catches at the Ecosystem Level will be renamed Report on Ecosystem Sustainability of Catches (RESC) to match the name of the section in the SSSs.

WG-ESA also discussed the need to update the underlying estimates of primary production that are fed into the EPP models to estimate TCI. There was agreement that this work needs to be prioritized, and supported the ongoing collaborations with STACFEN to this work completed.

iii) Workplan for Updating Ecosystem Summary Sheets

The ESSs for the Grand Bank (3LNO) and Flemish Cap (3M) Ecosystem Production Units (EPUs) were completed by SC in 2022, and a 5 year schedule was adopted for their update, unless changes in the ecosystems warrant an earlier update. This implies that the next ESSs update is scheduled for 2027, and the necessary work at WG-ESA should be completed at the 2026 meeting. This also implies that a regular monitoring is required to determine if the ESSs need to be updated ahead of schedule.

From an operational perspective, one important element for maintaining the ESS work and its updates going forward is filling the Ecosystem Designated Expert (EDE) positions. EDEs are expected to be primarily responsible for developing the workplan for updating the ESSs and to coordinate the necessary work. At present, and on an interim basis, the EDE for the Flemish Cap (3M) EPU is Diana González-Troncoso (IEO, Spain), but the EDE position for the Grand Bank (3LNO) EPU remains vacant. To address this vacancy, DFO granted initial authorization for the nomination of Robert Deering (DFO, Canada) as EDE for this EPU. WG-ESA endorsed this appointment, pending confirmation by SC and final approval by DFO.

UPDATE: By January 2024, Robert Deering was no longer available for working in NAFO, so the 3LNO EDE position is still vacant.

While ESSs summarize both, ecological and management aspects within an EPU, WG-ESA agreed that triggering an ESS update outside of its regular schedule needs to be based on significant ecological changes, and not on changes in the management regime and/or performance. Under this light, it was considered that an annual interim reporting focused on: a) trends in ocean climate and oceanographic features, b) trends and structure of the fish community and c) trends in trophic relationships (e.g. diet composition, stomach content weights), would provide sufficient information for the required monitoring and the determination if a special ESS update needs to be triggered.

These annual ESS interim monitoring reports would be initially prepared at WG-ESA, and presented at the STACREC meeting in May and SC meeting in June. The presentation at STACREC may involve only a partial reporting, depending on the available information at that time (e.g. STACFEN updates may not yet be ready for this meeting), but a full monitoring report should be presented at the SC June meeting.

In advancing with this ecosystem monitoring task, a summary on ecosystem structure and trends, food consumption and diets for the EPUs within the Newfoundland-Labrador Bioregion, and an update on ecosystem structure and trends for the Flemish Cap (3M) EPU were presented at WG-ESA (see below).

In terms of a workplan for the ESSs update for 2027, WG-ESA did not elaborate a full workplan, but started to examine the structure and content of the ESSs to begin identifying those sections that are expected to require more work towards the next update. The formalization of a full workplan for the ESSs update was deferred to the 2024 WG-ESA meeting, with the expectation that both EDEs can attend that meeting in person, while allowing for sufficient time for the EDEs to organize updating plans that can be discussed at WG-ESA.

In advance of the more comprehensive workplan to be developed in 2024, WG-ESA identified the analysis of by-catch and discards, and the lack of a NAFO list of ETP species as two elements informing the ESSs that are expected to require significant work.

After some discussion, WG-ESA agreed to start working on these items in parallel, with work dedicated to a) develop a proposal for building an ETP species list and b) consolidate and explore the information reported to NAFO that can support the estimation of by-catch and discards, as well as the identification of ETP species that are part of these.

The approach to be explored for building a proposal for the ETP list will be based on a series of considerations that include: a) inclusion of a range of taxa (i.e. not just fishes), b) compilation of available ETP lists from multiple sources (e.g. IUCN, ICES, coastal states regulations, etc.), and c) examination and filtering of the compiled lists based on the available regional information. This work will be carried out by a subgroup of WG-ESA members, and expected to report on progress in 2024.

The work on consolidation and exploration of information for the estimation of by-catch and discards would be initially focused on the sources of data available to NAFO, namely daily catch reports, haul by haul data, NAFO observers data, as well as the results from prior exercises on these issues carried out by other NAFO bodies (e.g. STACTIC, WG-BDS). This work will be initially led by the Secretariat due to the restrictions associated with privacy regulations that may limit the release of some of these data. The work will be focused on the comparability and consistency of the different data sources to estimate by-catch and discards and to explore these reports to assess the degree to which these data could potentially track catches of ETP species. A report back to WG-ESA is expected by 2024. Based on this initial exploration, WG-ESA will scope the viability of potential alternatives to assess and document by-catch and discards, and how ETP species may be impacted by these.

These initial explorations will also involve the EDEs, so that the emerging results can be factored into the development of the ESSs update workplan.

iv) Summary of the status and trends of the fish community, food consumption and diet composition in the Newfoundland Shelf (NAFO Divs. 2J3K), Grand Bank (NAFO Divs. 3LNO) and Southern Newfoundland Shelf (NAFO Divs. 3Ps) Ecosystem Production Units

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). These EPUs represent relatively well defined functional ecosystems, and are used by NAFO for ecosystem-level summaries and ecosystem management considerations (Pepin *et al*., 2014; Koen-Alonso *et al*., 2019).

In broad terms, the ecosystems in this bioregion experienced important changes in the 1990s, which involved the collapse of the groundfish community, a key prey like capelin (Buren *et al.*, 2019), and the increase in shellfish (dominated by Northern shrimp). 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, and coincided with modest improvements in capelin (Buren *et al.*, 2019; Murphy *et al.*, 2021), and the beginning of the shellfish decline (NAFO, 2021).

WG-ESA reviewed and summarized the status and trends of the Newfoundland Shelf (2J3K), Grand Bank (3LNO) and Southern Newfoundland (3Ps) EPUs.

Newfoundland Shelf (2J3K)

After the period of high dominance of shellfish during the 1990s and early 2000s, the biomass of the fish community has reverted to the type of groundfish dominated structure observed prior to the ecosystem collapse during the regime shift of the late 1980s and early 1990s (Figure 6.2). Within the last decade, total biomass seems to have improved from the low point in the mid 2010s, while the general structure of the community has shown little change in recent years for which data is available.

Within this EPU, the diets of key groundfish species including piscivores like Atlantic cod and Greenland halibut, but also large benthivores like American plaice, show capelin as an important prey, with *Pandalus* shrimp gaining importance during the period this ecosystem was dominated by shellfish (Figure 6.3). Diets from the last decade indicate that capelin was more important in the early 2010s than in recent years, but no major structural changes in diet composition are apparent.

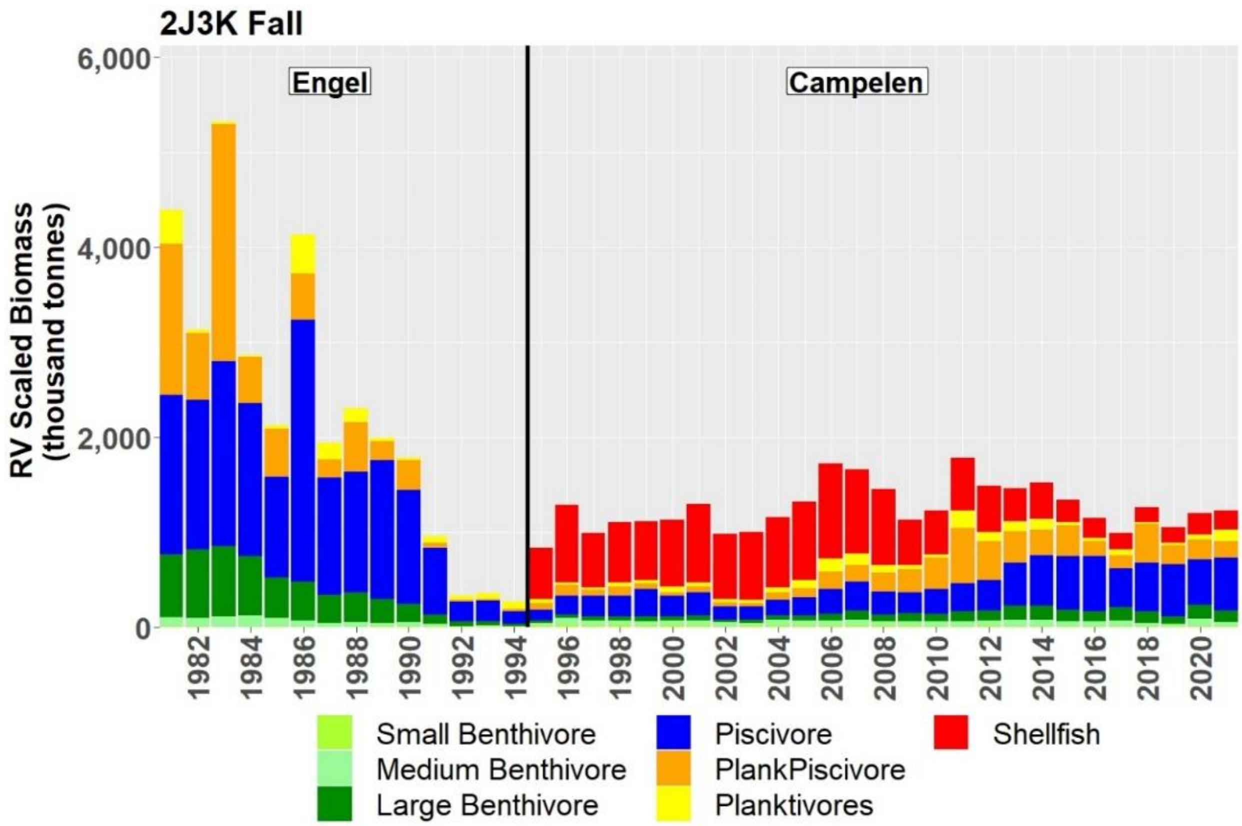

Figure 6.2. Research Vessel (RV) Fall biomass of the fish community in the Newfoundland Shelf (2J3K) EPU, discriminated by fish functional group. *Engel* and *Campelen* indicate the fishing gear used in each period. The biomass for the *Engel* period has been scaled so that the order of magnitude of the estimates are comparable between periods. There is no shellfish data is available for the *Engel* period.

