Northwest Atlantic Fisheries Organization

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SC WG ON ECOSYSTEM APPROACHES TO FISHERIES MANAGEMENT – NOVEMBER 2012

Report of the 5th Meeting of the NAFO Scientific Council
Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM)
NAFO Headquarters, Dartmouth, Canada
21-30 November 2012

Contents

Introduction

The NAFO Scientific Council (SC) Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM) operates within a set of long-term Themes and Terms of Reference (ToRs) (Annex 1) which are being systematically addressed over multiple meetings. These Themes and ToRs build on the "*Roadmap for Developing an Ecosystem Approach to Fisheries for NAFO*" (WGEAFM Report, NAFO SCS 10/19).

The work of WGEAFM involves two non-mutually exclusive general tasks:

1. work intended to advance the "Roadmap for the development of and ecosystem approach to fisheries (EAF) for NAFO" ("Roadmap to EAF", for short).
2. work intended to address specific requests from Scientific Council (SC) and/or Fisheries Commission (FC).

In this context, at the 2012 June Meeting in Dartmouth, Canada, SC approved that work during the 5th WGEAFM meeting to be focused on:

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

It is expected that updates from the NEREIDA project, as well as other surveys, will become available; these new studies will be presented and discussed under this ToR. Other elements to be discussed may include modeling VME distribution using habitat characteristics, as well as analyses of distribution of benthic communities.

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

It is expected that updated analyses considering temporal variability of ecoregions will be presented and discussed under this ToR. Advances on the integration of databases for the Northwest Atlantic integrated ecoregion analysis are also expected to be discussed here.

ToR 3. Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area.

It is expected to continue working on Fisheries Production Potential (FPP) models, as well as modeling of multispecies systems, and estimations of food consumption.

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

It is expected that work under this ToR would include a literature review on parameterizations for SAI analyses, as well as a brainstorming session on the details and caveats of using VMS data for SAI analysis.

During the 2012 NAFO Annual Meeting, FC put forward 16 requests to SC. From these requests, 5 have been forwarded by the SC chair to WGEAFM for consideration during it 2012 meeting.

FC Request # 7. Recognizing the work accomplished by the Scientific Council in 2012 on sea pens and sponges, Fisheries Commission requests the Scientific Council to complete request 17 of 2011 by making recommendations for encounter thresholds and move on rules for small gorgonian corals, large gorgonian corals, sea squirts, erect bryozoans, crinoids and cerianthid anemone which are VME indicator species that meet the FAO Guidelines for VME and SAI. Consider thresholds for 1) inside the fishing footprint and outside of the closed areas and 2) outside the fishing footprint in the NRA, and 3) for the exploratory fishing area of seamounts if applicable. In the case of sea pens and sponges make recommendations for encounter thresholds and move on rules for the exploratory fishing area of seamounts.

FC Request # 10. The Fisheries Commission requests the Scientific Council to use Annex 1.E.V of the NCEM to guide development of their workplan related to reassessment of fishing activity with respect to Significant Adverse Impact (SAI) on VME and would note that this assessment is a single component of the broader EAF Roadmap being developed separately by SC.

FC Request # 13. Report on the progress of the "Roadmap for developing an Ecosystem Approach to Fisheries for NAFO" regarding:

a) The general progress of the Roadmap;

b) Further developments on the stock interactions studies between cod, redfish and shrimp in the Flemish Cap by applying multi species models and by quantifying potential yield and biomass tradeoffs with different fishing mortalities in the multispecies context. The predation of cod over cod juveniles should be taken into account;

c) Developments on stock interaction studies for the Grand Banks (NAFO Divisions 3KL and 3NO). The spatial overlap between these stocks should be considered.

These developments should be considered as exploratory and be part of the progress on the "Roadmap for developing an Ecosystem Approach to Fisheries for NAFO".

FC Request # 14. The Scientific Advice for 3LNO shrimp is based on the assessment of fishable biomass and the trends of exploitation rates. The basic assumption is that exploitation levels are driving the dynamic of this stock. However, interactions between stocks are likely to occur and may substantially contribute to the total mortality of shrimp.

The Fisheries Commission requests the scientific council to incorporate as much as possible information on stock interaction between these stocks in the management advice of 3LNO shrimp and to provide sustainable exploitation rates on that basis.

FC Request # 16. Assessment of risk of significant adverse impacts on VME indicator aggregations and VME elements in the NAFO RA.

Fishing effort is not uniformly distributed throughout the NAFO Regulatory Area (NRA) and within the fishing footprint there is considerable variation in the intensity of fishing effort. Defining and mapping the high intensity fishing areas within the NRA would by definition represent low risk areas in terms of significant adverse impacts and therefore encounter protocols and move on rules would have little utility in these areas. Furthermore, an understanding of the relationship between the high intensity fishing areas and the environmental characteristics could be used to identify potential new low risk fishing areas. Further categories of risk should be assessed in relation to known and potential mapped VME areas and the maps of fishing intensity to support a risk based spatial management approach for all areas.

a) The Fisheries Commission requests the SC for an analysis of fishing effort (VMS data) in the NRA to define areas of different levels of fishing intensity (e.g a map of 90%, 80%, 70%... effort) and assess these in conjunction with habitat data in order to map out areas where fishing activities would therefore have no or little significant adverse impact on VMEs and where encounter protocols and move on rules would therefore have little utility. To achieve this, high resolution data is required, (derived from the 2003-present time series of VMS records and logbook records of fishing activity provided by the secretariat and NEREIDA data). The Fisheries Commission requests therefore to the Executive Secretary to provide to the Scientific Council anonymous VMS data and logbook records of fishing activity from 2003 to present.

b) In view of the area management currently implemented and to facilitate evaluation of the need for further protective measures in response to UNGA 61/105, the SC is requested to provide an assessment of risk of significant adverse impacts on VME indicator aggregations and VME elements in the NAFO RA. This assessment should consider spatial and temporal distribution of fishing activity (derived from the 2003-present time series of VMS records and logbook records of fishing activity provided by the secretariat), and the best available knowledge on the spatial distribution of VME indicators and VME indicator elements.

These FC requests fall under the general scope of WGEAFM long-term ToRs, and WGEAFM is actively engaged in developing those studies associated with the Roadmap to EAF. However, some of these requests could not be fully addressed by WGEAFM at this time due to a) lack of capacity/resources and/or logistical issues (e.g. the work involved to fully address FC Request #13 implies multi-year research projects), or b) because they also require input from other SC bodies (e.g. FC Request #14 is a core NAFO ICES *Pandalus* Assessment Group (NIPAG), but

WGEAFM can provide information that can be useful to NIPAG and SC when addressing this request). Regardless these shortcomings, WGEAFM attempted to address these requests as fully as possible.

Terms of Reference for the 5th NAFO SC WGEAFM meeting

The above FC requests, together with the agreed topics under the "Roadmap to EAF" have been amalgamated in the ToRs for the 5th WGEAFM as follows:

Theme 1: Spatial considerations

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

ToR 1.1. Update on NEREIDA-related analyses and results.

ToR 1.2. Given that VME-related NAFO closures (i.e. areas of high concentrations of corals, sponges, and seamounts) will be reviewed by FC in 2014 using the outcomes from the NEREIDA project, develop a workplan to make available all necessary information and analyses by the 6th WGEAFM meeting (2013), so it can be summarized for SC consideration at the 2014 June meeting.

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

ToR 2.1. [Roadmap to EAF] Update on ecoregion analyses, including temporal variability and the impact of taxonomical information on ecoregion delineation and boundaries.

ToR 2.2. [Roadmap to EAF] Preparatory work towards an integrated ecoregion analysis for the entire Northwest Atlantic.

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

ToR 3. Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area.

ToR 3.1. [Roadmap to EAF]. Report progress on the development of Fisheries Production Potential Models for NAFO ecosystems.

ToR 3.2. [FC Request # 13 – item b)]. Report progress on the studies between cod, redfish and shrimp in the Flemish Cap through multispecies models and by quantifying potential yield and biomass tradeoffs with different fishing mortalities in the multispecies context; the predation of cod over cod juveniles should be taken into account.

ToR 3.3. [FC Request # 13– item c) and FC Request #14]. Report progress on species/stock interaction studies for the Grand Banks (NAFO Div 2J3KLNO), considering spatial overlap whenever possible, and with special consideration of the impact of these interactions on 3LNO shrimp, and their potential implication for management advice.

Theme 3: Practical application of ecosystem knowledge to fisheries management

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

ToR 4.1. [FC Request # 7]. This is a follow-up work on encounter thresholds and move-on rules. For small gorgonian corals, large gorgonian corals, sea squirts, erect bryozoans, crinoids and cerianthid anemone, consider thresholds for 1) inside the fishing footprint and outside of the closed areas and 2) outside the fishing footprint in the NRA, and 3) for the exploratory fishing area of seamounts if applicable. In the case of sea pens and sponges consider encounter thresholds and move on rules for the exploratory fishing area of seamounts.

ToR 4.2. [FC Request # 16]. Begin the development of the assessment of risk of significant adverse impacts on VME indicator aggregations and VME elements in the NAFO RA by

a) Analyze fishing effort (VMS data) in the NRA to define areas of different levels of fishing intensity (e.g a map of 90%, 80%, 70%... effort) and assess these in conjunction with habitat data in order to map out areas where fishing activities would therefore have no or little significant adverse impact on VMEs and where encounter protocols and move on rules would therefore have little utility.

b) In view of the area management currently implemented and to facilitate evaluation of the need for further protective measures in response to UNGA 61/105, assess the risk of significant adverse impacts on VME indicator aggregations and VME elements in the NAFO RA. This assessment should consider spatial and temporal distribution of fishing activity, and the best available knowledge on the spatial distribution of VME indicators and VME indicator elements.

ToR 4.3. [FC Request # 13- item a)]. Summarize the general progress of the Roadmap to EAF.

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

ToR 5.1. [FC Request # 10]. This is a follow-up on the workplan for the reassessment of NAFO fisheries in 2016. Considering the modifications of the NCEM approved in the 2012 Annual Meeting, which focuses the fisheries assessments on SAI on VMEs, provide guidance to develop a workplan to achieve the reassessment of all NAFO fisheries by 2016 and every 5 years thereafter, identifying the necessary steps to be taken, as well as the information and resources to do so.

Theme 4: Specific requests

ToRs 6+. As generic ToRs, these are place-holders intended to be used when addressing expected additional requests from Scientific Council.

ToRs 6.1. Discussion on the potential role and participation of WGEAFM in the project “Scientific review of best practices in bottom trawling” led by Michel Kaiser (Bangor University), Simon Jennings (University of East Anglia and CEFAS), Ray Hilborn (University of Washington), Jeremy Collie (University of Rhode Island) Bob McConnaughey (NOAA), Steve Murawski (University of South Florida), Ana Parma (CENPAT, Argentina), Roland Pitcher (CSIRO, Australia), and Adriaan Rijnsdorp (Wageningen University, Netherlands).

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

ToR 1.1. Update on NEREIDA-related analyses and results.

Box core samples

Benthic infaunal samples collected using a box corer from in and around the northern Flemish Pass closed area (spanning NAFO subareas 3L and 3N) have been analysed together with existing infaunal data from in and around the Sackville Spur closed area (NAFO subarea 3L and 3M) to investigate patterns in faunal assemblage structure and composition. The dataset was analysed as a whole, as well as using only a subset of taxa thought to be indicative of Vulnerable Marine Ecosystems (VME). Several distinct assemblages were identified across the whole survey area based on selective analyses using either taxon presence/absence information (S), taxon abundance (N) or biomass (B).

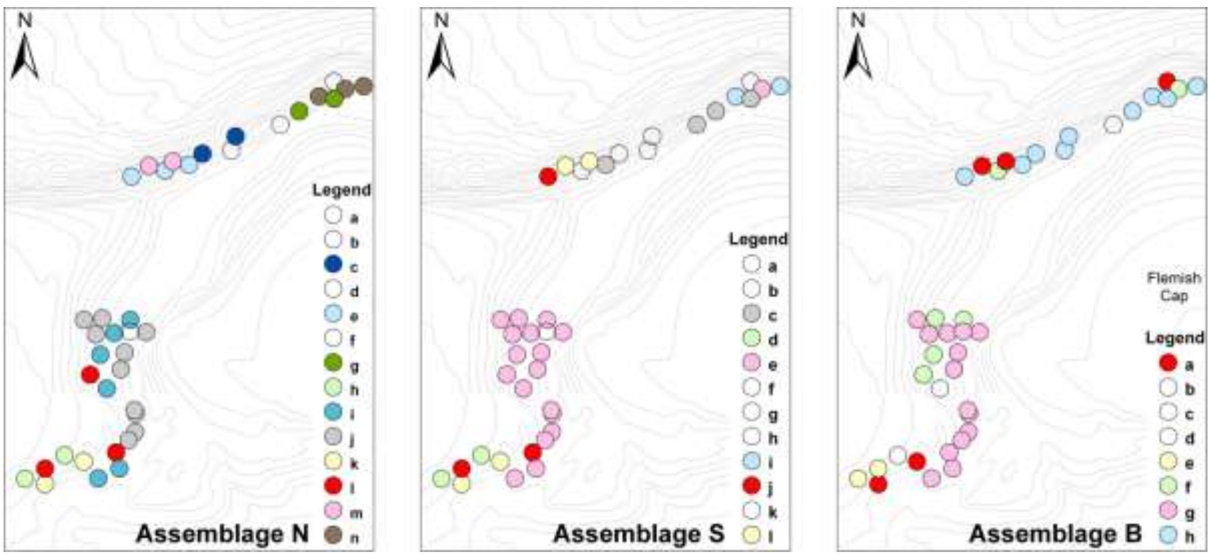


Figure 1.1 Distinct infaunal assemblages identified from the analysis of abundance (N), taxon presence/absence (S) and biomass (B). Colour-coding of different assemblages is not equivalent among figures.

Results from the analysis of biomass were considered the most intuitively useful for management, as the most taxon rich assemblages (assemblage a, e and f in Figure 1.1, right) were also the ones which had a greater number of taxa thought to be indicative of VME. This was not the case when using other datasets (i.e., there was a discrepancy between the most taxon rich assemblage and that which harboured the most taxa indicative of VME) (Figure 1.2).

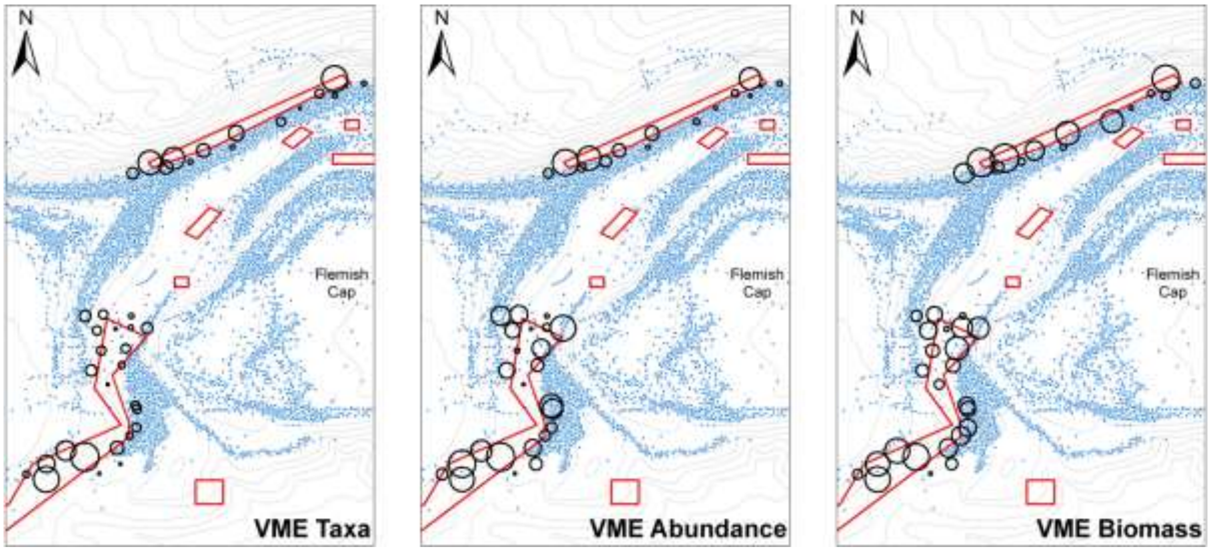


Figure 1.2. Relative number of potential VME indicative taxa, VME abundance and VME biomass across survey area.

Questions were raised during the presentation of these results over the criteria used for designating taxa as indicative of VME, primarily because of the coarse level of taxonomic resolution used for designation. Revision of such criteria was recommended before presenting any firm recommendations based on findings from this research.

Video and still photograph samples

Analysis of a video transect from the northeastern Flemish Cap slope has been completed and data entered into a dedicated Access database. Results revealed that 88% of taxa identified are sponges. Genetic samples from Hudson 2010-029 have all been processed; NEREIDA0509 samples awaiting results. Much of this work supports the identification of VME indicator species and is important for intended taxonomic publications.

The identification of fauna and biogenic structures from still photographs of the Flemish Pass is complete. Patterns in diversity, abundance and composition of megafauna have been analysed, as well as investigating the influence of abiotic variables on observed patterns. Each video transect harboured a different megafaunal assemblage. Assemblage structure also changed with depth. Chlorophyll and sponge abundance correlated with differences in the number of species between transects, while chlorophyll and depth explained a large amount of variance in megafauna abundance. A manuscript is in preparation which would contribute to the review process of VME closed areas in 2014.

Scientific trawl and rock dredge samples

Work on sponges is ongoing (50 spp have been identified so far). Other groups (corals, hydroids, echinorderms and molluscs) are complete. Still to do are arthropods, annelids, bryozoa, brachiopoda, sipuncula, nemertina and others. It is expected to finish the processing of all groups before the end of 2014. Biomass records from all 94 successful RD trawls are being processed in an attempt to investigate the distribution of epibenthic biomass across the survey area, and how this relates to major geomorphological features and environmental conditions.

Geological samples

All of the sediment push cores will have been analysed by March 2013 with stratigraphy and down-core physical properties available in an Open File. Another Open File is in advanced preparation on submarine landslides in NE Flemish Pass. The splitting and logging of piston cores collected in 2011 to ground-truth NEREIDA acoustic data is ongoing and will be completed by March 2013. Geological issues being currently addressed in the area include ^{14}C

dating of cores, origin of submarine canyons, cold dense water cascading in Flemish Pass, glaciations of Flemish Cap, geological conditions around sponge distribution, and origin of sediment drifts. Additional grain size information is being obtained from legacy samples on Flemish Cap and will be used to validate DFO current models.

Physical Oceanography Observations and Modelling

Spanish and Canadian CTD observations data have been QCd and made available on the NEREIDA ftp site. Bottom salinity and temperature data have been mapped over NEREIDA area. Oceanographic models used: GLORYS2, BIO-ORCA1, BIO-North Atlantic model. Model data on current, salinity and temperature uploaded to ftp site: surface, 500 m depth and bottom quantities at yearly or monthly frequencies and various degrees of resolution (1/12 to 1 degree). Other products available to extract from model on request. New technical reports will be available from DFO library by March 2013.

The Maximum Entropy model was run using environmental data derived from the GLORYS2 model (bottom and surface temperature, current strength, salinity and shear stress), depth and slope data extracted from a Canadian Hydrographic Service bathymetry layer, and ChlA data derived from ocean colour datasets produced by the NASA SeaWiFS programme within the NAFO Regulatory Area (NRA). Probability maps were produced showing the likelihood of distribution for sponges greater than 300 kg, Geodia, Asconema, Iophon, as well as small and large Gorgoneans. In addition to providing a general picture of likely distribution, the analysis also highlighted an area towards southeast of Flemish Cap as a hotspot for both sponges and corals. This model will be extended to the northern part of the west Atlantic along the continental shelf. Other modeling approaches are also being considered using the same datasets: Kernel Density and Random Forest. Data from the NRA was used to compare model approaches because the area is heavily surveyed and has an abundance of fisheries survey bycatch data and other biological and environmental datasets (NEREIDA and otherwise) that can be used by the model or in post-hoc analysis. The final review of all modeling approaches will be completed by February 2013.

ToR 1.2. Workplan for the review of VME closures in 2014

Given that seamount, coral and sponges protection zones in NAFO will be review by FC in 2014 using the advice provided by SC, which would include the outcomes from the NEREIDA project and other surveys, there is a need to develop a workplan to make available all necessary information and analyses by the 6th WGEAFM meeting (tentatively scheduled for November 2013), so it can be summarized for SC consideration at the 2014 June meeting.

Tasks

A considerable body of evidence has already been reported on VME status in the NRA since 2008 and each year an up-date of the NEREIDA programme analysis on VME related work has been conducted and reported. The data associated with these analyses is readily available to members of the NEREIDA programme.

In addition with already available data and ongoing analyses, new evidence is required through the additional processing of some of the key sample data sets, namely:

1. (NEREIDA) New video analysis from the Flemish Cap closures (DFO, Canada). This analysis will bring new information related to the assessment of biodiversity with respect to VME structure forming species which is required by UNGA Resolutions (61/105; 64/72; 66/68) and the FAO international guidelines for the management of deepsea fisheries in the high seas.
2. (NEREIDA) Analysis of rock dredge samples against recently produced list of VME indicator species (IEO, Spain). This is a unique benthic data set covering areas not sampled by the trawl surveys and collecting a different subset of the benthos not sampled by the trawls. The data will also be used for VME assessments and identification of benthic communities linked to Significant Adverse Impacts (SAI).
3. New Canadian and European research trawl survey data for years 2011/12/13 (IEO, Spain; DFO, Canada). This data underpins the original closed areas and annual updates provide additional locations of significant concentrations of VME taxa.
4. (NEREIDA) Box core sample species biomass layer (Cefas, UK). This is a unique benthic data set recording macrobenthic infauna which are important food for fish species. The samples provide a fully

quantitative description of the soft bottom habitat in the NRA. The data can also be used jointly with the biodiversity considerations under item 1 above.

5. (NEREIDA) Habitat suitability models results of VME indicator species distribution and abundance/biomass (DFO, Canada). This is useful for providing continuous distributions where limited catch data is available. The models will be used to support the filling of gaps associated with the environmental factors controlling VME status and distribution.
6. (NEREIDA) Examination of VME distributions within the wider biogeographic region of the NW Atlantic (DFO, Canada; IEO, Spain). These data will support the evaluation of the uniqueness and rarity criteria for VME as outlined in the FAO deepsea fisheries guidelines.
7. Analysis of fishing activity VMS data integrated with historic fishing effort maps to generate a map of fishing activity between 1987 and 2012 (NAFO). This will show the spatial relationship between active fishing areas and the VME fishery closures and help to define the closure boundaries and assessment of the SAI.

The above analyses will be undertaken to the extent possible during 2013 ahead of the WGEAFM meeting in November/December. The new data analyses will then be assessed in relation to the existing data layers (already reported) and a comprehensive assessment of current VME closure status undertaken. The report will also provide a narrative explaining the development of the work (mainly through the activities of the NEREIDA programme).

However, items 1, 2, 4, 5 and 6 (analysis of NEREIDA samples above) is critical for the delivery of the review of NAFO fisheries closures since it is the only source of benthic community data available which covers all of the closures in the fishing footprint and adjacent areas. The processing of these samples and data is entirely dependent on funds from the European Commission being made available in a timely fashion. In this respect it was agreed during the NAFO 34th Annual meeting (2012) the European Union would consider granting part of the funding necessary to complete the project through NAFO. In the case that funding is approved, this would be used for the analysis of samples in Spain (IEO) and UK (Cefas) for Fiscal Years 2013, and 2014. Funding for Canadian participation is available until March 31st 2014 (item 1 in part and item 5 above). It would be expected to analyze the samples from the NEREIDA project during the year 2013 in Spain (rock dredge samples), UK (box-corer samples) and Canada (video images), as well as to manage all the necessary information for the review of the VME-related NAFO closures.

WGEAFM therefore concludes that the Chair of Scientific Council should be notified as soon as possible of this risk and the potential of failure to deliver a robust review of current VME closures if EC funding is not made available by the end of January 2013 to undertake the tasks described above.

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

The value of applying an ecoregion approach to the delineation of Ecosystem Management Units should consider the correspondence between patterns of temporal (e.g. inter-annual) fluctuations in regional productivity of lower trophic levels and their relationship with environmental factors, that play a critical role as drivers of Fishery Production Potential (sensu Ryther-Ware). For example, findings by the Atlantic Zone Monitoring Program (AZMP) for the Newfoundland Region indicate that patterns of variation in zooplankton abundance on the NE Newfoundland Shelf (northern Ecoregion – Pepin et al. 2010) are closely associated with variations in the influx of Atlantic water whereas patterns of variation on the Grand Banks are more closely associated with inter-annual variations in temperature. Developing environmental overviews based on delineated ecoregions could serve to highlight the potential differences in environmental drivers that could affect regional differences in fishery production potential.

ToR 2.1. Update on ecoregion analyses, including temporal variability and the impact of taxonomical information on ecoregion delineation and boundaries.

2.1.1. Robustness of ecoregion delineation for the Newfoundland Shelf

Previous work of the WG had provided a substantive delineation of ecoregions on the US Northeast Atlantic Shelf (Fogarty and Keith, 2009; Areas 4X5YZe6ABC), the Scotian Shelf (Zwanenburg et al., 2010; Areas 4VsnWX) and the Newfoundland Shelf (Pepin et al., 2010; Areas 2J3KLNO) to identify potential management units for the EAM. The approach used in ecoregion delineation essentially relies on producing quantitative layers that link different features of the ecosystem, both physical and biological, through principal components analyses to define areas with similar features based on clustering algorithms (hierarchical agglomerative clustering (Fogarty and Keith, 2009; Zwanenburg et al. 2010), k-means (Pepin et al. 2010)) that group spatially resolved information. In comparison to the Scotian Shelf and US Northeast Atlantic Shelf, the Newfoundland Shelf was considered to be a relatively data poor system (NAFO, 2010) which had resulted in the delineation of ecoregions based on a subset of the variables that had been used by Fogarty and Keith (2009). As a result, Pepin et al. (2010) investigated the influence of data resolution and complexity on the correspondence between ecoregions defined using various subsets of information that represented the physical and biological field based on averages that represented several years or decades of observations. Pepin et al. (2010) concluded that for the Newfoundland Shelf, environmental variables were so strongly linked that the fundamental spatial structure of the ecoregions remained apparent when subsets or classes of information were removed from the analysis, which resulted in a robust definition of ecoregions. The strong latitudinal and cross-shelf gradients in physical and bathymetric had strong effects on the productivity and distribution of marine organisms.

WGEAFM (NAFO, 2010) concluded that in general terms, the ecoregion analyses presented to date provided a robust basis for the discussion and identification of ecosystem-level units to be used for the initial development and implementation of the “roadmap to EAF”. However, some key aspects of the analysis that were identified as needed to further strengthen the ecoregion delineation that would provide a sound biological basis against which WGEAFM could evaluate the current delineation process relative to earlier approaches (e.g. Halliday and Pinhorn, 1990). The first issue deals with the fact that the current ecoregion analyses do not contain information on the identity of the species included in the calculation of layers of biomass, richness and diversity. One consequence of this lack of taxonomic information is, for example, the classification of the Newfoundland Shelf and Southeast Shoal into the same cluster for some of the analyses done for the region. WGEAFM considered that it was important to devise a way to summarize taxonomic information in one (or few) layers and incorporate this type of data in the ecoregion delineation analysis. The second issue of concern dealt with the consideration that many of the ecosystems considered in the various analyses had undergone significant changes in structure as a result of environmental and anthropogenic stressors. Currently, ecoregion delineation analyses have been based on data layers that condensate multiple years; this makes sense because there is an expectation that these regions should be relatively stable over time. However, little change does not mean “no change”. In this context, exploring the variability of the ecoregions over time, at least in those cases where the data allow producing temporally tagged layers, could provide valuable insights, as well as reference states, to study how to incorporate these potential spatial changes in the development and implementation of ecosystem approaches to fisheries. To address the concerns raised by WGEAFM (2010), we undertook an assessment, based on the data available for the Newfoundland Shelf, to [1] determine the effects of temporal changes in the distribution, evenness and diversity, and [2] to assess the effects a few additional layers that would provide a description of the changes in species composition across this region.

To assess if changes in population abundance and ecosystem structure over time influence the potential delineation of ecoregions, we extended the analysis to include survey data prior to 1995 by combining information from Engels based (1980-1994) and Campelen based (1995-2010) surveys. Bathymetry and surface variables (temperature, phytoplankton abundance and production) kept constant but bottom temperature, biomass, diversity and richness (evenness) estimates using were based on averaging periods of 4 (Campelen) to 5 (Engels) years. The optimal number of clusters from Engels surveys variable over time, ranging from 2 during the earlier part of the series to 5 during the period of the collapse of the groundfish stocks, partly a result of changes in data extent and availability over time. The analyses did reveal that the period associated with collapse of NL ecosystem showed a high degree of spatial fragmentation in the distribution of biological variables. Although there was considerable stability in the loading of each variable in the principal components analyses, changes in association of biomass, diversity and richness relative to physical structure of environment (resulting from declines in demersal stocks) may also have led to variations in delineation of clusters for both the Engels and Campelen survey data. These results may be indicative that changes in community or ecosystem structure associated with either the collapse or recovery of stocks can be result in some degree of uncertainty and variability in the stability of ecoregion delineation (Fig. 2.1.1.1). We concluded that the delineation of ecoregions (clusters) was dependent on representativeness of data: the Campelen surveys provided more comprehensive sampling of ecosystem and therefore better representation and the limited coverage by Engels surveys affected value of these data in delineation of ecoregions. Changes in community or ecosystem status will affect ecoregion delineation process based on coarse (biomass, diversity, richness) metrics of biological variables, however, overall definition of ecoregions only modestly affected by changes in ecoregion delineation – Grand Banks and NL Shelf still appear as distinct. The significance of ecoregions to ecosystem function may be critical unknowns in identification of operational ecosystem elements (management units) but there is insufficient knowledge at this time to comment on the issue.

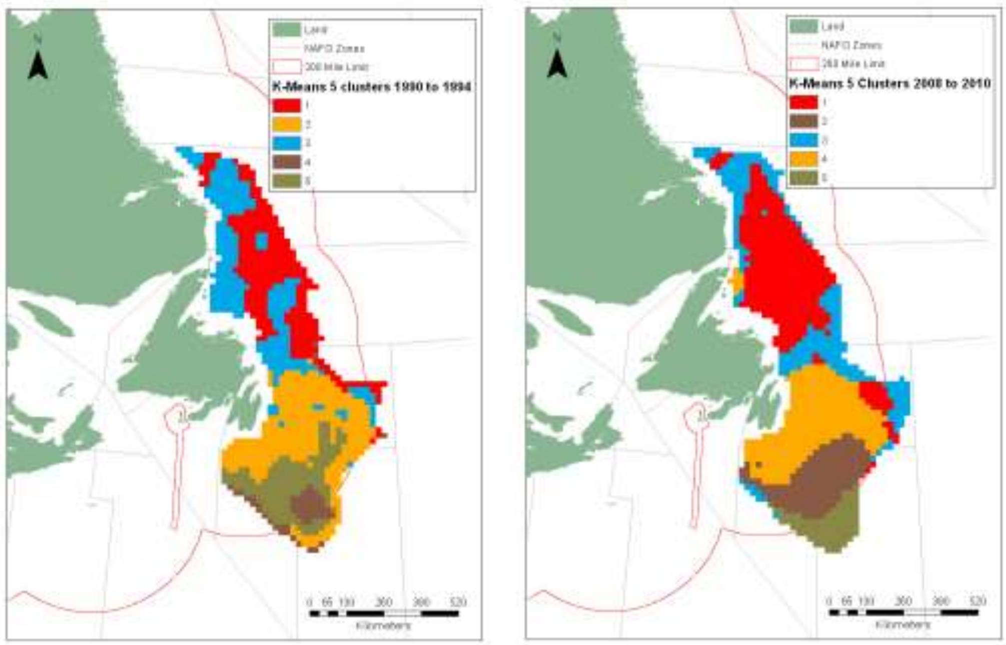


Figure 2.1.1.1. Maps of the k-means clustering results based on the first five principal components loadings for the Newfoundland Shelf based on the Engels (1990-1994) and Campelen (2008-2010) surveys.

To investigate whether the relatively simple descriptors from the trawl surveys (i.e. biomass, diversity, richness) were appropriate tools for the delineation of ecoregions when there is a significant spatial variation in community structure, we described community structure for the Engels (1980-1994) and Campelen (1995-2010) surveys based on a principal components analysis of community structure using each species biomass in each tow as a measure of abundance. Scores from first three principal components were input as additional variables to the ecoregion principal components analyses and clustering steps based on the average biological descriptors for the Engels (1980-1994) and Campelen (1995-2010) surveys, and the results were mapped. The first three principal components of the analyses of community structure explained 26 to 33% of the variation in the data. A limited number of "taxonomic" axes were added to the ecoregion in order not to overwhelm the subsequent analyses with an imbalance of information from a single source. The results indicate that community structure strongly tied to bathymetric and latitudinal gradients in the Newfoundland region. The addition of layers to represent the taxonomic diversity across the region had limited impact on the definition of ecoregions (Fig. 2.1.1.2). The greatest influence is on delineation of ecoregions, particularly in southern portion of the area, where the deep water community on southern edge of Grand Banks is different from the one east of the Newfoundland Shelf.

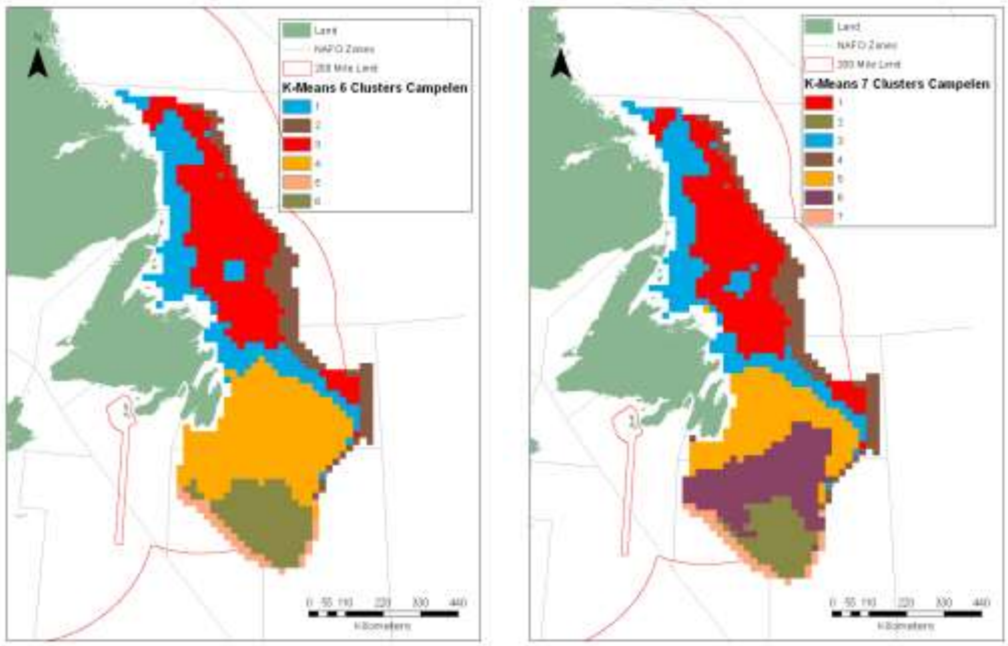


Figure 2.1.1.2. Maps of the k-means clustering results based on the first five principal components loadings for the Newfoundland Shelf based on the Engels (1980-1994) and Campelen (1995-2010) surveys in which taxonomic community structure was described based on independent multivariate analyses.

The results from both analyses reported here confirm earlier conclusions by Pepin et al. (2010) that the delineation of ecoregions on the Newfoundland Shelf appears to be robust to changes in information content of the analyses.

References

Fogarty, M.J. and Keith, C. 2009. Delineation of regional ecosystem units on the U.S. Northeast Continental Shelf. NEFSC Discussion Paper.

Halliday, R.G., and Pinhorn, A.T. 1990. The delineation of fishing areas in the Northwest Atlantic. J. North. Atl. Fish. Sci., 10: 1-51.

Pepin, P., Cuff, A., Koen-Alonso, M. and Ollerhead, N. 2010. Preliminary analysis for the delineation of marine ecoregions on the Newfoundland and Labrador Shelves. NAFO SCR Doc. 10/72, 24p.

NAFO. 2010. Report of the 3rd Meeting of the NAFO Scientific Council Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM). NAFO Science Summary Report Doc. 10/24, 75p.

Zwanenburg, K., Horsman, T., and Kenchington, E. (2010). Preliminary analysis of biogeographic units on the Scotian Shelf. NAFO Scientific Report Doc. 10/06, 30p.

2.1.2. Update on studies towards ecosystem-level management areas in the US Northeast Atlantic.

Proposed ecological production units on the Northeast U.S. Continental Shelf were developed based on an analysis of physiographic, oceanographic and biotic (lower trophic level) variables. These production units are under consideration as management units for implementation of Ecosystem-Based Fishery Management Units. The physiographic variables considered in this analysis include bathymetry and surficial sediments. The physical oceanographic and hydrographic measurements include satellite-derived estimates of sea surface temperature, annual temperature span and temperature gradients. We also employed ship-board estimates of surface and bottom temperature and salinity in spring and autumn based on Northeast Fisheries Science Center research vessel surveys. The biotic measurements considered include satellite-derived estimates of chlorophyll *a* and primary production, and chlorophyll gradients. Temperature and chlorophyll gradients are included to identify frontal zone positions. These most recent analyses do not include higher ecosystem-level metrics directly in defining ecoregions in recognition of the potentially dominant role of anthropogenic stressors, including fishing on upper trophic levels.

We employed a principal components analysis (PCA; e.g. Pielou 1984; Legendre and Legendre 1998) to examine the multivariate structure of the data and as a prelude to classification of ecological production units. We then used a K-means cluster analysis on the principal component scores to define our spatial units. The approach therefore closely parallels the methods employed for the Newfoundland Shelf (see Section 2.1.1. above). We identified seven major cluster units. The clusters represent major ecological production units on the shelf including (1) Eastern Gulf of Maine- Scotian Shelf, (2) Western-Central Gulf of Maine (3) Inshore Gulf of Maine, (4) Georges Bank-Nantucket Shoals (5) Intermediate Mid-Atlantic Bight (6) Inshore Mid-Atlantic Bight and (7) Continental Slope (Cape Hatteras to Georges Bank). These spatial units are considered to be open and interconnected, reflecting oceanographic exchange and species movement and migratory pathways.

We then consolidated some ecological subareas to reflect movement patterns of exploited species from both the shelf-break region and the immediate nearshore regions to the adjacent shelf areas. These regions are considered special zones associated with the adjacent shelf regions. We can further retain the option for special management considerations to be implemented in both nearshore and shelfbreak areas in a nested array to reflect the distribution of ecologically sensitive species, areas of high biomass and species richness, and the confluence of multiple human use patterns in nearshore regions. Following this approach, we specify four consolidated ecological zones including (1) the Western-Central Gulf of Maine, (2) the Eastern Gulf of Maine-Scotian Shelf, (3) Georges Bank-Nantucket Shoals, and (4) the Mid-Atlantic Bight (Figure 1). For the purposes of this representation, we have included estuaries and embayments with the nearshore regions but note that it may be desirable to identify these areas separately as yet another nested layer in the overall spatial structure.

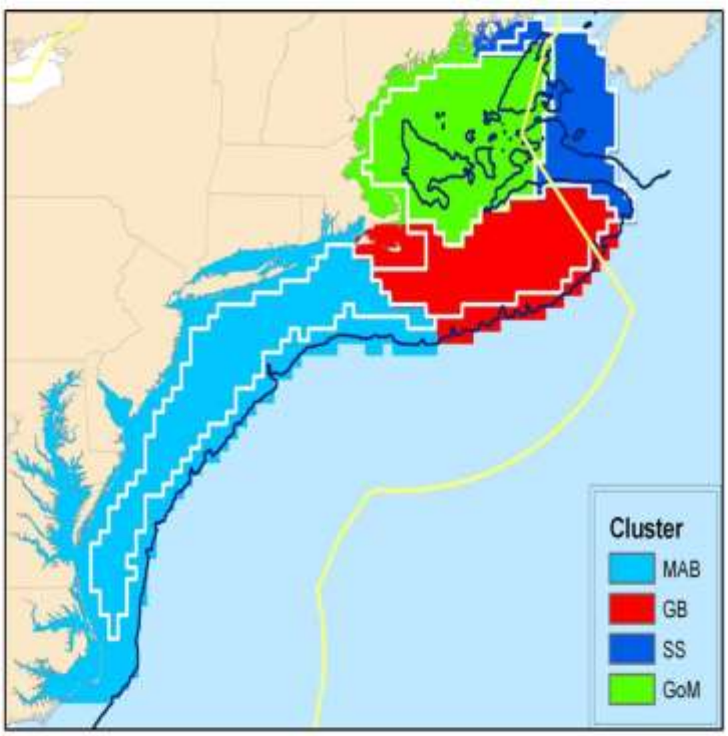


Figure 2.1.2.1. Proposed ecological subunits of the Northeast Continental Shelf including (1) Western-Central Gulf of Maine (GoM) (2) Eastern Gulf of Maine-Scotian Shelf (SS), (3) Georges Bank-Nantucket Shoals (GB) and (4) Middle-Atlantic Bight (MAB). White lines indicate boundaries between areas, including the designation of special areas at the edge of the continental shelf and in the immediate nearshore areas of the Middle-Atlantic Bight and the Gulf of Maine.

Consideration of the place of humans in fishery ecosystems and its implications for shaping spatial management units is no less important in devising effective strategies for EBFM and for gaining acceptance of this concept within fishing communities. The connection between humans and the geography of the sea has been well documented in the northeastern United States, providing important perspectives on how we might integrate the human dimension into spatial management within the general context of EBFM. To assess general concordance between our proposed ecological subregions and human use patterns (with a focus on fishing activity), we have mapped the distribution of fishing effort by vessel size, gear type, and port of origin. The observed distribution patterns reflect important social considerations on how, when, and where fishers operate as well as constraints imposed by logistical factors and management requirements. Not surprisingly, small vessels with more limited fishing ranges are often characterized by distribution patterns predominately in one of the proposed ecological units. Increasing vessel size and mobility is reflected in more spatially diverse fishing patterns and occupation of multiple ecological subunits. We find that fishing patterns also often follow major boundaries of our ecological subunits, reflecting topographical and productivity features that are often not represented by more conventional stock areas used under present management regimes.

An analysis of operational fishery units defined by species catch composition, seasonal and spatial fishing patterns, and gear type also finds strong correspondence between the proposed ecological subunits and the spatial extent of these fishing assemblages (Lucey and Fogarty 2012). The confluence between ecological structures related to productivity patterns and spatial fishing strategies does suggest the potential utility of the ecoregions defined in this study as management units for EBFM (see Figure 2.1.2.2).

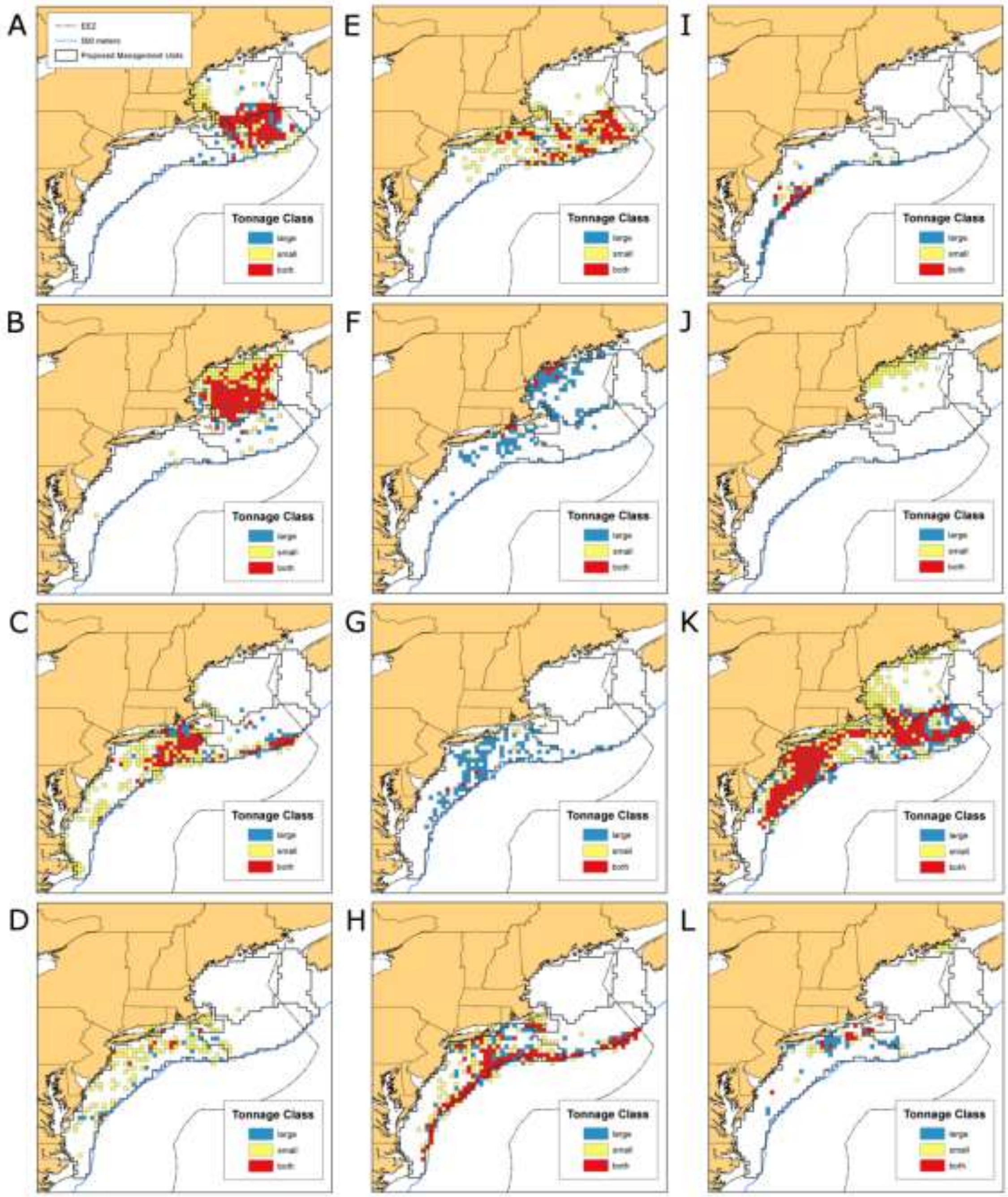


Figure 2.1.2.2. Spatial distribution patterns of distinct fleet sectors characterized by fishing location and species composition of the catch for 10 US trawl fisheries (panels A-J) and 2 US dredge fisheries (panels K-L). Ecoregion boundaries are shown in black.

References

Legendre, P., Legendre, L., 1998. Numerical Ecology: Second English Edition. Elsevier, Boston, MA.

Lucey, S. and M.J. Fogarty. 2013. Operational fisheries in New England: Linking current fishing patterns to proposed ecological production units. Fish. Res. 141 3-12

Pielou, E. 1984. The Interpretation of Ecological Data : A Primer on Classification and Ordination. J. Wiley and Sons, New York.

ToR 2.2. Preparatory work towards an integrated ecoregion analysis for the entire Northwest Atlantic.

To date, the ecoregion analyses has been carried out separately for the US-Continental Shelf (Fogarty and Keith 2009), the Canadian Scotian Shelf (Zwanenburg et al. 2010) and the Newfoundland Shelf (Pepin et al. 2010). In general terms , the approach consists of gathering data for a multitude of physiographic, oceanographic and biological variables that are clustered based on the results of a multivariate analysis, which served as a method to standardize approaches across the three jurisdictional areas. The outcome of these analyses essentially and correctly identified the major ecological regions which researchers had expected, but boundaries between those units were, in some instances, not at the same locations as existing management units. However, the differences were generally minor. The outcomes of these analyses reaffirmed that many of the major management units had been based on sound biological understanding of the key physical and ecological relationships that were reflected in the major commercial stocks. Furthermore, these structures are largely stable over time, but spatial fragmentation appears to vary during periods when ecosystems are under stress. However, concerns have been raised about how to combine and/or distinguish some of the finer scale ecological units identified in the analyses. To address this issue, a workshop, involving all the contributors to the ecoregion analysis exercises will take place in 2013/2014 to “Define objective criteria to identify biogeographic zones and the ecoregions (possible management subunits) within them” based on data from Hudson Strait to the mid-Atlantic Bight. A number of methodological issues are currently being addressed in order to combine data across regions. Coordination and compilation of information is currently being done with base at the Northwest Atlantic Fisheries Centre, DFO. The workshop has been tentatively scheduled for October 2013.

References

Fogarty, M.J. and Keith, C. 2009. Delineation of regional ecosystem units on the U.S. Northeast Continental Shelf. NEFSC Discussion Paper.

Pepin, P., Cuff, A., Koen-Alonso, M. and Ollerhead, N. 2010. Preliminary analysis for the delineation of marine ecoregions on the Newfoundland and Labrador Shelves. NAFO SCR Doc. 10/72, 24p.

Zwanenburg, K., Horsman, T., and Kenchington, E. 2010. Preliminary analysis of biogeographic units on the Scotian Shelf. NAFO Scientific Report Doc. 10/06, 30p.

ToR 3. Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area.

ToR 3.1. Report on progress on the development of Fisheries Production Potential Models for NAFO ecosystems.

The fishery production potential for a region is a function of the amount of primary production elaborated, the fraction of this production retained and available to higher trophic levels, the transfer efficiency between successive trophic levels, and the number of trophic levels through which energy must be transferred. In 2012, the WGEAFM continued its work in estimating Fishery Production Potential (FPP) for the NAFO convention area with a focus on the Newfoundland Shelf. Complementary work using the same methodology is underway in NAFO Statistical Areas 5 and 6 on the Northeast Continental Shelf of the United States. The approach taken to estimating fishery production potential is a modification of the Ryther-Ware method (Ryther 1969; Ware 2000) which traces production processes through a simplified food web.

Important regional variation in chlorophyll concentrations is evident on the eastern continental shelf of Canada with highest levels in near-coastal waters. Highest overall concentrations throughout the region are observed in the southwestern Gulf of St. Lawrence (particularly Northumberland Strait) and the upper reaches of the Bay of Fundy (Figure 3.1.1). These satellite-derived estimates of chlorophyll *a* concentrations provide the starting point for estimating primary production at the base of the food web within the region.

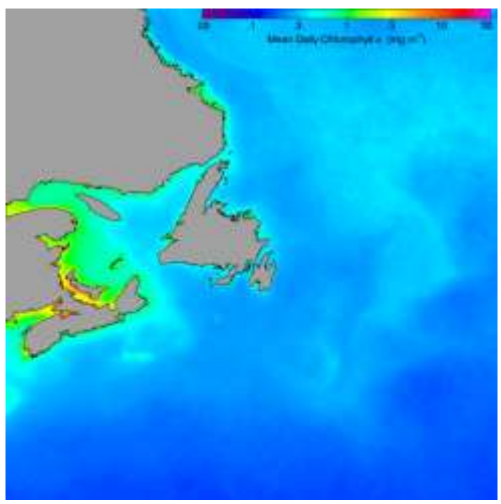


Figure 3.1.1. Satellite-derived estimates of chlorophyll *a* concentrations (mg $m^{-3}d^{-1}$) on the eastern continental shelf of Canada (annual mean for the period 1998-2011).

Estimates of phytoplankton productivity were made for using the Eppley (1972) variation of the Vertically Generalized Productivity Model (VGPM; Behrenfeld and Falkowski, 1997) and the Ocean Productivity from Absorption and Light (OPAL) model (Marra et al. 2003; 2007). The modeled estimates of primary productivity use a combination of remotely sensed satellite observations from ocean color (SeaWiFS and MODIS-Aqua) and thermal (AVHRR, MODIS-Aqua and MODIS-Terra) sensors (1997-2012). We next coupled phytoplankton taxonomic composition information (Uitz *et al*. 2009; 2010; Pan et al. 2011) with both productivity models to estimate size fractionated primary production on the Newfoundland Shelf. We grouped the phytoplankton community into two main phytoplankton categories, microplankton (>20m), and pico-nanoplankton (<20m) for further analysis (see below).

