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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

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Abstract

We provide a scientific basis for recommending commercial encounter protocols for sponges and sea pens in the NRA. For each we provide an assessment of significant adverse impact of bottom trawling taking into account published and new data on gear efficiency and selectivity, incidental mortality and recoverability. The proportion of VMS trawls in 2010 that would be impacted by lowering the current thresholds is estimated following previously established methods. Approaches to move-on rules are also considered.

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Introduction

Sea pen fields, large and small gorgonian coral stands and sponge grounds are important structure-forming taxa indicative of vulnerable marine ecosystems (VMEs) in the NAFO regulatory area (NRA) (Fuller et al. 2008). Significant concentrations of these have been identified and subsequently protected through area closures in accordance with paragraph 66 of the FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO 2009). However significant concentrations of these taxa remain unprotected within the fishing footprint of the NRA and in deep water along the continental slopes outside of the fishing footprint. The United Nations Sustainable Fisheries Resolutions (61/105, 64/72) state that RFMOs should have an appropriate protocol in place for how fishing vessels should respond to encounters with VMEs in the course of fishing operations (FAO 2009). This involves defining what constitutes evidence of an encounter with a vulnerable marine ecosystem (UNGA 64/72, para 119 (c)). Specifically, the guidance is:

67. States and RFMO/As should have an appropriate protocol identified in advance for how fishing vessels in DSFs should respond to encounters in the course of fishing operations with a VME, including defining what constitutes evidence of an encounter. Such protocol should ensure that States require vessels flying their flag to cease DSFs fishing activities at the site and report the encounter, including the location and any available information on the type of ecosystem encountered, to the relevant RFMO/A and flag State.

68. In designing such protocols and defining what constitutes an encounter, States and RFMO/As should take into account best available information from detailed seabed surveys and mapping, other relevant information available for the site or area, and other conservation and management measures that have been adopted to protect VMEs pursuant to paragraphs 70 and 71. (FAO 2009)

In 2010 NAFO set the encounter thresholds for all coral and for sponge as:

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 800 kg 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 (NAFO 2011a).

At the 2011 Annual General Meeting, NAFO voted to reduce the sponge encounter threshold to 400 kg outside of the fishing footprint, and to 600 kg inside of the fishing footprint but outside of the closed areas (NAFO 2012). This was done in a precautionary framework without specific scientific support for the threshold levels. FC further requested of the Scientific Council:

17. *Fisheries Commission requests the Scientific Council to make recommendations for encounter thresholds and move on rules for groups of VME indicators including sea pens, small gorgonian corals, large gorgonian corals, sponge grounds and any other VME indicator species that meet the FAO Guidelines for VME and SAI. Consider thresholds for 1) inside the fishing footprint and outside of the closed areas and 2) outside the fishing footprint in the NRA, and 3) for the exploratory fishing area of seamounts if applicable.*

This report is in response to this request of the Fisheries Commission for advice.

The VME indicator taxa named above are all highly aggregating. This property was exploited in the quantitative analyses of Kenchington et al. (2010a) and Murillo et al. (2010) who were able to identify a research vessel catch level (referred to as a threshold) which corresponded to a dense aggregation of sponges and sea pens respectively. In principle, the same approach could be used to identify when a commercial vessel has encountered such an aggregation. However, progress in establishing commercial by-catch values which would constitute evidence of an encounter has been hampered by the lack of commercial by-catch data. This has been discussed previously and compensated for by the development of a GIS-based simulation model (Kenchington et al. 2010a,b, Cogswell et al. 2010, Cogswell et al. 2011) which estimates commercial catches under various management scenarios. The model constructs a biomass layer derived from the research vessel catches; uses simulated trawl start and end positions and/or VMS data (Cogswell et al. 2011) to reflect commercial fishing; and calculates the biomass removed from under each fishing line to estimate commercial by-catch.

The model was first applied in 2010 to the sponge grounds in the NRA, using simulated trawl lines with effort-weighted start and end positions (NAFO 2010). The simulated trawls were not allowed to cross into the closed areas and were constrained to within the fishing footprint. That model application provided a fishery assessment 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. For example, advice was given in this context: Reducing the encounter threshold for sponges from 800 kg to 50 kg would only affect 5.5% of 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. Based on that analysis the WGEAFM recommended that the encounter threshold for sponges fished with bottom trawl gear be reduced from 800 kg to between 30 and 50 kg per tow. However, the Scientific Council (SC) was reluctant to endorse the WGEAFM report (NAFO 2011b) and raised a number of issues regarding this approach which we have addressed here and in Cogswell et al. (2011).

SC felt that the straight line, effort-weighted simulated tows used in the model were not characteristic of “real” fishing practices and that using the simulated lines would produce unrealistic results. This was a known issue (Kenchington et al. 2010a) however at the time there was no way to test this effect. However at the request of the FC, NAFO provided us with VMS data from 2010 (Cogswell et al. 2011). Cogswell et al. (2011) compared and contrasted model outputs using the two measures of fishing effort and show that in fact the simulated trawls produced very similar results to the VMS data over most of the by-catch range, with the former over-representing the very small catches and the latter the very large ones.

SC further noted that the model did not link specific thresholds to biological or ecological criteria (NAFO 2011b). This was identified also in the WGEAFM report (NAFO 2010). The model as presented was to guide managers towards precautionary decision making and to allow them to assess the potential impact of different threshold choices on the fishing industry. Lastly, SC disagreed with the application of the model in that the model was applied to an area outside of the closed areas to protect sponges as well as within the fishing footprint. The consequences of this are that the catch biomass range is reduced and the highest catches may no longer be indicative of sponge grounds. This is further exacerbated by fishermen avoiding sponge grounds resulting in effort-weighted catches further narrowing the catch biomass range. However, as we now have confidence in the use of the simulated straight-lines used to mimic fishing effort, the model outputs can be considered valid should managers wish to evaluate fishing measures in that context.

As a result of these issues, we have taken a different approach in our application of the model to address the concerns of the SC. In order to provide an ecological relevance to the threshold level we follow the same approach that we used to detect the significant concentrations or aggregations of sponges and sea pens that led to the implementation of the closed areas (Kenchington et al. 2010a,b, Cogswell et al. 2010, Murillo et al. 2010). The “threshold” for the identification of sponge grounds/sea pen fields was estimated by recording when the area occupied by catches greater than or equal to a threshold value, suddenly increased. This identifies the transition from the dense aggregations of these animals to the widespread occurrence of isolated individuals or small aggregations. Instead of using research vessel tows, we imposed 2000 random trawl start and end positions of commercial trawl length (13.8 nm see Cogswell et al. 2011) over the sponge/sea pen biomass layer derived from research vessel survey catch (Cogswell et al. 2011). This provides the commercial tow equivalent of the research vessel “threshold” catches used to identify sponge grounds and sea pen fields. Randomization of the tows (as opposed to positioning using weightings for fishing effort) is necessary in order to produce tows that fall cross the sponge grounds and sea pen fields which are to some extent avoided by the fleet. The threshold value would apply anywhere a commercial vessel encountered such habitats with similar species composition, both *1) inside the fishing footprint and outside of the closed areas* and *2) outside the fishing footprint in the NRA*, where these habitats occur.

Having used the model to identify a commercial encounter threshold indicative of the VME feature we then apply it as we did in the 2010 WGEAFM report (NAFO 2010) to assess the impact of that threshold on the 2010 fishing activities using the 2010 VMS data provided by NAFO.

Thus far we have not addressed significant adverse impacts (SAI) of fishing on the aggregations. The model outputs themselves are not influenced by gear selectivity or gear efficiency (catchability (q)) and SAI effects have no impact on the identification of aggregations using the area-occupied approach described above. This is because applying q across all areas would only proportionally change the catch values used to identify the significant aggregations. However, in order to assess immediate and cumulative impacts of encounters, gear efficiency and incidental mortality become important factors which influence recovery. We review the literature for these issues and present new information from the NEREIDA research programme for the species in the NAFO regulatory area.

NAFO uses move-on rules to mitigate "encounters" with small fish and bycatch of commercial species. When considering encounter thresholds for coral and sponge they also applied a move-on rule:

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

with associated procedural directions (NAFO 2012). As for the encounter thresholds, the move away distance has not been scientifically determined. The information on sponge biomass distribution used in our model can be used to inform captains on the "direction least likely to result in further encounters". We also explore various options for move-away rules which would support the conservation objective of preventing further damage to the VME.

Here we present data for sponge grounds and sea pen fields that we feel provide a first scientific basis for commercial encounter protocols and move-on rules for those taxa *1) inside the fishing footprint and outside of the closed areas* and *2) outside the fishing footprint in the NRA*. In doing so we discuss significant adverse impacts of bottom-contact gear on these taxa and other issues related to our results.

Sponge Grounds

GIS-Simulation of Commercial By-catch (Encounter) Thresholds Indicative of Sponge Grounds in the NAFO Regulatory Area (NRA)

Both the research vessel survey data used to estimate sponge biomass and fishing effort (by definition) fall within the fishing footprint. Consequently, we must make assumptions about sponge grounds outside of the fishing footprint in exploratory fishing areas on the slopes of the Flemish Cap and Grand Banks (seamounts are dealt with elsewhere). The assumption made is that the sponge grounds are the same or similar to the *Geodia*-dominated sponge grounds found in the fishing footprint and along the Canadian slope (Kenchington et al. 2010b, Fuller 2011, Murillo et al. 2012). These include aggregations of other large structure forming sponge species (ICES 2009) including glass sponges such as *Asconema* spp. Preliminary viewing of NEREIDA *in situ* imagery suggests that there may be such sponge grounds outside of the fished area, and we know that there are some unprotected sponge grounds within the NRA.

This simulation uses 2000 randomly placed and oriented straight line simulation trawls of median commercial tow length (13.8 nm) (see Cogswell et al. 2011). 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 closed areas so that the data could be collected on the appropriate thresholds for commercial vessels that encounter the sponge grounds, most of which have been protected by the closed areas (see explanation above). The extent of our analysis is limited to the footprint of the Spanish/EU research vessel 5 x 5 km cell sponge biomass surface (Cogswell et al. 2011) (Figure 1) which is used to estimate the commercial catches. We use only the Spanish/EU research vessel data for estimating the sponge biomass layer (Cogswell et al. 2011). This is because the Canadian research vessel data is restricted spatially and is derived from tows of a shorter duration than the Spanish/EU vessels (15 min vs. 30 min.). By using only the Spanish/EU data we avoid worsening spatial bias through scaling the Canadian data in order to standardize it (Cogswell et al. 2011).

The simulated commercial sponge catch was calculated from the 5 x 5 km gridded Spanish/EU research vessel survey sponge biomass layer and then used to create a smoothed sponge density layer (Figure 2) interpolated using the kernel density function with a search radius of 25 km (Kenchington et al. 2010a,b). This smoothing is necessary so that equal density polygons can be drawn around the area occupied by successive weight thresholds (following Kenchington et al. (2010 a,b) and Cogswell et al. (2010)). This density layer identified "hot spots" in locations similar to those in the research vessel sponge density layer used to identify the closed areas (Figure 2 compares the kernel density outputs from both the simulated trawl catch and research vessel by-catch). The major difference is in the relative densities and spread of the locations (due largely to the length of simulated commercial trawls (25.6

km) compared to the research vessel trawl length (2.8 km)) and particularly so in the area south of Sackville Spur on Flemish Cap.

Polygons of equal density were drawn around successive catch weights of sponge and the area occupied by each polygon was calculated. The “threshold” for the identification of sponge grounds was estimated by recording when the area occupied by catches greater to or equal to a threshold value, suddenly increased. This identified the transition from the dense aggregations of these animals to the widespread occurrence of isolated individuals or small aggregations. Figure 3 illustrates the relative change in area occupied by successive density polygons for 42 catch weight thresholds between 0.01 and 35,000 kg. Initially the area increases dramatically as the number of data points are small and the core of the sponge grounds are not yet established (Kenchington et al. 2010a). This initial increase in area is seen in Figures 3a and b, where the relative changes in area occupied and the actual area occupied by catches are illustrated for successive weight thresholds. The relative increase in area (Figure 3a) has its first threshold at catches greater than 10,000 kg where there is a relative increase of 1.5 times the area (the increase in area going from 35,000 to 15,000, and 15,000 to 10,000 kg are not shown but were even larger at 154 and 3 times respectively). Beyond this, the next largest change in area between successive catch thresholds occurred between catches of 3,000 and 2,000 kg (2.2 x) (Figures 3a and b). Catches of this size reflect sponge grounds dominated by the massive ball sponges of the genus *Geodia*.

The next largest change in area occurs between 300 and 200 kg. Catches of 300 kg or more occupy an area of 24,914 km^2 while catches of 200 kg or more occupy an area 1.5 times larger (36,548 km^2). The locations of the simulated commercial catches greater than or equal to 300 kg are illustrated in Figure 4 in relation to the closed areas. These catches correspond to the VME sponge grounds for both *Geodia*- and *Asconema*- dominated habitats. We also examined the next threshold which is between 200 kg and 100 kg (1.4 times change in area), however this is established by only 5 points (Figure 5) which is not considered to be a robust result (Kenchington et al. 2010a). Following the procedures used previously to identify significant concentrations of sponge from research vessel trawl survey catches, the threshold of 300 kg/13.8 nm trawl taken by a commercial vessel would indicate a significant concentration of sponge and could be used as the threshold for identifying an encounter by commercial vessels. Figure 6 illustrates a typical *Geodia*-dominated sponge catch near this 300 kg threshold limit.

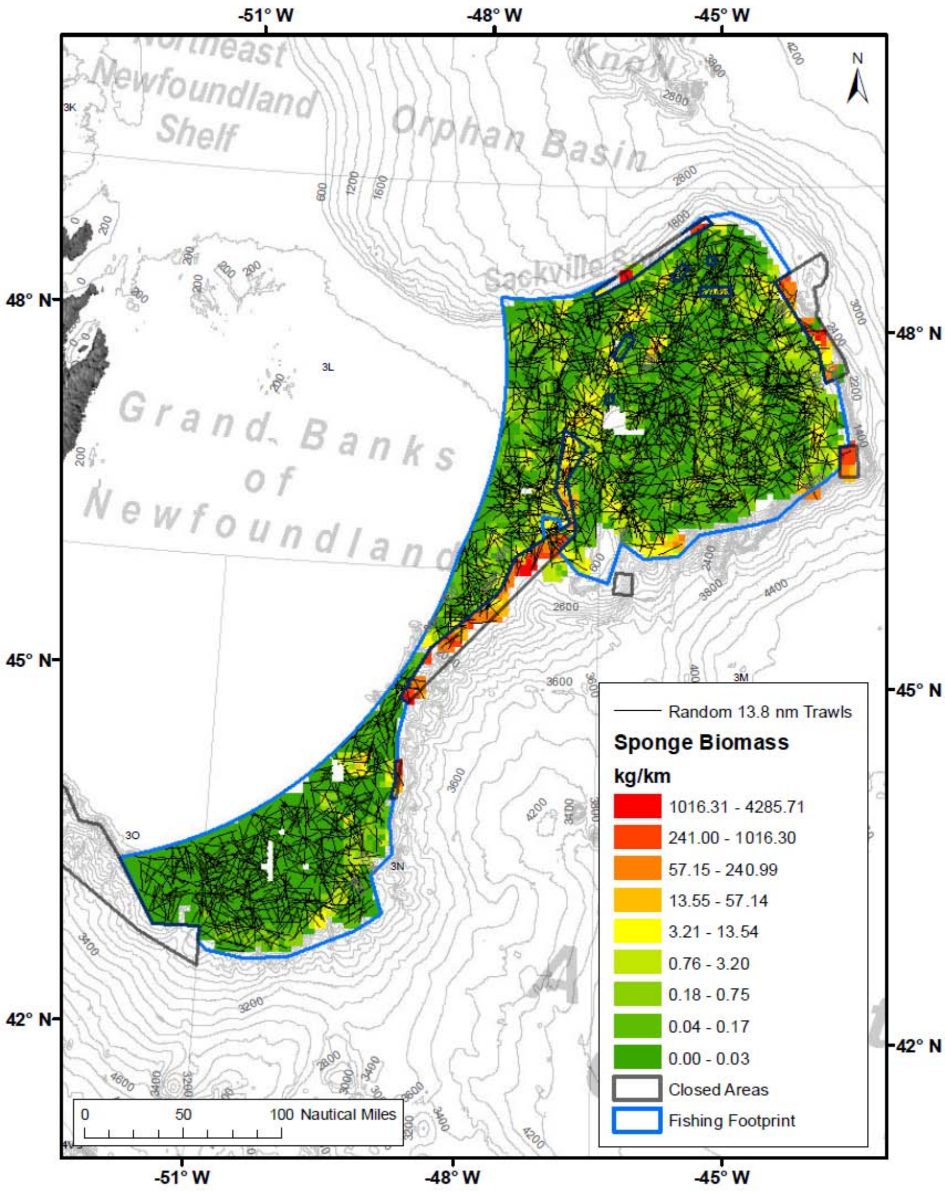

Figure 1. Simulated trawls (n=2000) with random start locations and orientation. Each trawl is of standard length (13.8 nm) and falls within the 5 x 5 km cell sponge biomass surface for the NRA.

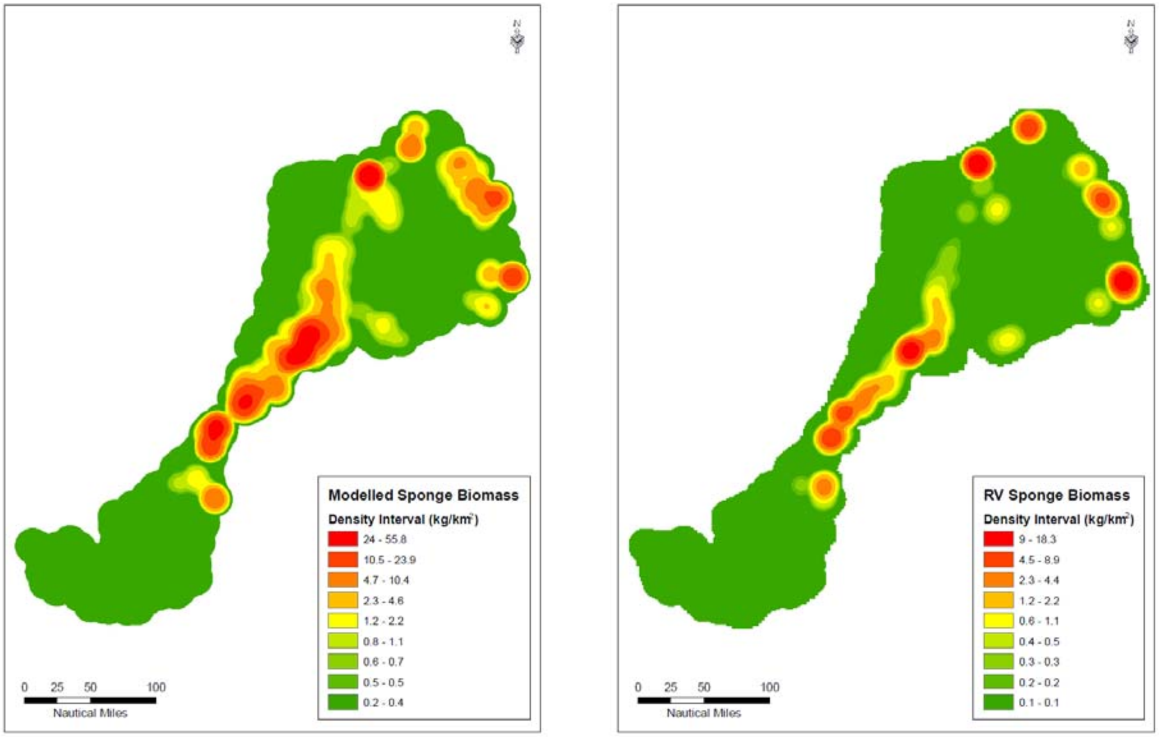

Figure 2. Sponge biomass (displayed using a geometric distribution in kg/km^2) in the NRA estimated from simulated commercial trawls with random start locations and orientation (left) and from Spanish/EU research vessel catches (right). Note maximum density values cannot be compared between the two methods.

