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Evaluation of the Effect of Spatial Extent on Kernel Density Analyses of Vulnerable Marine Ecosystem Indicators in the NAFO Regulatory Area

by

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Abstract

In support of the 2020 NAFO review of the closed areas to protect vulnerable marine ecosystems (VMEs) in the NAFO Regulatory Area, kernel density analyses (KDE) of the biomass of Large-sized Sponges, Sea Pens, Small and Large Gorgonian Corals, Erect Bryozoans, Sea Squirts (*Boltenia ovifera*), and Black Corals were undertaken using all available research vessel survey data (1995 – 2019). The results of those analyses were compared with those previously conducted in 2013 reviewed by the NAFO Working Group on Ecosystem Science and Assessment (WG ESA) at its 12th meeting in November 2019. At that meeting, members of WG-ESA queried the appropriateness of confining the analyses to the NRA and requested that additional analyses be conducted prior to the next review of the closed areas to determine the effect of including data from Canadian waters in identifying the VME polygons in the NRA. Here we present the results of that comparison using data from the Newfoundland and Labrador bioregion. The data from the different surveys were compiled for the same time periods as in the 2019 analyses so that there was no additional data from the NRA and all new data came from Canadian waters. The parameters for the KDE analyses were also held the same (search radius, cell size, biomass intervals) in order to control for differences due to the change in geographic coverage. The number of new records was considerable for all VME Indicator groups and for Sea Squirts increased by an order of magnitude. Of the seven VME Indicator groups evaluated, there was no change in the RV catch threshold used to delineate VMEs in three (Sea Pens, Large Gorgonian Corals, Erect Bryozoans). The thresholds were larger for two groups (Large-sized Sponges, and Sea Squirts) and smaller for two others (Small Gorgonian Corals and Black Corals). For the Large-sized Sponges and Sea Squirts the different thresholds did not translate to large changes in the VME polygons in the NRA. For the Black Corals, which remain rare in terms of record numbers, the new threshold increased a previously identified VME polygon and created two new VMEs, all in Flemish Pass. For Small Gorgonian Corals the new threshold was the same as that found in 2013 and that was considered in 2019. The new threshold, being lower than the current threshold for identification of VMEs in the NRA identified two new areas on the eastern slope of Flemish Cap and connected three smaller VMEs on the slope of the Tail of Grand Bank. Those new areas are small compared with the 1377% increase in area found between the 2013 and 2019 KDE analyses for this taxon. Collectively, the new analyses did not detect large differences in the delineation of the VME polygons in the NRA, as was anticipated by the technical experts. Greater precision of VMEs in the NRA through use of KDE is expected to occur through increased data from that area, as the analysis is driven by the local data neighbourhood.

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Introduction

Kernel density estimation (KDE) utilizes spatially explicit data to model the distribution of a variable of interest. It is a simple non-parametric neighbour-based smoothing function that relies on few assumptions about the structure of the observed data. It has been used in ecology to identify hotspots, that is, areas of relatively high biomass/abundance. With respect to marine benthic invertebrate species, it was first applied to the identification of significant concentrations of sponges in the NAFO Regulatory Area in 2009 (Kenchington et al., 2009) followed by an application to sea pens (Murillo et al., 2010). Since then, it has been used to identify significant concentrations (VMEs) of corals, sponges and other VME indicators from research vessel (RV) trawl survey catch data in both Canada (Kenchington et al., 2010; 2016) and in the NRA (NAFO, 2013; Kenchington et al., 2014; Kenchington et al., 2019; NAFO, 2019). In 2019, KDE biomass surfaces for seven VME indicator taxa were created: Large-sized Sponges, Sea Pens, Small Gorgonian Corals, Large Gorgonian Corals, Erect Bryozoans, Black Corals, and Sea Squirts (*Boltenia ovifera*), and the RV catch threshold that delineated the VME polygons determined. Comparisons were made with the boundaries produced from the previous assessment and any differences were explicable and due to increased data informing the models. Note that for the final VME polygon boundaries, the congruence between the KDE-generated VME polygons and areas of predicted occurrence derived from species distribution models (SDM) were examined, where available, and were used to modify the polygons to eliminate areas where the taxon was not predicted to occur (Kenchington et al., 2019; NAFO, 2019). During the presentation of those analyses members of WG-ESA queried the appropriateness of confining the analyses to the NRA and requested that additional analyses be conducted prior to the next review of the closed areas to determine the effect of including data from Canada in identifying the VME polygons in the NRA.

Spatial Extent Considerations

Ecological Unit

The application of KDE to the NRA uses biomass data to identify areas of significant concentrations of VME Indicator taxa. From an ecological point of view the analyses should only include data drawn from the same or similar faunal communities. Consequently, we have only used data from the DFO multispecies surveys of the Newfoundland and Labrador Region, and not survey data from the Gulf of St. Lawrence, the Scotian Shelf or the eastern Canadian Arctic which fall into different biogeographic zones (DFO, 2009). An illustration of the extent of that area is shown in Figure 1. Flemish Cap is considered both a bioregion and an ecosystem production unit (Koen-Alonso et al., 2019), based on analyses of a suite of physiographic, oceanographic and biotic variables (NAFO, 2015). For the VME Indicator taxa investigated the two ecoregions (Newfoundland and Labrador Shelves and Flemish Cap) are thought to have similar species.

The surveys from the Canadian EEZ and EU Spain 3LNO occur over shallower water (minimum 40m) than those conducted on Flemish Cap, which has a minimum depth of 122m. For some VME Indicator taxa this may influence the species composition, introducing shallow water/coastal species into the analyses. The influence of depth was considered for each species group but in the initial analyses the data were not restricted by depth (that is, to data ≥ 122m).

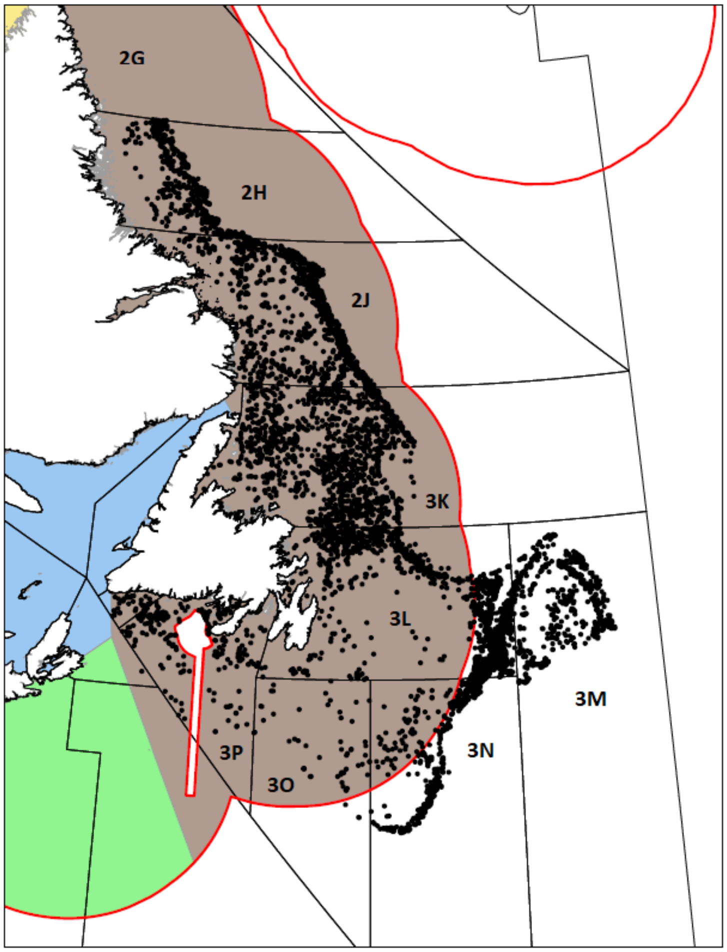

Figure 1. The biogeographic zones identified by DFO (DFO, 2009) showing the location of the Newfoundland and Labrador Shelves zone (brown). Data from within Canada for this study were restricted to this zone. Location of survey data showing presence of sponges are shown (black closed circles) to illustrate the full data extent into the NAFO Regulatory Area. NAFO Divisions within the biogeographic zone and the NRA are labelled. Red lines show the exclusive economic zones of Canada, Greenland and St. Pierre and Miquelon. Map projection: NAD 83 UTM 22N.

Search Radii and Grid Cell Size

The spatial extent of the data affects two key properties of the KDE, the search radius and the grid cell size (Figure 2). When determining the search radius around each data point (Figure 2), KDE by default uses a formula calculated based on the spatial configuration and number of input points, correcting for spatial outliers so they will not make the search radius unreasonably large. The grid cell size is calculated from the shorter of the width or height of the spatial extent divided by 250. The value inside each of the grid cells is taken from the value of the biomass from its central point, determined from the KDE surface (Figure 2). Each cell kernel value is the KDE biomass value divided by the search neighbourhood area. If two search circles are used to create the KDE biomass then the divisor is the area of both circles combined. This is done to standardize the KDE value, resulting in lower values where there is less data to support the prediction than when there are multiple intersections. Changing the spatial extent of the analyses will change the calculation of the search radius and cell size for each VME Indicator taxon.

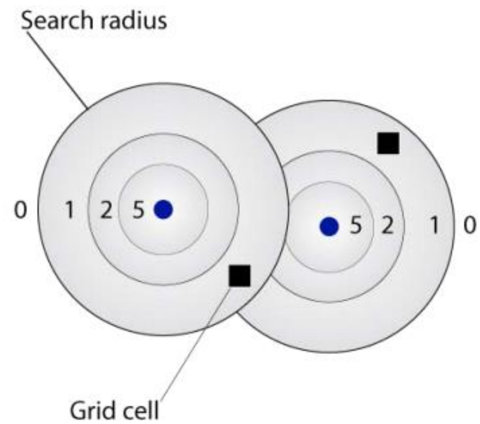

Figure 2. Illustration of the search radius extending from the datum points in blue (here 5 units). The biomass values within the circle are estimated from a 3D Gaussian curve fitted such that it is highest at the location of the datum point, and diminishing with increasing distance from the point, reaching zero at edge of the search radius. The biomass value in each grid cell (solid black square) is then determined from the midpoint of the KDE surface. When two or more search radii overlap, the values are summed.

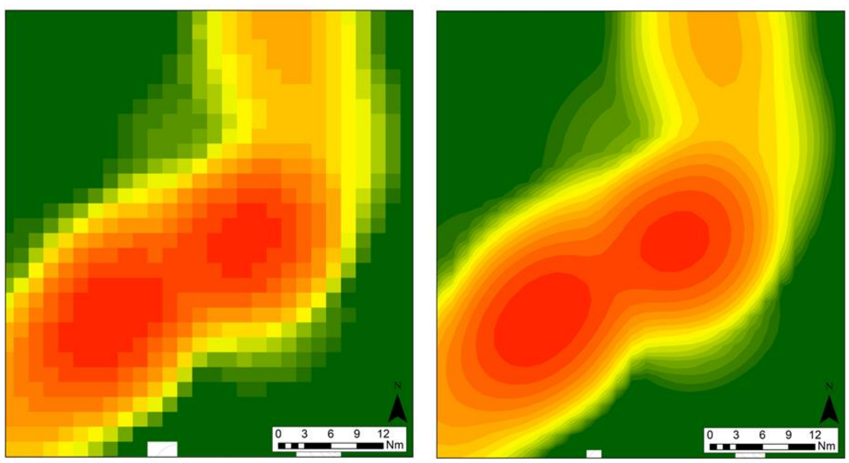

Figure 3. Illustration of how the KDE grid cell surface (left) is converted to a smooth surface using bilinear interpolation.

In order to control for the effect of the increased spatial extent we applied the search radii and cell sizes used in the 2019 analyses (Kenchington et al., 2019). This ensured that the same grid cell size was used to produce the KDE surface which was then converted to a smooth surface using bilinear interpolation (Figure 3). It is this smoothed surface that is used to overlay biomass contour lines at tightly spaced increments that are ultimately used to delineate the polygons at the set weight thresholds for calculation of the area encapsulated by successively larger polygons (Kenchington et al., 2014). Retaining the original search radius and grid cell size for each analysis ensures that any differences in the selected threshold values arise from differences in the biomass distribution of the added data. The KDE *Large-sized Sponge* biomass surface constructed using a search radius of 39.7 km derived from the new and larger spatial extent was compared with the surface created using the search radius of 25 km determined from the spatial extent used in the 2019 analyses of the NRA (Figure 4). The smaller search radius had a minimal effect on coverage or location of the hotspots. The differences in the KDE surface for *Large-sized Sponge*s using the two the radii are shown in Figure 4. The change to the search radius affected the grid cell size so that the grid cell used to calculate the KDE surface with the larger search radius of 39.7 km was 4763.2 m while with the 25 km search radius the cell size was 3097.9 m. The smaller search radius applied herein has minimal effect on coverage or location of the hotspots.

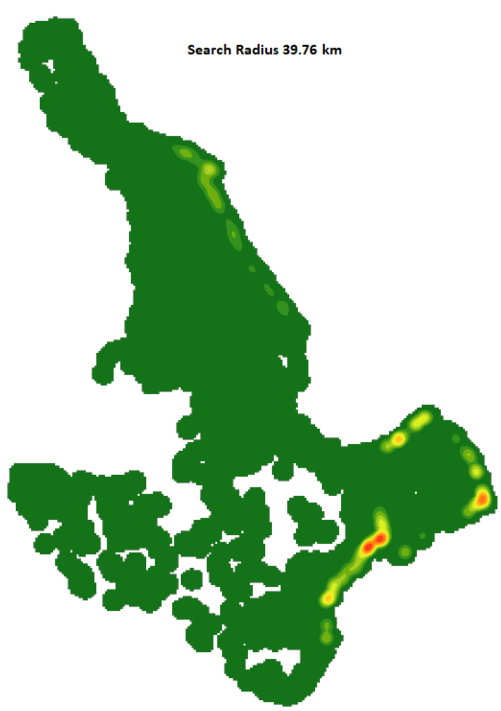

Figure 4. KDE *Large-sized Sponge* biomass surface constructed using a search radius of 39.7 km derived from the new and larger spatial extent (left panel) compared with the surface created using the search radius of 25 km determined from the spatial extent used in the 2019 analyses of the NRA (right panel). The smaller search radius has minimal effect on coverage or location of the hotspots as seen when comparing the two panels.

Decision Rules and Expected Results

Kernel density estimation (KDE) analysis identifies "hotspots" in catch biomass distribution. Using the output kernel biomass density surfaces (Figure 3), polygons are drawn around successively smaller catch values and the area occupied by each polygon is calculated (Kenchington et al., 2014). The catch value associated with the largest change in area between successive values is the VME, distinguishing habitat-forming dense aggregations from the broader occurrence of individuals as identified through rule-based decisions (NAFO, 2013):

Number of criteria considered:

1. Identification of catch biomass which shows the largest change in area after initial establishment of aggregations;
2. Number of data points contributing to changes between successive catch thresholds;
3. Spatial relationship of polygons created by biomass thresholds greater and lesser than potential threshold;
4. Position of new data points relative to previously established polygons.

Causes for rejecting a threshold:

1. Joining of smaller polygons with little evidence for continuous distribution within newly-formed area;
2. Gradual increase in area with every new polygon added, creating situation where no one successive change in area is especially larger or smaller than others (indicates no aggregation);
3. Increase in area established by creation of new areas of low density;
4. No large increase in area of individual polygons (but may show larger overall increase).

Note that when comparative maps are displayed for each VME Indicator as part of this process to determine the correct threshold, the KDE polygons delineated by the smaller catch thresholds underlie those of the higher catch thresholds and are masked by the later. Also in applying the rules threshold selection was determined from consensus of three independent technical experts.

As shown previously (NAFO, 2019), changes to the VME polygon boundaries within a fixed spatial extent may occur when additional data fill in data gaps. When the taxon is well sampled, the boundaries stabilize although there may be differences in the area threshold applied to determine the location of the boundaries.

What do we expect to occur when additional data are added? For the VME polygons highlighting the significant concentrations in the NRA to change it would require the additional data to have large areas with significantly higher biomass than found in the NRA (lower biomass would have no effect). That could occur through environmental differences creating unequal biomass distributions even when the species compositions are the same or similar.

Selection of the threshold according to the above rules (see NAFO, 2013) could also be affected by differences in discreteness of the habitats. The present-day distributions in both the NRA and Canada may be influenced by past fishing activity. If that has occurred differentially in the two areas then the distinction between the significant concentrations (VME habitat) and the broader distribution of the species may be blurred and show a gradual increase in area with the addition of new polygons (point 2 above in the causes for rejecting a threshold). For those VME Indicator groups that have relatively few records in the NRA (Small Gorgonian Corals, Large Gorgonian Corals, and Black Corals especially), use of the Canadian data to support threshold selection could be valuable, however it is anticipated that the next revision will add more data from the NRA surveys which will be of greater value to identifying VMEs in the NRA using KDE analyses.

Summary of Data Sources

Available data for the analyses were obtained from research vessel trawl surveys conducted by the EU and Canada (Table 1). These data included the same data used in Kenchington et al. (2019) for the reassessment of VMEs and closed areas in the NAFO Regulatory Area (NRA) (NAFO, 2019). In addition, data from the Newfoundland and Labrador Region of DFO (NAFO Divisions 2HJ, 3KLNOP) were added in order to test the effects on the VME polygon boundaries in the NRA of adding additional data to the analyses from areas outside of the NRA (Table 1). As KDE uses only the presence records the number of records in the analyses varied by VME Indicator and are reported separately therein. Further, for some analyses in the NRA small catches were removed in order to reduce the effects of the different gear types used (Kenchington et al., 2019). The same data treatments used in the 2019 analyses were applied herein. Some VME Indicator taxa were not recorded in all years. Taxon-specific data use is noted under the analyses for each VME Indicator.

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 Oceanografia; IIM, Instituto de Investigaciones Marinas; IPMA, Instituto Português do Mar e da Atmosfera.

Programme	Period	NAFO Divisions	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	2HJ, 3KLNOP	Campelen 1800	12.7	15	15 - 20

Review of Significant Concentrations of Large-sized Sponges

Significant concentrations of *Large-sized Sponges* have been determined previously in the NRA using kernel density analyses and an evaluation of the expansion of the area covered by successive density polygons (NAFO, 2019). There were significant differences among the catch series for each survey and differences in the number of small catch weights, likely due to differences associated with gear type, tow length, survey area and sampling protocol. When all records less than 0.5 kg were removed, there was no significant difference among the catch distributions (NAFO, 2013; NAFO, 2019). We applied the same data treatment here, excluding all catch records < 0.5 kg. The resulting data included 1825 records from the NRA: 1207 records from the EU surveys and 618 from the Canadian surveys, and 3624 records from the Canadian waters, for a total of 5449 records distributed as in Figure 5. Fuller (2011) identified the sponge taxa from the Newfoundland and Labrador bioregion and showed that the biomass was dominated by the same types of sponges found in the NRA (Murillo et al., 2012), that is, large structure-forming demosponges (Order Tetractinellida, Suborder Astrophorina) and glass sponges (*Asconema* sp.).

