



Biomass Estimates for Vulnerable Marine Ecosystems in the NAFO Regulatory Area

by

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Abstract

In support of the NAFO review of the closed areas to protect vulnerable marine ecosystems (VMEs) in the NAFO Regulatory Area, biomass estimates of Large-sized Sponges, Sea Pens, Sea Squirts (*Boltenia ovifera*), Erect Bryozoans, Black Corals, Large Gorgonian Corals, and Small Gorgonian Corals were undertaken using all available research vessel (RV) survey data (1995 – 2019). The spatial extent, which included the area inside the fishing footprint, and VME polygons and closed areas that crossed outside the fishing footprint into deeper water, was partitioned into 5,701 grid cells, each 5 km x 5 km in size. Mean biomass per RV trawl was calculated from the RV catch data for each VME Indicator within each grid cell and total biomass was estimated using the swept area of the trawl gear and upscaling to the cell area of 25 km². Cells with no RV data were populated using focal statistics in ArcMap version 10.7 with a 3 x 3 cell neighbourhood. Focal statistics were applied iteratively with the same neighbourhood size until all 5,701 grid cells were populated. This process was automated using ModelBuilder and documented in Appendices. The estimated total biomass for each of the 7 VME Indicators was calculated and tabulated for the spatial extent of the study, for the collective VME polygons for each Indicator, and in the closed areas – ultimately to evaluate the effectiveness of the closures in protecting VMEs. Additionally, the biomass of each VME Indicator were summated to give a total VME biomass for each grid cell, as a number of grid cells contained more than one VME Indicator in their catches (max. 6 of 7). As the VME polygon and closed area boundaries did not follow the perimeter of the grid cells, methodology to clip the biomass and estimate the portion inside the areas was implemented. For the evaluation of significant adverse impacts of fishing, the VME biomass inside the VME polygons is required as provided above, but at a 1 km x 1 km resolution to match the reporting of fishing activity through VMS. We explored the best way to achieve this and ultimately prepared equivalent biomass tables for this smaller scale by overlaying the 1 km x 1 km grid onto the 5 km x 5 km grid such that the total biomass in each 1 km² grid cell will be 1/25th of the total in the 25 km² grid cell. For both grid mesh sizes shapefiles of the estimated biomass for each VME Indicator separately and for the total VME biomass were produced.

Introduction

Biomass surfaces for the VME Indicators are required in order to evaluate impacts of fishing (significant adverse impacts; SAI) and the effectiveness of the closed areas. Previously, area occupied by the VME polygons and associated biomass were calculated for each VME Indicator type using the output kernel density raster surfaces, which measure biomass as kg per unit area (in this case, per km²) for each raster cell across the data range, and is therefore more accurately referred to as a biomass density rather than a true biomass (NAFO, 2020). The decision to use the KDE biomass surfaces to represent VME Indicator biomass was made knowing



that it was not the most accurate way to estimate true biomass. However, KDE surfaces were available for seven of the nine VME Indicator taxa and so allowed for the effectiveness of the closed areas to be initially examined (NAFO, 2020).

Pham et al. (2019) used two separate approaches to estimate sponge biomass in the NRA: (1) biomass calculated from a random forest regression model to predict the distribution of the sponge biomass using environmental predictors, their “modelling approach”; and (2) a gridded biomass surface based on individual research vessel (RV) survey records, their “grid-cell approach”. The modelling approach produced a continuous biomass surface and allowed for predictions in areas beyond the sampled locations based on environmental variables, thereby capturing the full extent of the sponge grounds, which in the NRA includes deep waters where there are relatively few RV trawls. In contrast, the gridded biomass surface used only the actual RV catch data to populate cells and so relied less on spatial interpolation/extrapolation. That approach was seen to be a better estimator of biomass within the fishing footprint. There was insufficient time to complete further work for the 12th meeting of the NAFO Working Group on Ecosystem Science and Assessment (WGESA). That work is taken up here using the grid-cell approach as it is intended that these layers be used primarily for evaluating the impacts of fishing on VMEs (Significant Adverse Impacts). What follows are technical details that record the different approaches we examined in constructing the VME biomass surfaces, with explanations for why we chose the procedures that were ultimately followed.

Methods

Summary of Data Sources

Available data for each VME Indicator type were obtained from research vessel trawl surveys (Table 1). These are the same data used to calculate the updated kernel density polygons (Kenchington et al., 2019) used to delineate the location of VMEs for the review of areas closed for their protection (NAFO, 2020).

Table 1. Data sources from contracting party research vessel surveys; EU, European Union; DFO, Department of Fisheries and Oceans; NL, Newfoundland and Labrador; IEO, Instituto Español de Oceanografía; IIM, Instituto de Investigaciones Marinas; IPMA, Instituto Português do Mar e da Atmosfera.

Programme	Period	NAFO Division	Gear	Mesh Size in Codend Liner (mm)	Trawl Duration (min)	Average Wingspread (m)
Spanish 3NO Survey (IEO)	2002 - 2019	3NO	Campelen 1800	20	30	24.2 – 31.9
EU Flemish Cap Survey (IEO, IIM, IPIMAR)	2003 - 2019	3M	Lofoten	35	30	13.89
Spanish 3L Survey (IEO)	2003 - 2019	3L	Campelen 1800	20	30	24.2 – 31.9
DFO NL Multi-species Surveys (DFO)	1995 - 2019	3LNO	Campelen 1800	12.7	15	15 - 20

Spatial Extent of the Analyses

In order to satisfy the dual requirements of providing a biomass surface for evaluating significant adverse impacts of fishing and for determining the degree of protection afforded the VME Indicators under different scenarios, the spatial extent shown in Figure 1 was used. This extent covers the NAFO NRA inside the fishing footprint, as well as significant concentrations of VME Indicators, i.e., VMEs (VME polygons: KDE polygons modified in some cases using species distribution models), and areas closed for their protection, outside of the fishing footprint. Area 14 was re-opened to fishing in January 2019 (NAFO, 2020), but is included in this assessment as part of an evaluation of that decision.

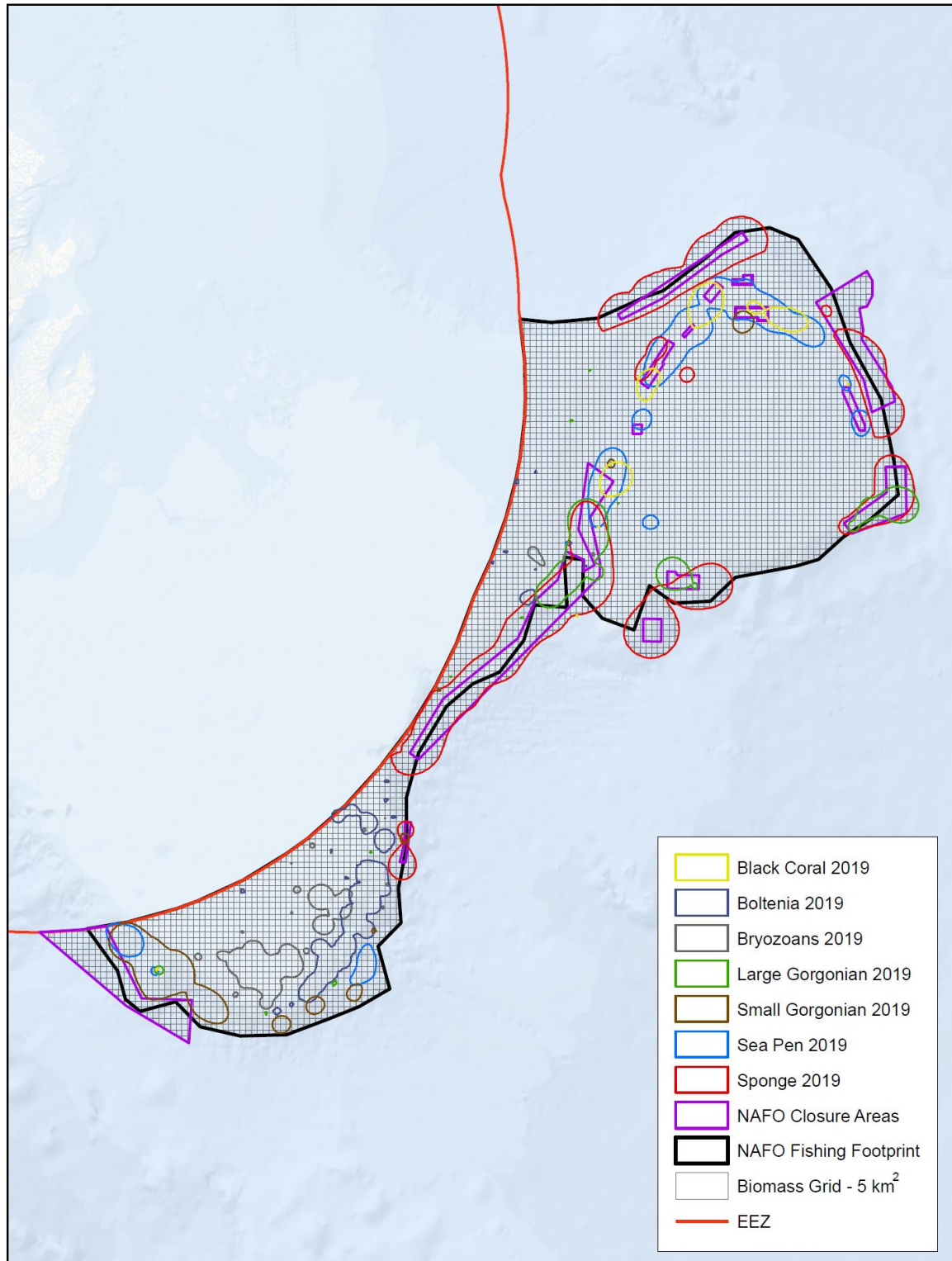


Figure 1. The spatial extent and 5 km x 5 km grid cell overlay used to estimate the biomass of VME Indicators in relation to the fishing footprint (heavy black line), areas closed to protect VME (purple outline), and the location of the VMEs (VME polygons) for seven VME Indicators (from Kenchington et al., 2019). Projection: NAD 1983 UTM Zone 23N projection coordinate system.

Determination of Grid Cell Size

The objective of this study was to provide 1 km x 1 km VME biomass estimates for each VME Indicator group (Kenchington et al., 2019) to match the spatial resolution of VMS data to be used for estimating biomass removals by commercial fishing in SAI assessments. Preliminary work was done to explore the possibility of creating a 1 km² grid biomass surface directly from the raw data. A mean biomass surface was created with a 1 km² grid using research vessel trawl sponge catch data along with focal statistics (3 x 3 cell neighbourhood reach) in ArcMap version 10.7, to fill in 'no data' areas. In Figure 2, sponge trawl data is shown in relation to the 1 km² grid resulting from this work. Examination of the resultant grid revealed the following issues:

- Most grid cells contained only a single biomass value or no values at all;
- The small grid size meant a reliance on increased interpolation using focal statistics.

These issues indicated that a 1 km² grid resolution is inadequate for these trawl biomass datasets. Further, EU trawl sets are approximately 3 km in length and therefore have a lower resolution than the 1 km² grid.

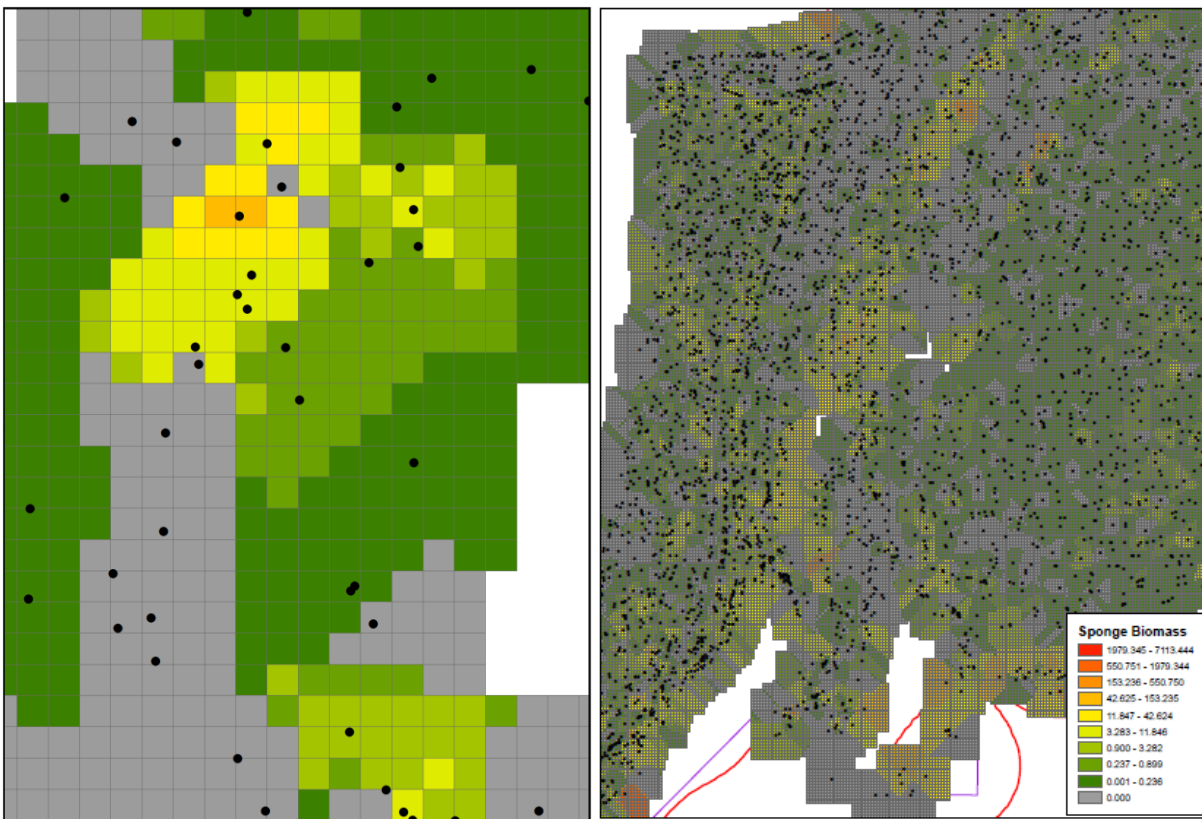


Figure 2. Illustration of a 1 km² sponge biomass (kg/km²) grid using data with two levels of magnification. Location of biomass data from the research vessel surveys are indicated by the black points. Coloured cells with no black dots indicate cells populated by focal statistics.

In previous work a 5 km x 5 km grid cell was used to calculate the mean biomass/cell. Details of the method used to create the surface are outlined in Cogswell et al. (2011), where for each grid cell, the mean biomass was calculated based on all the VME Indicator RV catch data and 'no data' cells were filled in using focal statistics (3 x 3 cell neighbourhood). The mean biomass estimates per cell are more robust with this larger grid size as they draw on more data points for the calculation of the mean, and have a resolution greater than that of the RV trawl data of 3 km. The 5 x 5 km sponge biomass data is shown in Figure 3 for a portion of the Flemish Cap and Flemish Pass.

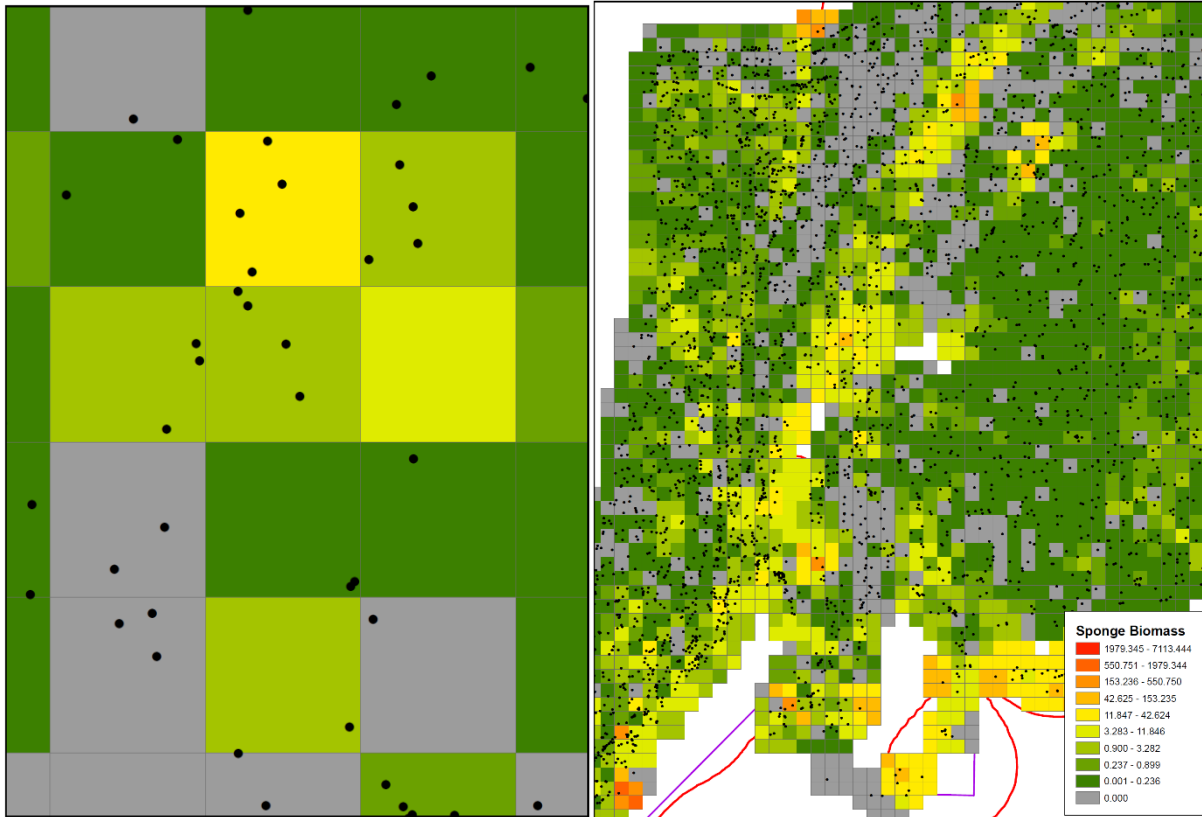


Figure 3. Illustration of a 25 km² sponge biomass grid using data with two levels of magnification. Location of biomass data from the research vessel trawl surveys are indicated by the black points. Coloured cells with no black dots indicate cells populated by focal statistics. Note the greater number of data records per cell compared with Figure 2.

Once the 25 km² grid was created, a 1 km² grid was overlain to satisfy the requirements for the evaluation of fishing impacts. Note that there are 25, 1 km² grid cells in each 25 km² cell and so the total biomass in each cell (see below) will be 1/25th of the total in the 25 km² grid cell. Figure 4 shows an example of this step using sea pen biomass data from the trawl surveys.

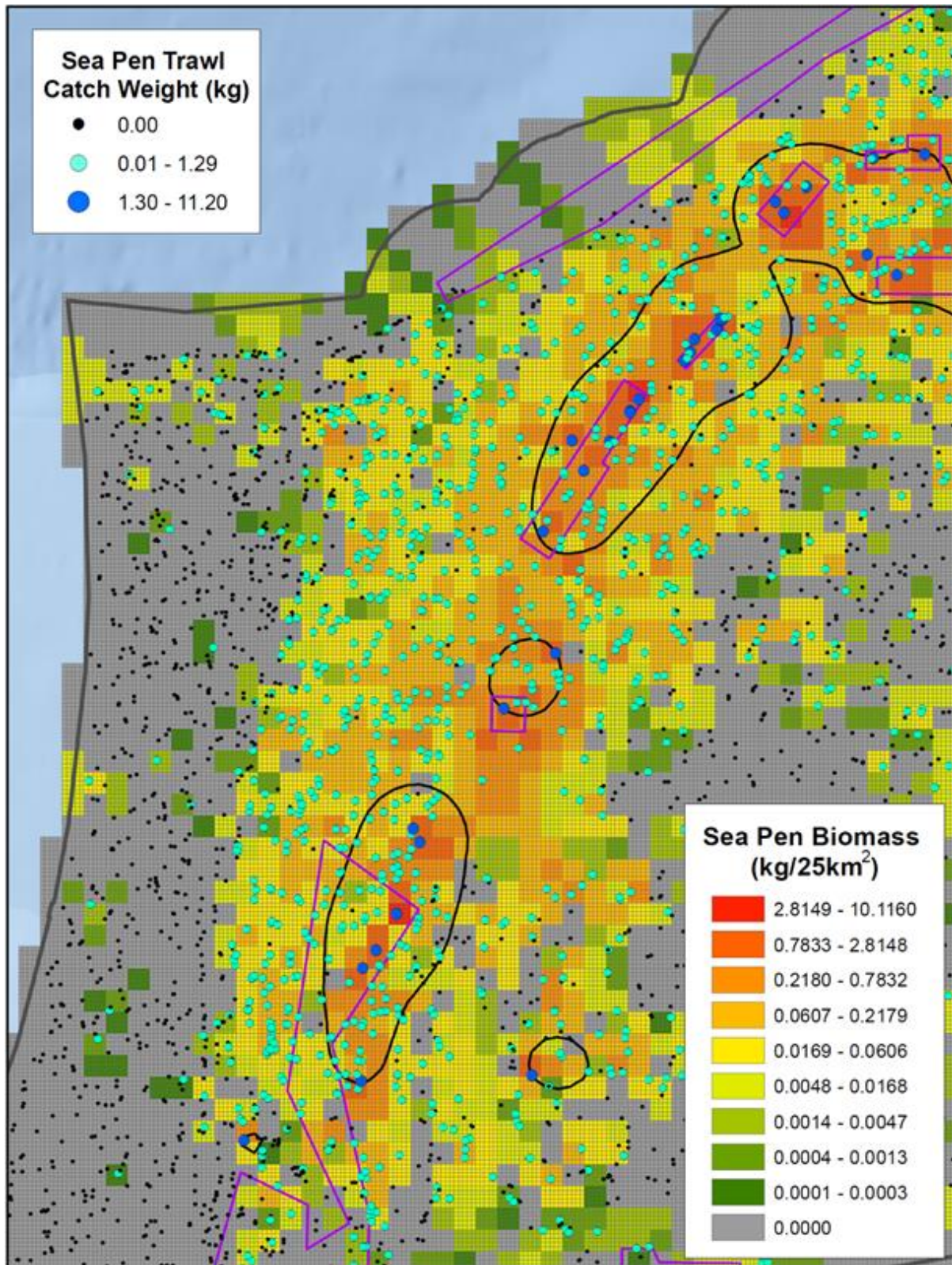


Figure 4. Illustration of a 25 km² grid sea pen VME mean biomass (kg/25 km²) layer created using focal statistics with a 3 x 3 cell neighbourhood to fill in 'no data' cells with a 1 km² grid overlay. Location of biomass data from the RV surveys are indicated by the closed circles (see legend). VMEs (dark outline) and closed areas (red outline) are shown for scale.