We also examined the ≥ 40 kg sponge catch threshold identified in the analysis (Figures 3a, b). The area occupied by catches ≥ 40 kg is 63,155 km^2 while catches ≥ 30 kg occur in an area covering 80,639 km^2 (Figure 3b). This is an increase of 1.3 times. The areas identified using this threshold extend over much of the Flemish Cap (Figure 7) in comparison with the area occupied by catches ≥ 300 kg (Figure 8) and the catch composition can also differ from that of the areas occupied by catches ≥ 300 kg. Those catches are composed primarily of the *Geodia*-dominated sponge grounds which occur from depths of ~ 800 to 1500 m (Murillo et al. 2012). A lower threshold of 40 kg may capture non-VME sponge taxa. For example in one research vessel trawl catch of ~70 kg of sponge from the SE Grand Banks taken in shallower water the sponges are represented by the families Halichondriidae and Myxillidae (Figure 9) which are not considered to be VME indicators (ICES 2009). Conversely, in some situations the lower 40 kg threshold could be dominated by other structure-forming but lighter weight VME taxa such as *Asconema* spp. This is illustrated by the 63 kg catch from the NRA that is dominated by this species (Figure 10). The glass sponge *Asconema* spp. (Class Hexactinellida) is a lighter sponge than *Geodia* and similar genera, and it is recognized as a structure-forming VME indicator. The highest concentrations of this genus are captured with the 300 kg threshold (2 points in the north of Flemish Cap at about 600 m depth) but the 40 kg threshold would be more conservative for these and similar species (e.g., *Thenea* spp., *Mycale* spp., *Iophon* sp.) that can be abundant at lower weight thresholds (Figure 11). However, there is insufficient data to develop a threshold by sponge species or family which might be lower for these lighter weight VME sponges.

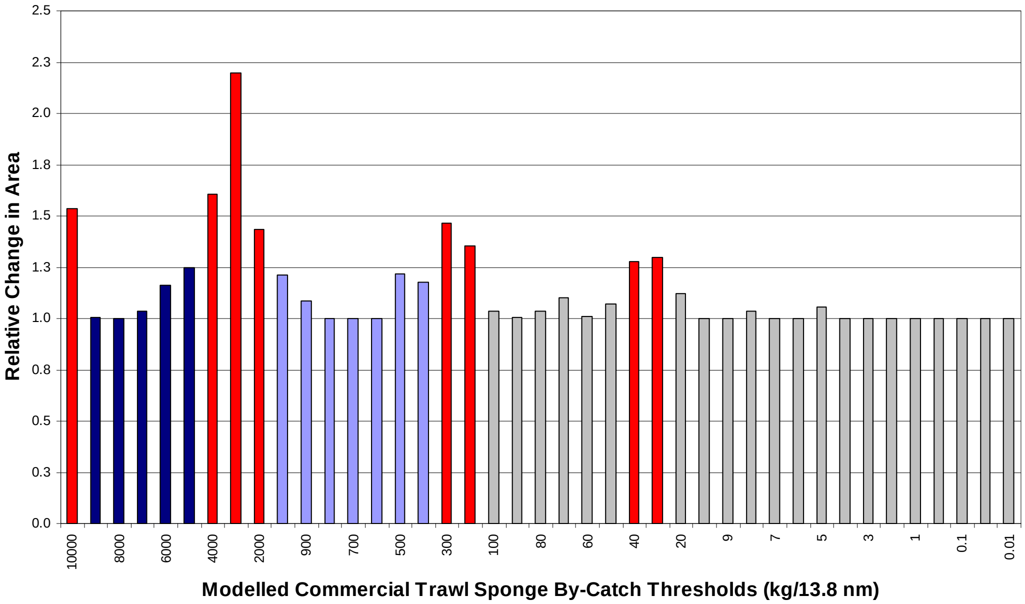

Figure 3a. Relative change in area occupied between successive catch thresholds from ≥10,000 kg to ≥ 0.01 kg. Dark blue bars correspond to the core of the *Geodia*-dominated sponge grounds. Light blue bars correspond to the VME sponge grounds for both *Geodia*- and *Asconema*- dominated habitats. The red bars indicate the levels where the greatest difference in area occupied occurred between successive catch weight values (greater than 1.3 times the area of the previous threshold).

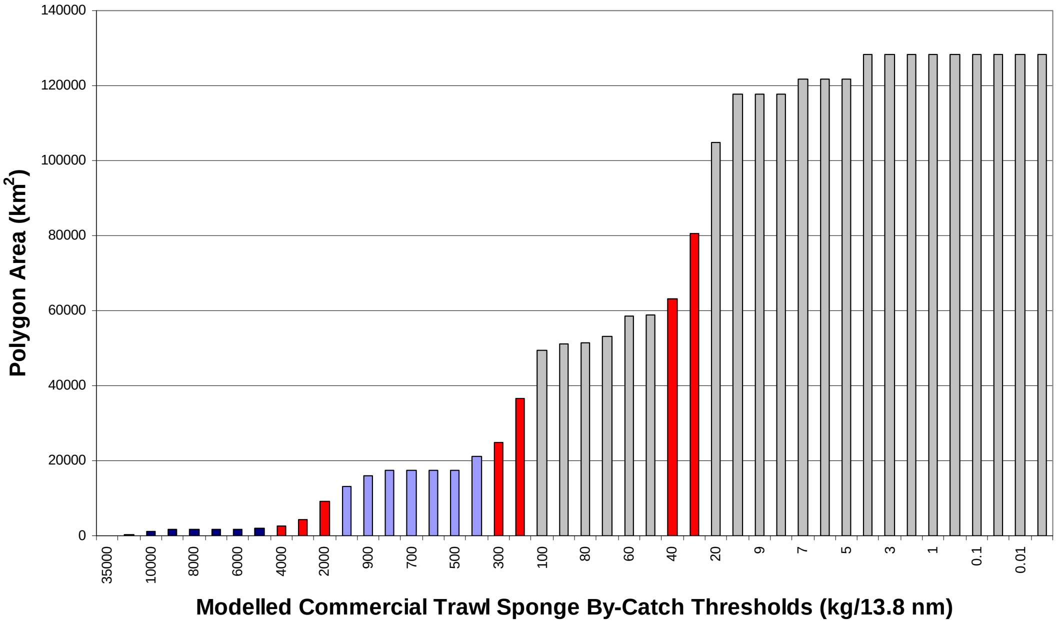

Figure 3b. Area occupied between successive catch thresholds from ≥35,000 kg to ≥ 0.001 kg. Dark blue bars correspond to the core of the *Geodia*-dominated sponge grounds. Light blue bars correspond to the VME sponge grounds for both *Geodia*- and *Asconema*- dominated habitats. The red bars indicate the levels where the greatest difference in area occupied occurred between successive catch weight values (greater than 1.3 times the area of the previous threshold).

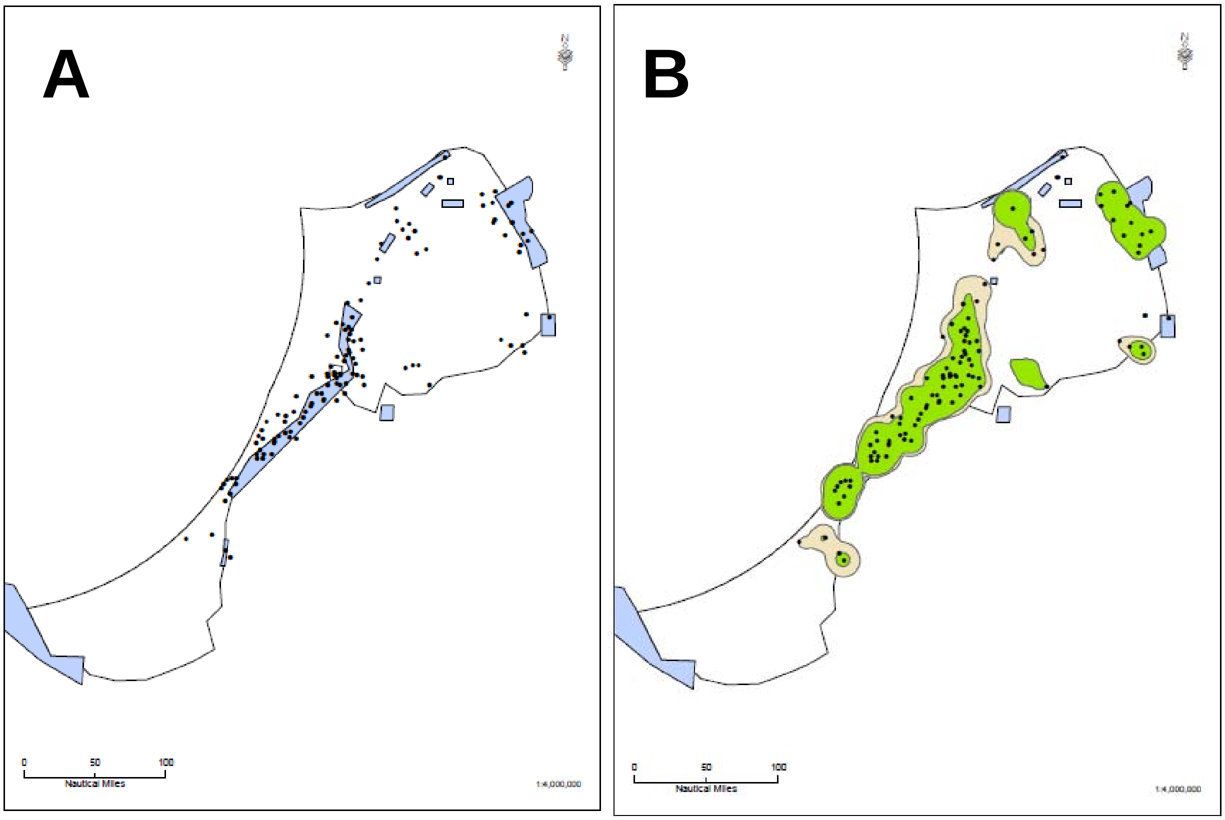

Figure 4. A) Location of the simulated commercial catches in the NRA ≥ 300 kg in relation to the current closed areas in the NRA (blue polygons). B) Polygons depicting the area occupied by simulated commercial catches in the NRA ≥300 kg (inner green coloured polygon) and ≥200 kg (outer beige coloured polygon). This represents a 1.5 times increase in area.

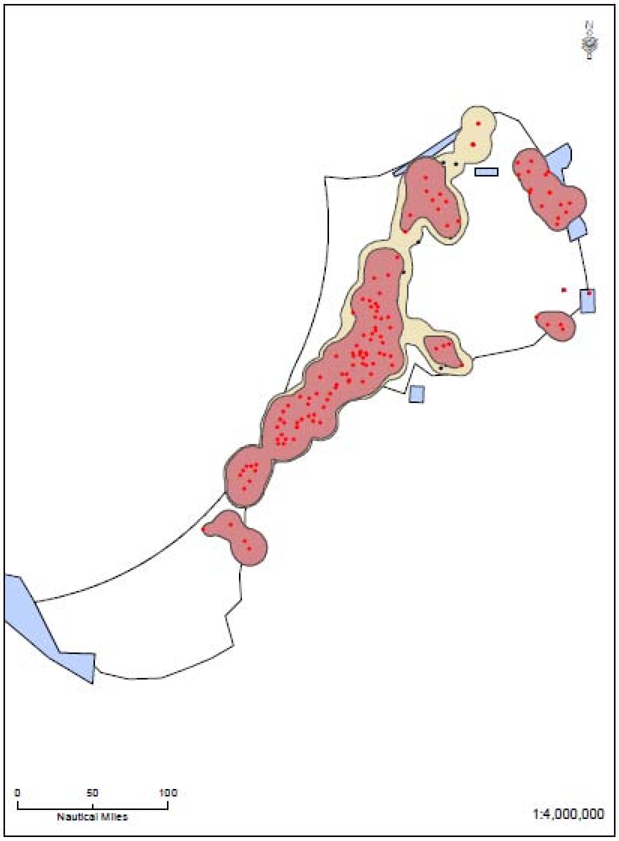

Figure 5. Polygons depicting the area occupied by simulated commercial catches in the NRA ≥200 kg (inner reddish coloured polygon) and ≥100 kg (outer beige coloured polygon). This represents a 1.3 times increase in area. Location of the simulated commercial catches ≥ 100 kg are shown in black and ≥200 kg in red. Note that only a few black points extend the polygon boundaries.

Figure 6. Photograph of a catch of 268 kg taken from the Tail of the Grand Banks in 2007 illustrating the numbers of sponge represented by this weight. Most sponges belong to the Geodiidae (Photo courtesy of F. J. Murillo, IEO-Vigo)

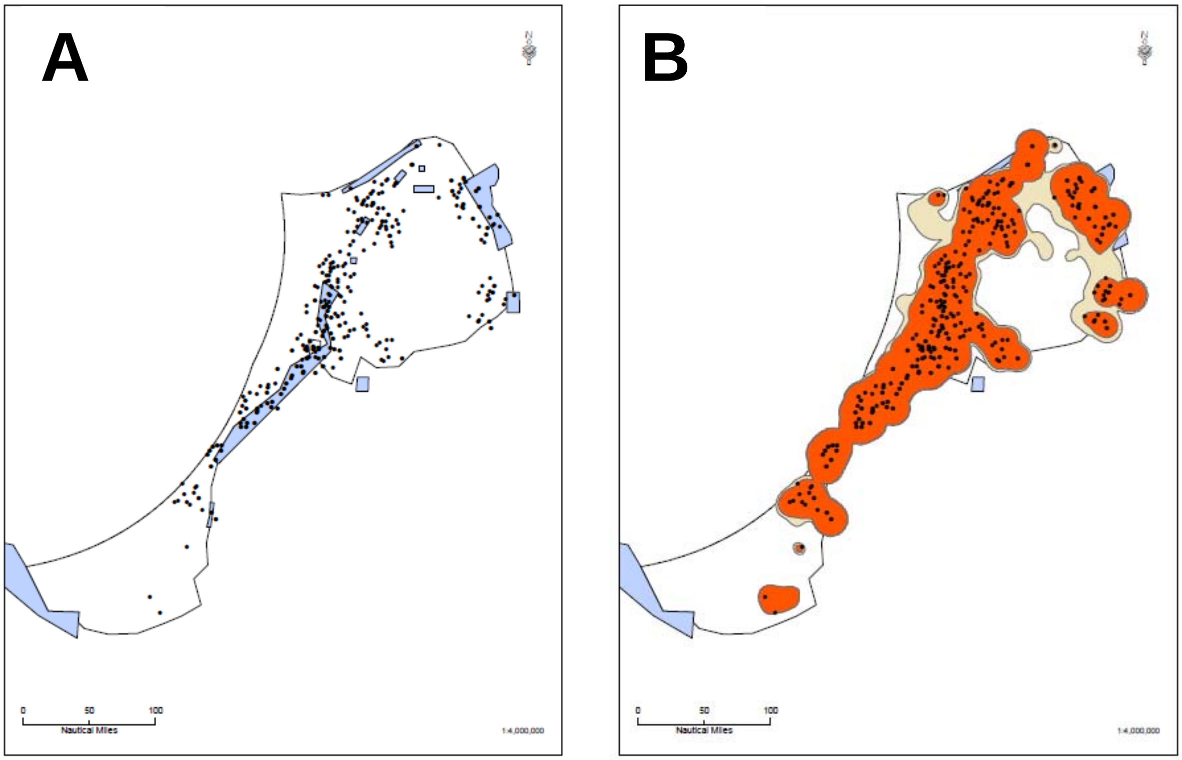

Figure 7. A. Location of the simulated commercial catches ≥ 40 kg are indicated in relation to the closed areas. B. Polygons depicting the area occupied by catches ≥40 kg (inner red coloured polygon) and ≥ 30 kg (outer beige coloured polygon).

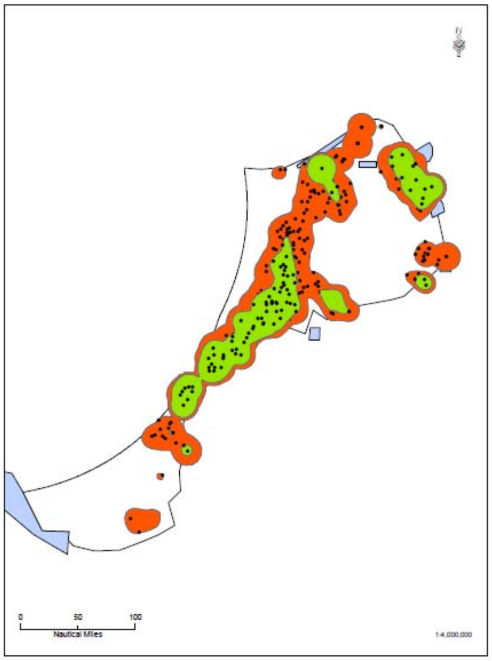

Figure 8. Area occupied by simulated commercial catches in the NRA ≥300 kg (inner green coloured polygon) and ≥ 40 kg (outer red coloured polygon). Locations of the simulated commercial catches used to delimit those polygons are indicated. Closed areas in blue are mostly masked by the catch polygons.

Figure 9. A catch of ~70 kg of sponge taken from the SE Grand Banks in the NRA. This catch was comprised of non-VME sponge taxa from the families Halichondriidae and Myxillidae (photo courtesy of F.J. Murillo, IEO-Vigo).

Figure 10. A catch of 63 kg of sponge taken from the NRA. This catch had various sizes of large *Stryphnus* sp. as well as other sponge fragments and some smaller sponge taxa (photo courtesy of F. J. Murillo, IEO-Vigo).

Figure 11. A catch of 99 kg of sponge taken from the NRA. This catch had various sizes of *Stryphnus* sp. as well as other structure forming sponges such as *Mycale* spp. or *Iophon* sp. in addition to sponge fragments and some smaller sponge taxa (photo courtesy of F. J. Murillo, IEO-Vigo).

Anticipated Impact on the Commercial Fishery of Using 300 kg and 40 kg Encounter Thresholds

The simulation model was run using 2000 randomly selected commercial trawls from data falling within the 95% confidence interval of the 2010 VMS data (see Cogswell et al. (2011) for description of all input layers). Fishing in 2010 was restricted to within the fishing footprint and outside of the closed areas. The model utilized the sponge biomass raster with a cell size of 5 x 5 km which is large enough to average approximately three Spanish/EU RV sponge records per cell.

Table 1. The number and percent of simulated groundfish trawls catching sponge at various encounter threshold levels. The shaded cells indicate the current sponge encounter threshold inside the fishing footprint (600 kg) as well as the thresholds identified in this analysis (300 kg and 40 kg).