Following previously established methods and assessment criteria, a kernel density surface was created, and the area of successive density polygons calculated. KDE parameters were: Search Radius = 25 km; Contour Interval = 0.01; Cell size default = 3097.9 m. The resulting kernel density biomass surface is shown in Figure 5. The kernel density distribution identified sponge grounds on the southern portion of Flemish Pass to southwestern Grand Bank, Beothuk Knoll, Sackville Spur and the east and southeast Flemish Cap as well as along the Labrador slope. The biomass is higher in the NRA then on the adjacent Canadian slopes (Figure 5), as previously observed by Fuller (2011).

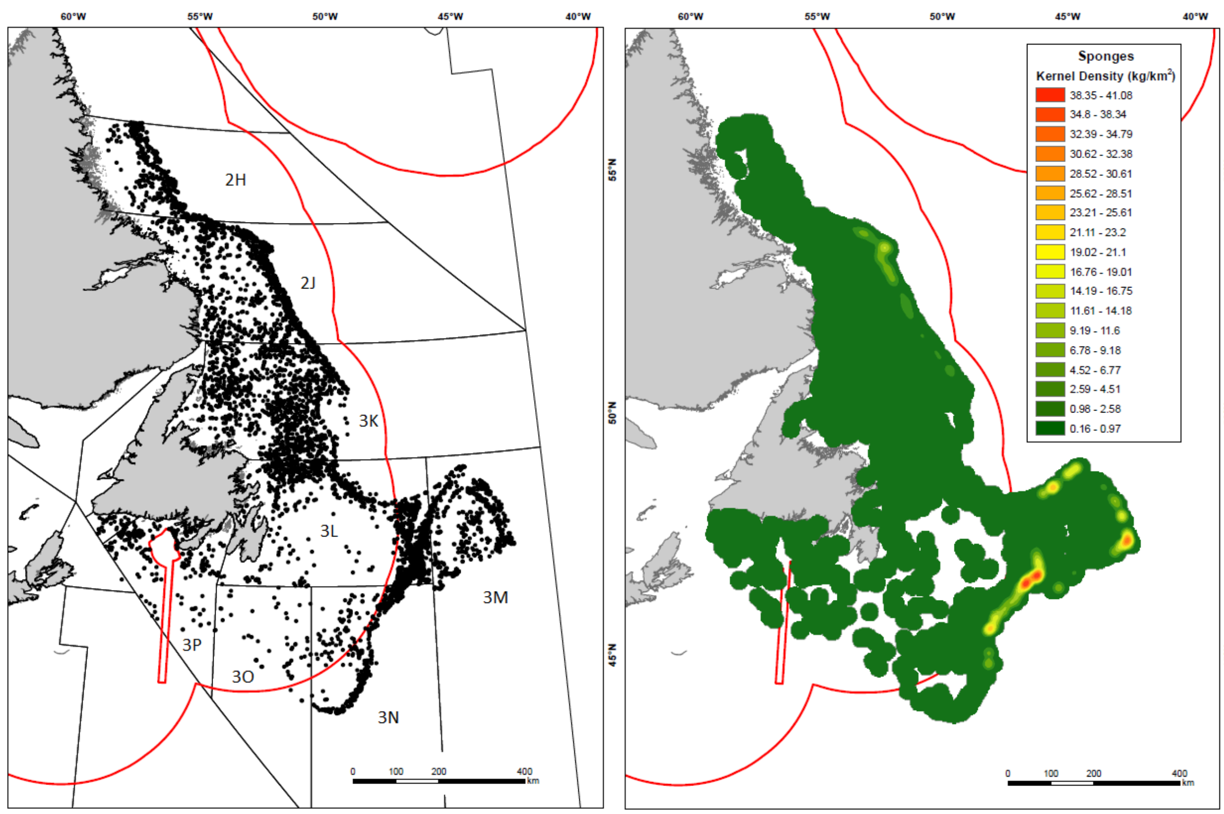

Figure 5. Distribution of records with *Large-sized Sponge* biomass (left) and the resulting kernel density biomass surface (right). NAFO Divisions are labelled on the left panel. Red lines show the exclusive economic zones of Canada, Greenland and St. Pierre and Miquelon. Map projection: NAD 83 UTM 22N.

Biomass contours were placed over the KDE surface in increments of 0.01 kg/km². Following the methodology applied by Kenchington et al. (2019), 34 weight thresholds were used to evaluate the change in area. These were based on numbers of data points accrued with each threshold change from the NRA data.

Following previously articulated procedures for identifying thresholds (NAFO, 2013), the 140 kg/RV tow density threshold emerged as potentially defining significant concentrations of *Large-sized Sponges* (i.e., sponge ground VME) as it is the first catch level where there is a large increase in area once the initial sponge grounds are delineated (Table 2, Figure 6). However only 5 additional data points delineated that threshold over the previous one. We examined the location of the polygons for weight thresholds 140 kg, 125 kg and 100 kg, and for the 20 kg and 25 kg next highest threshold (Figure 7).

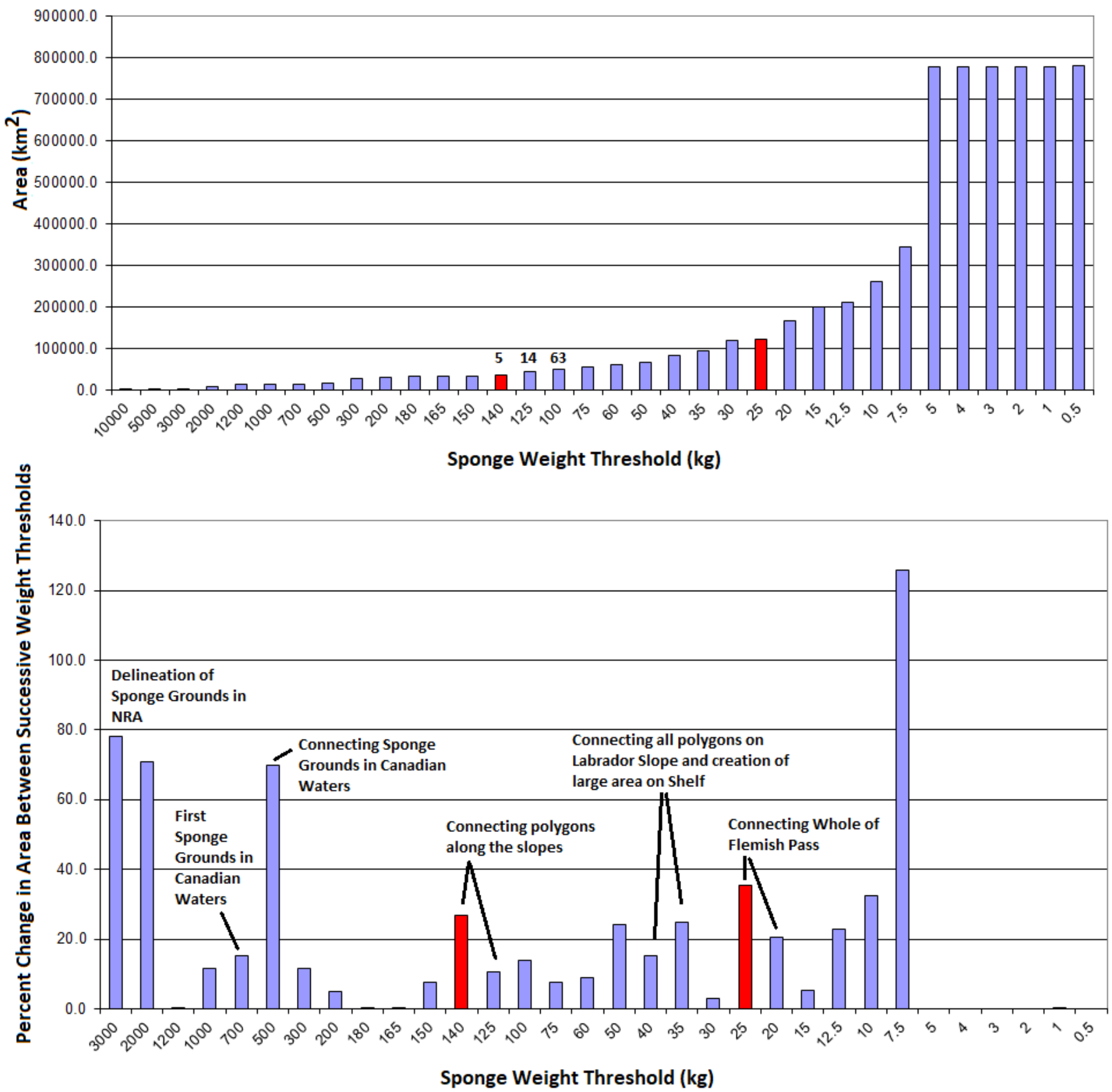

Figure 6. Bar graphs of the polygon area established by successively smaller research vessel sponge catch weight thresholds (upper panel) and of the annotated percent change in area created between successively smaller research vessel *Large-sized Sponge* catch weight thresholds (lower panel). Red bars indicate potential VME polygon thresholds examined. The number of additional data points added by the threshold change are shown in the upper panel for the primary VME polygon thresholds evaluated and are provided for all thresholds in Table 2.

Table 2. The number of points attributing to the delineation of *Large-sized Sponge* VME polygons based on successively smaller research vessel catch weight thresholds (kg). The area and number of observations used to define each polygon and the percent change in area and the number of additional observations between successive thresholds are provided. The shaded rows represent catch thresholds investigated as potential VMEs.

Sponge Catch Threshold (Kg)	Number of Observations in Polygons	Additional Observations Per Interval	Area of Polygons (km^2)	Percent Change in Area Between Successive Thresholds
10000	2		35.8	3172.2
5000	9	7	1170.7	259.4
3000	23	14	4207.5	78.2
2000	37	14	7498.0	70.9
1200	53	16	12814.8	0.2
1000	67	14	12841.5	11.5
700	86	19	14323.8	15.4
500	122	36	16523.1	69.8
300	168	46	28049.2	11.7
200	241	73	31334.4	4.9
180	249	8	32872.9	0.4
165	264	15	33018.5	0.4
150	283	19	33140.0	7.6
140	288	5	35652.1	26.8
125	302	14	45207.5	10.5
100	365	63	49947.4	14.1
75	415	50	56969.7	7.6
60	453	38	61300.8	9.1
50	502	49	66889.8	24.2
40	555	53	83076.0	15.3
35	583	28	95805.1	24.8
30	631	48	119532.6	3.1
25	684	53	123233.2	35.4
20	772	88	166840.6	20.5
15	894	122	201088.1	5.3
12.5	983	89	211696.9	22.9
10	1155	172	260175.3	32.3
7.5	1414	259	344234.7	126.0
5	1878	464	777874.0	0.0
4	2168	290	777874.0	0.0
3	2571	403	777874.0	0.0
2	3231	660	777874.0	0.0
1	4359	1128	777874.0	0.3
0.5	5449	1090	780148.5	

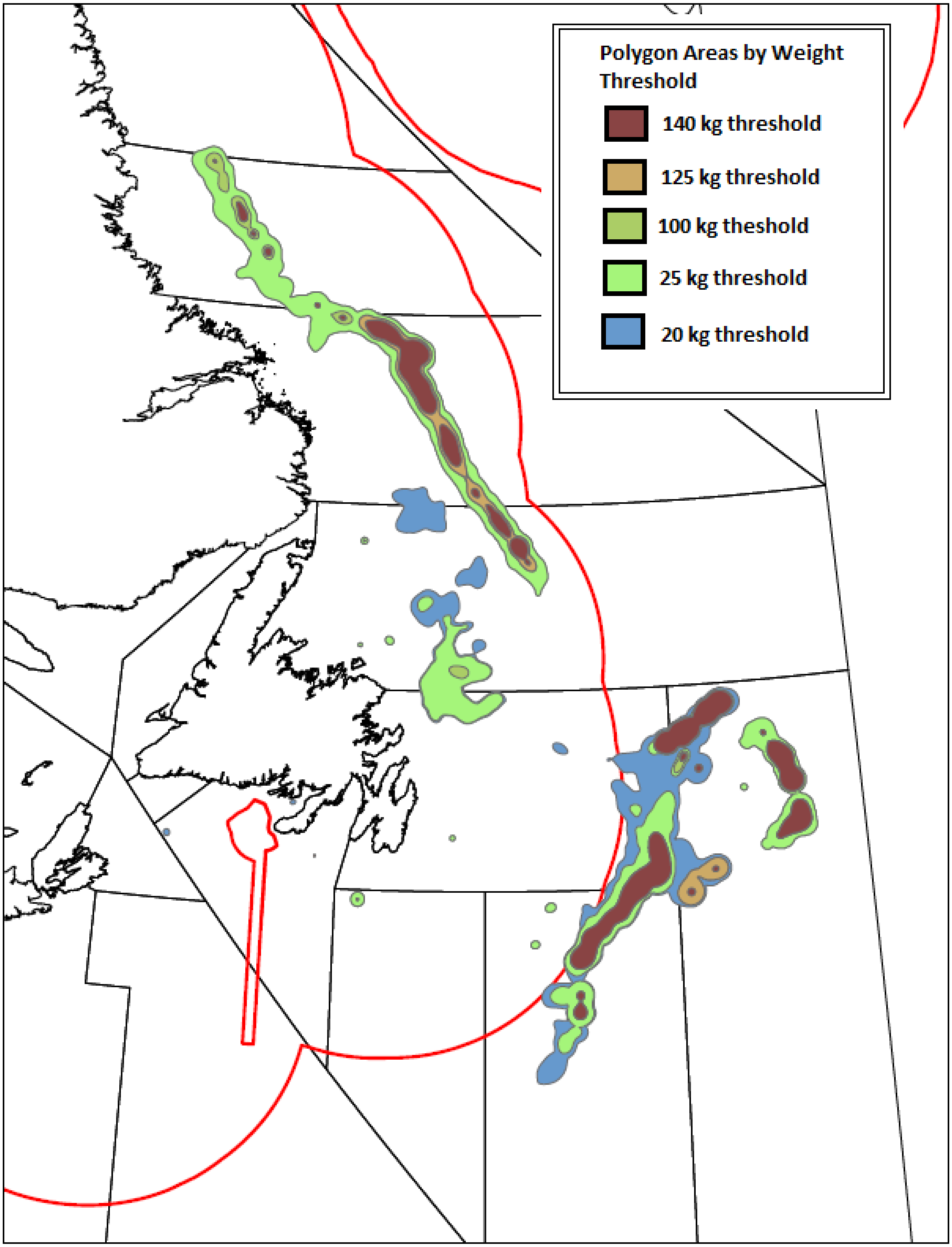

Figure 7. Spatial comparison of the areas covered by catches ≥ 100 kg, ≥ 125 kg and ≥ 140 kg and catches ≥ 25 kg and ≥ 20 kg; the areas covered by these thresholds are provided in Table 2. Map projection: NAD 83 UTM 22N.

The smaller thresholds were created by connecting the whole of Flemish Pass, much of the Labrador Slope and included areas up on the shelf (Figure 6). As decided previously (Kenchington et al., 2019), those lower thresholds were rejected based on their creation through the joining of smaller polygons with little evidence for continuous distribution within the newly formed area and relatively few data points populating the expanded area (Table 2). On the Newfoundland and Labrador Shelf, the large areas shown in Figure 7 may represent populations of *Phakellia* sp. (Fuller, 2011), a species not common in the NRA (Murillo et al., 2012).

Other potential thresholds evaluated were 140 kg, 125 kg and 100 kg (Figures 5, 6, Table 2). The 140 kg threshold showed the greatest change in area but was only created by 5 additional data points. The 125 kg threshold was created by 14 additional data points although the areal increase was smaller. This threshold could be considered as delineating the *Large-sized Sponge* VME polygons for the region (Figure 7). Stronger support is shown for the ≥ 100 kg threshold which is created by 63 additional points and a greater increase in area (14.1%; Table 2). That is the same threshold identified in the 2019 analyses using only data from the NRA and does not differ from the same threshold shown in Figure 7. Therefore, for the *Large-sized Sponge* including the data from the Labrador Shelves had no large effect on the delineation of their VMEs in the NRA. Only one small area was affected if the larger weight threshold was chosen (Figure 8).

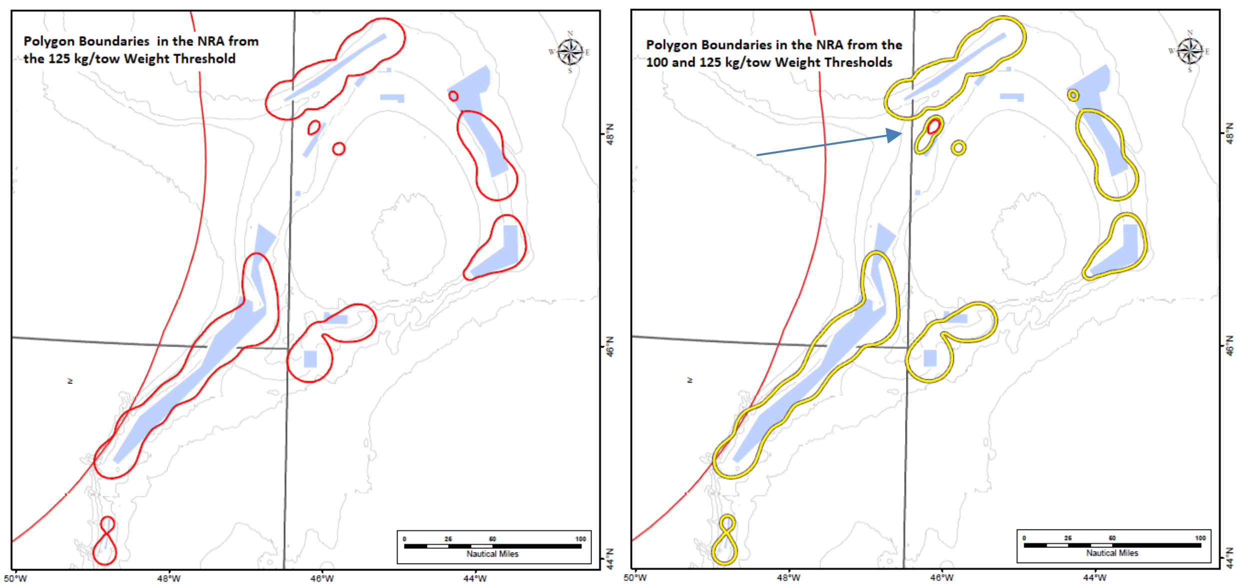

Figure 8. Comparison of the *Large-sized Sponge* VME polygons using the 125 kg threshold (red outline) with the sponge VME polygons established previously with the 100 kg threshold (yellow outline) (NAFO, 2019). Closed areas in place in 2019 are shown with blue shading for comparing with previous work (Kenchington et al., 2019; NAFO, 2019). The blue arrow points to the only difference in area identified when using the full data set as opposed to only the data from the NRA. Map projection: NAD 83 UTM 22N.

The differences produced from the ≥ 100 kg and ≥ 125 kg thresholds with the two data sets are shown in Table 3. The thresholds were very similar despite the addition of 107 or 170 data points from the Newfoundland and Labrador Shelves within each polygon area defined by the threshold of 125 and 100 kg respectively, and the near doubling of the area occupied by each threshold (Table 3). We conclude that for the *Large-sized Sponge* that the consideration of the additional data from the adjacent Newfoundland and Labrador Shelves bioregion did not substantially change the delineation of VMEs for that taxon in the NRA.

