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The Use of Density Analyses to Delineate Sponge Grounds and Other Benthic VMEs from Trawl Survey Data

by

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Introduction

The UN General Assembly Resolution 61/105 (UNGA, 2007), and the supporting International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO, 2009), identified cold water corals and sponge fields as vulnerable marine ecosystems (VMEs) and called upon member states and regional fisheries management authorities, such as NAFO, to adopt measures for their protection from serious adverse impacts from fishing operations. Within NAFO, the Working Group on the Ecosystem Approach to Fisheries Management (WGEAFM) was tasked with mapping significant concentrations of corals and sponges, while the *Ad hoc* Working Group on Fisheries Managers and Scientists (WGFMS) has discussed recommendations for encounter protocols for fishing vessels taking coral and/or sponge bycatch. The best available data for these applications comes from trawl survey data. Commercial data is incomplete and deemed unreliable at present, and *in situ* benthic surveys have been restricted to only a few small areas. Trawl survey data has broad coverage and uses similar sampling tools (trawls) to that of the commercial fisheries operating in the area, which makes the results more directly comparable than data collected using traditional benthic sampling tools such as grabs, sleds, and photographic imaging. However, trawls are not good benthic samplers for detailed analyses and so a general approach of using trawl data to identify the general location of the coral or sponge concentrations and following up with detailed benthic surveys using photographic methods to delineate the grounds more precisely is recommended. Both the need to map significant concentrations and to develop encounter protocols requires definition of what constitutes a sponge ground or coral bed.

The WGEAFM was the first to consider this question in their 2008 report. In considering the term “significant” for delineating concentrations of coral in the NRA, the WGEAFM developed a protocol using plots of the cumulative catch weight distribution from the groundfish trawl surveys (NAFO 2008a,b). The distribution of cumulative catch weights was highly skewed, with most tows catching small quantities, and only small numbers of tows with larger catches. The objective of their analysis was to identify bycatch weight thresholds which could be considered to be ‘evidence of a VME’, by exceeding a chosen threshold weight for each taxon, and then to use this information to map the location of the significant bycatch. This approach was independently used by the South Pacific Regional Fisheries Management Organization (SPRFMO; Penney et al. 2008) to evaluate commercial data for implementing encounter protocols.

The WGEAFM was unable to select a threshold for significant concentrations of coral using biological criteria, but opted to use the upper 97.5 quantile as a standard (2.5% of the sponge catches were above this value) due to the statistical relevance of this measure (NAFO 2008a,b). They argued that for some taxa there may be good reasons to choose lower thresholds and advocated the 90% quantile for their large gorgonian taxon (10% of RV tows capturing the taxon met this target), on the basis that these corals are particularly vulnerable to breakage and so the data are likely biased at the small catch end of the distribution by pieces of coral rather than whole colonies.

Faced with a similar challenge, Penney and colleagues (2008) remarked that in the absence of scientific rationale:

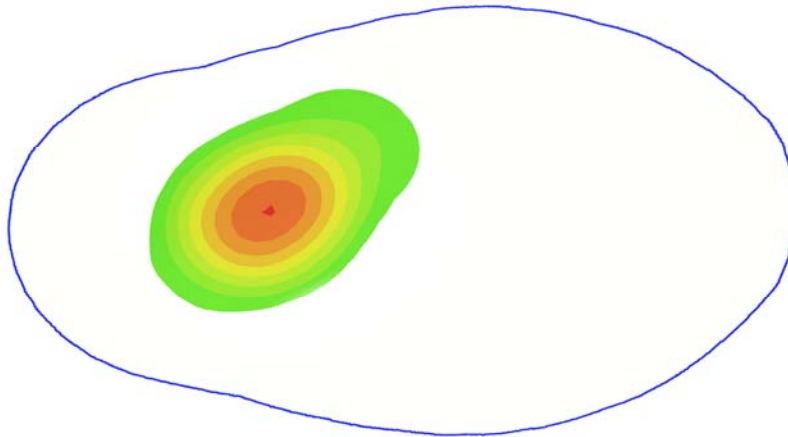
“The choice of what weight percentile to use as a threshold for determining evidence of a VME is essentially a management choice, amounting to choosing what percent of tows should qualify as VMEs, based on the data analyzed. This choice needs to be made between the extremes of presence / absence (any occurrence of a vulnerable species in a catch would be considered to be evidence of a VME) and high weight thresholds (only the largest recorded vulnerable species by-catch weights would qualify as evidence of VMEs).”

With the absence of any specified definition, or management objective, for ‘evidence of a VME’, they used a more conservative value (50% quantile = median) than proposed by WGEAFM.