Gridded Biomass Surface – Methodology on Automation and Data Interpolation

The requirements for this study were to have 1 km² gridded biomass surfaces created for seven VME Indicators and provide full coverage over the entire study extent, requiring interpolation to grid cells with no data. In previous studies, Cogswell et al. (2011) and Pham et al. (2019), only one or two biomass surfaces were required and the study extents were smaller. With the additional number of VME and expanded spatial extent used in this study, there was a need to automate, streamline and slightly modify the methodology outlined in Cogswell et al. (2011).

To achieve this, ArcGIS Model Builder was used to create: 1) a mean biomass grid surface from RV trawl VME biomass values and 2) fill in immediately adjacent ‘no data’ grid cell areas, using focal statistics. Focal statistics, as applied here, takes the mean of values from a conservative rectangular neighbourhood window of 3 x 3 cells to create a continuous surface (see Appendix 1, Model 1a for a detailed explanation of the methodology). This technique, i.e., only filling in ‘no data’ cells in immediately adjacent cells, did expand the biomass surface but did not provide full coverage over the larger study extent. To achieve full coverage, the methodology needed to be modified. Two approaches were examined to use focal statistics to fill in ‘no data’ areas beyond immediately adjacent cells for full spatial coverage. The sea pen VME Indicator data were used to explore these approaches.

Approach 1 – the *incremental approach* extends the application of focal statistics to fill in ‘no data’ cells by incrementally building the grid out to the edge of the study extent through an iterative process. Figure 5, Panel (a) shows the initial biomass layer (all grid cells contain trawl data) used as input to build out another set of biomass values in immediately adjacent ‘no data’ cells. Panel (b) shows the first set of ‘no data’ cells populated by focal statistics building out the biomass layer (build one). The blue lines point to the areas where ‘no data’ cells have been populated. Most of the interior ‘no data’ cells have been filled in this step with this data set. Panel (a) and (b) are the products of Model 1a in Model Builder (see Appendix 1). Panel (c) shows the second set of immediately adjacent cells populated by focal statistics (build 2). The blue lines show that a small ‘no data’ area is filled in the interior with most ‘no data’ cells now being filled along the edge. Panel (c) is the product of Model 1b in Model Builder (see Appendix 1) which used the previously produced grid, build one, as input. Panels (d) and (e) show the third and fourth set of ‘no data’ cells to be populated using focal statistics further expanding the biomass layer (builds 3 and 4). Panel (e) shows complete coverage of the study area in this area of the grid. It took 8 builds to completely cover the study area, see Figure 6. In all builds the focal statistics used the 3 x 3 cell neighbourhood.

Approach 2 – the *full out approach* creates the initial biomass layer as described in Approach 1 and ‘no data’ values are filled in just once using focal statistics with a much larger rectangular neighbourhood window. This approach populates all ‘no data’ grid cells to the study extent in one step using a neighbourhood window of 18 x 18 cells (Figure 7). Contrasting Figures 6 and 7 it can be seen that Approach 1 is more conservative in estimating biomass, with Approach 2 filling in cells that show zero biomass using Approach 1.

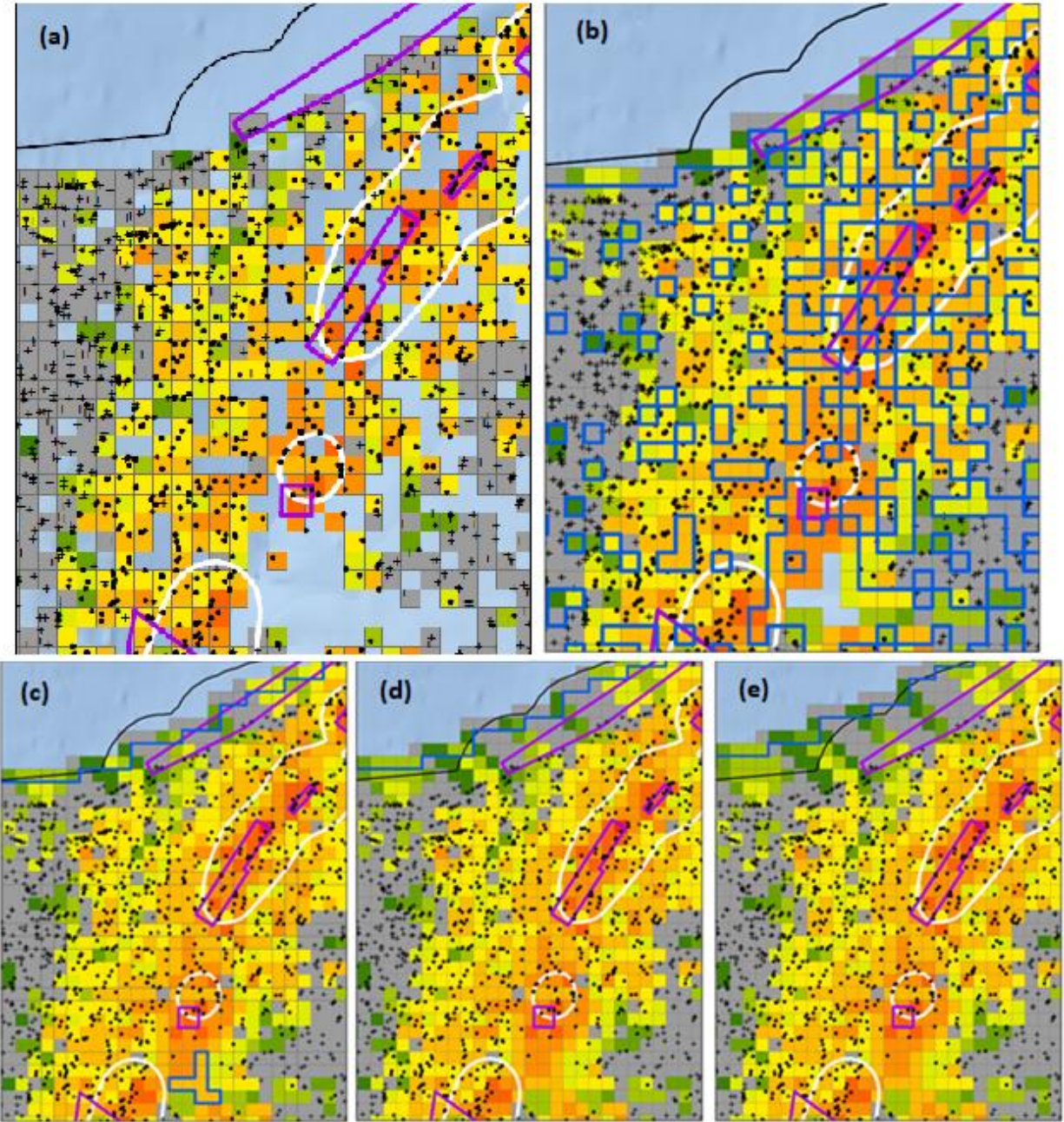


Figure 5. Illustration showing the *incremental approach* when creating a VME mean biomass layer. Blue lines show placement of interpolated 25 km² grid cells generated by focal statistics with each successive build (upper left in Panels d, e). See text for details. White lines indicate VMEs and purple lines indicate the closed areas.

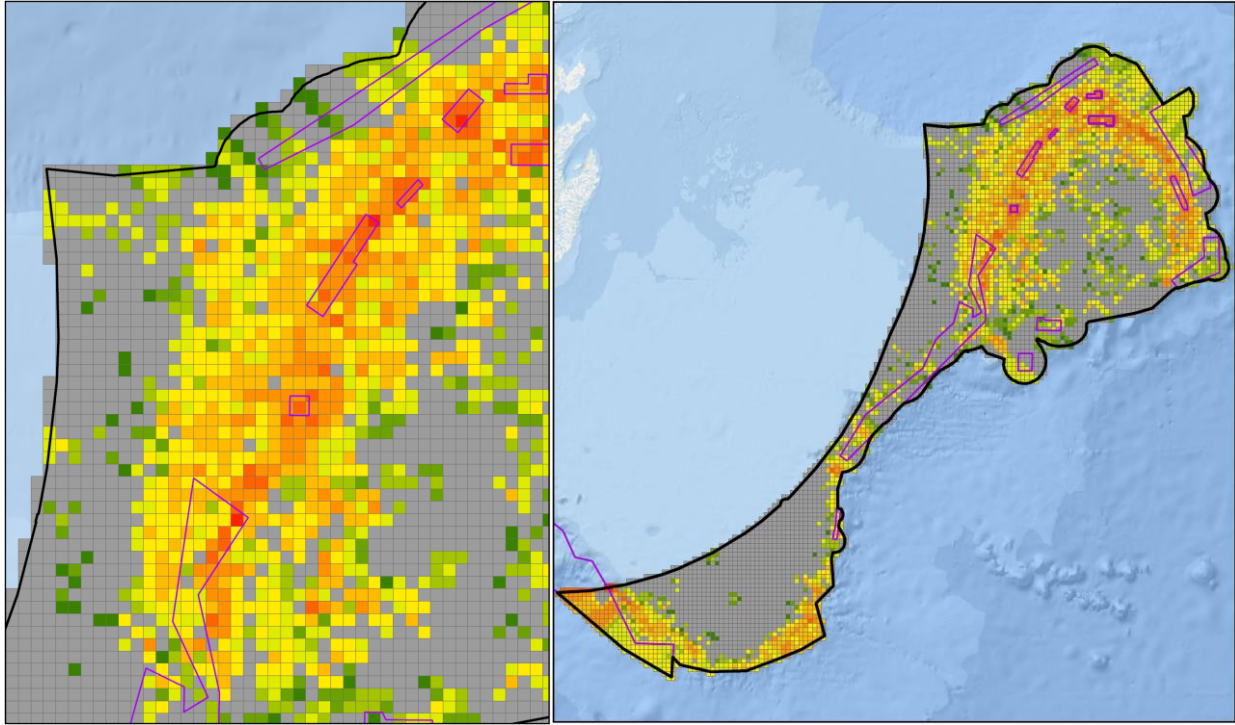


Figure 6. Final sea pen mean biomass 25 km² grid layer produced using *the incremental approach* (Approach 1) with repeated applications (8 builds) of focal statistics with a 3 x 3 cell neighbourhood to fill in 'no data' cells, shown at two magnifications.

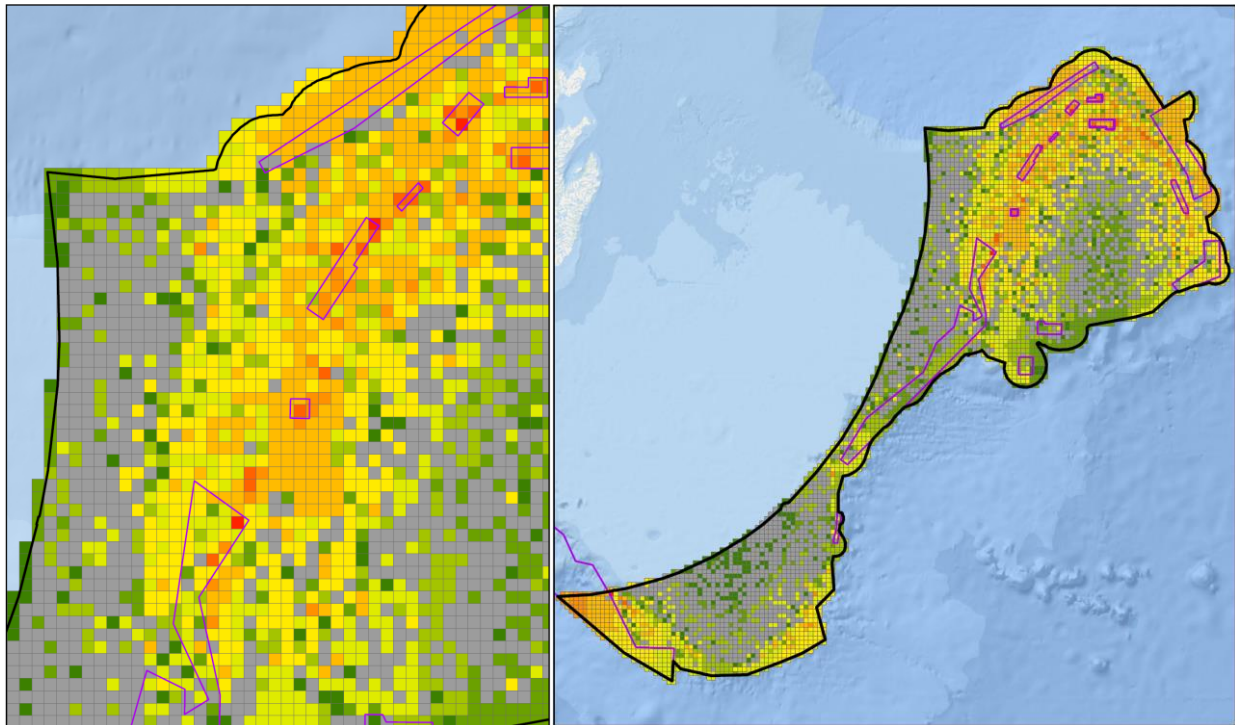


Figure 7. Final sea pen mean biomass layer produced using *the full out approach* (Approach 2) with a single focal statistics application using an 18 x 18 cell neighbourhood to fill in 'no data' cells in one step, shown at two magnifications.

Approach 1, the incremental approach, was selected as the method to extend the biomass grid to the study extent for the construction of the VME Indicator biomass surfaces. Using a small 3 x 3 cell neighbourhood in the focal statistics tool, 'no data' cells are filled in by nearby data cells reflecting more realistic values. Figure 8 shows Approach 1 has a mean biomass value over the spatial extent of 0.059 kg per 25 km² cell, which is closer to the original mean biomass value of 0.061 kg per 25 km² cell, than the inflated Approach 2 mean biomass value of 0.067 per 25 km². The latter is not unexpected as in Approach 2 the focal statistic values from the large 18 x 18 neighbourhood window fill in 'no data' cells from a large area and tends to overweight biomass values. Approach 2 is very limited in its ability to assign a zero biomass value to a cell. For example, the original biomass grid had 1,860 zero biomass values assigned to cells in the grid of 3,156 cells. Using Approach 1, a total of 2,742 grid cells were assigned a zero value in the full study extent grid of 5,701 cells. In Approach 2, only 1,876 cells, a few more than the original biomass grid, were assigned a zero biomass value out of 5,701 grid cells.

Original Mean Biomass	Mean Biomass – Approach 1	Mean Biomass – Approach 2
Field Final_BM	Field Final_BM	Field mean_biomass
Statistics: Count: 3156 Minimum: 0 Maximum: 10.116 Sum: 191.15268 Mean: 0.060568 Standard Deviation: 0.304229 Nulls: 0	Statistics: Count: 5701 Minimum: 0 Maximum: 10.116 Sum: 335.67767 Mean: 0.05888 Standard Deviation: 0.258975 Nulls: 0	Statistics: Count: 5701 Minimum: 0 Maximum: 10.116 Sum: 382.94098 Mean: 0.067171 Standard Deviation: 0.236038 Nulls: 0

Figure 8. Summary statistics of the original mean biomass grid and mean biomass grids created using Approaches 1 and 2.

VME Biomass Estimation

All biomass calculations were done in ArcMap version 10.7 with layers projected using the NAD 1983 UTM Zone 23N projection coordinate system using Approach 1 as explained above. Details of the method used to create the surface are outlined in Cogswell et al. (2011), where for each 5 km x 5 km grid cell the mean biomass was calculated based on all of the RV catch data (Table 1) for each VME Indicator group, in each cell, and then applied to the total cell area using the swept area of the gear (see Appendix 1 for details) to get an estimate of the total biomass in each cell. The value for cells with no RV trawl data is a function of the values of all the input cells that are in a specified neighborhood around that location, populated using Approach 1 as outlined above. Biomass calculations assume 100% catchability which is unlikely and so are expected to underestimate true biomass.

The total wet weight biomass in each grid cell was determined using ModelBuilder as outlined in detail in Appendix 1, Model 2. Notes on the impact of gear type assignment on biomass calculations are provided in Appendix 2. These resulted in small differences between total wet weight biomass estimates calculated using the 5 km x 5 km grid cell and the 1 km x 1 km grid cell caused by the two gear types operating in the NAFO Division 3L/3M border.

The Special Case of Sponge Biomass

The large-sized sponges in the NRA extend into deep waters outside of the fishing footprint and below the depth of the trawl surveys (Figure 1). Because the catches of sponges ranged by several orders of magnitude

and the biomass in the closed areas contains some of the highest biomass records, there was concern that the focal statistics would over-represent biomass in adjacent cells outside of the closed areas. To overcome this, we previously prepared a sponge biomass surface consisting of two merged grids (one clipped to and using data within closure areas and the other excluding data from within the closures) (Cogswell et al., 2011). This approach allowed us to capture the sharp transitions in biomass observed on the borders of some closed areas and therefore it provides a closer estimate of the actual sponge biomass in these areas (Figure 9). As other VME Indicators do not have the same sharp and large biomass transitions inside and outside their habitats, we did not apply this method for Indicators other than large-sized sponges. This was done following these steps:

Layer 1 - Using points only inside closure areas, a biomass layer is created inside closure areas.

Layer 2 - Using points only outside the closure areas, a biomass layer is created outside the closure areas.

Layer 3 - Using all sponge biomass points, a biomass layer is created in the part of VME polygons that are not inside the closure areas or in the NRA fishing footprint.

These biomass layers were merged together using two methods to create a total sponge biomass surface from the RV trawl data:

Method 1 - Merges three biomass layers - Layer 1, Layer 2 (outside closures but delimited to the fishing footprint) and Layer 3.

Method 2 - Merges two biomass layers - Layer 1 and Layer 2 (outside closures and not delimited to the fishing footprint).

The biomass layers produced for each Method are shown in Figures 10 and 11. It is clear that Method 1 estimates high total biomass of sponges in the deep waters, especially in the area below the Sackville Spur closed area on Flemish Cap (Figure 10). Data collected using underwater imagery (Beazley et al., 2015) and from species distribution modeling of sponge grounds (Knudby et al., 2013) indicates that the biomass is low in the deep water outside of that closed area. At the same time, underwater imagery from Closed Area 5 on the northeast of Flemish Cap shows high sponge abundance (NAFO, 2010). These independent data support the use of Method 2 which we used for the determination of sponge biomass in the NRA.

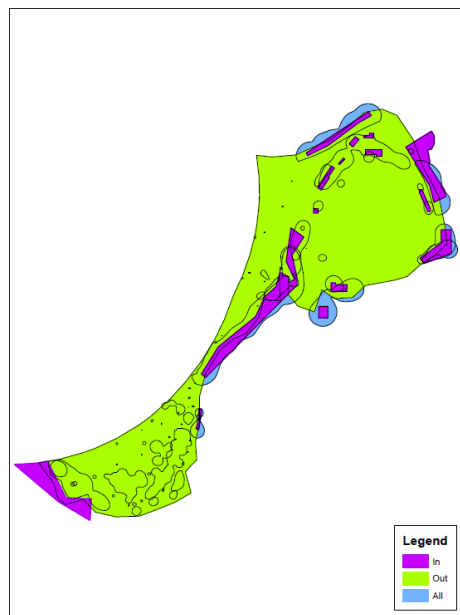


Figure 9. Illustration of the spatial extent used to calculate the total sponge biomass using focal statistics that were calculated separately for each area (in or out of closures) and then combined to produce the final layer. VME polygons are outlined on the map for reference.