Table 3. Comparison of the results of the KDE and spatial analyses for *Large-sized Sponge* conducted in 2019 using only data from the NRA and in the present analyses using data from both the NRA and Canadian waters. Shading shows the selection of thresholds from each assessment.

	NRA only (2019)				**NRA and NL (2022)**			
Interval	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km²)	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km²)
10000	2		3234.6	34.7	2		3172.2	35.8
5000	9	7	262.2	1156.2	9	7	259.4	1170.7
3000	23	14	78.6	4187.5	23	14	78.2	4207.5
2000	37	14	57.7	7480.5	37	14	70.9	7498.0
1200	53	16	0.2	11797.6	53	16	0.2	12814.8
1000	67	14	11.3	11821.7	67	14	11.5	12841.5
700	83	16	0.0	13162.2	86	19	15.4	14323.8
500	104	21	35.6	13162.2	122	36	69.8	16523.1
300	128	24	4.3	17851.1	168	46	11.7	28049.2
200	157	29	13.0	18619.6	241	73	4.9	31334.4
180	163	6	0.0	21032.0	249	8	0.4	32872.9
165	165	2	1.0	21032.0	264	15	0.4	33018.5
150	168	3	10.9	21244.0	283	19	7.6	33140.0
140	170	2	14.6	23564.6	288	5	26.8	35652.1
125	175	18	1.1	27010.5	302	14	10.5	45207.5
100	195	20	25.6	27314.6	365	63	14.1	49947.4
75	214	19	9.4	34318.4	415	50	7.6	56969.7
60	229	15	12.5	37554.3	453	38	9.1	61300.8
50	248	19	13.1	42244.5	502	49	24.2	66889.8
40	272	24	0.0	47758.6	555	53	15.3	83076.0
35	288	16	2.8	47758.6	583	28	24.8	95805.1
30	303	15	6.7	49087.6	631	48	3.1	119532.6
25	325	22	52.7	52373.4	684	53	35.4	123233.2
20	354	29	0.0	79952.9	772	88	20.5	166840.6
15	403	49	3.1	79952.9	894	122	5.3	201088.1
12.5	439	36	1.5	82450.8	983	89	22.9	211696.9
10	505	66	0.7	83706.1	1155	172	32.3	260175.3
7.5	586	81	25.2	84269.4	1414	259	126.0	344234.7
5	726	140	0.0	105521.8	1878	464	0.0	777874.0
4	818	92	0.0	105521.8	2168	290	0.0	777874.0
3	933	115	0.0	105521.8	2571	403	0.0	777874.0
2	1116	183	0.0	105521.8	3231	660	0.0	777874.0
1	1435	319	0.0	105521.8	4359	1128	0.3	777874.0
0.5	1778	343		105521.8	5449	1090		780148.5

Review of Significant Concentrations of Sea Pens

Significant concentrations of *Sea Pens* were identified previously in the NRA using kernel density analyses and an evaluation of the expansion of the area covered by successive density polygons (NAFO, 2013; 2017; 2019). The 2019 *Sea Pen* KDE polygons were overlain on the presence-absence prevalence threshold from the *Sea Pen* SDM (Knudby et al., 2013) that was used previously to evaluate whether the KDE polygons should be modified (NAFO, 2015). Most of the KDE area fell within the area of predicted presence, and consequently no modifications were made to the KDE polygons.

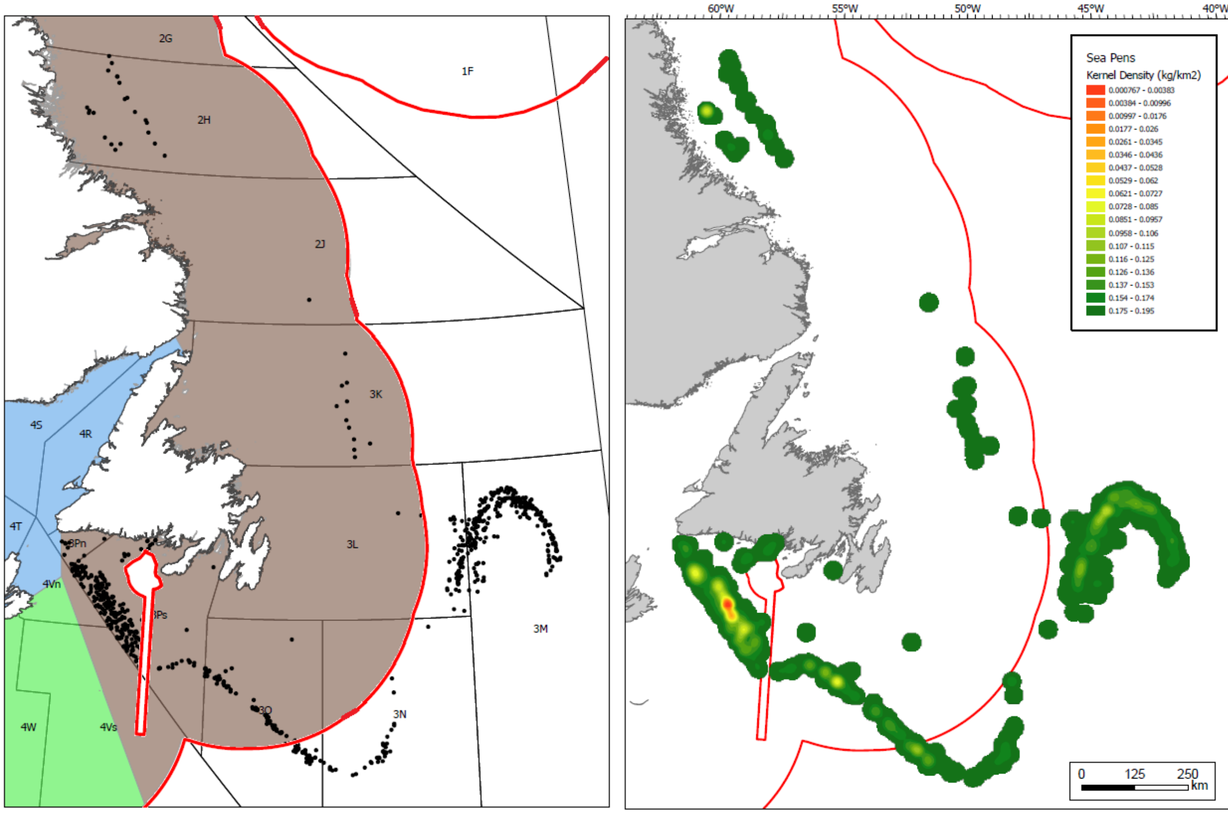

Figure 9. Distribution of records with *Sea Pen* biomass (left) and the resulting kernel density biomass surface (right). NAFO Divisions are labelled, and the biogeographic zones are shown on with differential shading on the left panel. Red lines show the exclusive economic zones of Canada, Greenland and St. Pierre and Miquelon. Map projection: NAD 83 UTM 22N.

As for sponges, there were significant differences among the catch series for each survey with the Campelen catches being more similar to one another than to the Lofoton catches (NAFO, 2013; 2019). Those dissimilarities were driven by differences in the number of small catch weights. When all records < 0.2 kg were removed, there was no significant difference among the catch distributions. Therefore, as for the previous analyses, the analyses herein were performed on catches ≥ 0.2 kg. For 2018, data from Canadian waters did not include 22 *Sea Pen* catches ≥ 0.2 kg as they were inadvertently omitted in the data transfer. The resulting data included 430 records from the NRA: 376 records from the EU surveys and 54 from the Canadian surveys, and 385 records from the Canadian waters, for a total of 815 records distributed as in Figure 9. For *Sea Pens* the highest biomass was found in the Laurentian Channel outside of the NRA. This differs from the sponges where the highest biomass was found in the NRA. KDE parameters were: Search Radius = 21.6 km; Contour Interval = 0.00005; Cell size default = 2589.39 m.

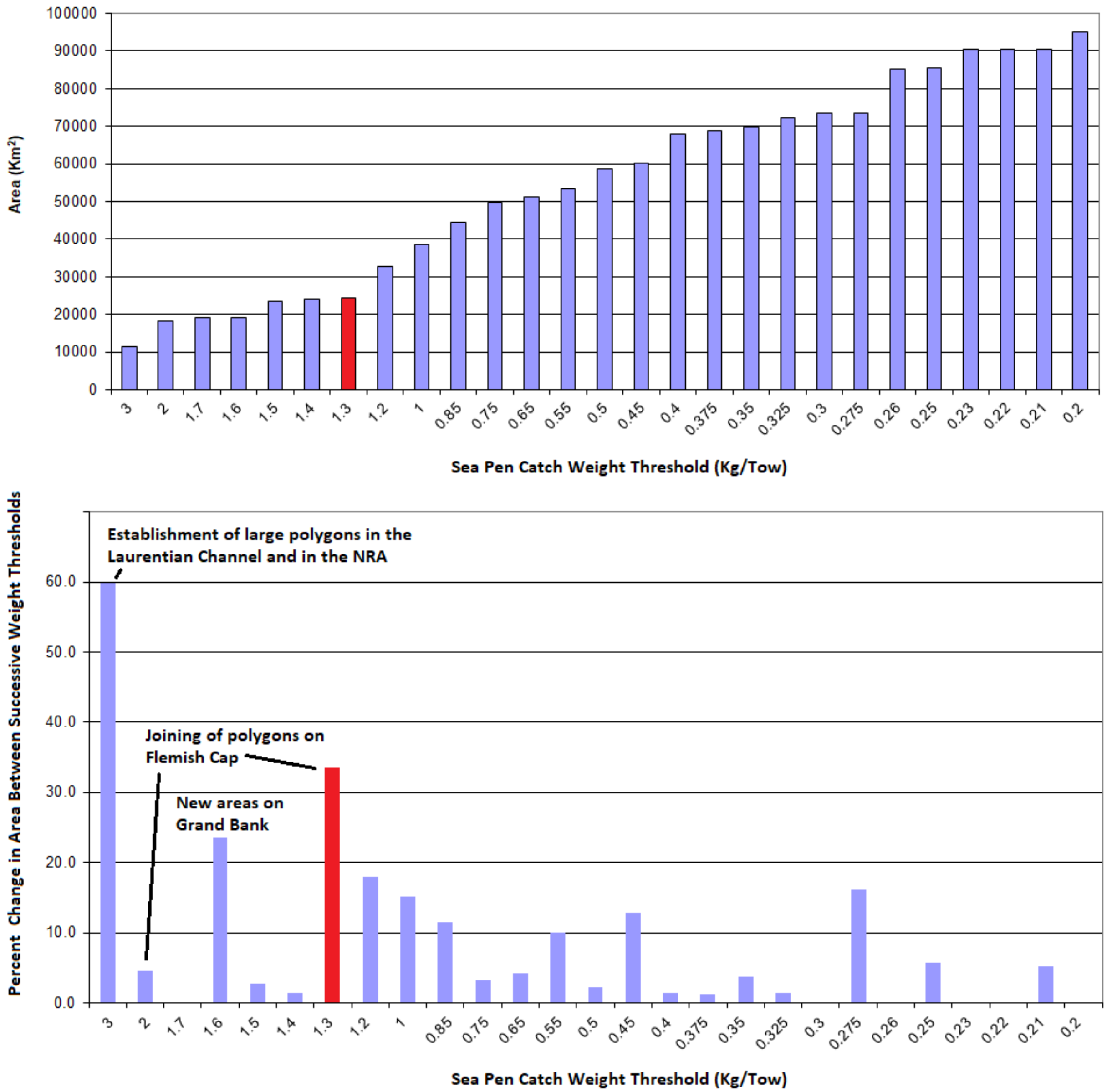

Figure 10. Bar graphs of the polygon area established by successively smaller research vessel *Sea Pen* catch weight thresholds (upper panel) and of the percent change in area created between successively smaller research vessel catch weight thresholds (lower panel). The red bar indicates the potential VME polygon threshold investigated.

The analyses identified the ≥ 1.3 kg threshold as the first to meet the criteria for identification of the VMEs (Figure 10). The first large change in area occurs with polygons surrounding catches ≥ 1.6 kg after the initial habitats are identified, however that change in area largely mapped out new areas on the Grand Bank and was weakly supported by the data (Figure 10, Table 4). The polygons on Flemish Cap were unchanged. The next large change in area was that occurring between the area covered by polygons ≥ 1.3 kg and those ≥ 1.2 kg. There that change in area (33.6%) was supported by a sufficient number of points (13; Table 4) and clearly established the threshold of 1.3 kg for the sea pen VME. This is the same threshold that was determined in the 2019 analysis of the data from the NRA only (Table 5; Kenchington et al., 2019). Consequently, the VME areas for *Sea Pens* remain the same in the NRA despite the inclusion of the data from Canadian waters which had the high biomass (Figure 9). The threshold in 2019 included 50 data points above the ≥ 1.3 kg threshold and the total area encompassed was 8,487.6 km^2. In the new analysis the threshold included 186 data records and covered an area of 24, 541.1 km^2 (Table 5).

Table 4. The number of points attributing to the delineation of sea pen VME polygons based on successively smaller research vessel sea pen catch weight thresholds (kg). The area and number of observations used to define each polygon and the percent change in area and the number of additional observations between successive thresholds are provided. The shaded row represents the threshold investigated as potentially delineating VMEs.

Sea Pen Catch Threshold (Kg)	Number of Observations in Polygon	Additional Observations Per Interval	Area of Polygon (km^2)	Percent Change in Area Between Successive Thresholds
3	65		11396.8	59.8
2	109	44	18212.5	4.6
1.7	136	27	19055.3	0.0
1.6	140	4	19055.3	23.6
1.5	157	17	23544.9	2.8
1.4	173	16	24195.1	1.4
1.3	186	13	24541.1	33.6
1.2	198	12	32781.0	17.9
1	232	34	38659.6	15.2
0.85	261	29	44548.1	11.5
0.75	282	21	49660.6	3.3
0.65	318	36	51293.8	4.2
0.55	353	35	53459.1	9.9
0.5	386	33	58775.3	2.3
0.45	413	27	60119.0	12.8
0.4	463	50	67799.7	1.4
0.375	484	21	68747.5	1.3
0.35	525	41	69659.0	3.8
0.325	557	32	72288.6	1.4
0.3	605	48	73326.2	0.1
0.275	632	27	73384.2	16.2
0.26	667	35	85259.7	0.1
0.25	695	28	85377.8	5.8
0.23	737	42	90293.2	0.1
0.22	757	20	90370.8	0.0
0.21	777	20	90370.8	5.2
0.2	815	38	95056.6	

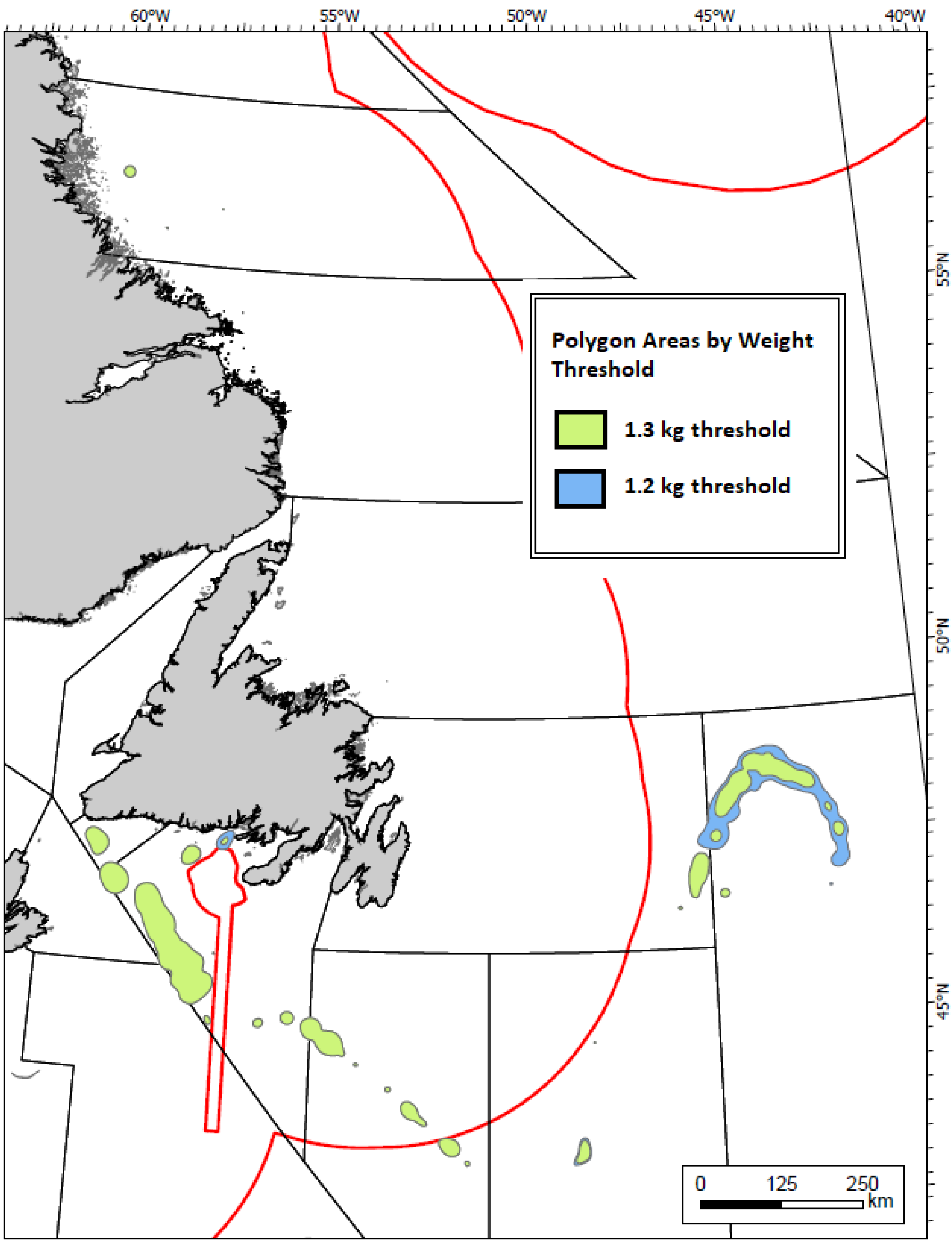

Figure 11. Spatial comparison of the areas covered by catches ≥ 1.3 kg and ≥ 1.2 kg; the areas covered by these thresholds are provided in Table 4. Map projection: NAD 83 UTM 22N.

Table 5. Comparison of the results of the KDE and spatial analyses for *Sea Pens* conducted in 2019 using only data from the NRA and in the present analyses using data from both the NRA and Canadian waters. Shading shows the selection of thresholds from each assessment.

