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Evaluating Sponge Encounter Thresholds through GIS Simulation of the Commercial Groundfish Fishery in the NAFO Regulatory Area

by

A. Cogswell[1], E. Kenchington[1], C. Lirette[1], B. Brodie[2], G. Campanis[3], A. Cuff[2], A. Perez[4], A. Kenny[5],
N. Ollerhead[2], M. Sacau[4], V. Wareham[2]

[1]Department of Fisheries and Oceans (DFO), Dartmouth, Nova Scotia, Canada
[2]Department of Fisheries and Oceans (DFO), St. John's, Newfoundland, Canada
[3]Northwest Atlantic Fisheries Organization (NAFO), Dartmouth, Nova Scotia, Canada
[4]Instituto Español de Oceanografía (IEO), Vigo, Spain
[5]Centre for Environment, Fisheries and Aquaculture Science (Cefas), Lowestoft, U.K.

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Abstract

This report utilizes a geographic information systems (GIS) modelling approach to simulate commercial groundfish trawling sponge by-catch in lieu of actual commercial observations within the confines of current management restrictions to fishing within the Northwest Atlantic Fisheries Organization Regulatory Area (e.g., coral and sponge closed areas). Simulated trawl start locations (1500) were generated by using an aggregated 2008-2009 groundfishing effort raster as a probability surface. This effort surface was also used to set a heading for each of the lines following the direction corresponding to the maximum sum of effort. Combined and standardized sponge by-catch data from the Spanish and Canadian research vessel trawls were used to create a by-catch sponge biomass surface. The model extracted the sponge biomass values to each line to calculate the total by-catch per line (kg). Artificially imposing a range of threshold values on simulated by-catch data showed very few simulated trawls (0.4%) would catch more than the 800 kg encounter threshold of sponge under current management conditions. The percentage of simulated trawls above the imposed range of threshold values does not start to increase quickly until the threshold was between ~30 and 50 kg. At 50kg of simulated by-catch, only 5.5% of simulated tows would be affected and could be easily avoided as the areas impacted are localized. If the current encounter threshold for sponges was reduced from 800 kg to between 30 and 50 kg per tow it is unlikely to have a large effect on the commercial fishery within the fishing footprint and would serve as a more effective sponge conservation measure in un-fished areas under an exploratory fishery.

Introduction

To meet the expectations of the United Nations General Assembly (UNGA) resolution 61/105, the Northwest Atlantic Fisheries Organization (NAFO) has implemented a series of sponge and coral concentration closed areas within its jurisdiction designed to prevent significant adverse impacts on Vulnerable Marine Ecosystems (VMEs) (UN 2007; NAFO 2010a). In addition to the 3O closure there are currently eleven areas closed to protect coral and sponge in the NAFO Regulatory Area (NRA). However, the UNGA resolution also calls upon regional fisheries management organizations to mandate that vessels cease bottom fishing where VMEs exist so that appropriate measures can be adopted in respect of the relevant site (UNGA Res. 61/105 article 83). This becomes particularly important should the slopes of the NRA outside of the fishing footprint (NAFO 2009a) be fished under exploratory fisheries, as it is expected that vulnerable VMEs will be present there. In order to implement this resolution an operational definition of an encounter is required.

NAFO has established conservation measures using encounter protocol provisions. An encounter is defined through the use of by-catch thresholds which were not scientifically based but established as interim measures until more scientifically-based estimates could be provided. The following is taken from the 2010 NAFO Conservation and Enforcement Measures (CEM) Article 5bis - Interim Encounter Provision:

> *"Definition of an Encounter – is an encounter, above threshold levels as set out in paragraph 3, with indicator species of coral identified as antipatharians, gorgonians, cerianthid anemone fields, lophelia, and sea pen fields or other VME elements. Any encounter with a VME indicator species or merely detecting the presence of an element itself is not sufficient to identify a VME. That identification should be made on a case-by-case basis through assessment by relevant bodies.*
>
> *3) For both existing and new fishing areas, an encounter with primary VME indicator species is defined as a catch per set (e.g., trawl tow, longline set, or gillnet set) of more than 60 kg of live coral and/or 800kg of live sponge. These thresholds are set on a provisional basis and may be adjusted as experience is gained in the application of this measure."*

Thus for sponges, an encounter is defined as any by-catch of live sponge greater than 800 kg. There are a number of problems with the NAFO encounter thresholds, including: the lack of a defined tow duration; varying gear types are treated equally; and, there is no use of species information even though a number of VME taxa are recognized in the official definition (NAFO 2010a).

The difficulty with this definition lies in establishing a quantity greater than a "presence" and sufficient enough to identify a VME. If commercial sponge by-catch data were available, it might be possible to examine the catch distribution in the same manner that was used to identify significant concentrations of sponge from research vessel by-catch using spatial analysis (NAFO 2009b). However, such data are not available, necessitating a modeling approach (Kenchington *et al.* 2010).

There are a number of assumptions and limitations to the model we have presented. First, the standard trawl lengths from which the by-catch is estimated are all straight lines. Use of start and end positions combined with tow duration and vessel course might allow for a more accurate determination of trawl length, but this was not possible with the data currently available. Second, there is an issue of retention efficiency of sponge by-catch. Ideally, biomass estimates used to create the sponge biomass raster would be gathered through visual and other ground truthing methods. By-catch from research vessel surveys underestimates actual sponge biomass because of: benthic obstructions (e.g., rocks, etc…) that can "shelter" sponge as the trawl travels over the rough bottom and more importantly through fragmentation when sponge impacts the fishing gear and is torn or shredded. Kenchington et al. (2010) describe null sets for coral in research vessel trawls in the Eastern Arctic that actually did catch coral but did not retain it. This was determined by the placement of linney bags outside the gear to catch material passing through the meshes. The sponges are also susceptible to breakage and passing through the meshes. However, retention will increase as the net fills. These factors will influence real commercial bycatch data. In our modelled bycatch estimates we assume 100% retention of sponge over the trawl line (this is 100% retention of sponge biomass calculated from a layer that is less than the actual sponge on the bottom as described above). Therefore the real commercial bycatch is expected to be less than that produced from our model.

This model does not evaluate the biological significance of the removals, nor does it make an assessment of significant adverse impact to the ecosystem, which would require more information on species composition. Given that the major sponge grounds in the fished areas have already been identified and protected (NAFO 2009c), areas with larger sponge biomass are unlikely to be from intact sponge grounds but may be fragments of former sponge grounds damaged by fishing, or aggregations of smaller sponge species.

The model provides a framework for evaluating where large catches could still be obtained outside of the closed areas and what proportion of the catches would be affected by altering by-catch thresholds. In a precautionary framework it is logical to reduce the threshold values towards smaller values, especially if only a small area and/or proportion of the catches would be affected.

GIS Simulation Model Methods

The model as described by Kenchington et al. (2010) has been updated and improved in this application. In essence the model uses a map of sponge biomass produced from research vessel survey bycatch from the Canadian and EU surveys and superimposes on it simulated commercial trawl lines. The commercial sponge bycatch is then calculated by estimating the sponge biomass under the simulated line.

Description of the Model Input Data Layers

Closed Areas

The closed areas that lie near, intersect, or are completely within the boundaries of the NRA fishing footprint as described by the NAFO SCS Doc. 09/21, were utilized to restrict the placement and orientation of simulated trawls developed by the model (Figure 1). The boundaries for the areas are listed in the NAFO CEM 2010- Article 16 - Coral and Sponge Protection Zones.

Incorporating coral and sponge closed areas into the model shifts simulated trawling effort to un-restricted fishing areas. The Division 3O closed area was closed effective January 1, 2008 while the remaining areas were closed effective January 1, 2010 (NAFO 2010a).

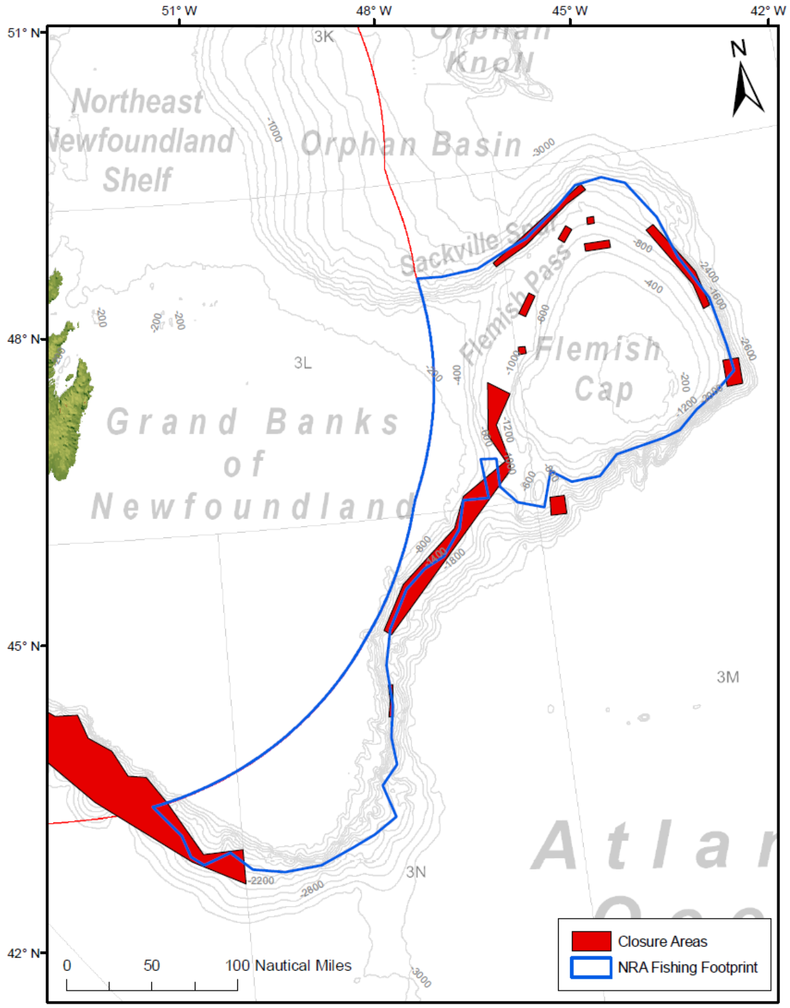

Figure 1. Coral and sponge closed areas within the model exercise area.

Fishing Effort Raster

The model requires a surface layer (raster) input describing fishing effort to direct the placement and orientation of simulated trawl lines to accurately predict fishing behaviour. A single surface representing the cumulative groundfish fishery effort from 2008 and 2009 was created for input as the effort raster in the model. As the Div. 3O closed area was effective January 1st, 2008 this representation of effort reflects the real-world constraints imposed by the Div. 3O closure during this time span.