In our analysis, we recognize two pathways for transfer of primary production in the system, the classical grazing food chain tracing the fate of new primary production, principally by diatoms in the microplankton community, and production involving transfer through the microbial food web originating with pico-nanoplankton production. The former involves grazing by mesozooplankton and filtering of diatom production by benthic invertebrates, particularly bivalves. The latter pathway entails consumption of nanoplankton by heterotrophic bacteria and feeding of microzooplankton on bacteria. Carnivorous zooplankton prey on microzooplankton in this representation. The microbial pathway therefore involves two or more trophic transfer steps before reaching mesozooplankton as a bridge to higher trophic levels. We then trace the pathways of energy flow through different ecosystem components including benthivores, planktivores, and upper trophic levels and culminating in catch in each of these components (Figure 3.1.2)

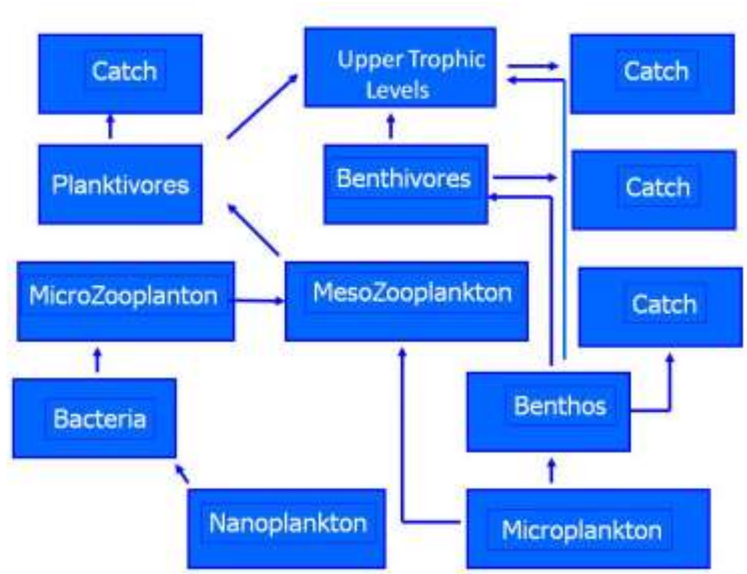


Figure 3.1.2. Energy pathways used in the Fishery Production Potential model

To trace the flow of energy though the system, we require estimates of ecological transfer efficiencies for each step. Estimates of transfer efficiencies between successive trophic levels were based on information in the literature for the microbial food web and on direct estimates from network models for North American ecosystems. For the microbial food web, we assumed that 50% of the nanoplankton is consumed by heterotrophic bacteria (Ware 2000). The gross growth efficiency of bacteria was taken to be 33% and the assimilation fraction to be 80% (Link et al. 2006). The transfer efficiency from bacteria to microzooplankton was taken to be 0.25 (Ware 2000).

For the grazing food chain, we partitioned the system into transfer from net phytoplankton to mesozooplankton and macrobenthic invertebrates and transfer from mesozooplankton to higher trophic levels. An emerging generalization is that the transfer efficiency from the first to second trophic level for this component is approximately 20% while the transfer efficiency between successive higher trophic levels is on the order of 10-15% (e.g. Lalli and Parsons 1997). We based our estimates on Ecopath results for the Labrador-Newfoundland shelf (A. Bundy, BIO personal communication). Estimates of transfer efficiencies to secondary producers (TL II) and from secondary to higher level consumers (TL II+) differed in two time periods for the Labrador-Newfoundland shelf with lower levels during 1995-2000 relative to 1985-97(A. Bundy, BIO personal communication). Comparisons with similar estimates for North American temperate and boreal marine systems are provided in Figure 3.1.3). The highest estimates of transfer efficiencies to secondary producers were for the Gulf of Alaska and for the Northeast US Shelf. The mean transfer efficiency over all systems from the first to second trophic level was 0.164 (SD=0.048) and between successive higher trophic levels it was 0.106 (SD=0.031).

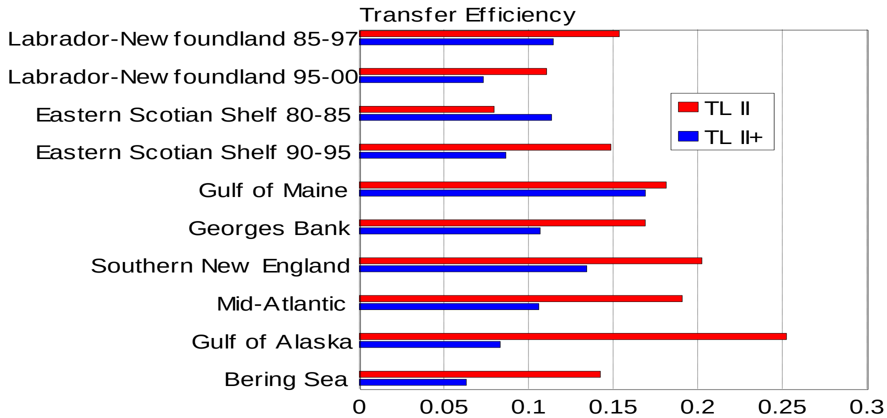


Figure 3.1.3. Estimates of transfer efficiencies to secondary producers (TL II) and from secondary to higher level consumers (TL II+) for North American ecosystems based on Ecopath model results (Fogarty et al. 2008).

To estimate the fishery production potential of the system, we need to specify the extraction of catches at different levels in the ecosystem. Extraction of catches lower in the food web leads to higher overall fishery yields (measured as biomass) because extraction at higher trophic levels entails harvesting ecosystem components in which more energy has been dissipated by passing through more trophic transfer steps. We have seen steady declines in the mean trophic level of the catch in all regions of the Canadian shelf over the last several decades (although a sharp resurgence has been seen in subregion 3M in the last decade; See Figure 3.1.4).

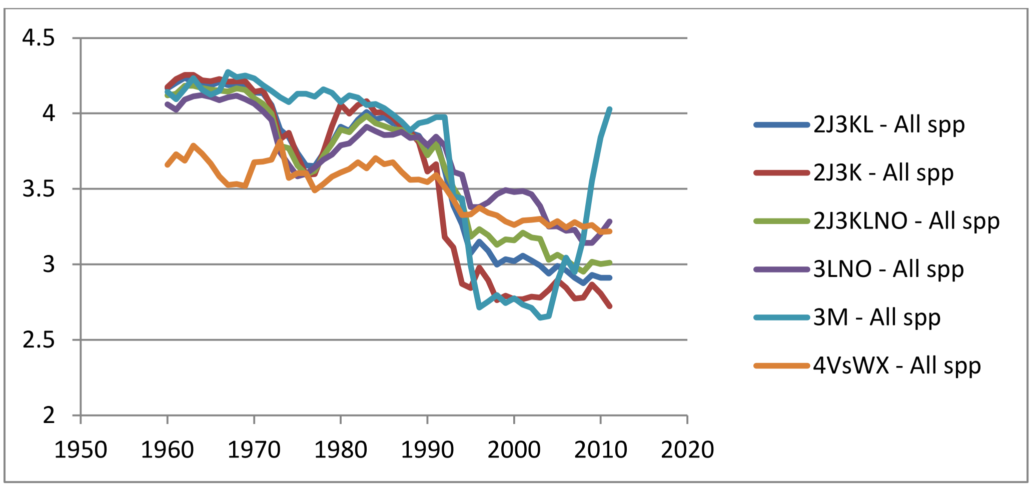


Figure 3.1.4. Change in mean trophic level of the catch in Canadian waters over the last five decades showing a trend toward harvesting lower in the food web.

To account for uncertainties, we specified probability distributions for the primary production by phytoplankton taxonomic group (based on interannual variation in chlorophyll levels); transfer efficiencies (based on literature values and the analysis of Ecopath results for system types defined by latitude and oceanographic domains described above); and trophic level of the catch (based on fractional trophic levels of species comprising the catch). These probability distributions for input variables will be used to develop probability distributions for the fishery production level. Options for a full Bayesian treatment are also being explored.

Although this research is progressing well, current point estimates for total fisheries production potential (Fig. 3.1.5) can only be considered as illustrative. A working meeting to further develops and refine these models, supported by DFO's International Governance Strategy (IGS) and NOAA, is planned for February 2013 at the Northeast Fisheries

Science Centre in Woods Hole, MA, and a complete analysis of these results is expected to be available for the next WGEAFM meeting in November 2013. The focus of this workshop would be to further refine the primary production estimates used as input in FPP models, as well as to further develop the modeling framework.

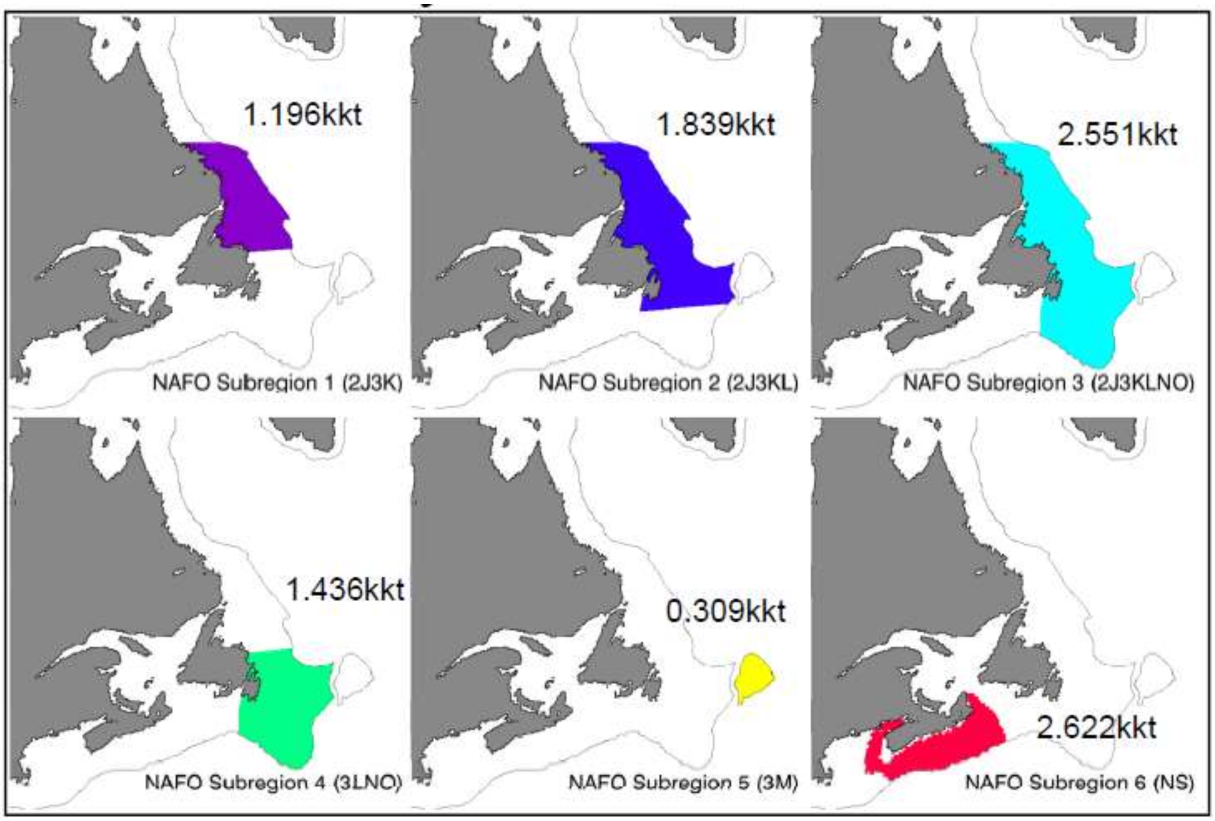


Figure 3.1.5. Preliminary total fish production potential estimates for different areas in the Northwest Atlantic. These initial estimates are only illustrative; refined estimations, including Monte-Carlo based simulation to incorporate uncertainty will be developed in February 2013. Determination of the permissible fraction of the production potential that can be extracted is necessary before translating these estimates to TACs or other management tools.

Fisheries production potential analyses are providing a conceptually different avenue from traditional fisheries surveys-based models to estimate the potential fisheries production of an area. The models currently in development are expected to provide acceptable estimates of total potential production at specific trophic levels, but a broader discussion and analysis is still required to refine the concept of what fraction of that production can be safely harvested without hindering the structure and function of the exploited ecosystems. Initial considerations suggest that the fraction of new production may be a useful upper bound for setting safe harvest limits.

References

Fogarty, M.J., W.J. Overholtz, and J. Link. 2008 Fishery production potential on the northeast continental shelf of the United States. GARM BRP Meeting WP 3.5

Lalli, C.M. and T.R. Parsons. 1997. Biological Oceanography: An Introduction. 2nd Ed. Butterworth-Heinemann, Oxford.

Link, J.S., Griswold, C.A. Methratta, E.M. & Gunnard, J. (eds). 2006. Documentation for the Energy Modeling and Analysis eXercise (EMAX). Northeast Fisheries Science Center Reference Document, 06-15. 166 pp.

Marra, J., Ho, C. and Trees, C. 2003. An alternative algorithm for calculating primary production from remote sensing data. LDEO.

Marra, J., C. C. Trees, and J. E. O'Reilly. 2007. Phytoplankton pigment absorption: A strong predictor of primary productivity in the surface ocean. Deep Sea Research Part I: Oceanographic Research Papers 54:155-163

Pan, X., A. Mannino, H. G. Marshall, K. C. Filippino, and M. R. Mulholland. 2011. Remote sensing of phytoplankton community composition along the northeast coast of the United States. Remote Sensing of Environment 115:3731-3747.

Ryther, J. 1969. Photosynthesis and fish production from the sea. Science 166:72-76.

Uitz, J., H. Claustre, B. Gentili, and D. Stramski. 2010. Phytoplankton class-specific primary production in the world's oceans: Seasonal and interannual variability from satellite observations. Global Biogeochemical Cycles 24:GB3016.

Uitz, J., H. Claustre, F. B. Griffiths, J. Ras, N. Garcia, and V. Sandroni. 2009. A phytoplankton class-specific primary production model applied to the Kerguelen Islands region (Southern Ocean). Deep Sea Research Part I: Oceanographic Research Papers 56:541-56

Ware, D.M. 2000. Aquatic ecosystems: properties and models. In P.J.Harrison and T.R. Parsons (Eds). Fisheries Oceanography: An Integrative Approach to Fisherues and Ecology and Management. Blackwell Sci., Oxford.

ToR 3.2. [FC Request # 18 – item b)].

Report progress on the studies between cod, redfish and shrimp in the Flemish Cap through multispecies models and by quantifying potential yield and biomass tradeoffs with different fishing mortalities in the multispecies context; the predation of cod over cod juveniles should be taken into account.

3.2.1. Estimation of redfish and cod consumption in the period 1993-2010.

A preliminary attempt to estimate the redfish and shrimp consumption by cod, and the shrimp consumption by redfish was done using a bioenergetic approach developed by Temming and Herrmann (2009).

Fish growth (considered as variation in weight) is dependent on two antagonistic processes, anabolism and catabolism.

$$\frac{dW}{dt} = Anabolism - Catabolism = EW_t^m - kW_t^n \qquad (1)$$

Where *W* is weight, *t* is time, and *E* and *k* are the constants representing the numerical strengths of the anabolic and catabolic processes, *n* is the catabolic exponent (n=1), and *m* is the allometric coefficient of consumption with fish weight. In previous experimental studies with cod and whiting it was determined that m=0.8.

Hence, from the whole amount of food ingested by a fish, there is a part that will be allocated to catabolism; it is called the maintenance ration while the remaining portion will be invested in fish growth (Figure 3.2.2.1). If fish consumption is below the maintenance ration, fish weight will decrease. On the contrary, when food intake is higher than the maintenance ration fish starts to grow (increases fish weight) in a proportional way to consumption. This proportionality is defined by the *K3* parameter, which is the slope of the Growth-Food intake relationship.

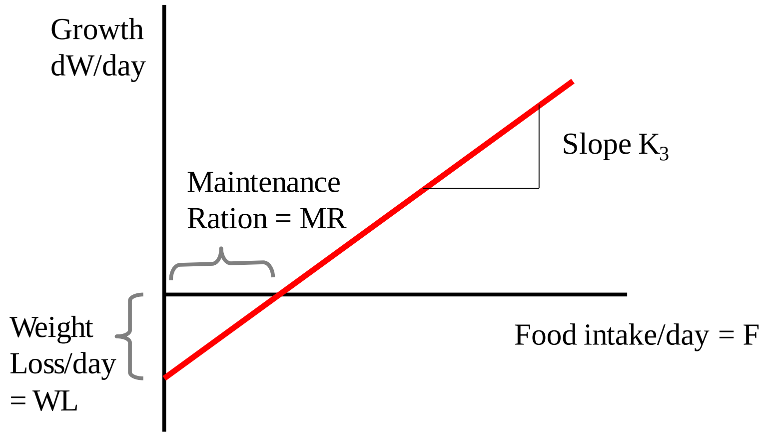


Figure 3.2.1.1. Important concepts of the conceptual framework of bioenergetic models (Adapted from Temming & Herrmann, 2009). The relationship between food intake and growth (slope *K3*) is assumed to be linear.

From Figure 3.2.2.1:

$$\frac{dW}{dt} = (K_3 \times F) - WL \tag{2}$$

From equations 1 and 2:

$$E \times W_t^m = K_3 \times F \tag{3}$$

$$F = \frac{1}{K_3} \times E \times W_t^m \tag{4}$$

The constant that determine the strength of metabolism may be defined by means of the parameters from the generalized von Bertalanffy growth function (*GBGF*), W_∞ and K:

$$E = 3 \times K \times W_\infty^{1-m} \tag{5}$$

Hence, from equation 4 and 5, fish consumption may be defined by means of:

$$F = \frac{1}{K_3} \times 3 \times K \times W_\infty^{1-m} \times W_t^m \tag{6}$$

3.2.1.1. Cod consumption

In the present preliminary study, in the absence of an alternative *m* value, the value *m*=0.8, utilized by Temming and Herrmann (2009), was assumed for the Flemish Cap cod. From growth feeding studies, *K3* spans between 0.55 (when good food) and 0.35 (bad food), with 0.45 for an intermediate value. *K* and *W∞* where obtained by fitting the *GBGF* to each cohort age-weight relationship:

$$W_t = W_\infty \left[\left(1 - e^{\left(\left(\frac{3D}{-b} \right) \times K \times (t - t_0) \right)} \right)^{\frac{b}{D}} \right] \quad (7)$$

where b=3 and $D = b \times (1 - m) = 3 \times 0.2 = 0.6$.

Due to the relatively reduced range of ages available for each cohort (usually contained in the range between 2 and 8 years old) in comparison to the actual range in cod lifespan, when the *GBGF* was fitted by cohort group the values obtained for *t0* and *W∞* were extremely variable and were out of the ranges acceptable based in the biological knowledge for these species. As a compromise solution, fixed values were assigned to *t0* and *W∞* based on the biological knowledge: *t0*=0 and *W∞*=14,000g, i.e. we assume that when weight is 0 age is also 0, and that the maximum weight is 14 kg. Hence, finally the only parameter to be estimated in both the equations 6 and 7 was *K* from the *GBGF*, i.e. the growth rate.

With equation 6, the total amount of food necessary across the whole year for an individual of age *a* getting the weight W_t given the growth curve defined by equation 7 was estimated. Next, the mean weight at age, as well as the abundance at age (González-Troncoso et al. 2012), were employed for the estimation of the annual total consumption by the entire Flemish Cap cod stock. Due to the high degree of similarity between both time series (Figure 3.2.1.2), it may be suggested that that total consumption has been mainly determined by the size of the stock (Pearson=0.98, *p-value*<0.001). These preliminary results suggest that total annual food consumption by cod has been around three times the estimated total cod stock biomass.

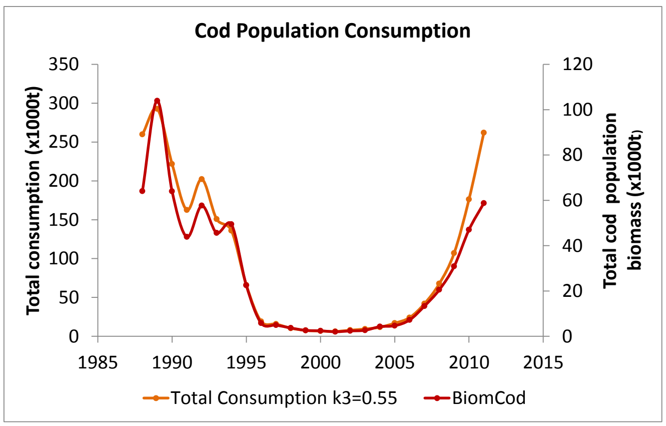


Figure 3.2.1.2. Total annual food consumption and total population biomass estimates. The intermediate food quality value (K_3=0.55 was employed).

In order to split the total consumption among the different prey species, the stomach content information for the Flemish Cap cod, available since 1993 to 2008, was employed. Since no feeding habits information was available for 2007, 2009 and 2011, the diet composition for these years was assumed as the average from previous and next years (2006, 2008, 2010 and 2012 were employed for this purpose). Next, the percentage of each prey over the total volume of stomach content analyzed was estimated for each 5 cm size class.

3.2.1.1.1. Redfish consumption by cod

The individual redfish consumption by cod between 40 and 75 cm showed a similar pattern than beaked redfish biomass estimated with XSA (Ávila de Melo et al. 2011), as showed in figure 3.2.2.3. However, in the early 2000s the increase in the consumption by individual was higher than the increase in redfish biomass.

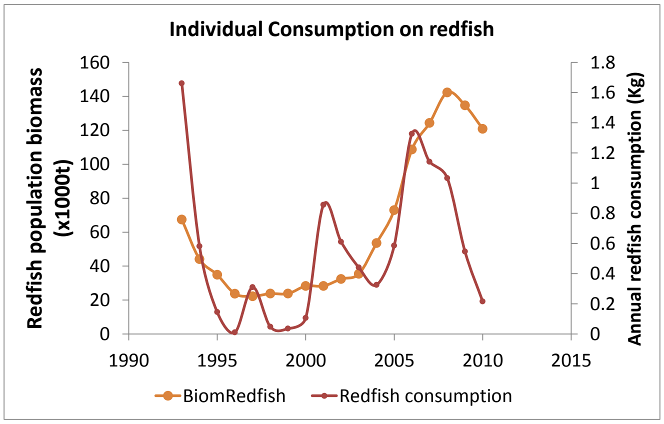


Figure 3.2.1.3. Total beaked refish biomass (Ávila de Melo et al, 2011) is shown in conjunction with the average consumption for an individual cod in the range 40-75 cm.

Total redfish consumption increased drastically since 2006, and in 2008 beaked redfish XSA biomass showed a marked decline (Figure 3.2.2.4).

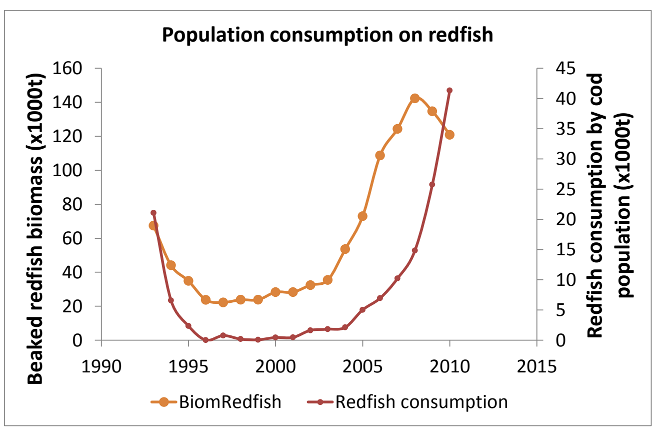


Figure 3.2.1.4. Estimated total beaked redfish biomass, and estimated annual redfish biomass consumed by the cod stock in the Flemish Cap.

However, interannual biomass changes are expected to occur as response not only to mortality and recruitment processes, but growth is also expected to have an important influence. To consider the potential influence of this factor, the number of redfish consumed by cod was also estimated. Previous analyses suggested that there is a positive relationship between cod and redfish size (Lilly 1983, Casas and Paz 1994). Casas and Paz (1994) found that redfish consumed by cod sized in average the 22.3% of cod size, while Lilly (1983) estimated that this proportion was higher, and the maximum size of preyed redfish was the 35% of cod size. With this information and the fact that redfish in important in the diet of the Flemish Cap cod from size 80 cm (Pérez-Rodríguez et al, 2011a), it could be considered that in average, redfish individuals consumed by the whole cod stock are in average 25 cm size. On average, a 25cm redfish individuals weighs 240g (estimated using the average size-weight relationship for redfish species; Weight=0.018Length$^{2.95}$, p-value<0.001). Using this average redfish weight, the total number of juvenile redfish individuals consumed by cod was estimated from the total redfish biomass consumed. The estimated numbers of redfish consumed per year were compared with the estimated annual changes in redfish abundance. These changes in abundance were approximated by the difference in XSA numbers between the year *t* and *t-1* (X_t-X_{t-1}) (Figure 3.2.1.5). These two series showed a negative correlation (Pearson=-0.45), as it would be expected if predation by cod was affecting the level of redfish abundance. However, it is more interesting to note that the negative changes in redfish abundance (i.e. loses) are observed in years when the cod stock was at high abundance level (i.e. before the 1995 collapse, and after 2006). If only those years of high cod abundance are considered, the correlation between cod consumption and redfish abundance loses becomes -0.59.

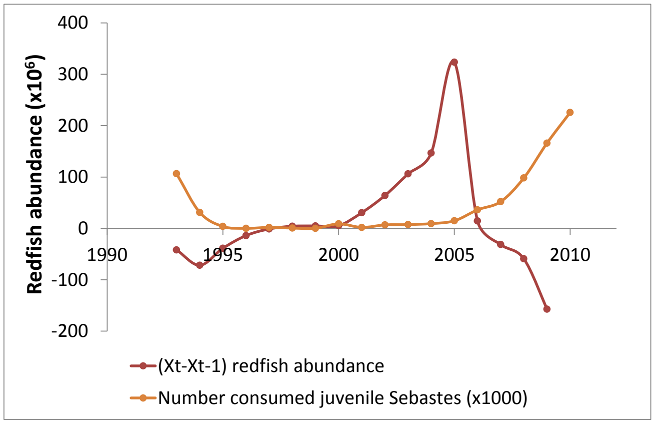


Figure 3.2.1.5. Total number of redfish consumed by cod, and the difference between consecutive years in redfish XSA abundance (X_t-X_{t-1}) in the Flemish Cap.

This observation may suggest that cod has a direct and negative impact on the dynamics of the redfish stocks when cod is present at high densities. However, when cod is at low densities, the expected positive effect (i.e. predation release) of a low predator density on the redfish stock is not as clear (e.g. Figure 3.2.1.6). It seems that the absence of predation only means the absence of a negative effect, but not necessarily a clearly positive one. Significant increases in the redfish stock would need of other drivers, like proper oceanographic and secondary production conditions for successful recruitment events, and not just a reduction in predation.

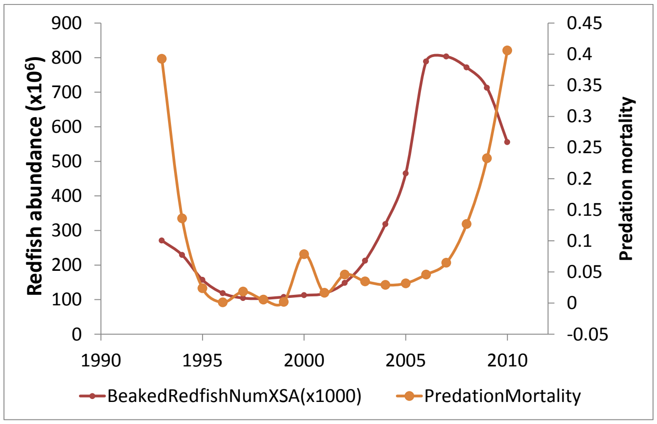


Figure 3.2.1.6. XSA estimated abundance of beaked redfish (Ávila de Melo et al, 2011), and estimated predation mortality produced by the cod (as ratio: Consumed redfish/Total beaked redfish abundance).

It is important to note that the XSA-based numbers used for these preliminary analyses include only beaked redfish (*Sebastes mentella* and *S. fasciatus*; Ávila de Melo, pers.comm.), while the estimates of redfish consumption by cod include all three *Sebastes* species (*S. mentella*, *S. fasciatu*s and *S. marinus*). Hence some differences may arise if *S. marinus* would be also considered in the XSA exercise. However, since indices of biomass from EU surveys for *S. marinus* and *S. fasciatus* have been very similar over the study period considered, it can be expected that the overall patterns and relationships described here would remain valid. However, this difference would influence downwards the illustrative predation mortality estimates depicted in Figure 3.2.1.6.

3.2.1.1.2. Shrimp consumption by cod

The average shrimp (*Pandalus borealis*) consumption by an individual cod showed high similarities with the index of biomass of shrimp form the EU July survey (Figure 3.2.1.7.). The decline in total shrimp biomass since 2005 was followed by the decrease in consumption by cod. However, the maximum values of shrimp biomass were not coincident with the maximum consumption by cod. These results would suggest that the consumption of shrimp by cod has been importantly driven by the biomass of this prey, although other factors not considered here, like cod population structure or spatial overlap are probably behind the mismatch between both variables as suggested in relation to variability in the diet of Flemish Cap cod across the period 1993-2008 (Pérez-Rodríguez et al, 2011).

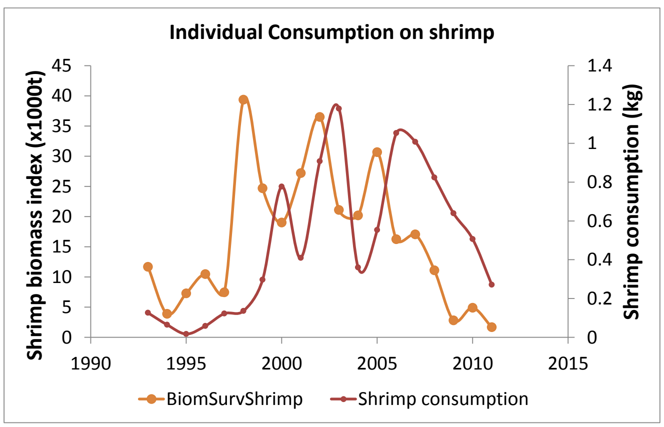


Figure 3.2.1.7. Total shrimp biomass Index (Casas-Sánchez 2012) is shown in conjunction with the average consumption for an individual cod in the range 40-75 cm.

Total shrimp consumption by the Flemish Cap cod population showed a similar pattern than the total consumption and total cod biomass showed in figure 3.2.1.2., which would suggest that cod population biomass was one of the main reasons for the decline of consumption on shrimp from 1993 to 1995 and the increment since 2005. However, in addition to the growth of cod population biomass, diet composition of cod was focused mainly on shrimp since 2005 (Pérez-Rodríguez et al. 2011), and this is another important reason for the increase in consumption of shrimp by cod since this year. The importance of shrimp in the diet of cod was so high than most of total population consumption since 2005 to 2009 was due to consumption on shrimp (figures 3.2.1.2 and 3.2.1.2).

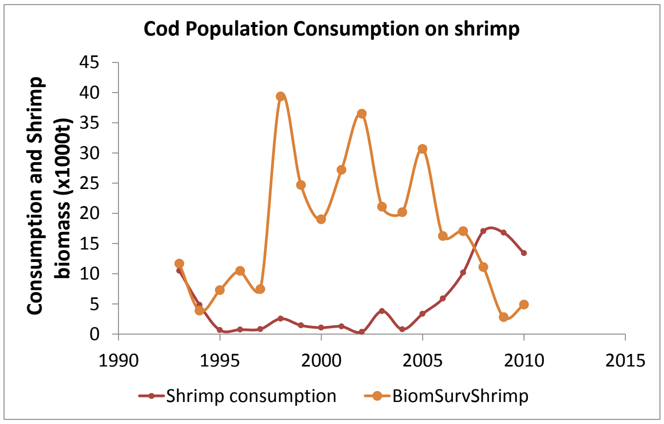


Figure 3.2.1.8.- Estimated total shrimp biomass index and total shrimp biomass consumed annually by the cod stock in the Flemish Cap.

3.2.1.2. Redfish consumption

No previous studies have been conducted with Redfish species of genus *Sebastes* that permit the estimation of the allometric coefficient of anabolism *m*. For this reason, the *m* value from the standard von Bertalanffy growth function has been employed for this predator, *m*=2/3 (Temming and Herrmann, 2009). The W∞ considered was 2200 gr. and K_3=0.55. Estimations have been developed using the abundance data for beaked redfish (*Sebastes mentella* and *S.fasciatus*; Ávila de Melo et al, 2011).

The total food consumption by redfish showed a similar pattern than the total beaked redfish biomass (Figure 3.2.1.9), suggesting that major changes in population consumption were due to variations in total biomass. Consumption/biomass ratio was 0.85 in average, although this value was higher than 1 since 2003, and decreased again after 2008. When an allometric coefficient of anabolism *m*=0.8 was introduced in the model, as used for cod, this ratio increased to values over 1.3, with a maximum value of 1.95 in 2008. This difference highlights the importance of increasing the knowledge about metabolism for the most important species in the Flemish Cap in order of developing more precise estimates of food consumption. In any case, food consumption by cod (average ratio=3.3) was always higher than in redfish due probably to the higher relative annual growth rate at age observed for cod until age 9 (Figure 3.2.1.10).

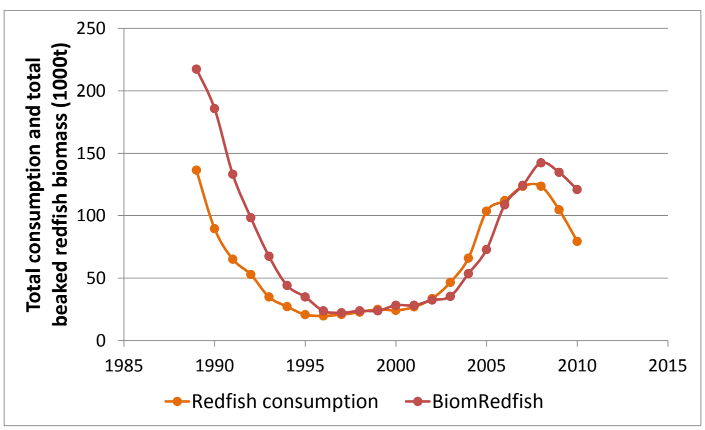


Figure 3.2.1.9. Total beaked redfish (*S. mentella* and *S.fasciatus*) biomass in the Flemish Cap (Ávila de Melo et al, 2011) and total redfish consumption in the period 1998-2010.

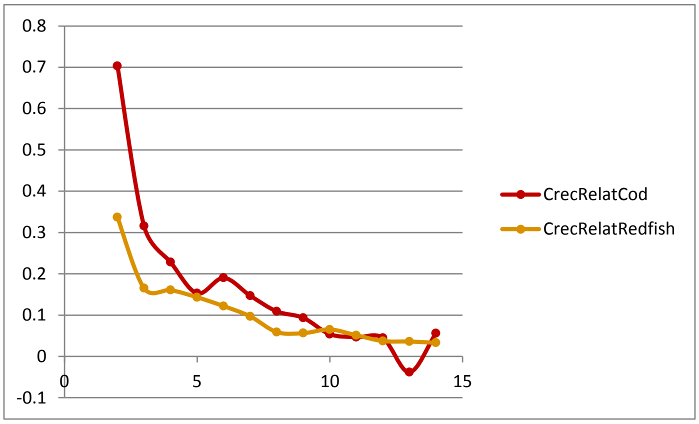


Figure 3.2.1.10. Average index of relative growth rate at age for beaked redfish and cod until age 15.

Consumption of shrimp by an average redfish individual showed important similarities with the EU index of total shrimp biomass (Figure 3.2.1.11), with the highest values in the period of maximum biomass for the Flemish Cap shrimp stock. However, as observed for cod, there remarkable mismatches, specialty during the late 1990's.

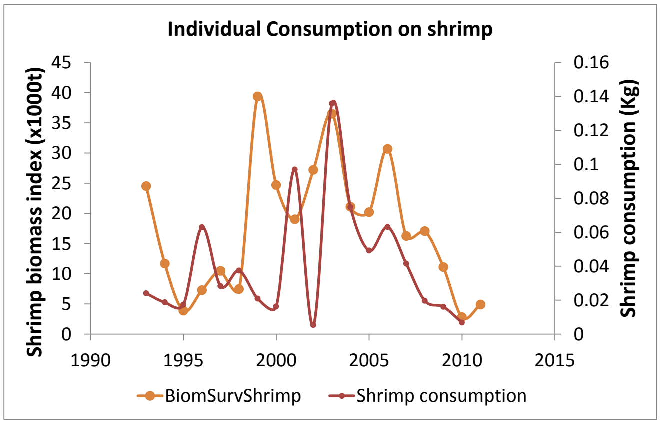


Figure 3.2.1.11. Total shrimp biomass Index (Casas, 2012) is shown in conjunction with the average consumption for an individual beaked redfish in the range 7-47 cm.

Total shrimp consumption exhibited a growing pattern since early 2000's (Figure 3.2.1.12), probably as result of the increased redfish population since 2003 and the increment of shrimp in the diet of large redfishes (especially since age 10). Since 2008, the decline of shrimp population was followed by the decrease in the consumption of this prey by the beaked redfish stock.

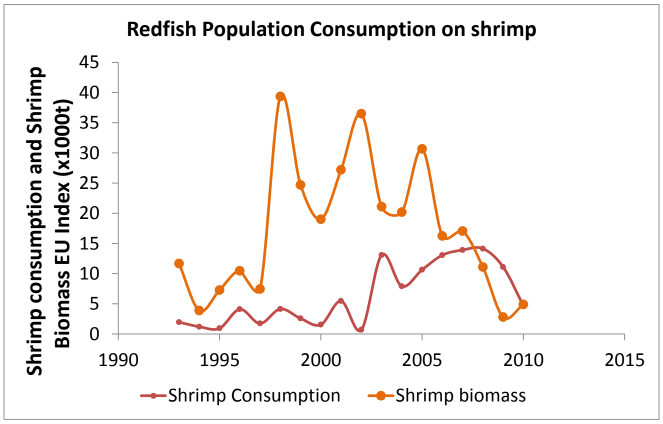


Figure 3.2.1.12.- Estimated total shrimp biomass index and total shrimp biomass consumed annually by the cod stock in the Flemish Cap.

3.2.1.3. Shrimp consumption by beaked redfish and cod

The total shrimp consumption by redfish and cod experienced a marked increase since 2003, coincident with the raise of redfish biomass, and a further augmentation since 2006, when the cod biomass increased and the redfish still stayed at high levels (Figure 3.1.2.13). As argued above, changes in total stock biomass and growth rates (especially in cod), in conjunction with the increase of shrimp in the diet of these predators, were probably the most important reasons for the increased consumption on shrimp since 2003. The rise in consumption by both redfish and cod was accompanied of a decline in the index of total shrimp biomass obtained from the July EU survey.

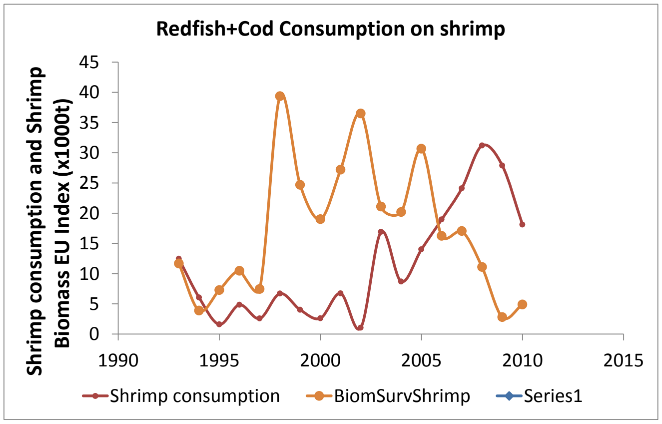


Figure 3.2.1.13- Estimated total shrimp biomass index from the July EU surveys (Casas and González Troncoso 2011) and total shrimp biomass consumed annually by the cod and beaked redfish stocks in the Flemish Cap.

Total shrimp consumption by cod and redfish showed values that were over the total shrimp biomass since 2006. This could be due to an overestimation of shrimp consumption by these predators. The introduction of variability in the diet across the seasons as well as variability between years in the value of parameters of bioenergetics models could contribute to the improvement of the estimations. Another interpretation to this difference in shrimp biomass and total consumption since 2006 and especially 2008, could be the consumption of most part of total productivity of shrimp stocks by cod and redfish, which would keep the shrimp stock at low levels despite a high annual productivity.

3.2.1.4. Canibalism in cod stock

The decline of the main cod preys, shrimp and redfish (since 2005 and 2008 respectively), in conjunction with the increase of cod stock biomass and larger individuals with more piscivorous feeding habits could increase cannibalism rates. This is especially plausible when good recruitment events contemporarily occur.

Estimations of total cod cannibalism corroborated these expectations, with the appearance and magnitude of cannibalism being coincident with the abundance of juvenile cod individuals (Figure 3.1.2.14). The increase on abundance of larger cod and the higher importance of cod in the diet since 2006 also contributed to higher values of total cannibalism. Total cannibalism was higher than 25000 tons in 2011. Total cod biomass in the Flemish Cap was estimated as 58766 tons (50% quantile, González-Troncoso et al. 2012). Consequently cod cannibalism could imply a drastic decline in cod stock biomass for the coming years.

It is important to highlight that estimations of consumption in 2011 have been made by assuming that in this year cod diet was the average between years 2010 and 2012. Annual analysis of diet composition, at least for the most important predator species in the Flemish Cap, could avoid the noise introduced by unregistered drastic interannual changes in diet composition.

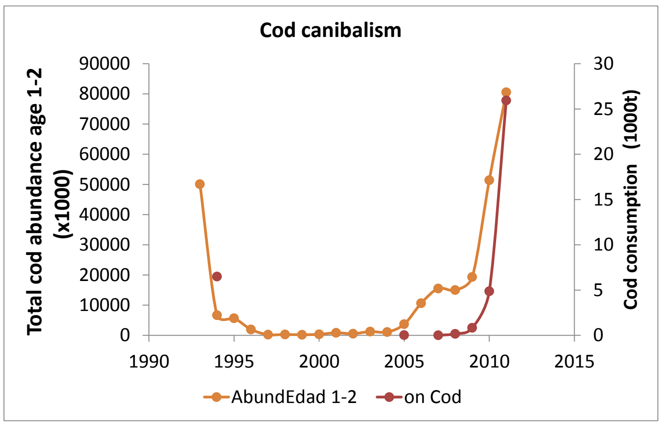


Figure 3.2.1.14. Estimated total cod abundance at ages 1-2 and cod cannibalism since 1993 to 2011.

3.2.1.5. Consumption on other prey by cod and redfish

Patterns of consumption on other fish species showed important similarities with cod stock indexes of biomass (Figure 3.2.1.15). Consumption on alternative fish prey species as Myctophidae and especially Barracudina species showed a marked increment after 2010, coincident with the decline of beaked redfish.

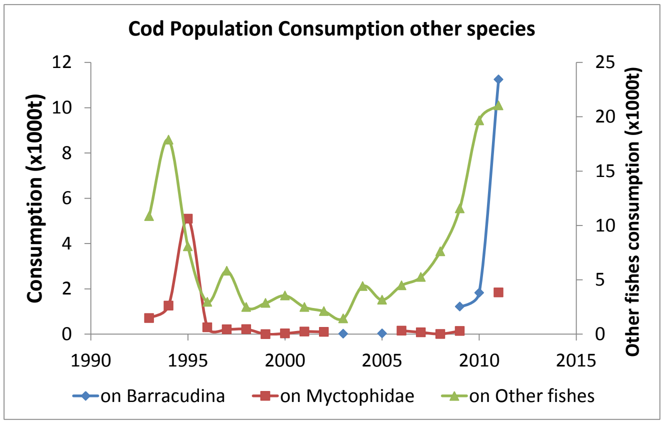


Figure 3.2.1.15. Estimated total biomass of Barracudina, Myctophiids and other fishes consumed annually by the cod stock in the Flemish Cap.

Consumption on Hyperiidea by cod showed also high similarities with patterns in total cod biomass (Figure 3.2.1.16). It is important to highlight the extreme importance of the hyperiids stocks biomass levels for cod. During 1993 and 1994, estimated total consumption was close to 100000 tons. On the other side, effect of cod predation may be influential on the dynamic of hyperiids stocks. This should be taken into account into future studies on fisheries potential production.

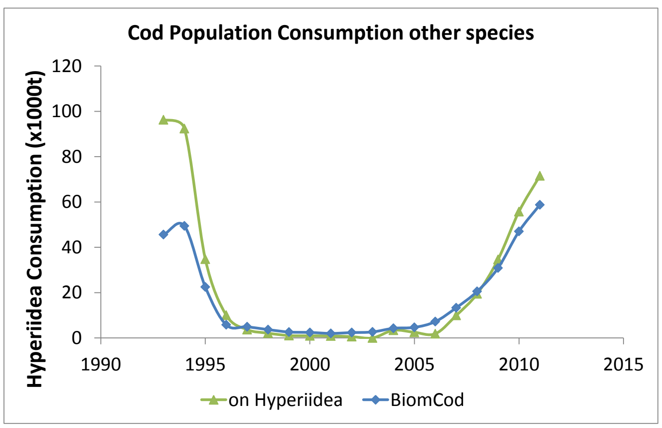


Figure 3.2.1.16. Total cod biomass (González-Troncoso et al, 2012) and estimated biomass of hyperiids consumed annually by the cod stock in the Flemish Cap.

In the case of beaked redfish, copepods are the main prey especially at juvenile stages. Consumption on these crustaceans increased from an average 6000 tons in the period 1993-2003 to 40000 tons in from 2004 to 2009. The sudden increase of redfish biomass in conjunction with the decline of shrimp could have triggered the consumption on copepods.

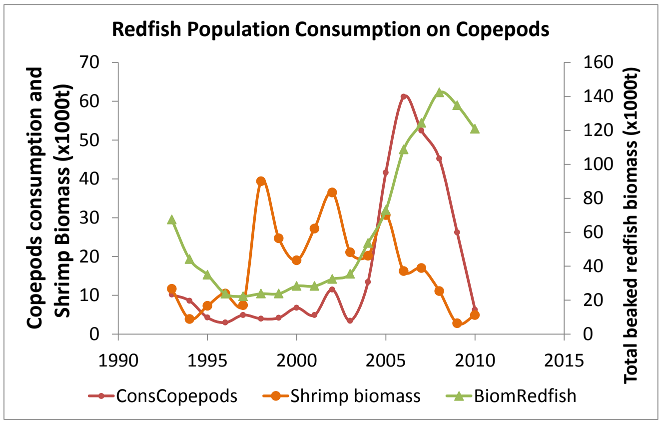


Figure 3.2.1.17. Total redfish biomass (Ávila de Melo et al, 2011), EU biomass index for shrimp and estimated biomass of copepods consumed annually by the beaked redfish in the Flemish Cap.

3.2.1.6. Other estimations of cod consumption

Other estimates based in the daily ration (González-Iglesias and Casas 2012a, González-Iglesias et al. 2012b) on shrimp and redfish consumption by cod showed similar patterns across years, however net values differed importantly in the case of shrimp (Figure 3.2.1.18).

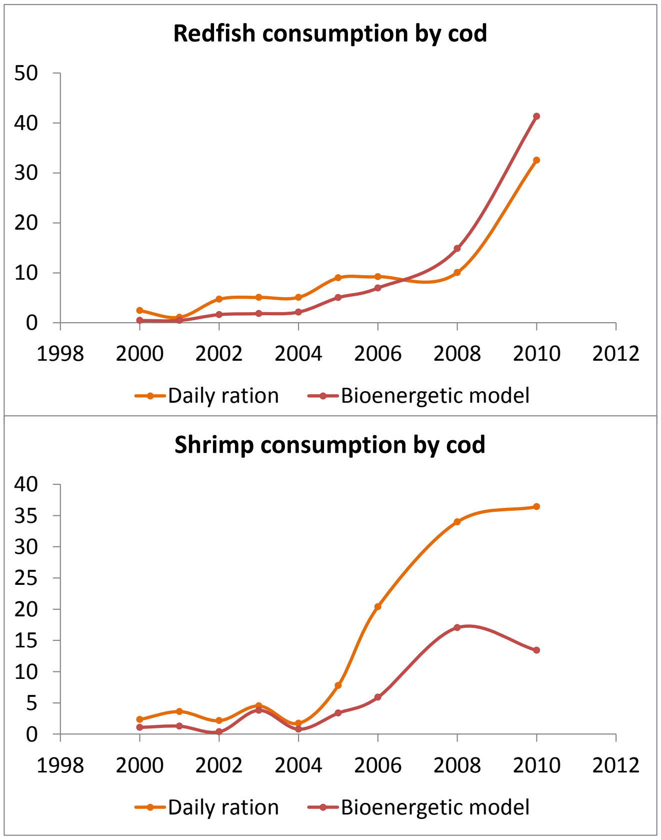


Figure 3.2.1.18. Estimates of total redfish and shrimp consumption by the Flemish Cap cod stock using the daily ration (González Iglesias et al, 2012) and the generic bioenergetics model across the period 2000 and 2010.

A deeper comparison and study on the pros and cons of both methodologies, as well as the refinement of some parameters and processes in both estimations, like the consideration of inter-seasonal variability in the diet or the variability in age at maturation over time will be necessary in the future in order of producing more accurate estimations of consumption by cod and other main predators in the Flemish Cap and the Northwest Atlantic ecosystems.

References

Ávila de Melo, A., F. Saborido-Rey, D. González Troncoso, M. Pochtar, and R. Alpoim. 2011. An assessment of beaked redfish (S. mentella and S. fasciatus) in NAFO division 3M (with an approach to the likely impact of recent 3m cod growth on redfish natural mortality). . NAFO SCR Doc 11/26.

Casas-Sánchez, J. M. 2012. Division 3M Northern shrimp (Pandalus borealis) – Interim Monitoring Update. NAFO SCR Doc. 12/42.

Casas, J. M. and D. González Troncoso. 2011. Results from bottom trawl survey on Flemish Cap on June-July 2011. NAFO SCR Doc. 11/21.

Casas, J. M. and J. Paz. 1994. Diet of Flemish Cap Cod with Particular Reference to Predation on Redfish: 1988-1993. NAFO SCR Doc. 94/24.

González-Iglesias, C. and J. M. Casas. 2012a. Atlantic Cod Predation on Northern shrimp in Flemish Cap. NAFO SCR Doc.12/55.

González-Iglesias, C., F. González-Costas, and D. González-Troncoso. 2012b. Antlantic cod predation on redfish in Flemish Cap. NAFO SCR Doc. 12/27.

González-Troncoso, D., C. Hvingel, A. Vázquez, and F. Saborido. 2012. Assessment of the cod stock in NAFO division 3M. NAFO SCR Doc 12/37.

Lilly, G. 1983. The food of cod on Flemish Cap in winter 1983. NAFO SCR 83/VI/65.

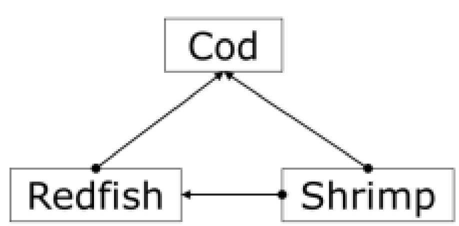
Pérez-Rodríguez, A., M. Koen-Alonso, C. González-Iglesias, and F. Saborido-Rey. 2011. Analysis of common trends in feeding habits of the main fish demersal species of Flemish Cap. NAFO SCR Doc 11/077.

Temming, A. and J. P. Herrmann. 2009. A generic model to estimate food consumption: linking von Bertalanffy's growth model with Beverton and Holt's and Ivlev's concepts of net conversion efficiency. Can. J. Fish. Aquat. Sci. **66**:683-700.

ToR 3.2.2. Flemish Cap multispecies model

3.2.2.1. Background

WGEAFM has been working on the development of a simple 3-species model for the Flemish Cap system to explore the joint dynamics of key species in this ecosystem. The species included in the model are Atlantic cod *Gadus morhua*, redfish *Sebates* spp., and shrimp *Pandalus* spp. The basic trophic interactions represented in the model are:



where both cod and redfish consume shrimp, and cod also consumes redfish. This simple food web is modeled using a discrete generalized Lotka-Volterra structure of the form:

$$B_{i,t+1} = B_{i,t} + r_i B_{i,t}\left(1 - \frac{B_{i,t} + \sum_J \alpha_{ij} B_{j,t}}{K_i}\right) - C_{i,t}$$

where *B* represents the stock biomass, *r* the intrinsic growth rate, *K* the carrying capacity, *C* the fisheries catches, and α is the interaction coefficient between the focal species *i* and other species *j*. The subindex *t* indicates the time step (year).

By considering the following production equation,

$$P_{i,t} = B_{i,t+1} - B_{i,t} + C_{i,t}$$

where *P* represents the annual production, and the other terms the same as above, the discrete generalized Lotka-Volterra formulation can be linearized as:

$$P_{i,t} = r_i B_{i,t} - \frac{r_i}{K_i} B_{i,t}^2 - \sum_J \frac{r_i}{K_i} \alpha_{ij} B_{i,t} B_{j,t}$$

The above linearized equation can be solved using standard multiple regression techniques by considering an observation equation of the form:

$$I_i = q_i B_i$$

where *q* is the catchability coefficient, and *I* is the observed index (e.g. survey biomass) corresponding to the actual stock biomass *B*, and assuming that *q*=1. This solution also assumes a process error only structure.

This model structure and solution, was used in 2011 to provide an initial analysis of model behavior, and to provide qualitative advice in terms of trade-offs among fisheries (NAFO, 2011). In that initial analysis, the model was fit to the data considering the conversion coefficients for the change in research vessel in the Flemish Cap developed by Pérez-Rodriguez and Koen-Alonso (2010).

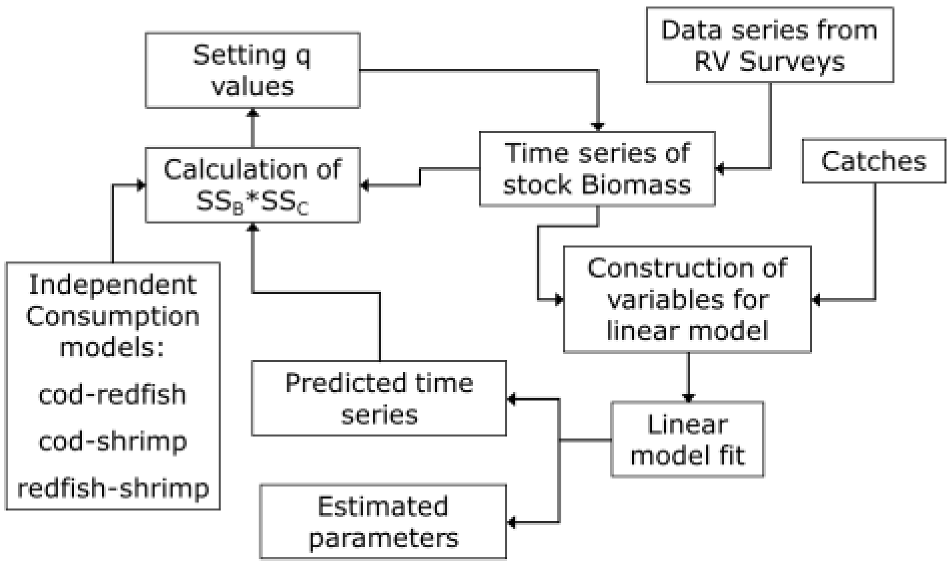
Although the initial analysis provided useful insights, there were several issues associated with model structure, assumptions, and data that needed to be further investigated before results from this exercise can be considered reliable enough to inform the process of developing quantitative tactical advice for the stocks included in the model.