	NRA only (2019)				NRA and NL (2022)			
Interval	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km^2)	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km^2)
3	12		359.4	1597.7	65		59.8	11396.8
2	22	10	4.7	7340.7	109	44	4.6	18212.5
1.7	33	11	0.0	7686.7	136	27	0.0	19055.3
1.6	35	2	10.3	7686.7	140	4	23.6	19055.3
1.5	43	8	0.1	8477.2	157	17	2.8	23544.9
1.4	46	3	0.2	8484.0	173	16	1.4	24195.1
1.3	50	4	90.6	8497.6	186	13	33.6	24541.1
1.2	56	6	0.3	16193.2	198	12	17.9	32781.0
1	75	19	4.0	16239.2	232	34	15.2	38659.6
0.85	93	18	29.2	16887.1	261	29	11.5	44548.1
0.75	107	14	2.5	21820.0	282	21	3.3	49660.6
0.65	126	19	6.3	22374.6	318	36	4.2	51293.8
0.55	142	16	18.0	23774.4	353	35	9.9	53459.1
0.5	159	17	2.0	28042.0	386	33	2.3	58775.3
0.45	175	16	1.5	28607.4	413	27	12.8	60119.0
0.4	199	24	3.8	29039.3	463	50	1.4	67799.7
0.375	214	15	0.9	30134.8	484	21	1.3	68747.5
0.35	239	25	12.4	30395.2	525	41	3.8	69659.0
0.325	262	23	0.0	34163.2	557	32	1.4	72288.6
0.3	283	21	0.2	34163.2	605	48	0.1	73326.2
0.275	302	19	28.2	34247.9	632	27	16.2	73384.2
0.26	326	24	0.0	43921.7	667	35	0.1	85259.7
0.25	350	24	0.0	43921.7	695	28	5.8	85377.8
0.23	374	24	0.0	43921.7	737	42	0.1	90293.2
0.22	390	16	0.0	43921.7	757	20	0.0	90370.8
0.21	407	17	9.8	43921.7	777	20	5.2	90370.8
0.2	430	23		48224.0	815	38		95056.6

Review of Significant Concentrations of Small Gorgonian Corals

Significant concentrations of *Small Gorgonian Corals* were determined previously in the NRA using kernel density analyses. Species distribution models were reviewed, and no modification of the KDE polygon boundaries was made (Kenchington et al., 2019). As for sponges and sea pens, there were significant differences among the catch series for each survey (NAFO, 2013; 2019). To remove the effect of differences in the gears, catches with biomass values ≥ 0.02 kg were used (Kenchington et al., 2019). For 2018, data from Canadian waters did not include 5 *Small Gorgonian Coral* catches ≥ 0.02 kg as they were inadvertently omitted in the data transfer. The resulting data included 218 records from the NRA: 156 records from the EU surveys and 62 from the Canadian surveys, and 203 records from the Canadian waters, for a total of 421 records distributed as in Figure 12.

Following previously established methods and assessment criteria, a *Small Gorgonian Coral* kernel density surface was created (Figure 12) and the area of successive density polygons calculated (Table 6, Figure 13). KDE parameters were: Search Radius = 22.1 km; Contour Interval = 0.0000025; Cell size default = 2656.7 m.

The KDE surface showed biomass peaks along the southern and eastern slopes of Grand Bank both inside Canadian waters and in the NRA (Figure 12). The threshold that emerged from the 2019 analysis was ≥ 0.2 kg/tow (Kenchington et al., 2019). The procedures for selecting the appropriate threshold would normally have accepted the ≥ 0.15 kg/tow threshold as the analysis is identifying new areas. However, in doing that, the merging of the ≥ 0.2 kg/tow areas on the Tail of Grand Bank based on only a few data points would result. Consequently, WG ESA adopted the ≥ 0.2 kg/tow threshold but highlighted the potential for *Small Gorgonian Coral* VME habitat on Flemish Cap from the ≥ 0.15 kg/tow threshold. Evaluation of the thresholds from the expanded area (Figures 13 and 14, Table 6) supported the ≥ 0.15 kg/tow threshold, as in 2019. However, in these analyses the threshold was supported by 92 data points, larger than the 39 available in 2019 (Table 7), and the percent change in area between that threshold and the next (≥ 0.10 kg/tow) was large (Figure 13).

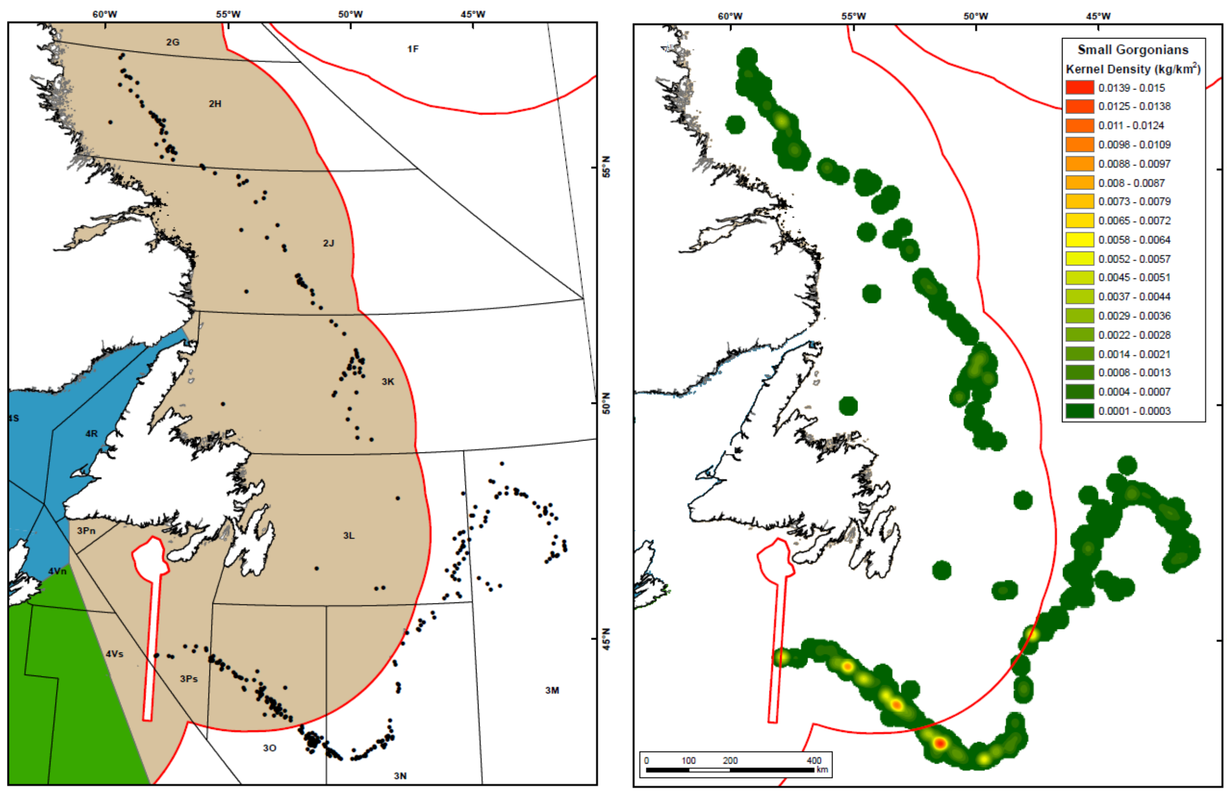

Figure 12. Distribution of records with *Small Gorgonian Coral* biomass (left) and the resulting kernel density biomass surface (right). NAFO Divisions are labelled, and the biogeographic zones are shown on with differential shading on the left panel. Red lines show the exclusive economic zones of Canada, Greenland and St. Pierre and Miquelon. Map projection: NAD 83 UTM 22N.

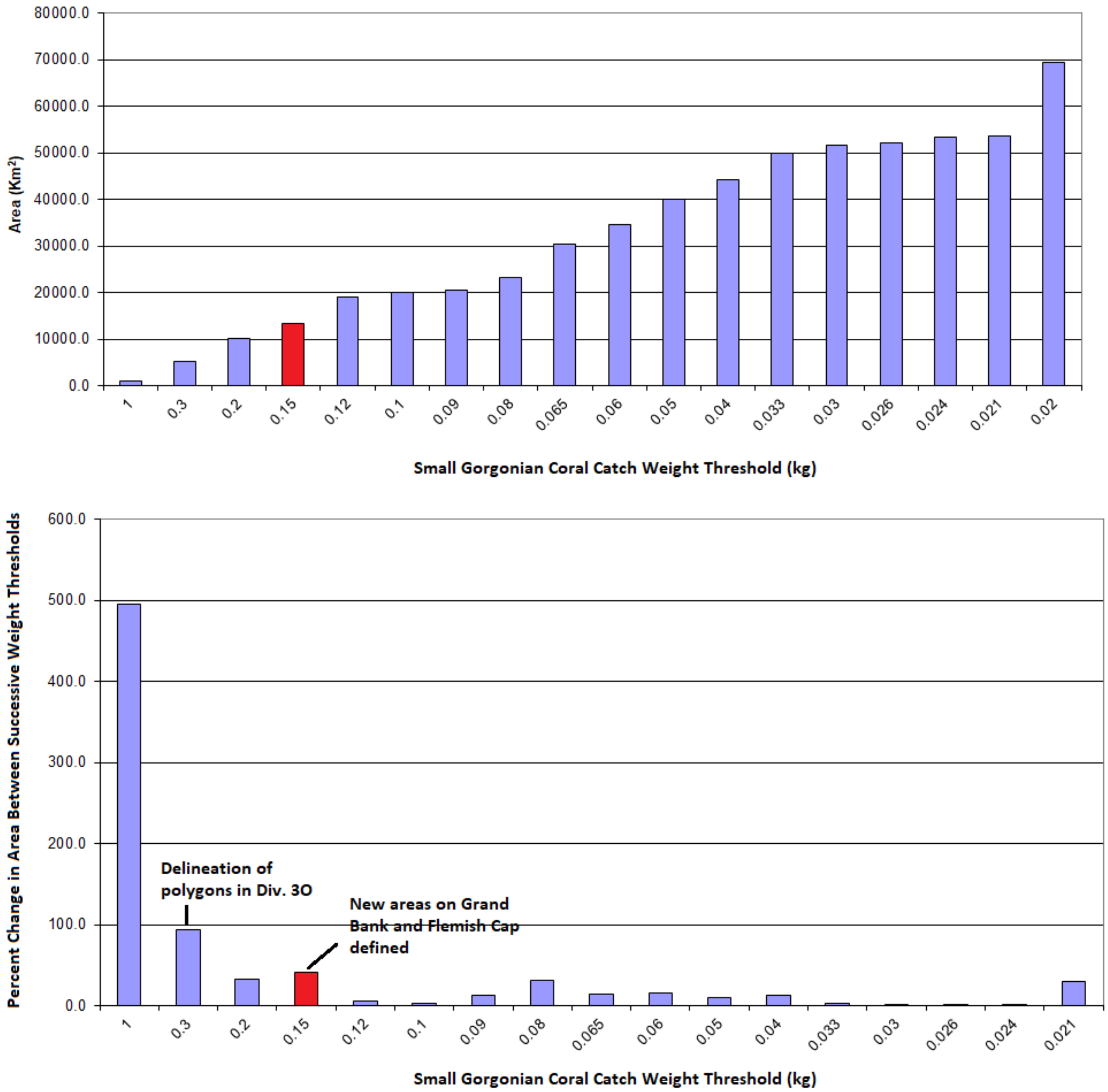

Figure 13. Bar graphs of the polygon area established by successively smaller research vessel *Small Gorgonian Coral* catch weight thresholds (upper panel) and of the percent change in area created between successively smaller research vessel catch weight thresholds (lower panel). Red bar indicates the potential VME polygon threshold.

Table 6. The number of points attributing to the delineation of small gorgonian coral VME polygons based on successively smaller research vessel *Small Gorgonian Coral* catch weight thresholds (kg). The area and number of observations used to define each polygon and the percent change in area and the number of additional observations between successive thresholds are provided. The shaded row represents the threshold investigated as potentially delineating VMEs.

Small Gorgonian Coral Catch Threshold (Kg)	Number of Observations in Polygon	Additional Observations Per Interval	Area of Polygon (km^2)	Percent Change in Area Between Successive Thresholds
1	14		881.4	494.7
0.3	45	31	5241.6	93.8
0.2	75	30	10159.2	32.3
0.15	92	17	13443.1	41.4
0.12	113	21	19002.4	5.5
0.1	133	20	20051.3	2.2
0.09	143	10	20496.5	13.0
0.08	160	17	23168.1	30.9
0.065	180	20	30331.8	13.9
0.06	202	22	34539.2	16.0
0.05	234	32	40060.5	10.2
0.04	267	33	44144.3	13.0
0.033	281	14	49898.5	3.3
0.03	312	31	51529.4	1.3
0.026	326	14	52219.0	2.2
0.024	338	12	53365.5	0.4
0.021	351	13	53573.9	29.6
0.02	421	70	69448.2	

The new threshold, being lower than the current threshold for identification of VMEs in the NRA (NAFO, 2019) identified two new areas on the eastern slope of Flemish Cap and connected three smaller VMEs on the slope of the Tail of Grand Bank (Figure 15). Those new areas are small compared with the 1377% increase in area found between the 2013 and 2019 KDE analyses for this taxon (Kenchington et al., 2019).

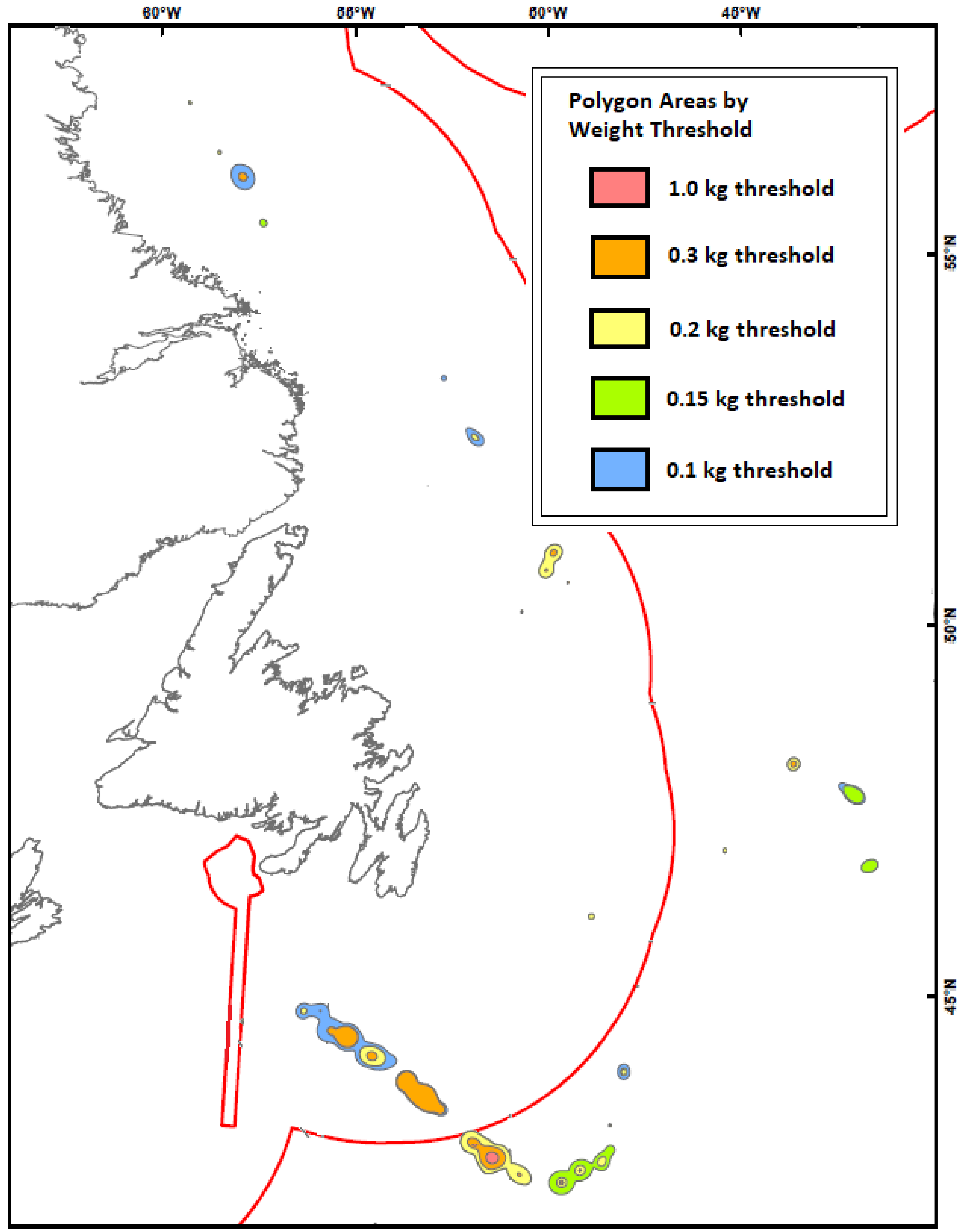

Figure 14. Spatial comparison of the areas covered by catches ≥ 1.0 kg, ≥ 0.3 kg, ≥ 0.2 kg, ≥ 0.15 kg and ≥ 0.1 kg; the areas covered by these thresholds are provided in Table 6. Map projection: NAD 83 UTM 22N.

Table 7. Comparison of the results of the KDE and spatial analyses for *Small Gorgonian Corals* conducted in 2019 using only data from the NRA and in the present analyses using data from both the NRA and Canadian waters. Shading shows the selection of thresholds from each assessment.

	NRA only (2019)				NRA and NL (2022)			
Interval	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km²)	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km²)
1	6		380.3	324.4	14		494.7	881.4
0.3	15	9	191.4	1558.0	45	31	93.8	5241.6
0.2	27	12	70.7	4540.2	75	30	32.3	10159.2
0.15	39	12	8.3	7748.2	92	17	41.4	13443.1
0.12	50	11	1.6	8388.5	113	21	5.5	19002.4
0.1	61	11	1.2	8520.2	133	20	2.2	20051.3
0.09	66	5	11.8	8622.8	143	10	13.0	20496.5
0.08	76	10	24.6	9637.9	160	17	30.9	23168.1
0.065	87	11	16.5	12012.9	180	20	13.9	30331.8
0.06	97	10	22.2	14001.0	202	22	16.0	34539.2
0.05	110	13	9.4	17107.5	234	32	10.2	40060.5
0.04	125	15	30.5	18714.4	267	33	13.0	44144.3
0.033	137	12	1.8	24416.0	281	14	3.3	49898.5
0.03	150	13	2.8	24849.2	312	31	1.3	51529.4
0.026	164	14	8.8	25553.4	326	14	2.2	52219.0
0.024	175	11	0.0	27801.5	338	12	0.4	53365.5
0.021	185	10	15.0	27814.7	351	13	29.6	53573.9
0.02	218	33		31977.1	421	70		69448.2

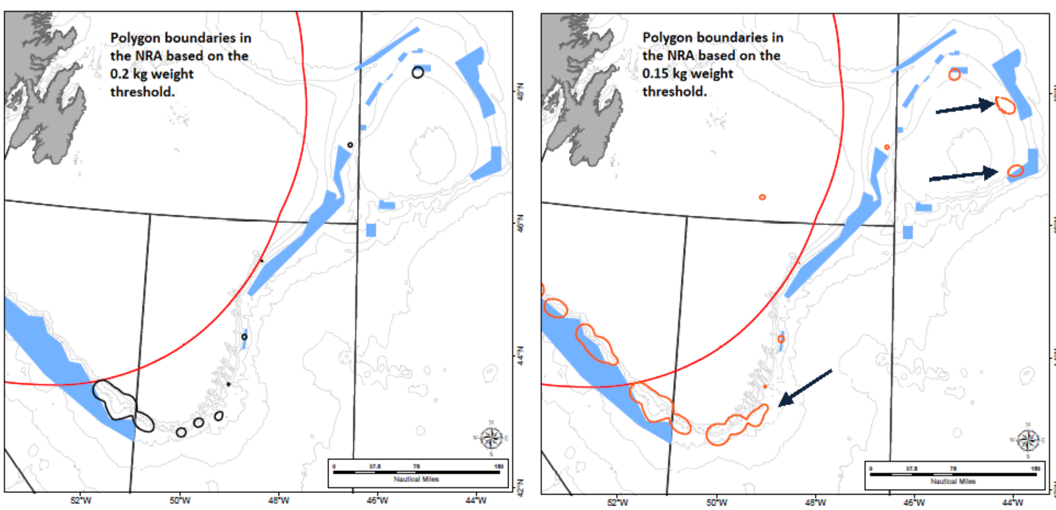

Figure 15. Comparison of the *Small Gorgonian Coral* VME polygons using the previously established threshold 0.2 kg threshold (black outline; NAFO, 2019) and the new 0.15 kg threshold (red outline). Closed areas in place in 2019 are shown with blue shading for comparing with previous work (Kenchington et al., 2019; NAFO, 2019). The arrows point to the difference in area identified when using the full data set as opposed to only the data from the NRA. Map projection: NAD 83 UTM 22N.