Vessel Monitoring System (VMS) positional (POS reports) data were used to create the 2008 and 2009 composite groundfish fishing effort raster. 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 2010).

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.

The data was 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). 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.

The total fishing hours were summed to 5x5 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 over the 2 year aggregated dataset (Figure 2).

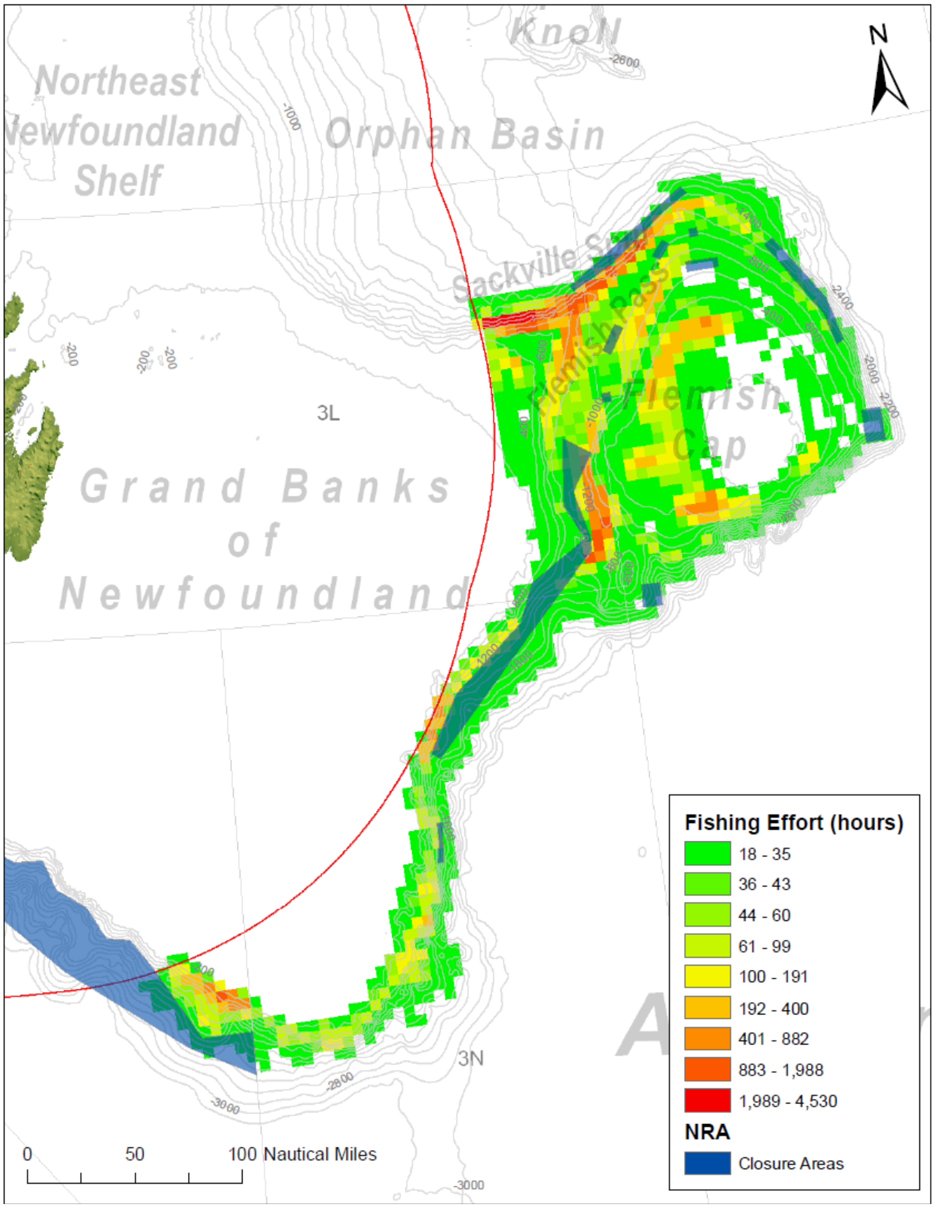

Figure 2. 2008 and 2009 aggregated groundfish fishing effort in the NAFO regulatory area.

Sponge By-catch Raster

The sponge by-catch data used to create the by-catch surface input for the model were derived from Canadian and Spanish depth-stratified random multispecies surveys using mainly a Campelen 1800 shrimp trawl with rockhopper foot gear (Walsh and McCallum 1997; Murillo *et al.* 2010). While both surveys used the same gear, standard tow lengths differed between countries. Spanish research vessels towed for 30 minutes at ~3 knots for an average standard tow length of 2.8 km (Murillo *et al.* 2010), 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 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 1221; Spain 1227) of the total 2448 sponge by-catch records that made up the dataset. Canadian sponge catch data spans from 1995-2008, while the Spanish records were filtered for data collected after 2004 (2005-2008). Prior to 2005 null sets were not recorded by the Spanish survey and could thus influence subsequent surface creation (Figure 3).

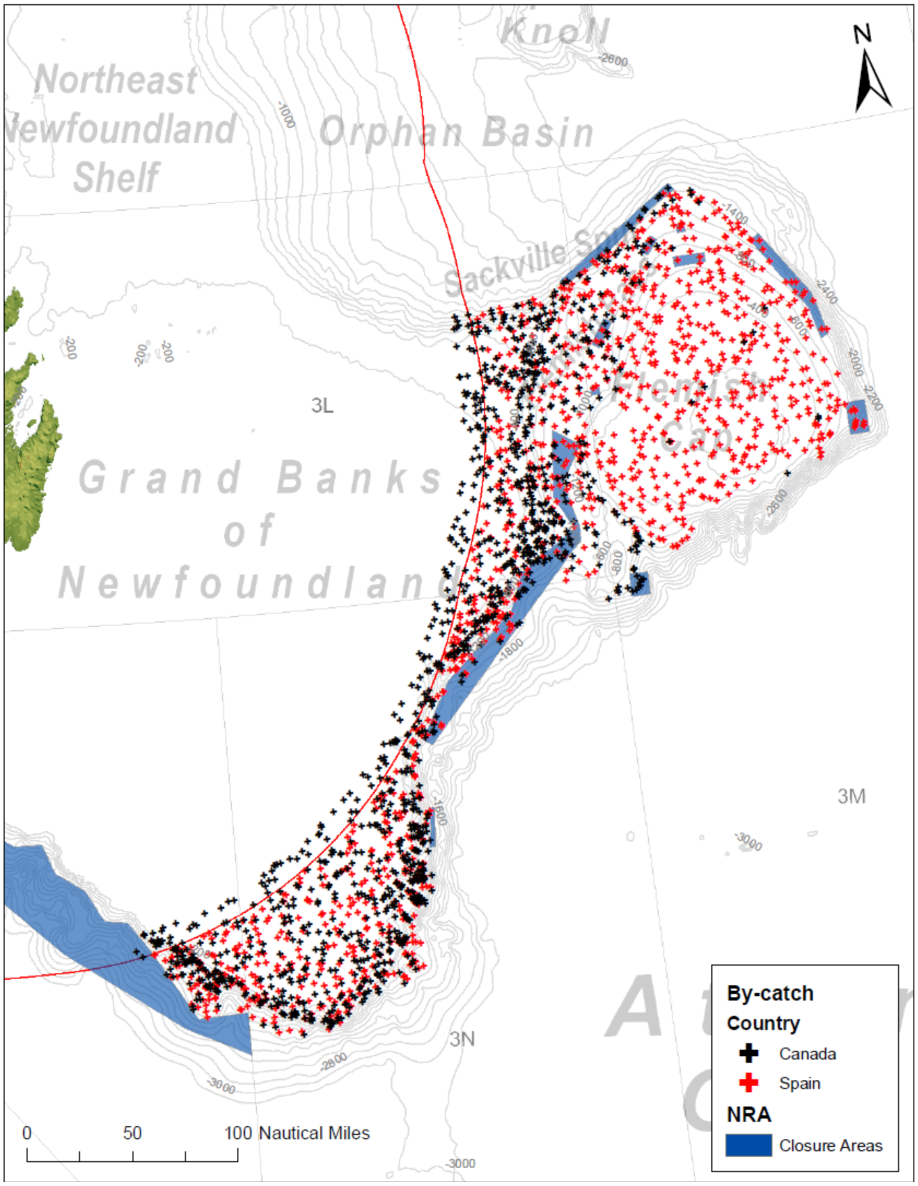

Figure 3. Location of research vessel trawls with sponge by-catch by country. This point data is the foundation for the sponge by-catch raster surface input for the model.

The aggregated sponge by-catch records were discrete data and highly right-skewed due to 0 kg by-catch records dominating the dataset (~57%). Continuous and normally distributed datasets are assumed pre-conditions for parametric interpolation methods (e.g. kriging) and can influence the values of predictive surfaces (Babish 2006). While exact deterministic methods (e.g. Inverse distance weighted) do not necessarily require normally-distributed datasets, the severely skewed sponge by-catch dataset dramatically underestimated areas of high by-catch. The dominance of 0 hindered any means of transformation to normalize the distribution. Attempts to bin the data into larger cells prior to interpolation (up to 30 km) could not remove the skewness from the distribution. For this reason, interpolation methods were abandoned in favour of creating a raster surface with cells representing the mean of by-catch within a standard cell size.

Using the "Calculate Distance Band from Neighbour Count" tool in ArcGIS (ESRI 2008), a raster cell size was determined from the average distance between one point and its nine closest neighbouring points based on Euclidean distances. Using the result of this analysis, the cell size of the raster was set at 12.5 x 12.5 km. The "Point to

Raster" tool was then used to produce a surface of 12.5 km cells with cell values representing the mean catch rate per cell (kg/km) (Figure 4).

