Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2018/015

National Capital Region

Analysis of the overlap between fishing effort and Significant Benthic Areas in Canada's Atlantic and Eastern Arctic marine waters

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March 2018

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Koen-Alonso, M., Favaro, C., Ollerhead, N., Benoît, H., Bourdages, H., Sainte-Marie, B., Treble, M., Hedges, K., Kenchington, E., Lirette, C., King, M., Coffen-Smout, S., and J. Murillo. 2018. Analysis of the overlap between fishing effort and Significant Benthic Areas in Canada's Atlantic and Eastern Arctic marine waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/015. xvii + 270 p.

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ABSTRACT

There are two basic pieces of information required for implementing Fisheries and Oceans Canada's (DFO) Policy on Managing the Impacts of Fishing on Sensitive Benthic Areas:

1. The identification and delineation of Significant Benthic Areas, and
2. The overlap between these Significant Benthic Areas and fishing activities.

This analysis builds on the most recent Significant Benthic Area delineations for Canada's Atlantic (Scotian Shelf –SS-, Gulf of St. Lawrence –GSL-, and Newfoundland-Labrador –NL-) and Eastern Arctic (EA) bioregions to address the overlap question. For this purpose, fisheries were grouped into 14 classes based on their general area of operation, target species, and gears used. Fishing effort was summarized for the 2005-2014 period on the basis of logbook and Vessel Monitoring System (VMS) data. Among all fishing effort recorded in logbooks, 23% of effort was georeferenced; however, most of the non-georeferenced effort was associated with the lobster fisheries class in inshore shallow areas, often in the Gulf of St. Lawrence. The analysis of all fishing effort from logbooks, indicated that GSL and SS experienced average total fishing effort densities (in units of vessel days –VD-) of 0.849 and 0.311 VD $km^{-2}\,yr^{-1}$ respectively, while NL and EA showed much lower values of 0.074 VD $km^{-2}\,yr^{-1}$ and 0.001 VD $km^{-2}\,yr^{-1}$ respectively. Georeferenced effort data was used to estimate footprints by fisheries classes, as well as for aggregates of fisheries classes (e.g. mobile gears, fixed gears, all fisheries). Overall, the spatial distributions indicated that, even though fishing footprints could be large, most of the effort was concentrated in relatively small fractions of the entire footprint. High fractions (~40-80%) of the Significant Benthic Areas, for all types present in SS, GSL, and NL bioregions, were exposed to fishing activities. In EA, the fraction of Significant Benthic Areas exposed to fishing activities was low (<10%). Significant Benthic Areas typically represented a small fraction (<10%) of the fisheries footprints in all bioregions. Although this analysis only describes the state of affairs in recent years, after the collapse of major groundfish fisheries in these bioregions, the estimated overlap between fishing effort and Significant Benthic Areas appears high enough to expect that they are likely being impacted by fishing activities. The extent and magnitude of these impacts will be a function of the indicator taxa involved, the level of perturbation, and the role of these Significant Benthic Areas in the overall ecosystem functioning.

Analyse du recoupement entre l'effort de pêche et les zones benthiques importantes dans les eaux marines canadiennes de l'Atlantique et de l'Arctique de l'Est

RÉSUMÉ

Deux renseignements de base sont requis pour la mise en œuvre de la politique de Pêches et Océans Canada (MPO) sur la gestion des impacts de la pêche sur les zones benthiques vulnérables :

1. La détermination et la délimitation des zones benthiques importantes;
2. Le recoupement entre ces zones benthiques importantes et les activités de pêche.

Cette analyse repose sur les délimitations les plus récentes des zones benthiques importantes de l'Atlantique canadien (plateau néo-écossais, golfe du Saint-Laurent et Terre-Neuve-et-Labrador) et les biorégions de l'Arctique de l'Est choisies pour répondre à la question du recoupement. Dans cette optique, les pêches ont été regroupées en 14 catégories, en fonction de leur secteur d'exploitation général, des espèces ciblées et des engins utilisés. On a compilé l'effort de pêche pour la période 2005-2014, en se basant sur les journaux de bord et les données du Système de surveillance des navires (SSN). De tous les efforts de pêche consignés dans les journaux de bord, 23 % ont été géoréférencés. La plupart des efforts non géoréférencés étaient associés à la catégorie des pêches au homard des zones côtières peu profondes, principalement celles du golfe du Saint-Laurent. L'analyse de tous les efforts de pêche consignés dans les journaux de bord indiquait que le golfe du Saint-Laurent et le plateau néo-écossais ont connu des densités totales moyennes (en unités de jour-navire [JN]) respectives de 0,849 et 0,311 JN/km-2/année-1, tandis que Terre-Neuve-et-Labrador et l'Arctique de l'Est affichaient des valeurs beaucoup moins élevées : 0,074 et 0,001 JN/km-2/année-1, respectivement. Les données des efforts géoréférencés ont été utilisées pour estimer les empreintes par catégories de pêches, ainsi que les agrégats des catégories (p. ex., engins mobiles, engins fixes, toutes les pêches). Dans l'ensemble, les répartitions spatiales indiquaient que, bien que les empreintes de la pêche pussent être vastes, la plupart des efforts étaient concentrés dans des parcelles relativement petites de l'ensemble de l'empreinte. Un pourcentage élevé (~40-80 %) des zones benthiques importantes a été exposé à des activités de pêche, et ce, pour tous les types présents dans les biorégions du plateau néo-écossais, du golfe du Saint-Laurent et de Terre-Neuve-et-Labrador. Dans l'Arctique de l'Est, le pourcentage de zones benthiques importantes exposées aux activités de pêche était faible (<10 %). Les zones benthiques importantes représentaient généralement un faible pourcentage (<10 %) des empreintes des pêches, et ce, dans toutes les biorégions. Bien que cette analyse décrive seulement la situation des dernières années, après l'effondrement des principales pêches du poisson de fond dans ces biorégions, le recoupement estimé entre l'effort de pêche et les zones benthiques importantes semble suffisamment élevé pour s'attendre à ce que les activités de pêche aient bel et bien un impact sur les zones. L'étendue et l'ampleur de ces impacts constitueront une fonction des taxons indicateurs impliqués, du niveau de perturbation et du rôle de ces zones benthiques importantes dans le fonctionnement global de l'écosystème.

INTRODUCTION

The implementation of Ecosystem Approaches to Fisheries requires, among other elements, the consideration of the impacts of fishing on non-target components of the ecosystem (e.g. NAFO 2010, 2011, 2012a, 2012b, 2013). Considerable attention has been put on benthic taxa, like cold-water corals and sponges, which are particularly vulnerable to impacts by fishing gear (by direct damage from physical contact and indirect damage from smothering), while having low recovery potential due to their life history characteristics (Sherwood and Edinger 2009, Boutillier et al. 2010, DFO 2010b, Buhl-Mortensen et al. 2016). These taxa provide structural complexity required for the formation of well-defined, spatially heterogeneous, benthic habitats (DFO 2006, 2010a, 2010b, 2015, 2017).

Over the last decade, and in no small part driven by international calls for the protection of high seas ecosystems (United Nations General Assembly Resolution 61/105; UN 2006), a significant international effort has been devoted to the delineation and protection of these types of vulnerable habitats, broadly described as Vulnerable Marine Ecosystems (VMEs), in waters beyond national jurisdictions. The Food and Agriculture Organization (FAO), has guided these efforts through the development of its “International Guidelines for the Management of Deep-sea Fisheries in the High Seas” (FAO 2009).

In the northwest Atlantic, the Northwest Atlantic Fisheries Organization (NAFO) has delineated VMEs within the NAFO Regulatory Area, and implemented a number of closures to bottom fishing activities to protect these areas from the impacts of bottom contacting gears. The protection provided by these closures is complemented by: the definition of the NAFO Fishing Footprint, the implementation of an exploratory fishing protocol for any bottom fishing activity outside the NAFO Fishing Footprint (which requires prior approval by NAFO before it can be entertained), and the closure to fishing of most seamounts within the NAFO Regulatory Area (NAFO 2016).

The progress made by NAFO towards protecting VMEs in the NAFO Regulatory Area has been underpinned by analyses on two basic topics, the identification and delineation of VMEs, and the mapping of fishing effort to begin assessing the potential impacts of fishing on those vulnerable habitats. These analyses provided the necessary basis for the discussion of management options, which eventually led to the suite of measures implemented today.

In Canadian waters, and within the umbrella provided by the Sustainable Fisheries Framework, Fisheries and Oceans Canada (DFO) adopted its Policy on Managing the Impacts of Fishing on Sensitive Benthic Areas (hereafter “Sensitive Benthic Areas Policy”) in 2009. However, to date, broad implementation of this policy is still pending. In March 2016, a Canadian Science Advisory Secretariat review process was conducted to identify Significant Benthic Areas in Canada’s Atlantic and Eastern Arctic waters (DFO 2017). Significant Benthic Areas are defined in DFO’s Ecological Risk Assessment Framework as “significant areas of cold-water corals and sponge dominated communities”, where significance is determined “through guidance provided by DFO-lead processes based on current knowledge of such species, communities and ecosystems” (DFO 2013). As per the Sensitive Benthic Areas Policy (DFO 2009), a Sensitive Benthic Area is defined as an area that is vulnerable to a proposed or ongoing fishing activity. For the purposes of this analysis, a Sensitive Benthic Area is a Significant Benthic Area that is vulnerable to a proposed or ongoing fishing activity.

Considering the aforementioned NAFO experience, the requirements identified in DFO guidance documents for implementing the Sensitive Benthic Areas Policy, the “Ecological Risk Assessment Framework for cold-water corals and sponge dominated communities” (DFO 2013), and the “Guidance for Implementation of the Policy for Managing the Impacts of Fishing on

Sensitive Benthic Areas" (DFO 2014), it is clear that the discussion of management options for implementing the Sensitive Benthic Areas Policy requires an assessment of how fishing activities potentially impact Significant Benthic Areas. A first step towards developing this knowledge is to understand to what extent fishing activities overlap with these areas. Since multiple fisheries may operate in the same area, the net impact on a given Significant Benthic Area will result from the cumulative effects from all fisheries interacting within it. This implies that both the assessment of the impact and the management actions implemented to minimize it, would be best served by an integrated fisheries approach instead of multiple, independent single-fishery approaches.

Therefore, the objectives of this study are to:

1. Provide a synoptic description of the distribution of fishing effort in Canada's Atlantic and Eastern Arctic waters
2. Provide an initial evaluation of the overlap between fishing effort and Significant Benthic Areas, and
3. Based on the results of the overlap analysis, identify areas of potential conservation concern.

METHODS

STUDY AREA

The study areas for this analysis are Canada's Atlantic and Eastern Arctic waters, which correspond to the following major Canadian bioregions (DFO 2009):

- Scotian Shelf (SS) bioregion (476,000 km^2)
- Gulf of St. Lawrence (GSL) bioregion (235,000 km^2)
- Newfoundland and Labrador (NL) bioregion (1,011,000 km^2)
- Eastern Arctic (EA) bioregion (627,000 km^2)

Taking into account that boundaries between bioregions are typically vague and represent transitional zones (DFO 2009), for the purpose of this study, bioregions were defined on the basis of the corresponding NAFO Divisions up to the limit of the 200-mile Canadian jurisdictional zone. In this study, the Scotian Shelf bioregion is defined by NAFO Divisions 4VnVsWX and 5YZe, the Gulf of St. Lawrence is defined by NAFO Divisions 4RST, Newfoundland and Labrador is defined by NAFO Divisions 2GHJ and 3KLNOPnPs, and Eastern Arctic is defined by NAFO Divisions 0AB (Figure 1). Some Significant Benthic Areas may straddle bioregions; however, the separation of fishing effort and Significant Benthic Areas into these categories allows identification of the administrative region that exerts the relevant fishing effort. Overall, these categories respect the broad bioregional identities in DFO (2009).

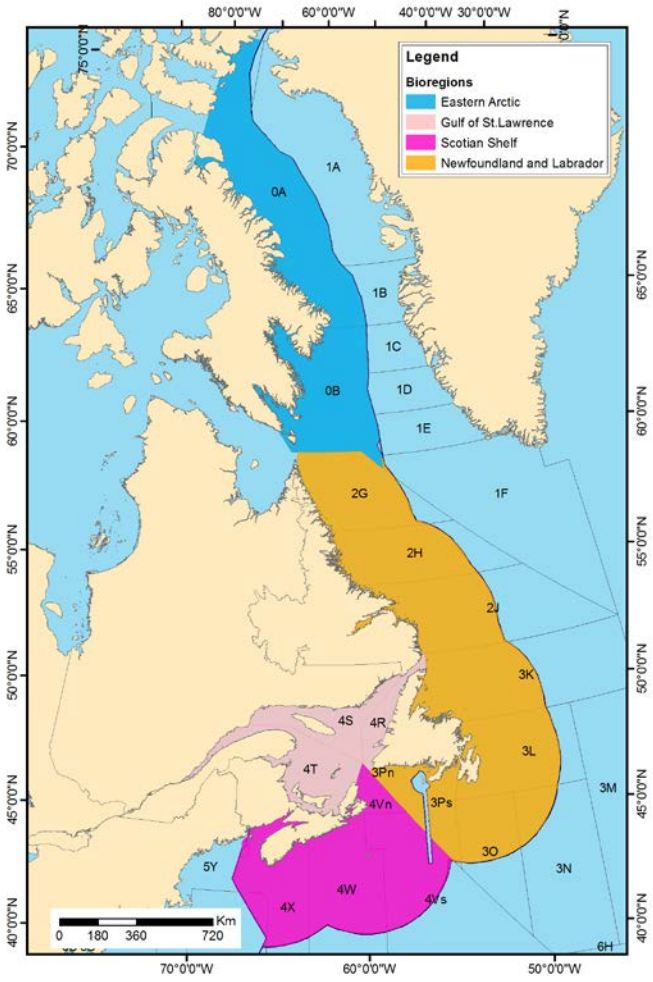

Figure 1. The Scotian Shelf (SS), Gulf of St. Lawrence (GSL), Newfoundland and Labrador (NL), and Eastern Arctic (EA) bioregions as considered in this study.

DELINEATION OF SIGNIFICANT BENTHIC AREAS

Initially, Kenchington et al. (2010) used kernel density estimation to provide guidance on location and extent of significant concentrations of corals and sponges. This methodology (Kenchington et al. 2014) was also used by NAFO for the delineation of VMEs and adopted by NAFO Scientific Council as the primary tool to quantitatively determine VMEs (NAFO 2014).

NAFO Scientific Council, in following the FAO “International Guidelines for the Management of Deep-sea Fisheries in the High Seas” (FAO 2009), and under the structure-forming criterion of the FAO guidelines, defined VME as “a regional habitat that contains VME indicator species at or above significant concentration levels. These habitats are structurally complex, characterized by higher diversities and/or different benthic communities, and provide a platform for ecosystem functions/processes closely linked to these characteristics”.

Given the similarities between the Significant Benthic Area and VME definitions, as well as the primary method used to quantitatively delineate them, it logically follows that Significant Benthic Area and VMEs are equivalent concepts as they pertain to cold-water corals and sponges. Explicitly recognizing this parallelism is important, because it provides a common basis for developing integrated, consistent, and coherent approaches to management when these

significant benthic communities straddle boundaries between domestic and international waters. It also allows for a direct application of the tools and knowledge developed for VMEs to the management of Significant Benthic Areas.

The Significant Benthic Areas considered in this analysis correspond to the polygons identified by DFO (2017). These polygons were defined by integrating results from kernel density estimation analyses and species distribution models (Kenchington et al. 2016), and represent the most updated delineation of existing benthic habitats defined by the aggregations of vulnerable cold-water corals and sponges, superseding previous exercises on this topic (DFO 2017).

CHARACTERIZATION OF FISHING EFFORT

The distribution and intensity of fishing effort during the period 2005-2014 was estimated on the basis of two data sources: logbook information and Vessel Monitoring System (VMS) data. Logbooks are records that are filled out by all fishers during fishing trips and contain details on the vessel, effort, catch characteristics, and in some fisheries, geographic position for location of fishing effort. VMS data contains geographic position information that is transmitted automatically at regular intervals via satellite from units on fishing vessels to a DFO office in Québec or Atlantic Canada. While VMS data is typically used for enforcement purposes, in some cases it can be made available for scientific studies. On its own, VMS data does not contain direct information on fishing activities (e.g. directed species, gear type, etc.), but these attributes can be extracted from corresponding logbook records (Appendix 1). The data from VMS provides high resolution positions recorded at higher frequencies when compared to logbook reporting. However, only some fisheries are part of the VMS system, and VMS implementation varies by region, gear type, target species and vessel size.

Because gear impacts from different fisheries vary greatly, effort was grouped into categories with similar gears and fishing behaviours. Specifically, fisheries classes were defined on the basis of target species/group, general areas of operation, and fishing gear, where major distinctions between mobile and fixed gears were considered. In defining fisheries classes, the emphasis was put on capturing key features that were deemed informative for understanding the potential impact of fishing on Significant Benthic Areas, instead of precisely identifying regulatory classifications.

A total of 13 fisheries classes were defined (Table 1). Full combinations of gear codes and species codes in each fishery class are provided in Appendix 1. Some of these classes correspond to single fisheries (e.g. shrimp), while others represent aggregates of fisheries sharing some common, general feature (e.g. pelagic). These 13 fisheries classes encompassed 98% of all the fishing effort recorded in fisheries logbooks across Canada's Atlantic and Eastern Arctic. The remaining 2% was grouped in a single fisheries class labelled "Other". The "Other" class includes records that did not match the criteria to be assigned to any of the other 13 classes defined.

*Table 1. Fisheries classes defined for the analysis of overlap between fishing effort and Significant Benthic Areas. *"Other" includes combinations of fishing effort with traps targeting pelagic species, and/or gear and species that are unspecified or likely erroneous – e.g. bottom trawl directed at a pelagic species, etc.*

Label	Location	Gear Category	Gears	Taxa
Groundfish Mobile	Offshore	Mobile	Trawls, bottom seines	Groundfish
Shrimp	Offshore	Mobile	Trawls	Shrimp
Scallop	Inshore	Mobile	Dredge	Scallop
Clam	Inshore	Mobile	Dredge, hydraulic device	Clams, oyster, whelks, cockles
Echinoderm	Inshore	Mobile	Dredge, drag	Urchins, sea cucumber
Groundfish Fixed	Offshore	Fixed	Gillnet, longline, handline, pots	Groundfish
Crab Offshore	Offshore	Fixed	Traps, pots	Snow crab, stone/king crab
Miscellaneous Offshore	Offshore	Fixed	Hagfish barrel, pots, traps	Hagfish, shrimp
Lobster	Mostly Inshore	Fixed	Pots	Lobster
Crab Inshore	Inshore	Fixed	Traps, pots	Crabs excluding snow crab and stone/king crab
Whelk	Inshore	Fixed	Traps, pots	Whelks
Miscellaneous Inshore	Inshore	Fixed	Eelpot, drag rake, rakes and tongs, fyke net, weir, diving, hand dredge, hand tools, miscellaneous gears	Groundfish, eel, clam, seaweeds, macroalgae, urchins, sea cucumber, oyster, mussel, lobster
Pelagic	Pelagic	Fixed & Mobile	midwater trawls, seines, gillnets, longline, jiggers, trolling, rod and reel, handline, harpoon, seal hunting	Pelagics, squid, seals
Other*	Inshore, offshore and pelagic	Fixed & Mobile	Unspecified gears, traps targeting a pelagic species	Unspecified species, pelagics

For each of the fishery classes, logbook reporting and VMS requirements varied, which influenced data availability for high resolution maps. At a minimum, all records in the fisheries logbooks have a statistical unit area associated with them. These statistical units correspond to polygons that define the NAFO Subdivision level. This level of resolution provides a general location for 100% of the fishing effort exerted in Canada's Atlantic and Eastern Arctic, but that level of resolution is too coarse to allow a detailed examination of the overlap between fishing effort and Significant Benthic Areas because the Subdivisions can be larger than individual Significant Benthic Area units. Sometimes logbook records are georeferenced, i.e. they report geographic position data (latitude and longitude) of the fishing operations, so those records can be mapped as a point location. However, because geographic coordinates in logbooks can be recorded by hand, in some cases they do not have sufficient resolution (i.e. not enough significant digits recorded) to allow for fine resolution mapping of the effort. As well, compared to VMS positions, they are more prone to error (misreading or misreporting by boat operator) or geographical imprecision (time lag between recording of position and actual fishing activity). Finally, some fisheries have VMS reporting requirements enabling the high resolution positional information to be joined with logbook information and produce highly accurate mapping of the effort. Therefore, in order to properly evaluate the overlap between fishing effort and Significant Benthic Areas, it is important to understand which fraction of the effort can be effectively mapped, as well as which fraction of the effort cannot be precisely or fully represented in a map.

Given the diversity of gears and modes of operation, the unit of effort considered for logbook data (when no VMS data was available) was the vessel-day (VD). This means that one fishing location in logbooks is displayed for a given vessel-day of fishing. This allows the comparison of fishing intensity across fisheries and vessels, which have different reporting requirements. That is, some logbooks report fishing locations once per day and others report locations multiple times per day. For all vessel-days with more than one set per day, the median distance between set locations was 7.9 km (interquartile range=3.1-16.3). In this analysis, vessels with different reporting requirements may be grouped in the same "fisheries class". Therefore, for those vessels that report more than one location per day in their logbook, one of those locations was randomly selected and assigned to that day. This procedure ensures that multiple positions from high-frequency reporting vessels do not over-contribute to the overall logbook effort.

Using VD allows for general comparisons across fisheries classes, but since these fisheries classes have different gears and modes of operation, the actual footprint of a single fishing event would necessarily be different among them (e.g. a single line of pots or traps does not have the same footprint/impact on the bottom than a single trawl-set). Therefore, this effort characterization only provides an approximation of the local neighbourhood affected by each individual fishing operation.

For VMS data, effort is expressed as hours fished where fishing effort was calculated as the sum of intervals for VMS points that were deemed to be "fishing points" (see Appendix 1 for details).

Where georeferenced data from logbooks and VMS were available, the footprint of fisheries classes was estimated by plotting fishing locations on a 1 km x 1 km grid, and the intensity of the fishing effort was calculated by the cumulated number of fishing observations within each cell of the grid. This allows defining the areal extent of the fishing operations, the footprint, and the intensity of use of different regions within that footprint. Depending on the data source, fishing footprints defined in this way may present a checkerboard pattern, where some cells in the grid within the general geographical area of the footprint are empty, while neighbouring cells concentrate fishing effort. This does not impact the ability to visually delineate the general footprint area in a map; however it does impact the calculated areal extent of the footprint, because in these cases the estimated footprint area is an underestimate of the actual value.

Statistical techniques (e.g. spatial averaging/smoothing) can be used to correct for these effects; however given the different resolution of geographic position data from the two sources (logbooks vs VMS), it was considered more useful to minimize data manipulation and show basic effort data from these sources independently.

For comparative purposes, fishing activity for each bioregion was standardized by converting fishing intensities to percentiles using VDs for logbooks, and hours fished per unit area for VMS. Percentiles based on areas with non-zero effort were calculated by summing the total effort a given fishery exerted in each grid cell, ranking cells by descending effort, and calculating the cumulative percentage of the total effort of the entire fishery (Figure 2). The cells were then categorized into 20-percentile bins of fishing activity. The 20th percentile bin represents the area where the most intense fishing occurred and the 100th percentile bin represents the area where the least amount of activity occurred. This procedure identified concentrations of fishing activities and provided standardization across data sources (logbooks and VMS) thereby allowing their integration.

1. *Tabulate effort per cell*

Cell	Effort (hours)
1	5.4
2	1.1
3	9.8
4	7.8
5	8.3
6	0.7
7	12.9
8	8.5
9	3.8
10	4.9
11	6.5
12	4.6
13	22.6
14	14.5
15	0.6
16	1.5
17	13.8
18	13.2
19	5.3
20	9.4
Total	155.2

→

2. *Sort by descending effort*

3. *Calculate effort as % of total, and calculate cumulative %*

4. *Group cumulated percentages into bins of 20*

Cell	Effort (hours)	Effort (%)	Cumulated effort (%)	Percentile bin
13	22.6	14.6	14.6	Top 20
14	14.5	9.4	23.9	20.1 - 40
17	13.8	8.9	32.8	20.1 - 40
18	13.2	8.5	41.3	40.1 - 60
7	12.9	8.3	49.7	40.1 - 60
3	9.8	6.3	56.0	40.1 - 60
20	9.4	6.1	62.1	60.1 - 80
8	8.5	5.5	67.6	60.1 - 80
5	8.3	5.3	72.9	60.1 - 80
4	7.8	5.0	77.9	60.1 - 80
11	6.5	4.2	82.1	80.1 - 100
1	5.4	3.5	85.6	80.1 - 100
19	5.3	3.4	89.0	80.1 - 100
10	4.9	3.1	92.1	80.1 - 100
12	4.6	3.0	95.1	80.1 - 100
9	3.8	2.4	97.5	80.1 - 100
16	1.5	0.9	98.4	80.1 - 100
2	1.1	0.7	99.1	80.1 - 100
6	0.7	0.5	99.6	80.1 - 100
15	0.6	0.4	100.0	80.1 - 100

Decreasing effort intensity

Figure 2. Schematic of steps used to classify grid cells into bins of fishing effort intensity. The top 20th percentile bin represents the cells with the most intense fishing activities and the 80th percentile bin (labelled "80.1-100") represents the cells with the least intense fishing.

If data from logbooks and VMS represent reasonable random samples of the same underlying fishing effort distribution, the percentile of effort within which a given cell in the grid falls would be expected to be the same regardless of the data source considered. If this statement holds, it follows that, when expressed in percentiles of effort, the distributions of effort from both sources could be merged to produce an integrated effort map.

Since the standardization into percentiles is done independently for each data source, the percentile assignations for a given cell are also independent. Therefore, by selecting those grid cells that have both logbook and VMS data, and identifying to which effort percentile those cells have been assigned to by data source, it is possible to construct percentile distributions for each data source and test if those distributions are statistically different or not. If differences are not significant, the percentile effort maps from logbooks and VMS can be merged without distorting the effort picture. The benefit of this merger is that it allows presentation of a single effort map of the full extent and intensity of the spatially resolved effort. These tests were carried out as described in Appendix 1. The resulting merged effort maps were used for displaying fishing overlaps with Significant Benthic Areas.

Whenever possible, logbook and VMS data were merged to produce maps of fishing locations by fisheries classes (Table 1). In cases where the fisheries classes involved vessels without VMS, analysis was based on logbooks only (details on the processing of logbook and VMS data are provided in Appendix 1). In some cases, logbooks only report statistical unit areas of operation, which prevented high resolution mapping of those fisheries classes.

Taking into account the areal extent of these bioregions, the average density of fishing effort was expressed as VD $km^{-2}\,yr^{-1}$. From a more focused benthic impacts perspective, these average effort densities were calculated excluding the pelagic fisheries class. These average fishing effort densities can be related by considering their inverse value, which corresponds to the average number of years that it would take for any a given km^2 to be subject to a VD of fishing effort, given the magnitude of the effort exerted in the 2005-2014 period, and assuming homogenous distribution of effort.

The type of characterization of effort in this study is focused on the use of space, and provides no direct information on productivity or socio-economic dimensions of the fishing activities.

OVERLAP BETWEEN SIGNIFICANT BENTHIC AREAS AND FISHING ACTIVITIES

Within each bioregion, overlap between Significant Benthic Areas and fishing activities (i.e. fishing effort) was evaluated in two ways, from the fishing activity perspective and the Significant Benthic Area perspective. These calculations included:

- % of footprint inside Significant Benthic Areas
- % of Significant Benthic Area being fished

These analyses were conducted for logbook and VMS data independently, as well as using a combined logbook/VMS effort layer (see details in Appendix 1). In those cases where VMS coverage is high, fishing footprint and overlap using VMS data is considered a better estimate for these indices than those calculated from logbooks.

When examining overlaps between Significant Benthic Areas and fishing effort, it is essential to remember that a large fraction of the effort for some fisheries classes is not georeferenced. The overlaps presented and discussed here only capture the fraction of fishing effort that can be associated with a geographic position. Interpreting these maps without keeping in mind this fundamental shortcoming could lead to erroneous conclusions.

The results of these analyses were used to identify areas of potential conservation concern.

RESULTS

FISHERIES CLASSES AND FISHING EFFORT

Overall, 23% of the total fishing effort recorded in logbooks was georeferenced (i.e. logbooks with recorded latitudes and longitudes and/or VMS data). When the distribution of fishing effort at the statistical unit scale is compared with the distribution of non-georeferenced effort (Figure 3), it becomes clear that the lack of georeferenced data is mostly associated with effort taking place in inshore areas and in the southern GSL. Most of the effort without georeferenced data is associated with the lobster fisheries class (Figure 4, Table 2).

Across the entire study area, most of the effort is associated with the lobster fishery class (58%), while the top seven fisheries classes (Lobster: 58%, Groundfish Fixed: 11%, Crab Offshore: 7%, Pelagic: 6%, Scallop: 5%, Shrimp: 4%, and Groundfish Mobile: 2%) accounted for 93% of the total effort (Figure 4, Table 2).

Fishing effort is unevenly distributed across bioregions; GSL and SS concentrate 82% of the total fishing effort (46% and 36% respectively), NL represents 17%, while EA accumulates less than 1%. Another difference among bioregions is the number of high effort (nominally defined as > 50,000 VD) fisheries classes; GSL has the highest number of high effort fisheries classes (n=8), while SS and NL both have lower numbers (n=5 each), while all EA fisheries classes have less than 50,000 VD. These differences are relevant not just in terms of the potential diversity of impacts on Significant Benthic Areas associated with multiple high effort fisheries, but also speak about the potentially higher complexity of the regulatory framework required to address these impacts.

The average density of fishing effort is 0.849 and 0.311 VD $km^{-2}\,yr^{-1}$ for GSL and SS respectively, the average effort density for NL is one order of magnitude lower (0.074 VD $km^{-2}\,yr^{-1}$), and the EA average effort density is yet one order of magnitude lower than NL (0.001 VD $km^{-2}\,yr^{-1}$).

For more focus on benthic impacts, these average effort densities can be calculated excluding the pelagic fisheries class, and limiting the area considered to waters shallower than 1,500 m, where bottom contacting gears are effectively used. Under these considerations, the average density of bottom-contacting gear effort is 0.789 and 0.589 VD $km^{-2}\,yr^{-1}$ for GSL and SS respectively, 0.097 VD $km^{-2}\,yr^{-1}$ for NL, and 0.001 VD $km^{-2}\,yr^{-1}$ for EA. Focusing on the non-pelagic fishing effort in waters shallower than 1500 m, every km^2 would be subject to one VD of fishing effort every 1.3 years in GSL, 1.7 years in SS, 10.3 years in NL, and 614.8 years in EA.

These simple calculations provide a general indication of where fishing impacts on benthic communities could be expected to be higher. Other things being equal, and if the observed effort levels from bottom contacting gears where high enough to affect functionality of benthic communities, these impacts would be expected to be highest in GSL, closely followed by SS; NL would show some intermediate level of impact, while EA would show the least amount of impact.

Although these figures may provide an initial indication of the difference in the scale of potential impacts across bioregions, actual impacts will depend of the types of gear used, spatial distribution and concentration of effort, and role of the impacted benthic communities on overall ecosystem functions, among other factors. Exploring the potential effects of fishing on the ecosystem function of benthic communities is beyond the scope of this analysis, but this general background of a potential cline of fishing impacts on ecosystems across these bioregions may help us understand the overall context for potential impacts of fishing on Significant Benthic Areas.

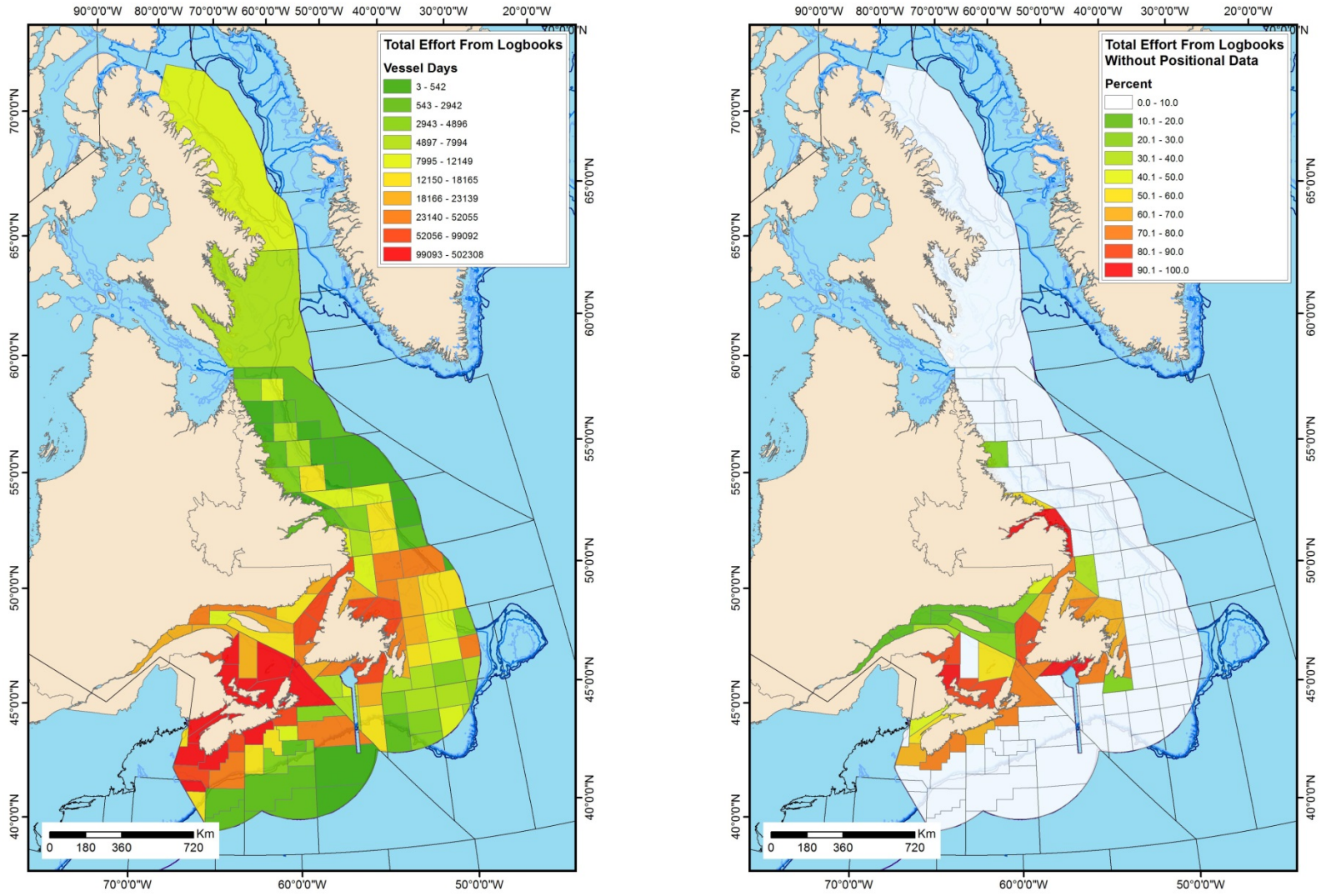

Figure 3. Distribution of fishing effort (vessel-days) by statistical unit area in Canada's Atlantic and Eastern Arctic waters in 2005-2014. Left: Total fishing effort, right: fraction of non-georeferenced fishing effort in each statistical unit area.

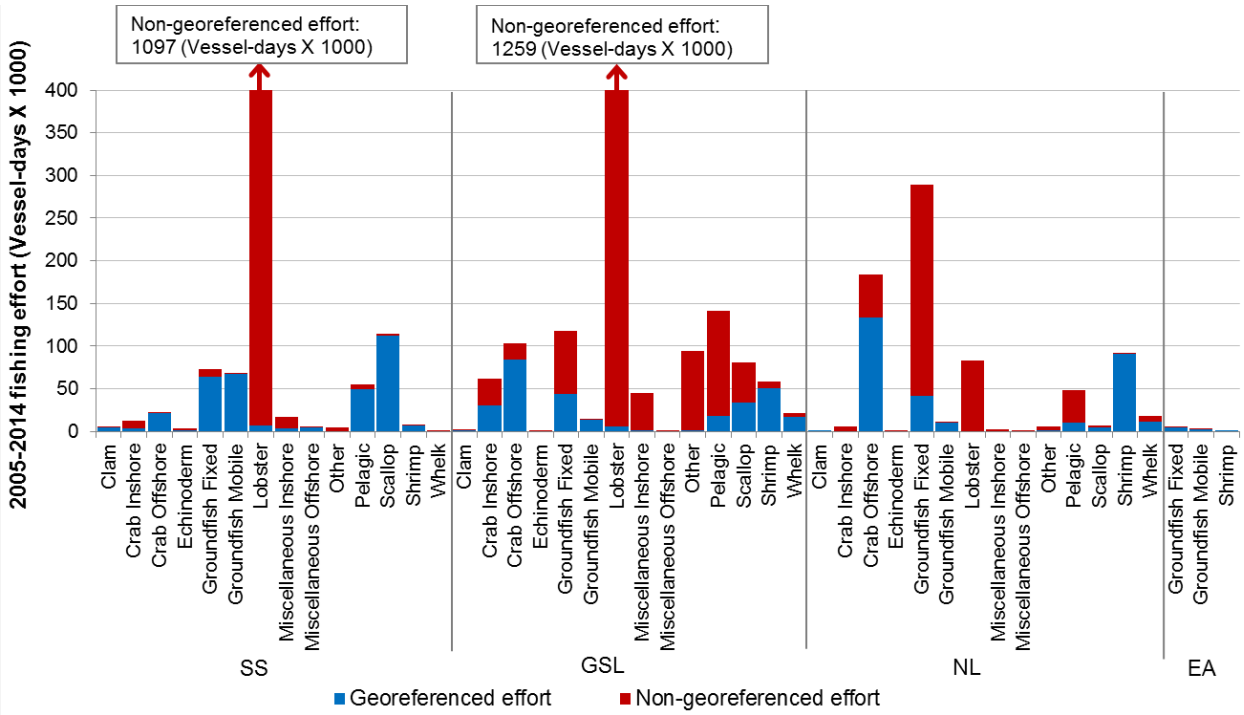

Figure 4. Distribution of logbook fishing effort from 2005-2014 by fisheries class and bioregion, with indication of amount of georeferenced and non-georeferenced data. SS: Scotian Shelf, GSL: Gulf of St. Lawrence, NL: Newfoundland-Labrador Shelf, EA: Eastern Arctic.

Table 2. General fishing effort information from logbooks by bioregion and fisheries class in the period 2005-2014. SS: Scotian Shelf, GSL: Gulf of St. Lawrence, NL: Newfoundland-Labrador Shelf, EA: Eastern Arctic. LOA: length over all, NA: not applicable. Effort in bioregion (%) is the percentage of a given fisheries class effort of total effort in that bioregion. Georeferenced effort (%) is the percentage of effort from a given fisheries class with geographic position data (latitudes and longitudes). All effort has a statistical unit area reported, but not all effort has geographic position data. Note: Eastern Arctic vessels do not report vessel LOA.

Bio-region	Fisheries class	Total fishing effort (VD)	Unique vessels (n)	Vessel LOA (ft)	NAFO areas reported	Effort in bioregion (%)	Geo-referenced (%)
SS	Lobster	1,103,874	3,737	<=141	4VnVsWX 5YZe	74.08	0.60
SS	Scallop	114,609	459	<=146	4VnVsWX 5YZe	7.69	97.73
SS	Groundfish Fixed	73,193	1,260	<=111	4VnVsWX 5YZe	4.91	87.47
SS	Groundfish Mobile	68,029	200	<=222	4VnVsWX 5YZe	4.57	99.23
SS	Pelagic	54,482	994	<=125	4VnVsWX 5YZe	3.66	91.17
SS	Crab Offshore	22,290	360	<=64	4VnVsWX	1.50	97.05
SS	Misc. Inshore	16,916	165	<=82	4VnVsWX 5YZe	1.14	19.81
SS	Crab Inshore	12,019	500	<=124	4VnVsWX 5YZe	0.81	28.20
SS	Shrimp	6,499	68	34-229	4VnVsWX	0.44	97.77

Table 2. Continued.

Bio-region	Fisheries class	Total fishing effort (VD)	Unique vessels (n)	Vessel LOA (ft)	NAFO areas reported	Effort in bioregion (%)	Geo-referenced (%)
SS	Misc. Offshore	5,490	63	24-50	4VnVsWX 5Ze	0.37	89.11
SS	Clam	5,092	8	44-229	4VnVsWX	0.34	99.71
SS	Other	4,121	594	<=135	4VnVsWX 5YZe	0.28	15.09
SS	Echinoderm	3,512	58	16-64	4VsWX 5Y	0.24	47.01
SS	Whelk	81	8	39-78	4VnVsWX	0.01	96.30
SS	All Fisheries	1,490,207	4,540	<=229	4VnVsWX 5YZe	100	23.28
GSL	Lobster	1,264,784	4,857	<=65	4RST	63.05	0.43
GSL	Pelagic	141,491	4,091	<=165	4RST	7.05	13.04
GSL	Groundfish Fixed	117,541	2,783	<=79	4RST	5.86	37.64
GSL	Crab Offshore	103,156	1,480	<=90	4RST	5.14	81.11
GSL	Other	93,722	2,239	<=86	4RST	4.67	1.33
GSL	Scallop	80,389	553	<=64	4RST	4.01	41.40
GSL	Crab Inshore	61,957	1,457	<=65	4RST	3.09	48.70
GSL	Shrimp	58,053	186	<=93	4RST	2.89	87.75
GSL	Misc. Inshore	44,968	1,644	<=49	4RST	2.24	1.91
GSL	Whelk	21,345	269	<=49	4RST	1.06	77.02
GSL	Groundfish Mobile	15,017	257	<=159	4RST	0.75	87.88
GSL	Clam	2,493	25	<=49	4RST	0.12	64.74
GSL	Echinoderm	957	11	32-59	4RST	0.05	56.84
GSL	Misc. Offshore	36	5	32-44	4ST	<0.01	5.56
GSL	All Fisheries	2,005,909	7,994	<=165	4RST	100	14.96
NL	Groundfish Fixed	289,303	5,792	<=156	2GHJ 3KLNOPnPs	38.68	14.30
NL	Crab Offshore	184,247	2,733	<=104	2GHJ 3KLNOPnPs	24.63	72.57
NL	Shrimp	92,291	427	<=243	2GHJ 3KLNPs	12.34	98.83
NL	Lobster	83,209	2,231	<=59	3KLNPs	11.13	NA
NL	Pelagic	48,103	3,818	<=114	2GHJ 3KLNOPnPs	6.43	22.00
NL	Whelk	17,535	372	17-64	2J 3KLPs	2.34	63.57
NL	Groundfish Mobile	9,971	99	<=231	2GHJ 3KLNOPnPs	1.33	98.46
NL	Scallop	6,637	217	<=134	2HJ 3KLNOPs	0.89	75.44
NL	Other	6,207	792	<=127	2HJ 3KLNOPnPs	0.83	11.20

Table 2. Continued.

Bio-region	Fisheries class	Total fishing effort (VD)	Unique vessels (n)	Vessel LOA (ft)	NAFO areas reported	Effort in bioregion (%)	Geo-referenced (%)
NL	Crab Inshore	6,194	234	16-60	2J 3KLPs	0.83	0.55
NL	Misc. Inshore	2,799	119	<=62	2J 3KLPnPs	0.37	0.18
NL	Clam	610	4	53-220	3LNOPs	0.08	100
NL	Misc. Offshore	420	4	25-64	3KOPs	0.06	99.52
NL	Echinoderm	402	23	34-62	3PS	0.05	37.07
NL	All Fisheries	747,928	8,006	<=243	2GHJ 3KLNOPnPs	100	40.75
EA	Groundfish Fixed	4,470	21	NA	0AB	56.57	99.42
EA	Groundfish Mobile	2,765	8	NA	0AB	34.99	99.96
EA	Shrimp	667	9	NA	0AB	8.44	100
EA	All Fisheries	7,902	31	NA	0AB	100	99.66

Only fishing effort and overlap maps relevant for the presentation of key results have been included in the main text of this document. Effort maps are presented by bioregion, and within each bioregion there are several larger scale maps to show more detail (inset maps). Fisheries footprints and effort distributions based on available georeferenced data for all fisheries classes and all regions can be found in Appendix 2. For all fisheries classes with sufficient data, overlap maps between them and Significant Benthic Areas have been produced and compiled in Appendices 3 and 4. Due to privacy regulations, maps for some specific fisheries classes are not included in the appendices, but that effort was included in the maps depicting all effort combined.

Scotian Shelf bioregion

The total fishing effort in the Scotian Shelf bioregion in the period 2015-2014 amounts to 1,490,207 VD. This effort is highly dominated by the lobster fishery class, which encompasses 74% of all the effort recorded in this bioregion (Table 3). Following in effort dominance are the Scallop (8%), Groundfish Fixed (5%), Groundfish Mobile (5%), and Pelagic (4%) fisheries classes. These top five fisheries classes accounted for 95% of the total fishing effort in the bioregion (Table 3).

Overall, only 23% of the fishing effort can be spatially resolved in the Scotian Shelf. The spatially resolved effort defines an estimated fishing footprint for all fisheries combined of 74,533 km^2 based on logbook georeferenced data and 205,577 km^2 from VMS data. This discrepancy arises from both the higher frequency of reporting of VMS and the checkerboard pattern associated with rounding of latitudes and longitudes in the logbook data. However, the general distribution of the effort from both sources is highly coherent, defining a very similar overall footprint (Figure 5). Logbook and VMS georeferenced data also provided a consistent picture in terms of areas of concentration of fishing effort (Figure 5). There is high variability in the reporting of fishing locations, ranging from very high to extremely low reporting rates depending on fishery class (Tables 3-5). This disparity has an important impact on the reliability of the fishing footprints estimated for the different fisheries; the footprints for those fisheries with

low reporting of fishing locations can only be considered indicative of the footprint in a very broad way.

The spatial concentration of effort within individual footprints seems to follow a similar pattern for fisheries with high and low rates of georeferencing. In general within each fishery class, effort appears highly concentrated in a relatively small fraction of the estimated fishing footprint, with highly fished areas (which concentrate up to 40% of the effort) typically representing less than 15% of the estimated footprint, while 80% of the effort is typically exerted in less than 50% of the estimated footprint (Table 3-5).

In terms of overlaps with Significant Benthic Areas (Tables 6-8), some of the key fisheries classes in the SS bioregion include Groundfish Fixed (Figure 6), Groundfish Mobile (Figure 7), Crab Offshore (Figure 8), and Pelagic (Figure 9).

Fisheries footprints and effort distributions based on available georeferenced data for all fisheries classes in this region can be found in Appendices 2 and 3.

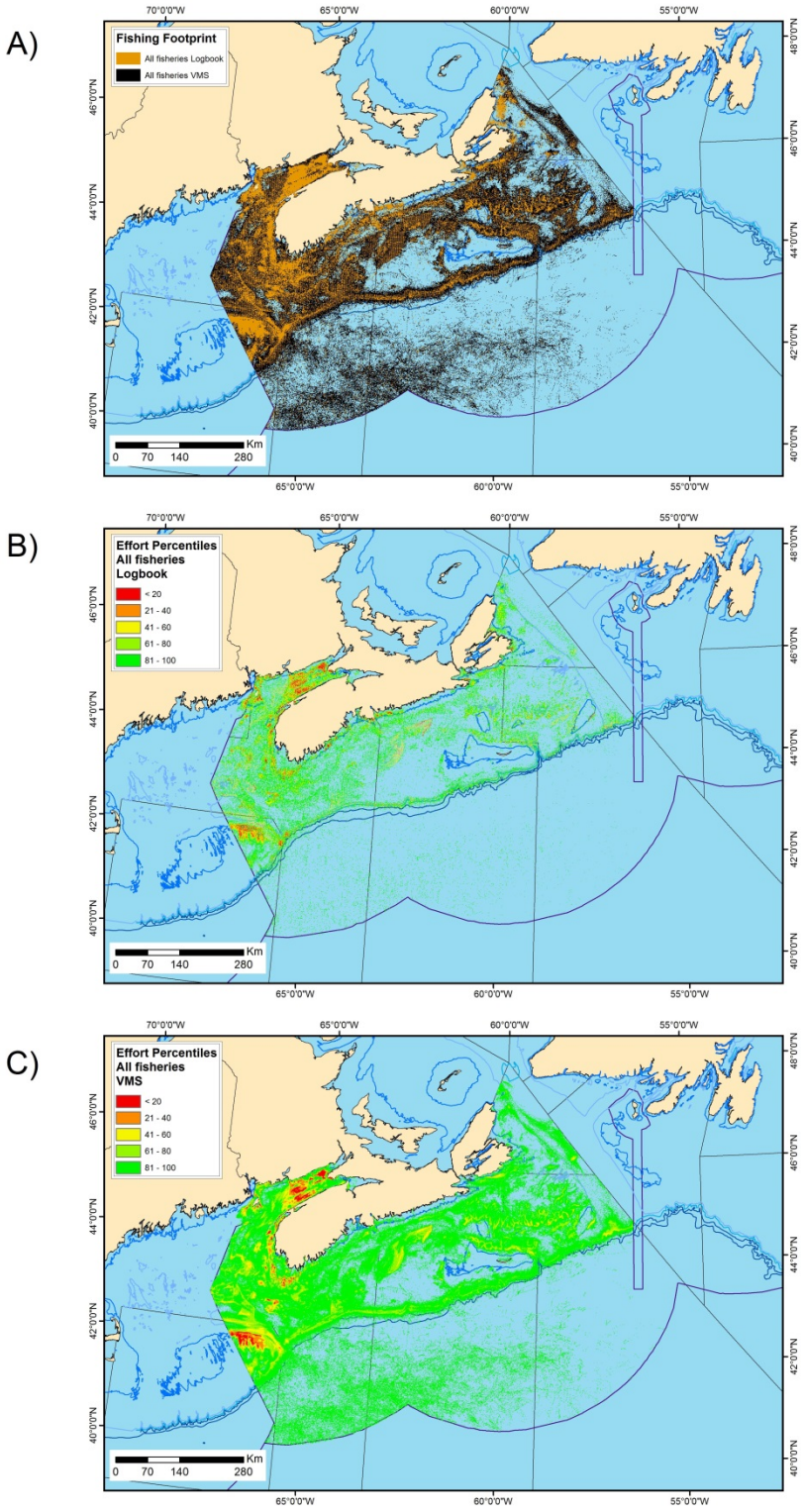

Figure 5. Distribution of the 2005-2014 georeferenced fishing effort for the Scotian Shelf bioregion for all fisheries classes combined. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

Table 3. Distribution of georeferenced fishing effort and fishery class footprints from logbook data for the Scotian Shelf bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Lobster	74.1	0.6	0.5	2,302	1.2	5.3	17.5	42.8
Scallop	7.7	97.7	8.0	14,374	2.8	8.3	17.5	34.1
Groundfish Fixed	4.9	87.5	12.3	28,481	2.9	11.2	26.3	55.1
Groundfish Mobile	4.6	99.2	16.8	16,131	2.6	8.4	18.7	39.0
Pelagic	3.7	91.2	20.1	15,539	0.8	3.5	11.9	36.3
Crab Offshore	1.5	97.0	21.6	8,007	3.3	10.5	23.8	47.7
Misc. Inshore	1.1	19.8	21.8	576	0.4	3.3	10.2	25.3
Crab Inshore	0.8	28.2	22.0	1,147	1.7	7.0	17.9	42.1
Shrimp	0.4	97.8	22.5	2,541	3.1	10.3	23.6	50.0
Misc. Offshore	0.4	89.1	22.8	2,470	0.5	2.8	20.8	60.4
Clam	0.3	99.7	23.1	1,303	3.3	11.1	23.0	42.8
Other	0.3	15.1	23.2	193	1.0	4.7	9.9	35.2
Echinoderm	0.2	47.0	23.3	399	1.8	5.3	11.5	30.8
Whelk	<0.1	96.3	23.3	66	7.6	28.8	51.5	75.8
All fisheries	**100.0**	**23.3**	**23.3**	**74,533**	**1.7**	**6.1**	**14.9**	**34.7**

Table 4. Distribution of georeferenced fishing effort and fishery class footprints from VMS data for the Scotian Shelf bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Lobster	74.1	1.0	0.8	17,811	1.2	4.4	11.1	27.0
Scallop	7.7	91.8	7.8	24,338	2.5	6.4	12.1	21.6
Groundfish Fixed	4.9	32.7	9.4	68,829	0.9	5.0	14.1	32.8
Groundfish Mobile	4.6	79.4	13.1	60,241	1.9	5.7	12.4	25.5
Pelagic	3.7	41.1	14.6	85,935	1.3	5.7	14.8	37.5
Crab Offshore	1.5	76.5	15.7	28,440	1.6	5.2	12.9	29.7
Misc. Inshore	1.1	3.8	15.8	303	1.7	5.0	9.6	20.8
Crab Inshore	0.8	4.1	15.8	1,313	1.7	4.7	11.8	32.8
Shrimp	0.4	61.0	16.1	6,134	1.6	5.1	11.7	23.9
Misc. Offshore	0.4	30.2	16.2	13,421	4.6	14.5	30.4	58.9
Clam	0.3	96.4	16.5	5,458	2.1	6.9	14.0	26.1
Other	0.3	10.1	16.5	2,769	3.2	11.4	28.4	58.9
Echinoderm	0.2	23.0	16.6	1,047	1.1	3.5	8.5	21.4
Whelk	<0.1	81.5	16.6	406	5.2	12.6	23.9	49.3
All fisheries	**100.0**	**16.6**	**16.6**	**205,577**	**0.8**	**2.2**	**5.9**	**16.5**

Table 5. Distribution of georeferenced fishing effort and fishery class footprints from merged logbook and VMS data for the Scotian Shelf bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Lobster	74.1	1.1	0.8	17,976	1.1	4.3	11.1	26.9
Scallop	7.7	97.8	8.4	25,795	2.4	6.1	11.5	20.8
Groundfish Fixed	4.9	87.7	12.8	76,592	1.0	5.2	14.6	34.9
Groundfish Mobile	4.6	99.2	17.3	62,562	1.8	5.5	12.0	24.7
Pelagic	3.7	90.2	20.6	91,397	1.2	5.5	14.3	36.5
Crab Offshore	1.5	97.1	22.1	30,249	1.6	5.2	13.4	30.3
Misc. Inshore	1.1	18.8	22.4	779	0.8	3.6	9.4	21.6
Crab Inshore	0.8	26.3	22.6	2,212	1.5	5.2	13.4	35.4
Shrimp	0.4	97.8	23.0	6,754	1.5	4.9	11.2	24.0
Misc. Offshore	0.4	89.1	23.3	14,739	4.3	13.6	29.6	59.5
Clam	0.3	99.7	23.7	5,688	2.1	6.6	13.6	25.4
Other	0.3	19.2	23.7	2,931	3.1	11.1	27.4	57.7
Echinoderm	0.2	49.0	23.9	1,242	0.9	3.0	7.5	20.5
Whelk	<0.1	96.3	23.9	440	5.5	15.0	25.9	50.7
All fisheries	**100.0**	**23.9**	**23.9**	**215,319**	**0.8**	**2.2**	**5.8**	**16.4**

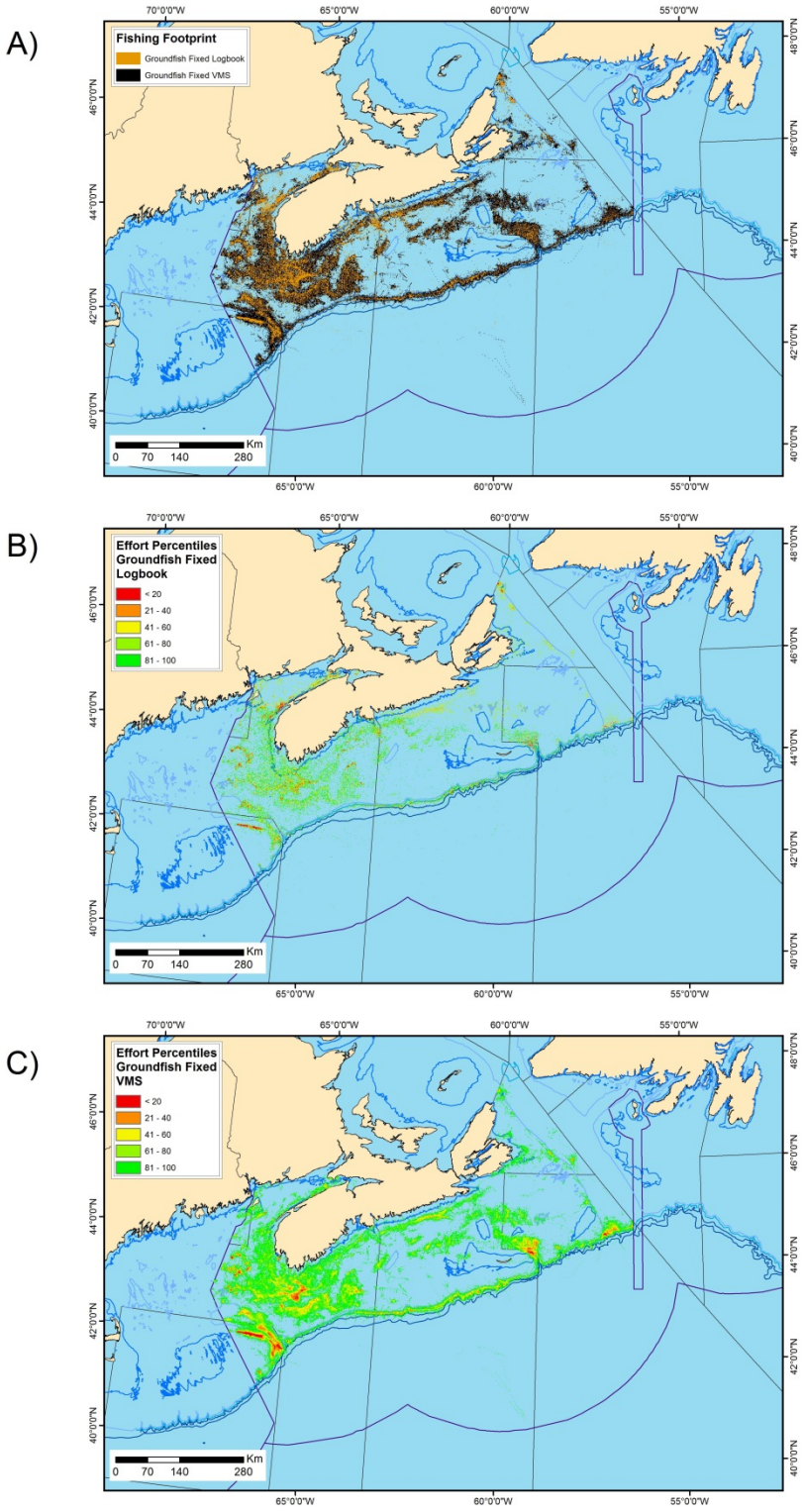

Figure 6. Distribution of the 2005-2014 georeferenced fishing effort for the Scotian Shelf bioregion for the Groundfish Fixed fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

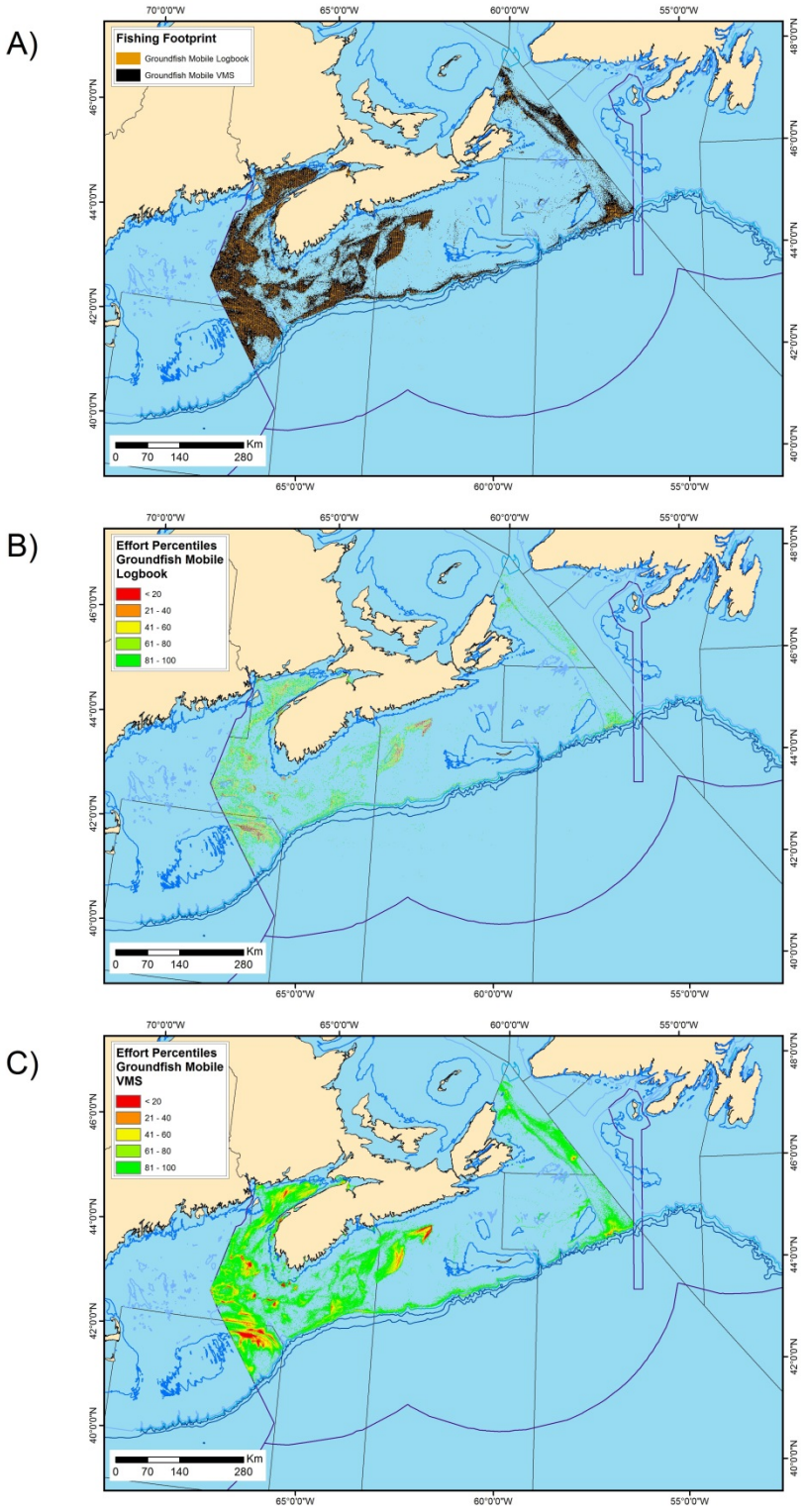

Figure 7. Distribution of the 2005-2014 georeferenced fishing effort for the Scotian Shelf bioregion for the Groundfish Mobile fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

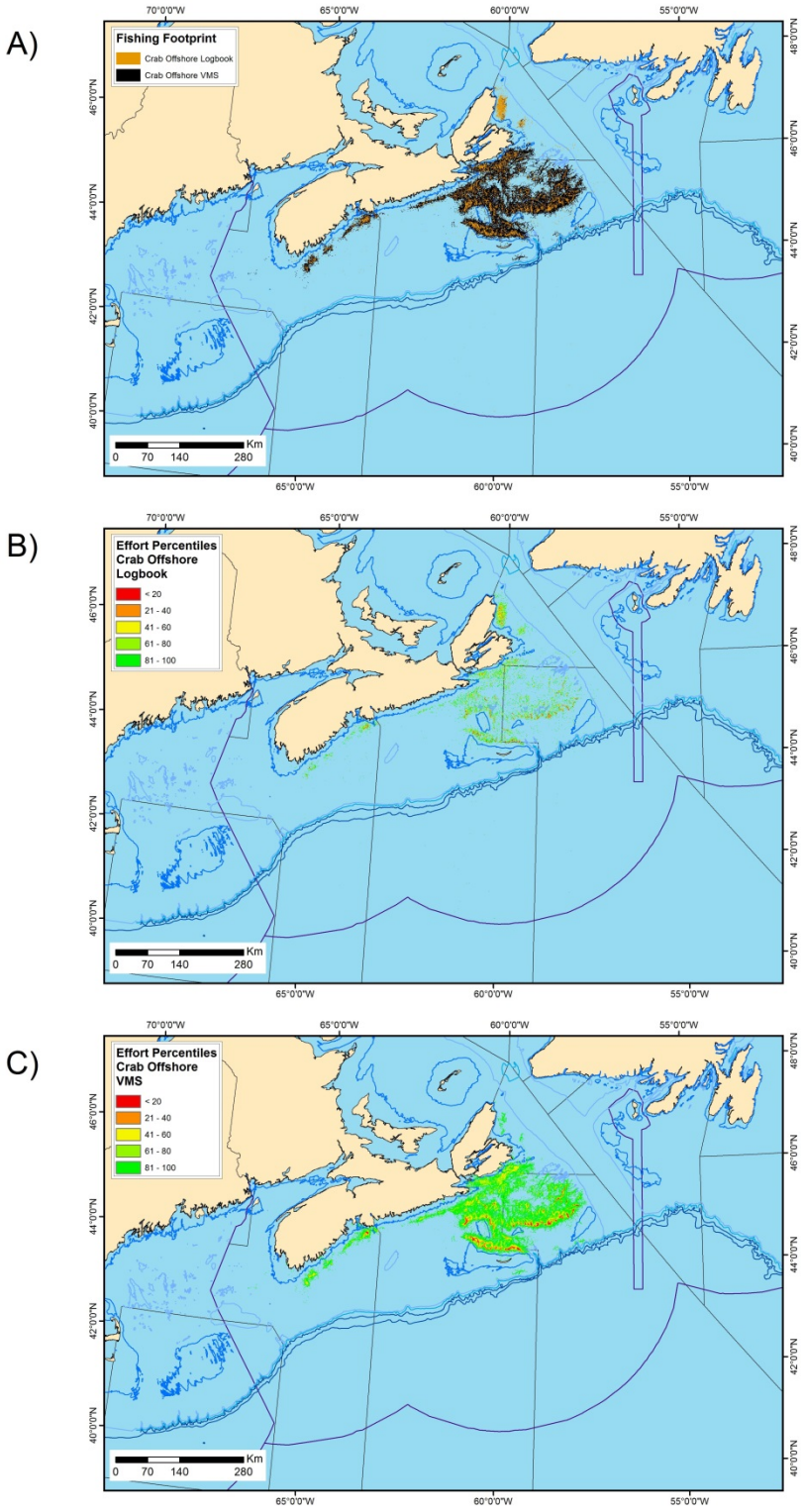

Figure 8. Distribution of the 2005-2014 georeferenced fishing effort for the Scotian Shelf bioregion for the Crab Offshore fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

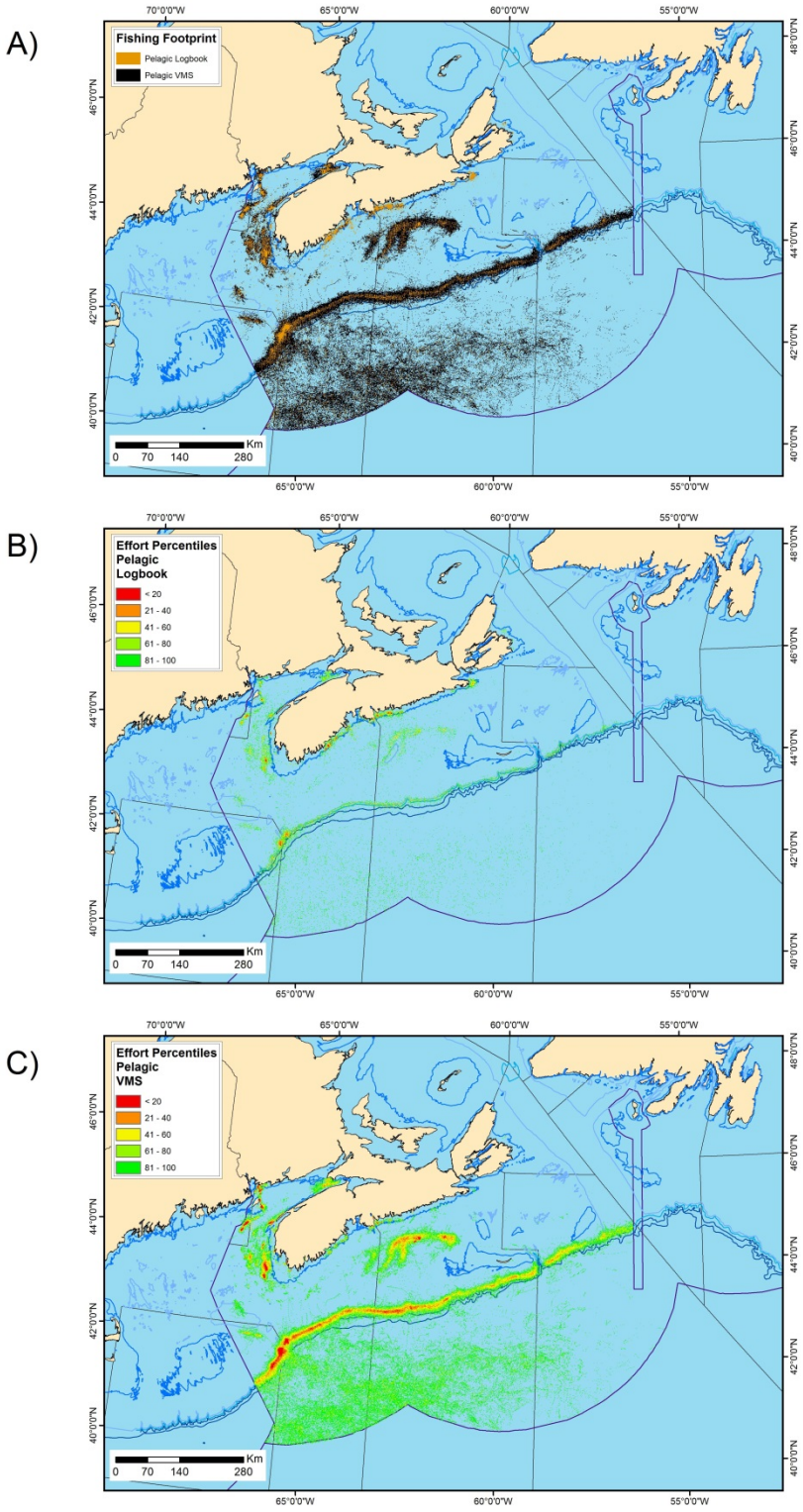

Figure 9. Distribution of the 2005-2014 georeferenced fishing effort for the Scotian Shelf bioregion for the Pelagic fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

*Table 6. Overlap between fishery class footprints and Significant Benthic Areas in the Scotian Shelf bioregion based on available georeferenced data from logbooks. The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 40,749 km^2, sea pen (SE) = 83,086 km^2, small gorgonian (SG) = 57,386 km^2, and sponge (SP) = 12,896 km^2 (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Clam	99.7	1,303	153	98	22	5	11.8	7.6	1.7	0.4	0.4	0.1	0	0
Crab Inshore	28.2	1,147	48	73	80	48	4.2	6.3	7	4.2	0.1	0.1	0.1	0.4
Crab Offshore	97	8,007	43	755	43	256	0.5	9.4	0.5	3.2	0.1	0.9	0.1	2
Echinoderm	47	399	5	1	10	5	1.1	0.3	2.5	1.2	0	0	0	0
Groundfish Fixed	87.5	28,481	4,764	3,656	2,875	2,610	16.7	12.8	10.1	9.2	11.7	4.4	5	20.2
Groundfish Mobile	99.2	16,131	2,281	2,165	1,937	931	14.1	13.4	12	5.8	5.6	2.6	3.4	7.2
Lobster	0.6	2,302	626	232	311	3	27.2	10.1	13.5	0.1	1.5	0.3	0.5	0
Misc. Inshore	19.8	576	0	10	1	6	0	1.7	0.2	1	0	0	0	0
Misc. Offshore	89.1	2,470	125	426	207	107	5.1	17.2	8.4	4.3	0.3	0.5	0.4	0.8
Other	15.1	193	20	34	22	12	10.2	17.6	11.5	6.4	0	0	0	0.1
Pelagic	91.2	15,539	3,023	2,955	3,680	970	19.5	19	23.7	6.2	7.4	3.6	6.4	7.5
Scallop	97.7	14,374	2,286	28	10	584	15.9	0.2	0.1	4.1	5.6	0	0	4.5
Shrimp	97.8	2,541	2	202	3	194	0.1	8	0.1	7.6	0	0.2	0	1.5
Whelk	96.3	66	0	0	0	0	0.2	0	0	0	0	0	0	0
All Fisheries	**23.3**	**74,533**	**9,849**	**8,957**	**7,149**	**4,444**	**13.2**	**12**	**9.6**	**6**	**24.2**	**10.8**	**12.5**	**34.5**

Table 7. Overlap between fishery class footprints and Significant Benthic Areas in the Scotian Shelf bioregion based on available georeferenced data from VMS. The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 40,749 km^2, sea pen (SE) = 83,086 km^2, small gorgonian (SG) = 57,386 km^2, and sponge (SP) = 12,896 km^2 ***(*Overlap between fishery class footprint and Significant Benthic Area (km^2),*** *† Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	**Georeferenced effort (%)**	**Fishing footprint (km^2)**	**LG***	**SE***	**SG***	**SP***	**LG†**	**SE†**	**SG†**	**SP†**	**LGº**	**SEº**	**SGº**	**SPº**
Clam	96.3	5,458	639	549	162	64	11.7	10.1	3	1.2	1.6	0.7	0.3	0.5
Crab Inshore	4	1,313	55	43	201	3	4.2	3.3	15.3	0.2	0.1	0.1	0.4	0
Crab Offshore	76.5	28,440	151	1,441	21	1,392	0.5	5.1	0.1	4.9	0.4	1.7	0	10.8
Echinoderm	23	1,047	53	7	39	45	5	0.6	3.8	4.3	0.1	0	0.1	0.4
Groundfish Fixed	32.7	68,829	13,439	11,152	10,190	5,601	19.5	16.2	14.8	8.1	33	13.4	17.8	43.4
Groundfish Mobile	79.4	60,241	9,281	10,861	9,029	3,601	15.4	18	15	6	22.8	13.1	15.7	27.9
Lobster	1.1	17,811	4,795	804	1,141	625	26.9	4.5	6.4	3.5	11.8	1	2	4.8
Misc. Inshore	3.8	303	0	0	0	4	0	0	0	1.3	0	0	0	0
Misc. Offshore	30.2	13,421	1,182	2,588	1,907	640	8.8	19.3	14.2	4.8	2.9	3.1	3.3	5
Other	10.1	2,769	231	244	87	193	8.4	8.8	3.1	7	0.6	0.3	0.2	1.5
Pelagic	41.1	85,935	12,395	16,730	17,976	3,407	14.4	19.5	20.9	4	30.4	20.1	31.3	26.4
Scallop	91.8	24,338	4,483	8	6	1,303	18.4	0	0	5.4	11	0	0	10.1
Shrimp	61	6,134	7	515	5	622	0.1	8.4	0.1	10.1	0	0.6	0	4.8
Whelk	81.5	406	0	18	0	0	0	4.5	0	0	0	0	0	0
All Fisheries	**16.6**	**205,577**	**24,269**	**31,565**	**25,606**	**9,647**	**11.8**	**15.4**	**12.5**	**4.7**	**59.6**	**38**	**44.6**	**74.8**

*Table 8. Overlap between fishery class footprints and Significant Benthic Areas in the Scotian Shelf bioregion based on available georeferenced data from merged logbooks and VMS. The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 40,749 km^2, sea pen (SE) = 83,086 km^2, small gorgonian (SG) = 57,386 km^2, and sponge (SP) = 12,896 km^2 (*Overlap between fishery class footprint and Significant Benthic Area (km2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Clam	99.7	5,688	674	581	185	68	11.9	10.2	3.2	1.2	1.7	0.7	0.3	0.5
Crab Inshore	26.3	2,212	101	115	275	51	4.6	5.2	12.4	2.3	0.2	0.1	0.5	0.4
Crab Offshore	97.1	30,249	186	1,968	62	1,433	0.6	6.5	0.2	4.7	0.5	2.4	0.1	11.1
Echinoderm	49	1,242	57	8	45	47	4.6	0.6	3.6	3.8	0.1	0	0.1	0.4
Groundfish Fixed	87.7	76,592	14,028	12,274	10,761	6,236	18.3	16	14.1	8.1	34.4	14.8	18.8	48.4
Groundfish Mobile	99.2	62,562	9,672	11,417	9,486	3,788	15.5	18.2	15.2	6.1	23.7	13.7	16.5	29.4
Lobster	1.1	17,976	4,828	834	1,172	627	26.9	4.6	6.5	3.5	11.8	1	2	4.9
Misc. Inshore	18.8	779	0	10	1	10	0	1.3	0.1	1.2	0	0	0	0.1
Misc. Offshore	89.1	14,739	1,223	2,779	1,959	717	8.3	18.9	13.3	4.9	3	3.3	3.4	5.6
Other	19.2	2,931	249	273	108	203	8.5	9.3	3.7	6.9	0.6	0.3	0.2	1.6
Pelagic	90.2	91,397	12,692	17,154	18,293	3,635	13.9	18.8	20	4	31.1	20.6	31.9	28.2
Scallop	97.8	25,795	4,539	36	15	1,331	17.6	0.1	0.1	5.2	11.1	0	0	10.3
Shrimp	97.8	6,754	9	584	8	657	0.1	8.7	0.1	9.7	0	0.7	0	5.1
Whelk	93.6	440	0	18	0	0	0	4.2	0	0	0	0	0	0
All Fisheries	**23.9**	**215,319**	**24,646**	**33,325**	**26,311**	**9,997**	**11.4**	**15.5**	**12.2**	**4.6**	**60.5**	**40.1**	**45.8**	**77.5**

In the Scotian Shelf, only 23% of the total fishing effort is georeferenced. Most of the non-georeferenced effort is associated with the lobster fisheries class, which represents 74% of the fishing effort in this bioregion. The remaining 26% of the effort in this bioregion is highly georeferenced (88%), but some specific fisheries classes, like Miscellaneous Inshore, and Crab Inshore were still low (20% and 28% respectively).