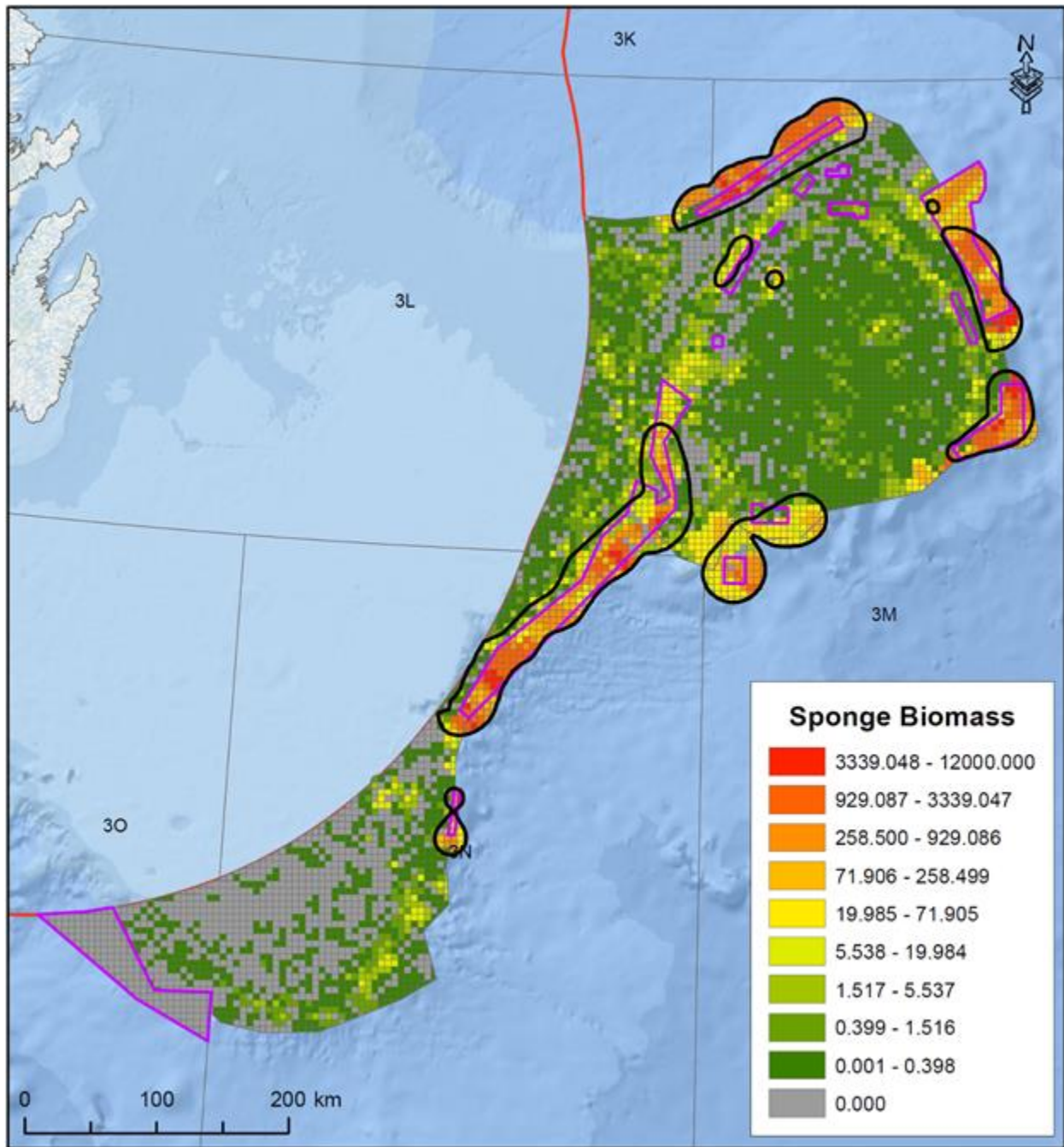


Figure 10. Application of the Method 1 approach to the estimation of total sponge biomass (kg per 25 km² grid cell). Black outlines indicate the VME polygons, purple lines indicated closed areas.

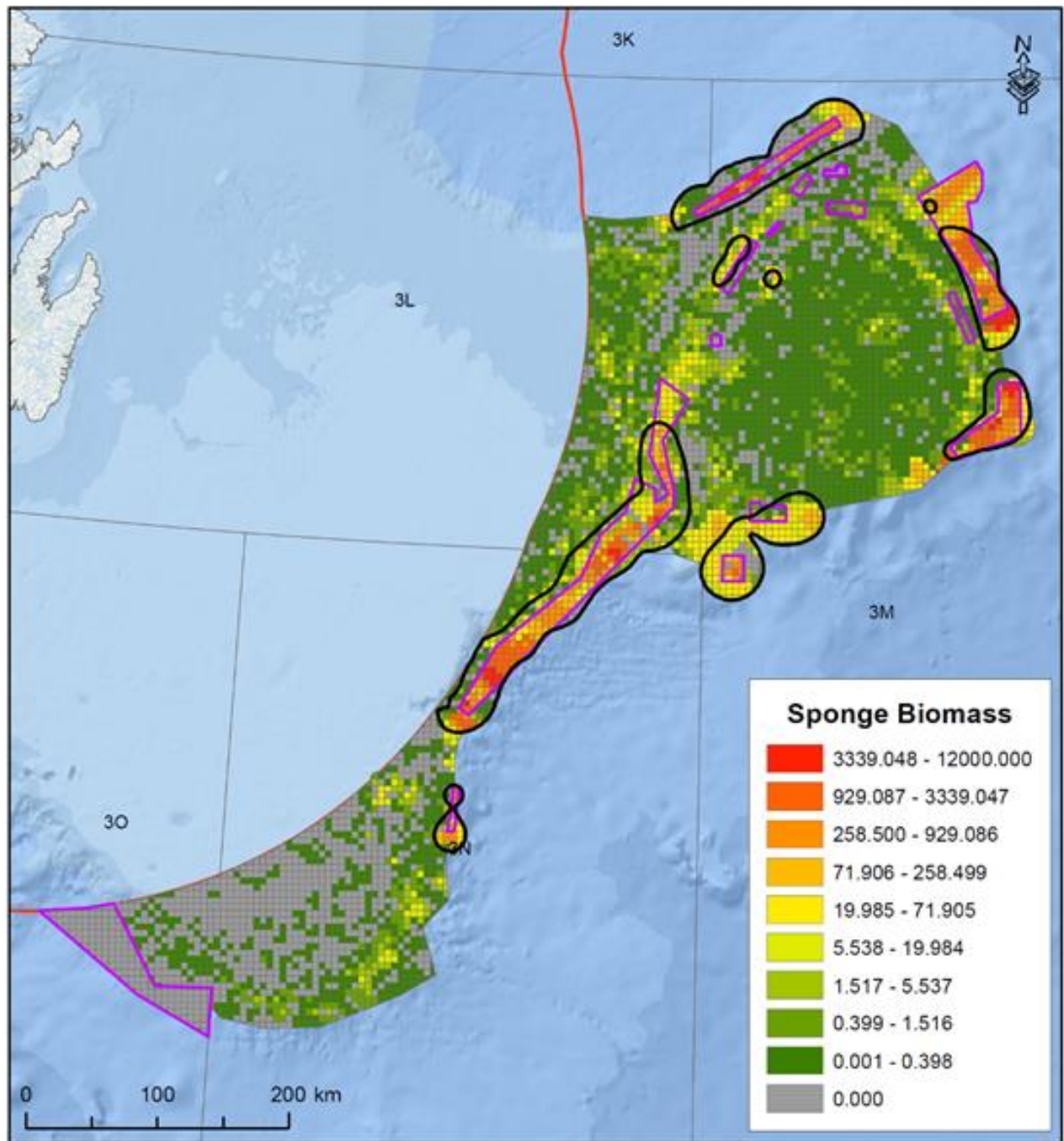


Figure 11. Application of the Method 2 approach to the estimation of total sponge biomass (kg per 25 km² grid cell). Black outlines indicate the VME polygons, purple lines indicated closed areas.

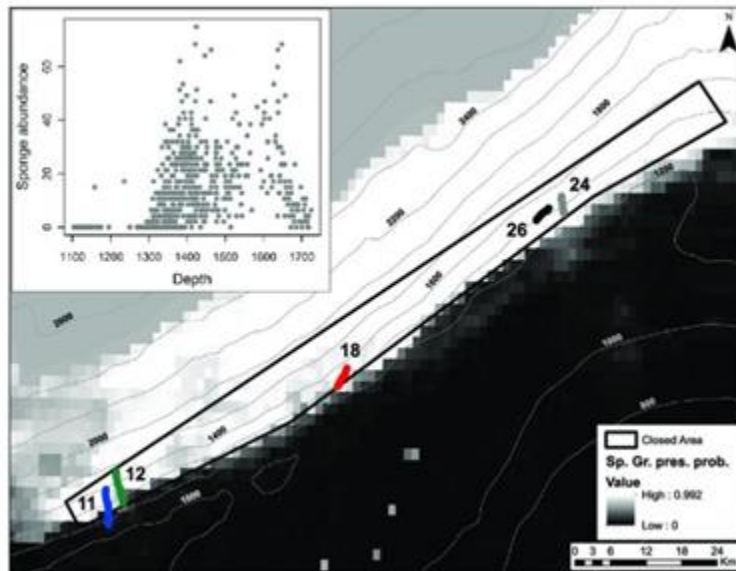


Fig. 4. Location of the benthic imagery transects on the Sackville Spur in relation to sponge ground presence probability (Sp. Gr. pres. prob.) prediction for the spur based on Random Forest analysis from Knudby et al. (2013b). Graph in upper left panel shows the overall abundance of structure-forming sponges per image by depth.

Figure 12. Data (Beazley et al., 2015) from Closed Area 6 (Sackville Spur) that can be used to evaluate the two approaches for inferring biomass in unsampled areas using focal statistics, i.e., Method 1 (Figure 10) and Method 2 (Figure 11) (see text above).

Total VME Biomass

In a number of areas the VME Indicator species overlap. In order to examine SAI on the total VME presence in an area, a total VME biomass layer was produced for both the 25 km² and 1 km² grids following the methods outlined in Appendix 3.

VME Biomass inside VME Polygons

The biomass inside each of the VME polygons was determined separately for each of the VME Indicator taxa used to create the polygon, and for all VME inside the polygon, following the methods outlined in Appendix 3.

Results and Discussion

Gridded Biomass of Sponges

Method 2 (see section The Special Case of Sponge Biomass, above) was used to produce the total biomass of sponges from RV trawls surface which merges the inside closed area surface with the outside closed area surface (Figure 11), and is shown again in Figure 13 in relation to the 8,714 RV survey data points (4,389 biomass records and 4,325 null (zero catch) records) used to construct the biomass surface. The total biomass determined from the RV survey trawl bycatch is 293,432,034.0 kg using the 5 km x 5 km grid cell and 293,222,474.5 kg using the 1 km x 1 km grid cell (Table 2).

Pham et al. (2019) using the grid-cell approach calculated with 2,769 RV survey data records from 2006-2010, estimated the total wet weight biomass of sponges to be 122,465,789 kg for a smaller area of seabed (123,307.31 km²). Our updated sponge biomass surface was determined from 8,714 RV survey data records from 1995-2019 (Table 1) and for the same spatial extent used in Pham et al. (2019) was more similar to their biomass calculated using predictive models of sponge biomass to populate grid cells (their 'modeling approach'), i.e. 231,136 t. This is due to having more records in the deep water areas where the sponges are found with high biomass in the present analyses than were used by Pham et al. (2019). The new data assessed here is an improvement on estimates in Pham et al. (2019).

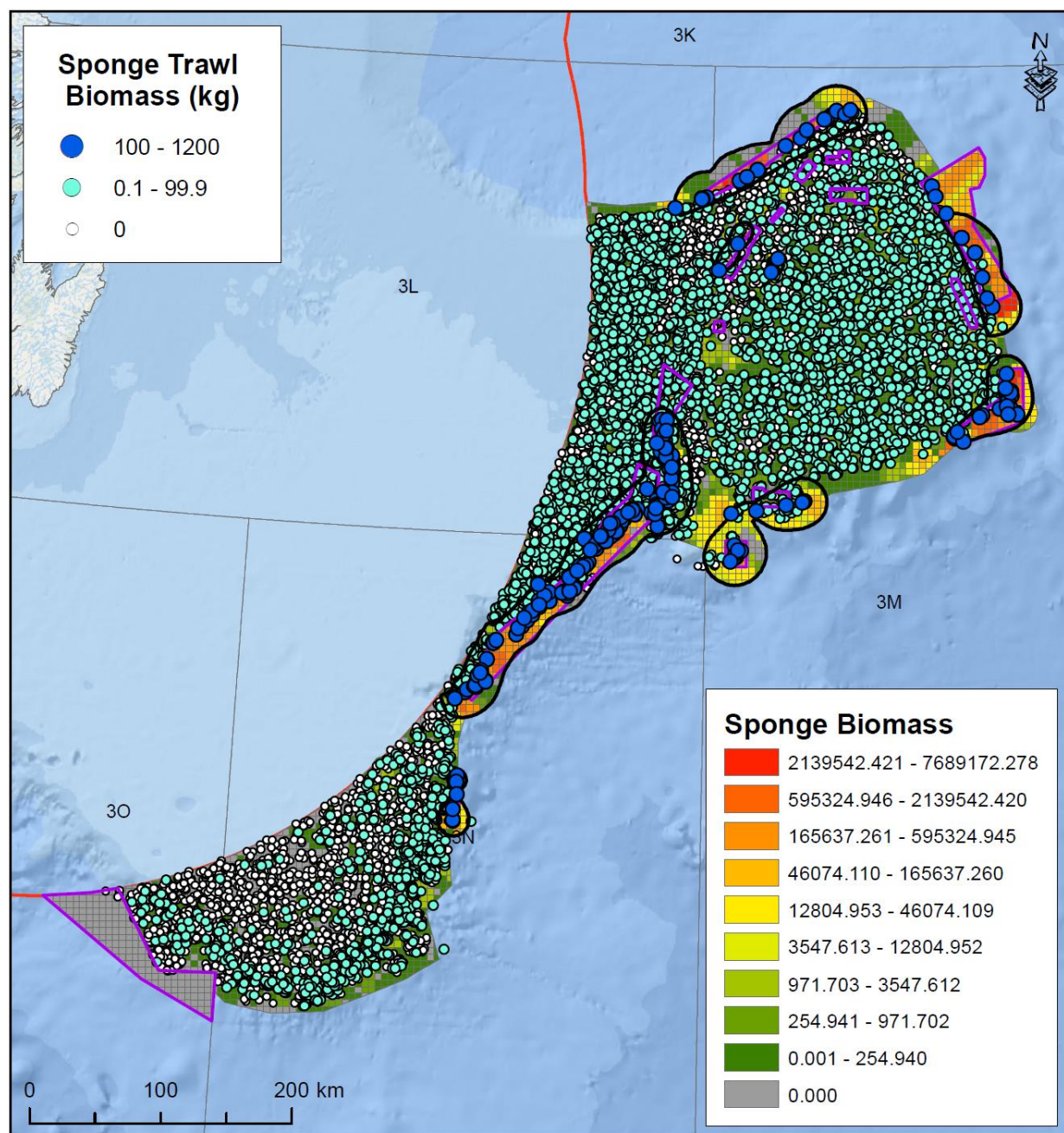


Figure 13. Estimation of total sponge biomass (kg per 25 km² grid cell) (see Figure 11) showing the location of the RV vessel sponge catch (kg) data points used to construct the surface. Black outlines indicate the VME polygons, purple lines indicated closed areas.

Gridded Biomass of Sea Pens

The total biomass surface of sea pens from 7,074 RV trawls (2,213 with biomass records and 4,861 null (zero catch) records) is shown in Figure 14, and in Figure 15 in relation to the RV survey data points used to construct the biomass surface. The total sea pen biomass is 170,906.8 kg for the 5 km x 5 km grid and 170,691.0 kg for the 1 km x 1 km grid (Table 2).

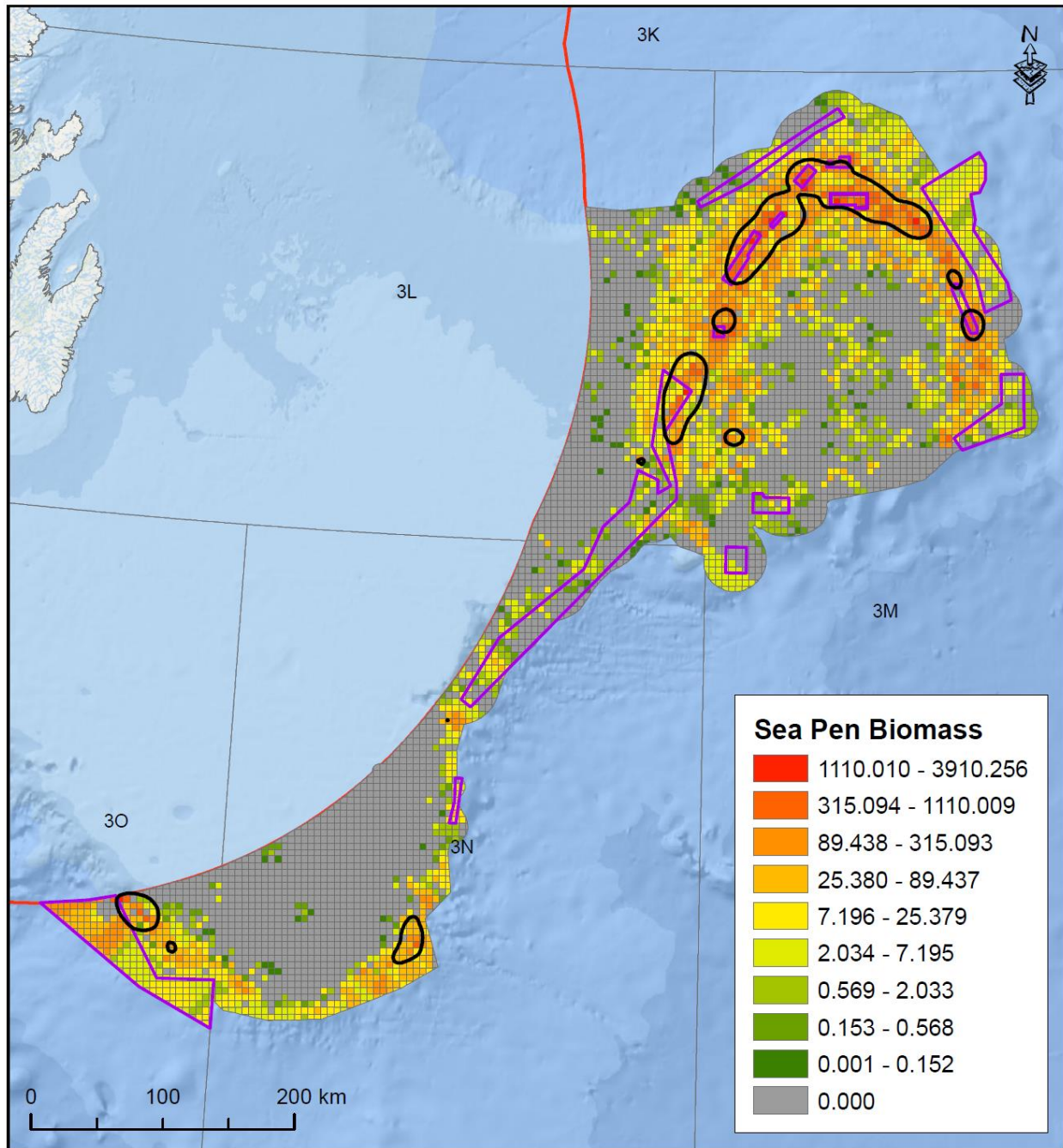


Figure 14. Estimation of total sea pen biomass (kg per 25 km² grid cell). Black outlines indicate the VME polygons, purple lines indicated closed areas.

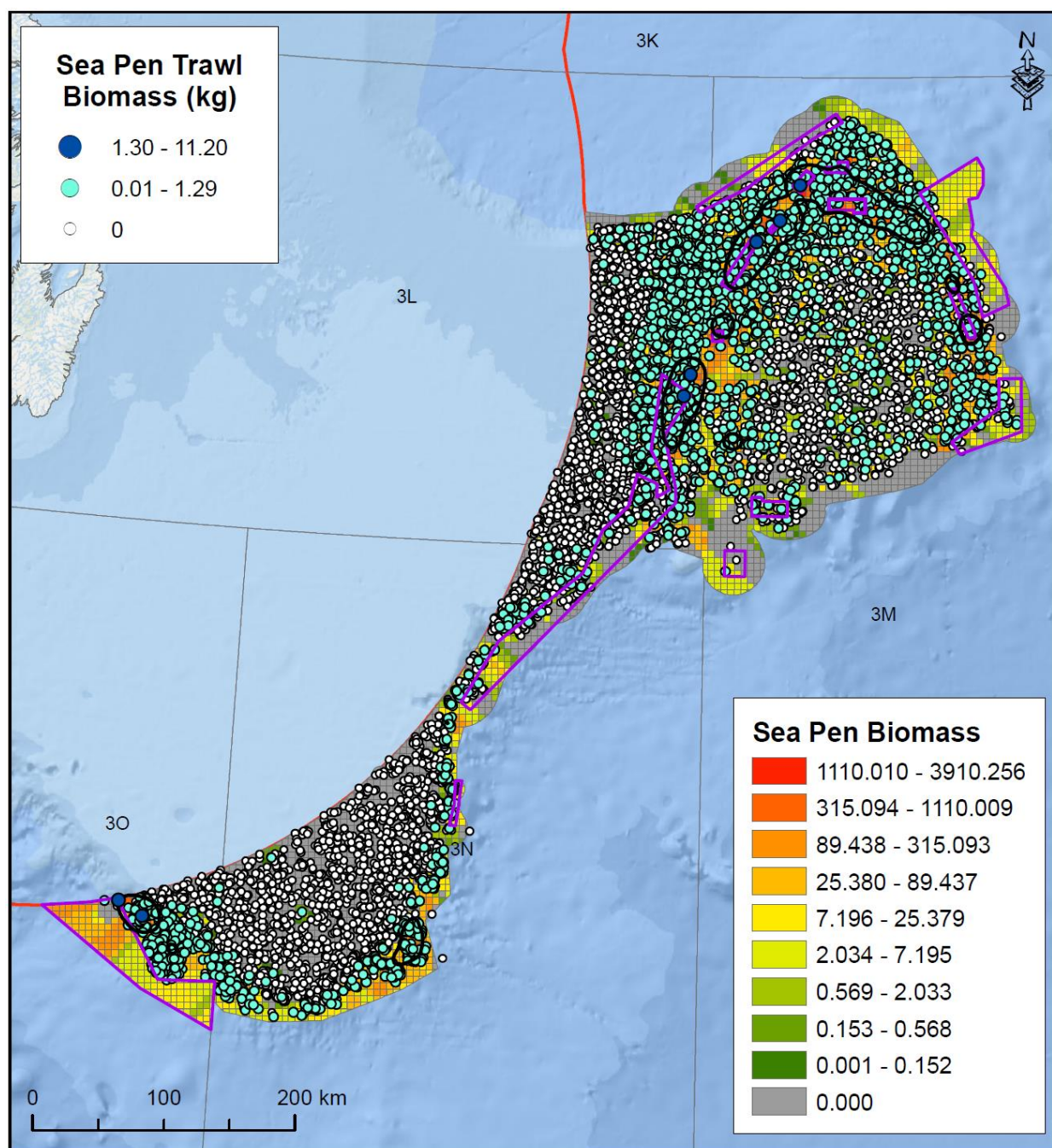


Figure 15. Estimation of total sea pen biomass (kg per 25 km² grid cell) showing the location of the RV vessel sea pen catch (kg) data points used to construct the surface. Black outlines indicate the VME polygons, purple lines indicated closed areas.