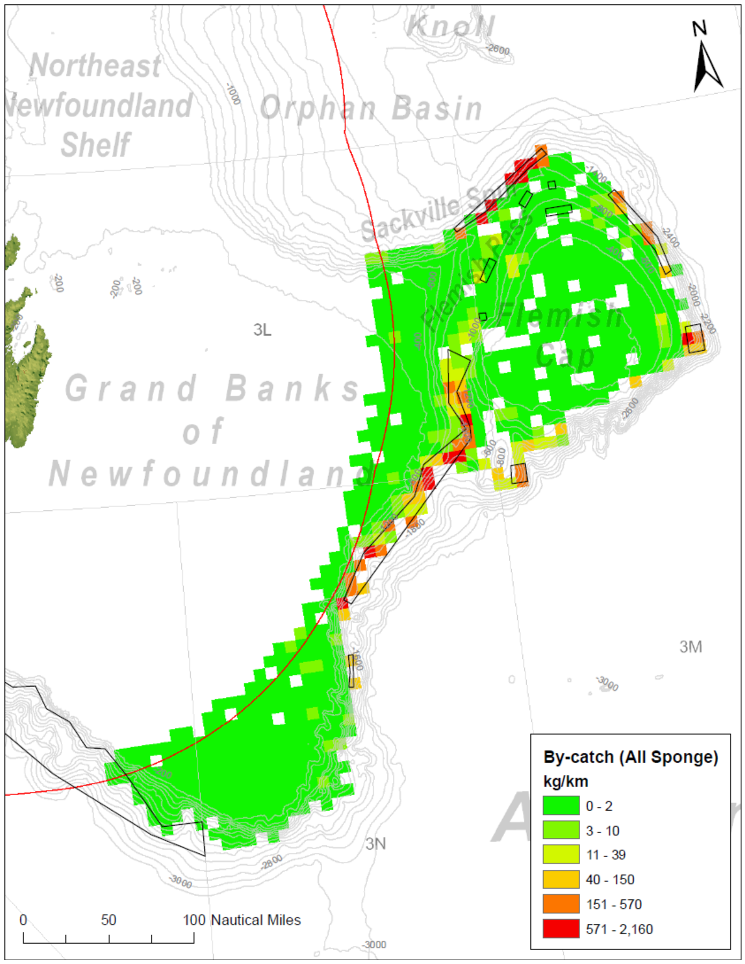

Figure 4. Sponge by-catch raster (12.5 x 12.5 km cell size). Note null cells present in center of surface.

Null values were 'filled-in' using the "Focal Statistics" tool, which calculates values for missing cells based on a user defined neighbourhood (ESRI 2008). A new raster was created using this tool by calculating the mean value for each cell using a rectangular 3x3 neighbourhood (ESRI 2008). The null value cells that are now 'filled-in' were extracted using the "Extract to Mask" tool (ESRI 2008), which used the inverse of the null cells from the original by-catch raster as the mask. The result is a raster with focal statistics values in the location of null cells from the by-catch raster (Figure 5). Using the "Raster Calculator", the sponge by-catch layer was then merged with the focal statistics raster, to 'fill in' the null values (ESRI 2008). The result is a continuous surface that was used by the model to evaluate sponge by-catch from simulated trawl lines (Figure 6).

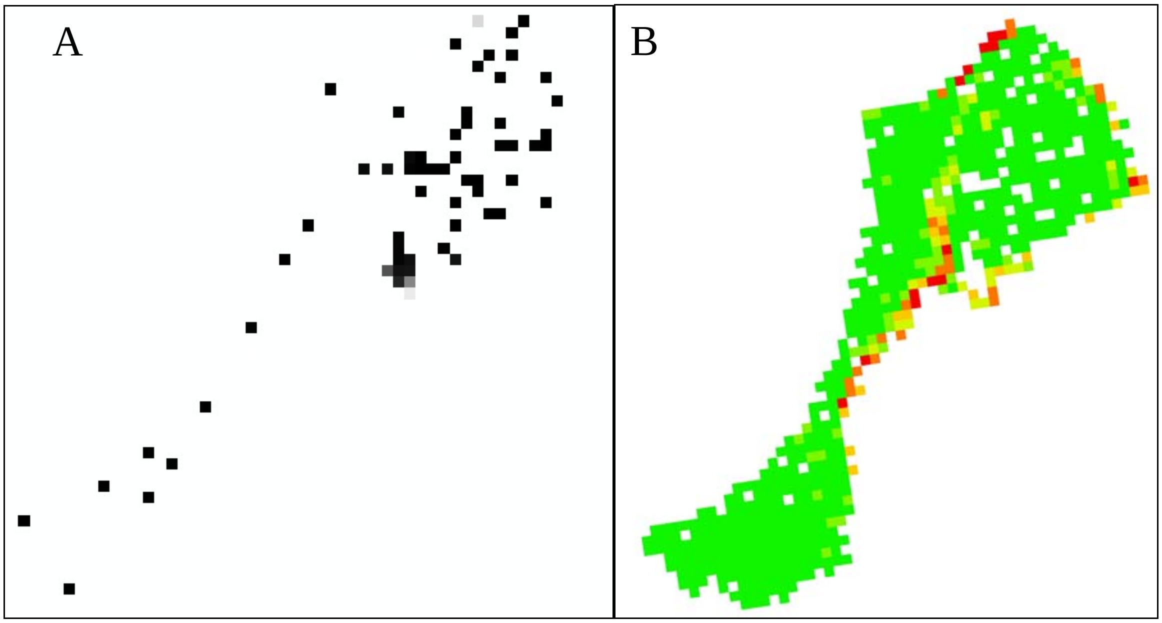

Figure 5. A. focal statistics layer clipped to only show missing null values from sponge by-catch (**B)**.

By-catch profiles from simulated trawl lines generated during preliminary model runs utilizing the continuous by-catch surface, and a more thorough examination of the by-catch raster itself, revealed areas that consistently over-estimated by-catch (see also Kenchington *et al.* 2010). This is illustrated by the creation of an "error" raster that contains the standard deviation of by-catch within raster cells with more than 2 samples or trawls contributing to the mean (Figure 7). Large error values were particularly evident on the border of the Sackville Spur and Flemish Pass closed areas. These areas are heavily fished (Figure 2), thus any error in these areas could artificially inflate by-catch values where relatively low sponge by-catches are known to occur. The Canadian and Spanish sponge by-catch records from Sackville Spur substantiated this result (Figure 8) as did benthic imagery analysis data from Sackville Spur which shows a rather sharp increase in the abundance of sponge upon entering the closed area (NAFO 2010b).

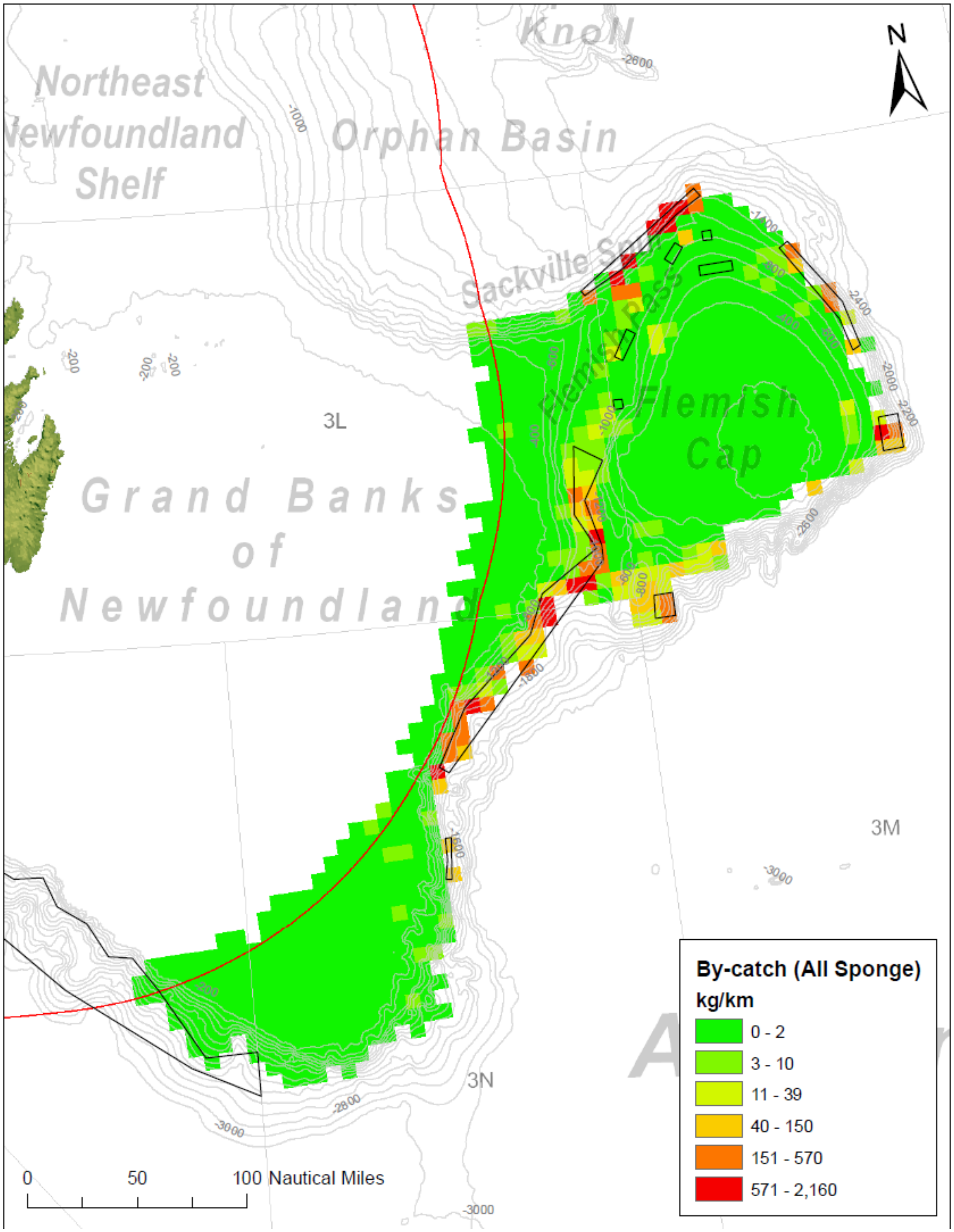

Figure 6. The combined sponge by-catch and focal statistics raster.