3.2.2.2. Issues explored in the current analysis

In this second iteration of model development, the issues explored in the current analysis were:

a) The assumption of *q*=1
b) The conversion factors for the data due to changes in research vessel

These issues were explored through the implementation of a mixed approach to parameter estimation. This approach effectively involved a nonlinear estimation of the catchability coefficients, and a linear estimation of the remaining parameters. The nonlinear estimation of the *q*s was based on the minimization of the sum of squares between observed and predicted biomasses (SS_B) and independently estimated food consumptions by cod and redfish (see section 3.2.1), and the consumptions predicted by the multispecies model (SS_c). These two steps were ran iteratively until a solution for the nonlinear component was found. Schematically, the estimation procedure can be depicted as:



This estimation structure allows exploring multiple alternative scenarios, ranging from fixing some *q*s and estimating others, considering only SS_B in the nonlinear component of the estimation, or estimating model parameters with different conversion factors due to research vessel changes.

a) Considerations for *q*-related analyses

From the three species considered in the model, only cod and redfish actually have analytical assessment models available for the estimation of *q*. For these species, besides estimating *q*s from the model, it is possible to approximate a generic *q* by simply dividing the survey indices by the corresponding estimated biomass from the assessment model. We did this for as many years as possible, and the median *q*s were $q_{cod} = 1.195$ and $q_{redfish} = 2.00$. Due to the way the model was programmed, the actual parameters being used are the inverse of *q* (i.e. $\frac{1}{q_{cod}} = 0.83$, and $\frac{1}{q_{redfish}} = 0.5$). These 1/*q* values can be used to fix *q*s in the model or to compare estimated values for these *q*s.

b) Considerations for the conversion factors due to change in research vessel

The EU survey in the Flemish Cap changed research vessels in the early 2000s. Although several studies were carried out to develop conversion factors for some key commercial species like cod, redfish and shrimp, there were no conversion analysis for most species until recently (Pérez-Rodriguez and Koen-Alonso 2010). This later study was intended to provide conversion factors for all species in the survey following a consistent analytical approach. A comparison between the currently accepted conversion factors, and the ones developed by Pérez-Rodriguez and Koen-Alonso (2010), indicates very little differences between approaches for cod and redfish, but an important difference for shrimp (Fig. 3.2.2.1).

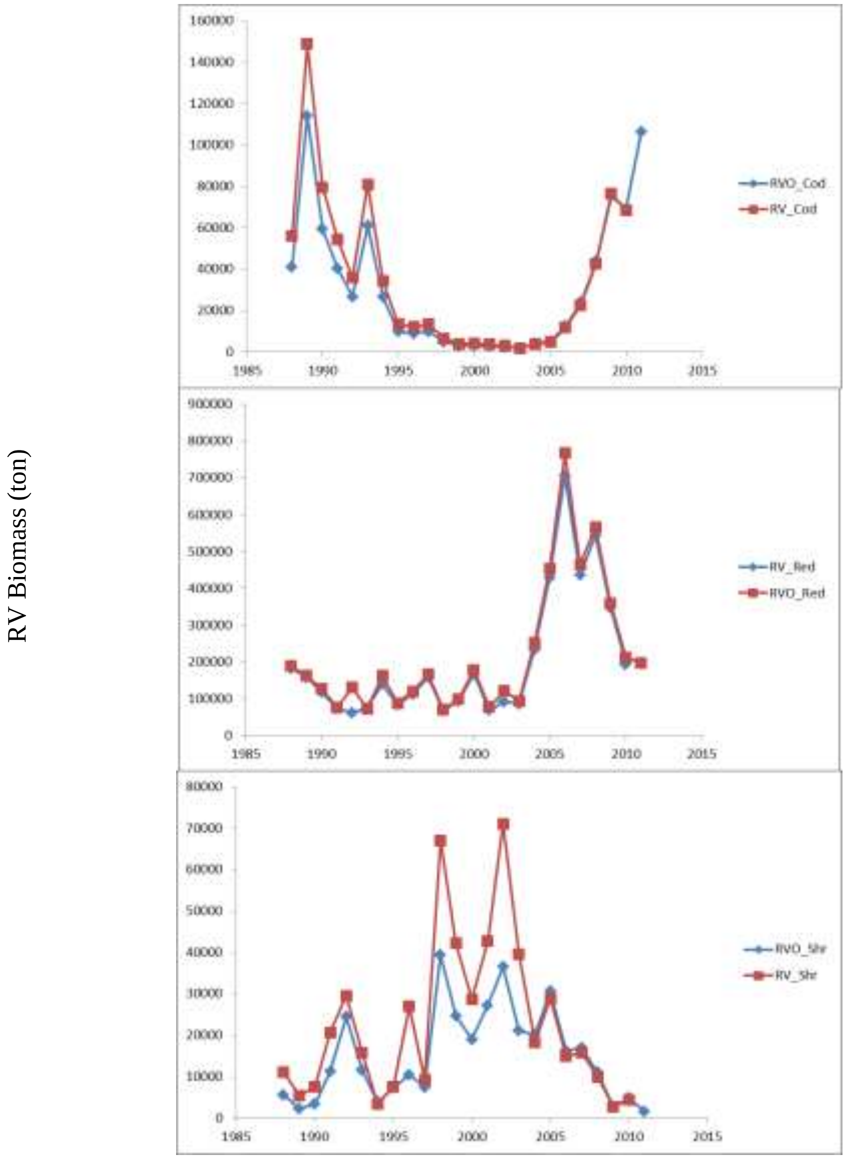


Figure 3.2.2.1. Comparison between the original conversion factors (RVO) and the new ones (RV) for cod (top panel), redfish (middle panel), and shrimp (bottom panel). The different conversion factors make very little difference for cod and redfish, but have an important effect on our perception of the shrimp stock trajectory; the more recent analysis (Pérez-Rodriguez and Koen-Alonso 2010) suggests that the increase in stock size in the late 1990s (and hence the following decline in the mid 2000s) was more marked than what is perceived by applying the currently accepted conversion factors.

3.2.2.3. Exploratory analyses

In order to explore the issues at hand, a total of eight different runs were made. These runs included four considering data derived using the new conversion factors (RV runs) (Pérez-Rodriguez and Koen-Alonso 2010), and four considering data derived using the currently accepted conversion factors (RVO runs). For each set of data, the same four scenarios were considered:

1) All *q*s fixed to 1 (i.e. mimicking the 2011 analysis; this allows comparing the influence of the conversion factors).
2) All *q*s variables, and estimated considering both the sum of squares from the biomass and consumption series.

3) Only q_{shrimp} variable, all other qs set to 1, and estimation done considering the sum of squares from the biomass time series only.
4) Only q_{shrimp} variable, all other qs set to $\frac{1}{q_{cod}} = 0.83$, and $\frac{1}{q_{redfish}} = 0.5$, and estimation done considering the sum of squares from the biomass time series only.

The results from these runs are summarized in Figs. 3.2.2.2 to 3.2.2.9, and a comparison of the estimated parameters is presented in Table 3.2.2.1.

In general terms, the difference in conversion factors for shrimp has a significant impact on model results. The model produces reasonable fits when the dataset derived from the new conversion factors is used. When the currently accepted conversions are applied to generate the dataset for fitting, the model either produces poorer fits to the shrimp data series or does not fit the data at all. The use of a dataset based on current conversion factors also produces parameter estimates which indicate interactions with outcomes opposite to expectations (e.g. shrimp, a prey of cod, have a negative impact on cod). The use of data derived from the new conversion factors consistently produce parameter estimates with signs matching the expectations for the interactions (e.g. both prey of cod had a positive effect on cod, while cod, as predator, has a negative effect on its prey).

Although it would be wrong to use these results to judge the appropriateness of a given suite of conversion factors (i.e. the model may very well fit perfectly a badly converted dataset), these discrepancies in model performance associated with the base data derived from different conversion factors clearly highlights the importance of further investigating the conversion factors currently in use. This is particularly critical for shrimp; the perception of its status and trajectory over time is highly linked to the conversion factor used. At the end of the day, depending on which conversion factors are deemed appropriate, this 3-species model could be considered a good initial model worthy of further development, or a bad one that has to be discarded, and prompting the development of a new one with a different model structure.

Regarding the impact of the original q assumptions, the results from these explorations suggest that although different values for qs can make big differences in the magnitude of the estimated parameters (i.e. the intensity of the interactions), they do not seem to impact the " direction" of the interactions. If the model is deemed acceptable, which depends on the conclusions about conversion factors, our results indicate that its qualitative results would be expected to be reasonably robust to the specific values taken by the qs. Interestingly enough, when the new conversion factors are used, the estimated values for q_{cod} and $q_{redfish}$ are very similar to the approximations derived from the relationship between survey and assessment data (0.889 vs 0.830 for cod and 0.561 vs 0.500 for redfish).

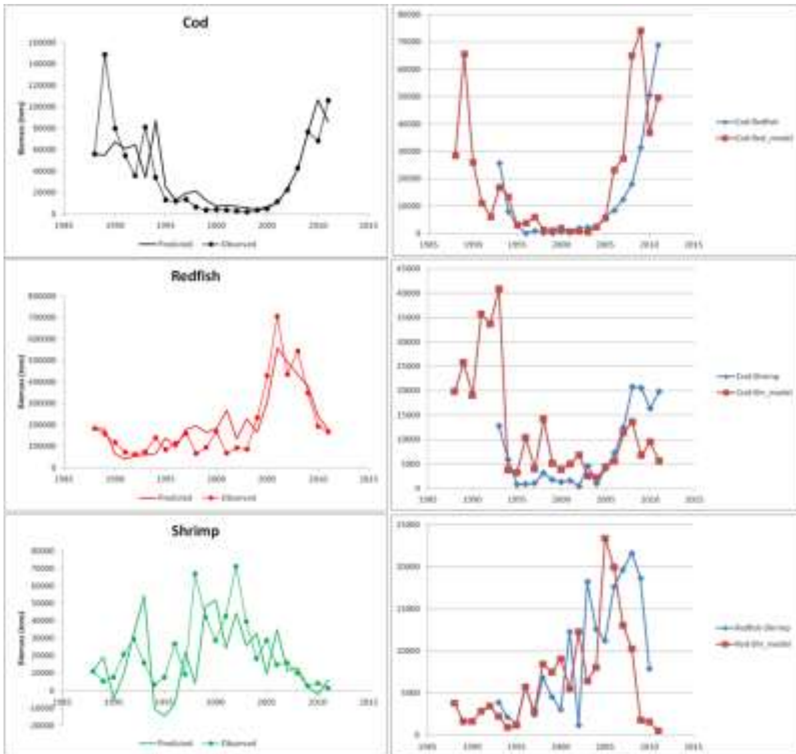
Overall, our analyses clearly indicate that resolving the issue of which conversion factor is more appropriate for shrimp, not only has implications on the assessment of that stock, but it heavily influences our confidence on the performance of this exploratory multispecies model.

On a side note, most q values appear to be higher than 1. This suggests that simple RV biomass indices are actually "overesetimating" the biomass of these species in the Flemish Cap. Although qs>1 are not a fundamental problem, this quasi-systematic result seems to suggest that either there is a significant herding effect of the gear, currently not accounted for, or the dimensions currently used for the estimation of the RV indices are not reflective of the actual swept area (e.g. gear width vs distance between doors).

Table 3.2.2.1. Comparison of point estimates for parameters in the eight alternative runs explored for the 3-species Flemish Cap model. Wherever applies, the fixed parameters are indicated in bold. **Note**: due to the specifics of the programing of the model, interaction terms with positive signs indicate negative effects, and vice versa.

Run #	1	2	3	4	5	6	7	8
Dataset	From new conversion factors (RV)				From current conversion factors (RVO)			
Scenario	1	2	3	4	1	2	3	4
Scenario details	All *q*s=1	All *q*s variable Uses SS_B and SS_C	q_{shrimp} variable Other *q*s=1 Uses SS_B	q_{shrimp} variable Other *q*s fixed to value Uses SS_B	All *q*s=1	All *q*s variable Uses SS_B and SS_C	q_{shrimp} variable Other *q*s=1 Uses SS_B	q_{shrimp} variable Other *q*s fixed to value Uses SS_B
Parameters								
r_{cod} (r_cod)	0.785	0.867	0.785	0.920	1.253	1.589	1.253	1.439
$r_{redfish}$ (r_red)	0.268	0.155	0.266	0.138	0.005	0.027	0.005	0.028
R_{shrimp} (r_shr)	3.344	3.397	3.319	3.319	2.377	2.671	2.578	2.578
K_{cod} (K_cod)	105467	101947	105467	99956	100278	85756	100278	91401
$K_{redfish}$ (K_red)	231496	69724	228796	54097	4314	10516	4314	10348
K_{shrimp} (K_shr)	79062	88104	74816	74816	25919	68607	53193	53193
$\alpha_{cod,redfish}$ (a_cod-red)	-0.071	-0.079	-0.071	-0.061	-0.015	0.033	-0.015	0.012
$\alpha_{cod,shrimp}$ (a_cod-shr)	-0.439	-0.279	-0.452	-0.229	0.800	0.454	0.543	0.532
$\alpha_{redfish,cod}$ (a_red-cod)	2.408	0.743	2.207	0.414	-0.196	-0.708	-0.196	-0.638
$\alpha_{redfish,shrimp}$ (a_red-shr)	-16.625	-8.795	-17.108	-8.548	-28.938	-8.405	-19.634	-9.145
$\alpha_{shrimp,cod}$ (a_shr-cod)	0.751	0.889	0.732	0.882	0.369	0.827	0.531	0.639
$\alpha_{shrimp,redfish}$ (a_shr-red)	0.045	0.086	0.043	0.086	-0.027	-0.077	-0.037	-0.073
$1/q_{cod}$ (1/q_cod)	1.000	0.889	1.000	0.830	1.000	0.730	1.000	0.830
$1/q_{redfish}$ (1/q_red)	1.000	0.561	1.000	0.500	1.000	0.525	1.000	0.500
$1/q_{shrimp}$ (1/q_shr)	1.000	1.060	0.971	0.971	1.000	1.693	1.474	1.474

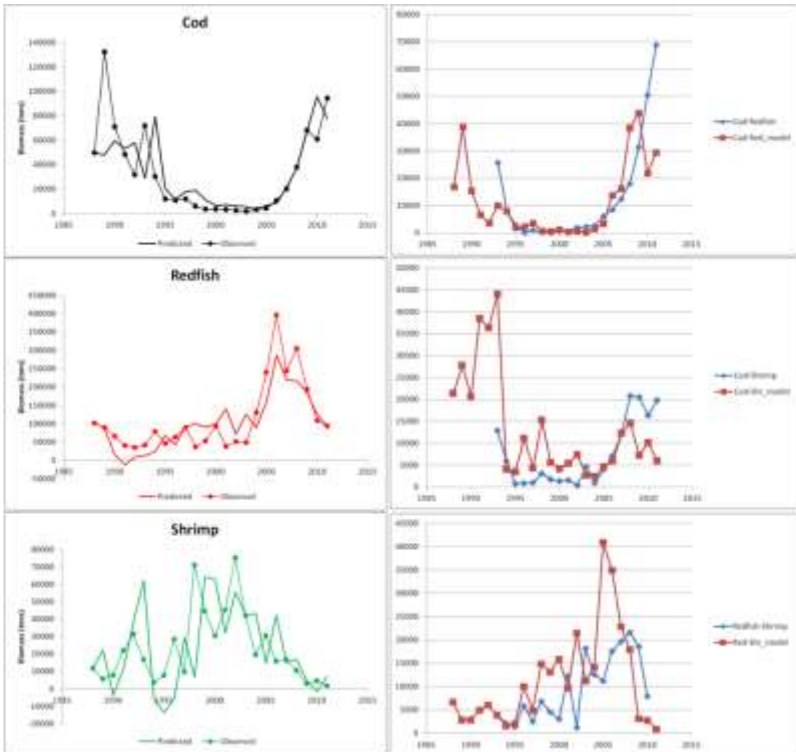
Stock Biomass | Food consumption | Parameters



r_cod	0.785
r_red	0.268
r_shr	3.344
K_cod	105467
K_red	231496
K_shr	79062
a_cod-red	-0.071
a_cod-shr	-0.439
a_red-cod	2.408
a_red-shr	-16.625
a_shr-cod	0.751
a_shr-red	0.045
1/q_cod	1.000
1/q_red	1.000
1/q_shr	1.000

Figure 3.2.2.2. Results from run 1. Scenario 1 (all *q*s fixed and equal to 1), and using data derived from the new conversion factors (RV data). Graphs on the left display the observed vs predicted biomass trajectories for cod (top), redfish (middle), and shrimp (bottom); these series are used to compute the $SS_{B.}$ Graphs in the center display the consumption from independent consumption models (blue) and the estimated consumption from this multispecies model (red) for the consumption of redfish by cod (top), of shrimp by cod (middle), and shrimp by redfish (bottom) (see section 3.2.1. for details on the independent consumption models); these series are used to compute SS_C. The table on the right display the point estimates for the parameters in this run.

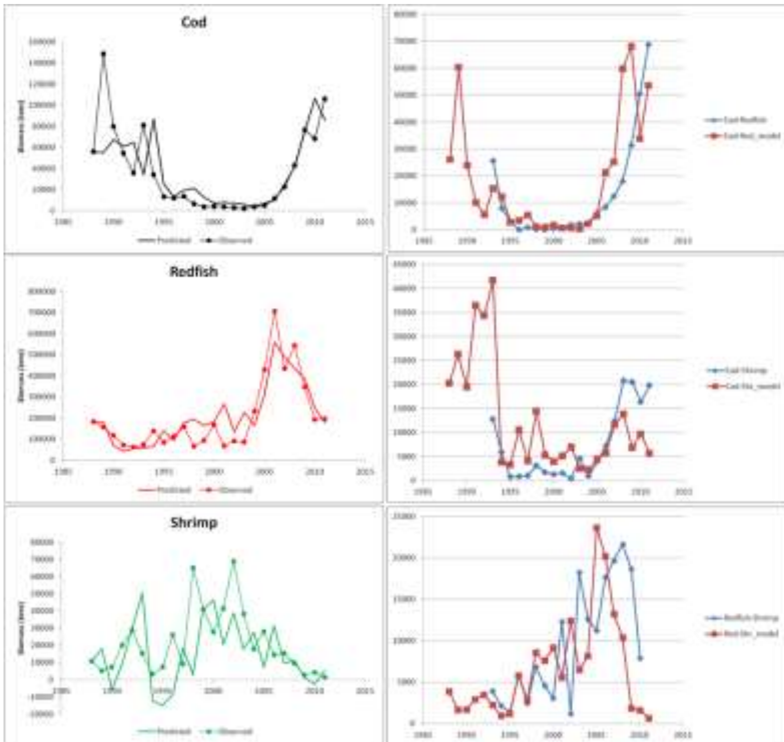
Stock Biomass Food consumption Parameters



r_cod	0.867
r_red	0.155
r_shr	3.397
K_cod	101947
K_red	69724
K_shr	88104
a_cod-red	-0.079
a_cod-shr	-0.279
a_red-cod	0.743
a_red-shr	-8.795
a_shr-cod	0.889
a_shr-red	0.086
1/q_cod	0.889
1/q_red	0.561
1/q_shr	1.060

Figure 3.2.2.3. Results from run 2. Scenario 2 (all *q*s are variable, estimation of *q*s considers both SS_B and SS_C), and using data derived from the new conversion factors (RV data). Graphs on the left display the observed vs predicted biomass trajectories for cod (top), redfish (middle), and shrimp (bottom); these series are used to compute the SS_B. Graphs in the center display the consumption from independent consumption models (blue) and the estimated consumption from this multispecies model (red) for the consumption of redfish by cod (top), of shrimp by cod (middle), and shrimp by redfish (bottom) (see section 3.2.1. for details on the independent consumption models); these series are used to compute SS_C. The table on the right display the point estimates for the parameters in this run.

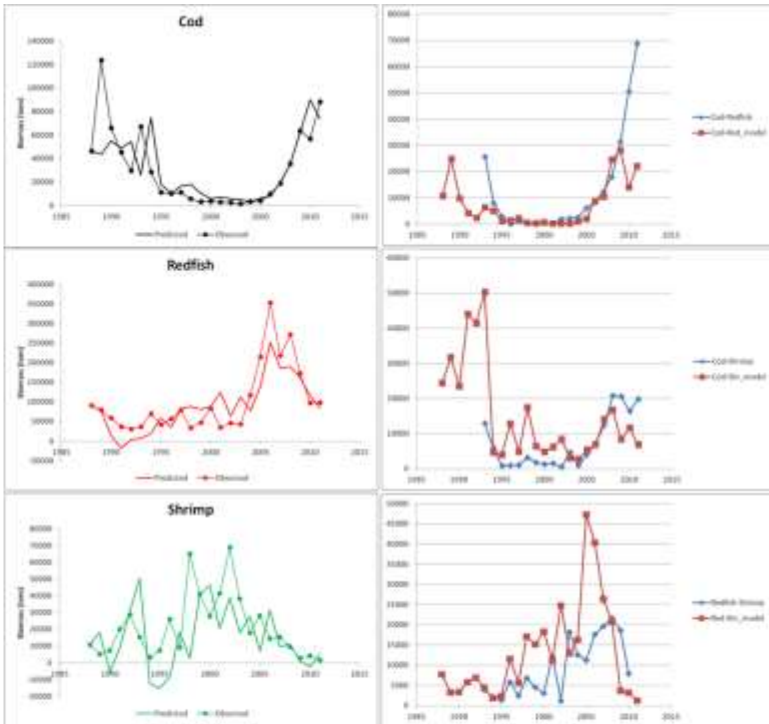
Stock Biomass Food consumption Parameters



r_cod	0.785
r_red	0.266
r_shr	3.319
K_cod	105467
K_red	228796
K_shr	74816
a_cod-red	-0.071
a_cod-shr	-0.452
a_red-cod	2.207
a_red-shr	-17.108
a_shr-cod	0.732
a_shr-red	0.043
1/q_cod	1.000
1/q_red	1.000
1/q_shr	0.971

Figure 3.2.2.4. Results from run 3. Scenario 3 (only q_{shrimp} is variable, all other qs set to 1, and the estimation of qs only considers SS_B), and using data derived from the new conversion factors (RV data). Graphs on the left display the observed vs predicted biomass trajectories for cod (top), redfish (middle), and shrimp (bottom); these series are used to compute the SS_B. Graphs in the center display the consumption from independent consumption models (blue) and the estimated consumption from this multispecies model (red) for the consumption of redfish by cod (top), of shrimp by cod (middle), and shrimp by redfish (bottom) (see section 3.2.1. for details on the independent consumption models); these series are used to compute SS_C. The table on the right display the point estimates for the parameters in this run.

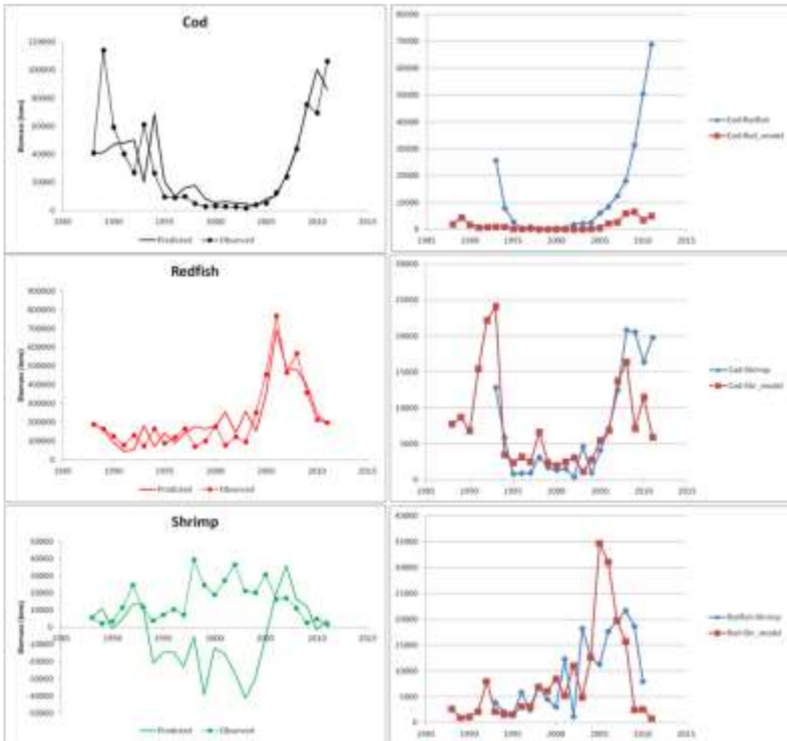
Stock Biomass Food consumption Parameters



r_cod	0.920
r_red	0.138
r_shr	3.319
K_cod	99956
K_red	54097
K_shr	74816
a_cod-red	-0.061
a_cod-shr	-0.229
a_red-cod	0.414
a_red-shr	-8.548
a_shr-cod	0.882
a_shr-red	0.086
1/q_cod	0.830
1/q_red	0.500
1/q_shr	0.971

Figure 3.2.2.5. Results from run 4. Scenario 4 (only q_{shrimp} is variable, all other qs set to $\frac{1}{q_{cod}} = 0.83$, and $\frac{1}{q_{redfish}} = 0.5$, and the estimation of qs only considers SS_B), and using data derived from the new conversion factors (RV data). Graphs on the left display the observed vs predicted biomass trajectories for cod (top), redfish (middle), and shrimp (bottom); these series are used to compute the SS_B. Graphs in the center display the consumption from independent consumption models (blue) and the estimated consumption from this multispecies model (red) for the consumption of redfish by cod (top), of shrimp by cod (middle), and shrimp by redfish (bottom) (see section 3.2.1. for details on the independent consumption models); these series are used to compute SS_C. The table on the right display the point estimates for the parameters in this run.

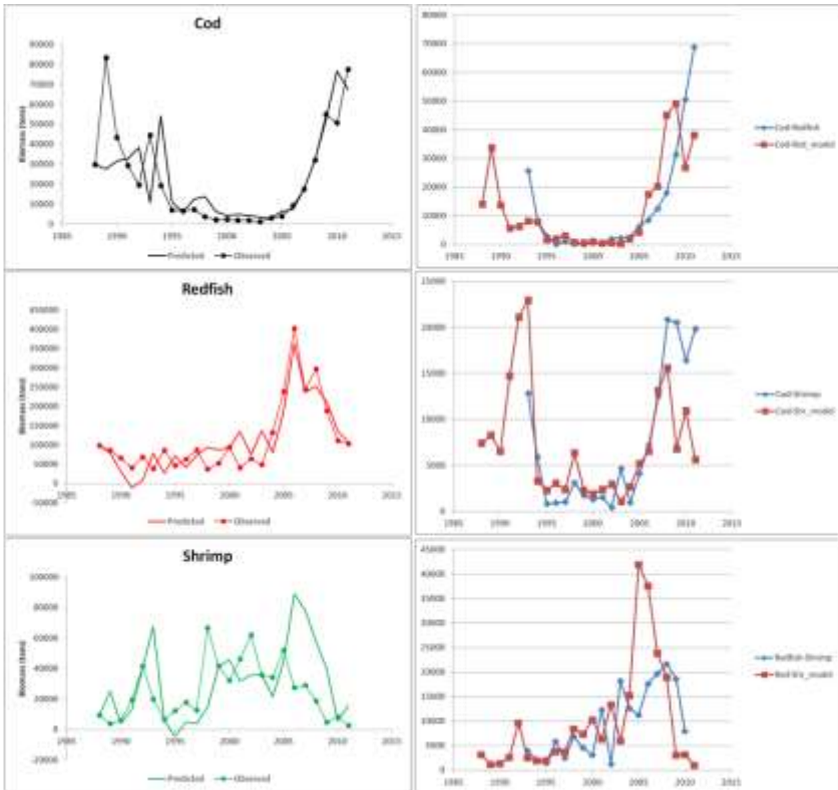
Stock Biomass Food consumption Parameters



r_cod	1.253
r_red	0.005
r_shr	2.377
K_cod	100278
K_red	4314
K_shr	25919
a_cod-red	-0.015
a_cod-shr	0.800
a_red-cod	-0.196
a_red-shr	-28.938
a_shr-cod	0.369
a_shr-red	-0.027
1/q_cod	1.000
1/q_red	1.000
1/q_shr	1.000

Figure 3.2.2.6. Results from run 5. Scenario 1 (all *q*s fixed and equal to 1), and using data derived from currently accepted conversion factors (RVO data). Graphs on the left display the observed vs predicted biomass trajectories for cod (top), redfish (middle), and shrimp (bottom); these series are used to compute the SS_B. Graphs in the center display the consumption from independent consumption models (blue) and the estimated consumption from this multispecies model (red) for the consumption of redfish by cod (top), of shrimp by cod (middle), and shrimp by redfish (bottom) (see section 3.2.1. for details on the independent consumption models); these series are used to compute SS_C. The table on the right display the point estimates for the parameters in this run.

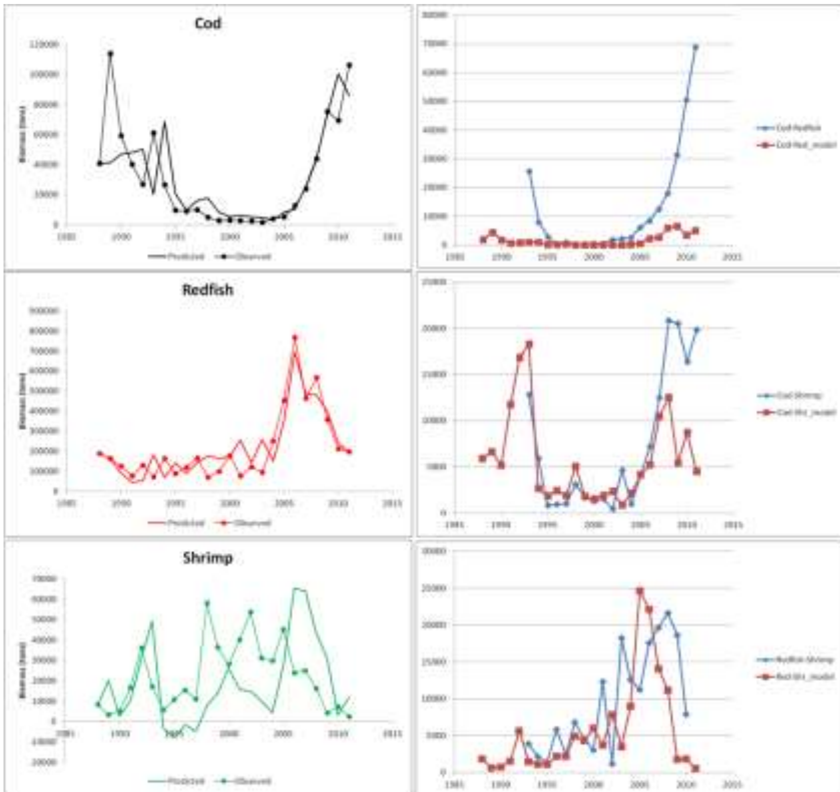
Stock Biomass | Food consumption | Parameters



r_cod	1.589
r_red	0.027
r_shr	2.671
K_cod	85756
K_red	10516
K_shr	68607
a_cod-red	0.033
a_cod-shr	0.454
a_red-cod	-0.708
a_red-shr	-8.405
a_shr-cod	0.827
a_shr-red	-0.077
1/q_cod	0.730
1/q_red	0.525
1/q_shr	1.693

Figure 3.2.2.7. Results from run 6. Scenario 2 (all *q*s are variable, estimation of *q*s considers both SS_B and SS_C), and using data derived from currently accepted conversion factors (RVO data). Graphs on the left display the observed vs predicted biomass trajectories for cod (top), redfish (middle), and shrimp (bottom); these series are used to compute the SS_B. Graphs in the center display the consumption from independent consumption models (blue) and the estimated consumption from this multispecies model (red) for the consumption of redfish by cod (top), of shrimp by cod (middle), and shrimp by redfish (bottom) (see section 3.2.1. for details on the independent consumption models); these series are used to compute SS_C. The table on the right display the point estimates for the parameters in this run.

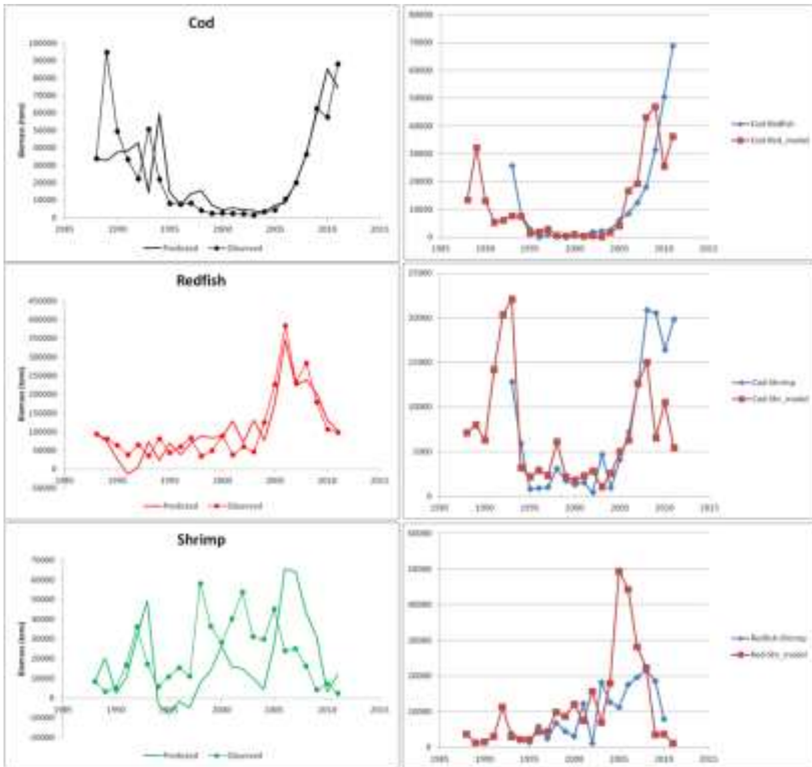
Stock Biomass | Food consumption | Parameters



r_cod	1.253
r_red	0.005
r_shr	2.578
K_cod	100278
K_red	4314
K_shr	53193
a_cod-red	-0.015
a_cod-shr	0.543
a_red-cod	-0.196
a_red-shr	-19.634
a_shr-cod	0.531
a_shr-red	-0.037
1/q_cod	1.000
1/q_red	1.000
1/q_shr	1.474

Figure 3.2.2.8. Results from run 7. Scenario 3(only q_{shrimp} is variable, all other qs set to 1, and the estimation of qs only considers SS_B), and using data derived from currently accepted conversion factors (RVO data). Graphs on the left display the observed vs predicted biomass trajectories for cod (top), redfish (middle), and shrimp (bottom); these series are used to compute the SS_B. Graphs in the center display the consumption from independent consumption models (blue) and the estimated consumption from this multispecies model (red) for the consumption of redfish by cod (top), of shrimp by cod (middle), and shrimp by redfish (bottom) (see section 3.2.1. for details on the independent consumption models); these series are used to compute SS_C. The table on the right display the point estimates for the parameters in this run.

Stock Biomass Food consumption Parameters



r_cod	1.439
r_red	0.028
r_shr	2.578
K_cod	91401
K_red	10348
K_shr	53193
a_cod-red	0.012
a_cod-shr	0.532
a_red-cod	-0.638
a_red-shr	-9.145
a_shr-cod	0.639
a_shr-red	-0.073
1/q_cod	0.830
1/q_red	0.500
1/q_shr	1.474

Figure 3.2.2.9. Results from run 8. Scenario 4 (only q_{shrimp} is variable, all other qs set to $\frac{1}{q_{cod}} = 0.85$, and $\frac{1}{q_{redfish}} = 0.5$, and the estimation of qs only considers SS_B), and using data derived from currently accepted conversion factors (RVO data). Graphs on the left display the observed vs predicted biomass trajectories for cod (top), redfish (middle), and shrimp (bottom); these series are used to compute the SS_B. Graphs in the center display the consumption from independent consumption models (blue) and the estimated consumption from this multispecies model (red) for the consumption of redfish by cod (top), of shrimp by cod (middle), and shrimp by redfish (bottom) (see section 3.2.1. for details on the independent consumption models); these series are used to compute SS_C. The table on the right display the point estimates for the parameters in this run.

References

NAFO, 2011. Report of the 4th Meeting of the NAFO Scientific Council Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM). NAFO SCS Document 11/22.

Pérez-Rodriguez, A., and M. Koen-Alonso. 2010. Standardization of time series for the EU bottom trawl Flemish Cap survey: Estimation of conversion factors between RV Cornide de Saavedra and RV Vizconde de Eza. NAFO SCR Document 10/22.

ToR 3.2.3. Integrative summary on the functioning of the Flemish Cap demersal community

Flemish Cap is an underwater mountain separated from the Newfoundland shelf by the deep Flemish Pass. Oceanographic properties are dominated by the Labrador Current, although the North Atlantic current also influences in the Cap and in conjunction produce a quasi-permanent anticyclonic gyre (Figure 3.1.1) that is highly influential in the dynamic of Flemish Cap ecosystem, especially for primary and secondary production and over fish egg and larval stages (Hayes et al. 1977, Konstantinov 1981, Serebryakov et al. 1987, Borovkov et al. 2006). This system of currents is the basis for a high productivity which has a clear seasonal cycle, with the primary production bloom starting usually not earlier than April and lasting until early autumn (Anderson 1990). Topographic and oceanographic features produce a high degree of isolation for population of shallow dwelling species from neighboring populations from the shelf.

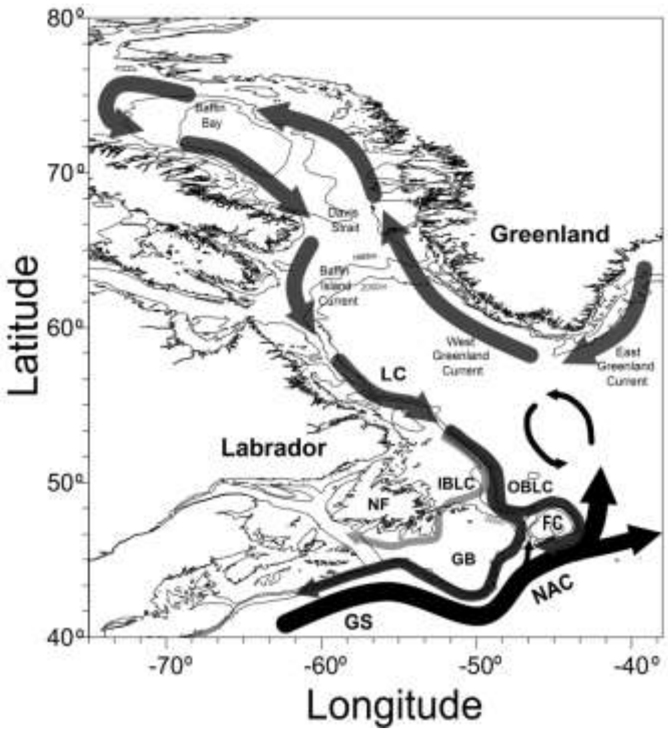


Figure 3.1.1.- Dominant pattern of currents in the Northwest Atlantic. The Labrador Current (LC) subdivides into the inner branch (IBLC) and the outer branch (OBLC) which met with the Gulf Stream (GS) in the tail of the Grand Bank (GB) forming the North Atlantic Current (NAC). The anticyclonic gyre over the Flemish Cap (FC) formed by the OBLC is also shown.

Intense fishing activity in the Flemish Cap started in 1960, but it was in 1977 with the establishment of the Exclusive Economic Zone (EEZ) when fishing pressure on cod Gadus morhua, redfish (Sebastes marinus, but especially S. mentella and S. fasciatus) and American plaice Hippoglossoides platessoides increased remarkably, mainly in the late 1980’s and early 1990’s, leading to the declaration of the collapse of the cod stock in 1998 (Figure 3.1.2). With the decline of cod population since 1960 the average age of catches experienced a marked decrease, from ages 5-9 in the 1960´s to ages 2-4 in the early 1990’s. Parallel to this, the Spawning Stock Biomass (SSB) presented also an outstanding decline. In the early 1990’s cod, American plaice and redfish populations were at the lowest historical levels, and since 1997, with the cod collapse, Greenland halibut Reinhardtius hippoglossoides and especially Northern shrimp Pandalus borealis hoarded most catches in Flemish Cap fishery. Since 2005 Northern shrimp catches declined and in 2010 in was at the collapse level, while the Greenland halibut fishery was subjected to a recovery plan. Fishing on cod was reopened in Flemish Cap in 2010, after good recruitments since 2006.

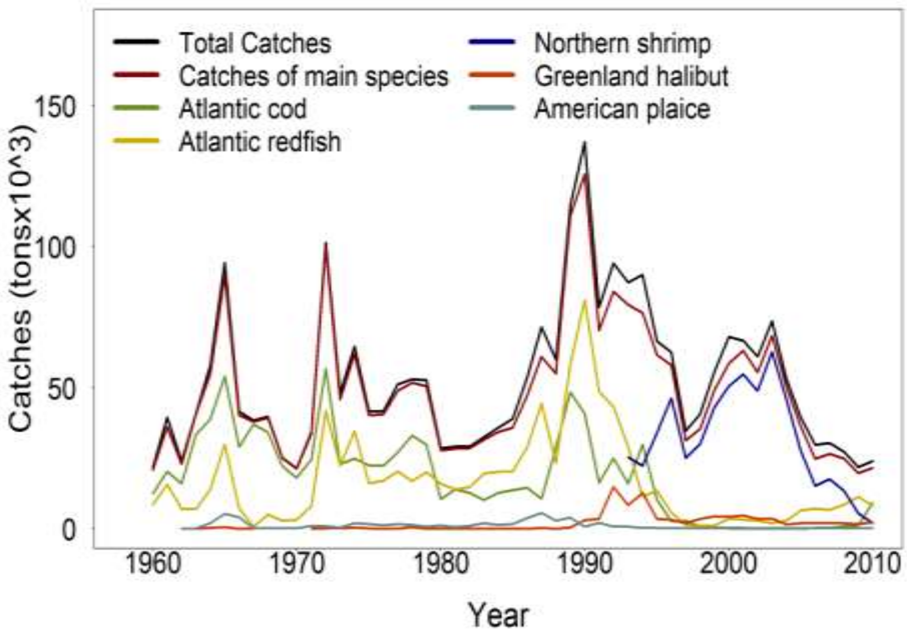


Figure 3.1.2.- Total catches and catches of the main targeted species in the Division 3M. These species accounted for 94% of total catches since 1960. The declared catches were considered up to 1988, since then the estimated catches were employed instead. These data were obtained from the NAFO website http://www.nafo.int/about/frames/about.html.

Across the period 1988-2008, the most abundant demersal species were cod, redfish, Northern shrimp and Greenland halibut accounting, as an average, for the 83.5% of total index of biomass every year. The analyses of biomass indices showed that the demersal community experienced notable variations across the period 1988-2008, due to changes in biomass of most of the 67 demersal populations studied. The Dynamic Factor Analysis (DFA) identified common trends in the trajectories of the 31 most abundant species in the demersal community (Figure 3.1.3). This suggests that the dynamics of the demersal species in the Flemish Cap are interconnected, and can be summarized by a few common patterns (Pérez-Rodríguez et al. 2011b). The explanatory variables considered in the analyses appeared to be consistently important for the population biomass dynamic of these species. Water temperature, along with predation and fishing mortality were significant drivers of the Flemish Cap demersal community. The abundance of the less common demersal species was related with water temperature, with a transition in the species composition between cold and warm periods. Changes in the demersal community were globally registered in the diversity indexes and the Abundance Biomass Comparison (ABC) method, with notable variations in the relative location of biomass and abundance k-dominance curves. The size based indicators showed marked declines in the size structure of the fish demersal community.

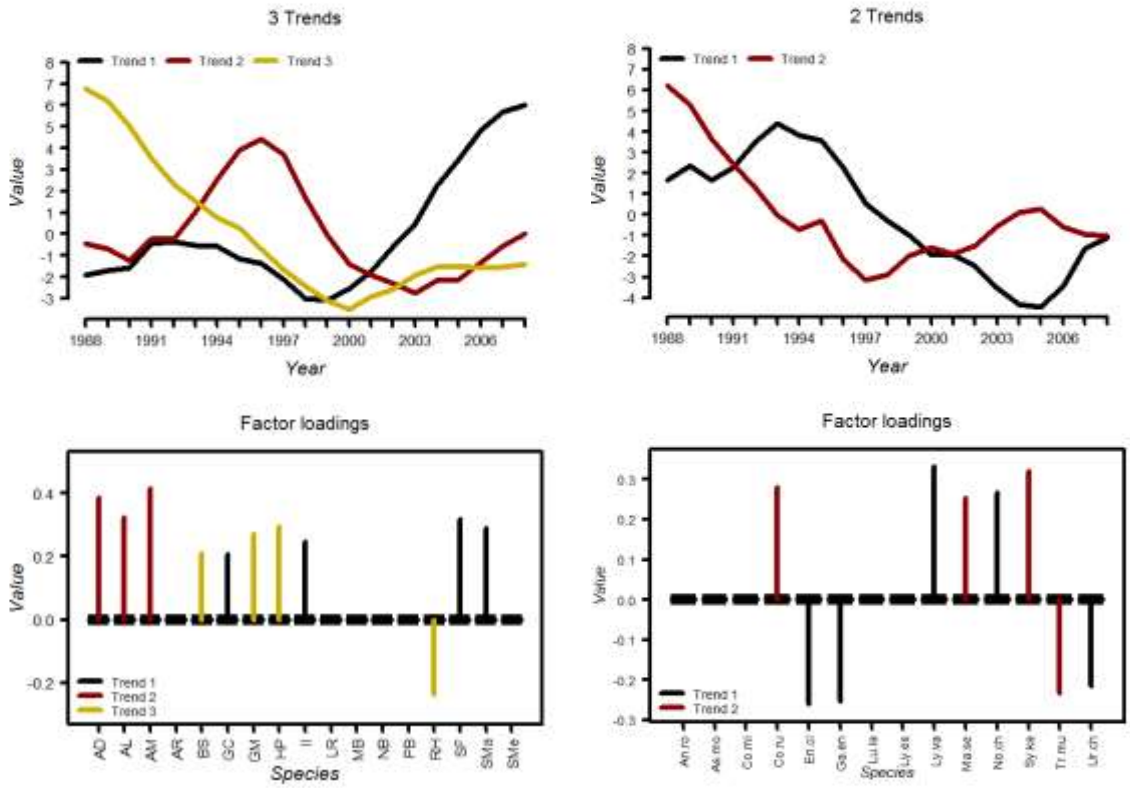


Figure 3.1.3.- Upper panels) Common trends for Groups I and II from the best DFA models without explanatory variables. (Lower panels) The single common trend for each of these groups obtained from the best DFA model when explanatory variables were included in the analysis. The variables included in the best DFA models were the NAO index, the AFI (Average Fishing Index), and the piscivorous abundance for both groups.

Parallel to these changes in the demersal community, since 1993 important variations in feeding habits for the most important fish species were observed (Pérez-Rodríguez et al. 2011a). First, strong variations in feeding habits with size were found in most fish species and hence, biological species were split into trophic species (Table 3.1.1). These trophic species belonged to four different trophic guilds, the bentho-pelagic invertebrate feeders, the benthic invertebrate feeders, the pelagic invertebrate feeders and the piscivorous guild. Not only intra-guild but also inter-guild common trends were found. The dominant common trend was the increase on shrimp consumption for most trophic species, although in the piscivorous guild the consumption of redfish also presented an increasing trend. Parallel to this, intra-guild common trends toward the decline on consumption of their usual preys like ophiuroids, hyperiids and copepods were also detected. The variables accounting for common trends were mainly the abundance of prey species, the intra-guild competition and the oceanographic conditions. These common trends led to a higher overlap in feeding habits at the end of the study period. These results highlight the importance of trophic interactions in management decisions. The importance of key preys like Northern shrimp or juvenile redfish for other commercial species would need to be considered when establishing fishing quotas, i.e. a multispecies approach to fisheries management instead of a monospecific approach. On the other hand, variations in feeding habits with fish length highlight the necessity of considering the demographic structure of both prey and predators when including trophic interactions in management decisions.

***Table 3.1.1**. Trophic species determined with chronological clustering alone. "juvenile" trophic species are numbered 1, while "adult" species are labeled 2.*

Species	Trophic Species
Amblyraja radiata	AR
Anarhichas denticulatus	AD
Anarhichas lupus	AL1; AL2
Anarhichas minor	AM1; AM2
Gadus morhua	GM1; GM2
Glyptocephalus cynoglossus	GC
Hippoglossoides platessoides	HP
Lycodes reticulatus	LR
Macrourus berglax	MB1; MB2
Nezumia bairdii	NB1, NB2
Phycis chesteri	PC
Reinhardtius hippoglossoides	RH1; RH2
Sebastes fasciatus	SF1; SF2
Sebastes juvenile	SJ
Sebastes marinus	SMa1; SMa2
Sebastes mentella	SMe1; SMe2

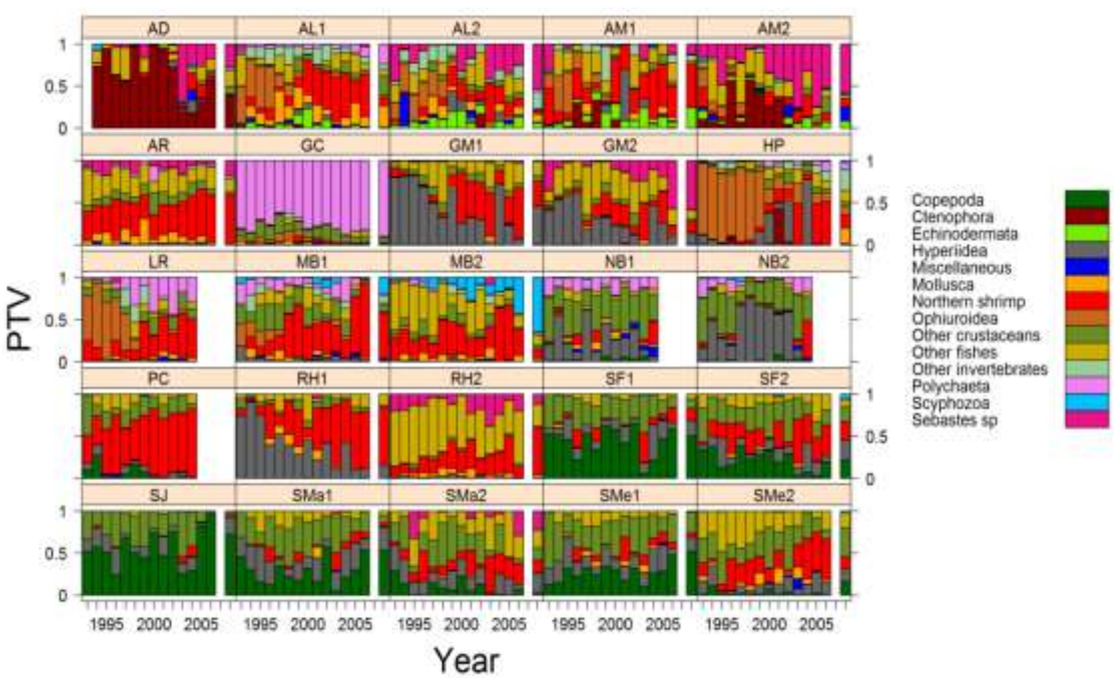


Figure 3.1.4. PTV (Percentage over Total Volume consumed) of the different preys along the period 1993-2008 for the different trophic species. Original preys were grouped to facilitate the interpretation of changes.

Contemporaneously with changes in abundance of the Flemish Cap cod, changes in reproduction, growth and condition were detected (Figure 3.1.5). The high fishing mortality registered in the late 1980's and early 1990's contributed very importantly to the observed decrease in cod biomass. A genetic change toward earlier age and smaller size at maturation was found already in the 1980's but especially in the early 1990's cohorts (Pérez-Rodríguez et al. 2013). The decrease in Female Spawning Stock Biomass (FSSB) as consequence of the steep decline of the population, in conjunction with the rejuvenation of the reproductive stock, led to the decrease in the Total Egg Production (TEP; Figure 3.1.6). The high correlation of TEP with the recruitment during this period supports that the decrease in the SRP was largely responsible of the recruitment failures since mid 1990's (Pérez-Rodríguez et al. 2011c). However, the low temperatures recorded between 1989 and 1997 may have also lead to unfavorable conditions for cod recruitment. Cod fishing still remained in the Flemish Cap until 1996, which in conjunction with the absence of good recruitments, was the final blow contributing to the collapse. Since then density-dependent processes led to an increase in condition and growth, favoring earlier maturation by phenotypic plasticity and a growing FSSB. Although not studied in this thesis, it is probable that during this period the higher fish condition would led to an increased relative fecundity, producing an increase in the TEP. In the absence of fishing pressure, a higher SRP together with improved feeding conditions and higher temperatures probably favored the good recruitment events observed since 2005 and the recovery of the stock.