Threshold (kg per tow)	No. Filtered VMS Trawls	% Filtered VMS Trawls ≥ Threshold	Threshold (kg per tow)	No. Filtered VMS Trawls	% Filtered VMS Trawls ≥ Threshold
800	0	0	80	44	2.2
700	0	0	70	48	2.4
600	1	0	60	55	2.8
500	1	0	50	63	3.2
400	5	0.3	40	78	3.9
300	11	0.6	20	89	4.5
200	23	1.2	10	127	6.4
100	35	1.8	1	260	13.0
90	38	1.9	0.1	869	43.5

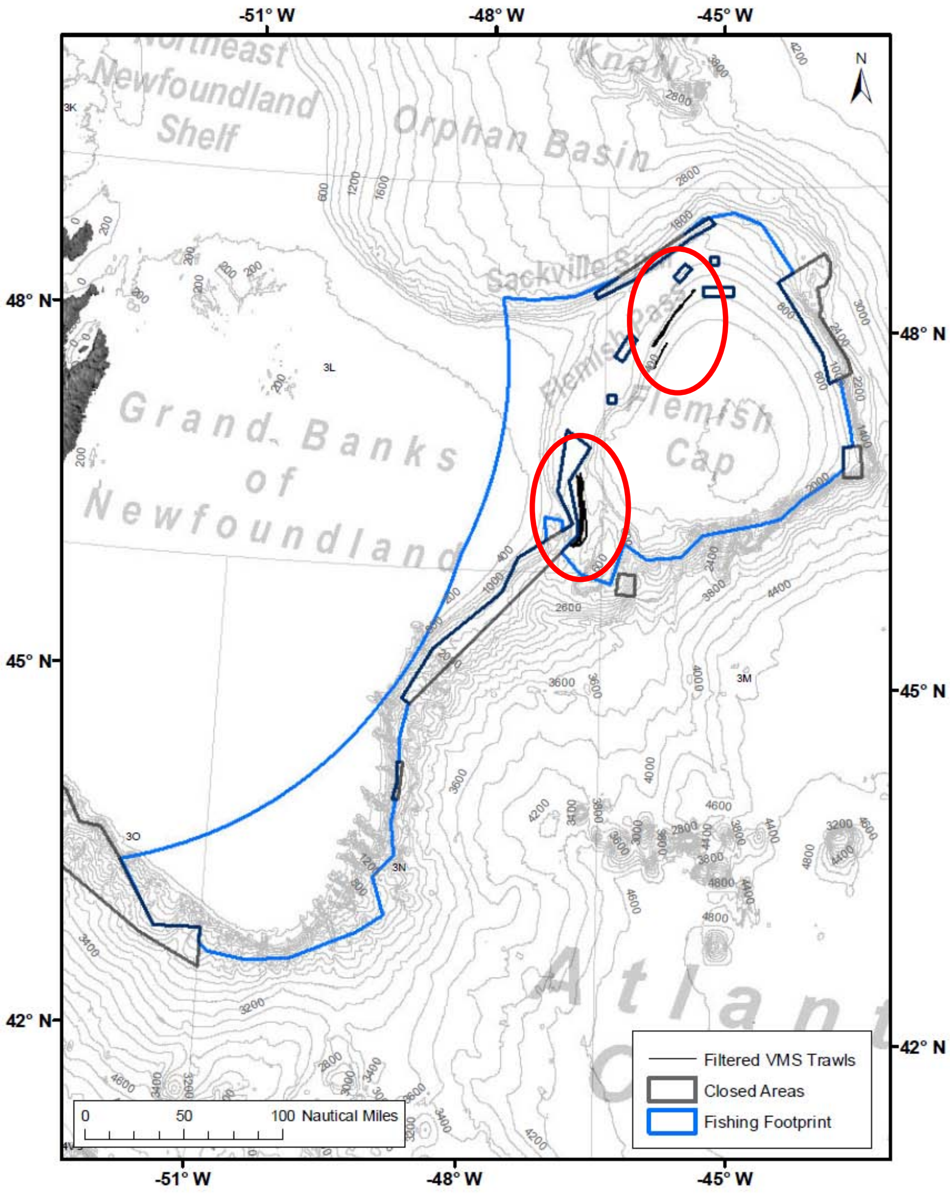

Figure 12. Location (red circles) of commercial trawls (black lines) expected to have caught ≥ 300 kg of sponge in 2010 (data from filtered VMS data set detailed in Cogswell et al. 2011).

According to this model the current sponge encounter threshold of 600 kg of live sponge from within the fishing footprint would have been encountered only once by commercial trawlers with the 2010 fishing effort distribution (Table 1). Lowering the threshold to 300 kg or 40 kg as identified through our analyses would impact 0.65 and 3.9% of the catches respectively. Catches of 300 kg or greater are expected to come from the two locations illustrated in Figure 12 following the 2010 fishing effort pattern, although there is potential for such catches to come from other areas with a change from the 2010 effort pattern (Figure 5). In particular the area between the closed areas in Flemish Pass and Beothuk Knoll were not fished in 2010 (see Cogswell et al. 2011) and this is one area where such catches could occur.

One of the advantages of our model is that it is easy to examine the model outputs to see how the results were obtained. For example, catches ≥ 400 kg come entirely from one location illustrated in Figure 13. Inspection of the biomass raster and point data (Figure 13) shows that VMS lines traverse along or near the 1200 m contour and most of the large sponge catches from the Spanish/EU RV survey occur in deep water, very near or in the closed area. Two of the high value biomass (orange) cells that VMS lines travel through are interpolated by focal statistics (Cogswell et al. 2011) and represent areas where there is no data available from Spanish/EU research trawls. It is likely that commercial trawlers are fishing very near the shallow water extent of sponge concentrations. However, without Spanish/EU RV data, the likelihood of an encounter with significant concentrations is difficult to predict. This is not the case for values less than 400 kg where inspection of the trawl tracks suggest that the catches of this level are clearly feasible.

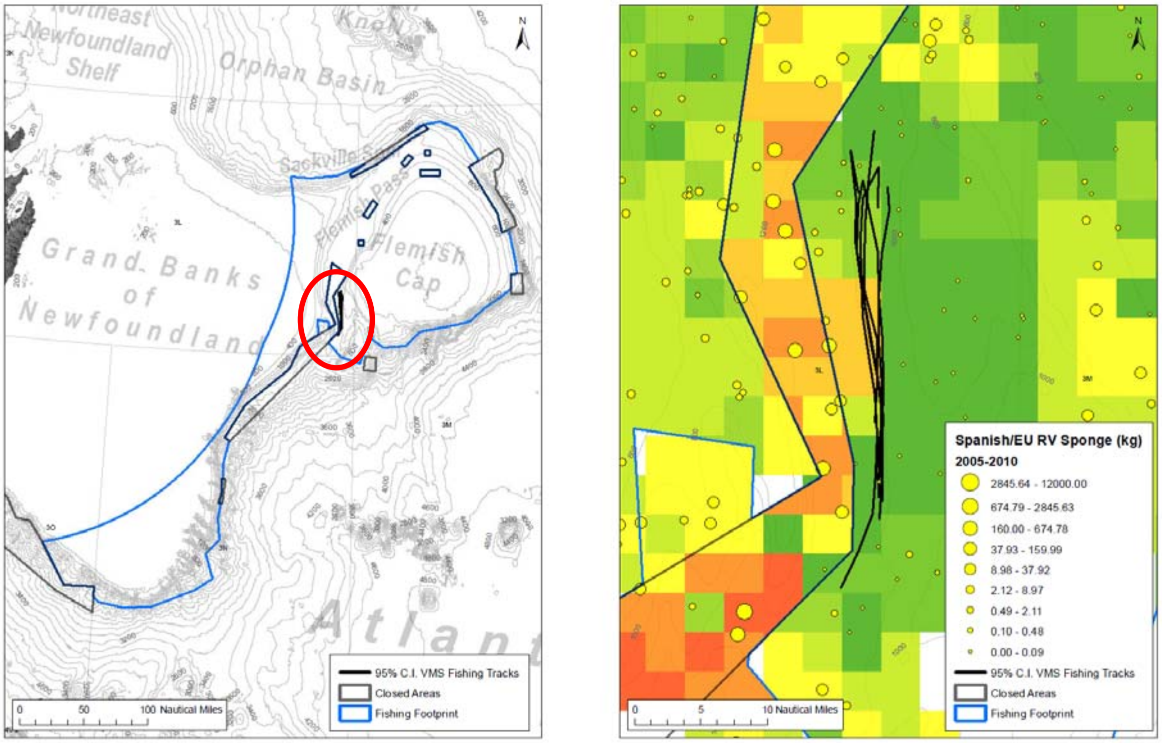

Figure 13. Left: Location (red circle) of commercial trawls (black lines) where the modeled results indicate ≥ 400 kg of sponge by-catch in 2010 could have been caught. Right: Close up of the location of commercial trawls with a modeled sponge catch ≥ 400 kg with the sponge biomass raster and research vessel catches presented. This figure 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 (red circle).

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

We examined the potential for significant adverse impact (SAI) on sponges of fishing within the fishing footprint and outside of the closed areas in the NRA by identifying areas where fishing and sponges co-occurred. A vector grid of 12.5 km^2 cells containing the 2010 effort data in hours per grid cell was provided by the NAFO Secretariat. A spatial join tool in ArcGIS was used to add the mean simulated commercial sponge by-catch to each “effort” cell. A new field was added to the grid attribute table which calculated mean sponge biomass (kg) x effort (hr). This calculation highlights cells where there is a sponge - effort interaction (Figure 14). While most of the fished area shows low to moderate interaction with the sponges there are areas where fishing could be causing SAI. Interpretation of this map requires knowledge of both effort patterns and high density sponge areas as a high interaction value could be achieved through high effort/low sponge or high sponge/low effort when what we are most concerned with is high effort/high sponge. Figure 15 further refines this interaction by first highlighting in red, cells that contain simulated commercial catch values in excess of 300 kg/ 13.8 nm tow (the proposed threshold value), and then by highlighting cells with greater than 40 kg of simulated commercial by-catch. This method clearly shows areas with potential for significant adverse impact to sponges by showing where high commercial by-catch is likely.

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

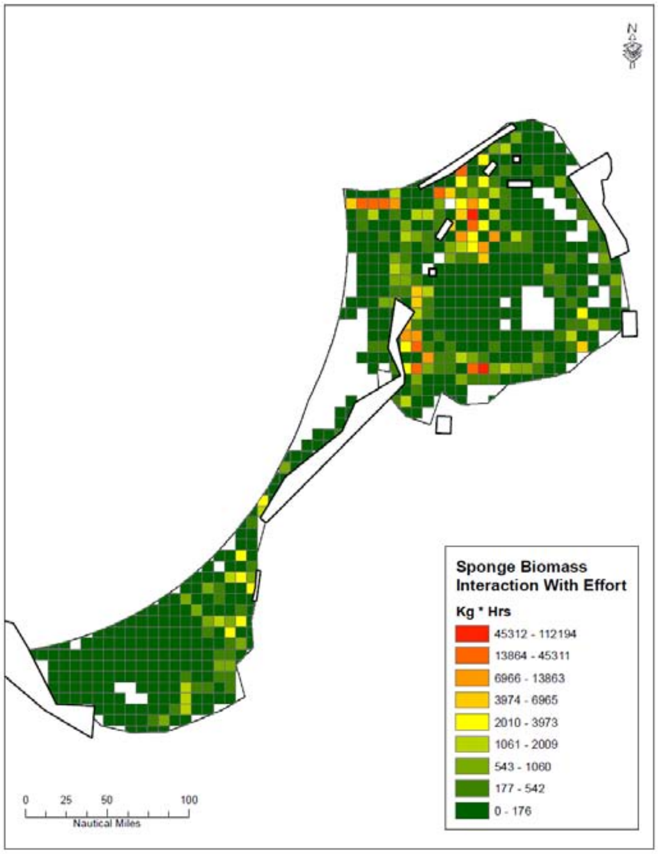

Figure 14. Interaction between fishing activity measured in hrs/km from the 2010 VMS fishing effort data with sponge biomass from the Spanish/EU research vessel surveys. Cell size of the grid is 12.5 km^2. Areas coloured red and yellow highlight areas where fishing could be causing significant adverse impact to sponges.

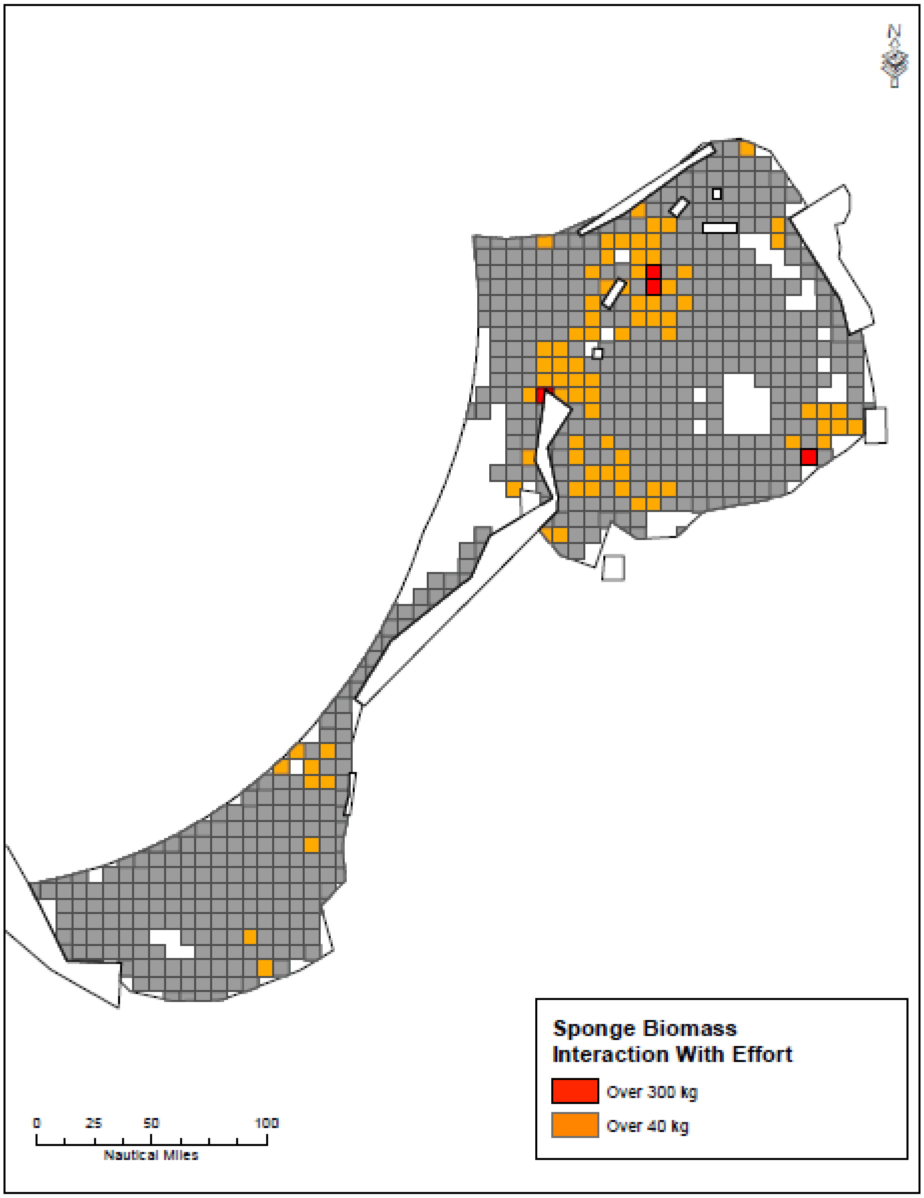

Figure 15. The interaction between the 2010 commercial fishing effort and sponge biomass is highlighted with cells with simulated commercial by-catch in excess of 300 kg in red and 40 kg in green. Grey cells represent areas where the simulated commercial by-catch values are less than 40 kg or where there was no effort. These coloured squares are areas where fishing may cause significant adverse impacts to sponge grounds.

Gear Efficiency and Selectivity on Sponges

Gear efficiency as used by fisheries scientists relates the true population size (biomass and/or abundance) to the capture or fishing mortality expressed as catch per unit effort (CPUE). It is sometimes referred to as "catchability" and is strongly related to gear selectivity. Different fishing gears have different hardware (e.g., net and mesh size, colour and configuration, rollers, doors) and consequently have different efficiencies and different selectivities. Further, the nets will fish differently under a wide range of operating conditions, such as with different trawl speeds, different tow lengths, different depths or depending on whether they are full of biomass or not. Environmental factors, such as bottom type and sea state, and for mobile species, behavioral factors such as reaction to the gear also influence both gear efficiency and selectivity. Consequently, the catchability coefficient (*q*) is very difficult to quantify.

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

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

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

There have been no experimental studies of gear efficiency for sponges in the NRA. However, crude estimates can be made for research vessel trawls (commercial trawl sponge by-catch data is not available). In the Sackville Spur area there are data from box cores and underwater images that can be used to estimate true population density and biomass, as well as a few research vessel trawls which can be used for capture mortality (Figure 16). The NEREIDA data used for this comparison are Box Cores 72 and 73 from the RV *Miguel Oliver* survey (Figure 17), benthic image transects (11 and 12) from the 2009 CCGS *Hudson* survey and trawl by-catch from six Canadian and one Spanish/EU research vessel trawls. These data are not close to one another but all fall within the area closed to protect the sponge grounds on Sackville Spur. The Canadian and Spanish/EU depth-stratified random multispecies surveys in this area use a Campelen 1800 shrimp trawl with rockhopper foot gear (Walsh and McCallum 1997) and a Lofoten trawl (Murillo et al. 2011) respectively. Standard tow lengths differ between countries. Spanish/EU research vessels tow for 30 minutes at ~3 knots for an average standard tow length of 2.8 km (Murillo et al. 2011), while Canadian vessels tow for 15 minutes at ~3 knots for an average tow length of 1.4 km (Kenchington et al. 2010a, Cogswell et al. 2010).

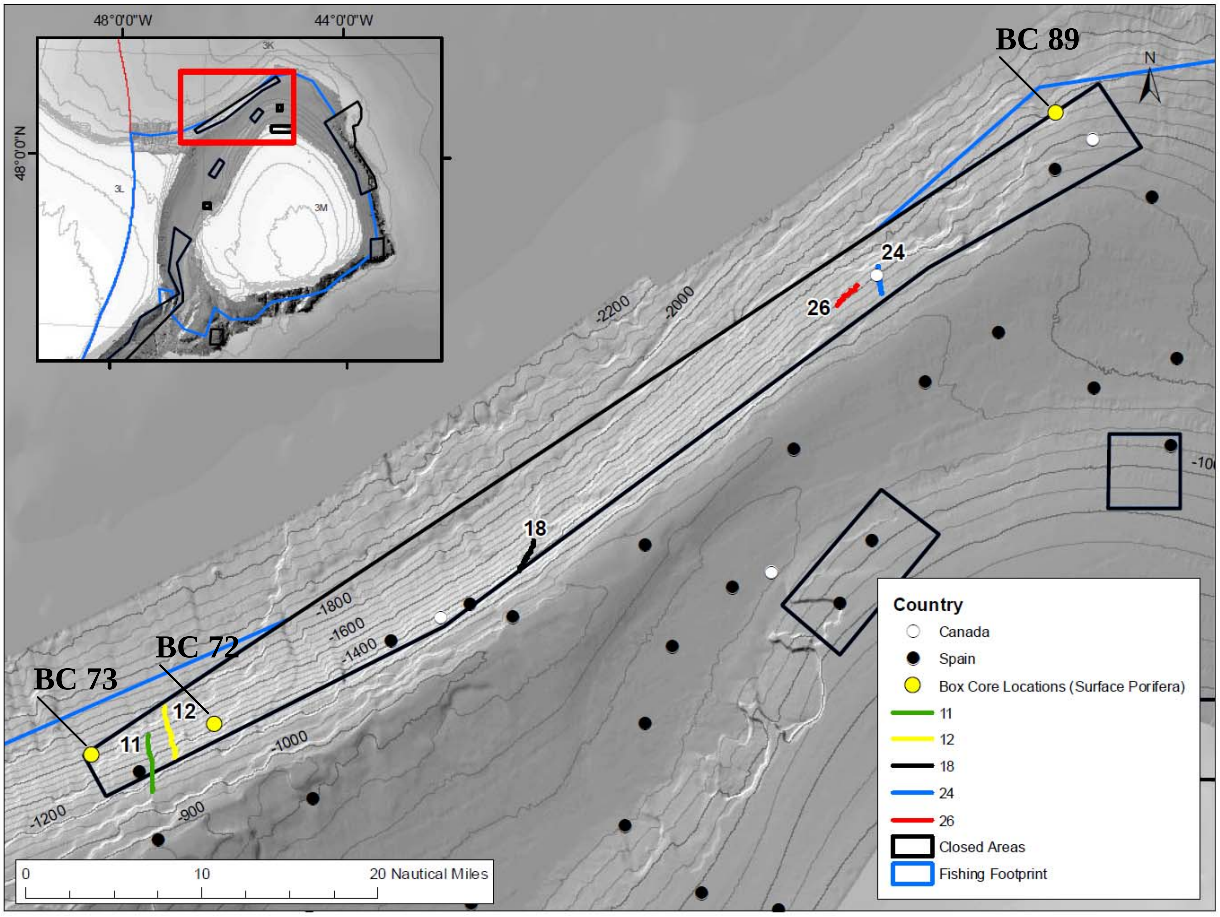

Figure 16. Box core locations (yellow circles) with surface sponge within the Sackville Spur closed area in relation to RV trawls (white circles - Canada, black circles - Spain) and 2009 camera transects (11, 12, 18, 24 and 26).

