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Northwest Atlantic Fisheries Organization

Serial No. N6002 **NAFO SCR Doc. 11/72**

SC WG ON THE ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT – DECEMBER 2011

Layers Utilized by an ArcGIS Model to Approximate Commercial Coral and Sponge By-catch in the NAFO Regulatory Area

by

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Abstract

This report specifically addresses Fisheries Commission Request #16: "Implement and/or further refine the existing GIS simulation/modelling framework, in conjunction with the VMS data supplied by the NAFO Secretariat ...", brought forth in the Fisheries Commission 33rd Annual Meeting Report (NAFO, 2011a). Data layers utilized by the model as well as their various means of construction are described in detail including the generation of NAFO VMS trawl lines. These VMS trawl line data were used to better understand fishing behaviour and also generate a new standard trawl length (13.8 nm) to be utilized by trawl simulations. The justification for utilizing just the Spain/EU research trawl by-catch dataset instead of the combined Canada/Spain/EU dataset for the production of higher resolution sponge and sea pen biomass surfaces is also made. It is demonstrated how this high resolution (5x5 km cell grid) Spain/EU data biomass layer could be utilized with 2000 randomly placed and oriented 13.8 nm simulation trawls to generate by-catch values, organized by thresholds, to capture the distributional extent of high concentration sponge and sea pen areas. This serves as the basis for a kernel density polygon analysis that calculates a commercial sponge and sea pen encounter threshold (Kenchington et al., 2011). Finally, using the Spain/EU only high resolution biomass surface, by-catch output from VMS trawls and their simulated 13.8 nm standard trawl line counterparts are compared.

Introduction

This report describes the evolution and application of various data layers for an existing ArcGIS model designed to approximate commercial sea pen and sponge by-catch within the Northwest Atlantic Fisheries Organizations Regulatory Area (NRA). Following a brief description of the model, the data layers are described in detail. Some of these layers control the extent of the commercial simulations while others provide the underlying source from which simulations draw their data. The report then describes the implementation of these layers for GIS simulations which define sponge and sea pen commercial trawling encounter thresholds. This document is an attempt to encapsulate the GIS methodology employed to prepare layers, acquire data though simulations and compare data output under varying scenarios. We specifically address questions raised by the Scientific Council regarding the use of modelled versus trawl lines derived from filtered NAFO Vessel Monitoring System (VMS) data. Some of these layers and results derived from these analyses are used to address encounter protocols for Vulnerable Marine Ecosystem (VME) taxa by Kenchington et al. (2011).

GIS Simulation Model Methods

The ArcGIS simulation model used within this report is a series of linearly connected ArcGIS tools managed by ArcGIS Model Builder to approximate commercial by-catch under various means of spatially adjusting/constraining the placement of simulated trawls (i.e., fishing boundaries and closed areas). The model gives the user flexibility to adjust the number of trawls and their length, while also defining their placement and orientation (e.g., random start locations and orientation as opposed to lines placed and oriented in response to an underlying probability surface which can effectively "weight" lines to approximate real world conditions).

Once simulated trawls are spatially defined, the model then approximates the commercial by-catch expected from each trawl. This step requires the introduction of a "biomass" surface layer. This layer represents fisheries research survey trawl by-catch weight data (as represented by the trawl start point) by creating a mean weight of all points within common cells of a polygon grid covering the extent of the by-catch data. The steps for generating this surface are provided in the following sections of this report. The resultant gridded polygon biomass layer contains cells with values representing the mean by-catch (kg) of fisheries research survey points falling within the cell. The mean biomass values in each cell are then length standardized by dividing by the trawl length to obtain the values as kilograms of biomass per kilometre towed (kg/km). The model then calculates, what is essentially the length weighted mean biomass (kg/km) for the entire trawl. This length weighted mean biomass value (kg/km) is then multiplied by the length of a standard commercial trawl to approximate total by-catch (kg). Upon completion of each ArcGIS simulation, by-catch data were exported to Microsoft Excel to be represented graphically.

A detailed description of the various tools utilized by the model is provided in Kenchington et al. (2010). While the input layers have been refined and adjusted substantially since Kenchington et al. (2010), the tools utilized by the model have been modified only slightly. For this reason, this report will describe modifications to input layers in detail but no further details of the working model will be provided.

Description of the Model Input Data Layers

Closed Areas

In Cogswell et al. (2010), the spatial extent of simulated lines produced by the model was restricted by both the NRA fishing footprint and the closed areas (NAFO, 2009a). The boundaries for the areas are listed in the 2010 NAFO Conservation and Enforcement Measures - Article 16: Coral and Sponge Protection Zones (NAFO, 2010a).

In 2011, Area #5 boundaries were expanded down slope to the 2500 m contour (Figure 1) (NAFO, 2012). This expansion is beyond the scope of the model simulations conducted herein, and did not affect either the positioning of simulated trawls or the resultant by-catch output from model runs.

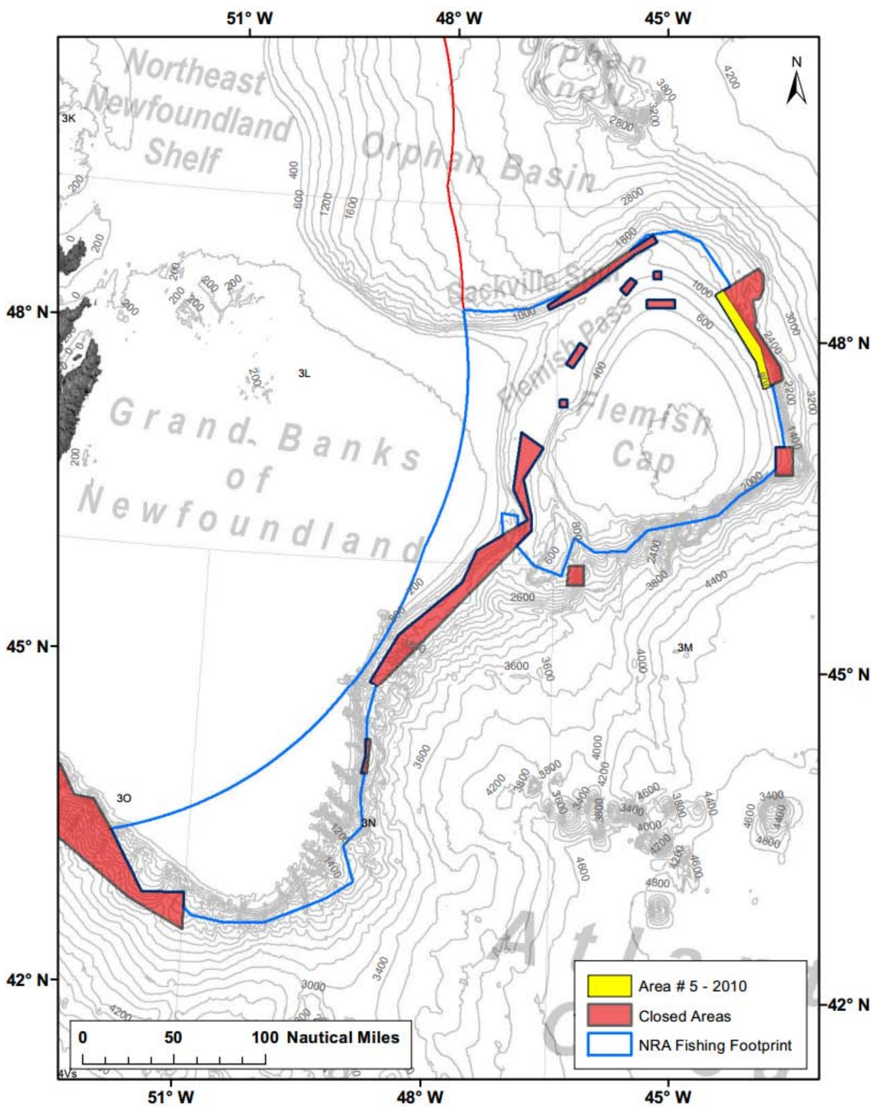

Figure 1. Coral and sponge closed areas within the model exercise area.

Fishing Effort Raster

The model requires a fishing effort surface (raster) to direct the placement and orientation of simulated trawl lines to predict fishing behaviour. This layer was updated from the 2008/2009 NRA groundfish fishery effort (Cogswell et al., 2010) to a surface representing just 2010 effort.

As with the 2008/2009 effort layer, Vessel Monitoring System (VMS) positional (POS reports) data were used to create the 2010 groundfish fishing effort surface. The determination of the directed fishery for each vessel was derived from the examination of both the depth from which fishing appeared to have taken place and the code for the directed fishery (PRA – Shrimp and GRO – Groundfish) as evaluated by the Catch-on-Entry (COE) and Catch-on-Exit (COX) VMS messages (Annex IX of NAFO, 2010a).
Average vessel speed was used as a proxy for trawling activity. Vessel speed was calculated by measuring the distance between two successive transmissions ($|p1 – p2|$) and dividing by the transmission interval ($\Delta t_{2\text{-}1n}$). The transmission interval (hours) was used to calculate total fishing effort. Data was excluded when the transmission interval was greater than 7 hours. A vessel was deemed to be fishing if the average speed between successive points was between 1-6 knots. A mid-point between successive vessel positions was identified as the location of the fishing activity.

While the 2008 and 2009 data were filtered based on the *a priori* condition of consistency with the known depth range of the commercial groundfish fishery in the NRA (700-2000 m), the reopening of the Cod fishery in Div. 3M, which covers a similar bathymetric range to the prawn fishery in this area, meant that this approach was no longer applicable for the 2010 data. Depth was extracted to each mid-point from the General Bathymetric Chart of the Oceans (GEBCO), a 1 min latitude and 1 min longitude grid (http://www.ngdc.noaa.gov/mgg/gebco/). While COE/COX reports and mid-point depth were used in combination to delineate the target fishery, the COE/COX reports took precedence in cases of disagreement for the 2008 and 2009 data, and was the only source of information used to identify target fishery for 2010.

The total fishing hours were summed to 5 x 5 nm cells within a grid covering the extent of fishing effort data, and projected to Zone 23, Universal Transverse Mercator (UTM) North American Datum 1983 projection. Empty cells represent locations where no effort was observed for the investigated fishery in 2010 (Figure 2). Some effort does appear to occur just inside the boundaries of some of the closed areas. In large part, but not entirely, this can be directly attributed to over-interpolation resulting from the 5 x 5 nm resolution of the effort layer. The next section of this report provides a higher resolution example of probable trawl lines as derived from VMS data.

Taking into account the differences in data processing highlighted above, the 2010 effort layer can be compared to the mean hours of the previous 2 years to show where and by what magnitude ground fishing effort can differ between years (Figure 3). Note a marked decrease in ground fishing effort along Sackville Spur and through Flemish Pass in 2010 (A). Even though this area is still heavily fished in 2010, there has been a substantial decrease in effort compared to the mean values from 2008 and 2009. There are other lesser areas (B, C, D and E) where effort has increased compared to 2008 and 2009 levels. As the effort layer influences placement and orientation of simulated trawl lines produced by the model, any changes in effort between years can impact the profile of simulated by-catch.

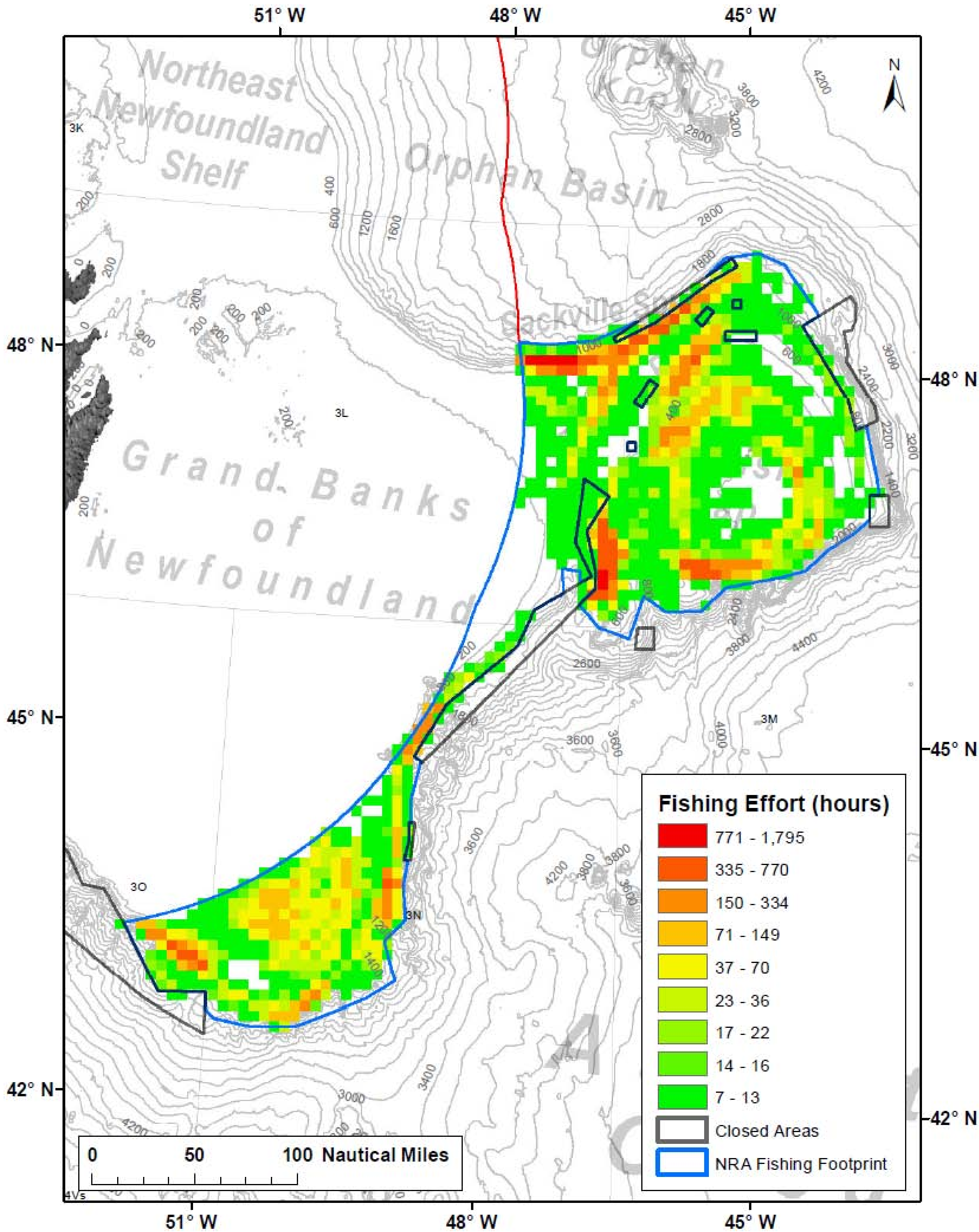

Figure 2. 2010 groundfish fishing effort in the NAFO regulatory area.

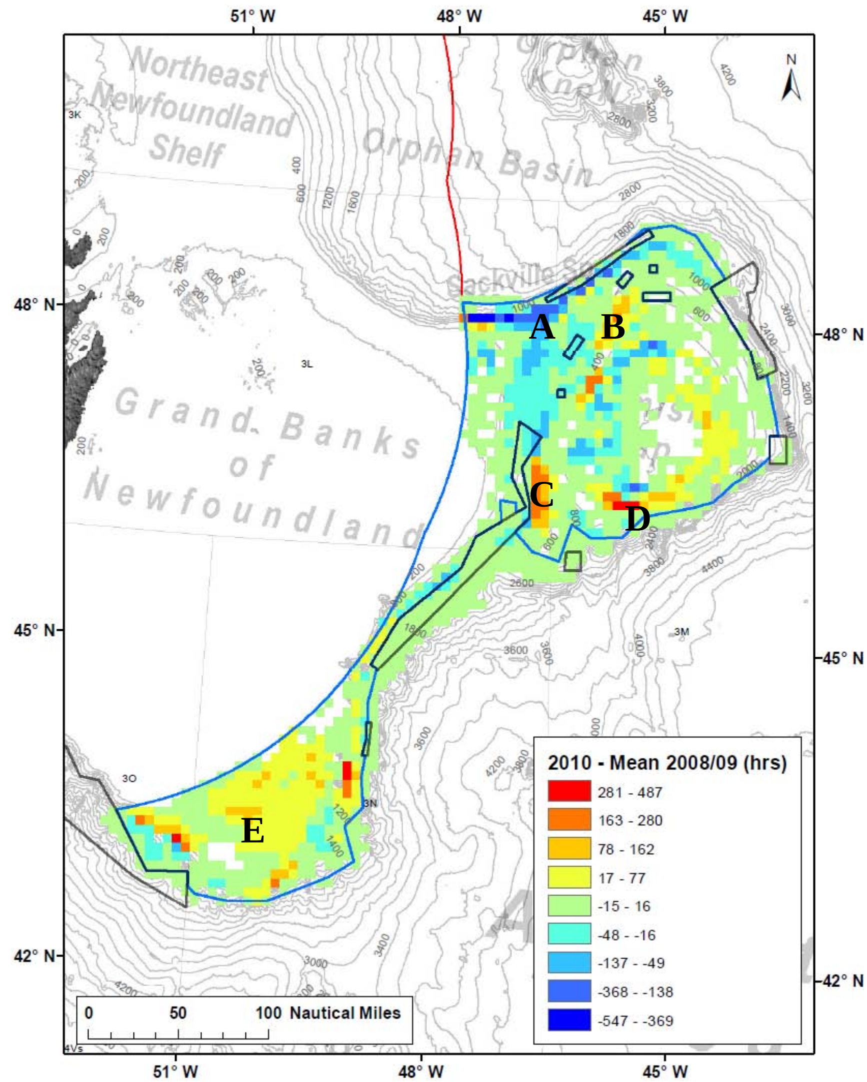

Figure 3. The difference in fishing effort between 2010 and the mean of 2008 and 2009 levels. Light and deep blue cells are areas where effort has declined from 2008 and 2009 levels (A), while orange and red cells indicate areas where there is an increase in effort in 2010 (B, C, D and E). Light green cells represent areas with little to no difference in effort between years.

NAFO Vessel Monitoring System Points

One of the criticisms of the previous version of the model was that the modeled commercial trawl lines were drawn as straight lines between the random weighted start and end points when it was known that real fishing would rarely follow a straight line (Cogswell et al., 2010). This was done because the WGEAFM did not have access to VMS point data. Following the request of Fisheries Commission from Annex 5 - 16 of the 2011 Fisheries Commission Report (NAFO, 2011a) NAFO has provided the requested 2010 VMS data. This information will be used to examine differences in model outputs between the straight line results and VMS fishing patterns.

The 2010 point VMS data were created by extracting "pings" with measured vessel speeds less than 6 knots. The tracks were created only where 2 or more consecutive "pings" at speeds <6 knots were observed. The derived point data set was then clipped to the NAFO fishing footprint area. "Pings" produced consecutively for a single vessel were labelled with a proxy identifier code and an order code. The ETGeowizards (Pretoria, South Africa) tool

"Point to Polyline" was used to create separate lines for each of the trawls. The resulting 3186 polylines are shown in Figure 4.

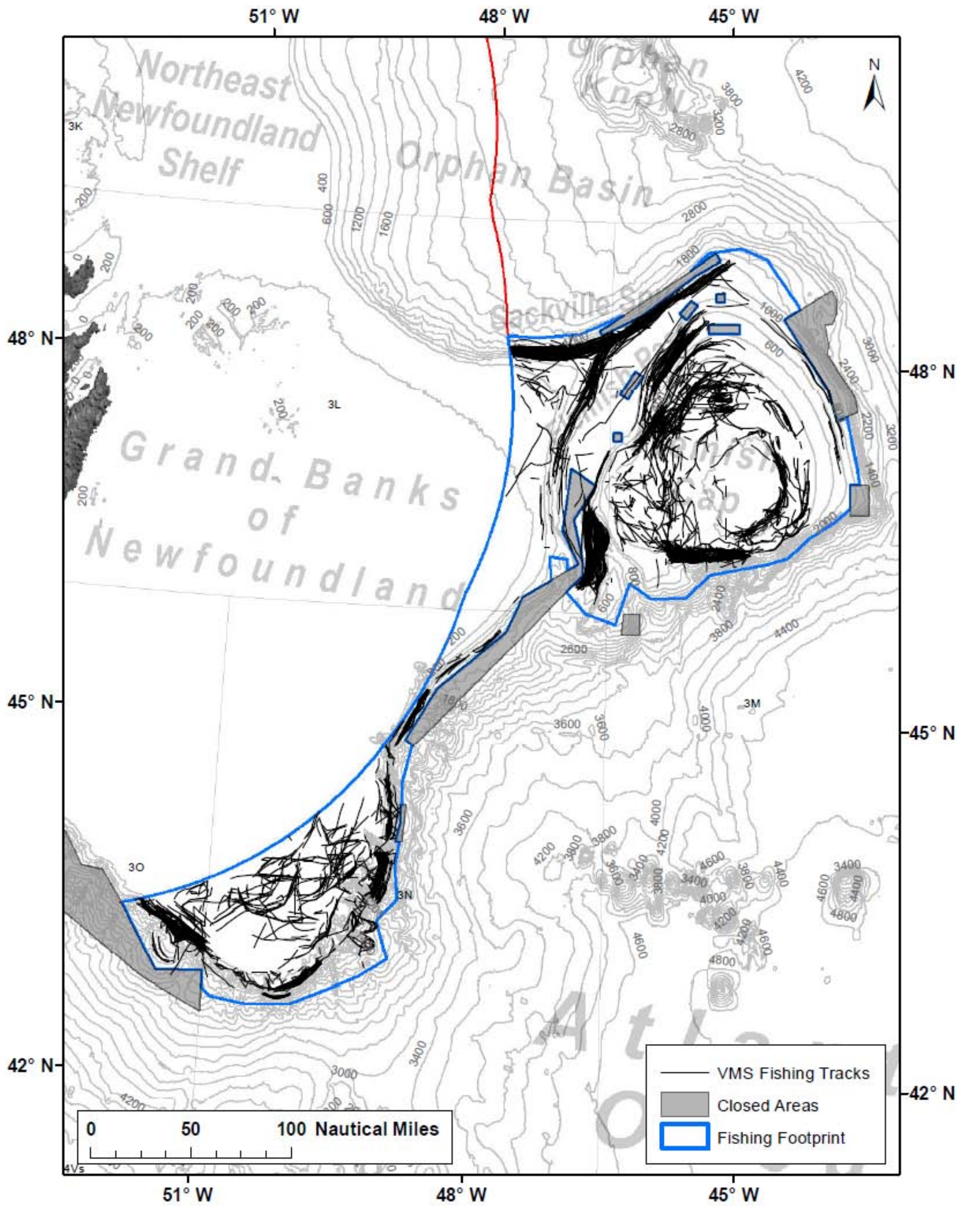

Figure 4. Location of the 3186 ground fish trawl lines derived from 2010 NAFO VMS data.

The previous analyses (Cogswell et al., 2010; NAFO, 2010b) used 15 nm or 27.78 km as the average tow distance. As simulated trawl lines are needed to address some fishing scenarios (see below), the median length of the 2010 VMS ground fish trawl lines (approximately 13.8 nm or 25.6 km, Figure 5) was used. Some VMS trawls were reported to be less than 1 nm (n=40) and some were reported over 60 nm (n=55) with a maximum of 179 nm. The most extreme trawl lengths appeared to be as a result of the vessel reversing course and traveling down the same line in the opposite direction, all the while maintaining a speed of less than 6 knots (Figure 6). For this reason it was thought prudent to filter the VMS line data to partially remove extreme values. First, the VMS trawl length data were transformed by 4th square root transformation to produce an approximately normal distribution. The transformed VMS dataset was modified by removing lines that fell outside of the 95% confidence interval (1.96 * Std. Dev (0.42) = 0.8281) (Figure 7). This meant that lines less than 1.1 (or ~ 1.46 nm (n=72)) and lines greater than 2.75 (or ~ 57.64 nm (n=68)) were removed. The median of the filtered VMS line length dataset (13.8 nm) was used as the standard simulated trawl length throughout this report. This is 1.2 nm shorter than the standard straight line simulated trawl length utilized by NAFO (2010b). This filtered data set, shown as trawl tracks, can be observed in Figure 8. These lines will be utilized by the model to reflect current fishing practices, effort and the simulated sponge/sea pen by-catch.