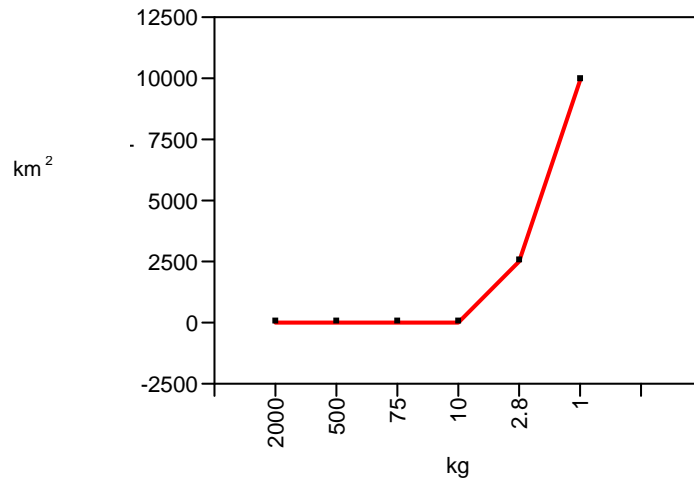
However, it may be possible to provide a biological basis for the selection of the appropriate threshold which would define when catches came from VME areas. Our methodology depends on a critical property of the distribution of these species: that they are aggregated in dense beds with only low density areas surrounding them. There are three lines of evidence to support that this is the case, separate from *in situ* observations elsewhere.

First, the cumulative frequency distribution of the trawl catches is highly skewed towards large numbers of tows catching only small amounts of coral or none at all. Only a few take very large catches and intermediate-sized catches are not common (NAFO 2008 a,b). Second, the catches of coral are not significantly different between the 15 min tows of the Canadian surveys and the 30 min tows of the Spanish/EU surveys (NAFO 2008a,b). The shorter tows are already larger than the coral beds and so once encountered continuing to tow longer does not significantly increase the catch, at least for relatively short tows such as these. Third, when the positions of the high concentration of coral were mapped they most commonly were grouped together forming “key locations”, with few single catches of large coral biomass.

Our work builds on this last point. If the tows with highest catches of coral or sponge are clumped within ‘key locations’ then there should be a discontinuity between those large catches and smaller catches caught nearby but outside the main concentration. The area occupied by these high catches serves as a useful metric for capturing this phenomenon. The area occupied by the very largest of the catches should not dramatically increase as additional nearby catches of slightly less weight are added. However, the area necessary to represent the data will precipitously increase when much smaller catches outside the extent of the highest weight records are added. This concept is illustrated below, with red representing high catches down to the blue boundary representing smaller catches:



We tested this concept by creating feature classes connecting tow locations of similar catch weights in localized areas by eye and calculating the area occupied for successive catch weight increments. We observed a common pattern that confirmed our ideas:



The area occupied (km²) by the catches above a certain level (here 10 kg) did not change dramatically, but smaller catches showed an exponential increase. Using this example, 10 kg appears to be the threshold weight which best defines the high density areas.

It was quickly realized that the analyses performed in this way was prone to bias and high subjectivity, especially when “deciding” which points would be incorporated in the boundaries of one location. In an effort to minimize subjectivity we chose a solution using spatial analysis software which would greatly increase the reproducibility of our results.

In applying this approach it should be irrelevant whether sponge grounds are assessed individually or over large spatial scales. Equally, there should be no difference between surveys with no significant difference in catches, as for example, between the Canadian and Spanish/EU surveys. This is because the sponge grounds and coral beds are climax communities with maximum habitat occupancy by the dominant species. Further, by definition and because these are VMEs, they will not have recovered from fishing activities in the past decades. Fishing would have the effect of reducing the area by eroding the periphery occupied by the sponge bed or fragmenting the bed over short distances (trawl width), but should not effect the pattern of transition with increasing catch weight. In short, the method should be suited to a wide variety of applications to similar macrobenthic species in a wide variety of locations. However, it will be important to have large numbers of tows with good spatial coverage of the analytical extent, and the thresholds values will differ among target species with different catchability and biological properties.

Sponge Density Analysis Methods

ArcGIS 9.2 (ESRI Canada Limited, Toronto, Ontario) was used to facilitate the process of creating a density map of sponge distribution along the Eastern Grand Banks and Flemish Pass/Cap area (Figure 1). The sponge records used for the analysis come from by-catch collected by Fisheries and Oceans Canada Research Vessel (R/V) Fisheries Surveys conducted between 1995 and 2008. These records were filtered for points within the NAFO Regulatory Area (NRA) which resides outside of Canada’s Exclusive Economic Zone (EEZ). Each of the 257 R/V sponge records in the NRA were collected with an Engel 145 otter trawl during 15 minute tows. In tows where only a few records were seen, each sponge was weighed individually; however, large catches were usually estimated to the 100 or 1000 kg level to expedite the process.