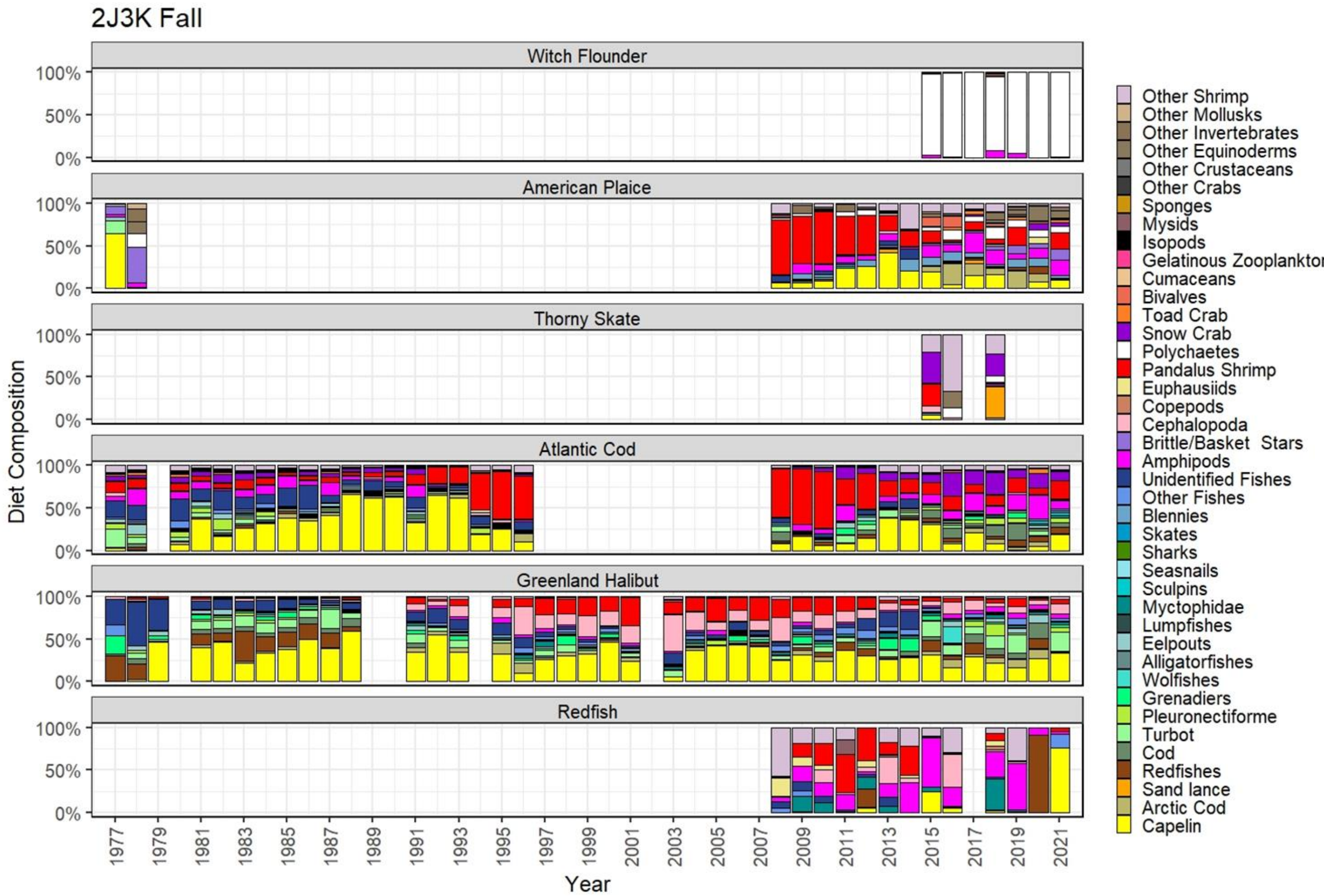

Figure 6.3. Diet composition for key species in the Newfoundland Shelf (2J3K) EPU from stomach contents collected during DFO Fall survey.

Grand Bank (3LNO)

This ecosystem also saw increases in shellfish after the collapse, but the overall ecosystem structure remained groundfish dominated (Figure 6.4). Total biomass increased from the low levels in the early 1990s to post-collapse highs in the early 2010s. During the last decade, clear declines were observed in the mid 2010s in both Spring and Fall surveys, with the Fall survey indicating a rebound in total biomass but without reaching the mid 2010s level yet. The Spring survey shows no indication of a rebound. This apparent discrepancy may be due to missing surveys in recent years; the most recent spring survey was in 2019, while the two subsequent surveys were both in the fall (2019 and 2020). The persistence of this increasing trend over the last three years and its true magnitude remain unknown.

Within this EPU, the diets of key groundfish species show capelin and sandlance as important prey (Figure 6.5). While both forage fishes are important, capelin appears to increase its importance for some predators in the spring, and sandlance in the fall. Diets from the last decade do not appear to indicate any major structural change in diet composition.

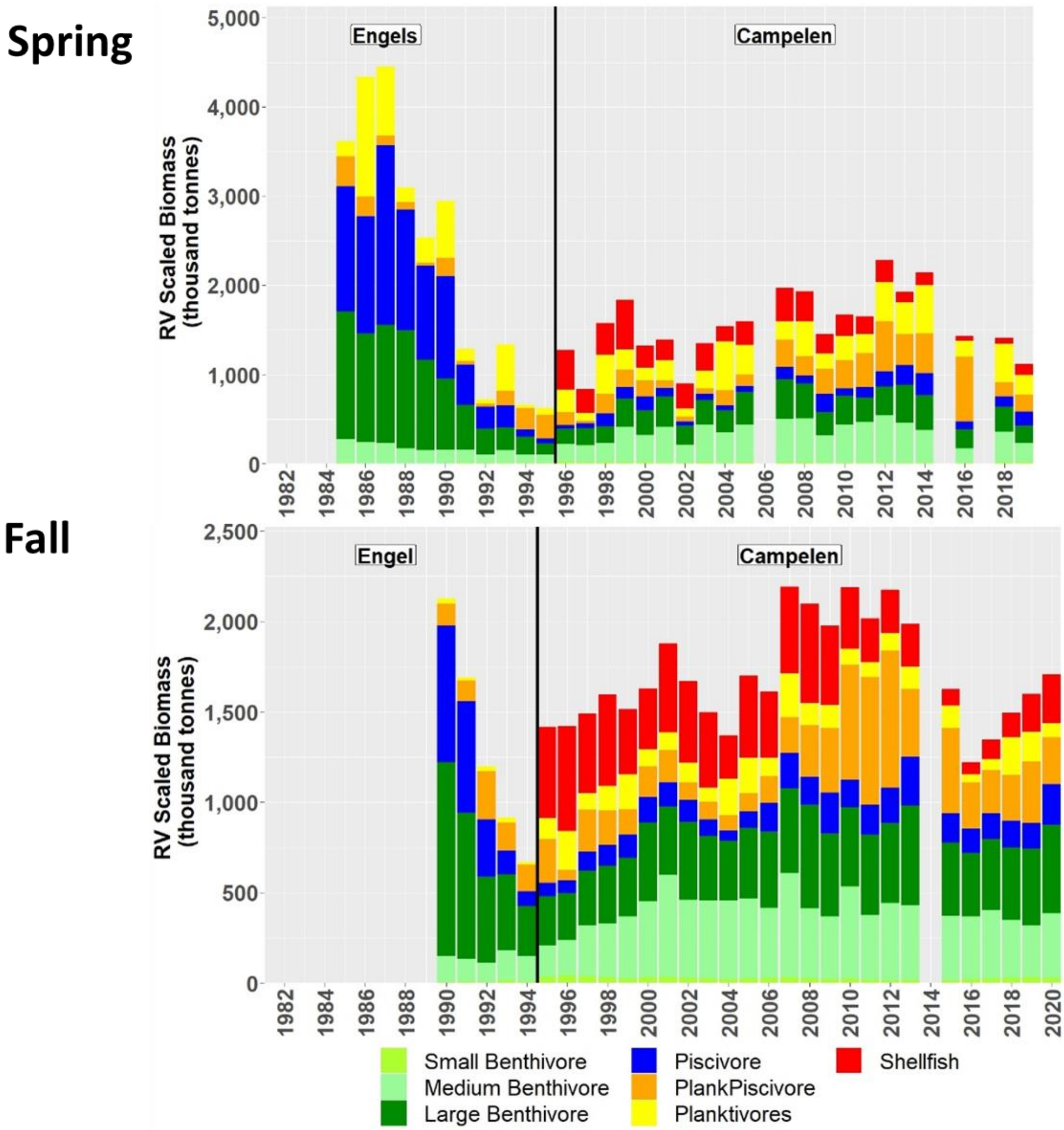

Figure 6.4. Research Vessel (RV) Spring (top) and Fall (bottom) biomass of the fish community in the Grand Bank (3LNO) EPU, discriminated by fish functional group. *Engel* and *Campelen* indicate the fishing gear used in each period. The biomass for the *Engel* period has been scaled so that the order of magnitude of the estimates are comparable between periods. There is no shellfish data is available for the *Engel* period.