The mean of the total weight of surface Porifera for box cores 72 and 73 is 1,202g. The area represented by the box core is 0.25 m^2 (0.5 x 0.5 m) or 4.808 kg of surface sponge/m^2. The swept area of a 30 min Spanish/EU research vessel Lofoten trawl is ~3.9 hectares (or 39,000 m^2). Therefore, the total biomass impacted by the Spanish/EU trawl in this area would be ~187,512 kg. The swept area of the Campelen trawl used by Canadian research vessels (15 min trawl) is ~2.3 hectares, or 23,391 m^2 (B. Brodie, personal communication). Using the same sponge biomass/m^2 as above, total biomass impacted by a Canadian research vessel trawls in this area would be ~112,464 kg. The mean of the Spanish research vessel trawl catches (n=4) was 3606 kg and the mean of the Canadian trawl catches (n=3) was 907 kg. This suggests that the gear efficiency is on the order of 1.9% for the Spanish/EU Lofoten gear and 0.8 % for the Canadian Campelen gear. This is a quick but not very robust method for estimating the biomass impacted by research vessel trawls. This estimation only considers the biomass from two box cores and does not account for the inherent variability associated with the patchy distribution of sponges or issues with scaling up biomass several orders of magnitude.

Benthic camera transects allow for abundance estimates to be determined from larger spatial scales. Benthic camera transects 11 and 12 conducted during the 2009 CCGS *Hudson* mission lie between box cores 72 and 73 (Figure 16). The transect lines were clipped to only include analyzed images from water depths in excess of 1400 m (Figure 18) where the sponge grounds start (NAFO 2010). The sponge counts in each image below 1400 m (Figure 19) were recorded and then converted to a biomass value by multiplying by the average weight of sponges from box cores 72 and 73 (150 g/sponge). This value, which represents the estimated weight of sponges within the ~0.42 m^2 field of view for each image, was then divided by 0.42 as an estimate of the sponge biomass/m^2 in each image.

Figure 17. Box cores 72 (A), 73 (B) gathered during the NEREIDA mission aboard the Spanish research vessel *Miguel Oliver* in June of 2009.

The depth-selected portions of transect lines 11 and 12 were then split into intervals of 1400 m in length to approximate the distance trawled by Canadian research vessels (Kenchington et al. 2010a). The ArcGIS "Spatial Join" tool was then used to calculate the median, mean, standard deviation, minimum and maximum sponge weight/m^2 for images within each 1.4 km section of the lines (Table 2). Multiplying the mean estimated weight per analyzed image by the swept area would provide an estimate of the biomass impacted by a Canadian research vessel trawl for each interval. For Spanish/EU trawls the intervals A and B were combined into a 2.8 km line (C) and the "Spatial Join" tool was used to calculate the median, mean, standard deviation, minimum and maximum sponge weight/m^2 over the length of the line. Based on the swept area for a Spanish/EU research vessel trawl and mean estimated weight per analyzed image, an estimate of the biomass within the swept area was calculated (Table 2). Benthic images from transects 11 and 12 representing the mean, minimum and maximum sponge biomass are displayed in Figure 19.

Table 2. Descriptive statistics of estimated sponge biomass for analyzed benthic images below 1400 m water depth in both transects 11 and 12. Refer to Figure 17 for position of the transects and intervals A, B and C.

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

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

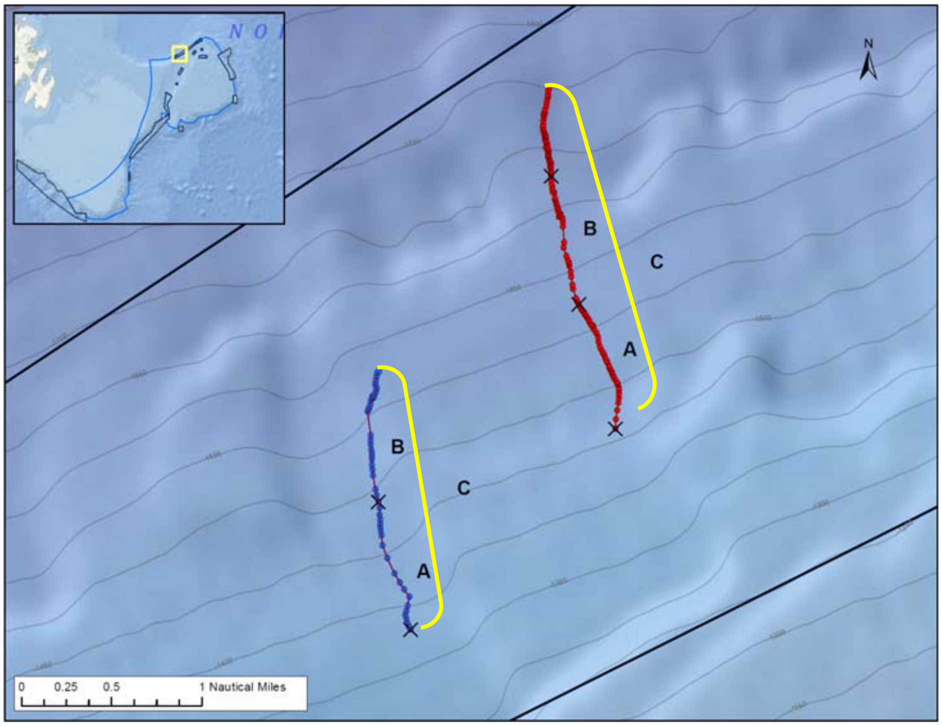

Figure 18. Camera transect lines 11 (blue) and 12 (red), run during CCGS *Hudson* mission in 2009. A and B represent 1.4 km sections on each line while C is the total line length of 2.8 km. Lines A, B and C were used to extract in situ abundance data of sponges on the Sackville Spur sponge grounds for estimation of gear efficiencies (see text for details).

The box core samples estimated *in situ* biomass of 4,808 g of surface sponge/m^2 in the Sackville Spur area. The benthic transect lines produced mean *in situ* biomass estimates ranging from 4,026 − 13,955 g of surface sponge/m^2 (range: 714 − 31,429 g surface sponge/m^2). For both transect lines, the mean sponge biomass increase is higher in the shallower portion of each line and there is quite a lot of variability in biomass estimates due to the patchy distribution of the sponges within the sponge grounds (Table 2).

Using the trawl catch mean of 3606 kg and 907 kg to represent capture mortality for the Spanish/EU and Canadian research vessels respectively, gear efficiencies of 0.3 − 1 % are estimated for the Canadian research vessels and 0.8 − 1.6 % for the Spanish/EU, depending on depth. This compares well with the 0.8% and 1.9% gear efficiency for Canadian and Spanish/EU research vessel trawls calculated from the smaller box cores (see above). While these figures are not very robust they are consistent with each other and suggest low gear efficiency or “catchability” of sponges with research vessel trawl gear on the Sackville Spur sponge grounds.

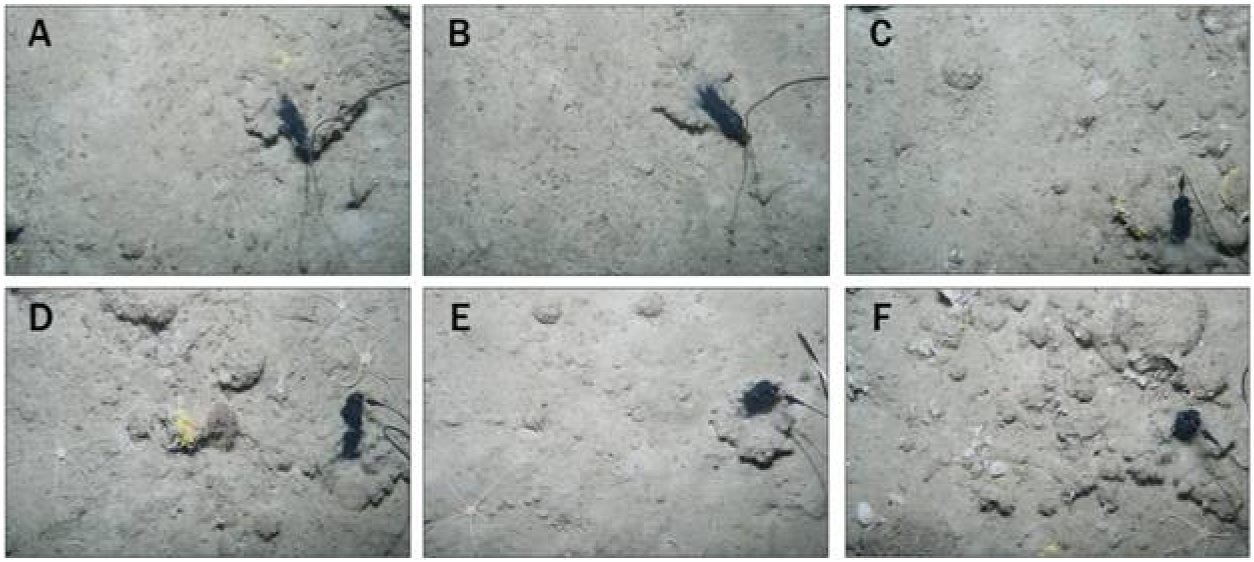

Figure 19. Photos representative of various sponge biomass on the Sackville Spur sponge grounds. A) the mean (5,868 g/m^2), B) the minimum (714 g/ m^2), and C) the maximum (12,500 g/m^2) biomass values from transect 11. D) the mean (11,325 g/m^2), E) the minimum (1,000 g/m^2), and F) maximum (31,429 g/m^2) biomass values from transect 12. Each image represents an approximate surface area of 0.42 m^2 (see Table 2).

Incidental Mortality

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

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

Recoverability

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

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

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

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

No investigations of the sexual reproduction of Geodiids and Ancorinids from the NW Atlantic have been carried out. However, the reproduction of the cold-water Arctic sponge, *Geodia barretti,* has been studied in Norway (Spetland et al. 2007). This species is oviparous and dioecious and undergoes synchronous spawning once or twice a year. The onset of reproduction coincides with the spring phytoplankton bloom with gamete release in early summer, just after the phytoplankton spring bloom is over and when organic matter sedimentation following the bloom is highest. A second release of gametes is associated with the fall bloom.

Sponge larvae are uniformly non-feeding and short-lived (except for rare known exceptions), generally staying only a few hours in the water column (Maldonado and Bergquist 2002) and settle in the vicinity of parental populations (Mariani et al. 2003). With such high levels of larval retention (Mariani et al. 2006) it is likely that connectivity among the sponge grounds is very low and that the patches are highly inbred and self-recruiting. *Geodia* is also known to produce gemmules (Burton 1949), or asexually produced buds, which are resistant to poor environmental conditions that can kill adult sponges. However, very little is known about the relative contribution of sexual and asexual reproduction in natural environments.

Evidence for Recoverability of Sponges in the NRA

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

Move-on rules for Sponges

There has been much debate over the usefulness of “move-on” rules as currently applied by RFMOs (Kenchington 2011). However, move-on rules are an essential companion to encounter thresholds, especially in new fishing areas. The objective of the rule is to move the vessel to an area where it will not encounter another VME.

We provide information on the minimum and maximum depth of the *Geodia*-dominated sponge grounds on the continental slopes in the NRA. These data are restricted to the research vessel survey area which extends outside of the fishing footprint (Figure 1). In this area sponge grounds form a linear band following depth contours. We identified five areas with significant sponge concentrations as defined previously (NAFO 2010; research vessel trawls with catches higher than 75 kg) in the NRA Div. 3LMNO (Figure 20): on the northeast slope of the Grand Banks (1), between the Nose and the Tail of the Bank, large catches of sponges were taken in a narrow band between 700 and 1470 m depth reaching maximum values larger than 5000 kg in one trawl around 1400 m depth; on the southeastern corner of the Beothuk Knoll (2) between 1000 and 1400 m depth seven catches between 100 and 1000 kg were found in a small area of about 120 km^2; on the southeastern corner of the slope of Flemish Cap (3) between 950 and 1330 m depth another area with significant catches of sponges was found. In this corner 8 trawls with catches between 100 to 5000 kg were found; on the eastern slope of the Flemish Cap (4) a band from north to southeast between 1050 and 1350 m depth was found with maximum values of 3000 kg per trawl around 1250 m depth; lastly, on the north slope of the Flemish Cap and Flemish Pass (5) in one area known as Sackville Spur, fourteen significant catches of sponges were found between 1250 and 1450 m depth. In this area the maximum catch of sponges (12,000 kg) in the NRA (Divs. 3LMNO) was taken at 1420 m depth (depth calculated from multibeam bathymetery from the NEREIDA surveys). This information (Table 3) can be used to construct move on rules for each area. For the maximum depth of the sponge grounds we used the 2000 m depth contour. This is because the maximum depths noted above were always the deepest trawl locations sampled in each area. Data from video transects suggest that the sponges are found to 2000 m.

Table 3. Minimum and maximum depth ranges for sponge grounds on the continental slopes of the NRA with a maximum move on distance based on average slope and a starting point of 2000 m, the maximum depth of the sponge grounds.

Slope Area	**Shallow End of Sponge Depth Range (m)**	**Average Slope over Depth Range of Sponge Grounds**	**Estimated Maximum Distance to Move km (nm)**
1 GB Nose & Tail	700	4.112	18.1 (9.8)
2 Beothuk Knoll	1000	5.011	11.4 (6.2)
3 SE Flemish Cap	950	4.198	14.3 (7.7)
4 E Flemish Cap	1050	3.861	14.1 (7.6)
5 Sackville Spur	1250	3.516	12.2 (6.6)

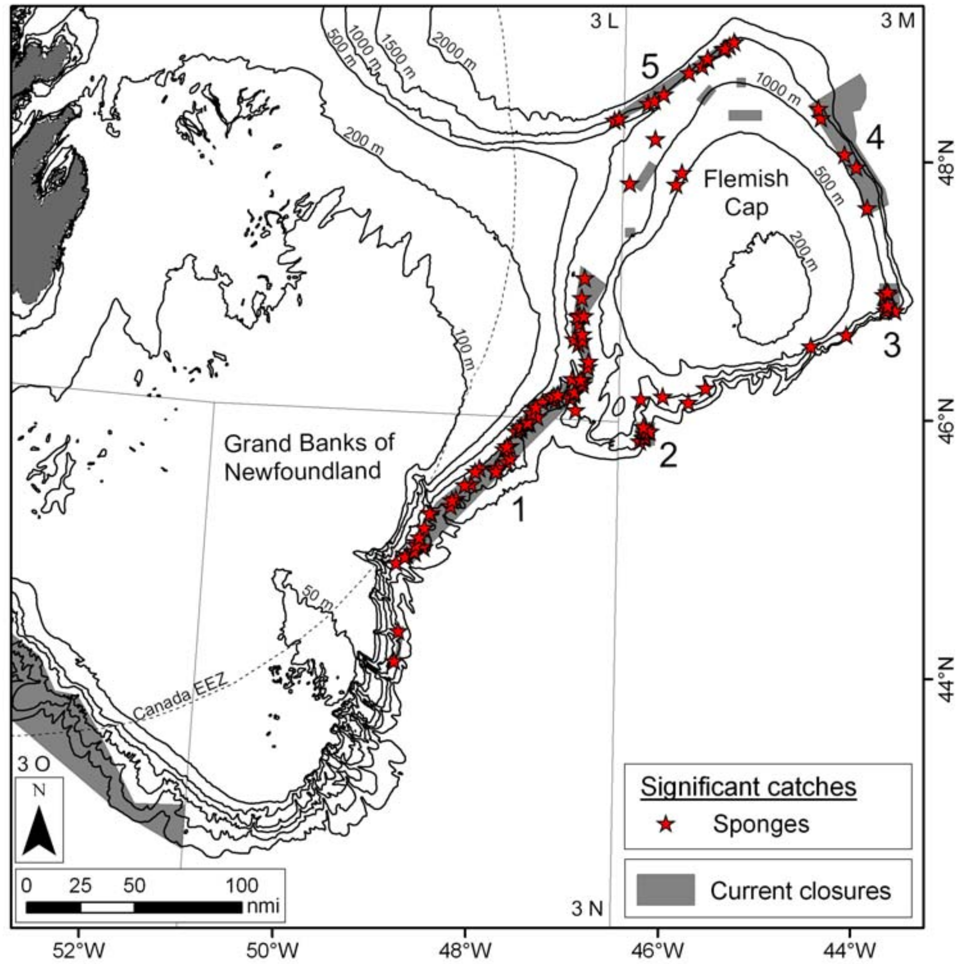

Figure 20. Map of all significant research vessel trawl sponge catches (> 75 kg) based on Spanish/EU and Canadian bottom trawl groundfish surveys. All areas currently closed to protect significant concentrations of corals and sponges in the Divisions 3LMNO of the NRA are indicated. The numbers 1-5 indicate the areas with large sponge catches evaluated in Table 3.

The move on rule would require the vessel to move from its position to shallow water ≤ 700 m in Slope Area 1, to ≤ 1000 m in Slope Area 2, to ≤ 950 m in Slope Area 3, to ≤ 1050 m in Slope Area 4 or to ≤ 1250 m in the Sackville Spur Area 5. If one rule were to be implemented for all areas it would be: the vessel is required to move to shallower water ≤ 700. Given the average slope of the continental slope in these areas (θ) (calculated from multibeam bathymetery from the NEREIDA surveys as illustrated for the Sackville Spur Area 5 in Figure 21) and the maximum sponge depth of 2000 m, the maximum move on distance would equate to (2000 – 700)/tan θ. This is the average distance from an "encounter" at the deepest part of the sponge grounds with a movement decision to go in the direction of shallow water. The maximum move on distance in the NRA would be 18.1 km or 9.8 nm in the shortest direction of shallower water. This would occur in Area 1 on the Nose and Tail of the Grand Bank (Figure 20).