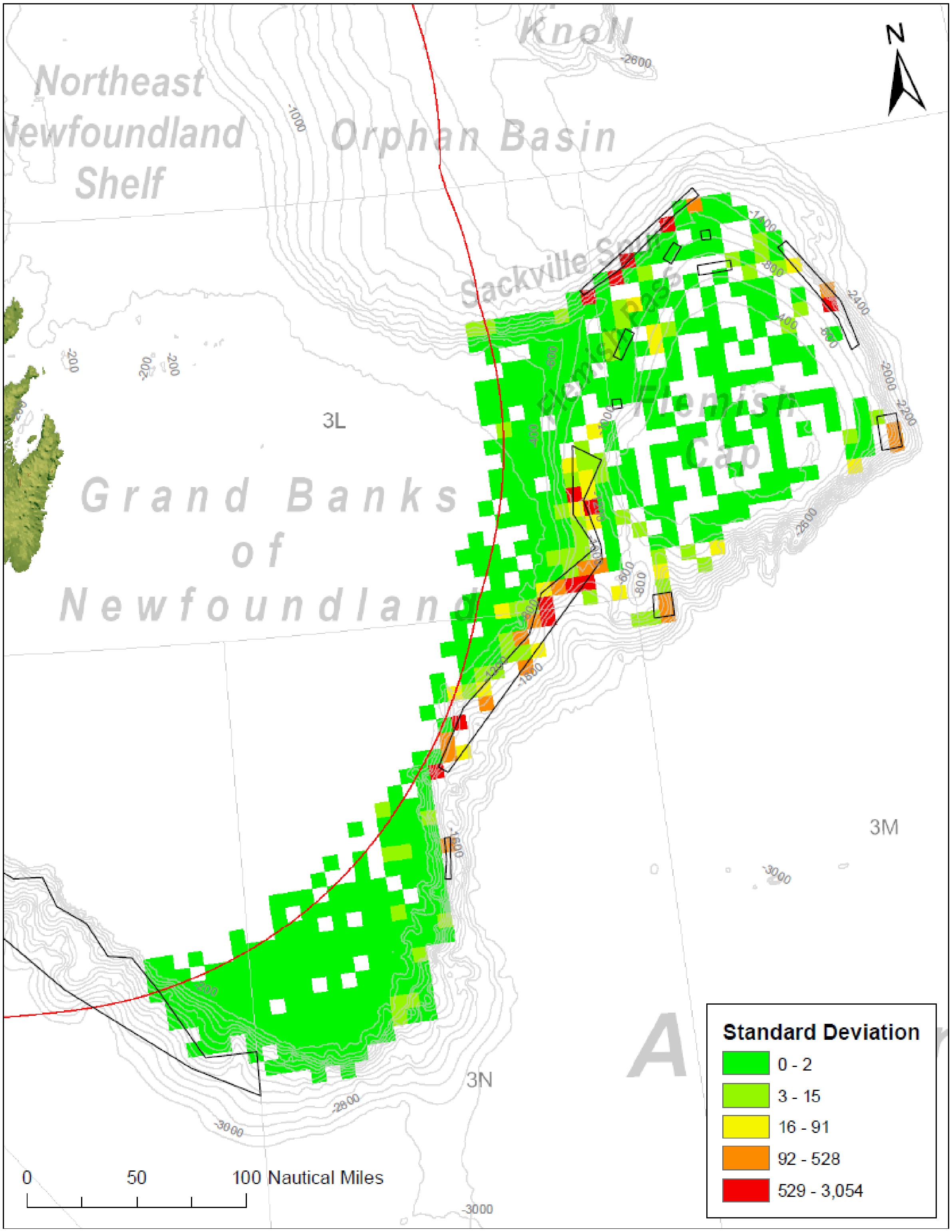

Figure 7. Standard deviation of sponge by-catch (kg/km) used to create the raster cell values. Standard deviation could only be calculated for cells containing 3 or more values. Note areas of high over-estimation bordering on the Sackville Spur closed area and Flemish Pass closed area. These border areas also coincide with high fishing effort (Figure 2).

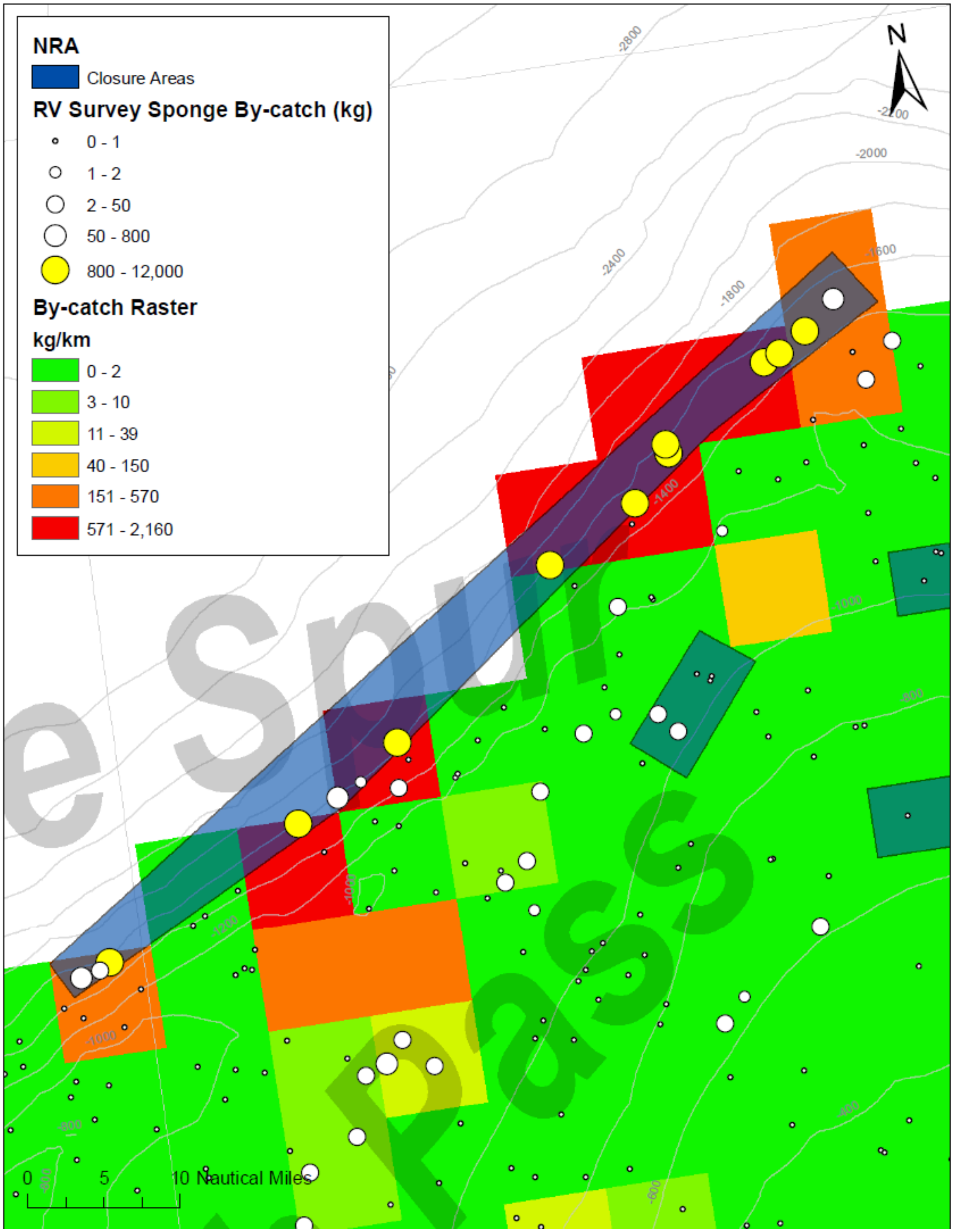

Figure 8. Graduated symbols displaying the position and relative sponge by-catch inside and outside of the Sackville Spur closed area. Yellow labels indicate a by-catch value from the Canadian and Spanish surveys equal to or greater than the current threshold limit of 800 kg per tow. Over-estimation is particularly evident in cells bordering on the closed area.

To reflect the highly zonal nature of sponge distribution bordering closed areas, a second by-catch raster excluding by-catch data within closed areas was created using the methods described above (Figure 9). This removed the influence of large sponge by-catch values from inside the closed areas on the mean by-catch values represented by the 12.5x12.5 km grid squares of the by-catch raster. This revised sponge by-catch raster was the surface utilized by the model to derive total simulated catch where trawls were restricted from entering closed areas. Figure 10 illustrates the decrease in overestimation based on this revised sponge by-catch raster.

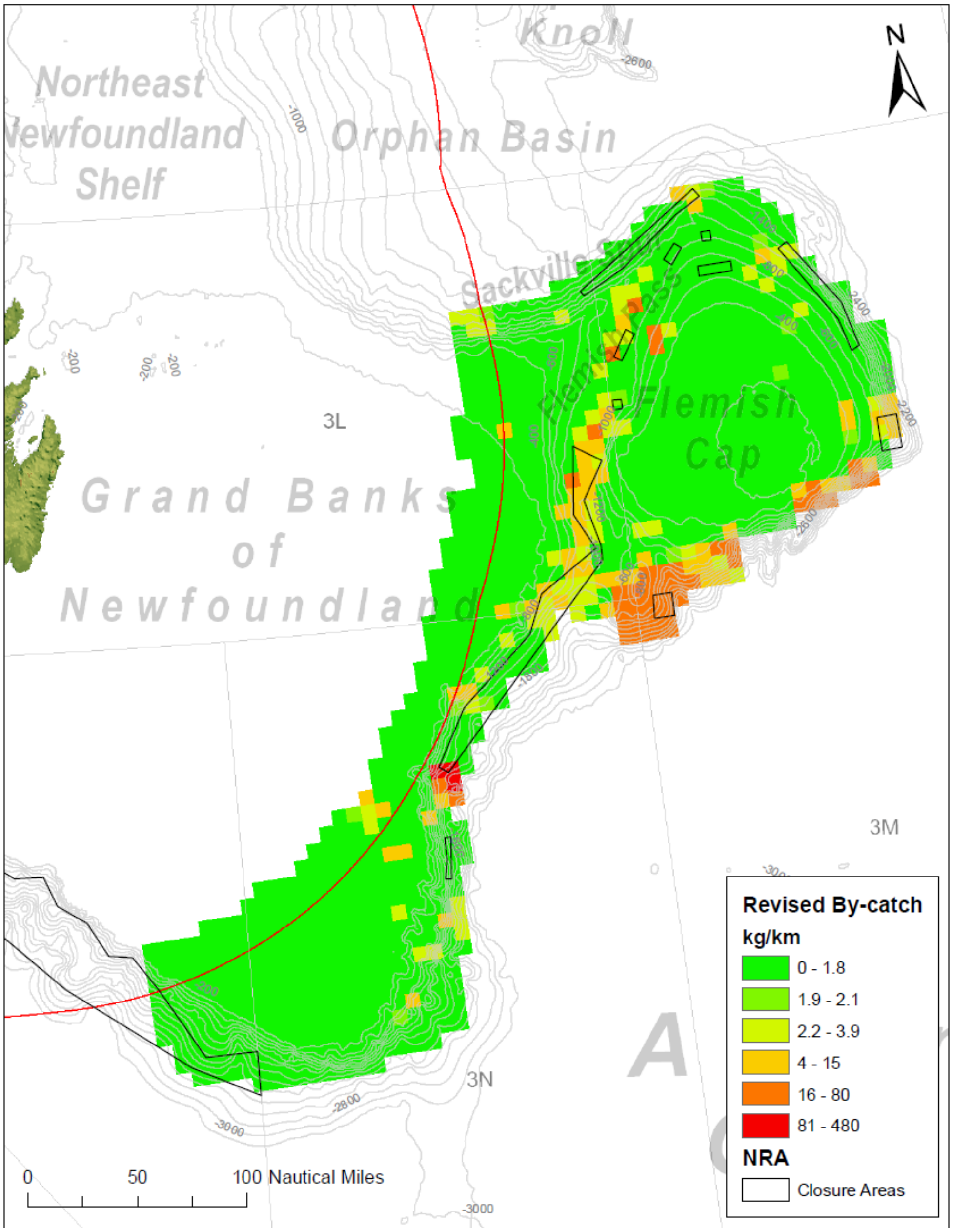

Figure 9. The revised by-catch raster excluding by-catch data within the closed areas. This raster has a maximum value of ~480 kg/km as opposed to the ~2160 kg/km seen in the surface created using all the by-catch data. Cells in closure areas are mean values created with only points lying outside of the closure or from the "Focal Statistics" calculation.