Regarding overlap of lobster fishing with Significant Benthic Areas, most of the lobster fisheries class effort takes place in inshore shallow waters (less than 50 m depth). There is an offshore component of the lobster fisheries class in this bioregion, but that component is not georeferenced. Given the depth distribution of the Significant Benthic Areas in this bioregion, and even without georeferencing for this fisheries class, it is reasonable to expect relatively low overlap values.

The fraction of the fishing effort that is georeferenced shows cumulative high overlap values with Significant Benthic Areas (Table 6-8, Figure 10). Although some key fisheries classes do show substantial individual overlaps with Significant Benthic Areas, the high total overlap values are a consequence of cumulative effects across fisheries classes (Tables 6-8). Considering aggregates by bottom-contacting gear groups only allows examining the overlaps without the influence of the Pelagic fisheries class, which may act as a confounding factor. Since mobile gears typically have higher impacts on the benthos, distinguishing between fixed and mobile gears can provide preliminary insights into the potential relative impacts on Significant Benthic Areas from various fishing activities. In this context, fixed gear fisheries have moderately higher overlaps with Significant Benthic Areas than mobile gear fisheries, but the orders of magnitude are very similar between these two gear groups (Table 9). Although large gorgonian and sponge Significant Benthic Areas have higher overlaps with fishing effort than sea pen Significant Benthic Areas, all of them have important overlaps with fishing (Table 9). Excluding the effort associated with pelagic gears, between 28-72% of the areas of each Significant Benthic Area class overlap with fishing activity. Overlap maps for the aggregates described in Table 9 are compiled in Appendix 4.

The fisheries classes with the highest individual overlaps with Significant Benthic Areas include Groundfish Fixed, Groundfish Mobile, and Pelagic, and to a lesser extent Crab Offshore, and Scallop (Table 6-8). All these fisheries classes have good georeferencing rates (Table 2, Figure 4).

For better visualization of the overlaps between fishing effort and Significant Benthic Areas, the Scotian Shelf bioregion has been divided into two insets (SS1 and SS2, Figure 10). When all georeferenced fishing effort is considered, seven areas of overlap can be highlighted in the western portion of the SS bioregion (Figure 11). Of these areas, only in SS1a and SS1g do the Significant Benthic Areas straddle the 50 m isobath, and hence, are potentially subject to additional (unmapped) effort from the lobster fisheries class.

The high fishing effort in SS1a observed in Figure 11 is not associated with a single fishery; it emerges from the use of this area by multiple fisheries classes. The effort in areas SS1b-g appears associated with the Groundfish Fixed (Figure 12), Groundfish Mobile (Figure 13), Scallop (Figure 14) and Pelagic (Figure 15) fisheries classes. The examination of the overlap maps by fisheries class, also allowed highlighting one additional area, SS1h, which shows higher effort by the Groundfish Fixed fisheries class (Figure 12) This area is associated with a Sponge Significant Benthic Area, and when effort by all fisheries is considered, it only shows moderate fishing intensities (Figure 11).

In the eastern portion of the Scotian Shelf (inset SS2), three areas show overlap between Significant Benthic Areas and higher fishing effort (Figure 16). The SS2a area corresponds to a Sponge Significant Benthic Area, while SS2b-c corresponds to regions where Sea pen, Small

Gorgonian, and in the case of SS2c, also Large Gorgonian Significant Benthic Areas overlap (Figure 16).

Fishing effort in the SS2a area is associated with Crab Offshore (Figure 17), Shrimp (Figure 18), and with less intensity to Groundfish Fixed (Figure 19) fisheries classes. The Groundfish Mobile fisheries class does not overlap with SS2a (Figure 20), but together with Groundfish Fixed (Figure 19) they are the main fisheries classes associated with the effort observed in SS2b, although Shrimp (Figure 18) also has fishing effort within Sea pen Significant Benthic Areas in this general region. The effort in SS2c is mainly associated to Groundfish Fixed (Figure 19), Groundfish Mobile (Figure 20), and Pelagic (Figure 21) fisheries classes.

*Table 9. Overlap between aggregates of fishery class footprints and Significant Benthic Areas in the Scotian Shelf bioregion based on available georeferenced data from logbooks, VMS, and merged effort (logbooks and VMS combined). The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 40,749 km^2, sea pen (SE) = 83,086 km^2, small gorgonian (SG) = 57,386 km^2, and sponge (SP) = 12,896 km^2 . (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)). All exc. pelagic = All fisheries excluding pelagic.*

Data source	Fishery class aggregate	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Logbook	Fixed	40,724	5,338	4,950	3,386	2,946	13.1	12.2	8.3	7.2	13.1	6	5.9	22.8
Logbook	Mobile	32,043	4,429	2,481	1,975	1,643	13.8	7.7	6.2	5.1	10.9	3	3.4	12.7
Logbook	All exc. pelagic	64,271	8,295	6,902	4,834	4,014	12.9	10.7	7.5	6.2	20.4	8.3	8.4	31.1
VMS	Fixed	105,161	14,833	13,749	11,319	6,726	14.1	13.1	10.8	6.4	36.4	16.5	19.7	52.2
VMS	Mobile	86,297	12,662	11,766	9,152	5,139	14.7	13.6	10.6	6	31.1	14.2	15.9	39.9
VMS	All exc. pelagic	148,399	19,930	21,686	16,606	8,913	13.4	14.6	11.2	6	48.9	26.1	28.9	69.1
Merged	Fixed	114,006	15,346	15,371	11,947	7,354	13.5	13.5	10.5	6.5	37.7	18.5	20.8	57
Merged	Mobile	90,182	13,035	12,423	9,631	5,349	14.5	13.8	10.7	5.9	32	15	16.8	41.5
Merged	All exc. pelagic	155,948	20,453	23,438	17,400	9,311	13.1	15	11.2	6	50.2	28.2	30.3	72.2

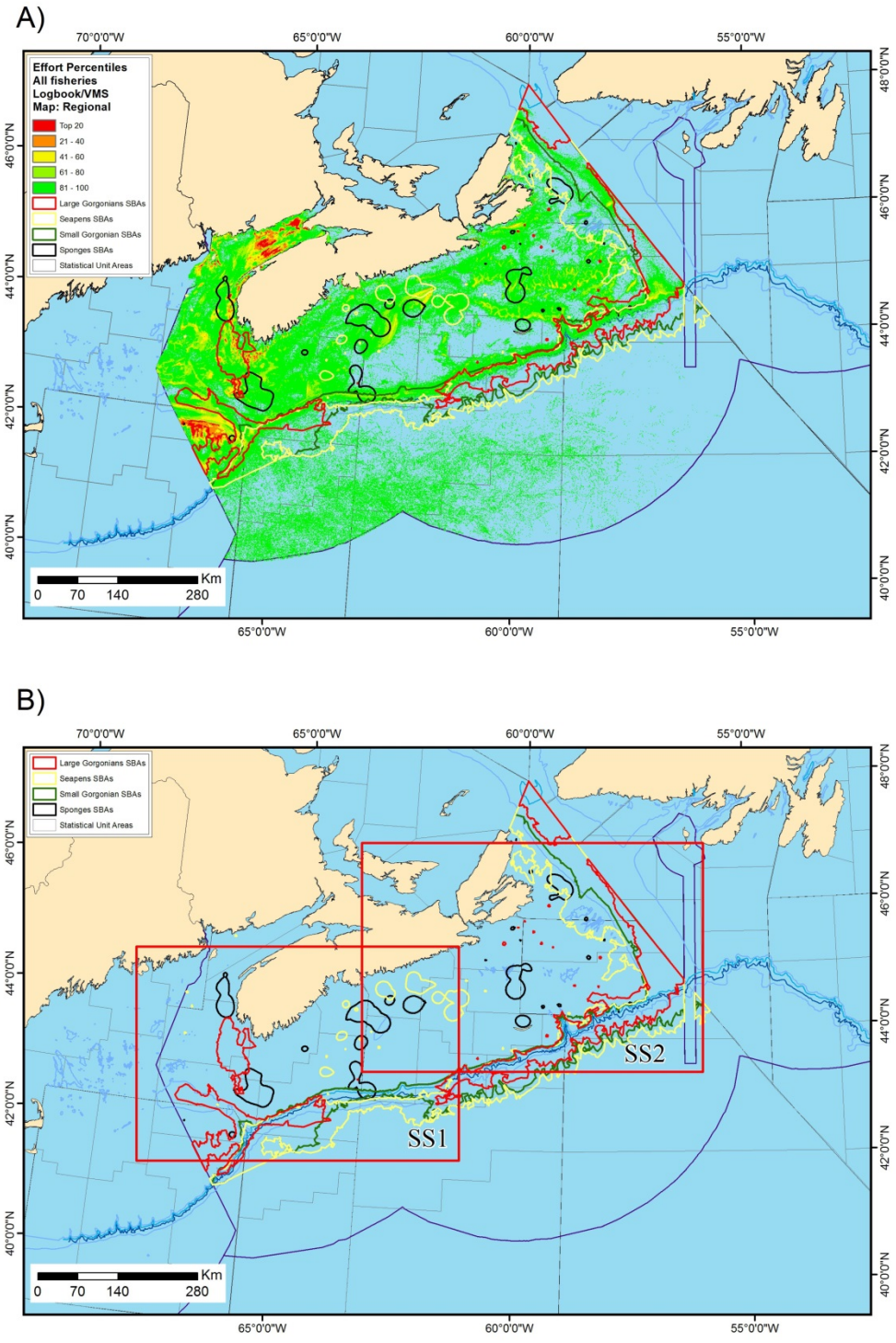

Figure 10. Overlap between all fishing effort and Significant Benthic Areas in the Scotian Shelf bioregion. A) Overlap between all Significant Benthic Area categories and fishing effort, where fishing effort intensity is displayed using the merged logbook/VMS percentile layer; B) Distribution of Significant Benthic Areas showing inset locations, SS1, and SS2, that display overlaps in more detail.

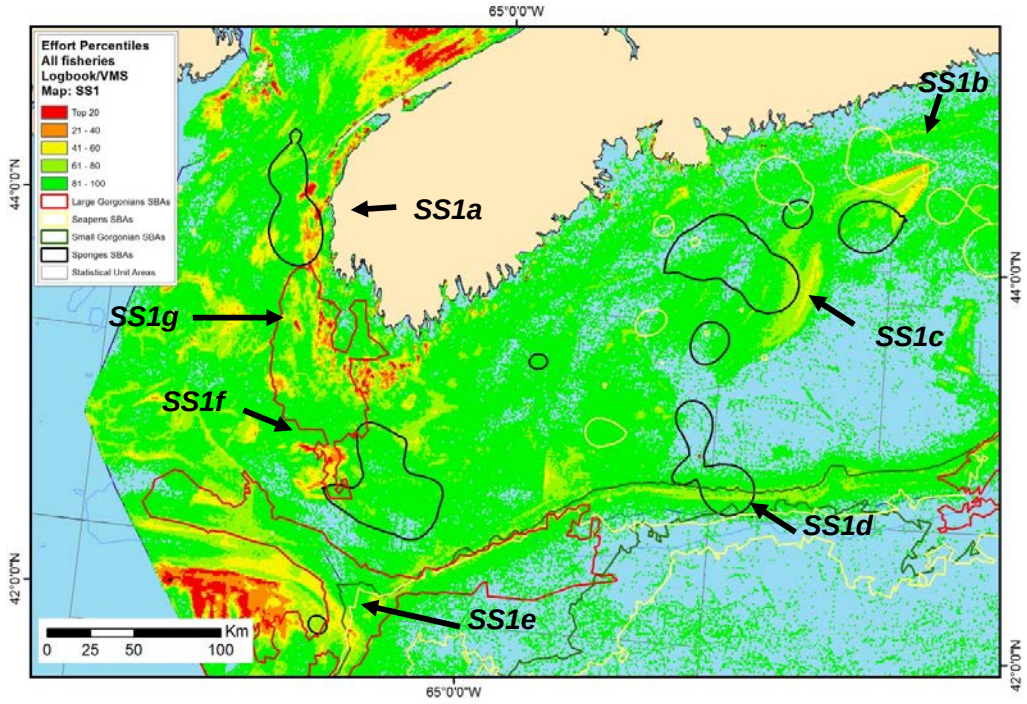

Figure 11. Overlap between all fishing effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS1. Arrows indicate general areas of overlap with higher fishing intensity.

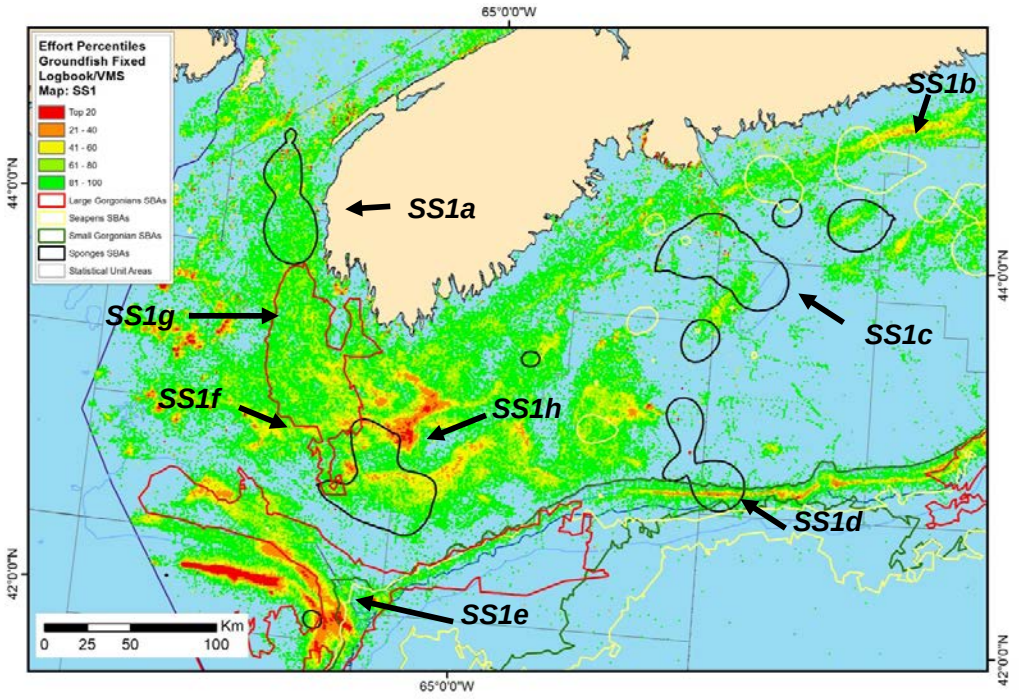

Figure 12. Overlap between Groundfish Fixed effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS1. Arrows indicate general areas of overlap with higher fishing intensity.

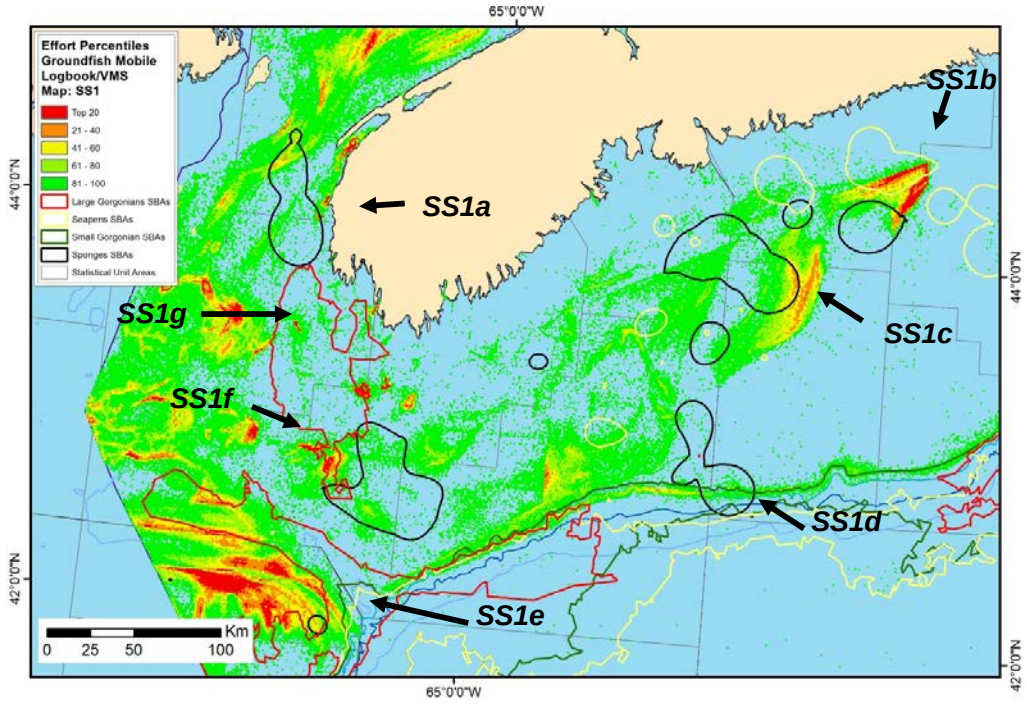

Figure 13. Overlap between Groundfish Mobile effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS1. Arrows indicate general areas of overlap with higher fishing intensity.

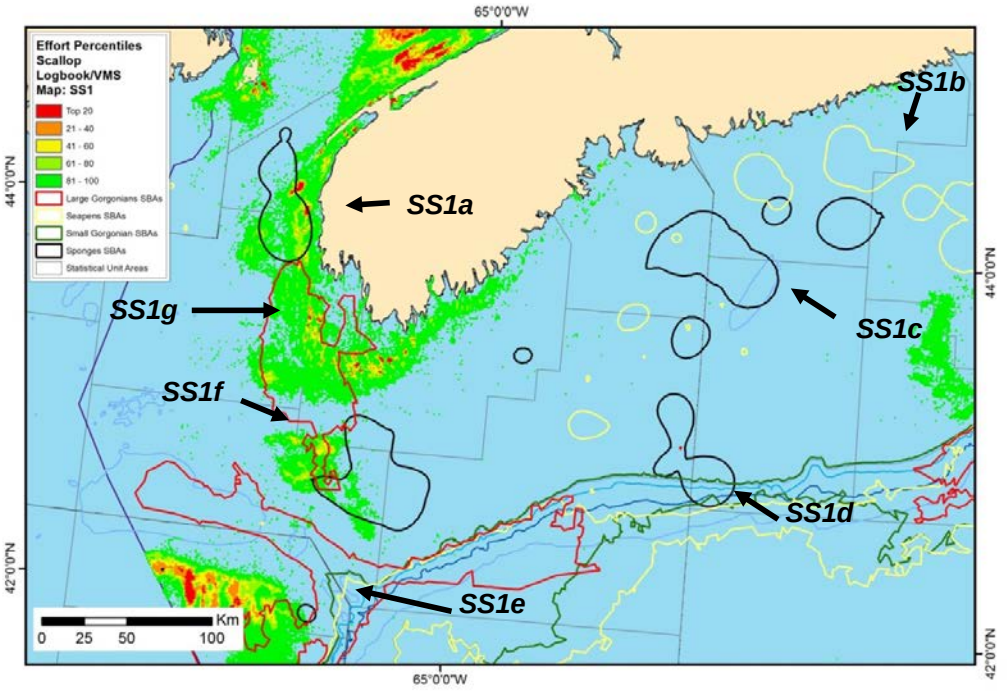

Figure 14. Overlap between Scallop effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS1. Arrows indicate general areas of overlap with higher fishing intensity.

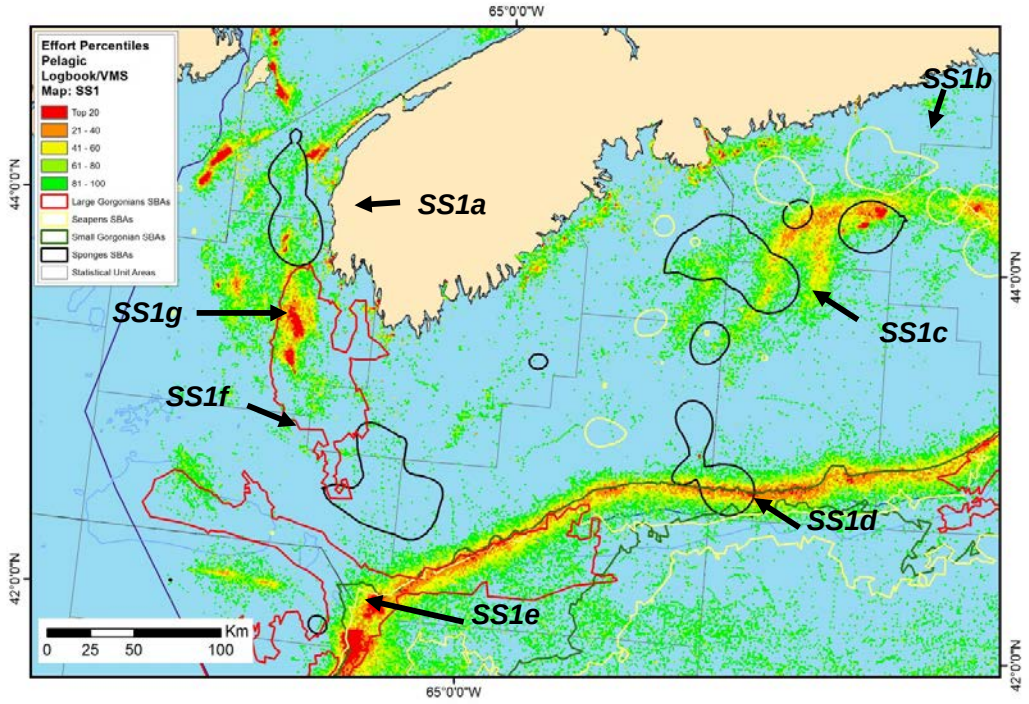

Figure 15. Overlap between Pelagic effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS1. Arrows indicate general areas of overlap with higher fishing intensity.

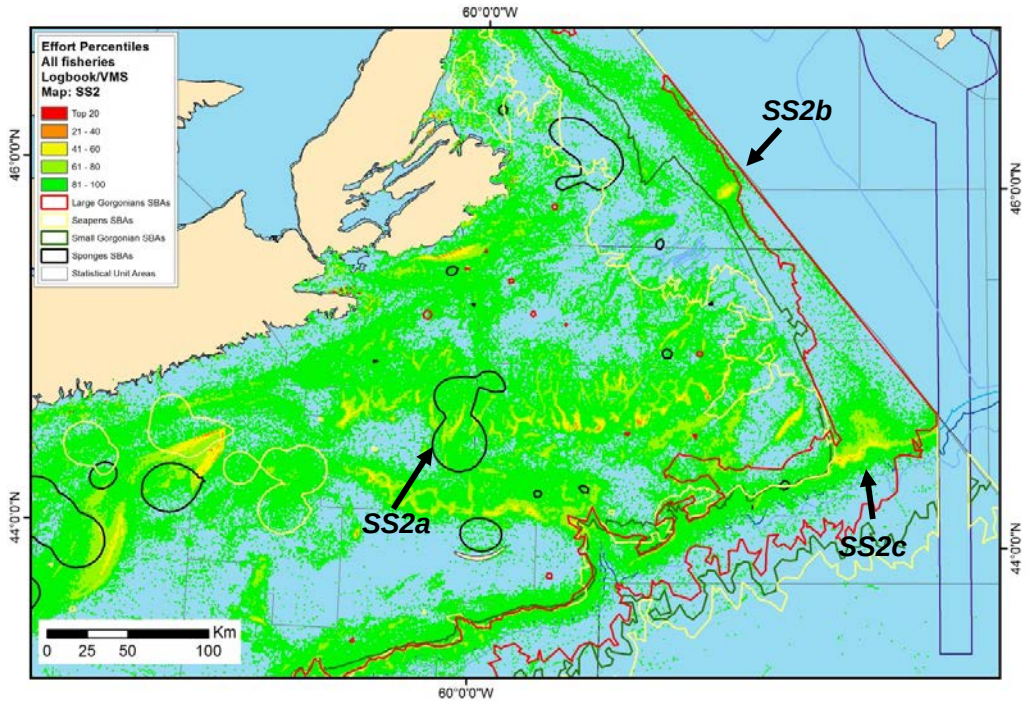

Figure 16. Overlap between all fishing effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS2. Arrows indicate general areas of overlap with higher fishing intensity.

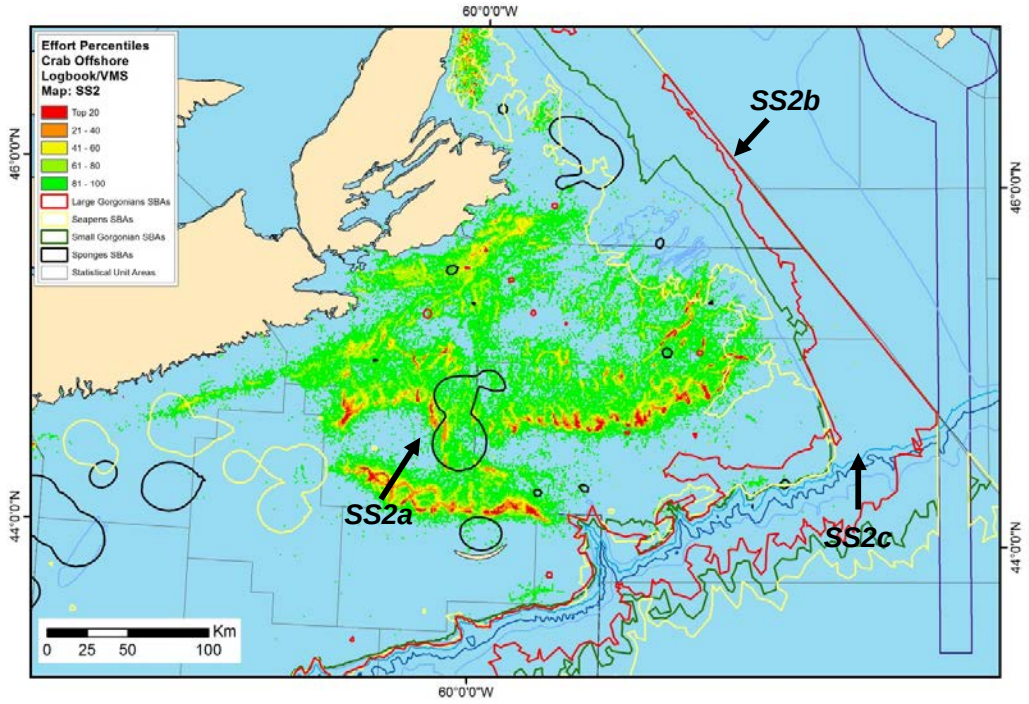

Figure 17. Overlap between Crab Offshore effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS2. Arrows indicate general areas of overlap with higher fishing intensity.

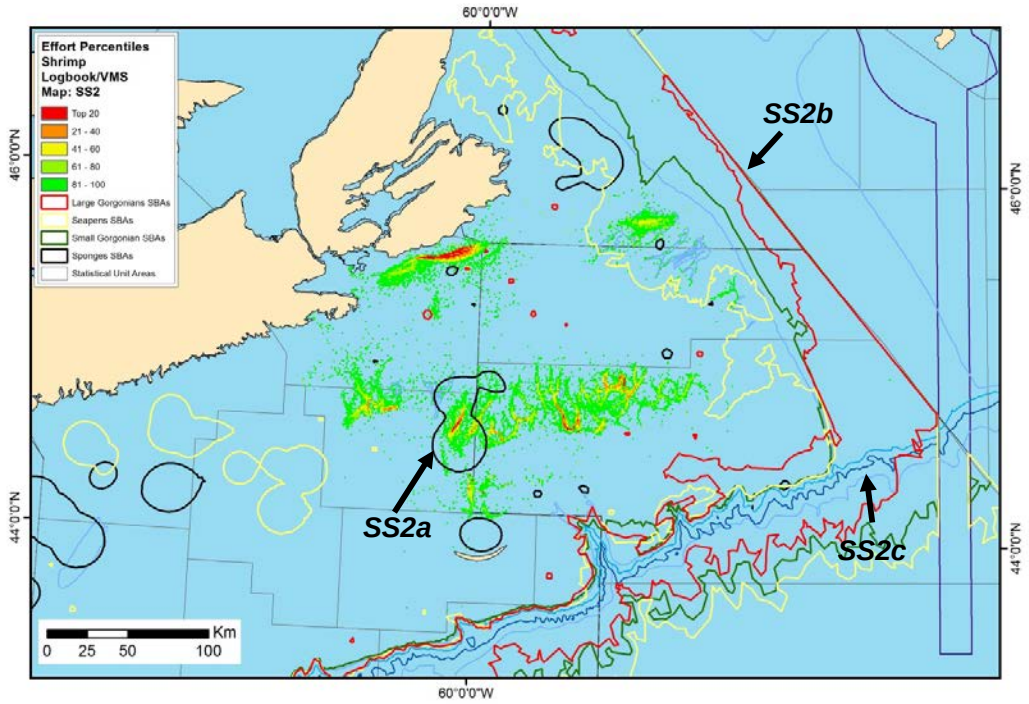

Figure 18. Overlap between Shrimp effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS2. Arrows indicate general areas of overlap with higher fishing intensity.

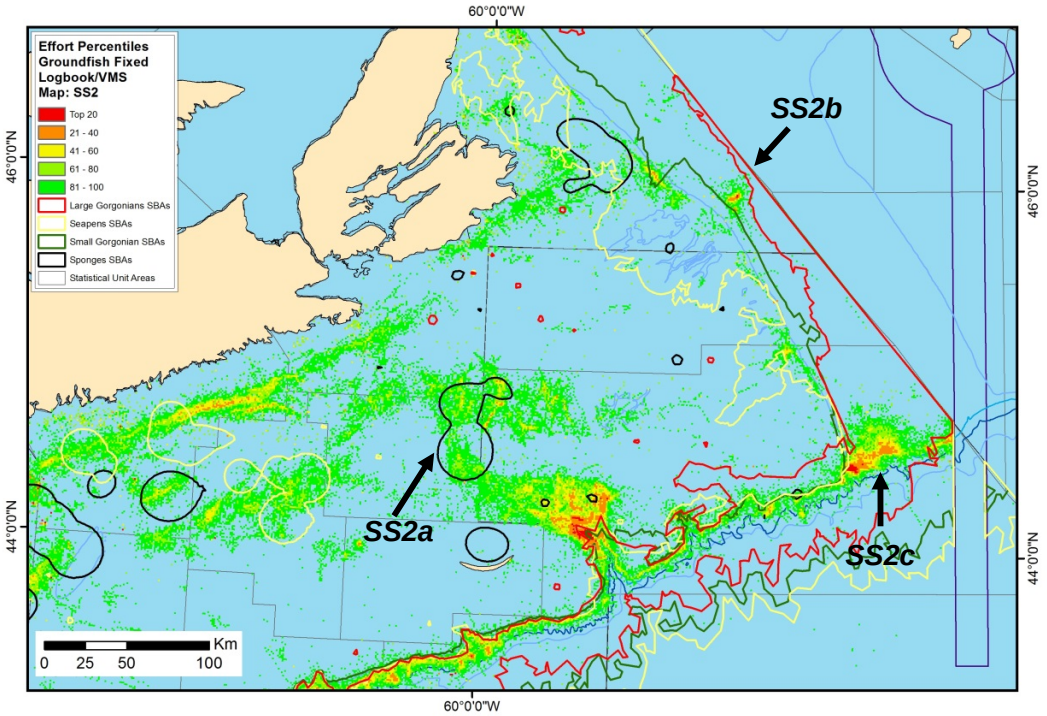

Figure 19. Overlap between Groundfish Fixed effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS2. Arrows indicate general areas of overlap with higher fishing intensity.

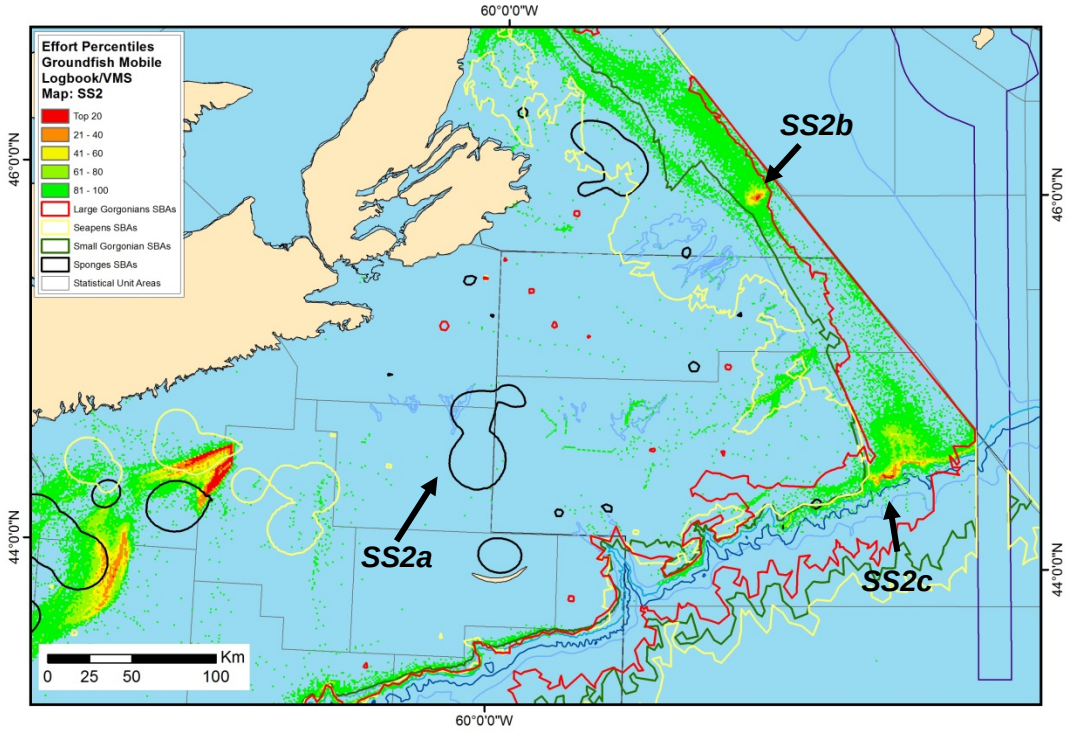

Figure 20. Overlap between Groundfish Mobile effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS2. Arrows indicate general areas of overlap with higher fishing intensity.

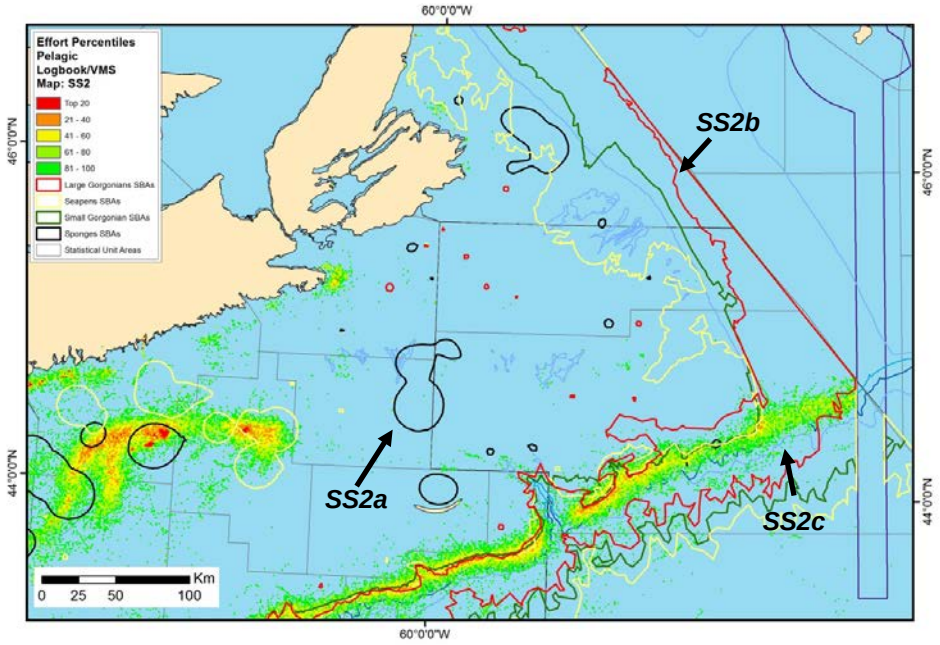

Figure 21. Overlap between Pelagic effort and Significant Benthic Areas in the Scotian Shelf bioregion, inset SS2. Arrows indicate general areas of overlap with higher fishing intensity.

Gulf of St. Lawrence bioregion

The total fishing effort in the Gulf of St. Lawrence bioregion in the period 2005-2014 amounts to 2,005,909 VD. This effort is highly dominated by the lobster fishery class, which represents 63% of all the effort recorded in this bioregion (Table 10). Following in effort dominance are the Pelagic (7%), Groundfish Fixed (6%), Crab Offshore (5%), Other (5%), Scallop (4%), Crab Inshore (3%), and Shrimp (3%) fisheries classes. These top eight fisheries classes accounted for 95% of the total fishing effort in the bioregion (Table 10).

Overall, 15% of the fishing effort is georeferenced in the GSL bioregion. The georeferenced effort defines an estimated fishing footprint for all fisheries combined of 74,064 km^2 based on logbook positional data and 97,757 km^2 from VMS data. Regardless of this discrepancy, the general distribution of the effort from both sources is highly coherent, defining a very similar overall footprint (Figure 22). Logbook and VMS georeferenced data also provided a consistent picture in terms of areas of concentration of fishing effort (Figure 22).

Similarly to the SS bioregion, there is high variability in the reporting of fishing locations, where some fisheries have very high reporting rates, while others are very low (Tables 10-11). The concentration of effort between fisheries with high and low reporting rates of fishing locations also shows a coherent picture in the GSL bioregion (Tables 10-11). Within each fisheries class, effort appears highly concentrated in a relatively small fraction of the estimated fishing footprint, where highly fished areas (which concentrate up to 40% of the effort) typically represent less than 15% of the estimated footprints, while 80% of the effort is exerted in less than 50% of the estimated footprint (Tables 10-12).

In terms of overlaps with Significant Benthic Areas (Tables 13-15), some of the key fisheries classes in this bioregion include Groundfish Fixed (Figure 23), Groundfish Mobile (Figure 24),Crab Offshore (Figure 25), and Shrimp (Figure 26). Fisheries class footprints and effort distributions based on available data for all other fisheries classes in this bioregion can be found in Appendices 2 and 3.

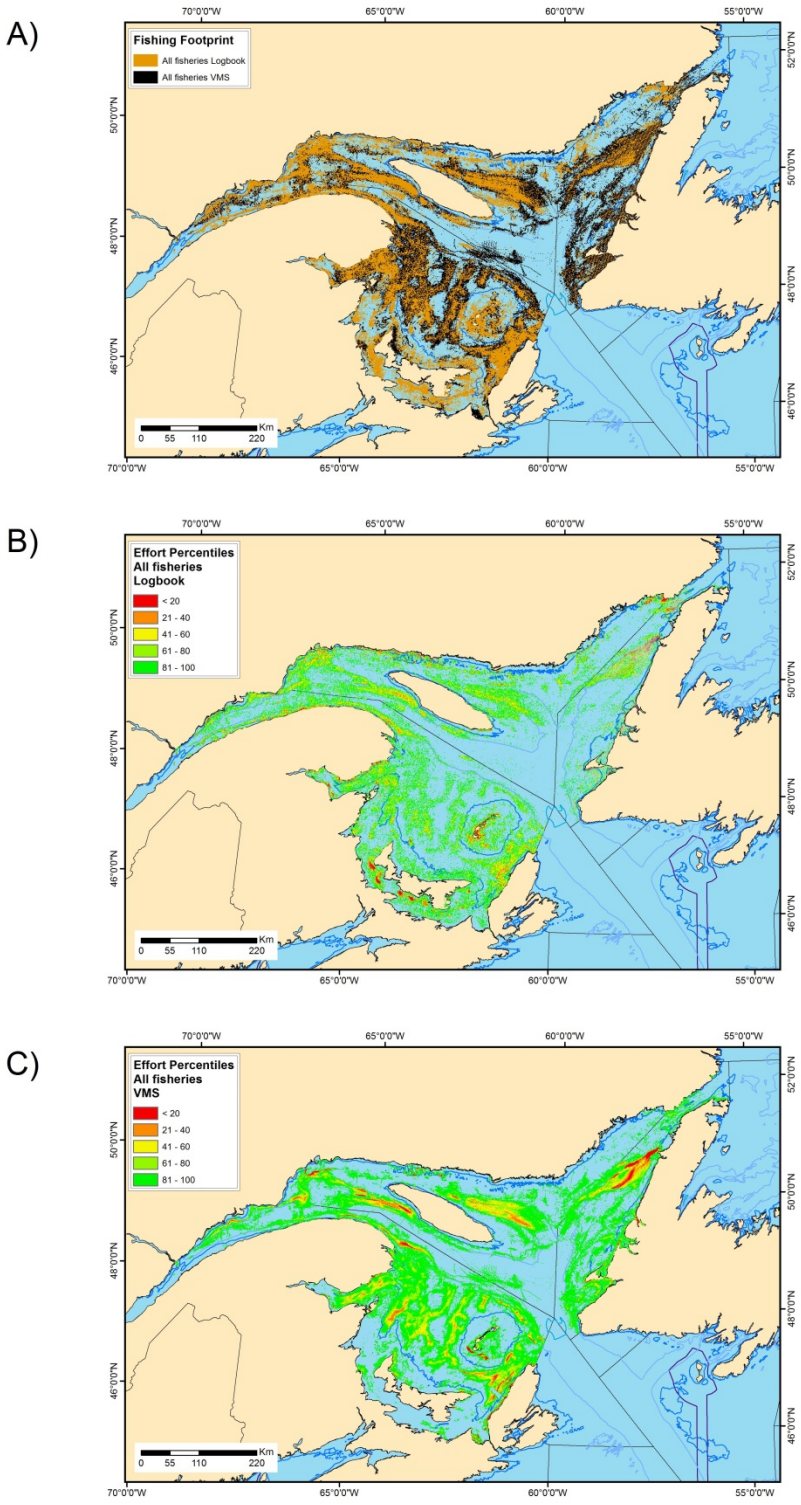

Figure 22. Distribution of the 2005-2014 georeferenced fishing effort for the Gulf of St. Lawrence bioregion for all fisheries classes combined. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

Table 10. Distribution of georeferenced fishing effort and fishery class footprints from logbook data for the Gulf of St. Lawrence bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Lobster	63.1	0.5	0.3	354	1.4	3.7	8.8	20.6
Scallop	7.1	15.2	1.2	5,951	1.5	5.9	17.1	42.1
Groundfish Fixed	5.9	40.1	3.4	18,340	1.8	8.7	22.7	51.8
Groundfish Mobile	5.1	87.2	7.6	28,506	4.1	12.1	25.1	48.9
Pelagic	4.7	1.6	7.6	249	0.8	3.6	8.4	23.7
Crab Offshore	4.0	46.3	9.3	3,240	1.5	5.3	12.9	29.3
Misc. Inshore	3.1	56.7	10.8	8,522	2.0	7.5	18.7	42.3
Crab Inshore	2.9	89.1	13.3	15,503	4.0	12.2	25.2	47.3
Shrimp	2.2	1.9	13.4	110	0.9	1.8	5.5	21.8
Misc. Offshore	1.1	81.5	14.2	2,773	1.8	5.7	13.2	30.3
Clam	0.8	90.4	14.9	3,632	0.8	3.0	9.9	33.4
Other	0.1	65.1	14.9	353	2.6	8.8	19.3	38.2
Echinoderm	<0.1	57.8	15.0	167	4.8	13.2	26.3	47.3
Whelk	<0.1	11.1	15.0	2	NA	NA	NA	NA
All fisheries	**100.0**	**15.0**	**15.0**	**74,064**	**1.6**	**7.3**	**18.7**	**40.4**

Table 11. Distribution of georeferenced fishing effort and fishery class footprints from VMS data for the Gulf of St. Lawrence bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Lobster	63.1	0	0	NA	NA	NA	NA	NA
Scallop	7.1	4.7	0.3	10,847	0.6	2.8	8.6	23.8
Groundfish Fixed	5.9	7.4	0.8	35,047	3.0	9.4	20.2	39.7
Groundfish Mobile	5.1	50.1	3.3	39,171	3.0	8.5	16.9	30.9
Pelagic	4.7	9.01	3.8	6,693	0.3	1.3	3.8	10.9
Crab Offshore	4.0	5.8	4.0	2,623	0.9	2.9	6.0	12.3
Misc. Inshore	3.1	0.4	4.0	950	2.1	8.3	19.4	40.0
Crab Inshore	2.9	40.5	5.2	20,284	3.5	9.8	19.2	34.2
Shrimp	2.2	1.0	5.2	335	0.3	0.6	1.2	11.1
Misc. Offshore	1.1	1.0	5.2	499	2.4	8.8	19.6	39.7
Clam	0.8	15.1	5.3	8,303	1.2	4.1	10.6	26.7
Other	0.1	3.2	5.3	96	2.1	7.3	13.5	25.0
Echinoderm	<0.1	63.3	5.4	389	1.0	4.4	9.5	17.7
Whelk	<0.1	16.7	5.4	63	7.9	22.2	39.7	63.5
All fisheries	**100.0**	**5.4**	**5.4**	**97,757**	**1.8**	**5.9**	**12.9**	**25.8**

Table 12. Distribution of georeferenced fishing effort and fishery class footprints from merged logbook and VMS data for the Gulf of St. Lawrence bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Lobster	63.1	0.5	0.3	354	1.4	3.7	8.8	20.6
Scallop	7.1	14.4	1.3	14,851	0.7	3.1	9.6	26.8
Groundfish Fixed	5.9	38.6	3.6	43,937	2.9	9.1	20.4	41.5
Groundfish Mobile	5.1	81.3	8.1	51,245	3.4	9.5	18.8	35.5
Pelagic	4.7	9.3	8.6	6,924	0.3	1.3	4	11.4
Crab Offshore	4	42.5	10.3	4,945	1.5	4.6	9.8	20.1
Misc. Inshore	3.1	48.3	11.8	9,046	2	7.4	18.4	41.6
Crab Inshore	2.9	88.6	14.5	24,538	3.1	8.8	17.4	32.5
Shrimp	2.2	2.2	14.6	410	0.2	0.5	1.2	12.2
Misc. Offshore	1.1	73.7	15.4	3,081	2	5.8	13.4	30.7
Clam	0.7	88	16	10,147	1	3.5	9.4	25.6
Other	0.1	62.9	16.1	399	2.8	8	15.8	31.8
Echinoderm	<0.1	62.9	16.1	409	1	4.2	9.1	17.1
Whelk	<0.1	19.1	16.1	65	7.7	21.5	40	63.1
All fisheries	**100**	**16.1**	**16.1**	**125,900**	**1.9**	**6.3**	**13.8**	**27.7**

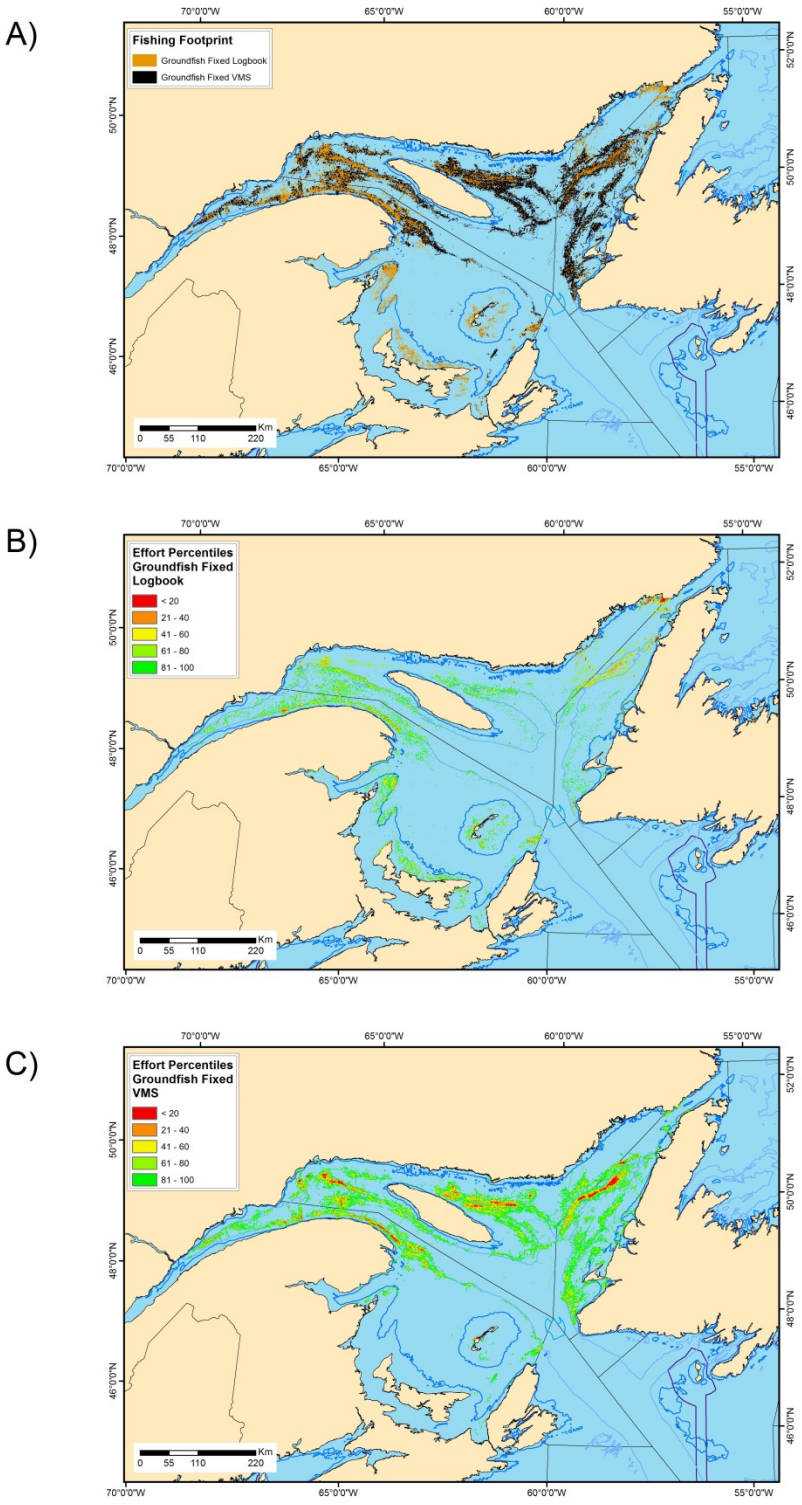

Figure 23. Distribution of the 2005-2014 georeferenced fishing effort for the Gulf of St. Lawrence bioregion for the Groundfish Fixed fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

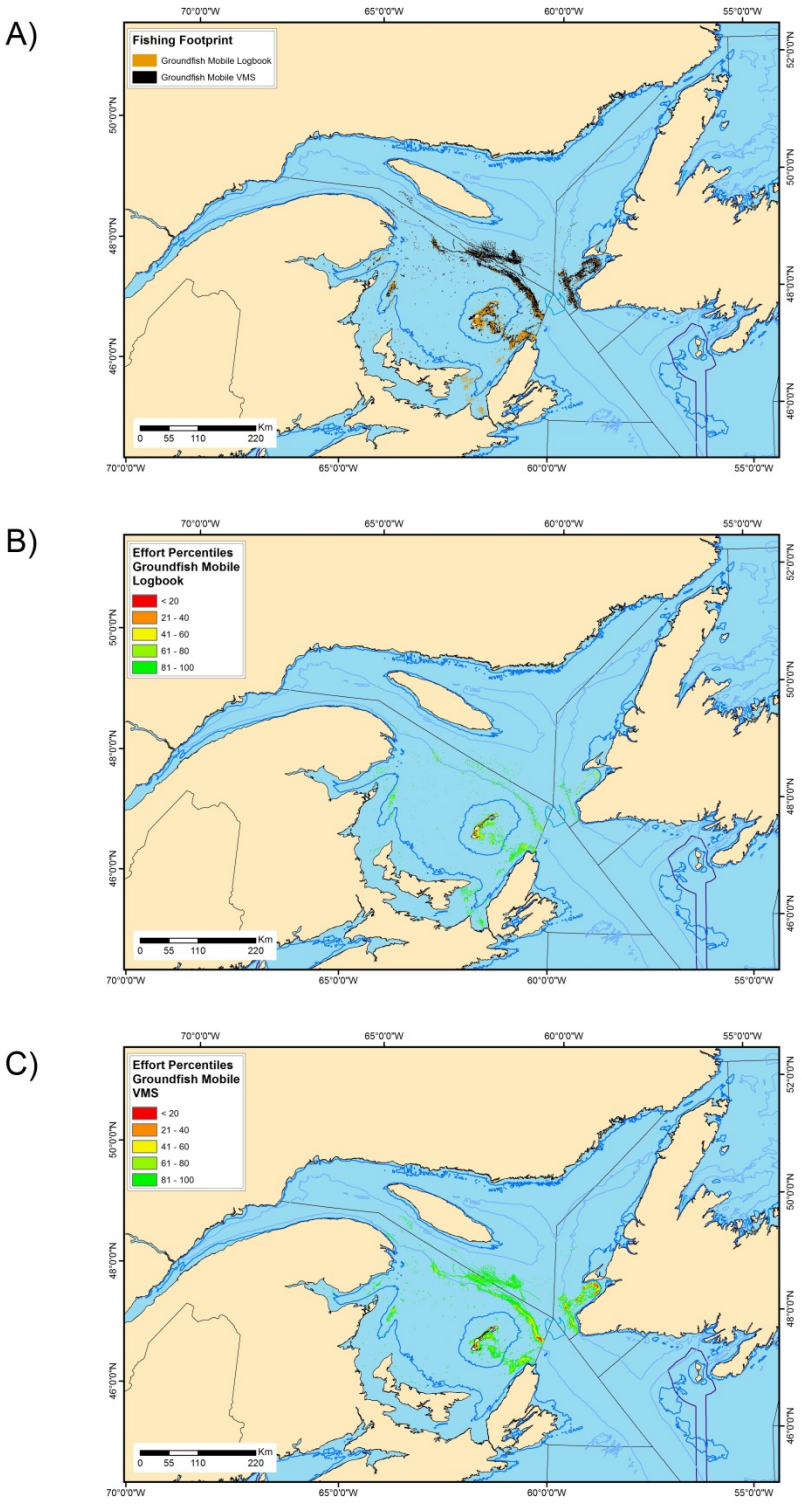

Figure 24. Distribution of the 2005-2014 georeferenced fishing effort for the Gulf of St. Lawrence bioregion for the Groundfish Mobile fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

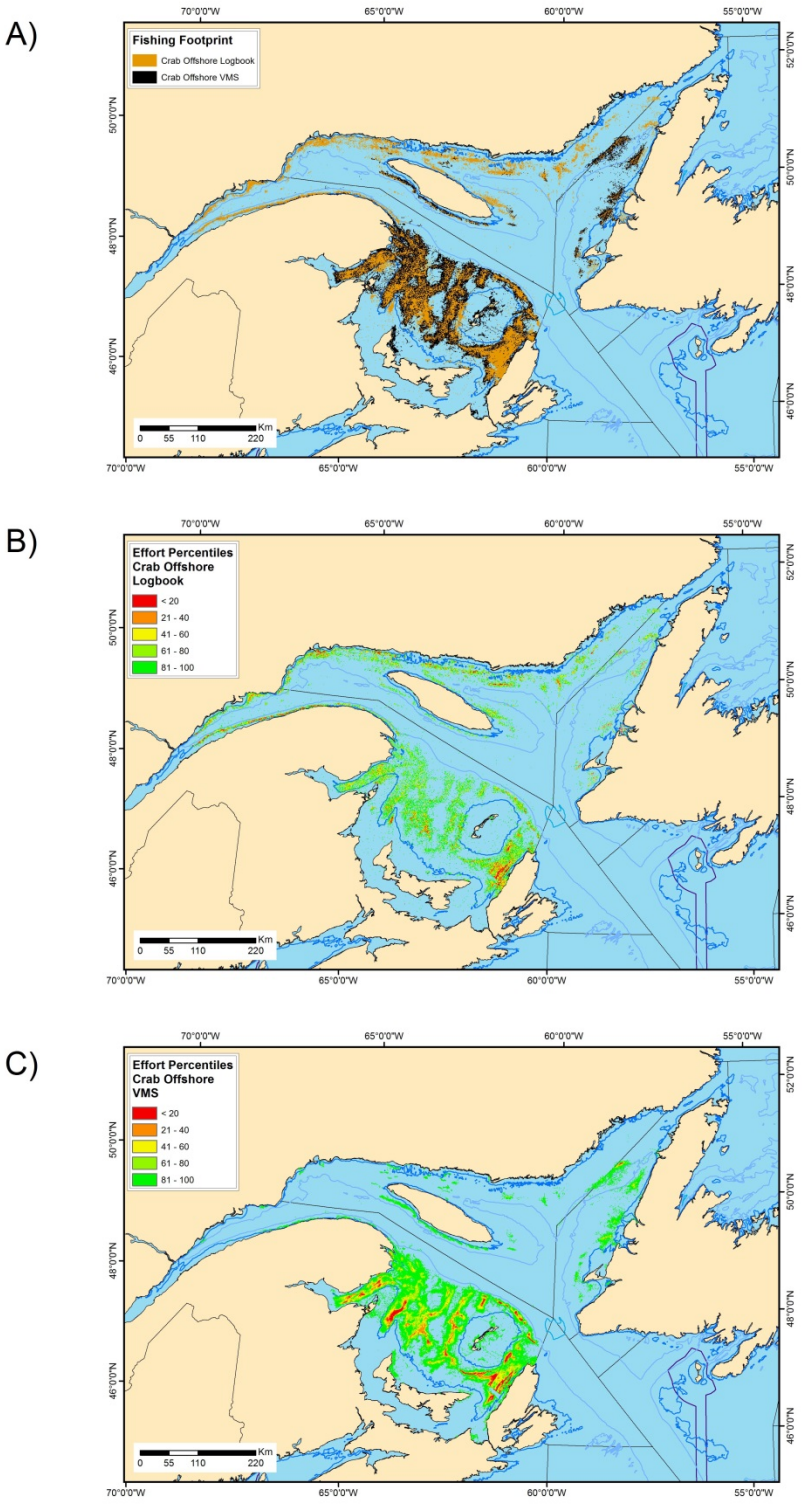

Figure 25. Distribution of the 2005-2014 georeferenced fishing effort for the Gulf of St. Lawrence bioregion for the Crab Offshore fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

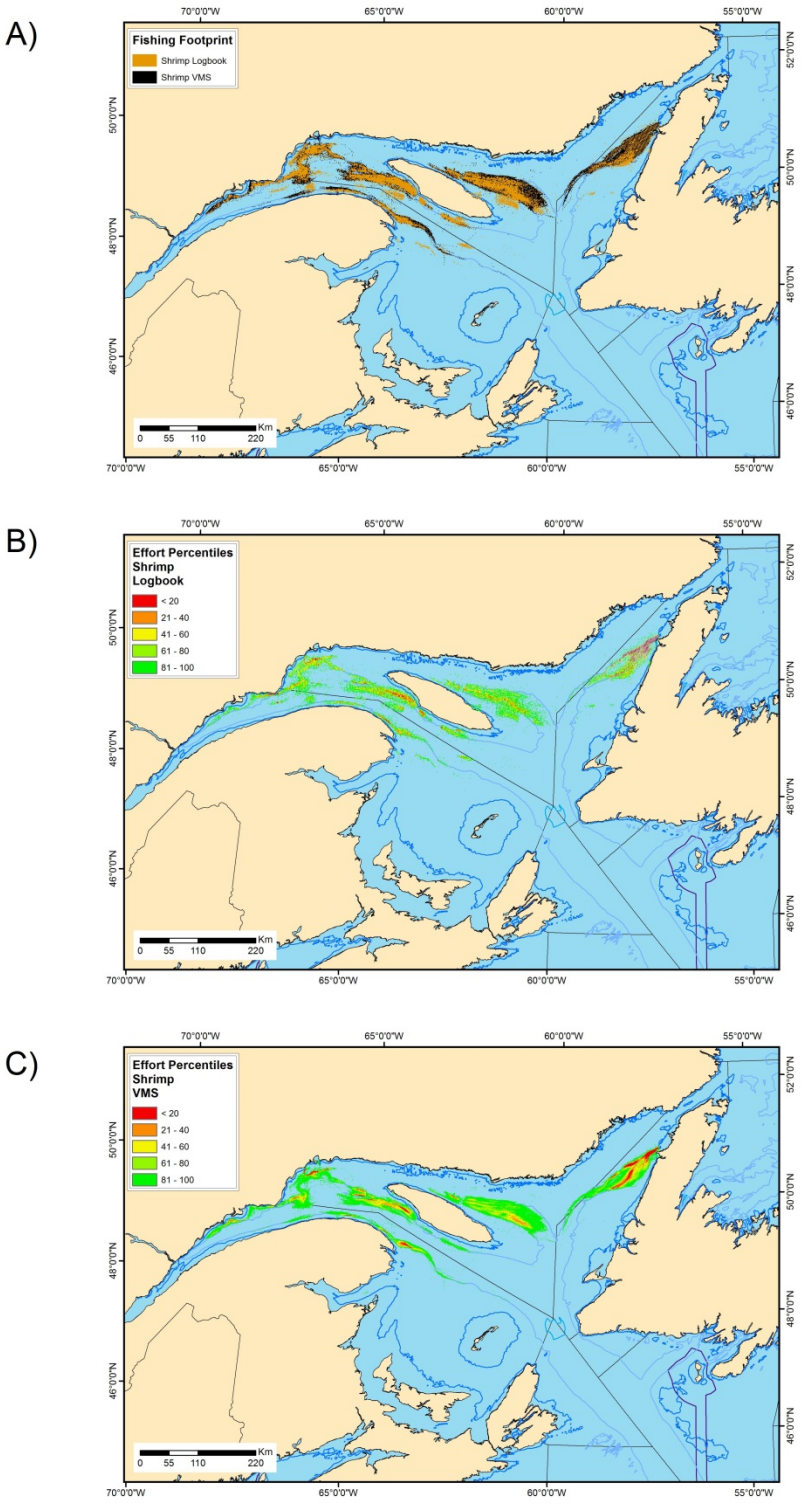

Figure 26. Distribution of the 2005-2014 georeferenced fishing effort for the Gulf of St. Lawrence bioregion the Shrimp fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

*Table 13. Overlap between fishery class footprints and Significant Benthic Areas in the Gulf of St. Lawrence bioregion based on available georeferenced data from logbooks. The surface areas of Significant Benthic Areas are: sea pen (SE) = 15,115 km^2, and sponge (SP) = 19,090 km^2. NA = not applicable (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	SE*	SP*	SE†	SP†	SEº	SPº
Clam	65.1	353	0	24	0	6.9	0	0.1
Crab Inshore	56.7	8,522	5	97	0.1	1.1	0	0.5
Crab Offshore	87.2	28,506	142	1,347	0.5	4.7	0.9	7.1
Echinoderm	57.8	167	0	0	0	0	0	0
Groundfish Fixed	40.1	18,340	1,425	1,381	7.8	7.5	9.4	7.2
Groundfish Mobile	90.4	3,632	372	54	10.2	1.5	2.5	0.3
Lobster	0.5	NA	NA	NA	NA	NA	NA	NA
Misc. Inshore	1.9	110	0	2	0	1.8	0	0
Misc. Offshore	11.1	2	0	0	0	0	0	0
Other	1.6	249	4	0	1.6	0.1	0	0
Pelagic	15.2	5,951	31	31	0.5	0.5	0.2	0.2
Scallop	46.3	3,240	9	105	0.3	3.3	0.1	0.6
Shrimp	89.1	15,503	1,242	848	8	5.5	8.2	4.4
Whelk	81.5	2,773	26	155	0.9	5.6	0.2	0.8
All Fisheries	**15**	**74,064**	**2,981**	**3,648**	**4**	**4.9**	**19.7**	**19.1**

*Table 14.Overlap between fishery class footprints and Significant Benthic Areas in the Gulf of St. Lawrence bioregion based on available georeferenced data from VMS. The surface areas of Significant Benthic Areas are: sea pen (SE) = 15,115 km^2, and sponge (SP) = 19,090 km^2 (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	SE*	SP*	SE†	SP†	SEº	SPº
Clam	3.2	96	0	37	0	38.3	0	0.2
Crab Inshore	0.4	950	0	24	0	2.5	0	0.1
Crab Offshore	50.1	39,171	96	976	0.2	2.5	0.6	5.1
Echinoderm	63.3	389	0	0	0	0	0	0
Groundfish Fixed	7.4	35,047	2,523	4,563	7.2	13	16.7	23.9
Groundfish Mobile	15.1	8,303	2,639	290	31.8	3.5	17.5	1.5
Lobster	0	NA	NA	NA	NA	NA	NA	NA
Misc. Inshore	1	335	0	0	0	0	0	0
Misc. Offshore	16.7	63	2	0	3.6	0	0	0
Other	9.0	6,693	0	20	0	0.3	0	0.1
Pelagic	4.7	10,847	152	270	1.4	2.5	1	1.4
Scallop	5.8	2,623	9	214	0.3	8.2	0.1	1.1
Shrimp	40.5	20,284	1,231	1,149	6.1	5.7	8.1	6
Whelk	1	499	8	32	1.6	6.4	0.1	0.2
All Fisheries	**5.4**	**97,757**	**5,661**	**6,647**	**5.8**	**6.8**	**37.5**	**34.8**

*Table 15. Overlap between fishery class footprints and Significant Benthic Areas in the Gulf of St. Lawrence bioregion based on available georeferenced data from merged logbooks and VMS. The surface areas of Significant Benthic Areas are: sea pen (SE) = 15,115 km^2, and sponge (SP) = 19,090 km^2 (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	SE*	SP*	SE†	SP†	SEº	SPº
Clam	62.9	399	0	42	0	10.5	0	0.2
Crab Inshore	48.3	9,046	5	102	0	1.1	0	0.5
Crab Offshore	81.3	51,245	210	2,022	0.4	3.9	1.4	10.6
Echinoderm	62. 9	409	0	0	0	0	0	0
Groundfish Fixed	38.6	43,937	3,114	5,019	7.1	11.4	20.6	26.3
Groundfish Mobile	88.0	10,147	2,741	311	27	3.1	18.1	1.6
Lobster	0.5	NA	NA	NA	NA	NA	NA	NA
Misc. Inshore	2.2	410	0	2	0	0.5	0	0
Misc. Offshore	19.1	65	2	0	3.5	0	0	0
Other	9.3	6,924	4	20	0.1	0.3	0	0.1
Pelagic	14.4	14,851	163	301	1.1	2	1.1	1.6
Scallop	42.5	4,945	14	245	0.3	5	0.1	1.3
Shrimp	88.6	24,538	1,915	1,608	7.8	6.6	12.7	8.4
Whelk	73.7	3,081	30	160	1	5.2	0.2	0.8
All Fisheries	**16.1**	**125,900**	**6,819**	**8,150**	**5.4**	**6.5**	**45.1**	**42.7**

The analysis of overlap between Significant Benthic Areas and fishing effort in GSL is complex, and can only render a partial and potentially biased perspective. Most of the fishing effort in this bioregion is not georeferenced. The lobster fisheries class represents 63% of the total effort, but it is constrained to shallow waters (less than 50 m), which likely implies low overlap between this class and Significant Benthic Areas. The remainder of the effort is only 40% georeferenced. Therefore, the results here should be considered a minimum estimation of overlap between fisheries effort and Significant Benthic Areas.

The fraction of the fishing effort that does have georeferencing shows high cumulative overlap values with Significant Benthic Areas (Tables 13-15, Figure 27). Similarly to SS, some individual fisheries classes do show high overlaps with Significant Benthic Areas, but the higher total overlap values is the result of cumulative effects across fisheries classes (Tables 13-15).

When aggregates of fisheries classes are considered, 30% and 11% of the Sea pen and Sponge Significant Benthic Areas, respectively, are subject to mobile fishing by bottom contacting gears, but there is a clear pattern of fixed gear fisheries having a higher overlap with Sponge Significant Benthic Areas than mobile gear fisheries classes (Table 16). Overlap maps for the aggregates described in Table 16 are compiled in Appendix 4.

On the basis of the available georeferenced data, the fisheries classes with the highest individual overlaps include Groundfish Fixed, Groundfish Mobile, and Shrimp, and to a lesser extent Crab Offshore (Tables 13-15). The Groundfish Fixed Fisheries class has 39%

georeferencing, but georeferencing for the other three fisheries classes is above 80% (Table 2, Figure 4).

The Gulf of St. Lawrence bioregion was divided into three insets corresponding to the northwestern, northeastern and southern Gulf of St. Lawrence (GSL1, GSL2, and GSL3 respectively, (Figure 27) to better display the overlaps between Significant Benthic Areas and fisheries classes.

*Table 16. Overlap between aggregates of fishery class footprints and Significant Benthic Areas in the Gulf of St. Lawrence bioregion based on available georeferenced data from logbooks, VMS, and merged effort (logbooks and VMS combined). The surface areas of Significant Benthic Areas are: sea pen (SE) = 15,115 km^2, and sponge (SP) = 19,090 km^2 (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ^{o}Percent Significant Benthic Area that overlaps with fishery class footprint (%)). All exc. pelagic = All fisheries excluding pelagic.*

Data source	Fishery class aggregate	Fishing footprint (km^2)	SE*	SP*	SE†	SP†	SE^{o}	SP^{o}
Logbook	Fixed	55,780	1,567	2,900	2.8	5.2	10.4	15.2
Logbook	Mobile	22,688	1,616	1,024	7.1	4.5	10.7	5.4
Logbook	All exc. pelagic	70,629	2,962	3,632	4.2	5.1	19.6	19
VMS	Fixed	72,753	2,575	5,439	3.5	7.5	17	28.5
VMS	Mobile	31,088	3,806	1,665	12.2	5.4	25.2	8.7
VMS	All exc. pelagic	90,907	5,642	6,425	6.2	7.1	37.3	33.7
Merged	Fixed	99,779	3,255	6,947	3.3	7	21.5	36.4
Merged	Mobile	39,514	4,563	2,166	11.5	5.5	30.2	11.3
Merged	All exc. pelagic	118,672	6,803	7,938	5.7	6.7	45	41.6

The general region of the St. Lawrence estuary and northwestern GSL is captured by inset GSL1 (Figure 27), and shows an overall high overlap between fishing effort and Significant Benthic Areas. Four areas within this region were highlighted due to the overlap of higher intensity fishing and Significant Benthic Areas (Figure 28). The GSL1a area is located in the St. Lawrence estuary and it is associated with a Sponge Significant Benthic Area. The overlap with fishing in this area is linked to the Groundfish Fixed (Figure 29), Crab Offshore (Figure 30), and Shrimp (Figure 31) fisheries classes. The general area GSL1b corresponds to the mouth of the St. Lawrence estuary and the Strait of Honguedo, which separates the Gaspé Peninsula and Anticosti Island. In this area, the overlap with Sponge and Sea pen Significant Benthic Areas is associated with Groundfish Fixed (Figure 29) and Shrimp (Figure 31) fisheries classes. The area GSL1c, to the northwest of Anticosti Island, is associated with Sponge Significant Benthic Areas, and the main fisheries classes overlapping with Significant Benthic Areas in this area are Groundfish Fixed (Figure 29) and Crab Offshore (Figure 30). The area GSL1d is to the east of the Gaspé Peninsula, along the southern fringe of the Laurentian Chanel, and involves a Sea pen Significant Benthic Area. The fishing effort in this area is associated with the Groundfish Fixed (Figure 29), Shrimp (Figure 31) and Groundfish Mobile (Figure 32) fisheries classes.

The northeastern Gulf of St. Lawrence is captured in inset GSL2 (Figure 27), and only contains Sponge Significant Benthic Areas. This region shows more marginal overlaps of fishing effort with Significant Benthic Areas, and only three general areas of overlap with high fishing effort were highlighted in this region (Figure 33) The area GSL2a, to the northeast of Anticosti Island, is associated with the Groundfish Fixed (Figure 34), and to a lesser extent the Crab Offshore

(Figure 35), fisheries classes. The fishing effort in area GSL2b, to the west of Newfoundland's Northern Peninsula, is linked to the Groundfish Fixed (Figure 34) and Shrimp (Figure 36) fisheries classes. The area GSL2c, to the west of Bonne Bay, NL, is characterized by effort from the Groundfish Fixed (Figure 34) and Crab Offshore (Figure 35) fisheries classes.

The southern Gulf of St. Lawrence and the southwestern shore of Newfoundland are captured in inset GSL3 (Figure 27). Four areas have been highlighted in this region (Figure 37). The GSL3a area is associated with the same Sea pen Significant Benthic Area where GSL1d is located. The fishing effort in this area is mostly linked to the Groundfish Mobile (Figure 38) fisheries class. Area GSL3b is associated with another Sea pen Significant Benthic Area, and the effort in this area is also linked to the Groundfish Mobile (Figure 38) fisheries class. The area GSL3c, to the west of Cape Saint John, NL, involves two Sponge Significant Benthic Areas. The effort in this area is driven by the Groundfish Mobile (Figure 38) and Groundfish Fixed (Figure 39) fisheries classes, with a small contribution by the Crab Offshore (Figure 40) fisheries class. Finally, area GSL3d, in shallow waters to the south of Magdalen Islands, is associated with a Sponge Significant Benthic Area. The effort in this area is linked to the Crab Inshore (Figure 41) and Scallop (Figure 42) fisheries classes.

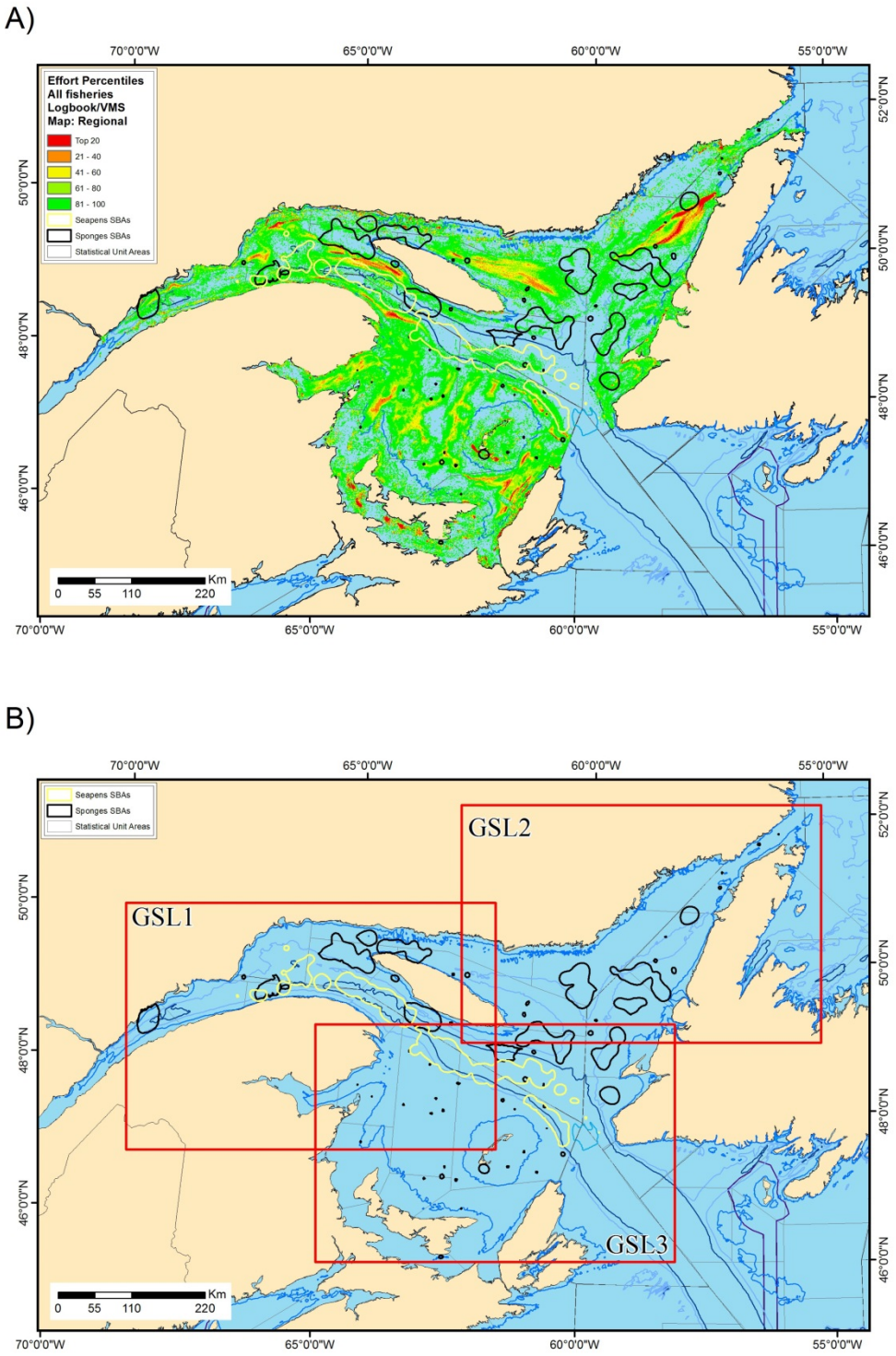

Figure 27. Overlap between all fishing effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion. A) Overlap between all Significant Benthic Area categories and fishing effort, where fishing effort intensity is displayed using the merged logbook/VMS percentile layer; B) Distribution of Significant Benthic Areas showing inset locations GSL1, GSL2 and GSL3 that display overlaps in more detail.