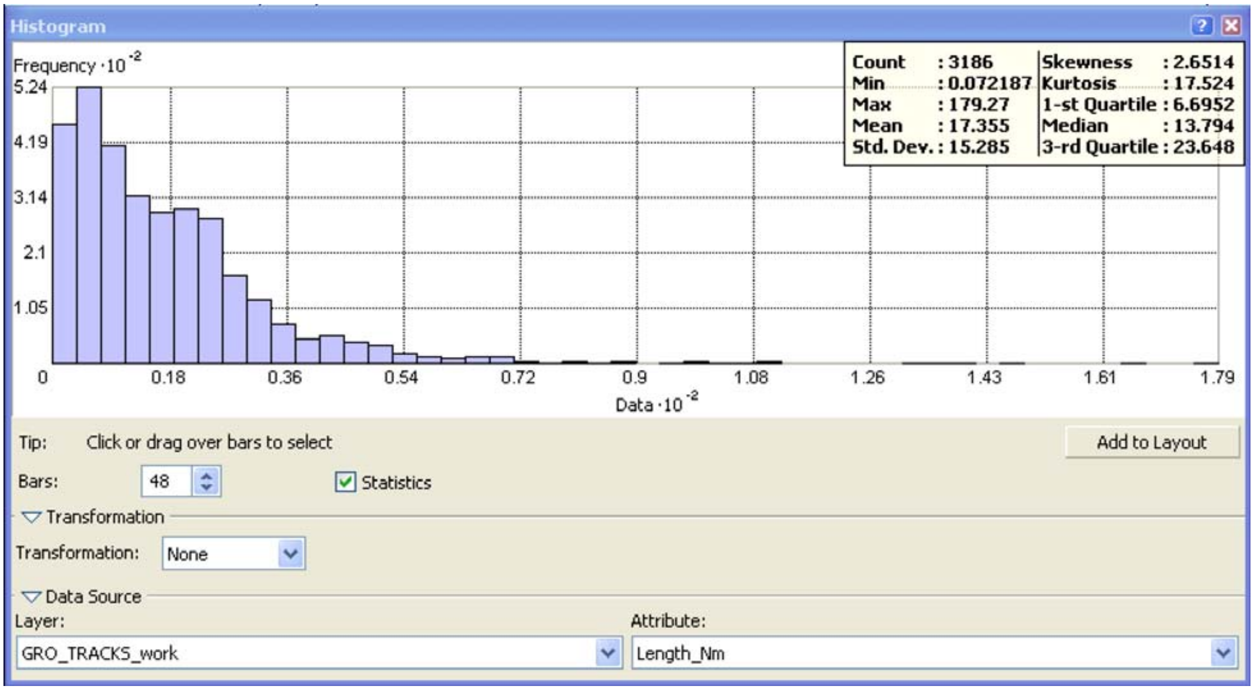

Figure 5. Histogram of line lengths in nautical miles (10^{-2}) with a median value of ~13.8 nm. The histogram is both left truncated by many very short trawls and right skewed by a few extremely long trawls (maximum = 179 nm) (see Figure 6).

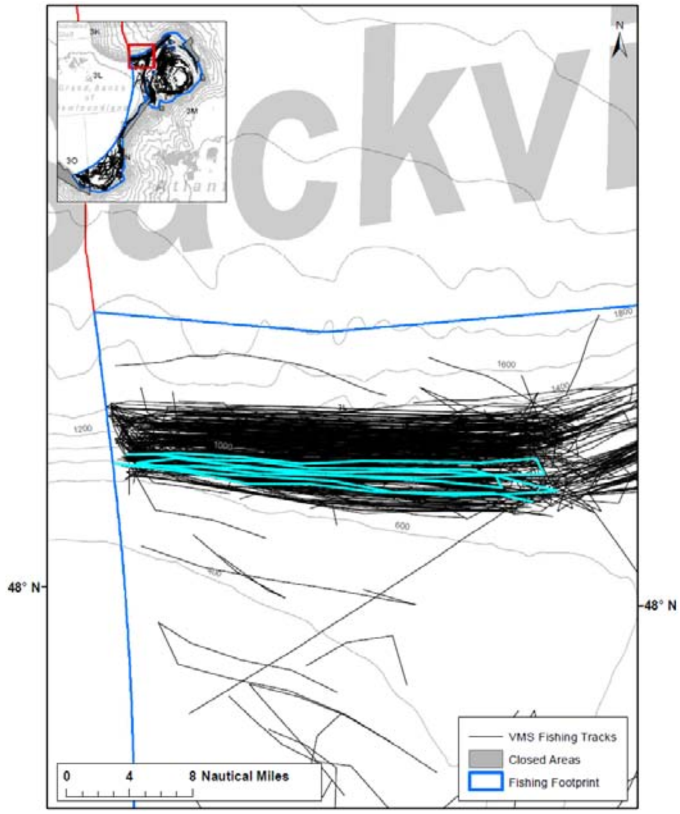

Figure 6. An example of a very long trawl (~179 nm) observed from compiled VMS data.

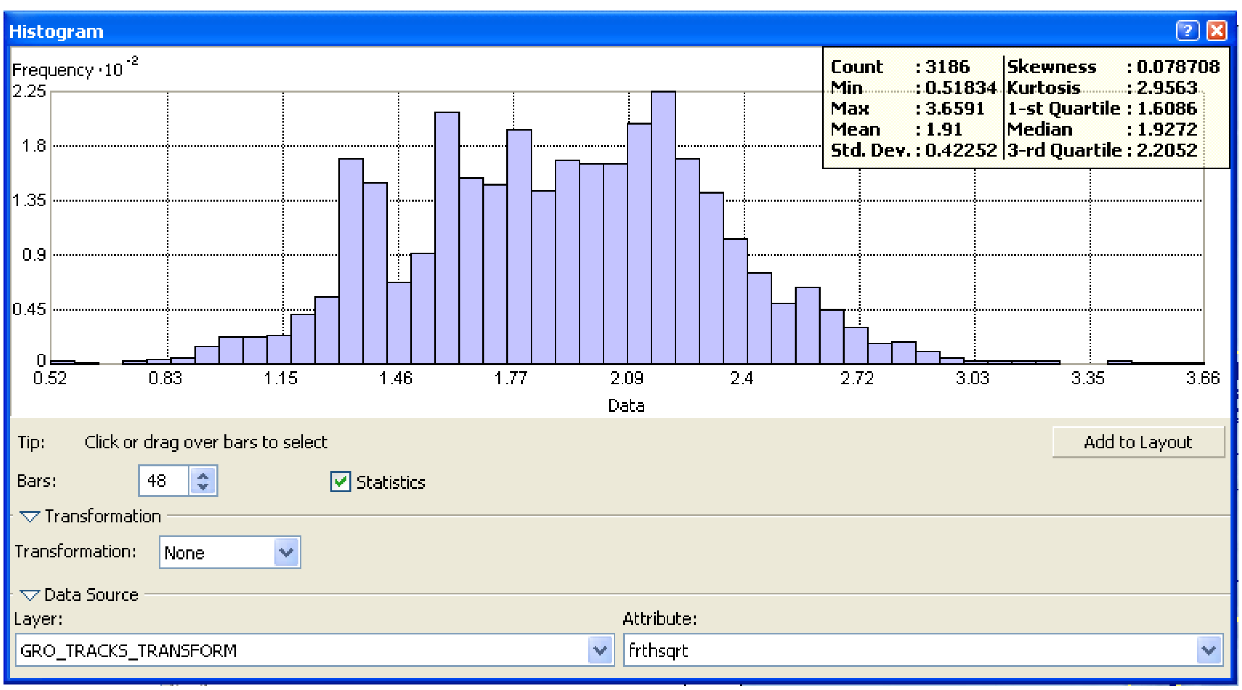

Figure 7. A histogram of the 4th square root transformation of VMS trawl line lengths. A reverse transformation of the mean value of the 4th square root transformation (1.91) is ~13.3 nm. Throughout this report the median value (13.8 nm) is used for the standard straight line simulated trawl distance.

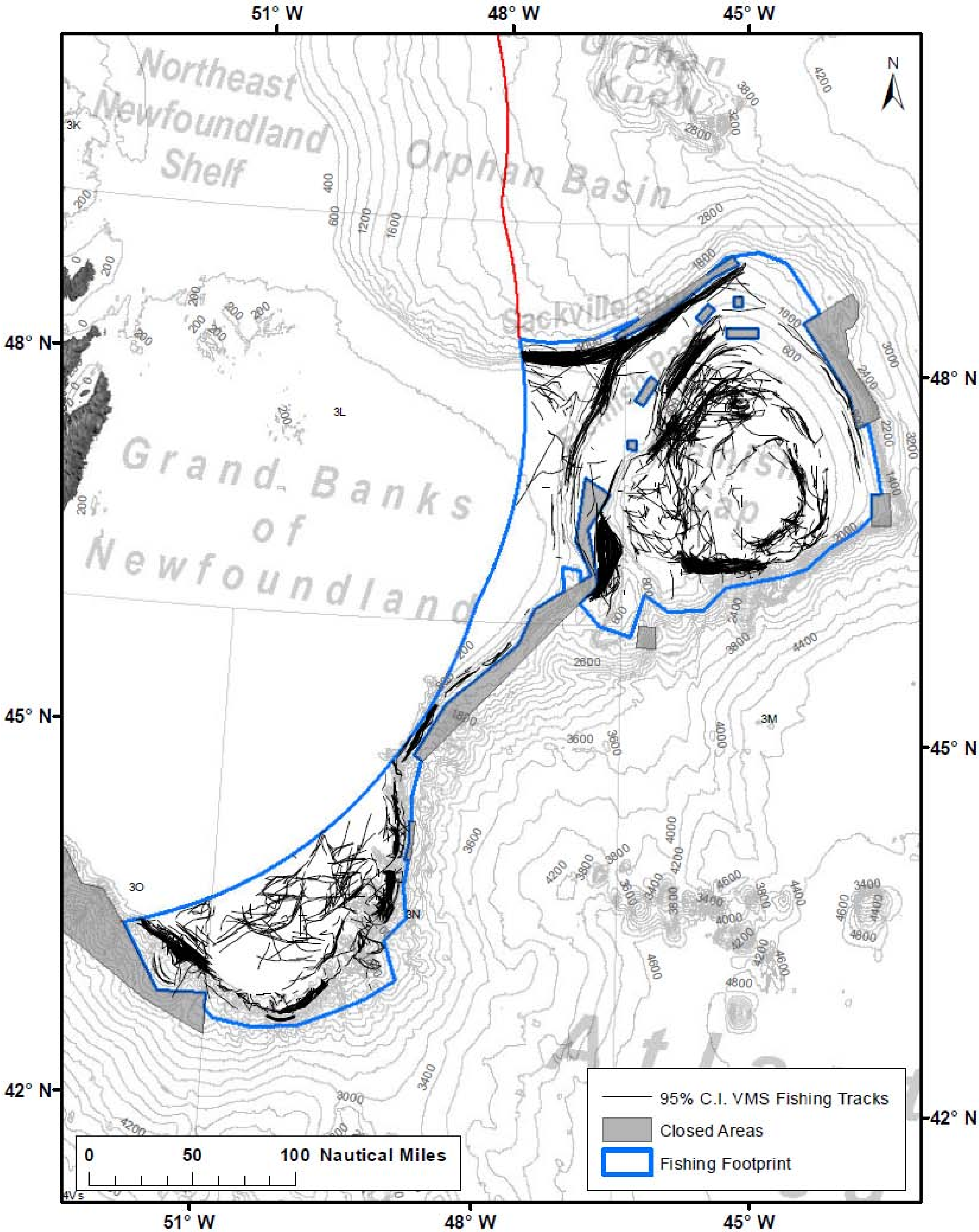

Figure 8. Polylines created from VMS data points and filtered to represent the 95% confidence interval of 4th root transformed line length data (n=3046).

Sponge Biomass Layer

As in Cogswell et al. (2010), point data used to generate the initial biomass raster were derived from Canadian and Spanish/EU depth-stratified random multispecies surveys.

Spanish/EU research vessels towed for 30 minutes at ~3 knots for an average standard tow length of 2.8 km (Murillo et al., 2011), while Canadian vessels towed for 15 minutes at ~3 knots for an average tow length of 1.4 km (Kenchington et al., 2010). Consequently, sponge by-catch values were standardized to kg of by-catch per km of towing (kg/km). Both Spanish/EU and Canadian vessels estimated large sponge by-catch to the nearest 100 kg, while catches less than 200 kg were weighed at least to the nearest kilogram (Vonda Wareham and Mar Sacau, Pers. Comm.).

Each country contributed to roughly half (Canada 1051; Spain/EU 1227) of the total 2278 sponge by-catch records that made up the dataset. Canadian sponge catch data spans from 1995-2008, while the Spanish/EU records were filtered for data collected after 2004 (2005-2008). Prior to 2005 null sets were not recorded by the Spanish/EU survey and could thus influence subsequent biomass surface creation (Figure 9).

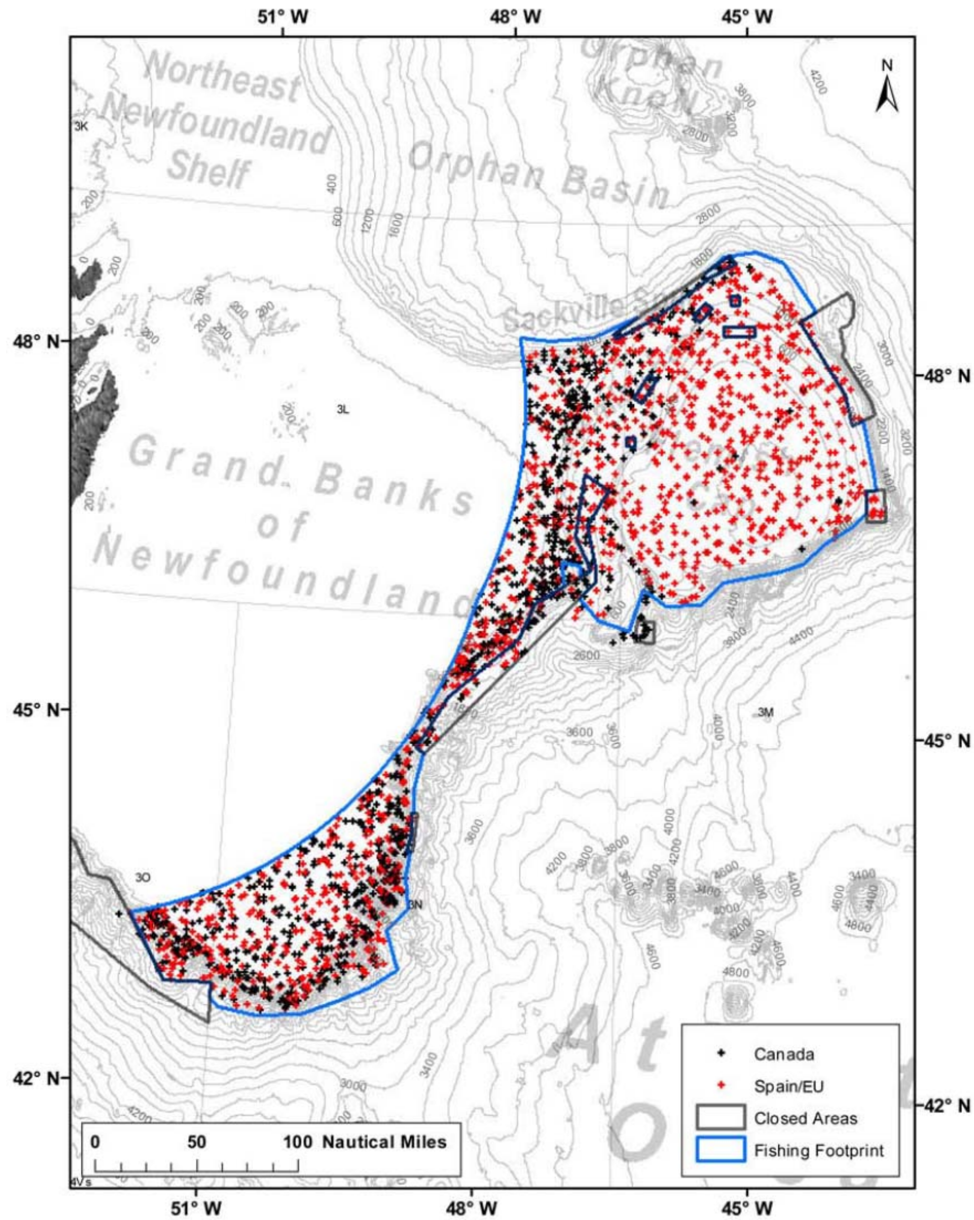

Figure 9. Location of research vessel trawls with sponge by-catch by country. This point data was the foundation for the sponge biomass raster surface input for the model in 2010.

Initially, as in Cogswell et al. (2010), two separate 12.8 x 12.8 km vector grid biomass surfaces were created from the above point data, one using data within closure areas and the other excluding data from within the closure areas. Neither iteration of the biomass layer on their own proved capable of reflecting the true reality of sponge distribution, especially at the borders of closed areas. For example, the Sackville Spur closed area is known to have a sharp delineation in sponge concentration roughly coinciding with it's shallower southern most border (Cogswell et al., unpublished). For this reason a more robust version of the biomass layer that takes into account these sharp closed area transitions was created. First, a single 12.8 x 12.8 km vector grid was created using the "create vector grid" tool in the ETGeowizards ArcGIS extension covering the extent of the joint Canada and Spanish/EU sponge by-catch dataset (Figure 10). The sponge point dataset was then split, using the ArcGIS "select by location" tool, into 2 separate point shape files: 1) only sponge by-catch records that fell outside of the closed areas but **Inside** the bounds of the official NAFO fishing footprint, and 2) only sponge by-catch records that fell **Outside** the fishing footprint but inside the closed areas. The ArcGIS "spatial join" tool was then used to calculate the mean sponge biomass (kg)/km of all of the points that fell within each cell. A new integer biomass field is created within the attribute table for both vector grids. This field was calculated from multiplying the biomass field (mean biomass of points within the cell in kg/km) by 100 000. This was necessary as a step further in the process, the "raster to polygon" tool, could only be performed on an integer raster.

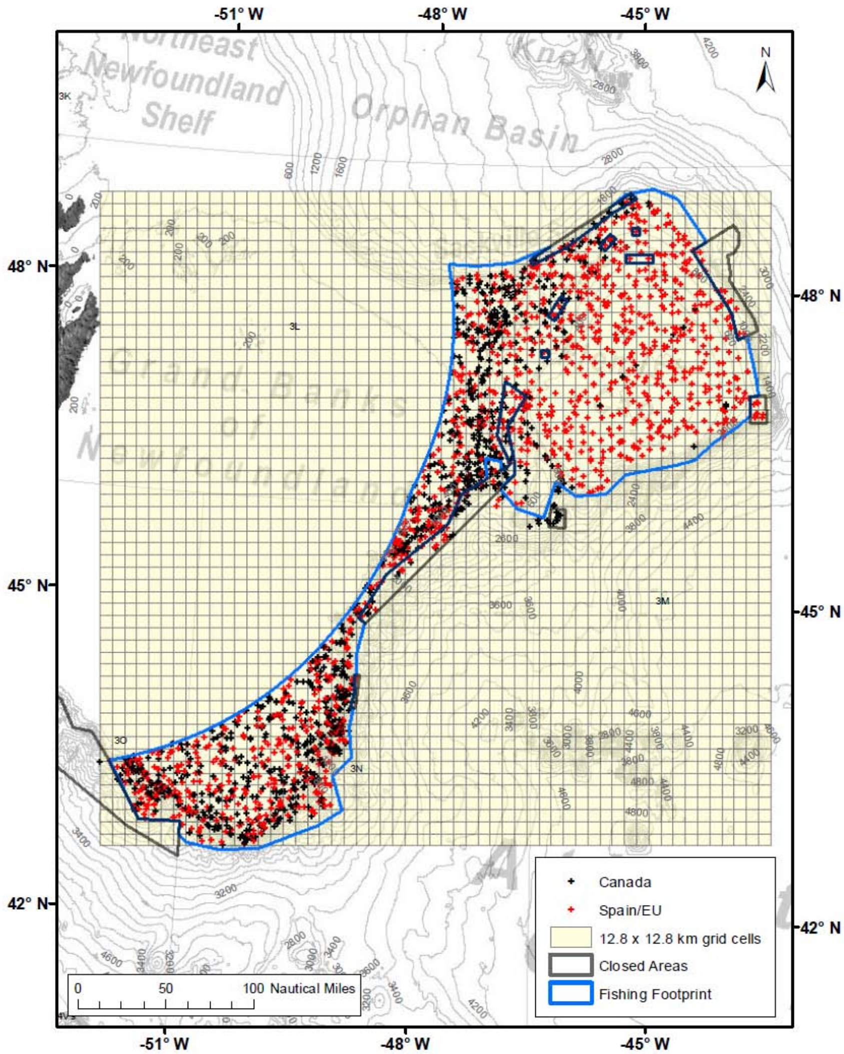

Figure 10. Grid (12.8 km x 12.8 km) covering the extent of Canadian and Spanish/EU sponge by-catch records in the NRA.

Using the "select by attributes" tool, only the cells of the "Inside" vector grid (only by-catch records in fishing footprint) with contributing by-catch record counts greater than or equal to a count of 1 were selected. These selected cells were exported to create a separate shape file (Figure 11 A). This layer was then erased, using the "erase" tool, from the "Inside" vector grid to create another grid representing all of cells with no data ("Inside Erase" - Figure 12A). The "polygon to raster" tool was then used to create a raster layer (with identical cell size) from the "Inside" polygon (Figure 13A). The "Inside" raster has a number of holes that need to be filled to create the continuous surface necessary for the simulated trawl lines to create an estimate of by-catch. The "focal statistics" tool was used to create an average cell value (kg/km) based on the cells immediately adjacent (3 x 3) (Figure 14A). The "extract by mask" tool, using the "Inside Erase" polygon (Figure 12A) as the mask, captured those cells falling in the no data areas of the "Inside" raster from the "focal statistics" raster (Figure 15A). The "mosaic to new raster" tool was then used to merge both the "Inside" raster (Figure 13A) and the focal statistics "Inside Erase" raster (Figure 14A), to create the "Inside Mosaic" raster (Figure 16A). The "raster to polygon" tool was then used convert the "Inside Mosaic" raster to the "Inside Mosaic" polygon. A new floating point field was then created in the "Inside Mosaic" attribute table and was calculated by dividing the raster value by 100 000 to arrive at the original cell values (kg/km). The polygon was clipped to the extent of the NAFO fishing footprint (Figure 17A).

The same procedures described above were applied to the "Outside" grid surface. Using the "select by attributes" tool, only cells of the "Outside" vector grid (only by-catch records Outside the fishing footprint but inside the closure areas) with contributing by-catch counts greater than or equal to 1 were selected. These selected cells were exported to create a separate shape file (Figure 11B). This layer was then erased, using the "erase" tool, from the "Outside" vector grid to create another grid representing all of the cells with no data ("Outside Erase" - Figure 12B). As with the "Inside" polygon above (Figure 11A), the "Outside" polygon was converted to a raster ("Outside" raster - Figure 13B), a 3 x 3 focal statistics raster was created (Figure 14B), the focal statistic raster was masked by the "Outside Erase" polygon (Figure 15B), and a "Outside Mosaic" comprised of both "Outside" raster (Figure 13B) and the "Outside Erase" raster (Figure 14B) was created (Figure 16B). This "Outside Mosaic" raster was then converted to a polygon. The fishing footprint was then erased from the "Outside Mosaic" polygon. This resulted in an "Outside Mosaic" polygon that describes sponge biomass outside the bounds of the NAFO fishing footprint and still in the NAFO Regulatory Area where by-catch data is available (Figure 17B.).