The sponge data were plotted in ArcGIS 9.2 using the UTM projected coordinate system North American Datum 1983 Zone 23 (Figure 1). The ultimate goal of the following model was to map sponge density and subsequently determine the area of polygons that follow density contours that fully encompass points representative of decreasing weight thresholds (>2000 kg, >1000, >500, >100, >90, >80, >70, >60, >50, >40, >30, >20, >10, >1, >.01). These thresholds were chosen to capture the few large tows and then to represent the majority of the data in equal 10 kg weight bins.

Model Builder, an ArcGIS 9.2 utility, was used to create the majority of steps necessary to create the polygons from which total area was determined. Figure 2 is a graphic output of the model, with the red circle representing the input data, the orange boxes representing the ArcGIS tool utilized, the blue ovals representing the adjustable variables for the tools to which they are attached, and the green ovals representing the output derived from each tool. The “Kernel” Density tool (Figure 2A) creates a density raster output (Figure 2B) by defining a circular neighbourhood (search radius – Figure 2C) around each cell, which for the preliminary analysis was taken as the default cell size calculated by ArcGIS. This was 1/250th of the smallest axis of the data extent, which for the R/V data was 2939.7 m x 2939.7 m or approximately 8.64 km². The tool then sums the total weight found within the search radius of the cell and then divides that number by the resulting area around each cell. This means that null data, or zero values, when added to the sum do not contribute to the density calculation for that cell. This means that null data, or zero values, when added to the sum do not contribute to the density calculation for that cell. The final result is a running average of features per unit area (Mitchell 2005). The model allows the user to change both the search radius around each cell, the cell size and the data column to be utilized for the density raster. While separate columns representing log, square root and fourth root transformed weights were created as field headings in the input data, early runs of the model indicated few obvious differences in the density raster outputs by utilizing transformed data so only the untransformed data were used for the analysis.