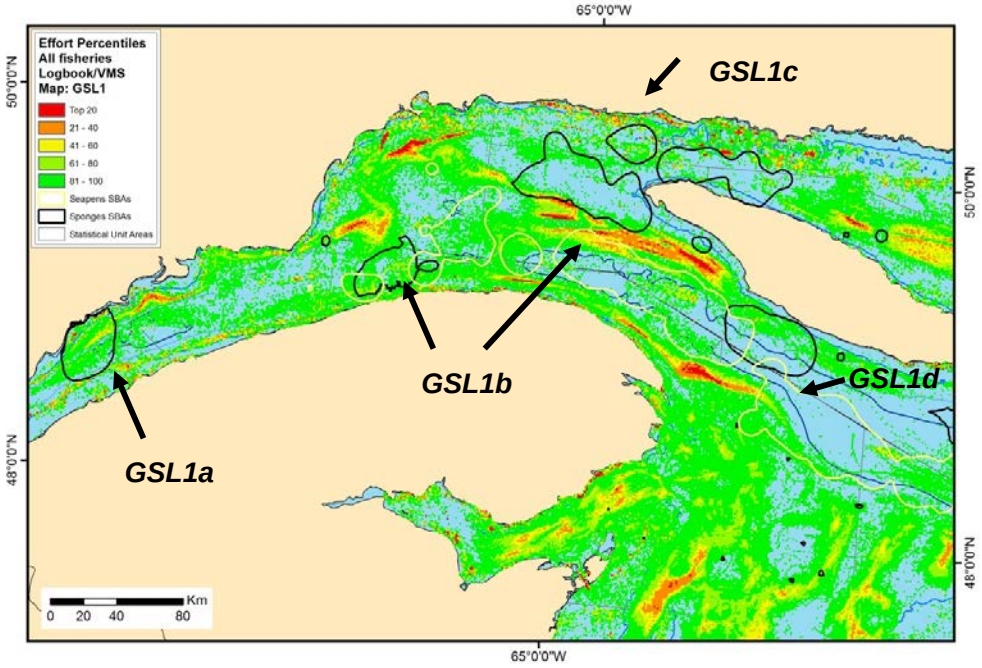

Figure 28. Overlap between all effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL1. Arrows indicate general areas of overlap with higher fishing intensity.

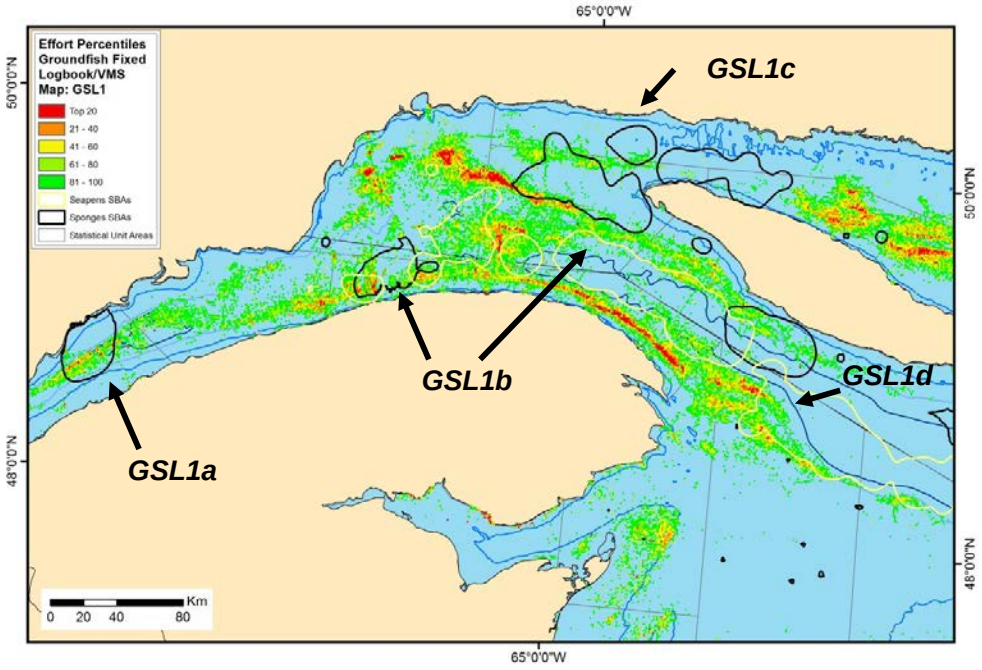

Figure 29. Overlap between Groundfish Fixed effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL1. Arrows indicate general areas of overlap with higher fishing intensity.

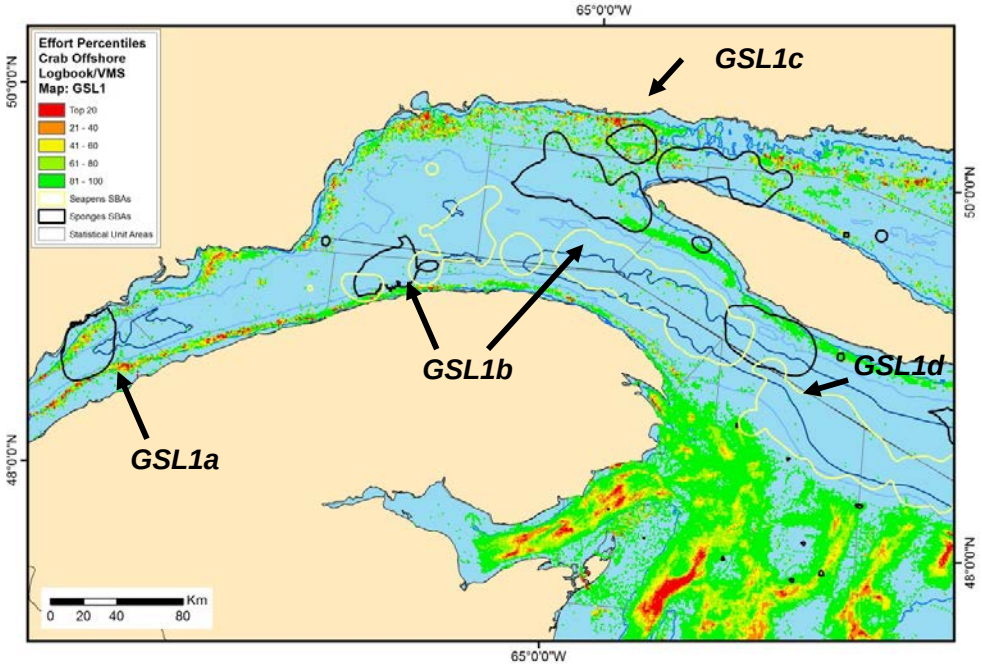

Figure 30. Overlap between Crab Offshore effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL1. Arrows indicate general areas of overlap with higher fishing intensity.

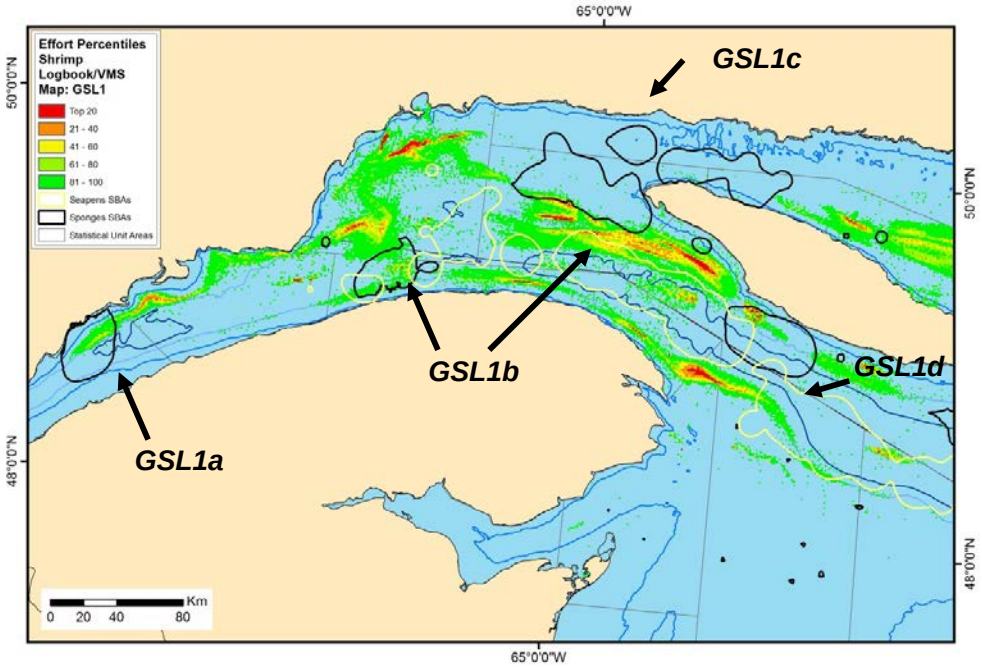

Figure 31. Overlap between Shrimp effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL1. Arrows indicate general areas of overlap with higher fishing intensity.

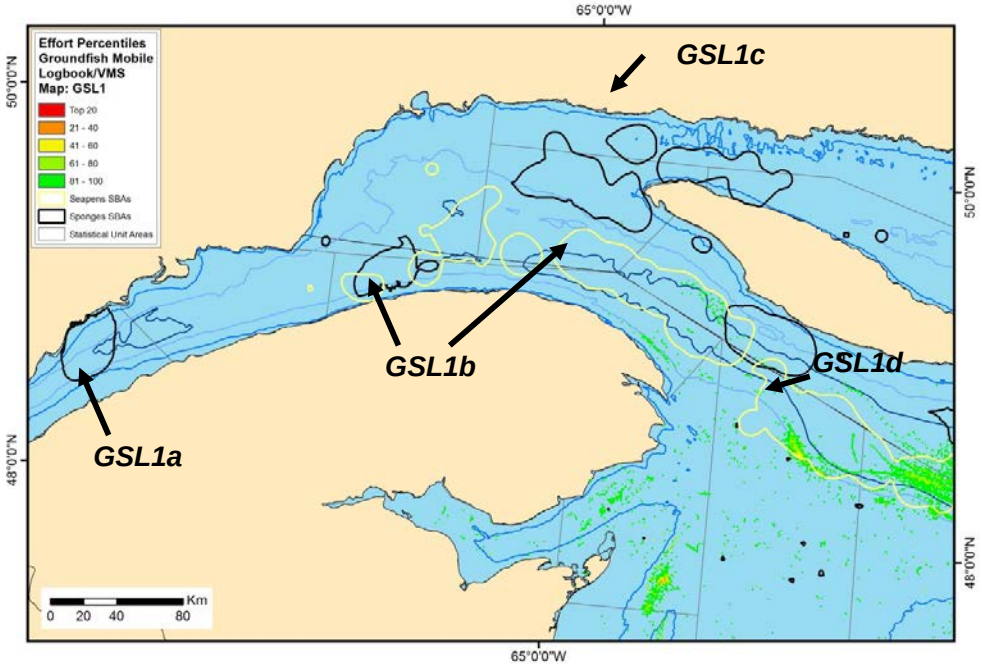

Figure 32. Overlap between Groundfish Mobile effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL1. Arrows indicate general areas of overlap with higher fishing intensity.

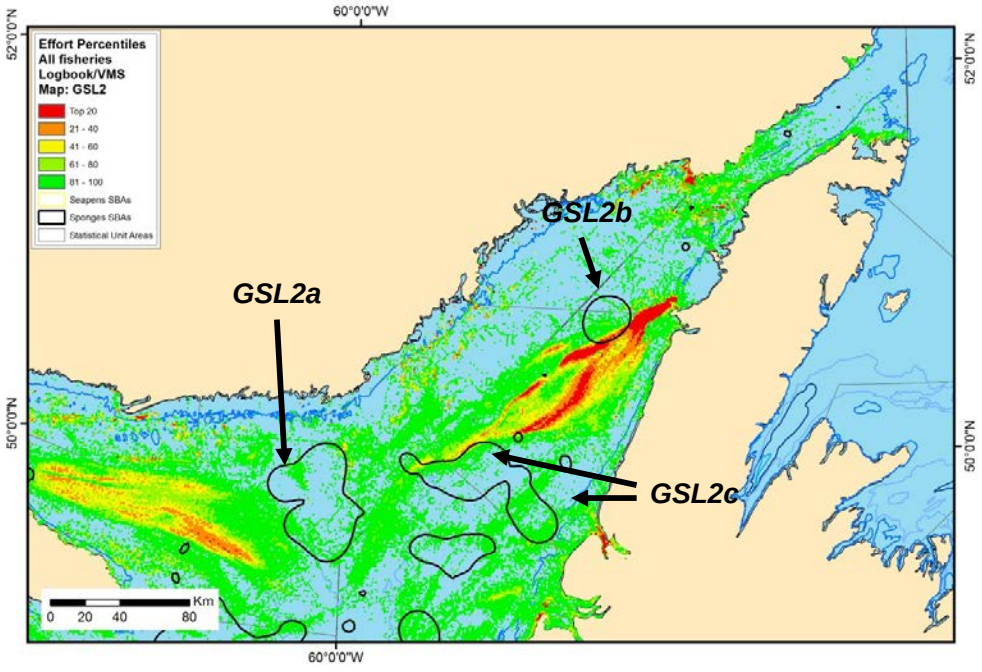

Figure 33. Overlap between all effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL2. Arrows indicate general areas of overlap with higher fishing intensity.

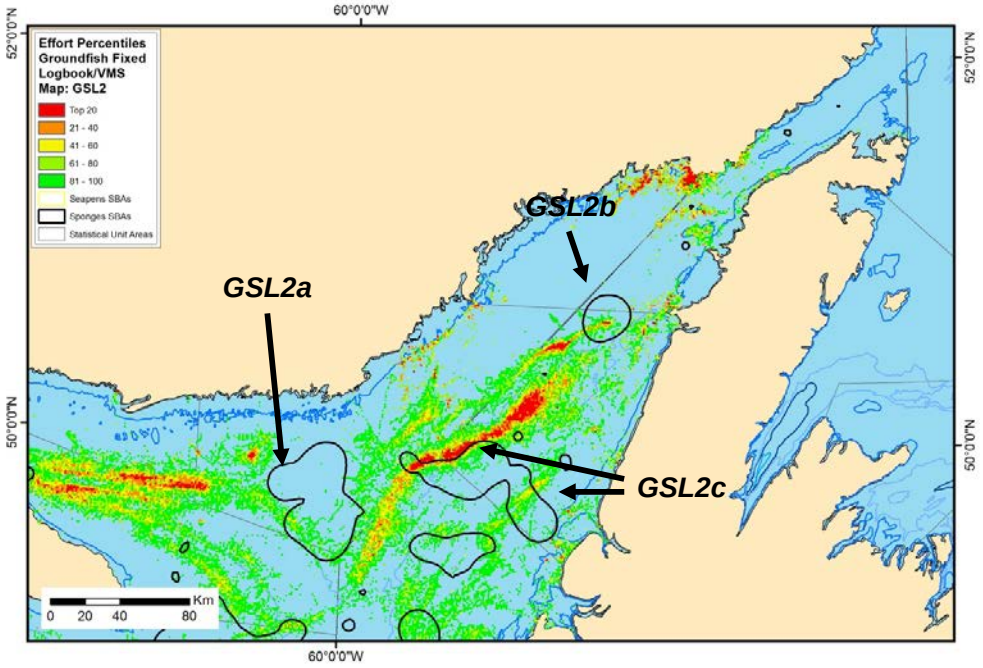

Figure 34. Overlap between Groundfish Fixed effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL2. Arrows indicate general areas of overlap with higher fishing intensity.

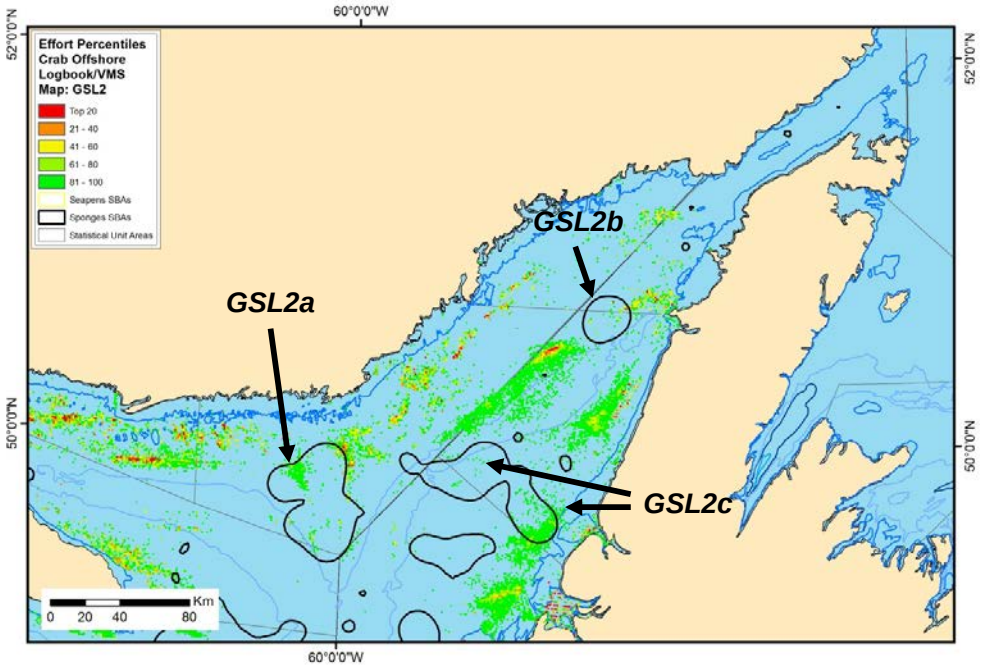

Figure 35. Overlap between Crab Offshore effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL2. Arrows indicate general areas of overlap with higher fishing intensity.

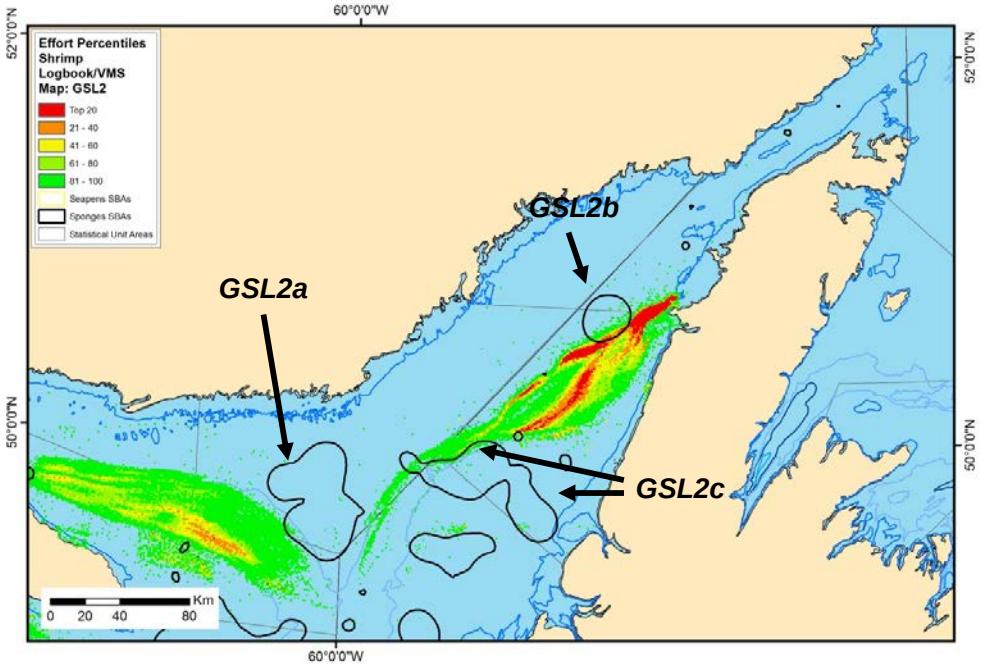

Figure 36. Overlap between Shrimp effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL2. Arrows indicate general areas of overlap with higher fishing intensity.

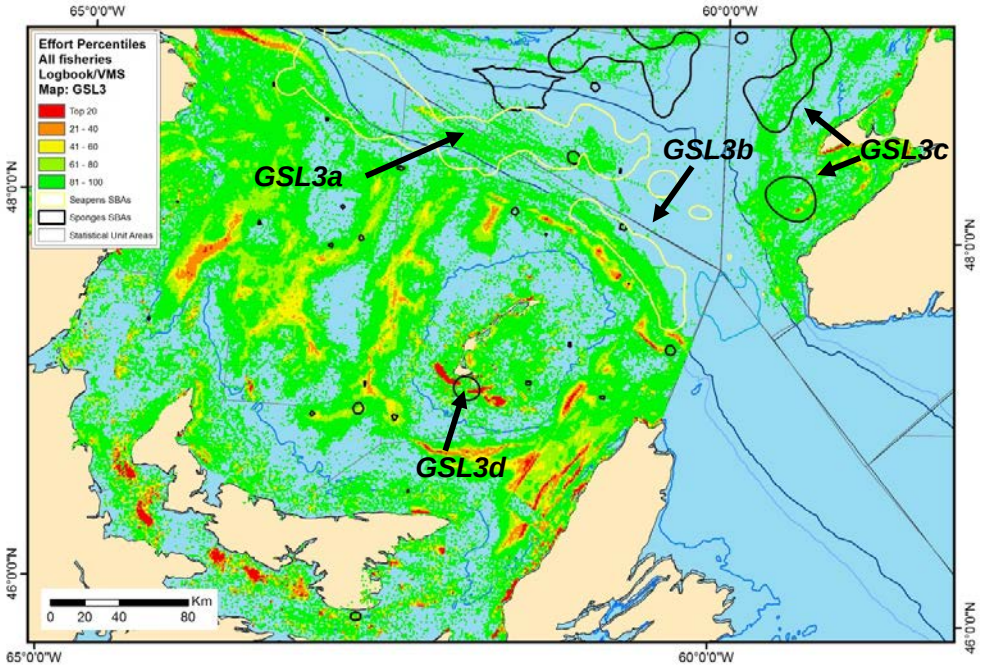

Figure 37. Overlap between all effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL3. Arrows indicate general areas of overlap with higher fishing intensity.

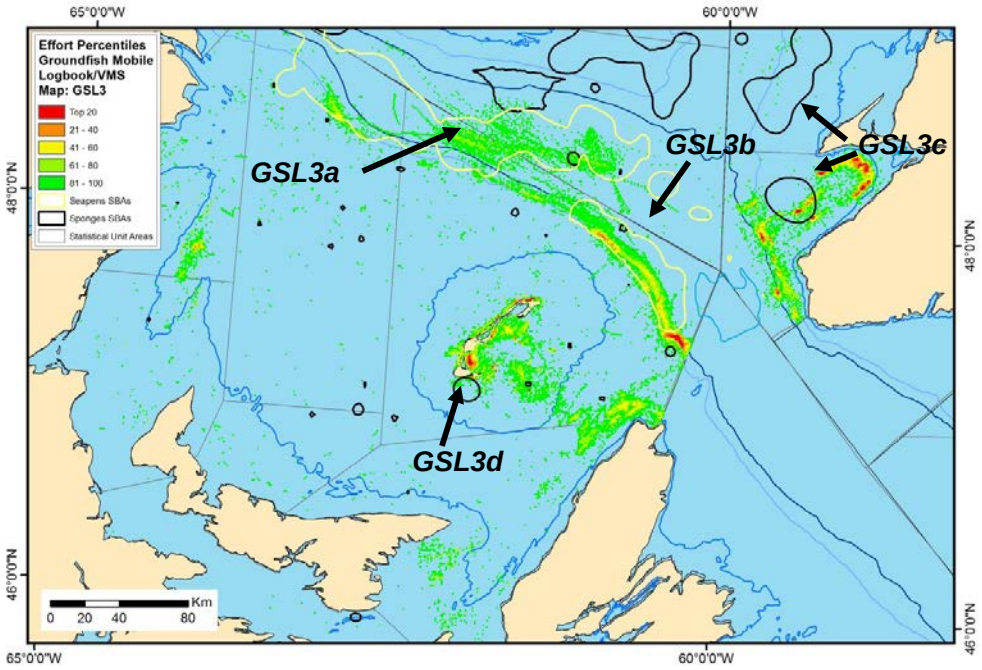

Figure 38. Overlap between Groundfish Mobile effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL3. Arrows indicate general areas of overlap with higher fishing intensity.

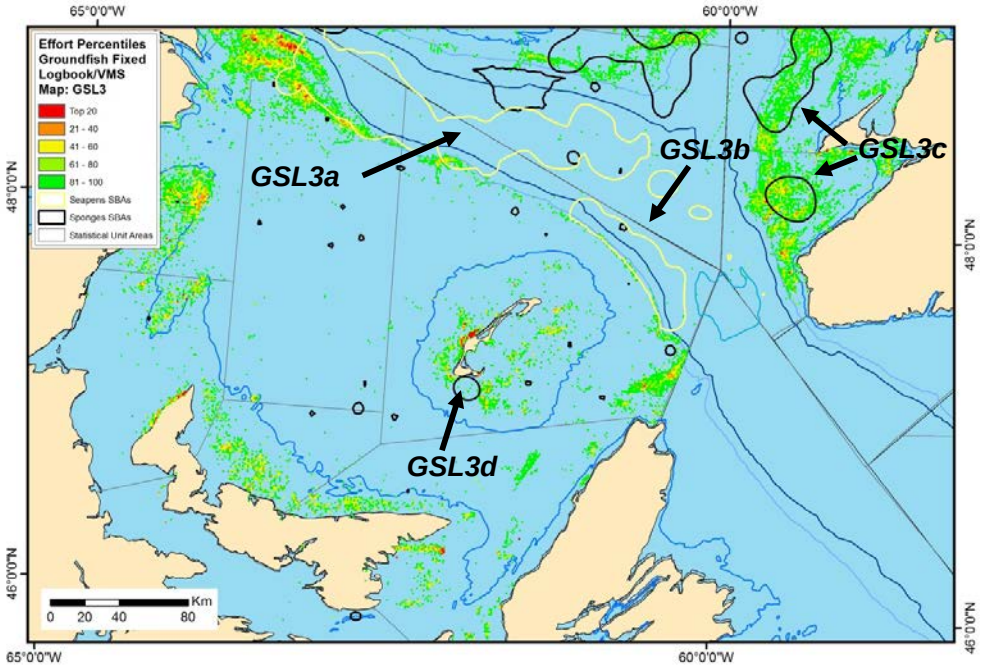

Figure 39. Overlap between Groundfish Fixed effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL3. Arrows indicate general areas of overlap with higher fishing intensity.

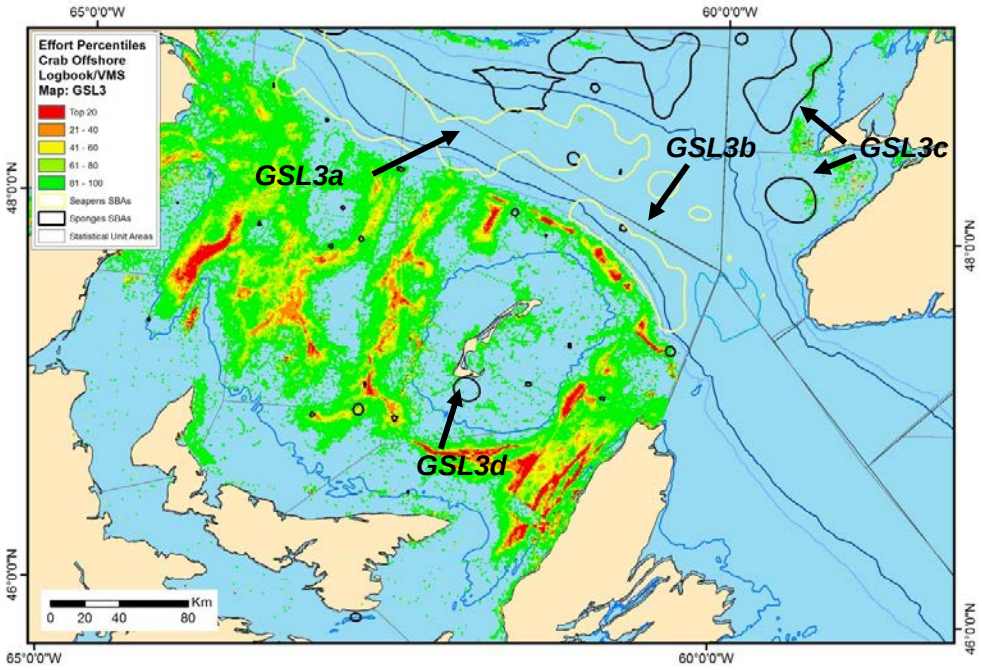

Figure 40. Overlap between Crab Offshore effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL3. Arrows indicate general areas of overlap with higher fishing intensity.

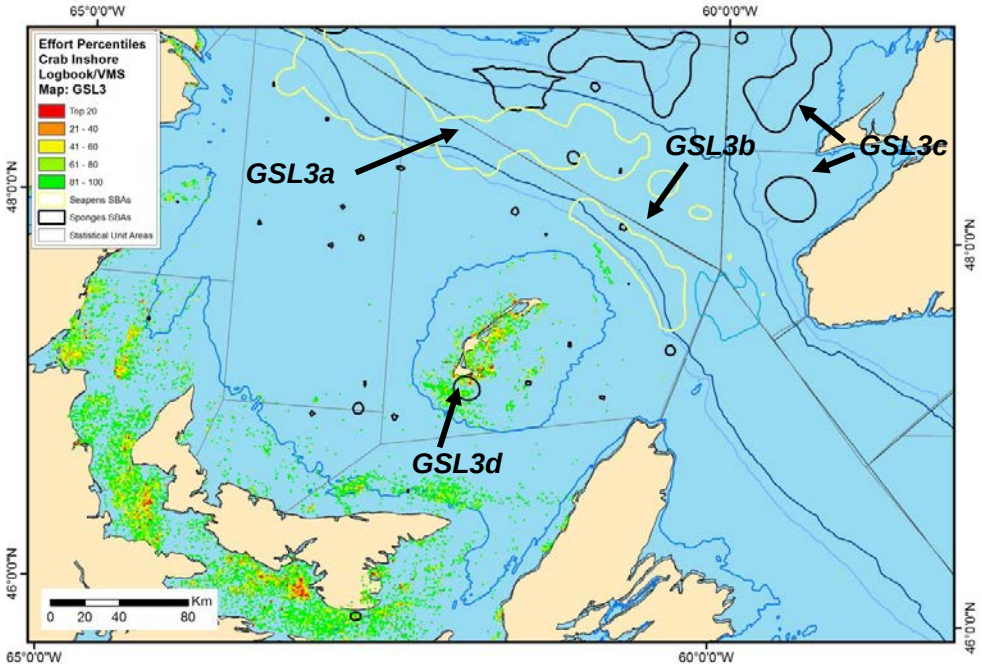

Figure 41. Overlap between Crab Inshore effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL3. Arrows indicate general areas of overlap with higher fishing intensity.

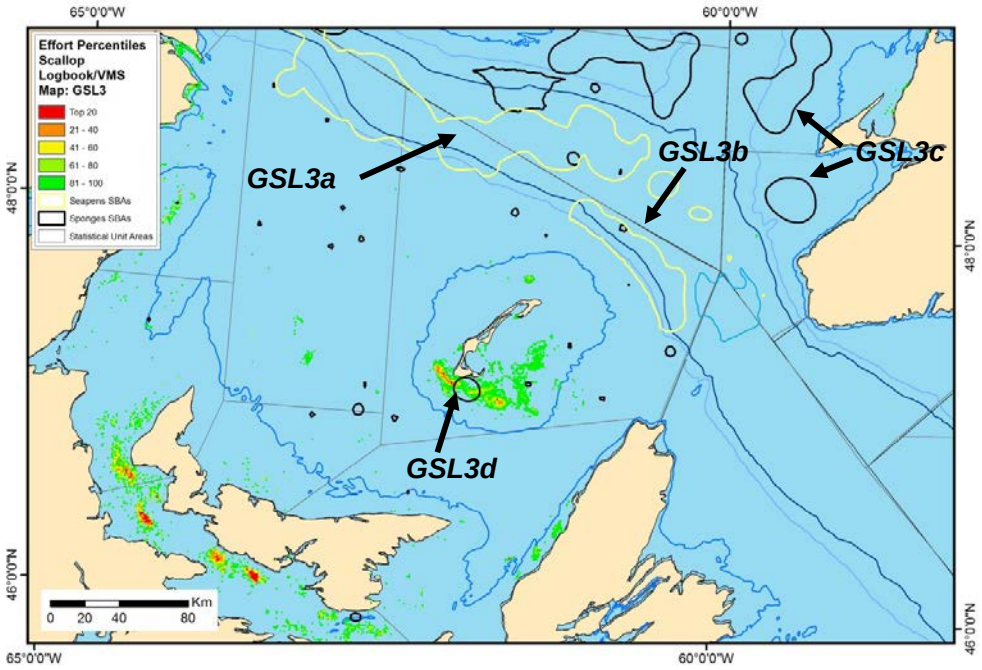

Figure 42. Overlap between Scallop effort and Significant Benthic Areas in the Gulf of St. Lawrence bioregion, inset GSL3. Arrows indicate general areas of overlap with higher fishing intensity.

Newfoundland and Labrador bioregion

The total fishing effort in the NL bioregion in the period 2005-2014 amounts to 747,928 VD. Unlike SS and GSL bioregions, fishing effort in NL is less skewed towards a single fishery (Figure 4). The dominant fisheries classes, in term of fishing effort, are Groundfish Fixed (39%), followed by Crab Offshore (25%), Shrimp (12%), Lobster (11%), and Pelagic (6%). These top five fisheries classes accumulated 93% of the total fishing effort in the bioregion (Table 17).

In NL, 41% of the total fishing effort is georeferenced. This effort defines an estimated fishing footprint of 82,113 km^2 based on logbook data, and 277,713 km^2 from VMS data. The general distribution of the effort from both sources is highly coherent, defining a very similar overall footprint (Figure 43). Logbook and VMS georeferenced data also highlight the same areas of concentration of fishing effort (Figure 43).

As observed for SS and GSL, effort in NL also appears concentrated, with highly fished areas representing relatively small fractions of the estimated footprints (Tables 17-19). In the NL bioregion, 40% of the effort is typically exerted in less than 20% of the estimated fisheries class footprints estimated from logbooks (Table 17), but the VMS-based footprint showed a higher concentration of effort where 40% of the effort was applied in 10% or less of the estimated footprints (Table 18). Overall, the VMS data showed a higher concentration of effort than the logbook data.

In terms of overlaps with Significant Benthic Areas (Tables 20-22), some of the key fisheries classes in this bioregion include Groundfish Fixed (Figure 44), Groundfish Mobile (Figure 45), and Shrimp (Figure 46). Fisheries footprints and effort distributions based on available data for all other fisheries classes in this bioregion can be found in Appendices 2 and 3.

Table 17. Distribution of georeferenced fishing effort and fishery class footprints from logbook data for the Newfoundland and Labrador bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Groundfish Fixed	38.7	14.3	5.5	13,198	4.9	15.4	32.4	65.1
Crab Offshore	24.6	72.6	23.4	38,582	7.3	18.3	34.0	59.0
Shrimp	12.3	98.8	35.6	29,937	6.8	17.1	33.0	59.8
Lobster	11.1	0.0	35.6	NA	NA	NA	NA	NA
Pelagic	6.4	22.0	37.0	3,131	4.0	13.0	29.5	62.3
Whelk	2.3	63.6	38.5	1,423	7.4	16.9	30.3	51.9
Groundfish Mobile	1.3	98.5	39.8	4,786	6.4	18.8	38.6	69.3
Scallop	0.9	75.4	40.5	885	5.3	13.5	29.5	60.6
Other	0.8	11.2	40.6	154	4.6	16.2	43.5	71.4
Crab Inshore	0.8	0.5	40.6	19	10.5	31.6	52.6	73.7
Misc. Inshore	0.4	0.2	40.6	4	NA	NA	NA	NA
Clam	0.1	100.0	40.7	183	9.3	22.4	46.4	73.2
Misc. Offshore	0.1	99.5	40.7	231	6.5	19.5	43.3	71.4
Echinoderm	0.1	37.1	40.8	33	6.1	18.2	30.3	60.6
All fisheries	**100**	**40.8**	**40.8**	**82,113**	**2.9**	**9.7**	**21.3**	**42.7**

Table 18. Distribution of georeferenced fishing effort and fishery class footprints from VMS data for the Newfoundland and Labrador bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Groundfish Fixed	38.7	8.8	3.4	63,060	1.3	5.8	14.6	32.2
Crab Offshore	24.6	40.3	13.4	124,096	3.7	9.9	19.5	36.1
Shrimp	12.3	90.7	24.5	103,906	3.1	8.1	16.3	31.8
Lobster	11.1	0.0	24.5	NA	NA	NA	NA	NA
Pelagic	6.4	17.9	25.7	18,972	0.8	3.6	11.0	30.9
Whelk	2.3	39.6	26.6	5,980	2.3	5.9	11.6	22.4
Groundfish Mobile	1.3	85.7	27.8	29,194	2.0	5.9	13.5	30.6
Scallop	0.9	48.3	28.2	2,678	1.6	4.2	8.4	16.1
Other	0.8	2.1	28.2	530	2.5	10.0	27.4	63.2
Crab Inshore	0.8	0.0	28.2	NA	NA	NA	NA	NA
Misc. Inshore	0.4	0.0	28.8	NA	NA	NA	NA	NA
Clam	0.1	97.5	28.3	850	1.8	4.5	9.1	18.7
Misc. Offshore	0.1	88.1	28.3	1,829	3.0	9.7	21.1	41.3
Echinoderm	0.1	34.8	28.4	112	0.9	3.6	8.0	18.7
All fisheries	**100**	**28.3**	**28.4**	**277,713**	**2.4**	**7.2**	**15.6**	**31.3**

Table 19. Distribution of georeferenced fishing effort and fishery class footprints from merged logbook and VMS data for the Newfoundland and Labrador bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Groundfish Fixed	38.7	14.5	5.6	66,617	1.3	5.9	14.8	33.0
Crab Offshore	24.6	72.5	23.6	136,130	4.0	10.4	20.2	37.4
Shrimp	12.3	98.8	35.8	106,358	3.0	7.9	15.9	31.7
Lobster	11.1	0.0	35.8	NA	NA	NA	NA	NA
Pelagic	6.4	25.5	37.5	20,527	0.9	4.0	11.9	33.2
Whelk	2.3	61.9	39.0	6,281	2.2	5.6	11.1	21.6
Groundfish Mobile	1.3	98.5	40.0	30,318	1.9	5.7	13.6	31.7
Scallop	0.9	73.1	41.0	3,064	1.6	4.2	9.9	22.3
Other	0.8	11.1	41.1	673	3.0	11.3	30.6	64.6
Crab Inshore	0.8	0.5	41.1	19	10.5	31.58	52.63	73.68
Misc. Inshore	0.4	0.2	41.1	NA	NA	NA	NA	NA
Clam	0.1	100.0	41.2	902	1.7	4.3	10.2	21.1
Misc. Offshore	0.1	99.5	41.2	1,872	2.9	9.6	21.1	41.9
Echinoderm	0.1	42.7	41.2	129	0.8	3.9	8.5	24.0
All fisheries	**100**	**41.2**	**41.2**	**293,715**	**2.5**	**7.4**	**15.9**	**31.5**

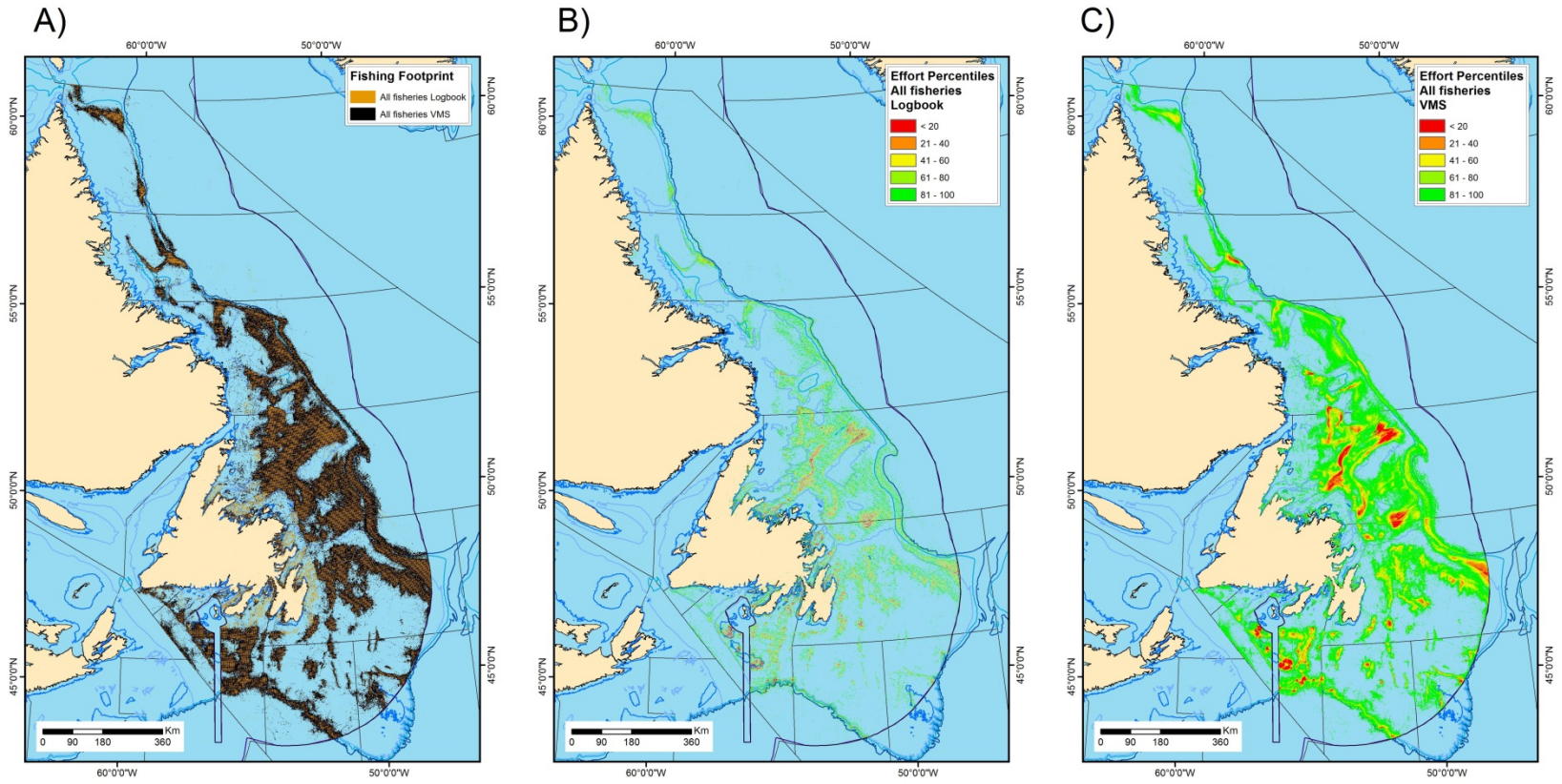

Figure 43. Distribution of the 2005-2014 georeferenced fishing effort for the Newfoundland and Labrador bioregion for all fisheries classes combined. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

*Table 20. Overlap between fishery class footprints and Significant Benthic Areas in the Newfoundland and Labrador bioregion based on available georeferenced data from logbooks. The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 15,542 km^2, sea pen (SE) = 37,457 km^2, small gorgonian (SG) = 4,987 km^2, and sponge (SP) = 43,472 km^2. NA = not applicable (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Clam	100	183	0	0	0	0	0	0	0	0	0	0	0	0
Crab Inshore	0.5	19	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Crab Offshore	72.6	38,582	62	155	5	228	0.2	0.4	0	0.6	0.4	0.4	0.1	0.5
Echinoderm	37.1	33	0	0	0	0	0	0	0	0	0	0	0	0
Groundfish Fixed	14.3	13,198	903	3,033	579	1,420	6.8	23	4.4	10.8	5.8	8.1	11.6	3.3
Groundfish Mobile	98.5	4,786	268	930	231	539	5.6	19.4	4.8	11.3	1.7	2.5	4.6	1.2
Lobster	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Misc. Inshore	0.2	4	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Offshore	99.5	231	47	58	13	0	20.1	24.9	5.8	0	0.3	0.2	0.3	0
Other	11.2	154	0	8	0	0	0	5.1	0	0	0	0	0	0
Pelagic	22	3,131	44	49	243	0	1.4	1.6	7.8	0	0.3	0.1	4.9	0
Scallop	75.4	885	0	22	0	0	0	2.4	0	0	0	0.1	0	0
Shrimp	98.8	29,937	613	995	15	1,894	2	3.3	0.1	6.3	3.9	2.7	0.3	4.4
Whelk	63.6	1,423	1	16	0	0	0.1	1.1	0	0	0	0	0	0
All Fisheries	**40.7**	**82,113**	**1,673**	**4,651**	**798**	**3,788**	**2**	**5.7**	**1**	**4.6**	**10.8**	**12.4**	**16**	**8.7**

*Table 21. Overlap between fishery class footprints and Significant Benthic Areas in the Newfoundland and Labrador bioregion based on available data from VMS. The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 15,542 km^2, sea pen (SE) = 37,457 km^2, small gorgonian (SG) = 4,987 km^2, and sponge (SP) = 43,472 km^2. NA = not applicable (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Clam	97.5	850	0	0	0	0	0	0	0	0	0	0	0	0
Crab Inshore	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Crab Offshore	40.3	124,096	386	264	32	1,583	0.3	0.2	0	1.3	2.5	0.7	0.6	3.6
Echinoderm	34.8	112	0	0	0	0	0	0	0	0	0	0	0	0
Groundfish Fixed	8.8	63,060	3,919	15,911	3,385	9,167	6.2	25.2	5.4	14.5	25.2	42.5	67.9	21.1
Groundfish Mobile	85.7	29,194	1,268	8,014	1,335	3,614	4.3	27.5	4.6	12.4	8.2	21.4	26.8	8.3
Lobster	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Misc. Inshore	0.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Misc. Offshore	88.1	1,829	265	338	95	0	14.5	18.5	5.2	0	1.7	0.9	1.9	0
Other	2.1	530	0	35	1	1	0	6.5	0.2	0.2	0	0.1	0	0
Pelagic	17.9	18,972	312	267	1,611	74	1.6	1.4	8.5	0.4	2	0.7	32.3	0.2
Scallop	48.3	2,678	0	7	0	0	0	0.3	0	0	0	0	0	0
Shrimp	90.7	103,906	1,515	3,288	54	5,948	1.5	3.2	0.1	5.7	9.7	8.8	1.1	13.7
Whelk	39.6	5,980	0	19	0	0	0	0.3	0	0	0	0	0	0
All Fisheries	**28.3**	**277,713**	**5,890**	**20,911**	**3,680**	**15,932**	**2.1**	**7.5**	**1.3**	**5.7**	**37.9**	**55.8**	**73.8**	**36.6**

*Table 22.Overlap between fishery class footprints and Significant Benthic Areas in the Newfoundland and Labrador bioregion based on available georeferenced data from merged logbooks and VMS. The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 15,542 km^2, sea pen (SE) = 37,457 km^2, small gorgonian (SG) = 4,987 km^2, and sponge (SP) = 43,472 km^2. NA = not applicable (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Clam	100	902	0	0	0	0	0	0	0	0	0	0	0	0
Crab Inshore	0.5	19	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Crab Offshore	72.5	136,130	411	411	37	1,649	0.3	0.3	0	1.2	2.6	1.1	0.7	3.8
Echinoderm	42.7	129	0	0	0	0	0	0	0	0	0	0	0	0
Groundfish Fixed	14.5	66,617	3,987	16,107	3,436	9,316	6	24.2	5.2	14	25.7	43	68.9	21.4
Groundfish Mobile	98.5	30,318	1,308	8,298	1,380	3,685	4.3	27.4	4.6	12.2	8.4	22.2	27.7	8.5
Lobster	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Misc. Inshore	0.2	4	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Offshore	99.5	1,872	275	347	98	0	14.7	18.5	5.2	0	1.8	0.9	2	0
Other	11.1	673	0	42	1	1	0	6.3	0.1	0.1	0	0.1	0	0
Pelagic	25.5	20,527	324	302	1,656	74	1.6	1.5	8.1	0.4	2.1	0.8	33.2	0.2
Scallop	73.1	3,064	0	28	0	0	0	0.9	0	0	0	0.1	0	0
Shrimp	98.8	106,358	1,555	3,519	58	6,125	1.5	3.3	0.1	5.8	10	9.4	1.2	14.1
Whelk	61.9	6,281	1	35	0	0	0	0.6	0	0	0	0.1	0	0
All Fisheries	**41.3**	**293,715**	**6,002**	**21,306**	**3,726**	**16,228**	**2**	**7.3**	**1.3**	**5.5**	**38.6**	**56.9**	**74.7**	**37.3**

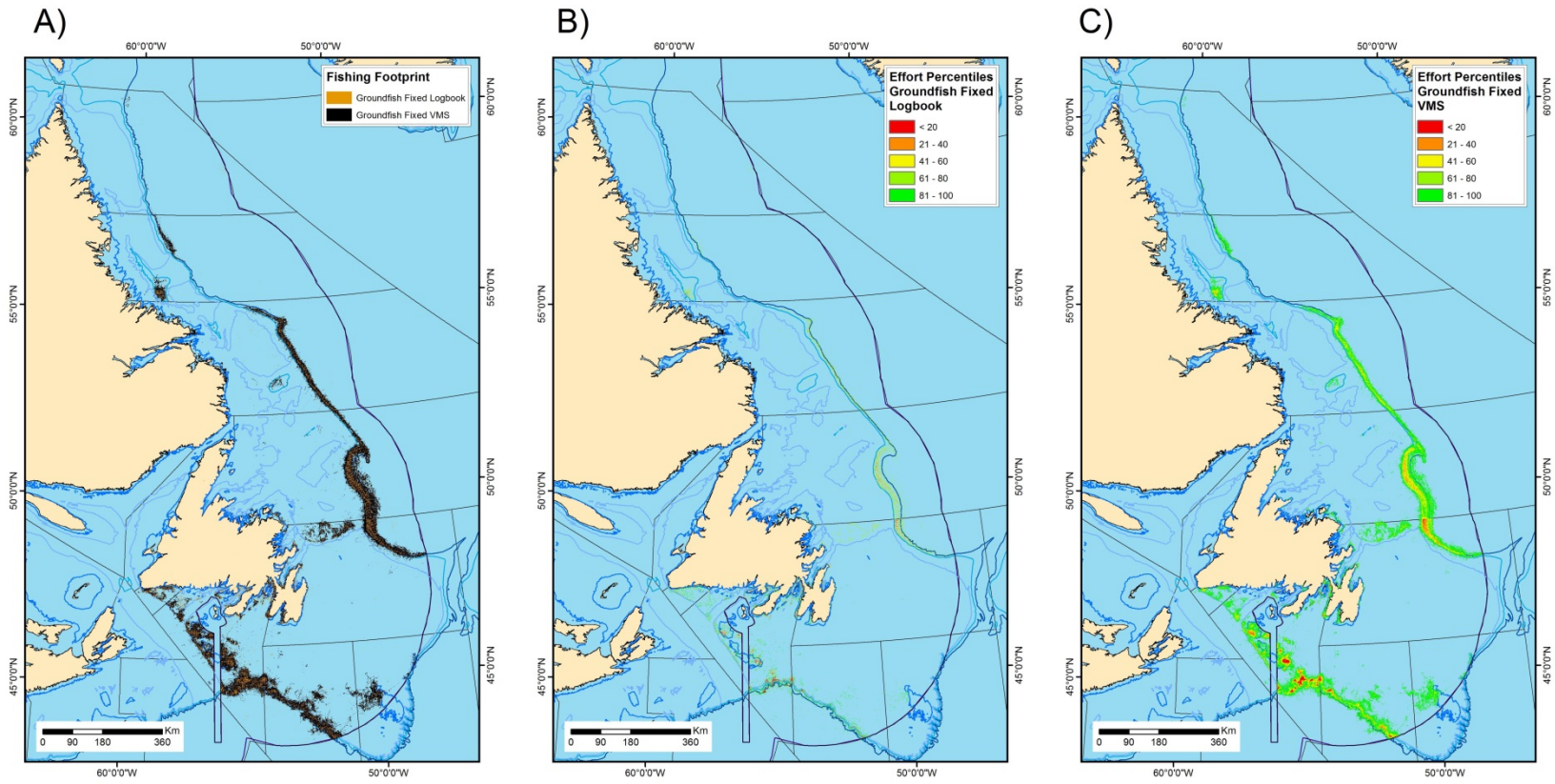

Figure 44. Distribution of the 2005-2014 georeferenced fishing effort for the Newfoundland and Labrador bioregion for the Groundfish Fixed fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

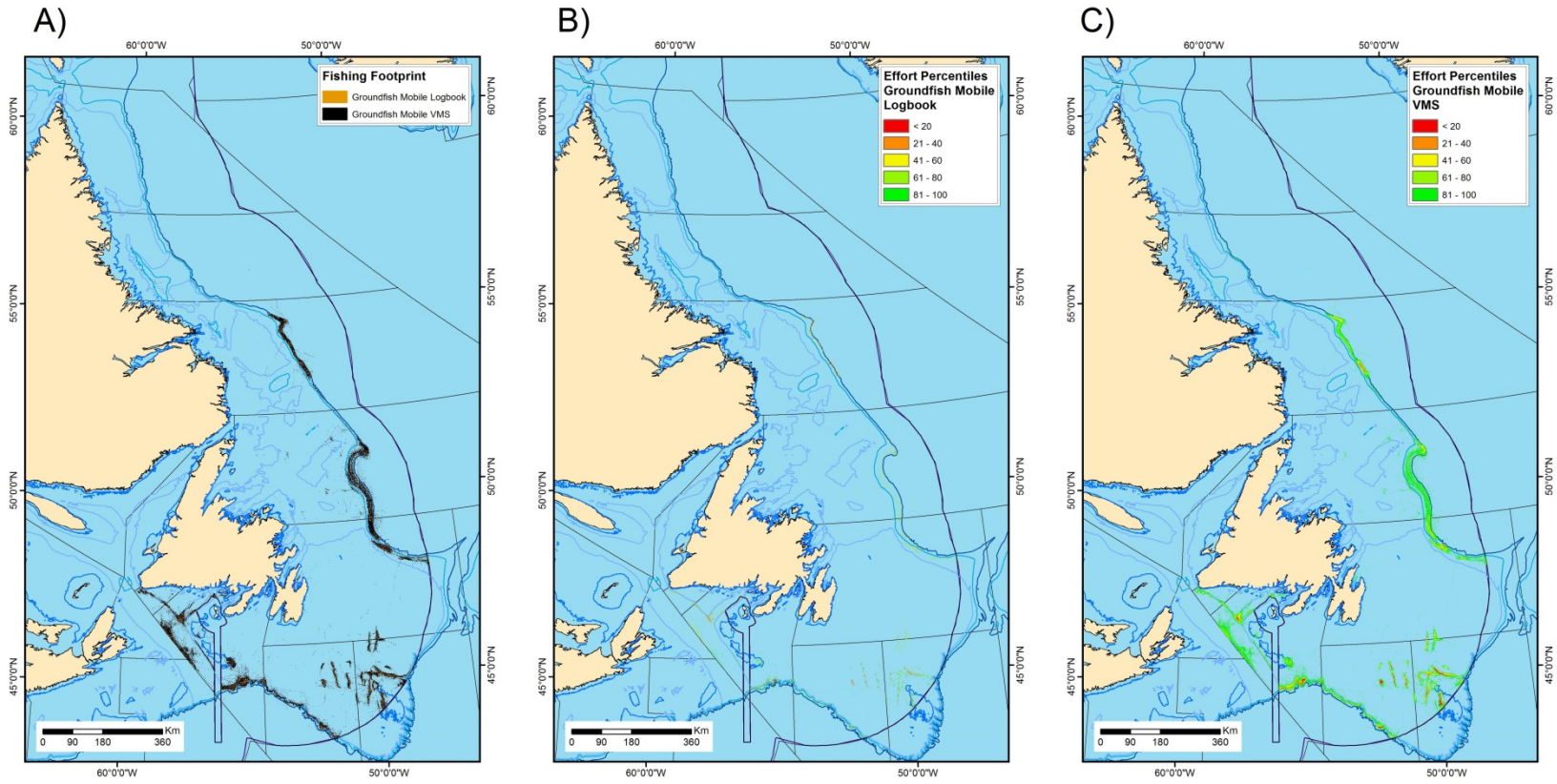

Figure 45. Distribution of the 2005-2014 georeferenced fishing effort for the Newfoundland and Labrador bioregion for the Groundfish Mobile fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

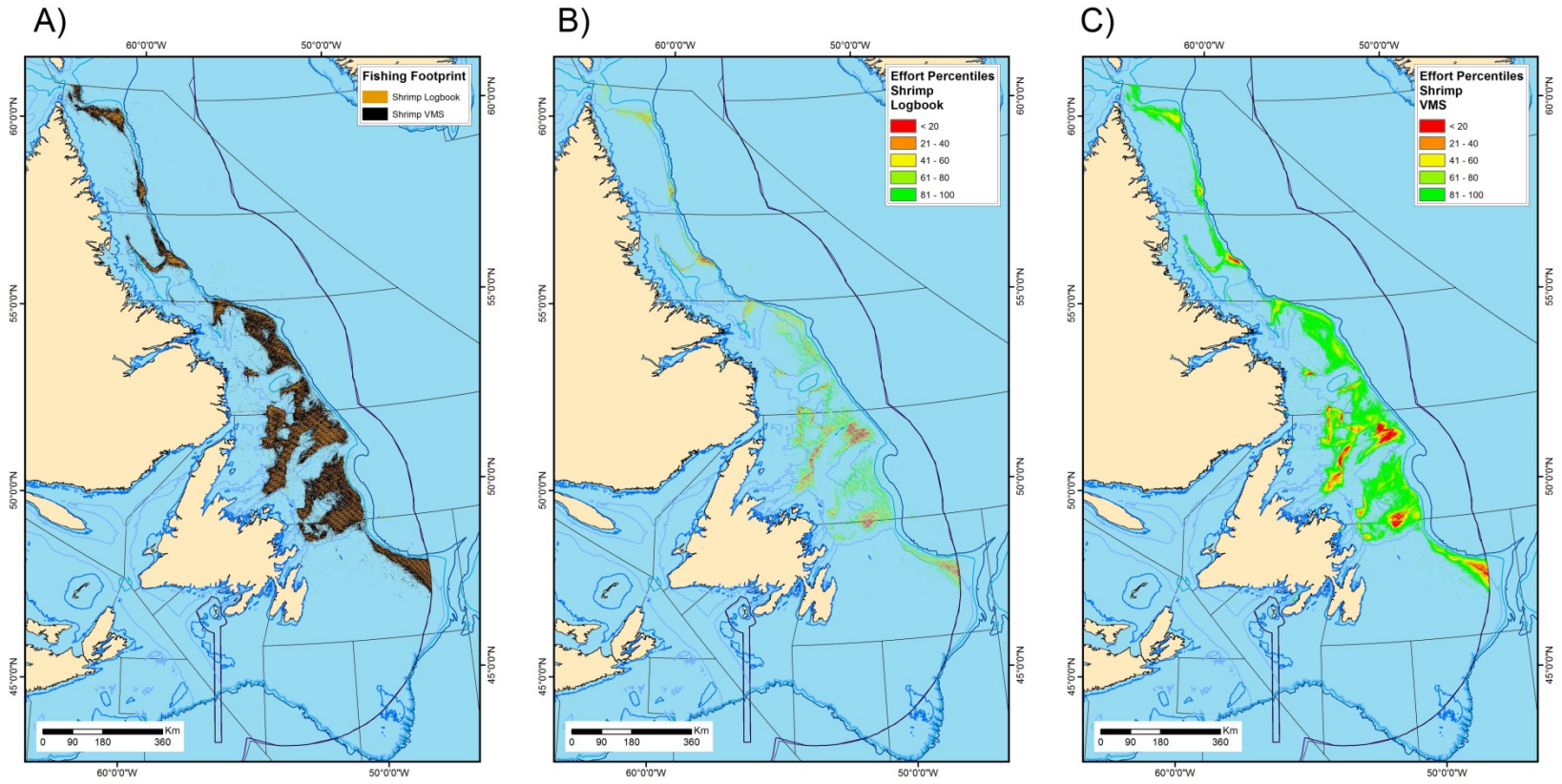

Figure 46. Distribution of the 2005-2014 georeferenced fishing effort for the Newfoundland and Labrador bioregion for the Shrimp fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

In comparison with SS and GSL, the NL bioregion has a higher percentage of georeferenced data (41%), with most effort non-georeferenced data in the inshore areas (Figure 3). Taking into account that all Significant Benthic Areas in this bioregion are in offshore waters (Figure 47), the estimated overlaps between Significant Benthic Areas and fishing effort are expected to be reasonably robust.

Following a similar pattern to that of SS and GSL bioregions, in NL the overall fishery overlaps for most Significant Benthic Area types are higher than the overlaps for individual fisheries classes, indicating that these higher values are emerging from the cumulative effects across fisheries classes (Tables 20-22). This bioregion also presents high overlaps in terms of effort aggregates by gear groups, with 37-72% of the Significant Benthic Areas overlapping with bottom-contacting gears, and with similar overlaps between fixed and mobile gears across most Significant Benthic Area types (Table 23). The only difference is the Small Gorgonian Significant Benthic Areas, whose overlap with fixed gear fisheries is twice those estimated for mobile gears (Table 23). Overlap maps for the aggregates described in Table 23 are compiled in Appendix 4.

The fisheries classes with the highest individual overlaps include Groundfish Fixed, Groundfish Mobile, and Shrimp, and to a lesser extent Pelagic, Miscellaneous Offshore, and Crab Offshore (Tables 20-22). The Groundfish Fixed fisheries class has only 14% georeferencing, but for Groundfish Mobile, and Shrimp it is around 98% (Tables 2 and 20, Figure 4). Pelagic georeferencing is 22%, while Miscellaneous Offshore, and Crab Offshore are 99% and 73% respectively.

The Newfoundland and Labrador bioregion was divided into three insets (NL1, NL2, and NL3, Figure 47) to better display the overlaps between Significant Benthic Areas and fisheries classes.

The Labrador Shelf is depicted in inset NL1 (Figure 48). This general region is characterized by Sponge, Small Gorgonian and Large Gorgonian Significant Benthic Areas, mostly arranged along the shelf break. Three areas were highlighted due to high intensity fishing overlapping with Significant Benthic Areas. Area NL1a is the northernmost and has Large Gorgonian and Sponge Significant Benthic Areas. The fishing effort in this area is almost exclusively associated with the Shrimp fisheries class (Figure 49). The general area NL1b encompasses Small and Large Gorgonian, and Sponge Significant Benthic Areas, and the fishing effort in this area is associated with the Groundfish Fixed (Figure 50), Shrimp (Figure 49), Crab Offshore (Figure 51) fisheries classes. The southernmost area identified in inset NL1 is NL1c, and encompasses a large Sponge Significant Benthic Area and a small Small Gorgonian Significant Benthic Area within it. The fishing effort in this area is linked to the Shrimp (Figure 49) and Crab Offshore (Figure 51) fisheries classes.

The Newfoundland Shelf is depicted in inset NL2 (Figure 52). In this region, two general areas were highlighted due to the overlap between high intensity fishing and Significant Benthic Areas. The first area, NL2a, corresponds to a very large Sponge Significant Benthic Area which encloses several smaller Large and Small Gorgonian Significant Benthic Areas, and which runs along the shelf break (Figure 52). The fishing effort in area NL2a is mainly linked to the Groundfish Fixed (Figure 53) and Groundfish Mobile (Figure 54) fisheries classes, although Shrimp (Figure 55) and Crab Offshore (Figure 56) also contribute with some effort in the northern margins of NL2a. The second area, NL2b, corresponds to a large Sea pen Significant Benthic Area, which overlaps in its northern boundary with the large Sponge Significant Benthic Area associated with NL2a and a Small Gorgonian Significant Benthic Area. It also encloses several Large Gorgonian Significant Benthic Areas in its southern region. Fishing effort in NL2b is mostly associated with the Groundfish Fixed (Figure 53) and Groundfish Mobile (Figure 54)

fisheries classes, with some contribution of the Shrimp (Figure 55) fisheries class along the shallower margins of the Sea pen Significant Benthic Area.

The southern Newfoundland region is depicted in inset NL3. In this region, three general areas were highlighted due to overlap with fishing activities (Figure 57). Area NL3a is located along the Laurentian Channel, and encompasses a large Sea pen Significant Benthic Area. The fishing effort within this Significant Benthic Area is linked to the Groundfish Mobile fisheries class (Figure 58). Area NL3b is associated with a Sponge Significant Benthic Area (Figure 57) and the fishing effort is associated to the Crab Offshore fisheries class (Figure 59). The last area, NL3c, is actually a chain of Significant Benthic Areas along the shelf break on the southeastern of the Grand Bank (Figure 57). This chain includes Sea pen and Small and Large Gorgonian Significant Benthic Areas. Unlike the other areas highlighted in this region, which had only one fisheries class operating, the fishing effort in NL3c is associated to multiple fisheries classes. The dominant ones are Groundfish Fixed (Figure 60), Groundfish Mobile (Figure 58), and Pelagic (Figure 61).

*Table 23. Overlap between aggregates of fishery class footprints and Significant Benthic Areas in the Newfoundland and Labrador bioregion based on available georeferenced data from logbooks, VMS, and merged effort (logbooks and VMS combined). The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 15,542 km^2, sea pen (SE) = 37,457 km^2, small gorgonian (SG) = 4,987 km^2, and sponge (SP) = 43,472 km^2 (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)). All exc. pelagic = All fisheries excluding pelagic.*

Data source	Fishery class aggregate	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Logbook	Fixed	51,887	963	3,185	588	1,645	1.9	6.1	1.1	3.2	6.2	8.5	11.8	3.8
Logbook	Mobile	35,609	880	1,925	246	2,431	2.5	5.4	0.7	6.8	5.7	5.1	4.9	5.6
Logbook	All exc. pelagic	80,031	1,658	4,624	694	3,789	2.1	5.8	0.9	4.7	10.7	12.3	13.9	8.7
VMS	Fixed	185,574	4,291	16,068	3,396	10,634	2.3	8.7	1.8	5.7	27.6	42.9	68.1	24.5
VMS	Mobile	134,474	2,762	10,964	1,387	9,446	2.1	8.2	1	7	17.8	29.3	27.8	21.7
VMS	All exc. pelagic	266,968	5,874	20,899	3,530	15,907	2.2	7.8	1.3	6	37.8	55.8	70.8	36.6
Merged	Fixed	199,940	4,369	16,329	3,449	10,835	2.2	8.2	1.7	5.4	28.1	43.6	69.2	24.9
Merged	Mobile	138,261	2,837	11,409	1,433	9,673	2.1	8.3	1	7	18.3	30.5	28.7	22.2
Merged	All exc. pelagic	282,832	5,986	21,290	3,582	16,205	2.1	7.5	1.3	5.7	38.5	56.8	71.8	37.3

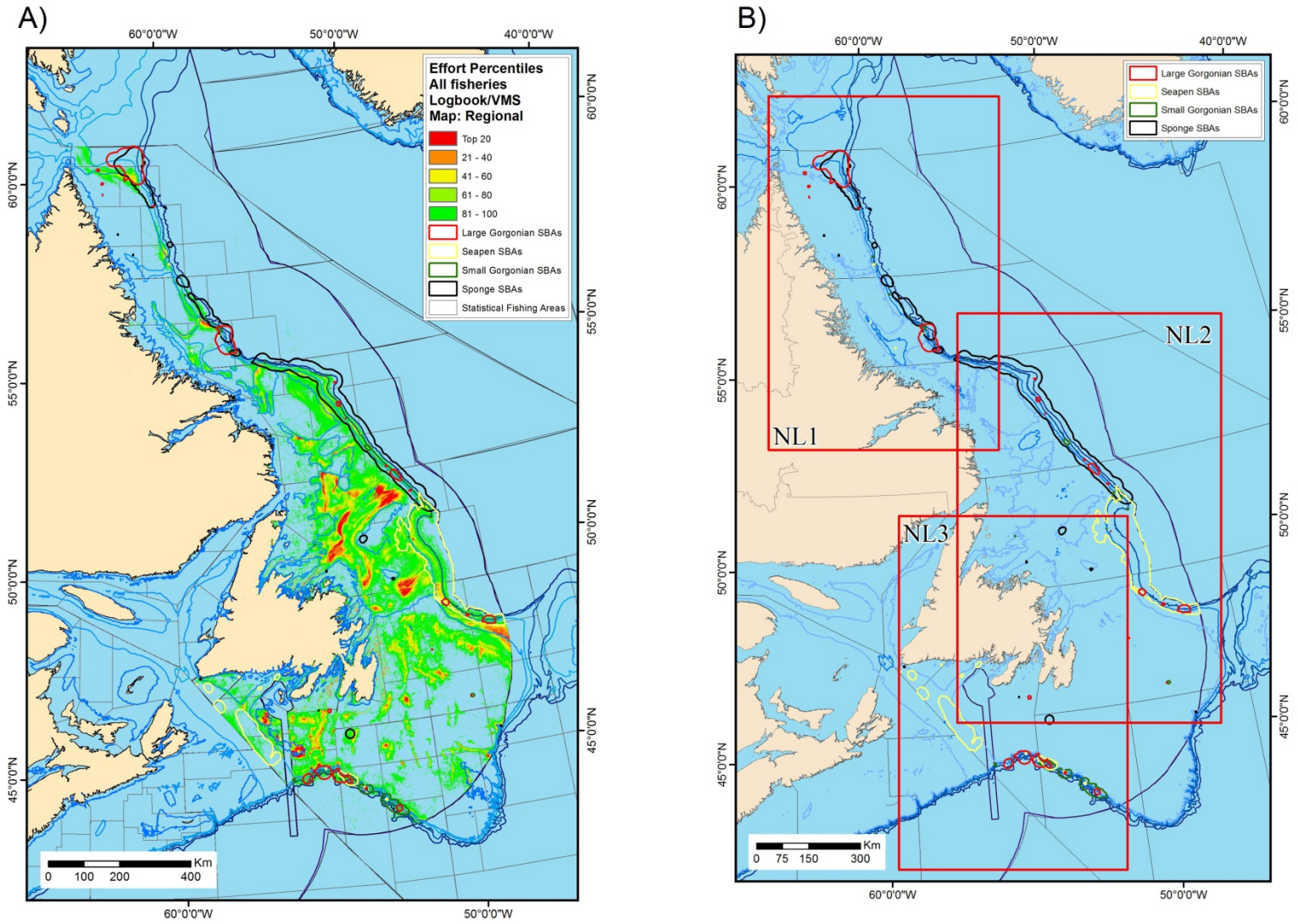

Figure 47. A) Overlap between all Significant Benthic Area categories and fishing effort, where fishing effort intensity is displayed using the merged logbook/VMS percentile layer. B) Significant Benthic Areas in the Newfoundland and Labrador bioregion showing inset locations, NL1, NL2 and NL3.

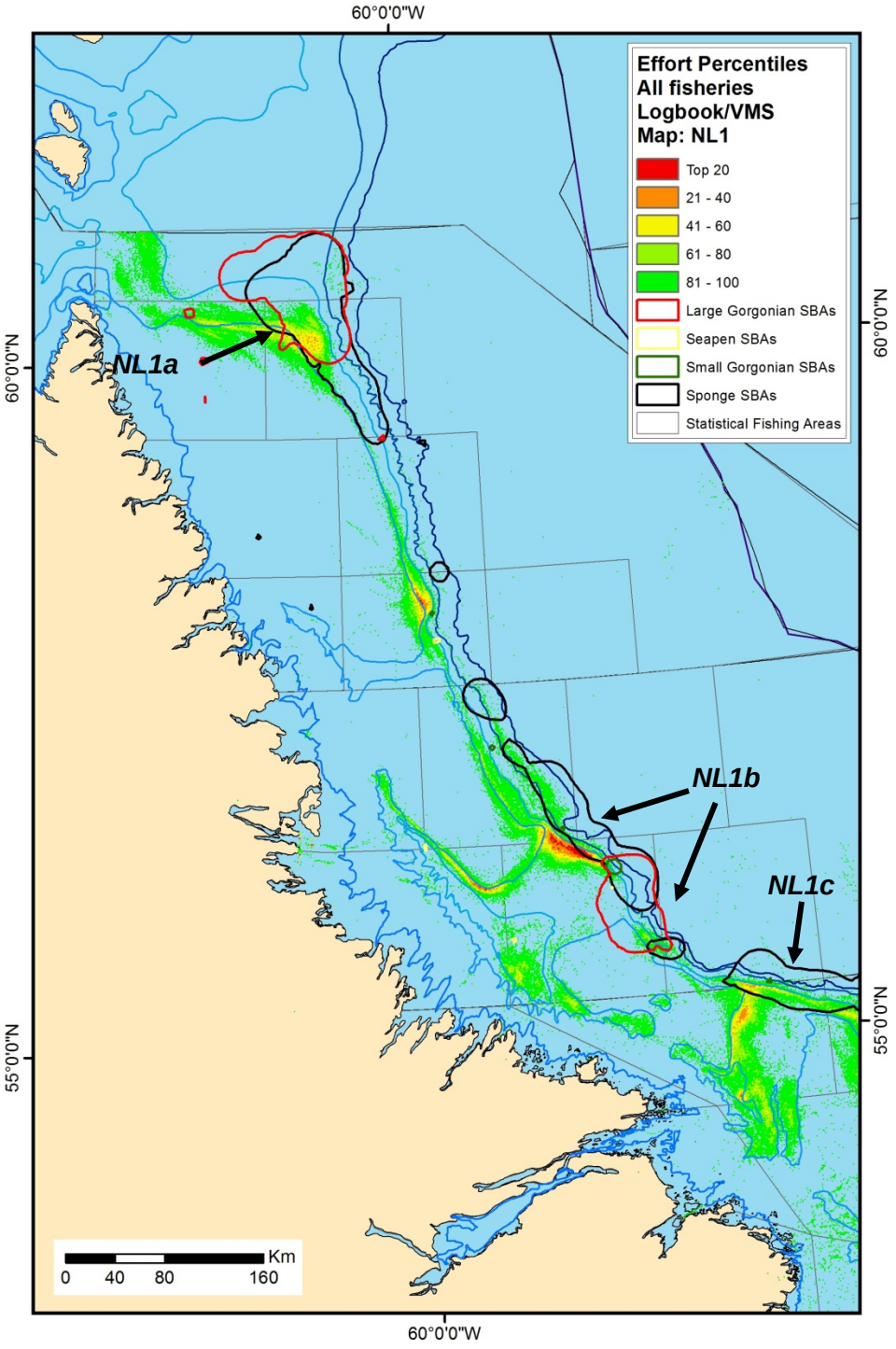

Figure 48. Overlap between all fishing effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL1. Arrows indicate general areas of overlap with higher fishing intensity.

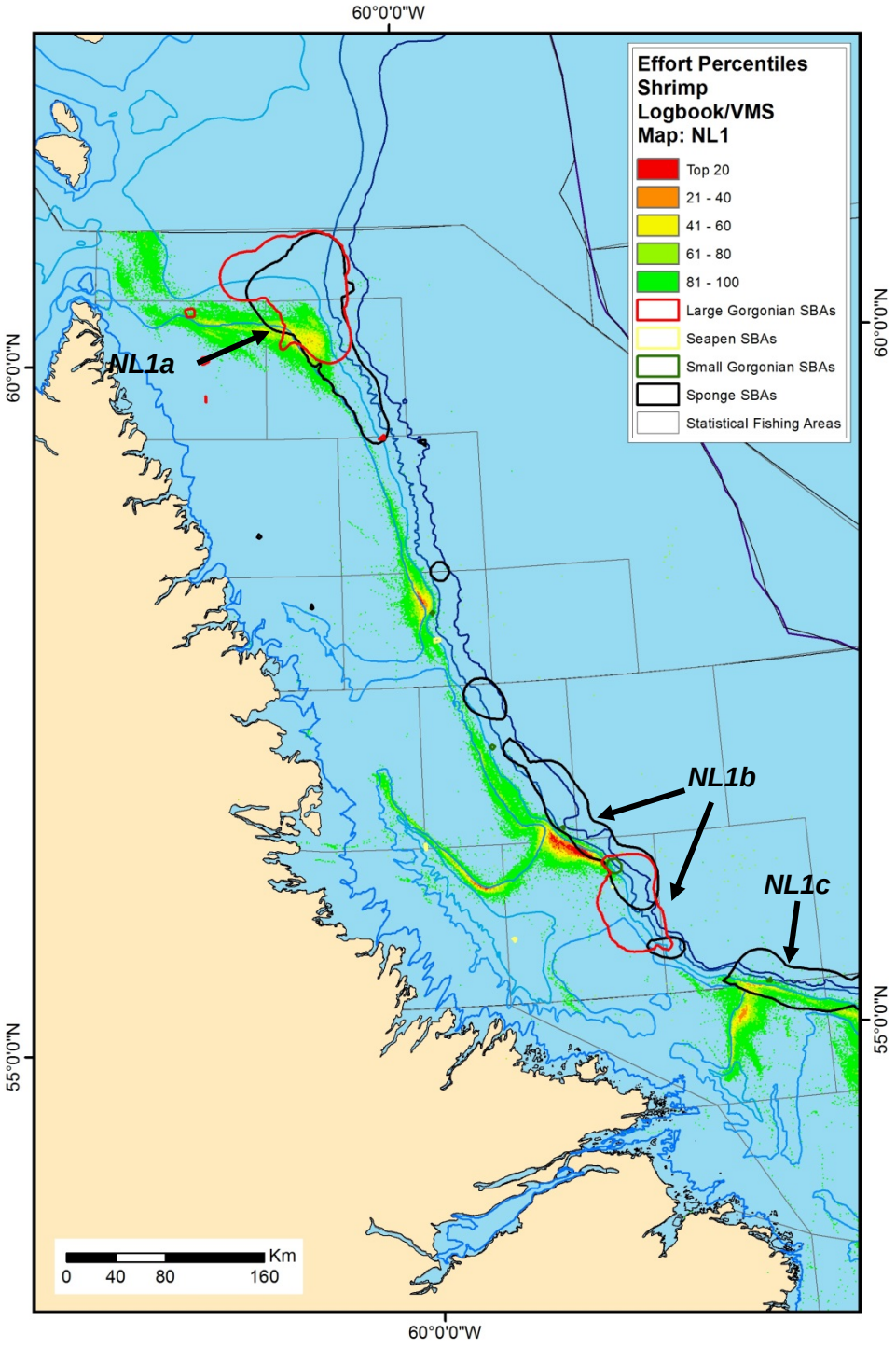

Figure 49. Overlap between Shrimp effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL1. Arrows indicate general areas of overlap with higher fishing intensity.