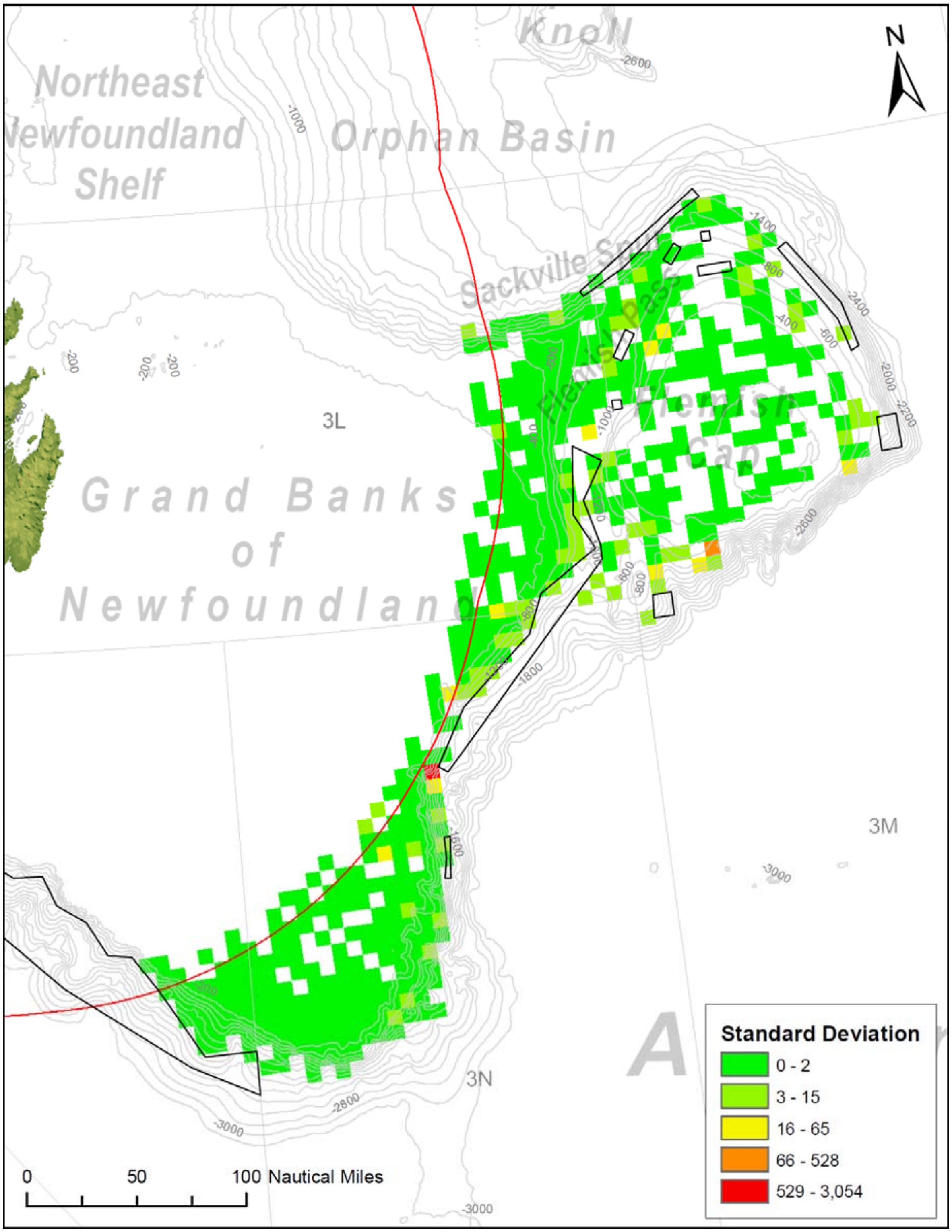

Figure 10. The revised standard deviation raster of sponge by-catch (kg/km). Note reduction of error in cells bordering closed areas when by-catch data within their borders were removed (compare with Figure 7).

Weighted Random Trawl Start Locations

The start locations for simulated trawls must be created and included as a data input along with the by-catch and effort surfaces prior to running the model. A "Generate Random Points" tool is available in the "Hawth's Tools" ArcGIS extension (www.spatialecology.com/htools.php). This tool used the 2008 and 2009 composite groundfishing effort surface as a probability raster to generate 1500 trawl start locations. It also restricted the points generated from entering specified polygons, in this case the NRA coral and sponge closed areas (Figure 11).

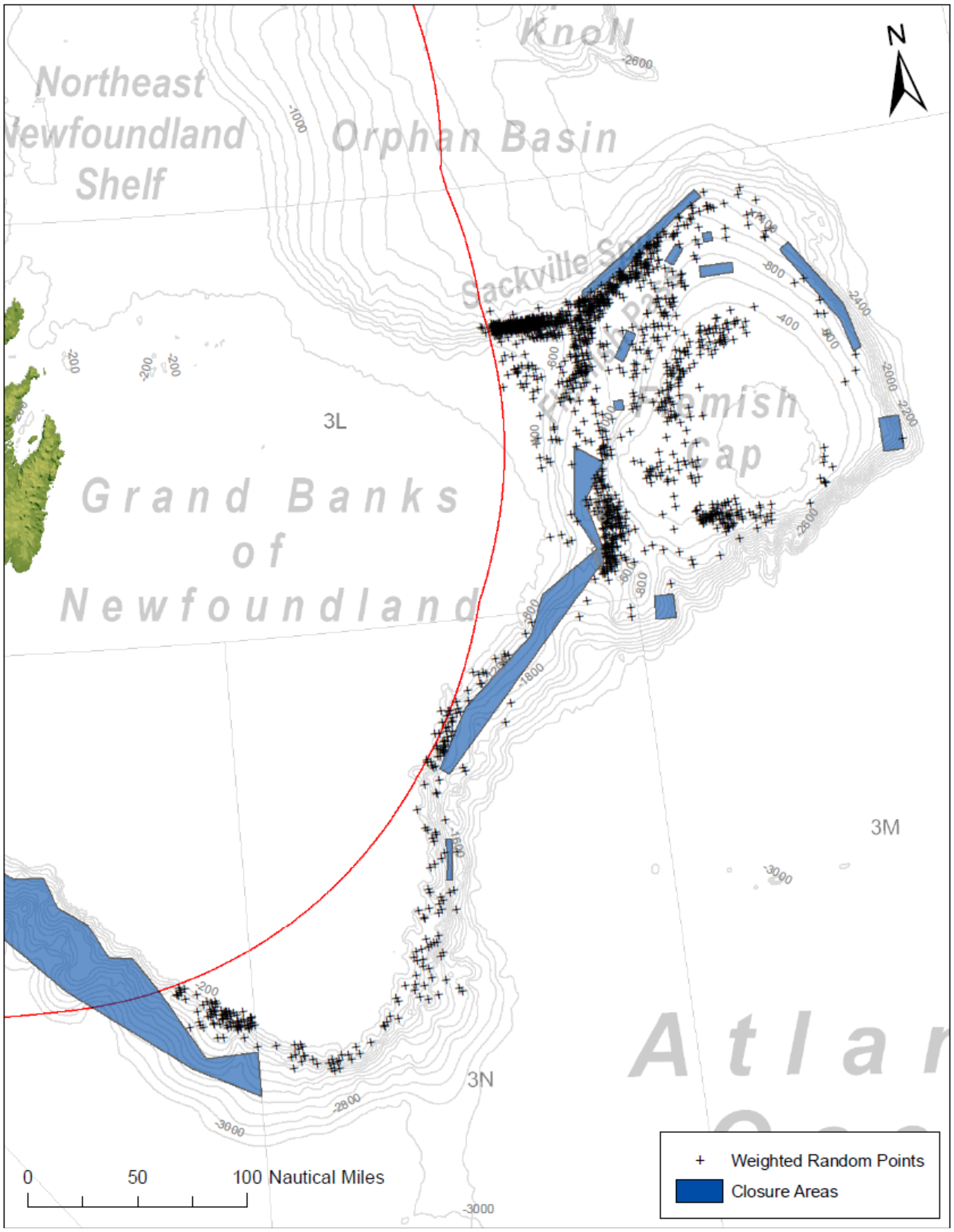

Figure 11. Trawl start locations produced by the "Generate Random Points" tool from the Hawth's Tools suite.

Model Description

The model was designed in ArcGIS "Model Builder" to simulate trawl by-catch based on the input of weighted random start locations, fishing effort raster and a by-catch raster. In short, using the data inputs provided, the model oriented the trawl lines from the weighted random start points in the direction of the greatest sum of fishing effort over that line.

The standard trawl lengths utilized by the model were derived from an at-sea trawling observation/inspection database of 1052 anonymous groundfish trawls from the NAFO Regulatory Area. 1500 simulated trawl lines were created for 2 separate line lengths, 1 representing the median trawl length (15 nm or 27.78 km) and the other representing the extreme 97.5 percentile (36 nm or 66.68 km). The median tow length data calculated from these data is comparable to the median tow length of 1164 trawls recorded by observers (23.7 km) from data provided by the NAFO Secretariat for a single NAFO member country for which digital data was readily available.

The model then calculated mean by-catch (kg/km) as extracted from the by-catch raster for each line and multiplied this value by the length of the line (km) to arrive at the total catch for the simulated tow (kg). Please refer to Kenchington et al. (2010) for an in-depth description of the model's various components.

Encounter Thresholds

Simulated trawl line model by-catch output data were selected for various threshold values at 100 kg intervals from 800 to 100 kg, 10 kg intervals from 100 to 10 kg, as well as 5, 1 and 0.1 kg. The lower threshold values (5, 1, and 0.1 kg) were used to illustrate the large increase in trawls with low levels of by-catch. Lines equal to or greater than each threshold limit were mapped and the number and percent of lines greater than that threshold value noted.

Results and Discussion

The running average of the simulated sponge by-catch for 1500 simulated trawls at 15 nm and 1500 simulated trawls at 36 nm excluded from coral and sponge closed areas, began to stabilize after approximately 800 simulated lines were generated (Figure 12). It was concluded that 1500 trawls are sufficient to draw conclusions on sponge by-catch from the models. The locations of these simulated trawl lines are illustrated in Figure 13.