Gridded Biomass of *Boltenia ovifera* (Sea Squirts)

The total biomass surface of sea squirts (only one species *Boltenia ovifera* is included) from 6321 RV trawls (334 with biomass records and 5,987 null records) is shown in Figure 16, and in Figure 17 in relation to the RV survey data points used to construct the biomass surface. The total biomass is 48,761.3 kg for both grid cell sizes (Table 2).

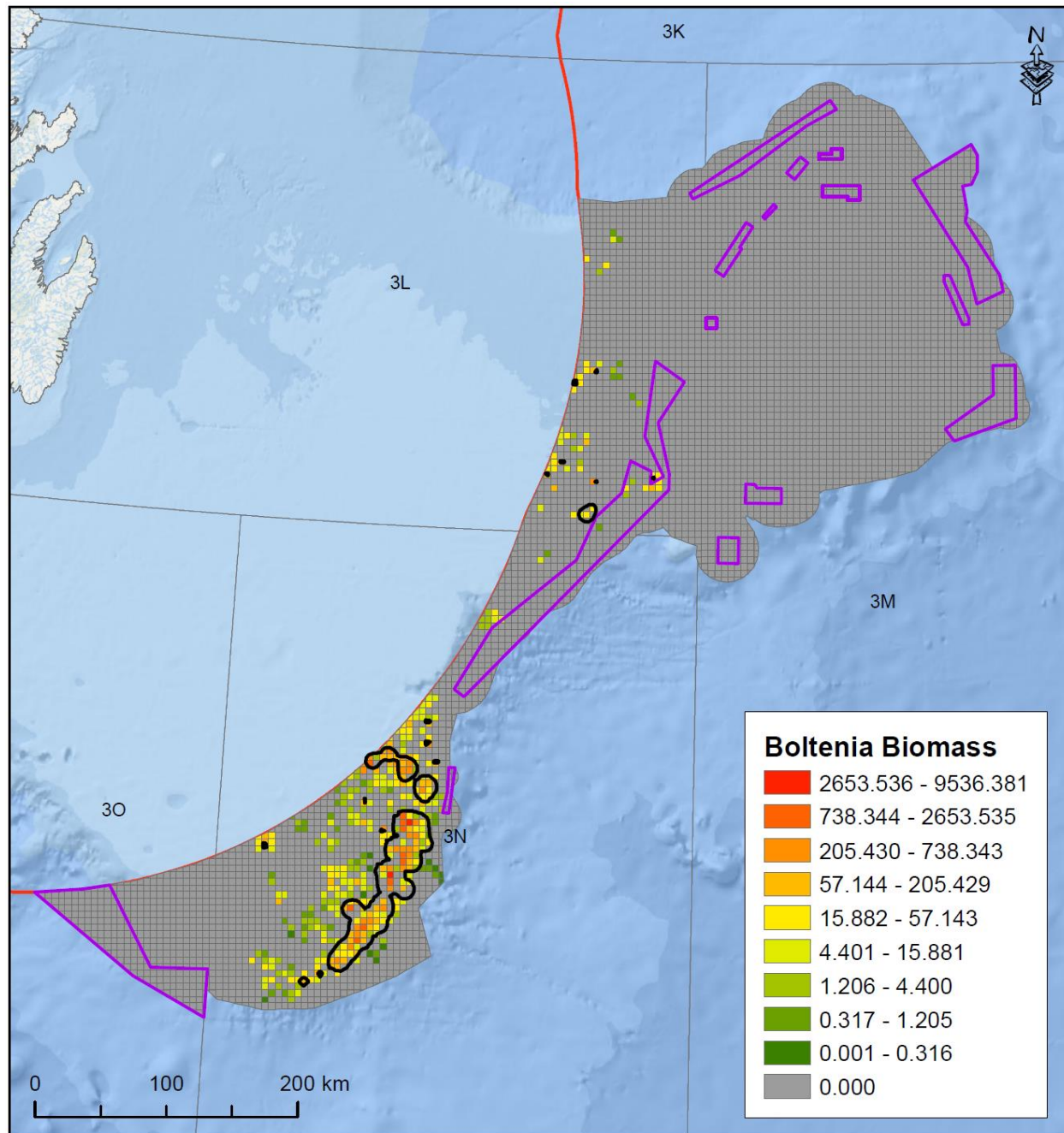


Figure 16. Estimation of total sea squirt biomass (kg per 25 km² grid cell). Black outlines indicate the VME polygons, purple lines indicated closed areas.

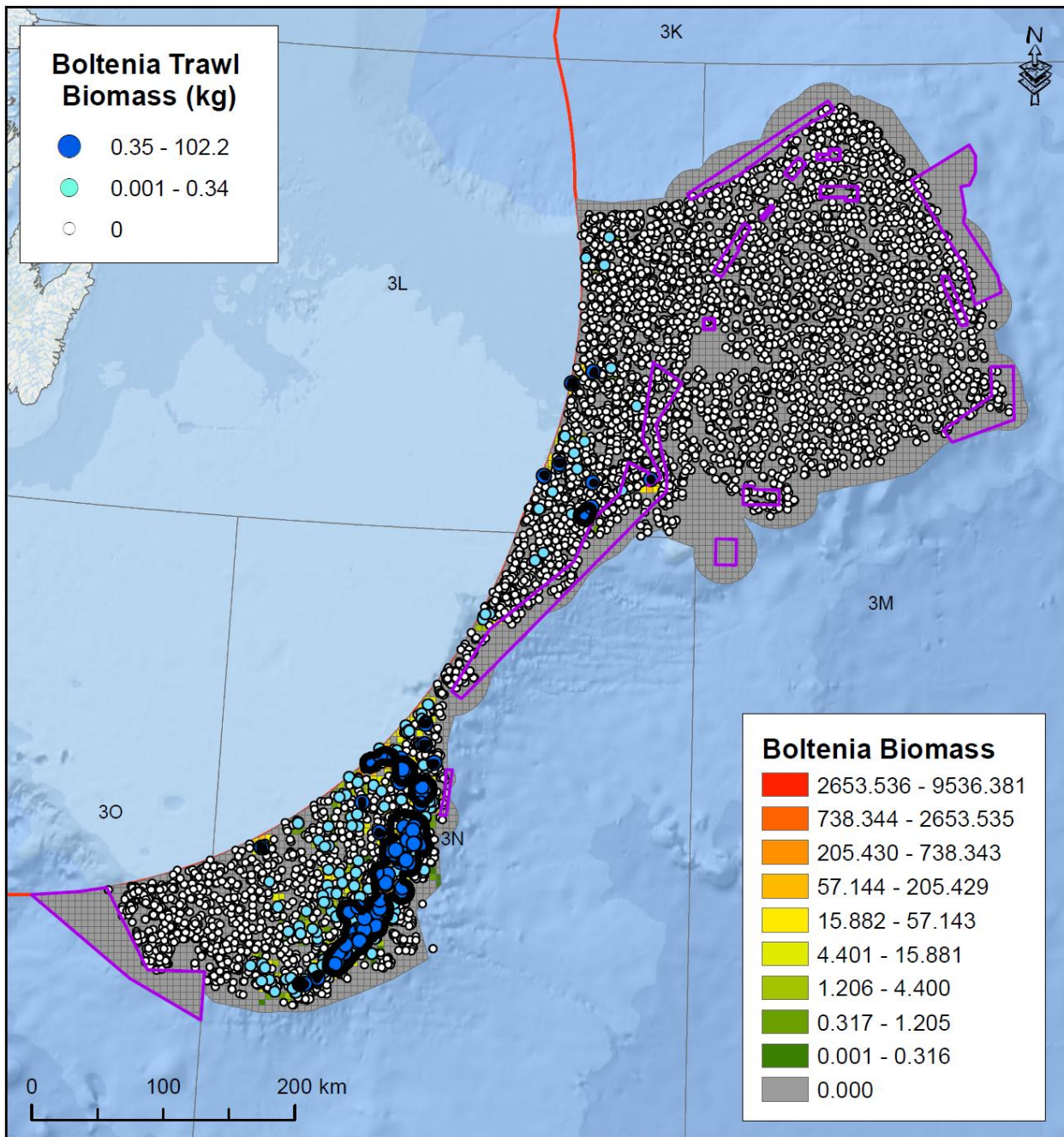


Figure 17. Estimation of total sea squirt biomass (kg per 25 km² grid cell) showing the location of the RV vessel sea squirt catch (kg) data points used to construct the surface. Black outlines indicate the VME polygons, purple lines indicated closed areas.

Gridded Biomass of Bryozoans

The total biomass surface of bryozoans from 5,728 RV trawls (774 with biomass records and 4,954 null (zero catch) records) is shown in Figure 18, and in Figure 19 in relation to the RV survey data points used to construct the biomass surface. For the 5 km and 1 km grid within the boundary of the study area, the total wet weight biomass is 72,069.3 kg and 72,069.0 kg respectively (Table 2).

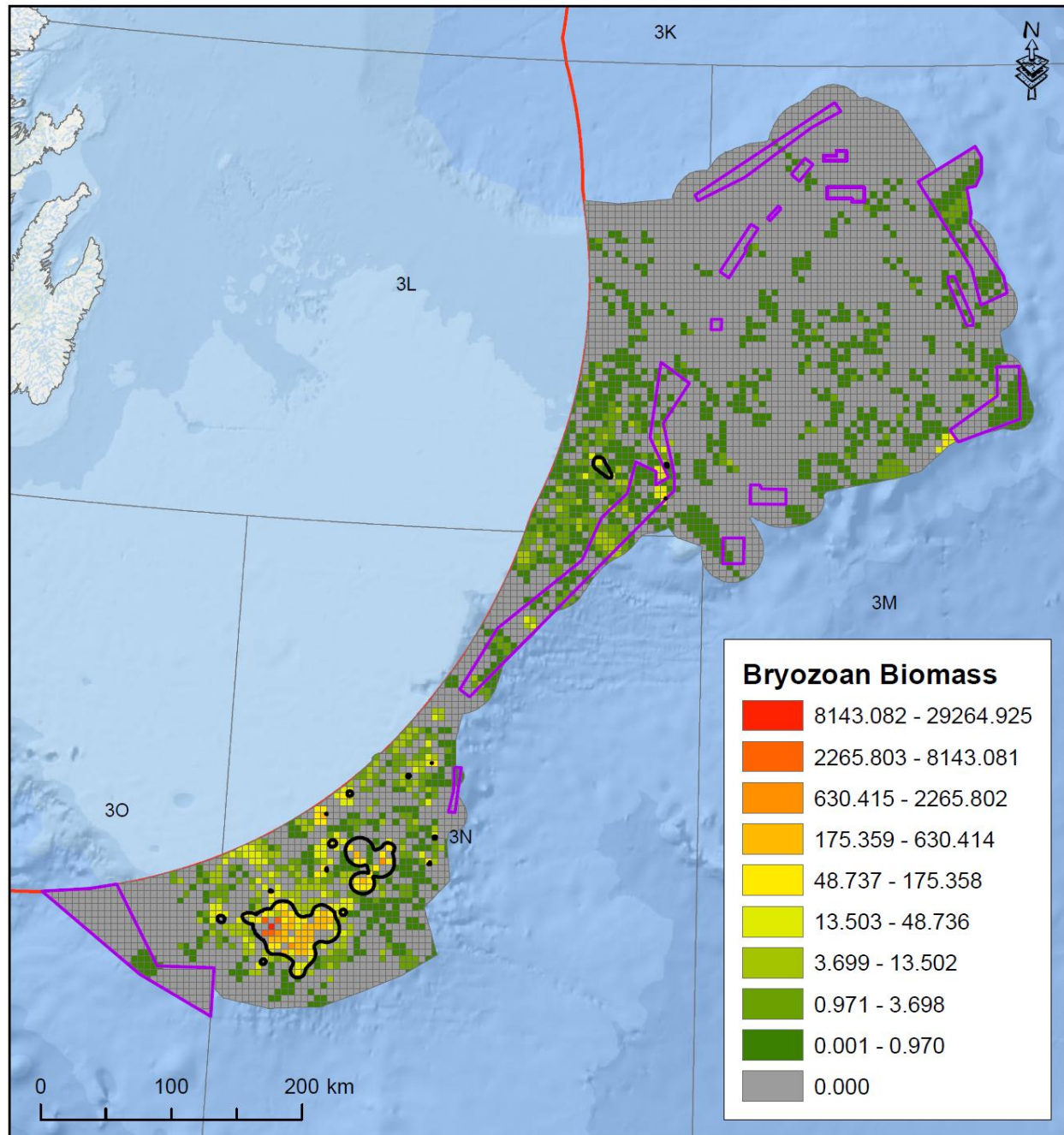


Figure 18. Estimation of total bryozoan biomass (kg per 25 km² grid cell). Black outlines indicate the VME polygons, purple lines indicated closed areas.

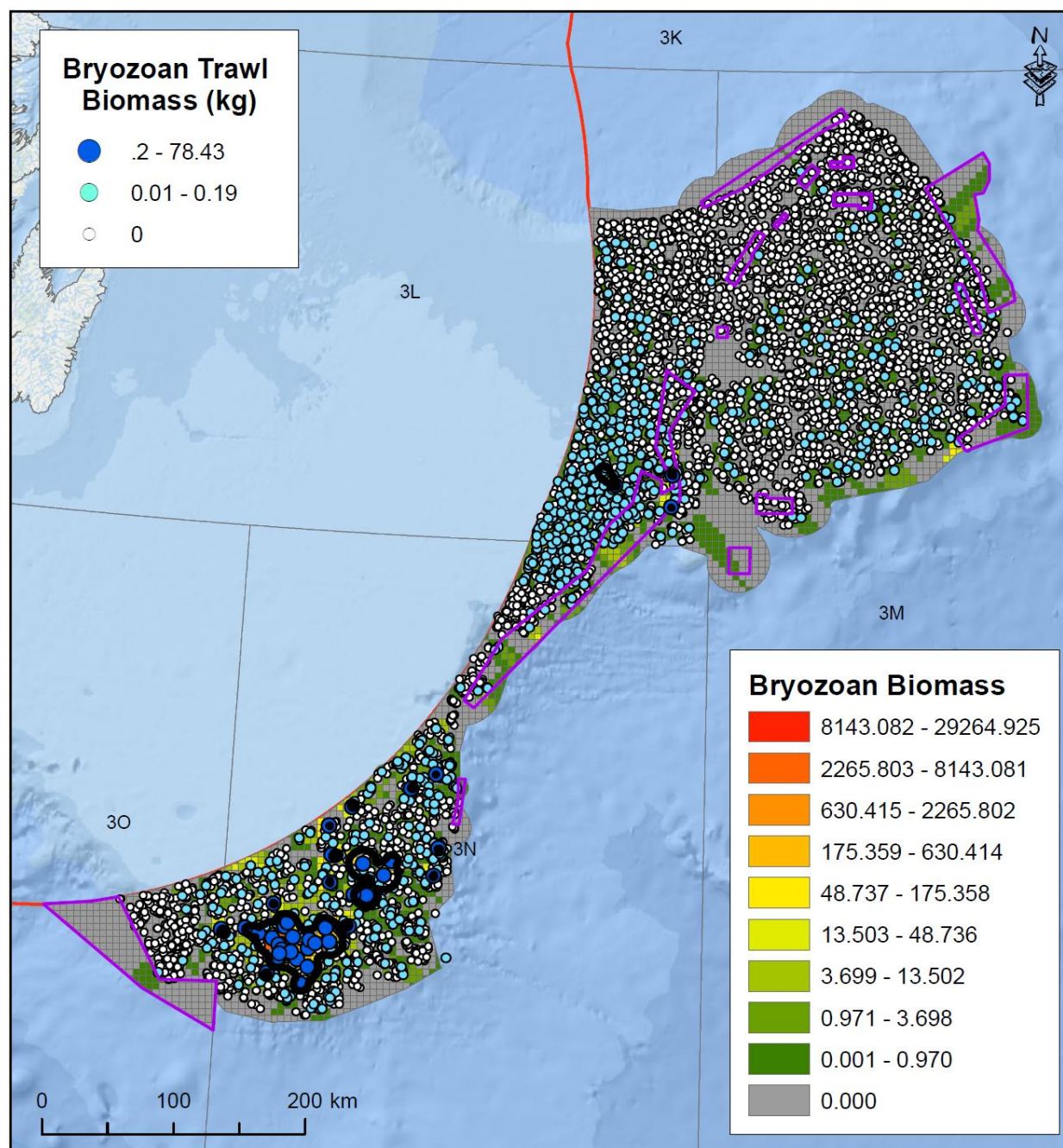


Figure 19. Estimation of total bryozoan biomass (kg per 25 km² grid cell) showing the location of the RV vessel bryozoan catch (kg) data points used to construct the surface. Black outlines indicate the VME polygons, purple lines indicated closed areas.

Gridded Biomass of Black Corals

The total biomass surface of black corals from 5,748 RV trawls (280 with biomass records and 5,468 null (zero catch) records) is shown in Figure 20, and in Figure 21 in relation to the RV survey data points used to construct the biomass surface. Within the boundary of the study area, the total wet weight biomass is 21,074.5 kg in the 5 km grid and 20,887.9 kg in the 1 km grid (Table 2).

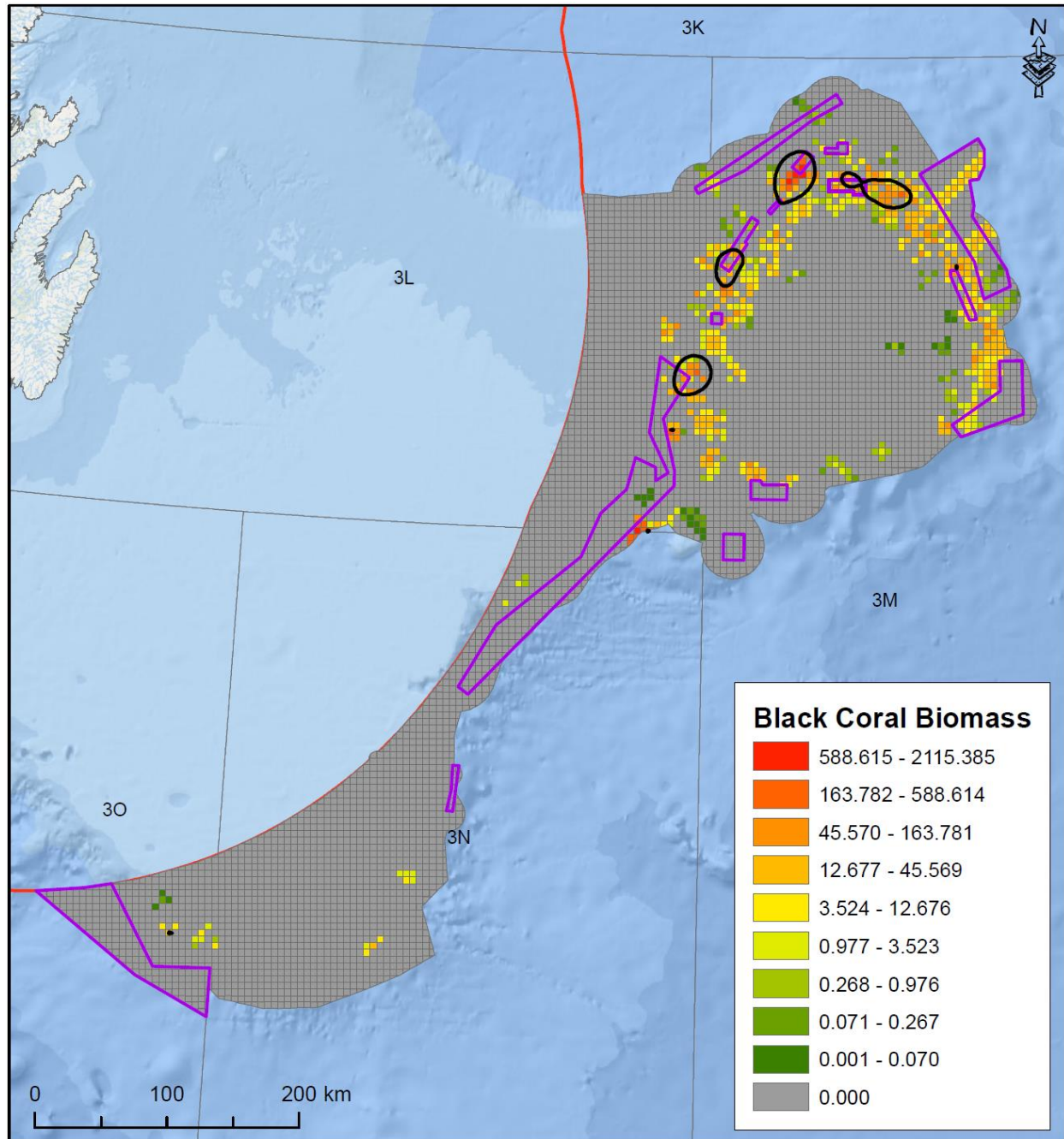


Figure 20. Estimation of total black coral biomass (kg per 25 km² grid cell). Black outlines indicate the VME polygons, purple lines indicated closed areas.