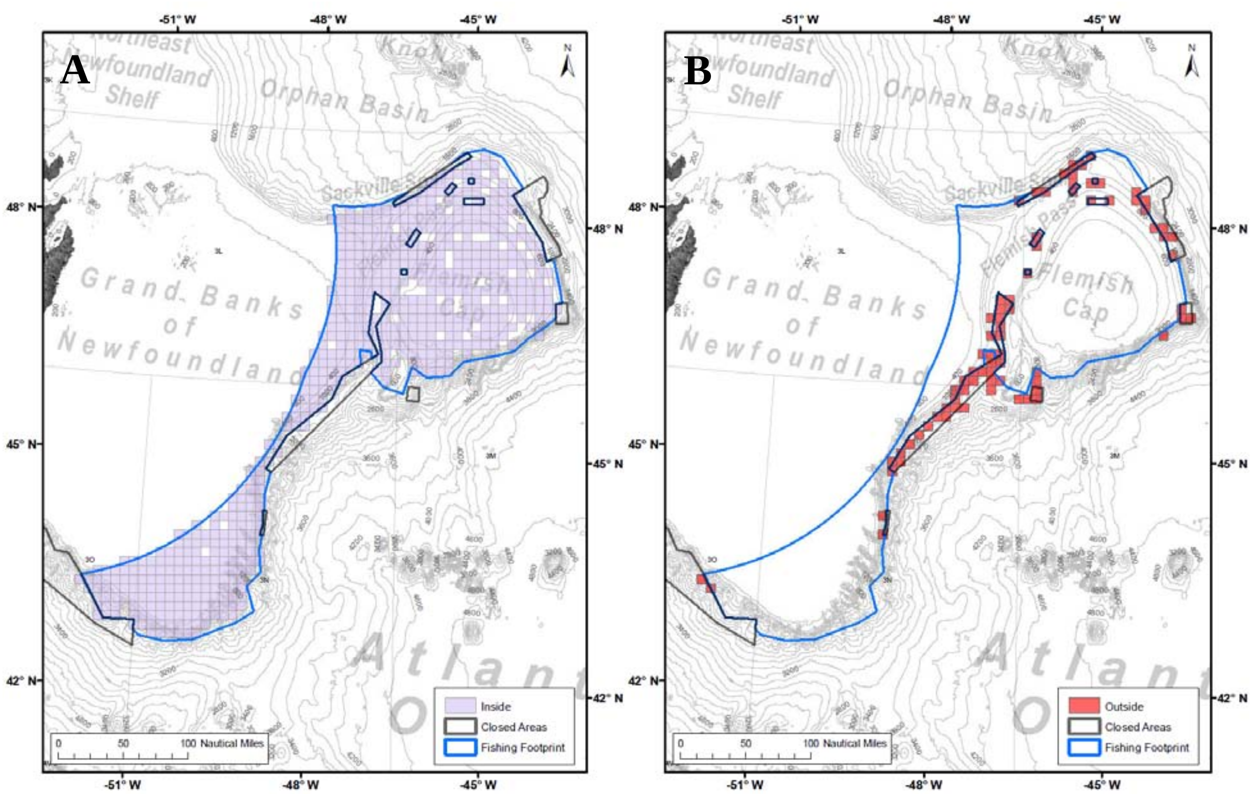

Figure 11. **A)** The "Inside" vector grid with cells representing points that are outside closed areas and inside the fishing footprint, and **B)** The "Outside" vector grid with cells representing points that are outside the fishing footprint and inside the closed areas.

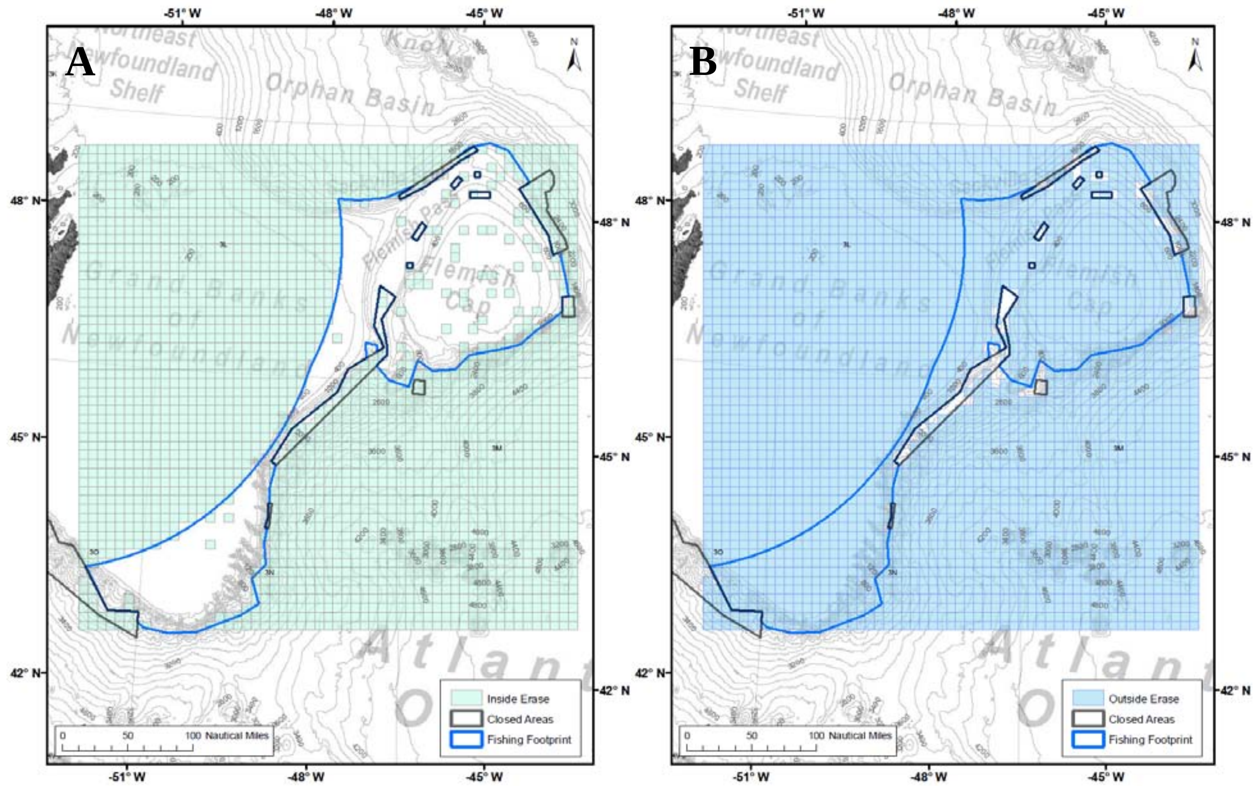

Figure 12. **A)** The "Inside Erase" polygon layer, and **B)** The "Outside Erase" polygon layer.

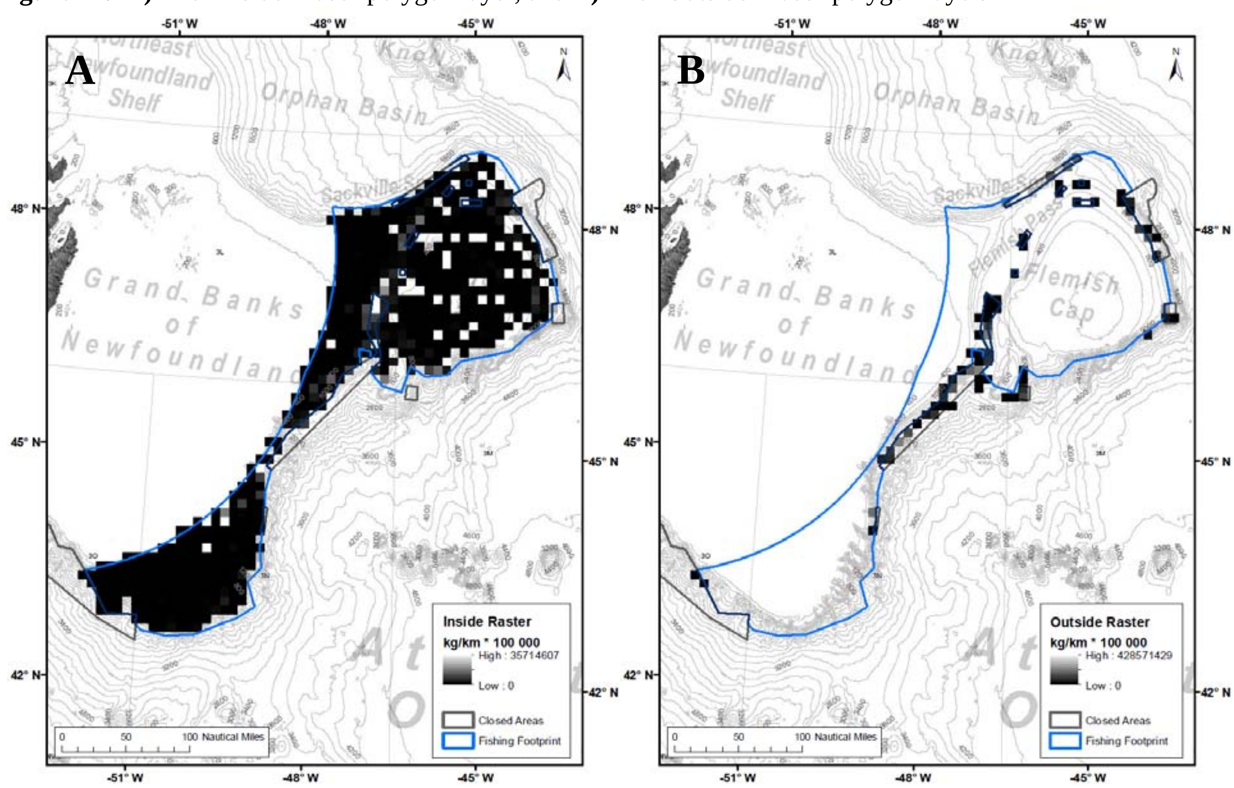

Figure 13. The "polygon to raster" tool was used to create, **A)** The "Inside Raster", and **B)** The "Outside Raster". Each cell represents the mean of the Canada and Spanish/EU by-catch points within it in kg/km multiplied by 100 000.

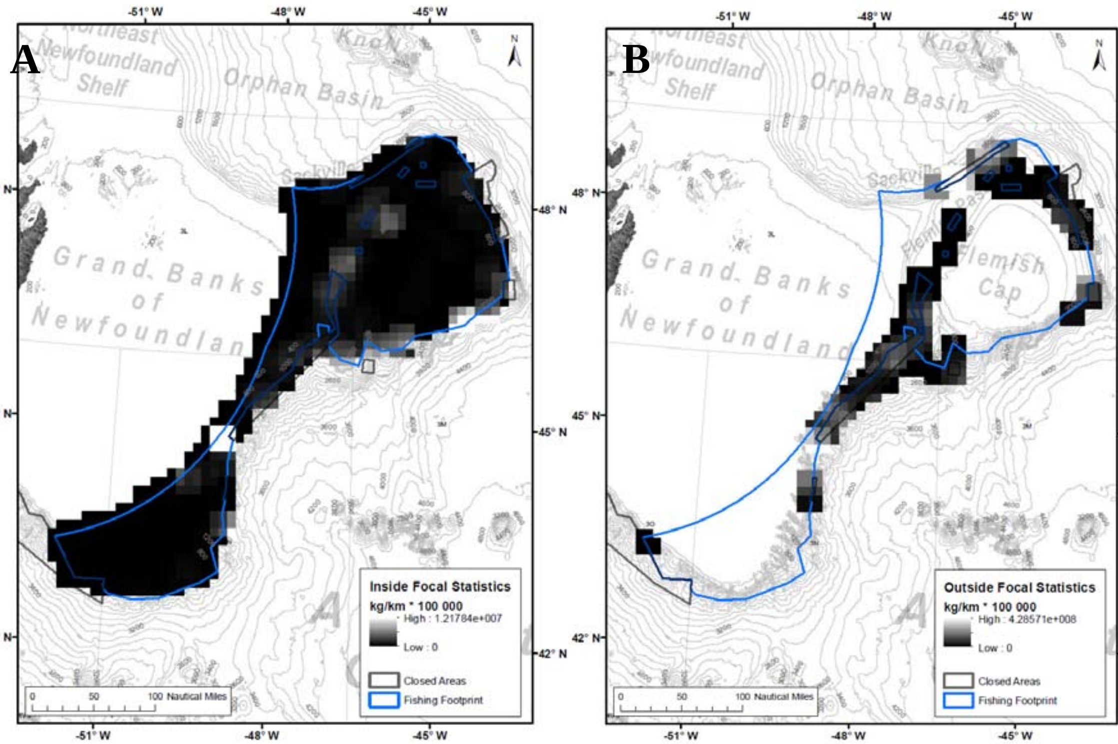

Figure 14. **A)** The "Inside Focal Statistics" raster, and **B)** The "Outside Focal Statistics" raster, both derived using corresponding "inside" and "outside" rasters from Figure 13.

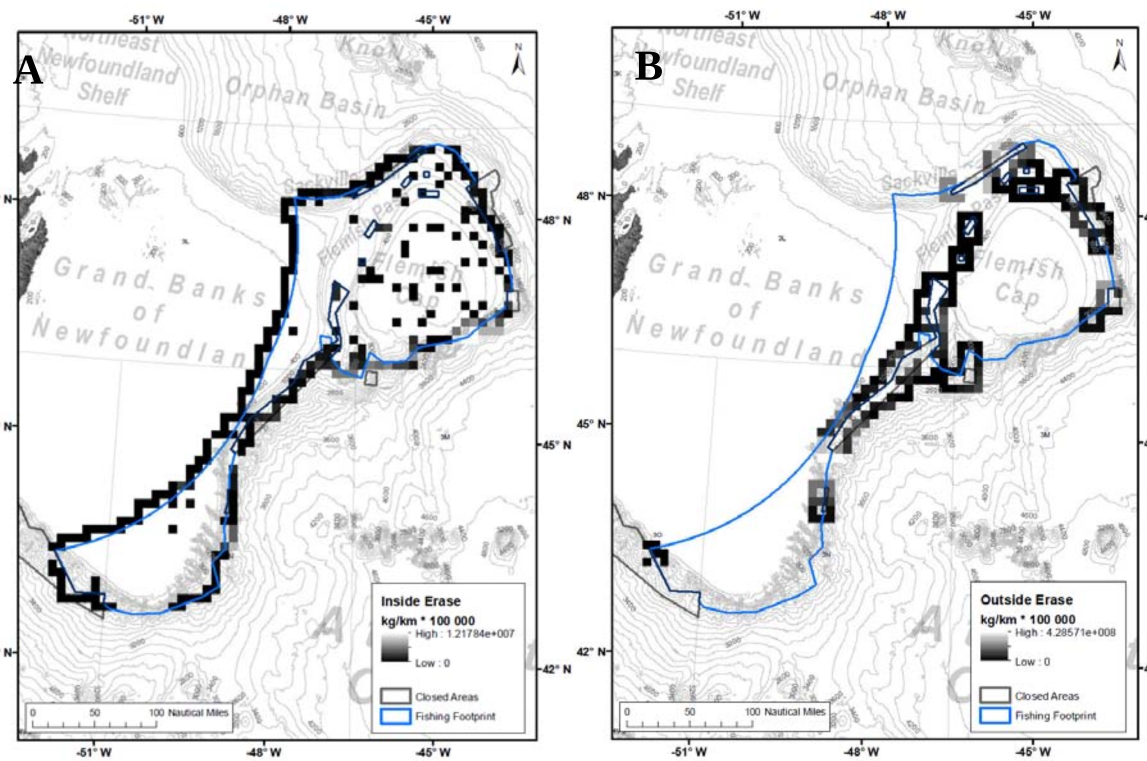

Figure 15. Using "Inside Erase" polygon from Figure 12, the "extract by mask" tool extracts, **A)** only the cells missing from the "Inside" raster to create the "Inside Erase" raster, and **B)** only the cells missing from the "outside" raster to create the "Outside Erase" raster.

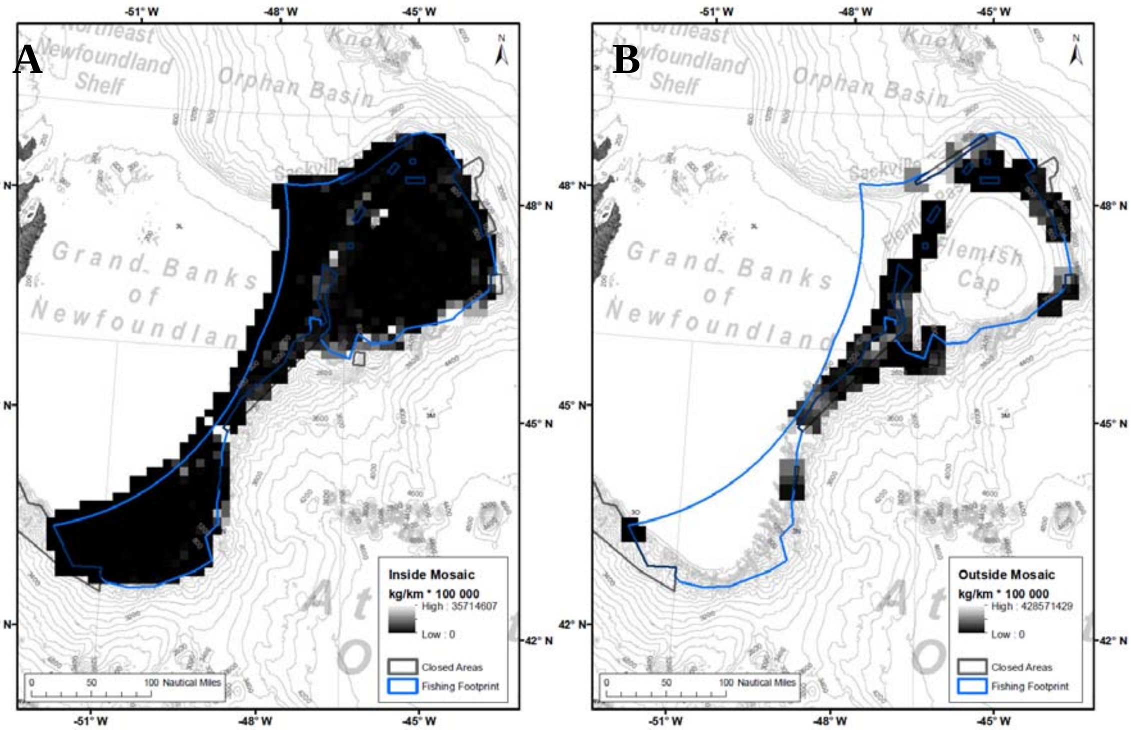

Figure 16. The "mosaic to new raster" tool was used to combine, **A)** the "Inside" raster and the "Inside Erase" raster, and **B)** the "Outside" raster and the "Outside Erase" raster.

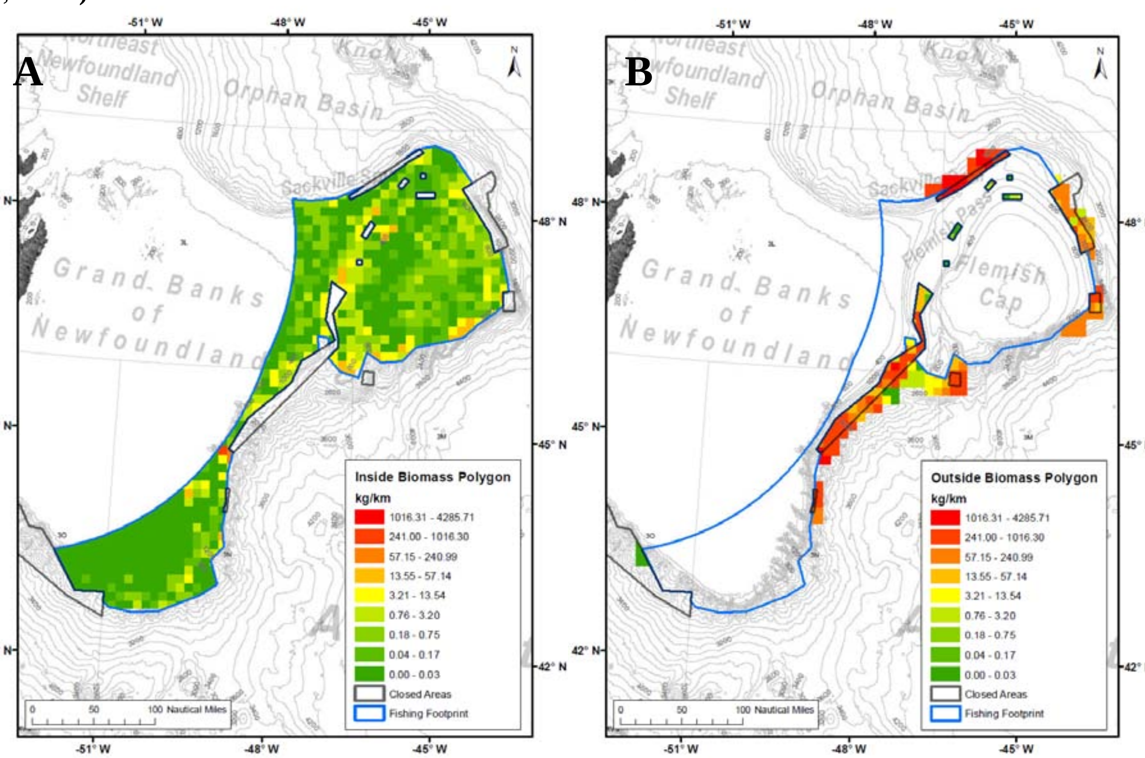

Figure 17. Using the "raster to polygon" tool the, **A)** "Inside Mosaic" raster was used to create a continuous biomass surface, "Inside Biomass Polygon", and **B)** "Outside Mosaic" raster was used to create the "Outside Biomass Polygon".

Finally, the "merge" tool was used to stitch the "Outside Mosaic" and the "Inside Mosaic" together to create the biomass layer that would be used by the model simulations described below (Figure 18A). This surface captures the sharp transitions in biomass observed on the borders some closed areas (Figure 18B). The techniques used to create this "merged" surface are used consistently throughout this report. As described below, after running the model numerous times using the 12.8 x 12.8 km gridded biomass surface described above (preceding and during the December 2011, WGEAFM meeting) it was realized that further modifications were necessary to accommodate recently observed deficiencies in the sponge by-catch point dataset from which the biomass surface arose.