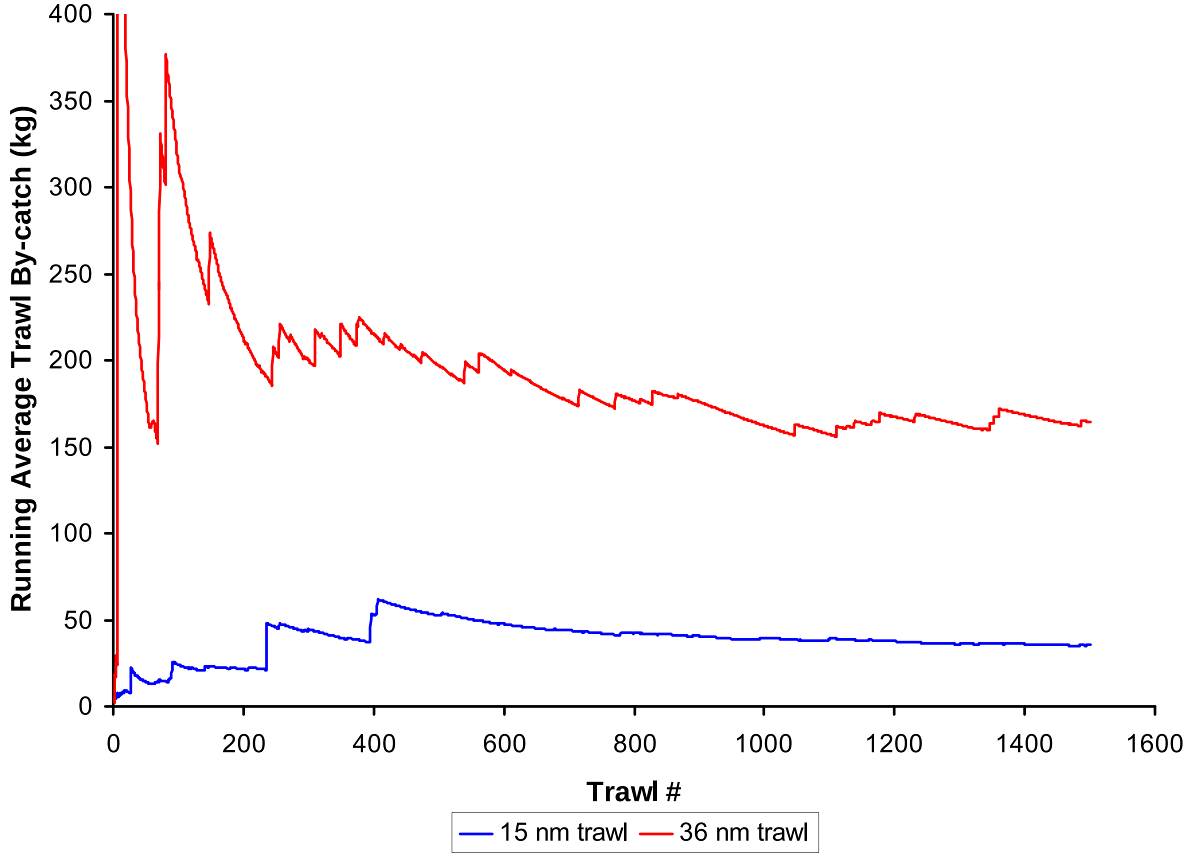

Figure 12. The running average of sponge by-catch from 1500 simulated trawls of 15 nm and 1500 simulated trawls of 36 nm. Simulated trawls were excluded from all coral and sponge closed areas on Flemish Cap and the southeast Grand Banks, including the 3O closed area. Trawl sponge by-catch was generated using the modified sponge biomass raster (excluding research vessel survey by-catch from within the closed areas).

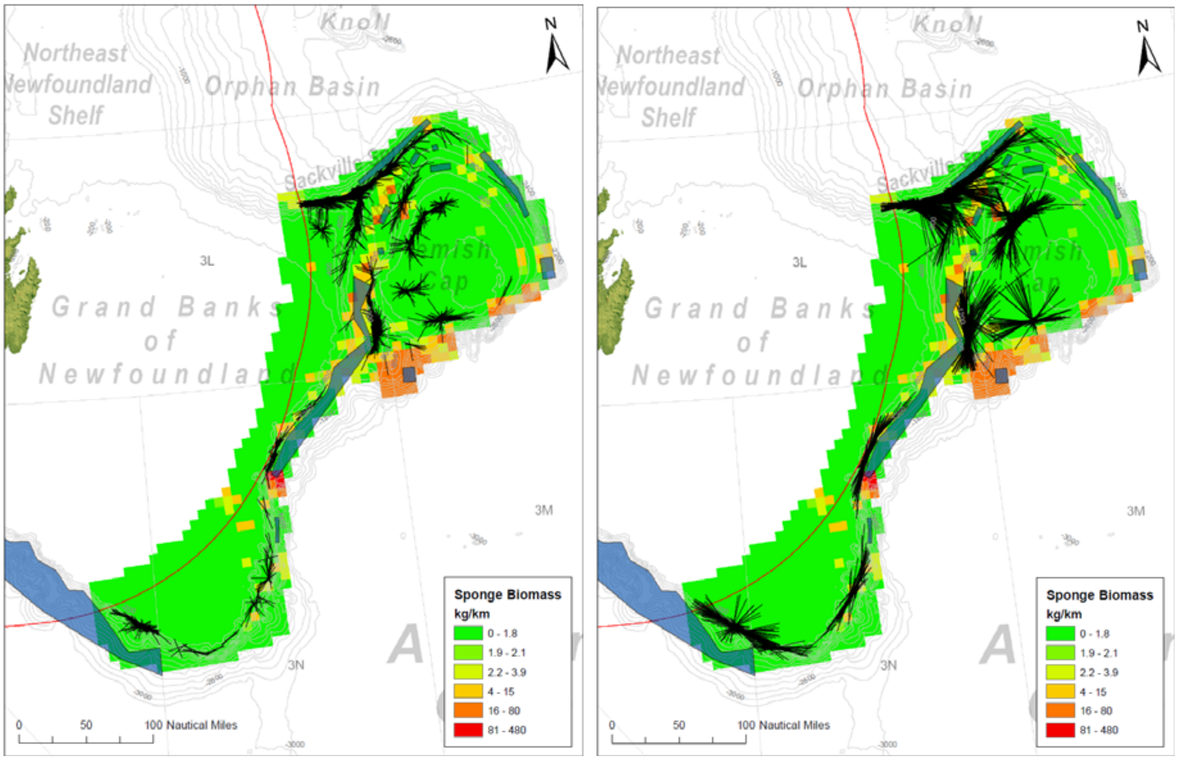

Figure 13. Location of 1500 simulated trawls of 15 nm (left) and 1500 simulated trawls of 36 nm (right) (black lines) excluded from all coral and sponge closed areas on the Flemish Cap and the southeast Grand Banks, including the 3O closed area. Closed areas are indicated by the blue shading. The simulated trawl lines are shown over sponge biomass, where green indicates small sponge biomass (0-1.8 kg/km) and red indicates higher sponge biomass (81-480 kg/km).

Evaluation of Potential Encounter Protocol Thresholds for Sponges in the NRA

As described above, the GIS model was used to simulate sponge by-catch from a modeled groundfish fishery with the coral and sponge closed areas in place, reflecting the current restriction on the fishery. Those outputs were used to evaluate the effect of various encounter threshold options on the fishery. Results generated describing encounter thresholds are more aptly described using the median trawl length of 15 nm but subsequent analysis were applied to both trawl lengths so the effect of the extreme trawling scenario could be evaluated.

For both scenarios, the simulated commercial sponge cumulative by-catch distribution was comparable to the research vessel sponge by-catch distribution (NAFO 2009a), with large numbers of small catches and a few very large catches. For the 15 nm (27.8 km) simulated trawls, 27% of the sponge catches were less than 1 kg while 64% were less than 10 kg (Table 1).

The current encounter threshold for sponges is 800 kg and our model suggested that very few groundfish trawls of median length (15 nm) would ever encounter this level under the current fishing effort patterns (0.4%) (Table 1 & Figure 14). For 15 nm trawls all six of the simulated catches > 800 kg came from one location (Figure 15), along the slope of the Grand Banks, near the Canadian EEZ. Reducing the encounter threshold for sponges to 50 kg would only affect 5.5% of the simulated trawls (94.5% of fishing would be unaffected) and those encounters could be avoided as catches > 50 kg are concentrated in just two areas in Flemish Pass outside of the closed areas (Figure 15 – right panel circled in red). The scenario posed by the 36 nm simulated trawls produced a comparable result but with substantially higher percentages of by-catch above 800 kg per tow (Table 1). It is interesting to note however that the percentage of trawls greater than the threshold does not begin to sharply increase until almost 100 kg under the extreme trawling scenario (Table 1). This suggests, that despite trawl length, the areas contributing to high by-catch values between 50 to 100 kg are quite localized and could be easily avoided, having little impact on the fishery.

Table 1. The number and percent of simulated groundfish trawls catching sponge at various encounter threshold levels. Shaded values indicate the range recommended by WGEAFM.

Threshold (kg)	15 nm Trawls > Threshold	15 nm % > Threshold	36 nm Trawls > Threshold	36 nm % > Threshold
800	6	0.4	36	2.4
700	7	0.5	36	2.4
600	10	0.7	37	2.5
500	15	1.0	39	2.6
400	26	1.7	41	2.7
300	37	2.5	64	4.3
200	44	2.9	88	5.9
100	58	3.9	202	13.5
90	62	4.1	222	14.8
80	67	4.5	258	17.2
70	73	4.9	307	20.5
60	77	5.1	342	22.8
50	82	5.5	525	35.0
40	113	7.5	846	56.4
30	169	11.3	846	56.4
20	284	18.9	981	65.4
10	546	36.4	1100	73.3
5	911	60.7	1181	78.7
1	1092	72.8	1319	87.9
0.1	1301	86.7	1446	96.4