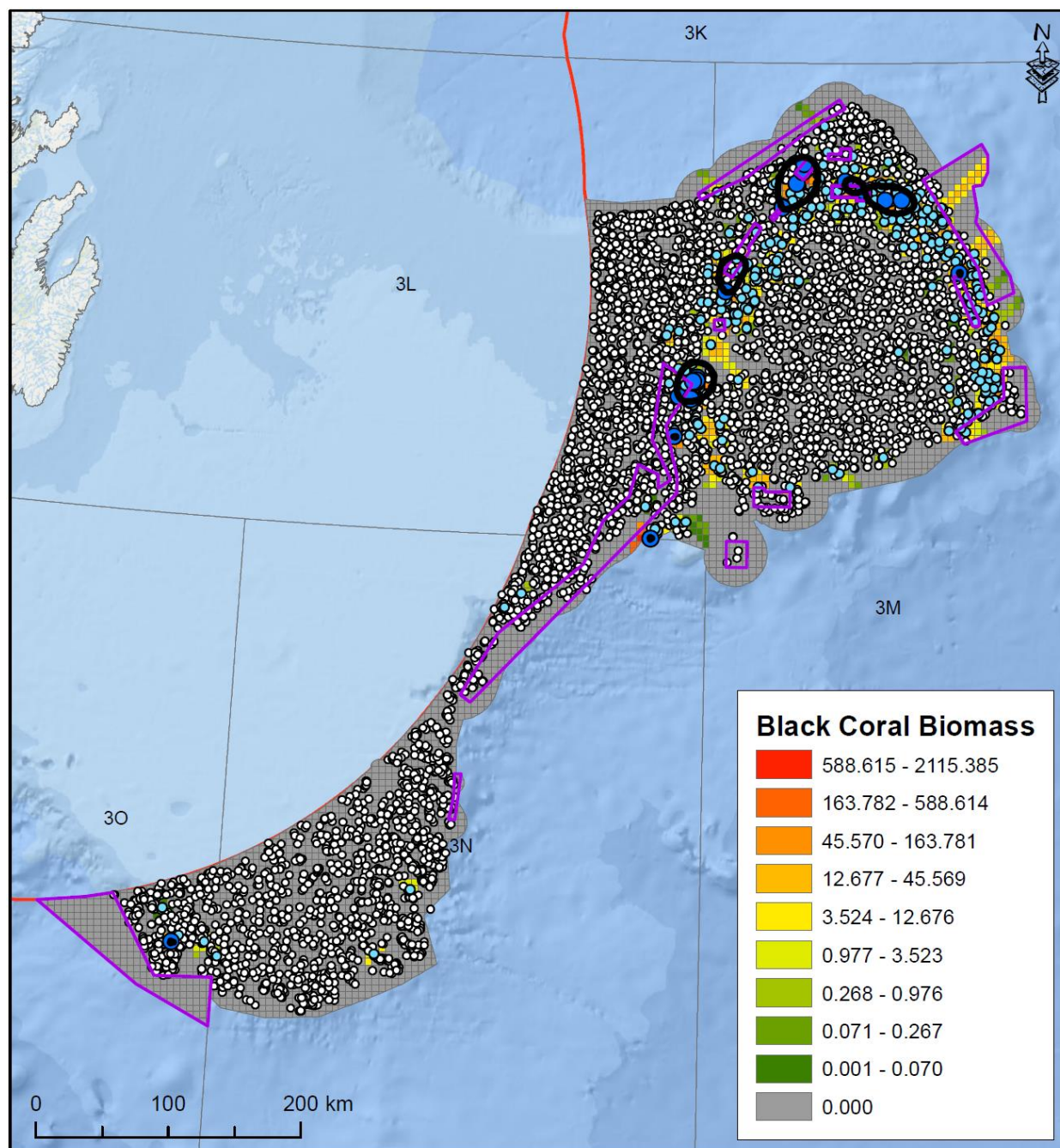


Figure 21. Estimation of total black coral biomass (kg per 25 km² grid cell) showing the location of the RV vessel black coral catch (kg) data points used to construct the surface. Black outlines indicate the VME polygons, purple lines indicated closed areas.

Gridded Biomass of Large Gorgonian Corals

The total biomass surface of large gorgonian corals from 6,430 RV trawls (283 with biomass records and 6,147 null (zero catch) records) is shown in Figure 22, and in Figure 23 in relation to the RV survey data points used to construct the biomass surface. Within the boundary of the study area, the total wet weight biomass is 150,723.5 kg in the 5 km grid and 149,440.6 kg in the 1 km grid.

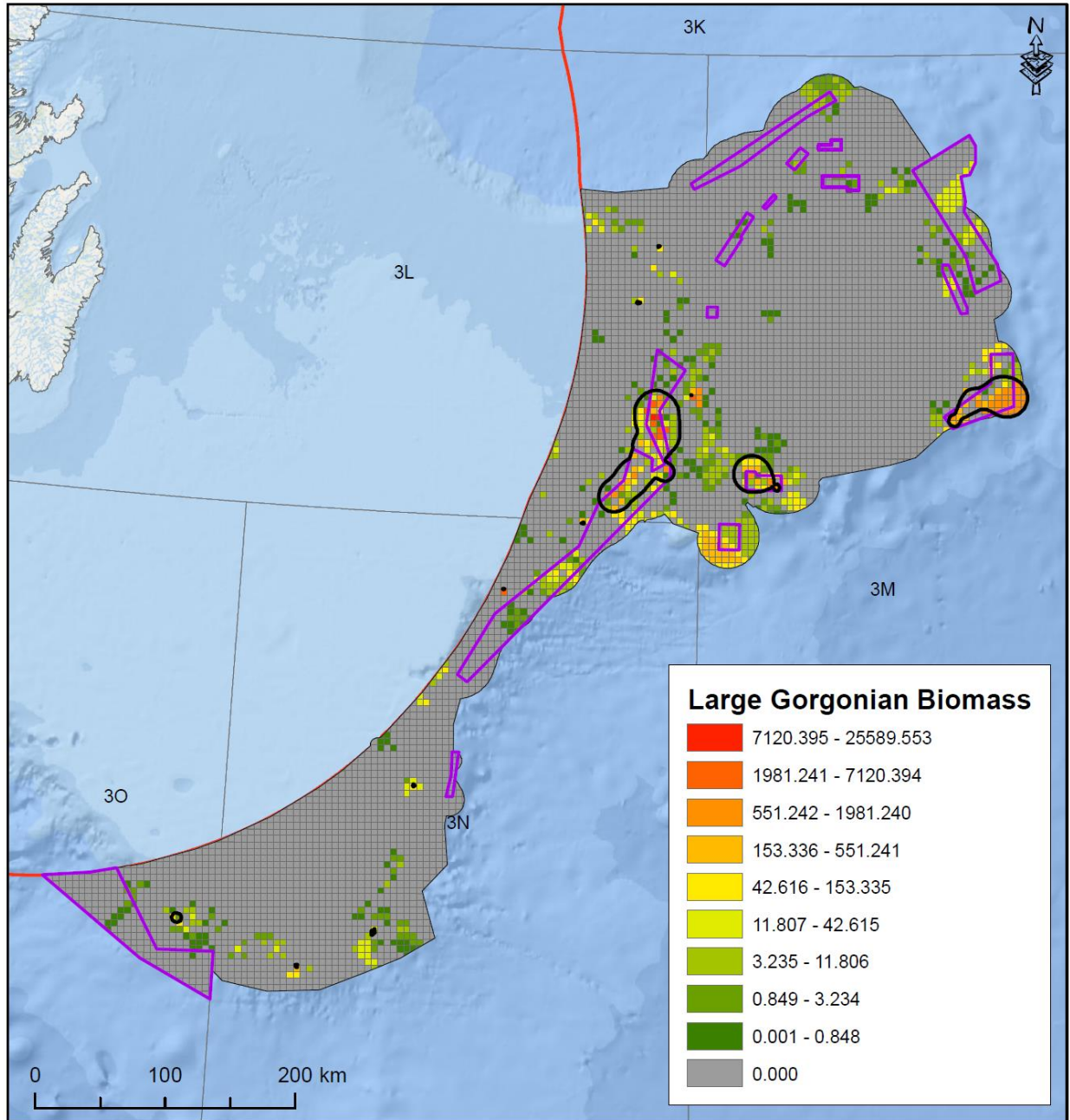


Figure 22. Estimation of total large gorgonian coral biomass (kg per 25 km² grid cell). Black outlines indicate the VME polygons, purple lines indicated closed areas.

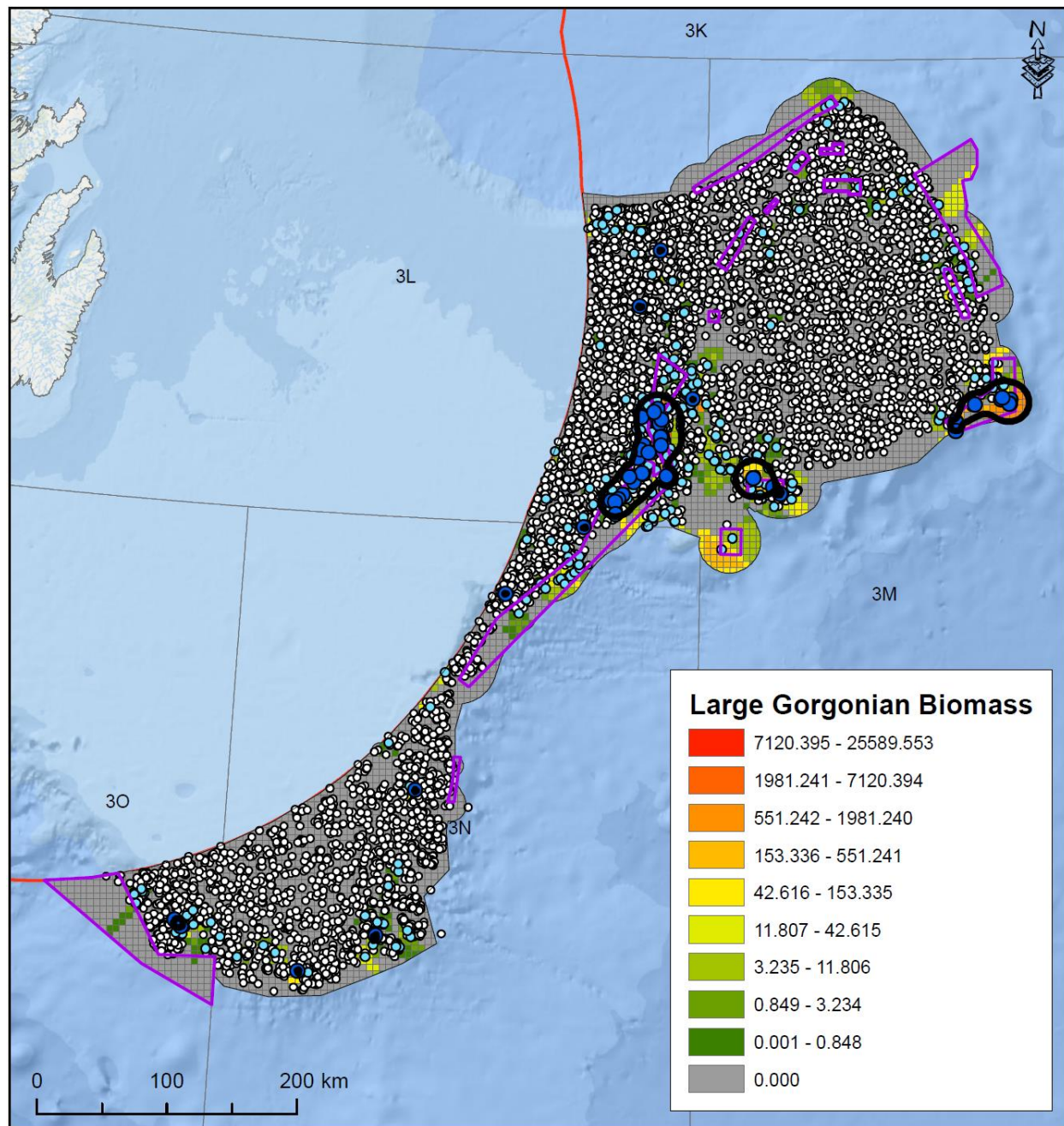


Figure 23. Estimation of total large gorgonian coral biomass (kg per 25 km² grid cell) showing the location of the RV vessel large gorgonian coral catch (kg) data points used to construct the surface. Black outlines indicate the VME polygons, purple lines indicated closed areas.

Gridded Biomass of Small Gorgonian Corals

The total biomass surface of small gorgonian corals from 6,649 RV trawls (688 with biomass records and 5,961 null records) is shown in Figure 24, and in Figure 25 in relation to the RV survey data points used to construct the biomass surface. Within the boundary of the study area, the total wet weight biomass is 13,850.3 kg in the 5 km grid and 13,845.5 kg in the 1 km grid (Table 2).

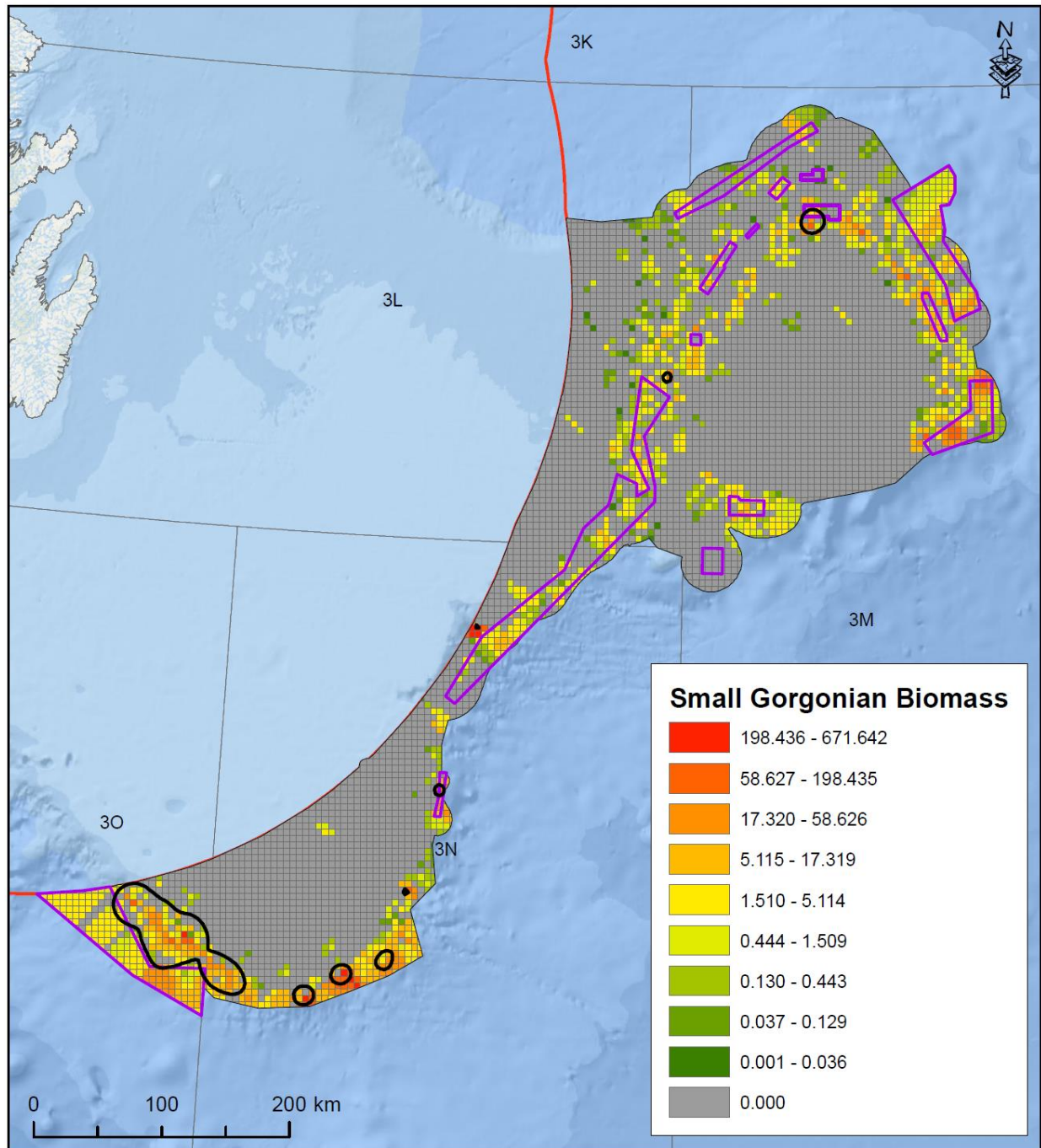


Figure 24. Estimation of total small gorgonian coral biomass (kg per 25 km² grid cell). Black outlines indicate the VME polygons, purple lines indicated closed areas.

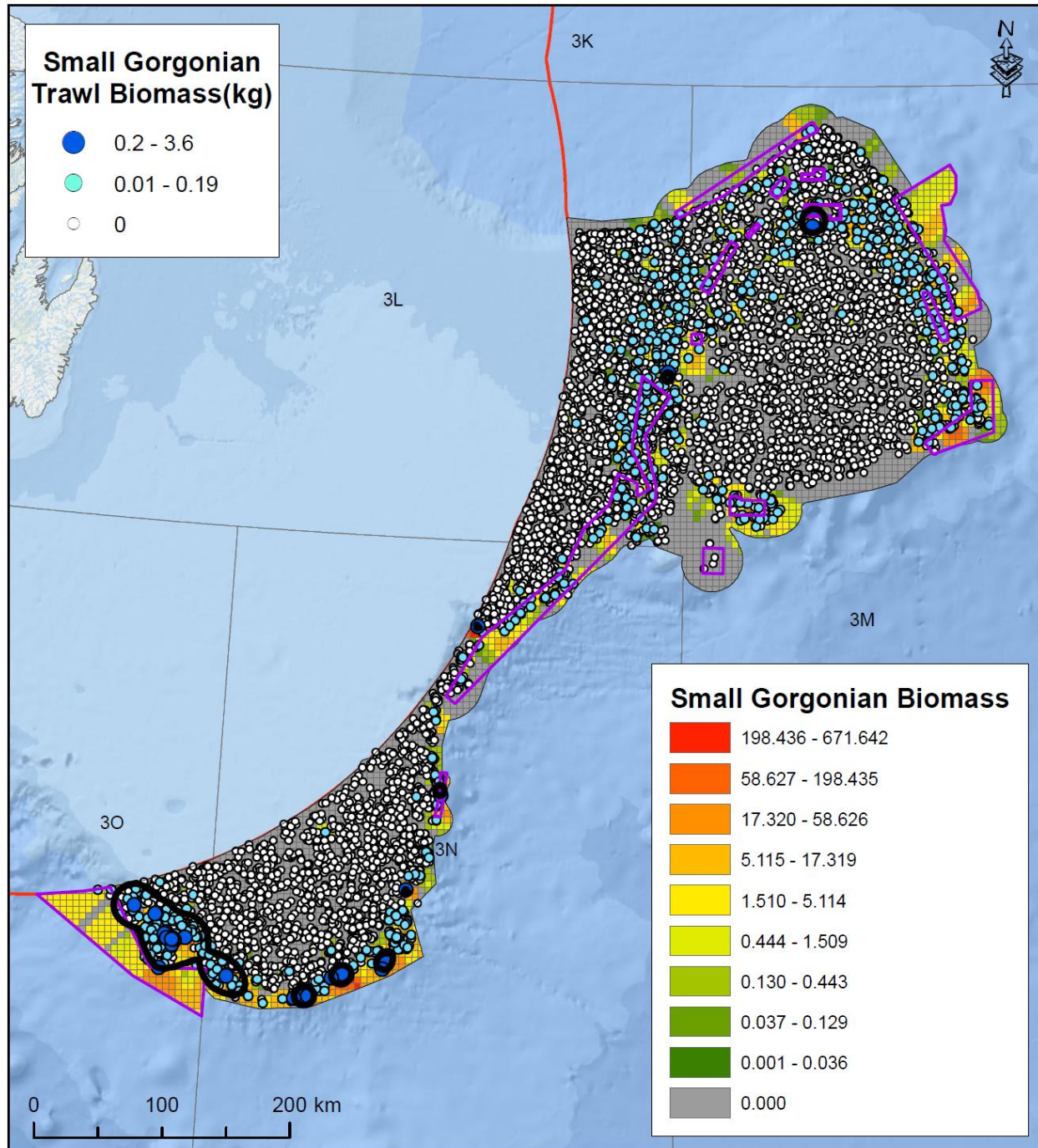


Figure 25. Estimation of total small gorgonian coral biomass (kg per 25 km² grid cell) showing the location of the RV vessel small gorgonian coral catch (kg) data points used to construct the surface. Black outlines indicate the VME polygons, purple lines indicated closed areas.

Summary of the Partitioning of VME Indicator Biomass Inside the VMEs and Inside the Closed Areas

The gridded biomass data was made available to WG-ESA in GIS format to further the work on SAI. To facilitate examination of the effectiveness of the closed areas in protecting VMEs we partitioned the VME Indicator

biomass into the total biomass found in the spatial extent (Figure 1), the biomass found within the KDE polygons described by Kenchington et al. (2019) as raw values and a percent of the total biomass, and the biomass found within the closed areas, also as raw values and the percent of the total biomass. This was done for both the 5 km and 1 km grids (Table 2). Values for six of the seven VME Indicators differ due to differences created in downscaling to the smaller grid size, however the biomass was at least 99% similar in all cases (see Appendix 2). The large-size sponges have the highest VME biomass in the spatial extent, and the largest proportion of that biomass encapsulated in the VME polygons and in the area closures. The large gorgonian corals have a large proportion of their biomass protected as well, however the other VME Indicators have low protection from the closed areas (Table 2). This is particularly true for sea pens that have a high total regional biomass of which only 25% is found in the closed areas. This includes Area 14 which is currently open to fishing; therefore the actual percentage of sea pen biomass under closed area protection would be even smaller. For most groups the VME polygons (Kenchington et al., 2019) capture a large proportion of their estimated biomass, the exception being the small gorgonian corals of which only 24% of the estimated total biomass in the region is within the VME polygons.

Table 2. Biomass estimates for each of 7 VME Indicators for the full spatial extent (Figure 1), the portion inside the VME polygons for the VME Indicator (Kenchington et al., 2019) and the portion inside the closed areas. Estimates made separately using the 5 km x 5 km and 1 km x 1 km grids.