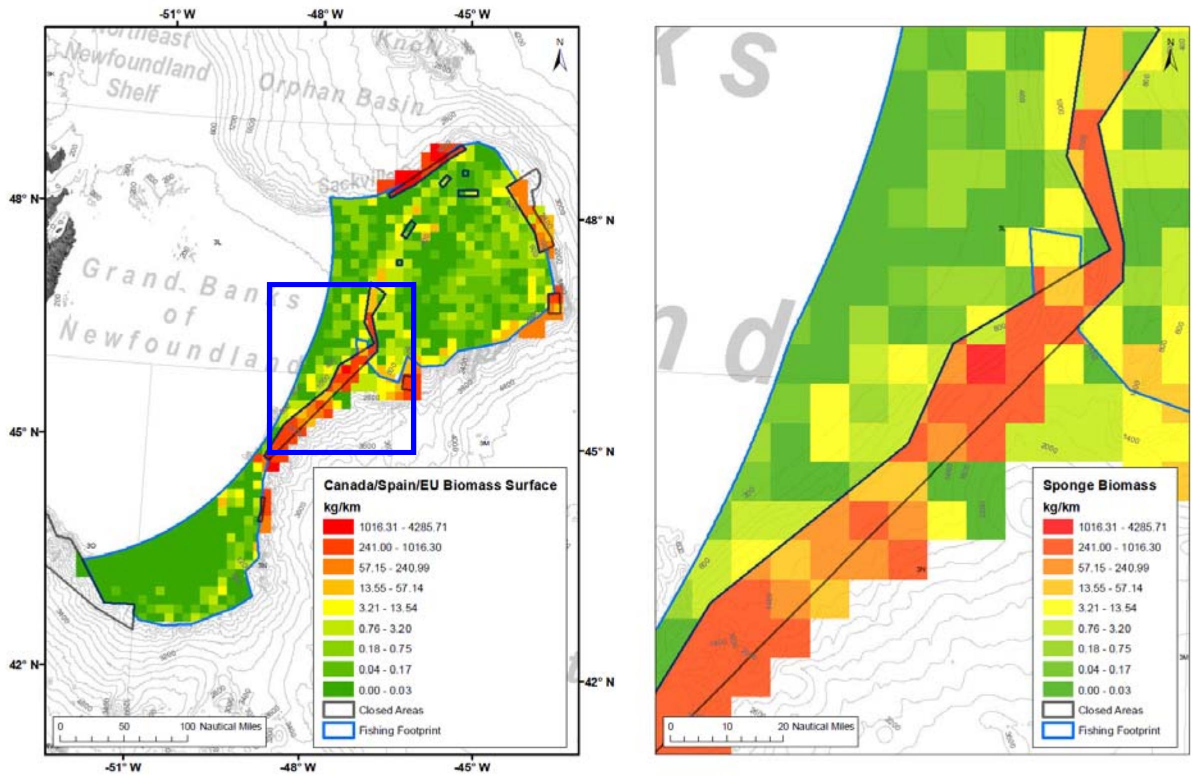

Figure 18. A) The Canadian and Spanish/EU biomass surface resulting from merging the "Inside Biomass" and "Outside Biomass" polygons from Figure 17. **B)** A close up of the Flemish Pass closed area (blue box, in A) showing the sharp delineation between high and low sponge concentrations generated by merging the 2 biomass polygon layers.

The Argument for Utilizing Only Spanish/EU Trawl Data

A key step to the procedures described above is to divide the by-catch (kg) by the trawl distance (km). This allows for the production of a sponge "concentration" surface that can be quantified by the model based on the distance of the simulated or VMS trawl. To do this however, there is an assumption made that the Canadian and Spanish/EU trawls are catching roughly the same amount of sponge over the same distance trawled. In the above analyses the Canadian sponge by-catch data were divided by the standard Canadian research vessel trawl length of 1.4 km, whereas the Spanish data were divided by 2.8 km. This is incorrect as the aggregated distribution of these organisms means that in most areas there is a non-linear relationship between trawl distance and catch.

A closer inspection and comparison of the Canadian and Spanish/EU data (Figure 19) was undertaken. To make this comparison, it was necessary for the Canadian and Spanish/EU data to maintain a common spatial extent. The "minimum bounding geometry" tool was used to create a minimum bounding box around the Canadian sponge by-catch data. This hull was modified slightly to reduce it's area but still represented 98% of all Canadian sponge data within the NRA (1021 out of 1051 records). Preparing the data for comparison, it became apparent that Canadian records prior to 2005 did not have any null sets and were removed from further comparison. Of the remaining 602

Canadian records remaining, 601 fell within the convex hull. Of these, 25% (151) are non-zero values, whereas in the same convex hull area out of the 778 Spanish/EU records, 49% (382) are non-zero values (Figure 20). The proportional abundance of null sets in the Canadian sponge by-catch dataset shows a difference possibly attributable to reporting and/or catchability between Canadian and Spanish/EU research vessel surveys. Nonetheless, the most likely cause of the discrepancy is difficult to pinpoint. This quick analysis comparing Canadian and Spanish point data within the same temporal and spatial context showed not only a difference in the data structure between Canadian and Spanish/EU datasets, but also a spatial bias for the Canadian dataset. Nearly all of the Canadian research trawler dataset gathered after 2005 is from the western half of the NAFO Regulatory Area fishing footprint (Figure 20).

Even after 0 values were removed from both the Canadian and Spanish/EU 2005-2008 datasets within the minimum bounding geometry, by-catch values were severely right skewed (Figure 21). A Box-Cox transformation of the non-zero data was performed on both datasets with a Lambda (λ) of -0.06 to normalize them (Figure 22). Normality was assessed for both datasets by a Normal QQPlot performed using the GeoSpatial Extension in ArcGIS 10. A Bartlett's Test was performed and suggested very strong evidence against the null that there was no significant difference between the variances of the datasets ($p<0.01$ and Chi square = 27.05). Both samples were roughly normal, but the sample sizes and variances are unequal. For this reason, a 2 tail Welch's t-test was performed and revealed a significant difference between the mean catch weight for Canadian and Spanish/EU sponges (0.34 kg and 1.69 kg respectively - $p<0.001$). This finding is consistent with NAFO (2009b) which used a Komogorov-Smirnov (K-S) test to compare the cumulative frequency distribution of sponge by-catch for both Canadian and Spanish data. The difference is that the analysis conducted in 2009 was not confined to data that fell within the minimum bounding geometry. When run again using all data within the minimum bounding geometry, it is demonstrated (like in 2009) that the location and shape of the Canadian and Spanish cumulative distribution curves are significantly different (KS - 0.369 & $P<0.001$). In 2009, the K-S test was conducted at varying weight intervals (0.1, 0.5, 1 and 10 kg) to determine if significant differences existed at large (or significant) by-catch values. For the purposes of the 2009 report, it was deemed appropriate to aggregate Canadian and Spanish sponge by-catch records in excess of 0.5 kg. If however, the purpose is to create a biomass surface that requires consistency between datasets (Canada and Spanish/EU) across the spectrum of by-catch values, then only one of the 2 layers should be utilized if they are significantly different.

The preceding comparisons show that Canadian research trawls that travel ~1.4 km covering approximately 25 000 m^2, have a significantly higher mean catch than Spanish/EU research trawls that travel 2.8 km and cover approximately 39 000 m^2. It suggests that despite the over abundance of zero values within the Canadian dataset within the same spatial extent as the Spanish/EU dataset, that Canadian vessels that do catch sponge have a higher mean (transformed) catch than their Spanish/EU counterparts. This suggests possible differences in reporting between Countries and/or different by-catch efficiencies (see Kenchington et al., 2011).

For the spatial and statistical reasons shown above there is ample justification to create a biomass layer derived from just the Spanish/EU sponge by-catch data.

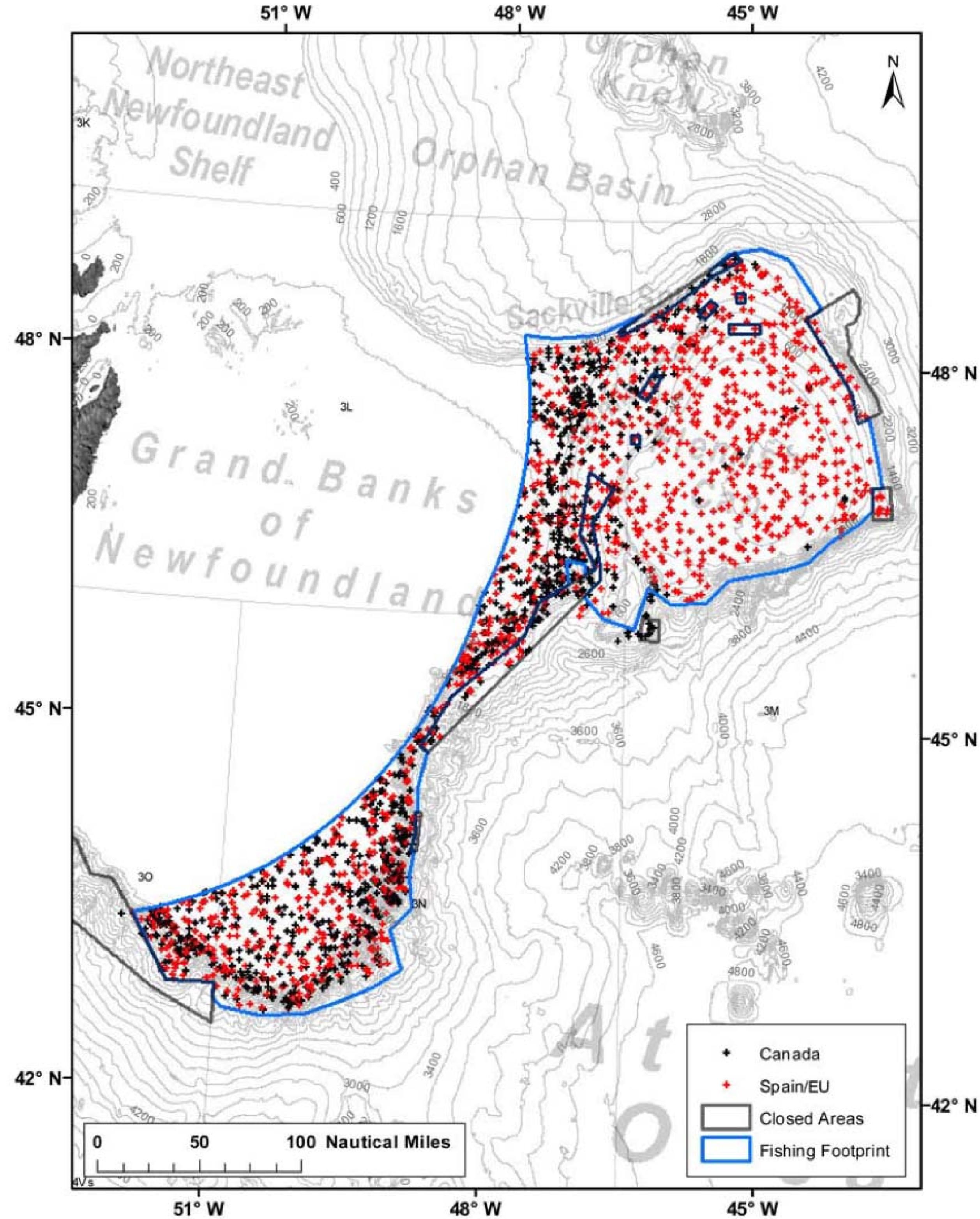

Figure 19. Note that Canadian research vessel by-catch data is almost entirely allocated to the western half of the NAFO fishing footprint.

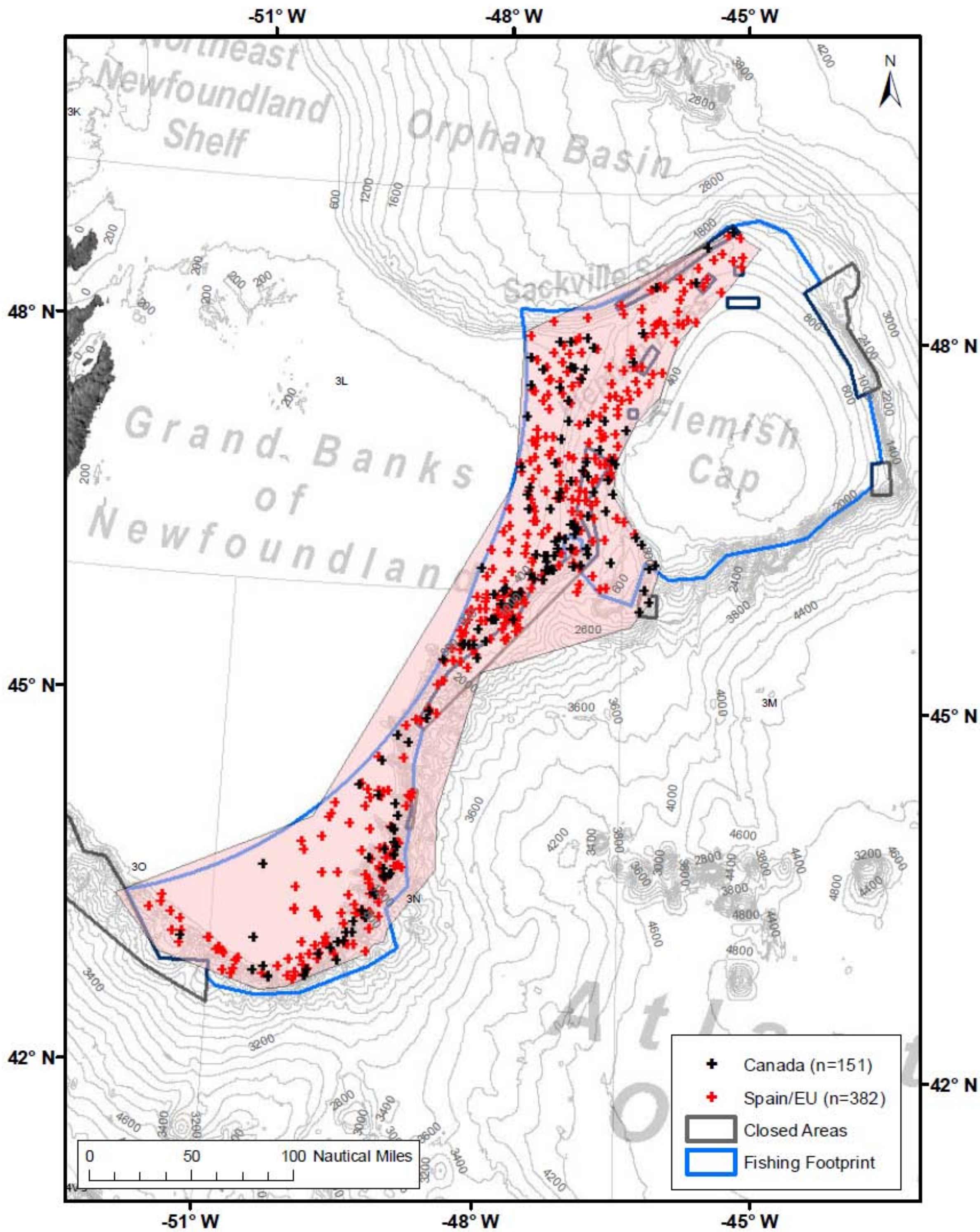

Figure 20. The minimum bounding geometry of the sponge by-catch records from the Canadian R/V surveys. This polygon represents the extent of ~100% of the Canadian R/V sponge by-catch data from 2005 to 2008. The non-zero values for both the Canadian and Spanish sponge within this minimum bounding geometry are shown.

Figure 21. A histogram of non-zero by-catch records from Canadian R/V trawls from 2005 to 2008 within the minimum bounding geometry in Figure 20. Spanish/EU by-catch values were similarly right skewed. Represented by many low by-catch values and few high by-catch values.

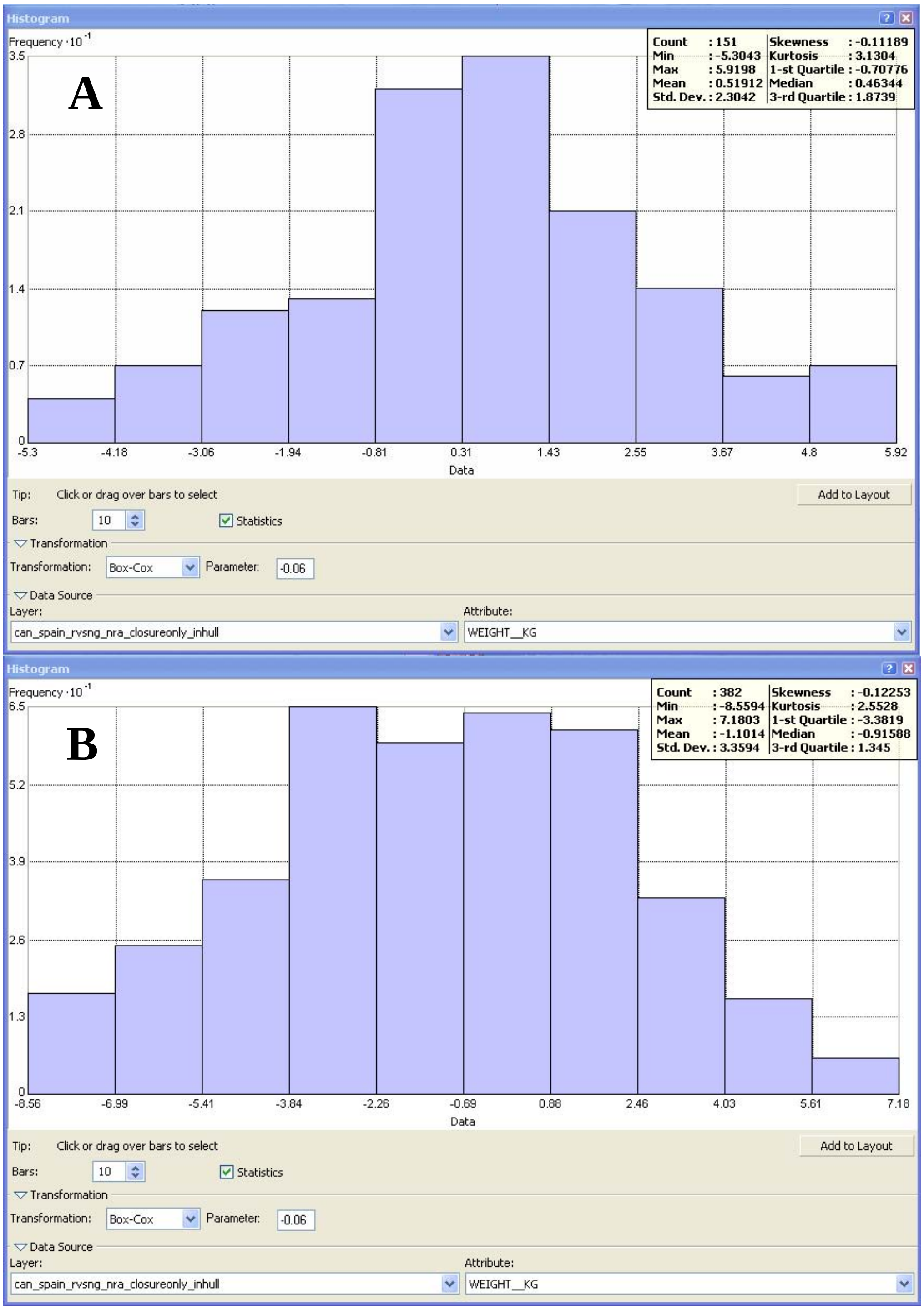

Figure 22. ArcGIS 10, Spatial Analyst histograms of Box-Cox transformed (Lambda (λ) of -0.06) non-zero, **A)** Canadian sponge by-catch records, and **B)** Spanish/EU sponge by-catch records from 2005-2008 within the minimum bounding geometry in Figure 20.

Comparing the Canada/Spain/EU Biomass Surface to the Spain/EU Only Surface

The combined Canadian and Spanish/EU 12.8 x 12.8 km biomass surface (Figure 19) appears to use two conflicting and not easily comparable datasets. Nonetheless, this form of the layer was utilized previously to suggest biologically justifiable encounter thresholds of sponge outside of the closed areas within the NAFO fishing footprint (Cogswell et al., 2010). For this reason, it is necessary to compare the two surfaces to highlight their key differences and to discuss their likely implications on simulated by-catch.

An additional 839 sponge by-catch records from 2009 and 2010 (2008-2010 for Div 3L) were added to the Spanish/EU research trawl point dataset and used in the Spanish/EU only biomass layer generated for this report. The entire Spanish/EU point dataset (N=2066, 2005-2010) can be observed in comparison to the Canadian and Spanish/EU point dataset used in 2010 in Figure 23. While both of the resulting biomass surfaces maintain a similar overall distribution, differences are observable in key areas where Canadian data dominate: Sackville Spur (1), Beothuk Knoll (2) and just south of the Flemish Pass closed area (3) (Figure 24). This analysis by no means discredits the value of the Canadian RV trawl by-catch dataset, but rather illustrates its incompatibility with a more spatially robust Spanish/EU dataset. The Canadian dataset should be used in concert to illustrate the data gaps in the Spanish/EU dataset where very high by-catch values have been observed. As stated previously, eliminating the Canadian data from the creation of the biomass surface appears to be a small spatial sacrifice for a large overall gain in data coherence.

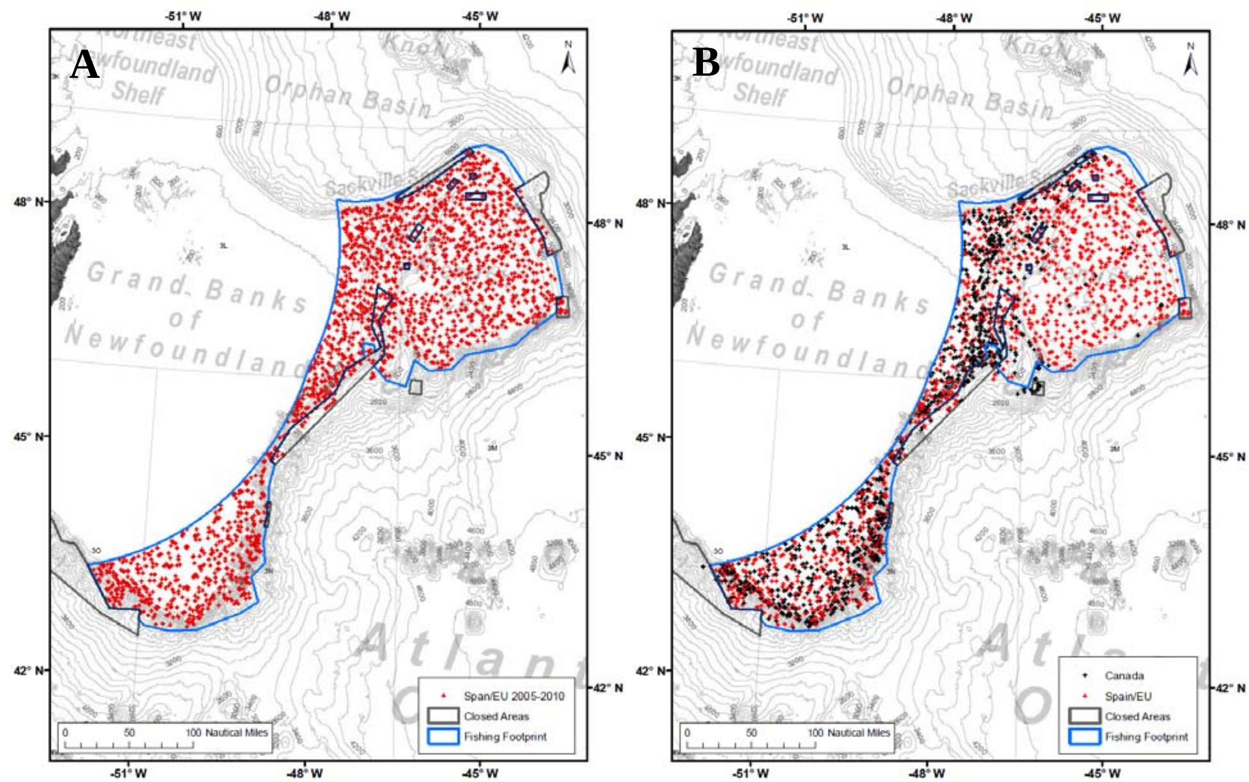

Figure 23. A) The Spain/EU only sponge record dataset used to produce the 12.8 x 12.8 km cell grid surface (Figure 24 A), and B) The combined Canadian and Spanish/EU point datasets used to create the 2010 12.8 x 12.8 km cell grid surface (Figure 24 B).