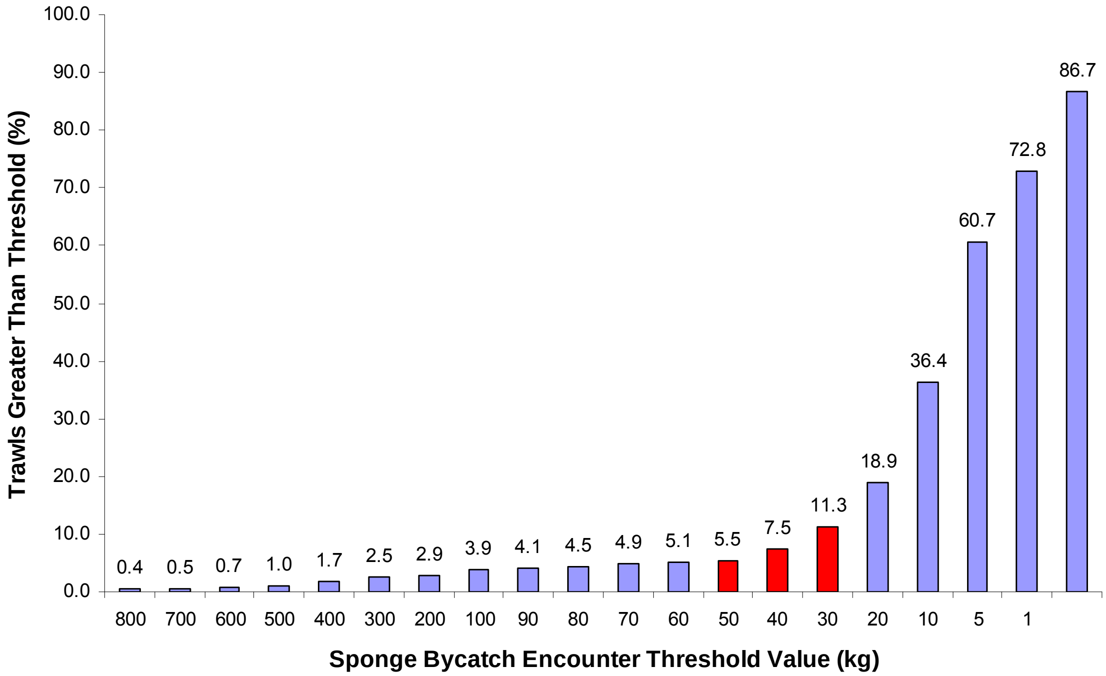

Figure 14. Graphical representation of Table 1 showing the proportion of simulated trawls with sponge catches greater than the sponge by-catch encounter threshold. Red bars indicate the area where the proportion of the trawls begins to increase rapidly, with decreasing threshold.

When considering lower encounter threshold values below 50 kg, it is important to look at the areas potentially affected. Figure 16 shows the location of 15 nm simulated groundfish trawls catching greater than 50, 40, 30, 20, 10, and 5 kg of sponge in the NRA. Reducing the level to 40 kg would begin influencing fishing near Sackville Spur, while reducing to 30 kg would affect the slope waters southwest of Flemish Cap and Beothuk Knoll.

We compared the locations of the simulated catches greater than 50 kg with the areas identified as having significant concentrations of sponge in the spatial analyses of the research vessel (RV) by-catch used to delineate the closed areas (Figure 17). Of the three areas with the greatest aggregations of simulated lines, two were also areas where significant concentrations of sponge were taken in the RV surveys. Those two areas were identified in the NAFO WGEAFM report as containing significant concentrations of sponge but were not included in the spatial closures that were ultimately implemented (Figure 18). The third area did not have high RV catches and the simulated catches were achieved by fishing across larger homogenous areas of medium bycatch (9-17 kg/km) to accumulate larger catches (Figure 13).

Data on species composition would help to determine the significant adverse impact of the threshold levels. For example, a single (large) specimen of *Geodia barretti*, caught off Greenland (Figure 19) was 55 cm in width and weighed 38.46 kg (M. Best, pers. comm.). Therefore reducing the encounter threshold to 50 kg might involve the collection of only a few sponges if the catch composition is comprised of large, massive structure forming species such as *Geodia* spp. Conversely, 50 kg could represent much larger numbers of less massive sponges which might also be vulnerable marine ecosystem components.

If the encounter threshold for sponges are reduced from 800 kg to between 30 and 50 kg per tow it is unlikely to have a large effect on the commercial fishery within the fishing footprint and would serve as a more effective sponge conservation measure in un-fished areas under an exploratory fishery. This range was selected because it was the range after which there was a large increase in the proportion of the fishery affected with lowering threshold using median tow lengths (Figure 14).

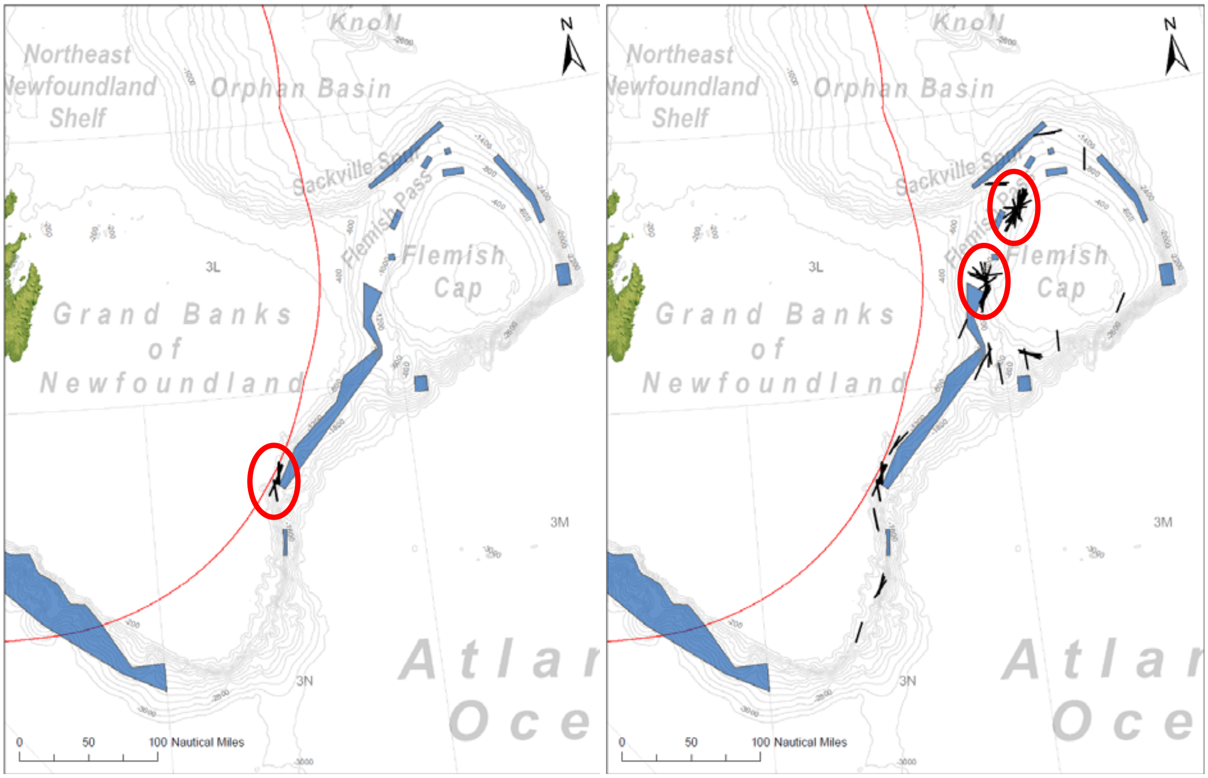

Figure 15. Location of simulated groundfish trawls catching > 800 kg (left) and > 50 kg (right) of sponge in the NRA based on a 15 nm trawl length. Note areas of concentration for simulated trawls greater than each threshold (red circles).

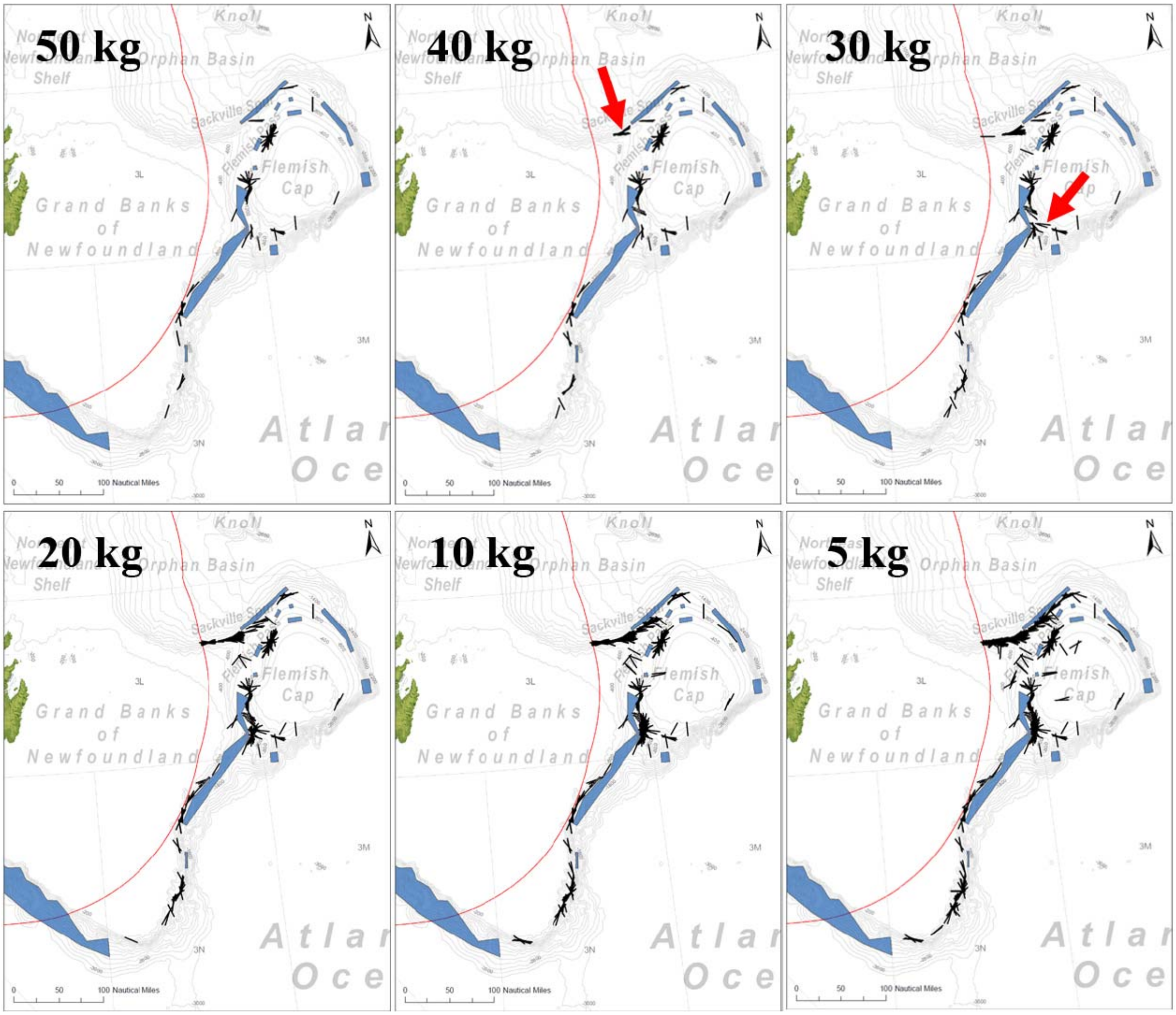

Figure 16. Location of simulated groundfish trawls catching greater than 50, 40, 30, 20, 10, and 5 kg of sponge in the NRA based on a 15 nm trawl length. Red arrows on the 40 and 30 kg panels indicate where new areas are formed relative to the 50 kg panel.