VME Indicator	5 km Grid (Total Biomass in Kg)	5 km Grid (Kg Biomass Inside VME)	% Biomass (Inside VME)	5 km Grid (Kg Biomass Inside Closed Area)	% Biomass (Inside Closed Areas)
Large-size Sponge	293,432,034.0	277,136,159.1	94.4	226,209,845.6	77.1
Sea Pens	170,906.8	88,682.1	51.9	42,744.5	25.0
Sea Squirts	48,761.3	41,558.8	85.2	290.0	0.6
Erect Bryozoans	72,069.3	65,545.6	90.9	541.4	0.8
Black Coral	21,074.5	9,609.7	45.6	3,303.7	15.7
Large Gorgonian Corals	150,723.5	124,004.1	82.3	96,311.0	63.9
Small Gorgonian Corals	13,850.3	3,325.3	24.0	3,042.9	22.0
Sum of VME Biomass	293,909,419.7	277,468,884.7	94.4	226,356,079.2	77.0
VME Indicator	1 km Grid (Total Biomass in Kg)	1 km Grid (Kg Biomass Inside VME)	% Biomass (Inside VME)	1 km Grid (Kg Biomass Inside Closed Areas)	% Biomass (Inside Closed Areas)
Large-size Sponge	293,222,474.5	277,886,809.0	94.8	225,750,338.4	77.0
Sea Pens	170,691.0	88,682.1	52.0	42,744.2	25.0
Sea Squirts	48,761.3	41,558.8	85.2	290.0	0.6
Erect Bryozoans	72,069.0	65,545.6	90.9	541.4	0.8
Black Coral	20,887.9	9,609.7	46.0	3,303.4	15.8
Large Gorgonian Corals	149,440.6	124,004.1	83.0	96,311.0	64.4
Small Gorgonian Corals	13,845.5	3,325.3	24.0	3,042.2	22.0
Sum of VME Biomass	293,698,169.8	278,219,534.6	94.7	225,896,570.7	76.9

Total Biomass of All VME Indicators Combined

The individual VME Indicator biomass 5 km grids were overlain on one another (these layers had already been through the iterative focal statistics steps). For each cell, the number of non-zero biomass layers was calculated to get the number of VME Indicators present (VME Indicator Diversity). In many grid cells there are more than one VME Indicator taxon present (Figure 26). The eastern Flemish Cap shows the greatest overlap with some cells having up to 6 of the 7 VME Indicators present. To get a total VME wet weight biomass for the spatial extent we summed the biomass of all VME Indicators in each grid cell (Figure 27).

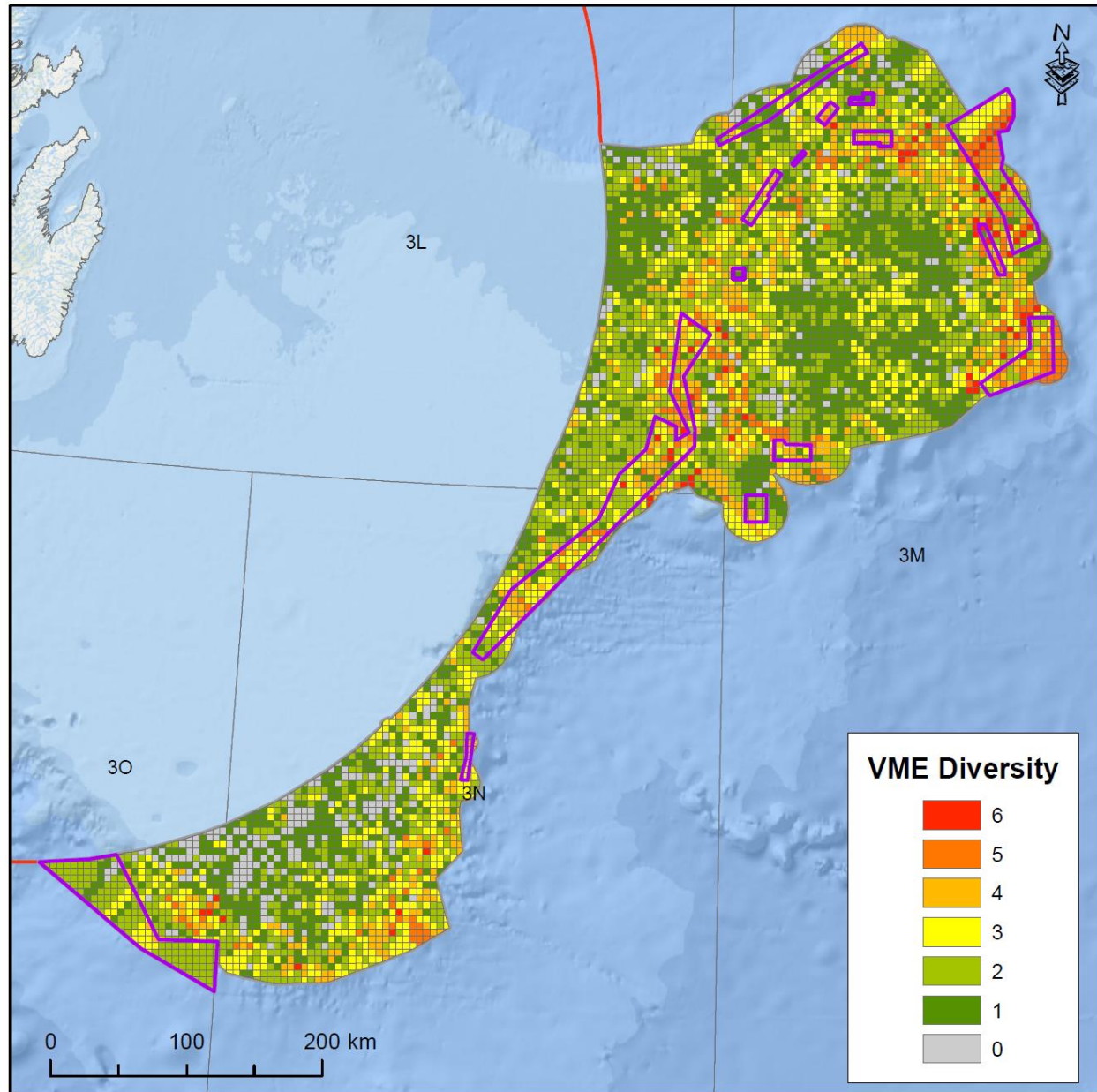


Figure 26. The number of VME Indicators found per 25 km² grid cell. Purple lines indicated closed areas.

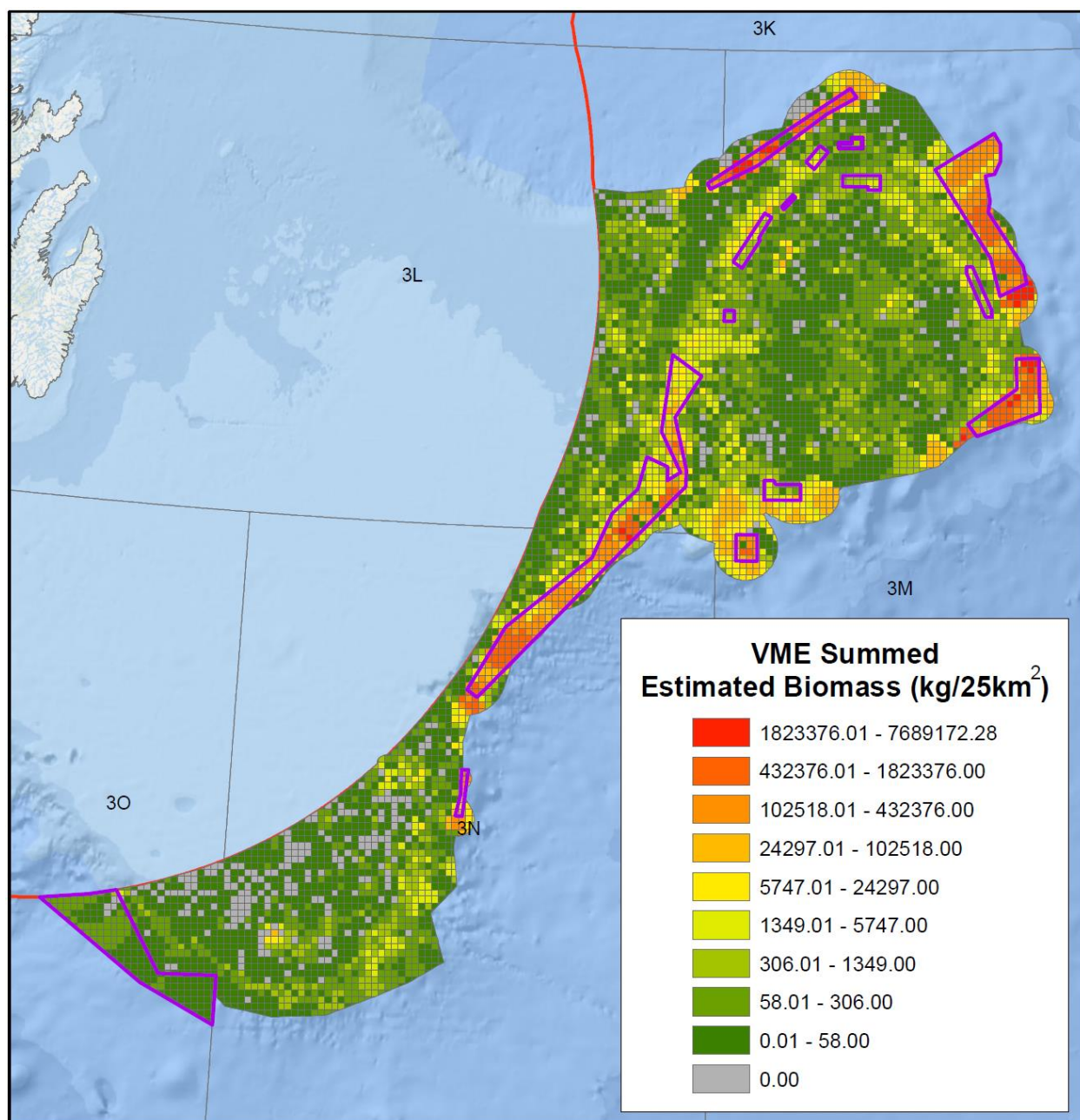


Figure 27. The total wet weight biomass of all VME Indicators found per 25 km² grid cell. Purple lines indicated closed areas.

Gridded Biomass of VME Indicator Species Inside VME Polygons

The focus of the work on SAI is on the portion of the VME polygons that are not protected by area closure measures. We have prepared gridded biomass surfaces for the total VME biomass inside the VME polygons (Kenchington et al., 2019) (Figure 28). The biomass of all VME Indicators in each grid cell inside the VME polygons is shown in Figure 29.

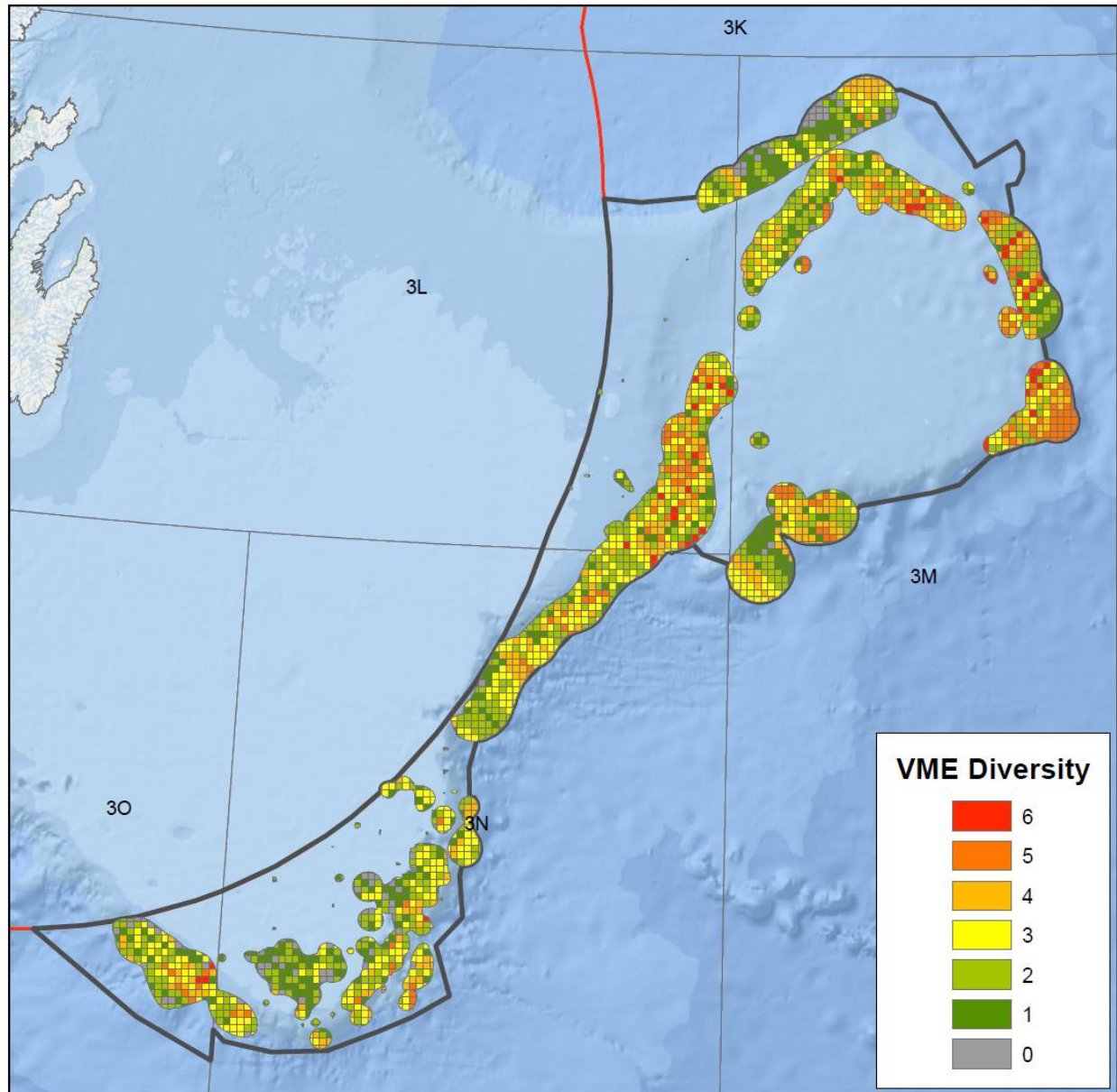


Figure 28. The number of VME Indicators present per 25 km² grid cell inside the VME polygons which are outlined in gray (Kenchington et al., 2019). The maximum possible number of Indicators is 7. Black line indicates the spatial extent of the analyses outside of the VME polygons (Figure 1).

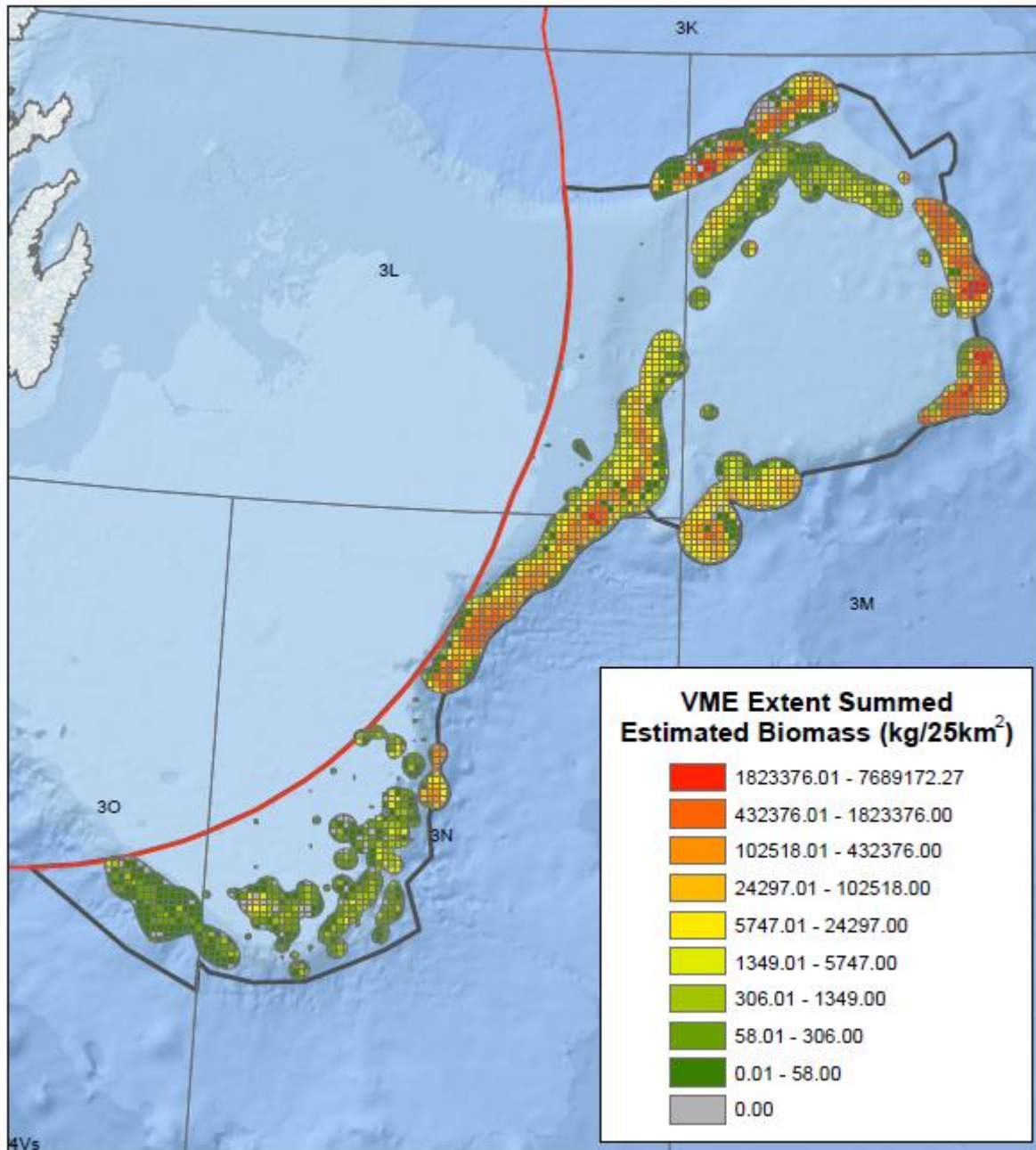


Figure 29. The total wet weight biomass (kg) of all VME Indicators found per 25 km² grid cell inside the KDE-derived VME polygons (Kenchington et al., 2019).

References

- Beazley, L., E. Kenchington, I. Yashayaev & F.J. Murillo, 2015. Drivers of epibenthic megafaunal composition in the sponge grounds of the Sackville Spur, northwest Atlantic. *Deep Sea Research I* 98: 102-114.
- Cogswell, A., E. Kenchington, C. Lirette, F.C. Murillo, G. Campanis, N. Campbell & N. Ollerhead, 2011. Layers Utilized by an ArcGIS Model to Approximate Commercial Coral and Sponge By-catch in the NAFO Regulatory Area. N6002. NAFO Scientific Council Research Document 11/72, 50pp.
- Kenchington, E., C. Lirette, F.J. Murillo, L. Beazley & A. L. Downie, 2019. Vulnerable Marine Ecosystems in the NAFO Regulatory Area: Updated Kernel Density Analyses of Vulnerable Marine Ecosystem Indicators. NAFO Scientific Council Research Document 19/058, Serial No. N7030, 68 p.
- Knudby, A., Kenchington, E. & F.J. Murillo, 2013. Modeling the Distribution of *Geodia* Sponges and Sponge Grounds in the Northwest Atlantic. *PLoS ONE* 8: e82306. doi:10.1371/journal.pone.0082306.
- NAFO. 2010. Scientific Council Meeting – June 2011. Report of the 3rd Meeting of the NAFO Scientific Council Working Group on Ecosystem Approaches to Fisheries Management (WGEAFM). NAFO Scientific Council Studies Document 10/ 24. Serial No. N5868. 75 pp.
- NAFO. 2020. SC Working Group on Ecosystem Science and Assessment – November 2019. Report of the 12th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO Scientific Council Studies 19/25. Serial No. N7027.
- Pham, C.K., F. J. Murillo, C. Lirette, M. Maldonado, A. Colaco & E. Kenchington, 2019. Removal of deep-sea sponges by bottom trawling in the Flemish Cap area: conservation, ecology and economic assessment. *Nature Scientific Reports* 9: 15843. <https://doi.org/10.1038/s41598-019-52250-1>

Appendix 1

Production of Total Biomass Layers using ModelBuilder in ArcGIS

ModelBuilder is a visual programming language for building geoprocessing workflows in ArcGIS (<https://pro.arcgis.com/en/pro-app/help/analysis/geoprocessing/modelbuilder/what-is-modelbuilder-.htm>). Geoprocessing models automate and document the spatial analyses and data management processes thereby increasing reproducibility, transparency and efficiency. In ModelBuilder, a model diagram is created that chains together sequences of processes and geoprocessing tools, using the output of one process as the input to another process. Connector arrows show the direction of processing. Below, details of the model diagrams used to create mean biomass, Models 1a and 1b, and the total biomass, Model 2, are described.

Model 1a - VME Mean Biomass Start Grid

The objective of this model is to create a 5 km mean biomass grid of a VME group and to process a first set of interpolated biomass values immediately adjacent (one layer deep) 'no data' grid cells using focal statistics.

The model diagram is shown in Figure S1 and numbers in bold below refer to steps in the model diagram for Model 1a.

The VME RV trawl dataset, with biomass and null catches, and a 5 km polygon grid are inputs for a spatial join where mean biomass value (MBV) is calculated and passed to the 5 km polygon grid **1**.

[A note regarding two model inputs: the 5 km polygon grid, used in Model 1a, and the 1 km polygon grid, used in Model 2. In preparation for the analysis, two fields were added in the attribute table for each grid, 'Gear' and 'SweptArea', and updated with the following information. For the Gear field, grid cells located in the 3M NAFO Division were selected and updated to "Lofoten" including those cells intersecting the 3L-3M border. The remaining grid cells, located in the 3NLO NAFO Divisions, were selected and updated to "Campelen". For the SweptArea field, grid cells in the 3M Division were updated with a value 39,000, the typical RV Lofoten Trawl swept area. Grid cells located in the 3NLO Divisions were selected and updated with a value of 67,000, a typical RV Campelen Trawl swept area. The area units are m².]