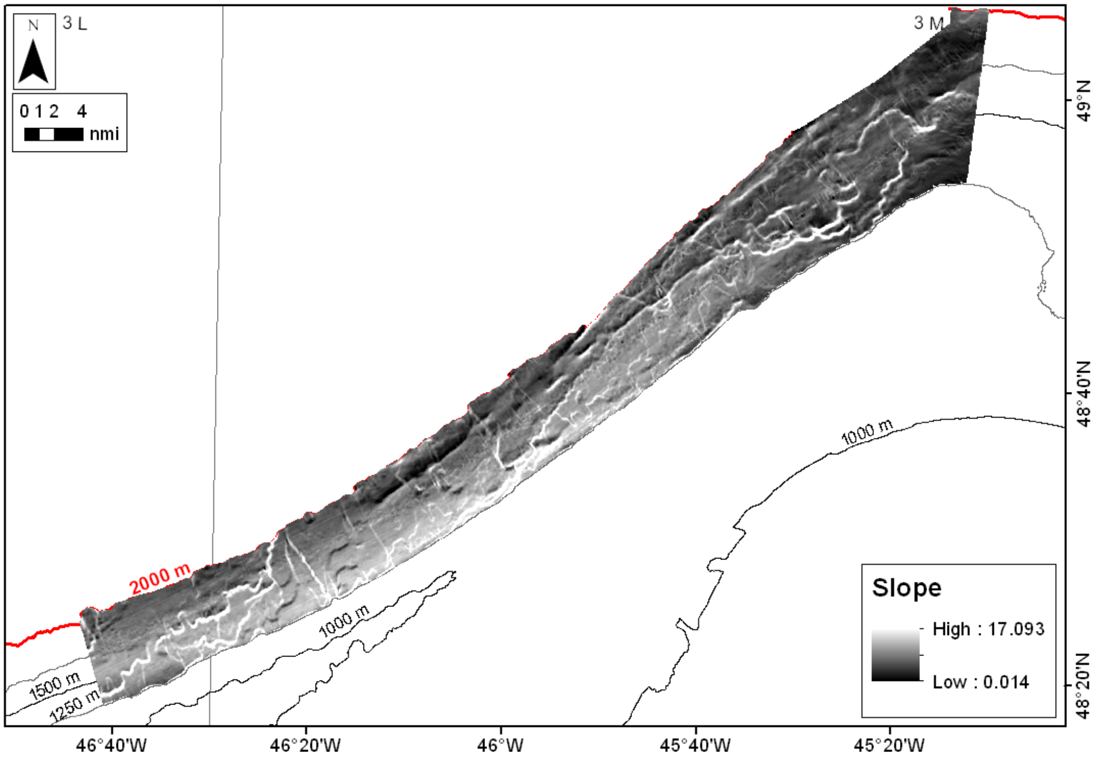

Figure 21. Slope between 2000 m and 1250 m determined for the Sackville Spur (Area 5) sponge grounds from multibeam bathymetric data collected during the NEREIDA mission. These data were used to calculate mean slope for the area.

Conclusions

Structural sponge habitat is extremely vulnerable to commercial and research trawling suffering immediate declines through direct removal of sponges and further reductions in population densities of sponges due to delayed mortality. We feel confident that an encounter threshold of 300 kg is sufficient to identify *Geodia*-dominated sponge grounds in the fishing footprint and outside the footprint on the continental slopes. This is the dominant structure-forming sponge in this area. This threshold will also identify the largest concentrations of lighter structure-forming glass sponges. At this time we are cautious about moving to a threshold of 40 kg as this will largely capture non-VME sponges and small aggregations of *Geodia* spp. however we recognize that this will be at the expense of some smaller aggregations of glass sponges. With more information on species composition in the near future we may be able to locate those areas and consider whether they need further protection. The literature reports a wide range of gear efficiencies for large sponges. Our data suggest that gear efficiency for both the Campelen and Lofoten trawl gear is on the order of 2%, however others report values of up to 70% for large sponges. Incidental mortality is also high with 55 to 95% of large sponges reported detached from the sea bed and 32% to 60% of attached sponges being damaged. In one case recovery occurred within a year, but generally, and in the few cold water studies recovery has not occurred within a year and is expected to take decades. Larval retention is likely high and increases the importance of maintaining sufficient densities of sponges within each sponge ground. These conclusions on the significant adverse impact of fishing on sponges would favour the 40 kg threshold as gear efficiency may be as low as 5% with high incidental mortality. However, given the uncertainties of the species composition associated with the locations where such catches occur we are reluctant to endorse this low value at this time.

Reducing the threshold inside the fishing footprint from 600 kg to 300 kg would affect 0.65% of trawls following the 2010 VMS fishing effort pattern (vs. 0.3 %) while reducing it to 40 kg would only affect 3.9% of such trawls.

We provide area-specific move-on rules which move effort away from known sponge grounds. Sponge grounds are localized in narrow bands along the slope of the Grand Banks and Flemish Cap and they extend to deep waters. We propose a move on rule that would require the vessel to move from its position to shallower areas where no sponge grounds are expected to occur. This rule would have to be applied through consideration of other VME species so as not to displace effort to other areas.

Sea Pen Fields

Sea pens are colonial organisms belonging to the order Pennatulacea. The generalized sea pen body plan takes the form of a rigid, erect stalk (the rachis) with one or more polyps raised into the water column, and a bulbous "root" or peduncle at its base which anchors it in the soft sediments of the sea floor (Williams 1995). All belong to the family Pennatulaceae (sea pens) with the longer species sometimes referred to also as sea whips. NAFO, following the guidelines of the FAO (FAO 2009), have identified sea pens as key structural components of soft-bottom vulnerable marine ecosystems in the Regulatory Area (Fuller et al. 2008, NAFO 2008a,b, Murillo et al. 2010). Aggregations of sea pens, known as “fields”, provide important structure in low-relief sand and mud habitats where there is little physical habitat complexity. These fields provide refuge for small planktonic and benthic invertebrates (Birkeland 1974), which in turn may be preyed upon by fish (Krieger 1993). They also alter water current flow, thereby retaining nutrients and entraining plankton near the sediment (Tissot et al. 2006). Sea pens fields belong to the Initial OSPAR List of Threatened and/or Declining Species and Habitats (OSPAR 2003).

NAFO Scientific Council (2008a) made recommendations for closing areas to protect deep sea corals, including sea pens. An extensive database from Canada and Spain/EU of 7,279 research vessel survey trawl records from NAFO Divisions 3LMNO covering a depth range of 31-1491 m were used to locate key concentrations of sea pens using the cumulative catch distribution to identify aggregations (NAFO 2008a). This was followed by the application of GIS modelling (Kenchington et al. 2010a) to identify significant concentrations using kernel density analysis (Murillo et al. 2010).

There is a high diversity of sea pens in Atlantic Canada and surrounds compared with other coral orders. Murillo et al. (2011) list 11 sea pen species from the NAFO Regulatory Area (NRA), and the NAFO Coral Identification Guide (Kenchington et al. 2009), which included only the more common taxa, lists 5 sea pen species and 2 other genera. However, the dominant sea pen taxa observed in the surveys are *Anthoptilum grandiflorum*, *Halipteris finmarchica* and *Pennatula aculeata* (Murillo et al. 2010). The first two are whip-like sea pens and the last is a smaller fleshy species; all of the common sea pens in the NRA fall into one or other of these morphologies.

At present, different coral groups do not have different encounter thresholds, despite their very different morphologies and biomass. The encounter threshold of 60 kg of live coral is very high for the smaller corals such as the sea pens and it is for this reason that we have chosen to include them, along with the sponges, in this first full assessment of encounter protocols and SAI.

GIS-Simulation of Commercial By-catch (Encounter) Thresholds Indicative of Sea Pen Fields in the NAFO Regulatory Area (NRA)

The layers used by the model to predict commercial sea pen by-catch under varying scenarios remain largely unchanged from those used for describing the model layers to estimate commercial trawl sponge by-catch. The only exceptions are the simulated trawl lines generated for each scenario and the sea pen biomass layer used to calculate by-catch for each simulated line. The former random trawl lines drawn for the sponge by-catch analyses had to be regenerated to allow for the different spatial footprint of the sea pen biomass raster.

The sea pen data set consists of 2588 records from Canadian (N=577) and Spanish/EU (N=2011) research vessel trawls from 2005 to 2010. Of these, 1,792 records represent null data points where no sea pen by-catch was observed (Figure 22). Further, of the 796 research trawls recording sea pens, 735 (~92%) were found in water depths greater than or equal to 300 m (Figure 22). That sea pen distribution is easily discernable as a horseshoe around Flemish Cap and a narrow band hugging the slope on the southeast Grand Banks and above the 3O closure (Figure 22).

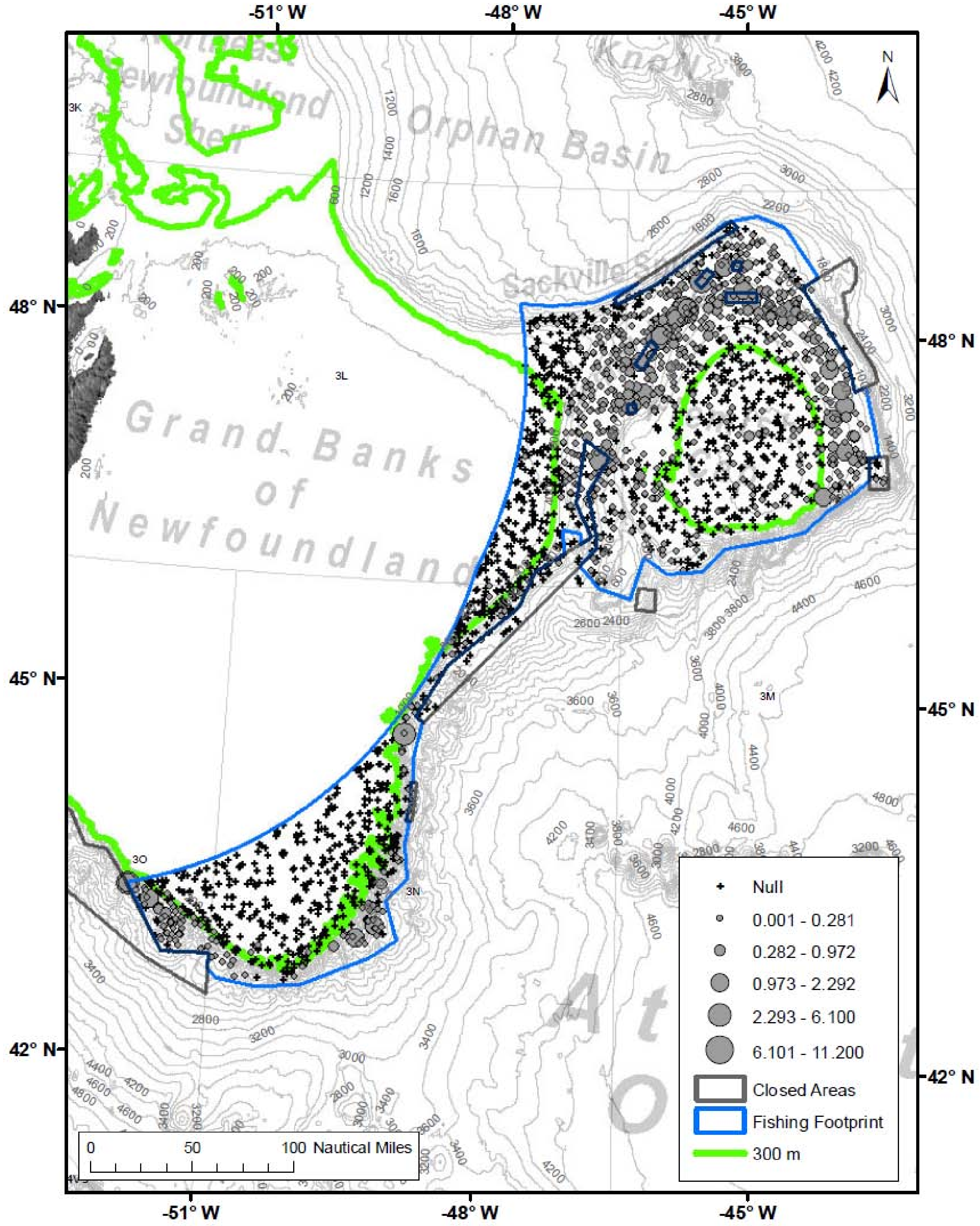
-51° W
-48° W
-45° W
48° N
45° N
42° N
N
Northeast Newfoundland Shelf
Orphan Knoll
Orphan Basin
Sackville Spur
Grand Banks of Newfoundland
Atlantic Ocean
3K
3L
3M
3N
3O
Null
0.001 - 0.281
0.282 - 0.972
0.973 - 2.292
2.293 - 6.100
6.101 - 11.200
Closed Areas
Fishing Footprint
300 m
0
50
100 Nautical Miles

Figure 22. The distribution of sea pen by-catch (grey circles - kg) and null sets (black cross) in relation to the 300 m contour (green line) and closed areas (grey polygons) in the NAFO Regulatory Area.

The sea pen biomass layer created for the model scenarios described below were created in a similar manner as the sponge by-catch raster, that is with 5 x 5 km cells and using only the Spanish/EU research vessel data (Cogswell et al. 2011). Canadian data was not used in the analysis to avoid introducing spatial bias through standardization methods as discussed above. The resultant sea pen biomass layer used for the GIS modelling is illustrated in Figure 23 and referred to as the 5 x 5 km sea pen biomass surface.

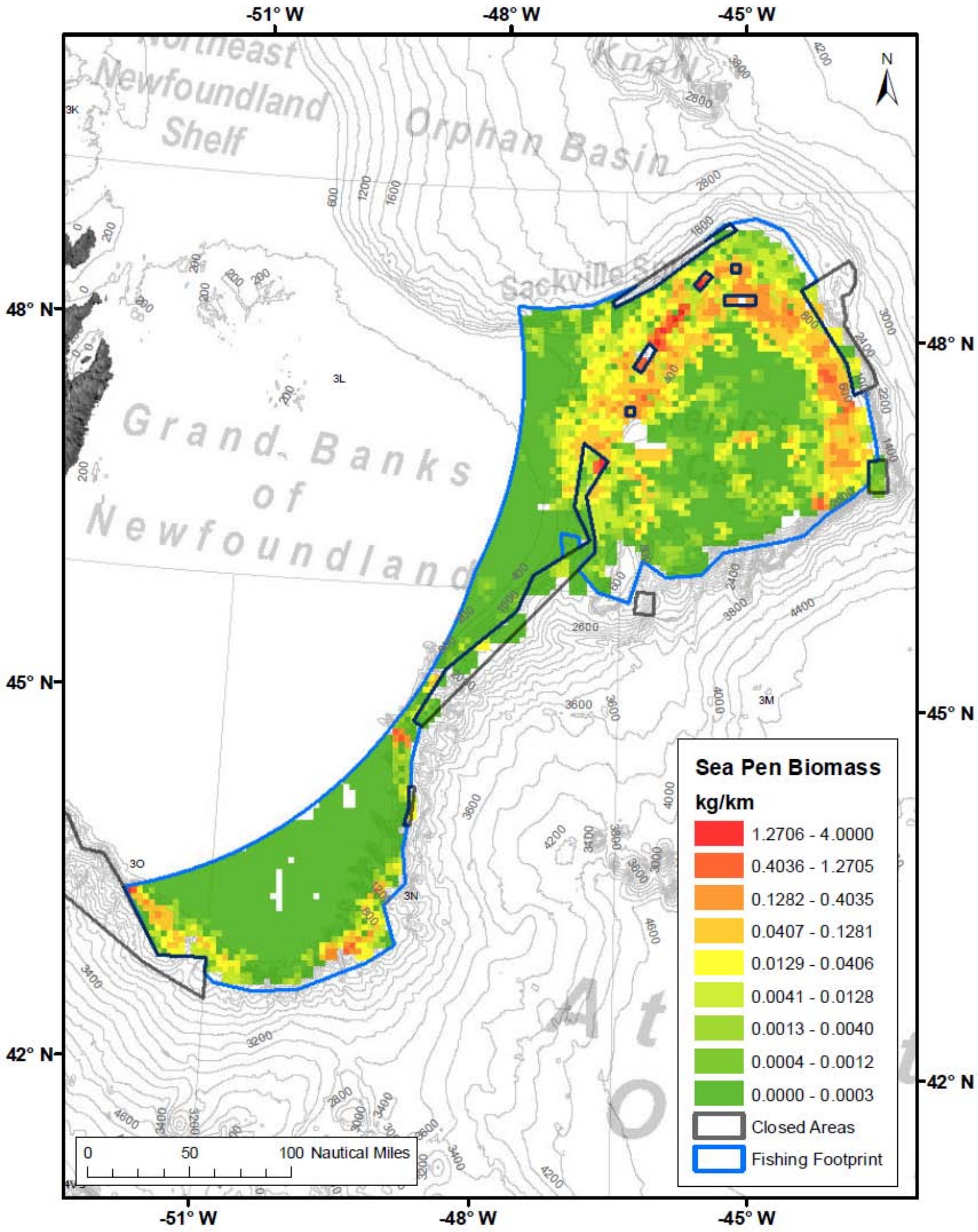

Figure 23. The sea pen biomass layer used to calculate simulated by-catch.

As for the analysis of sponge by-catch, this simulation uses 2000 randomly placed and oriented straight line simulation trawls of standard commercial tow length (13.8 nm) (Figure 24). 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. Lines were not restricted from crossing into a closed area, but were limited to within the footprint of the Spanish/EU research vessel 5 x5 km grid sea pen biomass surface (Figure 24). These lines are meant to mimic the research vessel random trawl stations with commercial length trawls to reproduce the protocol for sea pen field identification established previously (Kenchington et al. 2009, Cogswell et al. 2010, Murillo et al. 2010) only using commercial trawl threshold values. This is the same model application used for identifying sponge grounds.

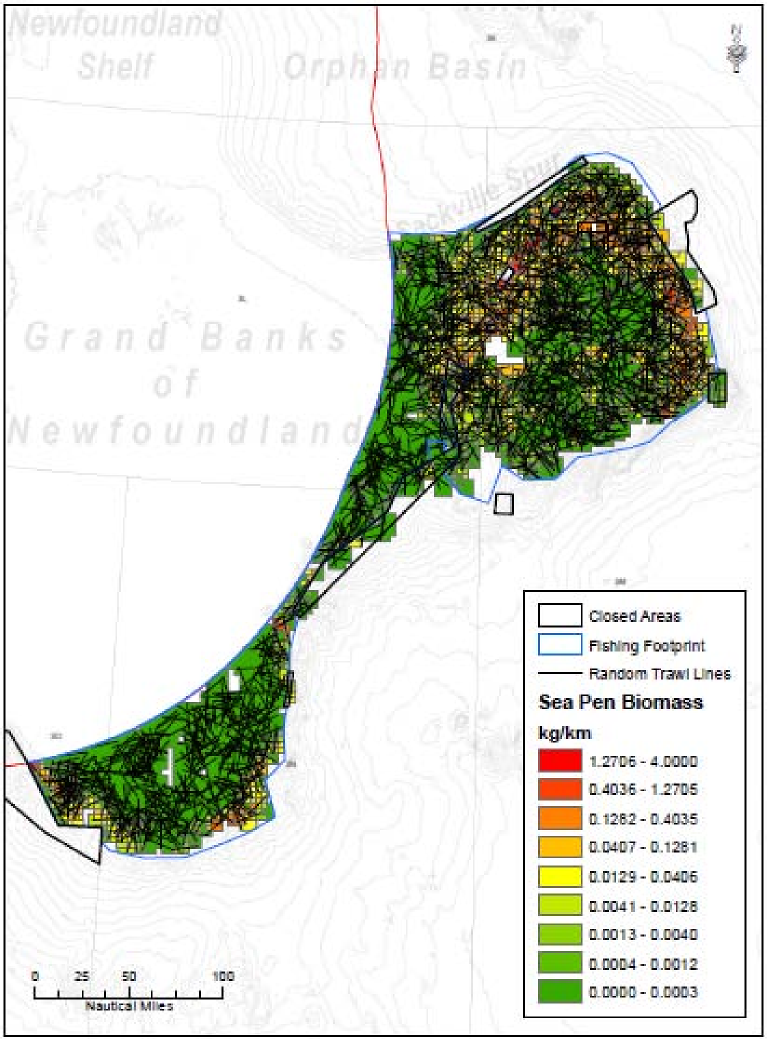

Figure 24. Simulated trawls (n=2000) with random start locations and orientation. Each trawl is of standard length (13.8 nm) and falls within the 5 x 5 km sea pen biomass surface for the NRA.

The simulated commercial sea pen by-catch was used to create a sea pen biomass layer interpolated using the kernel density algorithm with a search radius of 25 km (Figure 25) (Kenchington et al. 2010a), and polygons were drawn around the area occupied by successive weight thresholds following Kenchington et al. (2010a) and Kenchington et al. (2010b). This biomass layer identified “hot spots” in locations similar to those in the research vessel sea pen interpolated biomass layer used to identify the closed areas however the high density locations are more prominent in the modeled data from the simulated trawls.