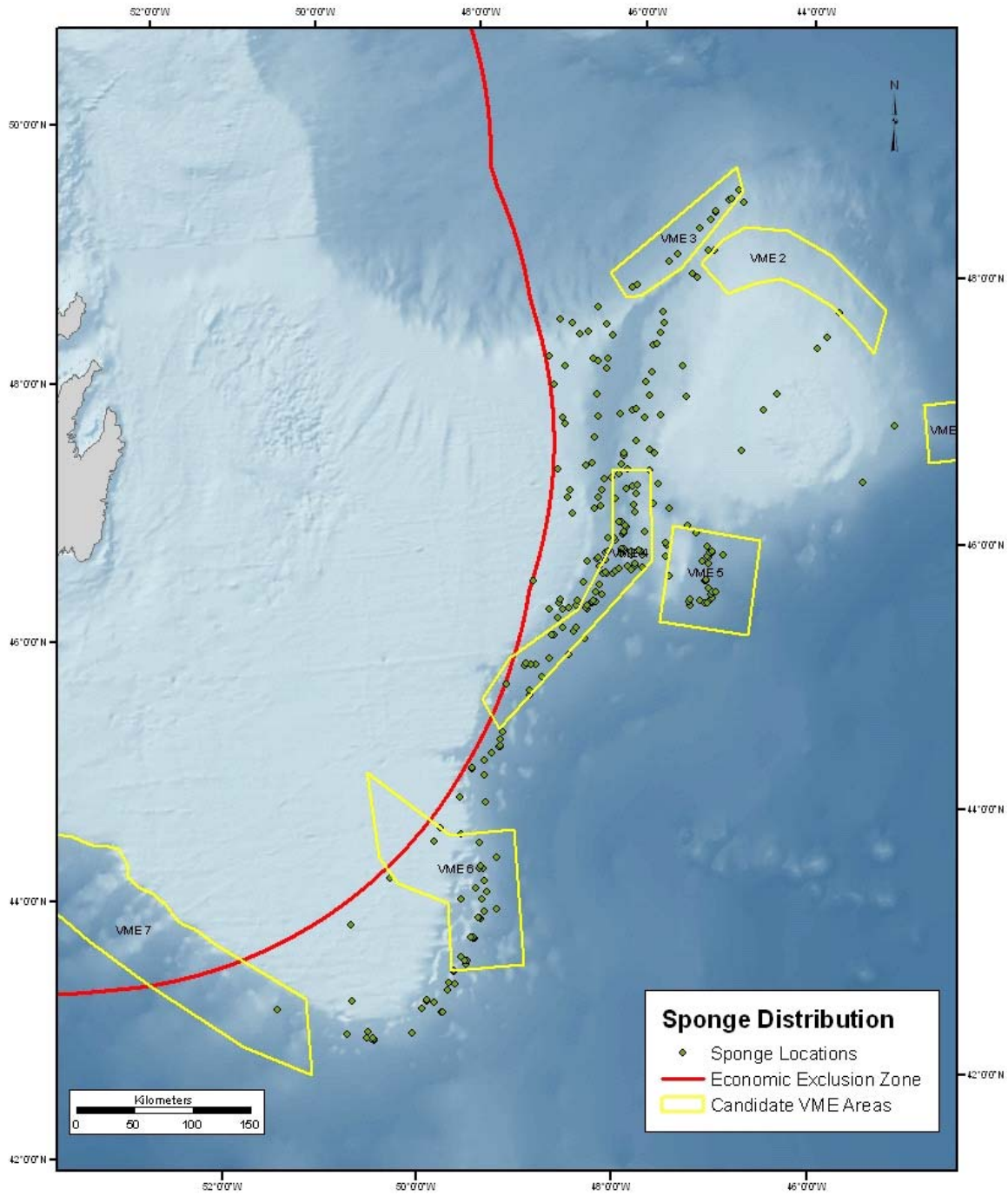


Figure 1. Fisheries and Oceans Canada R/V survey sponge bycatch records collected between 1995 and 2008 in the NAFO Regulatory Area. Only locations with sponge recorded are mapped.

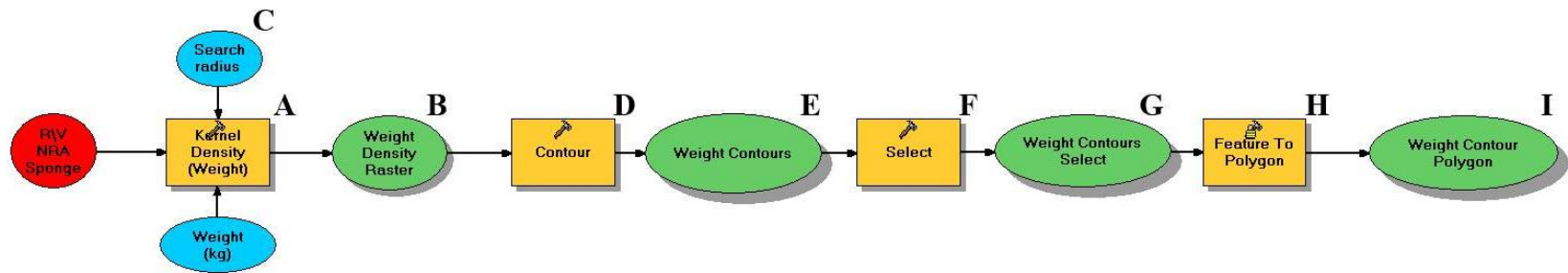


Figure 2. The model created in ArcGIS 9.2 used to describe sponge density in the NRA

Four search radii (10, 25, 37.5 and 50 km) were run through the model as shown in Figure 3. The 25 km search radius (1962.5 km²) adequately recognized some obviously distinct geographic features which are clumped together when using the larger search radii (Figure 3B). As a consequence 37.5 and 50 km radii, while they generally represented density on a regional scale, tended to over-interpret density in low density areas and under-value the true density of areas known to have a high density of sponge (Figure 3C,D). The 10 km search radius produced a fragmented raster output and did not adequately represent the data on such are large scale (Figure 3A). Nonetheless, a 10 km search radius was used recently on the Pacific coast of Canada to perform density analysis on the by-catch of coral and sponge (Ardron et al. 2007). Their justification for using this search radius was based on the median tow length of their commercial trawls below 500 m. The relatively incomplete coverage of Canadian R/V trawl data within the NRA would preclude using the median tow length (~1.4 km) as a means of assigning a search radius as there are too many gaps at this distance. Thus, the search radius must be large enough to incorporate geographic features which obviously contribute to distribution while small enough to not dramatically over-interpret the possible extent in areas where data may not exist.

The final steps of the model (Figure 2D-I), when using a search radius of 25 km, creates output contours of the density data in 0.1 kg/km² increments (Figure 2E), selects only contour values greater than 0 (Figure 2G) and then converts those selected contour lines into a polygons (Figure 2I). The contour value of 1.0×10^{-1} kg/km² was used because an interval of this size can be used to create polygons to adequately represent the entire extent of sponge distribution. It is suggested that future runs of the model should take into account the value derived from the minimum data value/neighbourhood search area to set the interval for the “Contour Tool” (Figure 2D). An example of the output polygons created by the model is shown in Figure 4B.