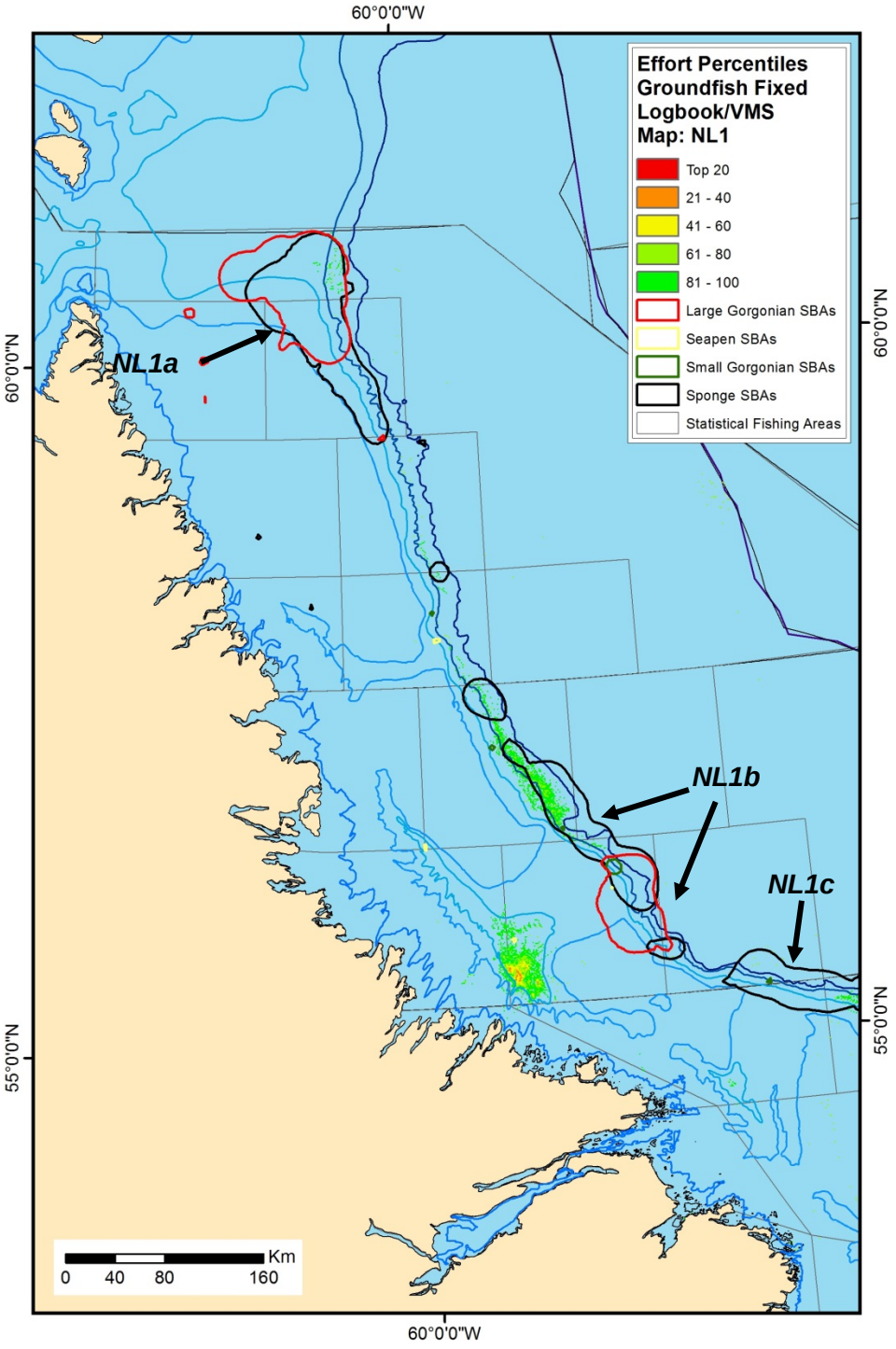

Figure 50. Overlap between Groundfish Fixed effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL1. Arrows indicate general areas of overlap with higher fishing intensity.

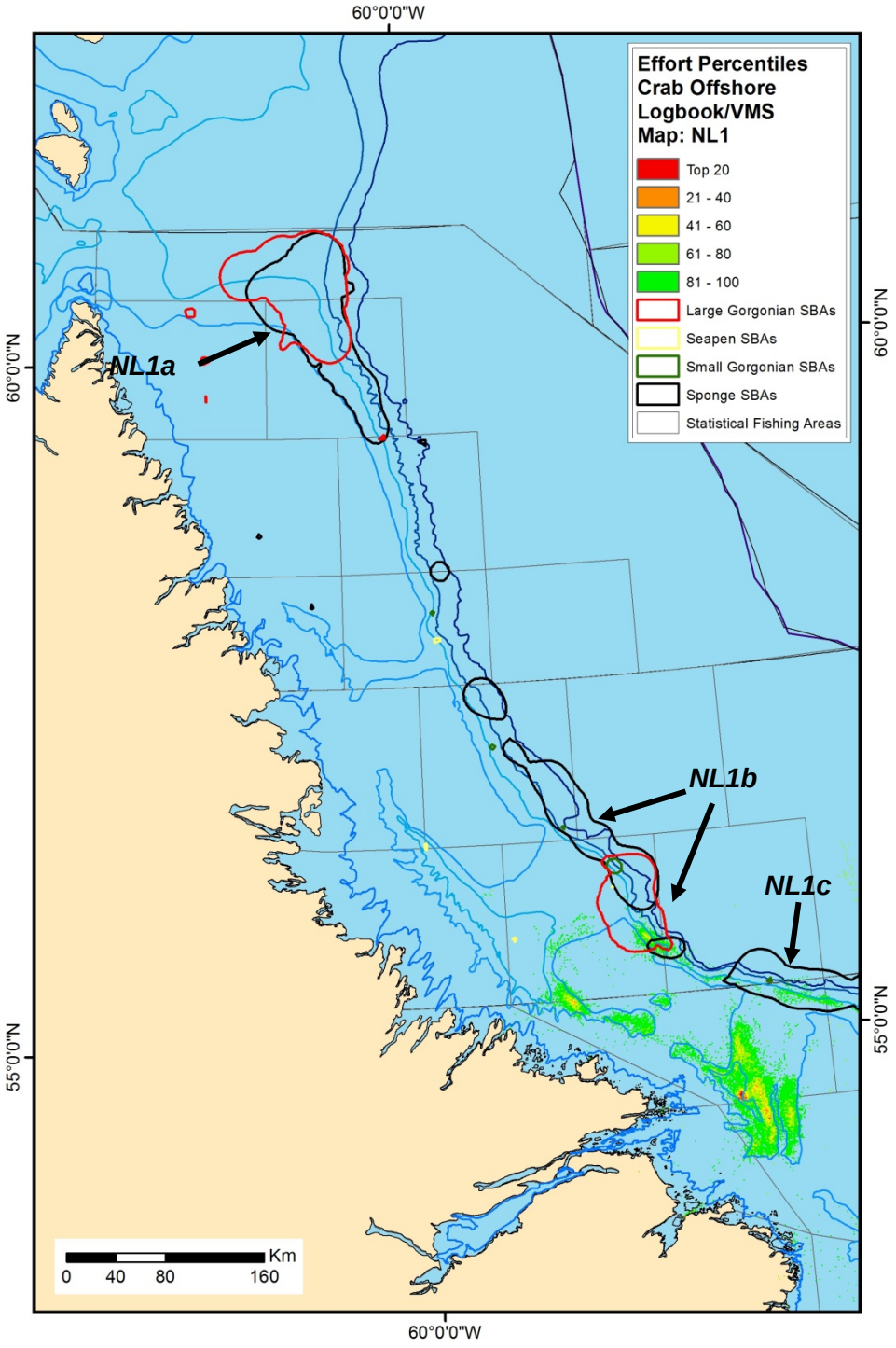

Figure 51. Overlap between Crab Offshore effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL1. Arrows indicate general areas of overlap with higher fishing intensity.

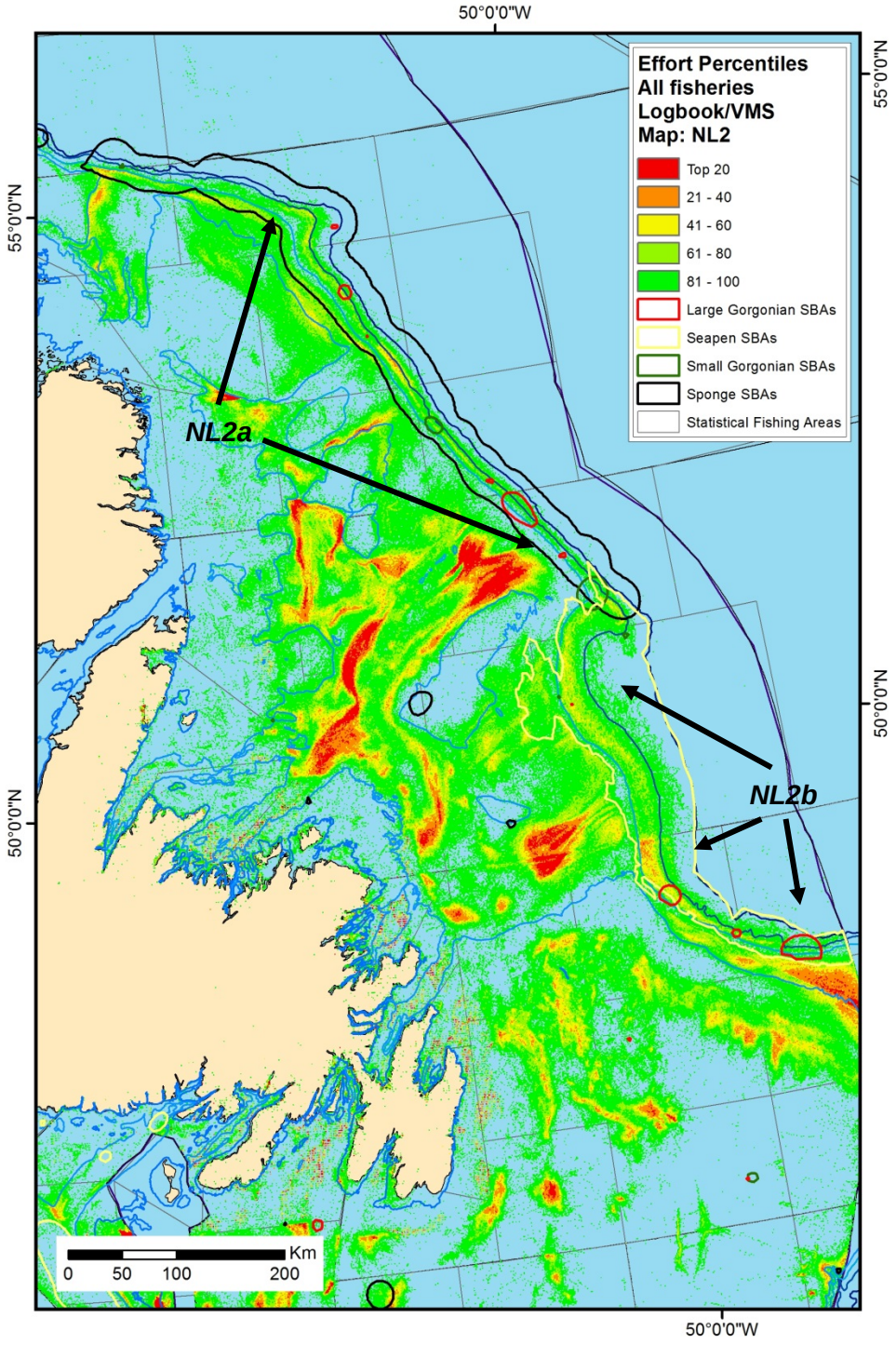

Figure 52. Overlap between all effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL2. Arrows indicate general areas of overlap with higher fishing intensity.

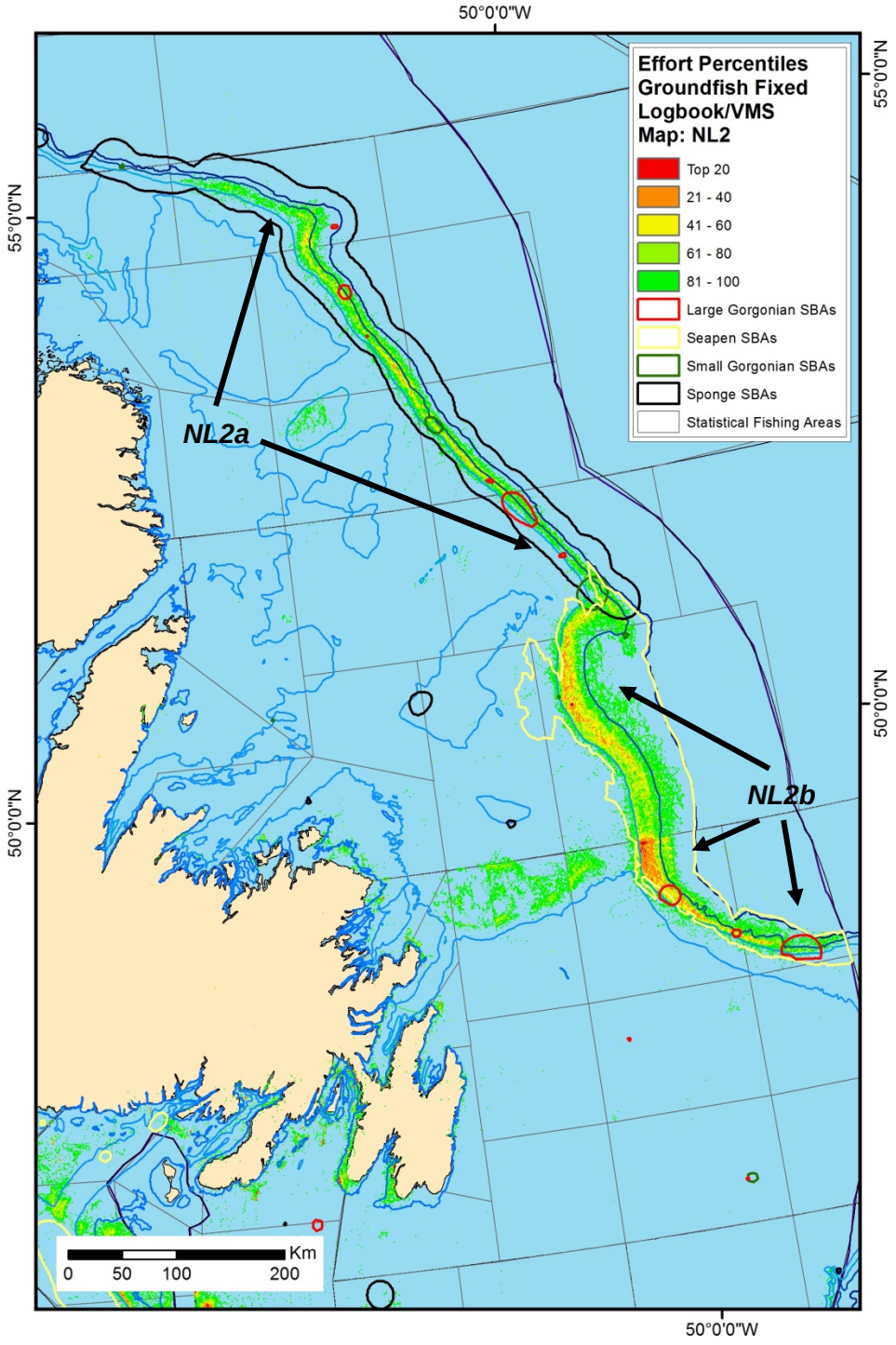

Figure 53. Overlap between Groundfish Fixed and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL2. Arrows indicate general areas of overlap with higher fishing intensity.

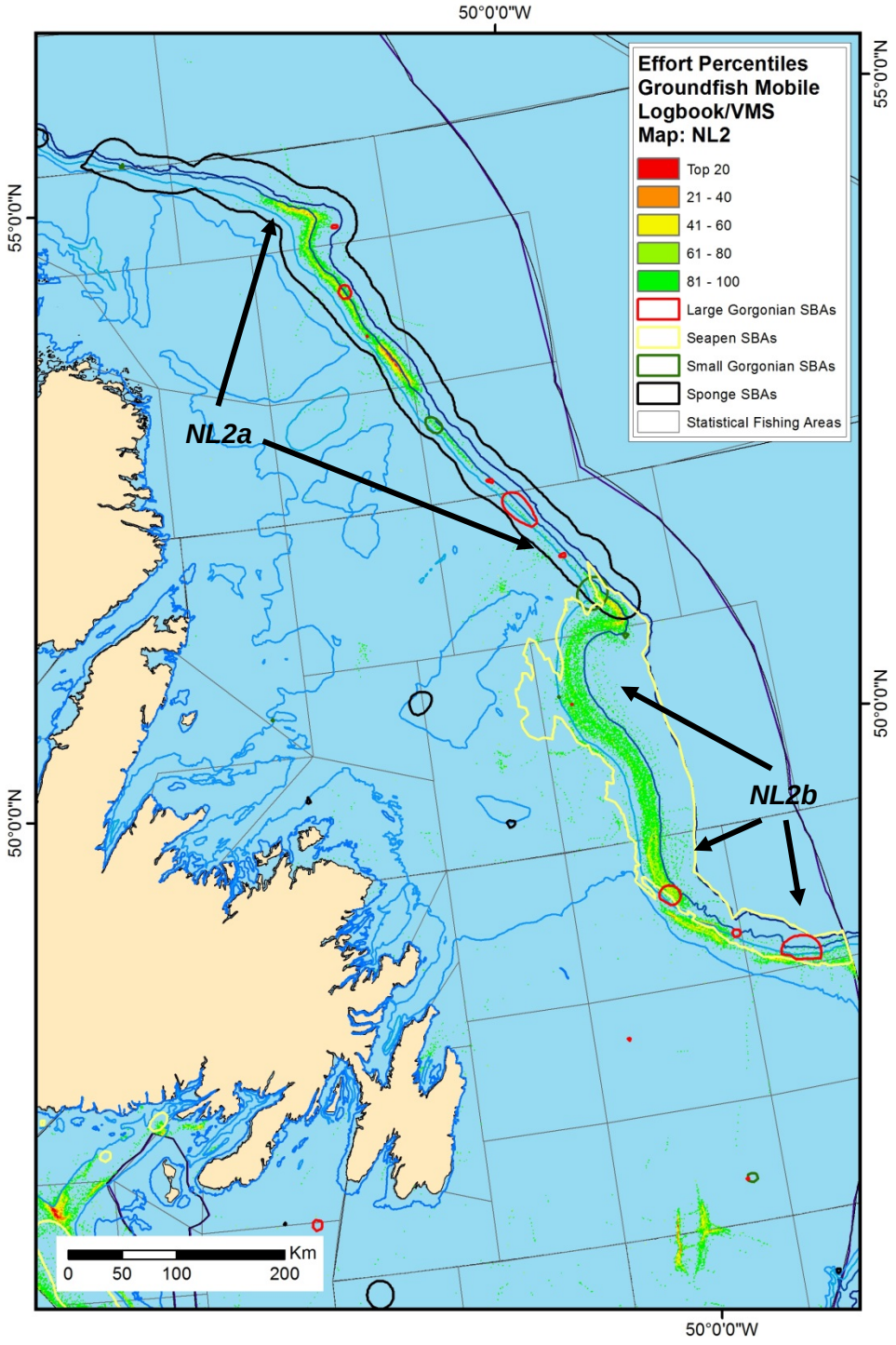

Figure 54. Overlap between Groundfish Mobile effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL2. Arrows indicate general areas of overlap with higher fishing intensity.

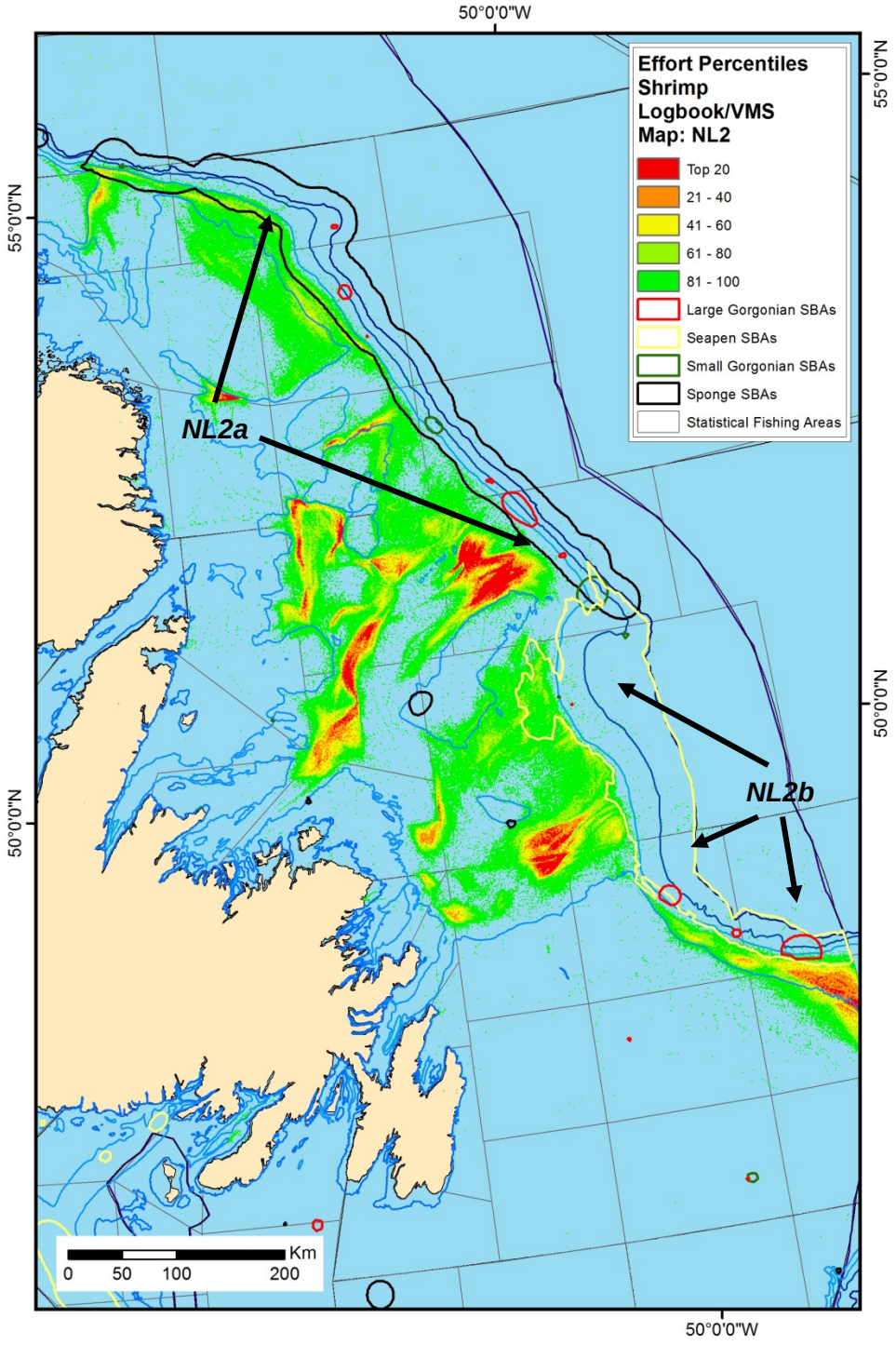

Figure 55. Overlap between Shrimp effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL2. Arrows indicate general areas of overlap with higher fishing intensity.

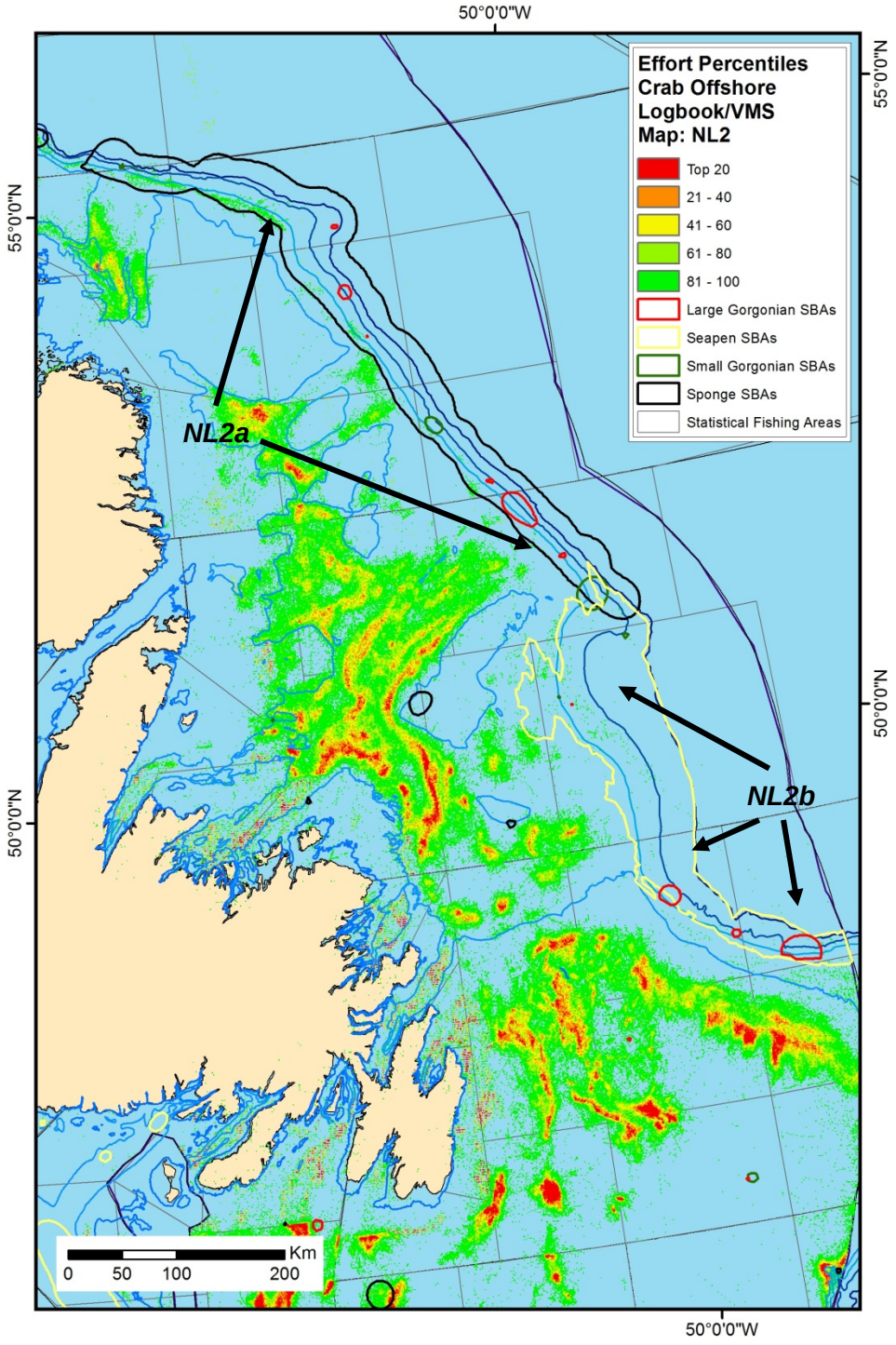

Figure 56. Overlap between Crab Offshore effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL2. Arrows indicate general areas of overlap with higher fishing intensity.

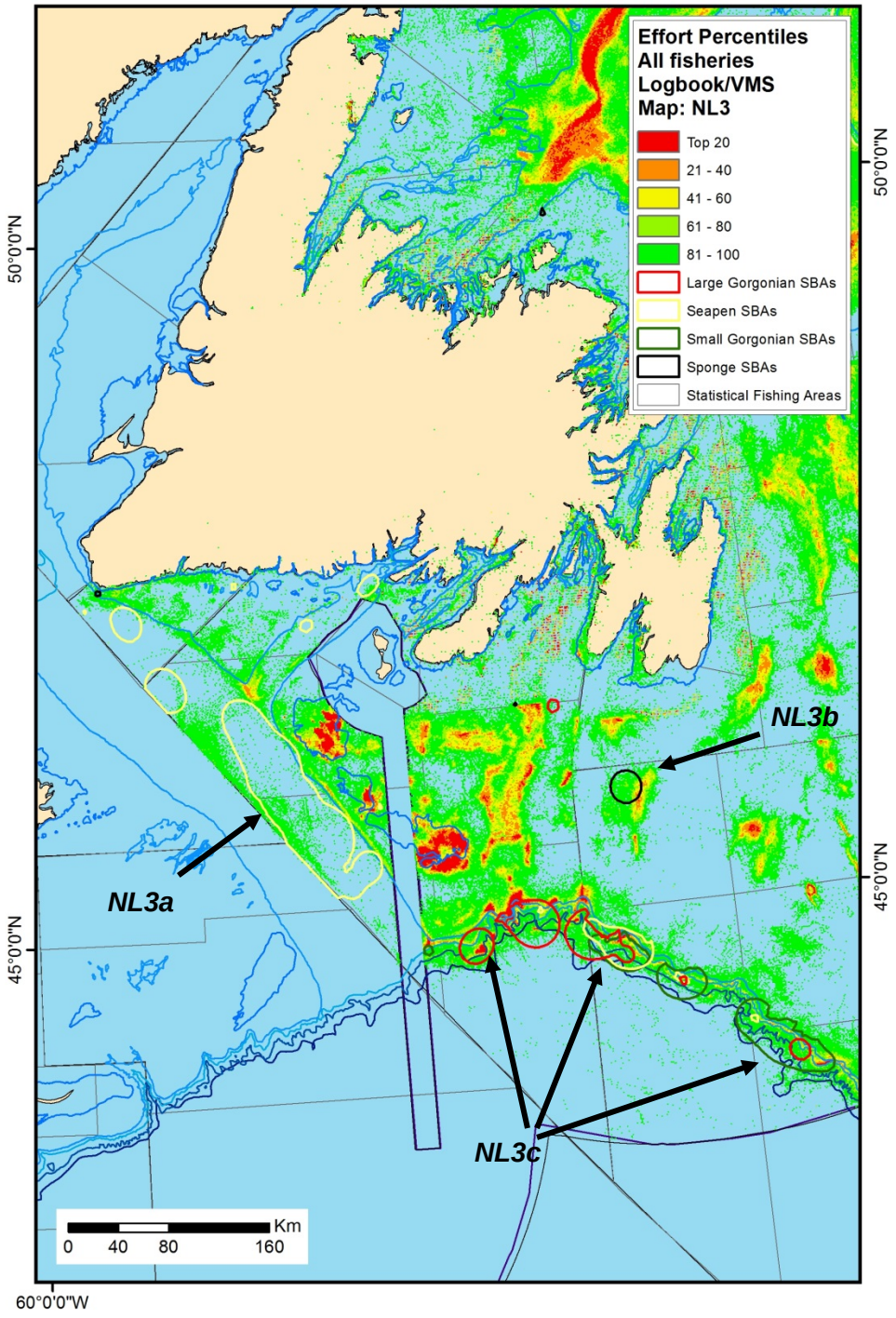

Figure 57. Overlap between all effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL3. Arrows indicate general areas of overlap with higher fishing intensity.

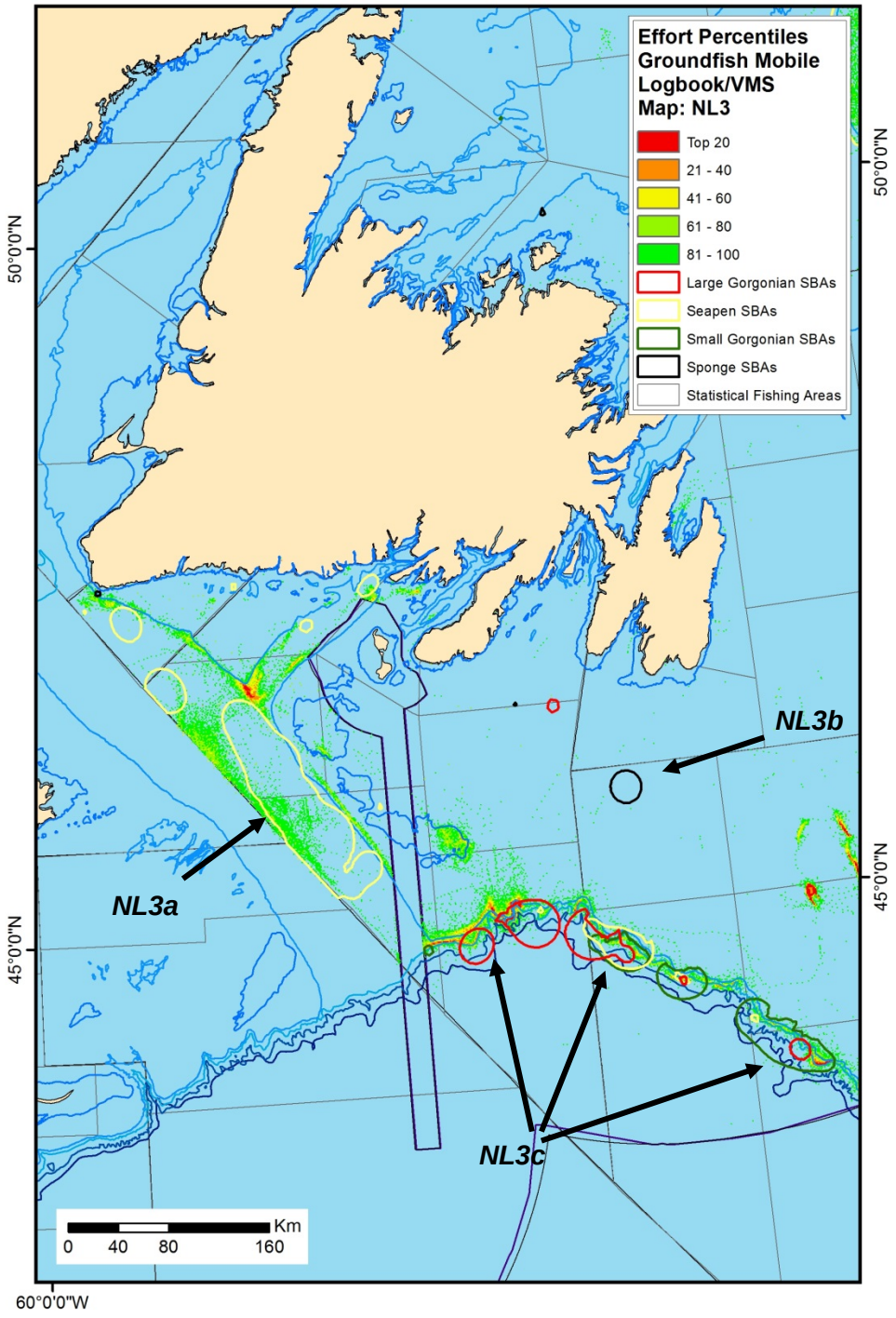

Figure 58. Overlap between Groundfish Mobile effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL3. Arrows indicate general areas of overlap with higher fishing intensity.

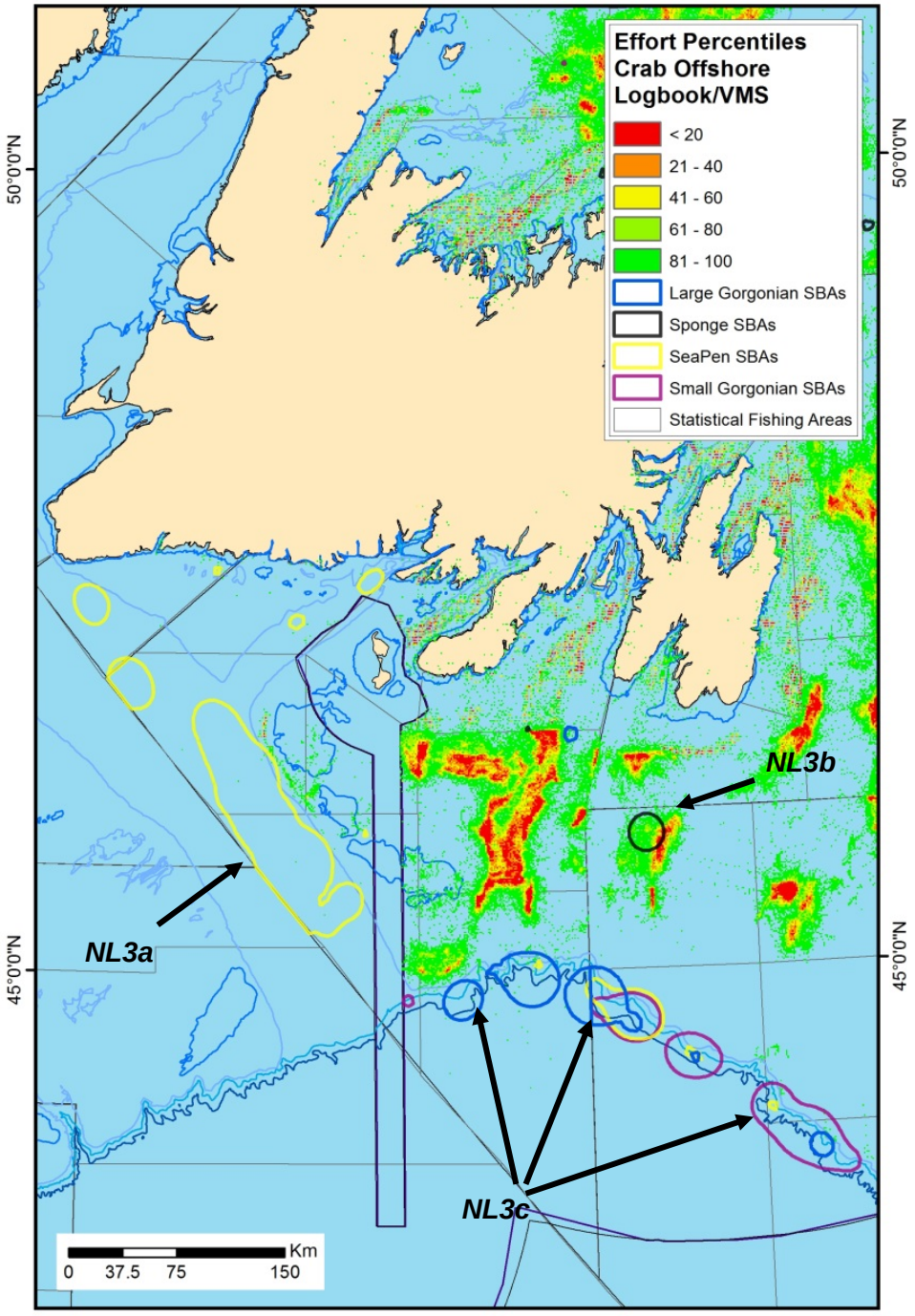

Figure 59. Overlap between Crab Offshore effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL3. Arrows indicate general areas of overlap with higher fishing intensity.

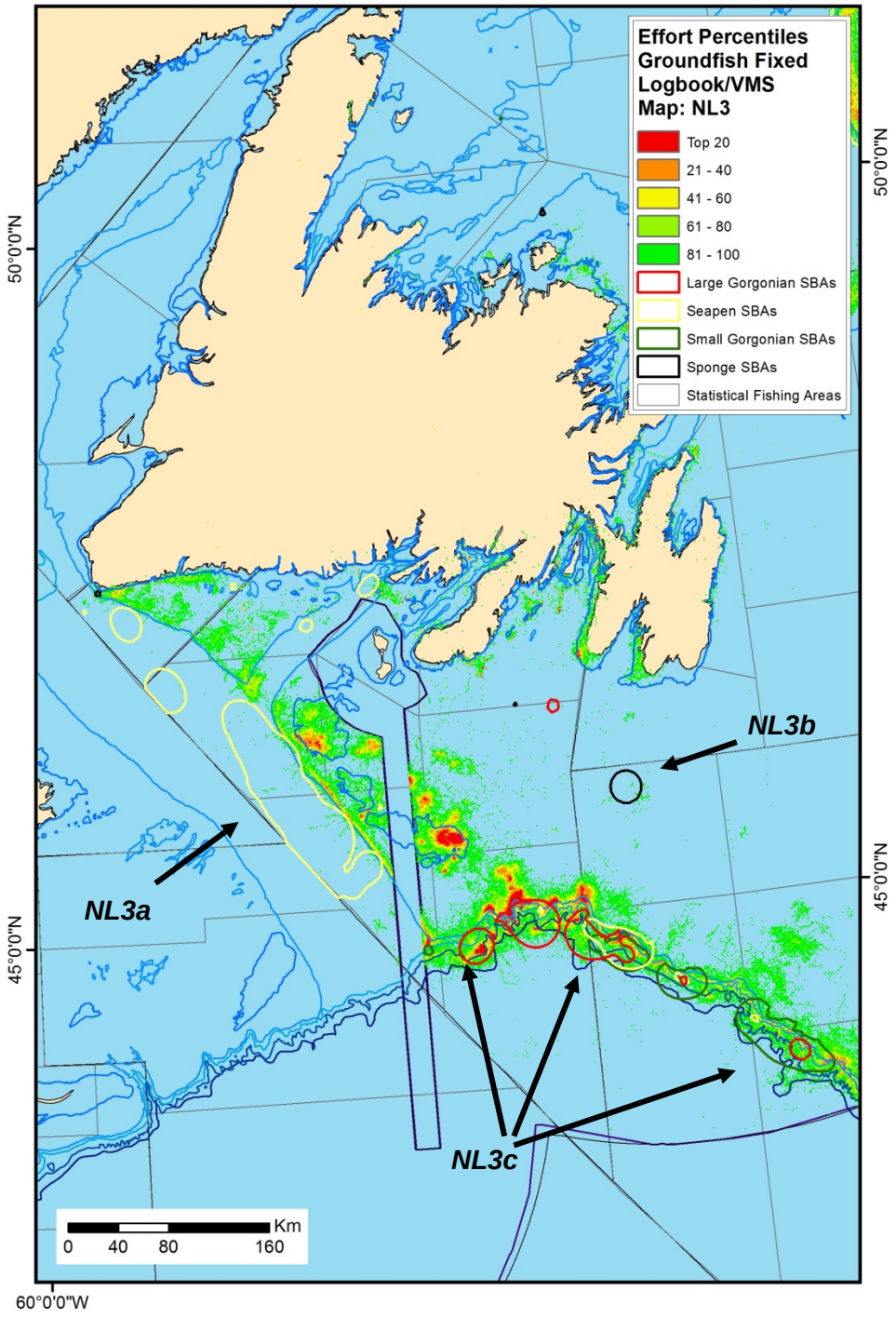

Figure 60. Overlap between Groundfish Fixed effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL3. Arrows indicate general areas of overlap with higher fishing intensity.

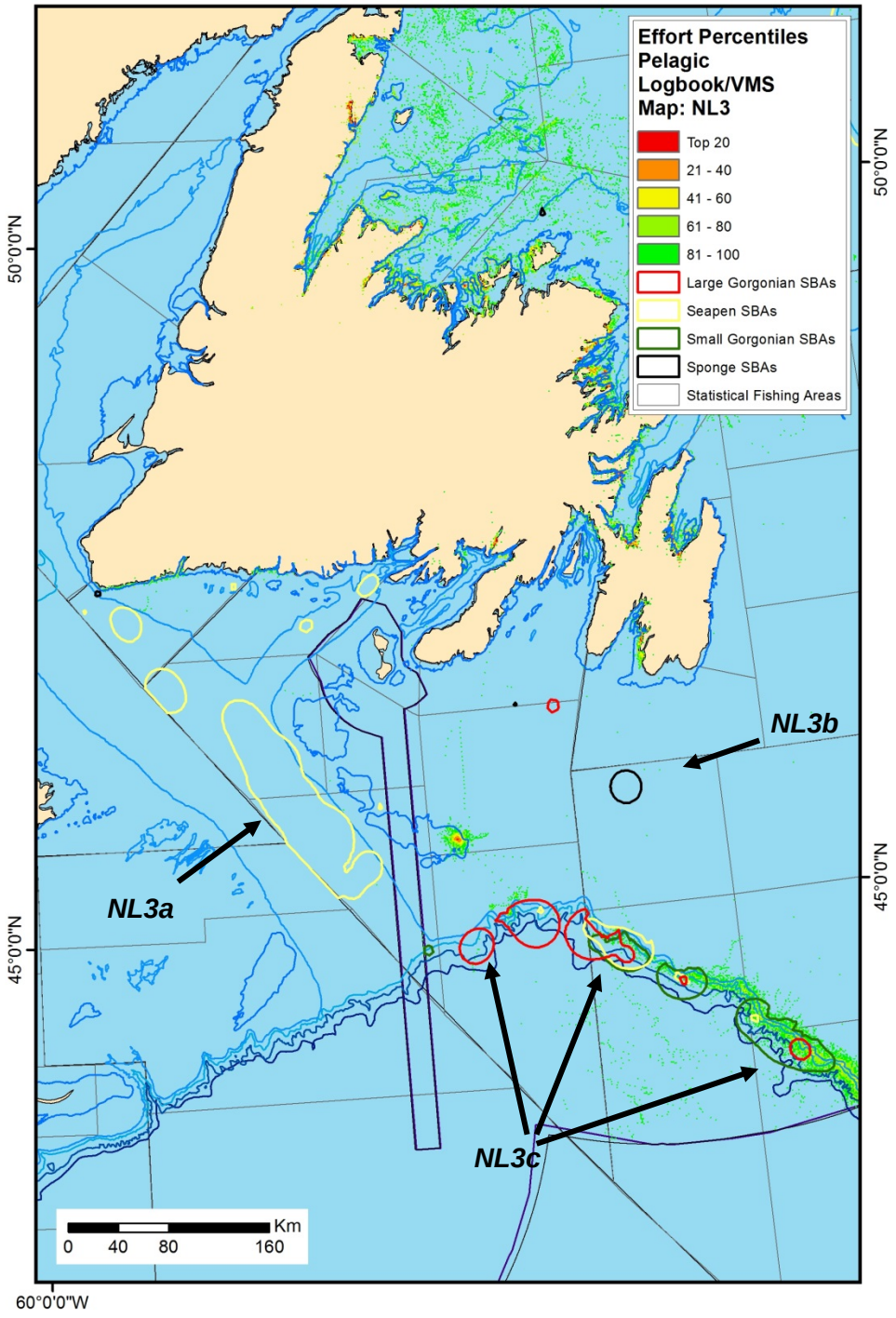

Figure 61. Overlap between Pelagic effort and Significant Benthic Areas in the Newfoundland and Labrador bioregion, inset NL3. Arrows indicate general areas of overlap with higher fishing intensity.

Eastern Arctic bioregion

The total fishing effort in the Eastern Arctic bioregion in the period 2005-2014 amounts to just 7,902 VD. Only three fisheries classes operate in this bioregion. The Groundfish Fixed fisheries class is the dominant one with 57% of the fishing effort, followed by the Groundfish mobile (35%) and Shrimp (8%) fisheries classes (Table 24).

Unlike other bioregions, 99.7% of the fishing effort in the Eastern Arctic is georeferenced. The estimated fishing footprint is 4,673 km^2 based on logbook georeferenced data and 28,910 km^2 from VMS data. Effort concentration in Eastern Arctic follows a pattern similar to all other bioregions. Given the full georeferencing in this bioregion, the comparison of the footprints obtained from logbook and VMS information allows for an unbiased examination of these two sources of spatially resolved data. Both fishing footprints clearly identify the same general fishing locations, but the comparison between logbook and VMS footprints highlights the advantages of VMS data (Figure 62). The higher frequency of data recording, together with the higher spatial resolution of VMS positions, renders a more complete picture of the fisheries footprint. This strongly supports the notion that, under reasonable levels of georeferencing, footprints derived from VMS data are a more reliable estimate of the actual fishing footprint. Although this observation seems self-evident given the nature of the data themselves, an important corollary is that the pattern of concentration of effort emerging from VMS data should also be more reliable than the one obtained from logbooks. In practical terms, this means that the higher concentration of effort in space identified in the VMS data (Table 25) is a better description of the fisheries classes operations, than the one depicted from logbooks (Table 24). The composition of effort for merged VMS and logbooks is shown in Table 26. It also follows that VMS data provides the more reliable estimate of the overlaps between Significant Benthic Areas and the fisheries classes footprints (Tables 27-29).

The estimated overlaps between fisheries classes and Significant Benthic Areas in this bioregion are summarized in Tables 27-29, while footprints for the Groundfish Fixed, Groundfish Mobile and Shrimp fisheries classes are depicted in (Figures 63-65).

Table 24. Distribution of georeferenced fishing effort and fishery class footprints from logbook data for the Eastern Arctic bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Groundfish Fixed	56.6	99.4	56.2	2,247	3.0	10.0	25.6	60.4
Groundfish Mobile	35.0	100.0	91.2	2,038	7.3	20.8	45.7	72.9
Shrimp	8.4	100.0	99.7	555	9.2	27.8	51.9	75.9
All fisheries	**100**	**99.7**	**99.7**	**4,673**	**3.5**	**13.4**	**32.6**	**66.3**

Table 25. Distribution of georeferenced fishing effort and fishery class footprints from VMS data for the Eastern Arctic bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Groundfish Fixed	56.6	96.2	54.4	14,437	1.3	4.0	11.1	31.7
Groundfish Mobile	35.0	93.3	87.0	14,279	3.4	10.0	21.1	41.6
Shrimp	8.4	76.0	93.4	4,160	4.4	13.1	27.6	52.6
All fisheries	**100.0**	**93.4**	**93.4**	**28,910**	**1.5**	**5.8**	**15.8**	**36.1**

Table 26. Distribution of georeferenced fishing effort and fishery class footprints from merged logbook and VMS data for the Eastern Arctic bioregion.

Fishery class	Effort within bioregion (%)	Georeferenced effort (%)	Cumulative total georeferenced effort (%)	Footprint size (km^2)	Footprint area associated with 20% cumulative fishing effort (%)	Footprint area associated with 40% cumulative fishing effort (%)	Footprint area associated with 60% cumulative fishing effort (%)	Footprint area associated with 80% cumulative fishing effort (%)
Groundfish Fixed	56.6	99.4	56.8	14,939	1.3	3.9	10.9	32.2
Groundfish Mobile	35.0	100.0	91.3	14,690	3.3	9.9	21.5	42.5
Shrimp	8.4	100.0	99.7	4,401	4.3	13.9	28.9	54.1
All fisheries	**100.0**	**99.7**	**99.7**	**29,841**	**1.4**	**5.7**	**15.7**	**36.7**

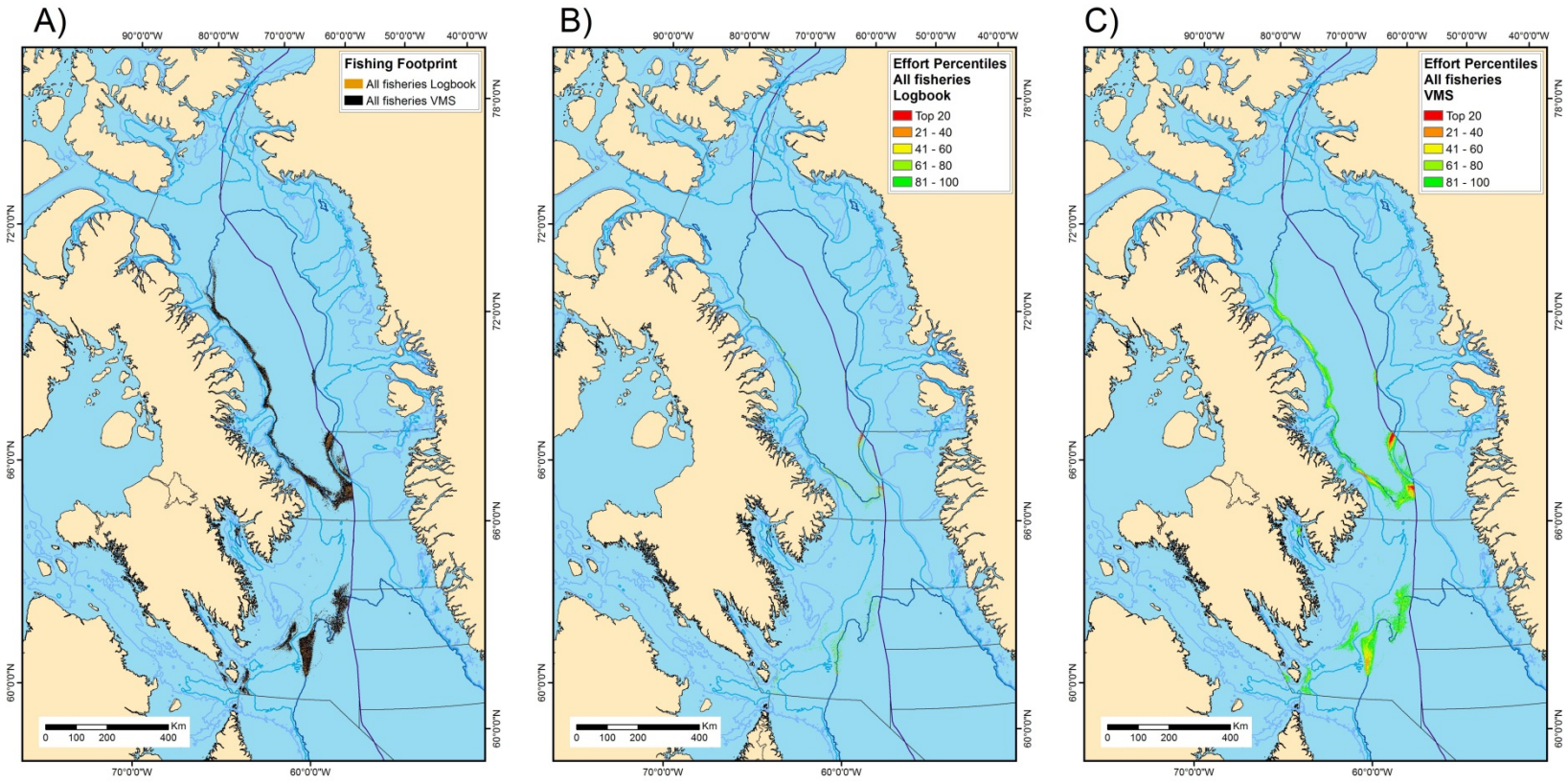

Figure 62. Distribution of the 2005-2014 georeferenced fishing effort for the Eastern Arctic bioregion for all fisheries classes combined. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

*Table 27. Overlap between fishery class footprints and Significant Benthic Areas in the Eastern Arctic bioregion based on available georeferenced data from logbooks. The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 7,199 km^2, sea pen (SE) = 16,123 km^2, small gorgonian (SG) = 6,320 km^2, and sponge (SP) = 36,136 km^2 (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Groundfish Fixed	99.4	2,247	67	309	40	89	3	13.8	1.8	3.9	0.9	1.9	0.6	0.2
Groundfish Mobile	100	2,038	9	78	21	291	0.4	3.8	1.1	14.3	0.1	0.5	0.3	0.8
Shrimp	100	555	12	5	0	32	2.2	0.9	0	5.7	0.2	0	0	0.1
All Fisheries	**99.7**	**4,673**	**83**	**385**	**60**	**376**	**1.8**	**8.2**	**1.3**	**8**	**1.2**	**2.4**	**1**	**1**

*Table 28. Overlap between fishery class footprints and Significant Benthic Areas in the Eastern Arctic bioregion based on available georeferenced data from VMS. The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 7,199 km^2, sea pen (SE) = 16,123 km^2, small gorgonian (SG) = 6,320 km^2, and sponge (SP) = 36,136 km^2 (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Groundfish Fixed	96.2	14,437	384	932	429	1,001	2.7	6.5	3	6.9	5.3	5.8	6.8	2.8
Groundfish Mobile	93.3	14,279	59	606	130	1,720	0.4	4.2	0.9	12	0.8	3.8	2.1	4.8
Shrimp	76	4,160	70	46	1	256	1.7	1.1	0	6.2	1	0.3	0	0.7
All Fisheries	93.4	28,910	470	1,436	518	2,308	1.6	5	1.8	8	6.5	8.9	8.2	6.4

*Table 29.Overlap between fishery class footprints and Significant Benthic Areas in the Eastern Arctic bioregion based on available georeferenced data from merged logbooks and VMS. The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 7,199 km^2, sea pen (SE) = 16,123 km^2, small gorgonian (SG) = 6,320 km^2, and sponge (SP) = 36,136 km^2 (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)).*

Fishery class	Georeferenced effort (%)	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Groundfish Fixed	99.4	14,939	393	938	448	1,032	2.6	6.3	3	6.9	5.5	5.8	7.1	2.9
Groundfish Mobile	100	14,690	67	621	143	1,752	0.5	4.2	1	11.9	0.9	3.9	2.3	4.8
Shrimp	100	4,401	76	49	1	275	1.7	1.1	0	6.2	1.1	0.3	0	0.8
All Fisheries	**99.7**	**29,841**	**487**	**1457**	**541**	**2373**	**1.6**	**4.9**	**1.8**	**8**	**6.8**	**9**	**8.6**	**6.6**

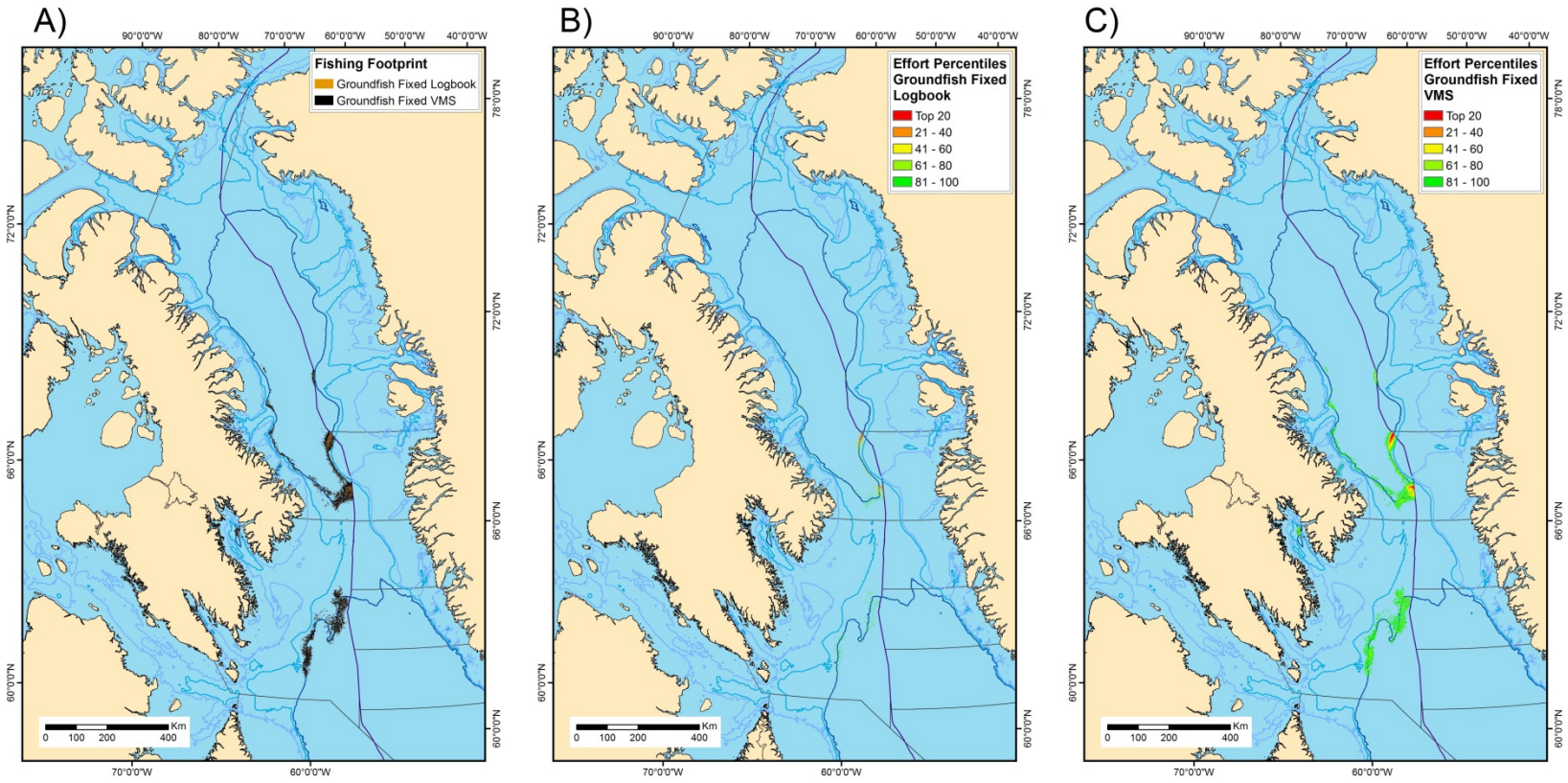

Figure 63. Distribution of the 2005-2014 georeferenced fishing effort for the Eastern Arctic bioregion for the Groundfish Fixed fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

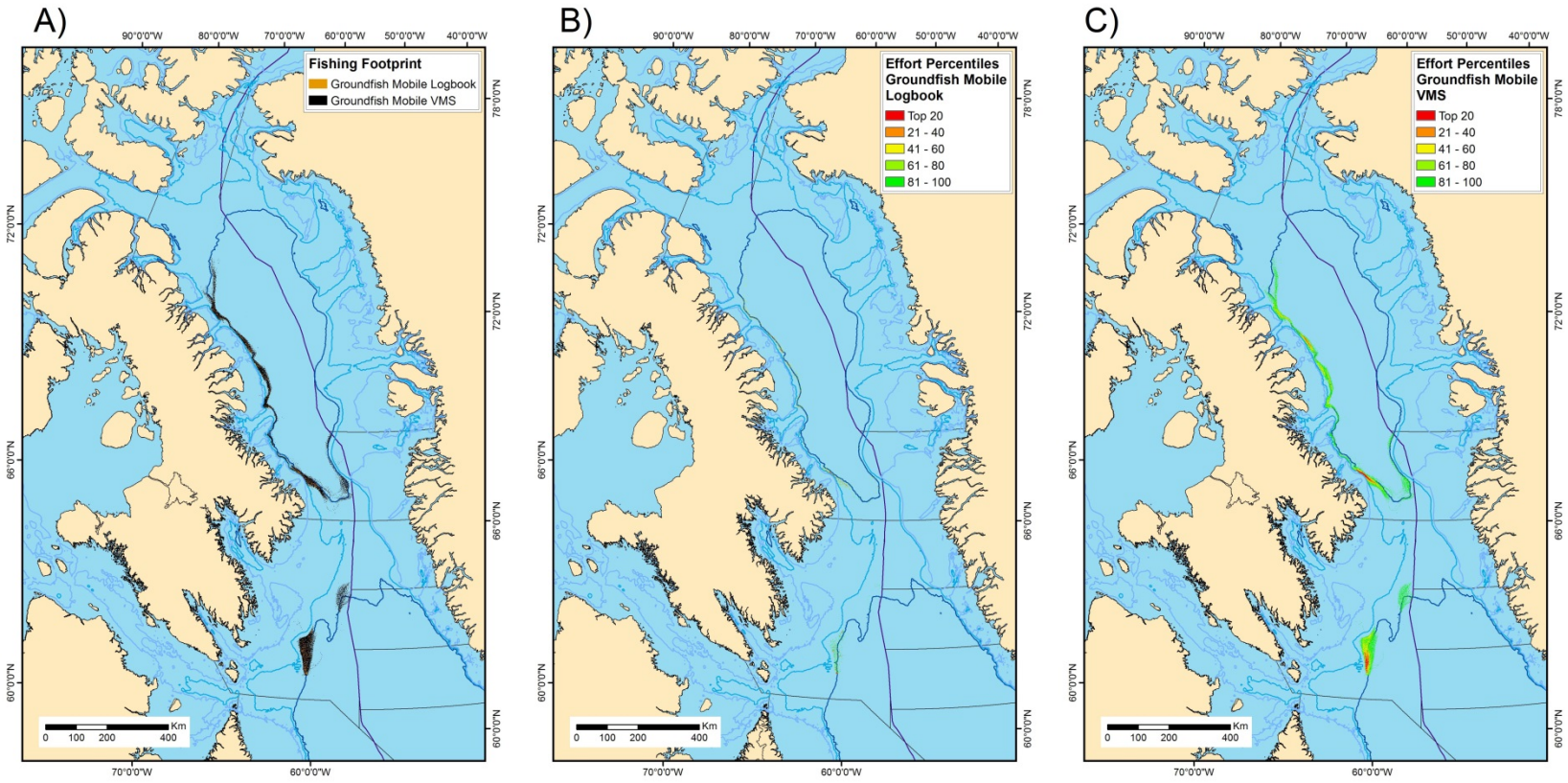

Figure 64. Distribution of the 2005-2014 georeferenced fishing effort for the Eastern Arctic bioregion for the Groundfish Mobile fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

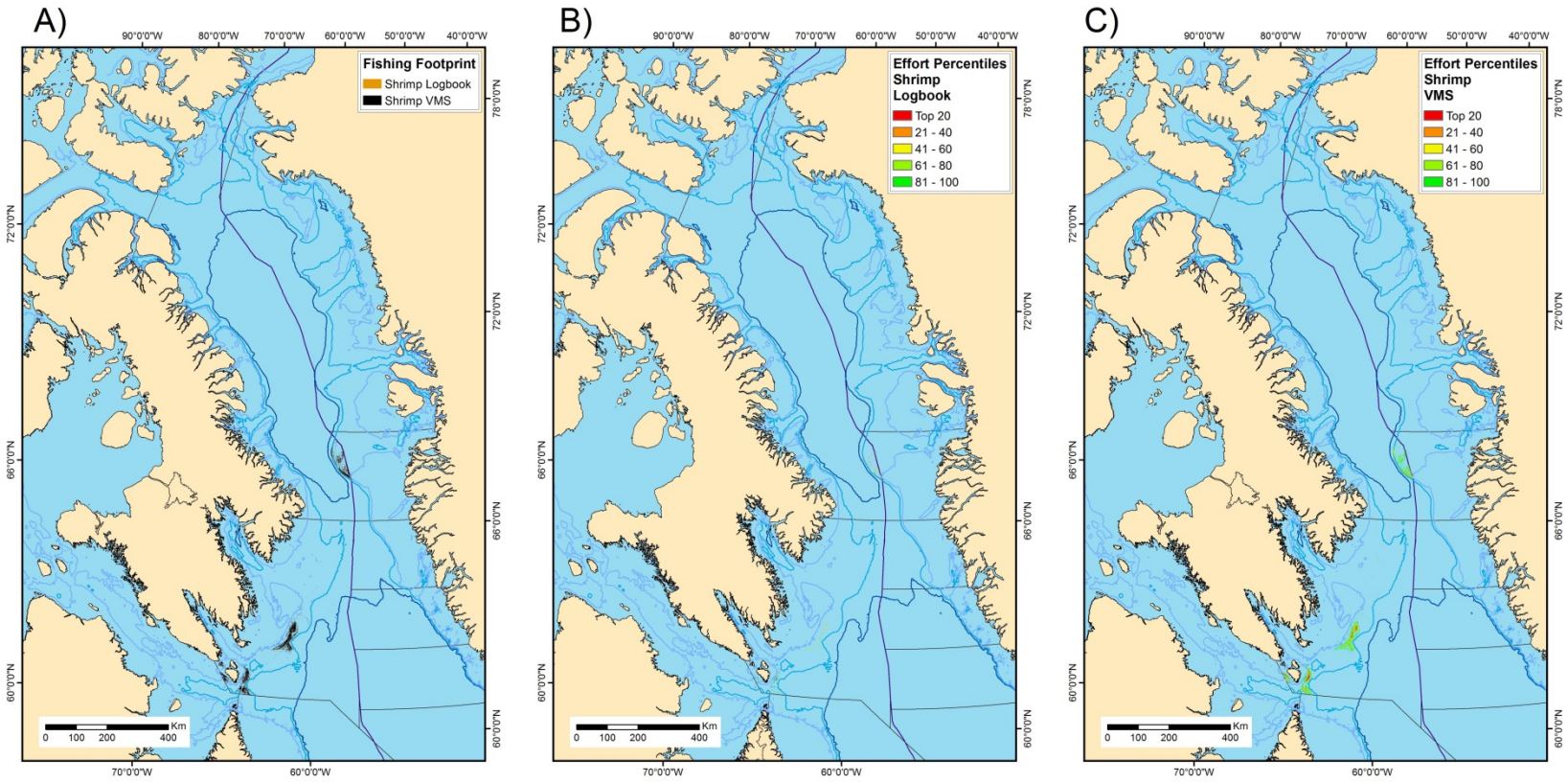

Figure 65. Distribution of the 2005-2014 georeferenced fishing effort for the Eastern Arctic bioregion for the Shrimp fisheries class. A) Fishing footprint from georeferenced logbook and VMS, B) Percentile distribution of the georeferenced logbook data, C) Percentile distribution of the VMS data.

In the Eastern Arctic bioregion 99.7% of the fishing effort is georeferenced (Table 2); therefore, the estimated overlaps between Significant Benthic Areas and fishing effort for this bioregion are expected to be highly accurate and robust.

This bioregion not only has the least number of fisheries classes operating within its boundaries, and the lowest density of fishing effort, but also shows the lowest overlaps between Significant Benthic Areas and fishing effort from all the bioregions examined in this study. Taking into account all effort combined, the estimated overlaps for each Significant Benthic Area type never reached 10% (Tables 27-29). In this bioregion, the overlaps calculated for fisheries class aggregates (Table 30) add little to the examination of the overlaps by fisheries classes (Tables 27-29), because only the Groundfish Mobile and Shrimp fisheries classes are aggregated, and there is only one fisheries class within the fixed gear aggregate. Overlap maps for the aggregates described in Table 30 are compiled in Appendix 4.

Even with the low fishing effort and overlaps observed in this bioregion, there is no single fisheries class with overlap values as high as the ones obtained by considering all effort together. This further strengthens the observations made in previous bioregions that cumulative effects across fisheries classes are at play, even at very low levels of fishing effort.

An overview of the overlap between Significant Benthic Areas and all fisheries classes combined is displayed in Figure 66. The Eastern Arctic bioregion was divided into three insets (EA1, EA2, and EA3, Figure 66) to better display the overlaps between Significant Benthic Areas and fisheries classes.

Overall, only four areas with overlaps between Significant Benthic Areas and higher fishing effort were highlighted in the entire bioregion (EA1a, EA2a, EA2b, and EA3a). A few additional areas were also highlighted, but these only involved areas where fishing effort was being exerted along the boundaries of Significant Benthic Areas.

In the northern extreme of this bioregion, roughly corresponding to the Baffin Bay area (inset EA1), only one area of overlap was highlighted (EA1a), and involved a Sea pen Significant Benthic Area (Figure 67). This effort was exclusively linked to the Groundfish Mobile Fisheries class (Figure 68). Further south (inset EA2), coarsely corresponding to the Davis Strait area, the next highlighted areas of overlap (EA2a and EA2b) involved Sea Pen and Large Gorgonian Significant Benthic Areas (Figure 69), but in this case the effort was mostly associated with the Groundfish Fixed fisheries class (Figure 70). Effort along the margins of a Sponge Significant Benthic Area was also highlighted in EA2 (area EA2c). This effort was mostly linked to the Groundfish Mobile fisheries class (Figure 71). In the southern extreme of this bioregion (EA3), the highlighted overlap area (EA3a) corresponds to a Significant Benthic Area complex defined by a large Sponge Significant Benthic Area which encloses Small and Large Gorgonian Significant Benthic Areas (Figure 72). The effort in EA3b is mainly driven by the Groundfish Mobile fisheries class (Figure 73), but this area also receives effort from the Groundfish Fixed fisheries class (Figure 74). Three areas with effort operating on the margins of Significant Benthic Areas were also identified in the EA3 region (Figure 72). These areas, collectively labelled EA3b, were associated with all the fisheries classes that operate in this region (Figures 73-75).

*Table 30. Overlap between aggregates of fishery class footprints and Significant Benthic Area in the Eastern Arctic bioregion based on available georeferenced data from logbooks, VMS, and merged effort (logbooks and VMS combined). The surface areas of Significant Benthic Areas are: Large gorgonian (LG) = 7,199 km^2, sea pen (SE) = 16,123 km^2, small gorgonian (SG) = 6,320 km^2, and sponge (SP) = 36,136 km^2 (*Overlap between fishery class footprint and Significant Benthic Area (km^2), † Percent fishery class footprint that overlaps with Significant Benthic Area (%), ºPercent Significant Benthic Area that overlaps with fishery class footprint (%)). All exc. pelagic = All fisheries excluding pelagic.*

Data source	Fishery class aggregate	Fishing footprint (km^2)	LG*	SE*	SG*	SP*	LG†	SE†	SG†	SP†	LGº	SEº	SGº	SPº
Logbook	Fixed	2,247	67	309	40	89	3	13.8	1.8	3.9	0.9	1.9	0.6	0.2
Logbook	Mobile	2,593	21	83	21	323	0.8	3.2	0.8	12.4	0.3	0.5	0.3	0.9
Logbook	All exc. pelagic	4,673	83	385	60	376	1.8	8.2	1.3	8	1.2	2.4	1	1
VMS	Fixed	14,437	384	932	429	1,001	2.7	6.5	3	6.9	5.3	5.8	6.8	2.8
VMS	Mobile	18,432	129	651	131	1,976	0.7	3.5	0.7	10.7	1.8	4	2.1	5.5
VMS	All exc. pelagic	28,910	470	1,436	518	2,308	1.6	5	1.8	8	6.5	8.9	8.2	6.4
Merged	Fixed	14,939	393	938	448	1,032	2.6	6.3	3	6.9	5.5	5.8	7.1	2.9
Merged	Mobile	19,083	143	671	144	2,027	0.7	3.5	0.8	10.6	2	4.2	2.3	5.6
Merged	All exc. pelagic	29,841	487	1,457	541	2,373	1.6	4.9	1.8	8	6.8	9	8.6	6.6

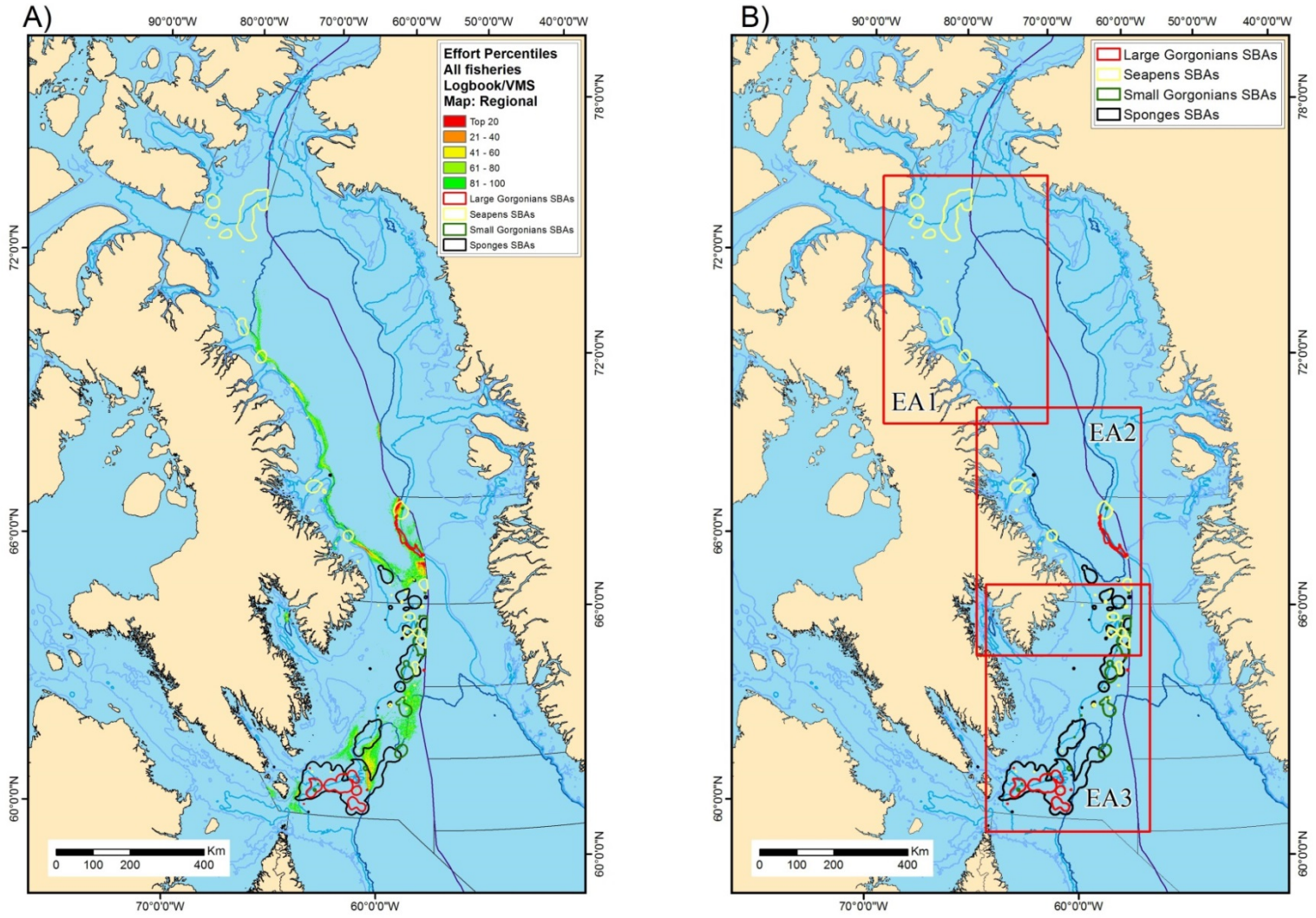

Figure 66. Overlap between all fishing effort and Significant Benthic Areas in the Eastern Arctic bioregion. A) Overlap between all Significant Benthic Area categories and fishing effort, where fishing effort intensity is displayed using the merged logbook/VMS percentile layer; B) Distribution of Significant Benthic Areas showing inset locations, EA1, EA2, and EA3 that display overlaps in more detail. Note that Significant Benthic Area locations in the Hudson Strait are not displayed as this analysis is restricted to NAFO Divisions 0AB.