Table 1 shows the summary statistics for the cells that make up the biomass layers. Both datasets are right skewed with the majority of both grid datasets represented by either 0 or very small values. Despite similarities in the dataset structure, the combined Canada/Spain/EU dataset has a higher mean, standard deviation, median and 3rd quartile. It was clear from the analysis in the previous section that not only were Spanish/EU and Canadian catch weights not proportional by length trawled, but that despite Canadian trawls being 1/2 as long as Spanish/EU trawls, Canadian trawls with sponge by-catch were still catching significantly more sponge. So, by dividing the Canadian catch values by 1.4 km to standardize to kg/km, the resulting Canadian data in the attribute table was disproportionably high compared to Spanish/EU data in the 2010 biomass layer.

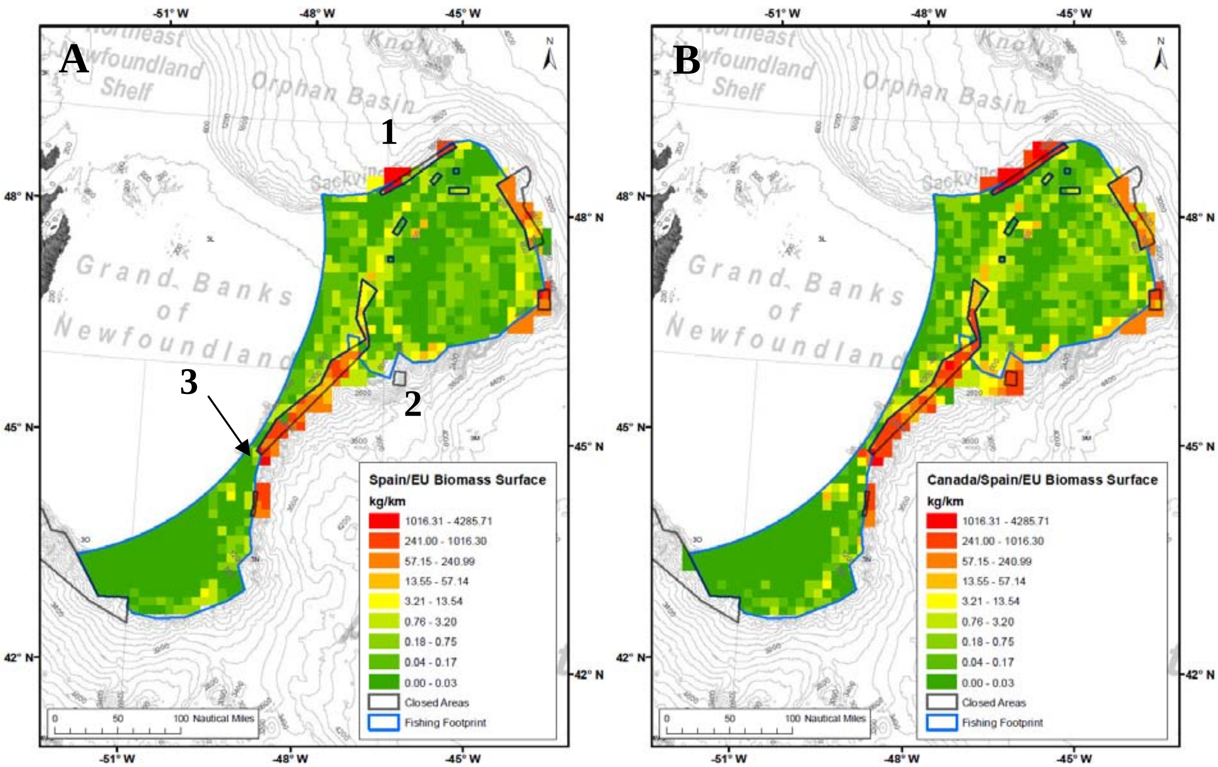

Figure 24. A comparison of the sponge biomass surfaces for just the Spanish/EU dataset (2005-2010) (A) and the combined Canadian (1995-2008) and Spanish/EU (2005-2008) datasets (B). Note locations 1, 2 and 3 where removing Canadian data caused obvious changes in the biomass surface.

Table 1. The summary statistics for the biomass surfaces shown in Figure 24 (kg/km).

Country	Cell Count	Min	Max	Mean	S.D.	Skewness	Kurtosis	1st Quartile	Median	3rd Quartile
Canada & Spain/EU	826	0	4285.7	82.81	334.15	7.68	78.85	0.02	0.28	4.26
Spain/EU	816	0	4285.7	50.63	281.43	10.55	139.76	0.01	0.13	1.59

Comparing Sponge By-catch Profiles from 12.8 x 12.8 km Cell Grid

This simulation uses 2000 randomly placed and oriented straight line simulation trawls of standard 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 revised by-catch layer (Figure 25). The purpose of this model run is to compare the by-catch profiles of the simulated lines, as the percentage of trawls above set thresholds, between the Spain/EU only and the Canada/Spain/EU biomass surfaces (Table 2).

Table 2 shows the summary statistics of sponge by-catch values derived from each of the 2 biomass surfaces being compared. As was seen with the direct biomass grid value comparison in Table 1 (kg/km), the Canada/Spain/EU biomass layer resulted in a higher mean, standard deviation and median by-catch than by-catch values derived from the Spain/EU only biomass layer (Table 2.). This is further demonstrated in Figures 26A and B, that shows the percentage of by-catch above various threshold values. Note that at the smallest threshold shown (0.1 kg) there is very little difference, illustrating that the majority of by-catch derived from either biomass layer is manifest as small values. The arrows highlight the threshold by-catch values where the % of trawls represented by subsequent thresholds begins to increase more rapidly (also observable in Table 3). It appears that using just the Spain/EU data to produce a biomass layer for the model increases the number of very small by-catches (below 0.1 kg) and results in an overall decrease in higher by-catch values. In either case though, the thresholds where the number of records begins to increase more rapidly is roughly similar, 4000 or 2000 kg depending on the layer, and 300 kg. These values are useful as they represent limits of biological distribution and concentrations useful for assigning a value to encounter protocols.

The comparison between the two layers provided in this and the previous section show that for reasons of data consistency and their comparatively similar overall threshold profiles, all model runs discussed in subsequent sections will utilize a biomass layer derived solely from Spain/EU sponge by-catch data.

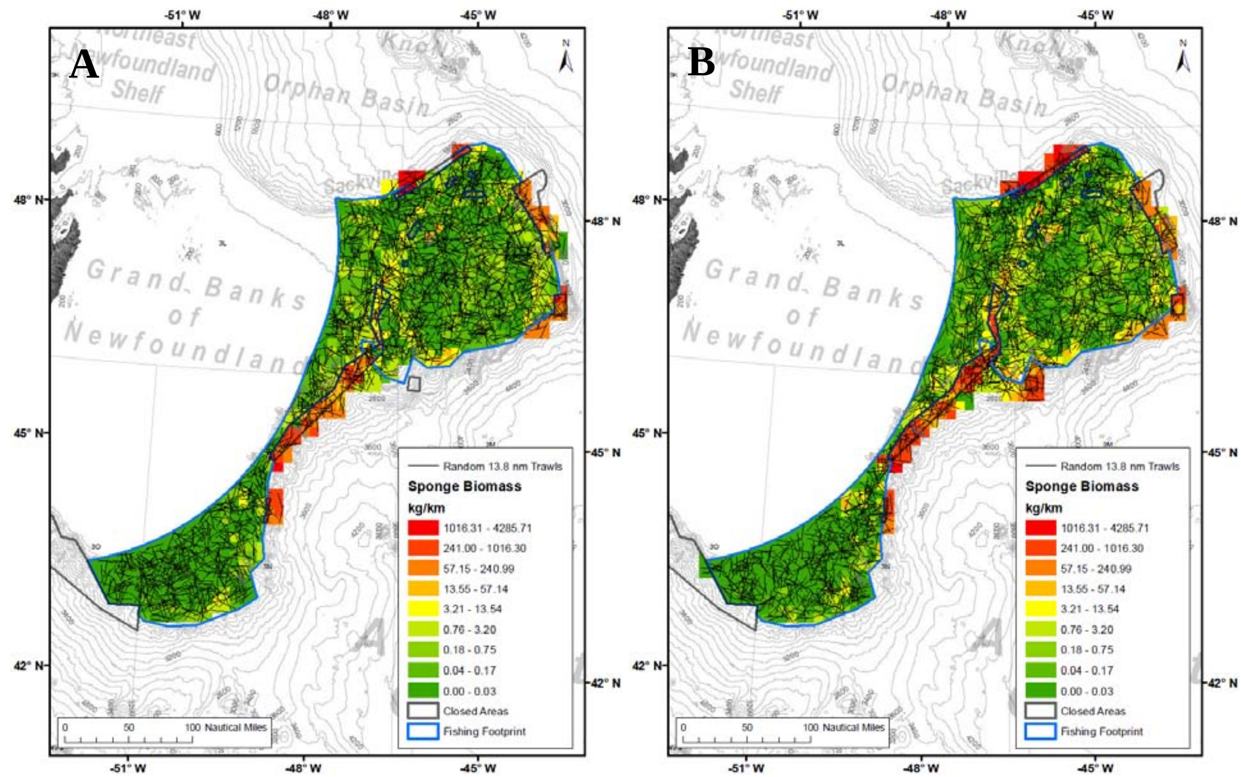

Figure 25. A) 2000 randomly oriented 13.8 lines over the extent of the 12.8 x 12.8 km Spanish/EU sponge biomass grid, and **B)** 2000 randomly oriented 13.8 nm lines over the extent of the 2010 Canadian/Spanish/EU sponge biomass grid.

Table 2. The resulting sponge by-catch summary statistics (kg) from the 2000 random simulated trawl lines for both the Spanish/EU and Canadian/Spanish/EU biomass surfaces (Figure 25).

Layer	Trawl Count	Min	Max	Mean	S.D.	Skewness	Kurtosis	1st Quartile	Median	3rd Quartile
Canada/Spain/EU	2000	0	79386	1176.74	4659.1	7.87	92.78	1.04	7.47	66.60
Spain/EU	2000	0	78047	733.3	4470	11.88	171.48	0.54	3.69	25.28

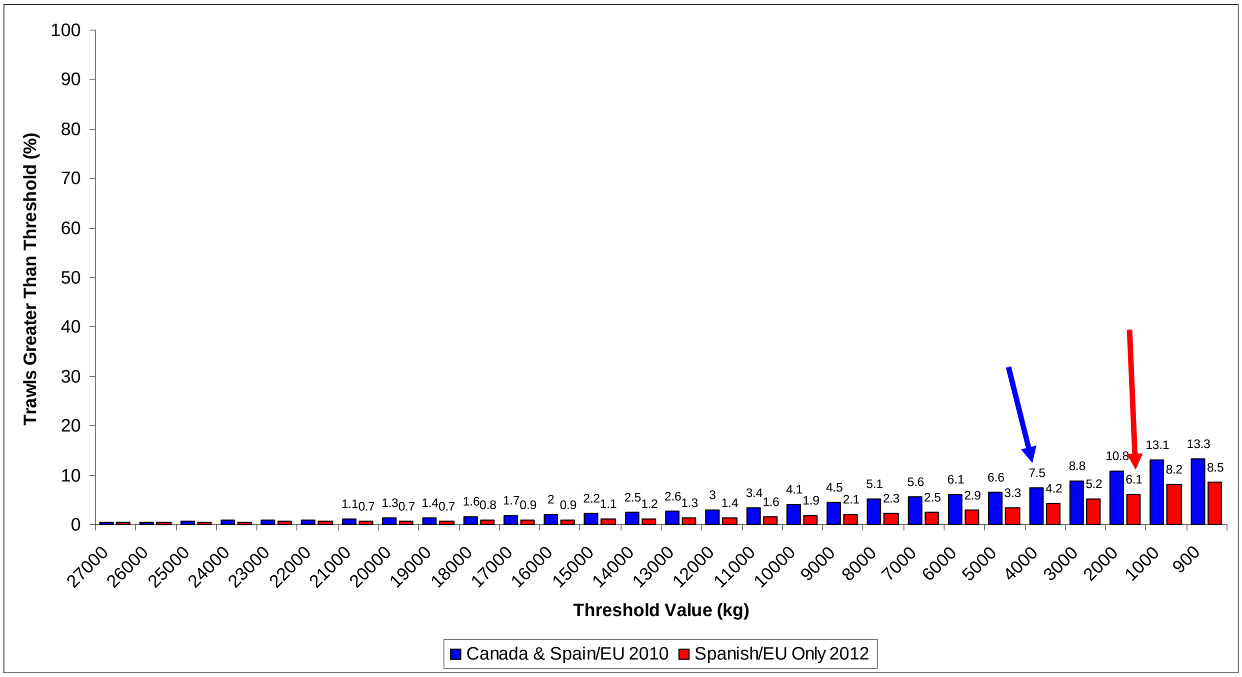

Figure 26A. The percentage of by-catch values of randomly oriented and placed lines using either the 2010 Canada/Spain/EU biomass surface or the 2012 Spain/EU only biomass surface. The bolded blue and red arrow (representing each biomass layer) shows where the number of trawls represented by each threshold starts to more rapidly increase.

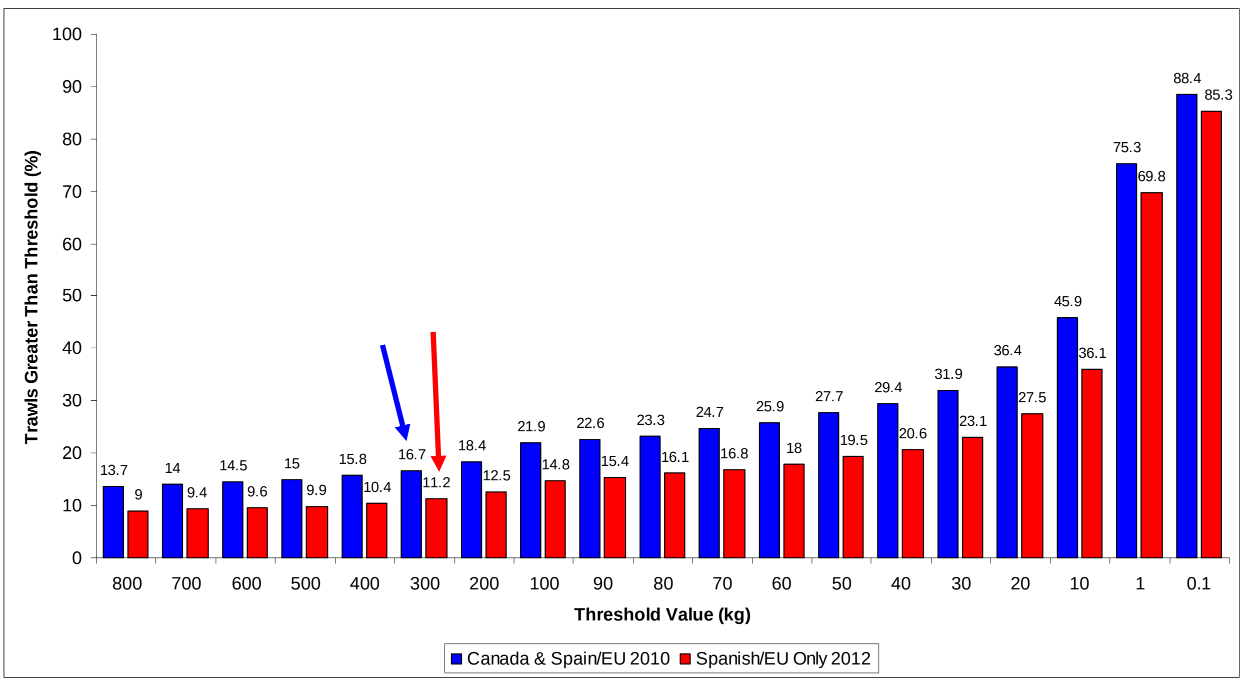

Figure 26B. The percentage of by-catch values of randomly oriented and placed lines using either the 2010 Canada/Spain/EU biomass surface or the 2012 Spanish/EU only biomass surface. The blue and red arrow (representing each biomass layer) shows where the number of trawls represented by each threshold starts to more rapidly increase.

Table 3. The number and percent of simulated randomly oriented and placed 13.8 nm trawls catching sponge at various encounter threshold levels. Blue and red shaded values indicate the arrows from Figures 26A and B.

Threshold (kg)	% > Threshold Canada/Spain/EU	Difference to next Threshold (%)	% > Threshold Spanish/EU Only	Difference to next Threshold (%)
27000	0.5	0	0.5	0
26000	0.5	0.1	0.5	0
25000	0.6	0.2	0.5	0
24000	0.8	0.1	0.5	0.1
23000	0.9	0	0.6	0.1
22000	0.9	0.2	0.7	0
21000	1.1	0.2	0.7	0
20000	1.3	0.1	0.7	0
19000	1.4	0.2	0.7	0.1
18000	1.6	0.1	0.8	0.1
17000	1.7	0.3	0.9	0
16000	2	0.2	0.9	0.2
15000	2.2	0.3	1.1	0.1
14000	2.5	0.1	1.2	0.1
13000	2.6	0.4	1.3	0.1
12000	3	0.4	1.4	0.2
11000	3.4	0.7	1.6	0.3
10000	4.1	0.4	1.9	0.2
9000	4.5	0.6	2.1	0.2
8000	5.1	0.5	2.3	0.2
7000	5.6	0.5	2.5	0.4
6000	6.1	0.5	2.9	0.4
5000	6.6	0.9	3.3	0.9
4000	7.5	1.3	4.2	1
3000	8.8	2	5.2	0.9
2000	10.8	2.3	6.1	2.1
1000	13.1	0.2	8.2	0.3
900	13.3	0.4	8.5	0.5
800	13.7	0.3	9	0.4
700	14	0.5	9.4	0.2
600	14.5	0.5	9.6	0.3
500	15	0.8	9.9	0.5
400	15.8	0.9	10.4	0.8
300	16.7	1.7	11.2	1.3
200	18.4	3.5	12.5	2.3
100	21.9	0.7	14.8	0.6
90	22.6	0.7	15.4	0.7
80	23.3	1.4	16.1	0.7
70	24.7	1.2	16.8	1.2
60	25.9	1.8	18	1.5
50	27.7	1.7	19.5	1.1
40	29.4	2.5	20.6	2.5
30	31.9	4.5	23.1	4.4
20	36.4	9.5	27.5	8.6
10	45.9	29.4	36.1	33.7
1	75.3	13.1	69.8	15.5
0.1	88.4		85.3	

<u>The Argument for Utilizing a Smaller Grid Size</u>

In NAFO (2011b) (Terms of Reference 4.1) it is proposed that the color coded biomass grid be utilized as a mechanism for fisherman to gauge risks of fishing in an area where high concentrations of sponges exist. For example, if a fisherman chooses to fish in a red 12.8 x 12.8 km box where concentrations of sponges exist above recommended thresholds but are currently outside of the recommended closed areas, then if an encounter above threshold values were to occur the fisherman would be subject to the terms of such an encounter (e.g., move away distance and/or time as recommended). Under such a scenario, the size of the cell in question could dramatically influence the placement of subsequent trawls.

The benefit of using a larger grid size of 12.8 x 12.8 km is that the area of the cell is reflective of the mean distance between 1 trawl and the 9 closest neighbouring trawls as determined by the ArcGIS "calculate distance band". In addition, a larger cell size means fewer interpolated cells via focal statistics. In addition to the considerations in the previous paragraph, additional downsides to large cells can arise in cases where trawl start points are clustered within a cell and as a result large portion of the cell would have a value that is not necessarily reflective of the majority of the habitat within it. As well, having a large cell size also creates problems in zones of transition (e.g., slope environments, changes in fauna concentrations, closed area boundaries, variable habitat, etc...) and can be reflected by high by-catch variance within a single cell.

A surface comprised of smaller cells means fewer points used to derive a cell value and would require more cells to be produced using focal statistics. Nonetheless, the overall area interpolated is likely comparable to a larger cell size grid surface. It is the use of focal statistics however that will allow the surface to take into consideration the value of near cells and thus create a more accurate picture of zones of transition not possible with a larger cell size. Nonetheless, despite the gains realized by a smaller cell size, the lower limit of cell size is ultimately dictated by the continuous nature of the surface. It is essential for the model to have a nearly continuous surface to extract biomass values to the simulated trawl lines. Any adjustment of cell size must ultimately fit this criteria. The cell size chosen is 5 x 5 km and is big enough to average approximately 3 Spanish/EU sponge records per cell (Figure 27). While the dataset profile is similar to those seen in the previous section for the 12.8 x 12.8 km cells, the summary statistics in Table 4 show that the profile for the cell values is even more right skewed and dominated by low by-catch values. In fact, of the 114,642 km^2 represented by 5 x 5 km grid surface area, ~91% of this area (or 104646 km^2) is represented by cell values less than 4 kg/km.

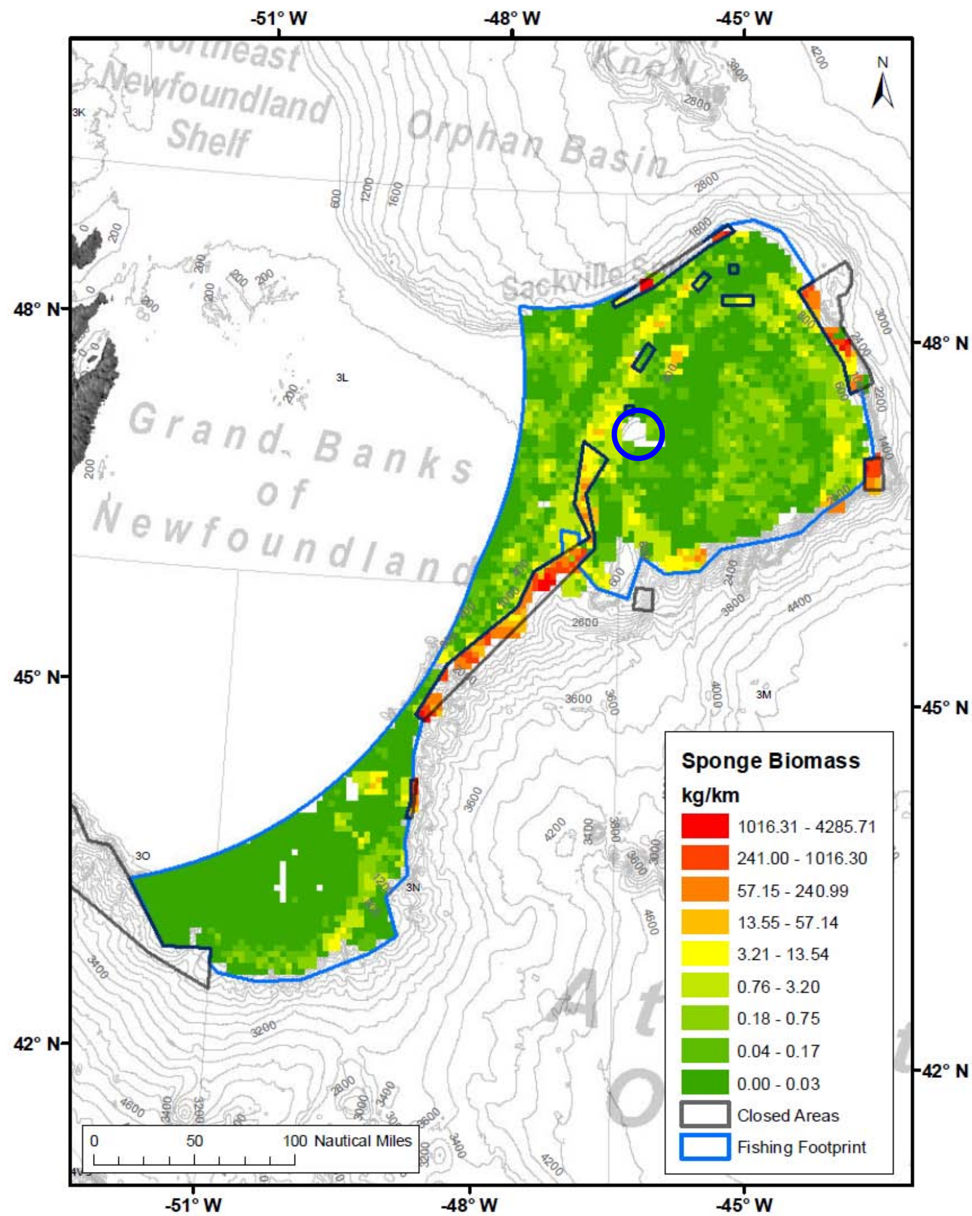

Figure 27. The Spanish/EU only 5 x 5 km cell sponge biomass grid surface proposed for subsequent model runs. Note areas where the surface has no data values. The area circled in blue is consistently avoided by Spanish/EU groundfish survey vessels because is an area where several "snags" were recorded in the past (A. Vazquez, Pers. Comm.).