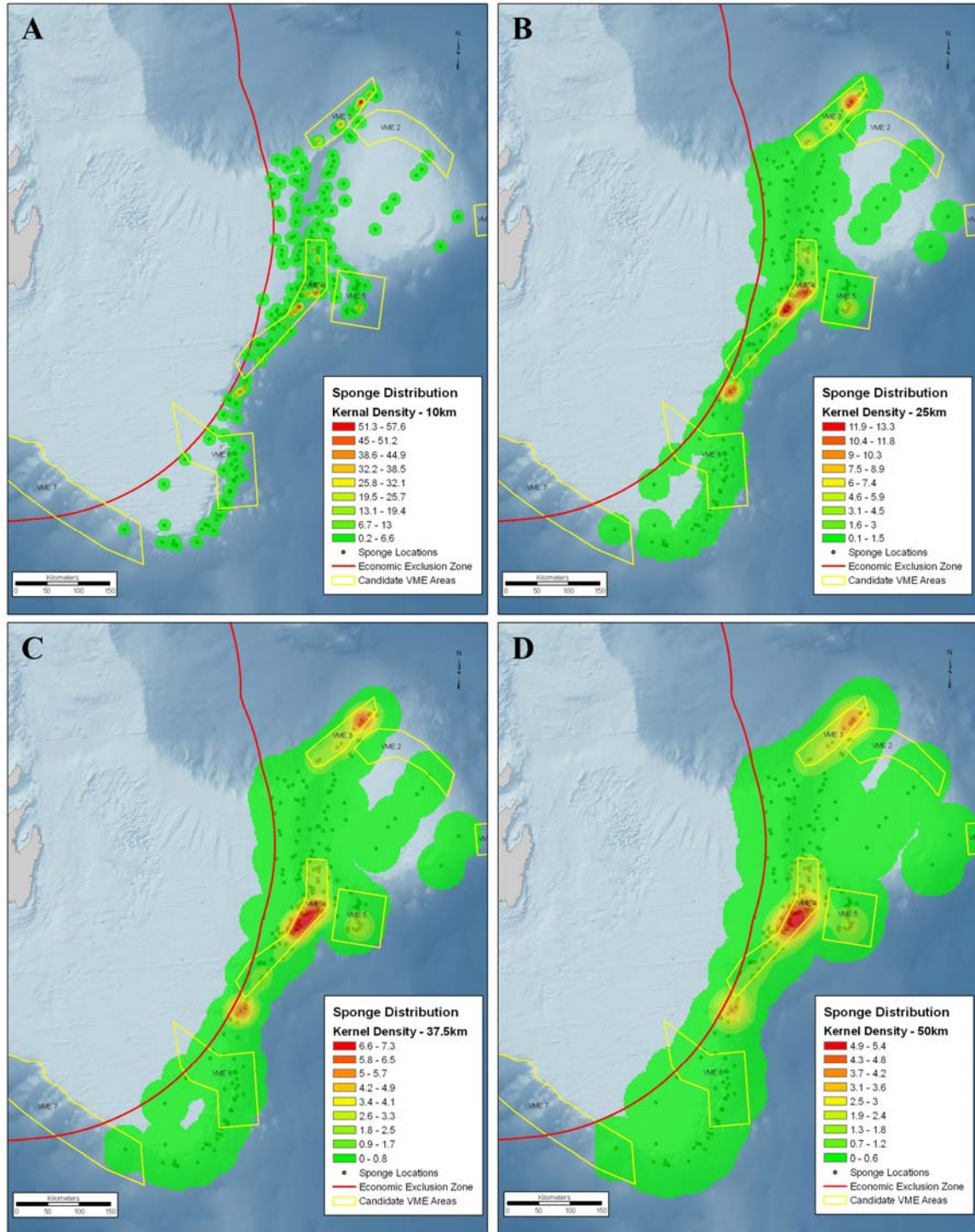


Figure 3. The weight density rasters created by the model for each of the 4 search radii (A-10 km, B-25 km, C-37.5 km, and D-50 km) used in preliminary analyses. The 25 km search radius was deemed the most useful for the present application (see text for details).

The final steps to calculate the minimum surface area following the derived contours that surround the data extent of each threshold, requires some subjectivity and rules for which model builder was not designed. In general, the next step required the user to select all of the polygons inside the minimum area that represents the entire extent of data within the weight threshold. The selected polygons were then exported to a new "Feature Class" and the "Dissolve" tool was used to merge polygons whilst simultaneously calculating the total area of the merged polygons which are representative of the geographic extent of the weight threshold (Figure 4D). Exceptions arise when a point is more than 20 km from its nearest neighbouring point, then the model user will exclude this value from the selected polygon at this weight threshold. In subsequent lower weight thresholds where other points are within 20 km of the previously excluded point, the polygon will then be expanded to encompass this point. This 20 km range was determined through expert opinion and based on the expected extent of sponge grounds based on the trawl locations, while being less than the search radius. This choice also avoids creating large area polygons with single or few points. Where clear delineation between high density areas, using known geographic features such as knolls, channels etc. is obvious to the model user but the search radius utilized creates artificially derived unions between two otherwise separate features, the polygon is manually split along its narrowest axis between the two features to best represent the data.