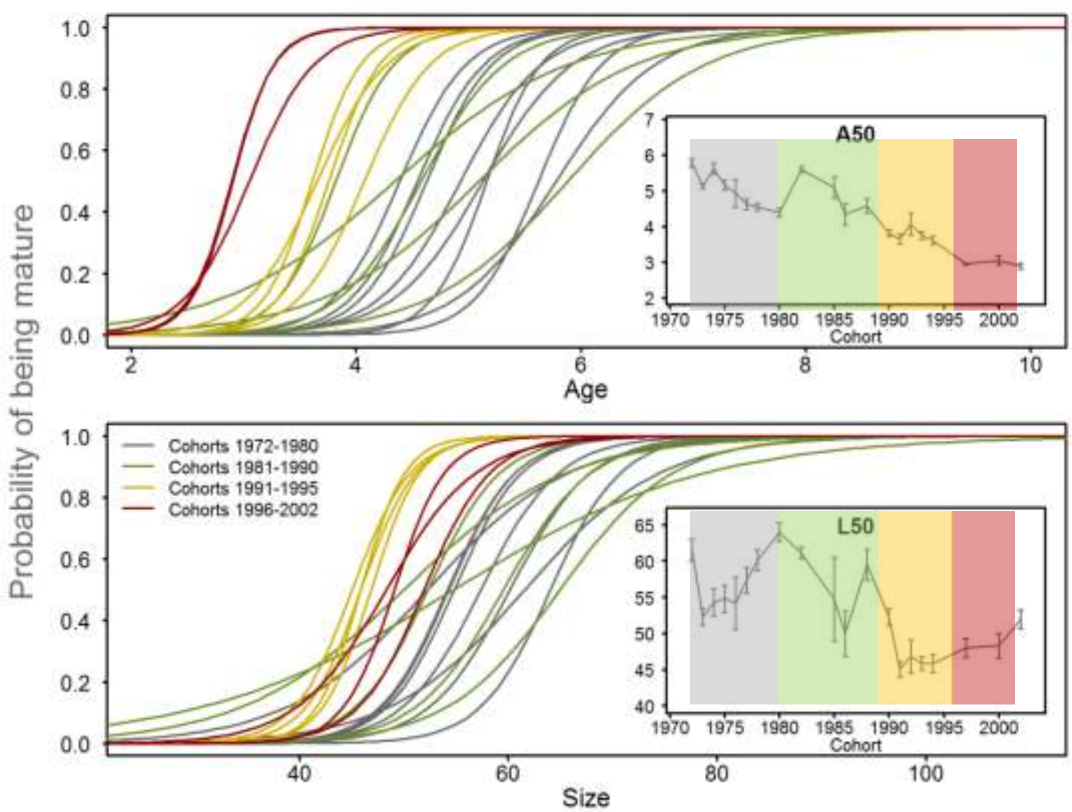


Figure 3.1.5. Maturation ogives for the probability of being mature by length (upper panel) and age (lower panel) by cohort for the Flemish Cap cod. The age and length at 50% probability of being mature by cohort are shown in the inner panels.

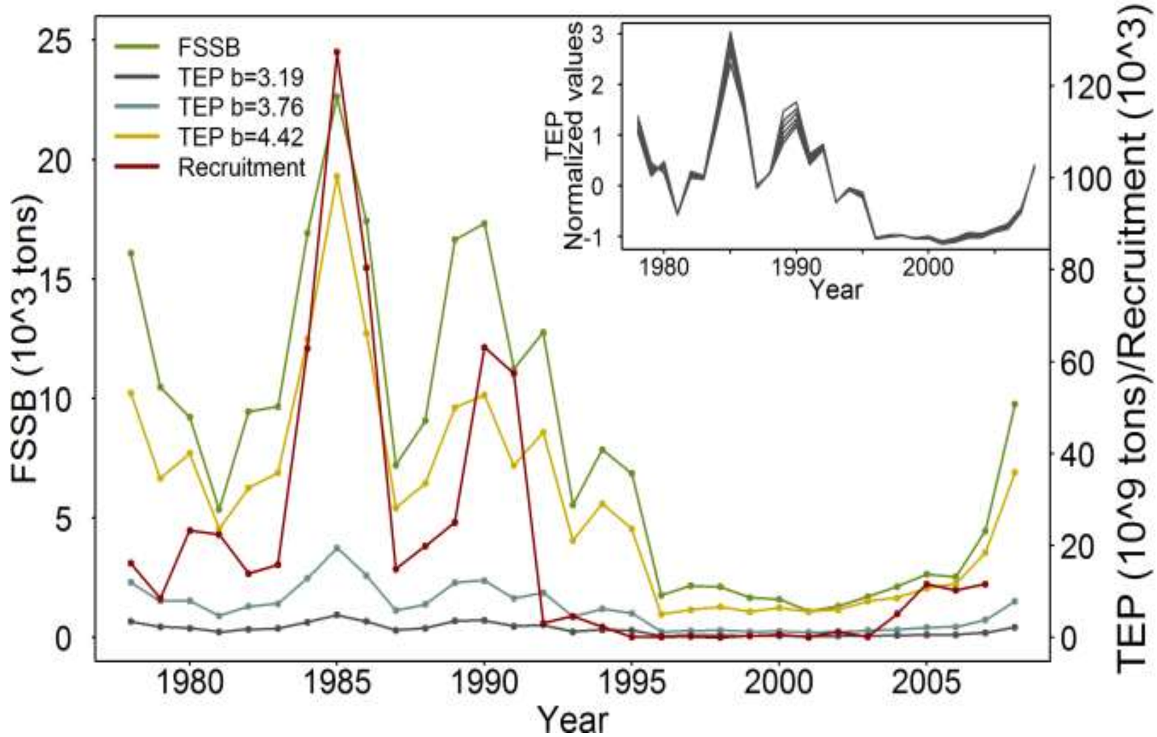


Figure 3.1.6. FSSB, Recruitment and TEPs for Flemish Cap cod. Recruitment data correspond to abundance of the age-1 class at year+1. Three TEP time series are shown corresponding to fecundity-length relationships with allometric coefficient equal to 3.19, 3.76 and 4.42 respectively. Inset: normalized TEP values for the six fecundity models.

With previous information, an extended food web model, including the 14 most important fish demersal species and their main preys were developed (Figure 3.1.7). Two main subsystems were identified, the pelagic and the benthic subsystems, being based on phytoplankton and detritus respectively. However, these subsystems are interconnected by the demersal community, which creates a constant flux between both components.

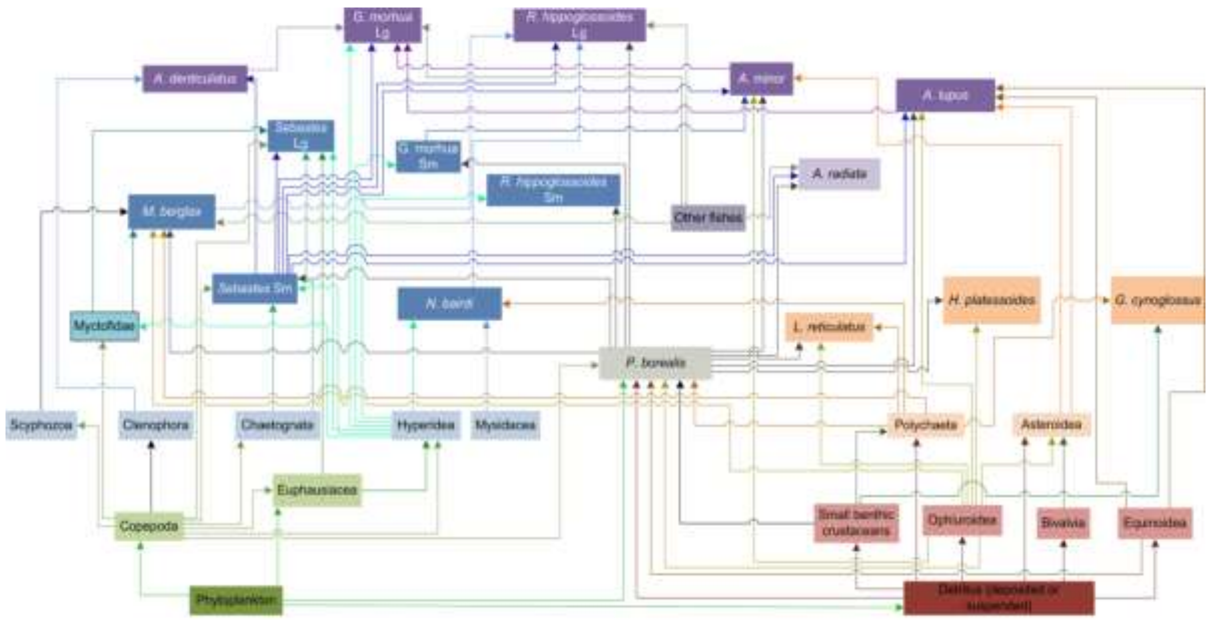


Figure 3.1.7. Food web model for the Flemish Cap with the detritus (right side) and the phytoplankton chains (left side). The 14 most important fish demersal species are included. Small (Sm) and large (Lg) trophic species determined in chapter IV for G. morhua, Sebastes and R. hippoglossoides are displayed

A simplified conceptual model with cod, redfish, shrimp and Greenland halibut trophic interactions, including all the main drivers for population and community dynamic was also created (Figure 3.1.8). This included inner drivers like population structure and abundance, growth, condition and SRP, and external drivers like oceanographic conditions, species interactions (mainly predation but also competition) and fishing. With this theoretical model and the information from previous analysis a description of the ecological functioning of the Flemish Cap demersal community was developed. Fishing activity in conjunction with predation and oceanographic conditions were considered the main drivers inducing changes in the population structure of various species through mortality of larval, juvenile and adult stages. These changes produced variations in trophic interactions between species, and density-dependent processes affecting to growth and condition. All these factors strongly affected to the SRP of populations, which in turn affected to population structure. Under this scenario, fishing on cod and redfish under adverse environmental conditions for recruitment and low SRP produced an imbalance in the ecosystem that led to the increase of shrimp and Greenland halibut by the release of predation and competition respectively. Redfish stocks benefited from the low biomass of a capital piscivorous like cod, showing excellent recruitments in a period of favorable oceanographic conditions. The higher availability of shrimp and redfish preys produced an increase in the SRP of cod, which favored the recovery of the cod stock since 2005. The increasing predation of a growing cod stock produced the decline of the redfish stock since 2008, while the Northern shrimp stock decline was ascribed to the increasing predatory pressure from both cod and redfish in conjunction with a very high fishing pressure.

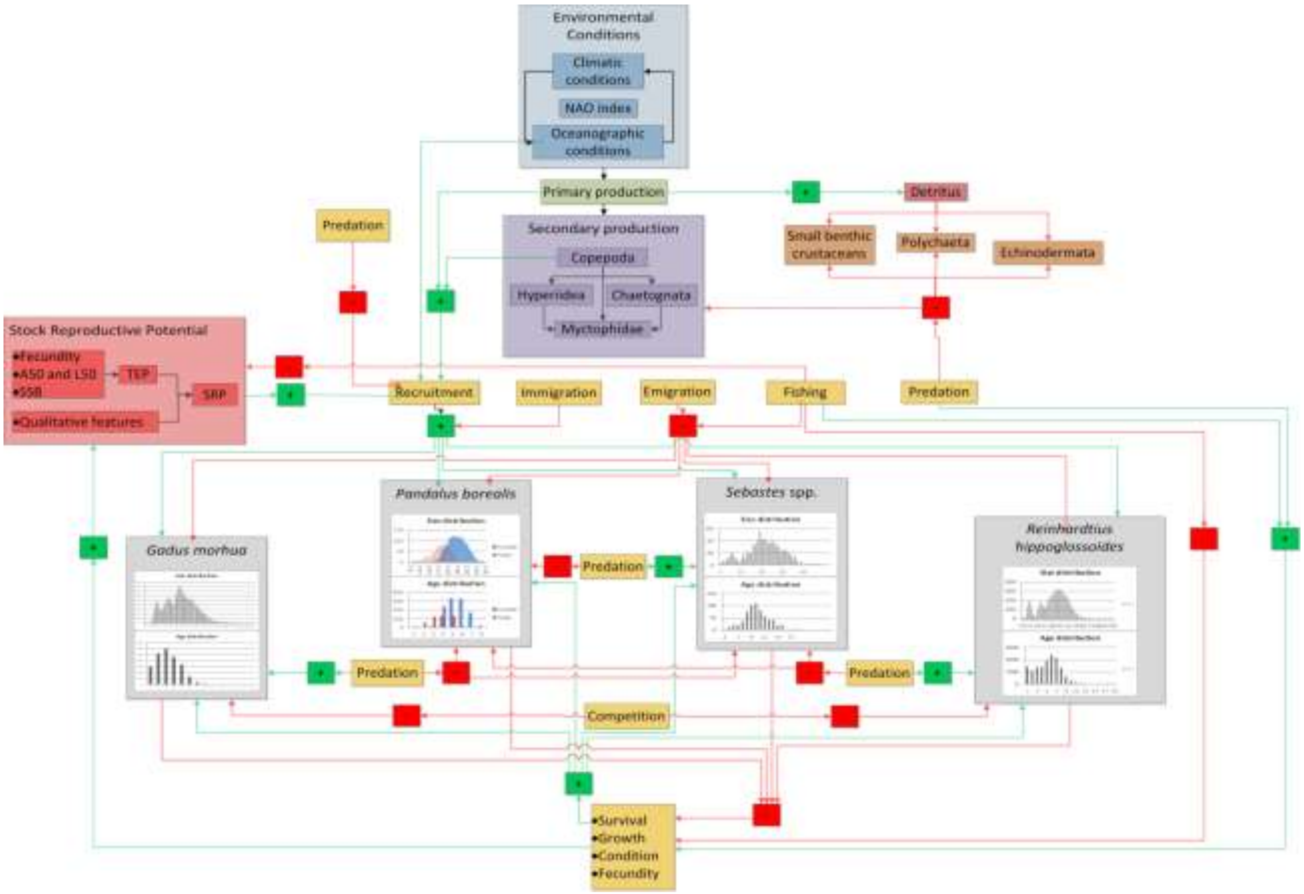


Figure 3.1.8. Schematic view of the Flemish Cap conceptual ecological model including internal and external drivers.

This conceptual model developed to study the ecological functioning of the demersal community in Flemish Cap supposes an integrative approach that represents an important step away from the traditional view of single species management in Flemish Cap. This type of contributions constitutes major steps towards a new framework for fisheries management that incorporates theoretical background on the functioning of marine ecosystems. Achieving a sustainable fishery requires to focus on sustaining relationships between species, which includes fishery within complex evolving ecosystems. Fisheries management should maintain these relationships stable and robust within a resilient ecosystem.

References

Anderson, J. T. 1990. Seasonal development of invertebrate zooplankton in Flemish Cap. Marine Ecology Progress Series **67**:127-140.

Borovkov, V. A., A. A. Vaskov, and A. L. Karsakov. 2006. The impact of water circulation on the year-class abundance dynamics of redfish and cod on the Flemish Cap. Journal of Northwest Atlantic Fisheries Science **37**:127-134.

Hayes, R. M., D. G. Mountain, and T. C. Wolfork. 1977. Physical oceanography and the abiotic influence on cod recruitment in the Flemish Cap region. NAFO Scientific Council Research Document.

Konstantinov, K. G. 1981. Influence of water temperature on cod year classes strength on the Flemish Cap Bank. NAFO SCR Doc 81/VI/77.

Pérez-Rodríguez, A., M. Koen-Alonso, C. González-Iglesias, and F. Saborido-Rey. 2011a. Analysis of common trends in feeding habits of the main fish demersal species of Flemish Cap. NAFO SCR Doc 11/77.

Pérez-Rodríguez, A., M. Koen-Alonso, and F. Saborido-Rey. 2011b. Changes and trends in the demersal fish community of the Flemish Cap, Northwest Atlantic, in the period 1988-2008. ICES Journal of Marine Science.

Pérez-Rodríguez, A., J. Morgan, F. Saborido-Rey, and M. Koen-Alonso. 2013. Disentangling genetic change from phenotypic response in reproductive parameters of Flemish Cap cod Gadus morhua. Fisheries Research **138**:62-70.

Pérez-Rodríguez, A., M. J. Morgan, R. Rideout, R. Domínguez-Petit, and F. Saborido-Rey. 2011c. Study of the relationship between total egg production, female spawning stock biomass and recruitment in Flemish Cap cod (Gadus morhua). Ciencias Marinas **In press.**

Serebryakov, V. P., A. V. Astafjeva, and V. K. Aldonov. 1987. USSR ichthyoplankton investigations on Flemish Cap. NAFO Scientifc Council Studies **11**:7-21.

ToR 3.3. Report on progress on species/stock interaction studies for the Grand Banks (NAFO Div 2J3KLNO), considering spatial overlap whenever possible, and with special consideration of the impact of these interactions on 3LNO shrimp, and their potential implication for management advice.

ToR 3.3.1. Summary on shrimp

The NAFO ICES Pandalus Assessment Group (NIPAG) is responsible for the assessment of six stocks of Northern Shrimp in the North Atlantic, ranging from Skagerrak and the Barents Sea in the north-east Atlantic, Denmark Strait and off East Greenland (EG), the Subareas 0 and 1 of West Greenland (WG), Grand Banks of Newfoundland in the NAFO Divisions 3LNO and on the Flemish Cap (FC) in NAFO div. 3M (Figure 3.3.1.1).

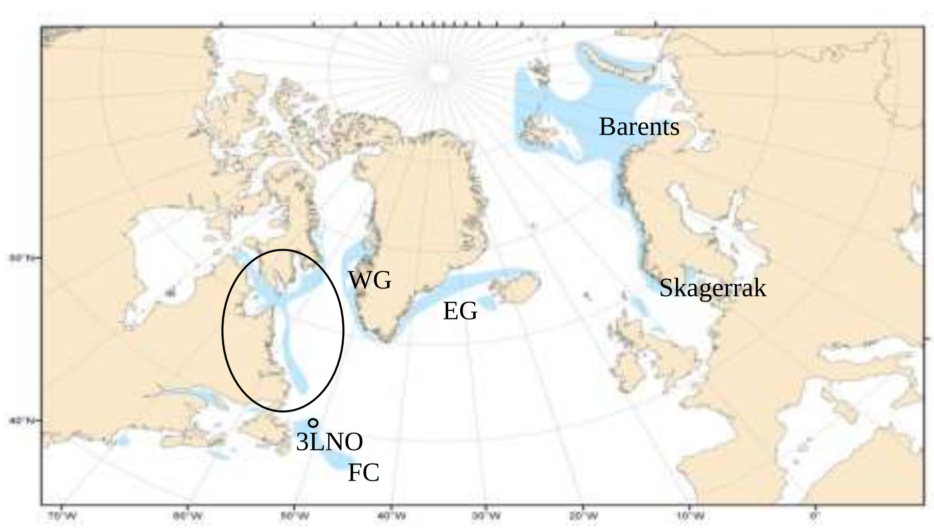


Figure 3.3.1.1 Northern Shrimp stocks assessed by NIPAG. Canadian domestic stocks are shown by the oval.

Presently, two of the stocks have a model-based assessment and 4 are qualitative. A Surplus Production Model (SPM) using Bayesian estimation with process error has been used for the stocks of West Greenland (Hvingel and Kingsley, 2003), and Barents Sea (Hvingel, 2011). The model used in West Greenland also incorporates cod predation on shrimp. The consumption was taken as a Holling type III functional-response that includes prey-switching (Holling, 1959).

The metrics for the current qualitative assessments vary, but most have time series of survey indices of biomass and recruitment. Also, time series of reported landings and effort from fisheries are available to construct catch per unit effort (CPUE) indices. Work is ongoing to advance a Bayesian SPM based assessment for 3LNO Shrimp, with the goal of providing advice on the risk of falling below B_{msy} or exceeding F_{msy} for various catch options. For the shrimp in Skagerrak a stochastic length-based assessment model was demonstrated for the first time in 2012. Although preliminary results were promising, there were concerns expressed about poor fits to the survey data.

Assessment results for the two Northern shrimp stocks relevant to the working group on Ecosystem Approach to Fisheries Management in the North-West Atlantic: Northern shrimp in Div. 3M, Northern shrimp in Div. 3LNO have similar trends in recruitment and biomass indices (Figure 3.3.1.2). Recruitment for 3M has been weak since 2004, while 3LNO has experienced a decline in recruitment since 2008 and is now close to the lowest observed values. The biomass index for Div. 3M was at a high level from 1998 to 2007, and has declined to its lowest level in 2012, well below Blim. Similarly, in Div. 3LNO, biomass indices increased to record levels by 2007, but decreased substantially to 2010 and changed little in 2011. The spring biomass indices remained at a low level in 2012. There has been no fishery in Div. 3M since 2010 and fishery removals in 3LNO are now approximately one third of the removals in 2009.

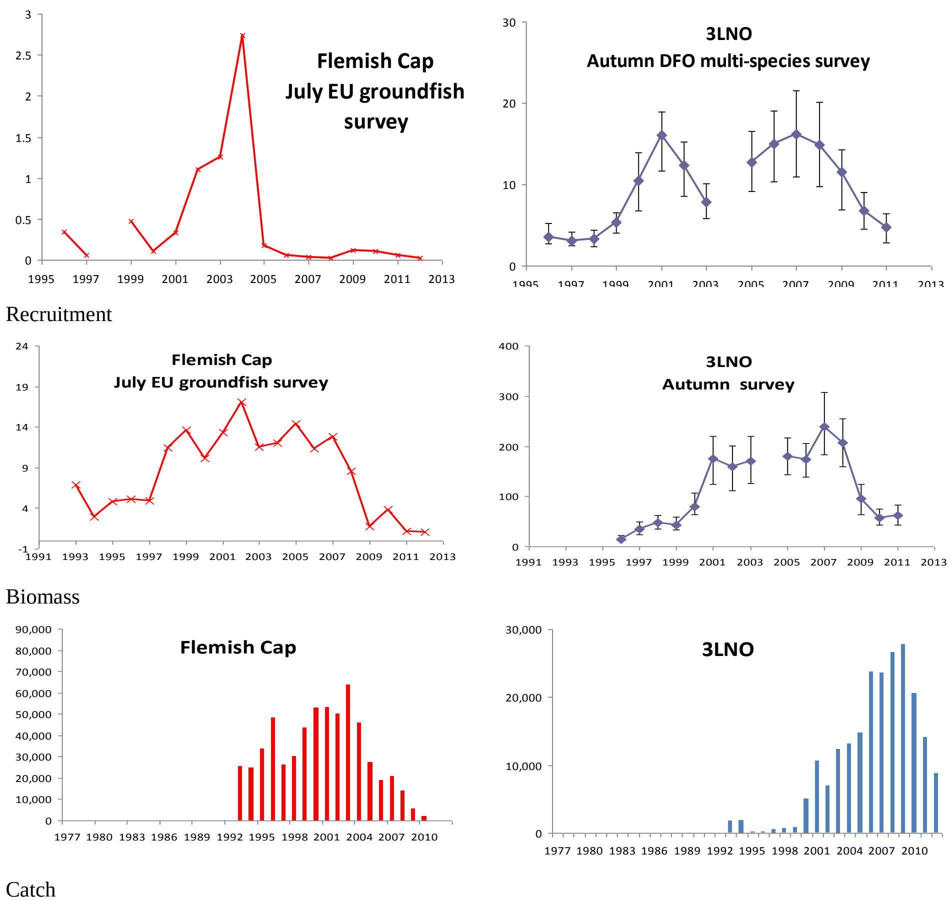


Figure 3.3.1.2. Time series of recruitment indeces (top), Biomass indices (middle) and reported catch for Northern shrimp in Div. 3M (left) and in Div. 3LNO (right)

ToR 3.3.2. Summary of the ERI-NEREUS research

The Ecosystem Research Initiative (ERI) was a DFO Science national program aimed at developing ecosystem research that could support the development of ecosystem approaches to management. This program ran from 2007 to 2012, and was implemented through regionally-specific components. The "Newfoundland and Labrador's Expanded Research on Ecosystem-relevant but Under-surveyed Splicers" (NEREUS) was the DFO Newfoundland and Labrador regional component of the ERI.

Between 2008 and 2012, the ERI-NEREUS program added new or redesigned sampling components in DFO Research Vessel surveys, such as the collection and processing of acoustic information, implementation of a grab sampling program on the Grand Bank, a new scheme for sampling of stomach contents of key fish species, and expanded sampling of non-commercial species.

The main outcomes of the ERI-NEREUS program have included a description of status and trends in main forage fish species, as well as the structure and changes in the fish community; a characterization of main components of benthic communities; and an analysis of trophic interactions among key components of the NL marine community.

The results from this program were presented and reviewed at a DFO Canadian Science Advisory Secretariat (CSAS) regional advisory process (RAP) meeting on January 17-19, 2012. The main conclusions from this meeting have been described in a DFO Science Advisory Report (SAR) (DFO, 2012). Some of the key summary bullets describing core findings of the ERI-NEREUS programs are:

- Results of the grab sampling program conducted at 58 stations over three NAFO Divisions (3NLO) showed that a total of 12 phyla were represented with three phyla (Annelida, Arthropoda and Mollusca), accounting for 86% of all recorded taxa. Echinodermata dominated biomass (58% of total), particularly the sand dollar, Echinarachnius parma (69% of total echinoderm biomass). The overall biomass of 228 g/m2 recorded in the NEREUS program is within the range of previous studies.
- Preliminary analysis of hydroacoustic data collected during fall bottom trawl surveys during 2008 indicated that auxillary acoustic may be useful to estimate availability to the bottom trawl of at least two forage species (Capelin and Sand Lance). New information on spatial variation of biological characteristics and feeding of forage species was collected and described.
- During the late 1980s and early 1990s most of the fish community in the Newfoundland and Labrador shelves marine ecosystem collapsed; the exceptions were small benthivore fish and especially shellfish, whose biomass increased significantly. Even though this collapse is often associated primarily with Atlantic cod in the early 1990s, declines in several functional groups started in the early 1980s. The collapse was observed throughout the system and involved commercial and non-commercial species alike. Current levels of some fish functional groups are still well below pre-collapse levels.
- Trophic structure indicators clearly show a transition from a large fish community to one of shrimp and small fish.
- Long time series on condition are only available for some commercially important species and generally indicate that fish were in better condition in the 1980s and into the early 1990s; the mid 1990s and early 2000s appear to be a period of poor fish condition; and condition seems to have improved in the late 2000s.
- In the mid 1990s, the contribution of Capelin to the diet of fish predators was reduced, while that of shrimp increased. Diets of some fish predators on the Grand Bank have been dominated by Sand Lance in recent years. For smaller/younger predators, amphipods are an important prey.
- Fishing appears as a consistent and significant driver of the trajectories of five key fish species of the NL marine community during the early-mid 1980s to the mid 1990s, and still remains as an important driver in more recent times (mid 1990s to 2008) when fisheries have been targeting mainly shrimp and crab. Environmental variables also appear as significant drivers, but their effect is less consistent than that observed for fishing.
- A study examined the relationship between seasonal sea ice dynamics, capelin biomass and timing of spawning to probe the hypothesis that capelin is environmentally regulated via food availability. The study found evidence of a regime shift and indicates that ice dynamics are a major driver of capelin dynamics. These findings suggest regulation of energy flow is bottom-up.
- A study on the drivers of Northern Cod trajectory tested competing hypotheses for patterns in the variation of the Northern Cod stock biomass since 1985: the roles of fisheries removals, predation by harp seals, and the availability of capelin, which is a key prey for cod. Among the factors considered, patterns of variation in stock biomass of Northern Cod appear to be influenced by fisheries and the availability of capelin, but not by seal predation.

References

DFO. 2012. Results and recommendations from the Ecosystem Research Initiative – Newfoundland and Labrador's Expanded Research on Ecosystem Relevant but Under-Surveyed Splicers. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/058.

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

ToR 4.1. [FC Request # 7].

This is a follow-up work on encounter thresholds and move-on rules. For small gorgonian corals, large gorgonian corals, sea squirts, erect bryozoans, crinoids and cerianthid anemone, consider thresholds for 1) inside the fishing footprint and outside of the closed areas and 2) outside the fishing footprint in the NRA, and 3) for the exploratory fishing area of seamounts if applicable. In the case of sea pens and sponges consider encounter thresholds and move on rules for the exploratory fishing area of seamounts.

4.1.1. Background

The FC Request #7 is a renewal of the request of the same number in 2011. In 2011, WGEAFM (NAFO 2011) completed the portion of the response related to sponges and sea pens, including extensive supporting documents on the model used to generate the results (Cogswell et al. 2011) and the results themselves (Kenchington et al. 2011). The Scientific Council reviewed and endorsed the response to Fisheries Commission who subsequently adopted the new encounter thresholds at its 2012 annual meeting.

4.1.2. Recommendations for Encounter Thresholds for Small Gorgonian Corals in the NRA

The current closed areas do not explicitly afford protection to small gorgonian corals. At the time when the boundaries were being assessed (2009) there were only three known significant catches (≥ 0.2 kg/RV trawl) of small gorgonian corals in all the NRA (Divs. 3LMNO) and they were surrounded by null records. New data have been collected since the previous assessment that shows significant catches in several locations in the NRA, only two of which corresponds with closed areas (Figure 4.1.1, Areas 1 and 7).

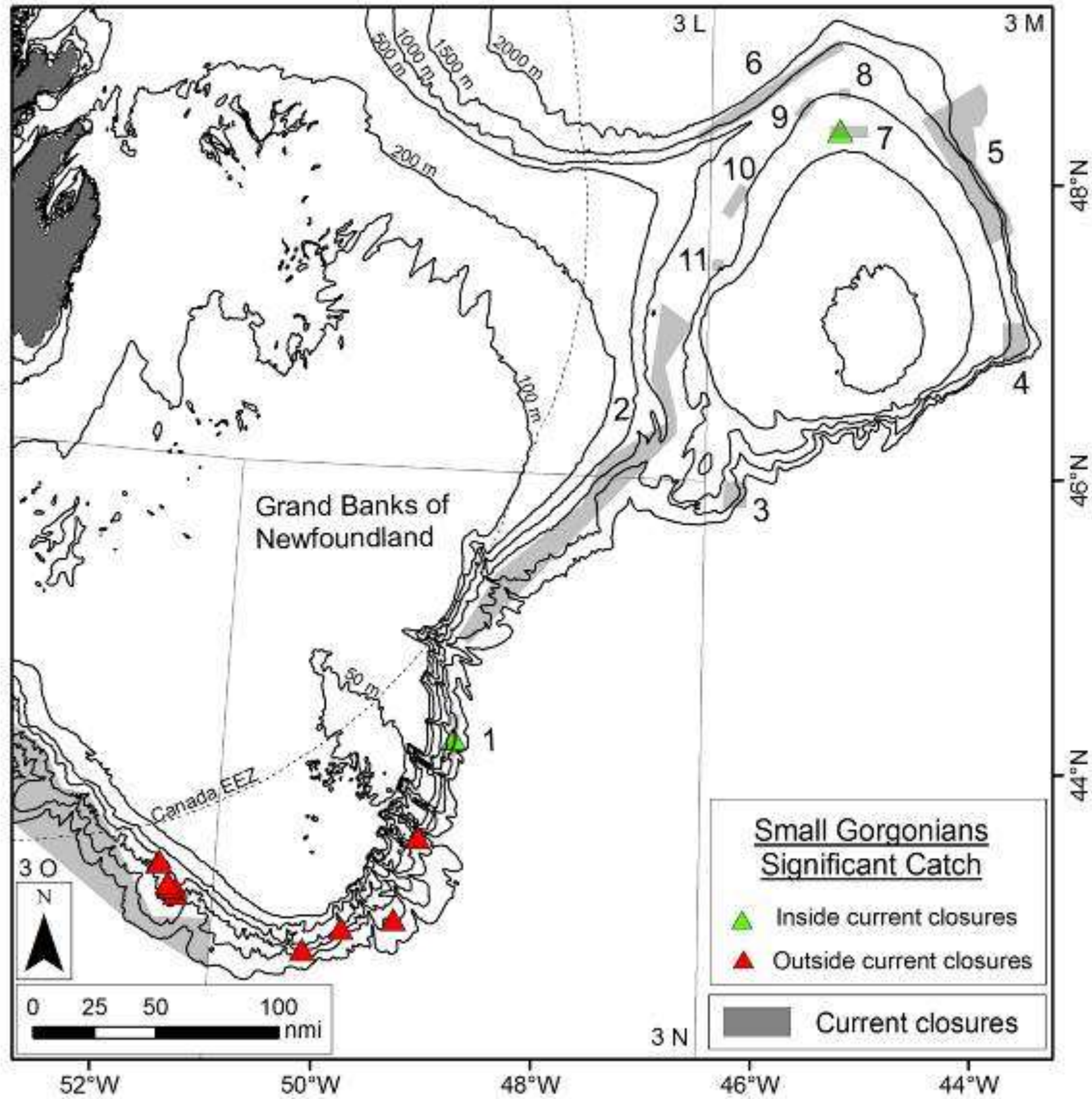


Figure 4.1.1. Location of significant catches of small gorgonians (≥ 0.2 kg/RV trawl) from research vessel surveys in the NRA (Divs. 3LMNO).

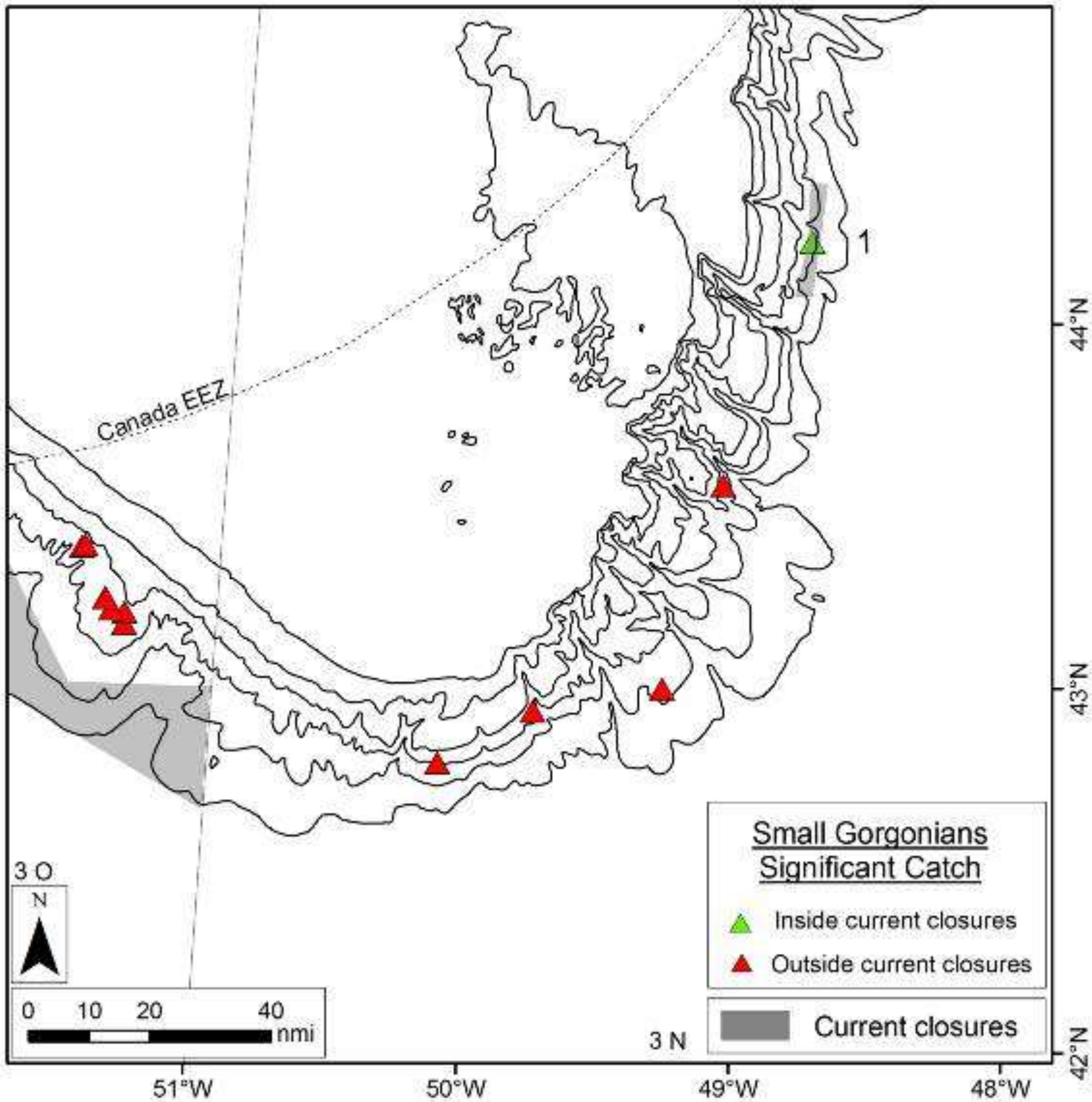


Figure 4.1.2. Magnification of Figure 4.1.1 for the Tail of the Grand Bank (NAFO Divisions 3NO).

The geospatial model used to generate encounter thresholds for sponges and sea pens was applied in exactly the same fashion to the small gorgonian corals. A biomass layer for the small gorgonian corals was created using the EU-Spain in Div. 3LNO and EU-Spain-Portugal in Div 3M trawl survey data for the period 2006-2010 (Figure 4.1.3). The simulation used 2000 randomly placed and oriented straight line simulation trawls of standard commercial tow length (13.8 nm). All lines generated by this method have a random start location and a randomly chosen heading between 0 and 360 degrees, at 1 degree intervals. As well, lines were not restricted from crossing into a closed area, and are limited to the footprint of the research survey small gorgonian biomass gridded surface layer. These lines are meant to mimic the research survey random trawl stations with commercial length trawls to reproduce the protocol for small gorgonian coral ground identification established previously (Kenchington et al. 2010, Cogswell et al. 2010) only using commercial trawl threshold values. We interpret the value to be the threshold that identifies a significant aggregation of small gorgonians. As the species are highly aggregated, the encounter value is not directly linked to the length of the trawl. The encounter could occur over a very short trawl or over a very long one. We have used the median trawl length to represent typical commercial tows.

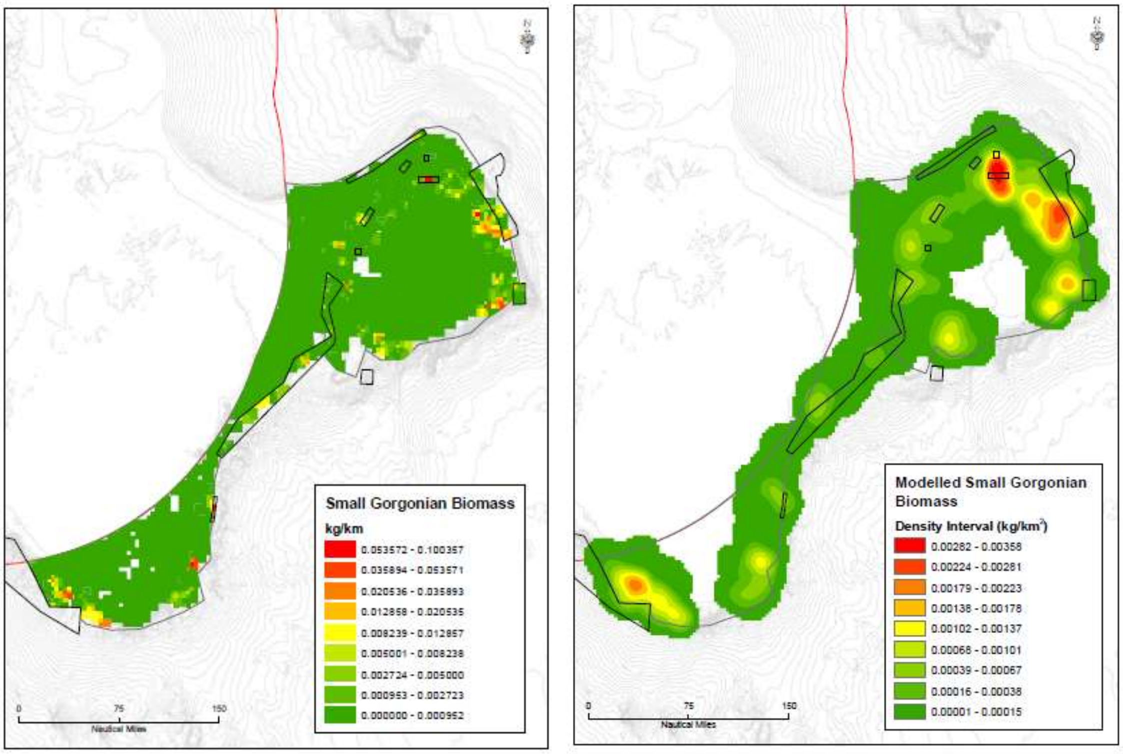


Figure 4.1.3. On the left small gorgonian coral gridded biomass distribution in the NRA based on Spanish/EU research vessel survey catch data (2006-2010). On the right, small gorgonian coral biomass in the NRA estimated from simulated commercial trawls.

Figure 4.1.4 illustrates the area occupied by the calculated density polygons for 13 catch weight thresholds between 0.0001 and 0.8 kg. In this series the first two weight categories have large increases in area as the polygons for the coral beds are established. Thereafter, the greatest change between successive categories occurs between 0.2 and 0.1 kg. Catches of 0.2 kg or more occupy an area of 9,231.9 km^2 in the NRA while catches of 0.1 kg or more occupy an area of 25,902.9 km^2, an increase of 180.6%. This threshold was established with a number of data points and the difference in area can be seen in Figure 4.1.5.

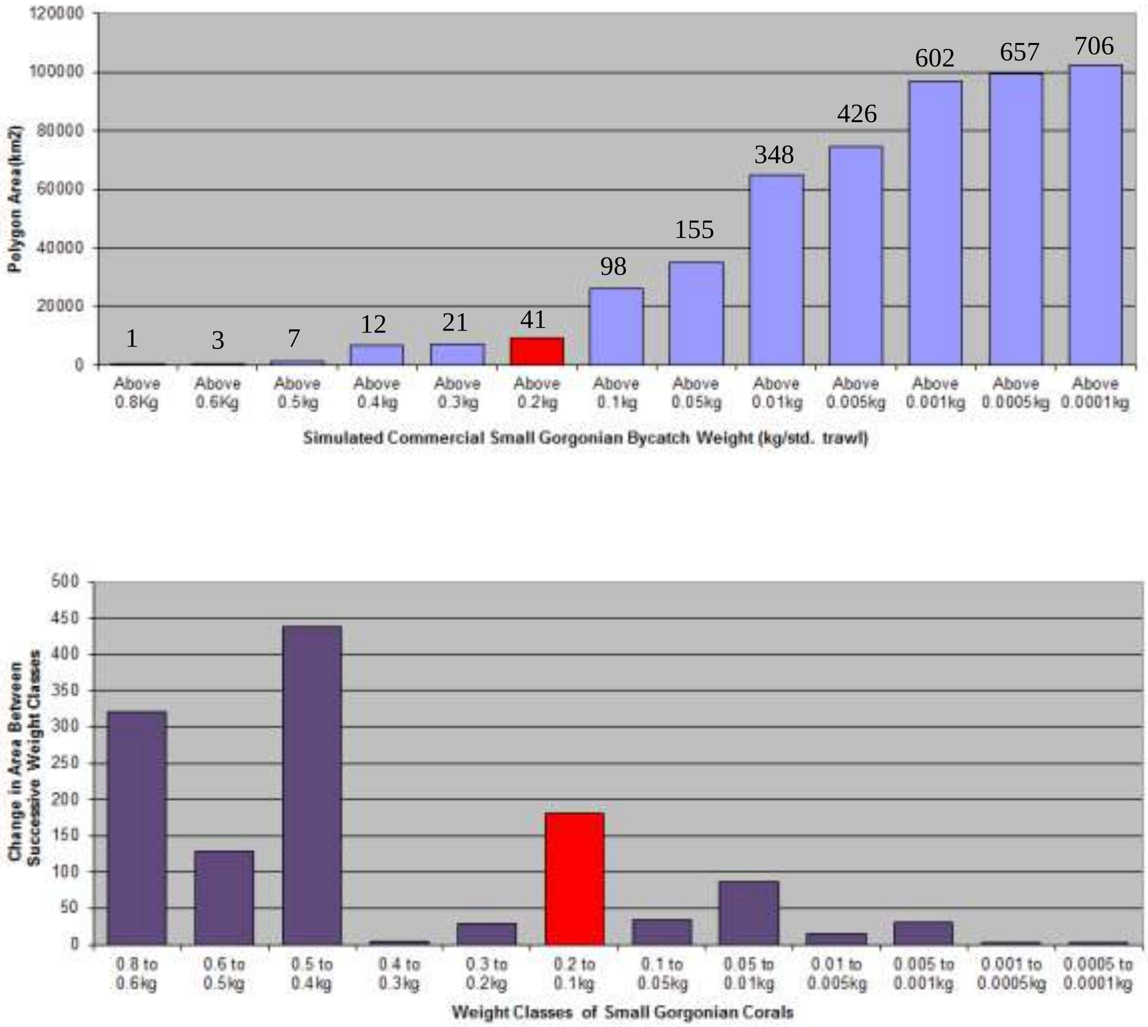


Figure 4.1.4. Area (km^2) occupied by tows with decreasing catch weight from ≥ 0.8 kg to ≥ 0.001 kg (upper). Increase in area between successive catch thresholds is indicated in the lower panel. The red bars indicates the selected level for the encounter threshold where the greatest difference in area occupied occurs between successive catch weight values and it is supported by a reasonable number of data points (indicated above the bars in the upper panel).

Figure 4.1.5. Polygons surrounding simulated trawl catches of ≥ 0.2 kg of small gorgonian corals (purple areas) compared with the area occupied by catches of ≥ 0.1 kg of small gorgonian corals (red areas) per standard trawl (13.8 nm).

An encounter threshold of 0.2 kg of small gorgonian corals could represent up to 30 colonies, although there is a lot of variation in size and therefore number. Figure 4.1.6 (left) illustrates a catch of 0.201 kg, which is the proposed threshold. The actual density *in situ* is unknown because we do not have any data about their catchability by the gear. However, given their preferred habitat on soft bottoms and their height off bottom of up to 30 cm (Kenchington et al. 2009; Figure 4.1.6) we believe that the catchability may be similar to that of the sea pens (Kenchington et al. 2011), that is enough to use the data as modeled above, to identify concentrations.

Figure 4.1.6. A catch of 0.201 kg of small gorgonian corals (*Acanella arbuscula*) from the NRA. (Photo courtesy of IEO) (left) and an underwater photo of *A. arbuscula* living on the soft sediments it is typically associated with (Photo courtesy of DFO).

The 2011 VMS fishing trawl lines were placed over the small gorgonian coral biomass layer in order to give some information on the impact of using this threshold on the fishing activities. 2000 commercial groundfish VMS lines were randomly chosen from within the 95% confidence interval of the normal transformed distribution of trawl length. The majority, 1321 (66.1%), of the commercial fishing in the NRA in 2011 would not have caught any small gorgonian corals. If a 0.2 kg encounter protocol were in place in 2011, 24 of the commercial trawls (1.2%) would have encountered small gorgonian coral above that threshold.

4.1.3 Recommendations for Encounter Thresholds for Large Gorgonian, Sea Squirts, Erect Bryozoans, Crinoids and Cerianthid Anemones in the NRA

They are issues with the data on large gorgonian corals, sea squirts, erect bryozoans, crinoids and cerianthid anemones when we go to apply the geospatial model developed for sponges, sea pens and small gorgonian corals. One of the issues is relating the research vessel catch biomass to *in situ* abundance. Catchability is believed to be very low for these taxa and trawls are not the appropriate gear to sample them. Therefore the WGEAFM has illustrated the known locations for these VME taxa, according to their relative abundance, as determined from the EU surveys noted above, and NEREIDA surveys in the NRA (2006-2010) (Figures 4.1.7, 8 and 9).

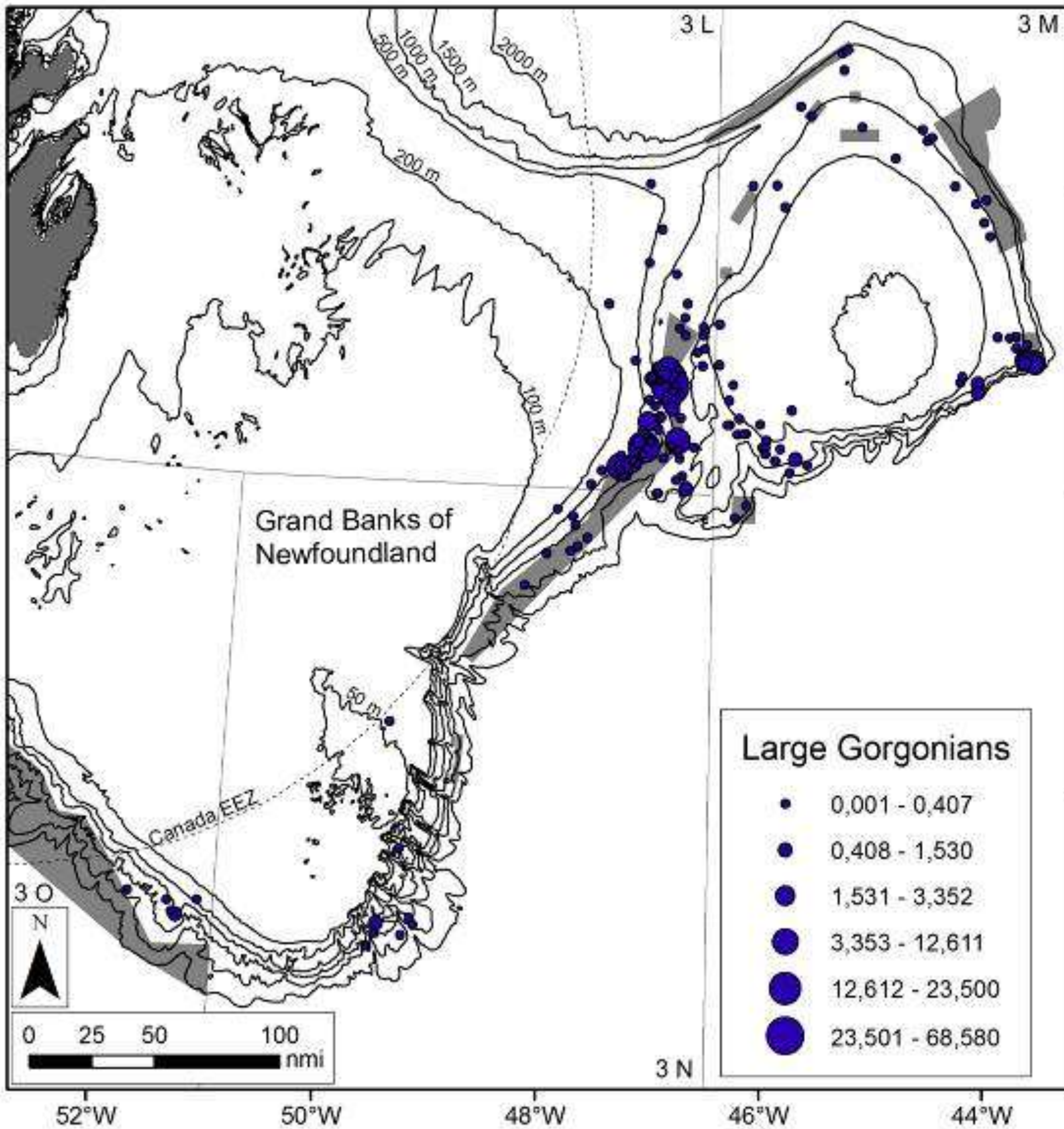


Figure 4.1.7. Relative abundance (kg/RV trawl) of large gorgonians from EU research trawl surveys in the NRA.