Table 4. The summary statistics for the Spanish/EU only 5 x 5 km biomass grid (kg/km).

Country	Cell Count	Min	Max	Mean	S.D.	Skewness	Kurtosis	1st Quartile	Median	3rd Quartile
Spain/EU	2996	0	4285.7	22.0	167.34	15.51	324.54	0.01	0.08	0.75

Sponge By-catch Profile From 5 x 5 km Cell Grid

Two thousand (2000) randomly placed and oriented simulated trawl lines were created within the extent of the 5 x 5 km sponge biomass layer (Figure 28). These trawls could pass into closed areas but were clipped when passing through no data areas. The summary statistics for the random simulated sponge by-catch are provided in Table 5 and as with the biomass grid, they show a highly right skewed data set.

A further break down of catches by various thresholds shows that at 200 kg and at approximately 50 kg, the percentage of trawls represented by that threshold takes a jump (Figure 29 and Table 6). As shown previously (Kenchington et al., 2010), sponges aggregate to form high concentrations representing relatively small, slowly increasing areas with each successive threshold. When a critical threshold is reached, the catch at this threshold represents the distributional extent of high concentration areas, while all subsequent thresholds represents new less concentrated areas that often just connect higher concentration areas. As shown in Kenchington et al. (2011), a combined kernel density/minimum binding polygon analysis reveals 300 kg and 40 kg as numerical thresholds that accompany a corresponding rapid increase in area represented by trawls in subsequent thresholds. The 300 kg threshold appears to coincide with the distributional extent of structure forming VME sponges (specifically Geodiid sponges), while the 40 kg threshold corresponds with many small non-VME species (Kenchington et al., 2011)

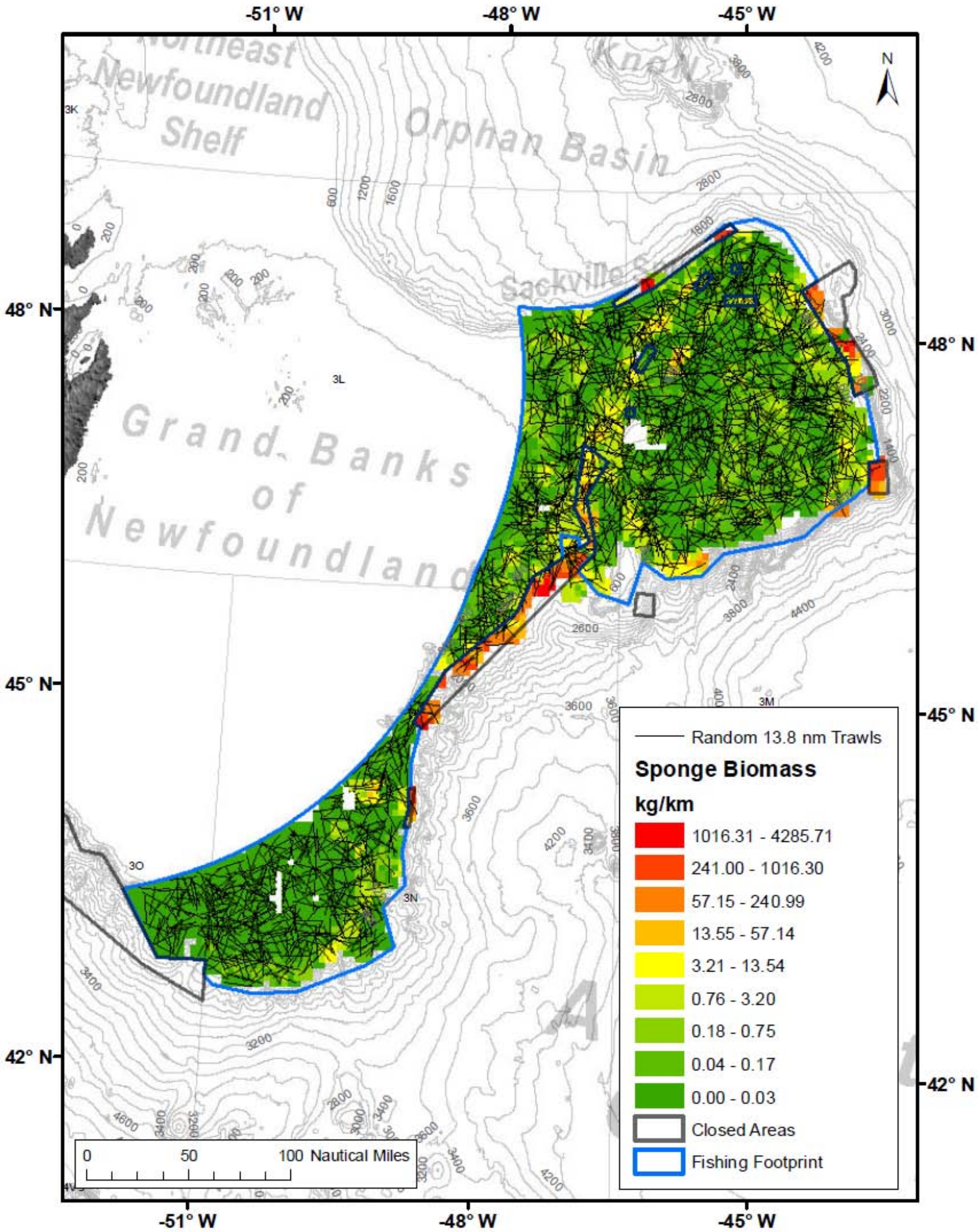

Figure 28. 2000 randomly oriented 13.8 lines over the extent of the 5 x 5 km Spanish/EU sponge biomass surface.

Table 5. The resulting sponge by-catch summary statistics from the 2000 random trawl lines run over the Spanish/EU 5 x 5 km sponge biomass surface (Figure 28).

Layer	Trawl Count	Min	Max	Mean	S.D.	Skewness	Kurtosis	1st Quartile	Median	3rd Quartile
Spain/EU	2000	0	35858	158.37	1219.7	17.698	424.31	0.38	2.82	14.61

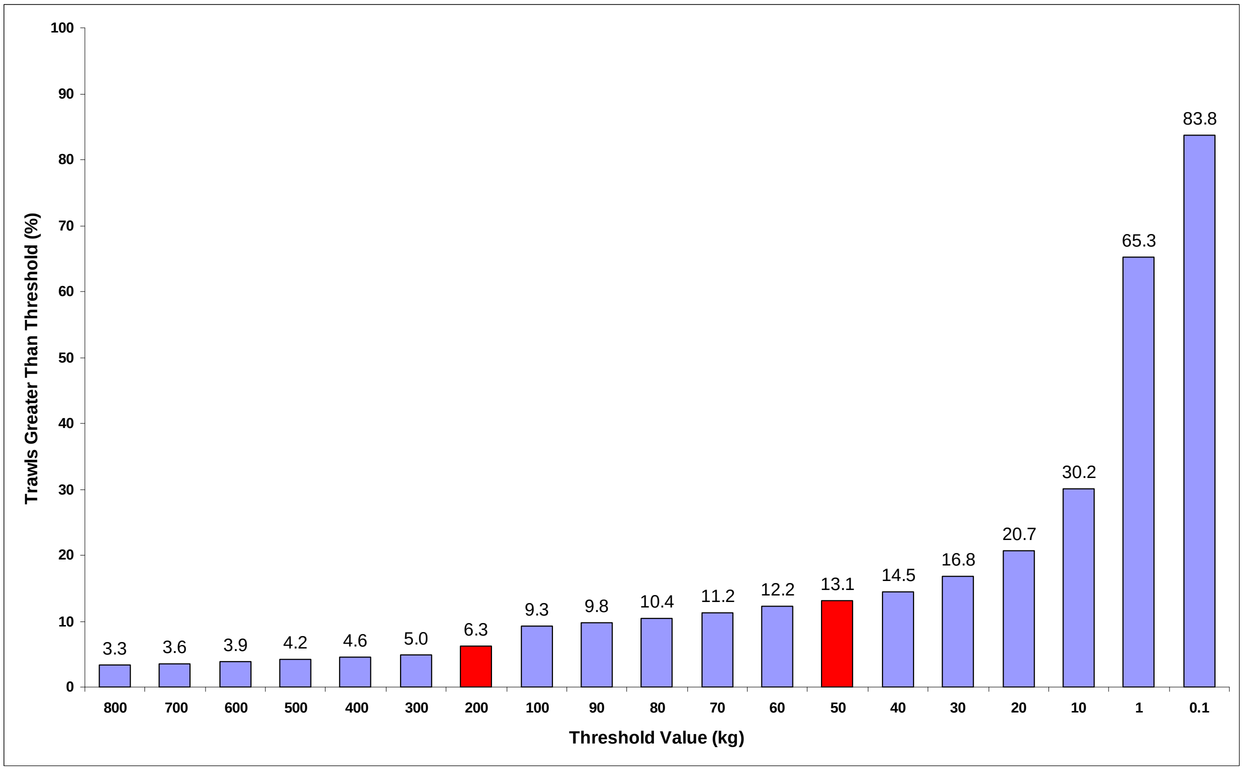

Figure 29. The percentage of by-catch values of randomly oriented and placed lines using the Spanish/EU only biomass surface. The red columns show where the number of trawls represented by each threshold starts to more rapidly increase.

Table 6. The percentage of by-catch values of randomly placed and oriented simulation trawls using the Spanish/EU only sponge biomass surface. The shaded rows below show where the number of trawls represented by each threshold starts to rapidly increase.

Threshold	Count Above Threshold	% > Threshold	Difference to Next Threshold
800	66	3.3	0.3
700	71	3.6	0.4
600	78	3.9	0.3
500	83	4.2	0.4
400	91	4.6	0.4
300	99	5.0	1.4
200	126	6.3	3.0
100	186	9.3	0.5
90	196	9.8	0.5
80	207	10.4	0.9
70	224	11.2	1.0
60	244	12.2	0.9
50	262	13.1	1.4
40	290	14.5	2.3
30	336	16.8	3.9
20	414	20.7	9.5
10	603	30.2	35.1
1	1305	65.3	18.5
0.1	1675	83.8	

Simulated VMS Sponge By-catch Versus Simulated Standard Trawl Sponge By-catch

This section compares the by-catch output of 2000 randomly selected trawls from the 95% confidence interval VMS data and 2000 simulated 13.8 nm standard trawls (Figure 30A and B). The model used to extract sponge by-catch values to the VMS data was a truncated version of the original model as described in Kenchington et al. (2010). For this VMS model run, it was not necessary to generate simulated trawl lines in the direction of the greatest effort because the VMS trawls are ultimately what the effort raster represents. Instead, station points were placed at 500 m along each VMS polyline and the data from the sponge by-catch raster was extracted to each point along the line, using the "Extract Values to Points" tool in ArcGIS 10. The by-catch values for all points (in kg of sponge by-catch per km) were averaged, effectively creating a close approximation of length weighted mean for by-catch. The average kg/km value calculated for the line is then multiplied by the length of the line (in km) to produce the simulated by-catch total for each line (in kg).

The model was also run using simulated 2000 13.8 nm straight line trawls, which were created by using the "generate random points" tool in the Geospatial Modelling Environment software. This tool has an option to input a "probability surface", in this case the 2010 groundfish fishing effort raster. This "probability surface" effectively weights the random placement of trawl start locations so the points generated reflect a semi-realistic set of simulated trawl start points (Figure 30B). As with Cogswell et al. (2010), the orientation of the lines is governed by the direction which would result in the highest cumulative effort along the line. The details of these steps in the model have been described at length in Kenchington et al. (2010). As with the VMS lines described in the preceding paragraph, station points were placed at 500 m intervals along each simulated trawl line, and the data from the sponge by-catch raster was extracted to each point along the line, using the "Extract Values to Points" tool in ArcGIS 10. The average kg/km value for the line is then multiplied by the length of the line to produce the simulated by-catch total for each line. These lines were limited to the current NRA fishing footprint and were thus restricted from entering the bounds of closed areas.

Figure 31 shows the running average of sponge by-catch values for the VMS fishing tracks and the simulated trawls (Figure 30A and B) as the number of trawls increases. The running average begins to level out at between 1400 and 1500 iterations, as was observed previously by Cogswell et al. (2010). In addition, it is clear that weighted random simulations are generally under-estimating by-catch compared to VMS trawls.

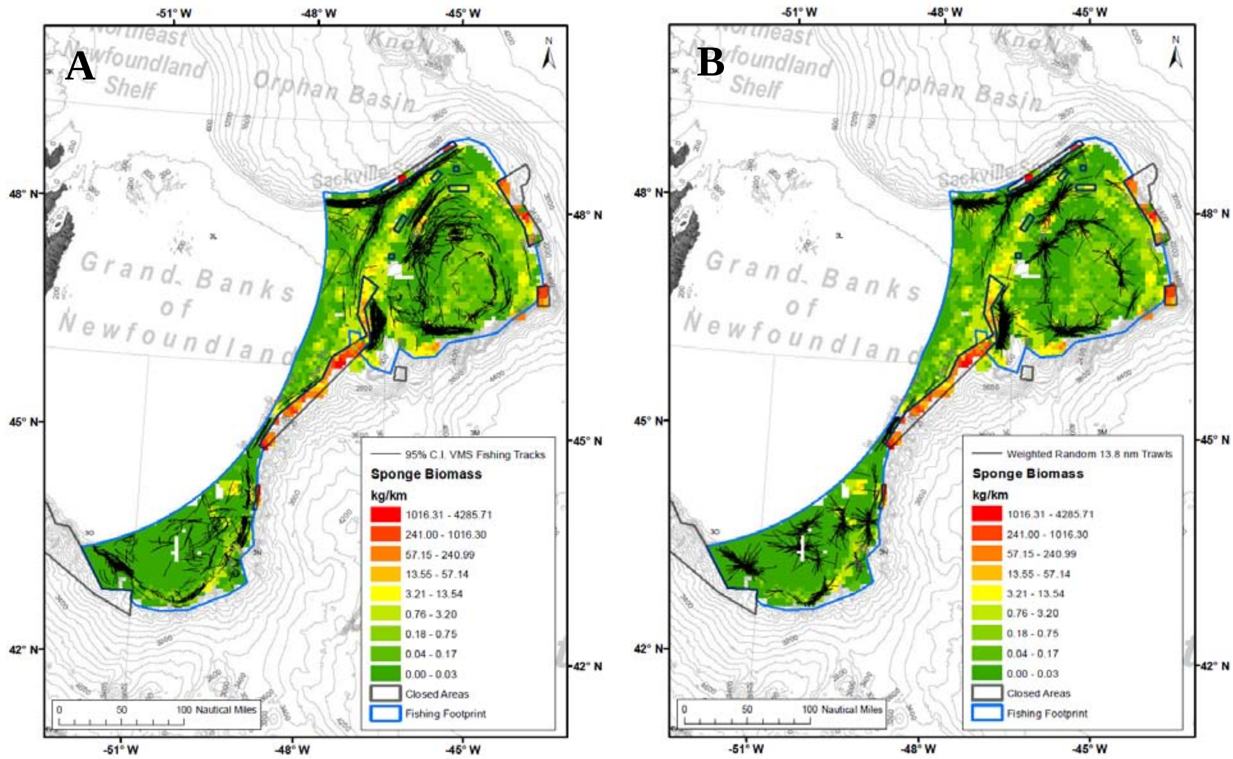

Figure 30. A) Distribution of 2000 randomly selected 95% confidence interval VMS fishing tracks in comparison to, **B)** 2000 weighted random 13.8 nm simulated trawls.

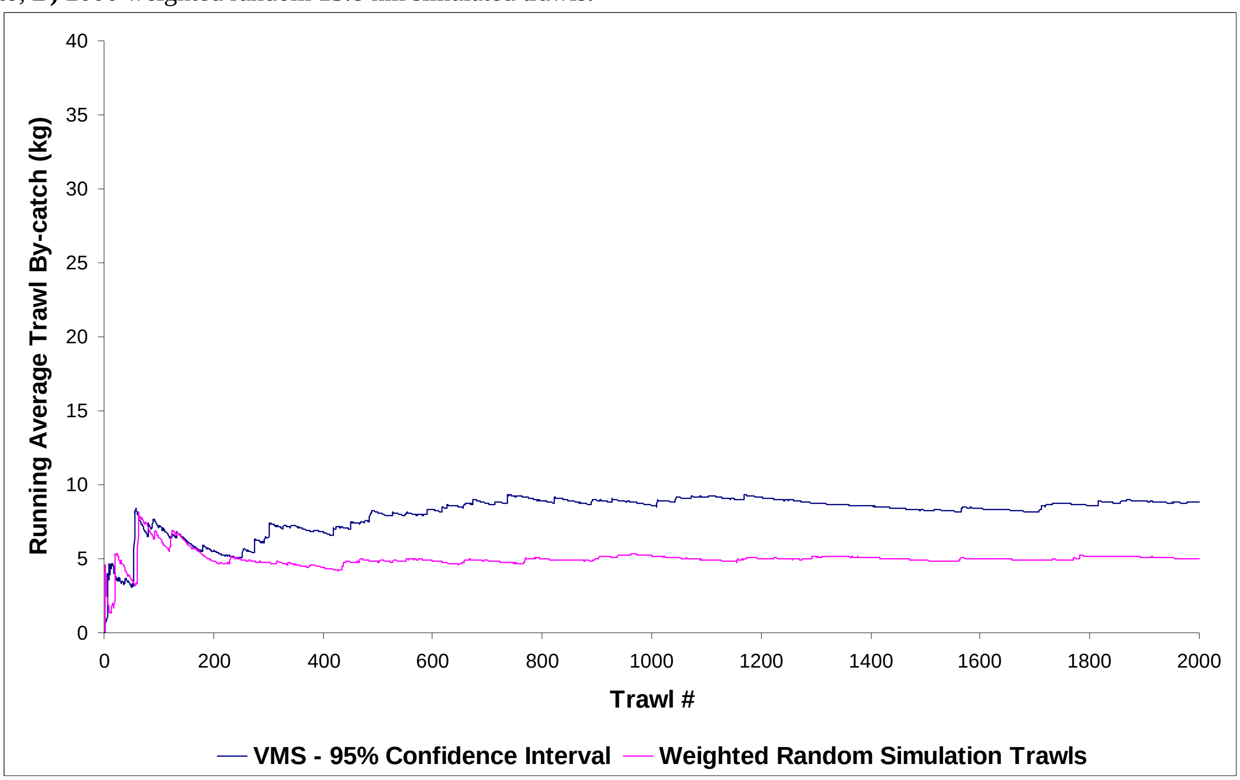

Figure 31. Running average of sponge by-catch for 2000 95% confidence interval VMS trawl lines and 2000 weighted random 13.8 nm straight line simulated trawls.

The resulting by-catch (kg) profiles for 2000 95% confidence interval VMS trawl lines and 2000 13.8 nm weighted random simulated trawls, shows that ~ 87% of simulated sponge by-catch for both datasets is less than 10 kg (Figure 32 or Table 7).

In Table 7 (Figure 32), only 1 of the 2000 randomly selected VMS trawls catch more than 600 kg of sponges, the current NAFO threshold limit within the NRA fishing footprint (NAFO, 2011a). Nonetheless, 11 of these trawls exceed 300 kg, the likely distributional limit of structure forming VME sponges (Kenchington et al., 2011). As described in Kenchington et al. (2011), of the simulated trawls catching more than 300 kg of sponge, most are as a result of longer than average trawl lengths in areas with moderate to high concentrations of sponges. In particular, the area east of the northern tip of the Flemish Pass closed area (Figure 33) is home to all VMS by-catch values in excess of 400 kg. Lines in this area are very near a closed area and they also pass through high value interpolated sponge biomass layer cells. Some of these cells contain no Spanish/EU research vessel data, but are interpolated via focal statistics. While just a slight shift in fishing effort down slope towards the closed area could result in catches in excess of the 300 kg threshold, it is unlikely given the ongoing commercial fishing effort at this site that commercial trawls are currently catching in excess of 400 kg of sponges. Kenchington et al. (2011) further describes the relevance of these simulated VMS by-catch values and the implications of their proximity to known concentrations of VME sponges.

As described above, VMS trawl lengths appear to be highly variable and excessively long trawls through low concentration sponge areas will generate sponge above threshold levels. This is in fact the case for many of the VMS trawls with less than 400 kg of sponge (Kenchington et al., 2011). For this reason, it may be useful to state potential by-catch threshold values in relation to distance trawled (e.g., approximately 11.7 kg/km for 25.6 km (13.8 nm) = ~300 kg). Since the model calculates simulated by-catch for each line by multiplying line length by the length weighted mean of sponge biomass (kg/km) for the line, this mean value can be used to highlight short VMS trawls with biomass less than the 300 kg threshold, in areas that may otherwise be ignored. Viewing the data in this way, by setting the VMS by-catch threshold at approximately 11.7 kg/km trawled, 2 areas that might achieve this level of interaction emerge (Figure 34). Both of these areas correspond with locations which saw an increase in effort in 2010 (Figure 3 - B and C). The area to the east of the Flemish Pass closure has been explained (Figure 33), but the area in the middle of Flemish Cap highlights a zone where interactions resulting in catches in excess of 11.7 kg/km could already be occurring, or may occur with just a slight shift in fishing practices. All 6 of the highlighted trawls shown in Figure 34 are below the 300 kg threshold with a mean trawl length of 11.7 km and ranging from 3.3 to 18 km.

In general, fewer trawls are represented by threshold values above 0.1 kg for weighted random simulation trawls. This is likely due to the inherent trawl length variability for VMS trawls. Nonetheless, as shown below in Figure 32, the difference appears remarkably consistent and does not seem to unduly affect the ability of simulated trawls to reflect sponge by-catch under most circumstances. It is proposed that further enhancements (via correction factors) of model output be conducted in the future so this output even more accurately reflects the reality of fishing behaviour in the area. Despite these differences however, it is suggested that the random weighted simulated trawls can be used to address the impacts of various management scenarios with the understanding that by-catch above 0.1 kg is consistently and predictably under estimated.

Table 7. The number and percent of simulated groundfish trawls catching sponge at various encounter threshold levels.