The next and final step in the process is to merge the polygon areas for each weight threshold using the "Merge" tool. The area for each threshold will then be extracted and then plotted against the by-catch weight threshold to determine the value(s) where the surface area necessary to describe the entire data extent takes a substantial increase.

The alternative method of creating areas from the model involves selecting the contour line that just encompasses the extent of the weight threshold and then using the ET (Edit Tools) Geowizard ArcView extension convert the polyline into a polygon. To calculate the area of the polygon, the "Feature to Feature" tool is used to convert the polygon to a feature class within a Geodatabase.

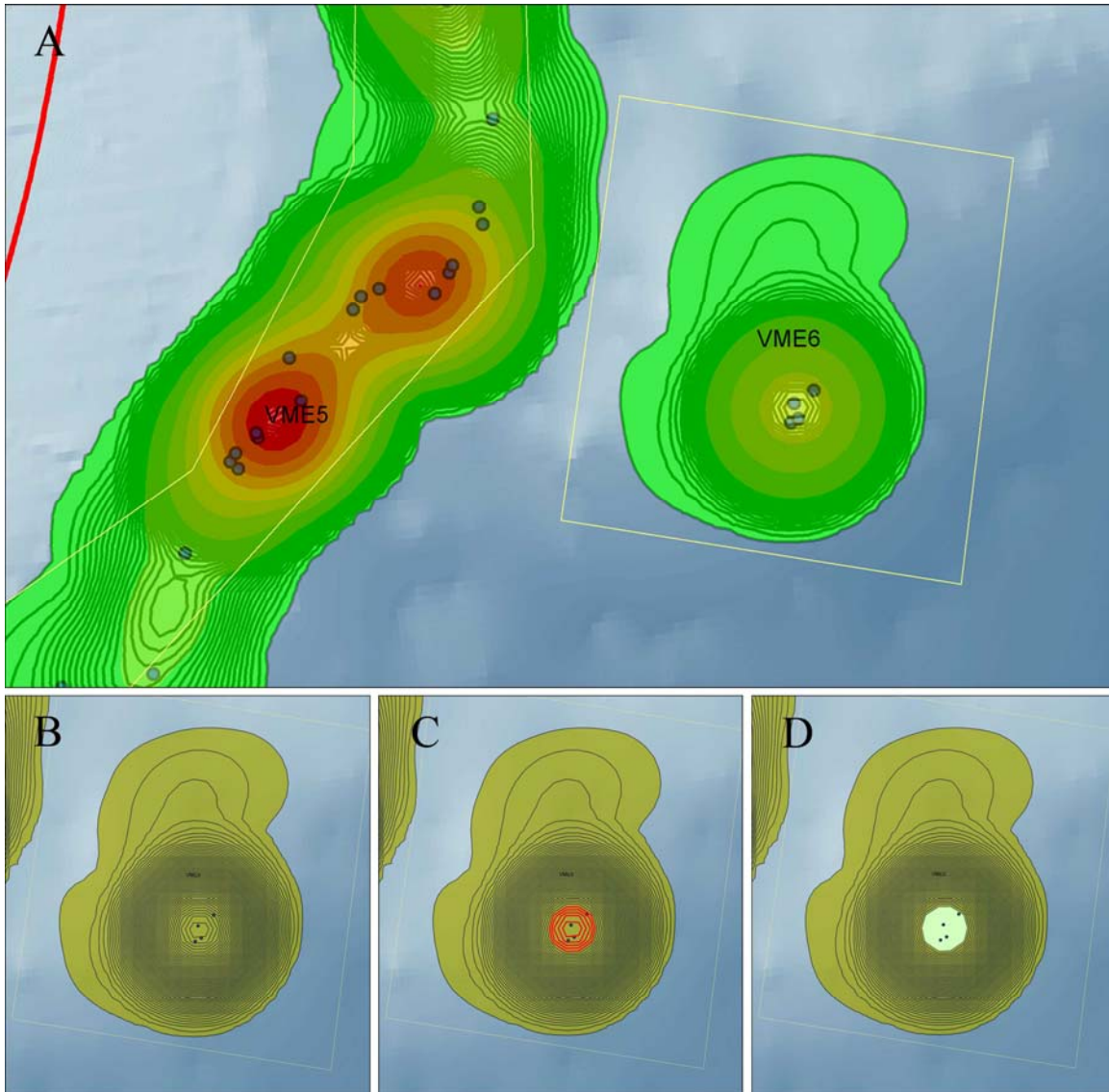


Figure 4. **A** – The 25 km search radius density map of Beothuk Knoll and adjacent Southern Flemish Pass at contour intervals of 0.1 kg/km^2 . **B** - represents the output of the polygon of the model, **C** – during this step, the minimum polygon area that describes the grouped points are selected (in red), **D** – the polygons are then “Dissolved” and exported as a Feature Class where the polygon area is automatically calculated in its own field.