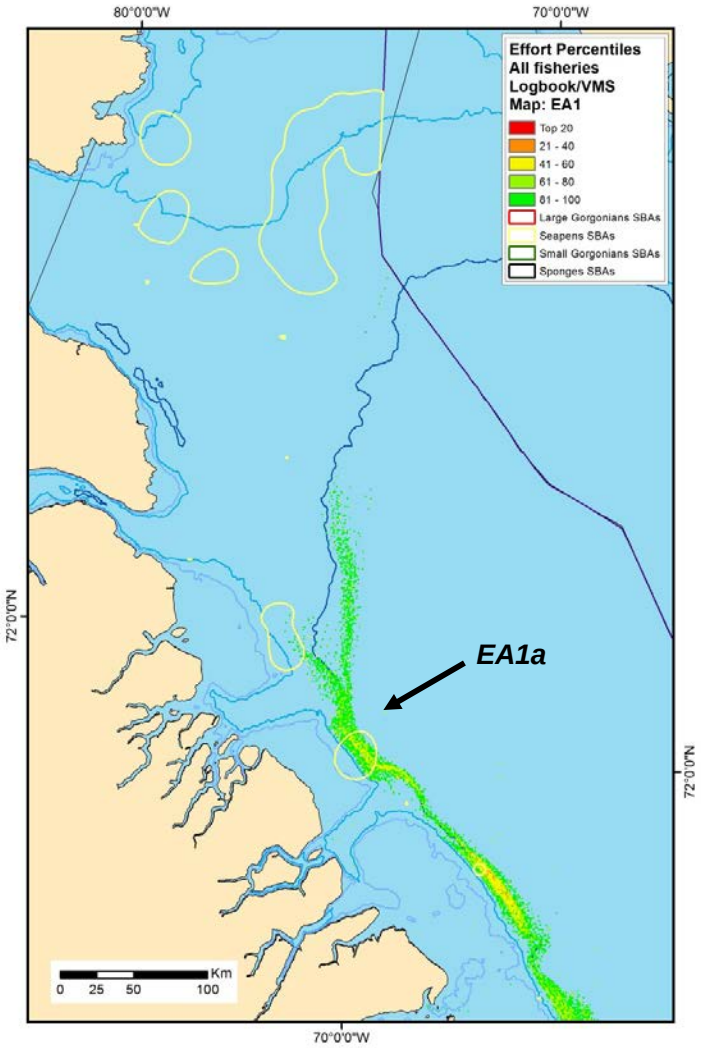

Figure 67. Overlap between all fishing effort and Significant Benthic Areas in the Eastern Arctic bioregion, inset EA1. The arrow indicates the general area of overlap with higher fishing intensity.

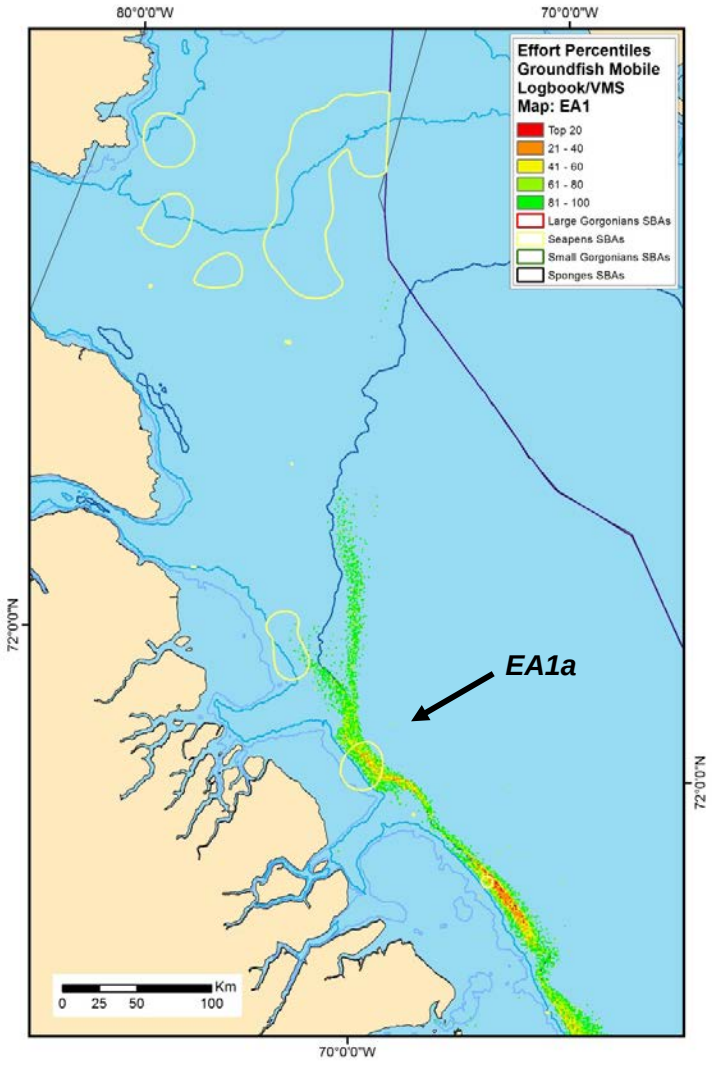

Figure 68. Overlap between Groundfish Mobile effort and Significant Benthic Areas in the Eastern Arctic bioregion, inset EA1. The arrow indicates the general area of overlap with higher fishing intensity.

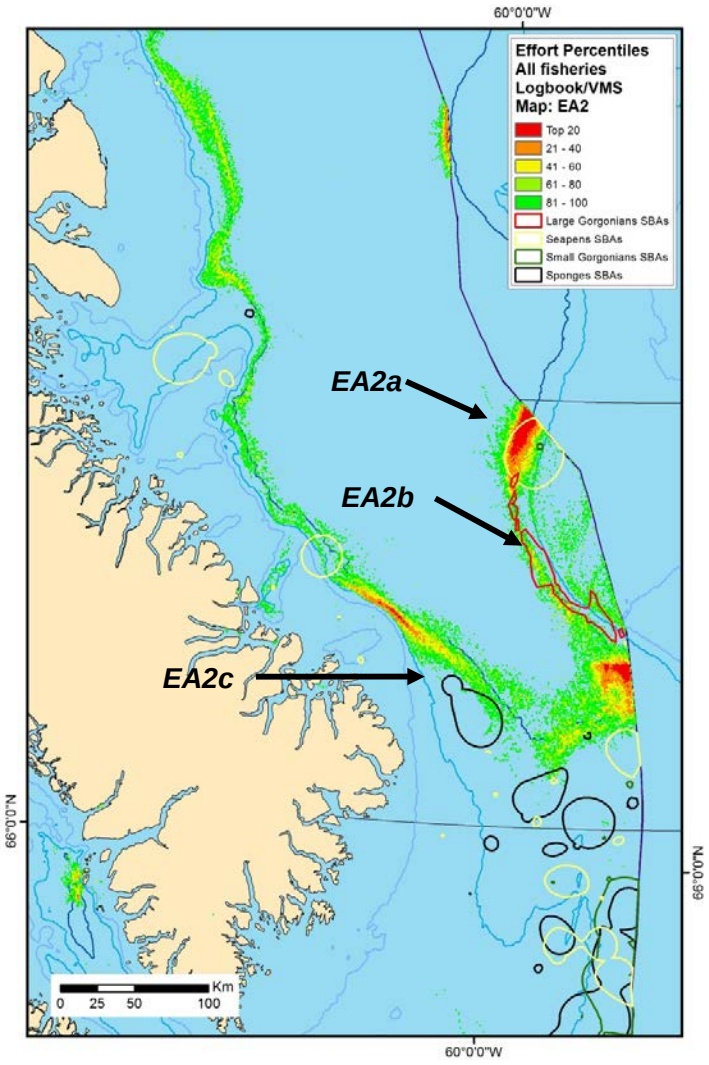

Figure 69. Overlap between all fishing effort and Significant Benthic Areas in the Eastern Arctic bioregion, inset EA2. Arrows indicate general areas of overlap with higher fishing intensity.

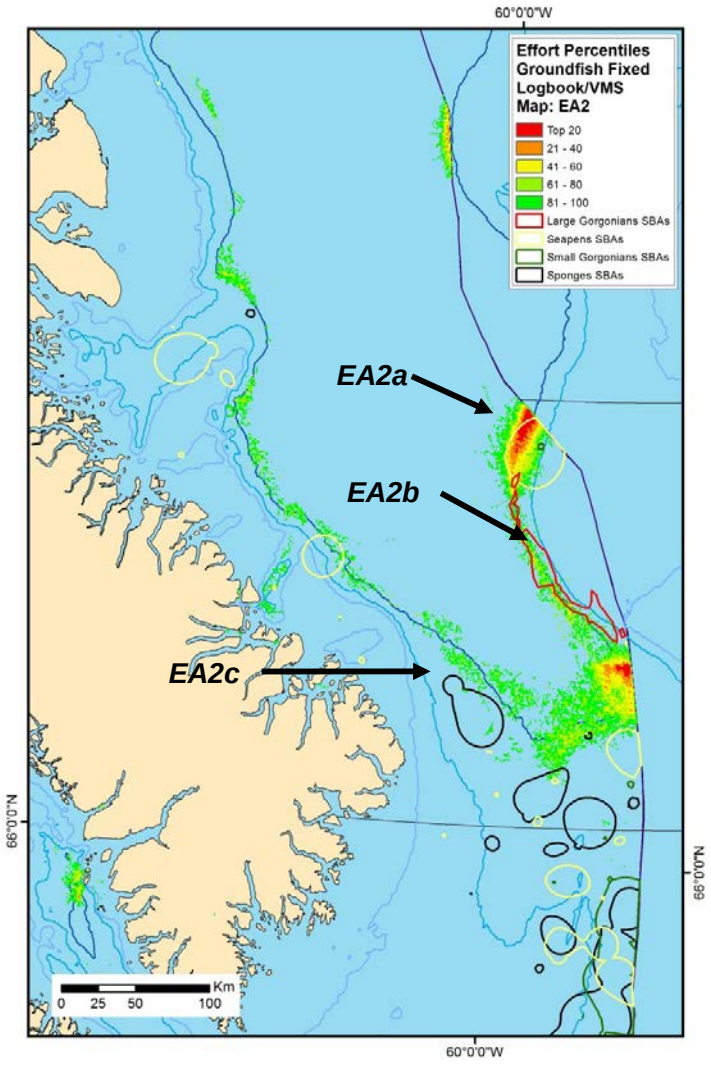

Figure 70. Overlap between Groundfish Fixed effort and Significant Benthic Areas in the Eastern Arctic bioregion, inset EA2. Arrows indicate general areas of overlap with higher fishing intensity.

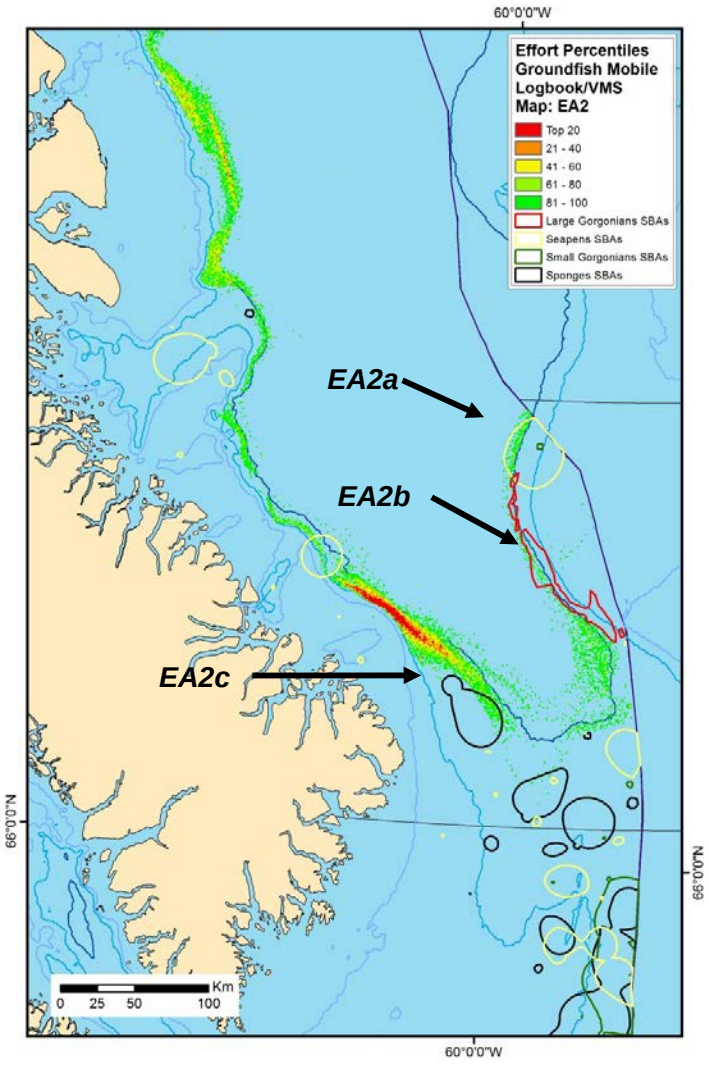

Figure 71. Overlap between Groundfish Mobile effort and Significant Benthic Areas in the Eastern Arctic bioregion, inset EA2. Arrows indicate general areas of overlap with higher fishing intensity.

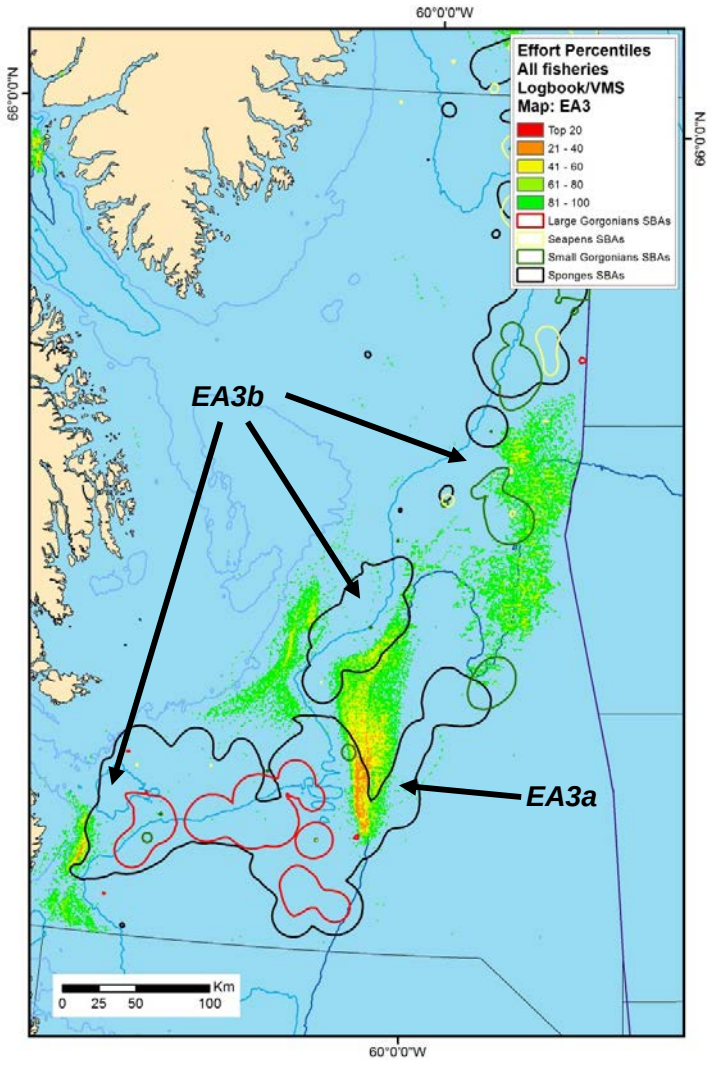

Figure 72. Overlap between all fishing effort and Significant Benthic Areas in the Eastern Arctic bioregion, inset EA3. Arrows indicate general areas of overlap with higher fishing intensity. Areas EA3b highlights fishing effort that is exerted along the boundaries of Significant Benthic Areas. The Significant Benthic Areas underneath the legend can be seen in Figure 69. There is no fishing effort overlapping those Significant Benthic Areas.

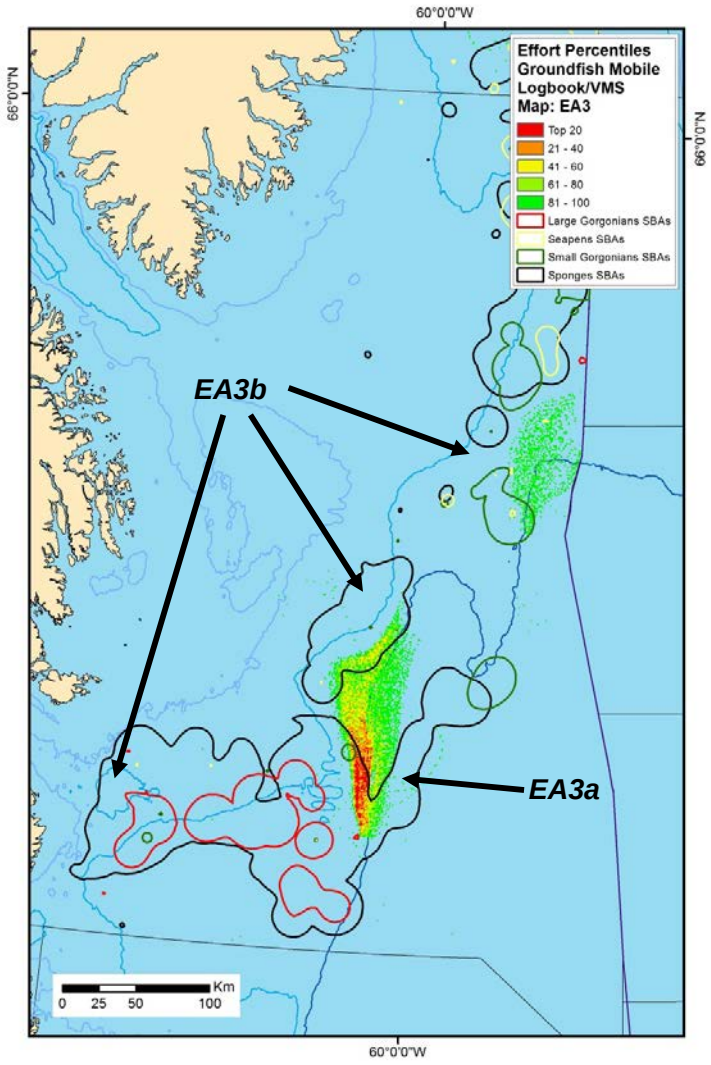

Figure 73. Overlap between Groundfish Mobile fishing effort and Significant Benthic Areas in the Eastern Arctic bioregion, inset EA3. Arrows indicate general areas of overlap with higher fishing intensity. Areas EA3b highlights fishing effort that is exerted along the boundaries of Significant Benthic Areas. The Significant Benthic Areas underneath the legend can be seen in Figure 69. There is no fishing effort overlapping those Significant Benthic Areas.

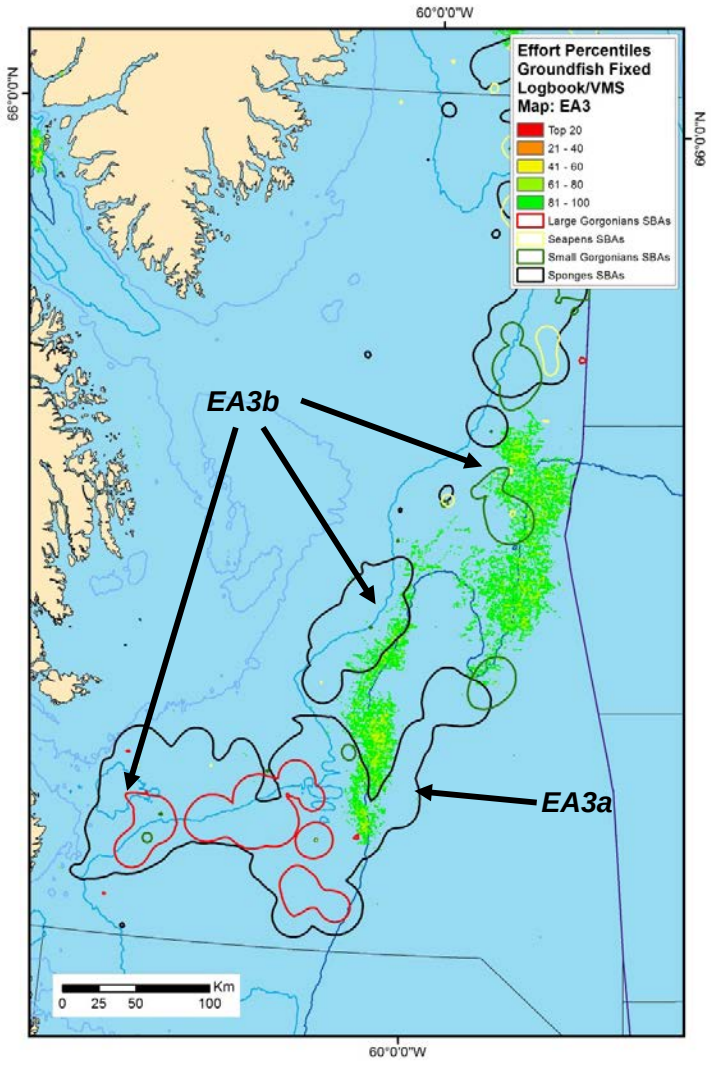

Figure 74. Overlap between Groundfish Fixed fishing effort and Significant Benthic Areas in the Eastern Arctic bioregion, inset EA3. Arrows indicate general areas of overlap with higher fishing intensity. Areas EA3b highlights fishing effort that is exerted along the boundaries of Significant Benthic Areas. The Significant Benthic Areas underneath the legend can be seen in Figure 69. There is no fishing effort overlapping those Significant Benthic Areas.

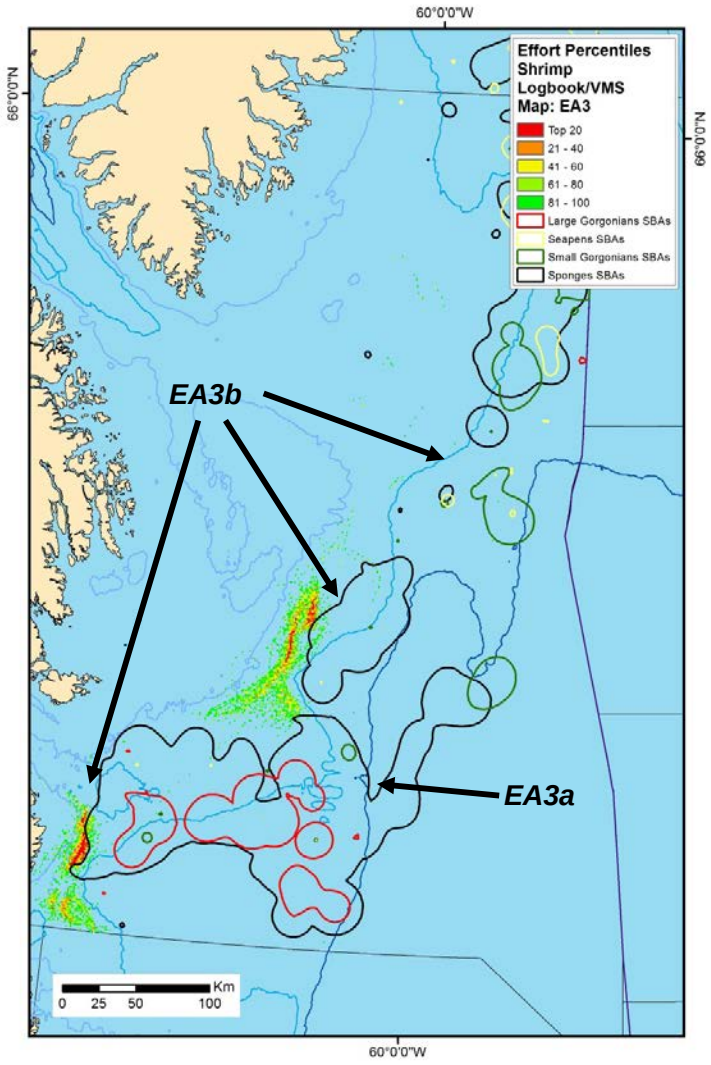

Figure 75. Overlap between Shrimp fishing effort and Significant Benthic Areas in the Eastern Arctic bioregion, inset EA3. Arrows indicate general areas of overlap with higher fishing intensity. Areas EA3b highlights fishing effort that is exerted along the boundaries of Significant Benthic Areas. The Significant Benthic Areas underneath the legend can be seen in Figure 69.

DISCUSSION

A total of 35 main areas have been highlighted in the Canada's Atlantic and Eastern Arctic bioregions due to overlaps between fishing effort and Significant Benthic Areas. In terms of numbers, the Gulf of St. Lawrence has the most areas (11), followed by Scotian Shelf (10), Newfoundland and Labrador (8), and lastly Eastern Arctic (6). However, these numbers should not be considered an index of relative concern across regions. These areas of concern involve drastically different Significant Benthic Area sizes, and the absolute surfaces of the overlaps involved in each one of them are also very different. Also, the effort analyzed here corresponds to a period after the collapses of major groundfish stocks, and hence it is unlikely to represent the situation prior the 1990s.

Furthermore, the overlap values estimated in this analysis, as well as the overlap maps, only reflect the fishing effort that is georeferenced, which represents 23% of the total fishing effort in the study area. Even though this figure seems low, the lobster fisheries class, which typically operates in waters shallower than 50 m depth, accounts for most of the non-georeferenced effort (Figure 3, Table 2), and the vast majority of non-georeferenced effort takes place in inshore areas and in the Gulf of St. Lawrence (Figure 3). Taking into account that most Significant Benthic Areas are in offshore waters, the limitations associated with georeferencing are not expected to have significant impacts on the results.

These areas of concern simply highlight general locations where interactions between fishing activities and Significant Benthic Areas are more likely to occur. It is the overall extent of these interactions, the level of harm involved, and the specific role of the concerned Significant Benthic Area type towards contributing to overall ecosystem functioning what would determine the actual adverse impact of these interactions.

DFO's Ecological Risk Assessment Framework (DFO 2013), defines Sensitive Benthic Areas (do not confuse with Significant Benthic Areas) as "areas that are vulnerable to a proposed or ongoing fishing activity. Vulnerability will be determined based on the level of harm that the fishing activity may have on the benthic area by degrading ecosystem functions or impairing productivity".

The areas identified in this document can be interpreted as candidate "Sensitive Benthic Areas". However, they should not be considered a totality, but rather a minimum candidate set, of Sensitive Benthic Areas. Because of the limitations due to availability of georeferenced data, it is possible, especially within the GSL, that there are other areas where fishing effort is overlapping with Significant Benthic Areas. Also, the percentile method used in this analysis allows identifying areas with higher fishing effort, but this does not mean that the effort exerted in low effort areas is not enough to cause harm to Significant Benthic Areas. It only means that there is less effort applied in those areas, and hence, the frequency of impacts is lower. Depending on the specific type of impact, and the Significant Benthic Area community involved, few interactions could be sufficient to cause irreversible harm (e.g. NAFO 2011) because the greatest impacts are caused by the first few fishing events (DFO 2006).

Overall, the amount of overlap between fishing effort and Significant Benthic Areas in all bioregions, with the exception of the Eastern Arctic, can be considered high (Figure 76). It is clear that the high overlap values emerge from the cumulative effect of multiple fisheries classes. The overlap of some Significant Benthic Area types onto the footprint of some fisheries class aggregates may display, on their own, more moderate values (Figure 76). It is also important to keep in mind that these overlaps are based on the Significant Benthic Areas identified from integrating kernel density estimation and species distribution model analyses. Although these analyses were, in a number of instances, validated with underwater camera observations and data not used in the analyses, they remain focus areas, rather than hard boundaries (Kenchington et al. 2016). Therefore, some of the observed effort along the boundaries of the Significant Benthic Areas may not actually be within the Significant Benthic Areas themselves.

The fraction of fishing footprints occurring over Significant Benthic Areas tends to be low (Figure 77), with the highest overlaps being observed for Sponge and Sea pen Significant Benthic Areas. Furthermore, fishing effort shows, across all bioregions and fisheries classes, a very clear concentration pattern, where a large fraction of the effort is exerted in a relatively small fraction of the footprint, which follows an exponential relationship (Figure 78). Therefore, these overlaps, which only consider the fishing footprint extent, may represent an upper estimate of the role that Significant Benthic Areas may contribute to actual fishing yields if these areas are

not highly fished. However, if Significant Benthic Areas actually represent core fishing areas, then their contribution to fishing yields could be more important than suggested by the overlap figures. This would also mean that Significant Benthic Areas have a more direct and important association with fish productivity.

In order to explore the potential for Significant Benthic Areas to be in core fishing areas, overlap values were estimated by considering partial fisheries footprints associated to different levels of effort concentration (Figure 79). This exploration indicates that in SS, GSL and NL, the overlap of the fisheries onto the Significant Benthic Areas is minimal when the core fishing areas concentrating the highest densities of fishing effort are considered, and this overlap increases as more marginal areas of the fishing footprints are incorporated. This overall pattern generally seems to hold for all Significant Benthic Area types, although it is less clear for Large Gorgonian Significant Benthic Areas, especially when most of the fishing footprint is considered (Figure 79). This suggests that overlap of fishing onto Significant Benthic Areas increases as marginal fishing areas are included in the overlap calculations, indicating that Significant Benthic Areas in these bioregions tend not to be core fishing areas.

However, a reverse pattern emerges when this analysis is conducted for the EA region (Figure 79). In this case, overlap of fishing onto Sea pen and sponge Significant Benthic Areas decreases as marginal fishing areas get incorporated into the overlap calculation. This suggests that Sea pen and Sponge Significant Benthic Areas in the EA bioregion are in core fishing areas.

The available evidence seems to indicate that the developmental stage of the fisheries in the EA bioregion may be a plausible explanation for these differences, but many factors are likely contributing. Fishing intensity in this bioregion is orders of magnitude lower that in the other three bioregions considered, and even though fishing may have a long history in EA, the intensity and extent of the activity is comparatively much less than what has historically occurred in SS, GSL, and NL. In this context, if new fisheries initially develop by targeting areas of high fishing yields, and these areas turn out to be Significant Benthic Areas, then the absence of Significant Benthic Areas as core fishing areas in SS, GSL, and NL could be interpreted as the result of historical fishing practices that removed them as fisheries developed (Moritz et al. 2015). This could mean that significant damage and/or removal of Significant Benthic Areas may have (or have had) a direct impact on fisheries productivity.

Overall, the results from this study indicate that, for most bioregions, there is clear evidence that the overlap between fishing effort and Significant Benthic Areas may be high enough to assume that Significant Benthic Areas are likely being impacted by fishing activities. Preliminary observations on coral and sponge communities outside the Northwest Atlantic suggest that impacts such as these may have the potential to affect ecosystem productivity (van Oevelen et al. 2009, Kutti et al. 2013, Cathalot et al. 2015, Rix et al. 2016). The actual extent and degree of fishing impacts will be a function of the Significant Benthic Area taxa involved, the level of perturbation, and the role of these Significant Benthic Areas in the overall ecosystem functioning. Although addressing these aspects was beyond the scope of this study, our results provide a first screening of the potential for these types of interactions to occur, and parts of Canada’s Atlantic and Eastern Arctic waters in which they are likely taking place.

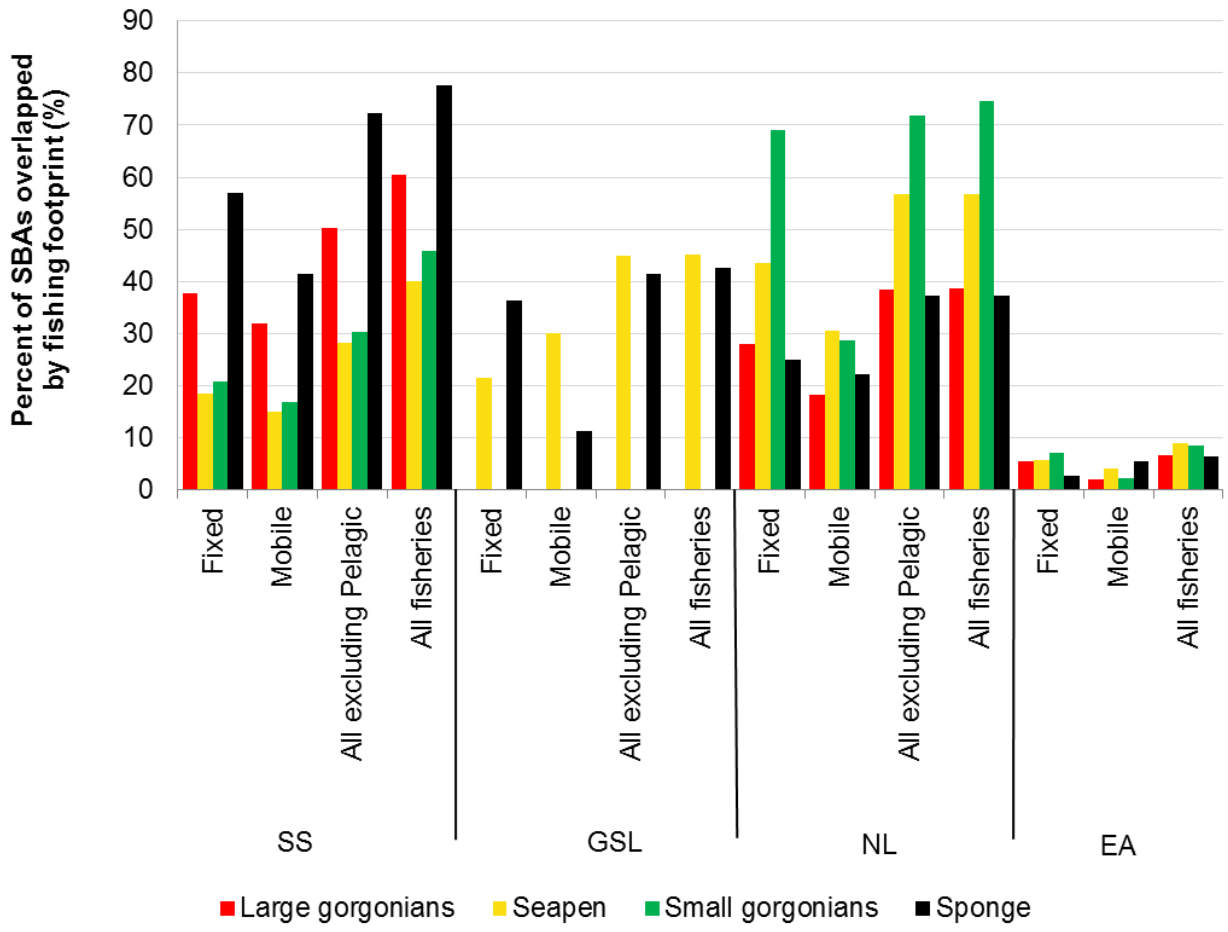

Figure 76. Comparison of the percent of Significant Benthic Areas (SBAs) that overlap with fishing footprints from different levels of aggregate fishing effort. All values correspond to the merged logbooks and VMS effort layers displayed in Tables 9, 16, 23, and 30.

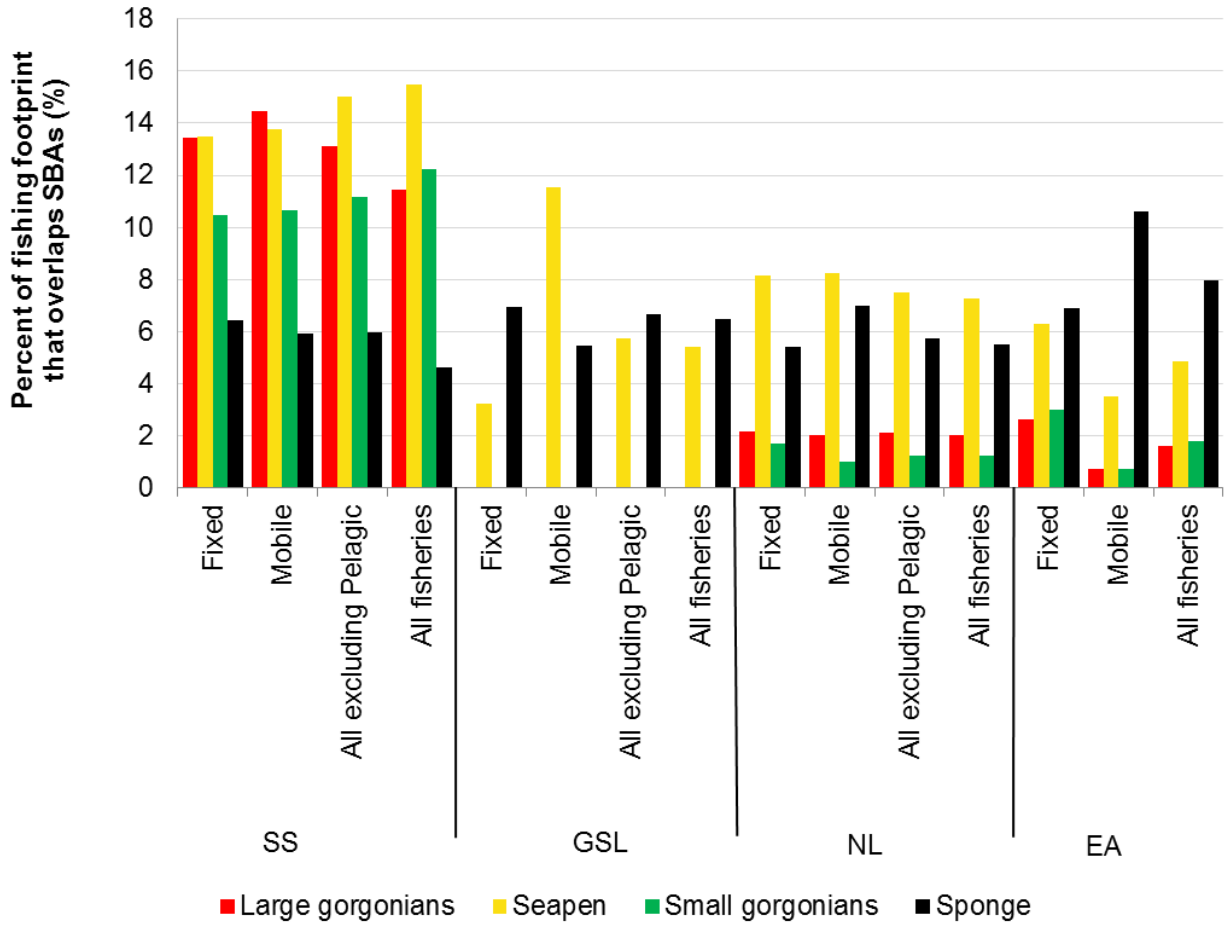

Figure 77. Comparison of the percent of fishing footprints overlapping Significant Benthic Areas (SBAs) across different levels of aggregate fishing effort. All values correspond to the merged logbooks and VMS effort layers displayed in Tables 9, 16, 23, and 30.

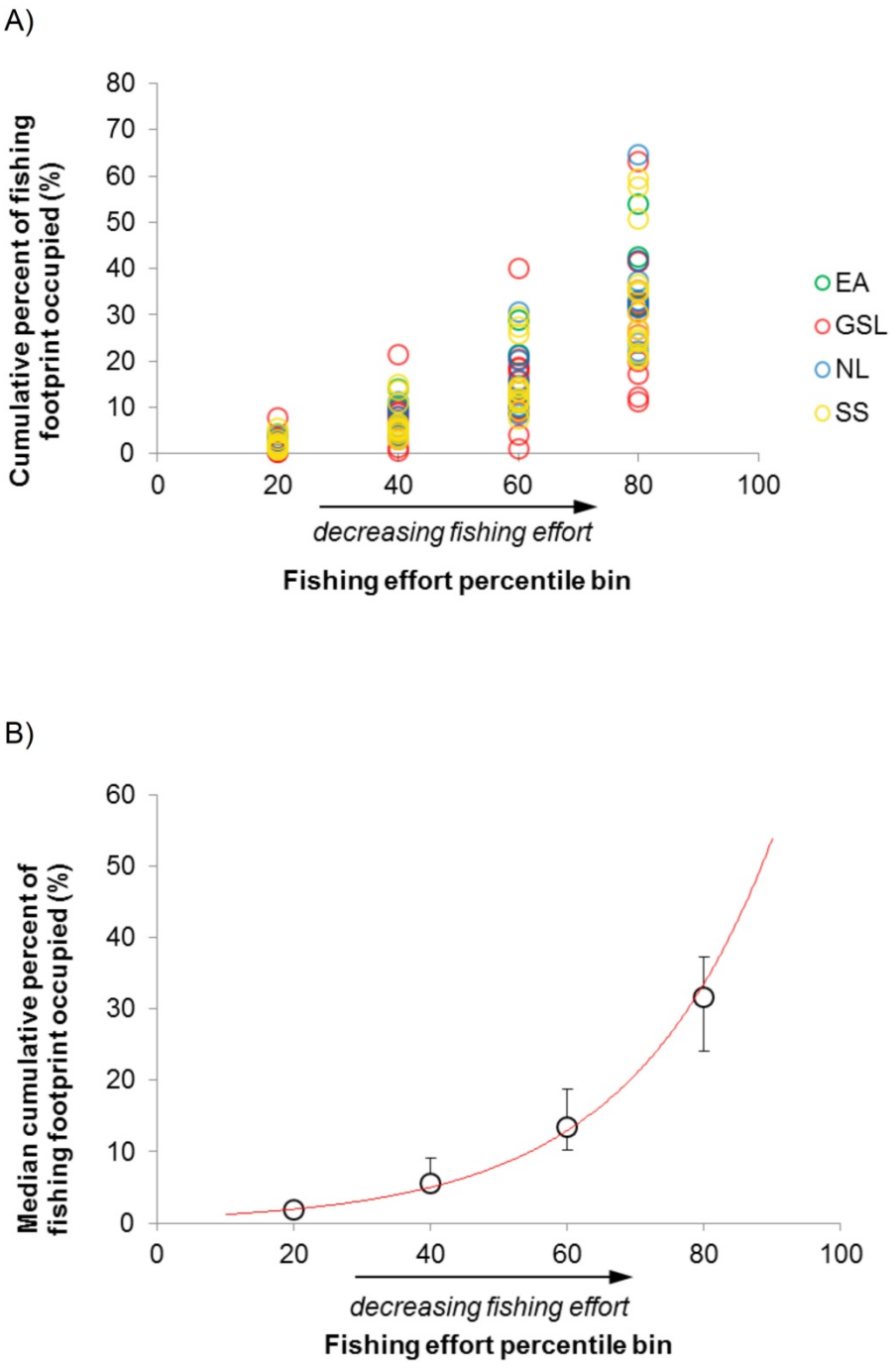

Figure 78. Concentration of fishing effort in space. Relationship between top fishing effort percentiles and the fraction of the total fishing footprint associated with them; each data point correspond to a single fisheries class within a bioregion; Median and interquartile (25-75%) ranges for the relationship between top fishing effort and fishing footprint occupancy displayed in (A); the line correspond to the fitted exponential regression (the corresponding equation is also presented in the figure). The effort and occupancy data used in these figures correspond to the merged logbook and VMS effort layer; all data is presented in Tables 5, 12, 19 and 26.

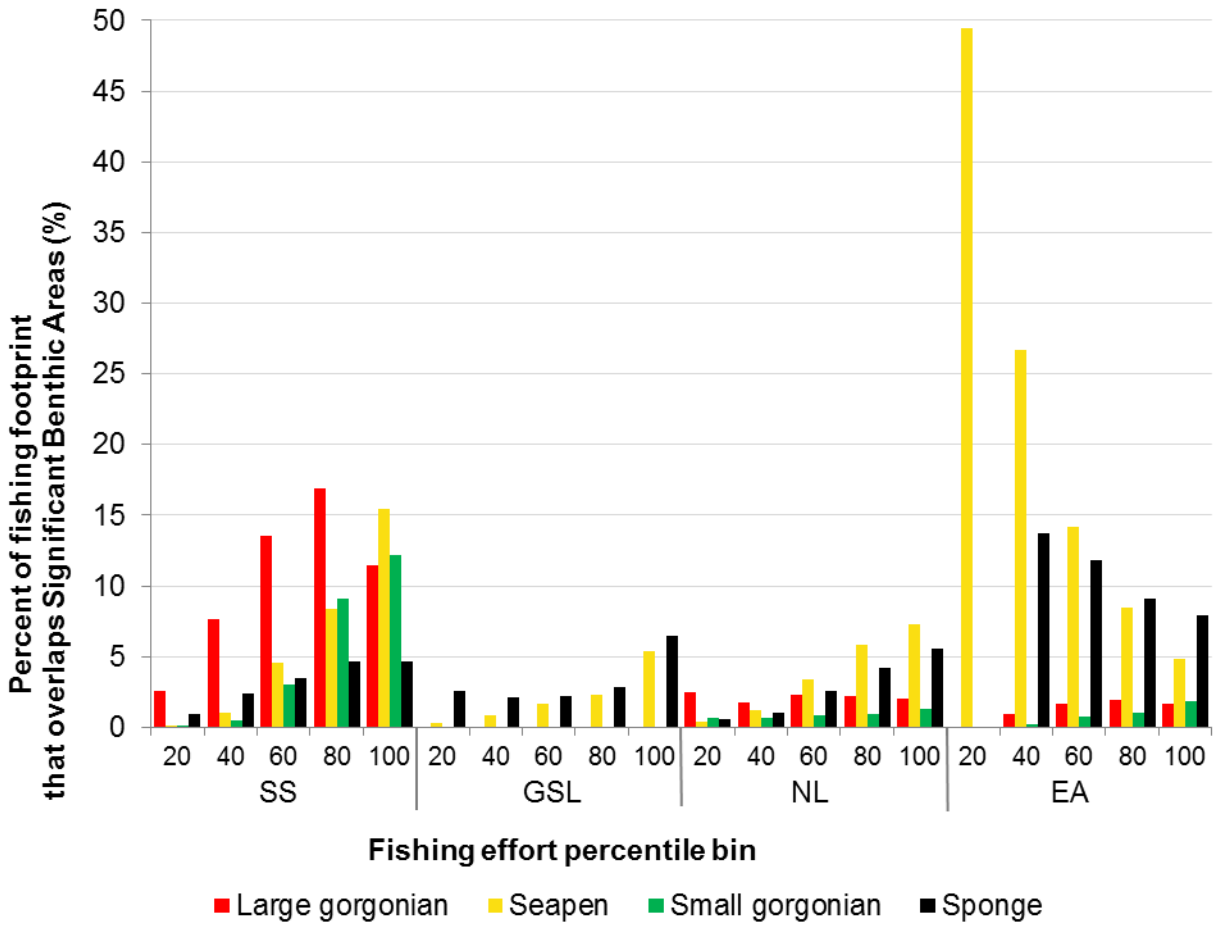

Figure 79. Changes in the percentage of total fishing footprint overlapping with Significant Benthic Areas in relation to fishing effort concentration expressed as top fishing effort percentiles (increasing numbers represent decreasing effort, i.e. the highest effort concentration is represented by the top 20% and the entire extent of the fishing footprint is represented by the 100%) in Canada's Atlantic and Eastern Arctic waters, and discriminated by Significant Benthic Area taxa. SS: Scotian Shelf, GSL: Gulf of St. Lawrence, NL: Newfoundland and Labrador, EA: Eastern Arctic.

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APPENDIX 1. PROCESSING OF VESSEL MONITORING SYSTEM (VMS) AND LOGBOOK DATA TO CHARACTERIZE FISHING EFFORT

DATA

To produce fishing effort maps, two types of data were used: Vessel monitoring system (VMS) data and logbook. VMS data is available from Fisheries and Oceans Canada National Vessel Monitoring System Program while logbook data is available from the Integrated Catch and Effort Regional System (ICERS) database at the DFO national Statistical Services office in Ottawa. Obtaining logbooks from the national, instead of the regional, office means that data from all vessels, including those originating in other regions, will be included.

Logbook and VMS data were obtained for all vessels on dates that spanned January 1, 2005 to December 31, 2014 in NAFO Divisions 0AB 2GHJ 3KLNOPnPs 4VnVsWX 5YZe. VMS data and logbook data with positions were clipped to domestic waters that extend to the 200-mile limit.

Logbooks

Logbook data contains on a day-by-day or tow-by-tow basis: vessel-specific information (Vessel Registration Number-VRN, length overall), fishing information (gear, directed species, latitude and longitude of fishing as available), landing date, catch date, and NAFO statistical area. Identifiers for vessel-day based on combinations of catch date (if available), landing date and trip number were also created. Records with obvious errors were removed, such as missing data, duplicated rows or where a catch date was reported to occur after a landing date.

Logbook records were classified into fisheries classes based on combinations of gear and directed species. The full combinations of gear and directed species, in each fisheries class, along with their species codes in the DFO Integrated Catch and Effort Regional System (ICERS) database are shown in Table A1 - 1

Table A1 - 1. Fisheries classes defined for the analysis of overlap between fishing effort and Significant Benthic Areas. The gears and species codes correspond to the ones used in DFO Integrated Catch and Effort Regional System (ICERS) database.

Label	Location	Gear group	Specific gears (codes)	Specific species or taxa (codes)
Groundfish Mobile	Offshore	Mobile	Trawls (9, 10, 11, 12, 13, 16), bottom seines (21, 22, 33)	Groundfish (100:199)
Shrimp	Offshore	Mobile	Trawls (9, 10, 11, 12, 16, 19, 33)	Shrimp (702, 712)
Scallop	Inshore	Mobile	Dredge (71)	Scallop (612, 617)
Clam	Inshore	Mobile	Dredge (71), hydraulic device (74)	Surf clam and other clams (600:609, 951), oyster (611), whelks (615), cockles (616)
Echinoderm	Inshore	Mobile	Dredge (71), drag (77)	urchins (650), sea cucumber (619)

Label	Location	Gear group	Specific gears (codes)	Specific species or taxa (codes)
Groundfish Fixed	Offshore	Fixed	Gillnet (41, 43), longline (51), handline (59), pots (62), cod pots (67)	Groundfish (100:199), lumpfish roe (928)
Crab Offshore	Offshore	Fixed	Traps (61), pots (62), japanese traps (66), other traps (68, 69, 78, 98, 99)	Snow crab (705), stone/king crab (708)
Miscellaneous Offshore	Offshore	Fixed	Hagfish barrel (86), pots (62), traps (61)	Shrimp (702,712), hagfish (197)
Lobster	Mostly Inshore	Fixed	Pots (62)	Lobster (700)
Crab Inshore	Inshore	Fixed	Traps (61), pots (62), japanese traps (66), other traps (68, 69, 78, 98, 99)	crabs EXCEPT snow crab and stone/king crab (701, 706, 707, 710, 711)
Whelk	Inshore	Fixed	Traps (61), pots (62), other traps (68, 69, 80, 87, 88, 89, 98)	whelks (615)
Miscellaneous Inshore	Inshore	Fixed	Eelpot (84), drag rake (93), rakes and tongs (91), fyke net (47), weir (63), diving (75, 76), hand dredge (72), hand tools (96), micellaneous (90), unknown (99)	groundfish (100:199), eel (352), clam (600, 601, 602), seaweeds/macroalgae (900:907), urchins (650), sea cucumber (619), oyster (611), mussel (610), lobster (700)
Pelagic	Pelagic	Fixed & Mobile	midwater trawls (14,15), seines (24, 25, 31, 32), gillnets (41, 42, 43), longline (51), jiggers (52, 53, 55), trolling (54, 60), rod and reel (58, 60), handline (59), harpoon (81), seal hunting (82)	pelagics (200:399), squid (613), seals (805)
Other	Inshore, offshore and pelagic	Fixed & Mobile	Unspecified gears (0, 99), Traps (61)	Unspecified species (0), pelagics (200:399),

VMS

Each VMS data ‘ping’ is comprised of a VRN, longitude, latitude, and a timestamp. The VRN listed in the VMS data is the same VRN that is present in the logbook data, which enables merging to obtain information on gear, directed species, and other vessel information.

VMS data requires cleaning before analysis as these data can sometimes include errors due to equipment malfunction or post-processing issues. A summary of the processing of raw VMS data applied to the dataset is in Table A1 - 2 and as follows:

First, we checked for obvious technological errors by removing points with incomplete timestamps, points with latitude and longitudes outside of earth's range, and duplicate points. We then removed points that occurred on land by clipping the data to the coastline. Next, we calculated the interval between subsequent pings for each vessel, which is typically one hour, but may vary between vessels. In this analysis, we removed those points that occurred less than 5 minutes after the previous point, which were deemed likely to be errors. Because instantaneous vessel speed is not recorded on many VMS units in Atlantic Canada, we derived an average speed by dividing the Great Circle distance travelled and time interval since the previous ping. We used functions for these calculations that are available in the open-source R package "VMStools". VMStools was originally created for European data (Hintzen et al. 2012), but some simple data formatting allows Canadian VMS data to be analysed with these peer-reviewed functions. We excluded points with a calculated speed > 25 knots (kn) as they were unrealistic travel speeds and unlikely to represent fishing behaviours. To exclude the data while the vessels were believed to be in port, we removed points within 1 km of communities. Community locations were obtained from the Atlas of Canada, Government of Canada, Natural Resources Canada, Mapping Information Branch (http://www.geogratis.gc.ca).

Table A1 - 2. Number of pings (n) in raw and final dataset with breakdown of numbers removed in various processing stages.

Region	Initial pings	Duplicate	Missing data	In harbour or on land	Interval < 5 min	Outside 200-mile limit	Over 25 knots	"Clean" pings
EA	780794	799	86279	2425	28072	100850	4375	557994
GSL	24908924	17	0	13132836	44802	0	6668	11724601
SS	18284236	2629	640	6343655	181079	387121	7900	11361212
NL	20547178	11745	302730	11057454	115963	340231	9245	8709810
Total	64521132	15190	389649	30536370	369916	828202	28188	32353617

Finally, before attempting linking the two datasets, we removed points from the VMS and logbook datasets for vessels that were not found in both datasets.

JOINING VMS TO LOGBOOKS

Data from VMS was merged to logbooks by matching VRN and date to obtain information on the fishing activities associated with pings on a vessel for a given day. Specifically, each VMS record was joined to the logbook event of matching catch date. The join was completed using the R Statistical Software (R Core Team, 2014) with the package dplyr (Wickham and Francois 2015). We were unable to join some records, possibly due to errors in dates reported in logbooks, VMS unit malfunction, or because there may have been no VMS requirement for a given fishery within a specific time period or area.

After relating VMS to logbook, we classified the pings as "fishing" or "non-fishing" by examining the distribution of speeds in each fisheries class. Speed profiles (histograms) for different

fisheries classes typically have two or three peaks that represent different behaviours (Figure A1 - 1 – A1- 4), with the tallest peak representing fishing activities. We visually examined speed histograms and set speed thresholds for fishing activities (Table A1 - 3) based on apparent boundaries of peaks and ensured speed thresholds were congruent with those used in other scientific literature (Lee et al. 2010). Speed thresholds were set with calculated speeds (for fisheries classes with 100 pings minimum), because we only received reported “instantaneous” speeds for a portion of the data.

Our procedure allows us to classify each ping as “fishing” or “not-fishing”, as well as to assign an amount of activity time to each ping depending on the interval time between VMS points (“ping time”). VMS effort was quantified as the sum of the fishing “ping time” (in hours) within each cell of the 1 km x 1 km grid used in this study.

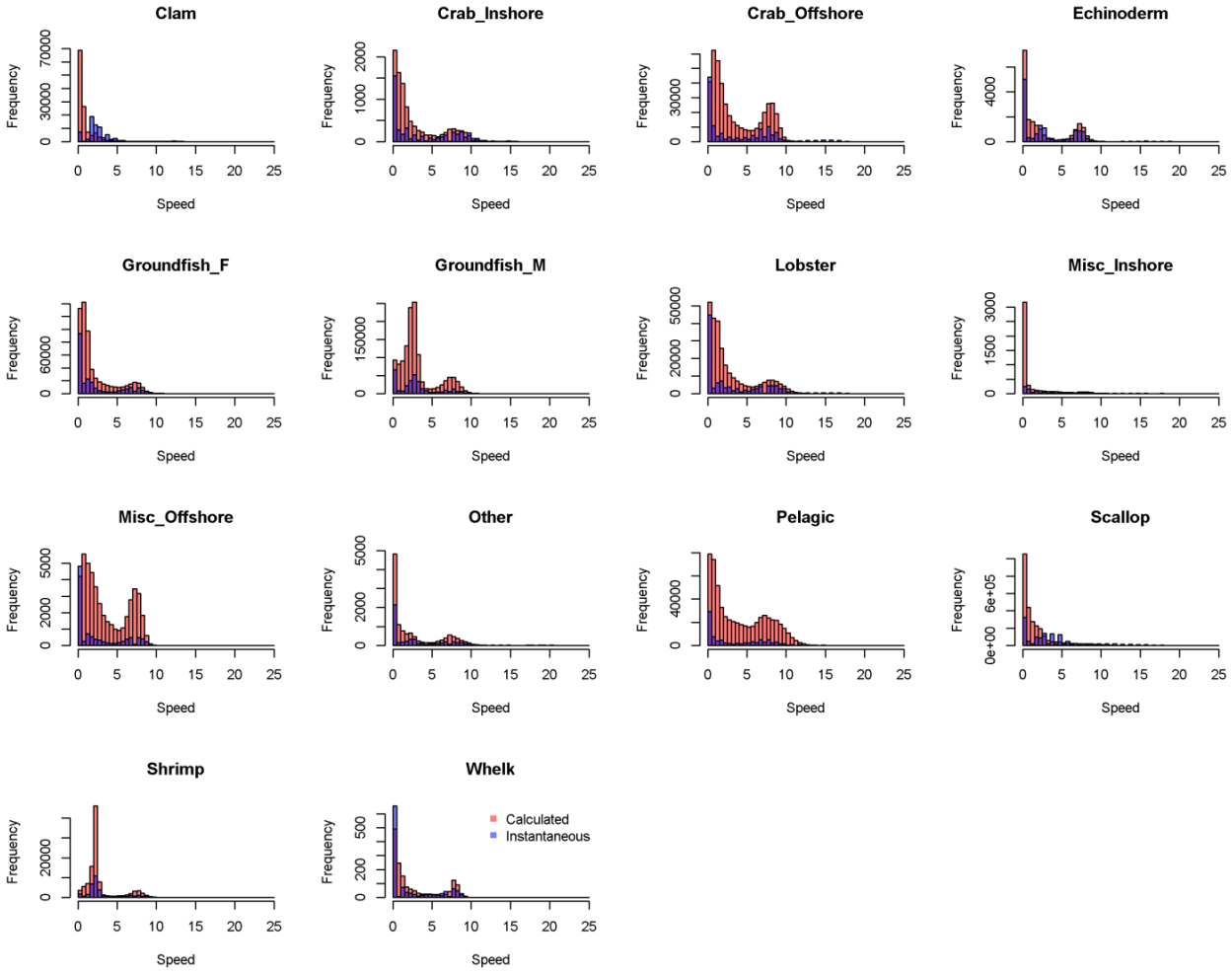

Figure A1 - 1. Scotian Shelf speed histograms. Calculated speeds refer to those that were derived from geographic positions and timestamps of a vessel, assuming straight-line travel. Instantaneous speeds refer to those transmitted by the VMS unit, as available.

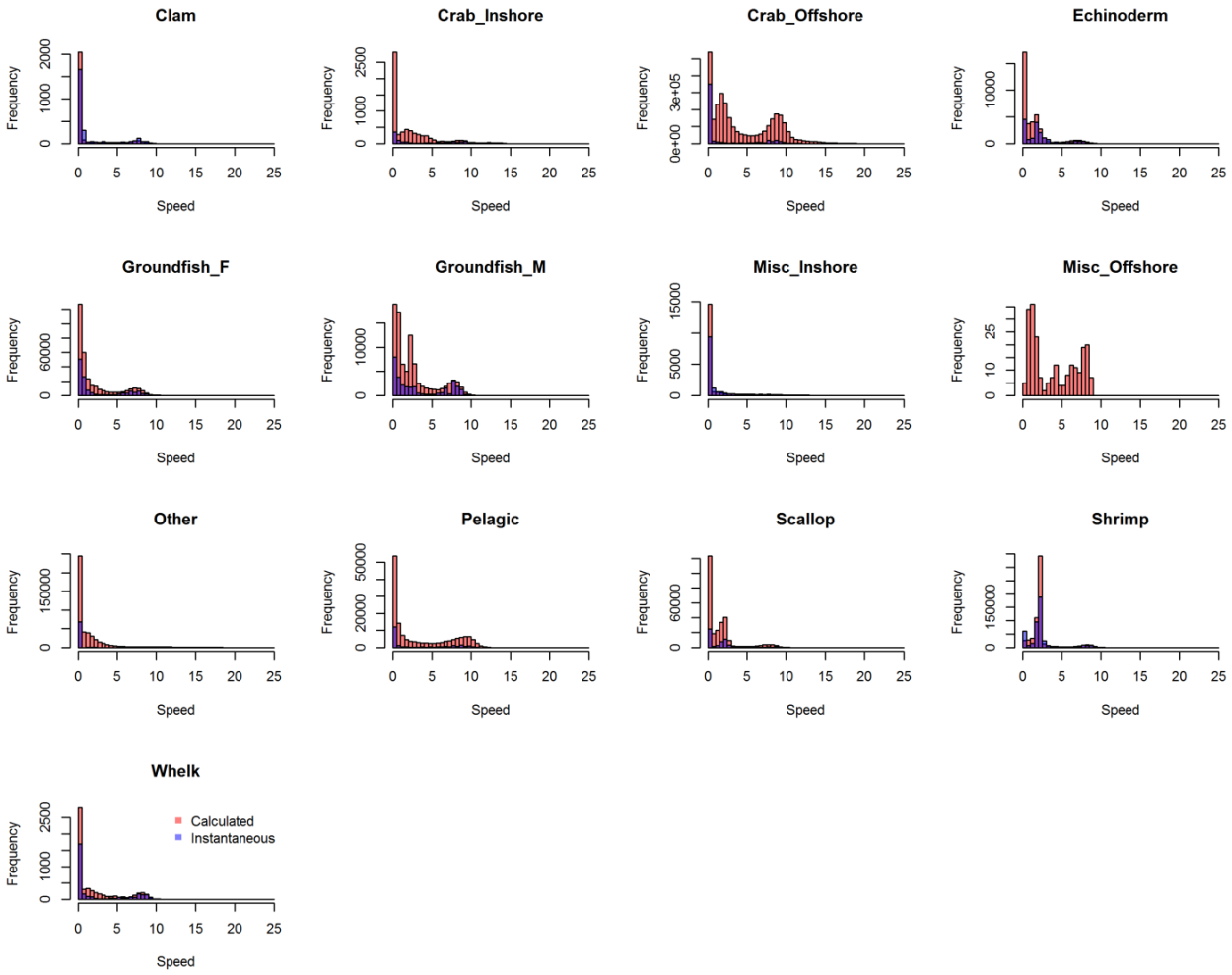

Figure A1 - 2. Gulf of St. Lawrence speed histograms. Calculated speeds refer to those that were derived from geographic positions and timestamps of a vessel, assuming straight-line travel. Instantaneous speeds refer to those transmitted by the VMS unit, as available.

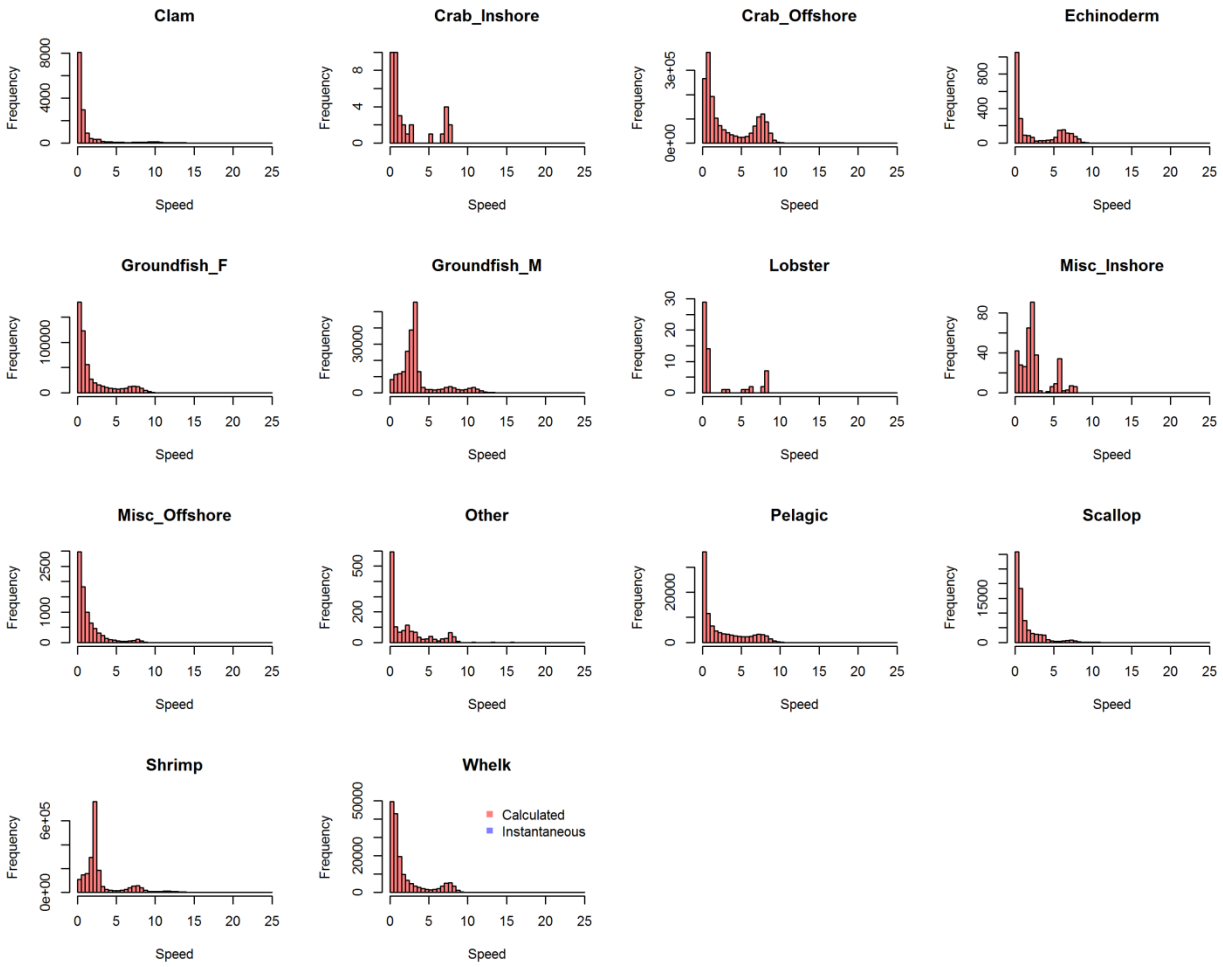

Figure A1 - 3. Newfoundland and Labrador speed histograms. Only calculated speeds were available for this bioregion.

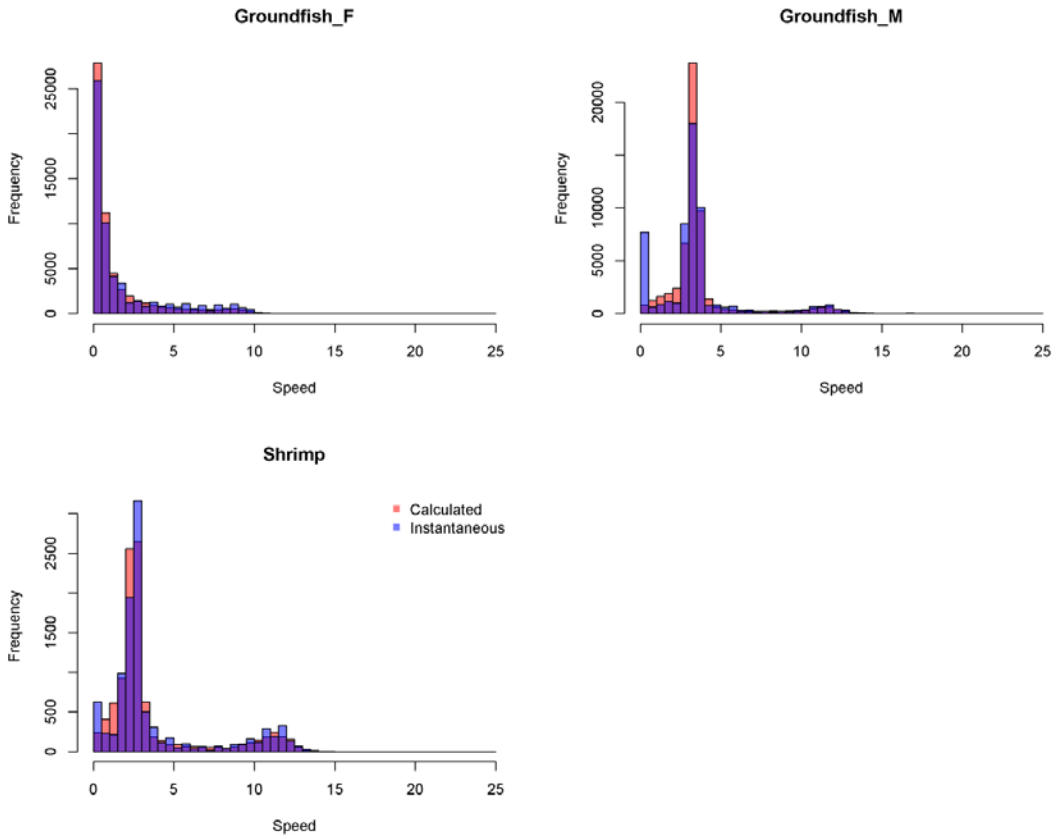

Figure A1 - 4. Eastern Arctic speed histograms. Calculated speeds refer to those that were derived from geographic positions and timestamps of a vessel, assuming straight-line travel. Instantaneous speeds refer to those transmitted by the VMS unit, as available.

Table A1 - 3. Speed thresholds for fishing speeds (kn), by bioregion and fishery class. Note, "-" in a cell means that a fishery class did not operate in that bioregion, or there were less than 100 pings in that bioregion's fishery class. EA = Eastern Arctic, GSL = Gulf of St. Lawrence, SS = Scotian Shelf, and NL = Newfoundland and Labrador.

Fishery class	EA lower speed	EA upper speed	GSL lower speed	GSL upper speed	SS lower speed	SS upper speed	NL lower speed	NL upper speed
Clam	-	-	0.1	3.5	0.5	4	0.1	3
Crab Inshore	-	-	0.1	5	0.1	5	-	-
Crab Offshore	-	-	0.5	5	0.1	5	0.1	5
Echinoderm	-	-	0.1	3.5	0.5	4	0.1	2.5
Groundfish Fixed	0.1	2	0.1	4.5	0.1	5	0.1	4.5
Groundfish Mobile	2.5	4.5	0.5	4.5	1	4.5	1	4.5
Lobster	-	-	0.1	5	0.1	5	-	-
Misc. Inshore	-	-	0.1	4	0.1	5	-	-
Misc. Offshore	-	-	0.5	5	0.1	4	0.1	4
Other	-	-	0.1	5	0.1	5	0.1	4
Pelagic	-	-	0.1	5	0.1	5	0.1	5
Scallop	-	-	0.1	3.5	0.1	4	0.1	4
Shrimp	1.5	5	1	4	1.5	4.5	1	4.5
Whelk	-	-	0.1	4	0.1	4.5	0.1	4.5

CREATING SPATIAL LAYERS

We had two main categories of spatial data – data from logbooks only, data from VMS records (with fishery information derived from logbooks).

For logbook records with geographic position data, and for VMS data, we aggregated fishing positions over a 1 km x 1 km grid in R using the packages rgdal (Bivand et al. 2014) and sp (Pebesma and Bivand 2005). We created shapefiles of the extent of fishing operations for our fishing footprint layers. Next, the intensity of fishing in the cell (vessel-days for logbooks or hours for VMS data) was used to calculate percentiles of effort. Layers with effort percentiles were created for each fishery, and each bioregion. As well, fishing footprint shapefiles and effort percentile raster layers were created for three aggregated categories: fixed gears, mobile gears, and a category with all fisheries classes excluding pelagic (See Table 1, main text). Data was mapped and visualized in ArcGIS 10.2.2 (Esri 2014).

INTEGRATION OF LOGBOOK AND VMS PERCENTILE LAYERS

If logbooks and VMS data are valid random samples of a common underlying distribution, specific cells would be expected to fall under the same percentile ranges irrespective to the data

source. For example, a given cell that belongs to the top 10 percentile in the true effort distribution would be expected to be assigned to the top 10 percentile irrespectively of which data source is used to define the percentiles of effort. Therefore, by selecting those cells that have both, logbook and VMS data, and comparing the percentiles to which those cells were independently assigned within each data source, we can test the hypothesis that the percentile distributions emerging from each data source are the same. If we reject that hypothesis, the two sources are not sampling/representing the same underlying distribution. If we do not reject it, then we can assume that a cell assigned to a given percentile in one source would have been assigned to the same percentile in the other. This means that we can plot both sources together, and complement the information we are getting from each of them. Since the spatial resolution of the VMS is higher that logbooks, when a given cell has both sources of data, then the value of the VMS should take precedent. Operating in this way allows use of logbook data to fill the gaps for those areas not covered by VMS.

We carried out two different tests to evaluate the similarity in the percentile distributions emerging from both data sources. Both tests compared the distributions of observations over 10 percentile bins (i.e. number of observations within percentiles 0-10, 10-20, 20-30, ..., 90-100). The first test was a two sample Kolmogorov-Smirnov (KS) test between the distributions constructed from logbook and VMS data. The second test assessed the confidence interval of the slope for a linear regression of the number of observations per percentile bin of VMS vs logbooks, where the intercept is assumed 0. If both distributions are the same, the slope of such a regressions should not be significantly different than 1 (i.e. 1 should be within the confidence interval of the slope, with $p < 0.05$). These analyses were carried out by bioregion, and for all fisheries classes combined, as well as for each fisheries class individually.

The results from these tests indicate that all KS were non-significant, as well as most regression analyses indicated the slopes were not significantly different than 1 (Table A1 - 4). On the basis of these results, a merged logbook/VMS percentile effort layer was produced. This was done by simply joining the percentile effort layers from both sources; for those grid cells with information from both sources, the VMS percentile was used. Given that in some cases, the slope was found different than one, the effort and overlap tables were generated by data source, as well as for the merged effort layer.

Table A1 - 4. Comparison of the percentile effort distributions between logbook and VMS data by bioregion and fisheries class. EA = Eastern Arctic, GSL = Gulf of St. Lawrence, SS = Scotian Shelf, NL = Newfoundland and Labrador, KS = Kolmogorov-Smirnov test, N: no, Y: yes, CI = Confidence interval.