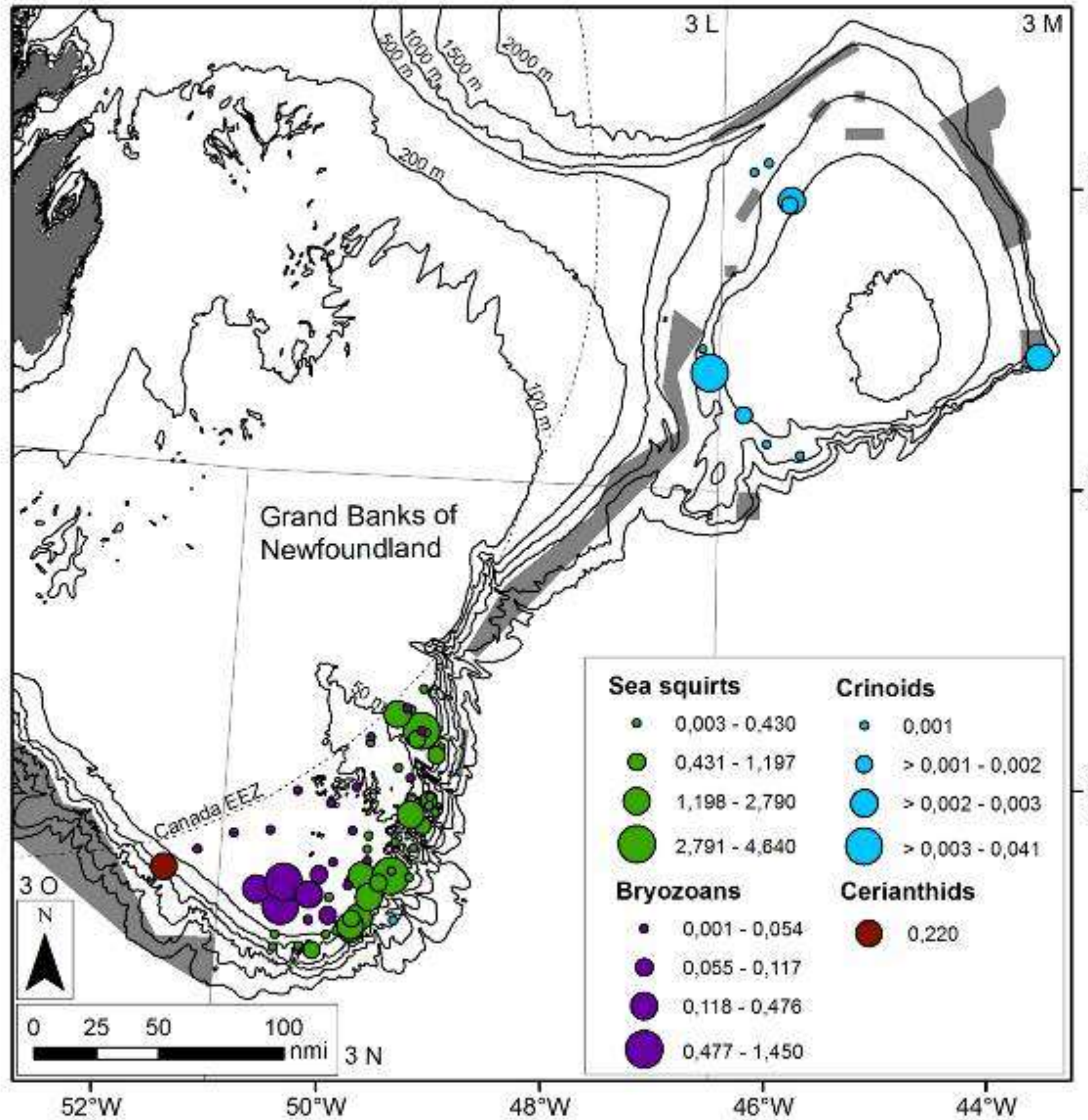


Figure 4.1.8. Relative abundance (kg/RV trawl) of sea squirts, crinoids, bryozoans and cerianthid anemones collected from EU research trawl surveys in the NRA.

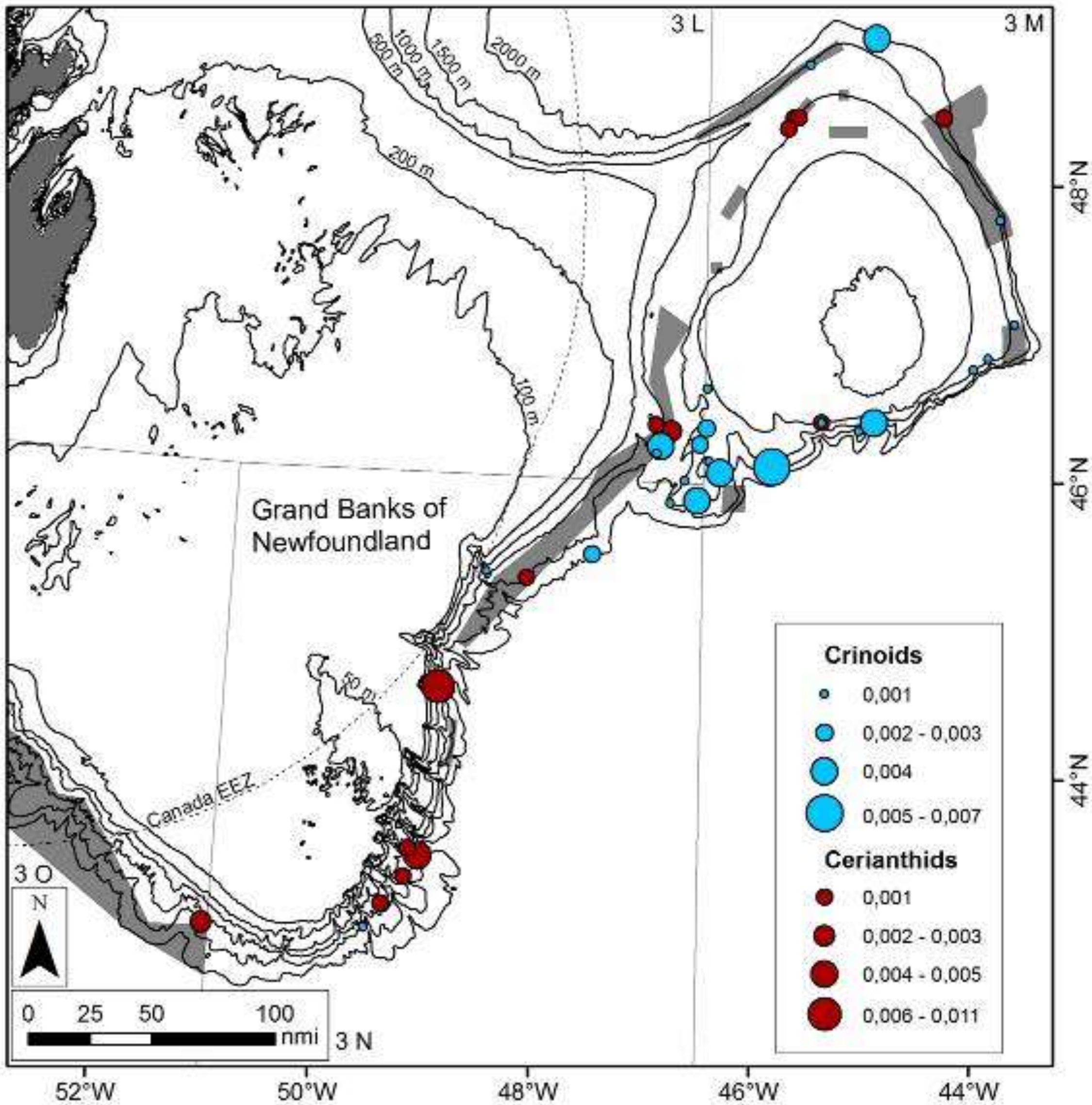


Figure 4.1.9. Relative abundance (kg/rock dredge set) of crinoids and cerianthid anemones collected from NEREIDA Project (Rock dredge sampler) in the NRA.

4.1.4. Recommendations for Encounter Thresholds for Large Gorgonian, Sea Squirts, Erect Bryozoans, Crinoids and Cerianthid Anemones Outside the Fishing Footprint in the NRA

There are not enough data available on the VME taxa outside the fishing footprint in the NRA. In the absence of data the same threshold defined for inside the fishing footprint should be applied. This is a reasonable assumption as similar sponge and other VME species straddle the slope waters.

4.1.5. Recommendations for Encounter Thresholds for Large Gorgonian, Sea Squirts, Erect Bryozoans, Crinoids and Cerianthid Anemones for the Exploratory Fishing Area of Seamounts

The different coral species composition and the likely absence of dense sponge and coral aggregations renders the GIS simulation/modeling framework useless to find a threshold for the exploratory fishing area of seamounts, even if suitable data were available. From our limited observations of these communities *in situ*, the WGEAFM speculate that individual coral and sponge species will occur at low density and <u>may or may not</u> be indicators for benthic communities dominated by other VME species. This situation may be similar to that seen with black corals around Flemish Cap. More data are needed to develop science-based encounter thresholds for the seamounts in the NRA. Exploratory fishing protocols should take every opportunity to fully document all benthic species by-catch so that we can better understand the vulnerability of the seamount benthos.

4.1.6. Recommendations for Move-on Rules for Large Gorgonian, Sea Squirts, Erect Bryozoans, Crinoids and Cerianthid Anemones for the Exploratory Fishing Area of Seamounts

Move-on rules for the small gorgonian corals discussed above would be very complex to apply. WGEAFM could calculate values based on the distribution maps provided above but the task of integrating the effects across the different VME species and fisheries would be complicated. Further, without scientifically based encounter thresholds for the other VME taxa, the associated move-on rule could not be proposed.

References

Cogswell, A., E. Kenchington, C. Lirette, B. Brodie, G. Campanis, A. Cuff, A. Perez, A. Kenny, N. Ollerhead, M. Sacau & V. Wareham. 2010. Evaluating sponge encounter thresholds through GIS simulation of the commercial groundfish fishery in the NAFO Regulatory Area. NAFO Scientific Council Research Document 10/71, Serial No. N5869, 26pp.

Cogswell, A., Kenchington E., Lirette, C., Murillo, F.J., Campanis, G., Campbell, N., & N. Ollerhead. 2011. Layers utilized by an ArcGIS model to approximate commercial coral and sponge by-catch in the NAFO Regulatory Area. NAFO SCR Doc. 11/72, Serial No. N6002, 50 pp.

Kenchington, E., M. Best, A. Cogswell, K. MacIsaac, F. J. Murillo-Perez, B. MacDonald, V. Wareham, S. D. Fuller, H. I. Ø. Jørgensbye, V. Sklyar, & A. B. Thompson. 2009. Coral Identification Guide NAFO Area. *Sci.Coun. Studies*, **42**: 1-35. doi:10.2960/S.v42.m1

Kenchington, E., A. Cogswell, C. Lirette & J. Rice. 2010. A GIS Simulation Model for Estimating Commercial Sponge Bycatch and Evaluating the Impact of Management Decisions. DFO Canadian Scientific Advisory Secretariat Research Document 2010/040. vi + 39 pp.

Kenchington, E., Murillo, F.J., Cogswell, A., & C. Lirette. 2011. Development of encounter protocols and assessment of significant adverse impact by bottom trawling for sponge grounds and sea pen fields in the NAFO Regulatory Area. NAFO SCR Doc. 11/75, Serial No. N6005, 51 pp.NAFO. 2011. Report of the NAFO SC

NAFO. 2011. Report of the NAFO SC Working Group on Ecosystem Approach to Fisheries Management (WGEAFM). NAFO SCS Doc. 11/22, Serial No. N6006, 126 pp.

ToR 4.2. [FC Request # 16].

Begin the development of the assessment of risk of significant adverse impacts on VME indicator aggregations and VME elements in the NAFO RA by

a) Analyze fishing effort (VMS data) in the NRA to define areas of different levels of fishing intensity (e.g a map of 90%, 80%, 70%... effort) and assess these in conjunction with habitat data in order to map out areas where fishing activities would therefore have no or little significant adverse impact on VMEs and where encounter protocols and move on rules would therefore have little utility.

b) In view of the area management currently implemented and to facilitate evaluation of the need for further protective measures in response to UNGA 61/105, assess the risk of significant adverse impacts on VME indicator aggregations and VME elements in the NAFO RA. This assessment should consider spatial and temporal distribution of fishing activity, and the best available knowledge on the spatial distribution of VME indicators and VME indicator elements.

4.2.1 Introduction

The United Nations General Assembly (UNGA) resolution 61/105 (2006)[1] requested RFMOs to, in accordance with the precautionary approach and ecosystem approaches, assess whether bottom fishing activities would have significant adverse impacts (SAIs) on vulnerable marine ecosystems (VMEs) and ensure that proper conservation and management measures are put into place to prevent such impacts.[2] It also requested RFMOs to close areas to bottom fishing where VMEs (including seamounts and cold water corals) are known to occur or are likely to occur (based on the best available scientific information) and ensure that such activities do not proceed unless conservation and management measures have been established to prevent SAIs on VMEs.[3]

Following a review of the implementation of UNGA Resolution 61/105, the UNGA Resolution 64/72 (2009) emphasized that impact assessments are to be conducted in accordance with the FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO Guidelines) criteria.[4] In addition, this resolution requested RFMOs and flag states to ensure that vessels do not engage in bottom fishing until such assessments have been carried out.[5]

The FAO Guidelines, besides providing guidance on the management of deep-sea stocks, describes what constitutes a VME, defines SAI and provides the criteria for assessing SAIs.[6]

In accordance with the FAO Guidelines, the definition of significant adverse impacts is the following:

those that compromise ecosystem integrity (i.e. ecosystem structure or function) in a manner that: (i) impairs the ability of affected populations to replace themselves; (ii) degrades the long-term natural productivity of habitats; or (iii) causes, on more than a temporary basis, significant loss of species richness, habitat or community types. Impacts should be evaluated individually, in combination and cumulatively.[7]

In addition, the following six factors should be considered when determining the scale and significance of an impact

i. the intensity or severity of the impact at the specific site being affected;

ii. the spatial extent of the impact relative to the availability of the habitat type affected;

iii. the sensitivity/vulnerability of the ecosystem to the impact;

iv. the ability of an ecosystem to recover from harm, and the rate of such recovery;

v. the extent to which ecosystem functions may be altered by the impact; and

vi. the timing and duration of the impact relative to the period in which a species needs the habitat during one or more of its life history stages.[8]

Temporary impacts are defined as those that are limited in duration and that allow the particular ecosystem to recover over an acceptable time frame. The FAO Guidelines recommends that such time frames is to be decided on a case-by-case basis and should be in the order of 5-20 years, taking into account the specific features of the populations and ecosystems.[9] However, in determining whether an impact is temporary, both the duration and the

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[1] UNGA Resolution on Sustainable Fisheries, A/RES/ 61/105 (2006), Para. 83.
[2] *Ibid*, Para. 83 (a).
[3] *Ibid*, Para. 83 (c).
[4] UNGA Resolution on Sustainable Fisheries, A/RES/64/72 (2009), Para. 119 (a).
[5] Ibid.
[6] Food and Agriculture Organization of the United Nations, International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (Rome: FAO, 2009).
[7] *Ibid*, Para. 17.
[8] *Ibid*, Para. 18.
[9] *Ibid*, Para. 19.

frequency at which an impact is repeated should be considered. If the interval between the expected disturbance of a habitat is shorter than the recovery time, the impact should be considered more than temporary.[10] In circumstances of limited information, the precautionary approach should be applied with respect to the nature and duration of impacts.[11]

The FAO Guidelines' provisions on SAI (as described above) were endorsed and incorporated by NAFO's Conservation and Enforcement Measures in its Art. 15 (9).[12] In addition, the criteria for assessing SAIs on a given area are also provided by the FAO Guidelines[13] and by NAFO Conservation and Enforcement Measures.[14] The criteria includes, but is not restricted to: fishing plans, baseline information on the ecosystems, habitats and communities; identification, description and mapping of VMEs known or likely to occur in the NAFO area; evaluation of occurrence, scale and duration of likely impacts, including cumulative impacts; VME elements; risk assessment of likely impacts to determine likely SAIs on VMEs; as well proposed mitigation and management measures to prevent SAIs on VMEs, and measures to be used to monitor effects of the fishing operations. The FAO Guidelines determines that the results of the impact assessments will contribute to the determination of proper conservation and management measures to ensure long-term conservation and sustainable utilization of low-productivity fishery resources in addition to measures that confer adequate protection and prevent SAIs on VMEs.[15]

A reassessment of bottom fishing impacts following the criteria described above will be conducted by NAFO by 2016.[16]

With respect to the adoption of encounter protocols and move on rules, as requested by UNGA and FAO, RFMOs are expected to take into account best available information from detailed seabed surveys and mapping, other relevant information available for the area, and other conservation and management measures to protect VMEs.[17] Such measures include, *inter alia*: effort and/or catch controls; temporal and spatial restrictions or closures; and changes in gear.[18]

As a result of the 2011 review of the implementation of the UNGA resolutions 61/105 and 64/72 by RFMOs, UNGA Resolution 66/68 called for the strengthening of the procedures for carrying out assessments to take into account individual, collective and cumulative impacts.[19] It also encouraged RFMOs to consider the results available from marine scientific research, including those obtained from seabed mapping progammes concerning the identification of areas containing VMEs and to adopt proper conservation and management measures, including closures.[20]

4.2.2 Assessment of the risk of significant adverse impacts on VME indicator aggregations.

It is the goal of these methods to estimate the interactions between varying levels of fishing intensity (2008-2011) and 2 VME taxa (sponge and sea pens) within the fishing footprint (NAFO, 2009) and immediately adjacent closed areas (NAFO, 2011) (referred to hereafter as the "**study area**" - Figure 4.2.2.1). The method essentially involves 3 steps which will be elaborated upon below, but in summary the first step generates a fishing intensity surface created for each year (2008-2011) by summing the number of NAFO Vessel Monitoring Service (VMS) pings (0.5 - 5 kts) per *master grid* cell. The values from the fishing intensity surface grid cells are sorted from the highest intensity to the lowest, then a surface is created that represents the highest intensity grid cells (e.g. those that make up the top 10% or 90th percentile of total effort). This was repeated successively for lower percentiles of effort intensity within each 5.5 x 5.5 km cell of the *master grid*. Second, biomass surfaces were created utilizing the specified VME

[10] *Ibid*, Para. 20.
[11] *Ibid*, Para. 20.
[12] NAFO/FC Doc. 13/1.
[13] FAO Guidelines, Para. 47.
[14] NAFO/FC Doc. 13/1, Annex I.E., Part V.
[15] FAO Guidelines, Para. 47 (vii), and 70.
[16] NAFO/FC Doc. 13/1, Art. 23.
[17] FAO Guidelines, Para. 68.
[18] *Ibid*, Para. 71.
[19] UNGA Resolution on Sustainable Fisheries, A/RES/66/68 (2011), Para. 129 (a).
[20] *Ibid*, Para. 132.

taxa caught by the EU trawl survey (2005-2010). Finally, for the preliminary study of interactions between VME indicator species and fishing activity, a composite fishing intensity surfaces was created using only cells for each fishing intensity interval common to each of the four years of VMS data available to this study (2008-2011). This layer was then assessed in relation to its overlap or interaction with the biomass layers of sponge and sea pen.

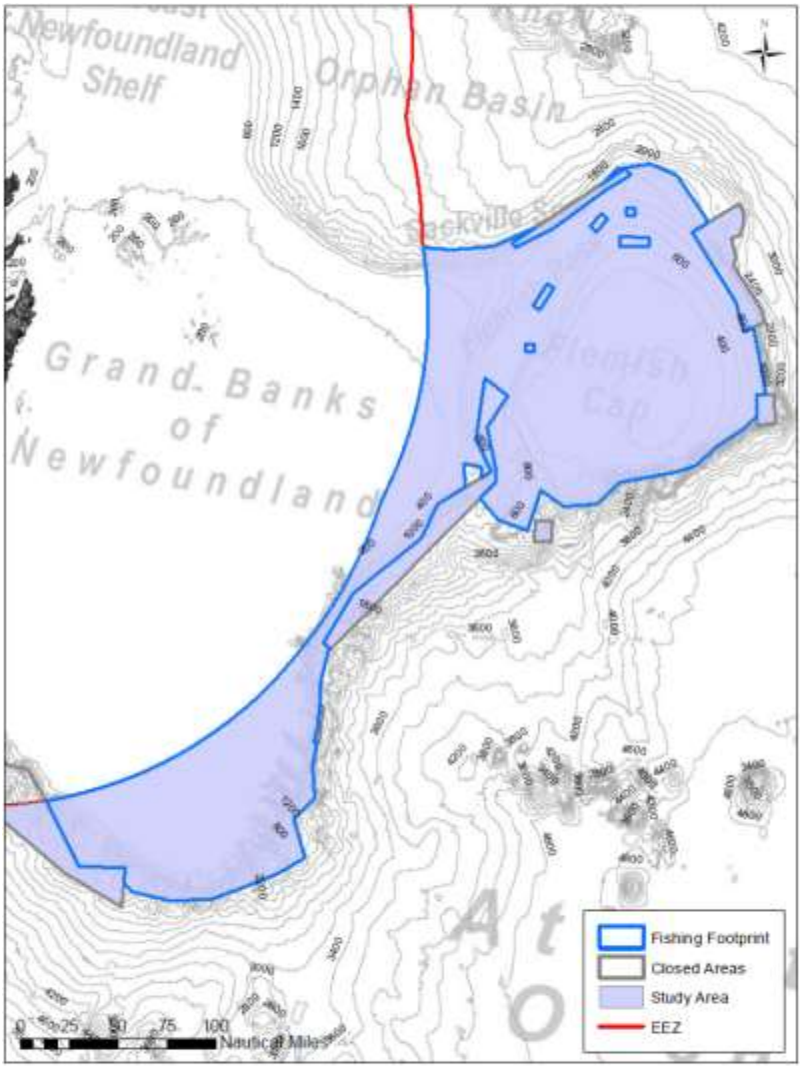

Figure 4.2.2.1. The study area comprised of the fishing footprint and the adjacent closed areas.

4.2.2.1 Fishing Intensity Surfaces

Processing of VMS Pings by NAFO

All VMS data (latitude, longitude, vessel identity, date, time and recorded speed) was extracted from the database by staff of the NAFO secretariat, on an annual basis, for the period 2008 – 2012. This time period was selected on the basis it represented a relatively stable and high frequency of pings for comparative inter annual analysis. The time duration associated with each VMS ping (time from one ping to the next from a particular vessel) was calculated and associated with each respective point. The data set was then filtered to include only those points at fishing speeds (0.5 – 5 knots). Identifying information was removed from the data set, which was then passed on for further analysis.

Fishing Intensity Percentile Areas

For each year where VMS data had been pre-processed (2008-1011), the ArcGIS "Spatial Join" tool was used to calculate the total number of VMS pings (0.5-5kts) within each cell of the master grid (Figure 4.2.2.1.1). For each year, the number of pings in each cell, a proxy of fishing intensity, was sorted from greatest intensity to least. This can be viewed graphically for each year in Figure 4.2.2.1.2, where the amount of fishing intensity per cell is plotted against the fishing intensity percentiles. The area represented by intensity percentiles can be viewed in two ways, namely; by maps representing the cells corresponding to each intensity threshold (Figure 4.2.2.1.3), and by plotting the cumulative area corresponding to each percentile for all years (Figure 4.2.2.1.4). It is noteworthy, that while there is an obvious difference in the number of pings between years at various percentiles (Figure 4.2.2.1.2), the total area represented by percentiles is similar between years (Figure 4.2.2.1.4).

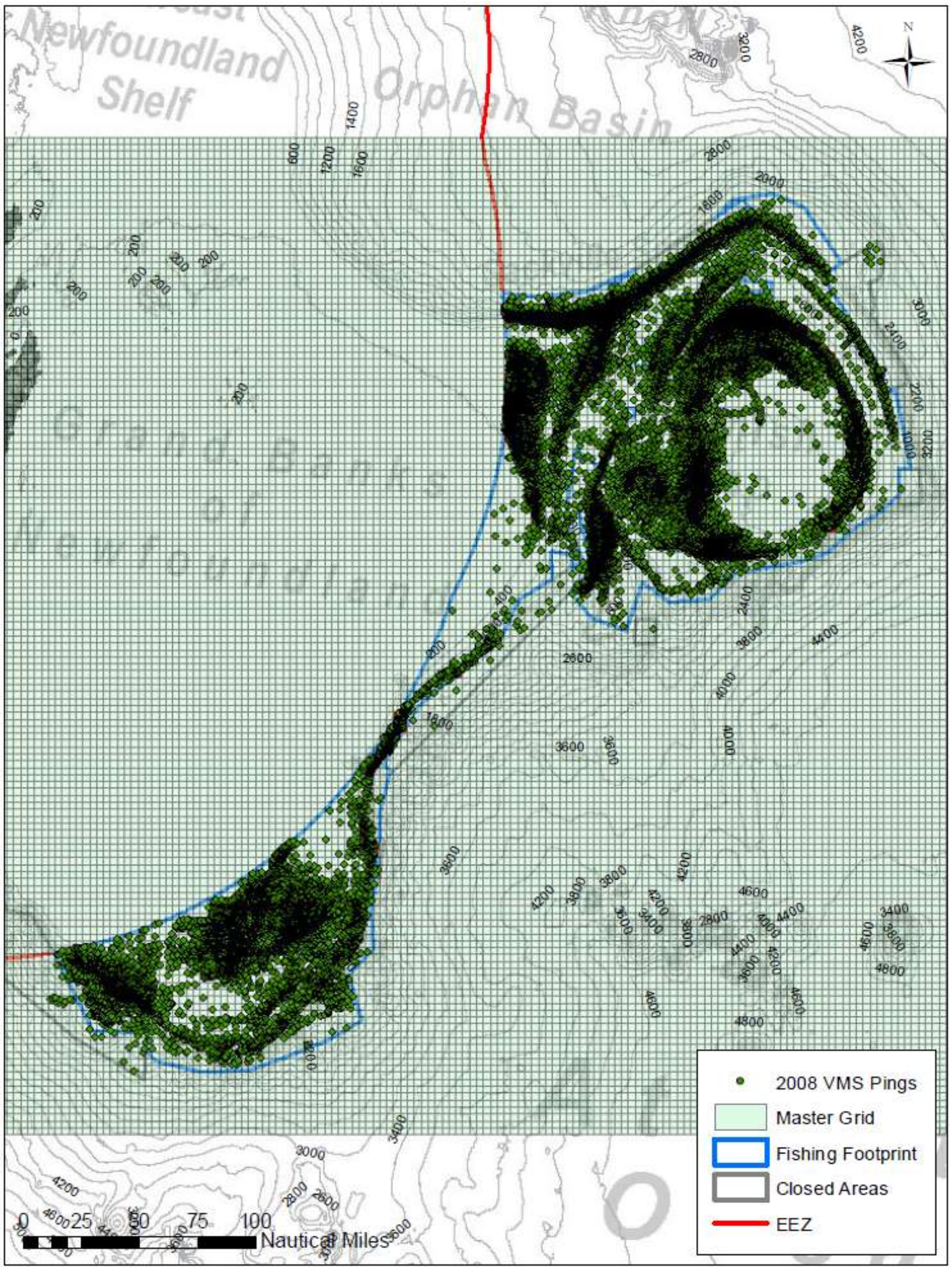

Figure 4.2.2.1.1 VMS pings from 2008 with speeds between 0.5 and 5kts, clipped to the extent of the study area. The VMS ping counts within each grid cell were calculated to create a proxy surface of fishing intensity for each year where VMS data were available (2008 - 2011).

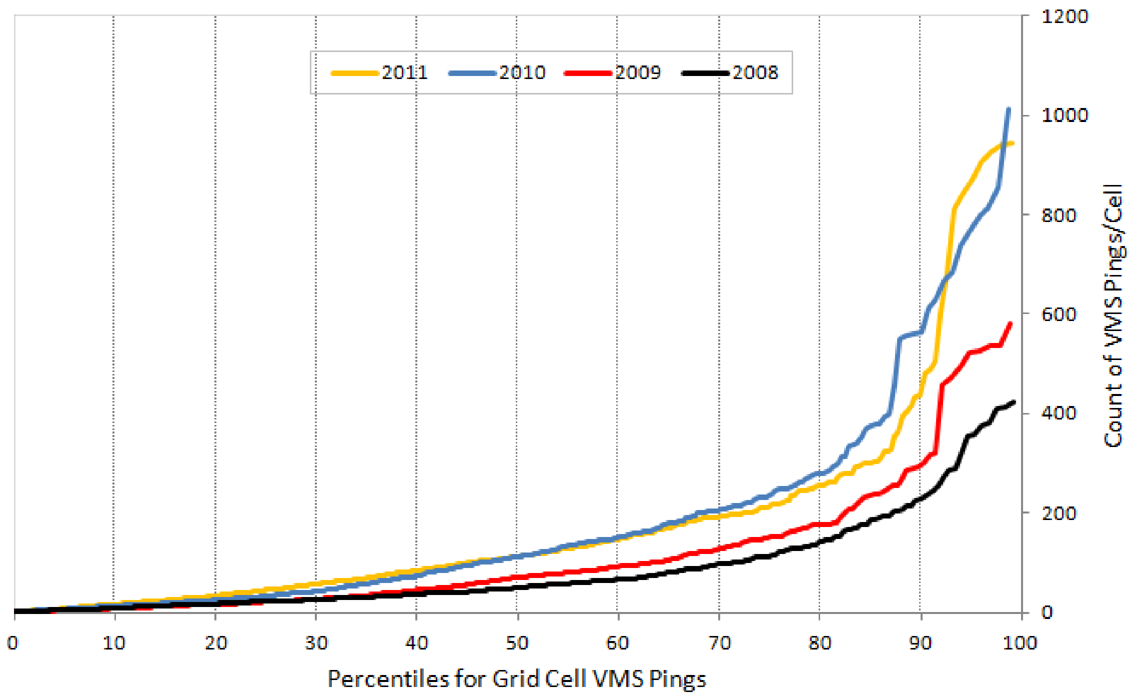

Figure 4.2.2.1.2 The percentile of pings (x) plotted against the actual number of pings encountered in each grid cell (y), for each year. Cells representing each percentile (e.g., 90 = 90 to 100, 50 = 50 to 100) are extracted and plotted for each year as shown below in Figure 4.2.2.1.3. The 90th percentile (top 10% of fishing activity), while represented by little surface area corresponds to the most heavily fished areas.

Each equal percentile interval has an equal amount of fishing effort (e.g. the same number of VMS pings).

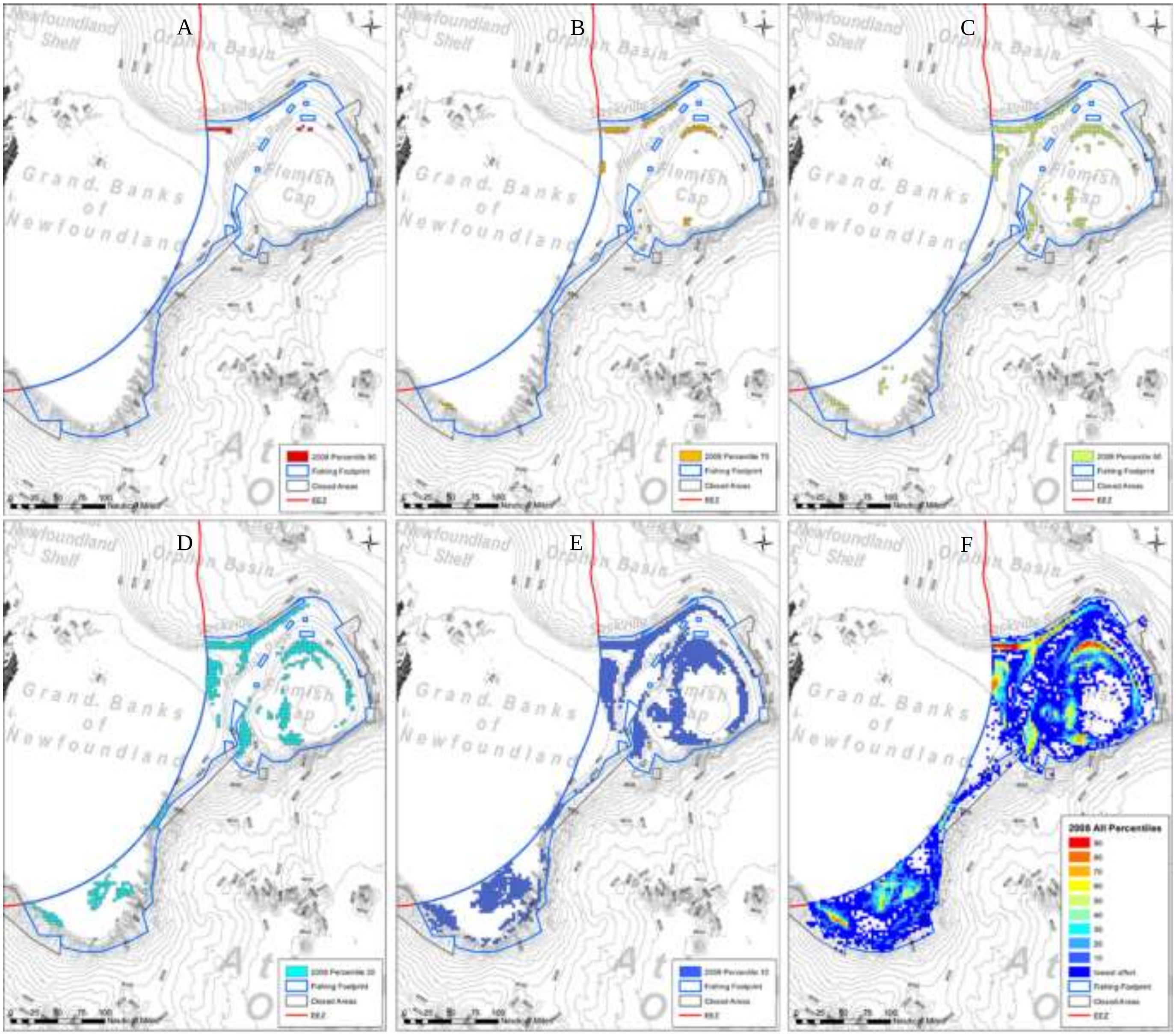

Figure 4.2.2.1.3. The area occupied by VMS pings which are greater than the 90th percentile (A), >70th (B), >50th (C), >30th (D), >10th (E), and the area representing all VMS ping percentiles from 2008, from high (red > 90%) to low (dark blue <10%) in intervals of 10% (F). These layers were produced for each year available, in order to compare inter-annual variability.

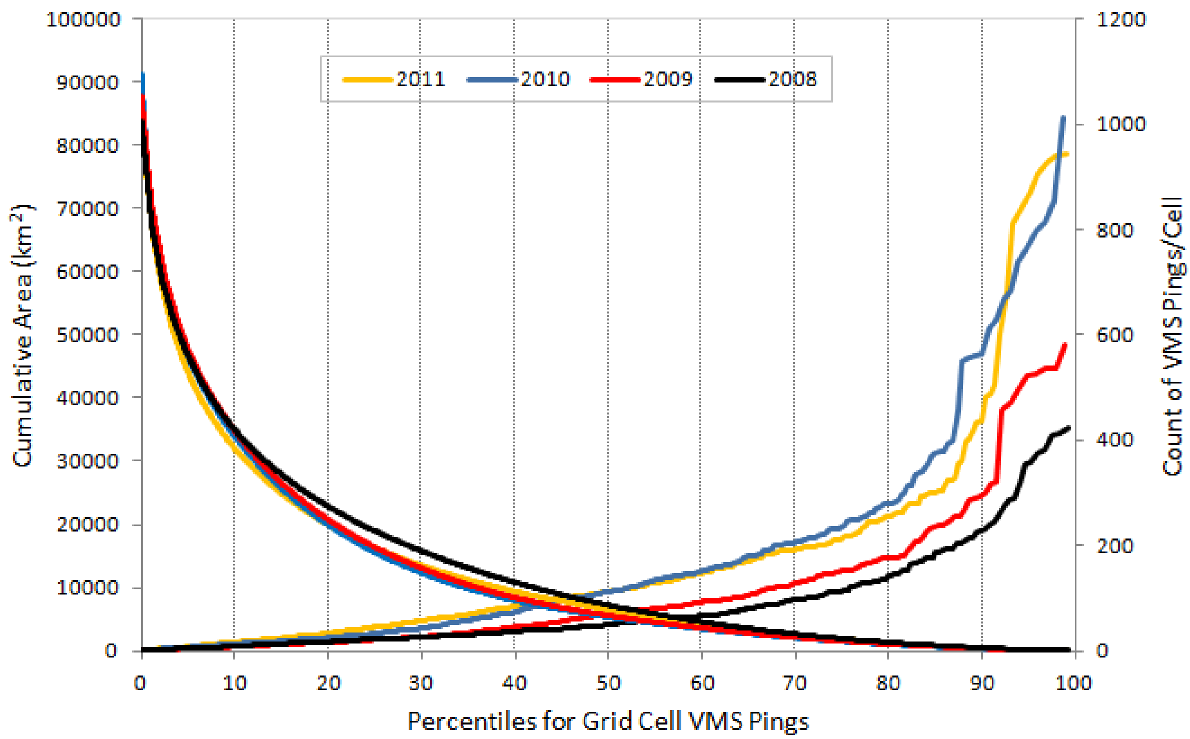

Figure 4.2.2.1.4. The cumulative area occupied by VMS ping percentiles for each year (2008-2011) (left x-axis), in relation to the number of VMS pings/cell at the same percentage. The area at the 50th ping percentile represents the area occupied by the top 50% of fishing intensity (50-100). Within the NRA, the areas fished most intensely represent only a small fraction of the total fished area for any given year.

From Figure 4.2.2.1.4, it can clearly be see that for the effort defined by the lowest number of VMS pings per cell (e.g. <10th percentile) there is a large increase in the cumulative area fished. By contrast the effort defined by the highest number of VMS pings per cell, corresponds to a very small area fished. Figure 4.2.2.1.5 shows a strong relationship between the standardized % of total fished area (percentile interval area/total fished area *100) and the standardized % effort per unit area (percentile interval VMS pings/total number of pings*100)/interval area). This relationship clearly shows a large and rapid reduction in the area fished between the 0 and 10th percentiles, above the 10th percentile the reduction in area declines rapidly whilst the intensity of fishing rapidly increases. From this analysis the cumulative area fished above the 10th percentile is about 15% of the total fished area, whereas the total area fished below 10th percentile is about 60% of the total fishable area (Figure 4.2.2.1.5). Given the relative rapid increase in the unit area of fishing intensity above the 10th percentile, and assuming this area has been fished at this level of activity for a large number of years, then the likelihood of present day or future encounters with VME indicator species will be low compared to the area of seabed defined by fishing below the 10th percentile.

To test this hypothesis, it is important we have an estimate the inter-annual variability in the spatial extent and location of fishing areas defined by each percentile interval, and to define the percentile areas which are common to all four years – as these will be the areas that have equal fishing intensity for a given percentile interval which we term "*composite or core fishing intensity areas*".

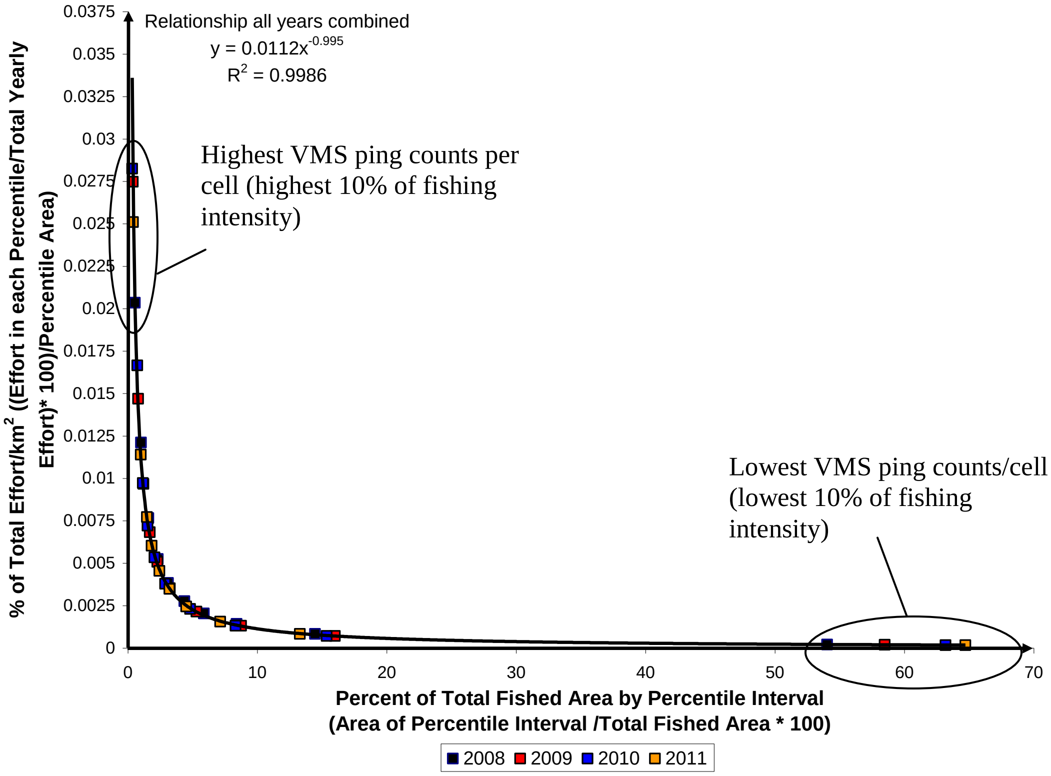

Figure 4.2.2.1.5. The relationship between area occupied by each fishing intensity percentile (x-axis) and corresponding fishing intensity/unit area within that interval area (y-axis). The lower right points represent intervals with low fishing intensity over a large area. The area for this interval is ~55-65% of the total area depending on the year. The upper left points represent high fishing intensity in a very small area representing a fraction of a percent of the total area fished for any one year.

Defining Composite Fishing Intensity Layers

To create percentile areas of fishing activity which are consistent between years, it was first necessary to create composite percentile area that incorporated cells common to all four years. Such composite percentile layers can then be used in combination with the biomass surfaces of sponge and sea pen to estimate the likely interactions between fishing intensity and biomass. Generating a composite layer clearly has the advantage of defining a "most likely" scenario for percentile areas, but disregards abrupt changes in fishing patterns between years that could be associated with the opening or closing of a particular fishery for example. While a "common composite" approach has been taken here, more thought must go into how varying percentiles of fishing intensity and the corresponding area for each percentile should be presented. A single high intensity year at one location, amongst many low or zero intensity years at the same location, may be deemed detrimental to some VME species, but relatively inconsequential to others. One alternative approach (not tested here) would be to define each percentile area as a sum of all years for a fixed interval of time (e.g. 4 years, 2008 to 2011), and then use this additive layer for each percentile interval to investigate the degree of interaction with VME indicator species. There is also the need to consider the risk or likelihood of a specific area of the seabed being impacted by bottom trawling. This can be calculated for each grid cell using the estimate of the density of pings per cell and the dimensions of the fishing gear making contact with the seabed. Whilst these calculations have not been performed in this assessment it is reasonable to assume that for any given percentile interval that those cells which are common to all four years will have a higher risk of impact than those which are defined by only one year (out of four years).

The GIS technique, as it was presented at the 2012 WGEAFM meeting, identifies the composite or "core" fishing areas for each intensity percentile. As with all surfaces created using GIS, it's power is a function of the data from which it is comprised and the resolution in which it is presented. The gridded "core" fishing surfaces created to demonstrate interactions is one of many possible solutions for defining varying levels of fishing intensity. It is likely that while the concept will continue to be utilized during future versions of the technique, the layers utilized will be adjusted as necessary to address the question at hand.

Creating Core Fishing Intensity Layers

The ArcGIS "Cell Statistics" tool was utilized to sum the raster cells from all 4 years (2008-2011) of a single percentile into a composite percentile surface that shows the area occupied by 4 classes of cells (1-4). A cell with a value of 1 is only represented by the percentile for a single year, while a value of 4 means that percentile intensity is present in those cells for all 4 years (Figure 4.2.2.1.6). For the purposes of this study, only the composite for each percentile common to all for years (defined as the core fishing area) was utilized in the next step to assess the likely interactions with the biological layers discussed in section 4.2.2.2. A few of core these percentile areas is shown in Figure 4.2.2.1.7. Figure 4.2.2.1.8 shows the cumulative area occupied by each of the core percentiles in comparison to the area occupied by each percentile on a yearly basis.

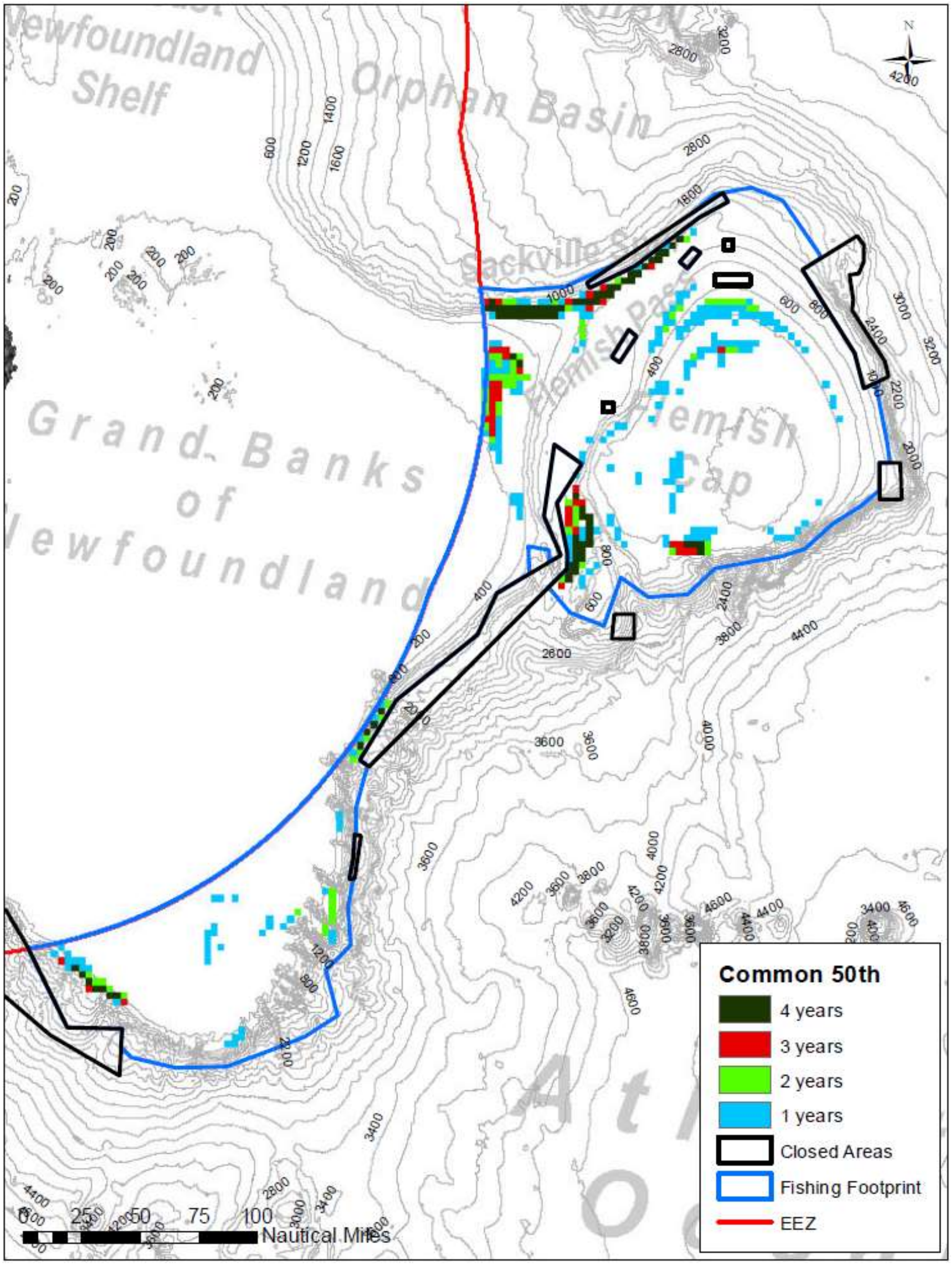

Figure 4.2.2.1.6. The composite area of the cumulative fishing activity greater than the 50th percentile (top 50% of fishing intensity). Black cells denote where this percentile is common to all four years.

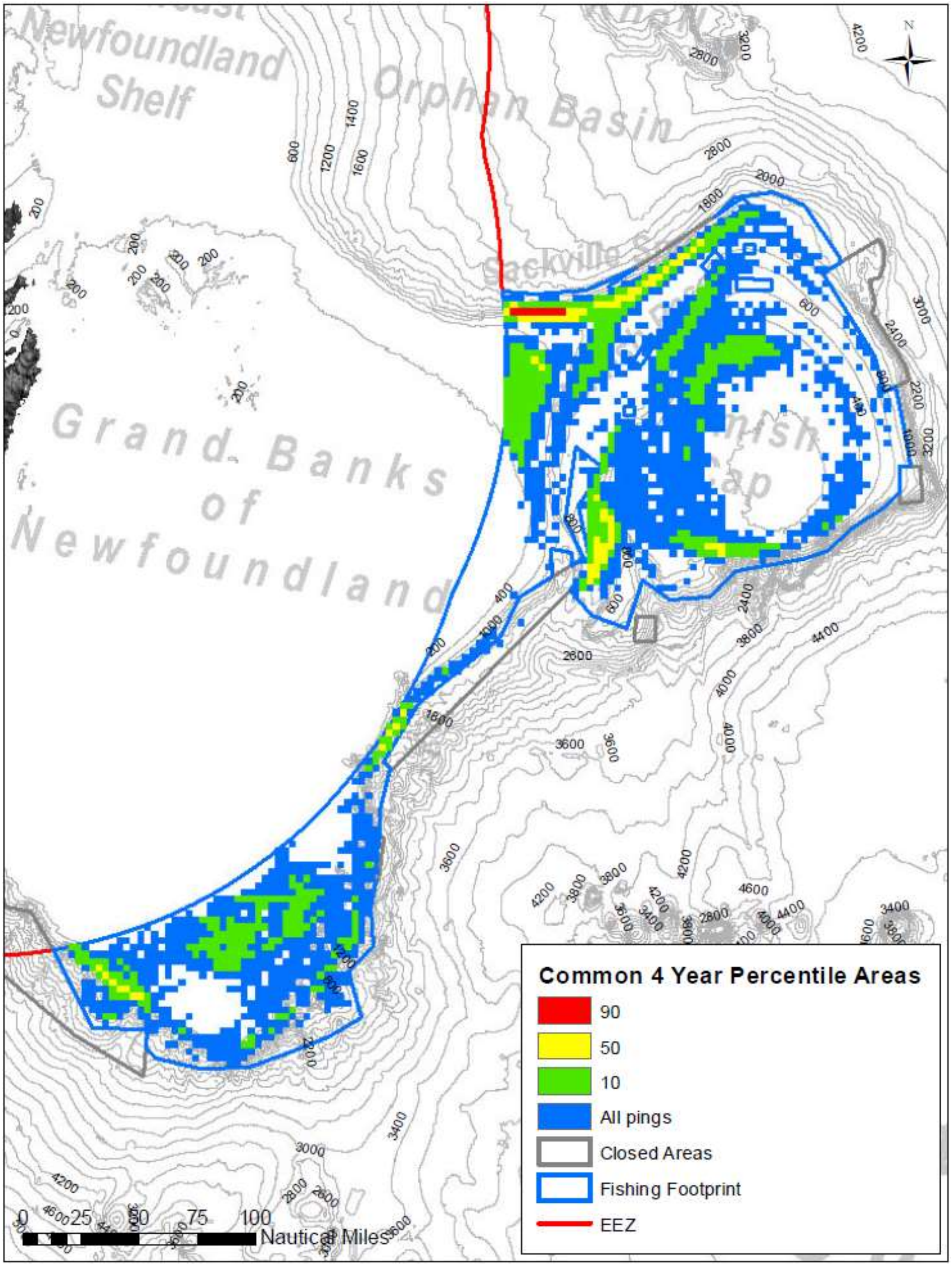

Figure 4.2.2.1.7. VMS ping intensity percentiles where each cell within a percentile is represented by each of the 4 years. The 90th percentile area (red) represents all the fishing activity greater than the 90[th] percentile e.g. it is the area with the highest 10% of ping intensity common to all 4 years.

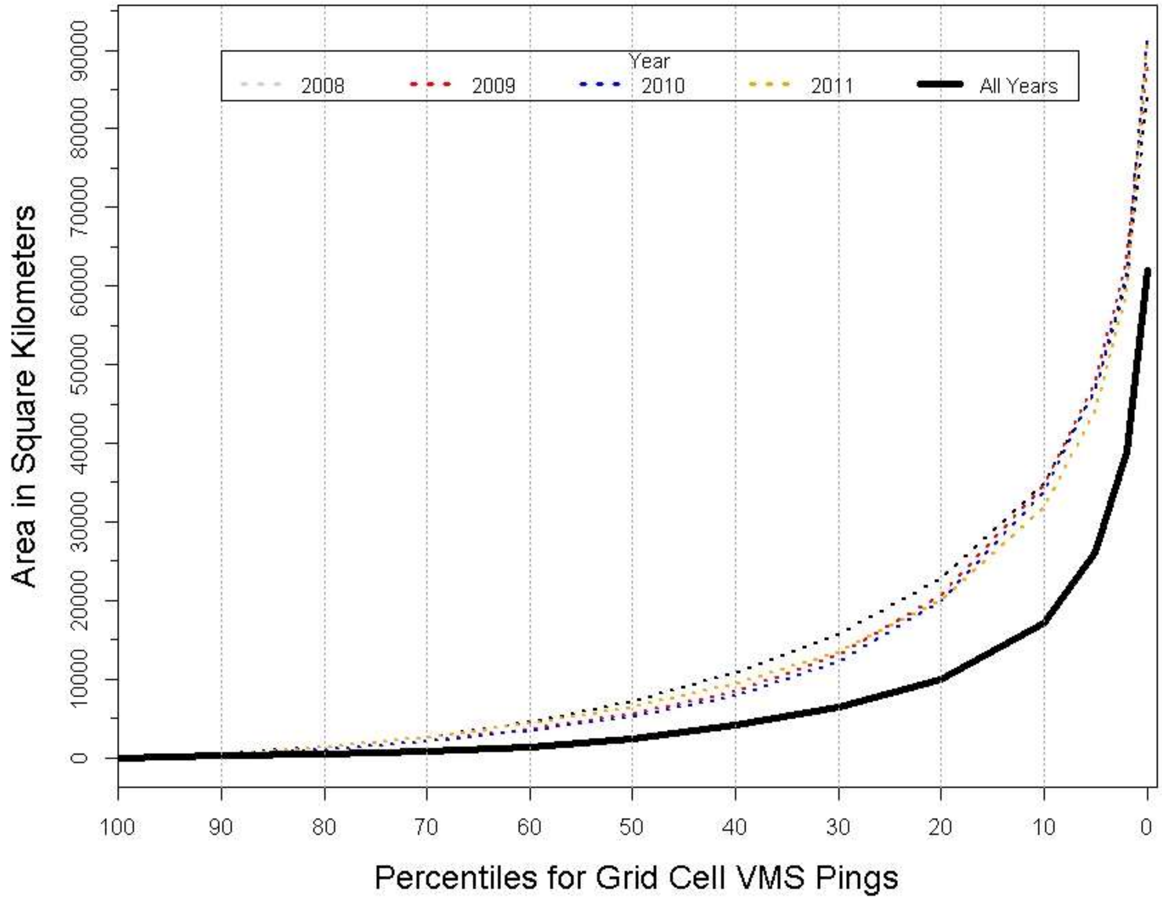

Figure 4.2.2.1.8. The area occupied by percentiles with cells common to all 4 years. This area represents the core fishing area for each percentile. The reduction in area associated with the "core" (all years) percentiles shows that while relative total area between years at each percentile remains constant, the distribution of that area differs between years.