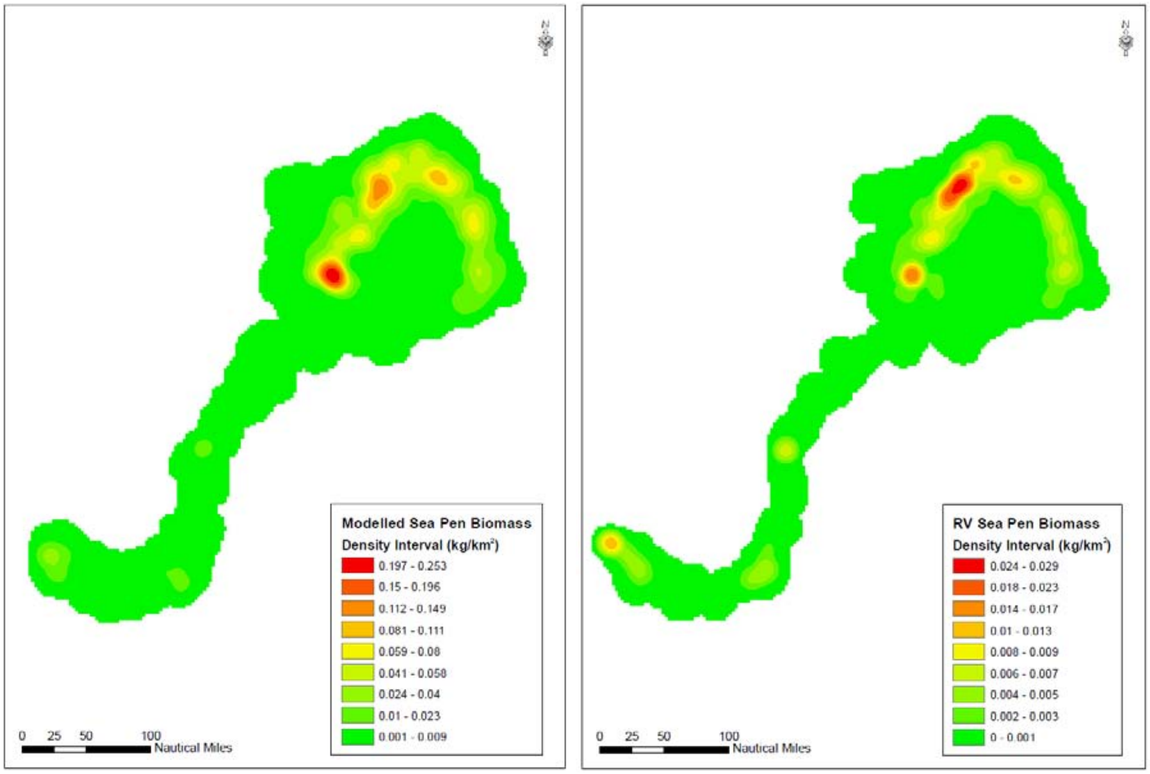

Figure 25. Modelled sea pen biomass (kg/km^2) in the NRA estimated from simulated commercial trawls with random start locations and orientation (Figure 24) (left) and from Spanish/EU research vessel catches (right). Note maximum density values cannot be compared between the two methods.

Figure 26 illustrates the area occupied by the calculated density polygons for 26 catch weight thresholds between 0.001 and 30 kg. In this series the largest change between successive categories occurs between 7 and 6 kg. Catches of 7 kg or more occupy an area of 5,000 km^2 while catches of 6 kg or more occupy an area 2.6 times larger (13,088 km^2). This threshold was established with 12 data points from the research vessel survey and so is considered to be a reliable indicator of sea pen fields (note sometimes aerial expansion can be created through only a few data points which we would not consider to be a robust estimator of the habitat area). The difference in area occupied by these catches is illustrated in Figure 26. Most of the catches ≥7 kg occurred outside of the current closed areas. A threshold of 7 kg equates to about 198 individuals of the short and fleshy species (based on mean individual weights of 220 *P. borealis*) and to about 583 of the sea whips (based on mean of individual weights of 306 *Anthoptilum grandiflorum*) (E. Kenchington, unpublished data). Figure 28 illustrates a mixed species catch of 388 sea pens weighing 5.7 kg taken from a research vessel trawl on Flemish Cap.

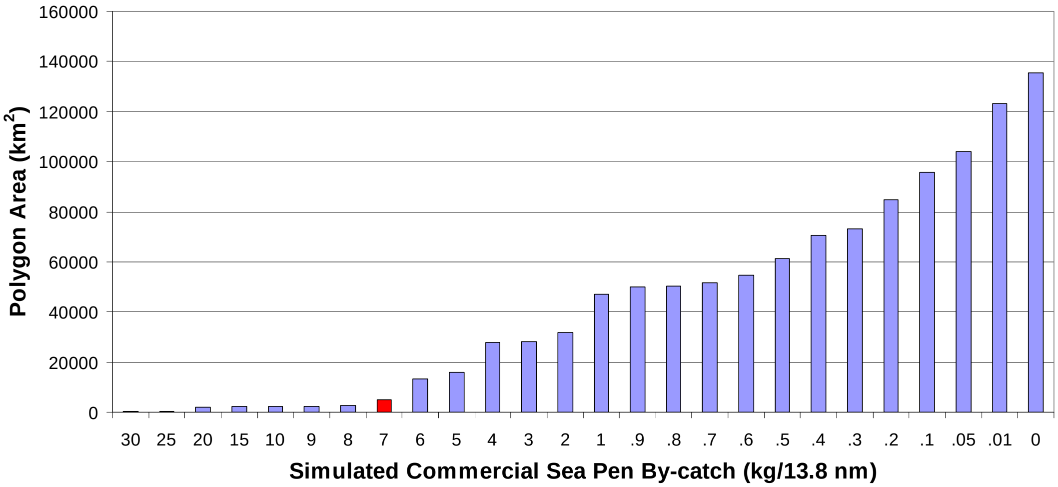

Figure 26. Area (km^2) occupied by tows with decreasing sea pen catch weight from ≥30 kg to >0 kg. The red bar indicates the levels where the greatest difference in area occupied occurs between successive catch weight values.

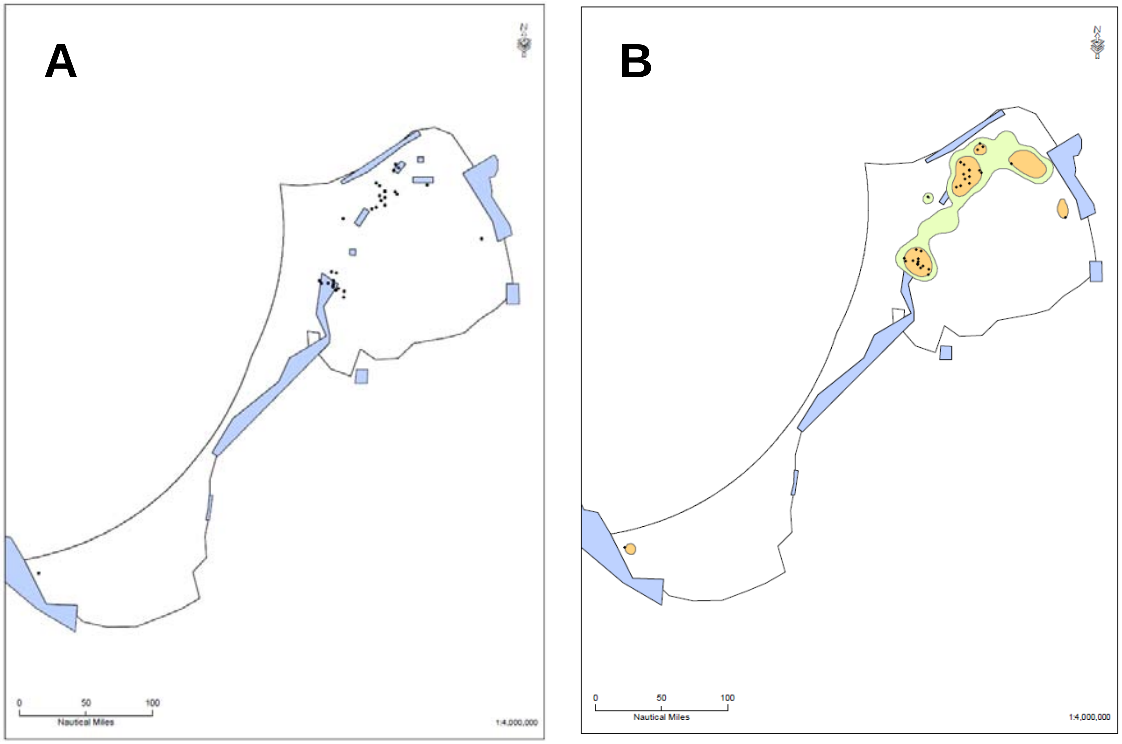

Figure 27. A) Location of simulated commercial catches with ≥7 kg of sea pen by-catch. Locations of the closed areas in the NRA are indicated as shaded light blue areas. B) Polygons depicting the area occupied by simulated commercial sea pen catches in the NRA ≥7 kg (inner darker orange coloured polygon) and ≥6 kg (outer lighter green coloured polygon). This represents a 2.6 times increase in area between the thresholds.

Figure 28. Photograph of a 5.7 kg catch of sea pens of mixed composition taken from Flemish Cap. *Halipteris finmarchica* (n=15, 0.55 kg), *Anthoptilum* sp. (n=363, 5.11kg), (*Funiculina quadrangularis* (n=8, 0.032kg), *Umbellula lindahli* (n=1, 0.017 kg), *Distichoptilum gracile* (n= 1, 0.008 kg) also present but not visible). (photo courtesy of F. J. Murillo, IEO-Vigo).

Anticipated Impact on the Commercial Fishery of Using a 7 kg Encounter Threshold

The simulation model was run using 2000 randomly selected commercial trawls from data falling within the 95% confidence interval of the 2010 VMS data (see Cogswell et al. 2011 for description of all input layers). Fishing in 2010 was restricted to within the fishing footprint and outside of the closed areas (Figure 29). The model utilized the sea pen biomass raster detailed above, and produced a highly skewed cumulative catch distribution as seen in the research vessel sea pen catch data (NAFO 2008a).

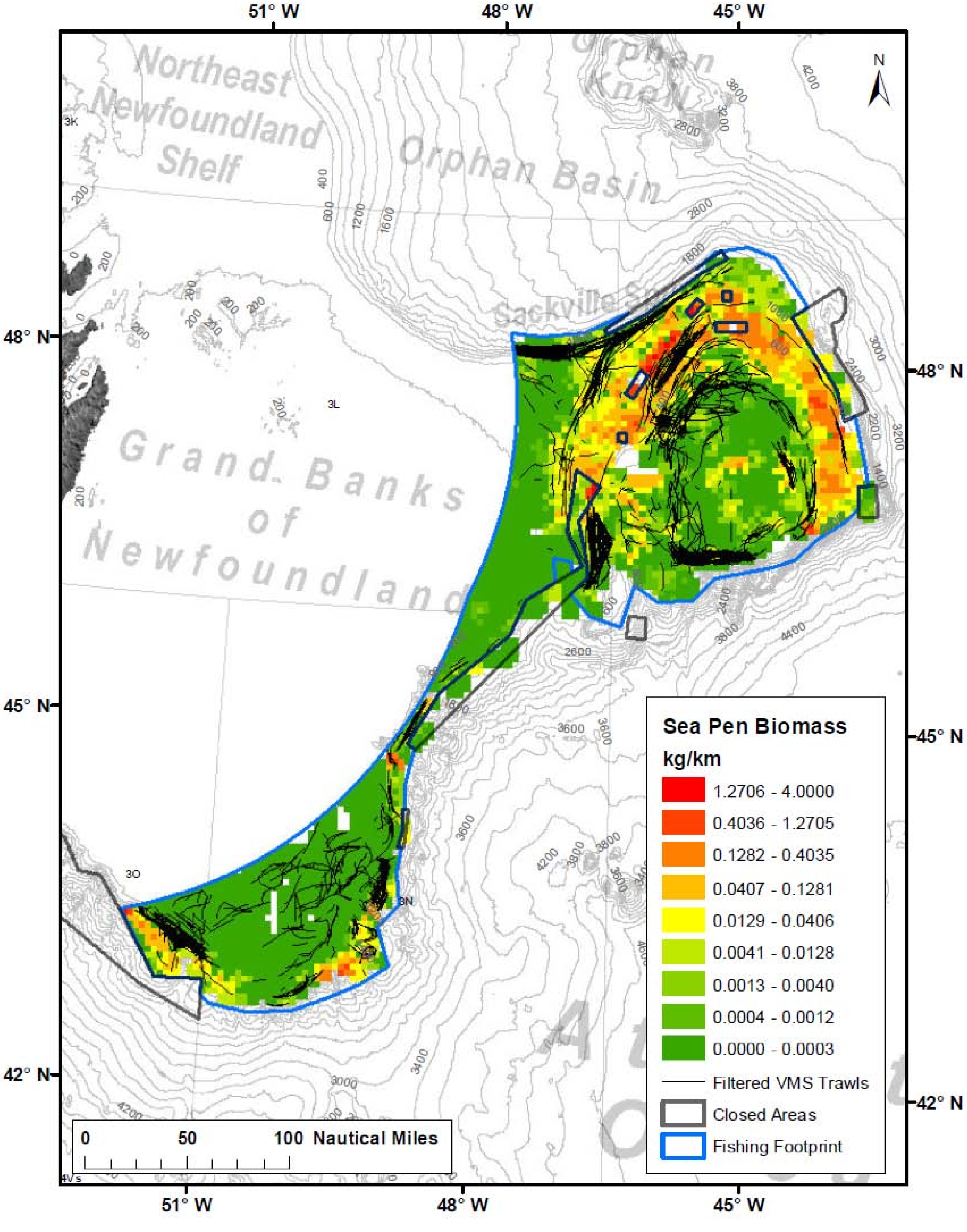

Figure 29. Location of 2000 randomly selected VMS trawl lines from the filtered 2010 fishing effort distribution superimposed over sea pen biomass as determined from Spanish/EU research vessel survey data.

Table 4. The number and percent of groundfish trawls catching sea pens at various encounter threshold levels. Trawl lines were randomly selected from VMS data falling within the 95% CI of the mean of that data. The shaded row indicates the proposed sea pen encounter threshold.

Threshold (kg per tow)	No. Filtered VMS Trawls	% Filtered VMS Trawls ≥ Threshold
16	2	0.1
15	5	0.3
14	6	0.3
13	6	0.3
12	6	0.3
11	6	0.3
10	6	0.3
9	8	0.4
8	8	0.4
7	8	0.4
6	15	0.8
5	17	0.9
4	26	1.3
3	41	2.1
2	72	3.6
1	129	6.5

According to this model the current sea pen encounter threshold of 60 kg of live coral would rarely if ever be caught. Reducing the encounter threshold to 7 kg would affect only 0.4 % of trawl sets fishing with the 2010 fishing effort distribution (Table 4). Following the fishing effort pattern of 2010, catches ≥ 7 kg are found in three locations (Figure 30). Two of these are on Flemish Cap and one just south of the Flemish Pass closed area. There are 8 VMS trawls, and the mean trawl length is 31 nm, with the shortest 13 and the longest 58 nm. Therefore the trawl length accounts for some of the values being so high. Figure 31 shows a close-up of 6 VMS tracks near the sea pen closed areas on Flemish Cap. Research vessel sea pen by-catch is high in adjacent unfished areas.

There are two morphologies of sea pens in the NRA. One group is short and fleshy with *Pennatula aculeata* being the most common, and the other group is long and thin and sometimes referred to as sea whips. *Anthoptilum grandiflorum* and *Halipteris finmarchica* are the most common of the second form. Figures 32 and 33 show that most of the 2010 fishing effort above the proposed threshold of 7 kg would impact the long thin species, or sea whips.

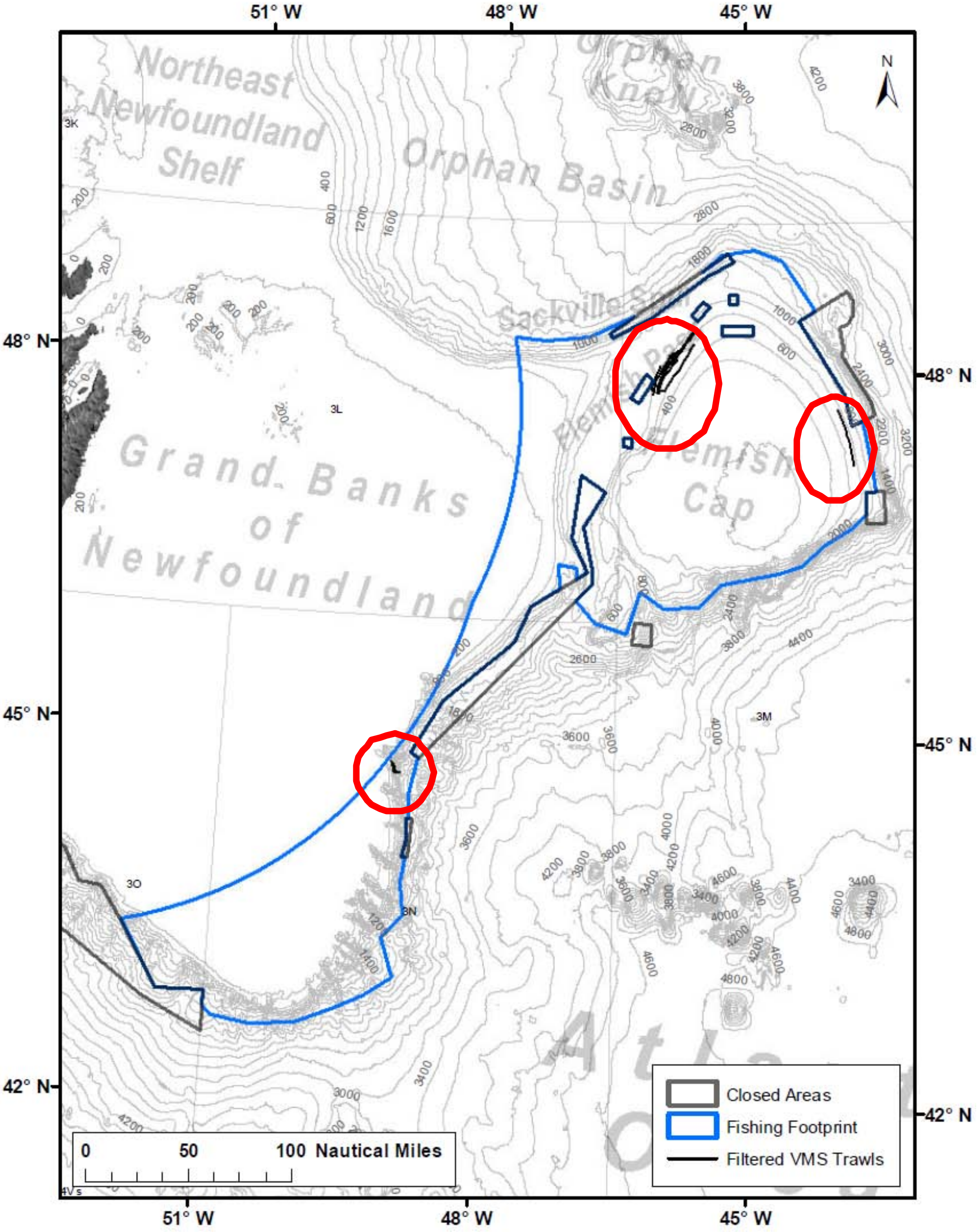

Figure 30. Location (red circles) of commercial trawls (black lines) expected to have caught ≥ 7 kg of sea pens in the NRA in 2010 (data from filtered VMS data set detailed in Cogswell et al. 2011).