Bioegion	Fisheries class	Number of percentile bins with data (N)	Cells with both logbook and VMS data (N)	KS statistic	KS p-value	Regression slope	Regression slope standard error	Regression slope coefficient p-value	Regression slope significantly different than 1?	Regression slope lower 95% CI	Regression slope upper 95% CI
SS	All fisheries	10	64791	0.1	1	1	0.01	0	N	0.99	1.01
SS	Clam	10	1073	0.2	0.99	1.07	0.04	0	N	0.97	1.17
SS	Crab Inshore	10	248	0.3	0.76	1.16	0.13	0	N	0.85	1.47
SS	Crab Offshore	10	6198	0.2	0.99	1.09	0.07	0	N	0.92	1.26
SS	Echinoderm	10	204	0.2	0.99	1.1	0.15	0	N	0.75	1.44
SS	Groundfish Fixed	10	20718	0.1	1	0.96	0.03	0	N	0.9	1.03
SS	Groundfish Mobile	10	13810	0.1	1	1.01	0.02	0	N	0.98	1.05
SS	Misc. Inshore	10	100	0.3	0.76	0.93	0.11	0	N	0.67	1.2
SS	Misc. Offshore	10	1152	0.4	0.4	1.11	0.22	0	N	0.61	1.61
SS	Other	10	31	0.6	0.05	0.86	0.45	0.09	N	-0.17	1.90
SS	Pelagic	10	10077	0.4	0.42	1.14	0.24	0	N	0.58	1.7
SS	Scallop	10	12917	0.2	0.99	1.05	0.01	0	Y	1.02	1.08
SS	Shrimp	10	1921	0.1	1	0.91	0.08	0	N	0.73	1.09
SS	Whelk	10	32	0.2	0.99	0.89	0.22	0	N	0.39	1.4
GSL	All fisheries	10	45921	0.1	1	0.93	0.05	0	N	0.81	1.05
GSL	Clam	9	50	0.33	0.7	0.71	0.13	0	N	0.4	1.02
GSL	Crab Inshore	10	426	0.1	1	0.96	0.04	0	N	0.87	1.06
GSL	Crab Offshore	10	16432	0.2	0.99	1.1	0.04	0	N	1	1.2
GSL	Echinoderm	10	147	0.2	0.99	0.81	0.07	0	Y	0.66	0.96
GSL	Groundfish Fixed	10	9450	0.3	0.79	1.03	0.18	0	N	0.61	1.45
GSL	Groundfish Mobile	10	1788	0.2	0.99	1.07	0.07	0	N	0.9	1.23

Bioegion	Fisheries class	Number of percentile bins with data (N)	Cells with both logbook and VMS data (N)	KS statistic	KS p-value	Regression slope	Regression slope standard error	Regression slope coefficient p-value	Regression slope significantly different than 1?	Regression slope lower 95% CI	Regression slope upper 95% CI
GSL	Misc. Inshore	8	35	0.25	0.96	1	0.21	0	N	0.48	1.52
GSL	Other	5	18	0.4	0.82	0.64	0.14	0.01	N	0.19	1.1
GSL	Pelagic	10	1947	0.2	0.99	0.72	0.19	0	N	0.28	1.16
GSL	Scallop	10	918	0.3	0.79	1	0.03	0	N	0.92	1.08
GSL	Shrimp	10	11249	0.1	1	0.86	0.07	0	N	0.7	1.03
GSL	Whelk	10	191	0.2	0.99	1.04	0.09	0	N	0.84	1.25
NL	All fisheries	10	66111	0.2	0.99	1.11	0.06	0	N	0.98	1.24
NL	Clam	10	131	0.4	0.4	0.6	0.16	0	Y	0.22	0.97
NL	Crab Offshore	10	26548	0.1	1	0.98	0.06	0	N	0.85	1.12
NL	Echinoderm	10	16	0.5	0.16	0.49	0.17	0.02	Y	0.1	0.87
NL	Groundfish Fixed	10	9641	0.1	1	0.94	0.09	0	N	0.74	1.14
NL	Groundfish Mobile	10	3662	0.3	0.79	0.88	0.08	0	N	0.69	1.07
NL	Misc. Offshore	10	188	0.2	0.99	1	0.1	0	N	0.77	1.22
NL	Other	9	11	0.11	1	0.65	0.32	0.08	N	-0.11	1.4
NL	Pelagic	10	1576	0.2	0.99	0.94	0.11	0	N	0.68	1.2
NL	Scallop	10	499	0.4	0.42	0.67	0.11	0	Y	0.42	0.92
NL	Shrimp	10	27485	0.2	0.99	0.88	0.08	0	N	0.69	1.06
NL	Whelk	10	1122	0.3	0.76	0.83	0.08	0	Y	0.65	1
EA	All fisheries	10	3742	0.2	0.99	0.97	0.07	0	N	0.8	1.12
EA	Groundfish Fixed	10	1745	0.2	0.99	0.98	0.07	0	N	0.81	1.15
EA	Groundfish Mobile	10	1627	0.2	0.99	0.98	0.05	0	N	0.87	1.09
EA	Shrimp	10	314	0.1	0.99	0.92	0.12	0	N	0.64	1.19

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APPENDIX 2. FISHERY CLASS SPECIFIC EFFORT MAPS

This appendix shows fishery class specific effort maps organized by bioregion. For each fisheries class within a bioregion, there are three panels showing a) fishing footprints derived from VMS and from logbooks together, b) percentiles of fishing effort derived from logbooks only, c) percentiles of effort derived from VMS. If a fisheries class had a very small fishing footprint not visible at the scale of the map, or did not meet privacy regulations (assessed by considering the number of individual vessels, licences and/or buyers aggregated within the fishery-specific map) the map is excluded from this appendix. Excluded fisheries classes are listed on the first page of the bioregion section.

Maps within each bioregion are shown alphabetically by fishery, beginning with a category for all fisheries effort combined. The “all fisheries” category includes effort for each fisheries class in the bioregion, even if the fisheries class-specific map is excluded. In each panel of each figure, the legend details information on the fishery and data sources within the map.

SCOTIAN SHELF (SS)

Maps are shown for the following fisheries classes in the Scotian Shelf bioregion:

- All fisheries combined
- Crab offshore
- Groundfish fixed
- Groundfish mobile
- Miscellaneous inshore
- Miscellaneous offshore
- Other
- Pelagic
- Scallop
- Shrimp

Due to either privacy regulations or data deficiency, maps are not displayed for the following fisheries classes: clam, crab inshore, echinoderm, lobster, and whelk.

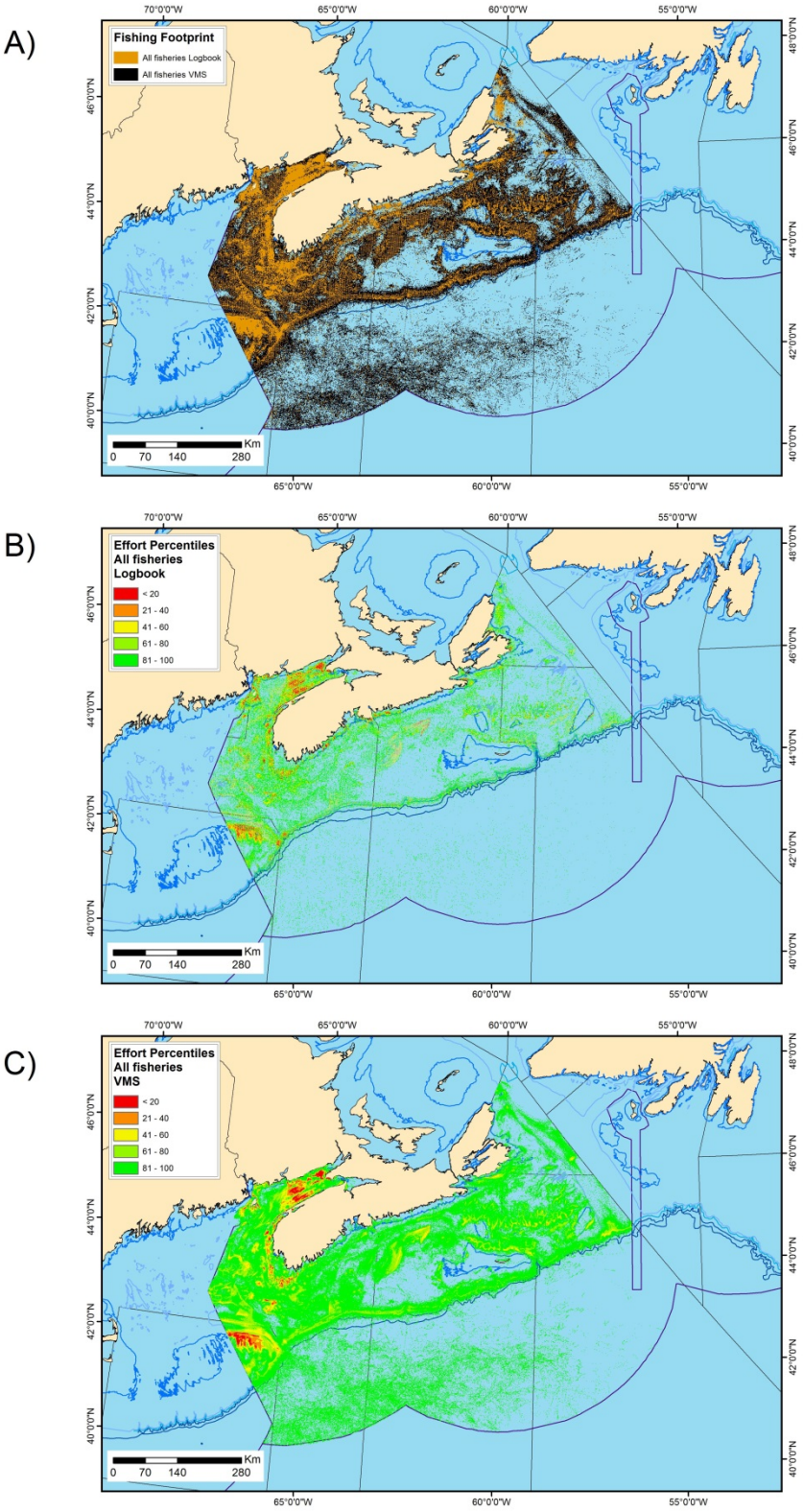

Figure A2 - 1. All fisheries combined.

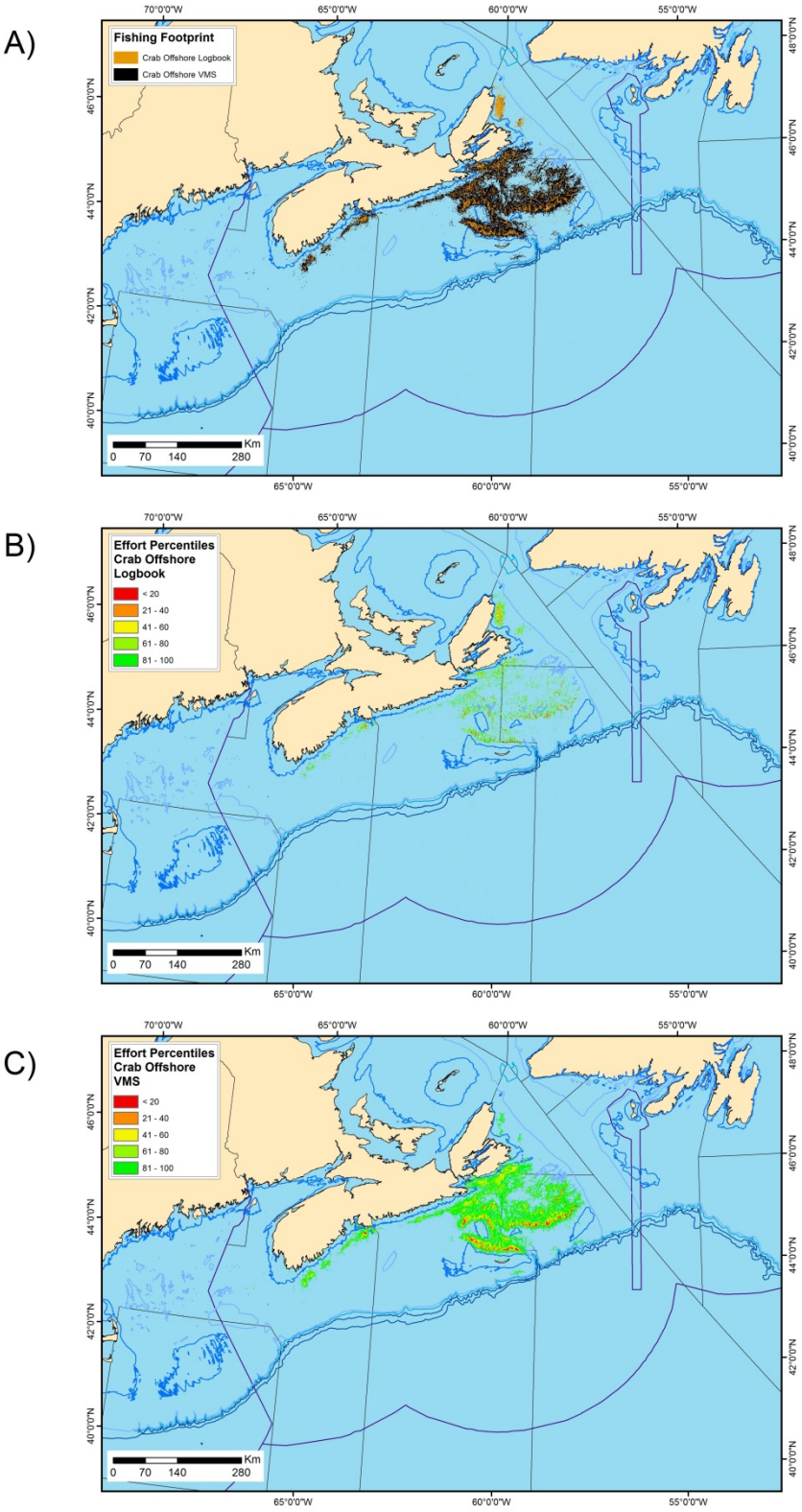

Figure A2 - 2. Crab Offshore.

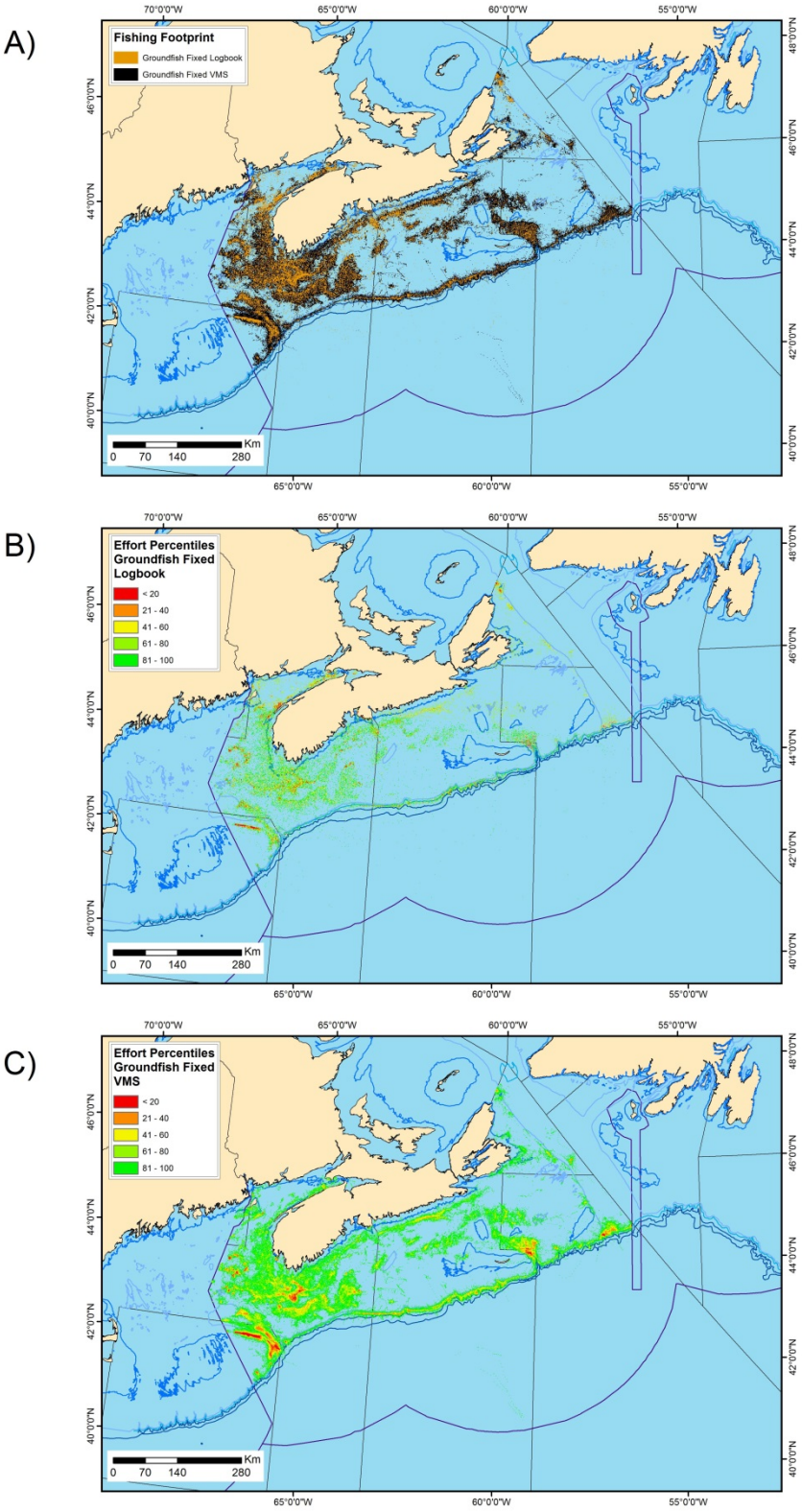

Figure A2 - 3. Groundfish Fixed.

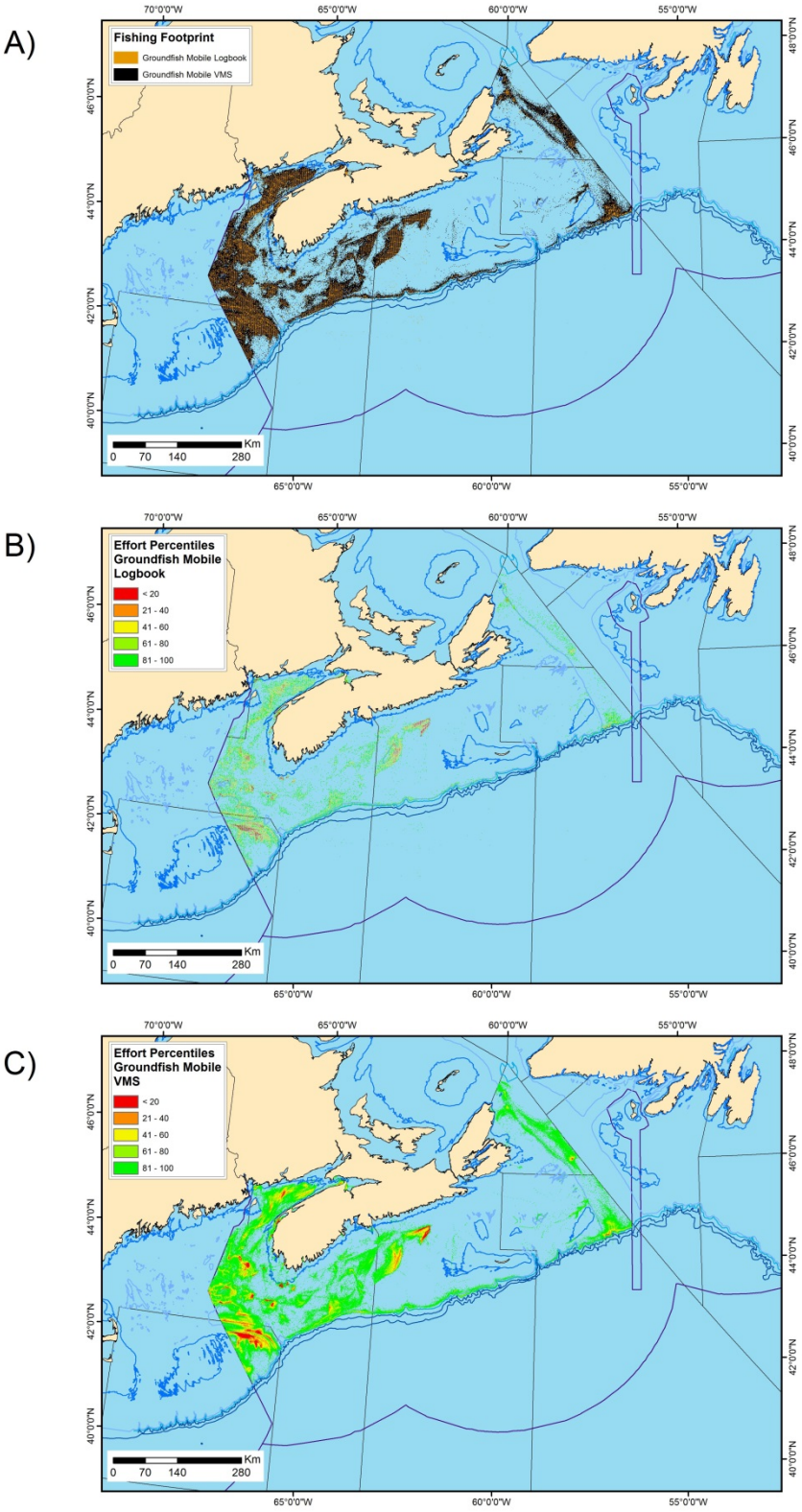

Figure A2 - 4. Groundfish Mobile.

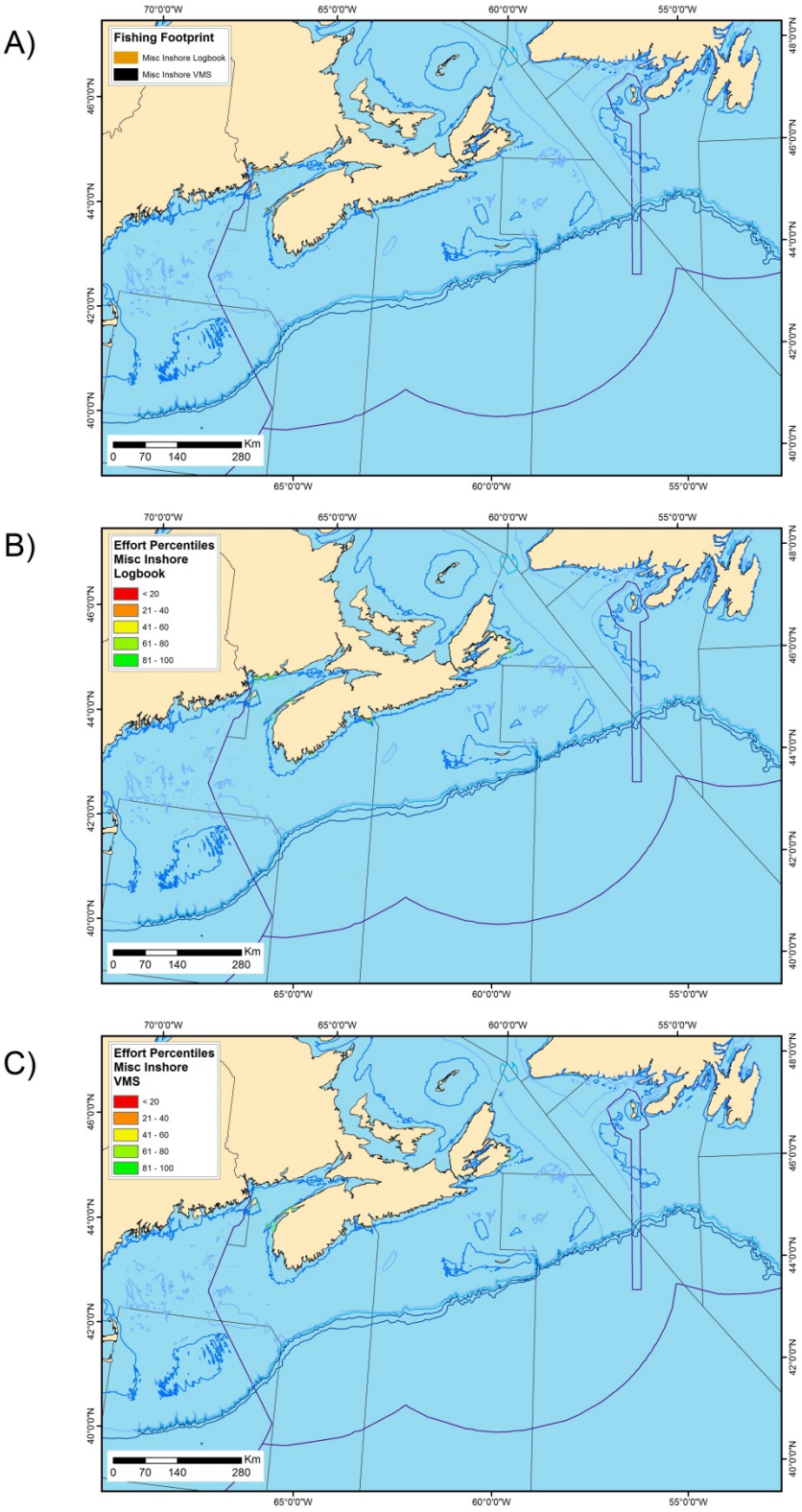

Figure A2 - 5. Miscellaneous Inshore.

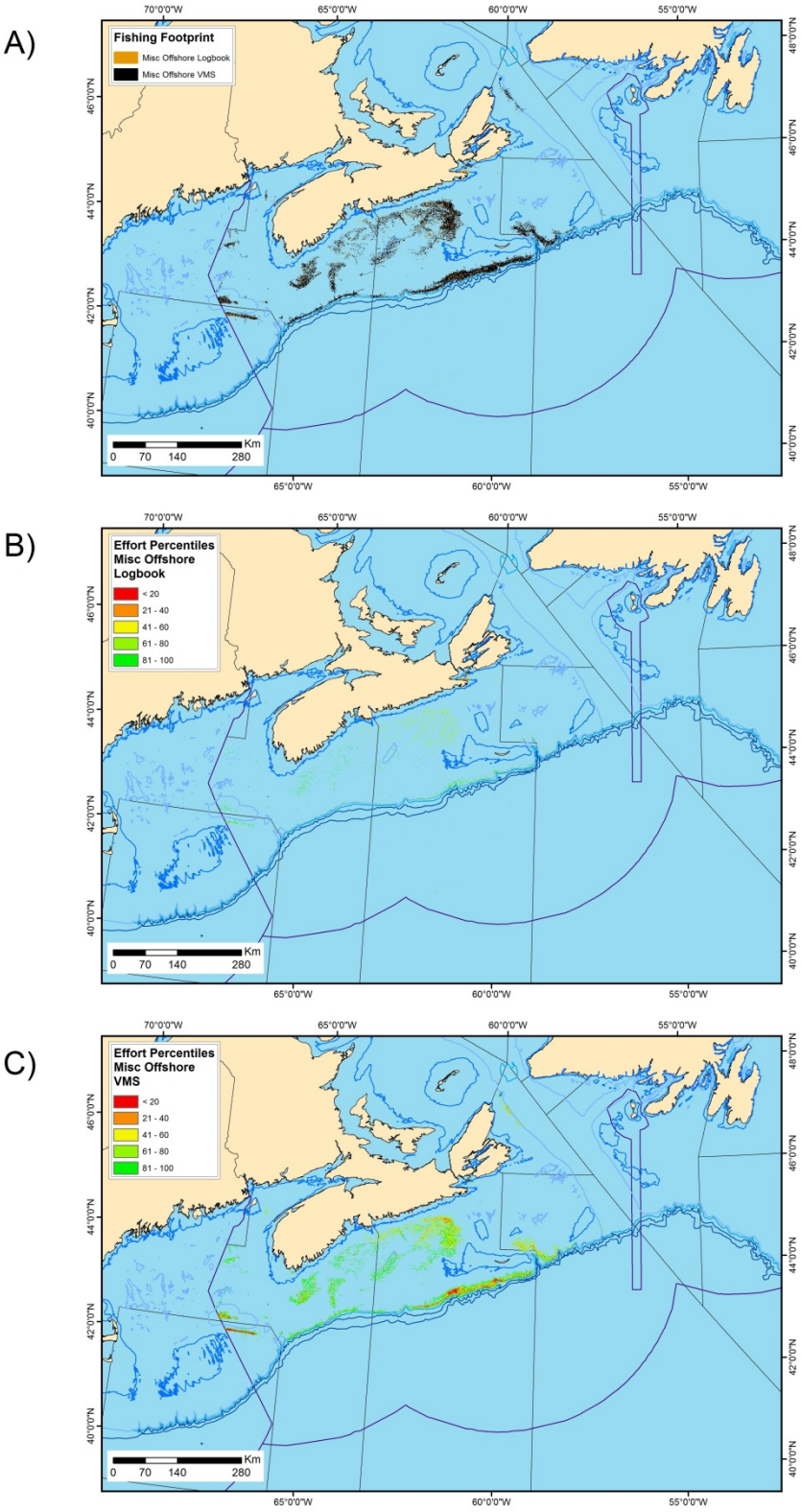

Figure A2 - 6. Miscellaneous Offshore.

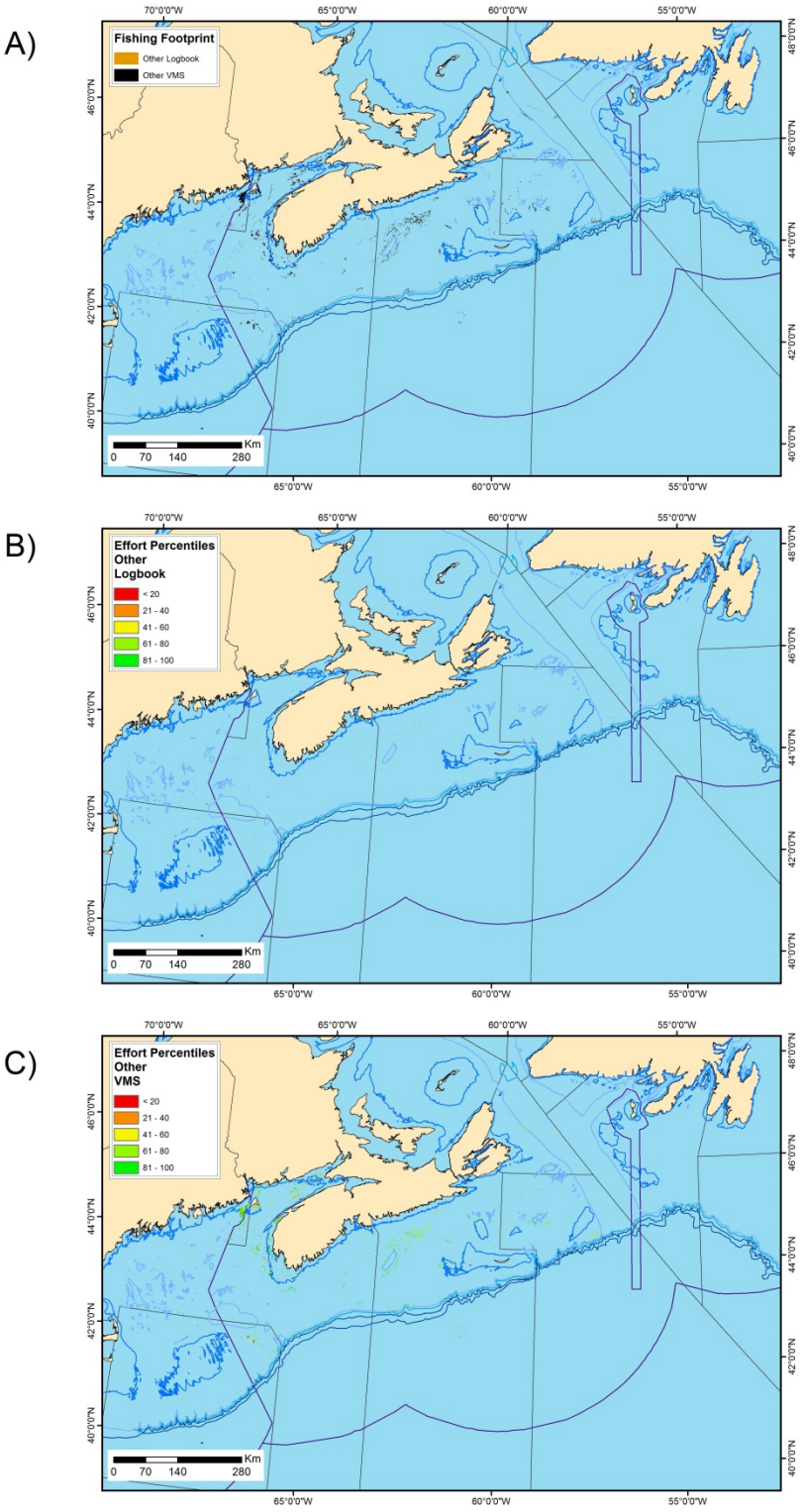

Figure A2 - 7. Other.

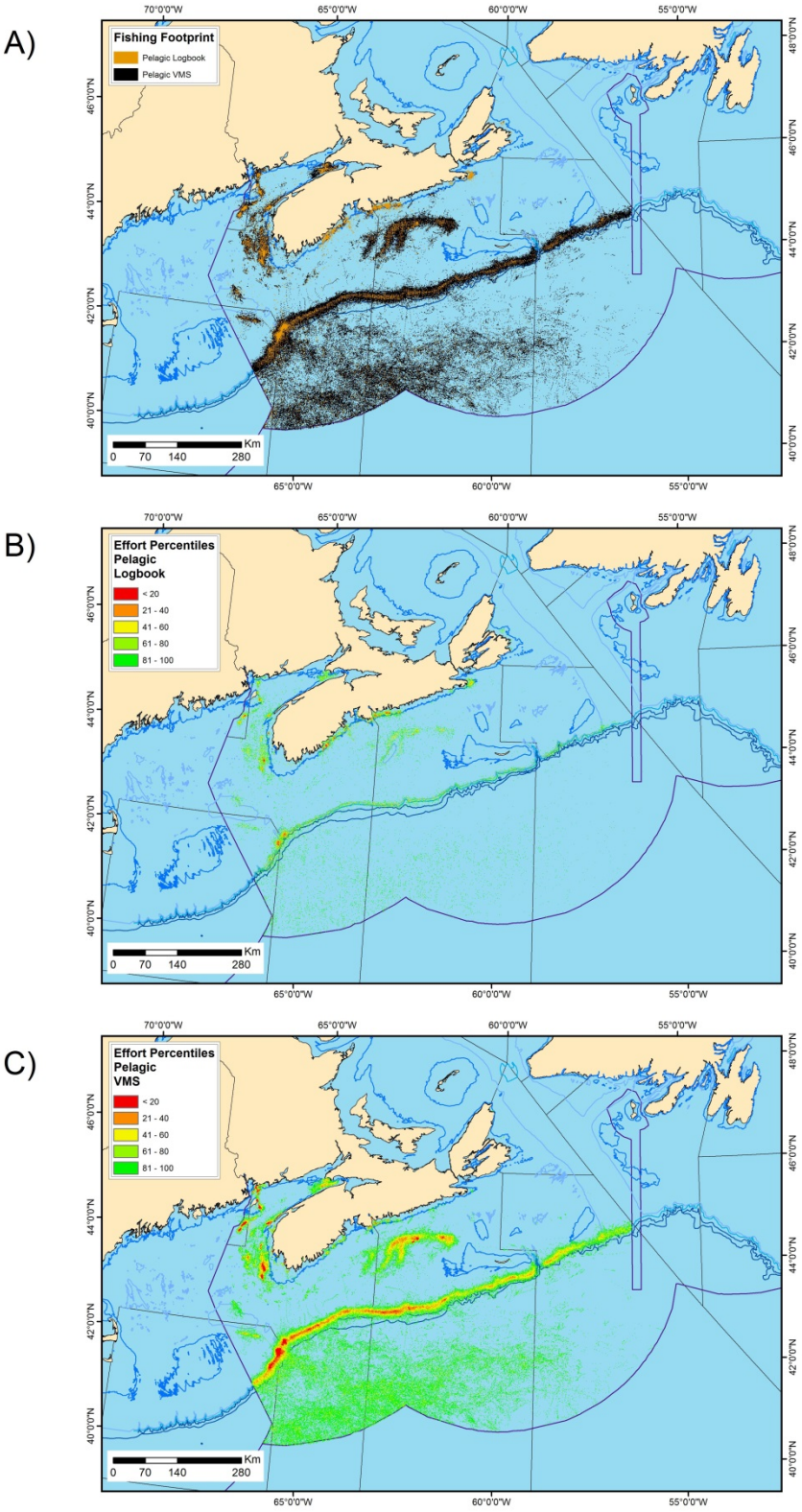

Figure A2 - 8. Pelagic.

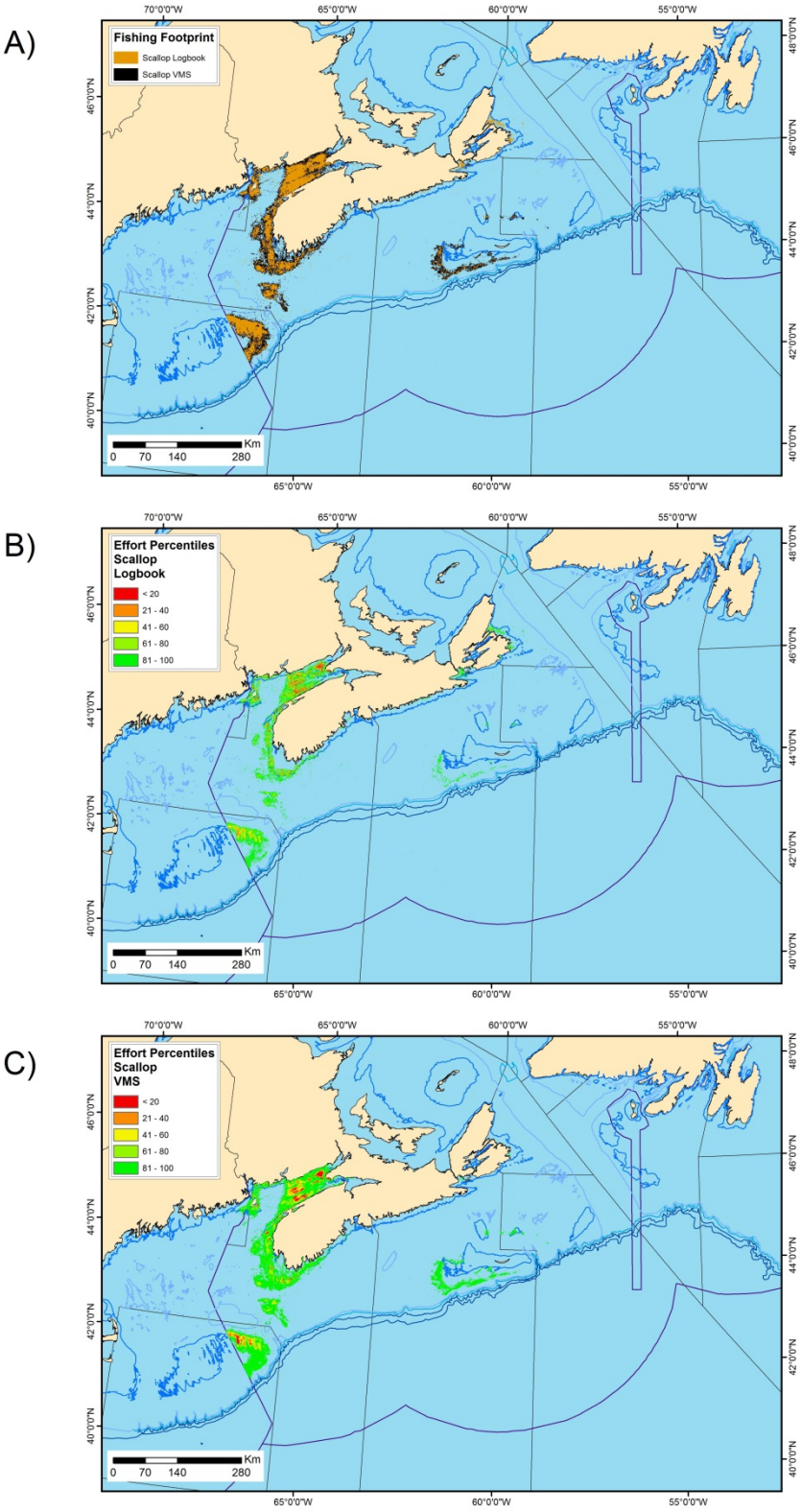

Figure A2 - 9. Scallop.

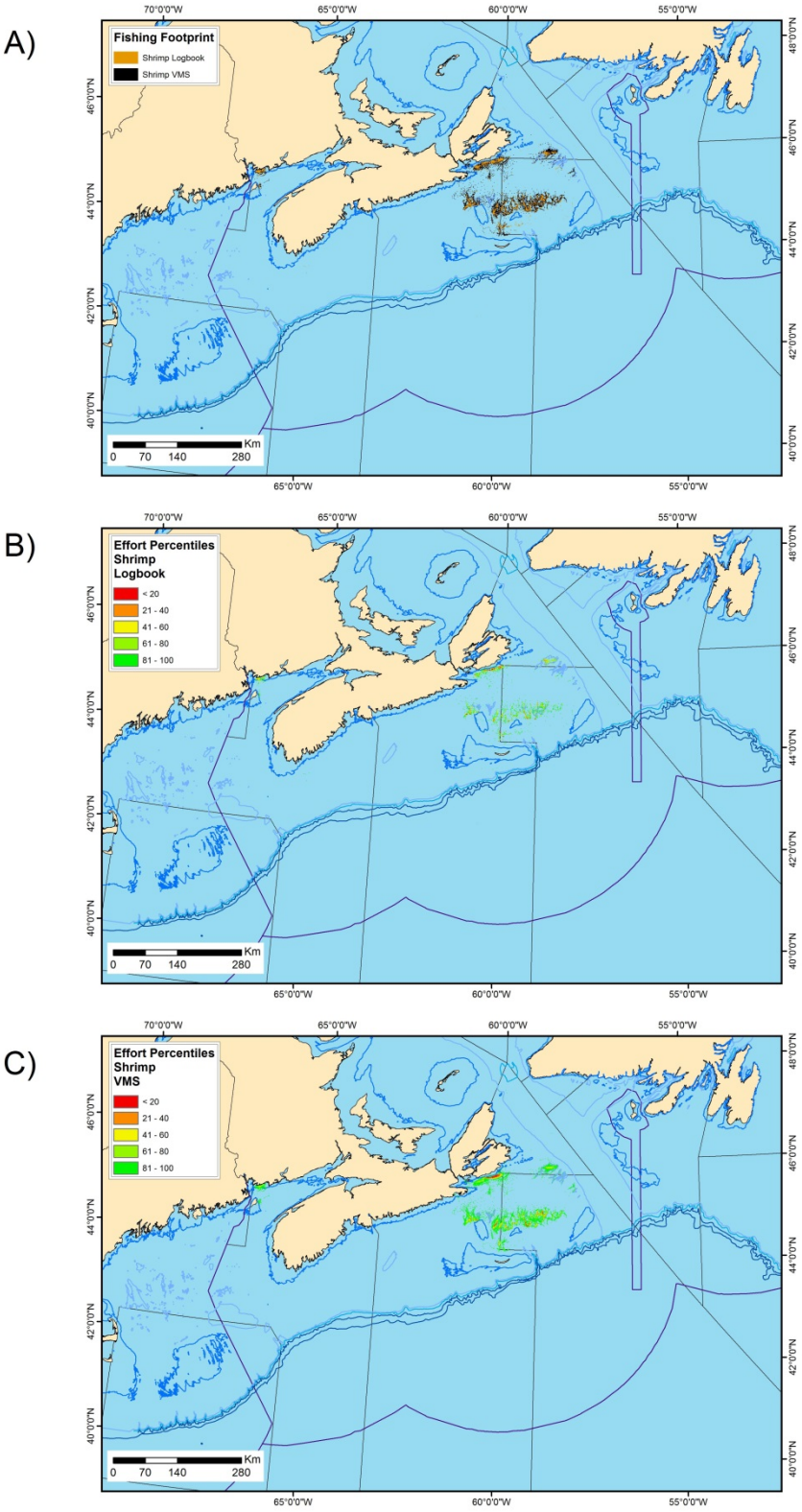

Figure A2 - 10. Shrimp.

GULF OF ST. LAWRENCE (GSL)

Maps are shown for the following fisheries classes in the Gulf of St. Lawrence bioregion:

- All fisheries combined
- Clam
- Crab inshore
- Crab offshore
- Echinoderm
- Groundfish fixed
- Groundfish mobile
- Miscellaneous inshore
- Other
- Pelagic
- Scallop
- Shrimp
- Whelk

Due to either privacy regulations or data deficiency, maps are not displayed for the following fisheries classes: lobster and miscellaneous offshore.

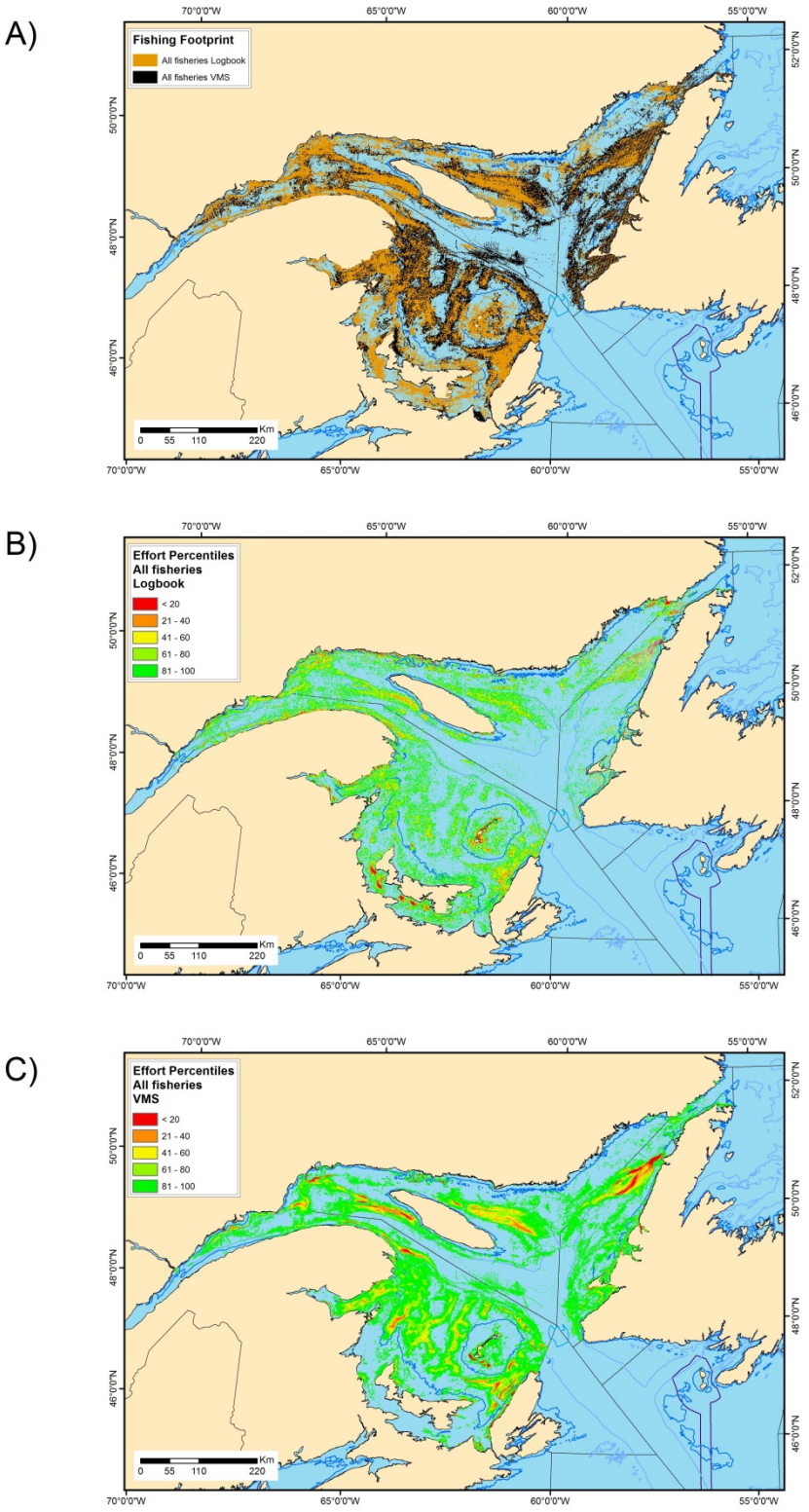

Figure A2 - 11. All fisheries combined.

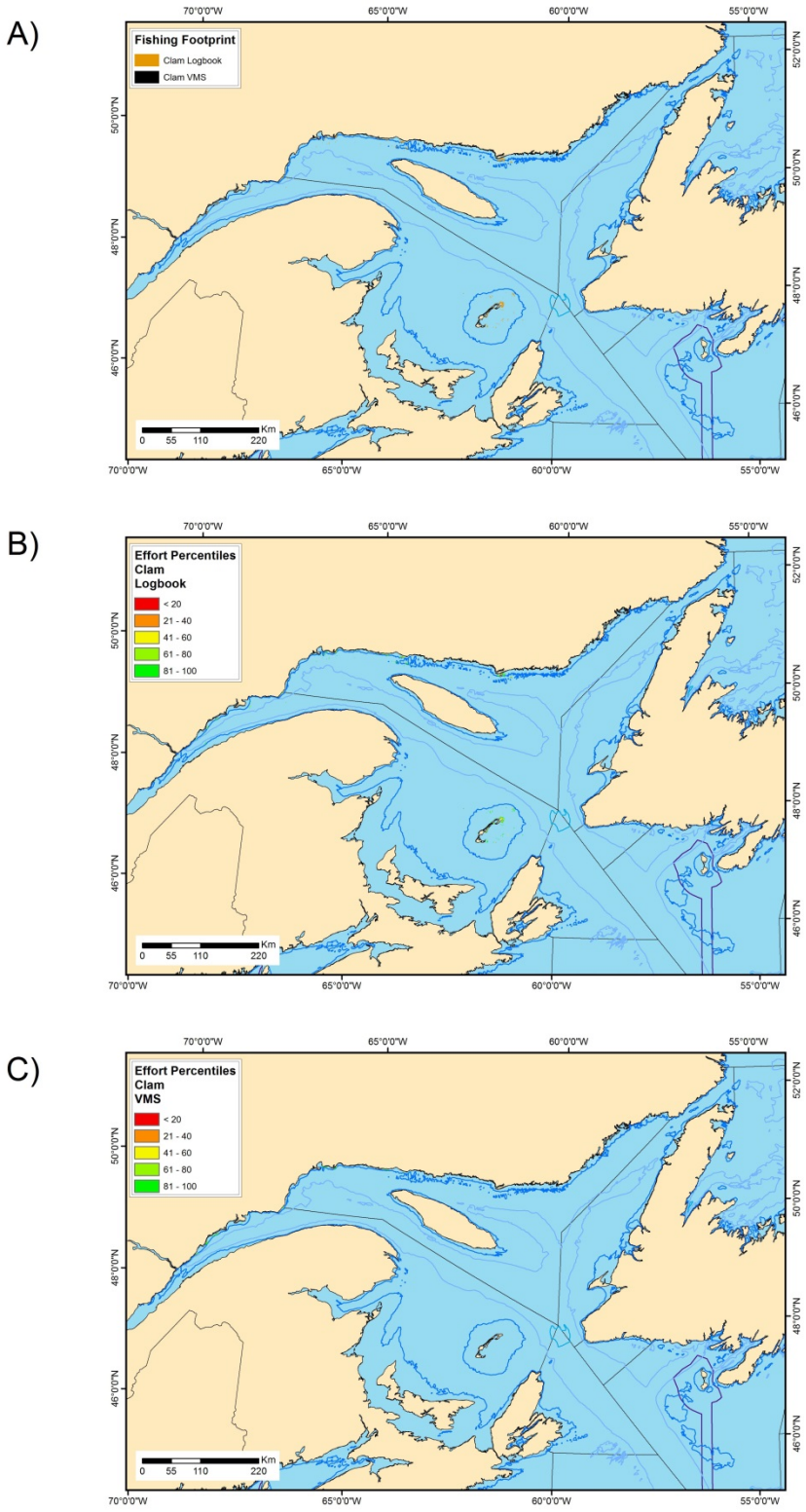

Figure A2 - 12. Clam.

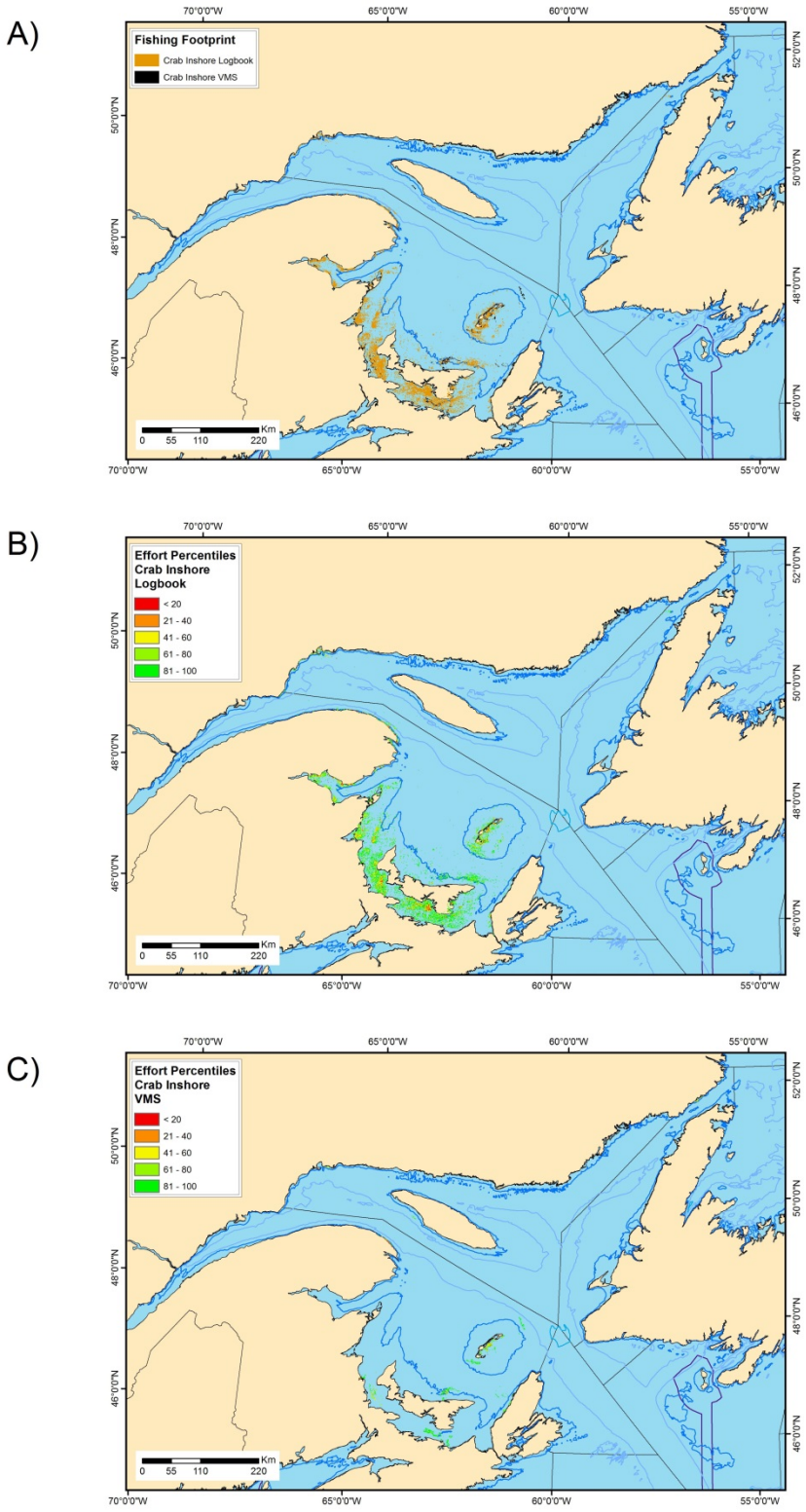

Figure A2 - 13. Crab Inshore.

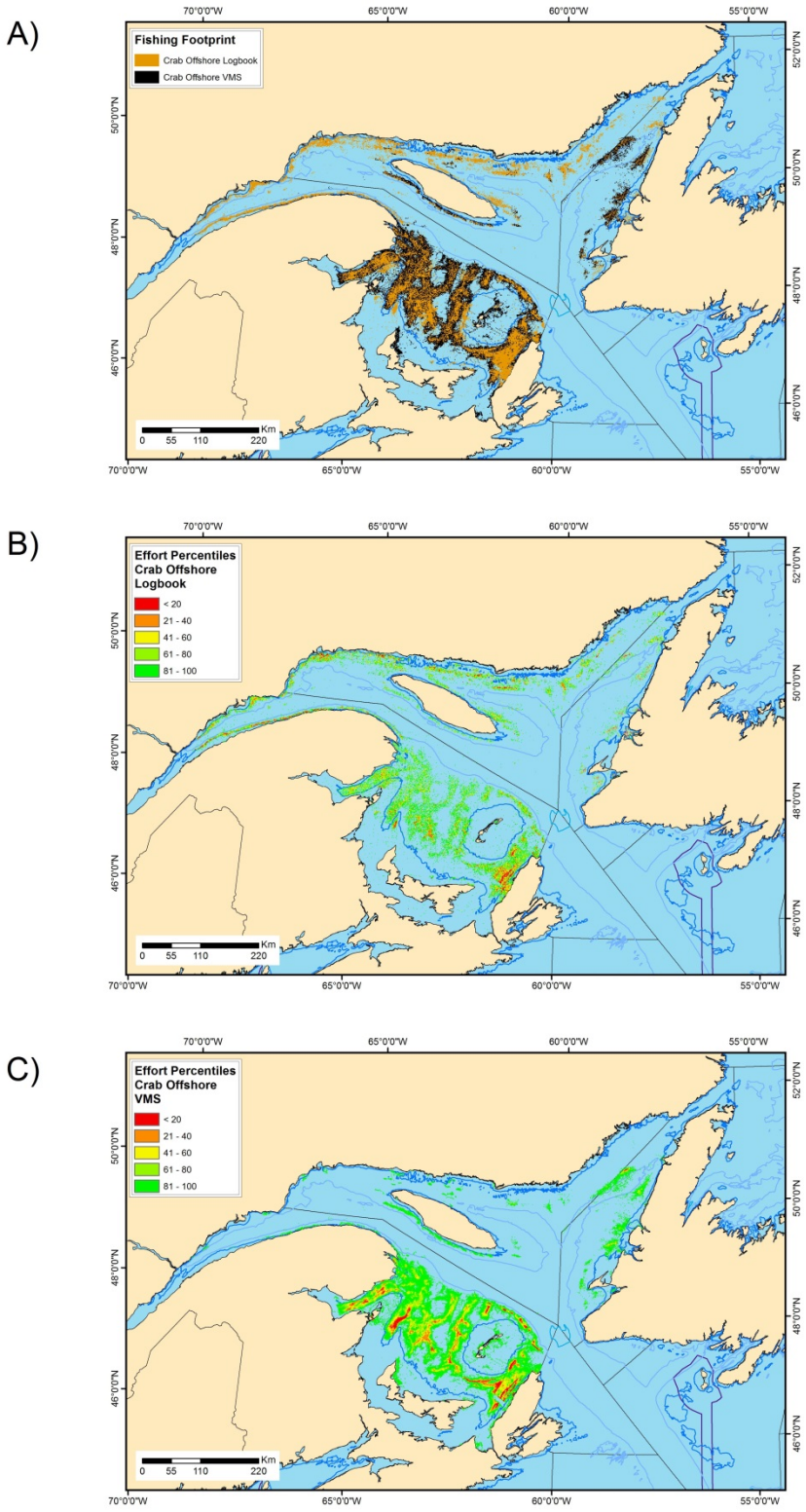

Figure A2 - 14. Crab Offshore.

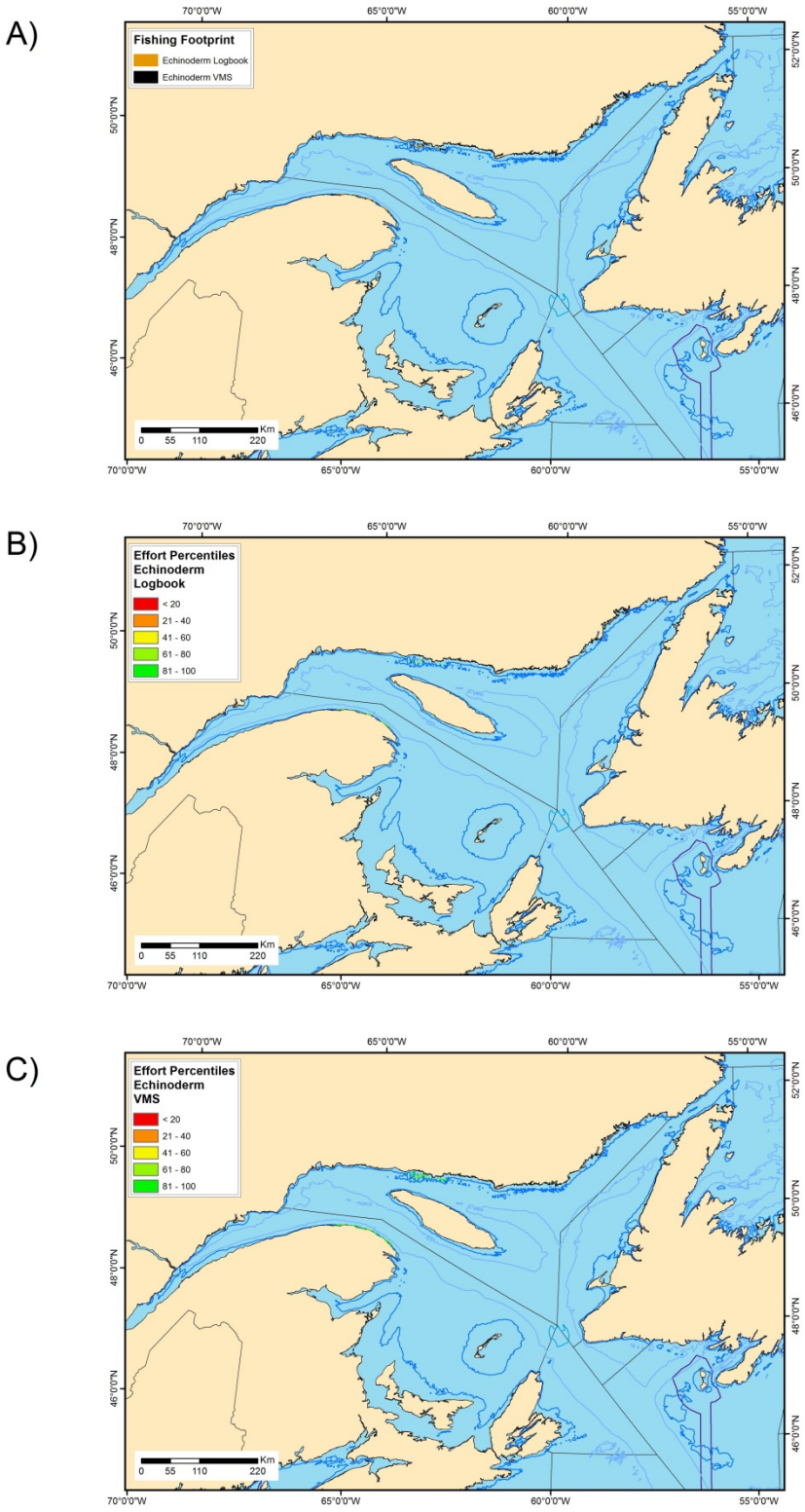

Figure A2 - 15. Echinoderm.

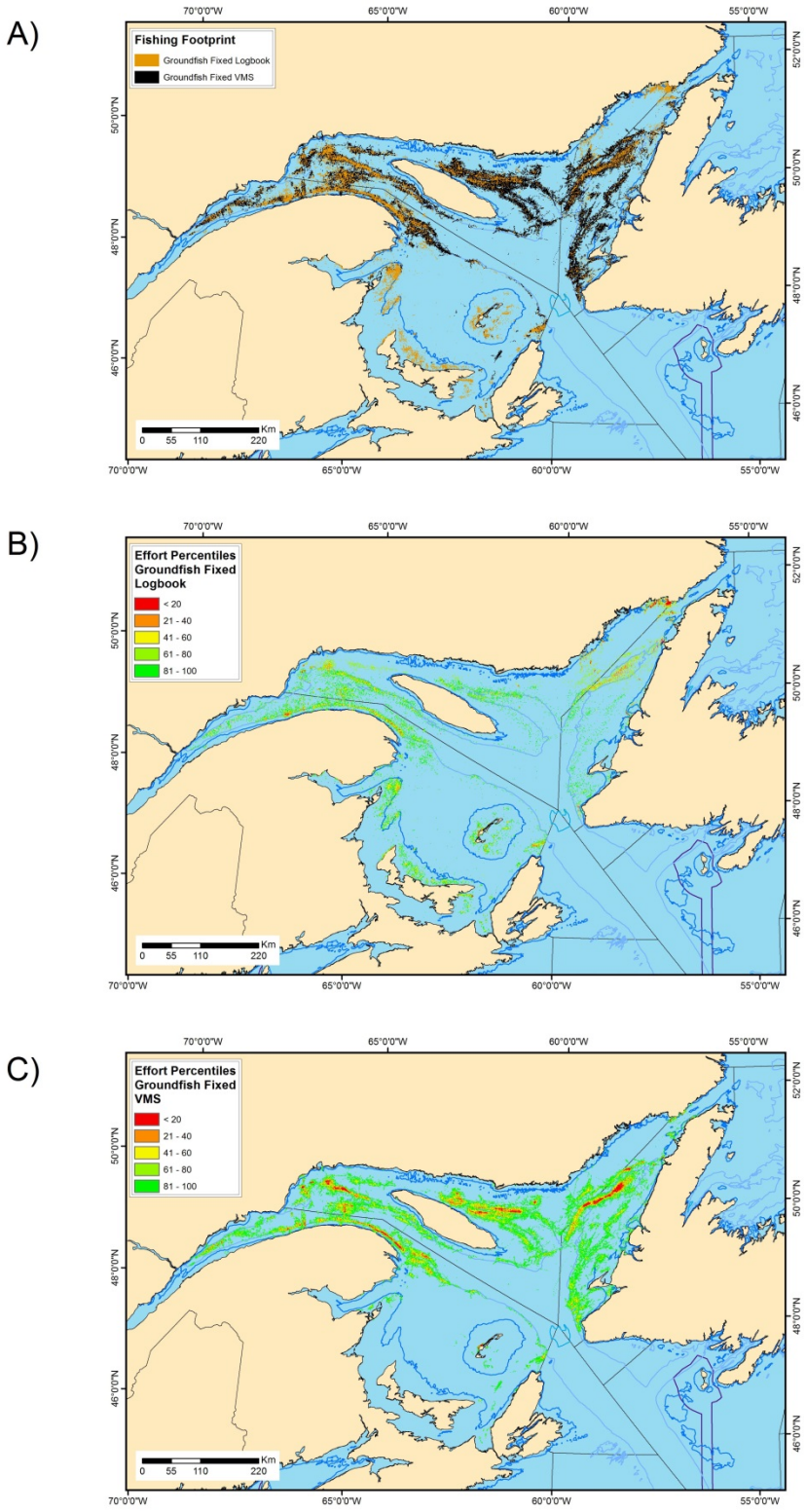

Figure A2 - 16. Groundfish Fixed.

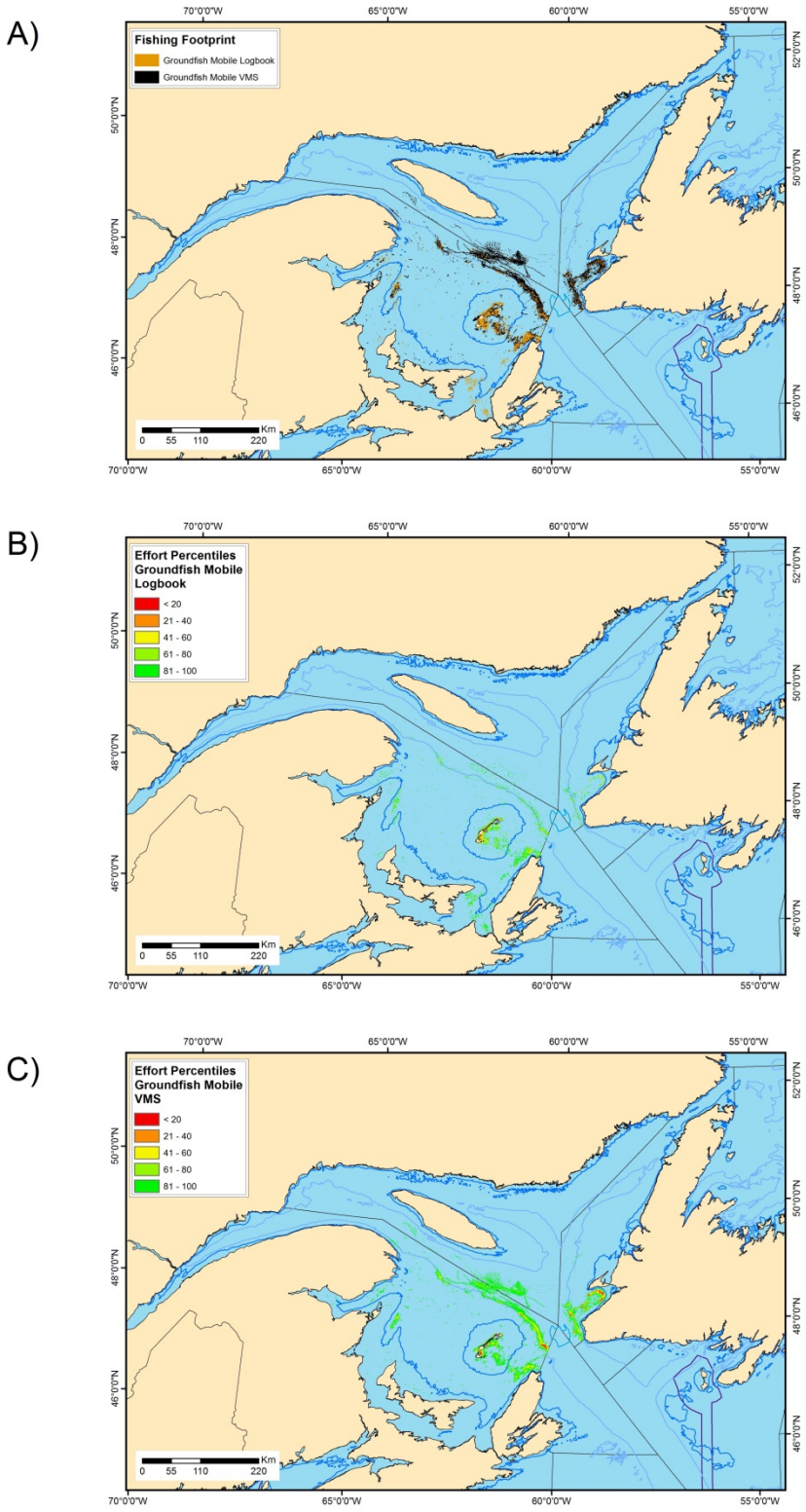

Figure A2 - 17. Groundfish Mobile.

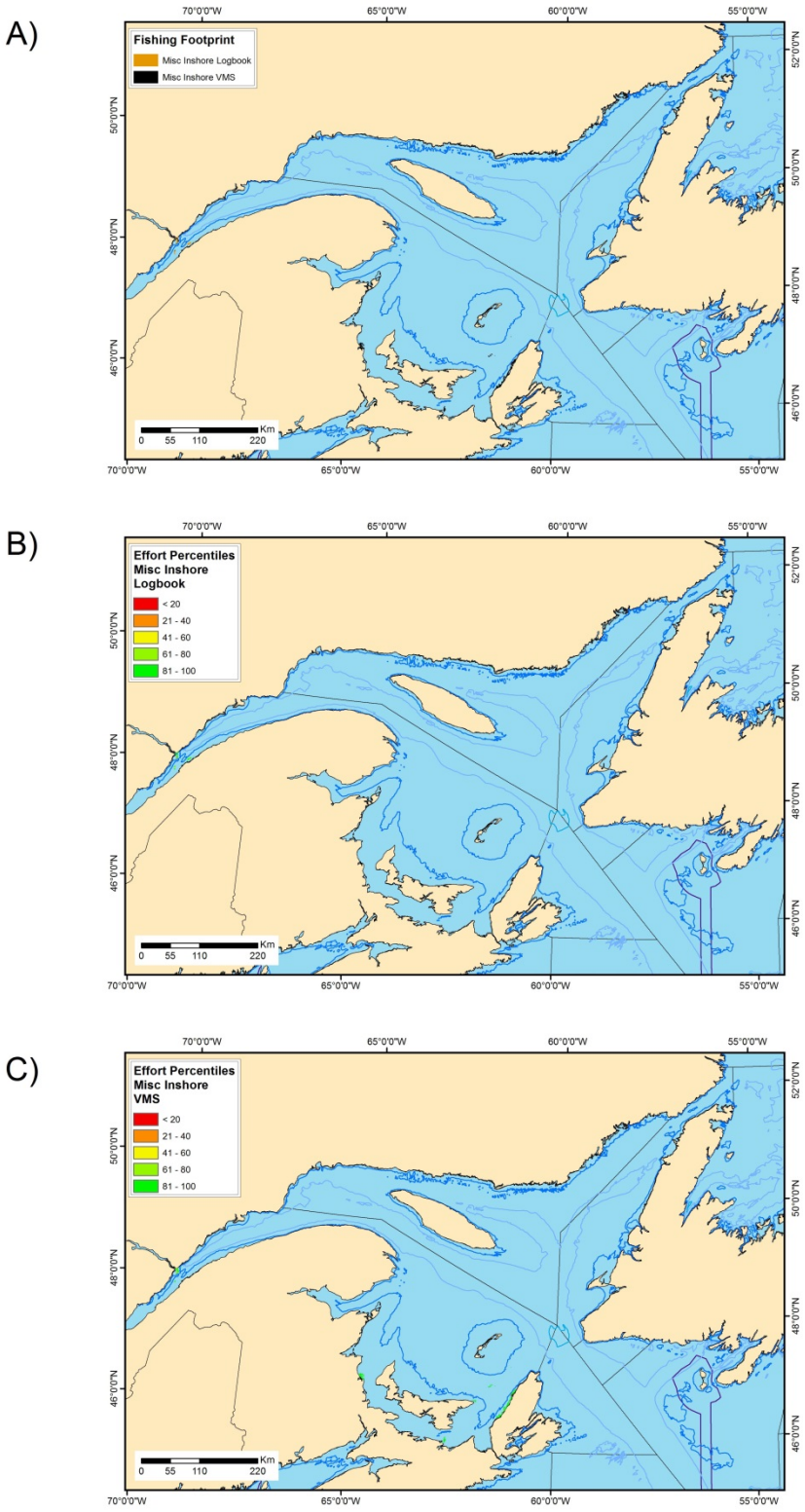

Figure A2 - 18. Miscellaneous Inshore.

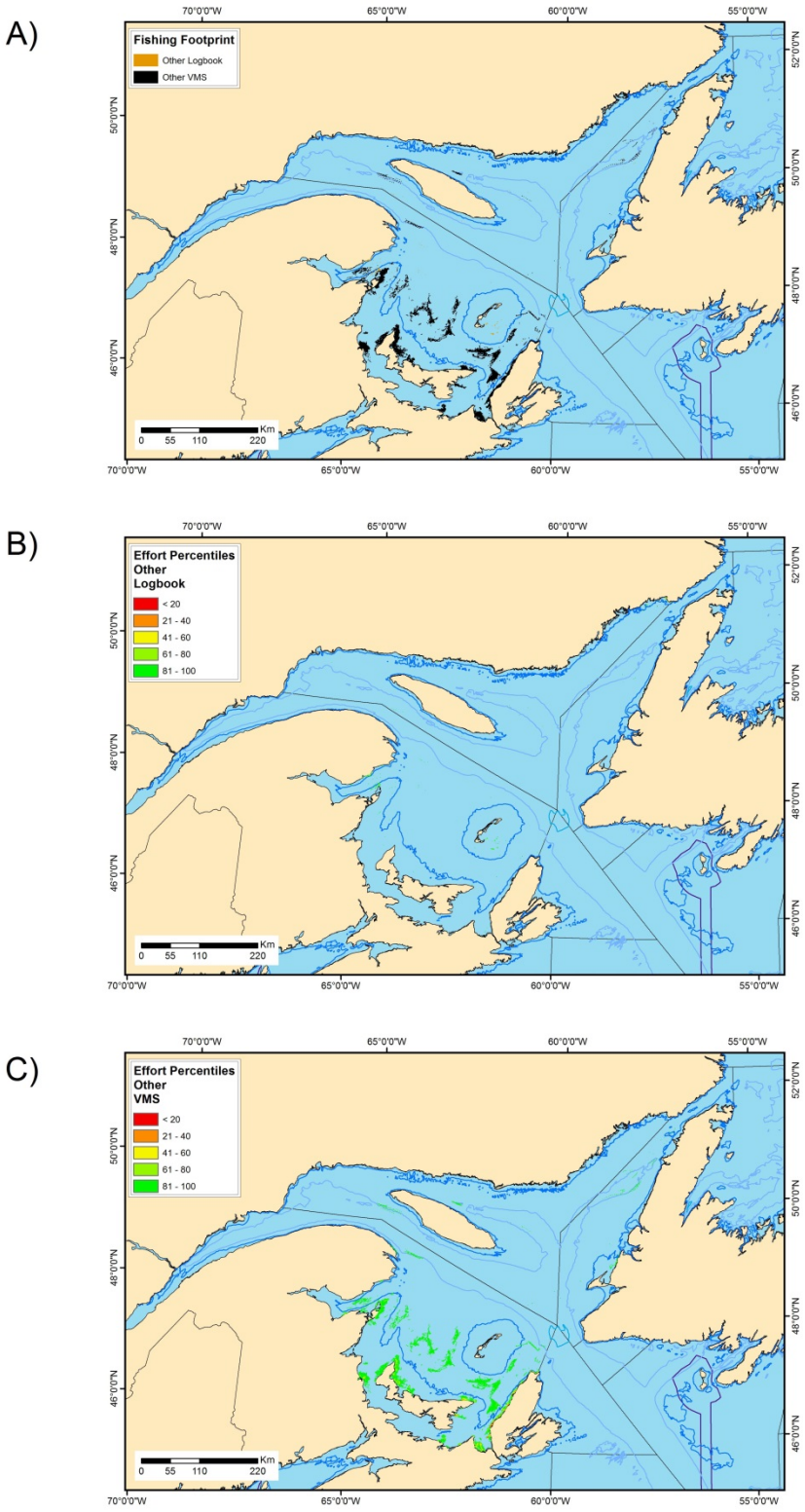

Figure A2 - 19. Other.