4.2.2.2 Creating the Biomass Surface Layers

Sponge

The sponge biomass surface was generated using 2,066 sponge (1,294) and null-sponge (772) catch records from the EU trawl survey from 2005 to 2010 (Figure 4.2.2.2.1). Below, Table 4.2.2.2.1 summarizes the EU trawl survey sponge catch within the study area. The Canadian trawl survey sponge catch data was not used for this study for reasons described in detail in Cogswell et al. (2011). As shown in Figure 4.2.2.2.2, 65 (~5%) of the total 1,294 EU survey sponge trawls accounted for ~95% of the total sponge biomass caught.

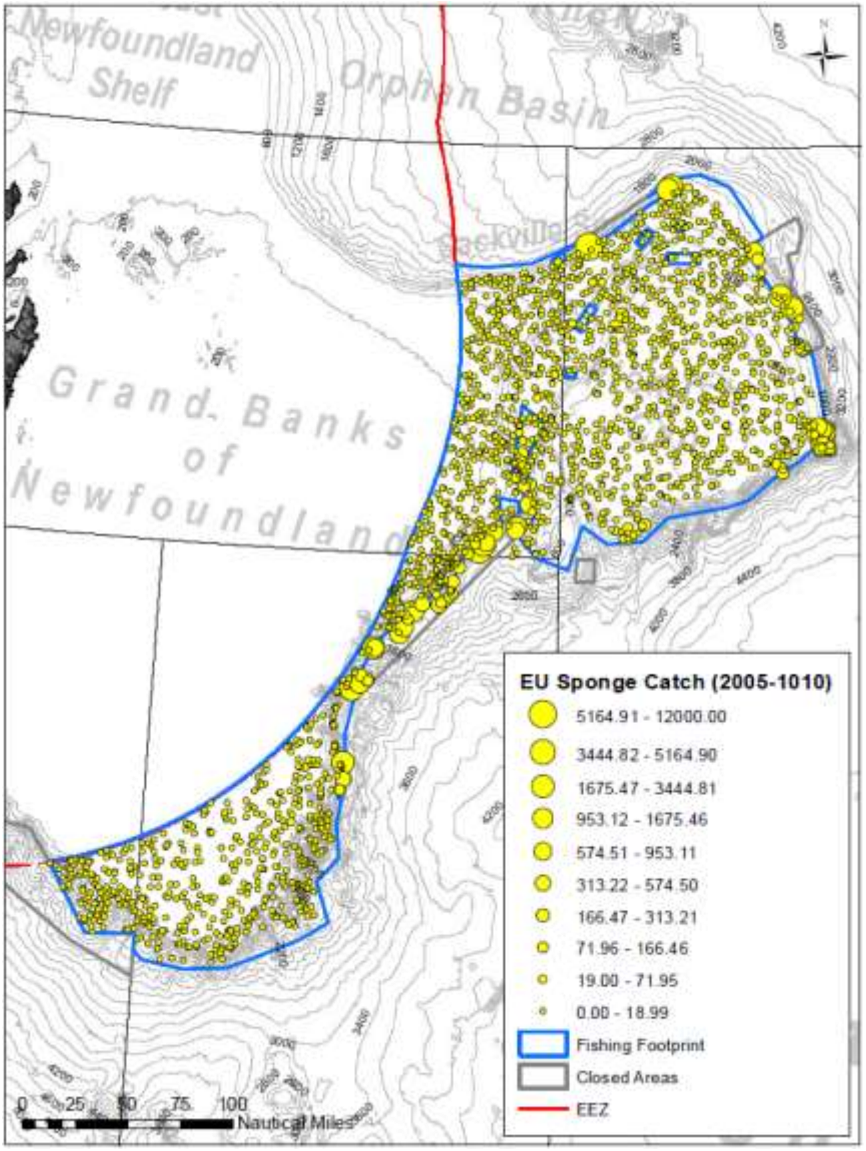

Figure 4.2.2.2.1 The EU trawl survey sponge (2005-2010) catch records (kg) within the *study area*.

Table 4.2.2.2.1. Summary of EU trawl survey sponge catch within the *study area* (2005-2010).

# Trawls	With Sponge	Total Catch (kg)	Min	Median	Max	Mean
2,066	1,294 (63%)	75,473	0.001	0.2	12,000	58

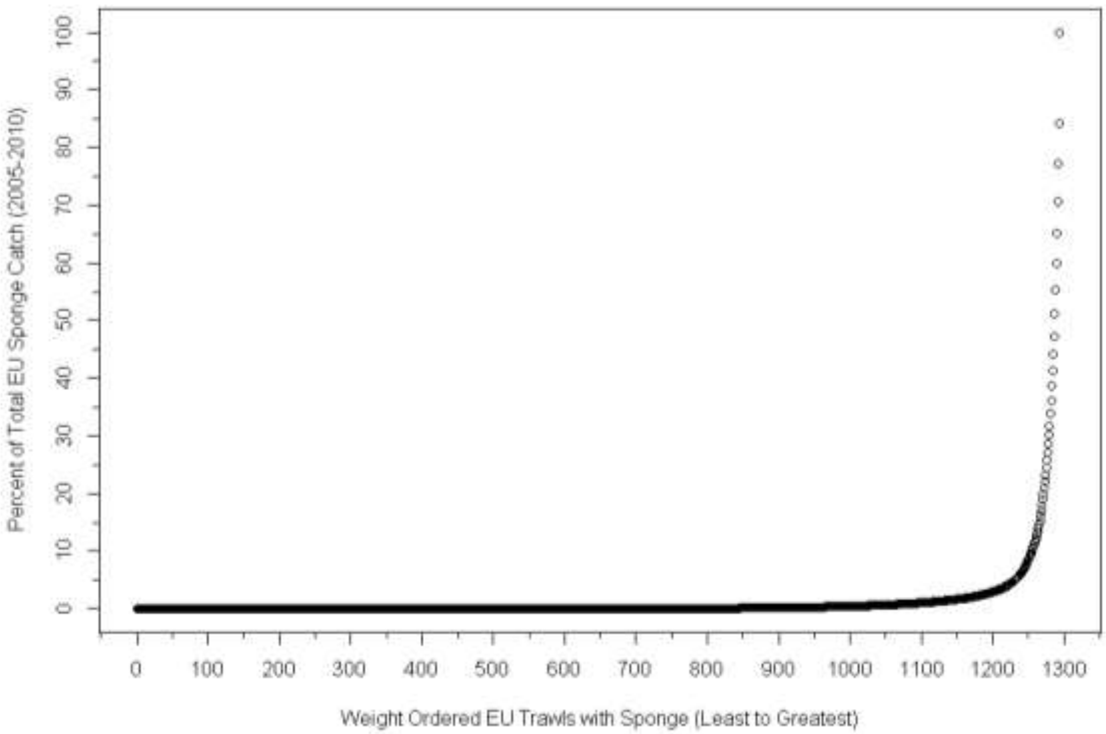

Figure 4.2.2.2.2 The majority of EU survey trawls catching sponge between 2005 and 2010 caught small amounts of sponge (95% where range is 1 gram to ~75 kg). Approximately 5% of the EU trawls (65 of 1,294) represents ~95% of the biomass caught (range is 85 to 12,000 kg).

The mean weight of EU sponge records within each cell of the *master grid* was calculated using the ArcGIS "Spatial Join" tool (Figure 4.2.2.2.3). The result was a proxy sponge biomass layer represented only by sponges caught by the EU survey trawls (Figure 4.2.2.2.4).

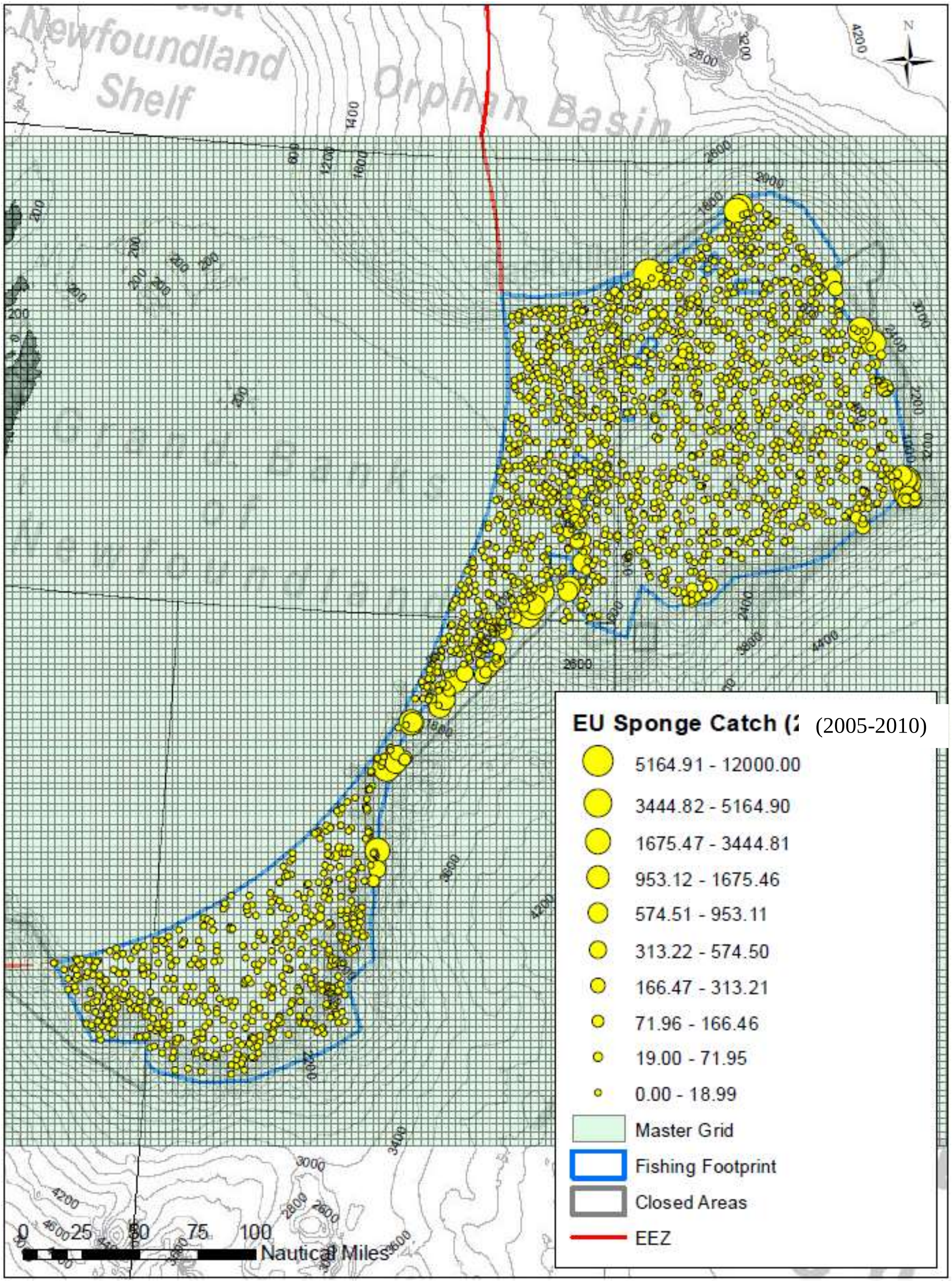

Figure 4.2.2.2.3. "Spatial Join" to calculate mean EU trawl survey sponge catch (kg) within each cell of the *master grid*.

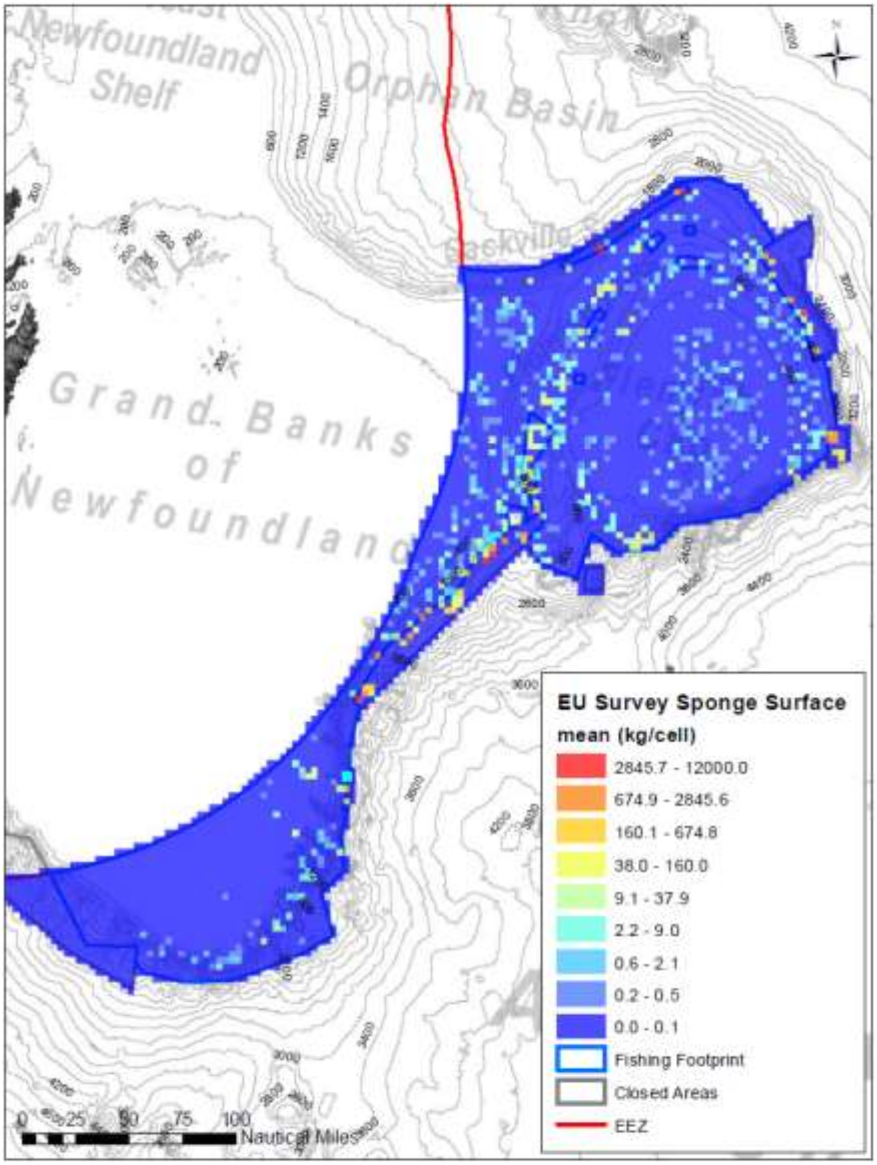

Figure 4.2.2.2.4. A proxy biomass surface generated from sponge collected in the EU trawl survey from 2005-2010.

Sea Pens

The sea pen biomass surface was generated using 2,011 sea pen and null-sea pen catch records from the EU trawl survey from 2005 to 2010 (Figure 4.2.2.2.5). Of these, 1,292 were null catches, with the remainder (719) containing sea pens. Table 4.2.2.2.2 summarizes the EU survey trawls containing sea pens within the *study area*. Unlike sponge catches, 719 EU survey trawls contained sea pen representing 36% of the trawls (Figure 4.2.2.2.6). In other words, while a random EU survey trawl over this area is 27% less likely to catch sea pens compared to sponges, when sea pens are caught they show less variability around their mean weight.

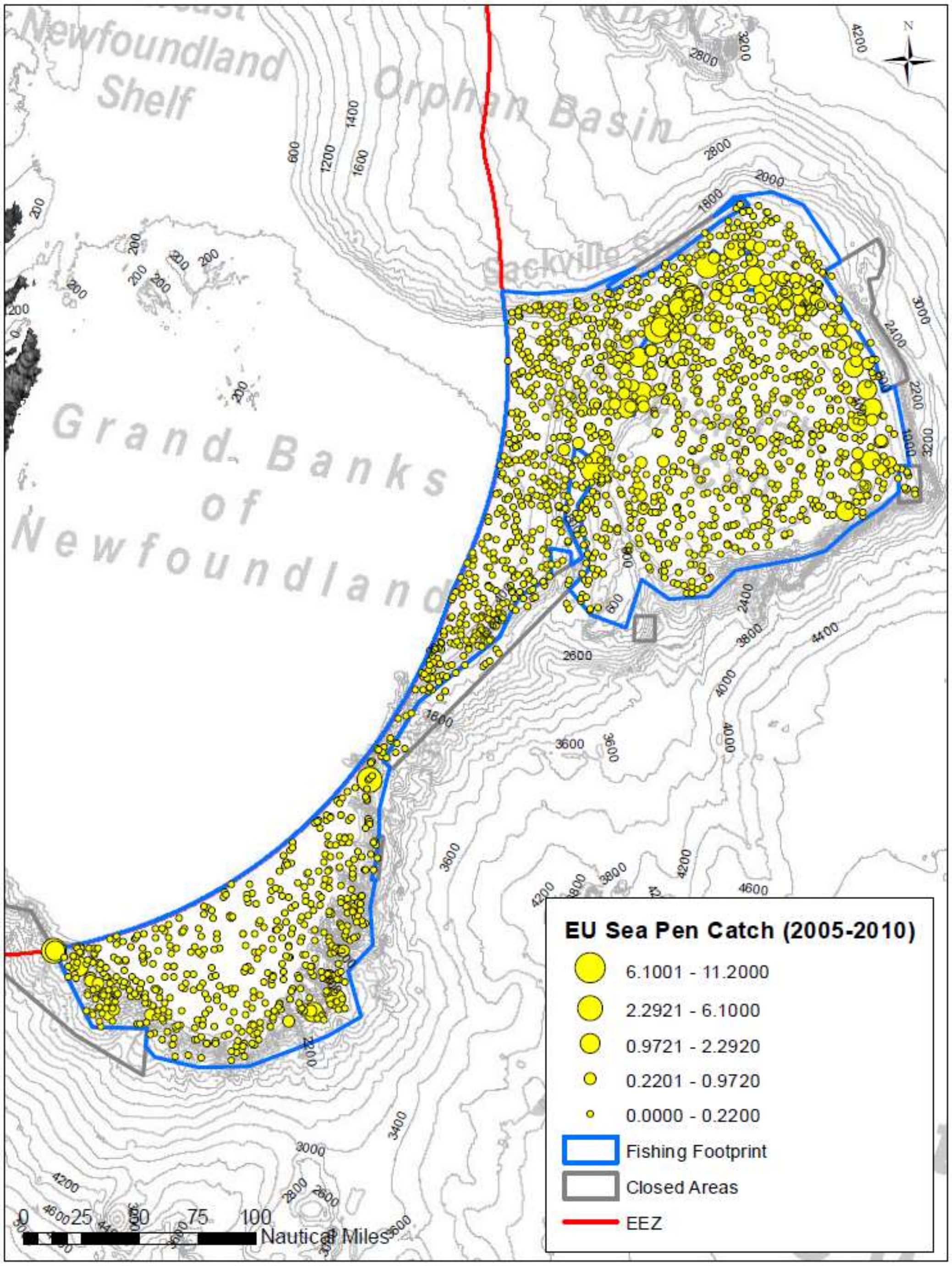

Figure 4.2.2.2.5. The EU trawl survey sea pen catch records (kg) within the study area.

Table 4.2.2.2.2. Summary table of EU trawl survey sea pen catch within the study area (2005-2010).

# Trawls	With Sea Pen	Total Catch (kg)	Min	Median	Max	Mean
2011	719 (36%)	167	0.001	0.04	11.2	0.2

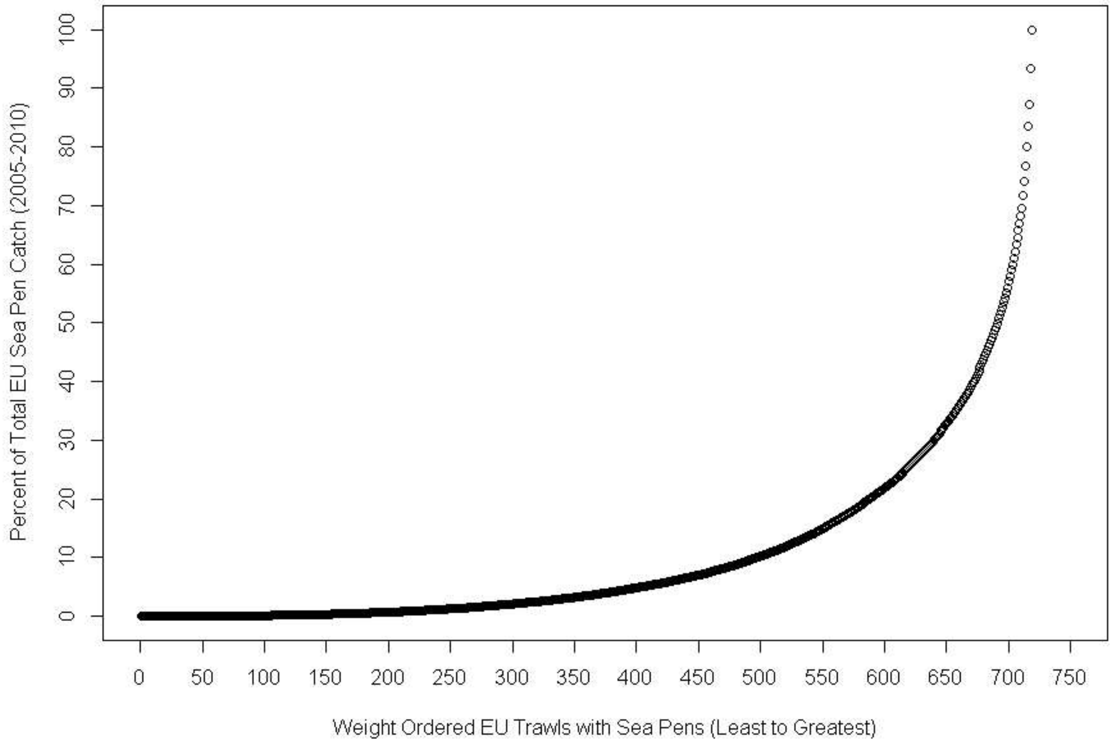

Figure 4.2.2.2.6. Cumulative sea pens catch from EU survey trawls between 2005 and 2010. The slope of the relationship is less severe than sponges. There is less variability around the mean catch for sea pens compared to sponges.

The mean weight of EU sea pen records in each 5.5 km x 5.5 km cell within the extent of the master grid was calculated using the ArcGIS "Spatial Join" tool. The result was a proxy sea pen biomass grid layer represented only by sea pens caught by the EU survey trawls (Figure 4.2.2.2.7).

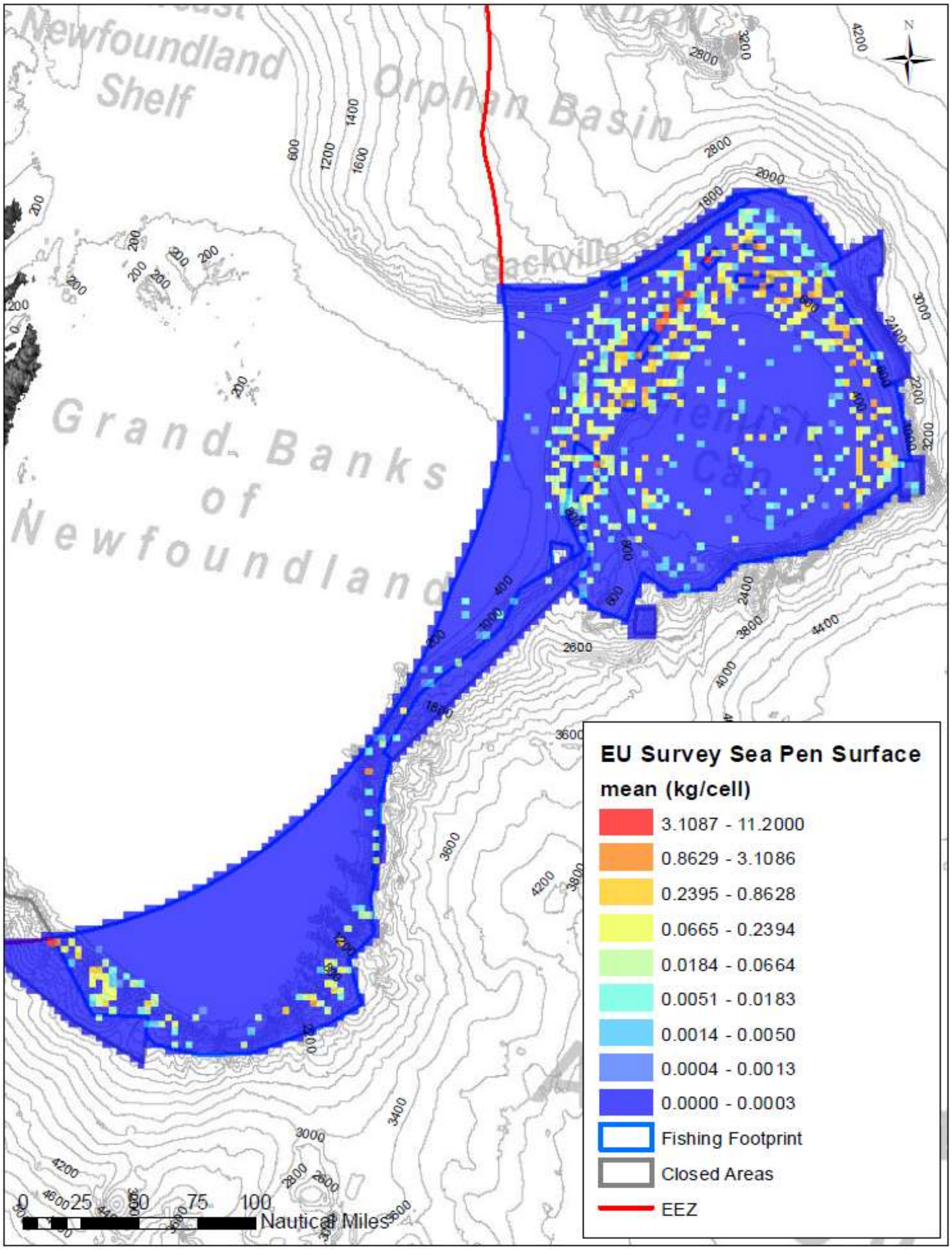

Figure 4.2.2.2.7. A proxy surface of biomass generated from sea pens collected in the EU survey trawls from 2005-2010.

4.2.2.3 Estimating Interactions Between Fishing Intensity and Biology

The objective of this step was to combine the fishing ‘core’ layers for the different percentile intervals (Section 4.2.2.1) with the proxy biomass layers for sponge and seapen and then to calculate the degree of potential for interaction or overlap. For example, a number of ‘core’ percentile interval rasters were produced (e.g. 98, 95, 90, 80, 70, 60, 50, 40, 30, 20, 10 and all pings or 0) and converted to point features using the "Raster to Point" tool. The "Spatial Join" tool was then used to extract the mean EU catch value from the biomass surfaces created in section 4.2.2.2. Figure 4.2.2.3.1 shows the relationship between each core percentile (common to all 4 years) and sponge/sea pen biomass. The "biomass" underlying each percentile should not be thought of as an absolute value of likely biomass caught, but rather a relative measure of the scale of potential interaction with varying levels of fishing intensity.

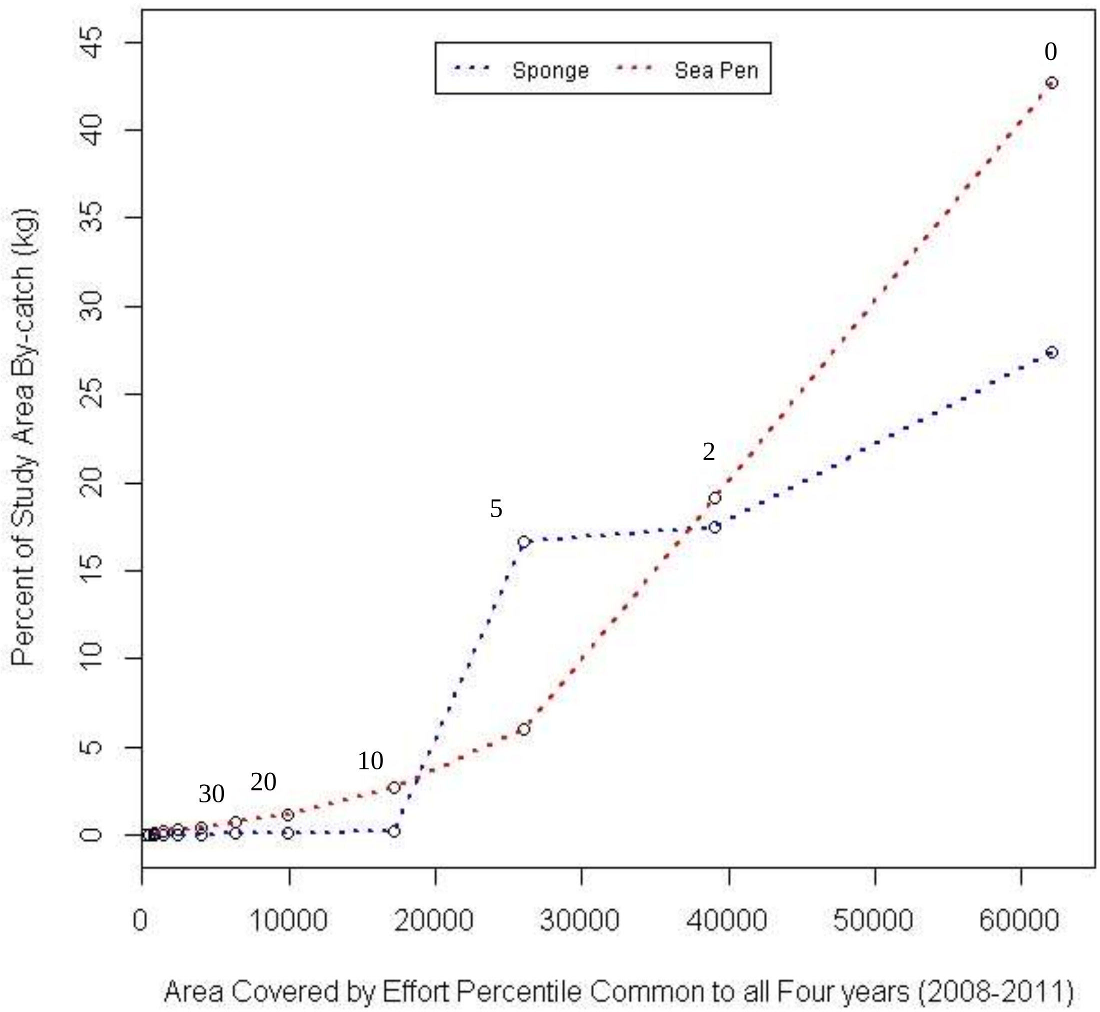

Figure 4.2.2.3.1. The percent of total EU trawl survey catch for each taxa between 2005 and 2010 within the area of each effort percentile common to all 4 years (only 0-30 are labeled).

Figure 4.2.2.3.1 highlights that it is the lowest effort percentiles (e.g 0, 2 and 5) where there is greater potential for interaction between effort and sponge/seapen biomass; it is this large area of lower fishing intensity where a higher proportion of the total sponge and seapen biomass is located. The figure also suggests a steep drop in interactions at the 10th percentile for sponge (the area representing the top 90% of effort). This precipitous drop in interaction is due to just 2 EU sponge records highlighted in red in Figure 4.2.2.3.2. These 2 records alone account for a 16%

drop in by-catch interaction when assessing the interaction between the 5th and 10th percentiles. This can be further illustrated in Figure 4.2.2.3.3 where the 5th percentile cumulative area is shown in relation to VMS lines generated from consecutive pings from 2010 and 2011 and a single 12,000 kg sponge record. This underscores some key points with regard to the sponge interactions. First, the cumulative area of the 10th percentile does not generally cross into closed areas and therefore is less likely to encounter high biomass catches as most of those are within the confines of the closed areas. Second, the resolution of the percentile areas over estimates the likelihood of interaction with high catch records close to the border of closed areas. Third, the "core" fishing grounds (represented by the cumulative area for the 10th percentile) occurs in areas that appear to have lower sponge biomass. This is very evident in Figure 4.2.2.3.1 and in Figure 4.2.2.3.4 where the 10th percentile area is plotted over the sponge biomass layer utilized in Cogswell et al. (2011).

The case for sea pen interactions appears to be more complicated than sponge. More of the total biomass for sea pens within the study area (~43%) are within the fishing footprint common to all four years (0 percentile - Figure 4.2.2.3.1). This suggests that there is more likelihood that interactions with sea pens will occur at the lower levels of fishing intensity within the *study area*. There is also a sharp drop (>20%) between the 0 and 2nd percentiles to levels comparable with sponge. The decline in interaction is less precipitous and gradually declines to close to 0 in areas were fishing is most intense (e.g. >50th percentile). These differences may indicate some increased resilience to bottom fishing pressure by sea pen compared to sponge under both infrequent fishing intensity and higher fishing intensities. It also suggests that sea pens do inhabit and survive in areas which are actively fished but at reduced fishing intensity.

Overall, most of the biomass of these VME species is found in areas of low fishing intensity, as would be expected since these cover a wider area of the NRA. As such further studies, for example, standardized by unit area, are required to fully characterize the likelihood of encounters, and hence, the full assessment of SAI on VMEs.

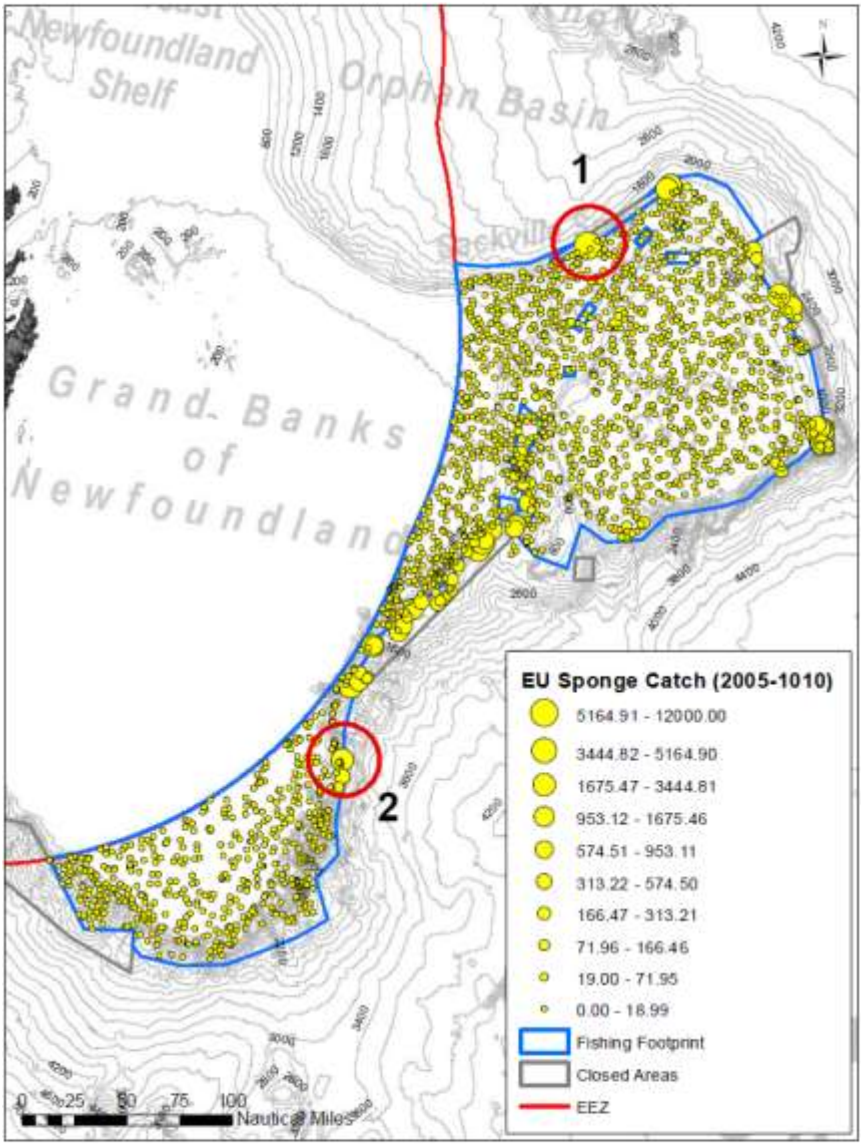

Figure 4.2.2.3.2. The 2 sponge records circled in this figure represent, 1) 12,000 kg and 2) 1,915 kg of EU trawl survey sponge catch.

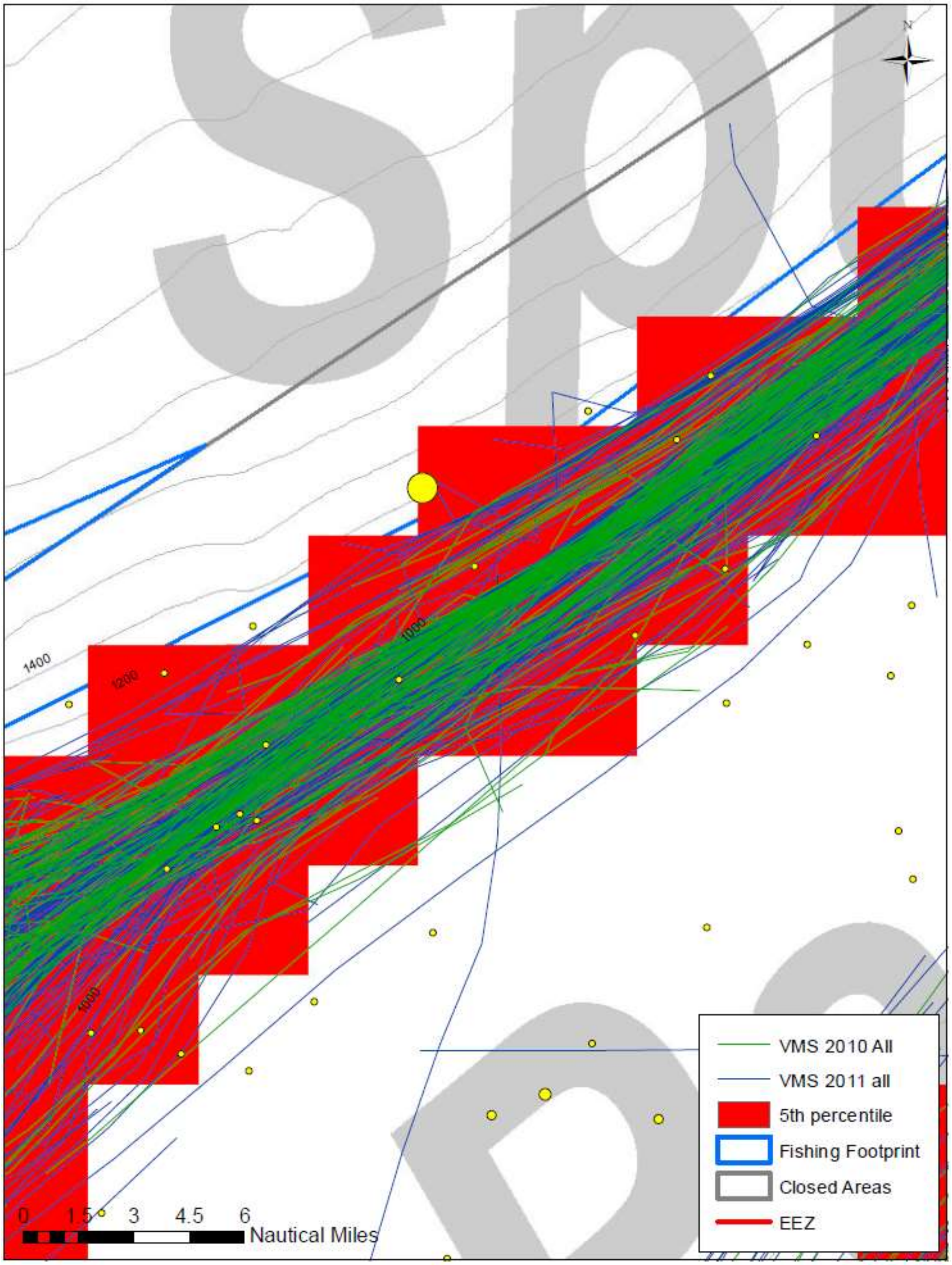

Figure 4.2.2.3.3. The sponge record 1) from Figure 4.2.2.3.2 on Sackville Spur in relation to VMS lines generated from consecutive pings in 2010 and 2011. In the cumulative area for >5th (5 - 100) percentile this record is captured, but at the >10th percentile (10 - 100) it is not.

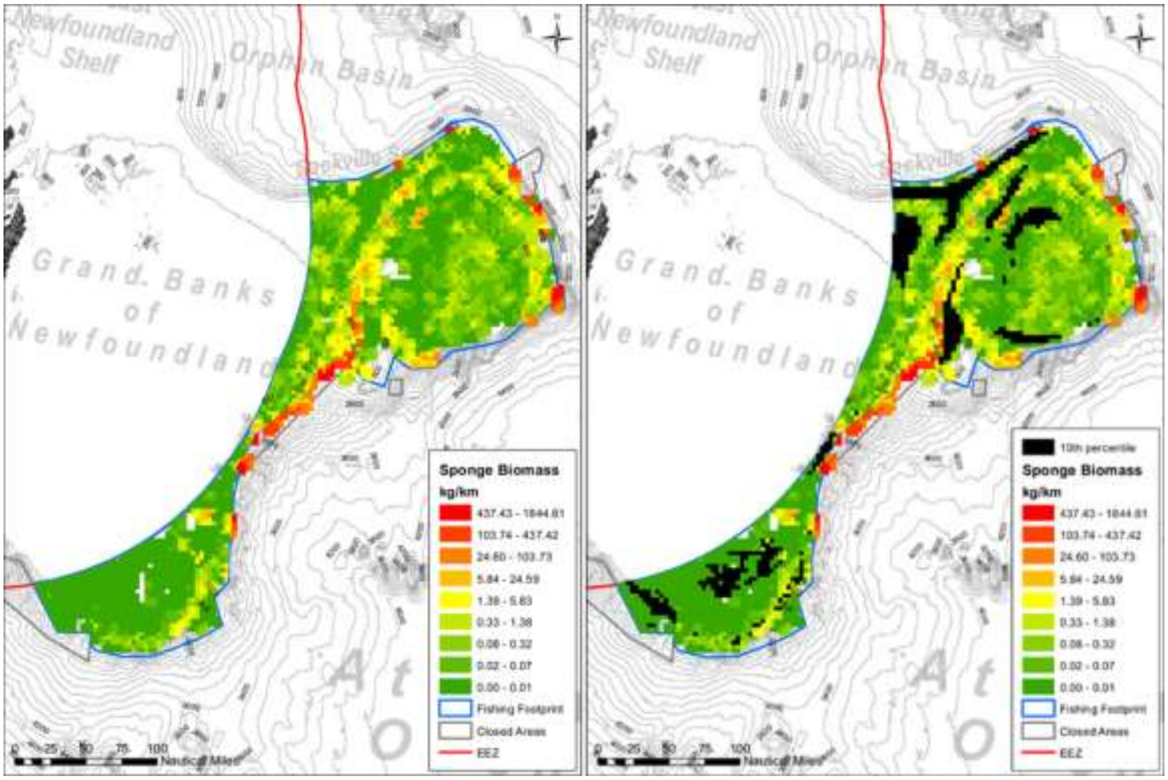

Figure 4.2.2.3.4. The sponge biomass surface created from Cogswell et al. (2011) (left), overlaid with the cumulative 10th percentile intensity layer (10-100%) common to all four years (2008-2011).

4.2.2.3 Conclusions and Recommendations

WGEAFM concludes:

1. The general pattern of fishing activity is remarkably consistent between years, at least in relation to the 4 years of VMS records which have been analyzed.
2. In general, high intensity fishing grounds border zones with elevated sponge concentrations.
3. The top 90% of all fishing activity occupies about 15% of the total area fished, whereas the bottom 10% of fishing activity occupies about 60% of the total area fished.
4. The 10th core effort percentile represents the inflexion point below which the rate of total area fished increases significantly.
5. Although results indicate that, overall, most of the biomass of these VME species is found in areas of low fishing intensity, further studies, for example, standardized by unit area, are required to fully characterize the likelihood of encounters, and hence, the full assessment of SAI on VMEs.
6. There is some evidence to suggest that the area of least fishing intensity (e.g. the area defined by the <10th percentile of effort) is steadily increasing in area (Figure 4.2.3.1).

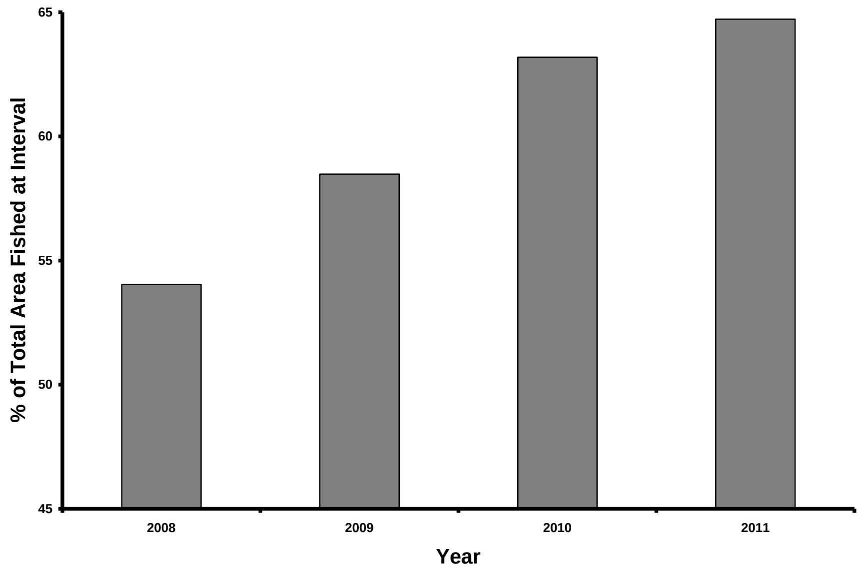

Figure 4.2.2.3.1. For each year, the percentage of the total area fished for the lowest 10% of fishing effort (<10th percentile of effort). In 2011, this interval represented nearly 65% of the total number of cells fished for that year.

WGEAFM recommends:

1. To characterize the likelihood of encounter by taking a biomass per unit area approach that can be better linked to the unit of fishing effort.
2. That an alternative core fishing layer be constructed using the combined area for all years (not just cells common to all years) for a given percentile, and that this be used to re-calculate the interaction with sponge and sea pen.
3. To support the assessment needs in 2016 – consideration should be given to examining site specific benthic data (from video, survey trawl and box core samples) in relation to the mapped fishing intensities so see if there is a direct relationship between fishing intensity and VME indicator biomass. This would provide some estimate of VME indicator species resilience.
4. Consideration should also be given to the development of a habitat suitability model for VME in the NRA. This would allow a more precise mapping of the potential risk of VME encounters in areas defined by the <10th percentile.

4.2.3 Assessment of Significant Adverse Impact of Bottom-Contact Gear on Sponges

Quantitative assessment of SAI of bottom-contact gear on sponges in the NRA requires information on gear efficiency and selectivity in order to assess the nature of removals. It also requires estimates of indirect mortality caused by the gear and on recovery trajectories. Recovery will be influenced by inherent biological properties of the species such as their ability to regenerate (wound repair) and recruit (clonally and/or sexually), growth rates, and disease resistance as well as community properties such as nearest-neighbour distances, patch size and habitat fragmentation which can be altered by the pattern of removals. Connectivity amongst the sponge grounds will also influence recovery dynamics. At present, modelling approaches which incorporate SAI are unlikely to be realistic given that so many of these parameters are not known for even well-studied species, let alone for poorly-studied temperate sponges.

4.2.3.1 Gear Efficiency and Selectivity on Sponges

Gear efficiency as used by fisheries scientists relates the true population size (biomass and/or abundance) to the capture or fishing mortality expressed as catch per unit effort (CPUE). It is sometimes referred to as "catchability" and is strongly related to gear selectivity. Different fishing gears have different hardware (e.g., net and mesh size, colour and configuration, rollers, doors) and consequently have different efficiencies and different selectivities.

Further, the nets will fish differently under a wide range of operating conditions, such as with different trawl speeds, different tow lengths, different depths or depending on whether they are full of biomass or not. Environmental factors, such as bottom type and sea state, and for mobile species, behavioural factors such as reaction to the gear also influence both gear efficiency and selectivity. Consequently, the catchability coefficient (q) is very difficult to quantify.

For the assessment of significant adverse impacts of bottom-contact fishing on sponges, some knowledge of both gear selectivity and efficiency is necessary if conclusions are to be drawn from by-catch data (commercial or research vessel). Few studies have examined both gear efficiency *and* selectivity to sponges. These generally use experimental trawling to record removals and underwater video to record the true population size. Wassenberg et al. (2002) quantified the catch and damage by a light weight McKenna fish trawl on sponges and used a video camera in the trawl net to observe the effects of fishing gear on sponges. This work was done on the northwest shelf of Australia using 30 min trawl tows at depths ranging from 25 to 358 m. They showed differential removal of sponge according to sponge shape and size class, and through literature comparison, with gear type. Approximately 70% of lump sponges (the large massive sponges of their study, e.g., *Xestospongia* spp.), passed into the net with at least 20% of those broken into pieces. The remaining 30% passed under the net and appeared undamaged. They found that 80% of lump sponges and 100% of branched sponges less than 300 mm, and 68% of lump sponges and 80% of branched sponges between 301 and 500 mm in height, passed under the net – equating to gear efficiencies of 0 to 32% for these smaller sizes. Fewer than 3% of the intermediate-sized sponges were broken up as they passed under the net. However, Moran and Stephenson (2000) report much lower gear efficiency on the general effects of a demersal otter trawl on sponges, soft corals and gorgonian corals greater than 20 cm, with less than 1% of "benthos" retained by the gear. Therefore it would appear that gear efficiencies may be anywhere from 1 to 70% for large sponges depending upon their shape.

Capture mortality of sponges is thought to be high. Sponges hauled on deck, even if they appear undamaged, will be drained of water and are unlikely to recover if they are thrown back into the sea as air will clog their aquiferous system which is essential for feeding (ICES 2009). Sponges brought to the surface and released before hauling on deck are also unlikely to survive as sponges sinking *en masse* back to the bottom may end up upside-down or on the wrong type of seabed (Klitgaard and Tendal 2004).

Estimating Gear Efficiency of Research Vessel Trawls on the Sackville Spur Sponge Grounds

There have been no experimental studies of gear efficiency for sponges in the NRA. However, crude estimates can be made for research vessel trawls (commercial trawl sponge by-catch data is not available). In the Sackville Spur area there are data from box cores and underwater images that can be used to estimate true population density and biomass, as well as a few research vessel trawls which can be used for capture mortality (Figure 4.2.3.1). The NEREIDA data used for this comparison are Box Cores 72 and 73 from the RV *Miguel Oliver* survey (Figures 4.2.3.1, 4.2.3.2), benthic image transects (11 and 12) from the 2009 CCGS *Hudson* survey and trawl catch from six Canadian and one Spanish/EU research vessel trawls. These data are not close to one another but all fall within the area closed to protect the sponge grounds on Sackville Spur. The Canadian and Spanish/EU depth-stratified random multispecies surveys in this area use a Campelen 1800 shrimp trawl with rockhopper foot gear (Walsh and McCallum 1997) and a Lofoten trawl (Murillo et al. 2011) respectively. Standard tow lengths differ between countries. Spanish/EU research vessels tow for 30 minutes at ~3 knots for an average standard tow length of 2.8 km (Murillo et al. 2011), while Canadian vessels tow for 15 minutes at ~3 knots for an average tow length of 1.4 km (Kenchington et al. 2010, Cogswell et al. 2010).