Review of Significant Concentrations of Large Gorgonian Corals

Significant concentrations of *Large Gorgonian Corals* in the NRA were previously identified using kernel density analyses and associated evaluation of the kernel surface (NAFO, 2013; 2019). Species distribution models were reviewed, and no modification of the KDE polygon boundaries was made (Kenchington et al., 2019). There were significant differences among the catch series for each survey (NAFO, 2013; 2019). When all records less than 0.1 kg were removed, there was no significant difference among the catch distributions and therefore the analyses here were performed on *Large Gorgonian Coral* catches ≥ 0.1 kg. For 2018, data from Canadian waters did not include 16 *Large Gorgonian Coral* catches ≥ 0.1 kg as they were inadvertently omitted in the data transfer. The resulting data included 89 records from the NRA: 60 records from the EU surveys and 29 from the Canadian surveys, and 234 records from the Canadian waters, for a total of 323 records distributed as in Figure 16.

Following previously established methods and assessment criteria, a kernel density surface was created, and the area of successive density polygons calculated. KDE parameters were: Search Radius = 19.2 km; Contour Interval = 0.000025; Cell size default = 2298.7 m. The highest densities were found in the Flemish Pass (Figure 16).

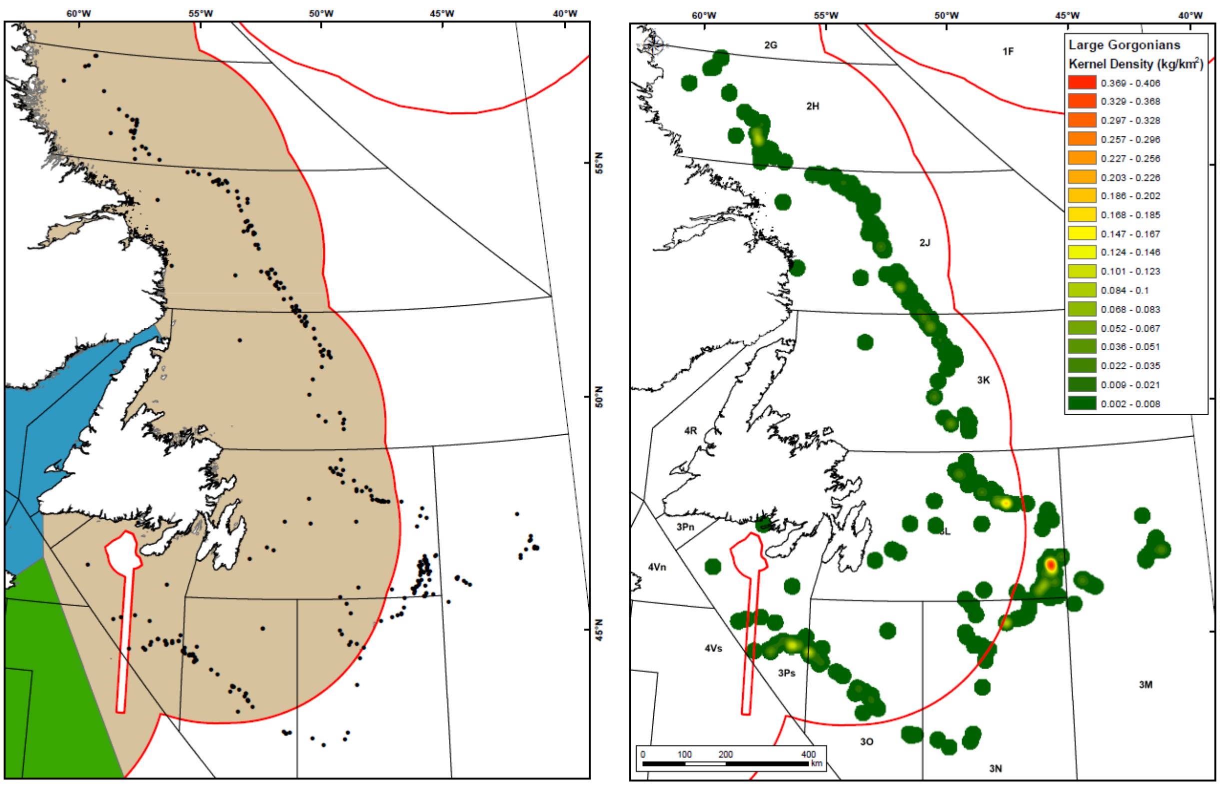

Figure 16. Distribution of records with *Large Gorgonian Coral* biomass (left) and the resulting kernel density biomass surface (right). NAFO Divisions and the biogeographic zones are shown on with differential shading on the left panel (Division labels are on the right panel). Red lines show the exclusive economic zones of Canada, Greenland and St. Pierre and Miquelon. Map projection: NAD 83 UTM 22N.

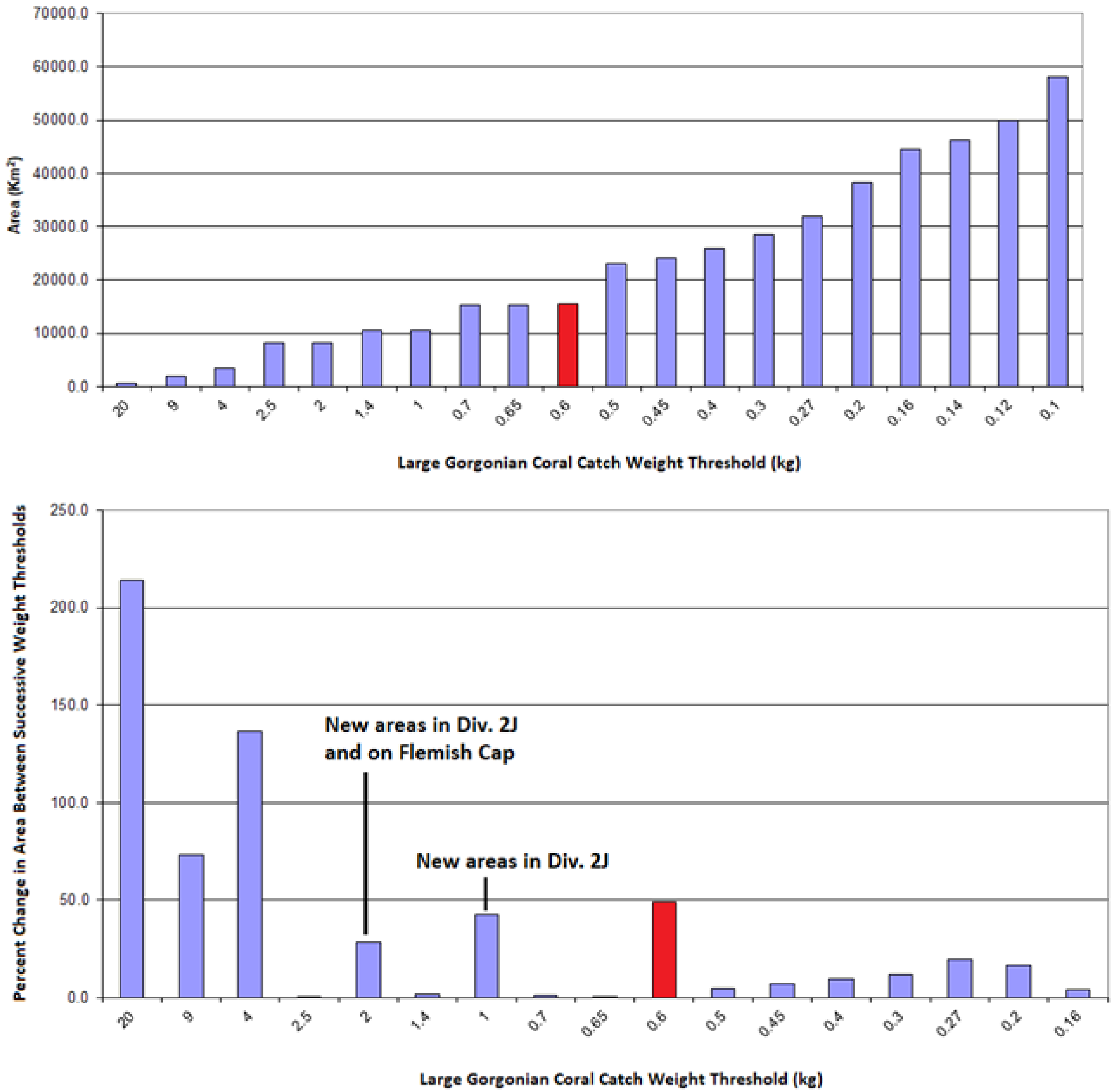

Figure 17. Bar graphs of the polygon area established by successively smaller research vessel *Large Gorgonian Coral* catch weight thresholds (upper panel) and of the percent change in area created between successively smaller research vessel catch weight thresholds (lower panel). Red bar indicates the VME polygon threshold.

The 1 kg threshold identified new areas in Divisions 2J, 3K, and 3N while joining other areas and so was not considered a threshold. Following the rules for choosing thresholds, the 0.6 kg/RV tow density threshold emerged as defining significant concentrations of *Large Gorgonian Corals* (i.e., *Large Gorgonian Coral* VME) (Table 8, Figures 17 and 18), which was the same threshold identified in the previous analysis (NAFO, 2019). It was the largest percent increase in area after the delineation of the VME habitats (Figure 17, Table 8) and showed a 7.2% increase greater than the 1 kg threshold which was the second largest (Figure 18). There were 128 data points within that threshold and the increase to the next lower threshold was established by 13 data points (Table 8). The addition of the new data reinforced same threshold that was selected in the 2019 analyses (Table 9).

Table 8. The number of points attributing to the delineation of *Large Gorgonian Coral* VME polygons based on successively smaller research vessel large gorgonian coral catch weight thresholds (kg). The area and number of observations used to define each polygon and the percent change in area and the number of additional observations between successive thresholds are provided. The shaded row represents the threshold used to define the VMEs.

Large Gorgonian Coral Catch Threshold (Kg)	Number of Observations in Polygon	Additional Observations Per Interval	Area of Polygon (km^2)	Percent Change in Area Between Successive Thresholds
20	9		634.5	213.8
9	23	14	1990.6	73.5
4	37	14	3454.7	136.6
2.5	56	19	8173.4	0.2
2	66	10	8186.1	28.4
1.4	79	13	10514.4	1.7
1	96	17	10697.9	42.5
0.7	119	23	15247.7	1.3
0.65	124	5	15449.5	0.6
0.6	128	4	15546.9	49.3
0.5	141	13	23210.1	4.7
0.45	150	9	24297.6	7.0
0.4	159	9	26010.2	9.7
0.3	182	23	28540.6	11.7
0.27	200	18	31893.8	19.8
0.2	241	41	38201.0	16.5
0.16	261	20	44503.1	4.1
0.14	274	13	46336.2	7.6
0.12	290	16	49854.6	16.6
0.1	323	33	58154.4	

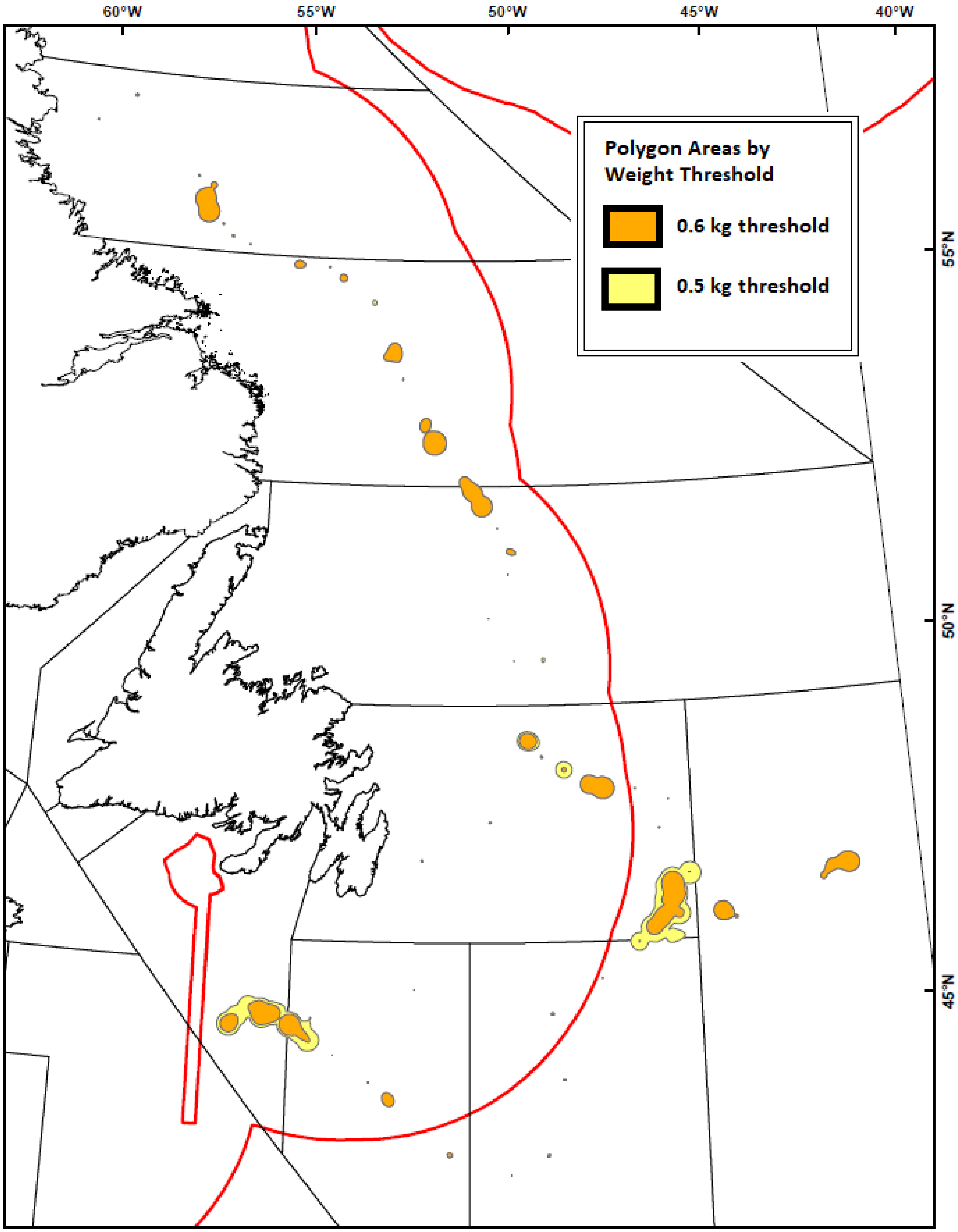

Figure 18. Spatial comparison of the areas covered by catches ≥ 0.6 kg and ≥ 0.5 kg; the areas covered by these thresholds are provided in Table 8. Map projection: NAD 83 UTM 22N.

Table 9. Comparison of the results of the KDE and spatial analyses for *Large Gorgonian Corals* conducted in 2019 using only data from the NRA and in the present analyses using data from both the NRA and Canadian waters. Shading shows the selection of thresholds from each assessment.

	NRA only (2019)				NRA and NL (2022)			
Interval	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km^2)	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km^2)
20	5		96.4	340.1	9		213.8	634.5
9	10	5	127.5	668.1	23	14	73.5	1990.6
4	14	4	143.8	1519.6	37	14	136.6	3454.7
2.5	20	6	0.1	3704.2	56	19	0.2	8173.4
2	26	6	20.1	3706.9	66	10	28.4	8186.1
1.4	31	5	0.5	4452.6	79	13	1.7	10514.4
1	36	5	11.2	4474.8	96	17	42.5	10697.9
0.7	41	5	0.0	4977.0	119	23	1.3	15247.7
0.65	43	2	0.2	4977.0	124	5	0.6	15449.5
0.6	44	1	78.6	4986.9	128	4	49.3	15546.9
0.5	47	3	0.0	8905.8	141	13	4.7	23210.1
0.45	47	0	19.3	8905.8	150	9	7.0	24297.6
0.4	53	6	0.1	10624.4	159	9	9.7	26010.2
0.3	58	5	5.1	10639.5	182	23	11.7	28540.6
0.27	65	7	3.9	11186.9	200	18	19.8	31893.8
0.2	70	5	14.5	11620.6	241	41	16.5	38201.0
0.16	76	6	0.0	13306.8	261	20	4.1	44503.1
0.14	81	5	4.8	13306.8	274	13	7.6	46336.2
0.12	85	4	0.0	13946.3	290	16	16.6	49854.6
0.1	89	4		13946.3	323	33		58154.4

Review of Significant Concentrations of Erect Bryozoans

Significant concentrations of *Erect Bryozoans* in the NRA were previously identified using kernel density analyses and associated evaluation of the kernel surface (NAFO, 2013; 2019). Species distribution models were reviewed, and no modification of the KDE polygon boundaries was made (Kenchington et al., 2019). To remove the effect of differences in the gears, catches with biomass values ≥ 0.02 kg were used (Kenchington et al., 2019). The resulting data included 174 records from the NRA: 162 records from the EU surveys and 12 from the Canadian surveys, and 217 records from the Canadian waters, for a total of 391 records distributed as in Figure 19.

Following previously established methods and assessment criteria, a kernel density surface for the *Erect Bryozoans* was created and the area of successive density polygons calculated. KDE parameters were: Search Radius = 12.4 km; Contour Interval = 0.00005; Cell size default = 1488.6 m. The largest *Erect Bryozoan* biomass was found on the Tail of Grand Bank in the NRA (Figure 19).