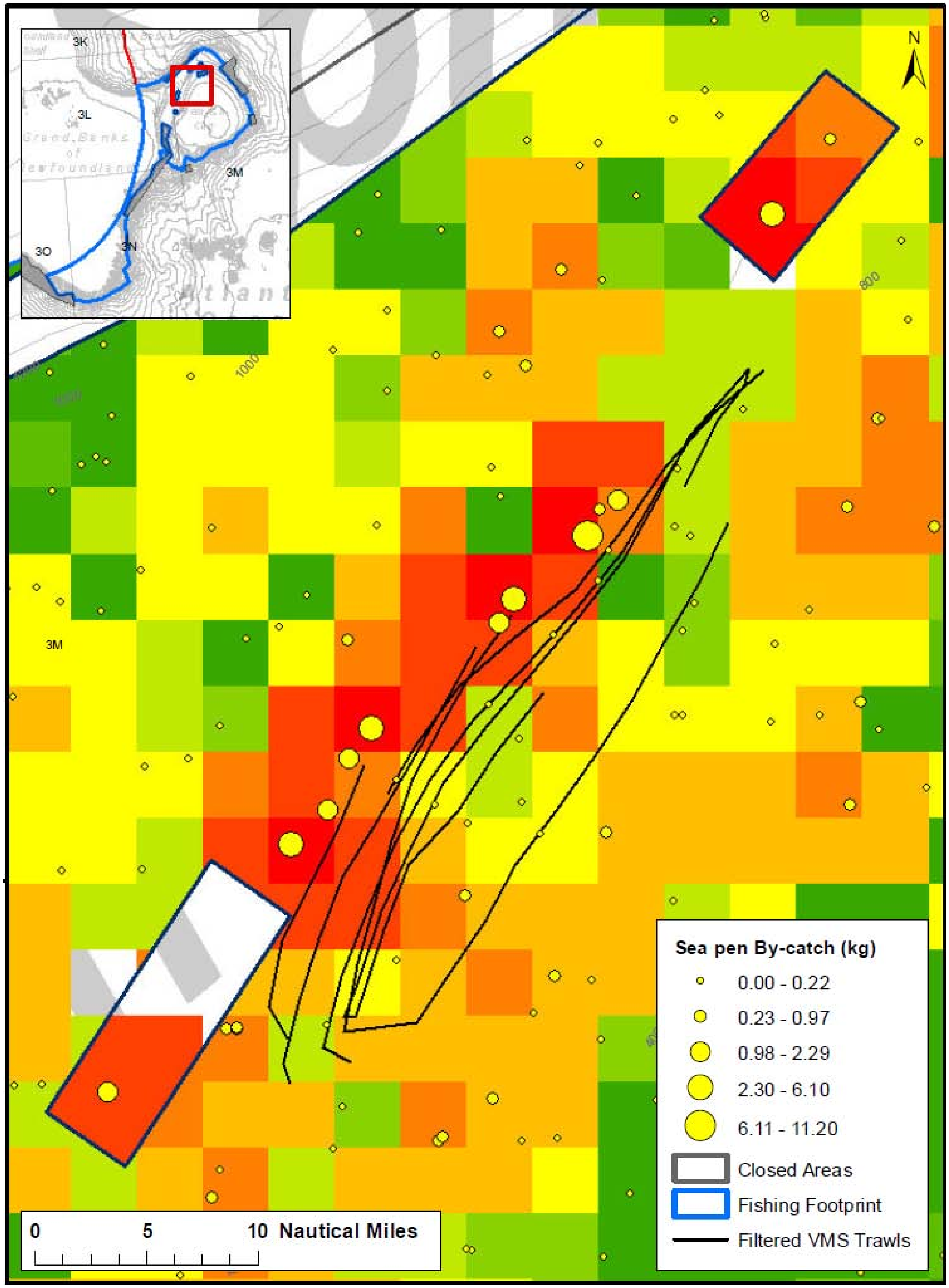

Figure 31. Location of the 6 commercial trawls (black lines) expected to have caught ≥ 7 kg of sea pens in the NRA in 2010 (data from filtered VMS data set detailed in Cogswell et al. 2011). The 5 x 5 km grid sea pen biomass surface is shown along with individual research vessel catches.

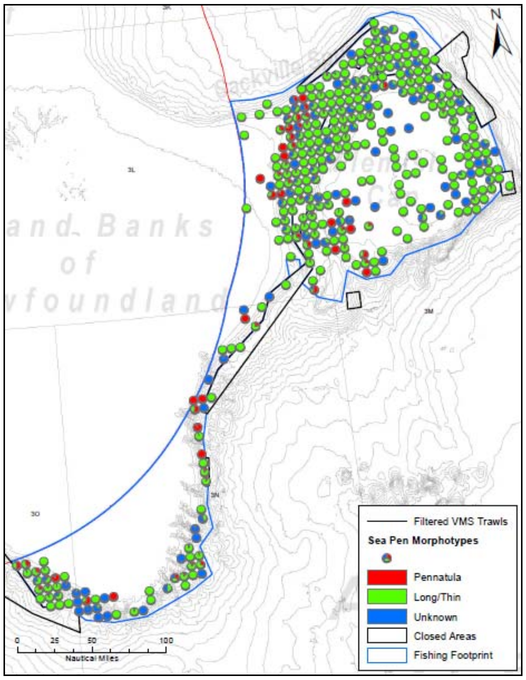

Figure 32. Relative proportion of short fleshy sea pens (*Pennatula* spp.) and long thin sea whips in the NRA as determined from research vessel surveys.

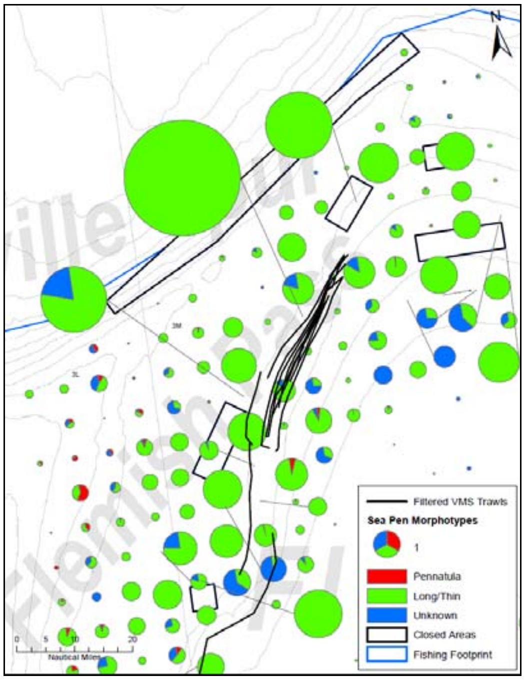

Figure 33. Close up of the area with greatest effort above the proposed sea pen threshold of 7 kg. The relative proportion of short fleshy sea pens (*Pennatula* spp.) and long thin sea whips in the NRA as determined from research vessel surveys is illustrated. Size of the circle represents the size of the catch (biomass). Location of commercial trawls (black lines) expected to have caught ≥ 7 kg of sea pens in the NRA in 2010.

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

Murillo et al. (2011) reported Pennatulaceans in 36% of 910 research vessel survey tows in the NRA. Quantitative assessment of significant adverse impact of bottom-contact gear on sea pens in this area requires information on gear efficiency and selectivity in order to assess the nature of removals (additional comments made for sponges above apply here as well). Figure 34 highlights areas outside of the closed areas where significant interactions between fishing and sea pens may have occurred. As for the sponges, this map cannot separate out cells with high effort and low sponge from those with high sponge and low effort. Figure 35 provides a further refinement by identifying only cells where simulated commercial sea pen by-catch above 7 kg occurred in areas that were fished in 2010.

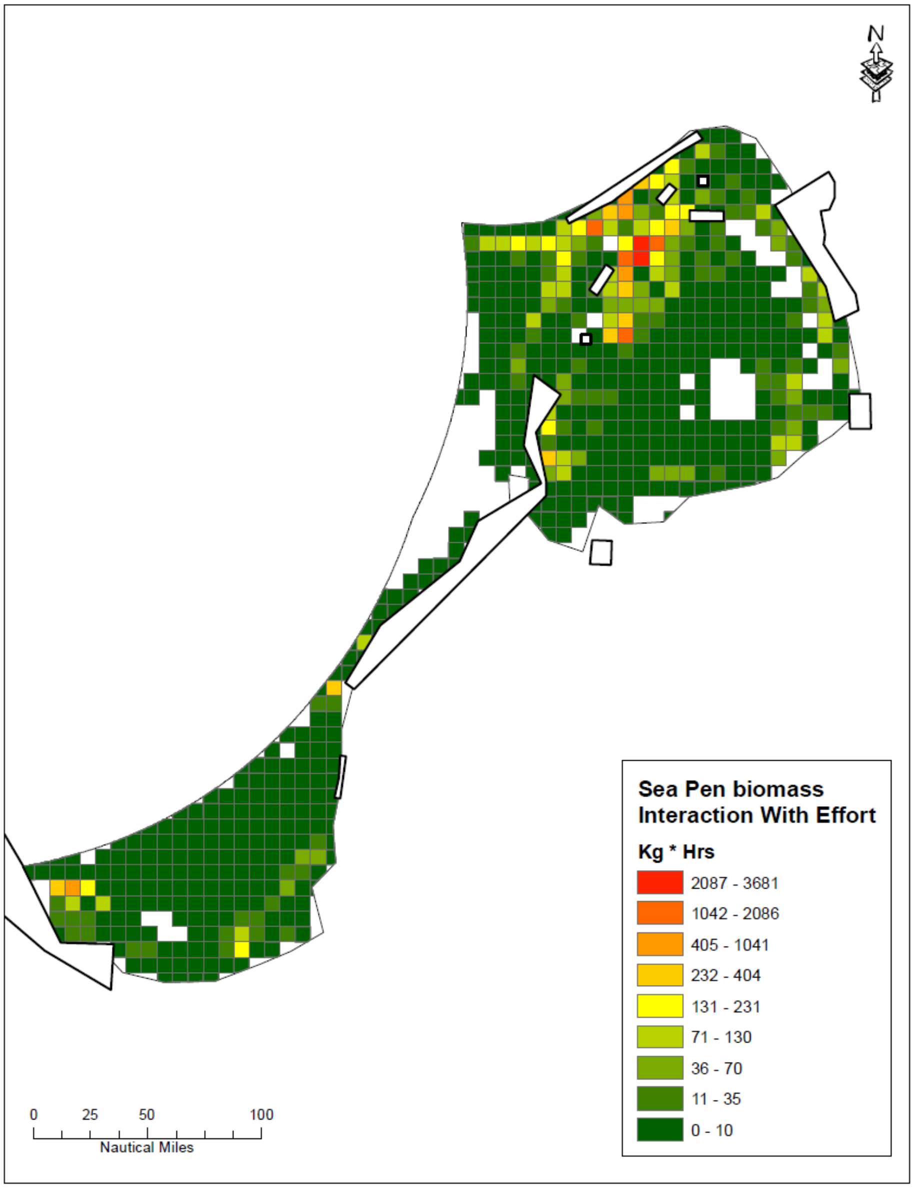

Figure 34. The interaction between fishing effort and sea pen biomass is identified for each 12.5 km^2 grid. Red and orange colours signify areas of relatively high effort in areas of generally high biomass (Figure 27). Green colours signify low potential for fishing interaction with sea pens.

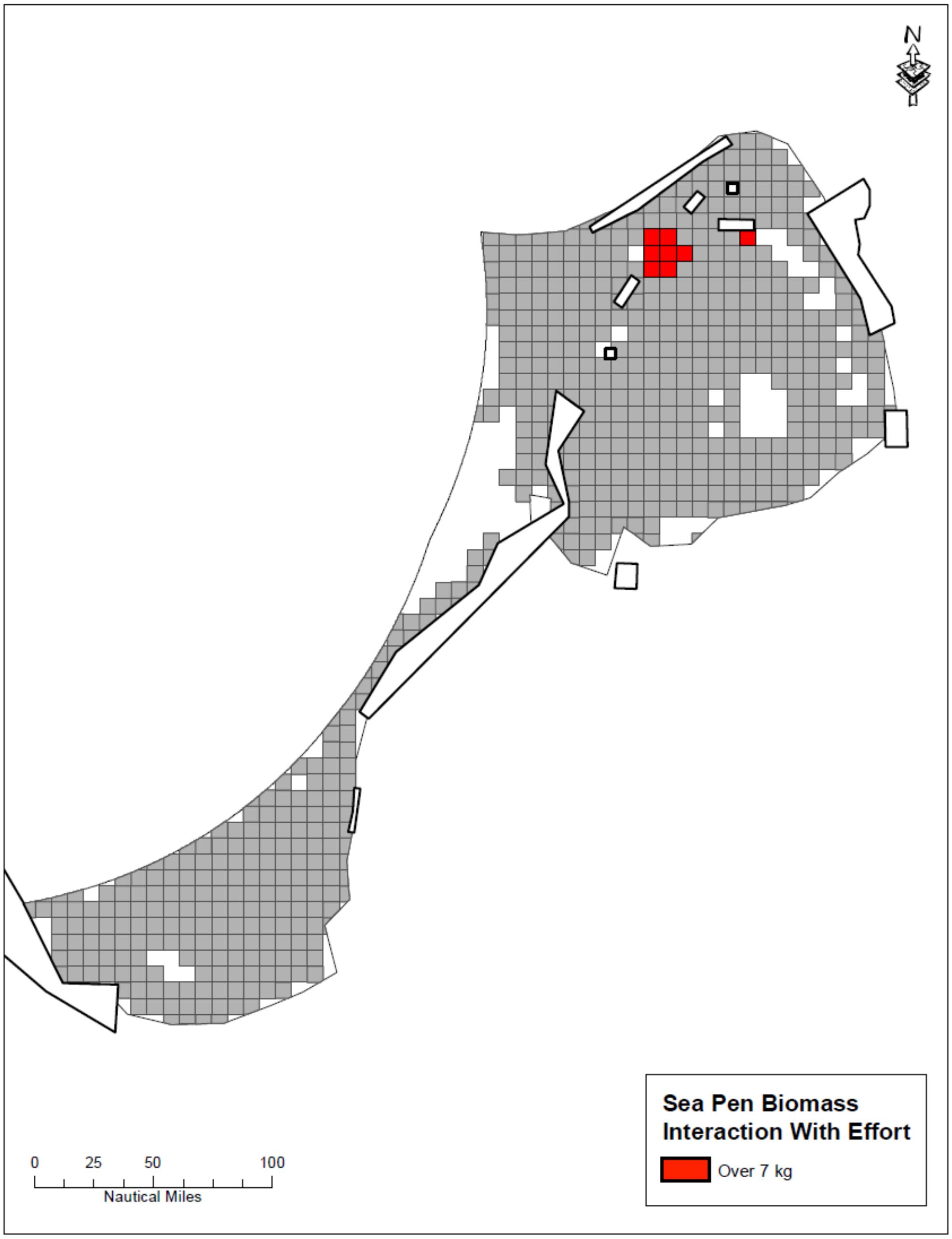

Figure 35. This interaction map highlights cells where fishing effort overlaps with simulated commercial by-catch in excess of 7 kg. These are areas where significant adverse impact of fishing on sea pens has the highest probability of occurring.

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

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

Gear Efficiency and Selectivity on Sea Pens

Troffe et al. (2005) conducted a study of the effects of a shrimp beam trawl and prawn traps on sea whips (*Halipteris willemoesi*) at two bays on Clio Channel, south central coast of British Columbia, Canada. No sea whips were caught in six beam trawls despite maximum mean densities of adults of about 18 m^2 and of juveniles of about 90 m^2, determined from underwater video. For this gear and species both gear selectivity and efficiency are 0%. The authors analyzed by-catch from 600 prawn trap sets at Turnour Bay, and found about 5% had sea whips entangled in the gear. The low efficiency of beam trawls in sampling sea pens was also observed in the Celtic Sea where despite the common occurrence of *Virgularia mirabilis*, as seen in video footage, none were caught by experimenatl beam trawls (Doyle et al. 2011). However this is a species that is able to retract into the sediment and so this low efficiency is likely due to gear avoidance. Tuck et al. (1998) also found no changes in density of this species following experimental trawling carried out repeatedly over an 18-month period.

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

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

Estimating Gear Efficiency of NAFO Research Vessel Trawls

During the summer of 2011, sea pen fields in the Laurentian Channel west of the Grand Banks were sampled with an underwater video device (Campod) operated from the CCGS *Hudson*. This area had been identified using the kernel density GIS model as having significant concentrations of sea pens (Kenchington et al. 2010b). Three video transects (numbered CON 33, CON 34 and CON 35) were completed in the vicinity of known research vessel trawls (Figure 36). The field of view area for the Campod video is roughly 56 x 43 cm or 0.24 m^2.

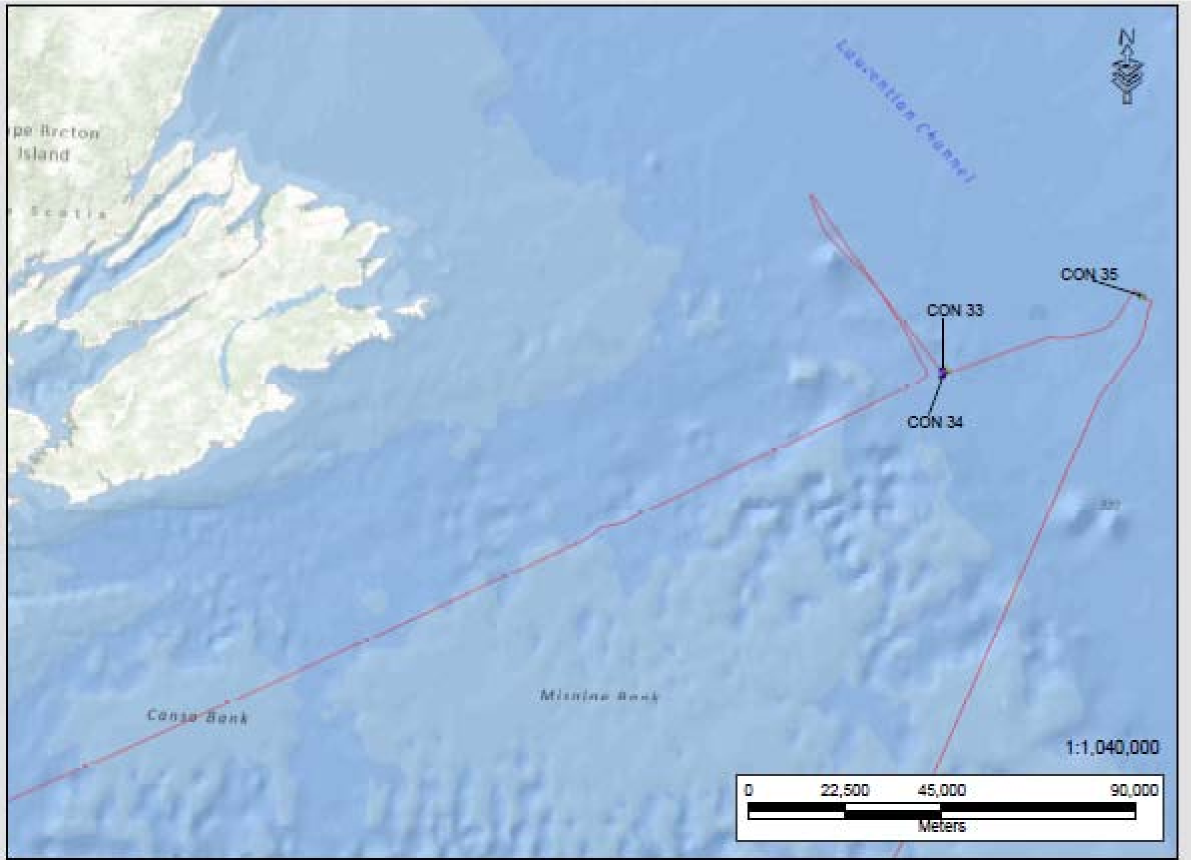

Figure 36. Location of the two video transect lines (CON 33, CON 34) used to determine the in situ biomass of sea pens for assessment of gear efficiency.