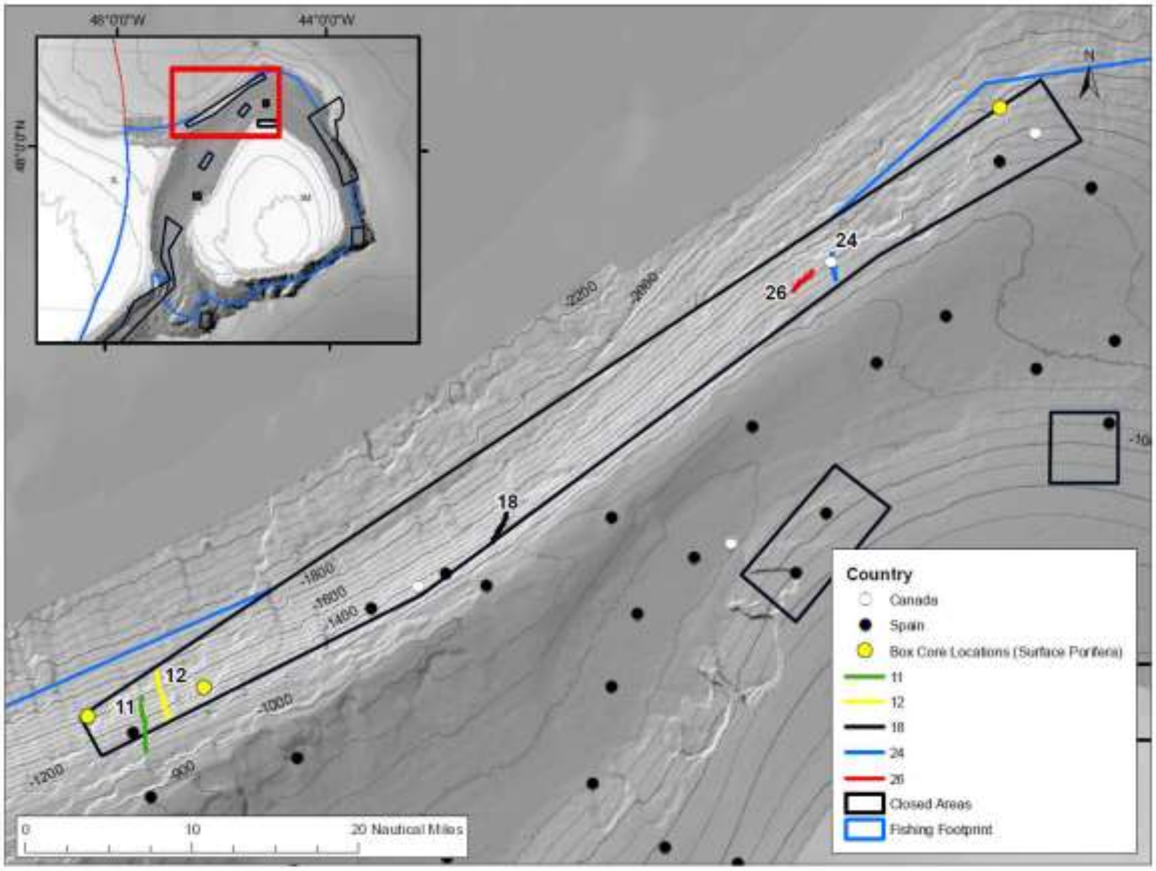

Figure 4.2.3.1. Box core locations (yellow circles) with surface sponge within the Sackville Spur closed area in relation to RV trawls (white circles - Canada, black circles - Spain) and 2009 camera transects (11, 12, 18, 24 and 26).

The mean of the total weight of surface Porifera for box cores 72 and 73 is 1,202g. The area represented by the box core is 0.25 m2 (0.5 x 0.5 m) or 4.808 kg of surface sponge/m2. The swept area of a 30 min Spanish/EU research vessel Lofoten trawl is ~3.9 hectares (or 39,000 m2). Therefore, the total biomass impacted by the Spanish/EU trawl in this area would be ~187,512 kg. The swept area of the Campelen trawl used by Canadian research vessels (15 min trawl) is ~2.3 hectares, or 23,391 m2 (B. Brodie, personal communication). Using the same sponge biomass/m2 as above, total biomass impacted by a Canadian research vessel trawls in this area would be ~112,464 kg. The mean of the Spanish research vessel trawl catches (n=4) was 3606 kg and the mean of the Canadian trawl catches (n=3) was 907 kg. This suggests that the gear efficiency is on the order of 1.9% for the Spanish/EU Lofoten gear and 0.8 % for the Canadian Campelen gear. This is a quick but not very robust method for estimating the biomass impacted by research vessel trawls. This estimation only considers the biomass from two box cores and does not account for the inherent variability associated with the patchy distribution of sponges or issues with scaling up biomass several orders of magnitude. Benthic camera transects allow for abundance estimates to be determined from larger spatial scales. Benthic camera transects 11 and 12 conducted during the 2009 CCGS *Hudson* mission lie between box cores 72 and 73 (Figure 4.2.3.2). The transect lines were clipped to only include analyzed images from water depths in excess of 1400 m (Figure 4.2.3.3) where the sponge grounds start (NAFO 2010). The sponge counts in each image below 1400 m (Figure 4.2.3.3) were recorded and then converted to a biomass value by multiplying by the average weight of sponges from box cores 72 and 73 (150 g/sponge). This value, which represents the estimated weight of sponges within the ~0.42 m2 field of view for each image, was then divided by 0.42 as an estimate of the sponge biomass/m2 in each image.

Figure 4.2.3.2. Box cores 72 (A), 73 (B) gathered during the NEREIDA mission aboard the Spanish research vessel *Miguel Oliver* in June of 2009.

The depth-selected portions of transect lines 11 and 12 were then split into intervals of 1400 m in length to approximate the distance trawled by Canadian research vessels (Kenchington et al. 2010). The ArcGIS "Spatial Join" tool was then used to calculate the median, mean, standard deviation, minimum and maximum sponge weight/m2 for images within each 1.4 km section of the lines. Multiplying the mean estimated weight per analyzed image by the swept area would provide an estimate of the biomass impacted by a Canadian research vessel trawl for each interval. For Spanish/EU trawls the intervals A and B were combined into a 2.8 km line (C) and the "Spatial Join" tool was used to calculate the median, mean, standard deviation, minimum and maximum sponge weight/m2 over the length of the line. Based on the swept area for a Spanish/EU research vessel trawl and mean estimated weight per analyzed image, an estimate of the biomass within the swept area was calculated (Table 4.2.3.1).

Benthic images from transects 11 and 12 representing the mean, minimum and maximum sponge biomass are displayed in Figure 4.2.3.4.

Table 4.2.3.1. Descriptive statistics of estimated sponge biomass for analyzed benthic images below 1400 m water depth in both transects 11 and 12. Refer to Figure 3 for position of the transects and intervals A, B and C.

Transect (Interval)	Image Count/ interval	Median (g/m^2)	Mean (g/m^2)	Standard Deviation (g/m^2)	Min (g/m^2)	Max (g/m^2)	Canadian Trawl Swept Area Biomass (kg)	Spanish/ EU Trawl Swept Area Biomass (kg)	Gear Efficiency based on Mean Biomass* (%)
11A	22	3,750	4,026	2,380	714	10,357	94,172		1.0
11B	36	7,857	6,994	2,918	714	12,500	163,597		0.6
11C	58	5,714	5,868	3,070	714	12,500		228,852	1.6
12A	51	8,214	9,188	5,337	1,000	25,357	214,917		0.4
12B	40	13,035	13,955	7,187	1,035	31,429	326,421		0.3
12C	91	10,000	11,325	6,648	1,000	31,429		441,675	0.8

*Mean biomass of Spanish research vessel trawls (3606 kg) and Canadian research vessel trawls (907 kg) within the Sackville Spur closed area.

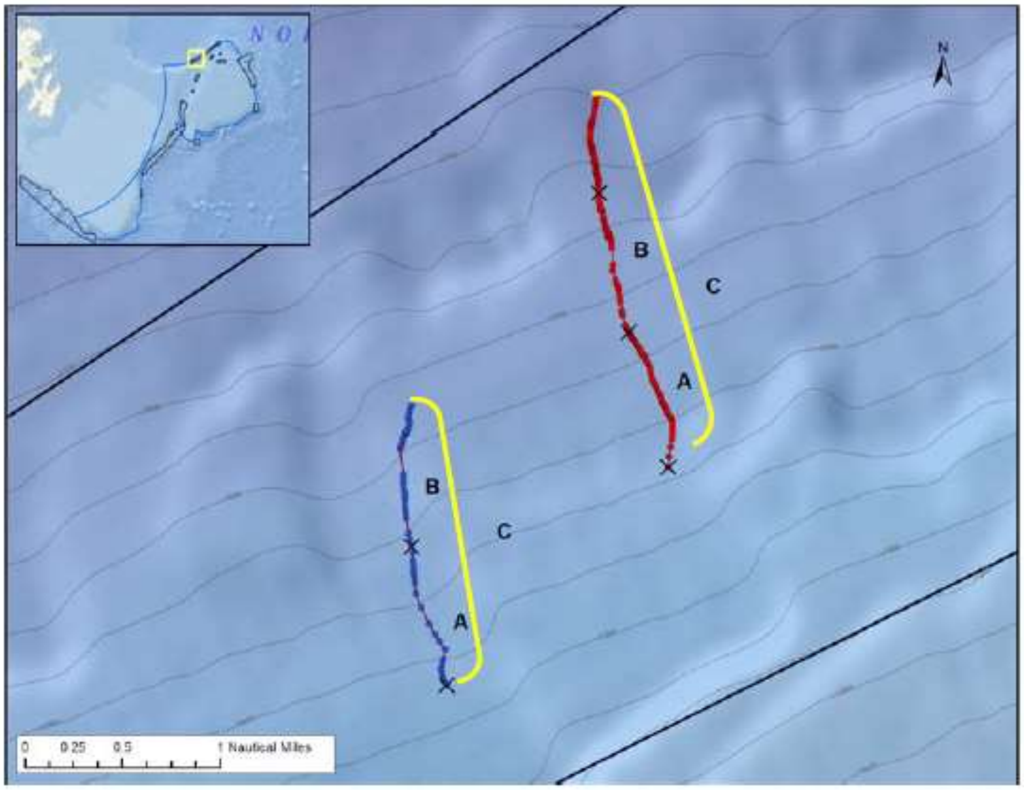

Figure 4.2.3.3. Camera transect lines 11 (blue) and 12 (red), run during CCGS *Hudson* mission in 2009. A and B represent 1.4 km sections on each line while C is the total line length of 2.8 km.

Lines A, B and C were used to extract in situ abundance data of sponges on the Sackville Spur sponge grounds for estimation of gear efficiencies (see text for details). The box core samples estimated *in situ* biomass of 4,808 g of surface sponge/m2 in the Sackville Spur area. The benthic transect lines produced mean *in situ* biomass estimates ranging from 4,026 − 13,955 g of surface sponge/m2 (range: 714 − 31,429 g surface sponge/m2). For both transect lines, the mean sponge biomass increase is higher in the shallower portion of each line and there is quite a lot of variability in biomass estimates due to the patchy distribution of the sponges within the sponge grounds (Table 4.2.3.1). Using the trawl catch mean of 3606 kg and 907 kg to represent capture mortality for the Spanish/EU and Canadian research vessels respectively, gear efficiencies of 0.3 − 1 % are estimated for the Canadian research vessels and 0.8 − 1.6 % for the Spanish/EU, depending on depth. This compares well with the 0.8% and 1.9% gear efficiency for Canadian and Spanish/EU research vessel trawls calculated from the smaller box cores (see above). While these figures are not very robust they are consistent with each other and suggest low gear efficiency or "catchability" of sponges with research vessel trawl gear on the Sackville Spur sponge grounds.

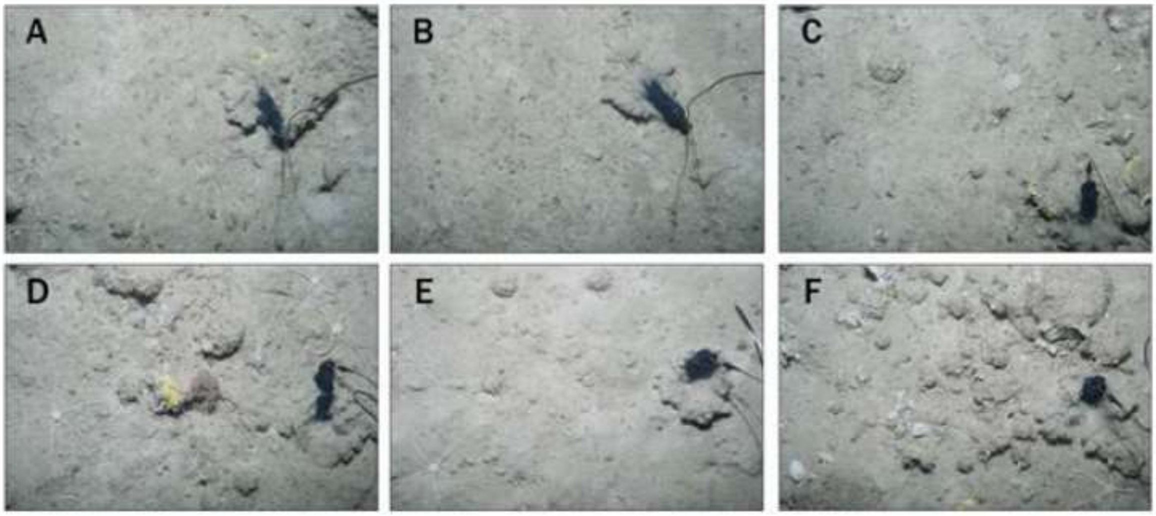

Figure 4.2.3.4. Photos representative of various sponge biomass on the Sackville Spur sponge grounds. A) the mean (5,868 g/m2), B) the minimum (714 g/ m2), and C) the maximum (12,500 g/m2) biomass values from transect 11. D) the mean (11,325 g/m2), E) the minimum (1,000 g/m2), and F) maximum (31,429 g/m2) biomass values from transect 12. Each image represents an approximate surface area of 0.42 m2 (see Table 1).

4.1.3.2 Incidental Mortality

Incidental mortality is mortality caused by the fishing gear other than capture mortality. Sponges can be dislodged, smothered or otherwise damaged by trawl gear. Sponges which are dislodged will eventually starve as they depend on attachment and orientation to the currents to feed (ICES 2009). Sponges are also not able to clear large amounts of silt stirred up by trawling plumes over soft sediments and may smother. Damage to sponges may be repaired, depending upon the age of the sponge and the location of the injury (ICES 2009). Moran and Stephenson (2000) report on the general effects of demersal otter trawls on sponges, soft corals and gorgonian corals greater than 20 cm in height off the sea floor, with 15.5% of "benthos" detached. Wassenberg et al. (2002) noted much higher incidental mortality in their study of fishing impacts on sponge grounds on the northwest shelf of Australia. The large massive (lump) sponges of their study (e.g., Xestospongia spp.), greater than 500 mm, were torn from the seabed and caught by the gear or rolled under it causing severe mortality. They estimated 55% of lump and branched sponges > 500 mm were dislodged. Sainsbury et al. (1997), also working in Australia, used a heavier Frank and Bryce wing trawl gear in experimental trawling studies. They estimated that between 43 and 95% of large sponges (>150 mm high) were detached from the seabed. Freese et al. (1999) conducted experimental trawling in Alaska and found that immediately post-trawl, density of sponges in eight trawl tracks was 16% lower than the density of sponges in the eight reference transects. Together, these studies suggest high incidental mortality for large sponges through detachment (of the size range of the Geodia-dominated grounds in the NRA).

Damage to sponges through interaction with the gear is also high. Van Dolah et al. (1987) found 32% damage to large (greater than 10 cm) barrel sponges (Cliona spp.) on hard substrate off southeastern Georgia following a single pass of their 40/54 roller-rigged trawl. Freese (2001), using larger and heavier gear in Alaska reported 67% damage to the large vase sponges along experimental trawl lines and only 2% in reference areas. Tilmant (1979) observed 50% of sponges damaged after experimental shrimp trawling in Biscayne Bay, Florida. Therefore, for those larger sponges that are not dislodged from the substratum by the gear, damage can be high.

4.2.3.3 Recoverability

There have been a few experimental studies which address recovery of large sponges after trawling. Van Dolah et al. (1987) showed a rapid recovery to a single trawl pass over hard bottom habitat off the southeastern Georgia where sponge population densities had returned to pre-trawl levels or greater in one year or less after trawling. They also noted that damaged sponges had healed and grown during that time. Conversely, Kefalas et al. (2003) report on the impacts of commercial scallop dredging on 48 sponge species in the northeastern Mediterranean by comparing species composition and density before and one year after intense commercial fishing. All but one species had lower density one year later and there were significantly fewer species and individuals. Similarly, Freese (2001) reported that one year after experimental trawling in Alaska, underwater video observations showed a 21% reduction in density which was an increase in mortality of 5% over immediate post-trawl reductions, presumably due to mortality of damaged sponges. Freese (2001) reports that one year later visible damage to *Geodia* species was 59.4% and 46.7% of all sponges still showed visible damage with no signs of repair. However necrosis was only observed on basket sponges. No new colonization of sponges was apparent in any of the three trawl paths. In the shallow water coral ecosystem of the Great Barrier Reef in Australia, Pitcher et al. (2009) found a 6% decline in sponge biomass six months after one pass of a shrimp trawl.

Rooper et al. (2011), also working in Alaska, used research vessel catch per unit effort (CPUE) as an index of abundance and modeled recovery rates using logistic population models to estimate growth rates. They estimated recovery of sponges from an equilibrium state to a post-trawl state of 67% mortality (drawn from Freese et al. (1999) damage estimates) would take from 13 to 36 years to achieve 80% of original biomass in the absence of further trawling.

Klitgaard and Tendal (2004) suggest that the dominant sponge species in the NE Atlantic ("ostur") are slow growing and take at least several decades to reach the sizes commonly encountered. In general, they are found in relatively constant environmental conditions that suggests they are dependant on a certain stability with respect to water mass characteristics, kinds and amount of particles in the water, and on low physical disturbance.

Few small specimens were found by Klitgaard and Tendal (2004) leading them to suggest that reproduction in boreal ostur areas is infrequent making ostur vulnerable to changes in hydrographic regime (climate change) as well as direct impacts of trawling.

No investigations of the sexual reproduction of Geodiids and Ancorinids from the NW Atlantic have been carried out. However, the reproduction of the cold-water Arctic sponge, *Geodia barretti,* has been studied in Norway (Spetland et al. 2007). This species is oviparous and dioecious and undergoes synchronous spawning once or twice a year. The onset of reproduction coincides with the spring phytoplankton bloom with gamete release in early summer, just after the phytoplankton spring bloom is over and when organic matter sedimentation following the bloom is highest. A second release of gametes is associated with the fall bloom. Sponge larvae are uniformly non-feeding and short-lived (except for rare known exceptions), generally staying only a few hours in the water column (Maldonado and Bergquist 2002) and settle in the vicinity of parental populations (Mariani et al. 2003). With such high levels of larval retention (Mariani et al. 2006) it is likely that connectivity among the sponge grounds is very low and that the patches are highly inbred and self-recruiting. *Geodia* is also known to produce gemmules (Burton 1949), or asexually produced buds, which are resistant to poor environmental conditions that can kill adult sponges. However, very little is known about the relative contribution of sexual and asexual reproduction in natural environments.

Evidence for Recoverability of Sponges in the NRA

Data are currently being analyzed to assess recoverability of sponge grounds in the NRA from a known research vessel trawl. *In situ* video was collected with the ROV ROPOS in 2010 from the eastern portion of the Flemish Cap as part of the NEREIDA project. Initially, two, approximately one-kilometer, parallel lines, one trawled (1085.21 m), and one not trawled (1129.27 m), were analyzed for the abundance of Porifera spp. and corals. Time constraints prevented us from analyzing the full video for the two lines, therefore, frame grabs were taken from the video footage at 20 m intervals and analyzed. The Porifera were divided into three groups: 1) *Asconema foliata*, 2) 'massive' Porifera (e.g. *Geodia* spp.), and 3) 'Fan-shaped' Porifera. These groups were further divided into three size-classes: < 10 cm, 10-20 cm, and > 20 cm. The lasers on the ROPOS, calibrated at 10 cm apart, were used to judge the size of the sponge. Sponge outside of these groups (e.g., *Euplectella* sp.), corals and other large megafauna were also counted, without regard to their size. Based on preliminary results, the data from a third (untrawled) video transect line is being analyzed and previously analyzed video is being re-examined with frame grabs at 10 m intervals.

4.2.4. Assessment of Significant Adverse Impact (SAI) of Bottom-Contact Gear on Sea Pens

Information on incidental damage and recovery from trawling informs the magnitude of the impact on the population. Sea pens have flexible axial rods and some species are able to re-anchor in the sediment if they are dislodged, however, mobility can be limited and species specific (Malecha and Stone 2009). The low catch threshold proposed for these species corresponds to a much higher catch in terms of numbers of individuals. As stated earlier, a threshold of 7 kg equates to about 198 individuals of the short and fleshy species and about 583 of the larger sea whips. Removals of these numbers of individuals will cause population-level impacts, possibly altering recruitment dynamics.

As well, long-term success of injured or dislodged sea pens can be relatively low. When compounded by large scale effects (i.e. population level) with low survival the result is a relatively high risk of SAI to sea pen populations, particularly with isolated communities.

4.2.4.1 Gear Efficiency and Selectivity on Sea Pens

Troffe et al. (2005) conducted a study of the effects of a shrimp beam trawl and prawn traps on sea whips (*Halipteris willemoesi*) at two bays on Clio Channel, south central coast of British Columbia, Canada. No sea whips were caught in six beam trawls despite maximum mean densities of adults of about 18 m2 and of juveniles of about 90 m2, determined from underwater video. For this gear and species both gear selectivity and efficiency are 0%. The authors analyzed by-catch from 600 prawn trap sets at Turnour Bay, and found about 5% had sea whips entangled in the gear. The low efficiency of beam trawls in sampling sea pens was also observed in the Celtic Sea where despite the common occurrence of *Virgularia mirabilis*, as seen in video footage, none were caught by experimenatl beam trawls (Doyle et al. 2011). However this is a species that is able to retract into the sediment and so this low efficiency is likely due to gear avoidance. Tuck et al. (1998) also found no changes in density of this species following experimental trawling carried out repeatedly over an 18-month period.

Hixon and Tissot (2007) compared trawled and untrawled areas off Oregon, United States at 200 m. Results showed large (30-50 cm) sea pens (*Stylatula* spp.) accounted for 95% of all invertebrates in the untrawled site. Conversely, the trawled site showed very few sea pens present. However, this type of comparison cannot attribute cause and effect.

Selectivity of sea pens by bottom-contact gear will vary based on species behavior and colony morphology (i.e. size and shape). Some sea pen species are capable of retracting within the sediment when disturbed (e.g., *Protoptilum carpenteri* and *Virgularia mirabilis*) and are believed to sense vibration in soft sediments substrates as bottomcontact gear approaches (Greathead et al. 2011). Positioning of a sea pen colony can also determine the selectivity. Small species such as *Kophobelemnon* spp. are positioned with the majority of the rachis (stalk) burried wihtin the sea floor with only the top portion containing the polyps exposed. This may explain the few records of *Kophobelemnon* observations in both the Canadian and Spanish/EU trawl survey data compared to 100s of *in situ* observations from camera surveys in the area. To our knowledge there have been no studies of gear selectivity on sea pens.

Estimating Gear Efficiency of NAFO Research Vessel Trawls

During the summer of 2011, sea pen fields in the Laurentian Channel west of the Grand Banks were sampled with an underwater video device (Campod) operated from the CCGS *Hudson*. This area had been identified using the kernel density GIS model as having significant concentrations of sea pens (Kenchington et al. 2010b). Three video transects (numbered CON 33, CON 34 and CON 35) were completed in the vicinity of known research vessel trawls (Figure 4.2.4.1). The field of view area for the Campod video is roughly 56 x 43 cm or 0.24 m2.

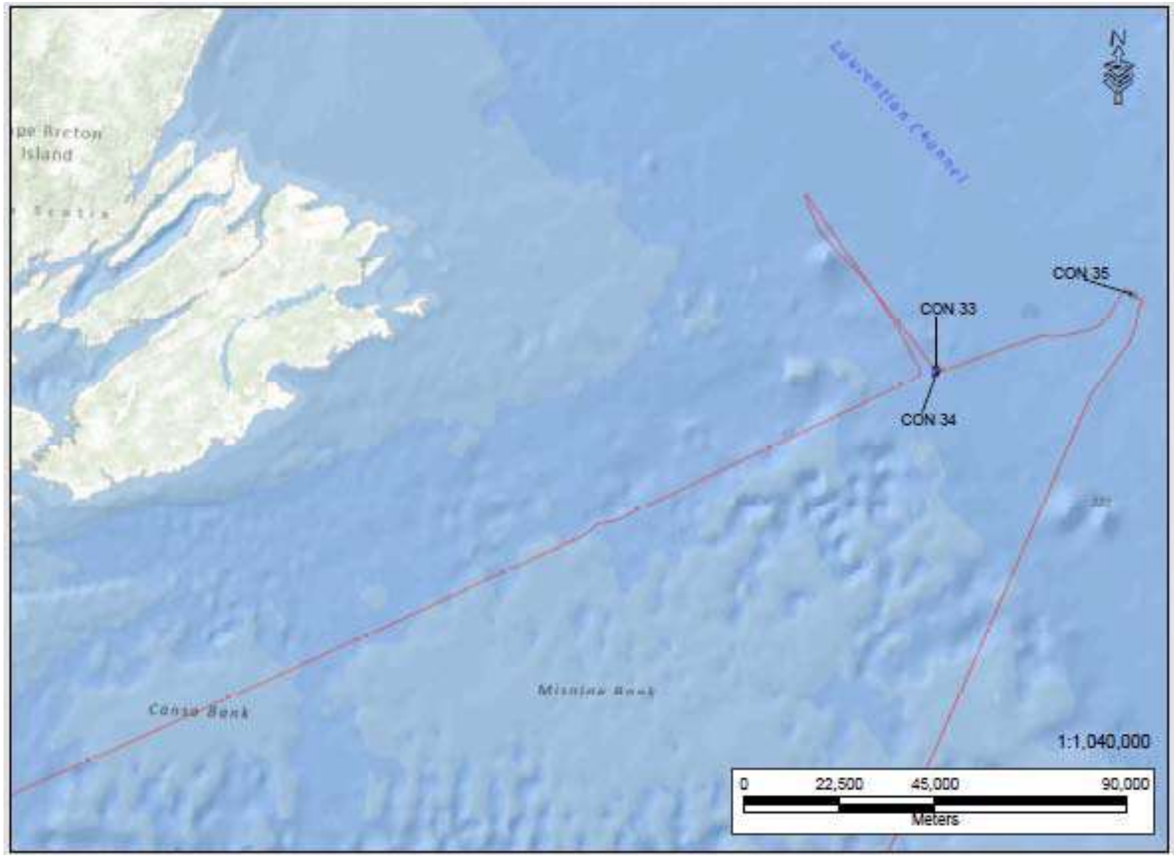

Figure 4.2.4.1. Location of the two video transect lines (CON 33, CON 34) used to determine the in situ biomass of sea pens for assessment of gear efficiency.

Tow transects (CON 33 and CON 34) fall near Canadian research vessel tows conducted with Western IIA trawl gear, and one (CON 35) near research vessel tows conducted with a Campelen trawl, allowing gear efficiency evaluations for these two types of gears. The on bottom length of transect CON 33 is ~1864 m for a total area analyzed covering ~447 m2 (Figure 4.2.4.2). The total number of sea pens viewed was 423. This is represented by 381 Anthoptilum spp. (~90%) and 42 Pennatula spp (~10%). This proportion is applied to the predicted abundance in the swept area of the gear and converted to a biomass by using median individual weights for each species. The concentration of sea pens for the area analyzed is ~ 1 sea pen / m2 of bottom. The comparative 2009 research vessel trawls were made with a Western IIA towed at a constant speed of 3.5 knots for approximately 30 minutes (Figure 4.2.4.3). The total swept area of one set is 0.0404 km2 or 40,400 m2.

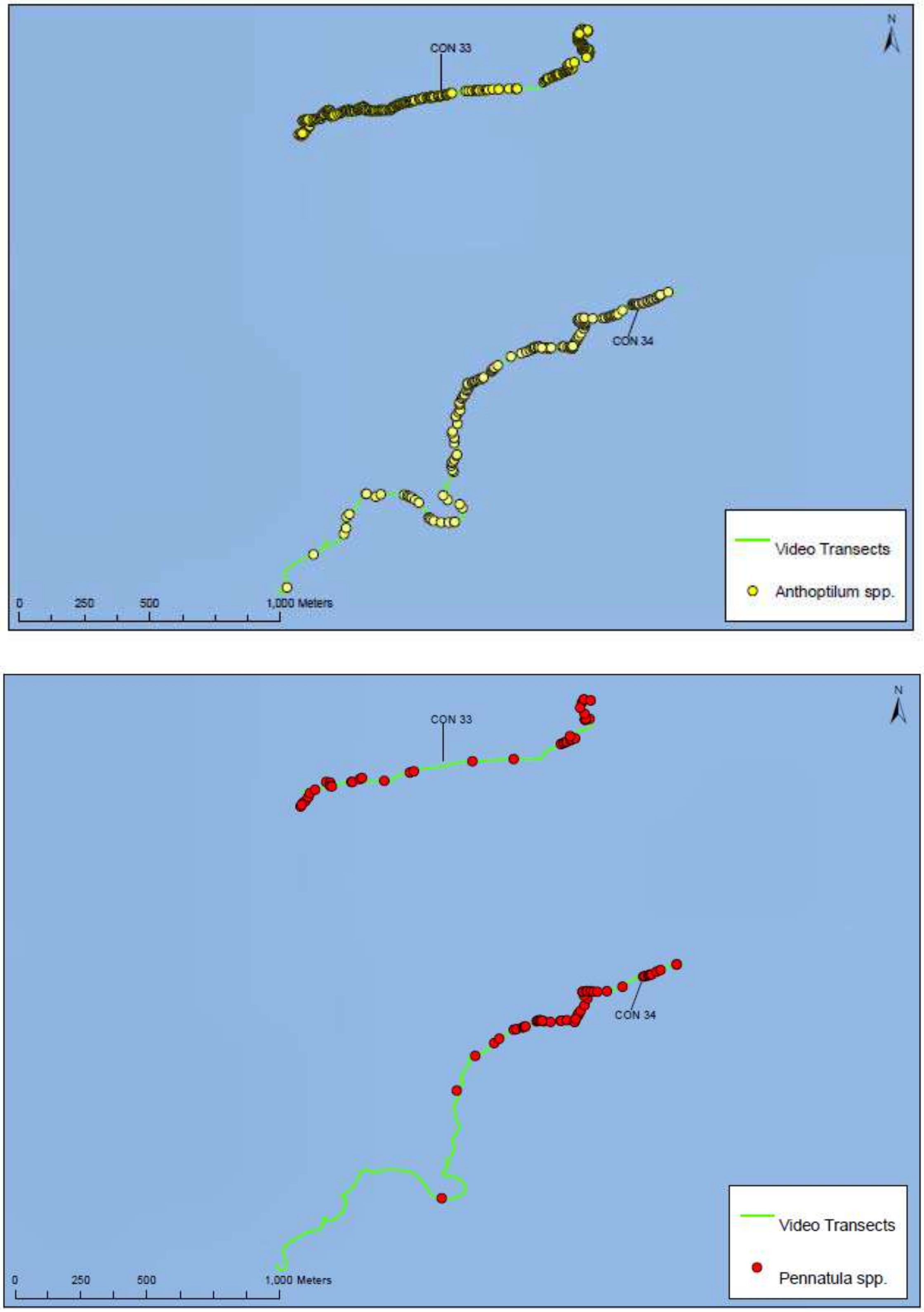

Figure 4.2.4.2. Detail of video transects CON 33 and CON 34 with data records for the sea pen *Anthoptillum* spp. indicated in the upper figure and *Pennatula* spp. in the lower figure.

The comparative trawls had a sea pen by-catch of 21.22 kg. Given the range of sea pen biomass impacted between CON 33 (572 kg) and CON 34 (259 kg), this amount of by-catch represents roughly 3.7 and 8.2% gear efficiency.

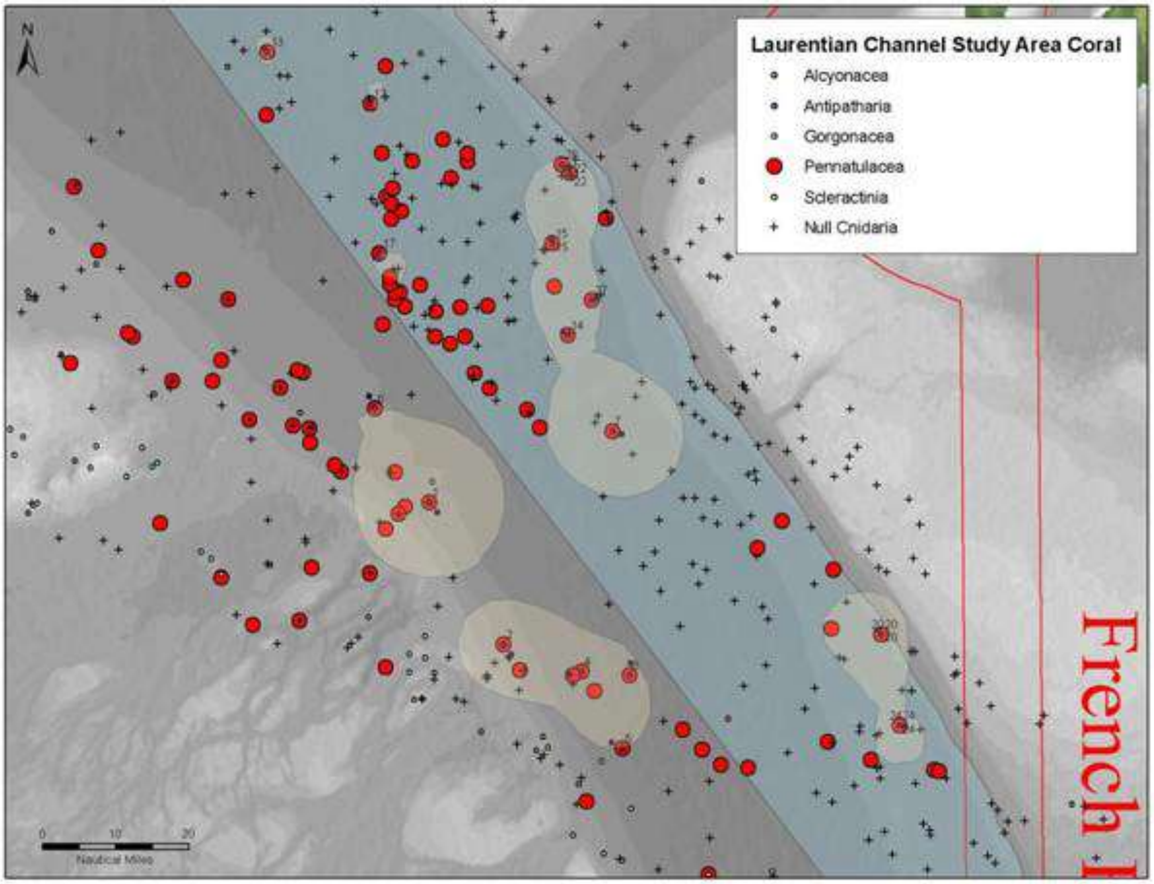

Figure 4.2.4.4.. Location of research vessel trawls in the vicinity of the study area. Red shaded circles distinguish trawl sets with sea pen by-catch. Light grey polygons represent areas of significant concentrations of sea pens identified in Kenchington et al. (2010b). The blue area depicts an area of interest for a MPA. The comparative tow for Western IIA gear is circled in red and is very close to the video transects CON 33 and CON 34.

One transect falls within the vicinity of research vessel trawls conducted with Campelen gear (CON 35) (Figure 4.2.4.5). The on bottom length of transect CON 35 is ~2297 m for a total area analyzed covering ~551 m2. The total number of sea pens viewed was 109. This is represented by 40 *Anthoptilum* spp. (~37%), 10 *Pennatula* spp. (~9%), 58 *Kophobelemnon* spp. (~53%) and 1 *Halipteris* sp. (~1%). This proportion is applied to the predicted abundance in the swept area of the gear and converted to a biomass by using mean individual weights for each species. The concentration of sea pens for the area analyzed is ~ 0.2 sea pen / m2 of bottom. The comparative 2009 research vessel trawl was made with a Campelen trawl as part of the Canadian research vessel surveys of the area. As noted previously, the best estimate of the swept area for this gear is 23,391 m2. This area would then hold approximately 4,678 sea pens. Given the mean weights of *Anthoptilum* spp. of 32 g (n = 86), *Pennatula aculeata* of 3.5 g (n = 30), *Halipteris finmarchica* sp. 15 g (n=31), and *Kophobelemnon stelliferum* 0.5 g (n=50) (F. J. Murillo, E. Kenchington and V. Wareham pers. comm.) from the NRA, an *in situ* biomass can be estimated: of the roughly 4,678 sea pens impacted by the Campelen trawl swept area, 1731 are *Anthoptilum* spp. representing ~ 55 kg, 2479 are *Kophebelemnon* spp. representing ~1.2 kg, 421 are *Pennatula* spp. representing 1.5 kg, and 47 are *Halipteris* sp. representing 0.7 kg. The total sea pen biomass that could be potentially captured in the nearby research vessel trawl, based on these density estimates on transect CON 35, would be ~ 58 kg. Of these genera, *Kophebelemnon* spp. are rarely caught in trawls as they are capable of retracting in the sediment. However, they contribute very little to the overall biomass and so are left in the calculations. The total sea pen by-catch from the 2007 Canadian RV comparative trawl using Campelen gear was ~3 kg. This represents a 5.2 % gear efficiency for sea pens with a Campelen trawl.

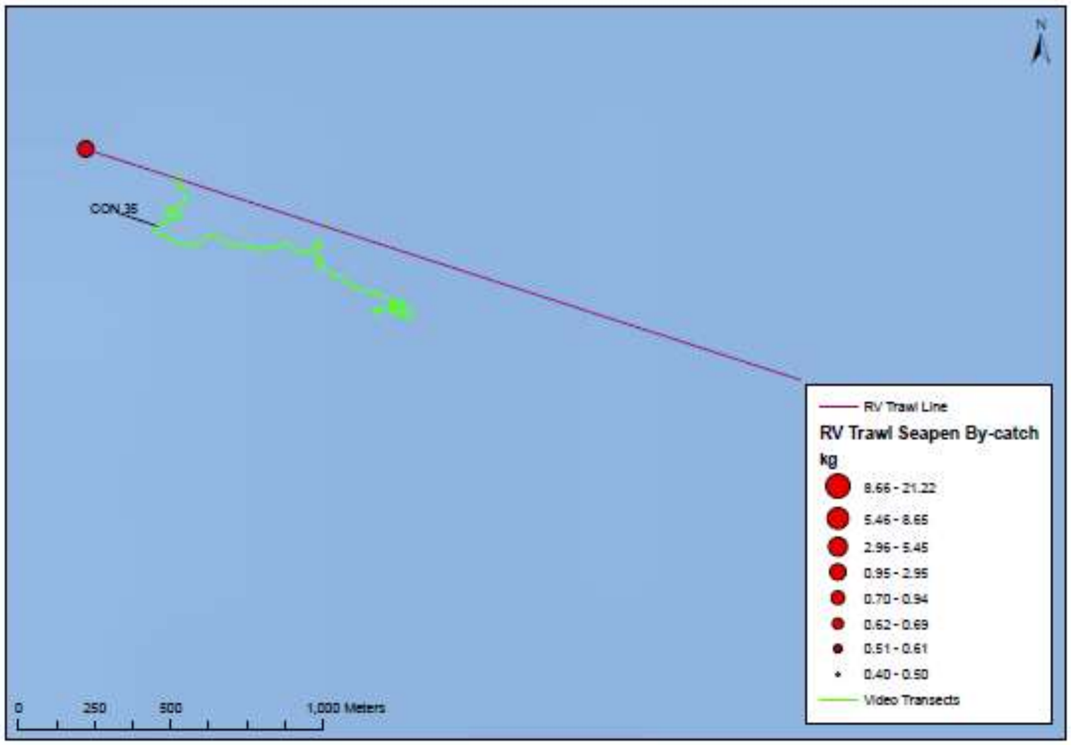

Figure 4.2.4.5. Location of CON 35 in relation to the comparative research vessel trawl done with Campelen gear.

4.2.4.2 Incidental Mortality of Sea Pens

Malecha and Stone (2009) conducted *in situ* experiments on the sea whip *Halipteris willemoesi* off Alaska. They simulated trawl disturbance and observed the response of the sea whips *in situ* over a period of about 1 yr in order to assess delayed mortality from sublethal injuries. Colonies of *H. willemoesi* were distressed in three ways which mimic the impacts of trawling: dislodgement, fracture of the axial rod, and soft tissue abrasion. Fifty percent of dislodged colonies demonstrated the ability to temporarily rebury their peduncles and recover to an erect position. However after one year most were in a prone position. None of the fractured colonies were able to repair their axial rods and only one was erect at the experiment’s conclusion with a broken rod. Light tissue abrasion was less lethal and all colonies were able to remain erect with this damage. Tissue losses among the dislodged and fractured sea whips increased throughout the experimental period and were attributed to predation by the nudibranch *Tritonia diomedea*. This predator has a strong scavenging response to sea whips lying on the seafloor. Sea whips that are damaged or dislodged colonies are likely more vulnerable to predation. Heifetz et al. (2009), using underwater video, observed 40% of sea whips and sea pens damaged in areas below 340 m off the central Aleutian Islands of Alaska that had been classified as having high-intensity trawling. This compared with only 1% damaged in other areas with little or no fishing. However, an experimental study looking at the effect of the *Nephrops* creel fishery in Loch Broom, Scotland found that the three sea pens present, *Virgularia mirabilis,Pennatula phosphorea* and *Funiculina quadrangularis*, were able to re-anchor themselves provided the basal peduncle remained in contact with the sediment surface, and mortality rates following experimental creel disturbance were very low (Kinnear et al. 1996).

Troffe et al. (2005) reported damage to sea whips entangled in prawn trap sets where 50% of the entangled colonies were damaged and often broken above the peduncle. Soft tissue abrasion along the axial rod was also noted.

4.2.4.3 Recoverability of Sea Pens

Troffe et al. (2005) found no significant difference in the density of juvenile or adult sea whips after the first pass of a beam trawl, however other comparative studies have found significantly lower sea pen density in areas of high trawling intensity (Engel and Kvitek 1998, Hixon and Tissot 2007, Adey 2007), indicating an inability to recover in the face of continued fishing pressure.

Information on age and growth is often used to estimate natural mortality or total mortality, which are key components in the calculation of important population and demographic parameters, such as population growth rates and generation times. The longevity of most sea pens is unknown. Despite their importance, published age and growth studies of sea pens are still scarce. Birkeland (1974) determined that the maximum age of the fleshy sea pen, *Ptilosarcus gurneyi*, in Puget Sound was about 15 years with sexual maturity at 5 or 6 years. *P. gurneyi* is a small, shallow water (to 70 m) west coast species similar in morphology and height to the *Pennatula* spp. in the NAFO area. In contrast, Wilson et al. (2002), working with the much larger and deeper-living sea whip, *Halipteris willemoesi* (maximum height in sample 167 cm) in Alaska, estimated longevity at about 50 years. He also noted a faster growth rate for medium-sized specimens compared with small and large-sized colonies.

Sea pens are gonochoric at the colony level with a sex ratio of 1:1. They typically produce large lecithotrophic eggs (Chia and Crawford 1973, Edwards and Moore 2008) which in aquaria float to the surface (Chia and Crawford 1973). They all appear to be broadcast spawners and female fecundity is high ranging from approximately 30,000–200,000 oocytes per colony (Chia and Crawford 1973, Tyler et al. 1995, Soong 2005, Edwards and Moore 2008), although not all oocytes are released at one time. Spawning is annual in some species such as *Ptilosarcus gurneyi* (Chia and Crawford 1973) and *Pennatula phosphorea* (Edwards and Moore 2008), although other species such as *Kophobelemnon stelliferum* (Rice et al. 1992) and *P. aculeata* (Eckelbarger et al. 1998) show no reproductive seasonality and are likely continuous spawners.

Birkeland (1974) also provided data on recruitment of *P. gurneyi* over a three year period in cleared plots. He manually cleared an area of a sea pen bed and then sampled the recruiting cohort for 3 years to determine growth rates (age-at-length) and validate the first three annual rings. *Ptilosarcus guerneyi* produces free-swimming planula larvae that do not feed and settle within seven days if a suitable substratum is encountered (Chia and Crawford 1973). Movement into the plots by drifting adults was low. Recruitment of juveniles occurred annually or every few years but was described as being highly clumped, spatially unpredictable and patchy. He estimated that 10-15% of the space within the sea pen field successfully recruited each year. Discrete size groups can be observed within the boundaries of the fields reflecting these recruitment events. Recruitment patches ranged from 20 to 200 m in length following an isobath. Large interannual differences in recruitment were also observed in *Renilla kollikeri*, a sea pen from the coast of California (Davis and Van Blaricom 1978).

References

Adey, J.A. 2007. Aspects of the sustainability of creel fishing for Norway lobster, *Nephrops norvegicus* (L.), on the west coast of Scotland. PhD thesis, University of Glasgow. 474pp.

Birkeland, C. 1974. The effect of wave action on the populatlon dynamics of *Gorgonia ventalina* Linnaeus. Studies in Tropical Oceanography, 12: 115-126.

Burton, M. 1949. Non-sexual reproduction in sponges, with special reference to a collection of young *Geodia*. Proceedings of the Linnean Society of London, 160: 163-178.

Chia, F.-S., and Crawford, B.J. 1973. Some observations on gametogenesis, larval development and substratum selection of the sea pen *Ptilosarcus gurneyi*. Marine Biology 23: 73-82.

Cogswell, A., Kenchington, E., Lirette, C., Brodie, B., Campanis, G., Cuff, A., Perez, A., Kenny, A., Ollerhead, N., Sacau, M., and Wareham, V. 2010. Evaluating sponge encounter thresholds through GIS simulation of the commercial groundfish fishery in the NAFO Regulatory Area. NAFO Scientific Council Research Document 10/71, Serial No. N5869, 26pp.

Cogswell, A., Kenchington, E., Lirette, C., Murillo F.J., Campanis, G., Campbell, N., and Ollerhead, N. 2011. Layers Utilized by an ArcGIS model to Approximate Commercial Coral and Sponge Bycatch in the NAFO Regulatory Area. NAFO Scientific Council Research Document 11/72.

Davis, N. and Van Blaricom, G.R. 1978. Spatial and temporal heterogeneity in a sand bottom epifaunal community of invertebrates in shallow water. Limnology and Oceanography, 23: 417-427.

Doyle, J., Lordan, C., Fitzgerald, R., O'Connor, S., Fee D., Nolan, C., and Hayes, J. 2011. Celtic Sea *Nephrops* Grounds 2011 UWTV Survey Report The Marine Institute, Fisheries Science Services, Renville, Oranmore, Galway, Ireland.

Eckelbarger, K.J., Tyler, P.A., and Langton, R.W. 1998. Gonadal morphology and gametogenesis in the sea pen *Pennatula aculeata* (Anthozoa: Pennatulacea) from the Gulf of Maine. Marine Biology, 132: 677-690.

Edwards, D.C.B., and Moore, C.G. 2008. Reproduction in the sea pen *Pennatula phosphorea* (Anthozoa: Pennatulacea) from the west coast of Scotland. Marine Biology, 155: 303–314.

Engel, J. and Kvitek, R. 1998. Effects of otter trawling on a benthic community in Monterey Bay National Marine Sanctuary. Conservation Biology, 12: 1204-1214.

FAO. 2009. International Guidelines for the Management of Deep-sea Fisheries in the High Seas. 73 pp, Rome.

Freese, J.L. 2001. Trawl-induced damage to sponges observed from a research submersible. Marine Fisheries Review, 63: 7–13.

Freese, L., Auster, P.J., Heifetz, J., and Wing, B.L. 1999. Effects of trawling on seafloor habitat and associated invertebrate taxa in the Gulf of Alaska. Marine Ecology Progress Series, 182: 199-126.

Fuller, S.D. 2011. Diversity of marine sponges in the Northwest Atlantic. Thesis, (PhD). Dalhousie University, Halifax. 215 pages.

Fuller, S.D., Murillo Perez, F.J., Wareham, V., and Kenchington, E. 2008. Vulnerable Marine Ecosystems dominated by deep-water corals and sponges in the NAFO Conventional Area. NAFO Scientific Council Research Document 08/22, Serial No. N5524, 24p.

Greathead, C., Demain, D., Dobby, H., Allan, L., and Weetman, A. 2011. Quantitative assessment of the distribution and abundante of the burrowing megafauna and large epifauna community in the Fladen fishing ground, Northern North Sea. Marine Scotland – Science ISSN: 2043-7722.

Heifetz, J., Stone, R.P., and Kalei Shotwell, S. 2009. Damage and disturbance to coral and sponge habitat of the Aleutian Archipelago. Marine Ecology Progress Series, 397: 295-303.

Hixon, M.A., and Tissot, B.N. 2007. Comparison of trawled vs untrawled mud seafloor assemblage fishes and macroinvertebrates at Coquille Bank, Oregon. Journal of Experimental Marine Biology and Ecology, 344: 23-34.

ICES. 2009. Report of the ICES-NAFO Joint Working Group on Deep-water Ecology (WGDEC), 9–13 March 2009, ICES CM 2009\ACOM:23, 94 pp.

Kefalas, E., Castritsi-Catharios, J., and Miliou, H. 2003. The Impacts of scallop dredging on sponge assemblages in the Gulf of Kalloni (Aegean Sea, northeastern Mediterranean). ICES Journal of Marine Science, 60: 402-410.

Kenchington, E., Best, M., Cogswell, A., MacIsaac, K., Murillo Perez, J., MacDonald, B., Wareham, V., Fuller, S.D., Jørgensbye Hansen, H.I.Ø., Sklyar, V., and Thompson, A.B. 2009. Coral Identification Guide NAFO Area. NAFO Scientific Council Studies, 42: 1-18.

Kenchington, E., Cogswell, A., Lirette, C., and Rice, J. 2010a. A GIS Simulation Model for Estimating Commercial Sponge Bycatch and Evaluating the Impact of Management Decisions. DFO Canadian Scientific Advisory Secretariat Research Document 2010/040. vi + 39 pp.

Kenchington, E., J. Murillo, A. Cogswell, and C. Lirette. 2011. Development of encounter protocols and assessment of significant adverse impact by bottom trawling for sponge grounds and sea pen fields in the NAFO Regulatory Area. SCR Doc. 11/75.

Kenchington, E., Lirette, C., Cogswell, A., Archambault, D., Archambault, P., Benoit, H., Bernier, D., Brodie, B., Fuller, S., Gilkinson, K., Levesque, M., Power, D., Siferd, T., Treble, M., and Wareham, V. 2010. Delineating Coral and Sponge Concentrations in the Biogeographic Regions of the East Coast of Canada Using Spatial Analyses. DFO Canadian Scientific Advisory Secretariat Research Document 2010/041. iv + 207 pp.

Kenchington, T.J. 2011. Encounter Protocols for Avoidance of Harm to Vulnerable Marine Ecosystems: A global review of experience to 2010. DFO Canadian Scientific Advisory Secretariat Research Document 2011/009. vi + 43 p.

Kinnear, J.A.M., Barkel, P.J., Mojseiwicz, W.R., Chapman, C.J., Holbrow, A.J., Barnes, C., and Greathead, C.F.F. 1996. Effects of Nephrops creels on the environment. Fisheries Research Services Report No. 2/96.

Klitgaard, A.B., and Tendal, O.S. 2004. Distribution and species composition of mass occurrences of large-sized sponges in the northeast Atlantic. Progress in Oceanography, 61: 57-98.

Krieger, K.J. 1993. Distribution and abundance of rockfish determined from a submersible and by bottom trawling. Fishery Bulletin, 91: 87-96

Maldonado, M. and Bergquist, P.R. 2002. Phylum Porifera. In: Young CM (ed) Atlas of marine invertebrate larvae. Academic, London, pp 21–50.

Malecha, P.W., and Stone, R.P. 2009. Response of the sea whip *Halipteris willemoesi* to simulated trawl disturbance and its vulnerability to subsequent predation. Marine Ecology Progress Series, 388: 197-206.

Mariani, S., Uriz, M.J., and Turon, X. 2003. Methodological bias in the estimations of important meroplanktonic components from nearshore bottoms. Marine Ecology Progress Series, 253: 67-75.

Mariani, S., Uriz, M.J., Turon, X., and Alcoverro, T. 2006. Dispersal strategies in sponge larvae: integrating the life history of larvae and the hydrologic component. Oecologia, 149: 174-184.

Moran, M.J., and Stephenson, P.C. 2000. Effects of otter trawling on macrobenthos and management of demersal scalefish fisheries on the continental shelf of northwestern Australia. – ICES Journal of Marine Science, 57: 510–516.

Murillo F.J., Durán Muñoz P., Altuna A., Serrano A. 2011. Distribution of deep-water corals of the Flemish Cap, Flemish Pass, and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): interaction with fishing activities. ICES Journal of Marine Science, 68: 319-332.

Murillo, F.J., Durán Muñoz, P., Cristobo, F.J., Ríos, P., González, C., Kenchington, E., and Serrano, A. 2012. Deep-sea Sponge Grounds of the Flemish Cap, Flemish Pass and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): distribution and species composition. Marine Biology Research. In press.

Murillo, F.J., Kenchington, E., Gonzalez, C., and Sacau, M. 2010. The use of density analyses to delineate significant concentrations of Pennatulaceans from trawl survey data. NAFO Scientific Council Research Document 10/07, Serial No. N5753, 7 pp.

Murillo, F.J., Wareham, V., Sacau, M., Román, E., and Durán Muñoz, P. 2011. New data on deep-water corals and sponges from Spanish/EU and Canadian bottom trawl groundfish surveys in the NAFO Regulatory Area (Divs. 3LMNO): 2008-2010 period. NAFO SCR Doc. 11/74.

NAFO. 2009. Report of the NAFO SC Working Group on Ecosystem Approach to Fisheries Management (WGEAFM). Response to Fisheries Commission Request 9.b and 9.c. Scientific Council Meeting, 4-18 June 2009, Dartmouth, Canada. Serial No. N5627. NAFO SCS Doc. 09/6, 26 pp.