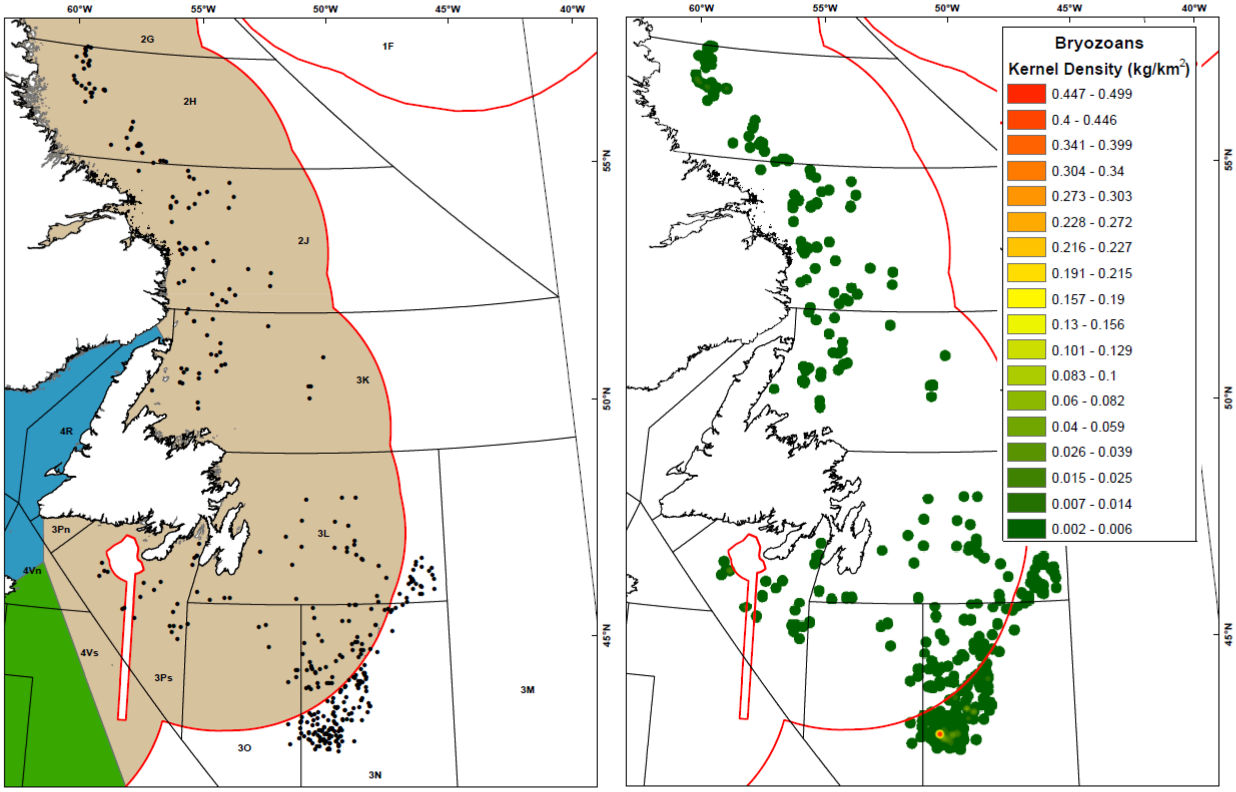

Figure 19. Distribution of records with *Erect Bryozoan* biomass (left) and the resulting kernel density biomass surface (right). NAFO Divisions are labelled, and the biogeographic zones are shown on with differential shading on the left panel. Red lines show the exclusive economic zones of Canada, Greenland and St. Pierre and Miquelon. Map projection: NAD 83 UTM 22N.

The 2019 kernel density distribution identified the 0.2 kg/RV tow density threshold as defining significant concentrations of erect bryozoans (NAFO, 2019). That was the same threshold identified in the 2013 analysis (NAFO, 2013). The main bryozoan species that constitutes the significant concentrations is *Eucratea loricata*. The new data also identified the 0.2 kg/RV tow threshold as the largest change in area after the establishment of habitats (Table 10, Figures 20, 21). A potential threshold of 0.25 kg was evaluated (Figure 21) but in addition to having 13.9% less difference in area, those polygons were only delineated by 7 data points (Table 10, Figure 21). The addition of the data from the Canadian waters (Table 11) provided additional support to the threshold selection derived from the data from the NRA only.

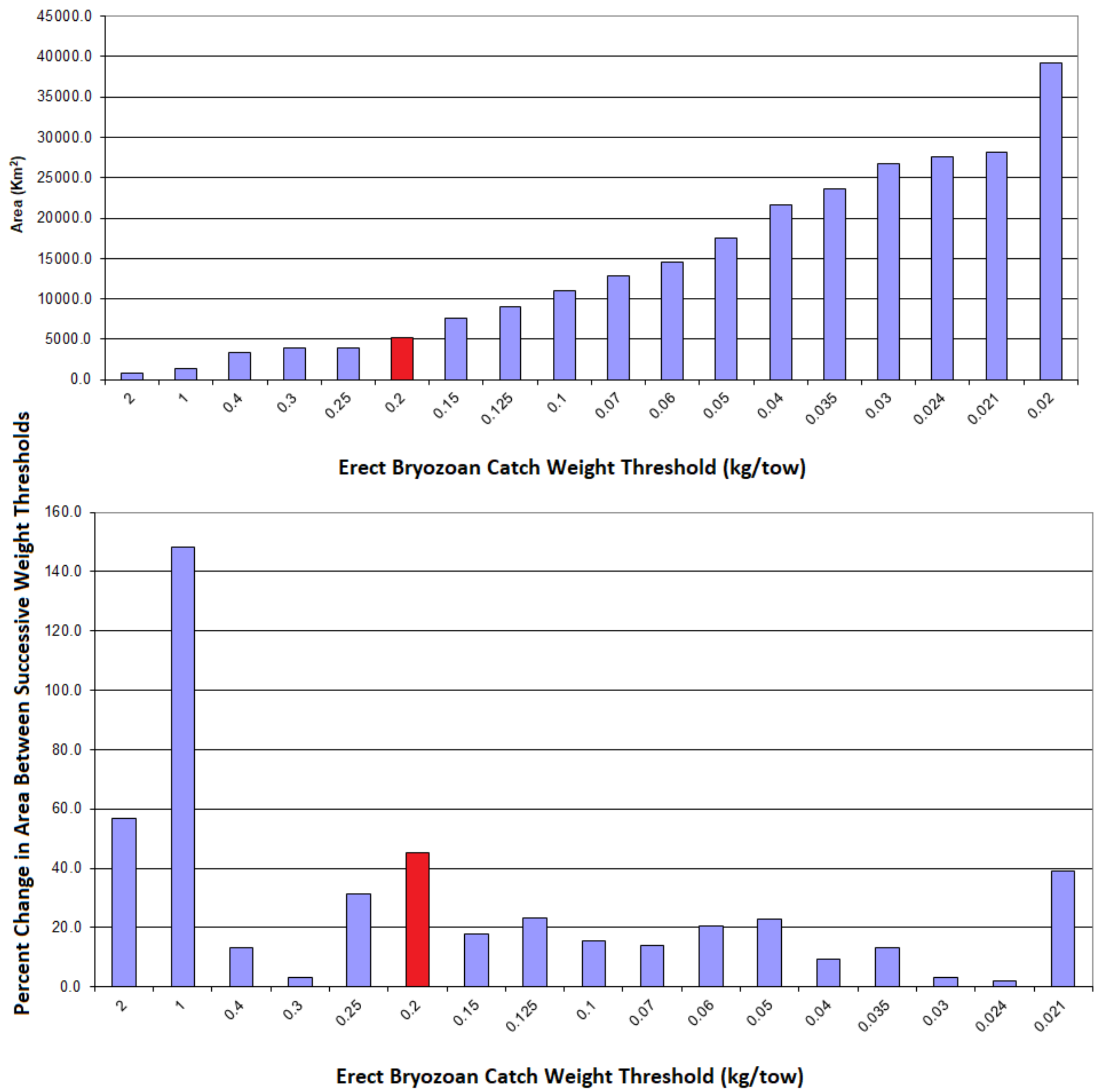

Figure 20. Bar graphs of the polygon area established by successively smaller research vessel *Erect Bryozoan* catch weight thresholds (upper panel) and of the percent change in area created between successively smaller research vessel catch weight thresholds (lower panel). Red bar indicates the potential VME polygon threshold.

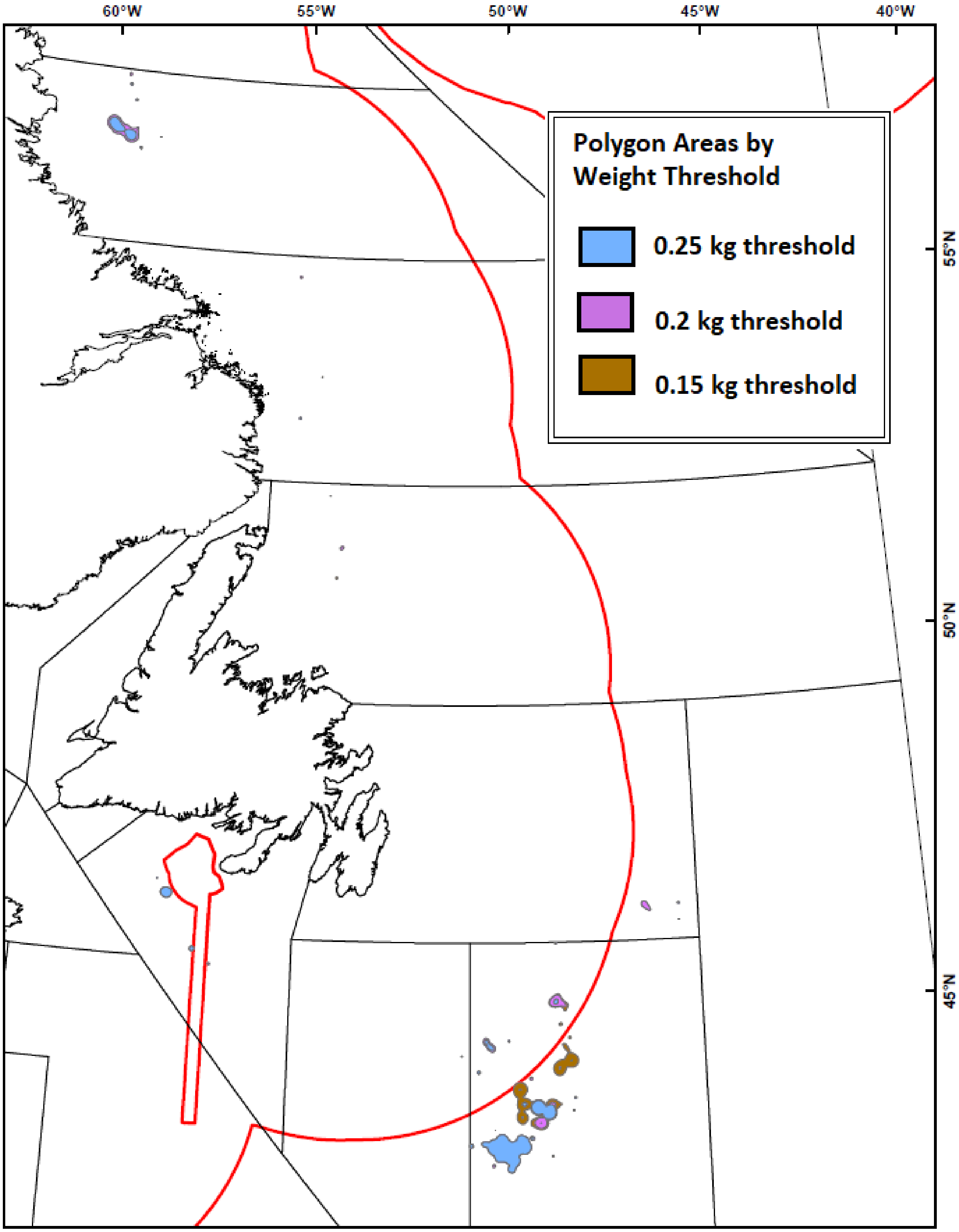

Figure 21. Spatial comparison of the areas covered by catches ≥ 0.25 kg, ≥ 0.2 kg, and ≥ 0.15 kg; the areas covered by these thresholds are provided in Table 14. Map projection: NAD 83 UTM 22N.

Table 10. The number of points attributing to the delineation of *Erect Bryozoan* VME polygons based on successively smaller research vessel *Erect Bryozoan* catch weight thresholds (kg). The area and number of observations used to define each polygon and the percent change in area and the number of additional observations between successive thresholds are provided. The shaded row represents the threshold used to define the VMEs.

Erect Bryozoan Catch Threshold (Kg)	Number of Observations in Polygon	Additional Observations Per Interval	Area of Polygon (km^2)	Percent Change in Area Between Successive Thresholds
2	10		877.6	56.7
1	24	14	1374.8	148.4
0.4	43	19	3415.1	13.4
0.3	53	10	3873.5	3.1
0.25	60	7	3994.4	31.4
0.2	72	12	5248.3	45.3
0.15	84	12	7626.2	17.7
0.125	96	12	8978.3	23.2
0.1	125	29	11065.6	15.6
0.07	150	25	12790.0	14.1
0.06	173	23	14598.0	20.6
0.05	209	36	17598.3	22.9
0.04	249	40	21620.4	9.2
0.035	260	11	23617.8	13.1
0.03	279	19	26713.9	3.1
0.024	290	11	27533.8	2.2
0.021	299	9	28134.0	39.3
0.02	391	92	39176.9	

Table 11. Comparison of the results of the KDE and spatial analyses for *Erect Bryozoans* conducted in 2019 using only data from the NRA and in the present analyses using data from both the NRA and Canadian waters. Shading shows the selection of thresholds from each assessment.

	NRA only (2019)				NRA and NL (2022)			
Interval	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km²)	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km²)
2	9		68.2	774.4	10		56.7	877.6
1	17	8	100.5	1302.8	24	14	148.4	1374.8
0.4	29	12	14.7	2611.6	43	19	13.4	3415.1
0.3	35	6	0.8	2995.1	53	10	3.1	3873.5
0.25	38	3	15.6	3019.7	60	7	31.4	3994.4
0.2	43	5	63.7	3491.5	72	12	45.3	5248.3
0.15	50	7	23.2	5714.0	84	12	17.7	7626.2
0.125	59	9	21.6	7038.9	96	12	23.2	8978.3
0.1	71	12	7.3	8558.0	125	29	15.6	11065.6
0.07	83	12	13.6	9183.4	150	25	14.1	12790.0
0.06	94	11	11.8	10431.4	173	23	20.6	14598.0
0.05	108	14	11.9	11658.0	209	36	22.9	17598.3
0.04	119	11	15.8	13046.6	249	40	9.2	21620.4
0.035	130	11	14.8	15104.9	260	11	13.1	23617.8
0.03	139	9	4.7	17342.3	279	19	3.1	26713.9
0.024	150	11	3.3	18165.3	290	11	2.2	27533.8
0.021	159	9	20.9	18765.4	299	9	39.3	28134.0
0.02	174	15		22693.7	391	92		39176.9

Kernel Density Analysis of Black Corals

Significant concentrations of *Black Corals* in the NRA were identified in 2019 for the first time using kernel density analyses and associated evaluation of the kernel surface (NAFO, 2019). Most of the high-density areas were from the Flemish Pass area. Species distribution models were reviewed, and the KDE polygons fell within the range of predicted distribution, therefore no modifications were made to the KDE polygons (Kenchington et al., 2019). As for other VME indicators it was previously determined that it is necessary to exclude some of the smaller catches in order to combine the data from the different gear types (Kenchington et al., 2019). Only catches ≥ 0.2 kg were included in the analysis to be comparable to the 2019 assessment. For 2018, data from Canadian waters did not include 4 *Black Coral* catches ≥ 0.2 kg as they were inadvertently omitted in the data transfer. The total number of *Black Coral* records was 62 with 18 from Canadian waters and 44 records from the NRA (6 from Canada and 38 from EU). Previously established methods and assessment criteria were followed for the analysis (NAFO, 2019), and the KDE parameters were: Search Radius = 19.8 km; Contour Interval = 0.000005; Cell size default = 2386.0 m.

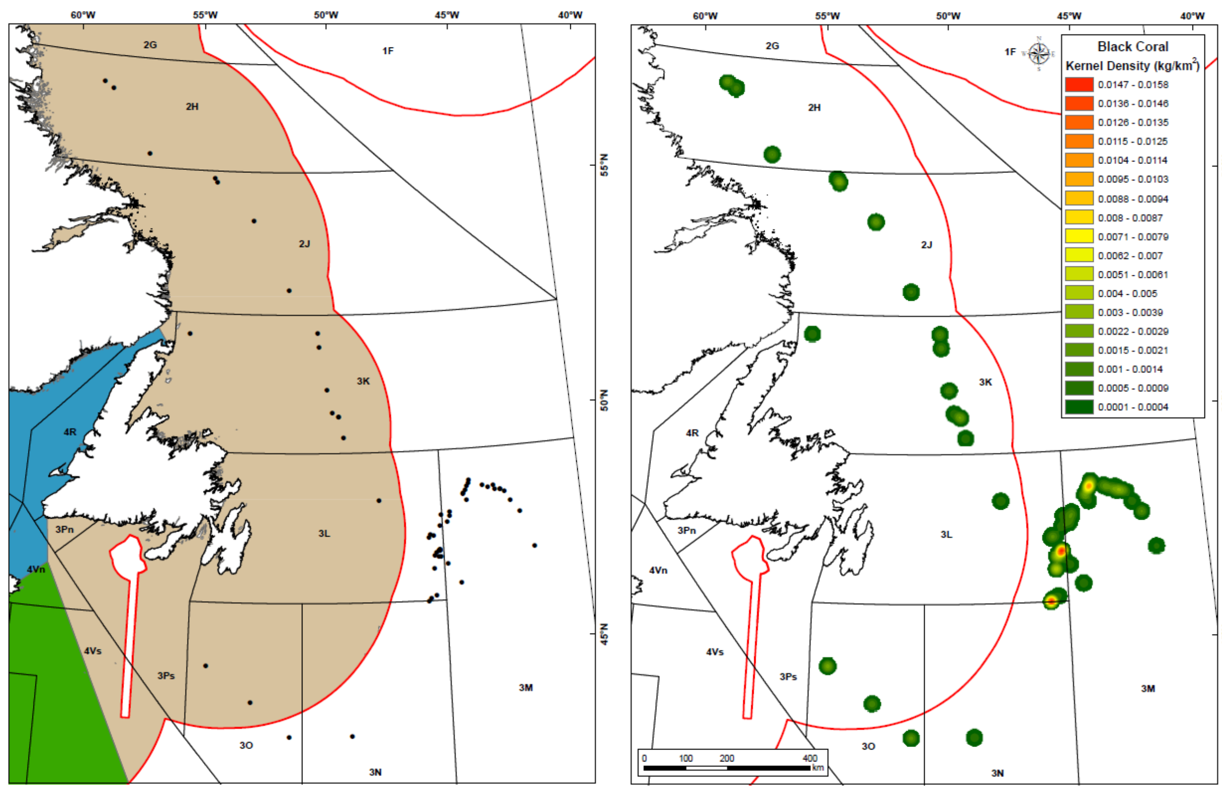

Figure 22. Distribution of records with *Black Coral* biomass (left) and the resulting kernel density biomass surface (right). NAFO Divisions are labelled, and the biogeographic zones are shown on with differential shading on the left panel. Red lines show the exclusive economic zones of Canada, Greenland and St. Pierre and Miquelon. Map projection: NAD 83 UTM 22N.

Table 12. The number of points attributing to the delineation of *Black Coral* VME polygons based on successively smaller research vessel black coral catch weight thresholds (kg). The area and number of observations used to define each polygon and the percent change in area and the number of additional observations between successive thresholds are provided. The shaded row represents the threshold used to define the VMEs.