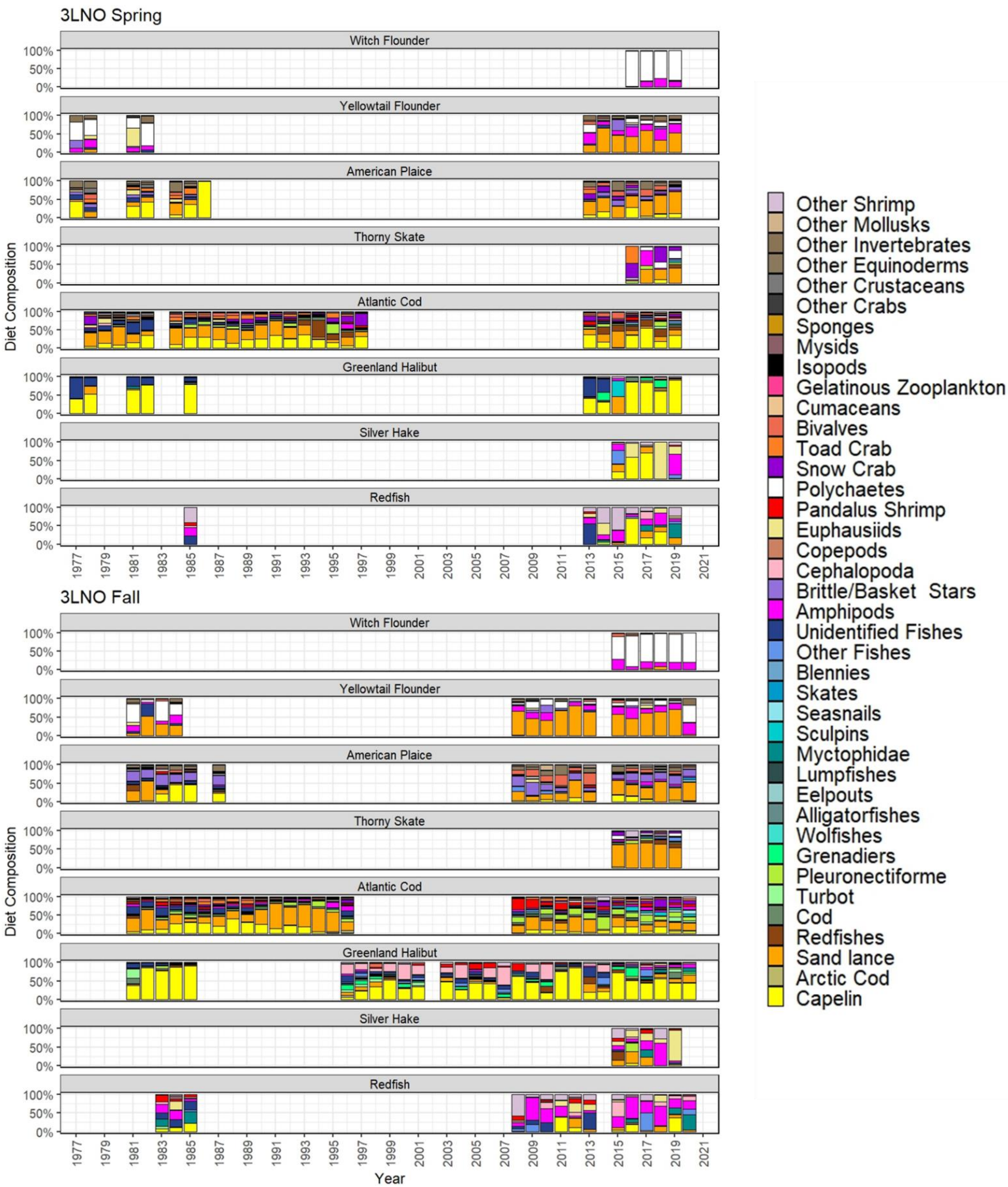

Figure 6.5. Diet composition for key species in the Grand Bank (3LNO) EPU from stomach contents collected during DFO Spring (top) and Fall (bottom) surveys.

Southern Newfoundland (3Ps)

Like other ecosystem units in the NL Bioregion, Southern Newfoundland also saw important declines in total biomass during the early 1990s, but in relative terms this biomass decline was less pronounced (Figure 6.6). However, unlike other EPUs, this ecosystem has not shown clear signals of rebuilding after the declines, apart from transitory spikes in the plankpiscivore functional group driven by redfish. Total biomass in this ecosystem unit has generally oscillated without a trend. During the last decade, and similarly to the other EPUs, reduced levels were observed after the mid 2010s. The last data available appears to suggest that improvements in total biomass may be occurring, but the lack of recent surveys has prevented a proper evaluation of this signal.

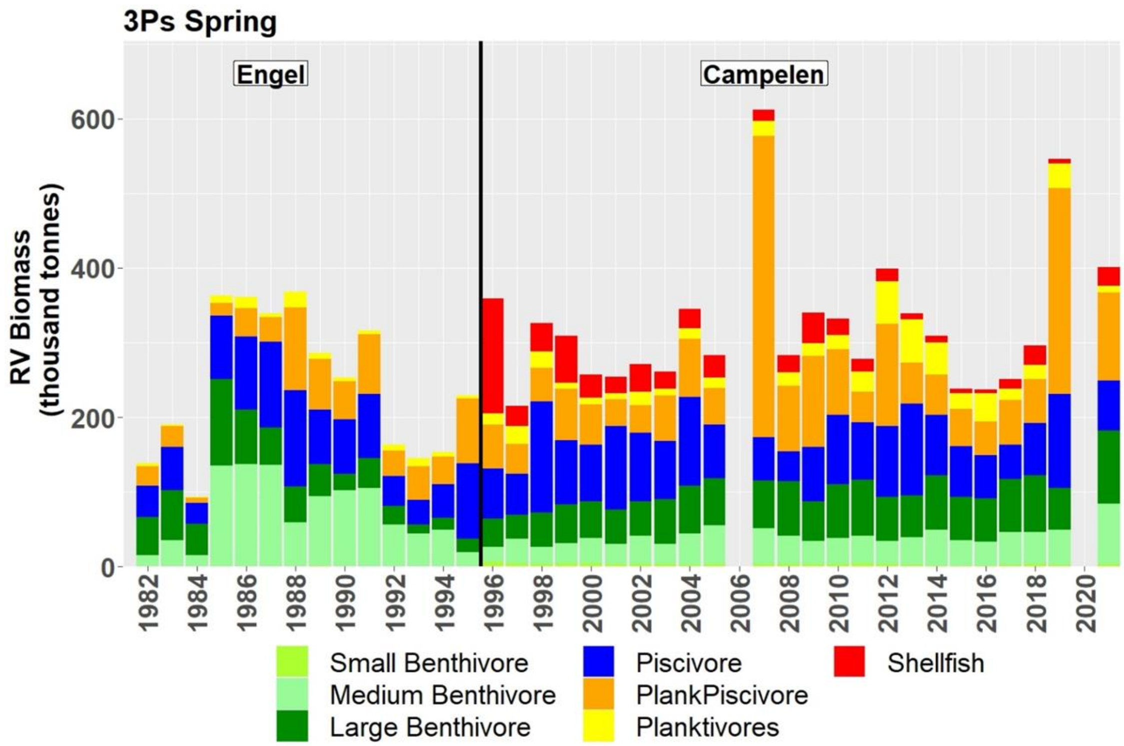

Figure 6.6. Research Vessel (RV) Spring biomass of the fish community in the Southern Newfoundland (3Ps) EPU, discriminated by fish functional group. *Engel* and *Campelen* indicate the fishing gear used in each period. Unlike the other EPUs in the NL Bioregion, the biomass for the *Engel* period has been not been scaled for this EPU, so the magnitude of the estimates is NOT directly comparable between periods. There is no shellfish data is available for the *Engel* period.

One important ecosystem change in this EPU has been observed in the piscivore functional group over the last decade, where silver hake has displaced Atlantic cod as the dominant species (Figure 6.7). The increasing in dominance of silver hake, and the high intrusion of spiny dogfish in 2019, both warmer water species, indicate this community is changing (NAFO, 2021). These changes have been associated with the warming observed in this EPU.

Diet information for key groundfish species from this EPU is sparser. Consistent sampling only started in the early 2010s, so long term characterizations of fish diets are not possible. Still, the available data indicates that sandlance is an important prey for several groundfish predators (Figure 6.8). Unlike other ecosystems, fish diets in this EPU appear more variable, suggesting a less stable prey field.