NAFO. 2010. Report of the 3rd Meeting of the NAFO Scientific Council Working Group on Ecosystem Approach to Fisheries Management (WGEAFM). NAFO Scientific Council Summary Document 10/24, Serial No. N5868, 75 pp.

Pitcher, C., Burridge, C., Wassenberg, T., Hill, B., and Poiner, I. 2009. A large scale BACI experiment to test the effects of prawn trawling on seabed biota in a closed area of the Great Barrier Reef Marine Park, Australia. Fisheries Research, 99: 168-183.

Rice, A.L., Tyler, P.A., and Paterson, G.J.L.1992. The pennatulid *Kophobelemnon stelliferum* (Cnidaria: Octocorallia) in the Porcupine Seabight (North-East Atlantic Ocean). Journal of the Marine Biological Association of the United Kingdom, 72: 417-434.

Rooper, C. N., Wilkins, M.E., Rose, C.S., and Coon, C. 2011. Modeling the impacts of bottom trawling and the subsequent recovery rates of sponges and corals in the Aleutian Islands, Alaska. Continental Shelf Research, 31: 1827-1834.

Sainsbury, K.J., Campbell, R.A., and Whitelaw, A.W. 1992. Effects of trawling on the marine habitat on the north west shelf of Australia and implications for sustainable fisheries management. In D. A. Hancock (Ed.), Sustainable Fisheries Through Sustaining Fish Habitat. Canberra, Australia: Australian Government Publishing Service. pp. 137-145.

Soong, K. 2005. Reproduction and colony integration of the sea pen *Virgularia juncea*. Marine Biology, 146: 1103-1109.

Spetland, F., Rapp, H.T., Hoffmann, F., and Tendal, O.S. 2007. Sexual reproduction of *Geodia barretti* Bowerbank, 1858 (Porifera, Astrophorida) in two Scandinavian fjords In: Custódio, M.R., Lôbo-Hajdu, G., Hajdu, E., Muricy, G. (eds). Porifera research: biodiversity, innovation and sustainability. Série Livros 28. Museu Nacional, Rio de Janeiro. pp. 233-237.

Tilmant, J.T. 1979. Observations on the impacts of shrimp roller frame trawls operated over hardbottom communities, Biscayne Bay, Florida. Natl. Park. Serv. Rep. Ser. No. P-553, 23 pp.

Tissot, B.N., Yoklavich, M.M., Love, M.S., York, K., and Amend, M. 2006. Benthic invertebrates that form habitat structures on deep banks off southern California, with special reference to deep sea corals. Fisheries Bulletin, 104: 167-181.

Troffe, P.M., Levings, C.D., Piercey, G.E. and Keong, V. 2005. Fishing gear effects and ecology of the sea whip (*Halipteris willemoesi* (Cnidaria: Octocorallia: Pennatulacea)) in British Columbia, Canada: preliminary observations. Aquatic Conservation: Marine and Freshwater Ecosystems, 15: 523-533.

Tuck, I.D., Chapman, C.J., Atkinson, R.J.A., Bailey, N., and Smith, R.S.M. 1997. A comparison of methods for stock assessment of the Norway lobster, *Nephrops norvegicus*, in the Firth of Clyde. Fisheries Research, 32: 89-100.

Tyler, P.A., Bronsdon, S.K., Young, C.M., and Rice, A.L. 1995. Ecology and gametogenic biology of the genus *Umbellula* (Pennatulacea) in the North Atlantic Ocean. Internationale Revue der Gesamten Hydrobiologie, 80: 187-199.

Van Dolah, R.F., Wendt, P.H., and Nicholson, N. 1987. Effects of a research trawl on a hardbottom assemblage of sponges and corals. Fisheries Research, 5: 39-54.

Walsh, S.J, and McCallum, B.R. 1997. Observations on the varying fishing powers of Canadian survey vessels and trawls. NAFO Scientific Council Research Document 97/66, Serial No. N2900, 9p.

Wassenberg, T.J., Dews, G., and Cook, S.D. 2002. The impact of fish trawls on megabenthos (sponges) on the north-west shelf of Australia. Fisheries Research, 58: 141-151.

Williams, G.C. 1995. Living genera of sea pens (Coelenterata: Octocorallia: Pennatulacea): illustrated key and synopses. Zoological Journal of the Linnean Society, 113: 93-140.

Wilson M.T., Andrews, A.H., Brown, A.L., Cordes, E.E. 2002.Axial rod growth and age estimation of the sea pen, *Halipteris willemoesi* Kölliker. Hydrobiologia, 471: 133-142.

ToR 4.3. [FC Request # 13- item a)]. Summarize the general progress of the Roadmap to EAF.

Since its creation, WGEAFM has had two primary activities, the development of long-term basis for an Ecosystem Approach to Fisheries (EAF) for NAFO, and to provide advice and information on specific requests related to ecosystem issues. In order to achieve its goals, WGEAFM operates with a stable set of Terms of Reference (Annex 1), which are addressed over multiple meetings.

In this general context, WGEAFM initially developed the "Roadmap to EAF" in 2010 (NAFO, 2010), to serve as a conceptual foundation from where SC could discuss and propose a way forward for the implementation of an ecosystem approach to fisheries for NAFO. The "Roadmap to EAF" was endorsed by SC, and it has served ever since as the guiding set of ideas that SC in particular, and NAFO in general, are following to develop an EAF for the organization. The "Roadmap to EAF" is not a fixed plan; as its name indicates, it is a guiding set of ideas whose details evolve as it is developed and implemented.

The "Roadmap to EAF" was originally developed around the concept of Integrated Ecosystem Assessments (IEA) (Levin et al. 2009) (Fig. 4.3.1), and its core premises are: a) the approach has to be objective-driven, b) it should consider long-term ecosystem sustainability, c) it has to be a place-based framework, and d) trade-offs have to be explicitly addressed.

The initial development was organized around three practical steps (Fig. 4.3.1). These steps were defined with the purpose of making tractable the process of developing the EAF framework, and where focused on the definition of regional ecosystem units, the understanding of ecosystem state and key functional processes, and examination and development of management tools. In terms of setting sustainable exploitation levels, the overall framework can be summarized as a 3-tiered, hierarchical one. The first tier defines fishery production potential at the ecosystem level, taking into account environmental conditions and ecosystem state. This allows a first order consideration for the potential influence of large scale climate/ecological forcing on fishery production, as well as explicitly considering the basic limitation imposed by primary production on ecosystem productivity. The second tier utilizes multispecies models to allocate fisheries production among a set of commercial species, taking into account species interactions as well as considerations on the resilience and stability of the exploited assemblage. This tier explicitly considers the trade-off among fisheries, and allows identifying exploitation rates which are consistent with multispecies sustainability. The third tier involves single-species stock assessment, where the exploitation rates derived from tiers 1 and 2 can be further examined to ensure single-species sustainability. This hierarchical sequence allows considering the sustainability of the exploitation at the ecosystem, multispecies assemblage, and single stock level.

As research progressed, a potential structure for the actual implementation of the Roadmap was developed (Fig. 4.3.2). This representation of the "Roadmap to EAF" provides a more operational view of how the EAF could be implemented, highlighting the different steps involved, a general perspective on which NAFO bodies would be expected to lead the work in each step, as well as integrating the different elements in a possible work-flow process. This more operational schematic not only incorporates the concept of the hierarchical approach to define exploitation rates, but also integrates the impacts on benthic communities (e.g. VMEs) associated with the different fisheries that take place within the ecosystem (Fig. 4.3.2). The more operational description of the "Roadmap to EAF" as depicted in Figure 4.3.2 presupposes that a spatially-explicit ecosystem-level management unit has been identified; the structure/process described in the figure applies to a single ecosystem management unit.

Although significant progress has been made since the original proposal of the "Roadmap to EAF" in 2010, there is still a fair amount of work that remains to be done. Addressing Fisheries Commission Request # 13 requires input not just from WGEAFM, but also from SC at large, and in some instances, even from FC itself. Summarizing the progress on the “Roadmap to EAF” should not be limited to the work done by SC and its WGs, it should also include the work that FC and its WGs have done. In order to provide a platform to summarize the progress on the “Roadmap to EAF” which could also be easily updated and complemented by other NAFO bodies, WGEAFM opted for describe the progress in a tabular form (Table 4.3.1). The information was schematically compiled following the steps (boxes) used in Figure 4.3.2 to describe the structure of the roadmap.

Overall, since the “Roadmap to EAF” currently galvanizes the efforts made by NAFO as a whole towards developing its own ecosystem approach to management, the initial compilation developed by WGEAFM, and presented here in Table 4.3.1, would only convey an incomplete picture of the progress made to date. Nonetheless, since WGEAFM spearheads the EAF development process within SC, Table 4.3.1 should be a reasonable starting point to address FC Request # 13, item a).

In conclusion, implementing the “Roadmap to EAF” requires knowledge of ecosystem status, the provision of multispecies advice that takes into consideration the effects of trophic interactions, and assessment of the likelihood of significant adverse impacts on VMEs. These elements can provide the context around which current assessment and management practices can be framed and evaluated. To date, WGEAFM has made significant progress toward the latter of these goals while important advancements have been achieved in the determination of fishery production potential, species interactions, common trends in species abundance and in the delineation of ecosystem management units (ecoregions).

To achieve further progress on implementation of the Roadmap to EAM, WGEAFM members agreed that activities of the WG should be focussed on comprehensive analyses that would provide <u>all the elements required for EAM for a focal ecoregion </u>that would serve the illustrate how application of more extensive knowledge base could enhance the advisory process. This would require development of an Integrated Ecosystem Assessment (IEA) and a multispecies and/or ecosystem model(s) for the focal area. Coordination of activities with STACFEN and the assessment groups would be required to obtain the data necessary to cover a broad range of trophic levels and environmental drivers. Development of the IEA should also take into consideration advancements achieved by the ICES Regional Seas Working Group (WGNARS) if at all possible.

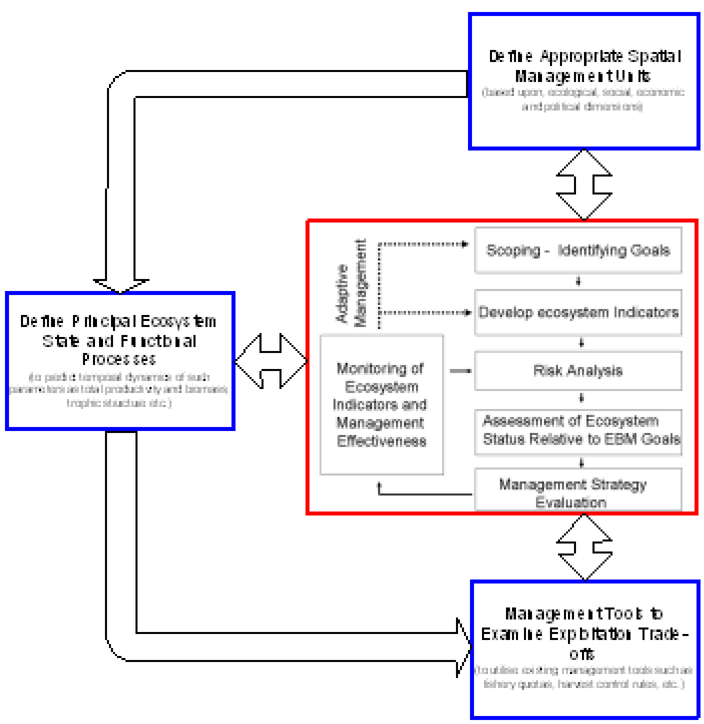

Figure 4.3.1. Original schematic for the “Roadmap to EAF” the relationship between the 3 practical steps in moving towards the implementation of an ecosystem approach to fisheries management (blue boxes) and the steps required to deliver effective holistic integrated ecosystem assessments (IEA) shown in the red box

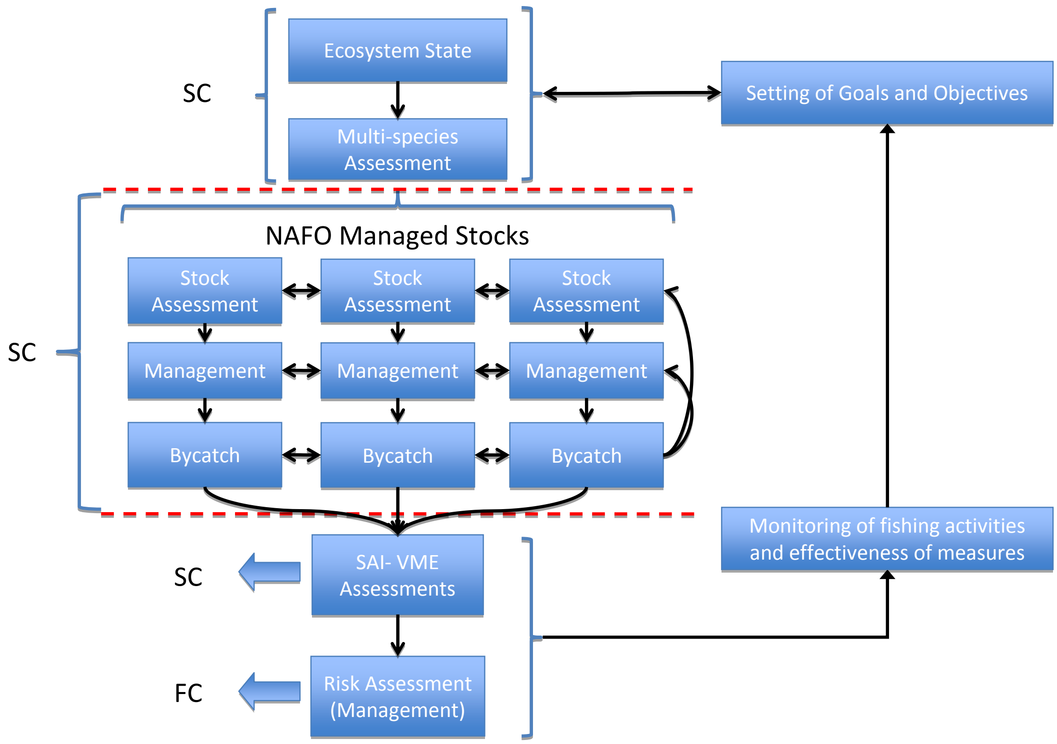

Figure 4.3.2. Current working template of the "Roadmap to EAF". This representation integrates both, the scientific aspects as well as management components, and allows interpreting the "Roadmap to EAF" as both, a guide to develop a management structure, and a representation of the process involved in making that structure operational. This diagram schematically describes the "Roadmap to EAF" as it would be applied to a previously identified (and spatially explicit) ecosystem-level management unit. The left hand-side is primarily the scientific side of the process, where most of the assessments and scientific evaluations are done, while the right hand-side correspond to the primarily management and policy side of the process, where management decisions, and monitoring/enforcement is considered. Still, the implementation of EAF is fundamentally an integrative process, so frequent and strong collaborations between scientists and managers are required for a successful outcome.

Table 4.3.1. Summary of progress on the development and implementation of the "Roadmap to EAF" to date. Information is schematically summarized following the steps (boxes) of the "Roadmap to EAF" as described in Figure 4.3.2. For each component (box), a brief description of the task associated with it, the progress to date, the work that still needs to be done, and some gaps deemed critical by WGEAFM is provided. In many cases, other NAFO bodies are expected to have relevant information that could add to the progress summarized here by WGEAFM; these expected contributions are also indicated in the table.

Component of the "Roadmap to EAF" as depicted on Figure 4.3.2	Progress done to date	Work to be done	Critical gaps identified by WGEAFM
Ecosystem State			
-defining spatial management units -exploring temporal variability of units -defining productivity state and its variability	-Ecoregion analyses for NL, Flemish Cap, US, partially Scotian shelf -Preliminary Fisheries Production Potential (FPP) models for NL, FC, SS, more for US -Preliminary Aggregate Biomass Production models NL, FC; more information exists. -initial studies linking elements of productivity and environmental drivers.	-integrate ecoregion analysis across NAFO convention area -Correspondence between stock boundaries and candidate ecosystem management units -Consideration of different scales and how to integrate them -identification of ranges of variability in the past compared to present. -Improved FPP and Aggregate biomass models - integrate environmental drivers into models of ecosystem productivity.	-integration with STACFEN -making more functional connections with ICES WGNARS -consideration of top predators (seabirds, sharks, seals, and cetaceans) -consideration of climate change impacts -incorporation of northern NAFO divisions (0 and 1) -incorporation of oceanic waters
Multispecies assessment			
-description of species interactions and trends -quantification of diets and predation -understanding the role of environmental drivers in ecosystem structure and dynamics -understanding the response of food webs to anthropogenic impacts	-studies of food habits in FC, NL, there is also information for SS and US -preliminary modelling of key species in FC - testing specific hypothesis of bottom-up and top-down regulation in NL -studies of common trends among multiple	-improving multispecies modelling for FC -developing preliminary multispecies models for NL -improved characterization of diets and its variability in space and time -improved/additional	-Considerations of environmental drivers and species interactions on reproductive potential. - promote integration/interaction with NAFO SC WGRP -enhanced participation and incorporation of information from Scotian Shelf and US

-definition of multispecies reference points -provision of advice on candidate TAC based on multispecies considerations	stocks in FC, and NL -estimation of consumption/predation for some stocks	estimation of consumption/predation for key stocks -improved understanding of the linkage between lower trophic level characteristics and dynamics and fish production. -study the role of environmental drivers in the regulation and structure of food webs.	-making more functional connections with ICES WGNARS
Stock Assessment			
-stock identification -assessment of the status of the stock -consideration of processes/environmental drivers affecting recruitment, growth, maturation and spatial distribution. -consideration of sources of mortality at the stock level	-current single-spp assessment -some shrimp assessments include predation -redfish assessment has considered the impact of predation in setting M [more to be added by SC]	-e.g. include predation in more assessments. [more to be added by SC]	-improve integration/interaction with SC -reliable estimates of fishery catches for their use in assessments [more to be added by SC]
Management			
-provision of advice on stock-specific TAC based on multispecies candidate -definition of stock-level reference points -development and implementation of harvest control rules, stock-specific management strategy evaluation frameworks and rebuilding plans	-provision of current TAC advice on NAFO stocks -PA and reference points for some stocks -MSE approach for Greenland halibut -rebuilding plans for some stocks are under development [more to be added by SC]	-further rebuilding plans -further reference points -revision of the PA -complete rebuilding plans (including harvest control rules) -develop mechanisms to links and evaluate TAC from multispecies candidates. [more to be added by SC]	-definition of explicit management objectives for each stock [more to be added by SC]

By-catch			
-evaluation of by-catch of commercial and non-commercial species (including VME-defining spp). -Reporting of bycatch for use in all assessments (stocks and SAI-VMEs) -development and implementation of measures to control by-catch levels.	-compilation of available information of bycatch by fishery for commercial spp. -suite of management measures associated with by-catch (e.g. limits of spp under moratoria in directed fisheries) -adoption of the catch reporting tow-by-tow [more to be added by SC]	-incorporation of non-commercial spp (including VME-defining spp) -improve reliability of catch information -link tow position with catch information (e.g. full use of VMS data for scientific analysis) -develop comprehensive approach to report bycatch across fisheries and make available to NAFO bodies for their inclusion in analyses. [more to be added by SC]	-lack of full catch information for both commercial and non-commercial spp, including VME-defining spp, on a tow-by-tow basis [more to be added by SC]
SAI-VME			
-what the nature of the VME is. -what the nature of the pressure is. -what the impact is, as a combination of the nature of the VME and pressure. -analysis of fishing impacts on benthic ecosystems	-identification and mapping of VME elements and indicator spp. -identification and review of impacts on seabed . -assessment of distribution and intensity of fishing activity (including initial evaluation of cumulative pressure from fishing), taking into account the type of fishery, gear employed, etc. -modelling VME indicator sp by-catch -modelling VME presence -evaluating criteria for VME indicator spp.	-assess VME resilience -integration of macro and megafauna data layers -determine the status of VMEs as essential fish habitats. -assessment of current closures for the protection of high concentrations of VME-indicator spp by 2014. -fisheries assessments regarding their impacts on VMEs (i.e. first assessments by 2016)	-lack of full catch information for both commercial and non-commercial spp, including VME-defining spp, on a tow-by-tow basis -understanding the functional relationships between VMEs and fisheries yields -determining what proportion of VMEs is optimal in a given fishery (i.e. how much VME we need to protect) -how VME closures relate to other human activities, and how these interactions may affect fisheries and fisheries resources.

Risk Assessment			
-assess the likelihood of significance adverse impacts on VMEs, in the context of current activities and objectives -assess the likelihood of fisheries having significant adverse impacts on ecosystem structure and function. -development and implementation of management actions in response to the outcomes of risk assessments	-development of selected VME-indicator spp maps, showing the risk of bottom fishing impacts. -implementation of closed areas for the protection of high concentration of selected VME-indicator spp. -implementation of encounter protocols for selected VME-indicator spp [more to be added by SC, FC, and SC-FC WGEAF]	-continue the development and implementation of management measures to minimize or prevent SAI on VMEs -develop guideline to ensure consistent application of risk assessment criteria in the context of current activities and objectives. [more to be added by SC, FC, and SC-FC WGEAF]	-develop, design, and implement a strategy to assess risk at the ecosystem level -ensure full interaction between all NAFO bodies to define risks in a manner that is acceptable and properly understood by all. [more to be added by SC, FC, and SC-FC WGEAF]
Monitoring			
-collection, analysis, and interpretation of data pertaining to ecosystem status and human activities relevant to the NAFO convention objectives. -use of available data to track the effectiveness of management measures	-RV surveys (stock status, ecosystem interactions, etc) -VMS (fishing footprint, intensity of fishing, compliance of management regulations) -NAFO and scientific observer programs [more to be added by SC, FC]	-improve/enhance collection of scientific information on non-commercial spp in RV surveys -improve reliability of catch information from commercial fleets -link tow position with catch information (e.g. full use of VMS data for scientific analysis) -develop and integrated way to summarize and track fleet composition and activities. [more to be added by SC, FC]	-lack of full catch information for both commercial and non-commercial spp, including VME-defining spp, on a tow-by-tow basis -basic scientific information lacking in some areas (e.g. seamounts, northern areas) -basic scientific data are very limited for some ecosystem components (e.g. epipelagic and bathypelagic zones). [more to be added by SC, FC]
Goal setting			
-Define ecosystem level objectives for the NAFO fisheries.	-initial discussions on the implications of species interactions in setting TAC for species in the FC.	-development of governance mechanisms to discuss/set multispecies objectives	-lack of explicit objectives [more to be added by SC, FC, and SC-FC

	-acknowledgement of the role of key forage species in the context of management of fisheries directed to these spp. [more to be added by SC, FC]	[more to be added by SC, FC, and SC-FC WGEAF]	WGEAF]

References

NAFO. 2010. Report of the NAFO Scientific Council Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM). 1-5 February, 2010, Vigo, Spain. NAFO Scientific Council Summary Document 10/19. Serial No. N5815.

Levin, P.S., M. J. Fogarty, S.A. Murawski, D. Fluharty. 2009. Integrated Ecosystem Assessments: Developing the Scientific Basis for Ecosystem-Based Management of the Ocean. PloS Biology. Vol.7 (1) e1000014. pp. 23-28.

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

ToR 5.1. [FC Request # 10].

This is a follow-up on the workplan for the reassessment of NAFO fisheries in 2016. Considering the modifications of the NCEM approved in the 2012 Annual Meeting, which focuses the fisheries assessments on SAI on VMEs, provide guidance to develop a workplan to achieve the reassessment of all NAFO fisheries by September 2016 and every 5 years thereafter, identifying the necessary steps to be taken, as well as the information and resources to do so.

Timing

The assessment will need to be completed by Scientific Council in June 2016, so WGEAFM needs to provide its contribution before this date (e.g. November/December 2015). There are 3 meetings of WGEAFM (4 including the meeting held in 2012) to prepare the assessment.

Tasks

The requirement for the assessment of bottom fishing activities in the NRA is set out in the NAFO Conservation and Enforcement Measures (NAFO/FC Doc, 13/1). Which states "assessments should consider the best available scientific and technical information on the current state of fishery resources." It also sets out a number of issues which should be addressed by the assessment, *inter alia*:

1. Type(s) of fishing conducted or contemplated, including vessels and gear types, fishing areas, target and potential bycatch species, fishing effort levels and duration of fishing (harvesting plan);
2. Existing baseline information on the ecosystems, habitats and communities in the fishing area, against which future changes are to be compared;
3. Identification, description and mapping of VMEs known or likely to occur in the fishing area;
4. Identification, description and evaluation of the occurrence, scale and duration of likely impacts, including cumulative impacts of activities covered by the assessment on VMEs;
5. Consideration of VME elements known to occur in the fishing area;
6. Data and methods used to identify, describe and assess the impacts of the activity, the identification of gaps in knowledge, and an evaluation of uncertainties in the information presented in the assessment;
7. Risk assessment of likely impacts by the fishing operations to determine which impacts on VMEs are likely to be significant adverse impacts; and
8. The proposed mitigation and management measures to be used to prevent significant adverse impacts on VMEs, and the measures to be used to monitor effects of the fishing operations.

WGEAFM notes that items 1 and 2 above will need input from STACFIS and STACFEN, respectively, and they should be made aware of this request so they can schedule a timely response to allow the integration of their assessments into the assessment being performed by WGEAFM. It will be important that there is participation at WGEAFM 2013 by STACFIS and STACFEN to coordinate our respective assessment tasks.

After careful examination of the CEM text (NAFO/FC Doc, 13/1), WGEAFM concluded, following discussion, that the focus of the assessment would therefore be on assessing Significant Adverse Impacts (SAIs) on Vulnerable Marine Ecosystems (VMEs) and importantly <u>not</u> an assessment of the status of commercial stocks. The following tasks are required to be undertaken to address the issues highlighted above:

- The work initiated in response to FC Request 16 in 2012 to map the fishing activity in relation to gear type and the mapping of VME elements and indicator species, will be developed during the 2013 and 2014 meetings of WGEAFM, e.g where possible site specific trawl tracks will be identified from VMS data and these will be investigated in combination with relevant video analysis surveys by DFO (cf Kenchington *et al.,* 2011). There may be an opportunity to target specific areas during the 2013 surveys by DFO to repeat the video analysis in the areas previously surveyed and known to be fished in order to quantify *in situ* direct impacts of trawling.
- An important component of the assessment will be the results/conclusions generated by the review of VME closed areas in 2014 (extent and status of VME) – see ToR 1.2. The results will be important in informing

what additional work needs to be done to integrate the results of the review with fishing pressure (effort and VMS) data analysis.

- A PhD studentship has been established at Oxford University, UK on the function and status of deep sea ecosystems with support of the NEREIDA programme (e.g. provision of benthic samples). This work will start in 2013 and hopefully will be completed by 2016. It is expected that this will provide some useful results to estimate the recovery potential of selected VMEs.
- Work started in 2011 to develop risk-based spatial management options in relation to SAI on VME (see FC Request 16 from 2012), this work will be continued in 2013 and 2014.
- A revised and more detailed workplan will be produced at the WGEAFM 2013 meeting following review of the closures and discussions with SC and other NAFO bodies.

Resource considerations

As noted in ToR 1.2, a large risk in delivery relates to the timing of potential EC funding to deliver tasks for the review of VME closures in 2013. The review of closures will form an essential component of the fisheries assessment.

An additional consideration is the workload of WGEAFM and how much time can be devoted during WGEAFM meetings to address the fishery assessment. It may be necessary to undertake work intersessionally to achieve the assessment aims, in which case this may require some additional funding.

ToRs 6+. As generic ToRs, these are place-holders intended to be used when addressing expected additional requests from Scientific Council.

ToRs 6.1.

Potential role and participation of WGEAFM in the project “Scientific review of best practices in bottom trawling” led by Michel Kaiser (Bangor University), Simon Jennings (University of East Anglia and CEFAS), Ray Hilborn (University of Washington), Jeremy Collie (University of Rhode Island) Bob McConnaughey (NOAA), Steve Murawski (University of South Florida), Ana Parma (CENPAT, Argentina), Roland Pitcher (CSIRO, Australia), and Adriaan Rijnsdorp (Wageningen University, Netherlands).

An initiative has been proposed by Ray Hilborn (USA), Simon Jennings (UK) and Mike Kaiser (UK) to conduct a global *“review of best practices in bottom fishing”*. The initiative is seeking support from stakeholders, e.g. RFMOs, through data sharing, understanding of current management practices and to engage in discussions to improve practices. A document which describes the initiative was circulated at WGEAFM and discussed in plenary. Essentially the initiative aims to establish an expert working group that will undertake a review over two years starting in 2013. The project is also supported by 3 PhD studentships and the working group is expected to consist of between 10 and 15 experts.

WGEAFM concluded that in principal this would be a good initiative for NAFO to support, so long as it does not place unreasonable demands on either the NAFO Secretariat or Scientific Council time or resources. It was noted that the objectives of the initiative (see Annex 2) were very closely related to the current work activities of WGEAFM, so most of the outputs likely to be of interest to the initiative have been documented already. In addition, the performance review of NAFO recommended support for developing co-operative relationships with other international fisheries management organisations and this initiative provides a basis (in part) for some cooperation. However, access to raw data would need to be considered for approval on a case by case basis, should it be required.

It was suggested that WGEAFM co-Chair Andrew Kenny would act as the point of contact between WGEAFM and the initiative following approval of formal links between NAFO SC and the initiative.

Other businesses

a) Report of the 3rd ICES WGNARS meeting in Falmouth, USA

ICES Working Group on the Northwest Atlantic Regional Seas (WGNARS)

The overarching objective of the ICES Working Group on the Northwest Atlantic Regional Seas (WGNARS) is to develop the scientific support for Integrated Ecosystem Assessments (IEA) of the Northwest Atlantic region to support ecosystem approaches to science and management. IEAs are defined as “a synthesis and quantitative analysis of information on relevant physical, chemical, ecological, and human processes in relation to specified ecosystem management objectives” (Levin et al. 2008, 2009), and they are a tool to provide scientific support to inform management decisions. WGNARS is part of the ICES Science Committee (SCICOM) Steering Group on Regional Sea Programmes (SSGRSP), whose mandate is to create regional seas programs in the ICES areas. The SSGRSP provides international-level coordination among the regional seas working groups to share progress, develop methodologies required by all the groups, and to develop best practices for IEA.

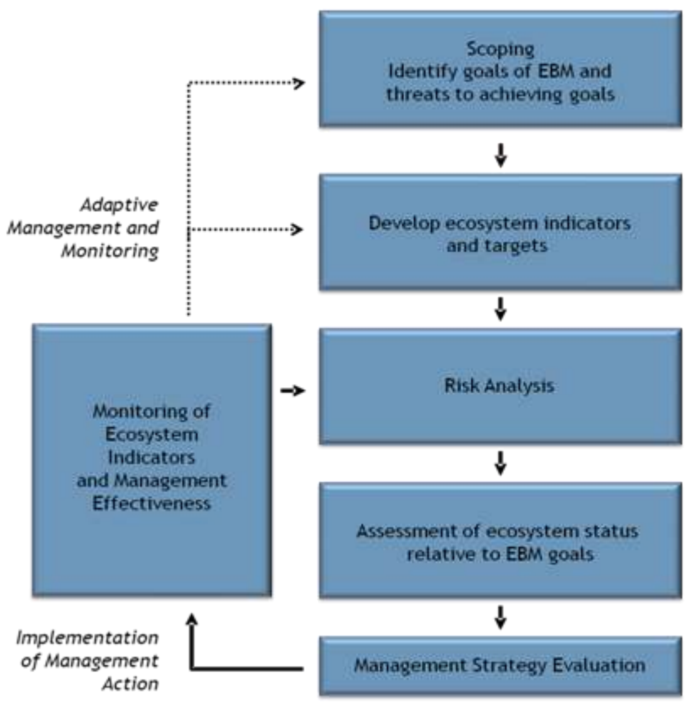

Figure a.1. Levin et al. (2009) framework for Integrated Ecosystem Assessment

The spatial scope for the group’s work is focused on the Canadian and northeast US continental slope system, and thus the main policy and governance context for ecosystem management considered by WGNARS includes the Fisheries Act and Oceans Act in Canada and the National Oceans Policy in the US. In this context, the group must consider a broad range of ocean uses, including but not limited to fishing. In the US, IEA development is coordinated at a national level by the NOAA IEA program, with regional implementation for the Northeast US Shelf system through the NOAA Northeast Fisheries Science Center (NEFSC). NOAA has adopted the Levin et al. (2009) framework for IEA (Figure a.1), which is an iterative five-step process that incorporates information from and facilitates collaboration among citizens, stakeholders, scientists, resource managers, and policy makers. The framework includes scoping to identify the goals and objectives of ecosystem management, development of indicators to assess ecosystem status, trends, and threshold values for management action, analysis of risk from human activities and natural processes, assessment of ecosystem status relative to the defined objectives, and management strategy evaluation to assess the ecosystem impacts of different possible strategies. In Canada, guidance for development of ecosystem based management is provided by the Policy and Operational Framework for Integrated Management of Estuarine, Coastal, and Marine Environments (http://www.dfo-mpo.gc.ca/oceans/publications/cosframework-cadresoc/index-eng.asp), but there is no formal coordination for IEA development at the national or regional level. Nevertheless, many of the elements of the Levin et al. (2009) framework were considered by the DFO Atlantic regions through the Integrated Management Planning process. To focus work toward an IEA, WGNARS has adopted a policy of ensuring that any science results presented to the group fits into the framework to evaluate how the work can contribute to the IEA process.

WGNARS work in 2012 focused on reviewing previous scoping exercises in IEA for management objectives and socio-economic utilities, refining candidate indicators and developing methodology to define thresholds for each indicator, and developing spatially explicit seascape models to support space and time based ecosystem management.

Due to the high cost and time investment required for scoping, US IEA regional programs are leveraging existing large scale scoping exercises. In addition, NEFSC social scientists presented results from a workshop on developing a conceptual framework for social sciences in ecosystem-based fisheries management, which defined human dimensions to include cultural diversity, institutions and governance, and valuation of ecosystem goods and services as well as work by the NEFSC Social Science Branch on defining social and economic performance measures and indicators for monitoring fisheries management outcomes, such as financial viability, distributional outcomes, stewardship, governance, and well-being. A case study demonstrated how economic and biological information could be integrated to evaluate alternatives to minimize the impacts of fishing on Essential Fish Habitat. Discussion of socio-economic considerations was also incorporated throughout the meeting discussions.

Extensive efforts have been made toward developing indicators in the NW Atlantic regions, but more work is required to enhance linkages between indicators and pressures, drivers, states, and responses. A comparison of indicators from multiple regions was used to develop a consensus statement of principles for IEA indicators which WGNARS proposed to focus future IEA indicator development. Thresholds of response indicators with respect to driver indicators are needed to inform management decisions. Discussions of methods for threshold development focused on the need for objective methods such as structural models, time series models, and spatial comparisons, as well as empirical vs. theoretical thresholds, and case studies for threshold development were presented that utilized statistical models and Management Strategy Evaluation simulations.

The habitat and spatial planning group continued to wrestle with issues central to ecosystem assessment and management in the North West Atlantic, including critical scales of variability for habitat effects on individuals and groups, effects of spatio-temporal habitat dynamics on whole system production dynamics, resilience and mechanisms behind behaviors of aggregate ecosystem indicators, and integration of dynamic pelagic processes with static seabed features into definitions of ocean habitat.

The WGNARS terms of reference for 2013 will focus on expanding the review of scoping exercises and identifying the next steps for refining goals for an IEA for the Northwest Atlantic as well as for vetting core indicators with relevant stakeholders; evaluating the risk of various multi-sector ocean-uses; and evaluating indicator performance with respect to important ecosystem drivers, emphasizing responses relative to candidate thresholds. Ongoing challenges for WGNARS include enhancing connections with governance and institutional structures in both the US and Canada and, in Canada, across the four Atlantic DFO regions, as well as developing an effective strategy to address the group’s multi-sectoral mandate.

Additional information about WGNARS, including the 2012 report and terms of reference for 2013, can be found on the ICES website:
http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=405

References

Levin, P.S., Fogarty, M.J., Matlock, G.C., and Ernst, M. 2008. Integrated ecosystem assessments. NOAA Technical Memorandum NMFS-NWFSC-92.

Levin, P. S., Fogarty, M. J., Murawski, S. A., and Fluharty, D. 2009. Integrated ecosystem assessments: developing the scientific basis for ecosystem-based management of the ocean. Public Library of Science (PLOS) Biology 7(1): e1000014 (0023–0028).

b) New NAFO SC/FC Working Group on Ecosystem Approaches to Fisheries Management

WGEAFM noted that a FC proposal was adopted in the September 2012 Annual Meeting for a new joint Scientific Council - Fisheries Commission working group that would focus on the development and implementation of ecosystem approaches to fisheries management. The terms of reference and workplan would be developed intersessionally, likely through a meeting of various committee and WG chairs, and then considered by both the Scientific Council and the Fisheries Commission at the 2013 annual meeting. It was recommended by FC that the Terms of Reference include consideration of all matters related to the Ecosystem Approaches to Fisheries Management (EAF), and the provision of advice to the Fisheries Commission on these matters. It was also recommended that the mandate incorporate the responsibilities outlined in the current FC Working Group of Fisheries Managers and Scientists on Vulnerable Marine Ecosystems, resulting in the eventual disbanding of that FC Working Group. SC also considered the new WG at the Annual Meeting and agreed with it in principle.

Recognizing that the chair(s) of WGEAFM would be involved in establishing the new joint WG, WGEAFM discussed some issues relevant to this. In implementing the EAFM, it was considered that evaluating the fisheries assessments (e.g risk of SAI on VMEs), and recommending management measures (as per existing FC WG) would likely be two main areas of focus for the new WG. Some thought will be required to ensure there is no overlap in the work of WGEAFM, SC, and the new joint WG, as well as to clearly define the roles and responsibilities of SC and FC members in the new joint WG. There will also be issues to be considered with rules for observer participation in the new WG (currently different in FC and SC), as well as governance, working procedure, and reporting, given there would be two parent bodies. Appropriate timing for the WG meetings will also be important.

It was thought that WGEAFM would continue its work as currently defined – focusing on the scientific aspects of EAFM, including evaluation of closed areas for 2014, fisheries assessments by 2016, and addressing the increasing number of FC requests related to ecosystems. Various options for the timing of future WGEAFM meetings were discussed, including continuation of the current arrangement, moving to a winter/spring time slot, and holding WG meetings concurrently with SC in June. WGEAFM evaluated these options from a number of perspectives, and concluded that the current schedule of late November meetings worked best. It was noted that increased participation from other SC members at the November WGEAFM meeting was occurring, but that more SC members are encouraged to participate. This will be particularly important as work progresses on the implementation of the “Roadmap to EAF”. As well, more WGEAFM members are encouraged to attend the June SC meetings. However, WGEAFM also recognized that attendance at more meetings is associated with additional costs, and that this is posing a challenge for CPs. Consequently, progress on the EAFM will be delayed at a critical juncture without the additional resources required for the increased participation. WGEAFM recommends that SC consider this issue and, if deemed appropriate, to discuss with FC.

c) Documents reviewed and/or produced during this meeting

From the work presented and discussed at this meeting, WGEAFM review and endorsed the following to be produced as SCR documents:

Pepin, P. M. Koen-Alonso, A. Cuff, J. Higdon, and N. Ollerhead. Robustness in the delineation of ecoregions on the Newfoundland and Labrador continental shelf. NAFO SCR 12/067, Serial No: N6135

Pérez-Rodríguez, A., and F. Saborido-Rey. 2012. Food consumption of Flemish Cap cod Gadus morhua and redfish Sebastes sp. using generic bioenergetic models. NAFO SCR 12/068, Serial No: N6136

Next Steps

a) Date and place for next meeting

It was proposed that the 6th WGEAFM meeting to take place in November 19-28, 2013 at the NAFO Secretariat in Dartmouth, Canada.

b) NEREIDA project meeting

It was agreed that a meeting of the NEREIDA project team will be hosted within the 6th WGEAFM meeting.

c) ToRs for next meeting

WGEAFM proposes that its 6th meeting should continue addressing the the long-term ToRs described as:

Theme 1: Spatial considerations

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

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

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

ToR 3. Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area.

Theme 3: Practical application of ecosystem knowledge to fisheries management

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

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

Theme 4: Specific requests

ToRs 6+. As generic ToRs, these are place-holders intended to be used when addressing expected additional requests from Scientific Council.

More specifically, work during the 6th WGEAFM meeting is proposed to be focused on:

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

Review for VME closures (see ToR 1.2 in this report)

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

Update on ecoregions and results from integrated ecoregion analysis

ToR 3. Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area.

Update on FPP modelling

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

Revised workplan for SAI-VMEs in 2016 (see ToR 5.1 in this report)

In addition to the work focused on the ToRs indicated above, WGEAFM would also be expected to dedicate time to address specific ToRs related to SC and/or FC requests.

If time allows, any study not pertaining to the focal ToRs indicated above, but still of relevance for addressing WGEAFM long-term ToRs may also be presented and discussed.

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ANNEX 1. Stable Long-Term Themes And Terms Of Reference (Tor) For The NAFO SC Working Group On Ecosystem Approaches To Fisheries Management (WGEAFM)

Theme 1: Spatial considerations

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

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

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

ToR 3. Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area.

Theme 3: Practical application of ecosystem knowledge to fisheries management

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

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

Theme 4: Specific requests

ToRs 6+. As generic ToRs, these are place-holders intended to be used when addressing expected additional requests from Scientific Council.

ANNEX 2. Trawling: finding common ground on the scientific knowledge regarding best practices

Ray Hilborn, Simon Jennings, Michael Kaiser

Executive Summary – summary and specific request sections

One of the most contentious issues in management of marine fisheries is the use of mobile bottom contact gears, trawls and dredges. About 25% of world fish catch comes from the use of these gears and catch from trawls is an important element in food security in much of the world. At present, a continental shelf area approximately equivalent to 3 times the area of Brazil is affected by mobile bottom contact gear. Trawls can dramatically transform sensitive benthic ecosystems, eliminating much of the associated emergent surface dwelling flora and fauna especially on hard bottoms. Conversely, extensive studies have shown that there are fewer changes to less sensitive habitats, particularly in regions subject to frequent natural disturbance.

We propose to establish a working group of experts in ecology and fisheries management to provide a scientific basis for evaluating policies on trawling. The project will consist of 5 phases.

(1) The first phase will examine the extent of trawling and habitats, compiling for as much of the world as possible data on the area trawled, the habitats trawled and the intensity of trawling. Particular attention will be paid to identifying data on the trends in the extent and frequency of areas trawled, and the distribution of trawl footprint across different habitat types.

(2) The second phase will compile and evaluate data on the impact of trawling on the abundance and diversity of biota, looking especially at the key factors of intensity of trawling and type of habitat trawled. Where possible, responses of key ecosystem services to trawl disturbance will be compiled or inferred from published studies.

(3) The third phase will use information from the first and second phases to develop methods for risk assessment and conduct a risk assessment of the effects of trawling and illustrate trends in risk of change to seabed habitats and communities among fisheries and through space and time

(4) The fourth phase will look at the medium and long term impact of trawling on the productivity and sustainable yield of different target species and from the ecosystem as a whole. It seems likely that trawling benefits some species and is detrimental to others. How does trawling affect the long-term sustainable yield of aquatic resources from an ecosystem? How does trawling affect other ecosystem services?

(5) The fifth phase will consider a range of best practices that might include defining what habitats should be closed to trawling, restrictions on the intensity of trawling by habitat type, and restrictions by habitat on the design of different trawls or other mobile bottom contact gear. For each possible type of practice, the impact on biota and yields of target species will be evaluated.

The project will be conducted by a working group of 10-15 over 2 years with a series of 4 meetings. Three post-doctoral fellows will provide the major work between group meetings.

Background/Problem Definition – the context and issues underlying the proposal

This proposal emerges from the ongoing concern about the impacts of bottom contact fishing gear, and the need for a synthesis of the scientific knowledge related to the issue. For the rest of this proposal we will use the term trawl to refer to all types of bottom contact gear, including trawls, dredges, and bottom contact by gears such as Danish Seine. Historical reviews of the subject have been performed by Jennings and Kaiser (1998), Kaiser (1998), The National Research Council (2002), Collie et al (2000), Kaiser et al. (2006) and Hinz et al. (2009). The major emphasis in these reviews was on the impact of trawling on bottom flora and fauna. There is now further information on this subject, and considerably more mapping of seafloor habitats and knowledge of trawl effort distribution in a number of areas. There has been limited attempt to estimate the impact of trawl disturbance on the productivity of target species, and there have been considerable developments in trawl gear technology that need to be summarized and evaluated. None of the earlier work attempted to define the consequences of a range of definitions of “best practice.”

In addition to the development of scientific knowledge of the impact of trawling over the last 10 years, there is increasing interest from a wide range of stakeholders on the impacts of trawling. In our discussions with NGOs and industry the subject of trawl impacts is almost always a major issue. Assembling the scientific information in a single data base accessible to all is of interest to all concerned. Furthermore, some major retailers now refuse to stock fish caught using trawl gears (e.g. Waitrose in the UK which accounts for 12% of UK fish retail sales).

Project Goals and Objectives – the expected result

There are three major goals and objectives

Goal #1: The first goal is to assemble data bases on the extent of trawling, habitats trawled, impacts of trawling on different biota in different habitats and impacts of trawling on ecosystem productivity and services. Once these data are assembled and analyzed these data bases will be made public.

Goal #2: Analyze the data bases to evaluate the overall extent of trawl impacts on biota, productivity and ecosystem services, to the extent possible by geographic regions.

Goal #3: Identify a range of "best practices" for trawling and determine the consequences of adoption of different best practices on biota, sustainable food production, ecosystems and ecosystem services.

Grant Term – expected start and end dates for the project

15 October 2012 – 14 October 2014

Project Activities and Timelines

Activity 1: Development of an international scientific team. Fall 2012

This project will be modeled on the "Finding Common Ground in Marine Fisheries Management" project sponsored by the National Center for Ecological Analysis and Synthesis that resulted in the Worm et al. 2009 paper in Science "Rebuilding Global Fisheries." We would aim for 10-15 participants drawn from a range of geographic regions and expertise. We would plan on meeting 4 times for 2-3 days over a period of 2 years. In the previous project the data base assembly, and analysis was largely conducted by post-doctoral fellows, and we suggest that three post-docs would be needed to complete this work.

This international team would not only perform this particular study, but would provide the basis for a long-term project that would maintain the data base and advance scientific knowledge of trawl impacts.

Activity 2: Expansion, development and maintenance of data bases on trawl distribution and impacts. Fall 2012-2013

Analyses will be based on three databases that describe (1) impact and recovery following trawl disturbance (2) the distribution of habitats that may be impacted by trawling and (3) the distribution and intensity of trawling pressure. The linking of these databases will provide a unique evidence-base from which to develop best-practice or guidance to minimize the effects of trawling on secondary production and ecosystem services. Each of these data bases is described below. The long-term relevance of these databases will require that they can be easily updated with new data as it emerges.

Data base # 1 Impact and recovery

A database will be constructed that integrates global quantitative measures of the direct response of benthic biota and biological habitat components to direct physical impact by towed bottom-fishing gear. There are presently >110 empirical peer-reviewed publications from which the data can be harvested. The following fields will be included: 'Gear type' (subdivided into different fishing activities according to differences in their mode of action – beam trawls, otter trawls, scallop and clam dredges). 'Regime' describes the number of discrete periods of disturbance. We also distinguish the acute disturbance of experimental fishing impact studies from comparisons of fished (chronically disturbed) and unfished areas. 'Size' of experimental plot will be included as the minimum dimension of any disturbed area because this is the smallest distance over which adults or larvae need to migrate to recolonize an area. 'Habitat' will be classified as mud, muddy sand, sand, gravel and biogenic. The biogenic category includes seagrass meadows or reef forming organisms such as mussel beds, sponge or coral reefs. The remaining variables are 'geographic region', 'water depth' of the study, and 'taxonomic grouping' (phylum, class, genus). The team will follow systematic review methodology as used to assess the performance of drug trials in the medical field (see Stewart et al. 2009 for an example). In addition, the team will harvest data from studies that focus on 'recovery' and those that have studied the response of communities to commercially relevant scales of fishing and that have quantified a gradient of fishing impact.

Data Base #2 Habitat

A database holding collated data on the spatial distribution of marine habitats on continental shelves and in the deep sea to the extent possible. Habitat classification would be consistent with the habitat classification defined to assess impacts and recovery (Database 1). The spatial resolution of data would be at nested scales, with scale reflecting the quality of habitat information available, from high resolution on continental shelves of some wealthy nations to lower resolution in other areas. Fields would be grid cell reference, latitude, longitude, cell area, classification.

Data Base #3 Fishing pressure

A database holding collated data on the distribution of trawl impacts in space and time. The primary aim would be to collate data for the time period from 2008-2010, with a secondary aim of establishing a time series for preceding years. The spatial resolution of data would be at nested scales, with scale reflecting the resolution of fishing effort data, from high resolution when VMS data are available to coarse resolution when aggregate statistics are available. Fields would be grid cell reference, latitude, longitude, cell area, year, fleet classification, gear classification, data source (VMS, logbooks etc) and hours trawling. The database would be publicly available after quality control and within two years.

Data base access: Made public in October 2014

Prof. Kaiser currently has a data base on impact and recovery, and at the end of this project this data base will be made public. The intention is to follow the principle of public access in which the existing version is available at http://www.ecoserve.ie/costimpact/data_impst.html. The data bases on impact and fishing pressure are generally held by fisheries management agencies, and some of the information, especially about fishing locations, is often confidential and access is restricted in various ways. At this point we cannot say how much of the information will be able to made publically available. We can certainly provide meta-data to point to the individual data bases and researchers.

Activity 3: Publications and presentations on trawl impacts and best practices. Late 2014

A key activity for this proposal will be a major synthesis paper summarizing the data, analysis and conclusions. Given the high-profile nature of the subject we anticipate a good chance of publication in one of the premier scientific journals.

We know that the impacts of trawling on biota are highly variable, with almost total ecosystem transformation in some biogenic habitats to no measureable impacts in highly disturbed habitats. Thus much of the discussion of trawl impacts has been totally distorted by "cherry picking" studies of one kind or another. The publication of an authoritative paper that summarizes the total range of knowledge, and most importantly looks at where trawling currently takes place will be of major significance.

In addition to the publications, a major activity of the working group will be talks given by group members. It is too early to identify specifics, but based on past working groups, especially the group "Finding common ground in marine fisheries management" that Hilborn, Jennings and Collie participated in, we can state with confidence that presentations will be a significant activity.

Project Indicators, Outcomes and Deliverables

Outcome 1: Defining the scientific information on best trawl practices.

This will be the major outcome of this project. We do not anticipate any single definition of best practice, but what we should be able to provide is an evaluation of the consequences of different definitions of best practices. For instance the two extremes would be a total ban on bottom contact gear, and no restrictions on bottom contact gear above and beyond those that are currently in place. For each of these extremes we can estimate the biological consequences measured by biodiversity changes and impacts on fish productivity, as well as the yield consequences. There are many possible “best practices” in between these two extremes, for instance a ban on bottom contact gear in specific sensitive biogenic habitats. We anticipate being able to evaluate the yield consequences of such a ban, at least for the areas where habitat and trawl effort are well mapped. It is our expectation that there will be some very clear cases where gear restrictions may have high biological benefits with low loss of yield. Such information is of paramount importance to processors and retailers looking for robust evidence on which to base their company buying policies.

Outcome 2: Finding common ground between NGOS and Industry.

Our working group team will be composed of scientists with a proven track record in marine fisheries and trawl impacts and younger researchers. To assure that the working group answers the key scientific questions of concern to stakeholders, we will hold a series of web based conferences with stakeholders where we will invite them to provide comment on the proposed work plan and as the work progresses to discuss results and conclusions. As the data bases develop these web conferences should provide an opportunity to find common ground between some of the NGO and industry groups who are willing to use data to reach conclusions about the extent of trawl impacts. We recognize that some industry and NGO groups will selectively use data sets to meet their own agendas, but we anticipate that a common data set will provide an opportunity for common ground among many of the parties that are truly interested in achieving sustainable marine fisheries management.

This outcome will be facilitated by the working groups meetings and data base but will largely occur outside of the regular group meetings in the web conferences.

The key deliverables will be the data bases and publications.

Project Management – brief description of how the project will be managed

The three PIs, Hilborn, Jennings and Kaiser will manage the project jointly, with a general division of the workload as follows. Kaiser will coordinate the data collection of the data bases on impact and recovery. Jennings will coordinate the data collection on extent of trawling on different habitat types. Hilborn will coordinate the data collection on impacts on productivity and ecosystem services. All three will coordinate the meetings and publications.

Literature Cited –

Collie, J. S., Hall, S. J., Kaiser, M. J., and Poiner, I. R. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. J. Anim. Ecol. 69: 785-798.

Hinz H., Prieto V. & Kaiser M.J. 2009. Trawl disturbance on benthic communities: chronic effects and experimental predictions. Ecological Applications 19: 761-773

Jennings, S., and Kaiser, M. J. 1998. The effects of fishing on marine ecosystems. Advances in Marine Biology. 34: 201-352.

Kaiser M.J., Clarke K.R., Hinz H., Austen M.C.V., Somerfield P.J., & Karakassis I. 2006. Global analysis and prediction of the response of benthic biota and habitats to fishing. Marine Ecology Progress Series 311: 1-14.

Kaiser M.J. 1998. Significance of bottom-fishing disturbance. *Conservation Biology,* 12: 1230-1235

National Research Council. 2002. Effects of trawling and dredging on seafloor habitat / Committee on Ecosystem Effects of Fishing: Phase 1--Effects of Bottom Trawling on Seafloor Habitats, Ocean Studies Board, Division on Earth and Life Sciences, National Research Council. National Academy Press, Washington, D.C.