Results

Applying this technique to the Canadian R/V sponge bycatch data using the $>2000 \text{ kg}$, >1000 , >500 , >100 , >90 , >80 , >70 , >60 , >50 , >40 , >30 , >20 , >10 , >1 , and $>.01 \text{ kg}$ thresholds produced the density maps illustrated in Appendix 1.

The total area output for each weight threshold was calculated and plotted (Figure 5). The area occupied by the highest catches is relatively constant, after an initial increase, until the 50 kg threshold. The location of these points is presented in Figure 6. Catches above 70 kg form a tight concentration whereas the tows with catches of 50-60 kg and even more so of 40-50 kg, begin to occur outside the 20 km nearest neighbour range applied to the polygon calculations. If a larger nearest neighbour range had been used we would have seen a sharper increase in area occupied at the 50 kg threshold. Consequently, for this application the threshold value appears to be 70 kg and greater for defining sponge grounds.

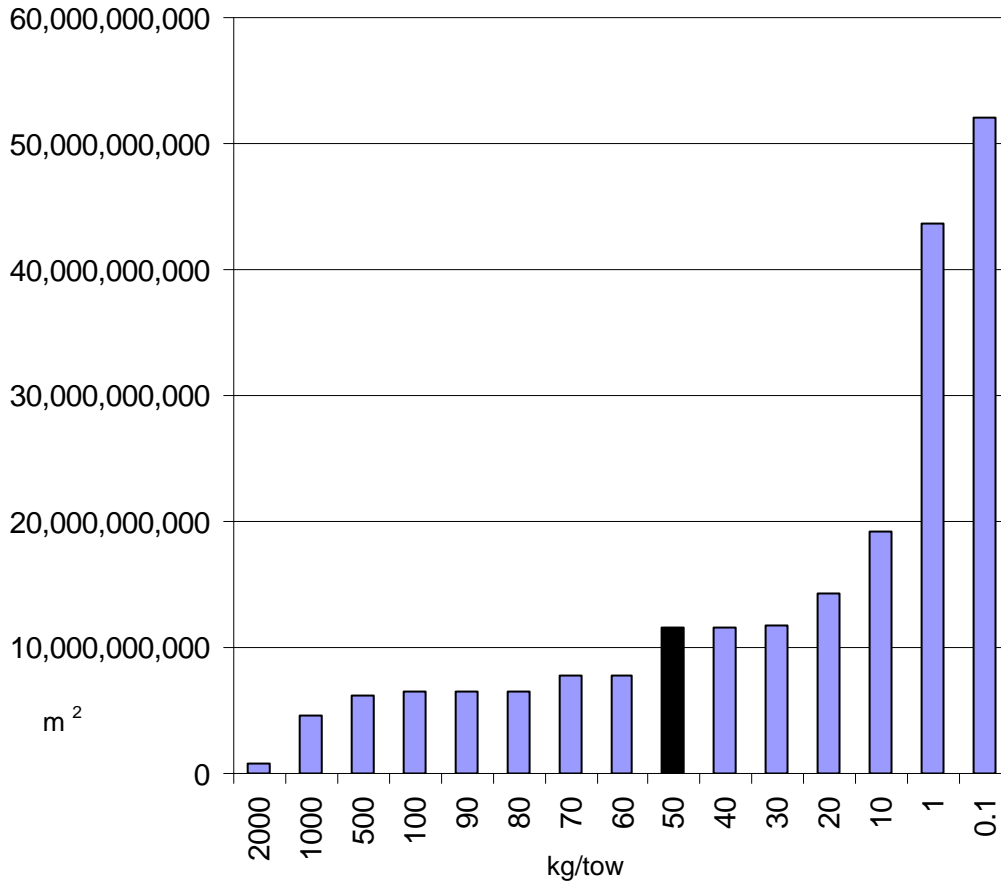


Figure 5. The minimum area required to encompass decreasing sponge catch weight thresholds. The arrow indicates the catch weight threshold which delimits the sponge grounds using this approach.