Threshold	95% C.I. VMS Fishing Tracks		Weighted Random Simulation Trawls	
	Count Above Threshold	%> Threshold	Count Above Threshold	%> Threshold
800	0	0	0	0
700	0	0	0	0
600	1	0	0	0
500	0	0	0	0
400	5	0.3	0	0
300	11	0.6	1	0.1
200	23	1.2	5	0.3
100	35	1.8	19	1.0
90	38	1.9	22	1.1
80	44	2.2	24	1.2
70	48	2.4	29	1.5
60	55	2.8	39	2.0
50	63	3.2	41	2.1
40	78	3.9	52	2.6
30	89	4.5	62	3.1
20	127	6.4	94	4.7
10	260	13.0	178	8.9
1	869	43.5	712	35.6
0.1	1437	71.9	1492	74.6
0.01	1771	88.6	1767	88.4
0.001	1886	94.3	1908	95.4
0.0001	1907	95.4	1926	96.3
0	2000	100.0	2000	100.0

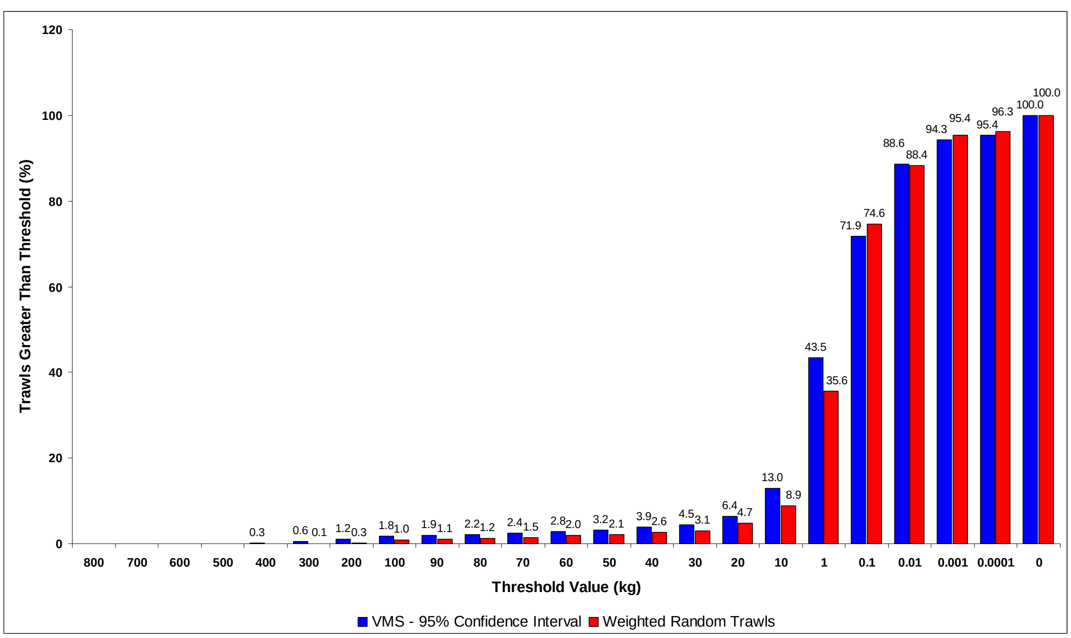

Figure 32. Graphical representation of Table 7 showing the proportion of trawls with simulated sponge by-catch greater than the thresholds.

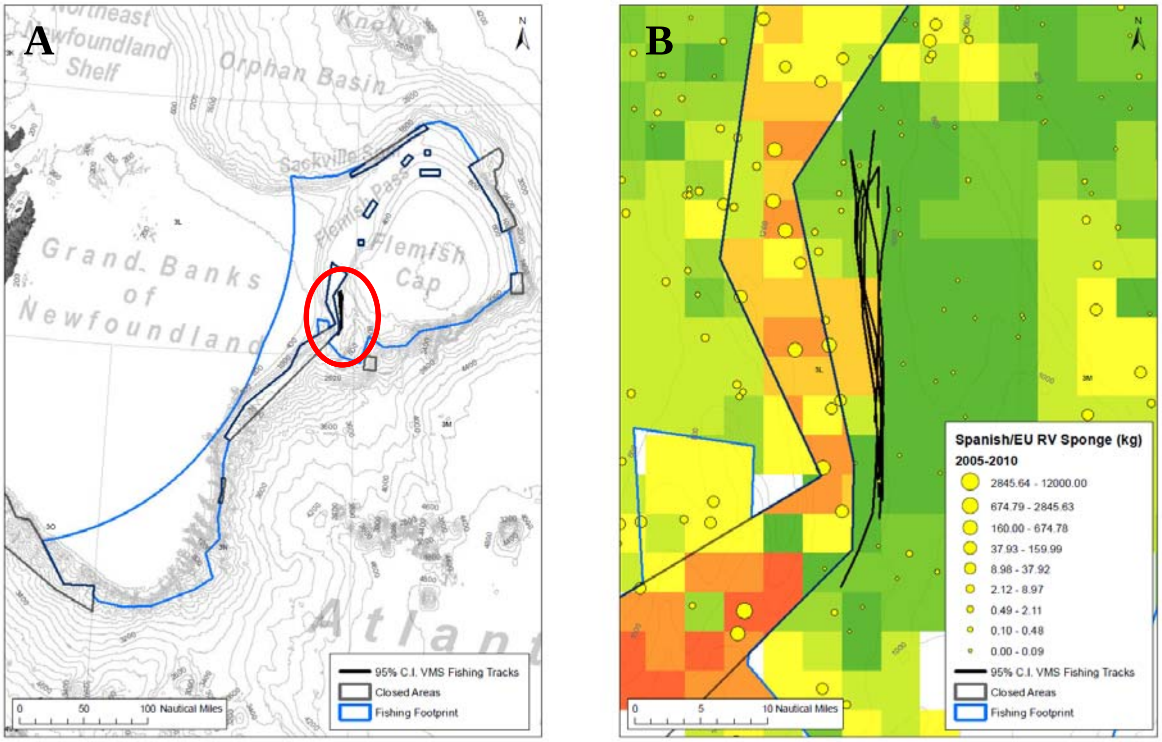

Figure 33. A) Location (red circle) of commercial trawls (black lines) where the modeled results indicate ≥ 400 kg of sponge by-catch in 2010 (data from filtered VMS data set detailed above). **B)** Close up of the commercial trawls (Filtered VMS) with modeled by-catch ≥ 400 kg of sponge with the sponge biomass polygon surface and in relation to research vessel catches. This illustrates why the model may have overestimated those catches. Note the 0 or low sponge by-catch points near the trawls and the lack of Spanish/EU point data in high value interpolated biomass cells along the trawl tracks (Kenchington et al. 2011).

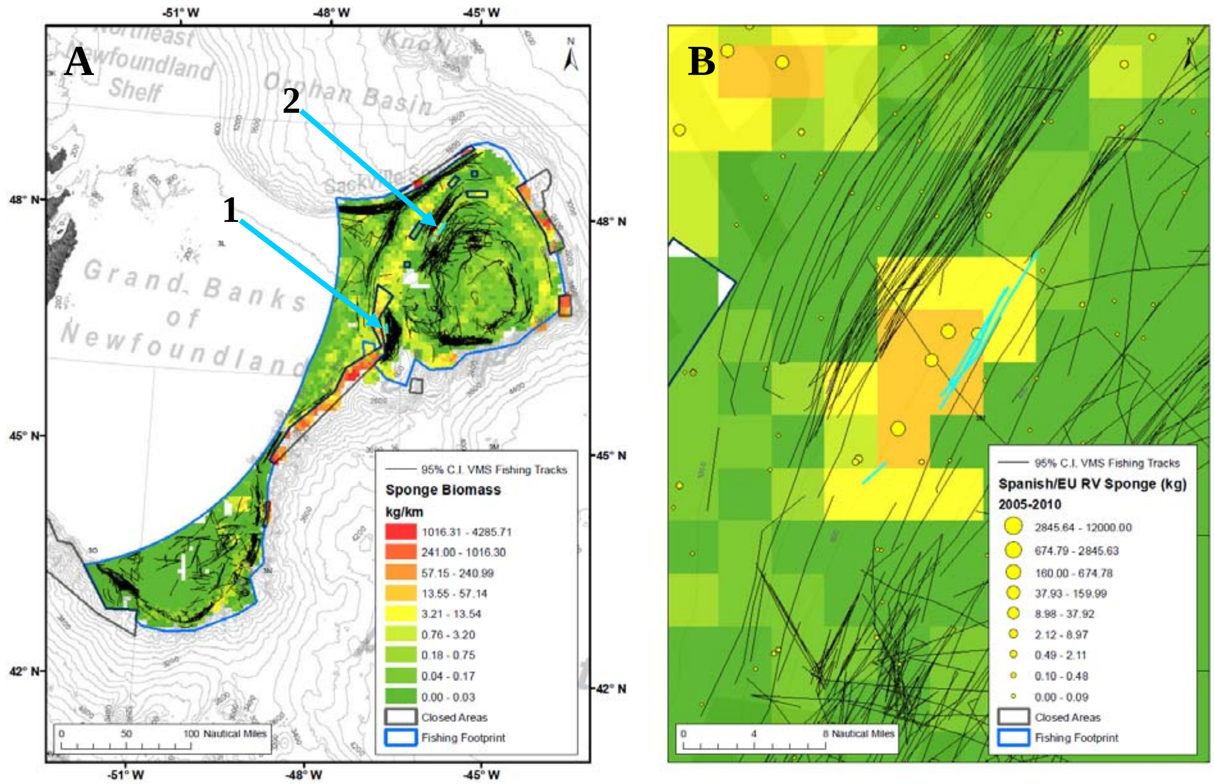

Figure 34. A) shows VMS lines (light blue) with by-catch rates in excess of 11.7 kg/km (or roughly 300 kg for a 13.8 nm straight line simulation trawl), and **B)** shows zoom of location 2, where it appears interactions may already be occurring or could occur with just a slight shift in fishing effort.

Sea Pen Biomass Layer

As with sponge, both Canadian (N=577) and Spanish/EU (N=2011) research vessel trawl by-catch data are available for incorporation into a sea pen biomass layer (Figure 35). Unlike with the sponge biomass section of this report, in-depth analysis will not be performed to justify the utilization of only Spain/EU data in the generation of the biomass surface. As with the sponge data, Canadian research trawl sea pen by-catch data is limited spatially to the western third of the NRA. This and other points brought up in the previous section relating to the overall reliability of Canadian by-catch data, the overabundance of zero values (Canadian - 87% or 500/577 versus Spanish/EU- 64% or 1292/2011) and the associated and apparently paradoxical increase in catch efficiency as observed through the elevated mean of Canadian non-zero by-catch values is enough to justify utilizing just the Spanish/EU research trawl sea pen by-catch data to produce the biomass surface for the model. As well, there were no areas covered by Canadian trawl data that were not within the spatial extent of the Spanish/EU data.

In the sponge biomass layer section of this report, a justification for using a smaller grid size was made. The same rationale is applied with sea pens to produce a 5 x 5 km grid representing on average 3 sea pen by-catch records per cell as determined by the ArcGIS "calculate distance band" tool described previously. The resulting sea pen biomass surface is nearly continuous except for some no data areas which closely resemble those in the sponge biomass surface (Figure 36). This layer was created in the same way as described for the sponge biomass raster, by calculating 1 biomass surface for inside and outside closed areas and creating a mosaic from those. As the summary statistics in Table 8 show, while the structure of the biomass surface (highly right skewed and an over abundance of near zero values) is similar to what was seen for sponges in Table 4, the difference in scale is orders of magnitude. In addition, while there appears to be some overlap in distribution between high concentrations of sea pens and sponges, the highest concentrations of sponges are recorded on the periphery of the NRA fishing footprint in the deep slope waters, while sea pens are primarily concentrated below 300 m in a horseshoe pattern around Northern Flemish Cap (Figure 37).

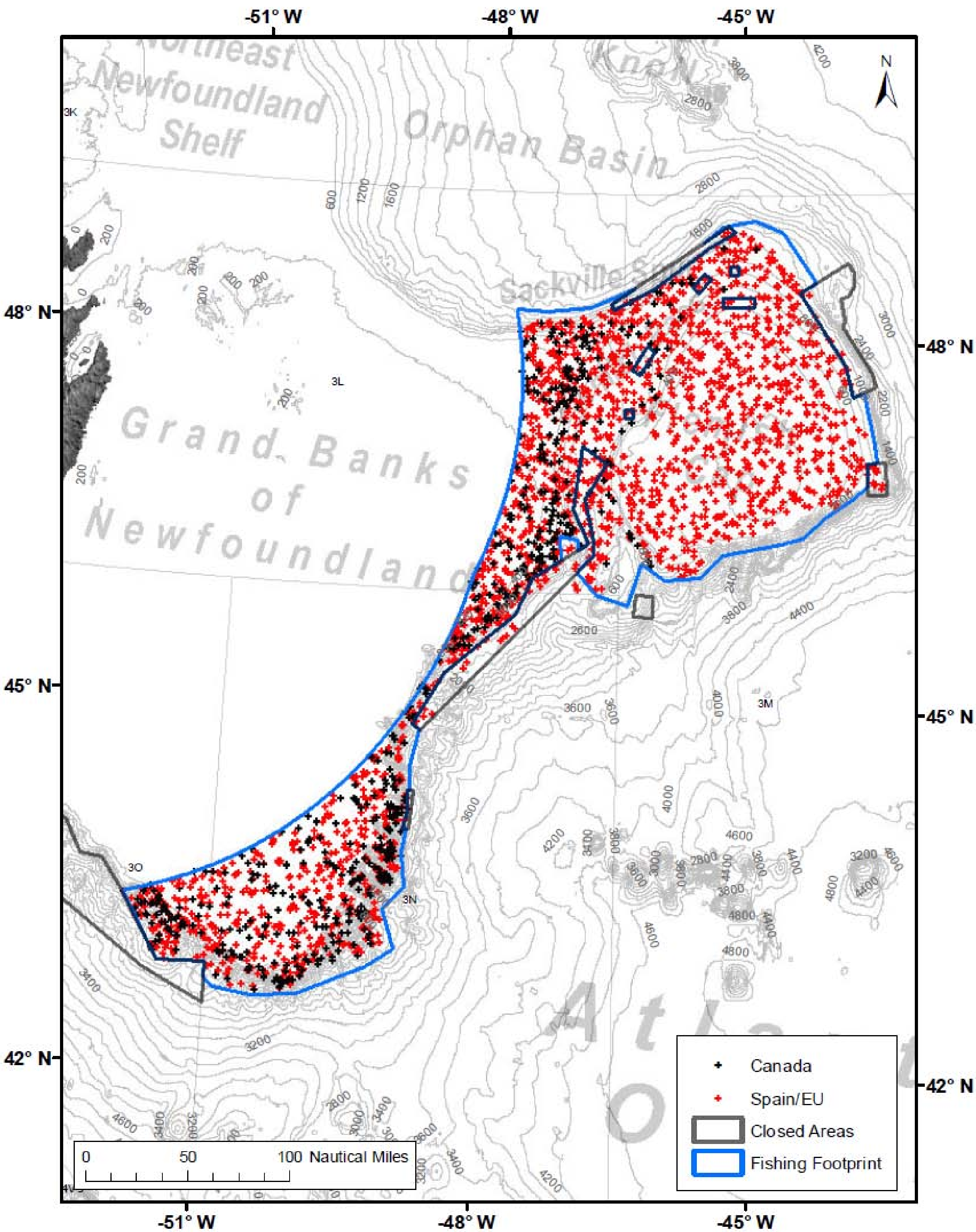

Figure 35. The Canadian and Spanish/EU trawl sea pen by-catch datasets. The Canadian dataset was not included in the creation of the final sea pen biomass surface because of the reasons described above for sponge by-catch.

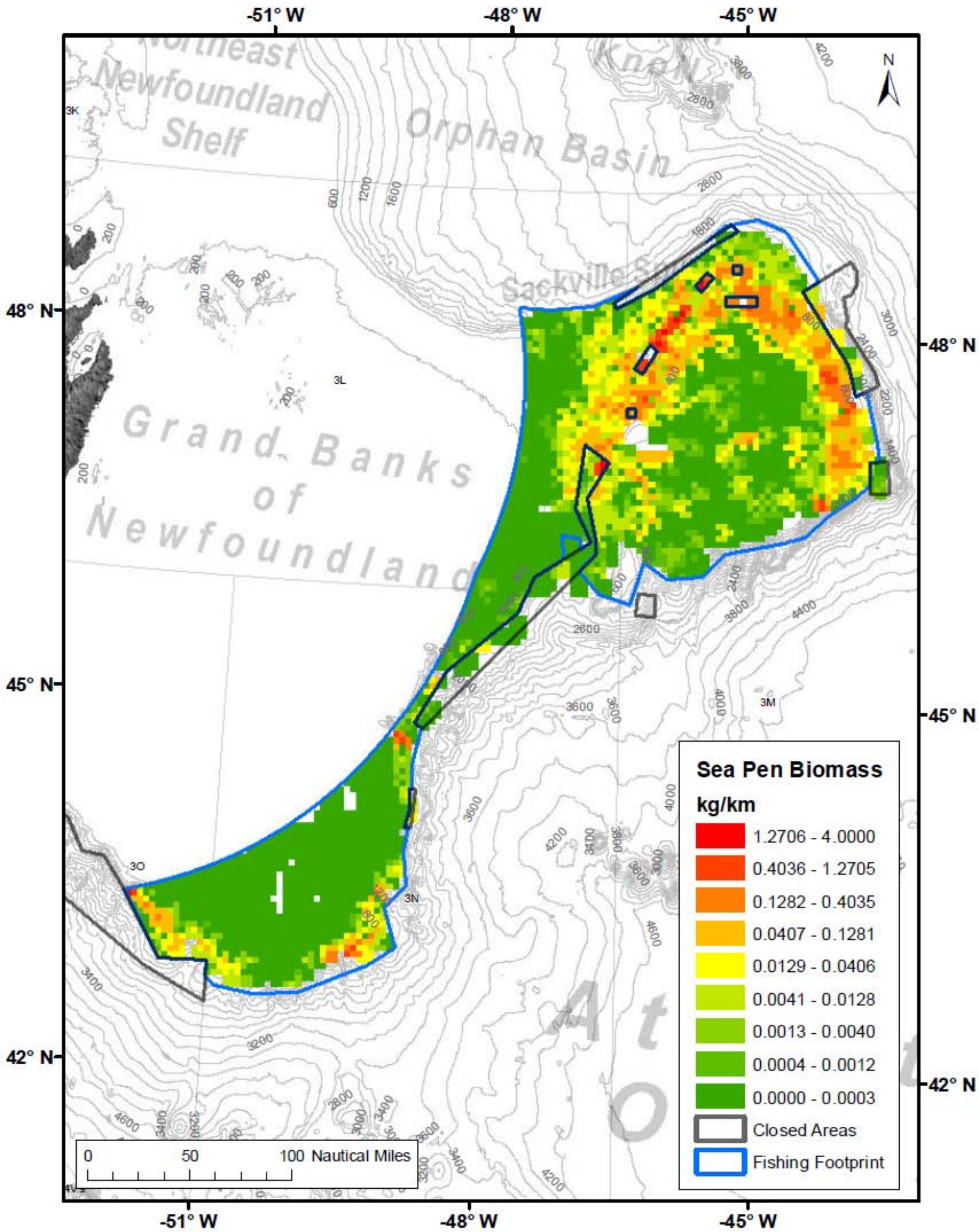

Figure 36. The Spanish/EU only 5 x 5 km sea pen biomass surface used for all subsequent model runs in this report.

Table 8. The summary statistics for the 5 x 5 km all Spanish/EU sea pen biomass grid (kg/km).

Country	Cell Count	Min	Max	Mean	S.D.	Skewness	Kurtosis	1st Quartile	Median	3rd Quartile
Spain/EU	1837	0	4	0.06	0.20	11.13	174.83	0.002	0.01	0.05

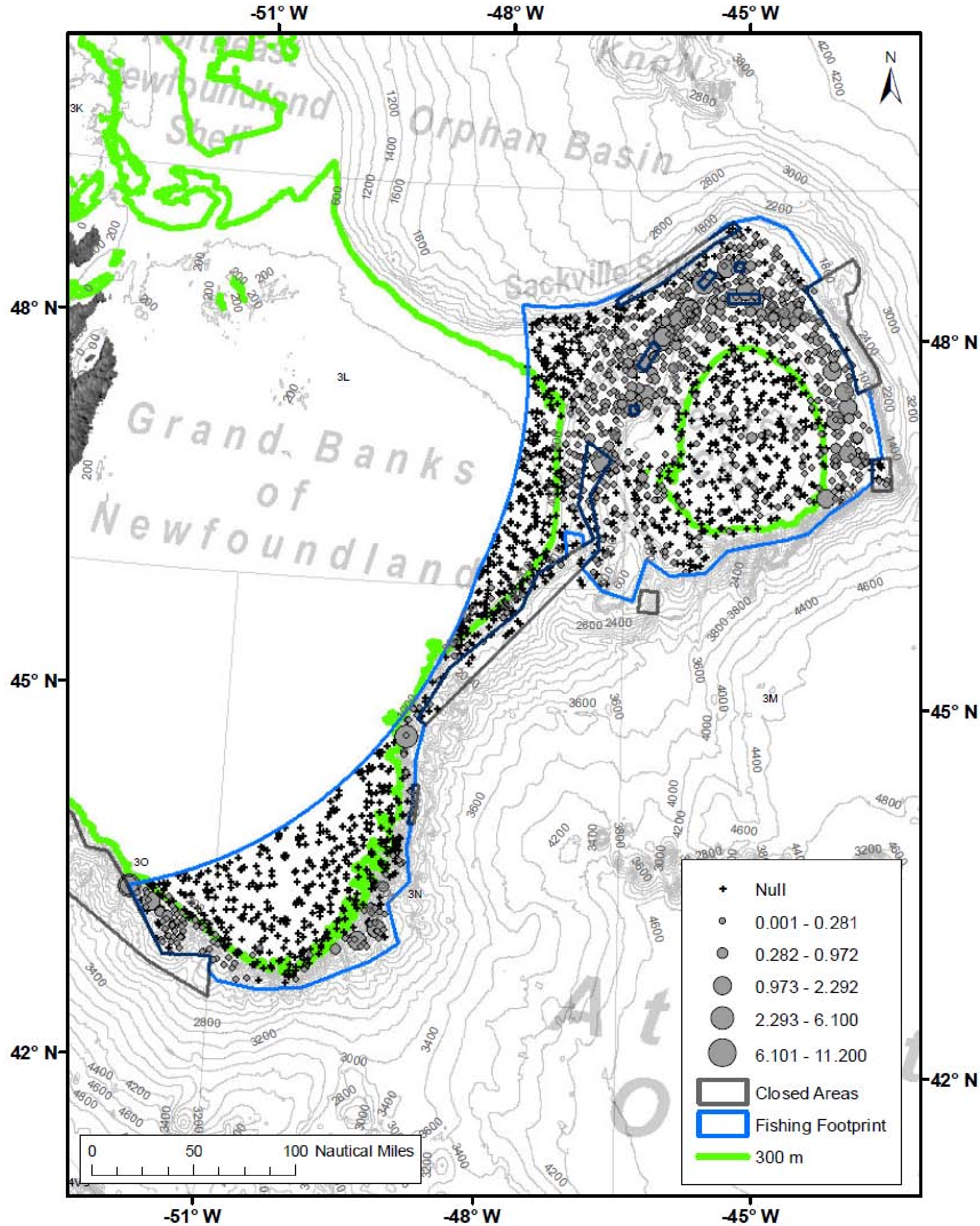

Figure 37. The distribution of sea pen by-catch (grey circles - kg) and null sets (black cross) in relation to the 300 m contour (green line) in the NAFO Regulatory Area (Kenchington et al., 2011).

Sea Pen By-catch Profile From 5 x 5 km Cell Grid

As with sponge in the previous section of this report, 2000 randomly placed and oriented simulated trawl lines were created within the extent of the 5 x 5 km sea pen biomass layer (Figure 38). These trawls could pass into closed areas but were clipped when passing through no data areas. The summary statistics for the sea pen by-catch are provided in Table 9 and as with the biomass grid (Table 8), they show a right skewed data set. This shows that for sea pens, the current encounter thresholds for live corals (60 kg) would never be reached even if trawls were allowed to pass through closed areas.

A further break down of catches by various thresholds shows that at 5-6 kg, the percentage of trawls represented by that threshold starts to rapidly increase (Figure 39 and Table 10). As shown previously (Kenchington et al., 2010), sea pens (like sponges) aggregate to form high concentrations representing relatively small, slowly increasing areas with each successive threshold. When a critical threshold is reached, the catch at this threshold represents the distributional extent of high concentration areas, while all subsequent thresholds represents new less concentrated areas that often just connect higher concentration areas. As shown in Kenchington et al. (2011), a combined kernel density/minimum binding polygon analysis reveals 7 kg as the numerical threshold that is accompanied by a corresponding rapid increase in area represented by trawls in subsequent thresholds.