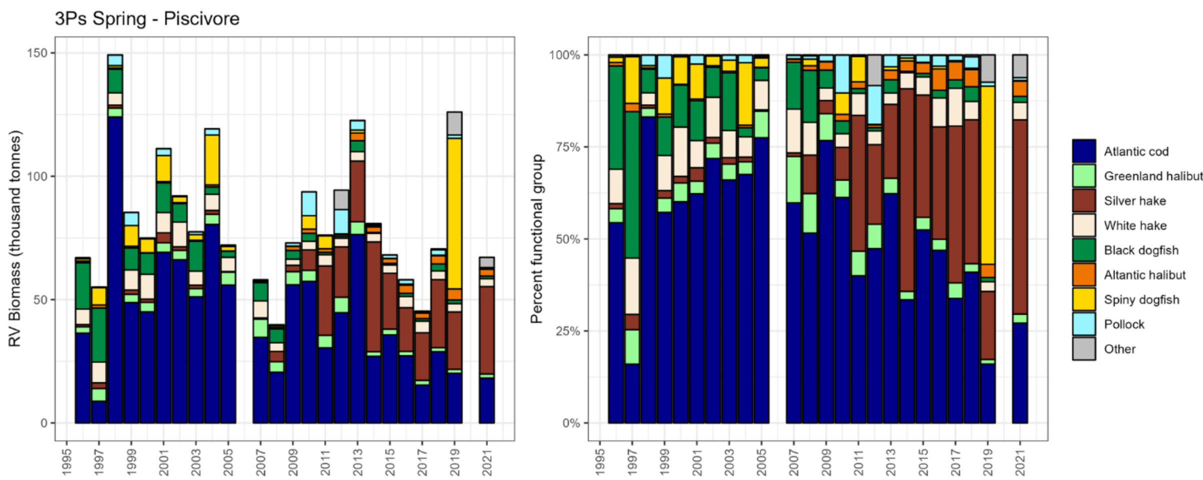

Figure 6.7. Trends in RV biomass (left) and structure (right) of the piscivore functional group in the Southern Newfoundland (3Ps) EPUs (NAFO, 2021).

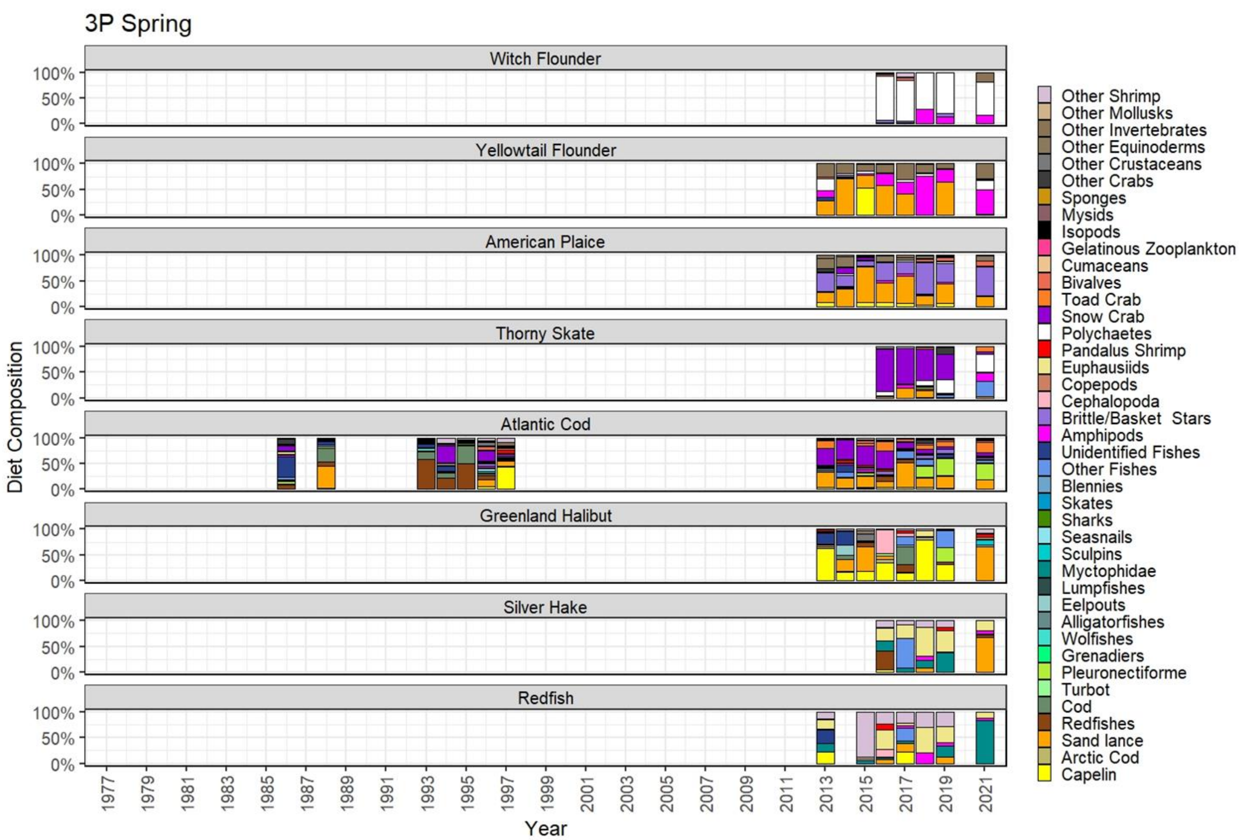

Figure 6.8. Diet composition for key species in the Southern Newfoundland (3Ps) EPU from stomach contents collected during DFO Spring survey.

Comparisons among EPUs

The regime shift in the early 1990s involved the entire fish community. While substantial increases in shellfish were part of the changes, these increases did not compensate for the loss in groundfish (Figure 6.9). These EPUs have sustained significantly lower biomass densities since the collapse , indicating that after the regime shift these ecosystems have been experiencing reduced productivity conditions (Koen-Alonso *et al.*, 2022).

Within this context of persistent lower productivity, the last decade saw declines in all EPUs in the mid 2010s, but the most recent available data suggest positive trends since.

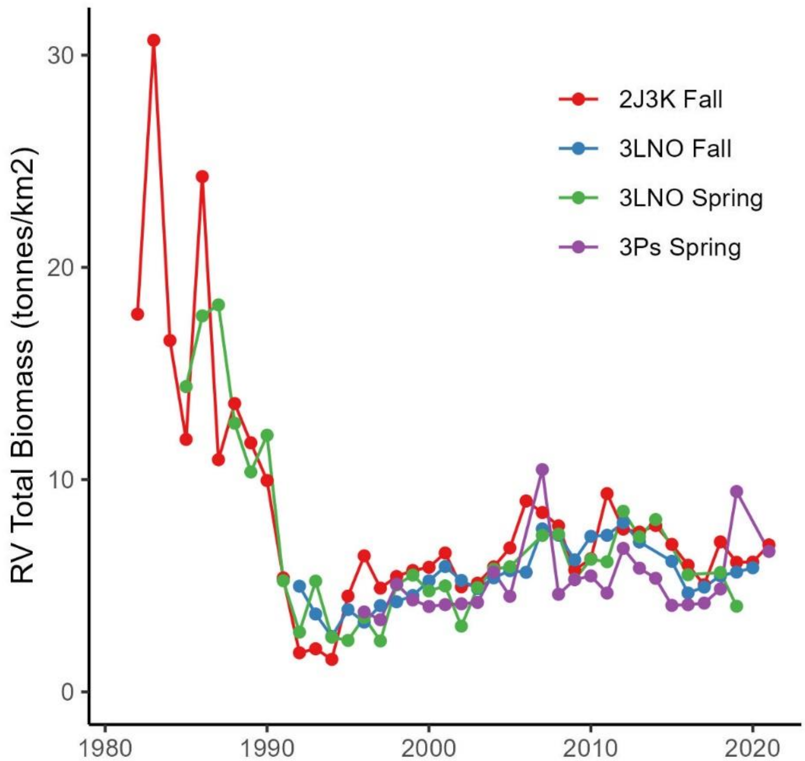

Figure 6.9. Total RV biomass density across EPUs in the NL bioregion.

In terms of community structure, there are clear differences among EPUs (Figure 6.10). While all ecosystems saw increases in shellfish after the collapse, there is a clear north to south gradient in the level of shellfish dominance observed. The fish community in the Newfoundland Shelf (2J3K) EPU was strongly dominated by shellfish after the collapse, while the other two EPUs were never dominated by this functional group, and the Southern Newfoundland (3Ps) EPU saw the weakest shellfish response to the groundfish collapse. Another structural differences among EPUs include the higher dominance of benthivores in the Grand Bank (3LNO) in comparison with the other EPUs, and the higher dominance reached by piscivores in the Newfoundland Shelf (2J3K) after this ecosystem unit returned to a groundfish dominated structure. Despite the longer-term changes, the general structure of these ecosystem units has remained relatively stable during the last decade, but this structural stability does not necessarily imply stability within functional groups, as the case of piscivores in Southern Newfoundland (3Ps) clearly demonstrates (Figure 6.7).