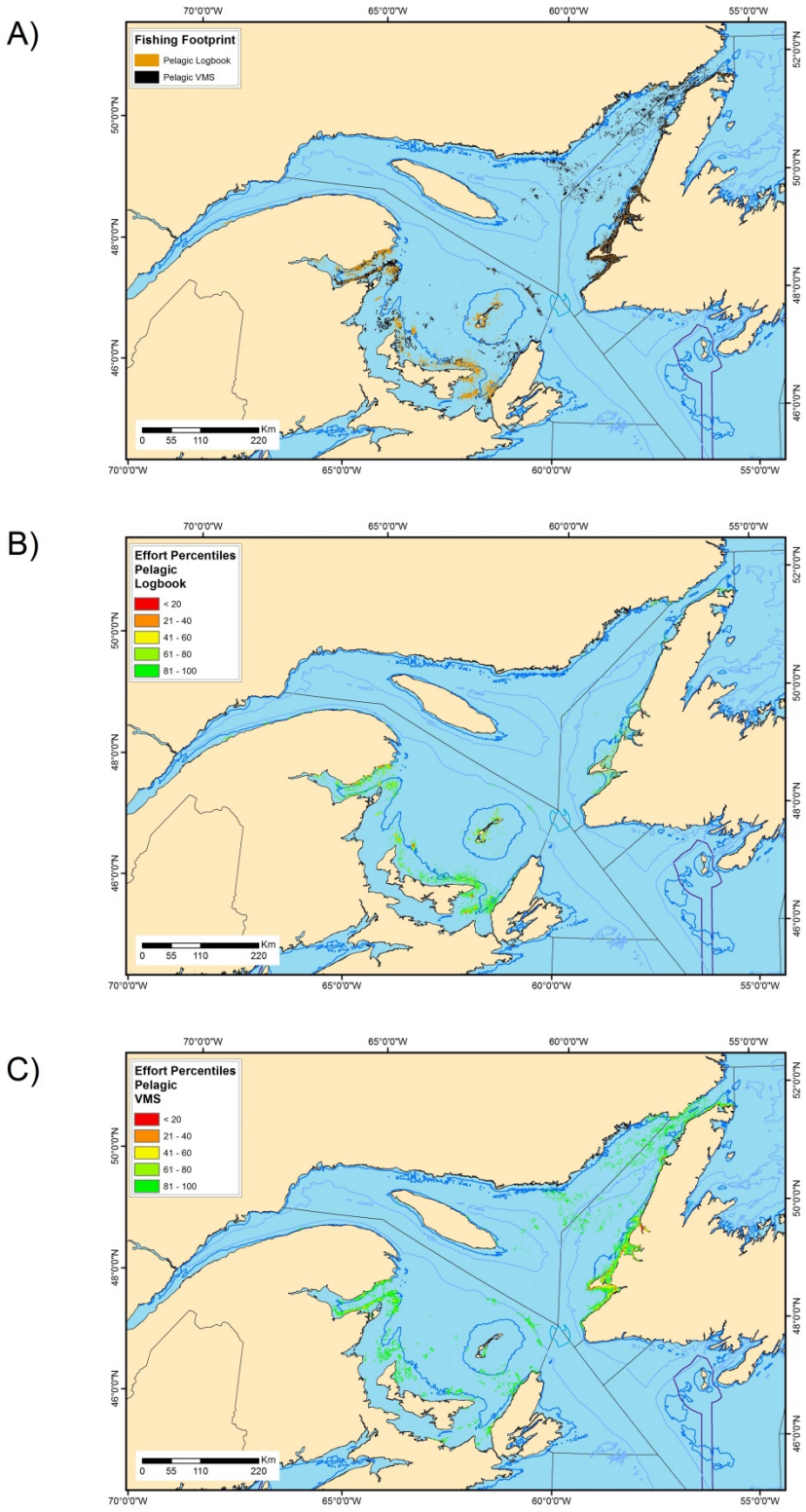

Figure A2 - 20. Pelagic.

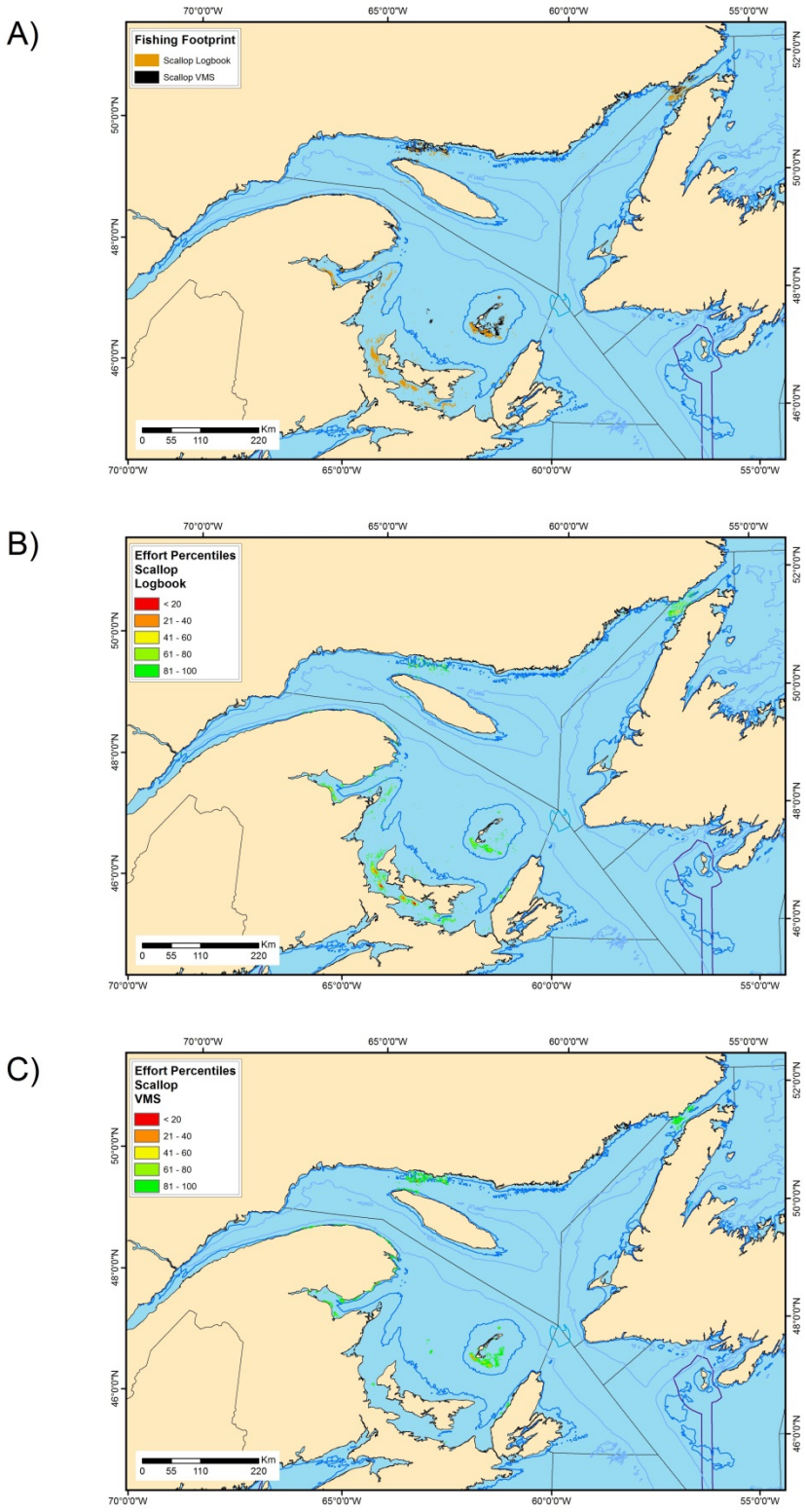

Figure A2 - 21. Scallop.

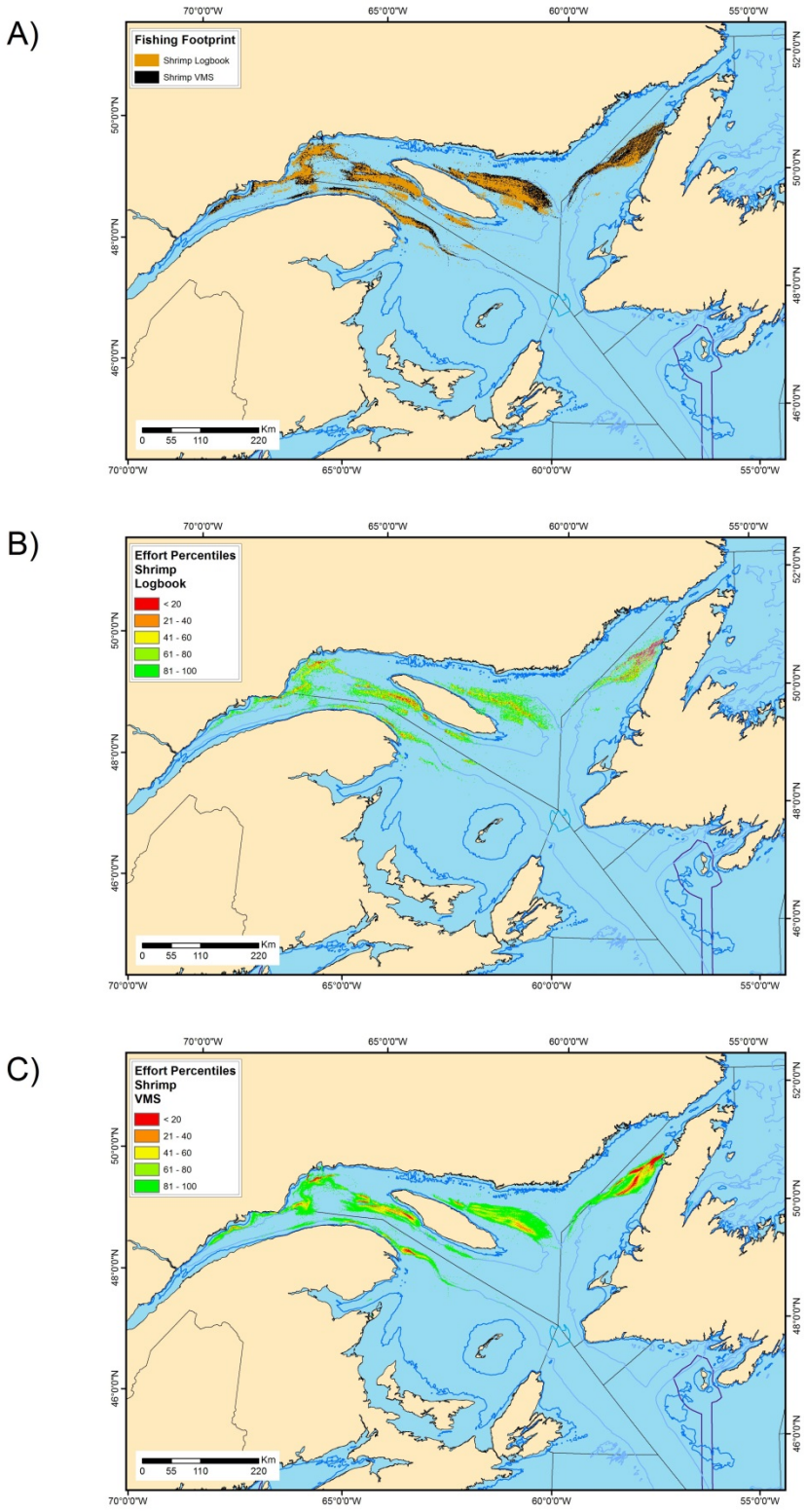

Figure A2 - 22. Shrimp.

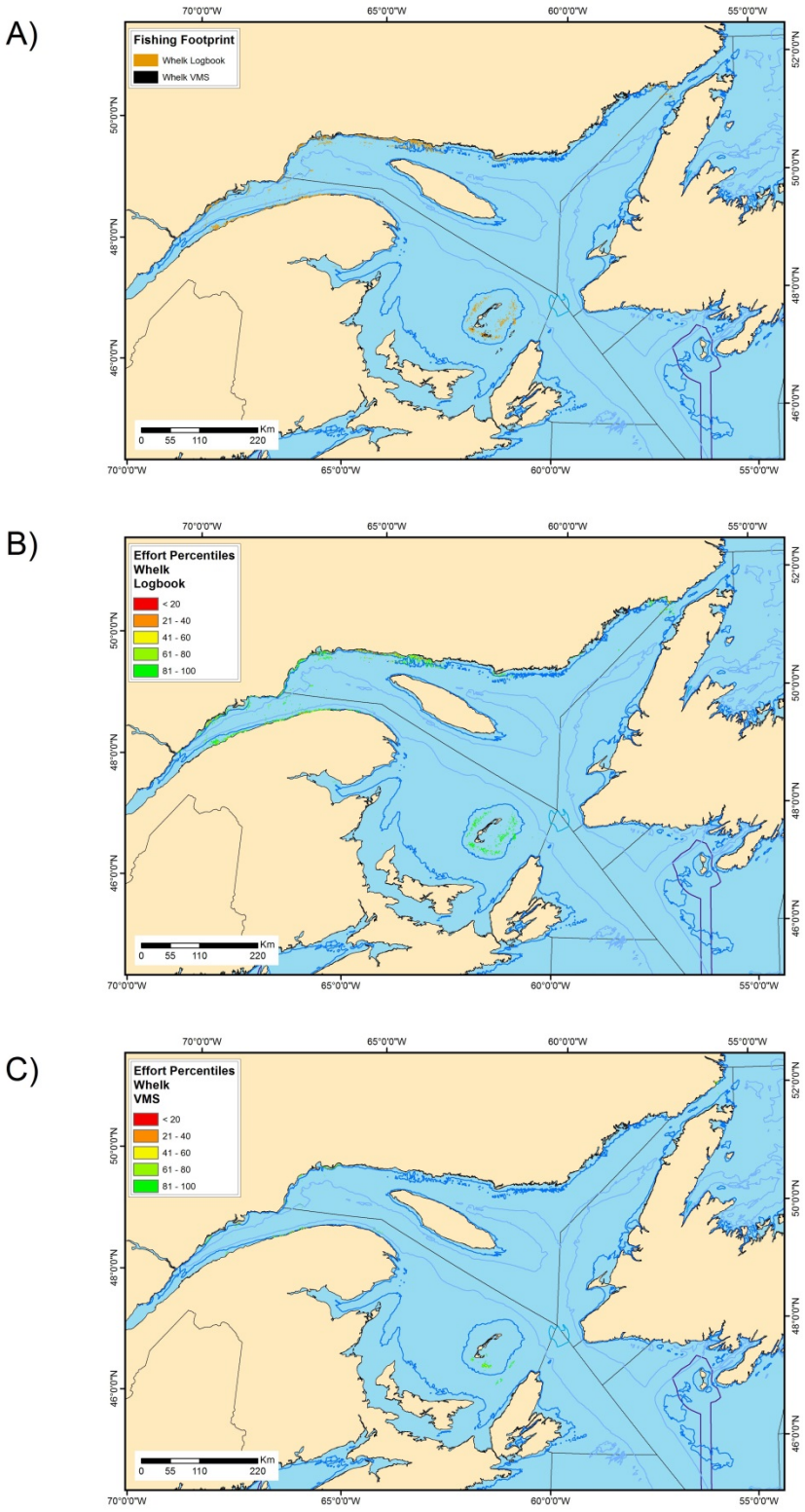

Figure A2 - 23. Whelk.

NEWFOUNDLAND AND LABRADOR (NL)

Maps are shown for the following fisheries classes in the Newfoundland and Labrador bioregion:

- All fisheries combined
- Crab inshore
- Crab offshore
- Echinoderm
- Groundfish fixed
- Groundfish mobile
- Other
- Pelagic
- Scallop
- Shrimp
- Whelk

Due to either privacy regulations or data deficiency, maps are not displayed for the following fisheries classes: clam, crab inshore, lobster, miscellaneous inshore, and miscellaneous offshore.

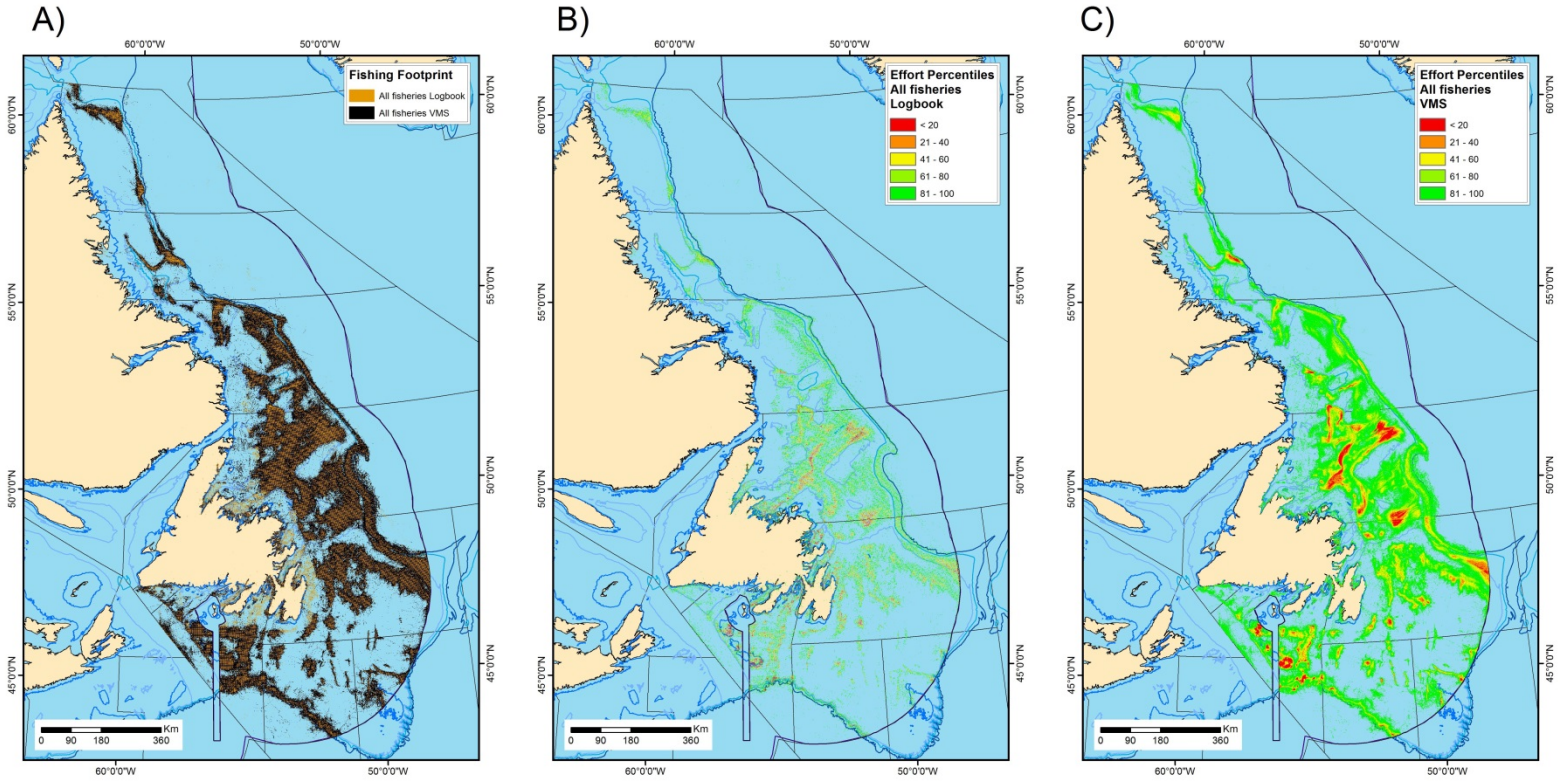

Figure A2 - 24. All fisheries combined.

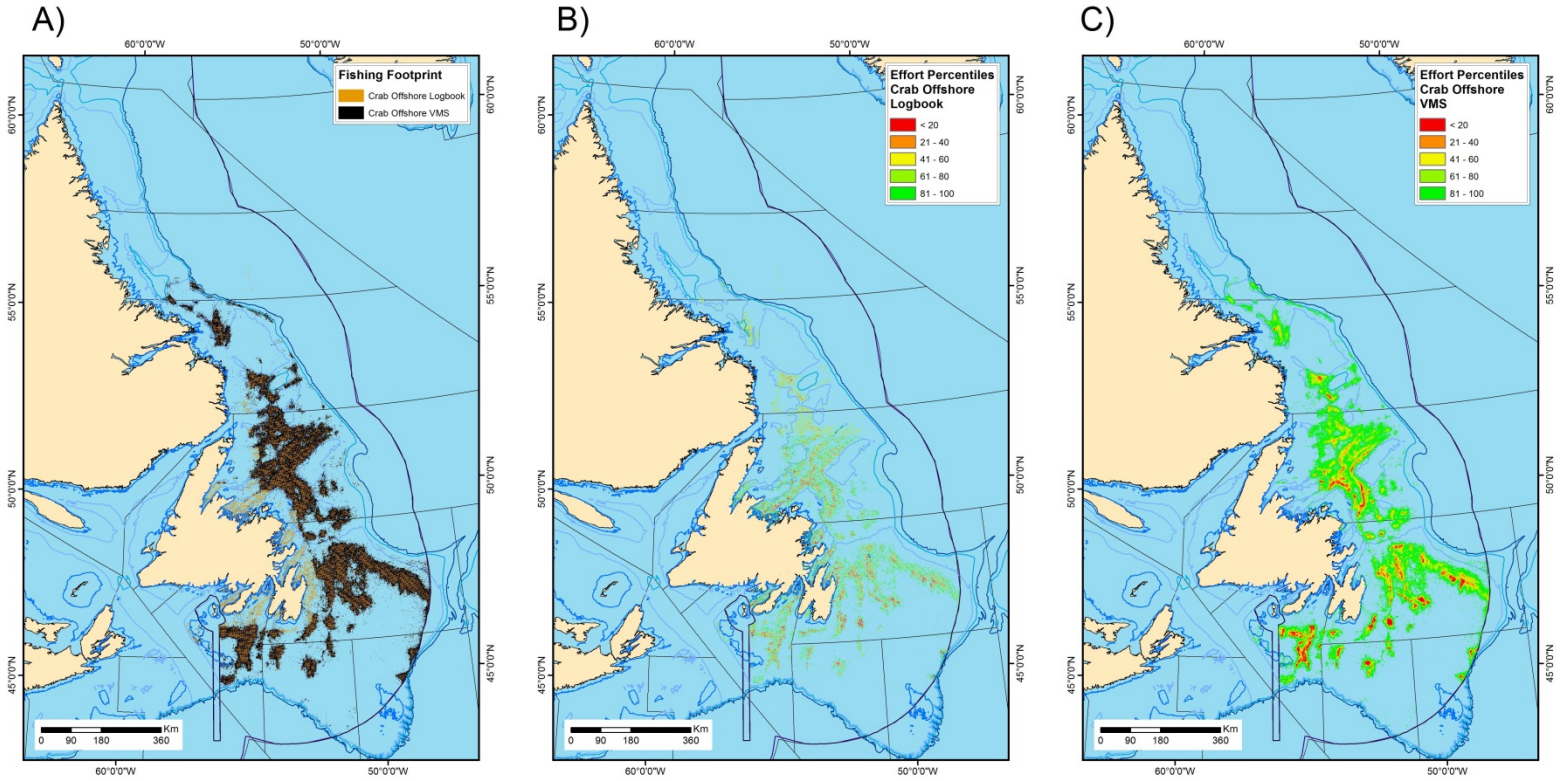

Figure A2 - 25. Crab Offshore.

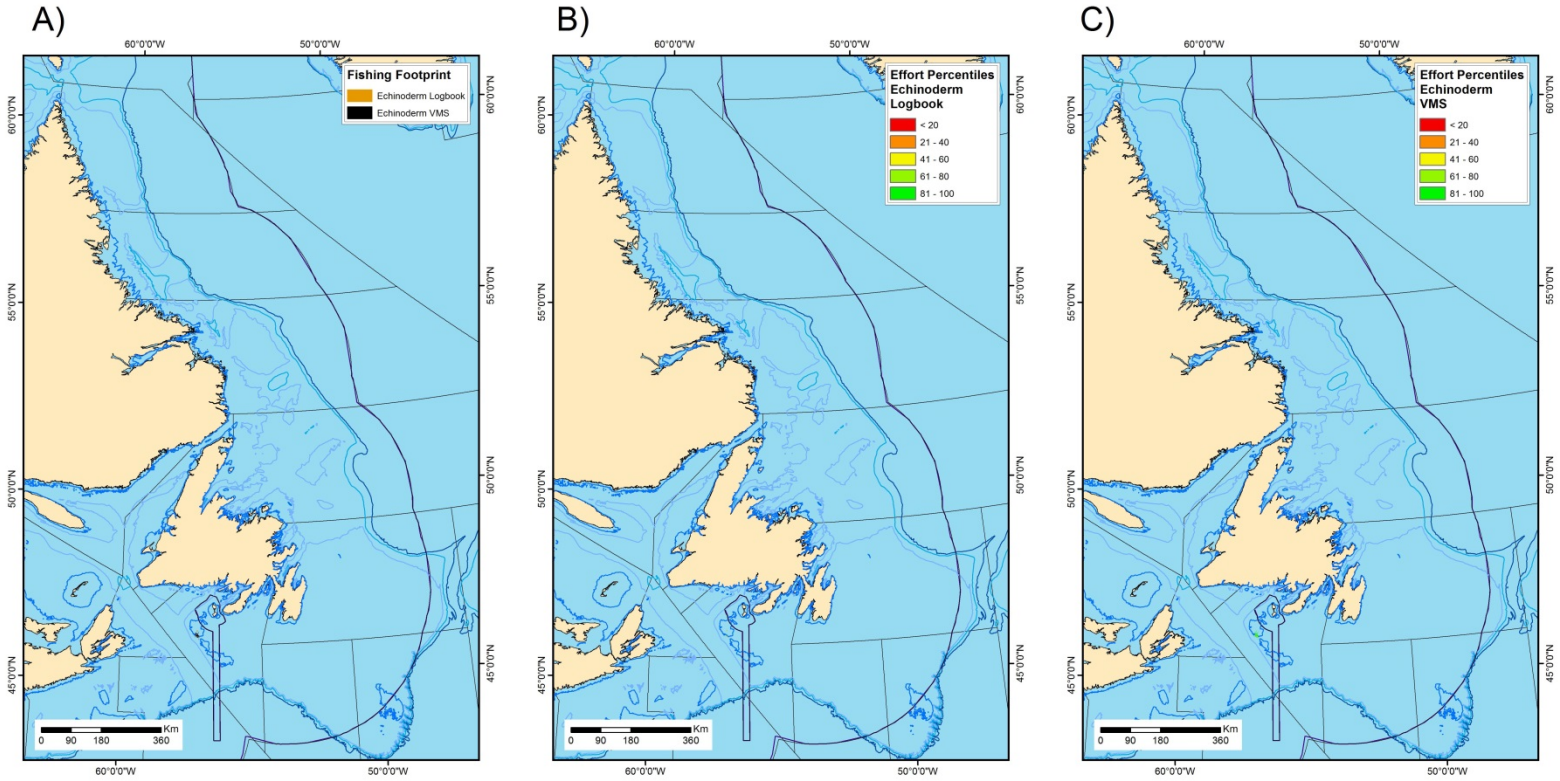

Figure A2 - 26. Echinoderm.

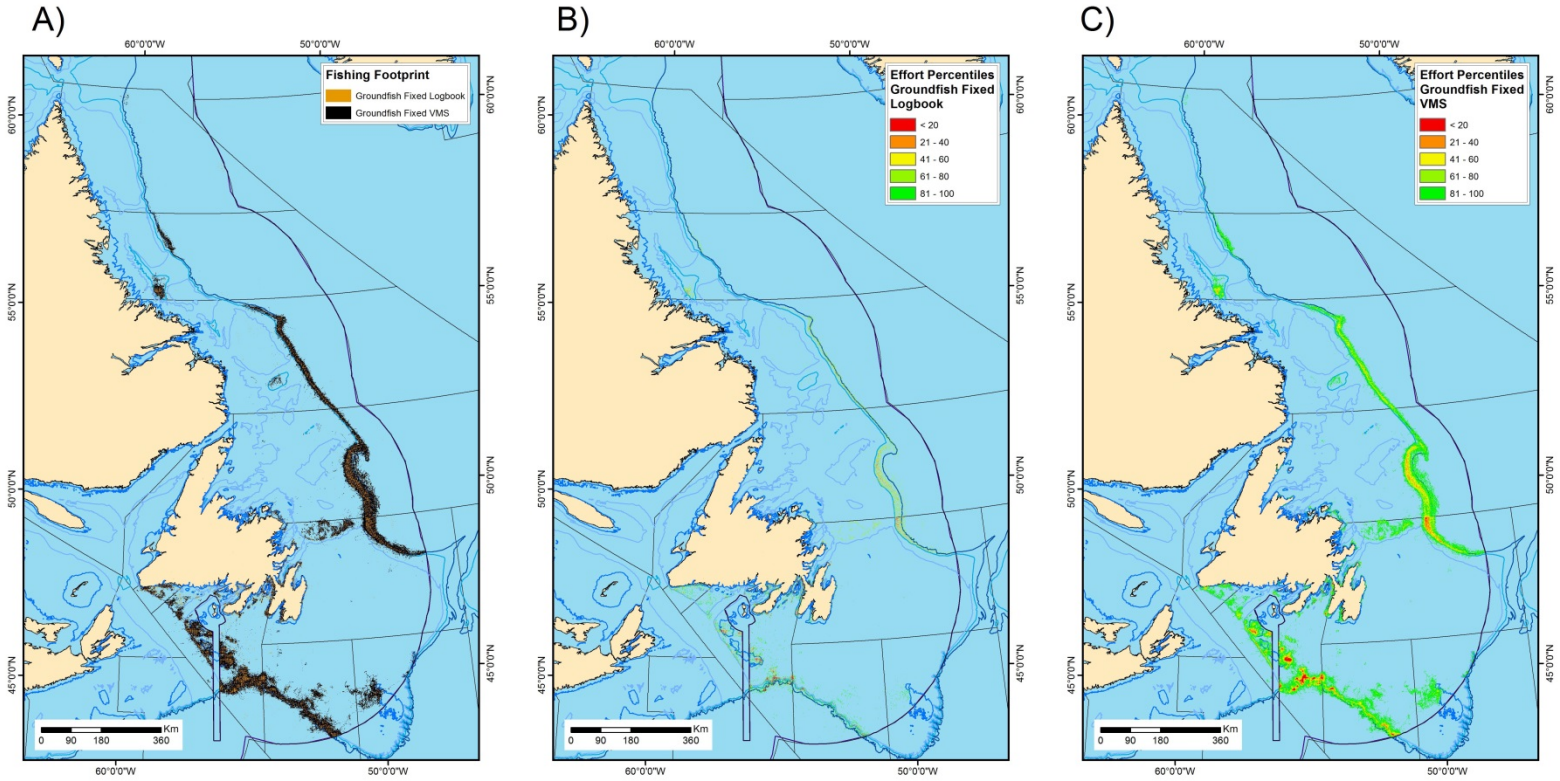

Figure A2 - 27. Groundfish Fixed.

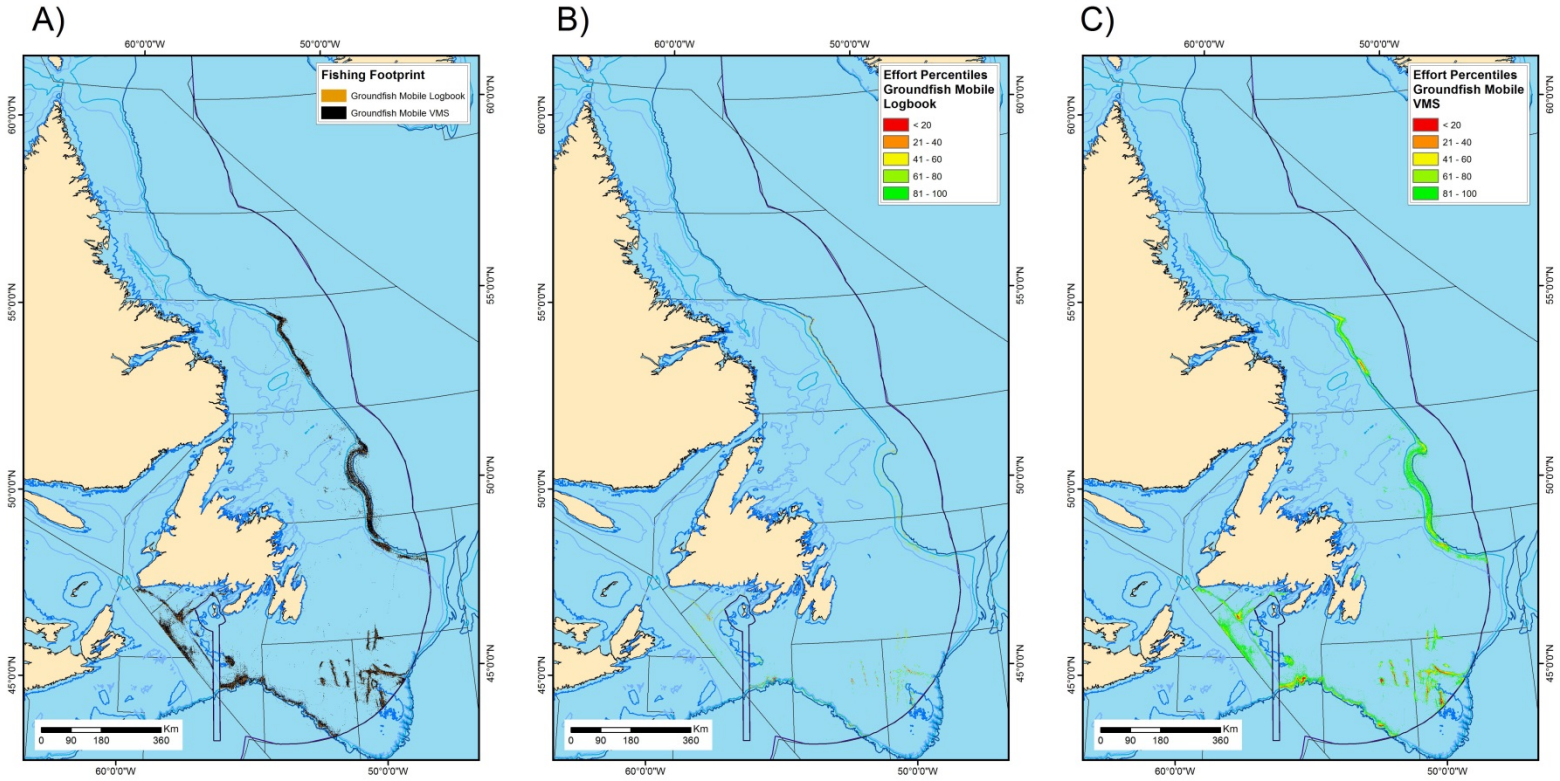

Figure A2 - 28. Groundfish Mobile.

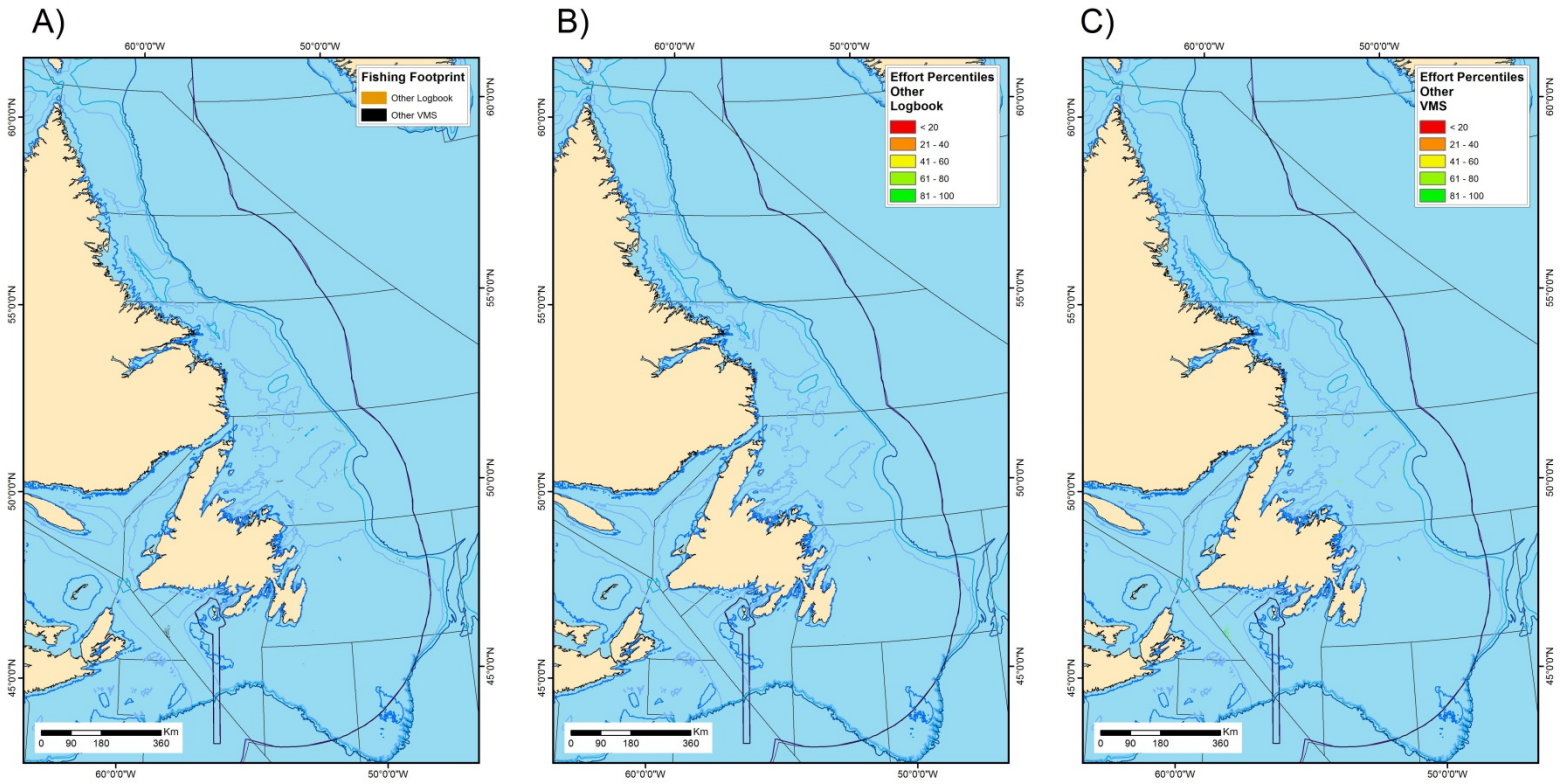

Figure A2 - 29. Other.

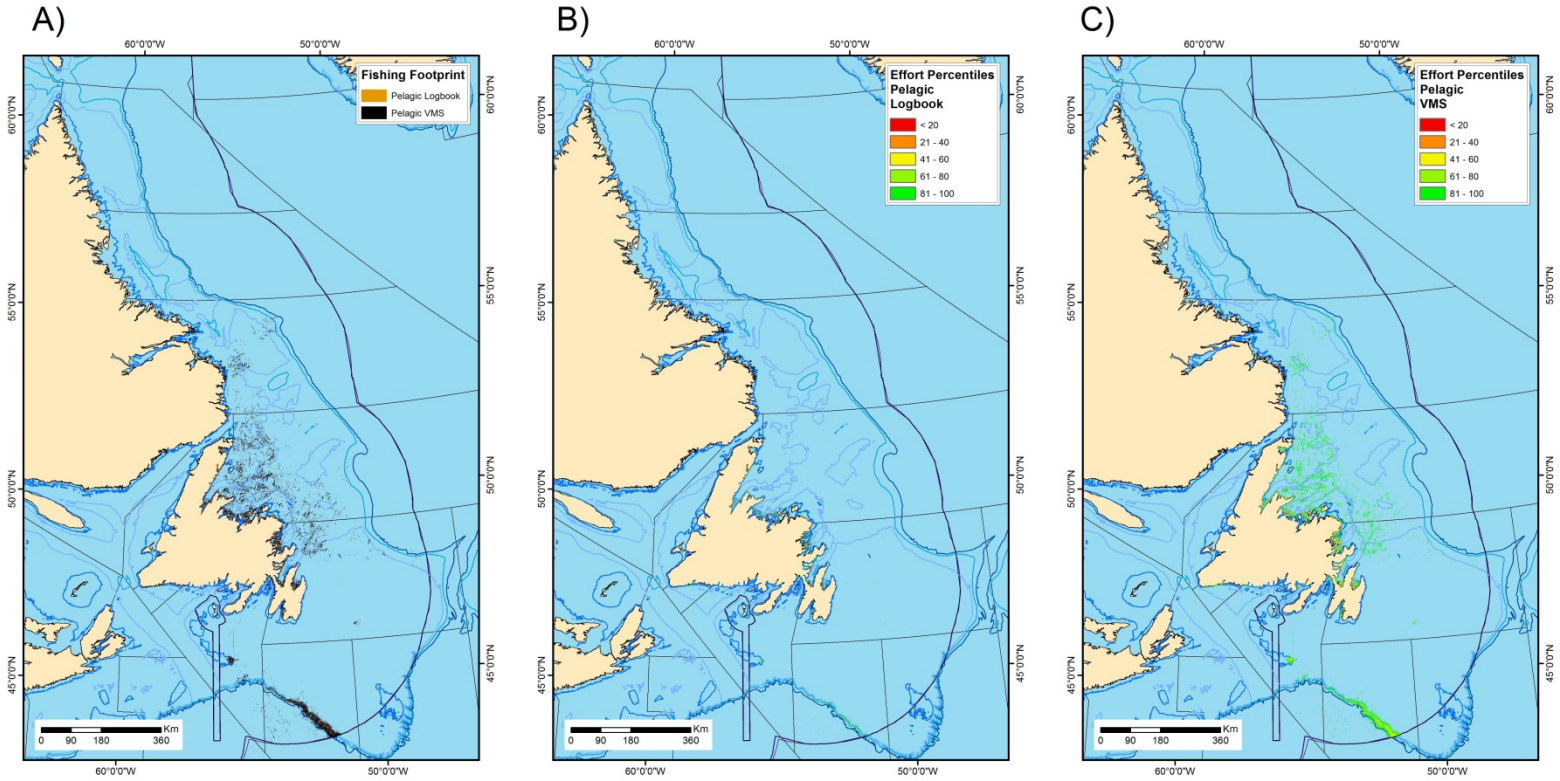

Figure A2 - 30. Pelagic.

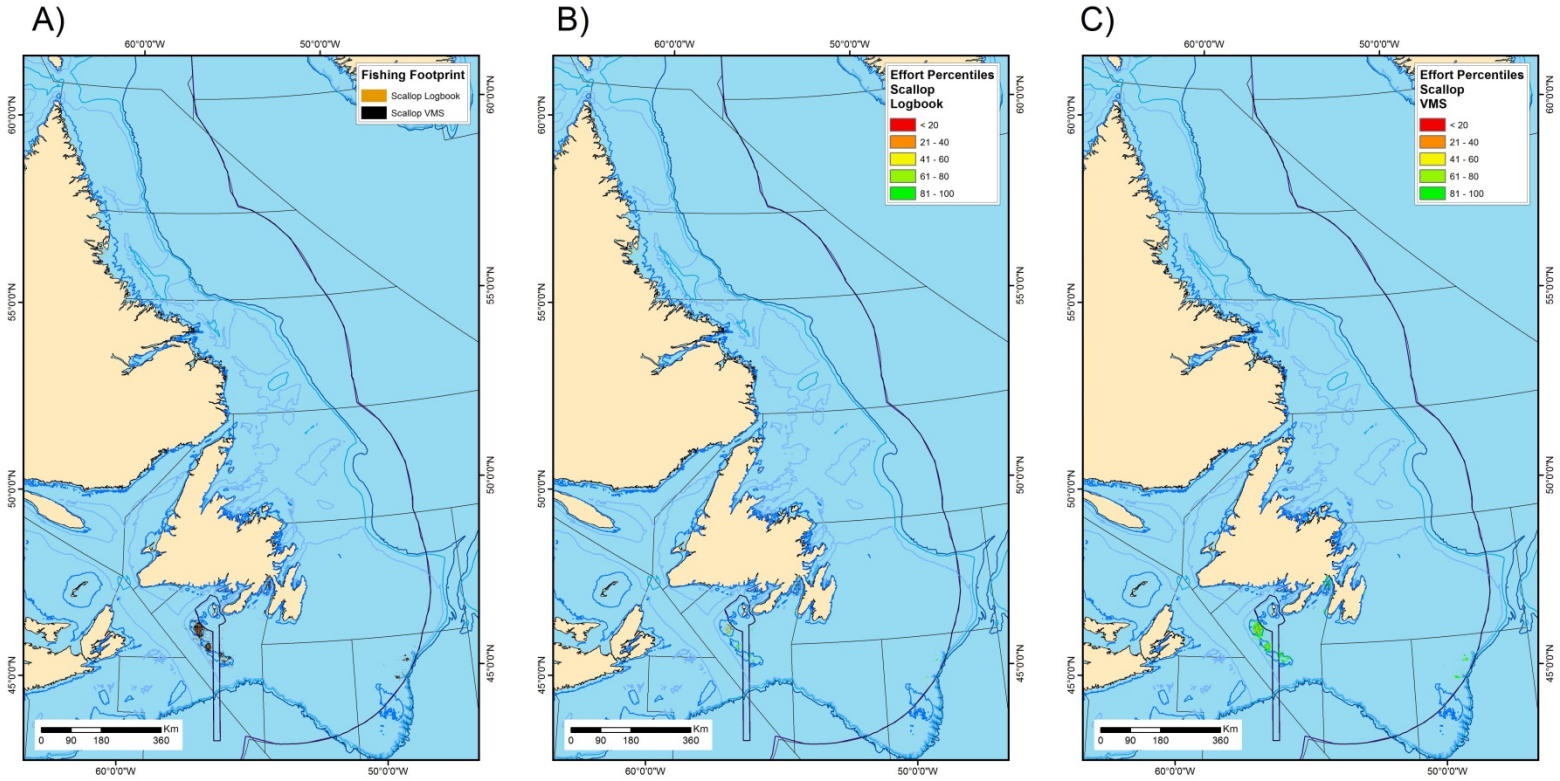

Figure A2 - 31. Scallop.

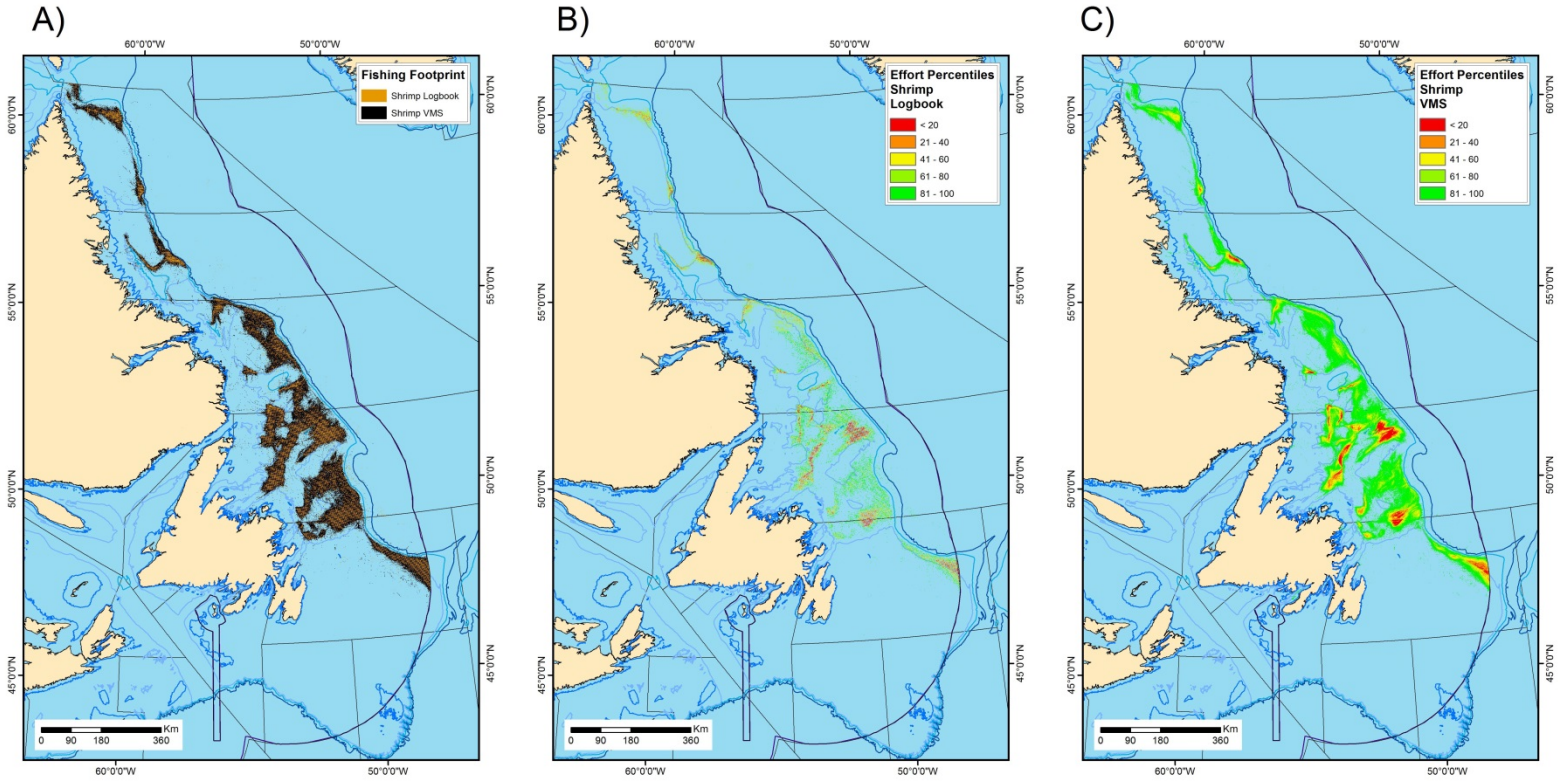

Figure A2 - 32. Shrimp.

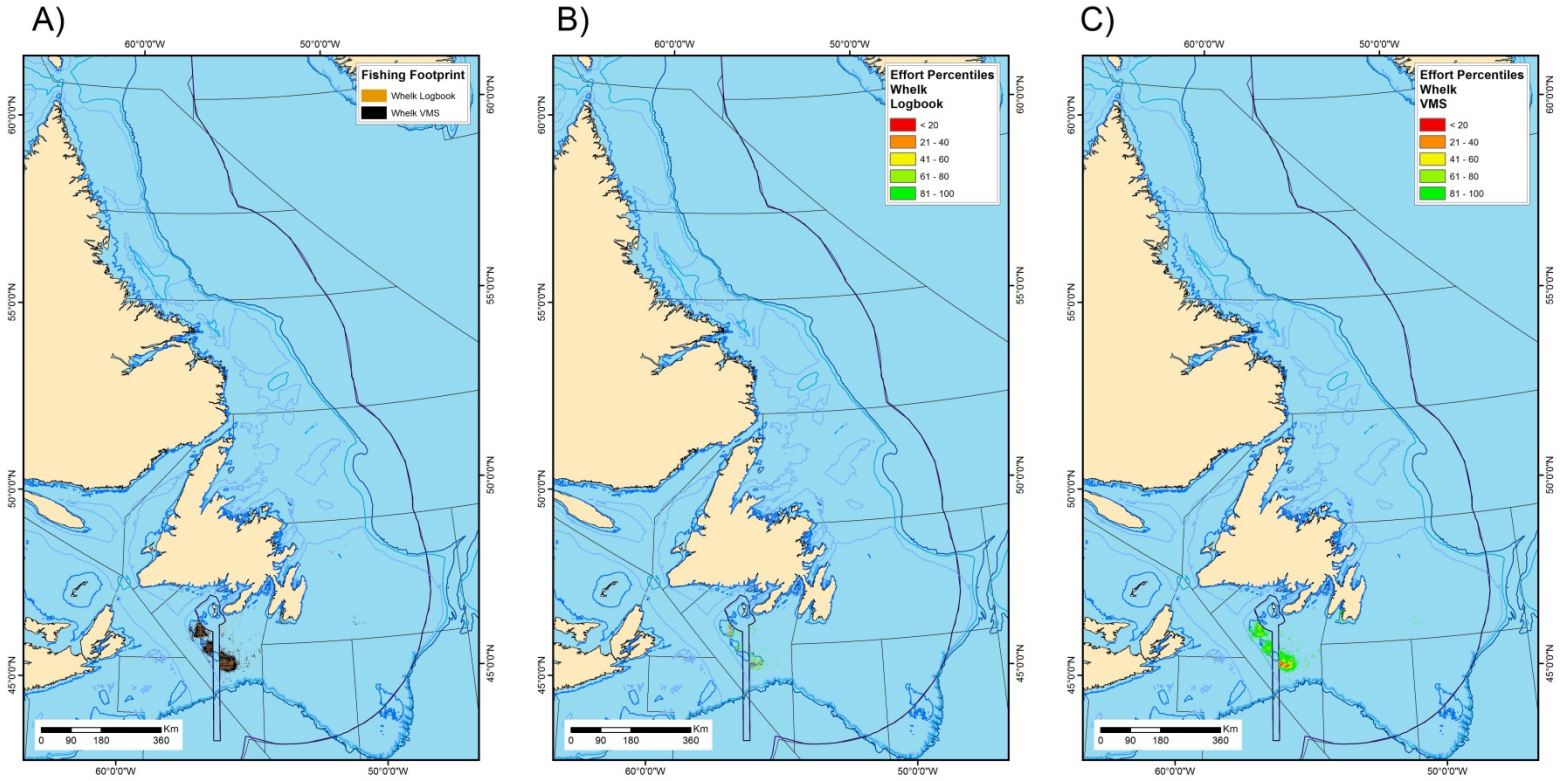

Figure A2 - 33. Whelk.

EASTERN ARCTIC (EA)

Maps are shown for the following fisheries classes in the Eastern Arctic bioregion:

- All fisheries combined
- Groundfish fixed
- Groundfish mobile
- Shrimp

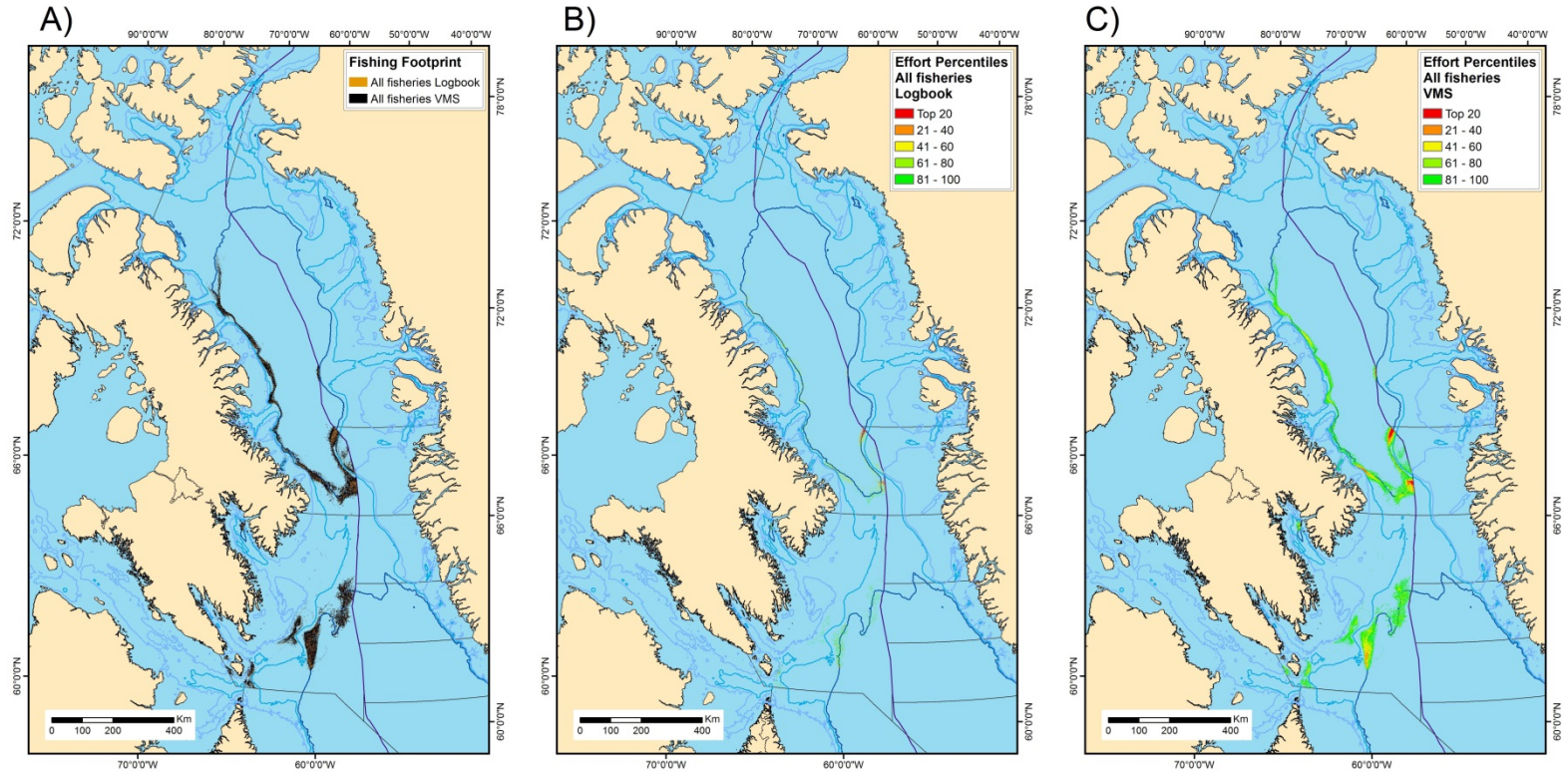

Figure A2 - 34. All fisheries combined.

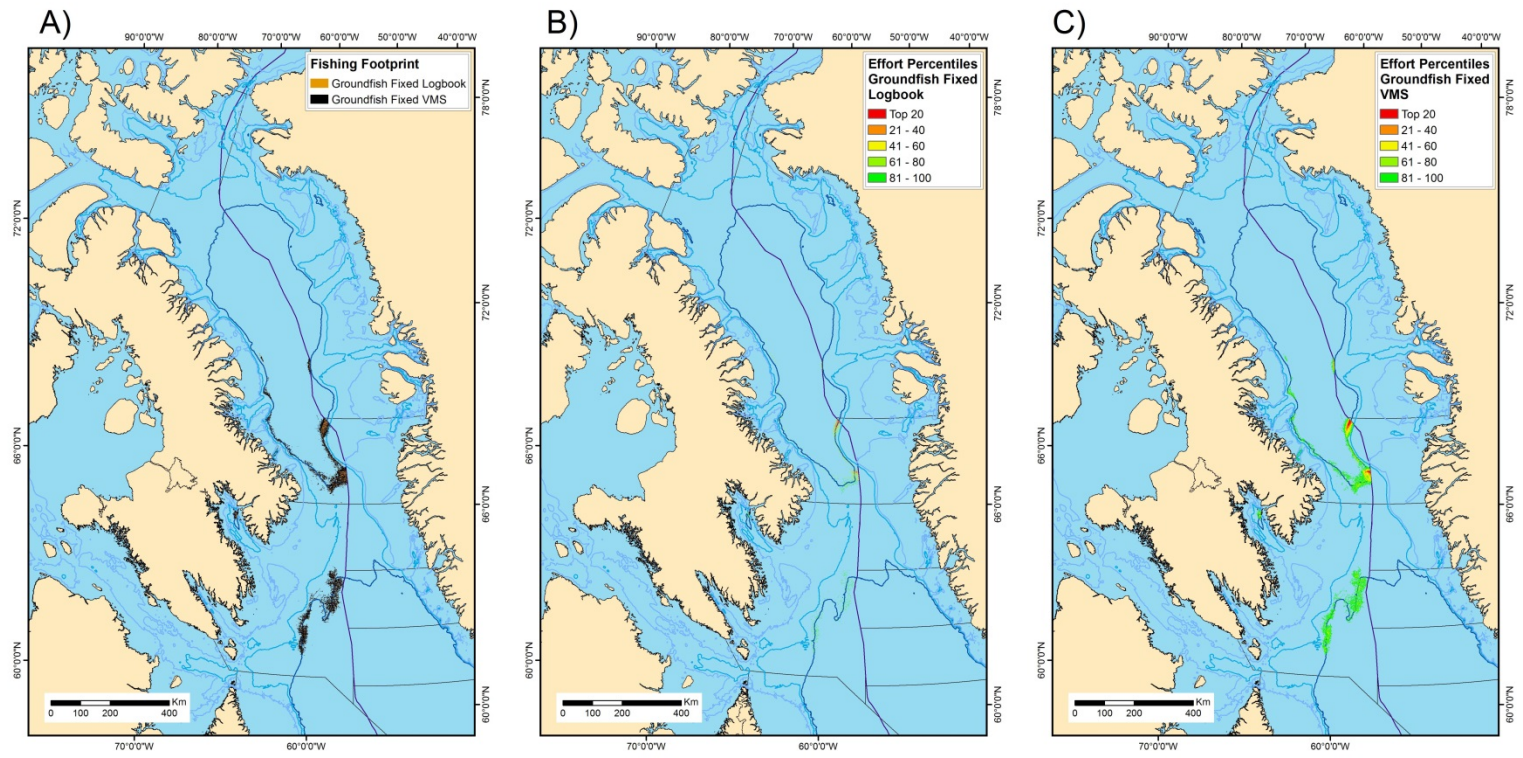

Figure A2 - 35. Groundfish Fixed.

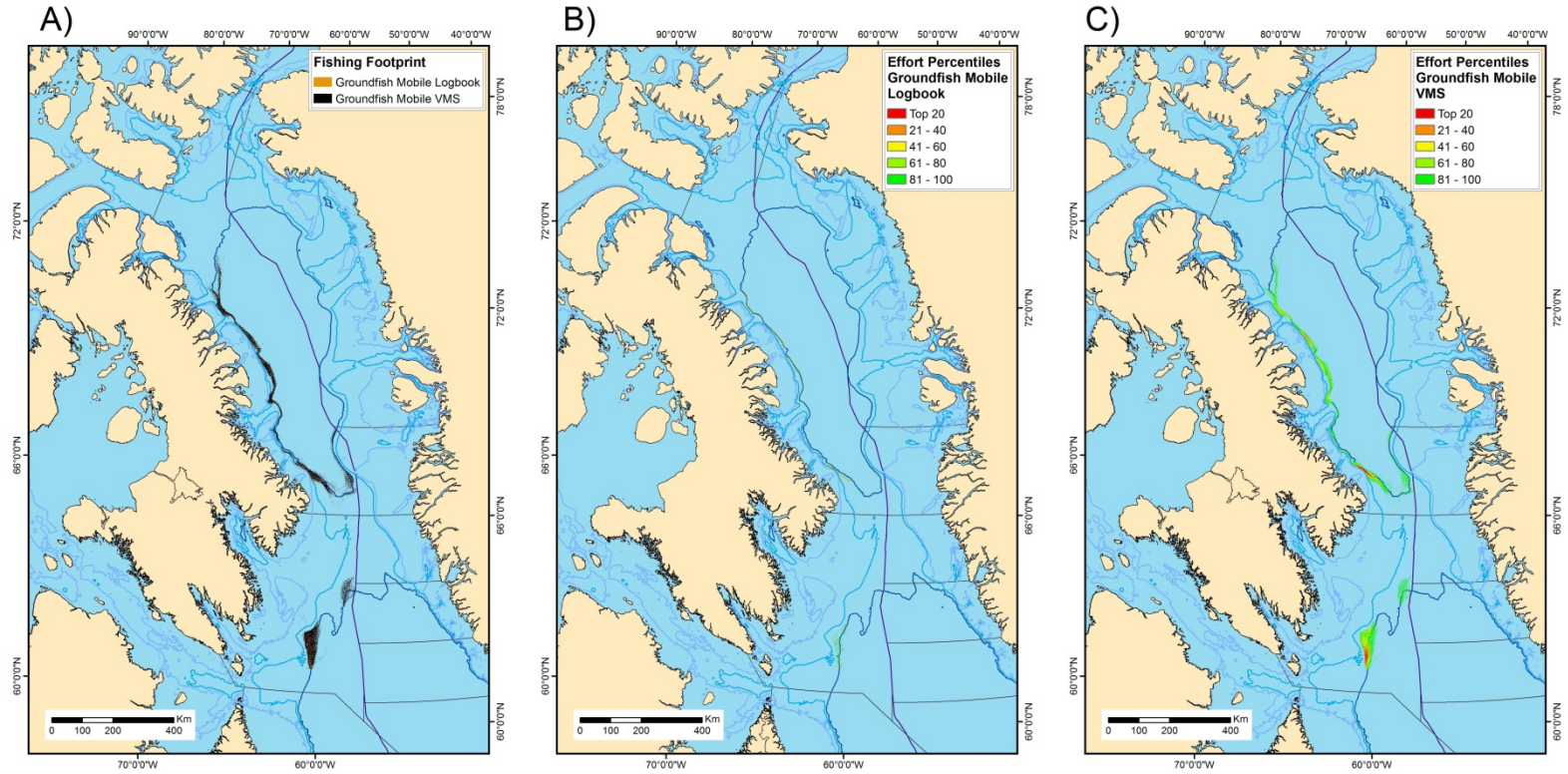

Figure A2 - 36. Groundfish Mobile.

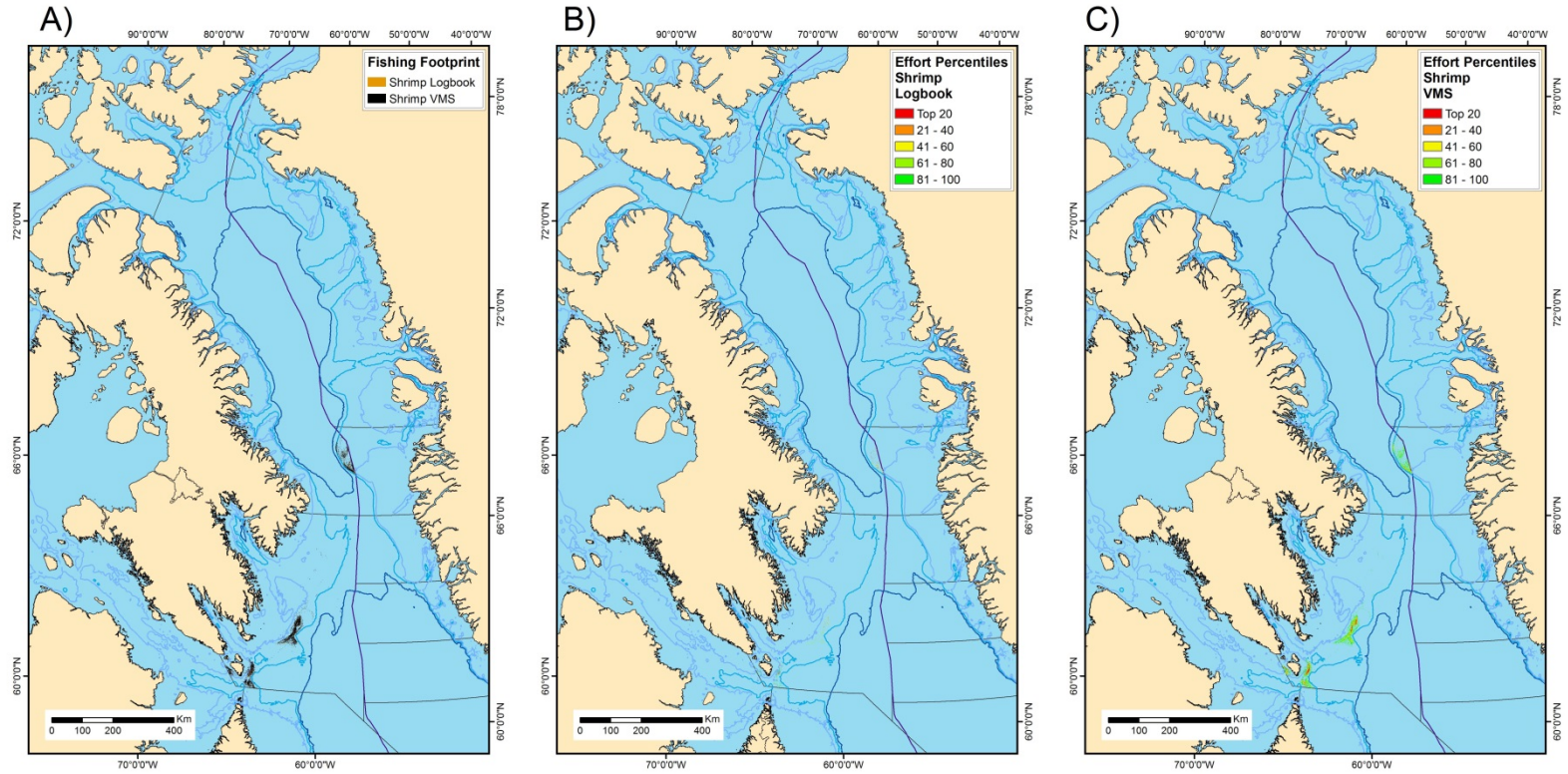

Figure A2 - 37. Shrimp.

APPENDIX 3. COMBINED VMS/LOGBOOK EFFORT LAYERS

This appendix shows combined effort layers (merged effort from logbooks and VMS data) for each fisheries class overlaid with Significant Benthic Area outlines. Significant benthic areas of each type present in a bioregion (small gorgonian, large gorgonian, sea pen or sponge) are all included together on maps marked with different colours.

For each bioregion, the first map shows the distribution of Significant Benthic Areas without fishing effort. Extent indicators for more detailed maps of effort and Significant Benthic Areas are marked on the full size map. The “zoomed-in” maps (insets) are shown below the full extent map to allow a closer look at the effort within a Significant Benthic Area. Maps of fishing effort and Significant Benthic Areas within each bioregion are shown alphabetically by fishery, beginning with a category for all fisheries effort combined. The “all fisheries” category includes effort for each fisheries class in the bioregion, even if the fisheries class-specific map is excluded. In each panel of each figure, the legend details information on the fisheries and data sources within the map.

SCOTIAN SHELF (SS)

In the Scotian Shelf, there are three types of Significant Benthic Areas: large gorgonian, sea pen and sponge. The first map within this section shows the Significant Benthic Areas without any fishing effort, followed by fisheries class-specific maps for the following fisheries classes in the Scotian Shelf bioregion:

- All fisheries combined
- Crab offshore
- Groundfish fixed
- Groundfish mobile
- Miscellaneous inshore
- Miscellaneous offshore
- Other
- Pelagic
- Scallop
- Shrimp

Due to either privacy regulations or data deficiency, maps are not displayed for the following fisheries classes: clam, crab inshore, echinoderm, lobster, and whelk.

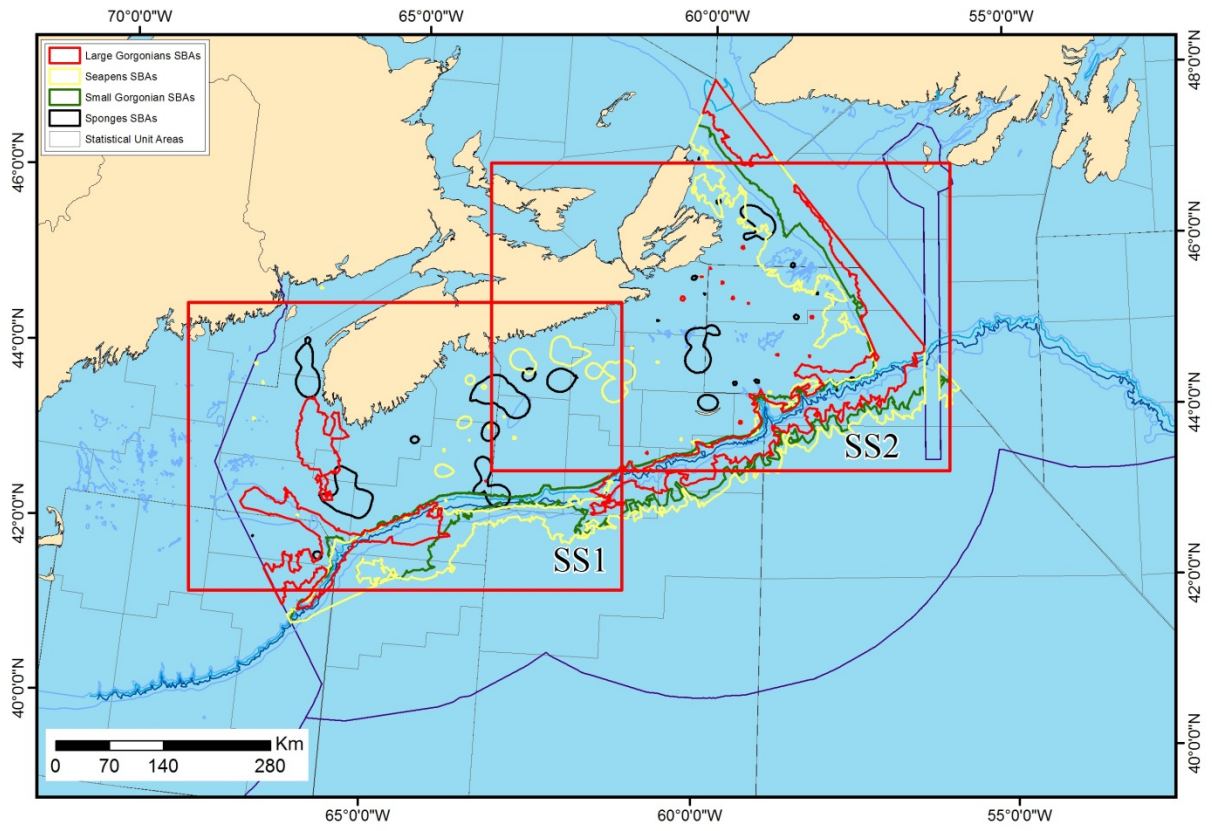

Figure A3 - 1. Inset Index.

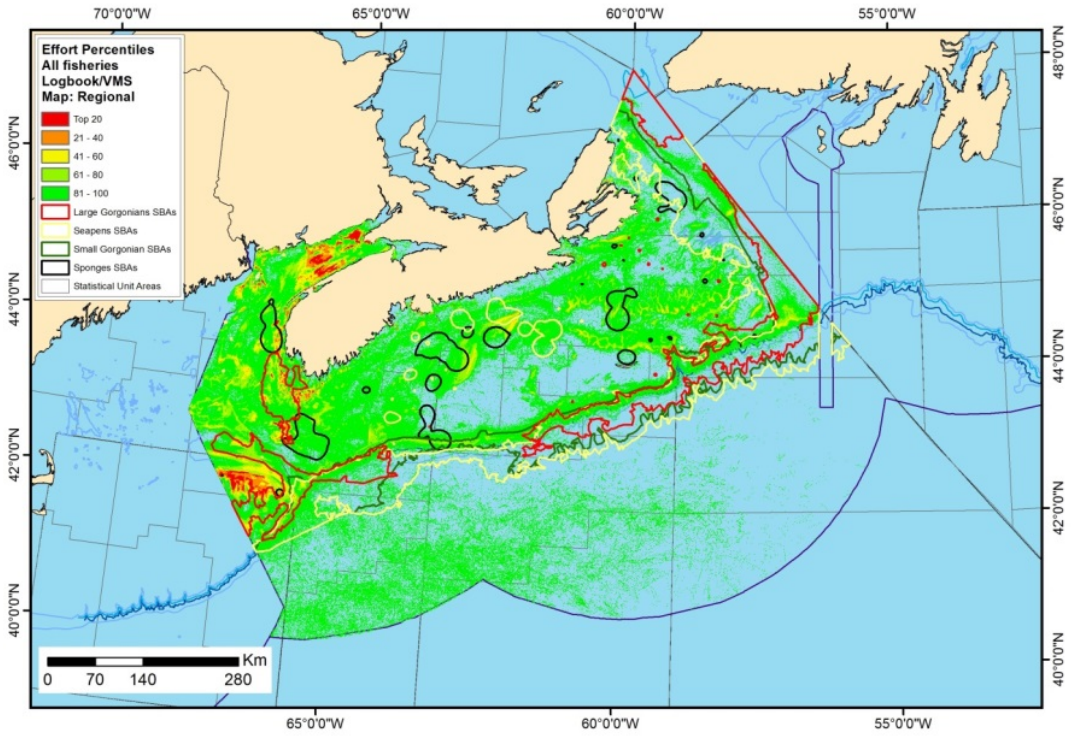

Figure A3 - 2. All fisheries, regional map.