Tow transects (CON 33 and CON 34) fall near Canadian research vessel tows conducted with Western IIA trawl gear, and one (CON 35) near research vessel tows conducted with a Campelen trawl, allowing gear efficiency evaluations for these two types of gears. The on bottom length of transect CON 33 is ~1864 m for a total area analyzed covering ~447 m^2 (Figure 37). The total number of sea pens viewed was 423. This is represented by 381 *Anthoptilum* spp. (~90%) and 42 *Pennatula* spp (~10%). This proportion is applied to the predicted abundance in the swept area of the gear and converted to a biomass by using median individual weights for each species. The concentration of sea pens for the area analyzed is ~ 1 sea pen / m^2 of bottom. The comparative 2009 research vessel trawls were made with a Western IIA towed at a constant speed of 3.5 knots for approximately 30 minutes (Figure 38). The total swept area of one set is 0.0404 km^2 or 40,400 m^2.

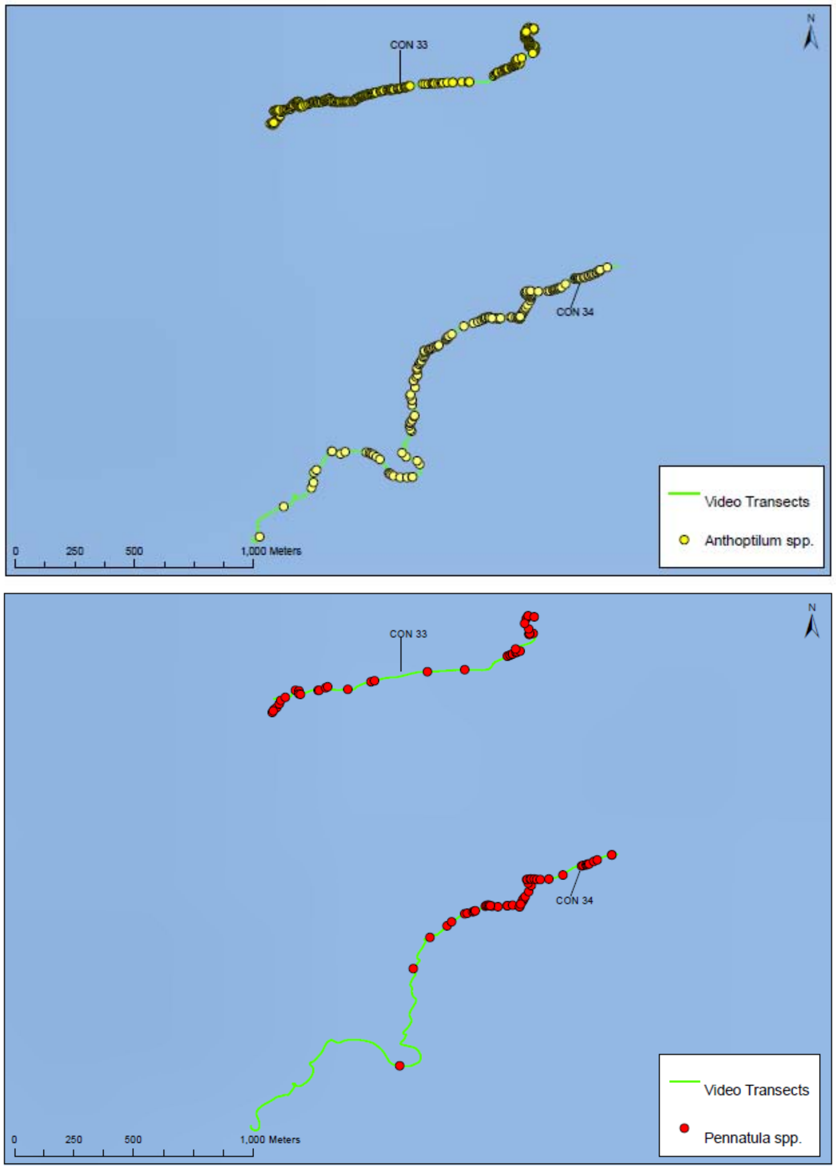

Figure 37. Detail of video transects CON 33 and CON 34 with data records for the sea pen *Anthoptillum* spp. indicated in the upper figure and *Pennatula* spp. in the lower figure.

The comparative trawls (Figure 40) had a sea pen by-catch of 21.22 kg. Given the range of sea pen biomass impacted between CON 33 (572 kg) and CON 34 (259 kg), this amount of by-catch represents roughly 3.7 and 8.2% gear efficiency.

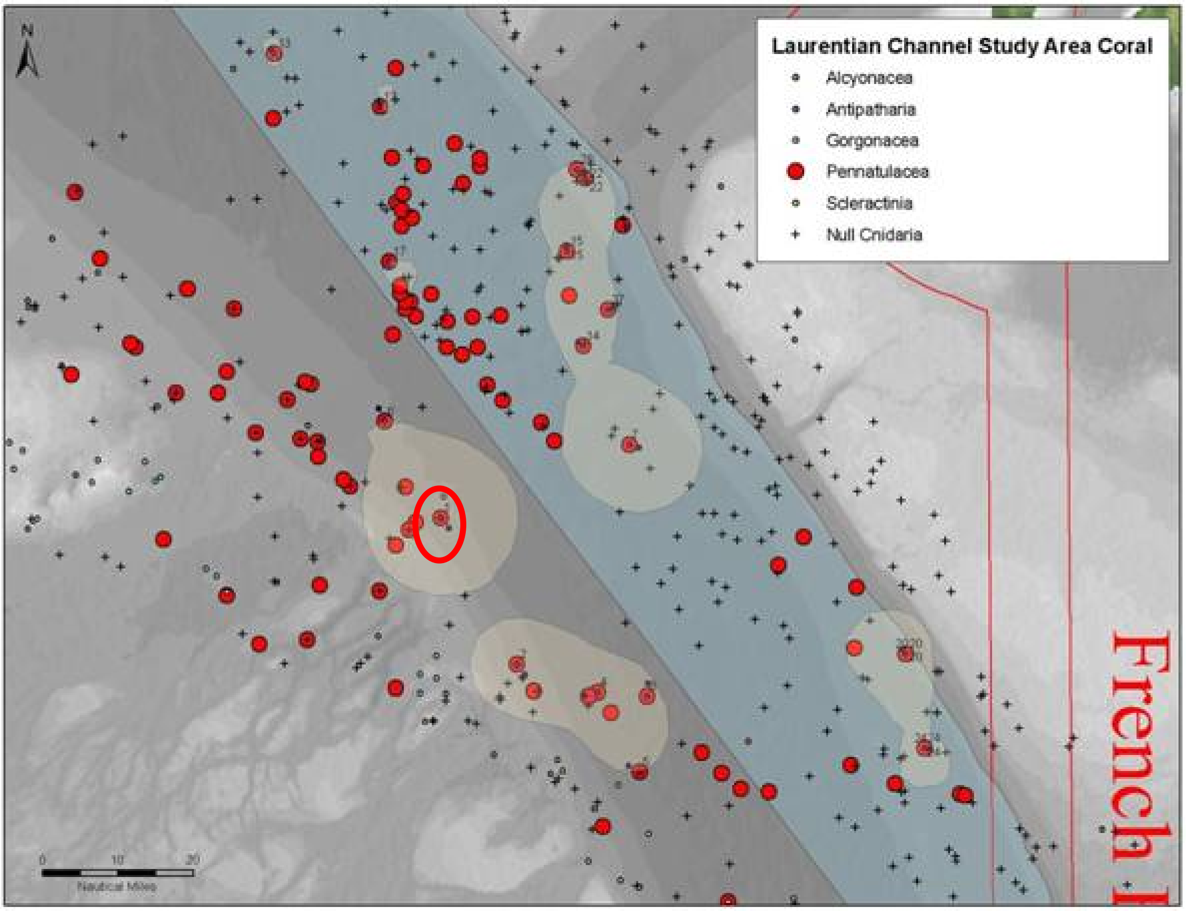

Figure 38. Location of research vessel trawls in the vicinity of the study area. Red shaded circles distinguish trawl sets with sea pen by-catch. Light grey polygons represent areas of significant concentrations of sea pens identified in Kenchington et al. (2010b). The blue area depicts an area of interest for a MPA. The comparative tow for Western IIA gear is circled in red and is very close to the video transects CON 33 and CON 34.

One transect falls within the vicinity of research vessel trawls conducted with Campelen gear (CON 35) (Figure 39). The on bottom length of transect CON 35 is ~2297 m for a total area analyzed covering ~551 m^2. The total number of sea pens viewed was 109. This is represented by 40 *Anthoptilum* spp. (~37%), 10 *Pennatula* spp. (~9%), 58 *Kophobelemnon* spp. (~53%) and 1 *Halipteris* sp. (~1%). This proportion is applied to the predicted abundance in the swept area of the gear and converted to a biomass by using mean individual weights for each species. The concentration of sea pens for the area analyzed is ~ 0.2 sea pen / m^2 of bottom. The comparative 2009 research vessel trawl was made with a Campelen trawl as part of the Canadian research vessel surveys of the area. As noted previously, the best estimate of the swept area for this gear is 23,391 m^2. This area would then hold approximately 4,678 sea pens.

Given the mean weights of *Anthoptilum* spp. of 32 g (n = 86), *Pennatula aculeata* of 3.5 g (n = 30), *Halipteris finmarchica* sp. 15 g (n=31), and *Kophobelemnon stelliferum* 0.5 g (n=50) (F. J. Murillo, E. Kenchington and V. Wareham pers. comm.) from the NRA, an *in situ* biomass can be estimated: of the roughly 4,678 sea pens impacted by the Campelen trawl swept area, 1731 are *Anthoptilum* spp. representing ~ 55 kg, 2479 are *Kophebelemnon* spp. representing ~1.2 kg, 421 are *Pennatula* spp. representing 1.5 kg, and 47 are *Halipteris* sp. representing 0.7 kg. The total sea pen biomass that could be potentially captured in the nearby research vessel trawl, based on these density estimates on transect CON 35, would be ~ 58 kg. Of these genera, *Kophebelemnon* spp. are rarely caught in trawls as they are capable of retracting in the sediment. However, they contribute very little to the overall biomass and so are left in the calculations. The total sea pen by-catch from the 2007 Canadian RV comparative trawl using Campelen gear was ~3 kg. This represents a 5.2 % gear efficiency for sea pens with a Campelen trawl.

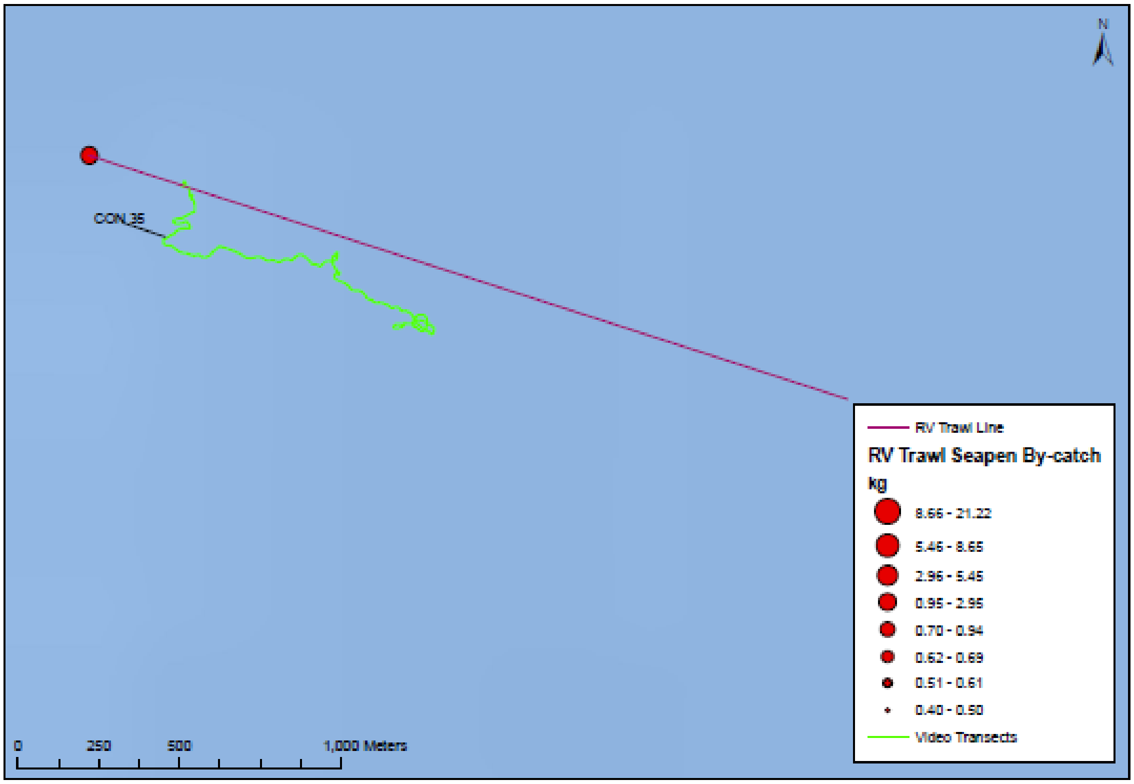

Figure 39. Location of CON 35 in relation to the comparative research vessel trawl done with Campelen gear.

Incidental Mortality

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

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

Recoverability

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

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

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

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

Move-on rules for Sea Pens

NAFO has four areas closed to bottom-contact gear to protect sea pens on Flemish Cap. Sea pen fields in the NRA are concentrated in shallower water than the sponge grounds and so it is more difficult to establish a depth-based move-on rule option. Murillo et al. (2010) identified the location of significant locations of sea pens in the NRA from research vessel data. The threshold value for identification of sea pen fields was 0.5 kg. To determine the maximum distance that a vessel would have to move (either shallower or deeper), we calculated the centroid of each polygon in ARCGIS. The "feature to point tool" was used to get the centroid point location for each of the 6 polygons (Figure 40) (note a 7th polygon was too small to do this calculation with). These area-specific move-on distances range from 4 km to 20 km or 2.4 to 10.7 nm. However, this may have the consequence of forcing the vessel off the fishing grounds, as the sea pen habitat is quite extensive. More work should be done on this issue to accommodate fishing activities while protecting the sea pen fields.

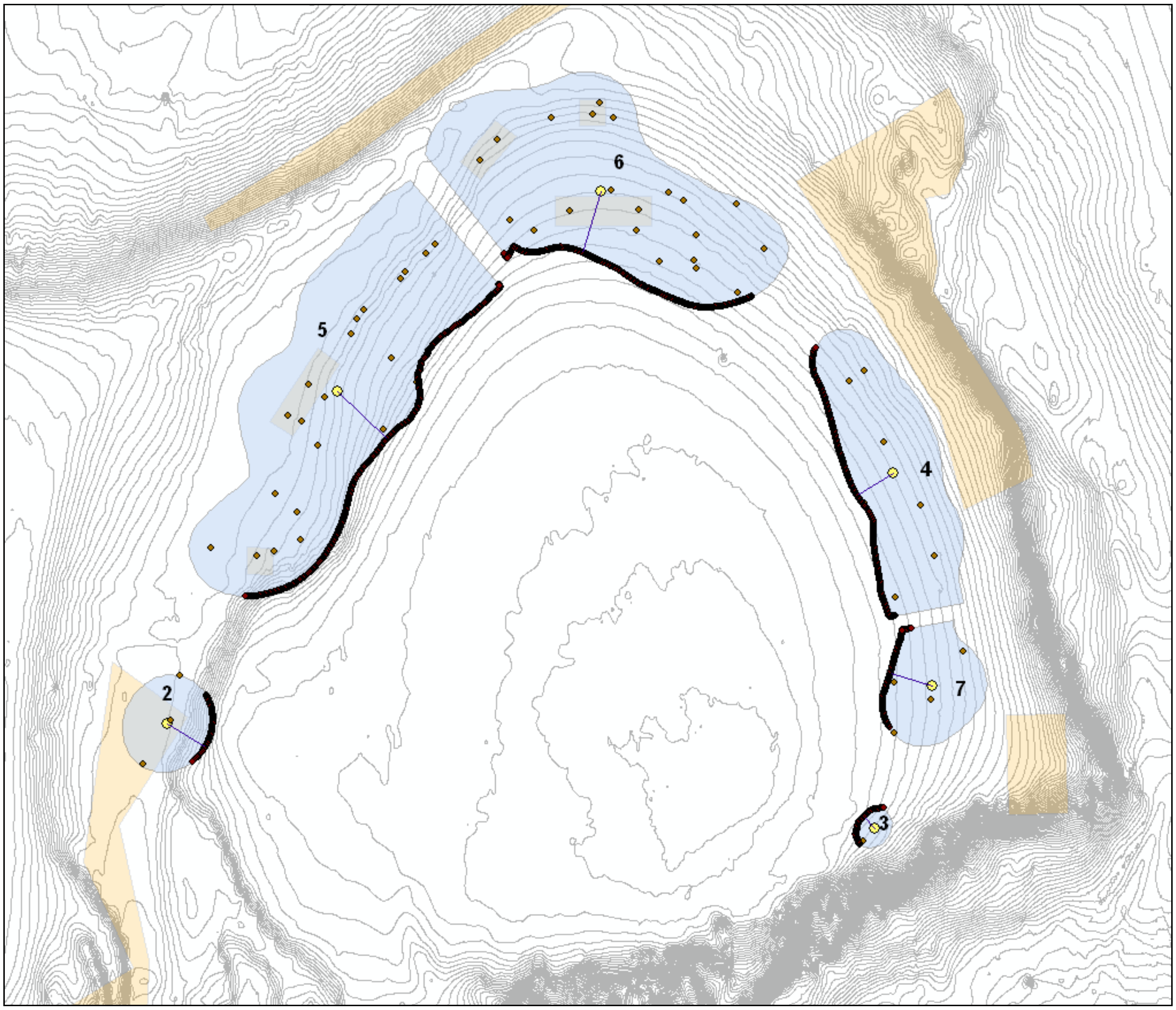

Figure 40. Location of significant area polygons for sea pens as presented in Murillo et al. (2010). For each line polgon the centroid is calculated and the distance to the closest edge was determined (Table 5).

Table 5. Distances from the polygon centroid to the shallow leading edge as illustrated in Figure 39.

Polygon Number (Figure 41)	**Distance from Centroid to Leading Edge km (nm)**
2	12.8 (6.9)
3	4.4 (2.4)
4	12.2 (6.6)
5	19.8 (10.7)
6	18.3 (9.9)
7	12.6 (6.8)

Conclusions

Sea pen fields have been classified as vulnerable marine ecosystems by NAFO. In this report we recommend that a 7 kg encounter threshold of sea pens be put in place. If the 2010 VMS effort pattern is followed, this change would affect less than 0.5 % of fishing trawls in the fishing footprint. Although this encounter threshold value is small, it represents 100s of individuals and is shown to represent sea pen fields through our quantitative analyses based on occupied habitat area. Further, although gear efficiency for sea pens is low (less than 10% in our study and as low as 0% in the literature), incidental mortality can be high, ranging from 40 to 50% in the literature over time frames of up to one year post trawl. This means that a catch of 7 kg could cause incidental mortality to an additional 3.5 kg of sea pen on the sea floor. Recovery is not well studied but recruitment may occur annually or every few years but can be spatially unpredictable and patchy. There is some evidence that cumulative impacts may cause local depletion of sea pen fields. To determine the maximum distance that a vessel would have to move after an encounter (either shallower or deeper), we calculated the centroid of each polygon in ARCGIS. These area-specific move-on distances range from 4 km to 20 km or 2.4 to 10.7 nm. However, the effective of such movements may be to force the vessel from the fishery and so more thought should go into this issue.

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