Once the mean biomass grid has been created, the next step in the model is to begin the process of increasing the coverage of the biomass layer using focal statistics. The focal statistic tool is a raster tool; the polygon grid is converted to a raster. In ArcGIS, to convert a polygon grid to raster, values must be of an integer datatype. In steps **2** and **3** the model adds an integer field, Int, in the polygon grid and the MBV is calculated here to an integer number. [To maintain precision in the integer, MBV were multiplied by 100000 for all VME except for Sponge, with a higher maximum MBV, 10000. A higher multiplier increases precision. Example: a MBV of .0001 has an integer value of 100000 X .0001 = 10.]

With the biomass grid now having mean biomass values in an integer format the model splits where a definition query is applied to the grid using the 'Make Feature Layer' tool which selects all cells that do not contain data in the polygon grid, a 'No Data' layer **4** and the polygon grid is converted to an integer raster **5**.

The integer raster is now used as input for the focal statistics tool where default settings are maintained: 'Neighbourhood' is Rectangle, 'Neighbourhood Settings' are Height 3 and Width 3, 'Units' = Cell, 'Statistics Type' is Mean and 'Ignore NoData in Calculation' is checked. The effect of these settings increases the raster by one row of raster cells along the edge of the input raster, **6**.

The focal statistics raster and the 'NoData' layer produced in **4** are used as inputs for the 'Extract By Mask' tool, **7**. The 'No Data' layer is a mask that extracts focal statistic values only where there is no data, the outer edge of cells in the focal statistics raster where there had previously been no data in the input raster.

The integer raster produced in **5** and the output from the 'Extract by Mask' tool are used as inputs to the 'Mosaic to New Raster' tool where the two rasters are merged to produce a raster that maintains the original MBV in **5**

and adds a layer of new interpolated MBV raster cells along the edge of the original raster which were created by focal statistics, **8**.

The raster created in **8** is now converted back to a polygon using the 'Raster to Polygon' tool, **9**.

The polygon grid produced in **9** is spatially joined to a 5 km grid using the Match Option – WITHIN CLEMENTINI. This option directly copies the values of the previous polygon to a new polygon where all individual 5 km grid cells are present, **10**.

The final step adds a 'Mean Biomass' field, **11**, where integer values are converted back to the original MBV precision by dividing by the same value used in step 3, **12**.

Model 1a has now created the first mean biomass grid (MB Grid1) with the first build of interpolated biomass cells along the edge of the original cells.

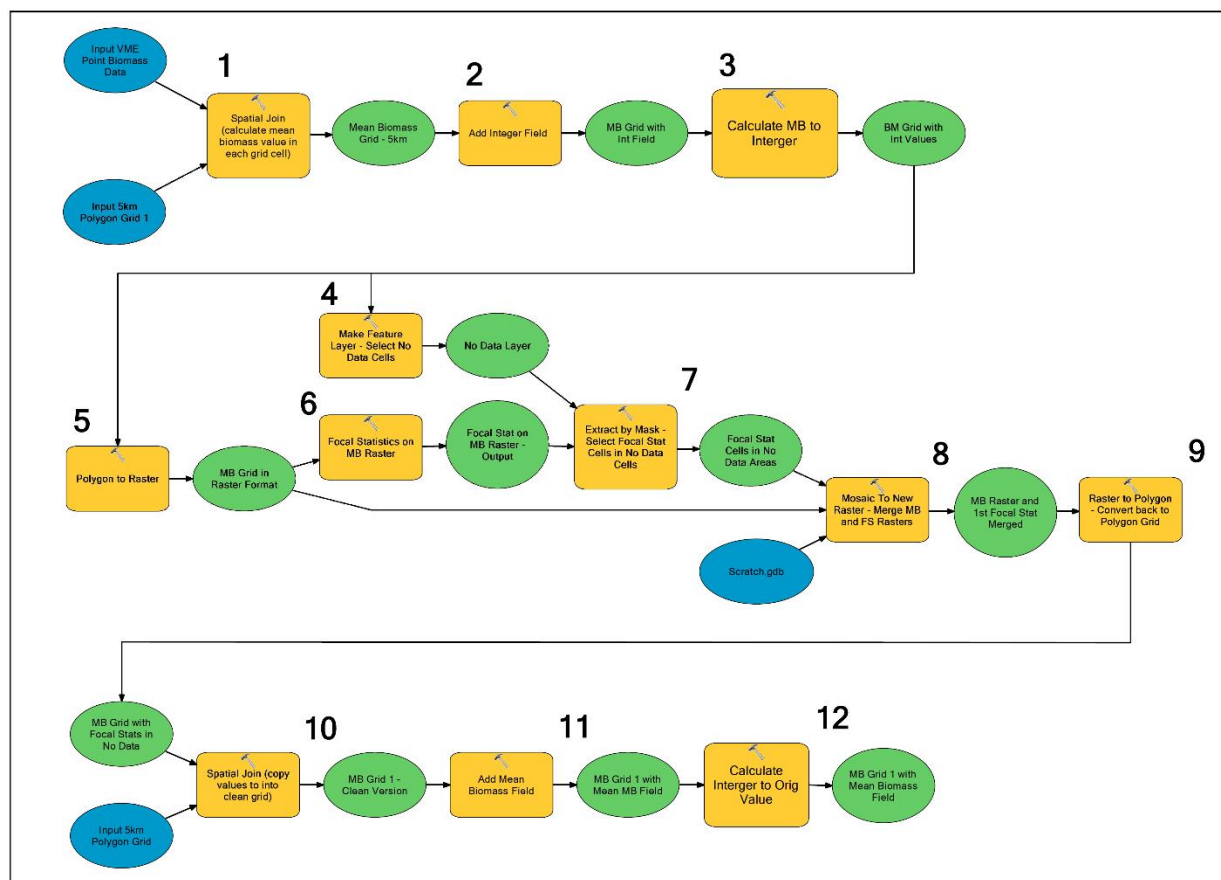


Figure S1. Model 1a diagram displaying a chain of geoprocessing tools used to produce an initial mean biomass layer and first build of interpolated biomass values in nearby 'no data' cells using focal statistics. The model was created in ModelBuilder ArcGIS v10.7 <https://desktop.arcgis.com/en/arcmap/latest/analyze/modelbuilder/a-quick-tour-of-modelbuilder.htm> ; blue polygons indicate inputs, green polygons indicate outputs and orange polygons indicate where modeling tools are applied. These polygons are linked with connector lines indicating the path the model takes in its development. Numbers refer to steps outlined in the text for Model 1a.

Model 1b – VME Mean Biomass Build Grid

The objective of this model is to incrementally expand the mean biomass polygon grid produced in Model 1a until the grid reaches the edge of the study extent. The output of Model 1a, MB Grid 1, is now entered as input into Model 1b. Model 1b is essentially a copy of Model 1a. The only difference is found at the beginning of the model where the spatial join tool is not required as the, MB Grid 1, is used as input. The rest of Model 1b then proceeds exactly as it did in Model 1a.

The output of Model 1b, MB Grid 2, now has two layers of cells along the outer edge of the original mean biomass grid. The output, with two layers of focal statistic produced cells, is now re-entered into Model 1b to produce an output with three layers of focal statistic cells, MB Grid 3. This ‘building’ of the biomass layer goes on until it reaches the study extent shown in Figure 1 of the manuscript. Typically, the final grid reaches a MB Grid of 10 to 15, **MB Grid Final**.

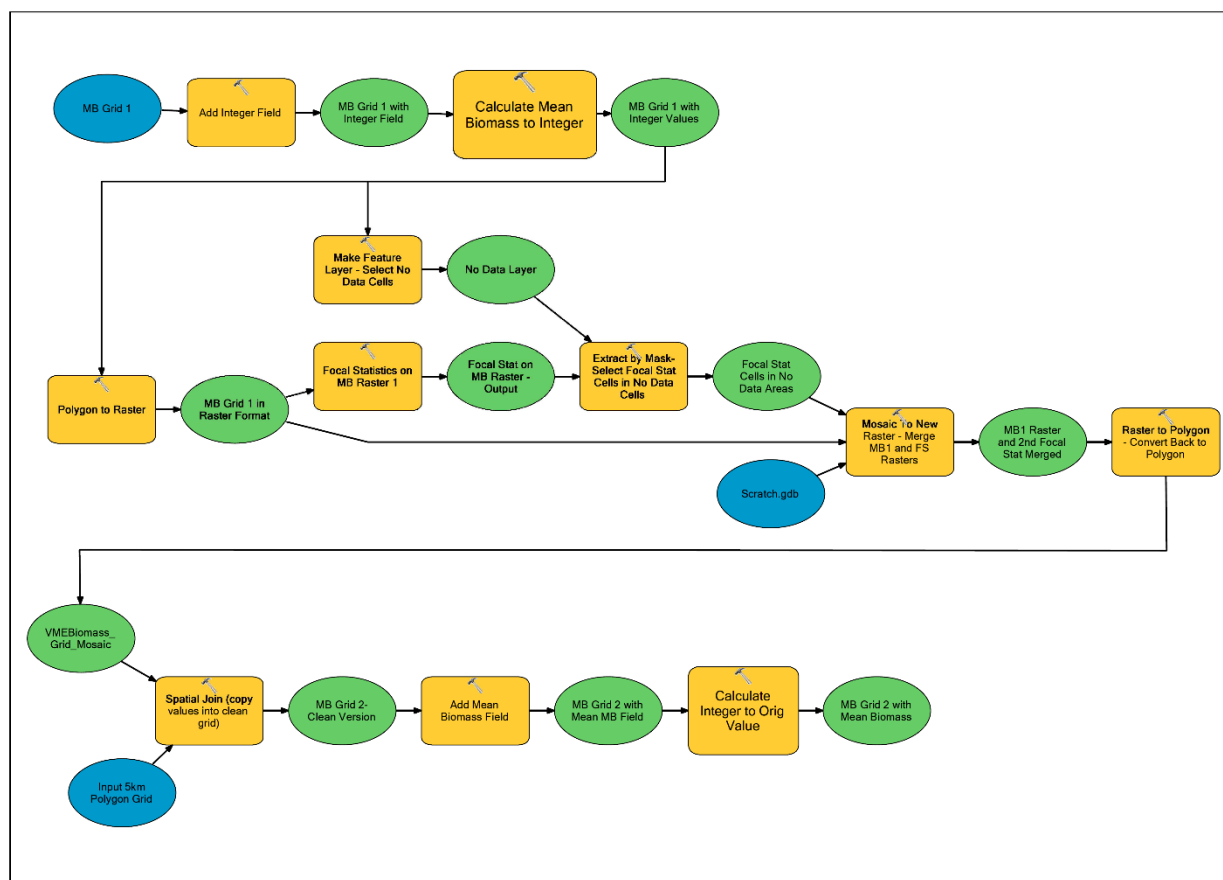


Figure S2. Model 1b diagram used to incrementally expand the mean biomass grid surface following Model 1a. See Figure S1 caption for details of the diagram.

Model 2 - VME Grid Total Biomass Calculator

Model 2 calculates the trawled biomass in each grid cell for both a 5 km grid and a 1 km grid. In essence, the model is calculating how much VME biomass could be caught in a grid cell if completely trawled. Once the trawled biomass is determined in each cell, the sum of the trawled biomass over the total grid provides the total biomass from RV trawls inside the study area.

The input for Model 2 is the MB Grid Final (output from Model 1b) clipped to the study extent. Gear and SweptArea fields are present in the attribute table. The first part of the model calculates the 5 km Trawled

Biomass. The model begins by creating a field called, SweptFactor, **1**. SweptFactor is the number of typical RV trawls that can be completed within a grid cell. It is calculated by dividing the area of a 5 km cell into the swept area of a trawl (SweptFactor = Cell Area / Trawl Swept Area). A 5 km grid cell has an area of 25 million square metres, a Campelen trawl has a swept area of 67,000 square metres and a Lofoten trawl has a swept area of 39,000 square metres. So, Campelen trawls have a swept factor of 373.134 (25,000,000/67,000) and Lofoten trawls have a swept factor of 641.026 (25,000,000/39,000) in 5 km cells. The SweptFactor is the first calculation in the Model, **2**. Note, along the edge of the study area extent, cells are clipped so the area of those cells decrease. With the reduction in the area of these cells, the SweptFactor value changes accordingly.

Next, the model creates a new field, Trawled Biomass, **3**. Trawled Biomass is the product of the mean biomass in a cell and the SweptFactor. Using the 'Calculate Field' tool, Trawled Biomass values are calculated, **4**. This completes the trawled biomass calculation in the 5 km grid cell. The values of the trawled biomass in each cell in the study area are summed to produce the total trawled biomass of a VME.

The 5 km trawled biomass grid, MB Grid Final, now containing a 'Trawled Biomass' field in the attribute table, is used in a spatial join which transfers the Trawled Biomass values in 5 km grid to the 1 km grid, **5**. The model repeats the process above to produce 1 km trawled biomass values. A SweptFactor field is created and is calculated for the 1 km grid. The SweptFactor is 14.925 (1,000,000/67,000) for Campelen trawls and 25.6410 (1,000,000/39,000) for Lofoten trawls, **6** and **7**. A Trawled Biomass Field is created, **8**, and the Trawled Biomass in 1 km² cells are calculated, **9**. The Biomass values can now be summed to determine the Total Biomass within the study limit.

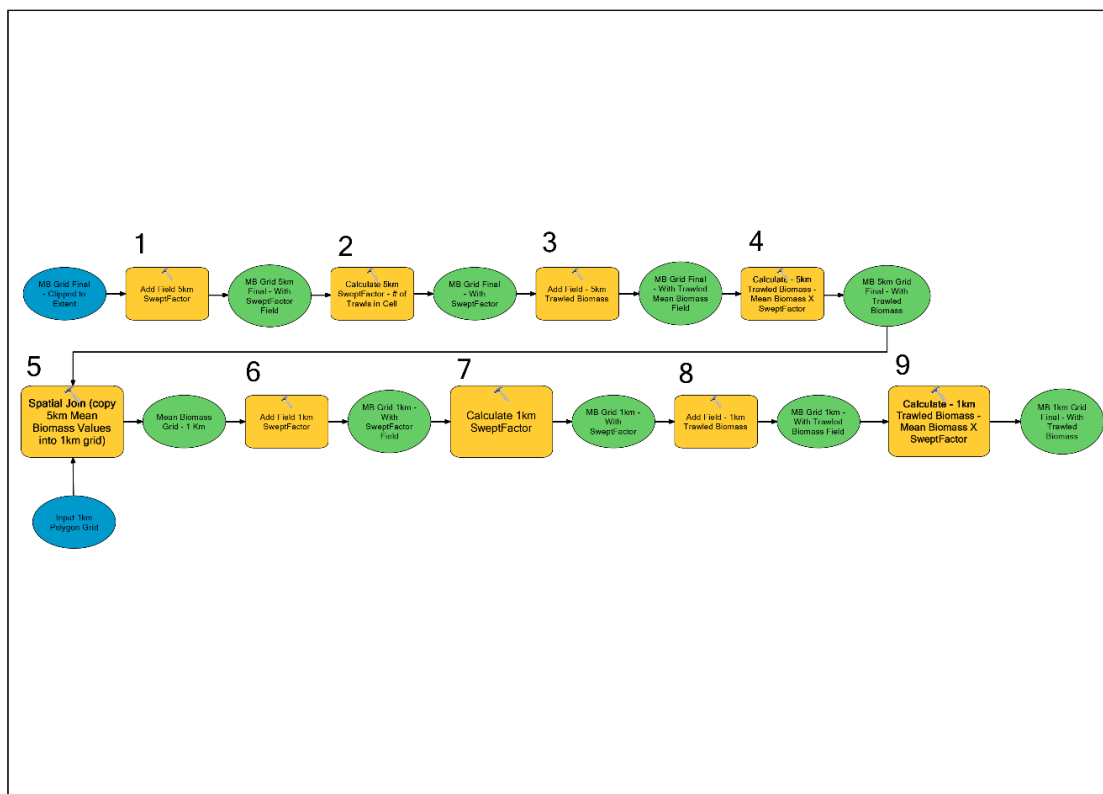


Figure S3. Model 2 diagram displaying the steps in calculating total VME biomass inside the study area. Numbers refer to steps outlined in the text for Model 2.

Appendix 2

Explanation for Small Biomass Differences Observed in 5 km and 1 km Grids

Small differences in biomass values between 5 km and 1 km grids were observed in six of the seven VME biomass surfaces (Table 2). Upon investigating the cause of those differences, the models (Appendix 1) were found to be working correctly, in that there were no errors in the workflow. However, the differences observed were the result of a gear assignment issue in grid cells along the 3L-3M NAFO Division border. In the model (Appendix 1), a rule was followed where grid cells in the 3M NAFO Division are assigned the Lofoten gear type, which is the trawl gear used in the research vessel surveys in that area. Grid cells outside 3M were assigned the Campelen gear type for the same reason. The Campelen has a larger swept area than the Lofoten. Each 5 km x 5 km cell has a single gear type. In cells where the NAFO Division 3L-3M border crosses the cell, the entire cell is assigned to 3M and so has Lofoten gear scaling factors 'SweptFactors' (Figure S4). When the 1 km grid is overlain on the 5 km grid the same issue arises but at a smaller scale. As the model applies the gear scaling factors after the 1 km grid is overlain, cells that were formerly assigned Lofoten gear scaling factors in the 5 km grid, now have Campelen scaling factors. This is the reason for the differences in total biomass between the two grid sizes as shown in Table 2. The degree of difference will depend on the distribution of the data and the biomass relative to the border. We confirmed this explanation by matching the gear assignments in both grids and observed 99.99% match in biomass. We did not attempt to make any adjustments to the biomass surfaces for the VME indicators in the model as the overall effect was very small (<1% total biomass) and the correct rule to follow would depend on the location of the catches within each cell at each scale which was not automated. A future solution to this issue could be to clip and merge the grids along the division border and assign gear type to these partial cells along the 3L-3M border, however while that would automate the process the impacts of that solution would still require examination of the individual cells relative to the trawl data to determine accuracy.

Below, differences in VME biomass values between the 5 km and 1 km grids are listed for each VME Indicator (Table 2).

Sponge Total Biomass

5 km grid = 293,432,034.0 kg

1 km grid = 293,222,474.5 kg

The difference in weight is 209,559.5 kg. These weights are 99.93% similar but a large weight difference nonetheless.

Sea Pen Total Biomass

5 km grid = 170,906.8

1 km grid = 170,691.0

The difference in weight was 215 kg and they are 99.87% similar.

Black Coral Total Biomass

5 km grid = 21,074.5

1 km grid = 20,887.9

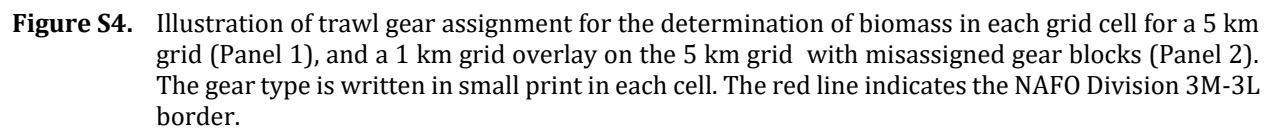
The difference in weight was 186 kg and they are 99.11% similar.

Large Gorgonian Total Biomass

5 km grid = 150,723.5

1 km grid = 149,440.6

The difference in weight was 1,282.9 kg and they are 99.15% similar.



Small Gorgonian Total Biomass

5 km grid = 13,850.3

1 km grid = 13,845.5

The difference in weight was 4.8 kg and they are 99.96% similar.

Bryozoan Total Biomass

5 km grid = 72,069.3

1 km grid = 72,069.0

The difference in weight was 0.3 kg and they are 99.99% similar.

A note on *Boltenia*

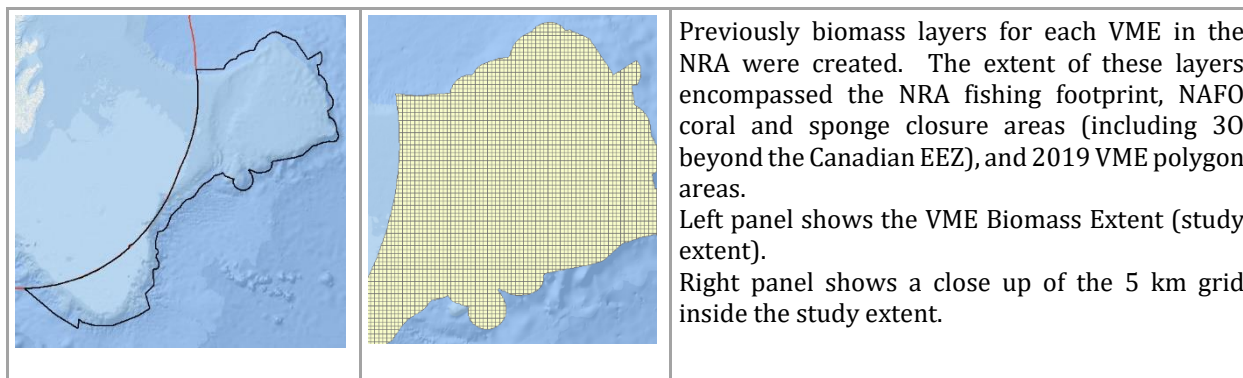
In the initial analysis, it was noticed that *Boltenia* biomass did not have any difference in biomass values between the 5 km and 1 km grid estimates. *Boltenia* does not have any biomass values present along the 3L-3M border so biomass values are not affected by gear assignments in this area.

Appendix 3

Creating a Summed VME Biomass Layer and Diversity Index in the Study Extent and Inside 2019 VME Polygon Area Extents

Task 1 - Create a 5 km and 1 km gridded VME Summed Biomass Layer and VME Diversity

VME Biomass Layer Extent



Goal:

To pass on 5 km and 1 km VME total biomass layer values to one grid so the combined biomass from these groups is determined and to create a VME Diversity Index and map.

The respective 5 km and 1 km VME biomass layers were each spatially joined to an empty grid layer (Sum Grid) using a 'Contains Clementini' match option. Each spatial join added VME biomass values to the sum grid layer. Once all the VME biomass values were added to the grid, they were summed using the field calculator in the attribute table.