Black Coral Catch Threshold (Kg)	Number of Observations in Polygon	Additional Observations Per Interval	Area of Polygon (km²)	Percent Change in Area Between Successive Thresholds
1.5	4		42.8	1742.9
1	9	5	788.0	92.4
0.5	24	15	1516.1	78.2
0.4	33	9	2701.0	33.2
0.32	41	8	3598.2	4.5
0.3	48	7	3761.0	21.2
0.25	55	7	4558.0	39.3
0.2	62	7	6348.7	

A kernel density surface was created (Figure 22) and the area of successive density polygons calculated (Table 12). The first increases in area occurred through identification of high-density areas in Flemish Pass with catches ≥ 1 kg (Table 12, Figure 23). At thresholds ≥ 0.5 kg new areas were established on the slopes of Sackville

Spur (northern Flemish Cap) and on the Labrador Slope (Figures 23, 24). With the establishment of the highest density polygons the next largest increase in area occurred at the ≥ 0.25 kg threshold where the percent change in area between that and the next threshold was 39.3%. Catches ≥ 0.4 kg, the previous weight threshold, established new areas in Flemish Pass and showed a smaller increase in area between that and the next threshold (33.2%) (Table 12).

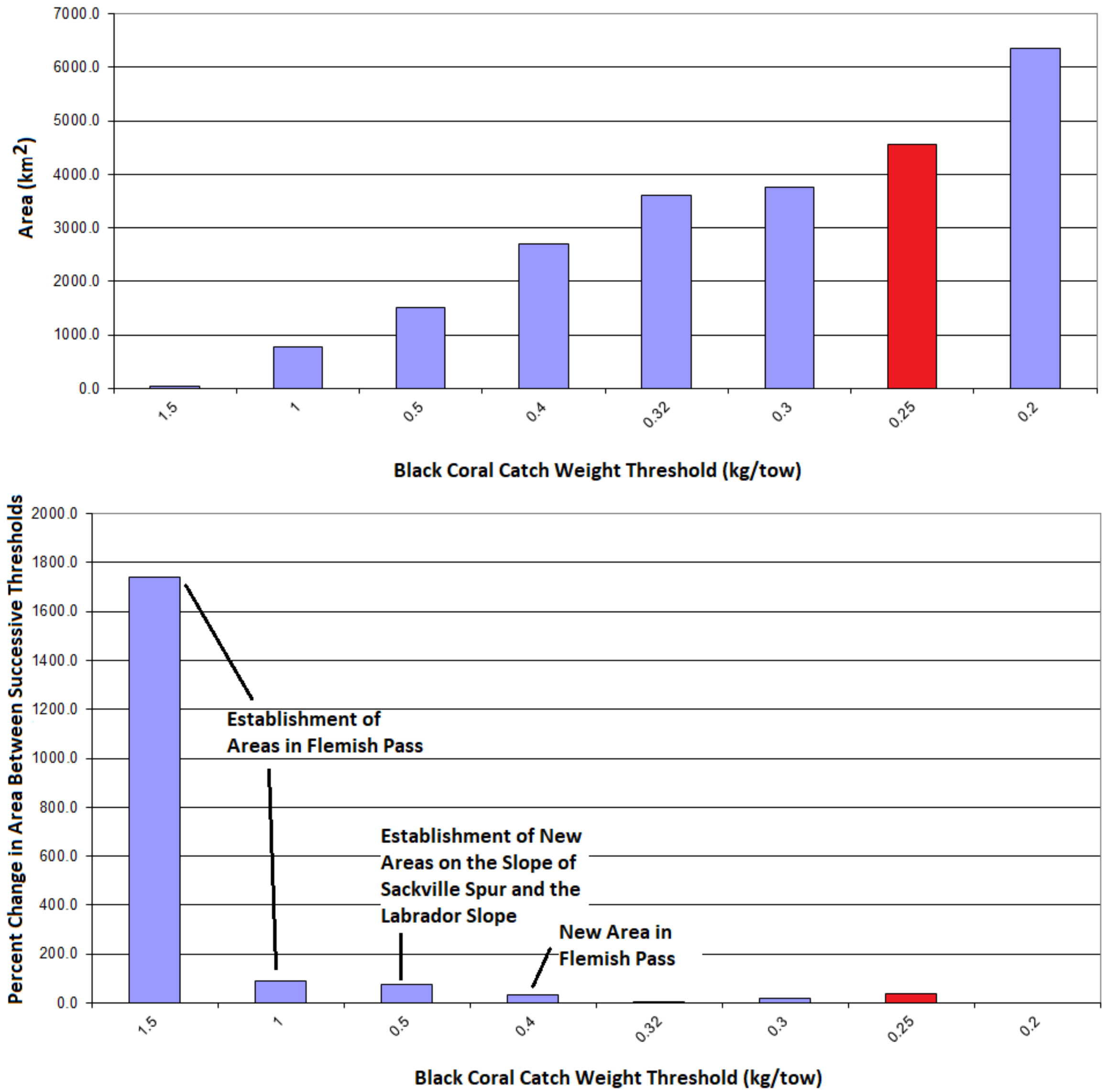

Figure 23. Bar graphs of the polygon area established by successively smaller research vessel *Black Coral* catch weight thresholds (upper panel) and of the percent change in area created between successively smaller research vessel catch weight thresholds (lower panel). Red bar indicates the potential VME polygon threshold.

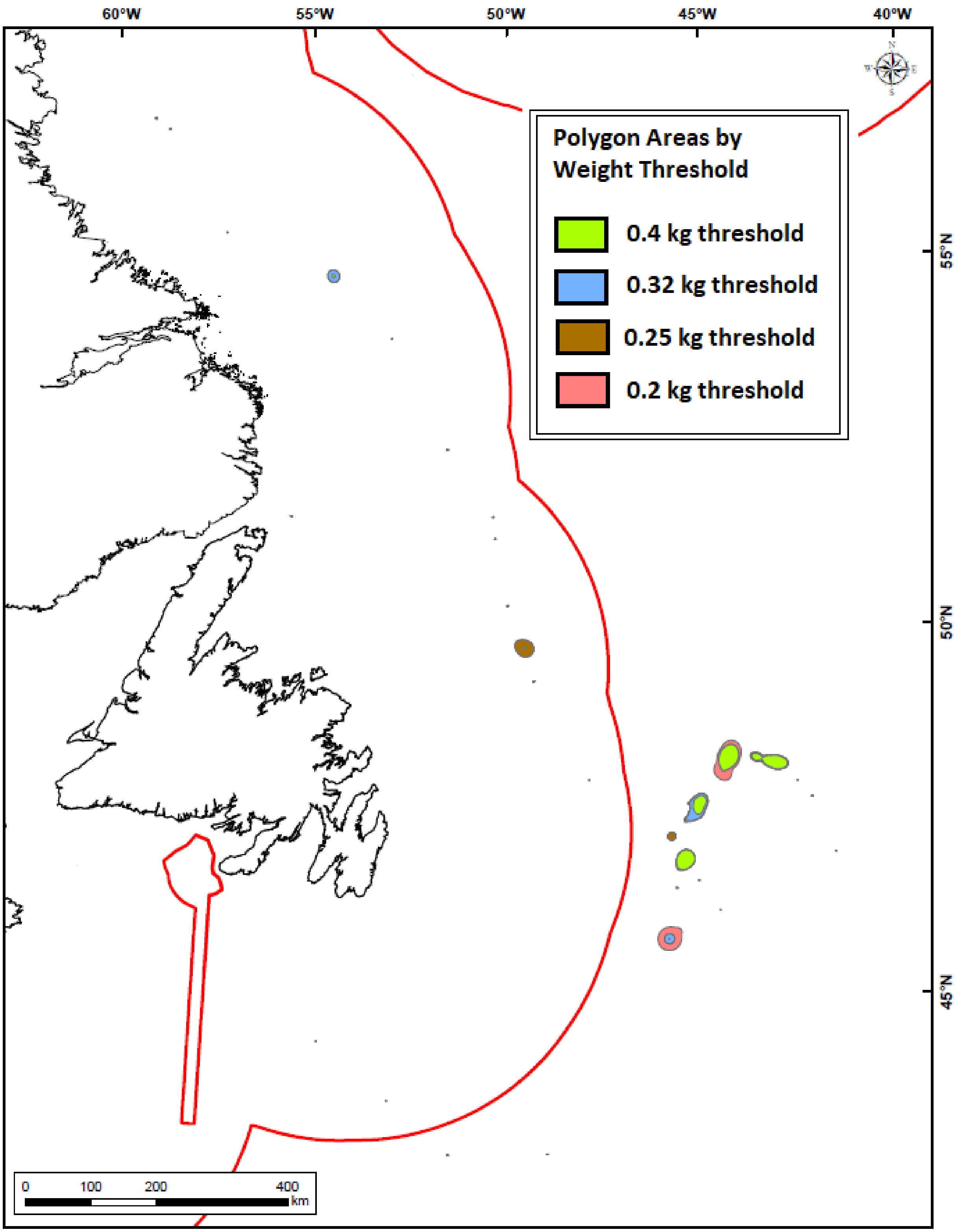

Figure 24. Spatial comparison of the areas covered by *Black Coral* catches ≥ 0.4 kg, ≥ 0.32 kg, ≥ 0.25 and ≥ 0.2 kg; the areas covered by these thresholds are provided in Table 14. Map projection: NAD 83 UTM 22N.

Consequently the ≥ 0.25 kg threshold was considered to represent the VMEs in this new analysis. This is a lower threshold than previously identified using only data from the NRA (≥ 0.4 kg), although most of the aerial expansion occurred in Canadian waters (Figure 24, brown coloured polygons) so for the NRA portion the threshold would not affect the VME areas to a large degree (Figure 25). The new threshold is supported by 55 data points and covers an area of 4558 km^2 (Table 13).

Table 13. Comparison of the results of the KDE and spatial analyses for *Black Coral* conducted in 2019 using only data from the NRA and in the present analyses using data from both the NRA and Canadian waters. Shading shows the selection of thresholds from each assessment.

	NRA only (2019)				NRA and NL (2022)			
Interval	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km^2)	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km^2)
1.5	4		1667.2	44.6	4		1742.9	42.8
1	8	4	89.2	787.7	9	5	92.4	788.0
0.5	15	7	76.5	1490.3	24	15	78.2	1516.1
0.4	21	6	25.4	2631.1	33	9	33.2	2701.0
0.32	26	5	5.0	3300.1	41	8	4.5	3598.2
0.3	32	6	6.8	3463.5	48	7	21.2	3761.0
0.25	37	5	48.3	3699.5	55	7	39.3	4558.0
0.2	44	7		5487.8	62	7		6348.7

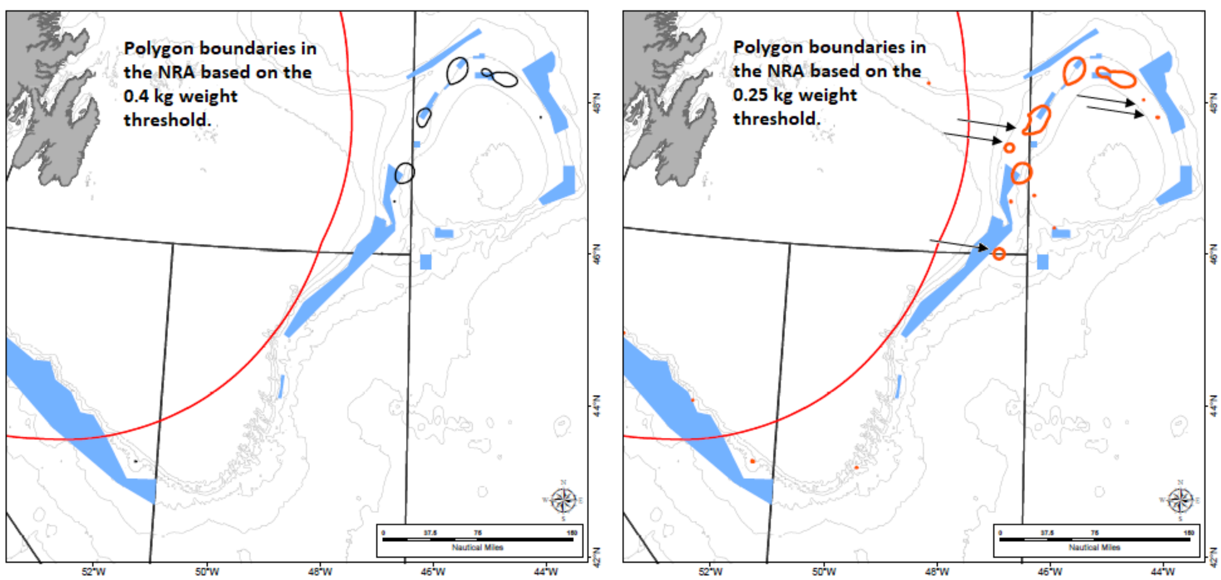

Figure 25. Comparison of the *Black Coral* VME polygons using the previously established threshold 0.4 kg threshold (black outline; NAFO, 2019) and the new 0.25 kg threshold (red outline). Closed areas in place in 2019 are shown with blue shading for comparing with previous work (Kenchington et al., 2019; NAFO, 2019). The arrows point to the larger differences in area identified when using the full data set as opposed to only the data from the NRA. Map projection: NAD 83 UTM 22N.

The new analysis with the lower threshold expands one previous black coral VME and creates two new VMEs in Flemish Pass (Figure 25). These new areas are consistent with the predicted distribution of *Black Corals* in the NRA (Kenchington et al., 2019).

Review of Significant Concentrations of Sea Squirts

Sea Squirts (specifically stalked tunicates) were identified as VME indicators in Murillo et al. (2011) and accepted by NAFO as such (NAFO, 2012). There are two species of *Boltenia*, *B. ovifera* and *B. echinate* in the study area. The catches in the NRA are mainly of *B. ovifera*, a habitat-forming stalked tunicate VME indicator, and all are located on the Tail and Nose of Grand Bank. Following previously established methods and assessment criteria (NAFO, 2019), significant concentrations of *Sea Squirts* in the NRA were identified. Species distribution models were reviewed, and the KDE polygons fell within the range of predicted distribution, therefore no modifications were made to the KDE polygons (Kenchington et al., 2019). The data for the current analyses included 1340 records of sea squirts (334 from the NRA: 172 from Canadian surveys, 162 from EU surveys; 1006 from Canadian waters), and no data were excluded as there was no significant difference in catches between the gears (Kenchington et al., 2019). The temporal range of the data was from 2004 to 2019. This represents 1006 more observations than were available in the previous KDE analysis (NAFO, 2019). KDE parameters were: Search Radius = 10.1 km; Contour Interval = 0.00005; Cell size default = 2897.8 m.

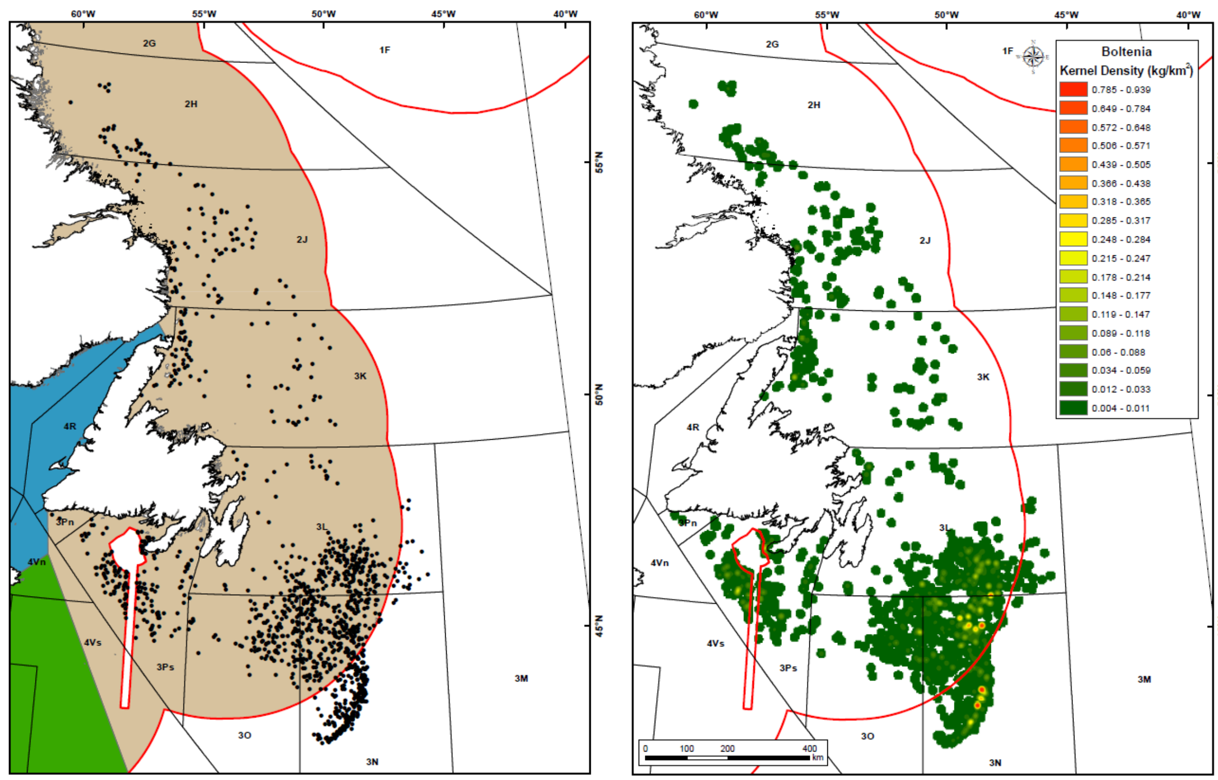

Figure 26. Distribution of records with *Sea Squirt (Boltenia)* biomass (left) and the resulting kernel density biomass surface (right). NAFO Divisions are labelled, and the biogeographic zones are shown on with differential shading on the left panel. Red lines show the exclusive economic zones of Canada, Greenland and St. Pierre and Miquelon. Map projection: NAD 83 UTM 22N.