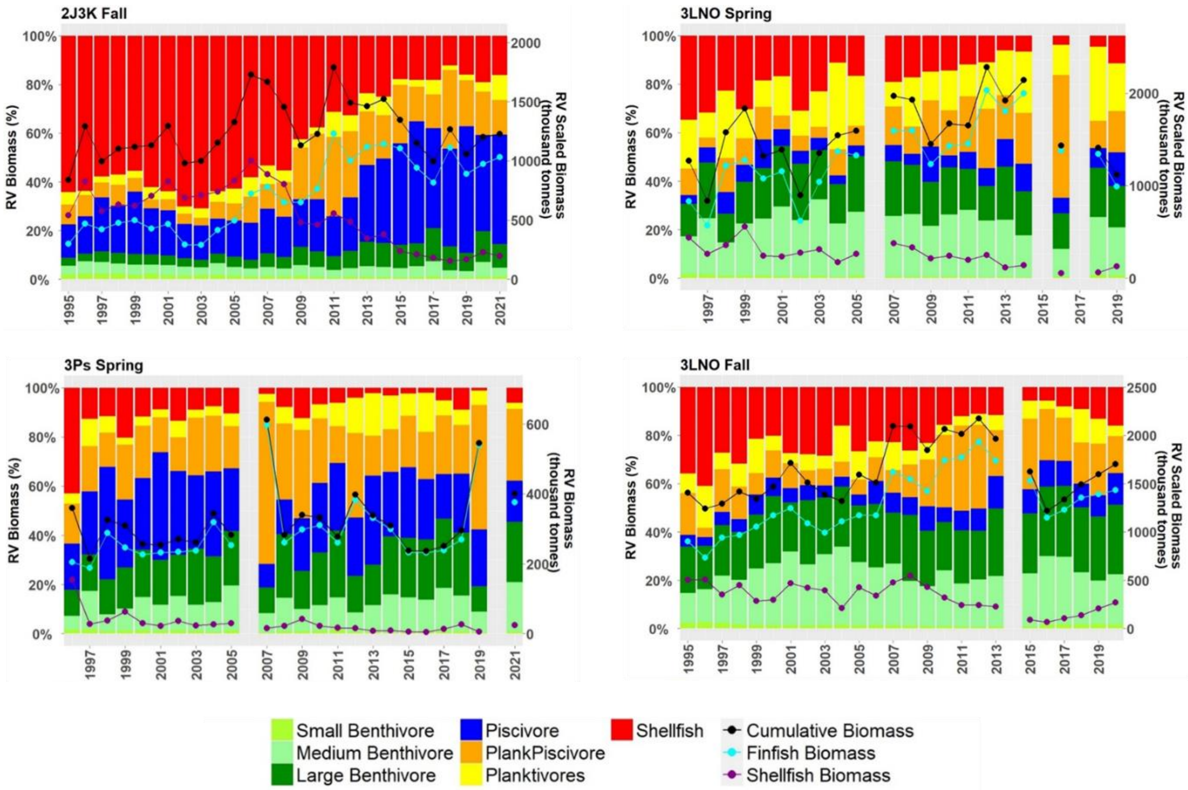

Figure 6.10. Synoptic comparison of the trends (total, finfish and shellfish biomass) and structure (fish functional groups) of the fish communities after the ecosystem collapse. Top left: Newfoundland Shelf (2J3K) from Fall survey, Right: Grand Bank (3LNO) from Spring (top) and Fall (bottom) surveys, Bottom left: Southern Newfoundland (3Ps) from Spring survey.

From a trophic perspective, the long-term signal in the average stomach content weights of Atlantic cod and Greenland halibut (also known as Turbot) across EPUs (Figure 6.11) shows a consistent pattern with the trend in total biomass density (Figure 6.9). This relationship is significant and suggests that food availability has been one of the drivers of ecosystem change in the NL Bioregion. While the overall ecosystem collapse is expected to have resulted from a combination of multiple factors (e.g. high fishing pressure, extreme environmental conditions, the collapse of capelin), the long-term association between total biomass density and feeding performance of high trophic level fish predators seems to indicate that bottom-up mechanisms may be behind the persistent low productivity that these ecosystems have been experiencing since the collapse.

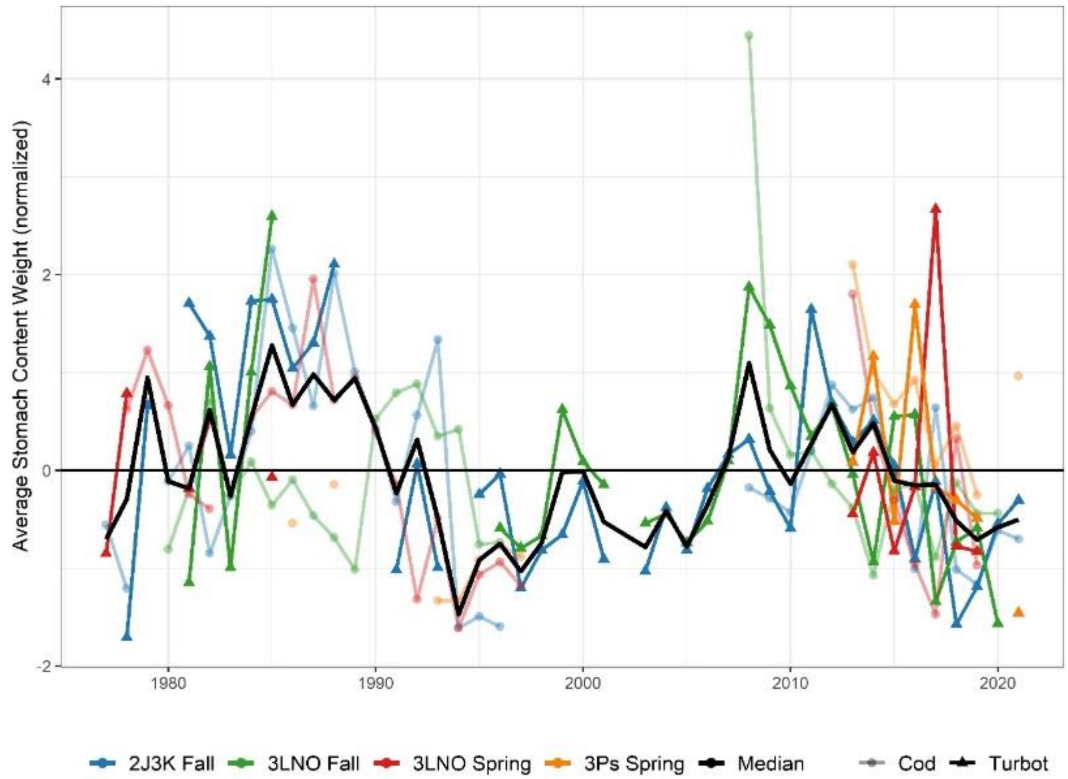

Figure 6.11. Average stomach content weights of Atlantic cod and Greenland halibut (also known as Turbot) across the EPUs in the NL Bioregion (fish sizes limited to 30-55 cm and excluding empty stomachs to minimize the effects of changes in size distributions and the variability in the determination over time of what constitutes an "empty stomach").

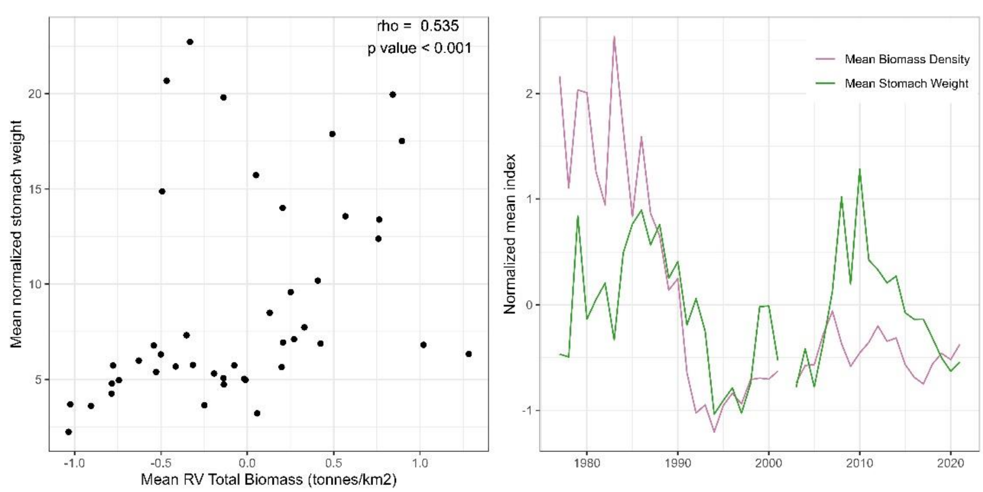

Figure 6.12. Comparison between average stomach content weights (Figure 6.11) and the average of the total biomass density (Figure 6.9). These two signals are positively and significantly correlated (Spearman correlation).

v) Update on ecosystem structure and trends for the fish community of the Flemish Cap (3M)

The Flemish Cap bioregion (3M) encompasses a single Ecosystem Production Unit (EPU). This EPU represents a well-defined functional ecosystem, and is used by NAFO for ecosystem-level summaries and ecosystem management considerations (Pepin *et al.*, 2014; Koen-Alonso *et al.*, 2019).