Below is the attribute table for the 5 km Sum Grid. Included are fields for the biomass values of each VME as well as the summed biomass for each grid cell.

NRA_VME_Sum_Biomass_In_KDE_5kmGrid												
OBJECTID *	Shape *	SGC_BM	SP_BM	LGC_BM	BR_BM	TU_BM	BC_BM	S_BM	Sum_Biomass	Shape_Length	Shape_Area	
1	Polygon	14.093284	0	0	0	0	0	0	14.093284	20000	25000000.000009	
2	Polygon	0	0	0	0	0	0	0.093001	0.093001	8187.279779	3115536.348664	
3	Polygon	0	0	0	0	0	0	21.600071	21.600071	8983.273325	3259470.205178	
4	Polygon	0	0	0	0	0	0	746268.652981	746268.652981	20000	25000000.000009	
5	Polygon	0	13.333409	0	0	0	4.488753	0	17.822162	18894.54763	15205793.338542	
6	Polygon	0	95.47227	0	0	0	0	0	95.47227	17948.67692	19700626.938333	
7	Polygon	0	0	0	0	0	0	340.544792	340.544792	7408.432023	2425061.358644	
8	Polygon	0	0	52.634615	0	0	0	0	52.634615	20000	24999999.999977	
9	Polygon	12.996269	0	0	0	0	0	0	12.996269	20000	25000000.000009	
10	Polygon	0	0	0	0	0.034721	0	0	0.034721	2335.501853	232632.137298	
11	Polygon	0	0	0	0	0	0	0	0	16071.649458	16334887.104444	
12	Polygon	0	0	0	0	0	0	18855.818033	18855.818033	20000	24999999.999977	
13	Polygon	0	0	0	0	0	0	2472.896536	2472.896536	15874.137983	14668131.279899	

The table below is the summed total biomass (kg/25 km²) for VME in their respective grid as well as the combined biomass of all VME found in the study extent.

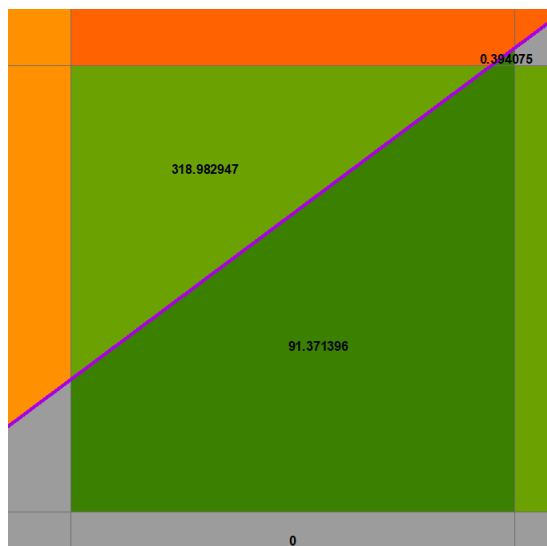
VME	5 km Grid	1 km Grid
Small gorgonian coral; SGC_BM	13,850.3	13,845.5
Sea pen; SP_BM	170,906.8	170,691.0
Large gorgonian coral; LGC_BM	150,723.5	149,440.6
Bryozoan; BR_BM	72,069.3	72,069.0
Tunicate; TU_BM	48,761.3	48,761.3
Black Coral; BC_BM	21,074.5	20,887.9
Sponge; S_BM	293,432,034.0	293,222,474.5
Combined Total Biomass	293,909,419.7	293,698,169.8

- Note the small differences in biomass observed between the 5 km and 1 km grids are due to gear assignment along the 3L-3M border (see Appendix 2). Total biomass is 99.93% similar.

Summing the Sponge Biomass Layer

The sponge biomass layer was created in two parts: Inside closure and outside closure areas. In areas along the edge of closure boundaries there can be instances where two biomass values overlay one (sum grid) cell. When this condition occurs, these values were summed in the spatial join, within the grid cell, and passed on to the Sum Grid layer.

Below is an example of two biomass values within one grid cell (light and dark green areas). These two values were summed, 410.35 kg, and passed on to the Sum Grid.



VME Diversity

The number of VME Indicators present in each grid cell was determined. Additional fields were added to the attribute table to determine presence of each VME in each grid cell within the study extent. Below, the attribute table of the 5 km sum grid shows presence/absence fields for each VME with an additional field, Pres_Sum,

which contains the sum of the number of VME present within each grid cell. It is the VME Diversity Number or Index. See figure 27, a map showing the number of VME Indicators per 5 km grid cell.

OBJECTID *	Shape *	SGC_BM	SP_BM	LGC_BM	BR_BM	TU_BM	BC_BM	S_BM	Biomass_Sum	Shape_Length	Shape_Area	SGC_PA	SP_PA	LGC_PA	BR_PA	TU_PA	BC_PA	S_PA	Pres_Sum
388	Polygon	0	64.74359	0	0	0	0	0	64.74359	20000	25000000	0	1	0	0	0	0	0	1
389	Polygon	0.083333	72.301282	0	0.051282	0	13.865385	0	86.301282	20000	25000000	1	1	0	1	0	1	0	4
390	Polygon	0	0	0	0	0	0	0	0	20000	25000000	0	0	0	0	0	0	0	0
391	Polygon	0	0	0	1.686567	0	0	513.582097	515.268664	20000	25000000	0	0	0	1	0	0	1	2
392	Polygon	0	0	0	0	0	0	1.923077	1.923077	20000	25000000	0	0	0	0	0	0	1	1
393	Polygon	0	0	0	0	0	0	41.346154	41.346154	20000	25000000	0	0	0	0	0	0	1	1
394	Polygon	0	0	0	0	0	0	1332.692301	1332.692301	20000	25000000	0	0	0	0	0	0	1	1
395	Polygon	0	5.128205	0	0	0	1.282051	14.102564	20.51282	20000	25000000	0	1	0	0	0	1	1	3
396	Polygon	0	0	0	0	0	0	0.279043	0.279043	4602.388196	649161.797067	0	0	0	0	0	0	1	1
397	Polygon	0	0.373134	0	0.373134	0	0	254.104476	254.850745	20000	25000000	0	1	0	1	0	0	1	3
398	Polygon	0	0	0	1.282051	0	0	653.589753	654.871805	20000	25000000	0	0	0	1	0	0	1	2
399	Polygon	21.685897	12.070513	91.025641	0.108974	0	8.224359	298069.657813	298202.773197	20000	25000000	1	1	1	1	1	0	1	6
400	Polygon	2.403846	26.602564	0	0	0	0.160256	362.692306	391.858973	20000	25000000	1	1	0	0	0	1	1	4
401	Polygon	0	1.615872	0	1.119403	0	0	44.226358	47.063433	20000	25000000	0	1	0	1	0	0	1	3
402	Polygon	0	3.205128	0	0	0	0	6.410256	9.615384	20000	25000000	0	1	0	0	0	0	1	2
403	Polygon	0	0	0	0	0	0	16.025641	16.025641	20000	25000000	0	0	0	0	0	0	1	1

Task 2a – Clipping Estimated Total VME Biomass Layer to their respective VME polygon and adding a selection code

Goal: For each VME, determine the Total VME Biomass within their respective significant area VME polygon, see the Sponge VME map example below.

To achieve this, using ArcGIS, each 5 km and 1 km Total VME Biomass grid, was clipped to its respective significant area VME polygon. Along the edge of the polygon, clipped grid cells only retained the biomass proportional to the area within the polygon. For example, if the biomass in a full cell is 100 kg and 50 % of that cell was removed when clipped, only 50 kg of biomass was retained in that cell.

Polygon Selection Code

Within the attribute table, for each of these clipped layers, a selection code was created to allow for easy manipulation of individual VME polygons within a taxa group. Each VME polygon was given a code name using the following syntax:

PolyID.VMETaxa.ClosureArea.NumberInClosureArea

Where:

- PolyID = Unique number ID, polygon area is ordered such that 01 has the largest area, 02 has the next largest area and so on
- VMETaxa = Code for VME Taxa groups
 - BC = Black Coral
 - BR = Bryozoans
 - LGC = Large Gorgonian Corals
 - SGC = Small Gorgonian Corals
 - SP = Sea Pens
 - S = Sponge
 - TU = *Boltenia*
- Closure Area where:
 - A01- A14 = Sponge, Coral and Sea Pen Closures
 - A15 = 30 Closure
 - A00 = Not in Closure Area
- Number in Closure Area:
 - Sequence Number - 01 indicates 1st largest polygon in a given area
 - 02 is next largest and so on.

Example 1:

01.BC.A09.01

This is the largest (01) Black Coral VME polygon (BC). Part of the biomass grid polygons are inside the Area 09 Closure (A09). This is the largest polygon that overlaps with Closure Area 09 (01).

Example 2:

09.S.A05.02

This is the ninth largest (09) Sponge VME polygon (S). Part of the biomass grid polygons are inside the Area 05 closure (A05). This is the second largest polygon to overlap with Area 05 (02).

Example 3:

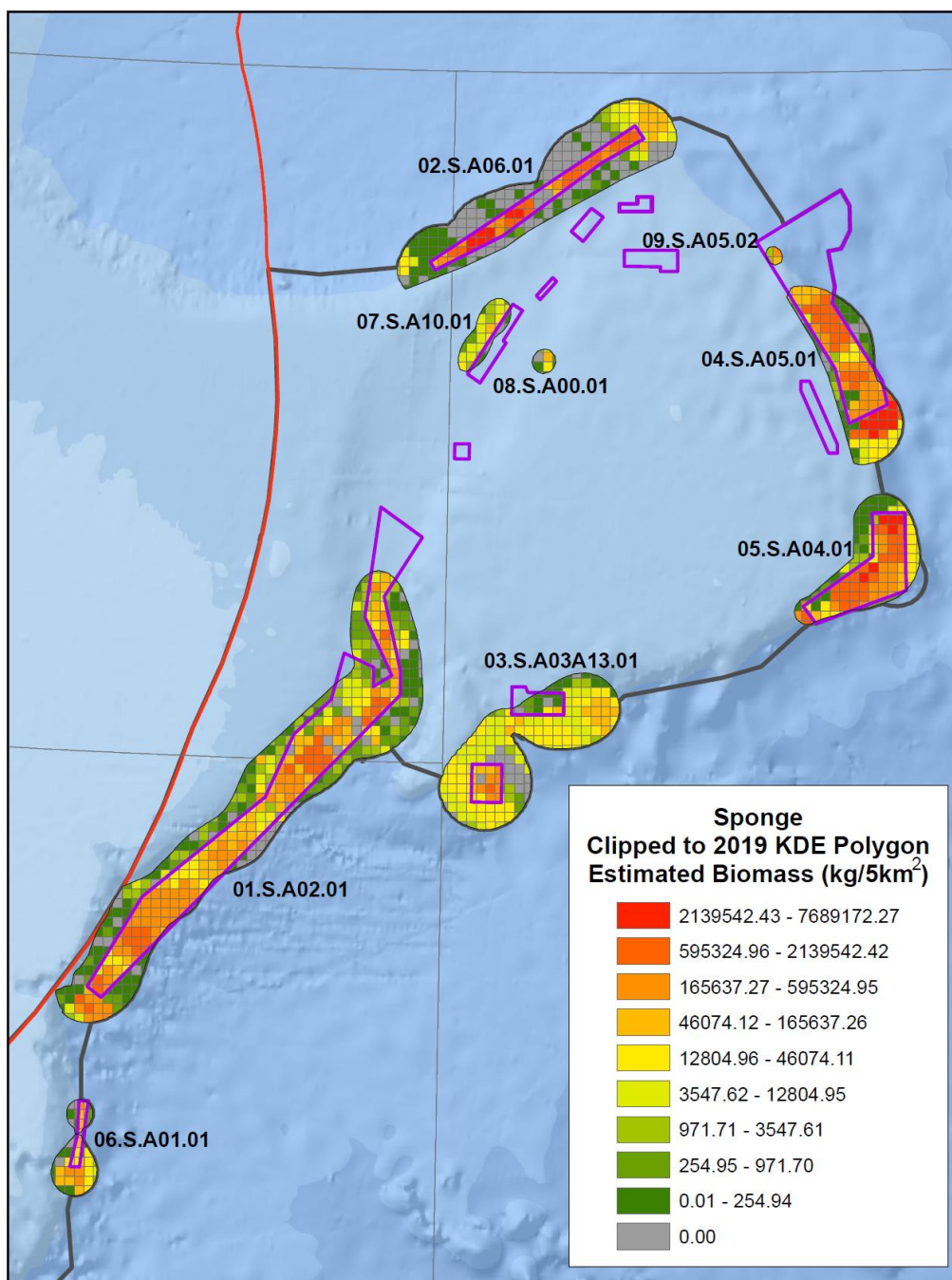
11.BR.A00.11

This is the 11th largest (11) Bryozoan polygon (BR). All the biomass grid polygons are outside closure areas (A00). In this example, none of the Bryozoan polygon entered a closure area.

Below are the number of individual polygons for each VME Significant Areas.

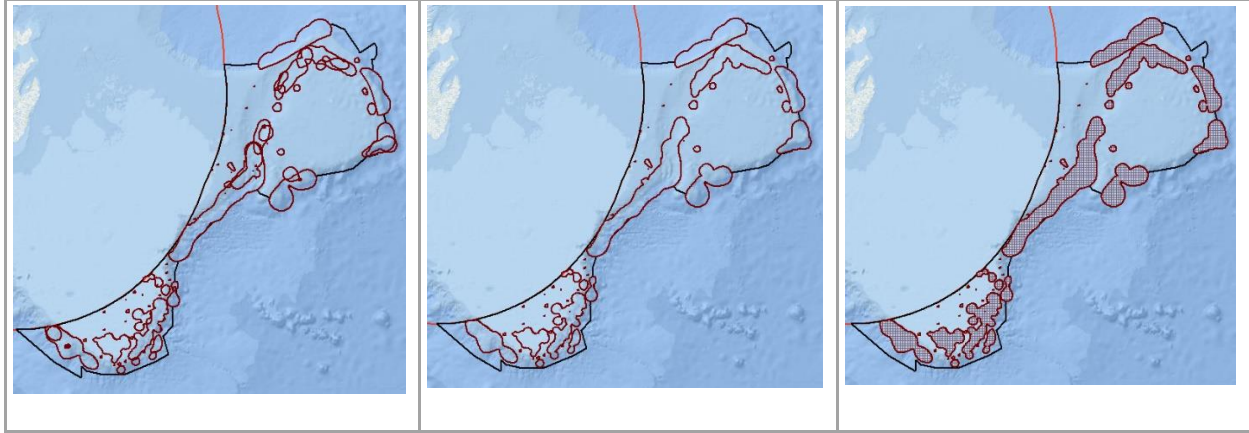
VME_Polygon_Name	Count
NAFO_2019_BlackCoral_Int_pt4_SigPoly_v1	8
NAFO_2019_Boltenia_Int_pt35_SigPoly_v1	18
NAFO_2019_Bryozoans_Int_pt2_SigPoly_v1	17
NAFO_2019_LgGor_Int_pt6_SigPoly_v1	12
NAFO_2019_SeaPens_Int_1pt3_SigPoly_v1	11
NAFO_2019_SmGor_Int_pt2_SigPoly_v1	9
NAFO_2019_Sponge_Int_100_SigPoly_v1	9

An example of the labelled sponge VME polygons is illustrated below:



Task 2b - Create a 5 km and 1 km Combined VME Summed Biomass Grid inside the 2019 VME polygon area extent

In ArcGIS, significant area VME polygons created in 2019 (Kenchington et al., 2019), were merged (Panel 1) and then dissolved to create a 'combined VME polygon area extent' (Panel 2). The dissolved area was used to clip 5 and 1 km empty grids to the combined VME extent (Panel 3).



The 5 km and 1 km VME total biomass grids were clipped to their respective VME polygon area and spatially joined to the 'combined VME extent' empty grid using a 'Contains Clementini' match option. Like Task 1, each spatial join added individual VME biomass values to the 'combined VME extent' grid. Once all the VME biomass values were added to the grid, they were summed using the field calculator in the attribute table.

Below is the attribute table for the 5 km 'combined VME extent' grid. Included are fields for the biomass values of each VME as well as the summed biomass for each grid cell.

NRA_VME_Sum_Biomass_In_KDE_5kmGrid												
OBJECTID *	Shape *	SGC_BM	SP_BM	LGC_BM	BR_BM	TU_BM	BC_BM	S_BM	KDE_Sum_Biomass	Shape_Length	Shape_Area	
1	Polygon	14.093284	0	0	0	0	0	0	14.093284	20000	25000000.000005	
2	Polygon	0	0	0	0	0	0	0.093001	0.093001	8187.279779	3115536.348664	
3	Polygon	0	0	0	0	0	0	21.600071	21.600071	8983.273325	3259470.205179	
4	Polygon	0	0	0	0	0	0	746268.652981	746268.652981	20000	25000000.000009	
5	Polygon	0	13.333409	0	0	0	4.488753	0	17.822162	18894.54763	15205793.338542	
6	Polygon	0	95.472227	0	0	0	0	0	95.472227	17948.67692	19700626.938333	
7	Polygon	0	0	0	0	0	0	340.544792	340.544792	7408.432023	2425061.358644	
8	Polygon	0	0	52.634615	0	0	0	0	52.634615	20000	24999999.999977	
9	Polygon	12.996269	0	0	0	0	0	0	12.996269	20000	25000000	
10	Polygon	0	0	0	0	0.034721	0	0	0.034721	2335.501853	232632.137299	
11	Polygon	0	0	0	0	0	0	0	0	16071.649458	16334887.104445	
12	Polygon	0	0	0	0	0	0	18855.818033	18855.818033	20000	24999999.999977	
13	Polygon	0	0	0	0	0	0	2472.896536	2472.896536	15874.137983	14668131.279899	
14	Polygon	0	0	0	0	0	0	60327.414922	60327.414922	18974.807623	23272388.971896	
15	Polygon	0.671642	135.914179	0	0	0	0	0	136.585821	20000	25000000.000019	
16	Polygon	0	0	0	0	0	0	486006.919416	486006.919416	20000	24999999.999986	
17	Polygon	0	0	0	0	0	0	67573.975372	67573.975372	20000	25000000.000005	
18	Polygon	0	0	0	0	0	0	3.009092	3.009092	16748.65478	16350665.471918	
19	Polygon	0	0	0	0	0	0	0	0	19158.742829	21466670.915292	
20	Polygon	0	0	0	0	0	0	0	0	18579.57123	22021256.965142	

VME Diversity inside the 'combined VME extent'

As with the full study extent, additional fields were added to the attribute table to indicate presence/absence in each grid cell and the VME diversity for each grid cell, see Figure 29 of the manuscript.

NRA_VME_Sum_Biomass_In_KDE_5kmGrid																			
OBJECTID *	Shape *	SGC_BM	SP_BM	LGC_BM	BR_BM	TU_BM	BC_BM	S_BM	KDE_Sum_Biomass	Shape_Length	Shape_Area	SGC_PA	SP_PA	LGC_PA	BR_PA	TU_PA	BC_PA	S_PA	Pres_KDESum
202	Polygon	0	0	0	0	0	0	0	10853.940214	5376929.159591	0	0	0	0	0	0	0	0	0
203	Polygon	0	0	0	0	0	0	2263473.880095	2263473.880095	20000	25000000.000019	0	0	0	0	0	0	0	1
204	Polygon	0	608.974359	0	0	0	76.923078	0	685.897437	20000	25000000.000005	0	1	0	0	0	0	0	2
205	Polygon	0	0	0	0	0	0	1854274.584237	1854274.584237	20000	25000000.000005	0	0	0	0	0	0	1	1
206	Polygon	0	0	333.582086	0	0	0	333.582086	333.582086	20000	25000000.000005	0	0	0	1	0	0	0	1
207	Polygon	0	0	3.391172	0	0	0	80223.880195	80227.271367	20000	25000000.000009	0	0	1	0	0	0	0	2
208	Polygon	0	0	0	0	0	0	22706.538167	22706.538167	19240.817656	24041129.171975	0	0	0	0	0	0	0	1
209	Polygon	0	0	0	0	0	0	0.746269	0.746269	20000	24999999.999977	0	0	0	0	0	0	0	1
210	Polygon	0	125.450464	0	0	0	0	0	125.450464	16916.16134	14961981.936094	0	1	0	0	0	0	0	1
211	Polygon	0	0	0	0	0	0	0	18099.896863	14033813.618861	0	0	0	0	0	0	0	0	0
212	Polygon	0	0	0	10.708874	0	0	0	10.708874	17597.584405	19391745.039019	0	0	0	1	0	0	0	1
213	Polygon	0	0	6.559042	1.445706	0	0	1057368.065323	1057376.07007	20000	24999999.999986	0	0	1	1	0	0	0	3
214	Polygon	0	119.613526	0	0	0	0	119.613526	14200.763231	10389593.547869	0	1	0	0	0	0	0	0	1
215	Polygon	0	1524.358997	0	0	0	0	173575.900039	175100.259036	20000	25000000.000019	0	0	1	0	0	0	0	2
216	Polygon	0	0	3.205128	0	0	0	3.205128	20000	25000000.000009	0	0	0	1	0	0	0	0	1
217	Polygon	0	0	0	0	0	0	2342.656875	2342.656875	20731.443851	21003689.773001	0	0	0	0	0	0	0	1
218	Polygon	0	0	0	7.339053	0	0	7.339053	18841.064951	20488190.545629	0	0	0	0	1	0	0	0	1
219	Polygon	0	0	0	0.219772	0	0	0	0.219772	3334.430829	498130.056854	0	0	0	1	0	0	0	1
220	Polygon	0	34.308116	0	0	0	0	34.308116	19020.170612	18905792.1172	0	1	0	0	0	0	0	0	1
221	Polygon	0	0	0	0	0	0	371872.446836	371872.446836	25000000	0	0	0	0	0	0	0	0	1
222	Polygon	0	0	0	0	0	0	0	18038.751774	18768884.262587	0	0	0	0	0	0	0	0	0
223	Polygon	0	0	0	0	0	0	1.044144	1.044144	4549.207987	628419.953175	0	0	0	0	0	0	0	1