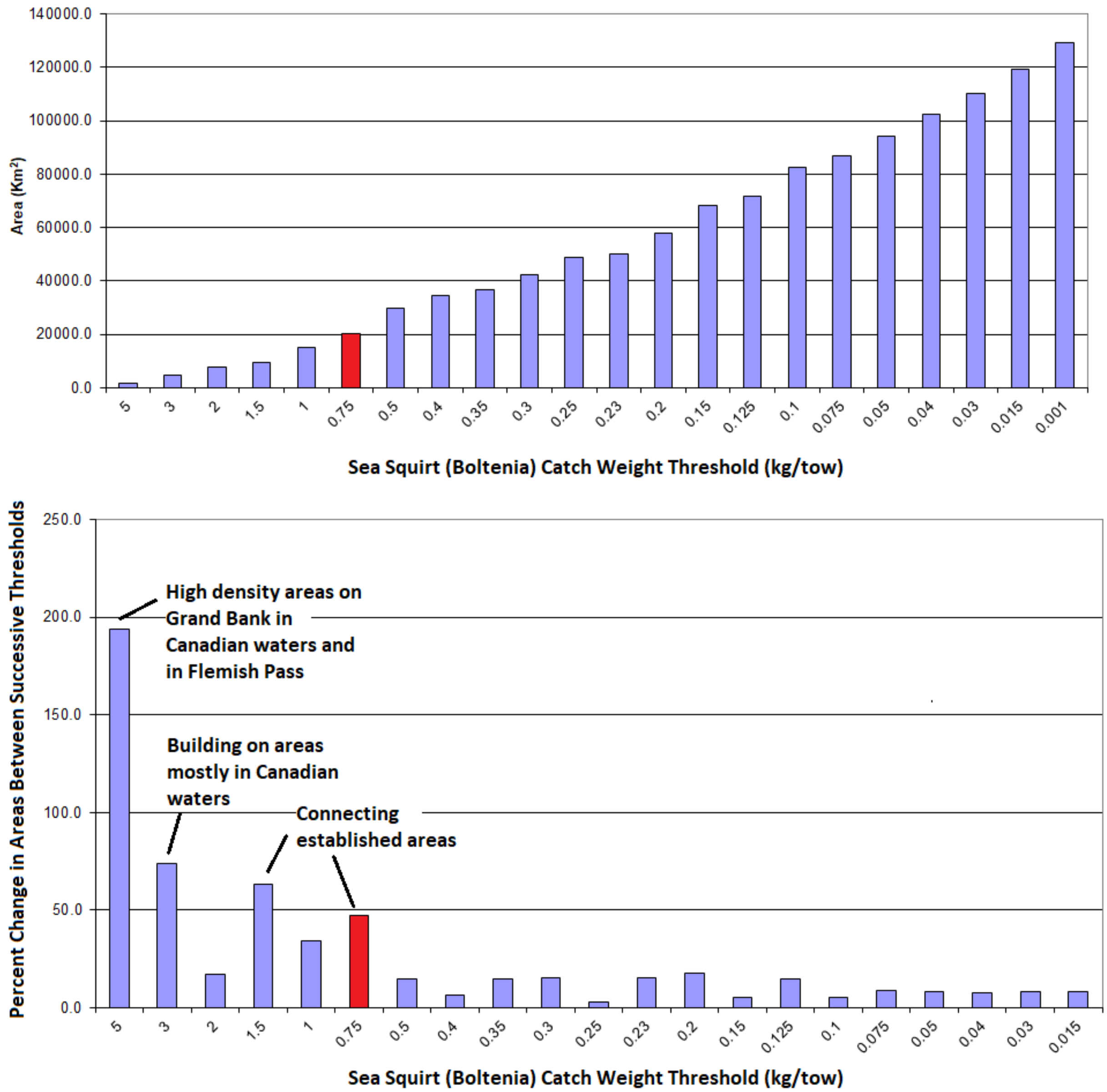

Figure 27. Bar graphs of the polygon area established by successively smaller research vessel *Sea Squirt* (*Boltenia*) catch weight thresholds (upper panel) and of the percent change in area created between successively smaller research vessel catch weight thresholds (lower panel). Red bar indicates the potential VME polygon threshold.

Table 14. The number of points attributing to the delineation of *Sea Squirt* (*Boltenia*) VME polygons based on successively smaller research vessel sea squirt catch weight thresholds (kg). The area and number of observations used to define each polygon and the percent change in area and the number of additional observations between successive thresholds are provided. The shaded row represents the threshold used to define the VMEs.

Boltenia Catch Threshold (Kg)	Number of Observations in Polygon	Additional Observations Per Interval	Area of Polygon (km^2)	Percent Change in Area Between Successive Thresholds
5	66		1557.1	193.7
3	131	65	4572.8	74.0
2	187	56	7956.5	17.1
1.5	226	39	9313.8	63.0
1	317	91	15185.9	34.3
0.75	384	67	20402.0	47.1
0.5	500	116	30020.7	15.0
0.4	558	58	34526.5	6.6
0.35	597	39	36814.2	14.5
0.3	648	51	42158.3	15.5
0.25	708	60	48685.9	2.8
0.23	733	25	50071.6	15.3
0.2	794	61	57716.8	18.1
0.15	886	92	68138.9	5.3
0.125	934	48	71734.1	15.0
0.1	1027	93	82478.4	5.2
0.075	1084	57	86763.9	8.8
0.05	1165	81	94399.8	8.3
0.04	1200	35	102260.3	7.7
0.03	1244	44	110151.6	8.2
0.015	1292	48	119169.4	8.3
0.001	1340	48	129094.1	

Following previously established methods and assessment criteria (NAFO, 2019), a kernel density surface was created (Figure 26). The area of successive density polygons was calculated (Table 14). The analysis performed well, and a clear threshold value of 0.75 kg was established (Table 14, Figures 27 and 28), which is higher than the previous threshold of 0.35 kg (NAFO, 2019).

Threshold values increased with new data in the NRA from the 2013 (NAFO, 2013) to 2019 (NAFO, 2019) assessment. The addition of over 1000 records from the Canadian waters further increased the threshold. Table 15 compares the results from the 2019 assessment using data from the NRA only, and this one, while Figure 29 spatially compares the VME polygons established in the NRA under both analyses. The change in VME area in the NRA occurred largely in the edge effects of the 2019 polygons and only some of the isolated single record VME polygons on the Nose and Tail are lost.

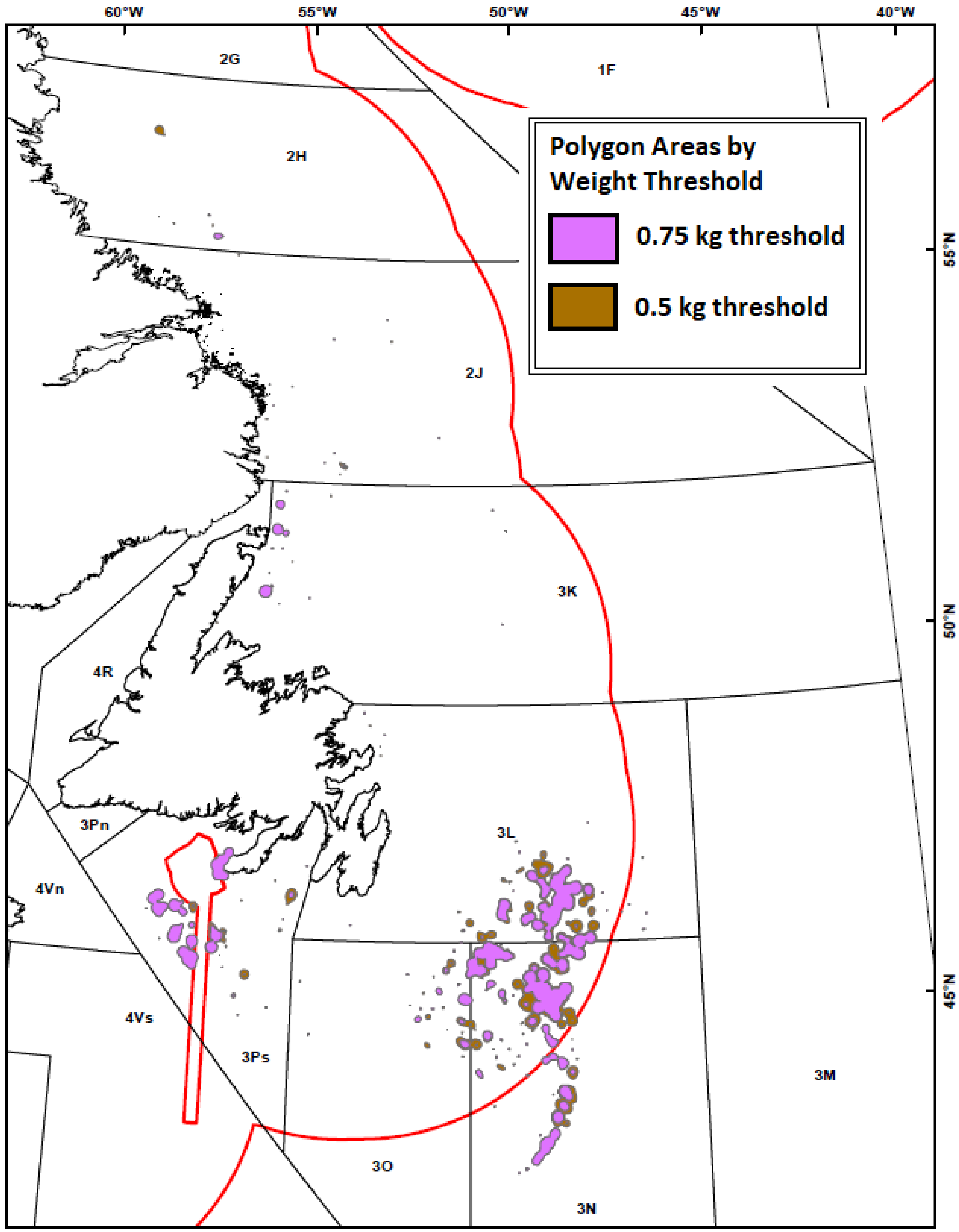

Figure 28. Spatial comparison of the areas covered by *Sea Squirt (Boltenia)* catches ≥ 0.75 and ≥ 0.5 kg; the areas covered by these thresholds are provided in Table 14. Map projection: NAD 83 UTM 22N.

Table 15. Comparison of the results of the KDE and spatial analyses for *Sea Squirts* conducted in 2019 using only data from the NRA and in the present analyses using data from both the NRA and Canadian waters. Shading shows the selection of thresholds from each assessment.

	NRA only (2019)				**NRA and NL (2022)**			
Interval	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km^2)	Points in Polygon	Additional Points Per Interval	Percent Change in Area	Area (km^2)
5	10		45.4	384.7	66		193.7	1557.1
3	22	12	22.3	559.3	131	65	74.0	4572.8
2	36	14	8.0	684.0	187	56	17.1	7956.5
1.5	50	14	152.0	738.6	226	39	63.0	9313.8
1	63	13	11.6	1861.2	317	91	34.3	15185.9
0.75	79	16	48.5	2076.9	384	67	47.1	20402.0
0.5	95	16	27.8	3084.7	500	116	15.0	30020.7
0.4	106	11	3.4	3943.5	558	58	6.6	34526.5
0.35	118	12	47.6	4076.7	597	39	14.5	36814.2
0.3	132	14	0.0	6018.6	648	51	15.5	42158.3
0.25	142	10	15.3	6020.0	708	60	2.8	48685.9
0.23	149	7	0.7	6944.0	733	25	15.3	50071.6
0.2	168	19	0.8	6994.7	794	61	18.1	57716.8
0.15	182	14	8.8	7050.3	886	92	5.3	68138.9
0.125	197	15	0.2	7674.0	934	48	15.0	71734.1
0.1	214	17	4.0	7690.3	1027	93	5.2	82478.4
0.075	235	21	37.1	8001.7	1084	57	8.8	86763.9
0.05	253	18	9.3	10968.9	1165	81	8.3	94399.8
0.04	269	16	1.2	11984.0	1200	35	7.7	102260.3
0.03	292	23	17.6	12127.2	1244	44	8.2	110151.6
0.015	313	21	40.3	14257.5	1292	48	8.3	119169.4
0.001	334	21	45.4	20008.3	1340	48		129094.1

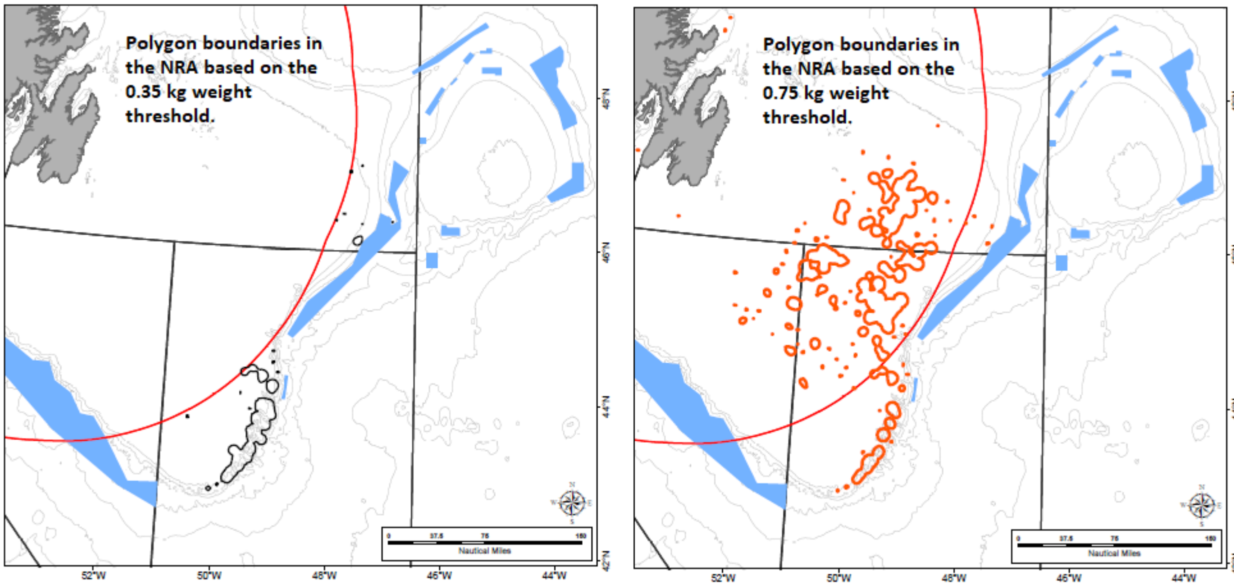

Figure 29. Comparison of the *Sea Squirt (Boltenia)* VME polygons using the previously established threshold 0.35 kg threshold (black outline; NAFO, 2019) and the new 0.75 kg threshold (red outline). Closed areas in place in 2019 are shown with blue shading for comparing with previous work (Kenchington et al., 2019; NAFO, 2019). Map projection: NAD 83 UTM 22N.

Conclusions

Previously, WG ESA compared the stability of the VME polygons in the NRA in their reanalysis conducted in 2019. The differences between 2013 and 2019 were due to additional data collected in the surveys from the NRA (Table 16). In 2013 the fewer data required the search radii in the KDE analyses to be adjusted so that continuous biomass surfaces could be created. However, in 2019 the default parameters (determined from the spatial extent of the data) were used, which in future will create even further stability to the results. For that reason, we retained the KDE parameters used in 2019 in the 2022 analyses. The 2022 analyses did not change the amount of data in the NRA from the 2019 work (Kenchington et al., 2019), but added many more records from Canadian waters for all VME Indicator groups (Table 16). This is especially the case for the *Sea Squirts* where the data used increased by an order of magnitude.

Of the seven VME Indicator groups evaluated, there was no change in the RV catch threshold used to delineate VMEs in three (*Sea Pens*, *Large Gorgonian Corals*, *Erect Bryozoans*). The thresholds were larger for two groups (*Large-sized Sponges*, and *Sea Squirts*) and smaller for two others (*Small Gorgonian Corals* and *Black Corals*).

For the *Large-sized Sponges* and *Sea Squirts* the different thresholds did not translate to large changes in the VME polygons in the NRA. For the sponges only one of the smaller polygons was altered and for the sea squirts some of the small isolated VME polygons around single records were lost. The changes in threshold were largely driven from the distribution in the Canadian waters.

Table 16. Comparison of RV catch thresholds produced from the KDE analyses conducted herein in 2022, and previously in the 2019 and 2013 assessments of the closed areas, by VME indicator group.

VME Indicator	Year of Analyses	Number of Records in Analyses	RV Catch Threshold for Delineating VME polygons	Implications of 2022 Analyses for VME in the NRA
Large-sized Sponge	2022	5449	125 kg	Contracted area for small VME polygon on northern Flemish Cap
Large-sized Sponge	2019	1825*	100 kg	
Large-sized Sponge	2013	1154	75 kg	
Sea Pen	2022	815	1.3 kg	No Change
Sea Pen	2019	430	1.3 kg	
Sea Pen	2013	262	1.4 kg	
Small Gorgonian Coral	2022	421	0.15 kg	Two new areas on the eastern slope of Flemish Cap and connected three smaller VMEs on the slope of the Tail of Grand Bank
Small Gorgonian Coral	2019	218	0.2 kg	
Small Gorgonian Coral	2013	85	0.15 kg	
Large Gorgonian Coral	2022	323	0.6 kg	No Change
Large Gorgonian Coral	2019	89	0.6 kg	
Large Gorgonian Coral	2013	58	0.6 kg	
Erect Bryozoans	2022	391	0.2 kg	No Change
Erect Bryozoans	2019	174	0.2 kg	
Erect Bryozoans	2013	343**	0.2 kg	
Sea Squirts	2022	1340	0.75 kg	Change largely in the edge effects of the 2019 polygons; some of the isolated single record VMEs on the Nose and Tail are lost
Sea Squirts	2019	334	0.35 kg	
Sea Squirts	2013	88	0.3 kg	
Black Coral	2022	62	0.25 kg	Expands one previous VME and creates two new VMEs in Flemish Pass
Black Coral	2019	44	0.4 kg	

*Misreported as 1797 records in Kenchington et al. (2019). **In 2013 the data were only from the EU-Spanish 3NO and 3L surveys (NAFO, 2013) and so no gear catch threshold was applied.

For the *Black Coral* the number of records for the analyses are still small (62 records for the whole of the 2022 study area including the NRA and the Newfoundland and Labrador bioregion). The change in the threshold is not surprising and resulted in increasing a previously identified VME polygon and the creation of two new VMEs all in Flemish Pass. The location of the new VME polygons fit within the predicted distribution of this taxon in the NRA (Kenchington et al., 2019) and so in this case the additional data may have offered useful input to the delineation of VMEs in the NRA. The *Small Gorgonian Coral* threshold calculated in 2022 was the same as that calculated in 2013. There was some discussion of the selection of thresholds for this taxon in 2019 (Kenchington et al., 2019). The threshold that emerged from the 2019 analysis was ≥ 0.2 kg/tow, however there were two new areas on Flemish Cap that emerged with the ≥ 0.15 kg/tow threshold. The procedures for selecting the appropriate threshold would normally have accepted the ≥ 0.15 kg/tow threshold as the analysis was identifying new areas. However, in doing that, the merging of the ≥ 0.2 kg/tow areas on the Tail of Grand Bank based on only a few data points would have resulted. Consequently, in that case WG ESA recommended the ≥ 0.2 kg/tow threshold but highlighted the potential for small gorgonian coral VME habitat on Flemish Cap from the ≥ 0.15 kg/tow threshold. Here we support that assessment with the inclusion of the data from Canadian waters. The new threshold, being lower than the current threshold for identification of VMEs in the

NRA (NAFO, 2019) identified two new areas on the eastern slope of Flemish Cap and connected three smaller VMEs on the slope of the Tail of Grand Bank.

Taken together, the results of the new analyses did not greatly change the delineation of VME polygons in the NRA despite the large increase in data and the inclusion of new environmental spaces (e.g., records from shallower shelf areas). This was not entirely unexpected, although the degree of stability was not anticipated (no change to 3 of the 7 VME Indicator groups). This is because hotspots are identified by the local data neighbourhood. Under similar species compositions and environments, the largest catches would be expected to be similar, as well as the biomass thresholds defining the habitats. Testing that theoretical expectation with empirical evidence provides stronger support for the ecological relevance of the habitats. Additional data within the NRA as seen in the comparison of thresholds between 2013 and 2019, has a greater effect than increasing the geographic coverage because it affects the number of records in the local data neighbourhood. This was shown to be the case especially for those taxa that had low numbers of biomass records (Kenchington et al., 2019).

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