Total biomass is around the long-term average, indicating normal productivity conditions. During the 1990s and early 2000s this EPU saw an increase in dominance of shellfish (driven by *Pandalus* shrimp), and an important increase in total biomass was observed in the mid 2000s driven by plankpiscivores due to high recruitment of redfish (Figure 6.13).

During the last decade, total biomass returned to the long-term average, and community structure has remained stable, with high dominance of piscivores (mainly Atlantic cod) and plankpiscivores (mainly redfish) (Figure 6.14).

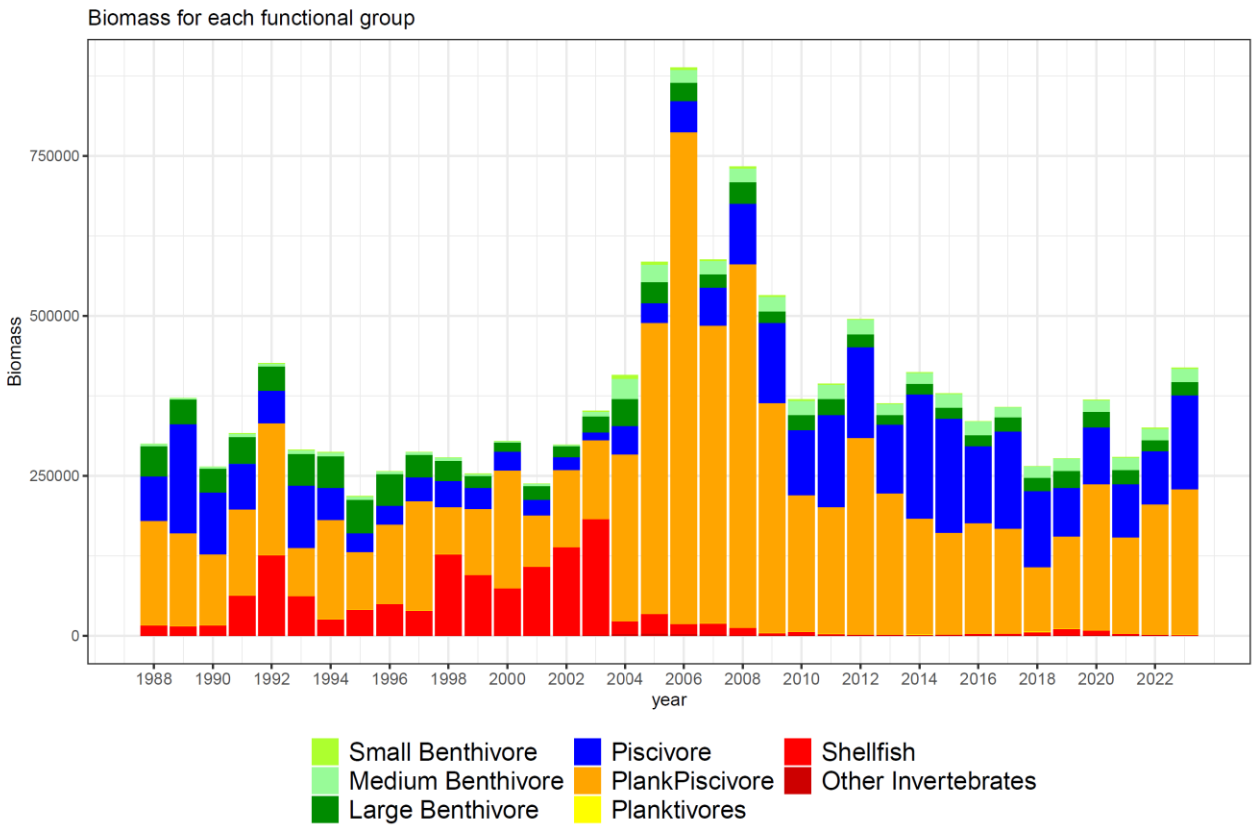

Figure 6.13. Research Vessel (RV) biomass (t) of the fish community in the Flemish Cap (3M) EPU, discriminated by fish functional group. The data for 2023 are preliminary and are subject to revisions.

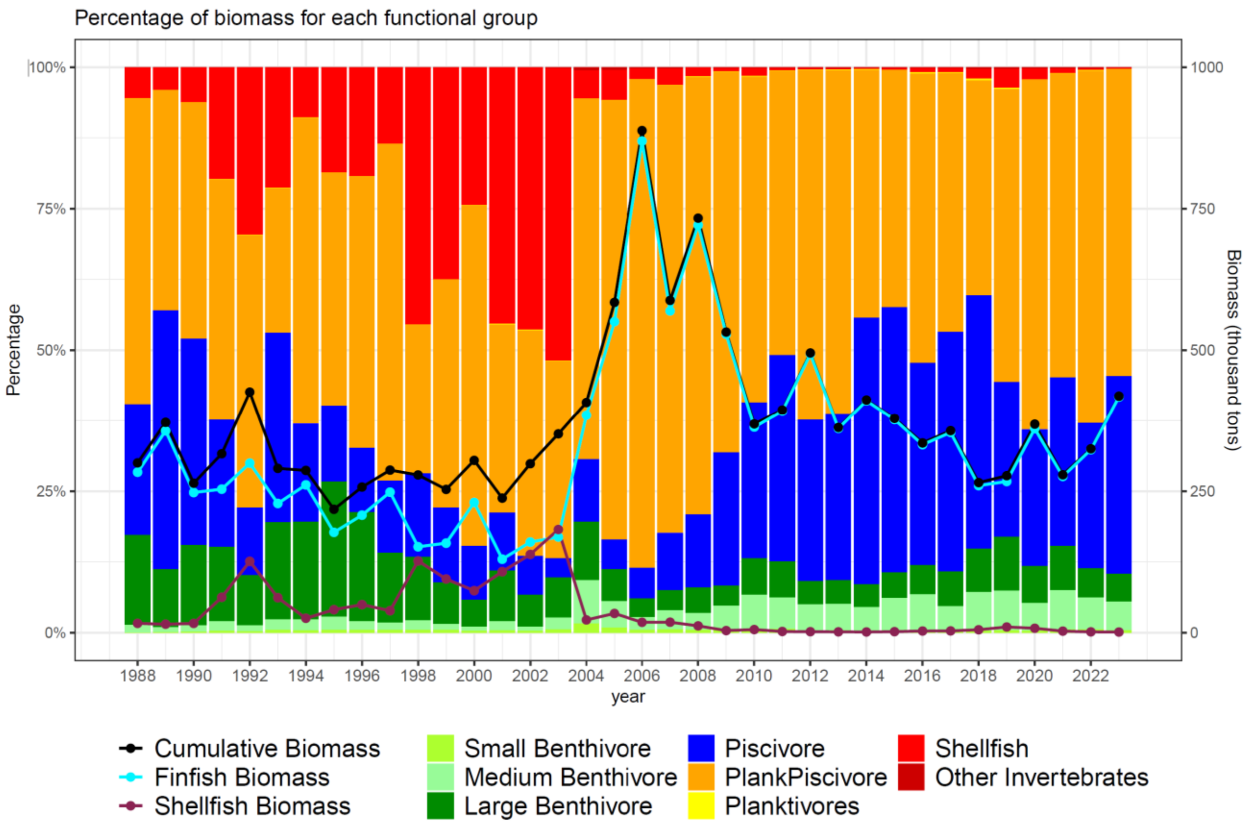

Figure 6.14. Synoptic view of the trends (total, finfish and shellfish biomass) and structure (fish functional groups) of the fish community in the Flemish Cap (3M) EPU. The data for 2023 are preliminary and are subject to revisions.

References

Buren, A. D., Murphy, H. M., Adamack, A. T., Davoren, G. K., Koen-Alonso, M., Montevecchi, W. A., Mowbray, F. K., Pepin, P., Regular, P.M., Robert, D., Rose, G.A., Stenson, G.B., Varkey, D., 2019. The collapse and continued low productivity of a keystone forage fish species. Marine Ecology Progress Series, 616: 155-170.

Koen-Alonso, M., Pepin, P., Fogarty, M., and Gamble, R. 2022. Review and Assessment of the Ecosystem Production Potential (EPP) model structure, sensitivity, and its use for fisheries advice in NAFO. NAFO SCR Document, 22/002: 1-52.

Koen-Alonso, M., Pepin, P., Fogarty, M. J., Kenny, A., and Kenchington, E. 2019. The Northwest Atlantic Fisheries Organization Roadmap for the development and implementation of an Ecosystem Approach to Fisheries: structure, state of development, and challenges. Marine Policy, 100: 342-352.

Murphy, H. M., Adamack, A. T., and Cyr, F. 2021. Identifying possible drivers of the abrupt and persistent delay in capelin spawning timing following the 1991 stock collapse in Newfoundland, Canada. ICES Journal of Marine Science, 78: 2709-2723.

NAFO 2021. Report of the 14th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA), 16-25 November 2021. NAFO SCS Document, 21/21: 181pp.

Pepin, P., Higdon, J., Koen-Alonso, M., Fogarty, M., and Ollerhead, N. 2014. Application of ecoregion analysis to the identification of Ecosystem Production Units (EPUs) in the NAFO Convention Area. NAFO SCR Document, 14/069: 1-13.