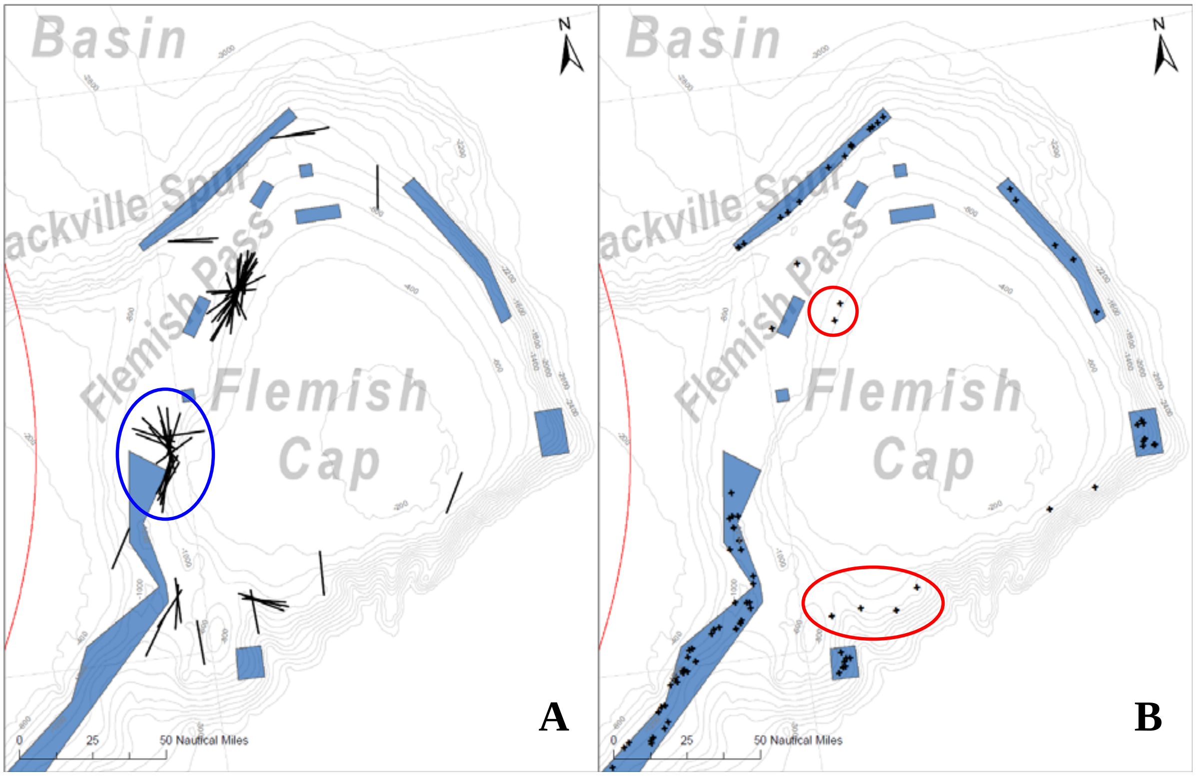

Figure 17. Panel **A** shows the location of simulated trawl lines which caught more than 50kg of sponge. Panel **B** shows the location of actual research vessel (RV) trawl catches that caught more than 75 kg of sponge, the value used to identify sponge grounds ("significant catches") in NAFO (2009b). The blue circle on panel **A** indicates an area where simulated trawl lines with more than 50 kg sponge by-catch were concentrated AND where there were no large RV catches. The red circles on panel **B** indicate an area where simulated trawl lines with more than 50 kg sponge bycatch were concentrated AND where there were large RV catches (> 75kg) identified but not protected by area closures.

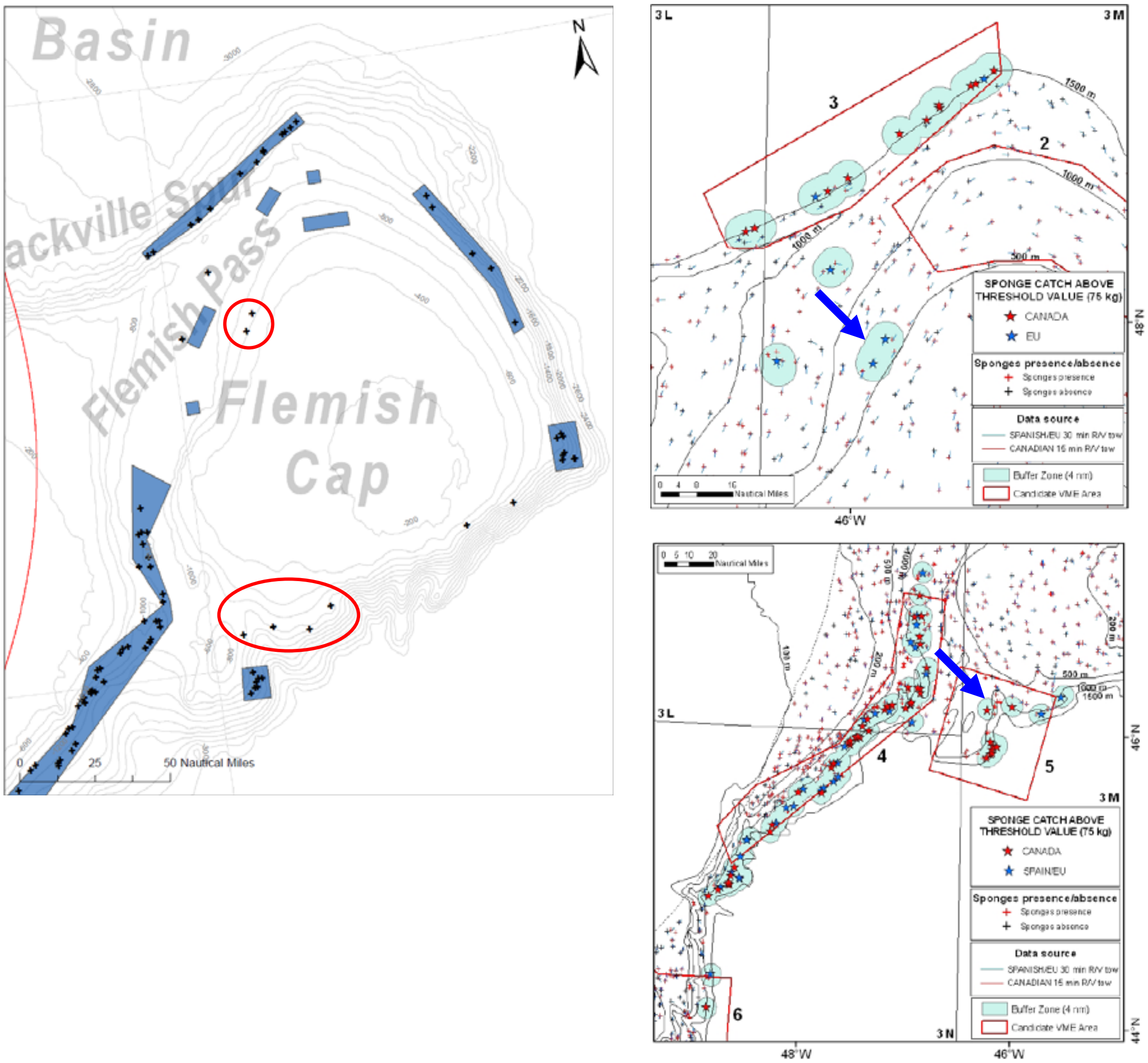

Figure 18. Left: The location of actual research vessel (RV) trawl catches that caught more than 75 kg of sponge, the value used to identify sponge grounds ("significant catches") in NAFO (2009b). The red circles indicate an area where simulated trawl lines with more than 50 kg sponge bycatch were concentrated AND where there were large RV catches (> 75kg) identified but not protected by area closures (shaded blue polygons). **Right**: Figure 10 (upper) and Figure 11 (lower) from NAFO (2009b) with blue arrows indicating location of significant concentrations of sponges not protected by the closed areas and corresponding to the areas circled on the left side panel.

Figure 19. A single specimen of *Geodia barretti*, 38.46 kg and 55 cm in diameter, caught off Greenland (Photo courtesy of M. Best, DFO).

References

Babish, G. *Geostatistics Without tears: a Practical Guide to Surface Interpolation, Geostatistics, Variograms, and Kriging. Environment Canada, Ecological Research Division, Environmental Conservation Branch, Edition 2006.03.*: 2006.

ESRI. *ArcGIS Version 9.3.1. Desktop Help for ArcGIS release 9.3 Environmental Systems Research Institute (ESRI), Redlands, CA, USA.*: ESRI, Inc., 2008.

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. Canadian Science Advisory Secretariat Research Document. 2010/040: 1-40

Murillo, F.J., Munoz, P.D., Altuna, A. and Serrano, A. 2010. 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. doi: 10: 1-14

NAFO. 2009a. Delineation of Existing Bottom Fishing Areas in the NAFO Regulatory Area. NAFO SCS Doc. 09/21 (N5676): 1-9

NAFO. 2009b. Report of the NAFO Scientific Council Working Group on Ecosystem Approach to Fisheries Management (WGEAFM) in Response to Fisheries Commission Request 9b and c. NAFO SCS Doc. 09/6 (N5627): 1-25

NAFO. 2009c. Report of the Ad Hoc Working Group of Fishery Managers and Scientists on Vulnerable Marine Ecosystems (WGFMS), 17-18 September 2009, Bergen, Norway. NAFO/FC Doc. 09/6 (N5693): 1-19

NAFO. 2010a. Northwest Atlantic Fisheries Organization Conservation and Enforcement Measures. NAFO/FC Doc. 10/1 (N5740): 5-95

NAFO. 2010b. Report of the Working Group on Ecosystem Approach to Fisheries Management (WGEAFM) - December 2010. NAFO SCS 10/24. (N5868): In Press

UN. 2007. Resolution Adopted by the General Assembly - Agenda Item 71 (b). Sustainable Fisheries, Including Through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and Related Instruments. General Assembly Resolutions and Decisions. A/RES/61/105: 1-21

Walsh, S.J. and McCallum, B.R. 1997. Performance of the Campelen 1800 Shrimp Trawl During the Northwest Atlantic Fisheries Centre 1995 Fall Groundfish Surveys. NAFO SCS Doc. 97/29: 105-116