The location of distinct sponge grounds and the weight threshold feature class areas derived from Canadian sponge data are illustrated in Appendix 1.

Conclusions

Running the ArcGIS model (Figure 2) produces a digital representation of sponge density which is intrinsically reliant upon both the coverage extent of the survey data and the search radius chosen prior to running the model. Here we demonstrate that this method can be used to estimate the catch weight thresholds to define VMEs. The raster output and derived feature class areas are useful tools for providing a general location for high density sponge areas and for estimating the approximate biological mass extent of the sponge bed by graphically interpreting the greatest percent increase in area associated with decreasing weight thresholds. Where the model requires further refinement for other applications such as density mapping (for which it was designed), is through incorporating biologically limiting distribution factors such as depth, slope, substrate, etc... Future work will include steps in the model to extract relevant bathymetric data to each point from multibeam bathymetry data that is to be gathered through an international survey led by Spain which begins May 23rd, 2009. The model raster outputs could then be filtered and weighed by the associated high resolution depth, slope and substrate information which should result in a final product which accurately depicts not only the location of highest density areas but the extent of the distribution from this high density centroid.

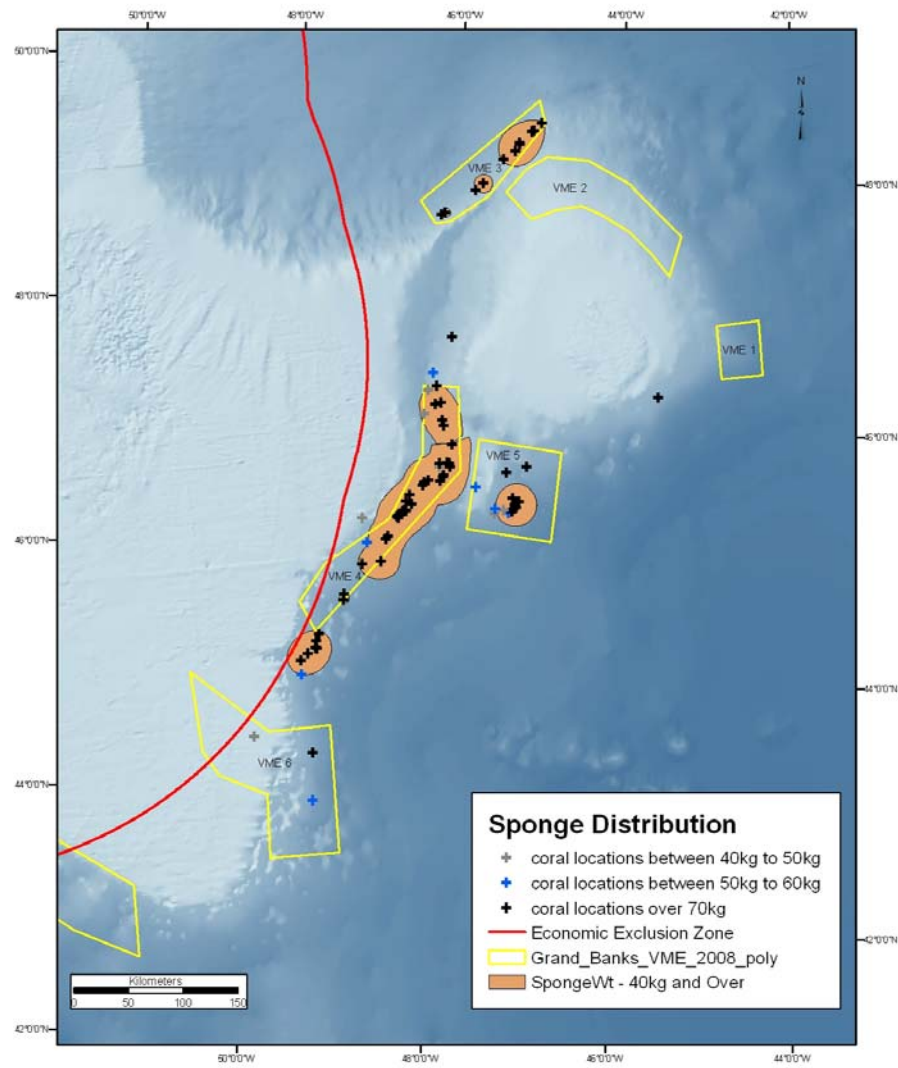


Figure 6. Location of sponge tows greater than 70 kg (black), from 50-60 kg (blue) and from 40-50 kg (gray).

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Appendix 1. Area occupied by density rasters for selected catch weights of sponge from the Canadian RV tows. Note the increase in area with the inclusion of lower catch weights.