THEME 4: OTHER MATTERS

7. Other business

a) ToR 4.1. Update on the FAO EAFM Symposium planning

Tony Thompson presented an update on the FAO/NAFO EAFM symposium "Application of the Ecosystem Approach to Fisheries Management in ABNJ – recent developments in the monitoring, assessment and mitigation of ecosystem impacts of fisheries" to WG-ESA. NAFO's agreed to become an organising partner at the September 2023 NAFO SC meeting and further details are given in the SC report (NAFO SCS Doc. 23/22). The three-day symposium in planned for early 2025 under the auspices of the FAO Deep-sea Fisheries (DSF) Project. The proceedings will be published in the NAFO JNAFS.

Tony presented three items of special interest to WG-ESA:

- The request to ICES to be a co-sponsor,
- the draft symposium agenda,
- preparatory work with RFMOs to develop an EAFM "roadmap", and
- the symposium organizing committee.

It was noted that the request to ICES for sponsorship would need to include details such as website development, promotional material, gender balance and support for early-career scientists. It was agreed that the symposium organizing committee would meet in December 2023 to finalise the request for ICES sponsorship. Andy will make the application to ICES with support from Tony.

The symposium would focus on three aspects of the ecological aspects of EAF: retained catch, discarded catch and ETP species, and ecosystem considerations. Day 1 would deal with the scientific elements, Day 2 on moving from science to management (including thresholds and impact assessments), and Day 3 on EAFM "roadmaps" to support implementation. As presented, it was felt that Day 1 on the scientific aspects could be overwhelming. Panel type set-ups with 15 min presentations was a suggested format to keep focus, direction and efficiency.

There was support for the DSF Project to work with RFMOs in the lead-up period to try to develop a generalized "roadmap" that would form a foundation for the Day 3 discussions and symposium output. The DSF Project would start this work with RFMOs and keep the organising committee informed.

It was suggested that Diana González-Troncoso and Brynhildur Benediktsdottir would join the NAFO organizing committee and Andy could move to the ICES organizing committee. Other NAFO people would be Mariano Koen-Alonso, Miguel Caetano, Rick Rideout and Tom Blasdale. For the DSF Project, Eszter Hidas and Tony Thompson.

b) ToR 4.2. Update on the BBNJ Symposium

The High Seas Treaty Symposium was held in Edinburgh, UK on 6-7 October 2023 focusing on aspects relevant to the entry into force and implementation of the Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ Agreement). The Symposium brought together over 500 participants from around the world, from 50 nations with representatives from governments (including some NAFO delegates), treaty negotiators, the private sector, intergovernmental organisations, civil society and academia. Delegates from Argentina, Australia, Austria, Bangladesh, Belgium, Belize, Brazil, Cameroon, Canada, Chile, China, Costa Rica, Democratic Republic of the Congo, Denmark, Ecuador, Fiji, Finland, France, Germany, Honduras, Iceland, India, Iran, Ireland, Italy, Jamaica, Kenya, Mauritania, Morocco, New Caledonia, Nigeria, Norway, Pakistan, Panama, Poland, Portugal, Samoa, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Taiwan, Netherlands, Trinidad and Tobago, Tunisia, United Kingdom, Uruguay and USA joined the symposium. Video recordings of the event are available on the symposium website (http://high-seas-treaty.org) and the Symposium organising committee continue to meet to discuss academic outputs from the meeting and a potential follow up symposium in 2024.

All panels of the Symposium discussed the interface between the BBNJ Agreement and competent bodies, such as NAFO, to some degree. To date, the Agreement was adopted in June 2023 and opened for signature on 20 September 2023, and at the time of writing this report, it has gathered 83 signatures, including from several NAFO Contracting Parties (UNTC, 2023). For the Agreement to enter into force, 60 instruments of ratification, approval, acceptance or accession are required (Art 68(1)). Once it enters into force, the Agreement's Parts III on area-based management tools (ABMTs), including marine protected areas (MPAs), and IV on environmental impact assessments (EIAs) will possibly have the most direct implications for NAFO. Part II on marine genetic resources (MGRs) could potentially have some indirect effects for NAFO scientists with respect to the requirements for notification of collection of *in-situ* MGRs in ABNJ and digital sequence information, if applicable, with a view to "generate knowledge, scientific understanding and technological innovation, including through the development and conduct of marine scientific research" (Art 9(c)). Among other things, the Agreement defines ABMTs, MPAs, EIAs and MGRs (see Art 1).

The symposium also discussed, among other things, the operationalisation of the non-undermining clauses of the Agreement whereby the "Agreement shall be interpreted and applied in a manner that does not undermine relevant legal instruments and frameworks, and relevant global, regional, subregional and sectoral bodies and that promotes coherence and coordination with those instruments, frameworks and bodies" (Art 5(2)). To this end, and especially with regards to decisions of the BBNJ Agreement Conference of the Parties on ABMTs and the development of standards and guidelines for EIAs, opportunities for cooperation between the Agreement's Scientific and Technical Body and NAFO's Scientific Council may exist. This could include opportunities for the co-development of proposed ABMTs, including MPAs, management plans that could be located within the NRA. On EIAs, NAFO's work and expertise on the assessment of significant adverse impacts (SAIs) on VMEs could add value to the BBNJ Agreement in several ways, including by sharing expertise and knowledge about methods to measure SAI thresholds, ecological functions and services, connectivity patterns and avoidance of SAIs. Therefore, the relationship between the BBNJ Agreement STB (once established) and NAFO scientific bodies (SC and relevant WGs, such as WG-ESA) can offer an opportunity for better assess cumulative pressures (including from other sectors) to marine biodiversity, ecosystems and ecosystem functions and services in the NAFO regulatory area.

References

Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Agreement). https://treaties.un.org/doc/Publication/CTC/Ch_XXI_10.pdf

UNTC. 2023. United Nations Treaty Collection, Status of the Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction - list of signatories. https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXI-10&chapter=21&clang=_en

c) ToR 4.3 Update on the BBNJ Agreement.

The Executive Secretary informed WG-ESA that the BBNJ Agreement was opened for signature in New York in September 2023. In November 2023 83 nations had signed, but none had jet ratified, acceded, or accepted the Agreement. For it to come into effect it needs to be ratified by at least 60 UN member states, that might take several years. Some aspects of the new BBNJ Agreement that might be of relevance to the NAFO work in future include:

1. Scope;

   The Agreement shall be interpreted and applied in a manner that does not undermine relevant legal instruments and frameworks and relevant global, regional, subregional and sectoral bodies and that promotes coherence and coordination with those instruments, frameworks and bodies. NAFO is one of the regional bodies that are referred to in this article.

2. Area based management tools;

   The Agreement stipulates that the BBNJ COP shall establish area based management tools, may take decision on areas that are compatible with those adopted by other bodies, or may propose area measures to other relevant bodies.

3. Environmental Impact Assessment;

The Agreement stipulates "That the potential impacts of the planned activity or category of activity have been assessed in accordance with the requirements of other relevant legal instruments or frameworks or by relevant global, regional, subregional or sectoral bodies"

It needs to be seen how and to what extent NAFO´s work will be impacted when the Agreement comes into force, but it will probably call for increased communication within and between sectors and agreements including NAFO.

d) ToR 4.4. FAO-Deep Sea Fisheries Project.

The Executive Secretary informed WG-ESA that recent work of the NAFO Secretariat on the FAO-Deep Sea Project include reviewing introductory material on deep sea fishing and a preliminary review of RFMOs performance regarding various international instruments. Preparations for the FAO-NAFO and preliminary ICES Ecosystem Approach Symposium is ongoing and planned for early 2025.

e) ToR 4.5. NAFO-ICES MoU.

The Executive Secretary informed WG-ESA that the revised MoU with ICES has been approved by the NAFO Commission and signed by the President. It has been sent to ICES for their signature.

f) WG-ESA Participation

The group discussed the benefits and drawbacks of virtual versus in person participation in WG-ESA meetings. Overall, it was generally felt that hybrid meetings allow for broader participation by members that may otherwise not be able to attend.Consequently, there were also disccussions on the drawback of virtual participation, and the limtations it presents, including decreased complexity of discussions and interpersonal exchanges during meetings, as well as outside of the meeting room, that facilitate the work of the group.

Additionally, other challenges of hybrid meetings were discussed such as different time zones for virtual participants from different Contracting Parties, resulting in overseas participants having to attend in early mornings or late evenings. As such, this often results in virtual participants being expected to work their daily workload and add meeting participation in off hours on top of that, resulting in double workday hours during meetings.

It was suggested that future hybrid meetings might have to be scheduled in a manner that facilitates the different time zones of virtual and in person members with a focus on minimizing early morning and late evening meeting hours as much as possible for all attendees, including daily meeting hours potentially being shortened as well as coffee and lunch breaks.

It was noted that limiting daily meeting time can have implications for the amount of work that can be finished in each meeting. This in turn might mean having to prioritize projects to manage the work load or having additional meetings per year.

8. Date and Place of Next Meeting

The next WG-ESA meeting is scheduled for 12-21 November 2024, in Halifax, Nova Scotia, Canada.

9. Adjournment

The Chairs thanked the participants for their hard work and cooperation of this year's meeting. There being no other business, the meeting was adjourned at 11:00 on 23 November 2023.

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

NAFO headquarters, Halifax, 14-23 November 2023

Details of the meeting ToRs are given in **ANNEX 1** (see below).