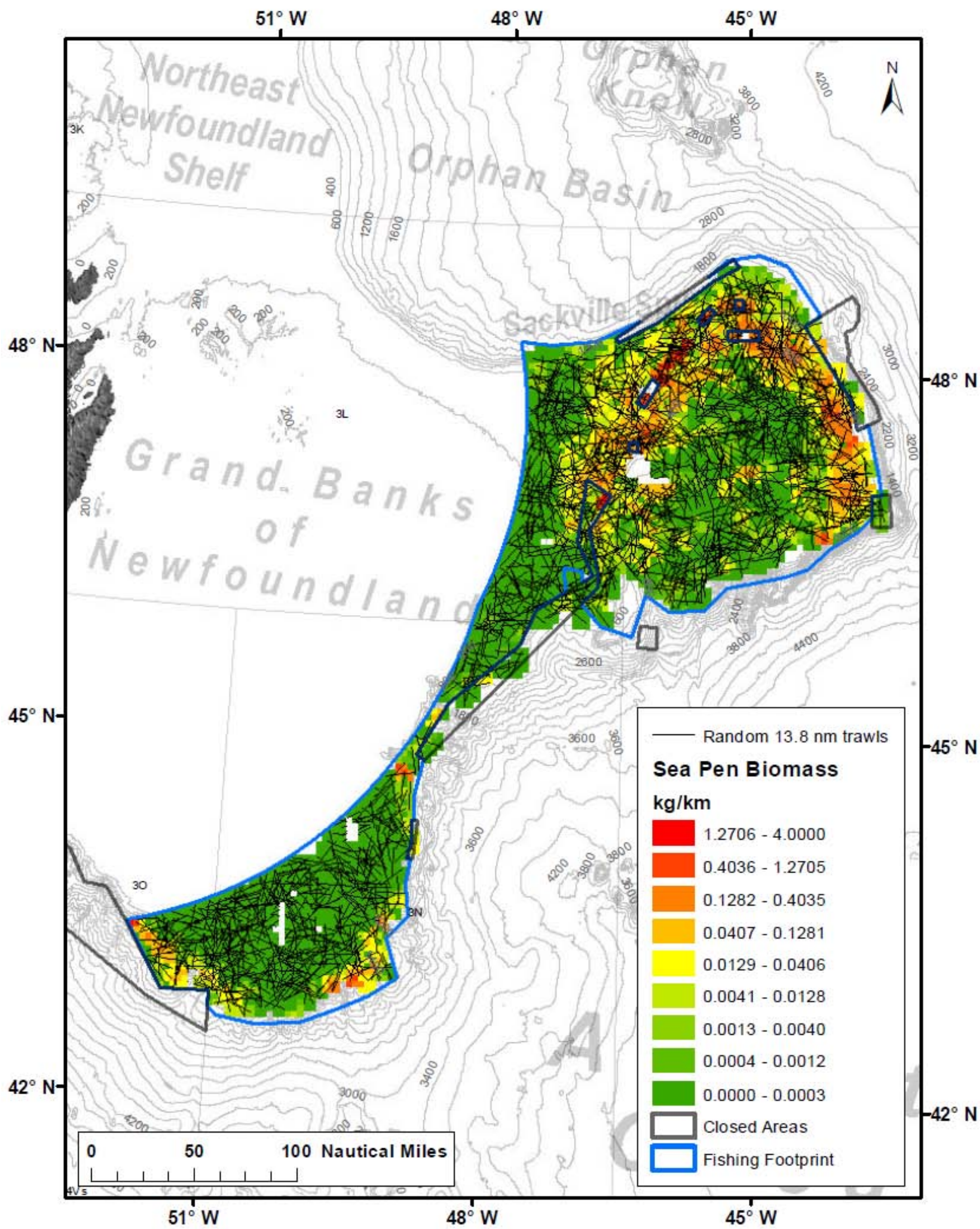

Figure 38. 2000 randomly oriented 13.8 lines over the extent of the 5 x 5 km Spanish/EU sea pen biomass surface.

Table 9. The resulting sea pen by-catch summary statistics from the 2000 random trawl lines for the Spanish/EU 5 x 5 km sea pen biomass surface (Figure 38).

Layer	Trawl Count	Min	Max	Mean	S.D.	Skewness	Kurtosis	1st Quartile	Median	3rd Quartile
Spain/EU	2000	0	43.37	0.96	2.75	6.66	65.11	0	0.06	0.70

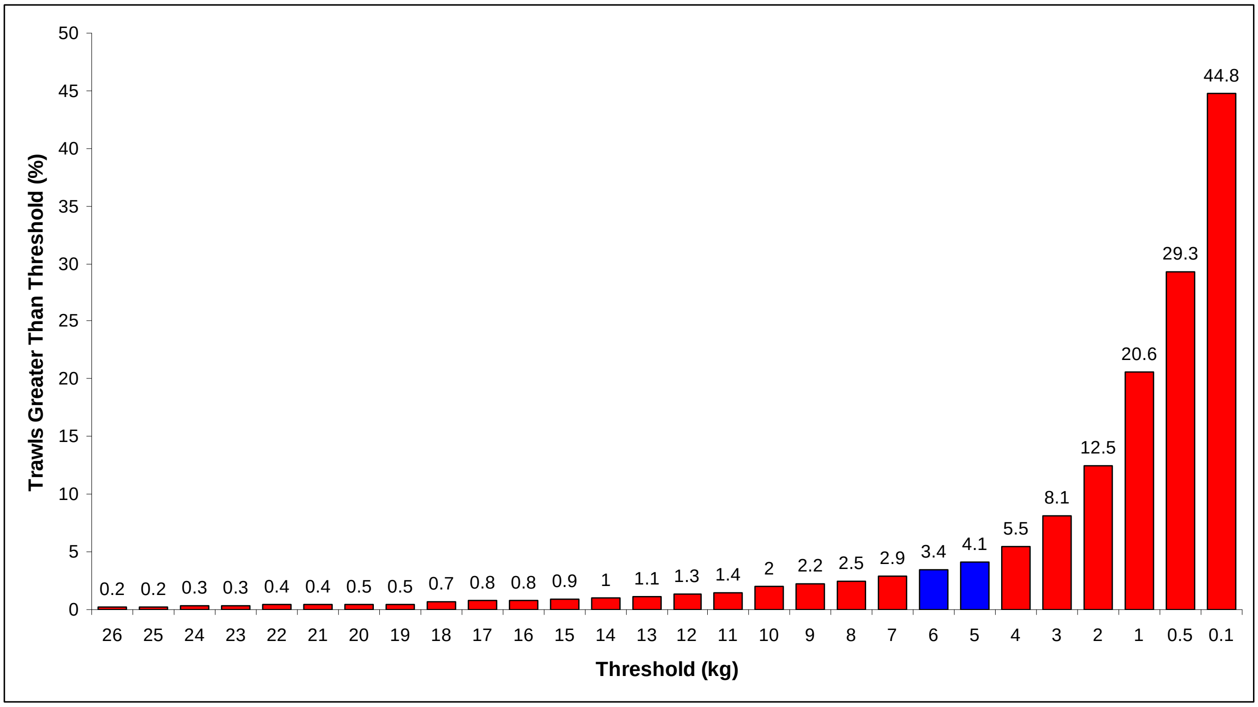

Figure 39. The percentage of by-catch values of randomly placed and oriented lines using the Spanish/EU only biomass surface. The 2 blue columns show where the number of trawls represented by each threshold starts to more rapidly increase.

Table 10. The percentage of by-catch values of randomly placed and oriented simulation trawls using the Spanish/EU only sea pen biomass surface. The shaded rows below show where the number of trawls represented by each threshold starts to rapidly increase.

Threshold	Count Above Threshold	% > Threshold	Difference to Next Threshold
26	3	0.2	0
25	4	0.2	0.1
24	6	0.3	0
23	6	0.3	0.1
22	7	0.4	0
21	7	0.4	0.1
20	10	0.5	0
19	10	0.5	0.2
18	14	0.7	0.1
17	15	0.8	0
16	15	0.8	0.1
15	17	0.9	0.1
14	20	1	0.1
13	22	1.1	0.2
12	25	1.3	0.1
11	28	1.4	0.6
10	40	2	0.2
9	44	2.2	0.3
8	49	2.5	0.4
7	57	2.9	0.5
6	68	3.4	0.7
5	81	4.1	1.4
4	109	5.5	2.6
3	162	8.1	4.4
2	250	12.5	8.1
1	410	20.6	8.7
0.5	586	29.3	15.5
0.1	895	44.8	17.6
0.01	1248	62.4	9
0.001	1427	71.4	28.6
0	2000	100	

Simulated VMS Sea Pen By-catch Versus Simulated Standard Trawl Sea Pen By-catch

The model was initially run using 2000 randomly selected trawls from the 95% confidence interval VMS data (Figure 40A). The model used to extract sea pen by-catch values to the VMS data was a truncated version of the original model as described in Kenchington et al. (2010). For this VMS model run, it was not necessary to generate simulated trawl lines in the direction of the greatest effort, because the VMS trawls are ultimately what the effort raster represents. Instead, station points were placed at 500 m along each VMS polyline and the data from the sea pen by-catch raster was extracted to each point along the line, using the "Extract Values to Points" tool in ArcGIS 10. The by-catch values for all points (in kg of sea pen by-catch per km) were averaged, effectively creating a close approximation of length weighted mean for by-catch. The average kg/km value calculated for the line is then multiplied by the length of the line (in km) to produce the simulated by-catch total for each line.

The model was also run using 2000 13.8 nm simulated trawls that were created by using the "generate random points" tool in the Geospatial Modelling Environment software (Figure 40B). This tool has an option to input a "probability surface", in this case the 2010 groundfish fishing effort raster. This "probability surface" effectively weights the random placement of trawl start locations so the points generated reflect a realistic set of simulated trawl start points. As with Cogswell et al. (2010), the orientation of the lines is governed by the direction which would result in the highest cumulative effort along the line. The details of these steps in the model have been described at length in Kenchington et al. (2010). As with the VMS lines described in the preceding paragraph, station points were placed at 500 m intervals along each simulated trawl line, and the data from the sea pen by-catch raster was extracted to each point along the line, using the "Extract Values to Points" tool in ArcGIS 10. The average kg/km value for the line is then multiplied by the length of the line to produce the simulated by-catch total for each line. These lines were limited to the current NRA fishing footprint and were thus restricted from entering the bounds of closed areas (Figure 40 B).

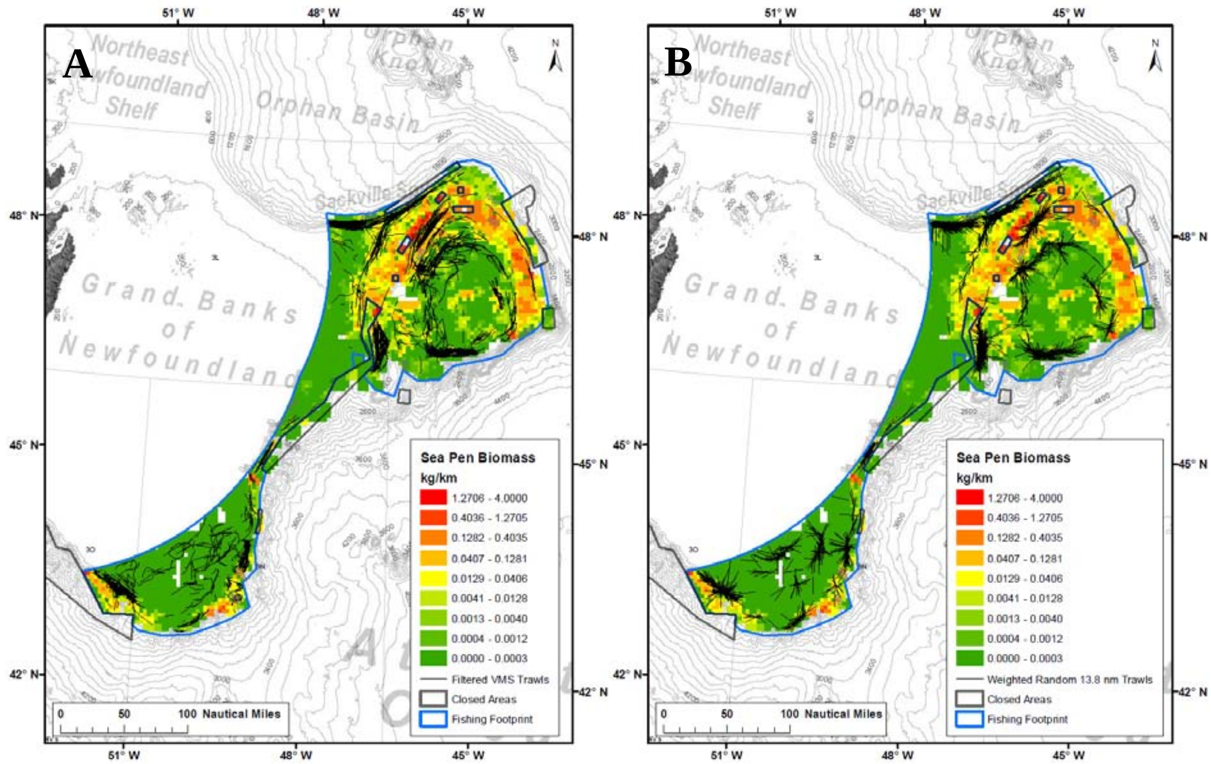

Figure 40. A) Distribution of 2000 randomly selected 95% confidence interval VMS fishing tracks in comparison to, **B)** 2000 weighted random 13.8 nm simulated trawl lines.

A comparison of the simulated by-catch values in relation to various thresholds for both the VMS trawls and the 13.8 nm straight line weighted random trawls is provided in Table 11 and Figure 41. As with sponges, the by-catch profiles of both simulations show a similar pattern but a fewer number of straight line trawls result in by-catch over 7 kg. In fact, many of the high catch VMS trawls were likely realized in the smaller thresholds of the weighted random 13.8 nm straight line trawl data. This is as a result of the very long VMS trawl lengths which can elevate by-catch values above recommended threshold values without necessarily crossing into high sea pen concentration areas. To catch 7 kg of sea pens over a 13.8 nm trawl (25.6 km), the length weighted mean for the line would have to be roughly 0.28 kg/km. Since the model calculates simulated by-catch for each line by multiplying line length by the length weighted mean of sea pen biomass (kg/km) for the line, this mean value can be used to highlight short VMS trawls with biomass less than the 7 kg threshold in areas that may otherwise be ignored. Figure 42 (A) compares VMS trawls with simulated by-catch ≥ 7 kg, to (B) VMS trawls that catch sea pens at a rate ≥ 0.28 kg/km. While the placement of the trawls are in the same locations (1-4), the emphasis (the number of trawls) switches from very long trawls (Location 1 in Figure 42 A) to areas where geographic restrictions on trawling result in shorter trawls (2 and 3) (in 42 B).

Table 11. The number and percent of simulated groundfish trawls catching sea pens at various encounter threshold levels.

Threshold	95% C.I. VMS Fishing Tracks		Weighted Random 13.8 nm Simulation Trawls	
	Count Above Threshold	% > Threshold	Count Above Threshold	% > Threshold
17	1	0	0	0.0
16	2	0.1	0	0.0
15	5	0.3	1	0.1
14	6	0.3	1	0.1
13	6	0.3	1	0.1
12	6	0.3	1	0.1
11	6	0.3	1	0.1
10	6	0.3	1	0.1
9	8	0.4	1	0.1
8	8	0.4	1	0.1
7	8	0.4	1	0.1
6	15	0.8	1	0.1
5	17	0.9	2	0.1
4	26	1.3	4	0.2
3	41	2.1	7	0.4
2	72	3.6	27	1
1	129	6.5	81	4
0.5	247	12.4	238	12
0.1	662	33.1	779	39
0.01	1245	62.3	1413	71
0.001	1560	78	1736	87
0	2000	100	2000	100

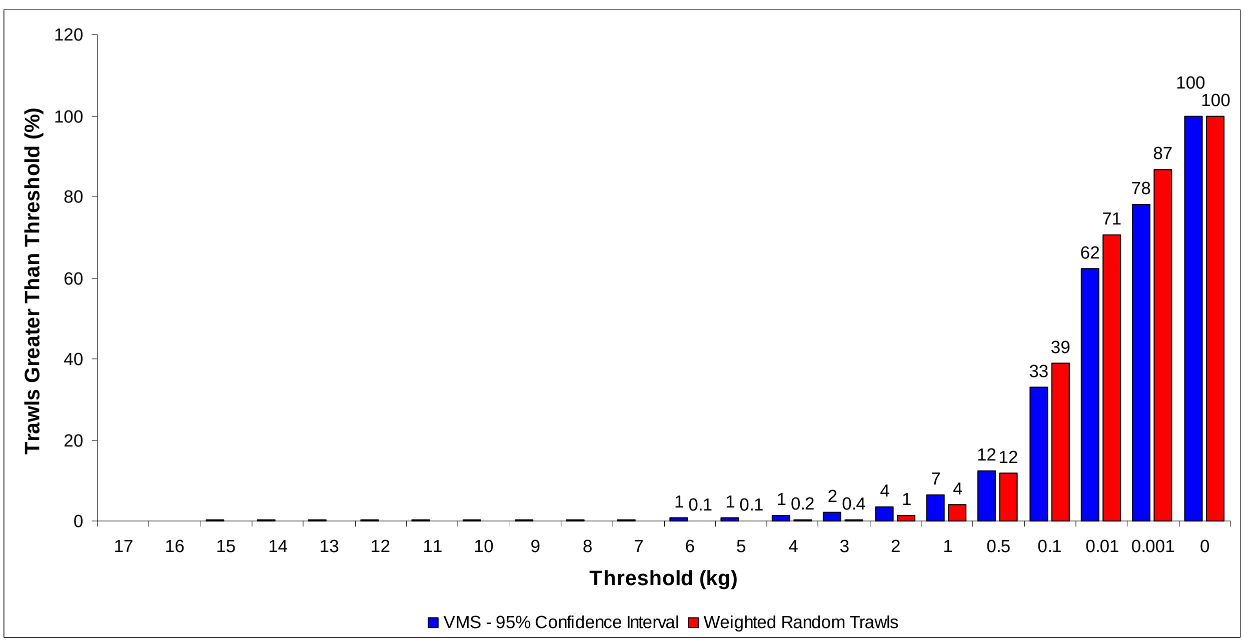

Figure 41. Graphical representation of Table 11 showing the proportion of trawls with simulated sea pen by-catch greater than the thresholds.

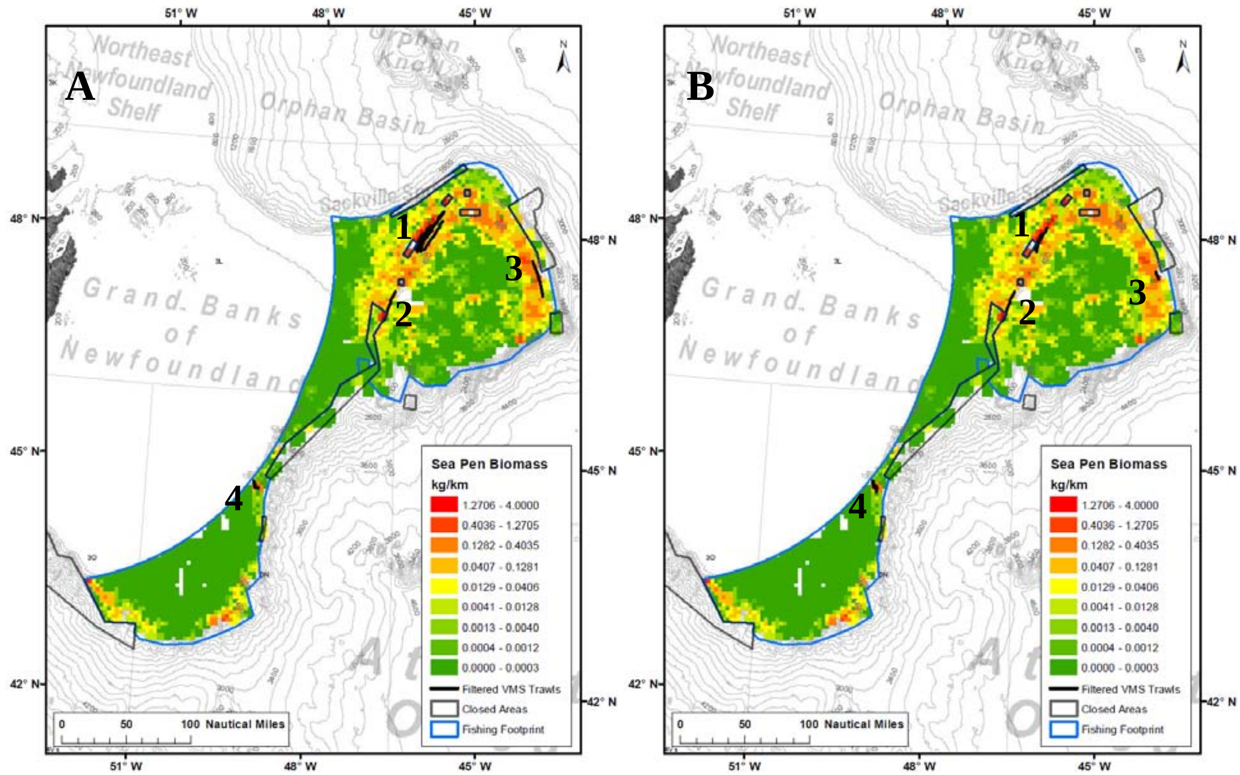

Figure 42. A) VMS trawls with by-catch in excess of 7 kg (n=8) and B) VMS trawls with by-catch rates in excess of 0.28 kg/km (n=7). Of the 7, only 4 showed by-catch in excess of 7 kg. Fewer long trawls were represented at site 1 and more short trawls at sites 3 and 4.

References

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 SCR Doc. 10/71, Serial No. N5869. 26 pp.

Kenchington, E., Cogswell, A., Lirette, C., and Rice, J. 2010. A Geographic Information System (GIS) Simulation Model for Estimating Commercial Sponge By-catch and Evaluating the Impact of Management Decisions. DFO Canadian Science Advisory Secretariat Research Document. 2010/040. vi + 39 pp.

Kenchington, E., Murillo, F.J., Cogswell, A., and Lirette, C. 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. 53 pp.

Murillo, F.J., Duran Muñoz, P., Altuna, A. and 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.

NAFO. 2009a. Delineation of Existing Bottom Fishing Areas in the NAFO Regulatory Area. NAFO SCS Doc. 09/21, Serial No. N5676. 9 pp.

NAFO. 2009b. Report of the NAFO Scientific Council 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. NAFO SCS Doc. 09/6, Serial No. N5627. 26 pp.

NAFO. 2010a. Northwest Atlantic Fisheries Organization Conservation and Enforcement Measures. NAFO/FC Doc. 10/1, Serial No. N5740. 95 pp.

NAFO. 2010b. Report of the 3rd Meeting of the NAFO Scientific Council Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM): NAFO headquarters, Dartmouth, Canada 1-10 December 2010. NAFO SCS Doc. 10/24, Serial No. N5868. 75 pp.

NAFO. 2011a. Report of the Fisheries Commission: 33rd Annual Meeting, 19-23 September 2011, Halifax, Nova Scotia, Canada. NAFO/FC Doc. 11/38, Serial No. N6000. 107 pp.

NAFO. 2011b. Report of the 4th Meeting of the NAFO Scientific council Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM): NAFO headquarters, Dartmouth, Canada November 30 to December 9, 2010. NAFO SCS Doc. 11/22, Serial No. N6006. ## pp.

NAFO. 2012. Northwest Atlantic Fisheries Organization Conservation and Enforcement Measures. NAFO/FC Doc. 12/1, Serial No. N6001. 101 pp.