Provisional Agenda and Terms of Reference (ToRs)

1. **Opening by the Chairs, Mar Sacau (EU) and Diana González (EU).**
2. **Appointment of Rapporteur**
3. **Adoption of Agenda**
4. **Review of Annual Meeting 2023 outcomes**
5. **Commission requests for advice on management in 2024 and beyond, requiring input from WG-ESA in 2023 to be presented at the Scientific Council meeting June 2024.**

a) COM Request #4. The Commission requests that the Scientific Council continue to work on tiers 1 and 2 of the Roadmap, specifically to:

a. Annually provide catch information in relation to 2TCI, including recent cumulative catch levels and a scoping of expected cumulative catch levels;

b. As practicable and taking into account Scientific Council capacity constraints, develop stock summary sheets for NAFO managed stocks that are evaluated using HCR or MSE processes.

b) COM Request #9. The Commission request the SC to monitor and provide regular updates on relevant research related to the potential impacts of activities other than fishing in the Convention Area, subject to the capacity of the Scientific Council.

c) COM Request #10[7]**.** The Commission requests that the Scientific Council at its 2024 meeting: summarize the information it currently has available regarding the current and future impacts of climate change on NAFO-managed stocks, non-target species, and associated ecosystems; and identify any consequential data gaps, research needs and opportunities for productive research.

6. Commission requests for advice on management in 2024 and beyond, requiring longer term input from WG-ESA.

a) COM Request #5. In relation to the habitat impact assessment component of the Roadmap (VME and SAI analyses), the Commission requests that Scientific Council:

a. Support the Secretariat in developing a centralized data repository using ArcGIS online to host the data and data-products for scientific advice;

[7] SC proposed setting up a steering group to develop terms of reference (ToRs) for the consultant. These ToRs are currently under initial development and may be presented and discussed during the WGESA, if this document is more or less finalized.

b. Continue working with WG-EAFFM towards developing operational objectives for the protection of VMEs and biodiversity in the NRA; and

c. Work towards the reassessment of VMEs and impact of bottom fisheries on VMEs for 2026.

7. Other Business
8. Date and place of next meeting
9. 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; EU-Spain Groundfish Surveys and Canadian Surveys (Bárbara/Sara/Santi/Mar/Pablo)
2. Workplan on VMS data filtering (Neil Ollerhead).
3. Update and discussion on standardized GIS data layers and data repository (COM. Request#5a). (Anna, Cam, Neil, Lauren, Tom)
4. Impact of Cerianthids on benthic biodiversity and Ecosystem Functioning in a Sub-Arctic Fjord (Bárbara/Stephan Hamisch)
5. Update on the Newfoundland and Labrador Comparative Fishing Program (Laura Wheeland).

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. Update on VME Connectivity analysis (Ellen's group).
2. Role of Astrophorina sponges (Demospongiae) in food-web interactions at the Flemish Cap (NW Atlantic) (Tanja Stratmann /Ellen's group)
3. Up-date on the analysis on the functional significance of VME in relation to fish (Anna)
4. Up-date on the analysis of SAI impact thresholds based on the cumulative response curves (James Bell)
5. Workplan for next VME and SAI reassessments for 2026 (COM. Request#5c). (Andy, Anna, Ellen, etc)
6. Preliminary analysis of the methodology to study the bottom fishing footprint in the NRA (NEREIDA project) (Irene Garrido)
7. The CC work and the development of the FAO-NAFO ToRs (COM. Request #10) (Tony Thompson, Diana, Mariano, Miguel, etc)
8. Climate-change refugia for the large gorgonian coral *Paragorgia arborea* in the Scotian Slope (COM Request #10) (Javier Murillo)

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. Preparation of the OECM nomination template, especially in relation to the seamount evidence, for the CBD and UNESP WDC on OECMs (Andy, Daniela)
2. Summary of the Workshop to evaluate long-term biodiversity/ecosystem benefits of NEAFC closed and restricted areas (WKECOVME) (Ellen)
3. Overview of the effects seismic surveying on snow crab, and preliminary findings pertaining to groundfish, resources in the Newfoundland and Labrador offshore. (COM. Request#9) (Corey Morris)
4. Emerging research on abandoned well sites in the Newfoundland and Labrador offshore (COM. Request#9) (Corey Morris)
5. NEREIDA Planned Activities Overview: activities other than fishing in the NRA (Marine Litter and Offshore Oil & Gas) (COM. Request#9) (Pablo/Mar)
6. Continue working towards developing operational objectives for the protection of VMEs and biodiversity in the NRA (COM. Request#5b) (Andy)
7. Workplan for TCI and next ESS update in 2026 (COM. Request#4). (Mariano, Diana, Robert, etc)

THEME 4: OTHER MATTERS

1. Update on the FAO EAFM Symposium planning (Tony Thompson)
2. Update on the BBNJ Symposium (Daniela)
3. Update on the status of the BBNJ (Brynhildur Benediktsdottir)
4. Update on the FAO Deep Sea Fisheries Project (Brynhildur Benediktsdottir)
5. Update on the NAFO-ICES MoU (Brynhildur Benediktsdottir)

APPENDIX II. LIST OF PARTICIPANTS

Name	Affiliation	E-mail
CHAIRS		
González-Troncoso, Diana	Instituto Español de Oceanografía (COV-IEO), CSIC, Spain	diana.gonzalez@ieo.csic.es
Sacau Cuadrado, Mar	Instituto Español de Oceanografía (COV-IEO), CSIC, Spain	mar.sacau@ ieo.csic.es
CANADA		
Command, Rylan	Fisheries and Oceans Canada, St. John's, NL	rylan.command@dfo-mpo.gc.ca
Deering, Robert	Fisheries and Oceans Canada, St. John's, NL	robert.deering@dfo-mpo.gc.ca
Gullage, Lauren	Fisheries and Oceans Canada, St. John's, NL	lauren.gullage@dfo-mpo.gc.ca
Hamisch, Stephan	Memorial University, St. John's, NL	shamisch@mun.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
Krohn, Martha	Fisheries and Oceans Canada, Ottawa, ON	martha.krohn@dfo-mpo.gc.ca
Lirette, Camille	Fisheries and Oceans Canada, Dartmouth, NS	camille.lirette@dfo-mpo.gc.ca
Munro, Hannah	Fisheries and Oceans Canada, St. John's, NL	hannah.munro@dfo-mpo.gc.ca
Murillo-Perez, Francisco Javier	Fisheries and Oceans Canada, Dartmouth, NS	javier.murillo-perez@dfo-mpo.gc.ca
Neves, Bárbara	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
Simpson, Mark	Fisheries and Oceans Canada, St. John's, NL	mark.simpson@dfo-mpo.gc.ca
EUROPEAN UNION		
Abalo, Sara	Instituto Español de Oceanografía (COV-IEO), CSIC, Spain	sara.abalo@ieo.csic.es
Caetano, Miguel	Instituto Português do Mar e da Atmosfera, Lisbon, Portugal	mcaetano@ipma.pt
Durán Muñoz, Pablo	Instituto Español de Oceanografía (COV-IEO), CSIC, Spain	pablo.duran@ieo.csic.es
Garrido, Irene	Instituto Español de Oceanografía (COV-IEO), CSIC, Spain	irene.garrido@ieo.csic.es
Gonçalves, Patricia	Instituto Português do Mar e da Atmosfera, Lisbon, Portugal	patricia@ipma.pt
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

Palas, Santiago	Instituto Español de Oceanografía (COV-IEO), CSIC, Spain	santiago.palas@ieo.csic.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
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND		
Bell, James	CEFAS, Lowestoft Laboratory, Lowestoft, UK	james.bell@cefas.gov.uk
Downie, Anna	CEFAS, Lowestoft Laboratory, Lowestoft, UK	anna.downie@cefas.gov.uk
Diz, Daniela	The Lyell Centre, Heriot-Watt University, Scotland	d.diz@hw.ac.uk
Kenny, Andrew	CEFAS, Lowestoft Laboratory, Lowestoft, UK	andrew.kenny@cefas.gov.uk
UNITED STATES OF AMERICA		
Hendrickson, Lisa	National Marine Fisheries Service, NEFSC, USA	lisa.hendrickson@noaa.gov
Mencher, Elizabethann	National Marine Fisheries Service, Office of International Affairs and Seafood Inspection, NOAA, USA	elizabethann.mencher@noaa.gov
Sosebee, Katherine	National Marine Fisheries Service, NEFSC, USA	katherine.sosebee@noaa.gov
INVITED GUESTS		
Thompson, Tony	Food and Agriculture Organization	Anthony.thompson@fao.org
OBSERVERS		
Devine, Brynn	Oceans North, Halifax Office, Halifax, NS, Canada	bdevine@oceansnorth.ca
Fuller, Susanna	Oceans North, Halifax Office, Halifax, NS, Canada	susannafuller@oceansnorth.ca
NAFO SECRETARIAT		
Benediktsdóttir, Brynhildur	NAFO Secretariat, Halifax, NS, Canada	bbenediktsdottir@nafo.int
Bell MacCallum, Dayna	NAFO Secretariat, Halifax, NS, Canada	dbell@nafo.int
Blasdale, Tom	NAFO Secretariat, Halifax, NS, Canada	tblasdale@nafo.int

.