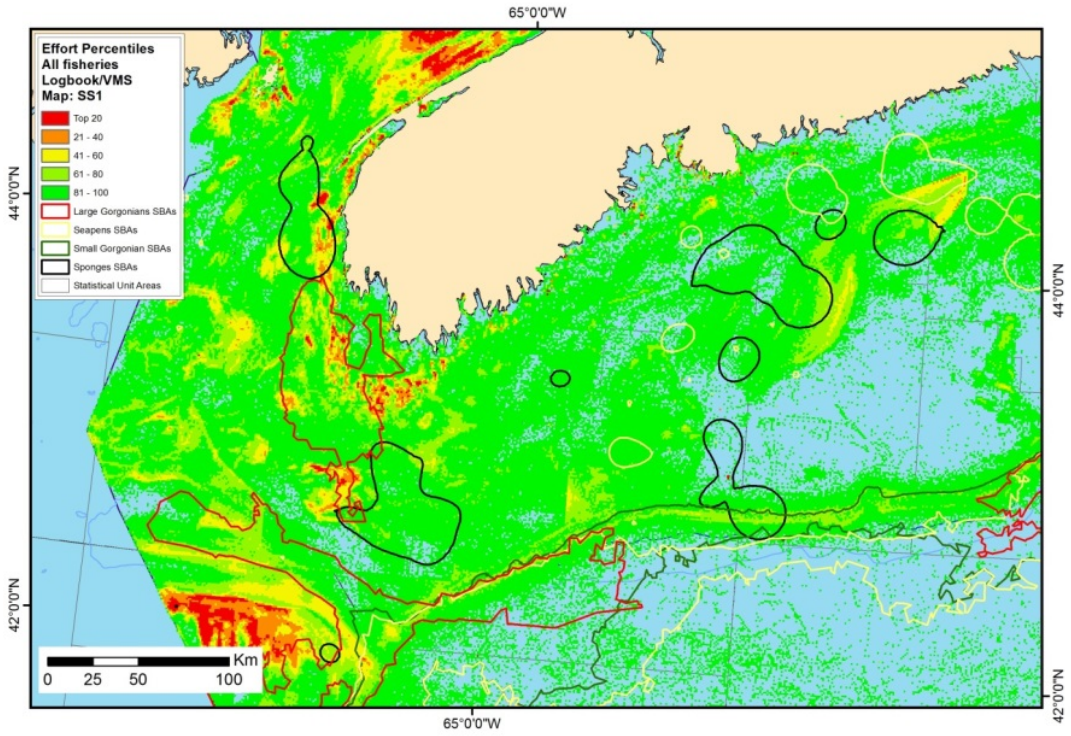

Figure A3 - 3. All fisheries, inset SS1.

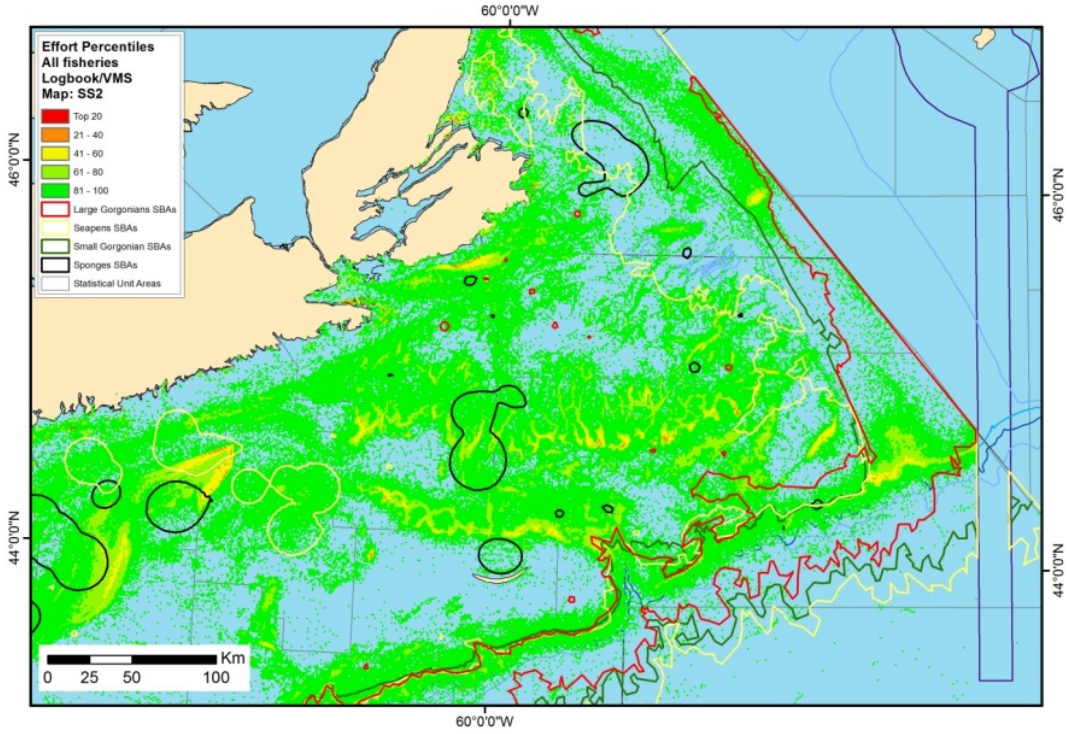

Figure A3 - 4. All fisheries, inset SS2.

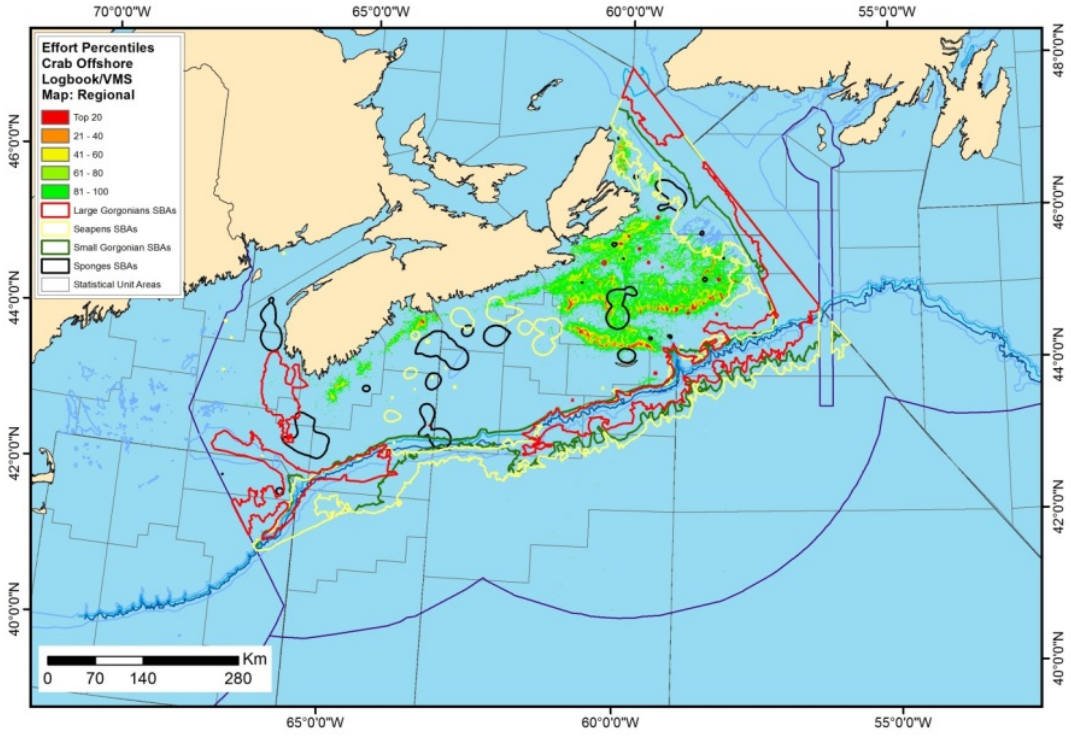

Figure A3 - 5. Crab offshore, regional map.

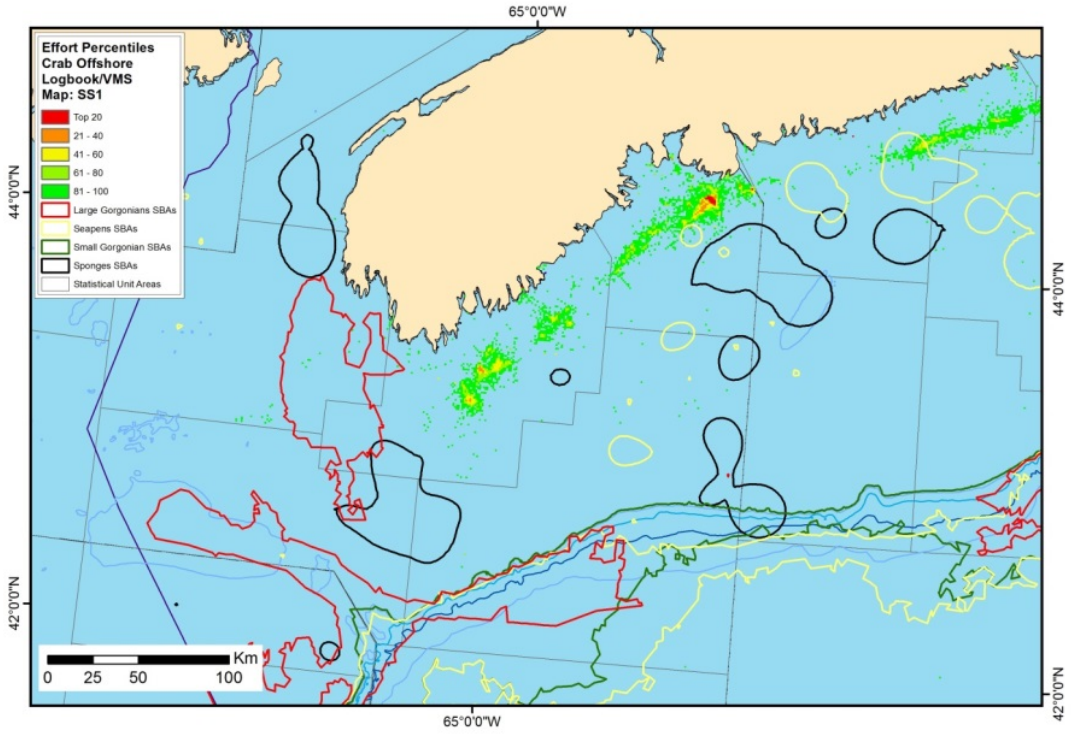

Figure A3 - 6. Crab offshore, inset SS1.

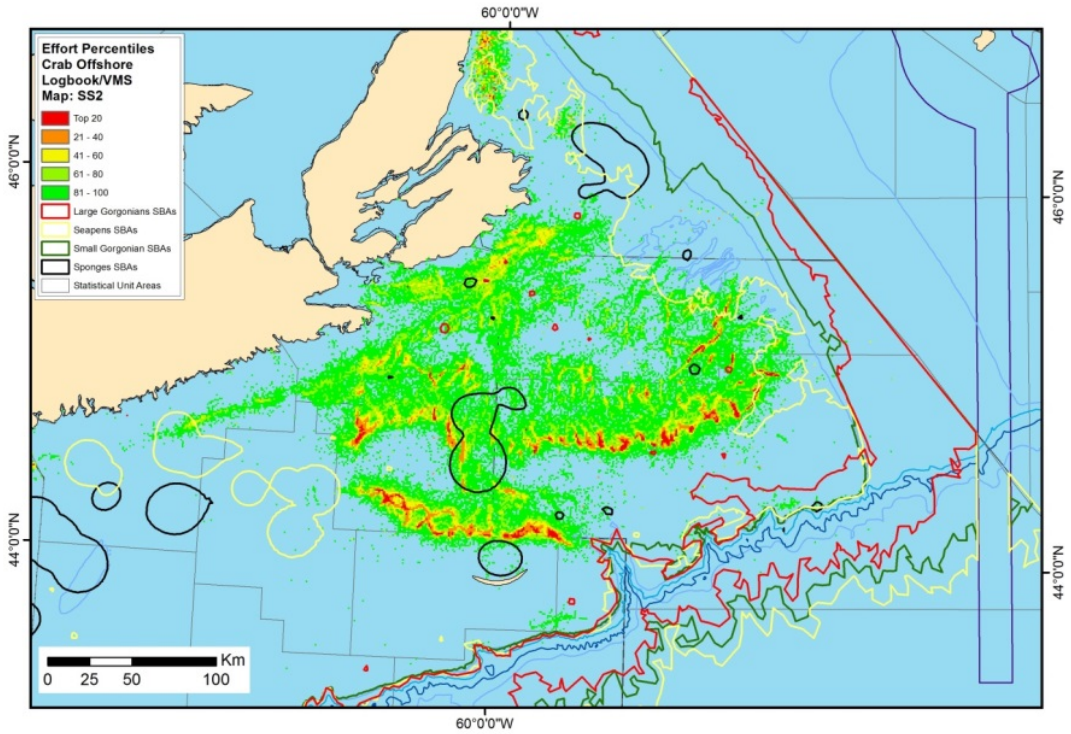

Figure A3 - 7. Crab Offshore, inset SS2.

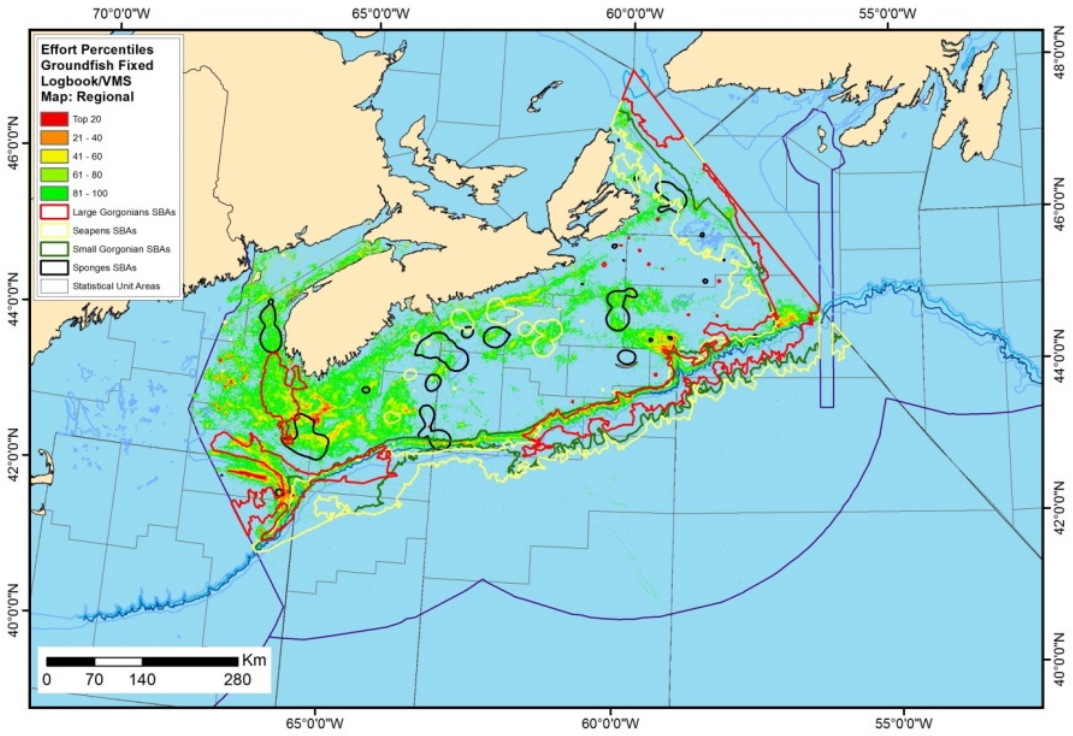

Figure A3 - 8. Groundfish Fixed, regional map.

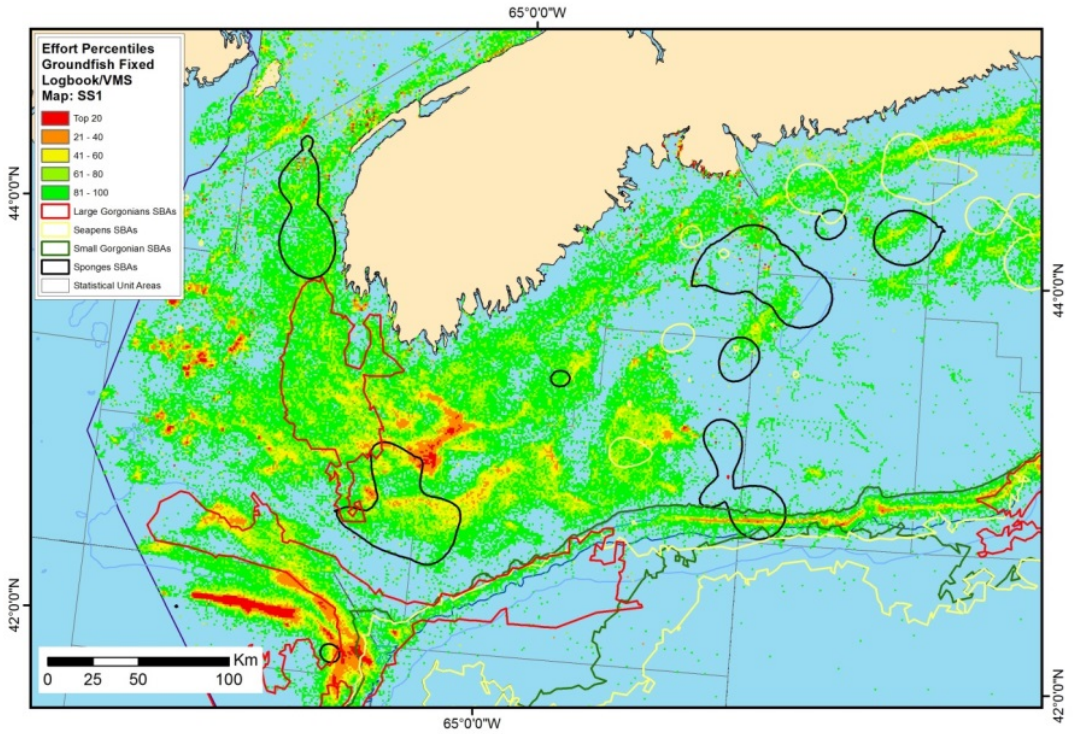

Figure A3 - 9. Groundfish Fixed, inset SS1.

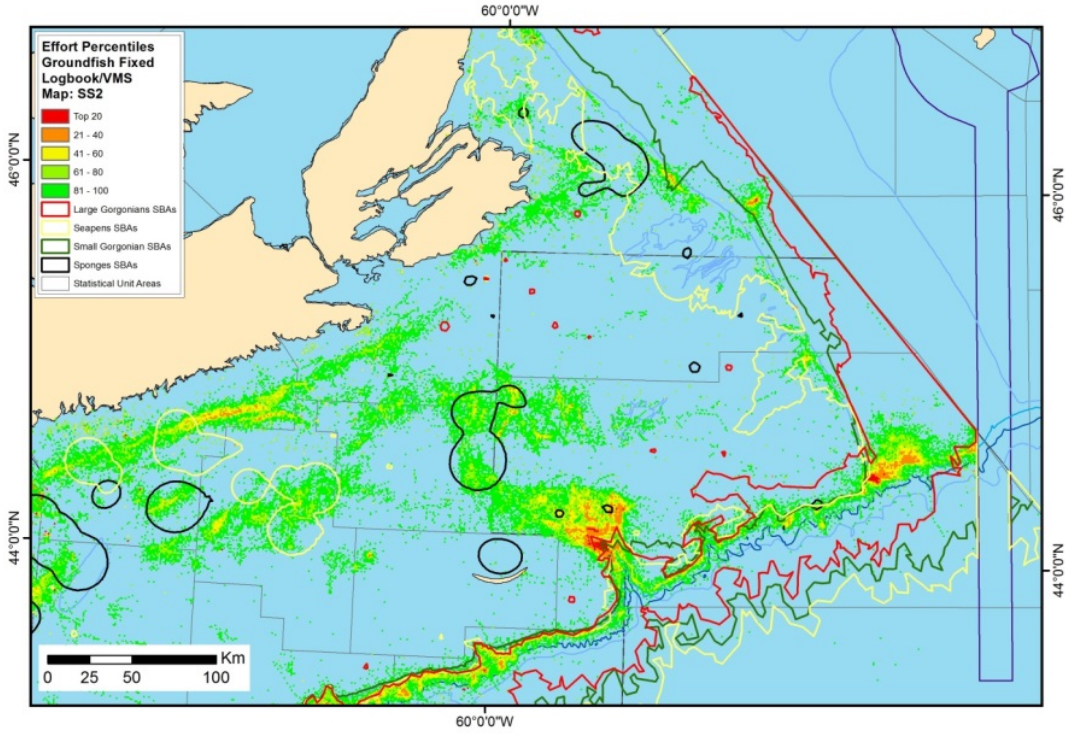

Figure A3 - 10. Groundfish Fixed, inset SS2.

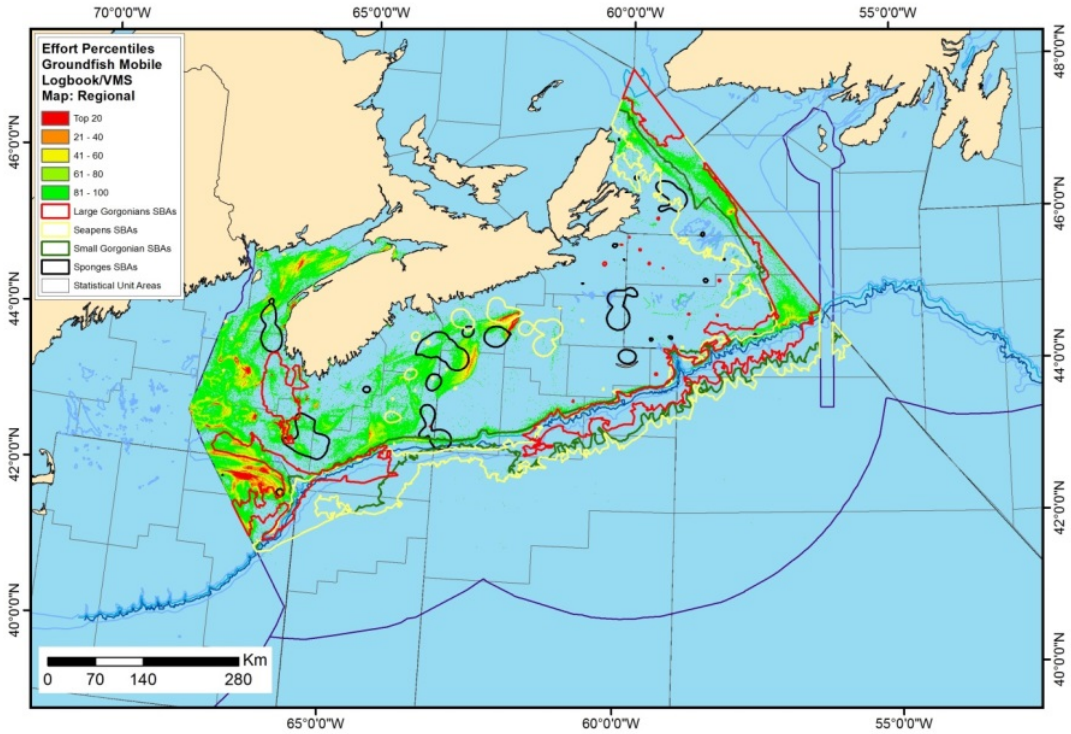

Figure A3 - 11. Groundfish Mobile, regional map.

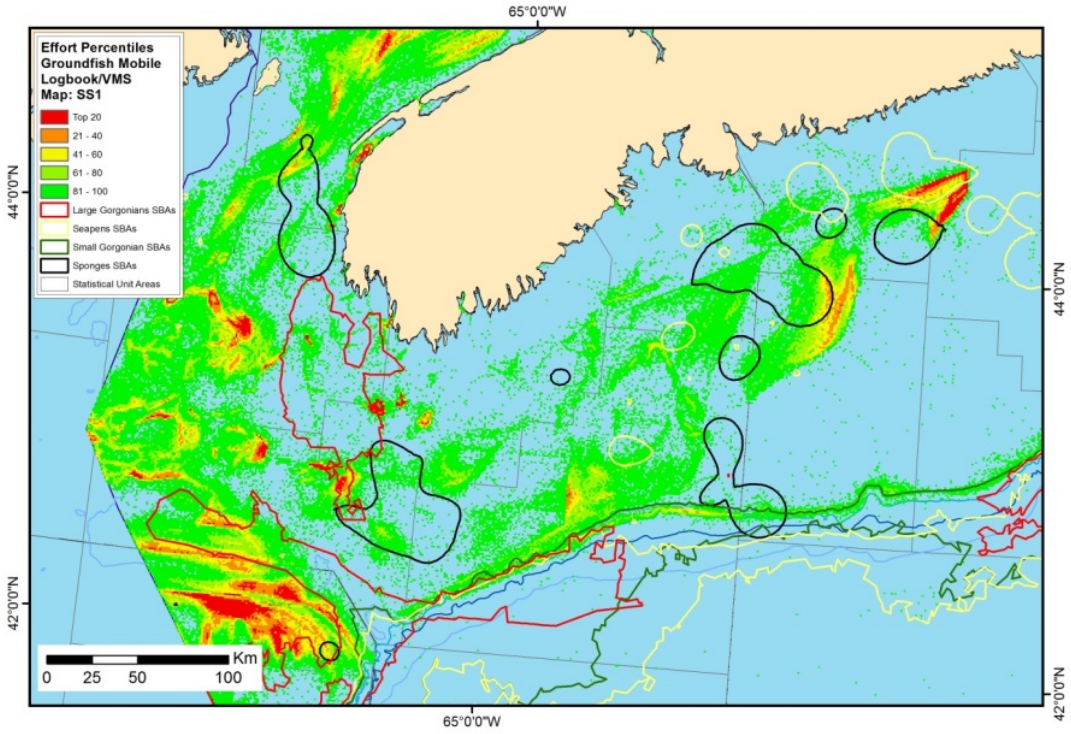

Figure A3 - 12. Groundfish Mobile, inset SS1.

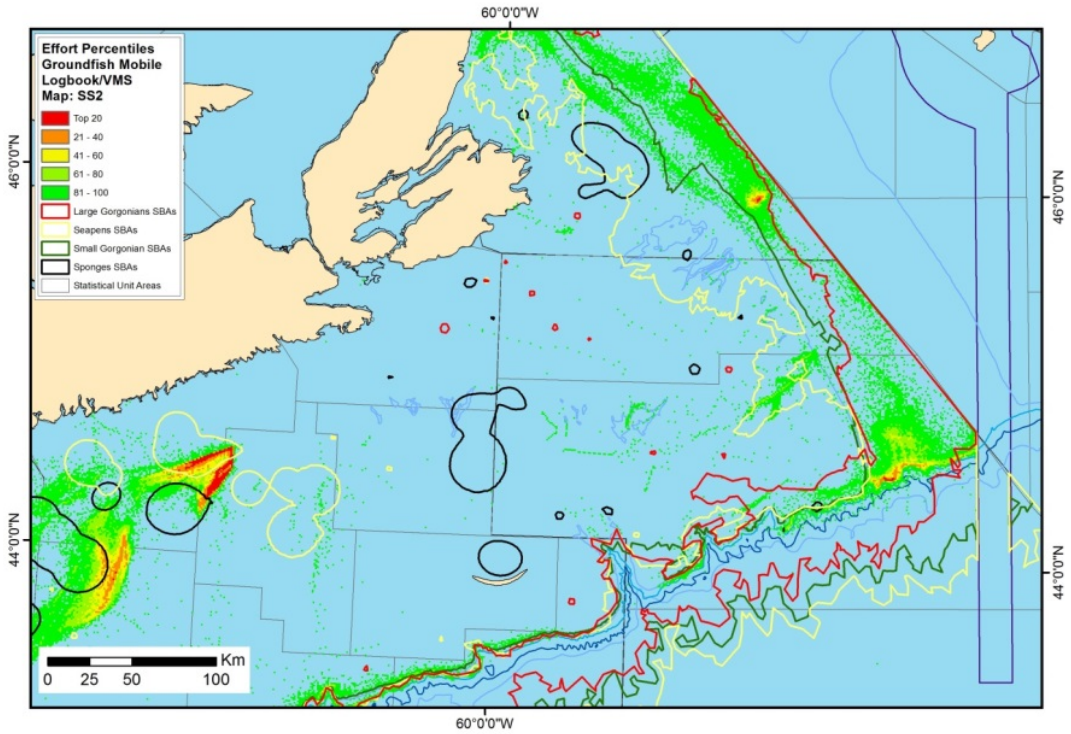

Figure A3 - 13. Groundfish Mobile, inset SS2.

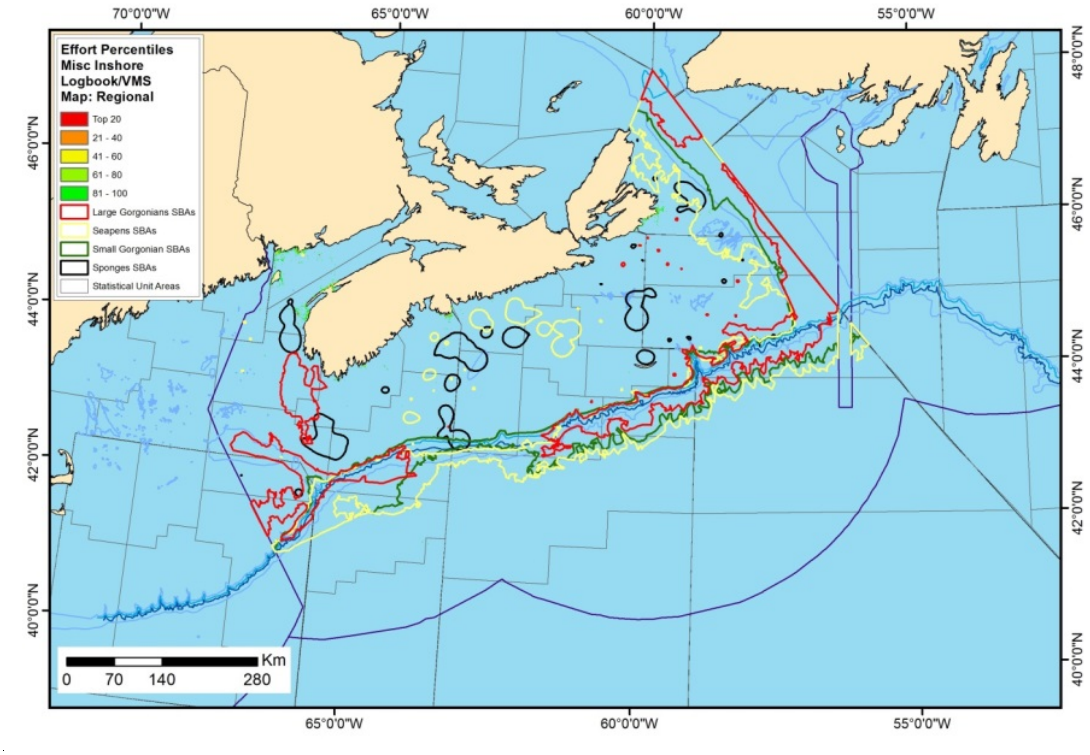

Figure A3 - 14. Miscellaneous Inshore, regional map.

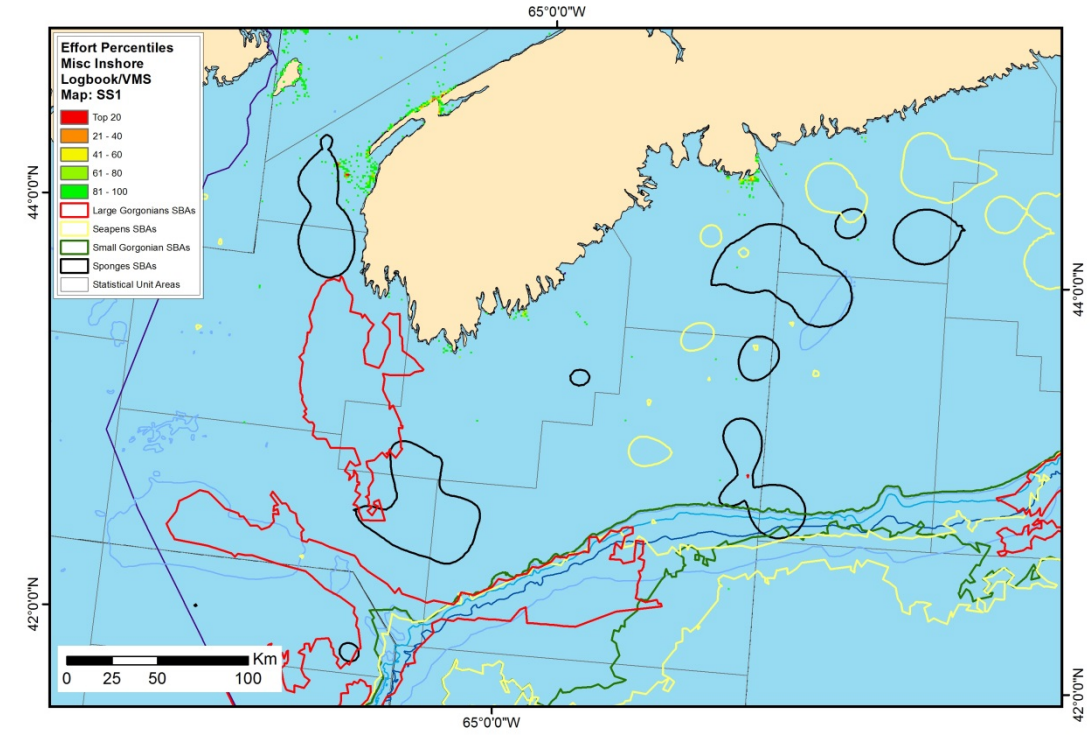

Figure A3 - 15. Miscellaneous Inshore, inset SS1.

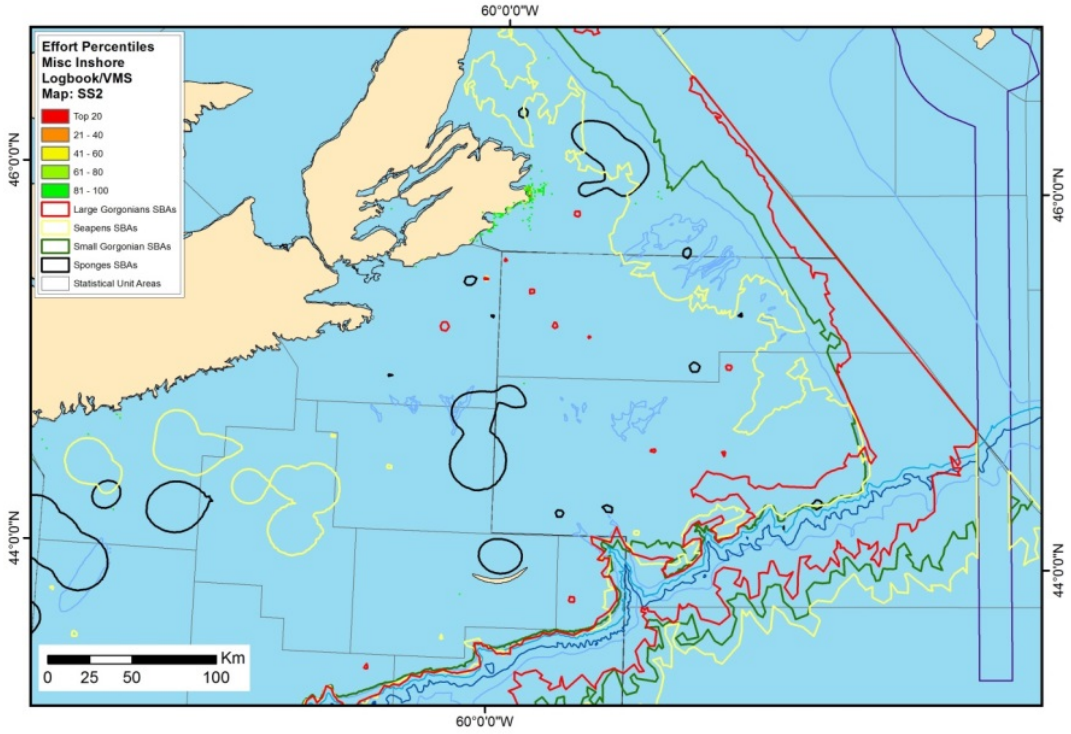

Figure A3 - 16. Miscellaneous Inshore, inset SS2.

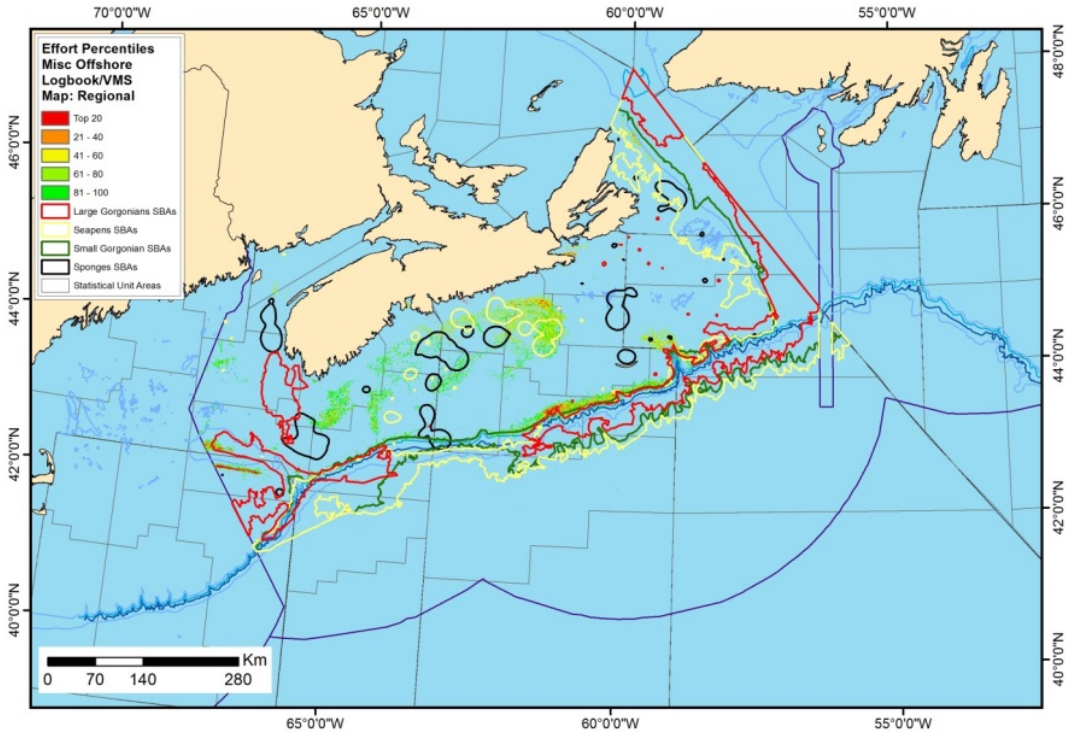

Figure A3 - 17. Miscellaneous Offshore, regional map.

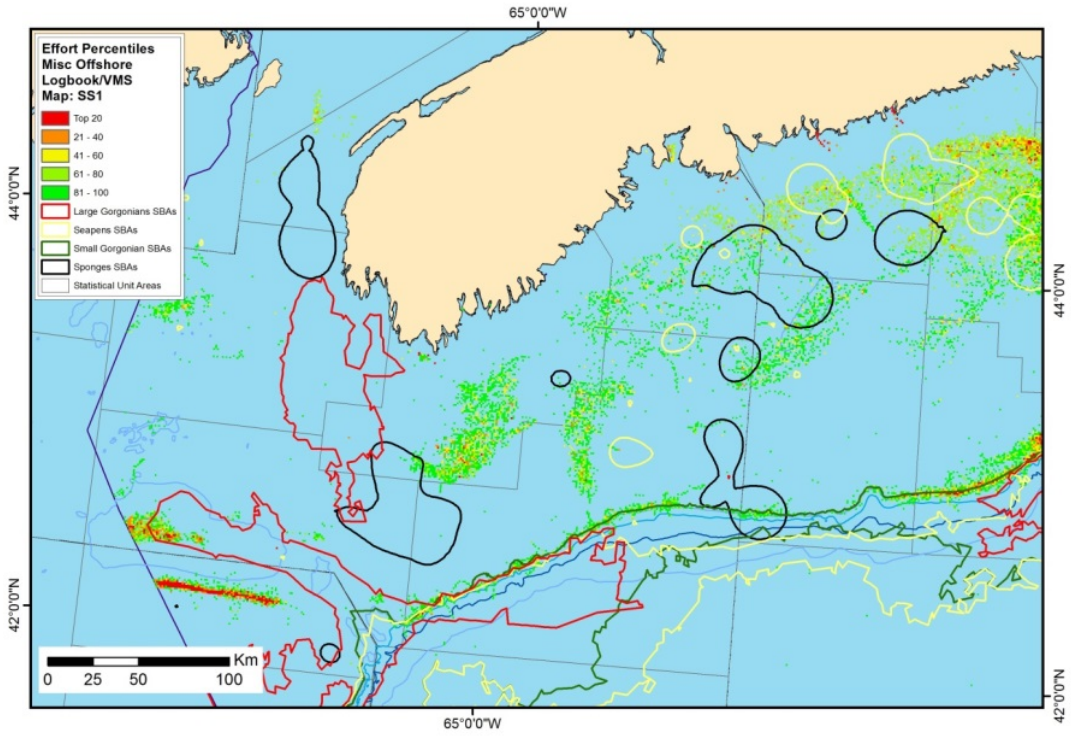

Figure A3 - 18. Miscellaneous Offshore, inset SS1.

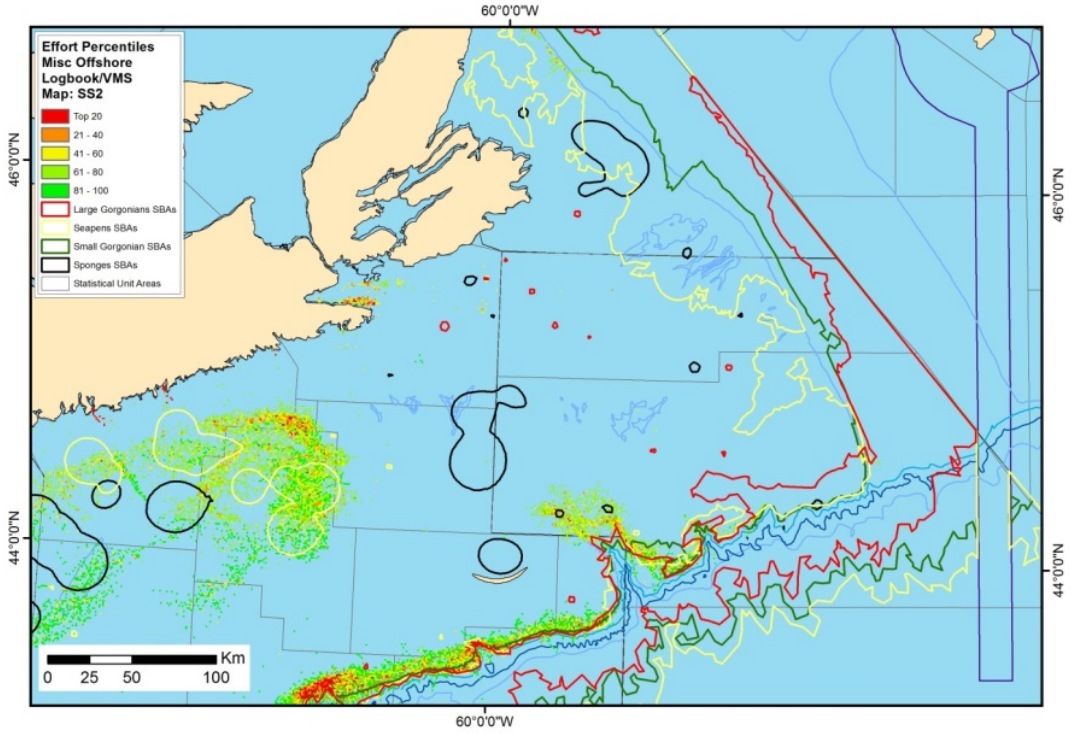

Figure A3 - 19. Miscellaneous Offshore, inset SS2.

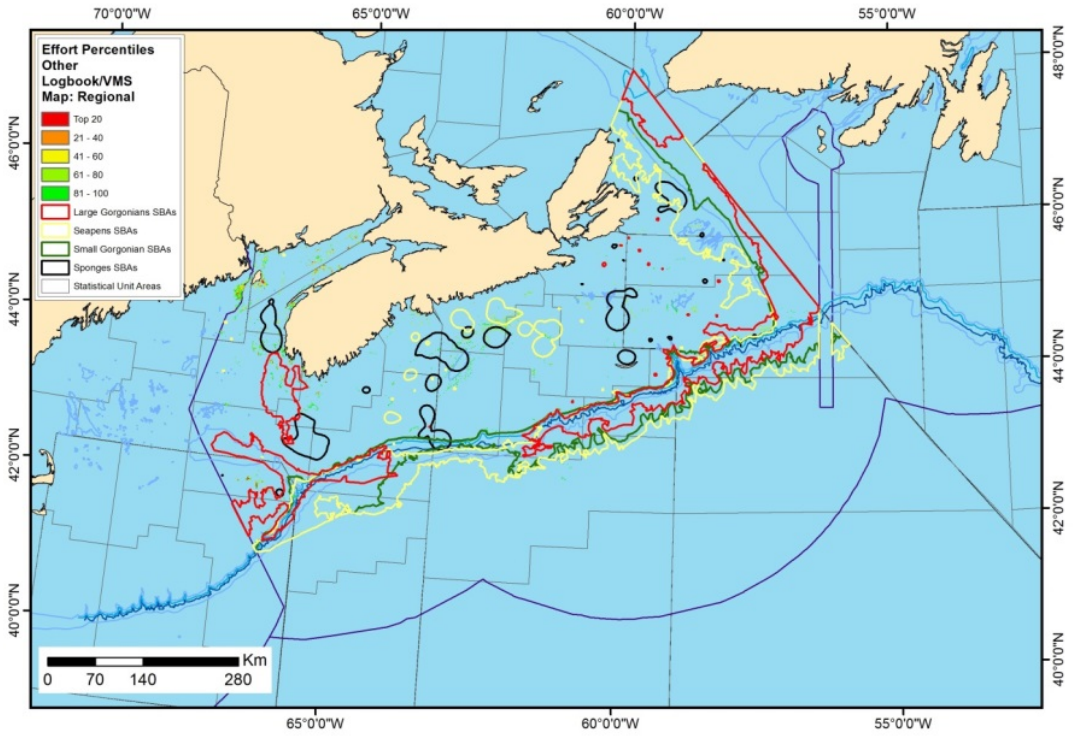

Figure A3 - 20. Other, regional map.

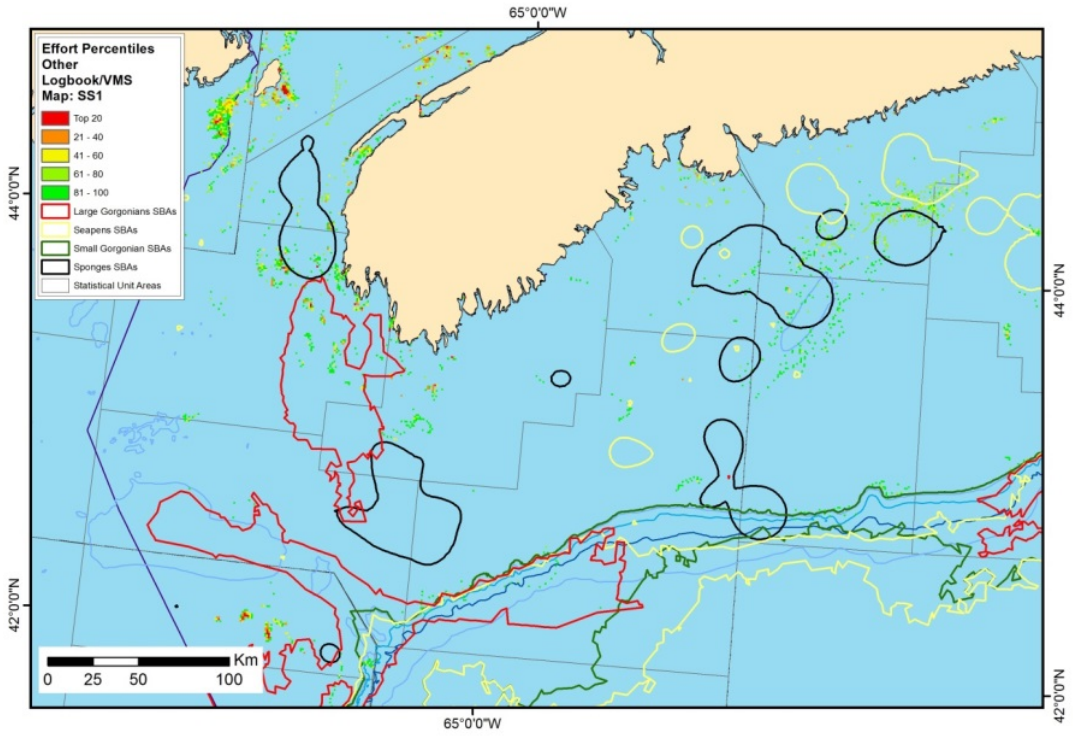

Figure A3 - 21. Other, inset SS1.

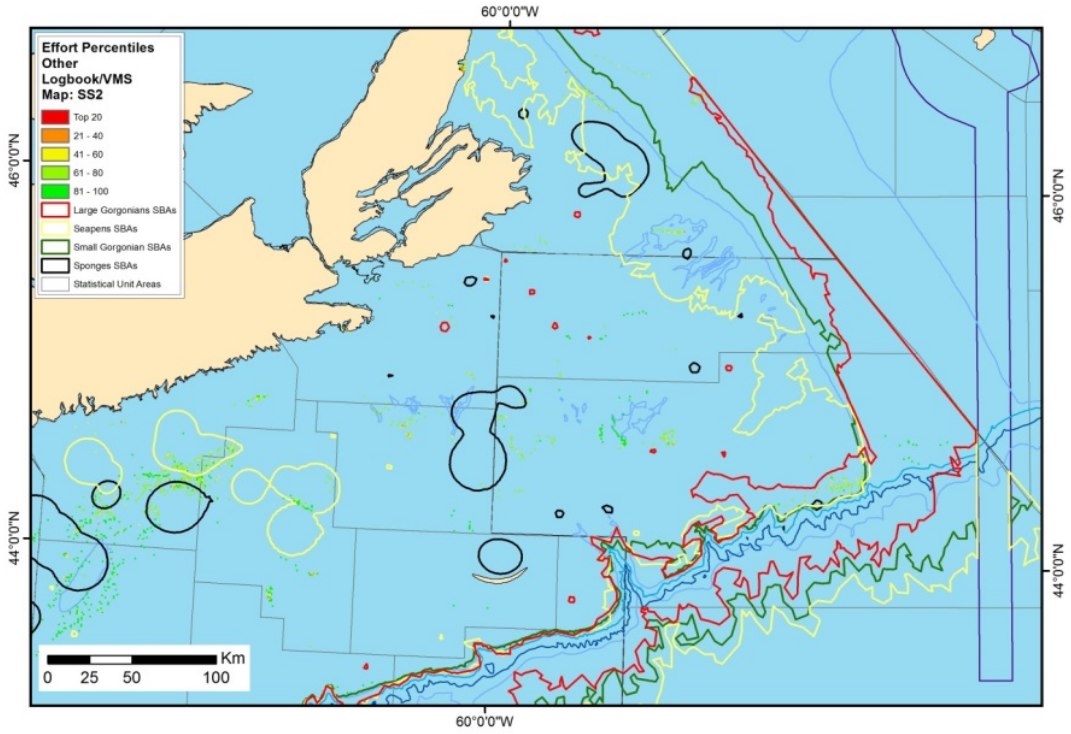

Figure A3 - 22. Other, inset SS2.

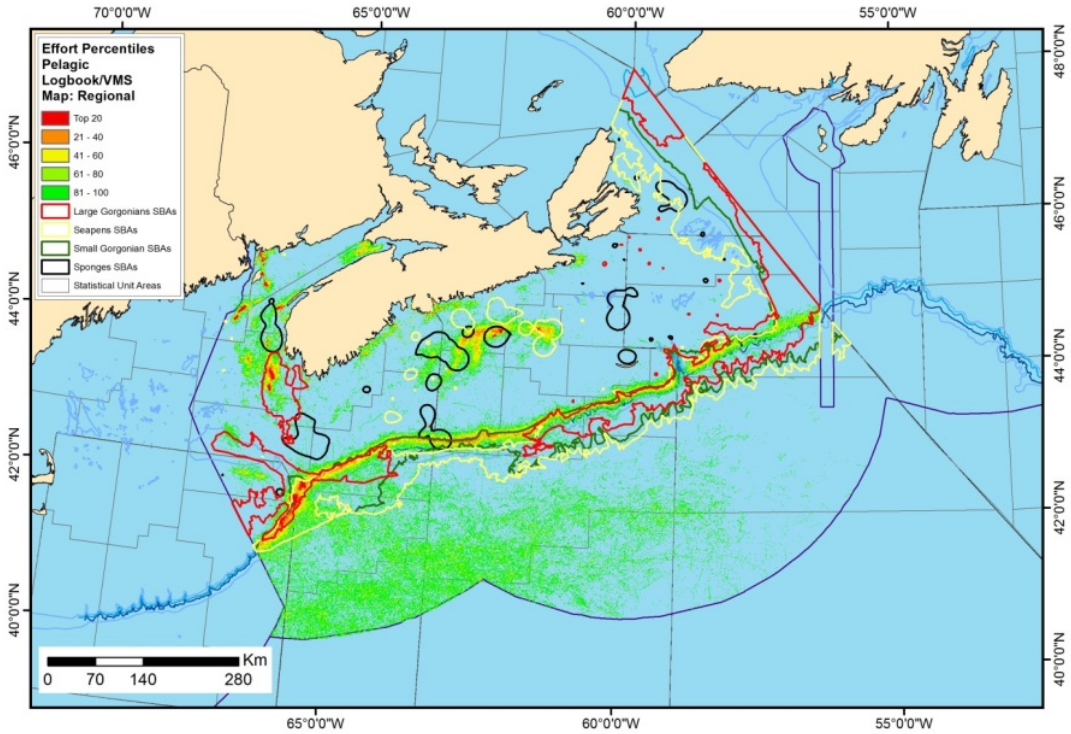

Figure A3 - 23. Pelagic, regional map.

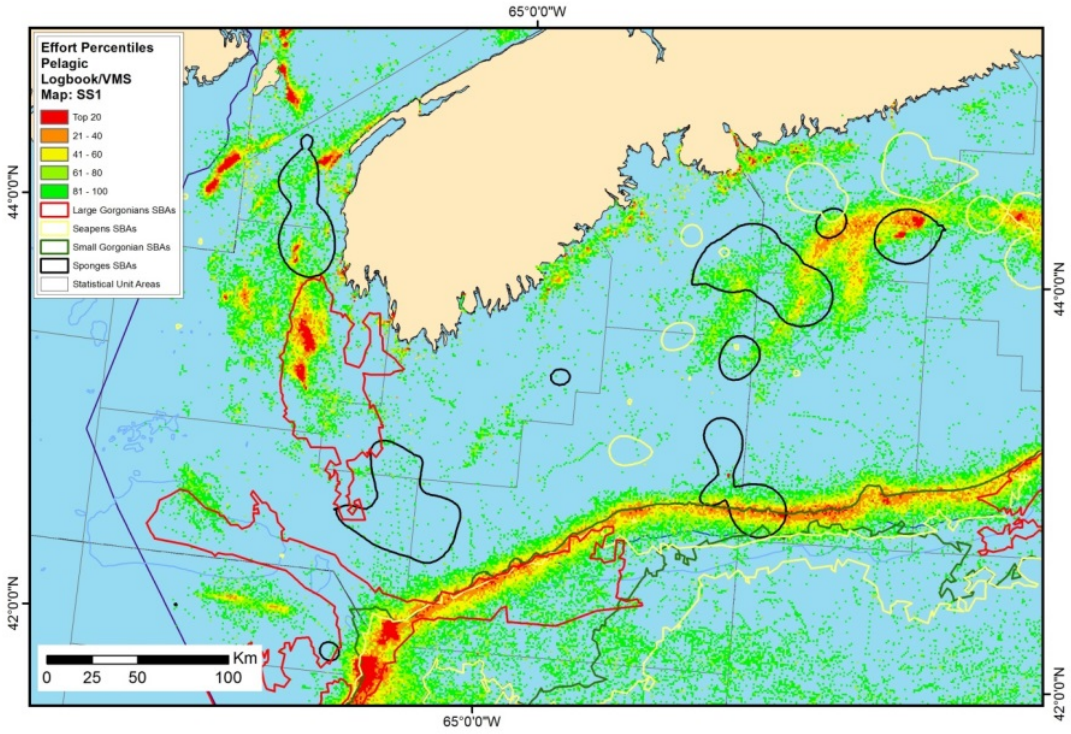

Figure A3 - 24. Pelagic, inset SS1.

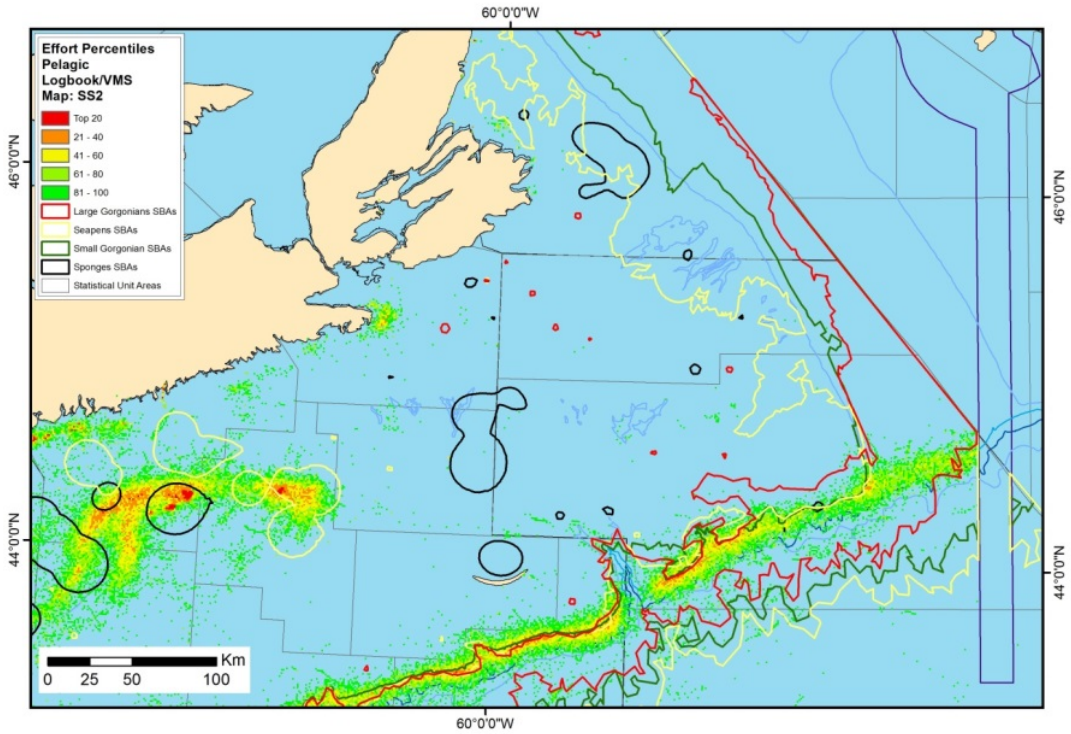

Figure A3 - 25. Pelagic, inset SS2.

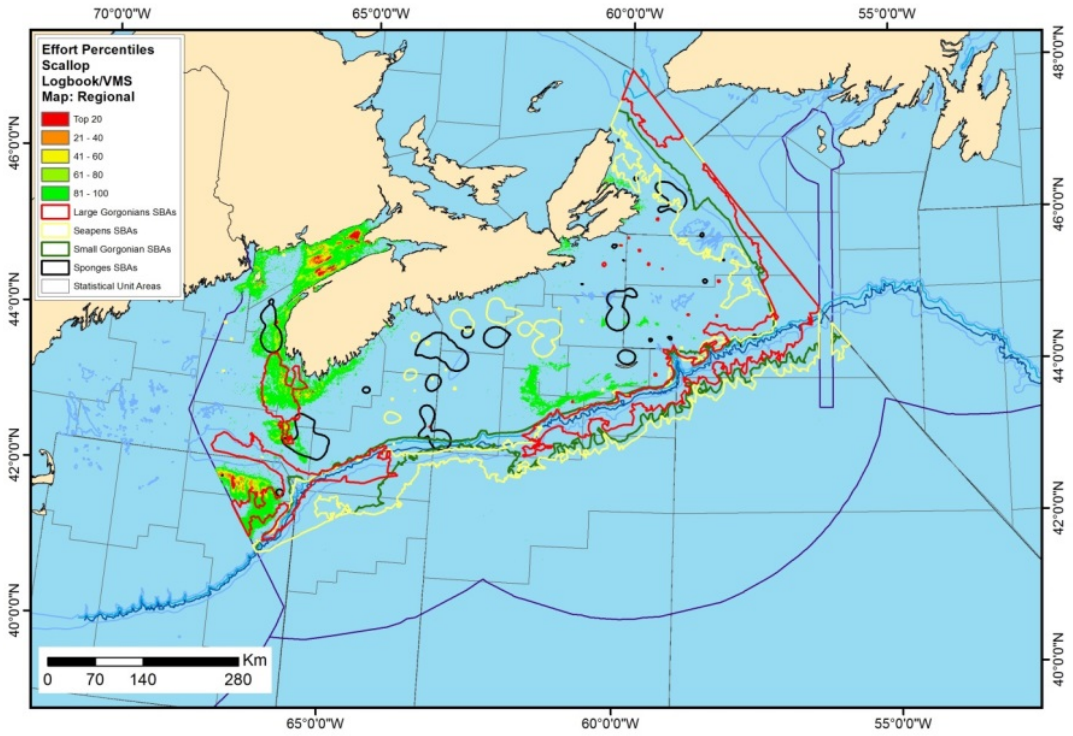

Figure A3 - 26. Scallop, regional map.

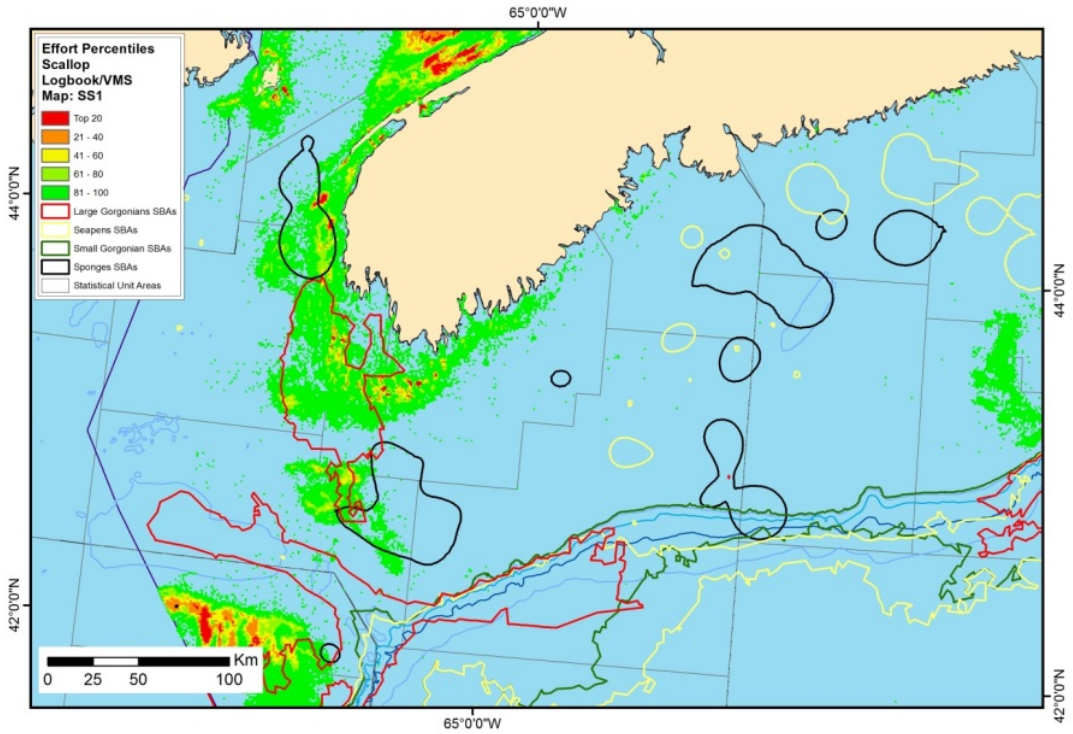

Figure A3 - 27. Scallop, inset SS1.

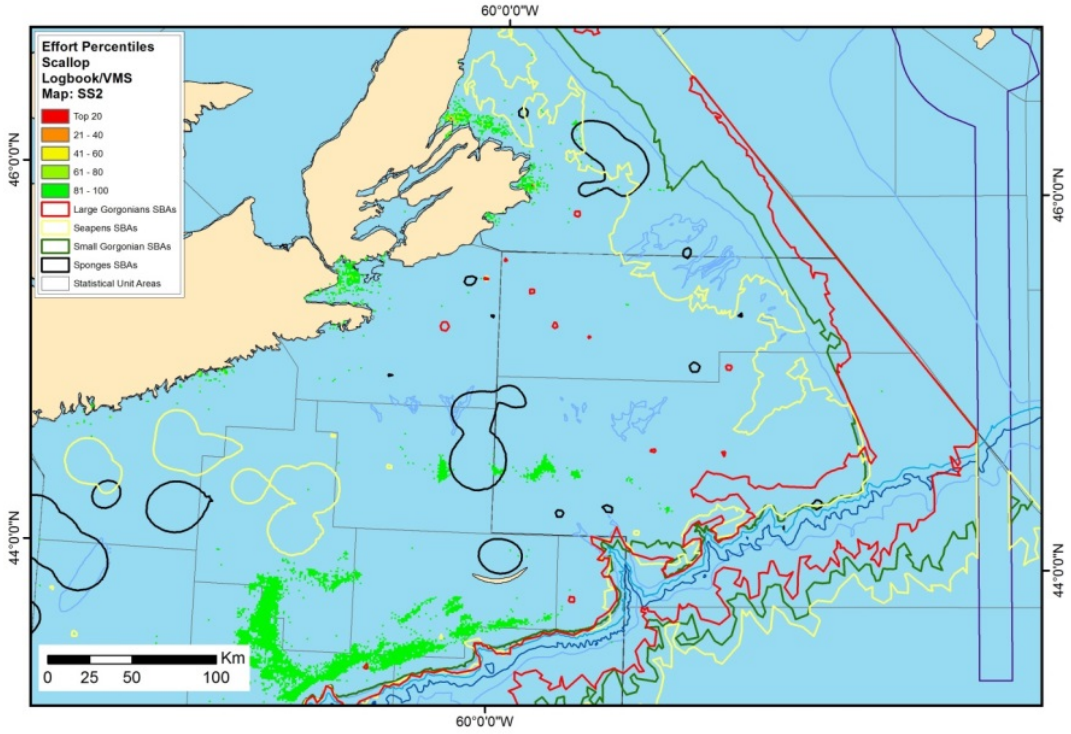

Figure A3 - 28. Scallop, inset SS2.

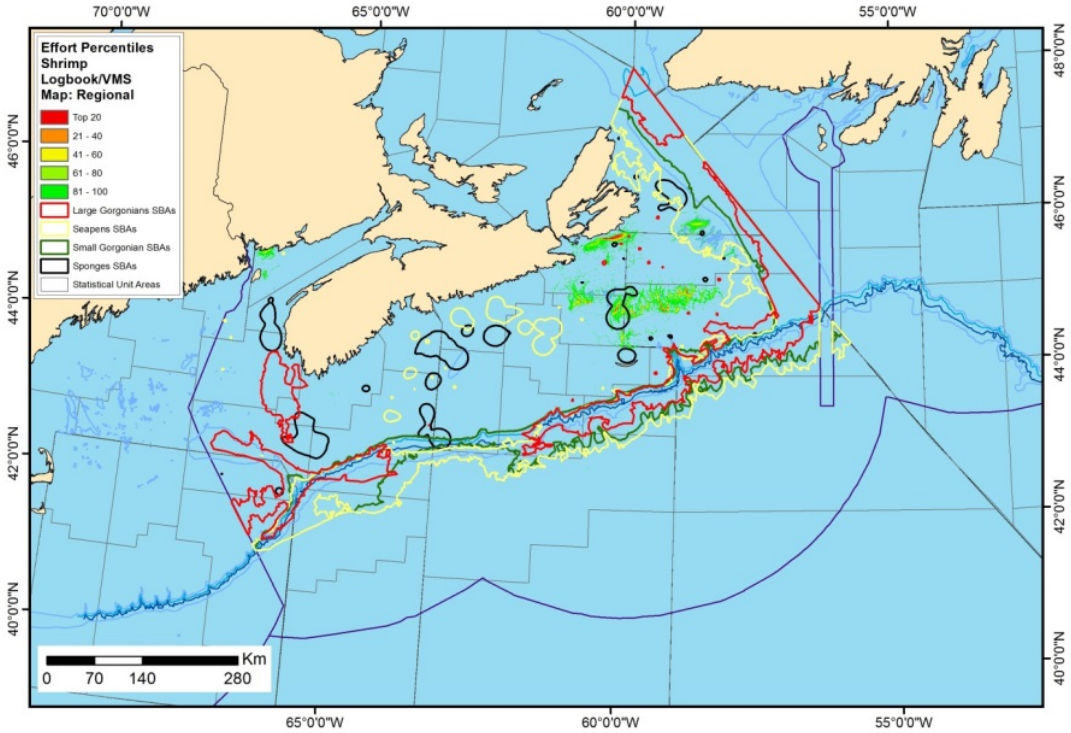

Figure A3 - 29. Shrimp, regional map.

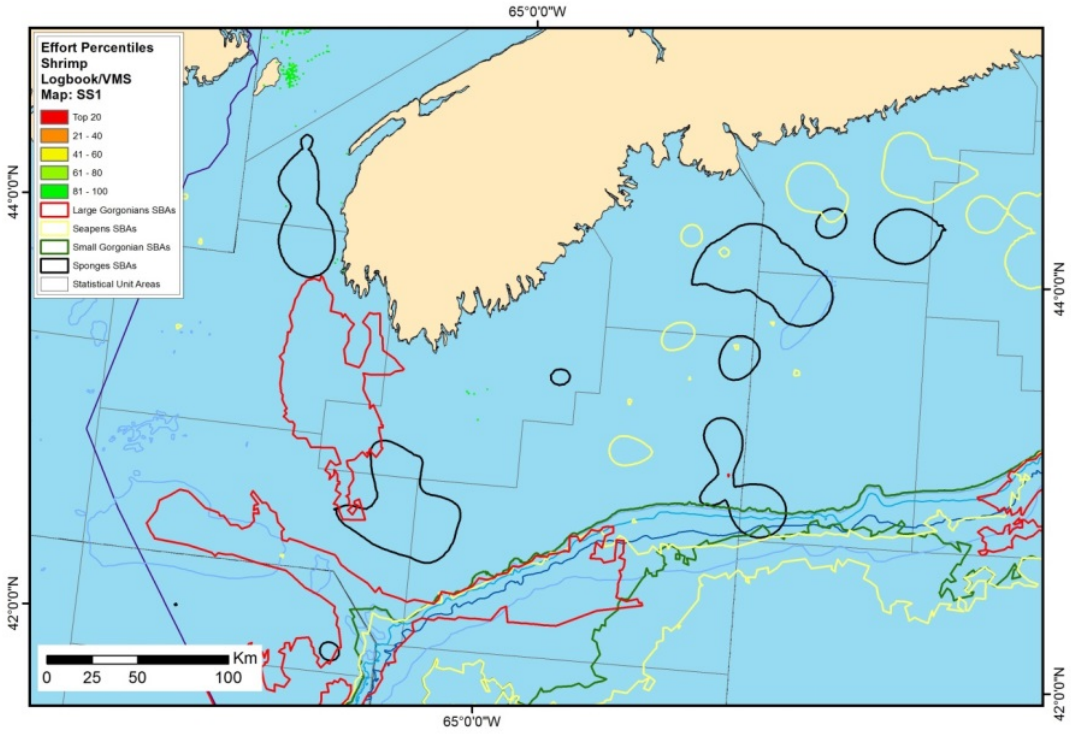

Figure A3 - 30. Shrimp, inset SS1.

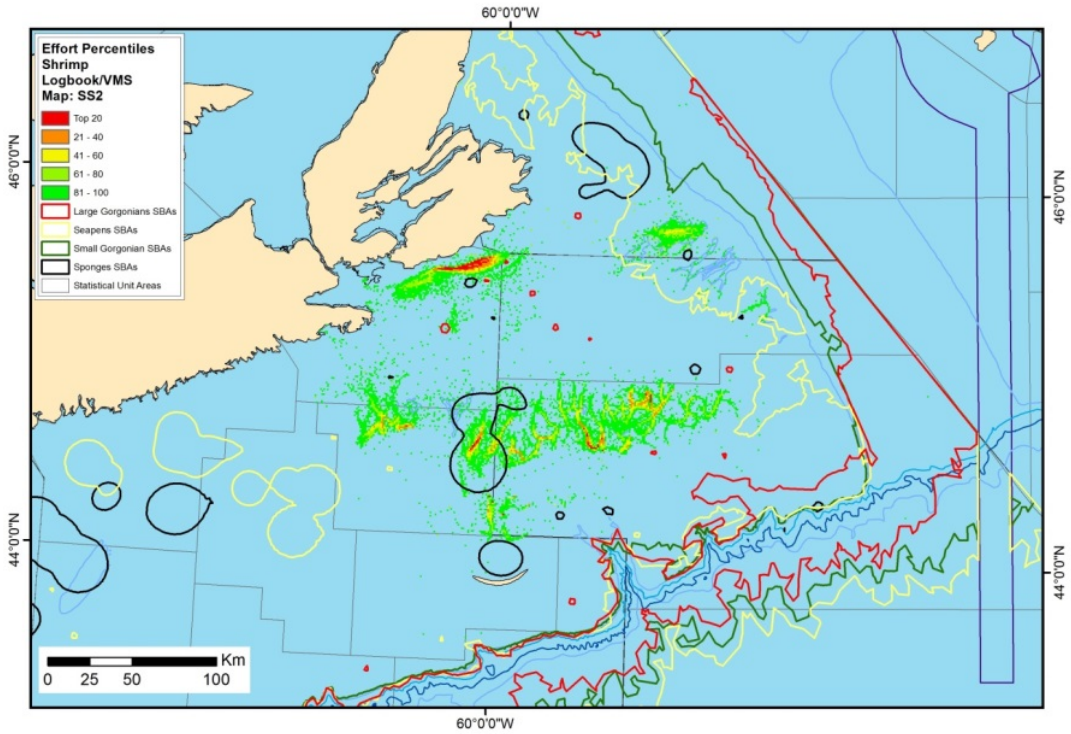

Figure A3 - 31. Shrimp, inset SS2.

GULF OF ST. LAWRENCE (GSL)

In the Gulf of St. Lawrence, there are two types of Significant Benthic Areas: sponge and sea pen. The first map within this section shows the Significant Benthic Areas without any fishing effort, followed by fisheries class-specific maps for the following fisheries classes in the Gulf of St. Lawrence bioregion:

- All fisheries combined
- Clam
- Crab inshore
- Crab offshore
- Echinoderm
- Groundfish fixed
- Groundfish mobile
- Miscellaneous inshore
- Other
- Pelagic
- Scallop
- Shrimp
- Whelk

Due to either privacy regulations or data deficiency, maps are not displayed for the following fisheries classes: lobster and miscellaneous offshore.

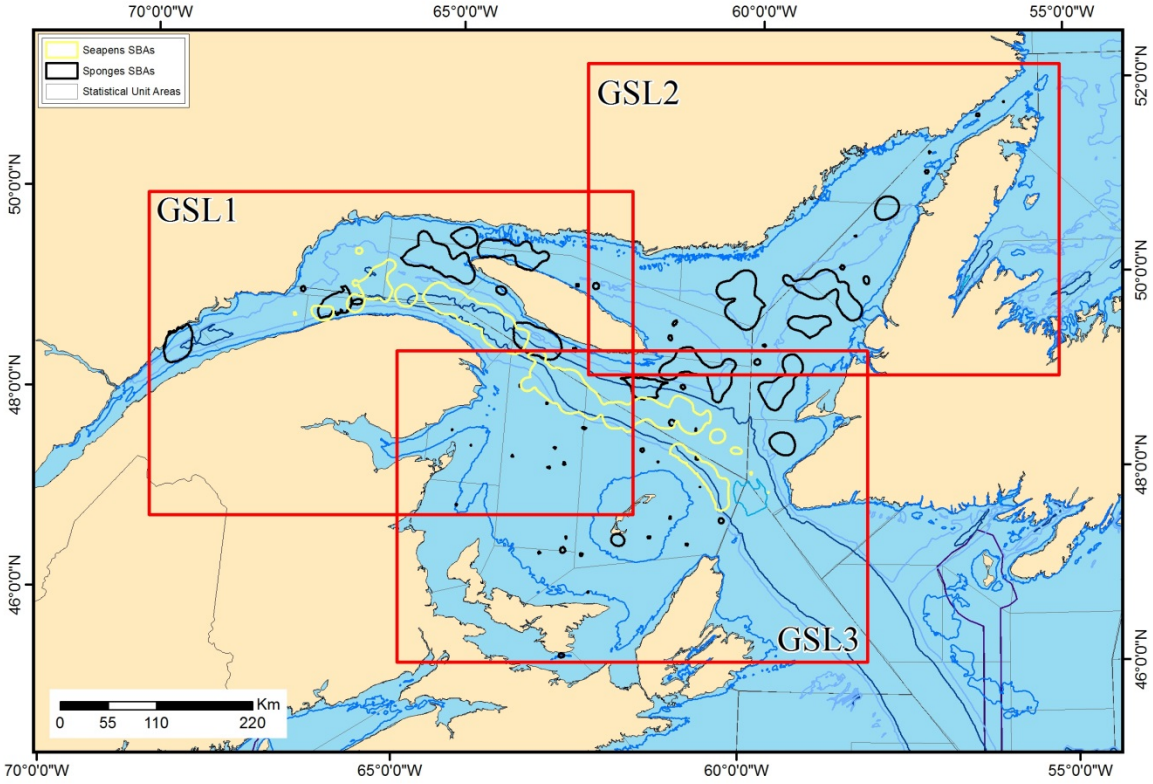

Figure A3 - 32. Inset Index.

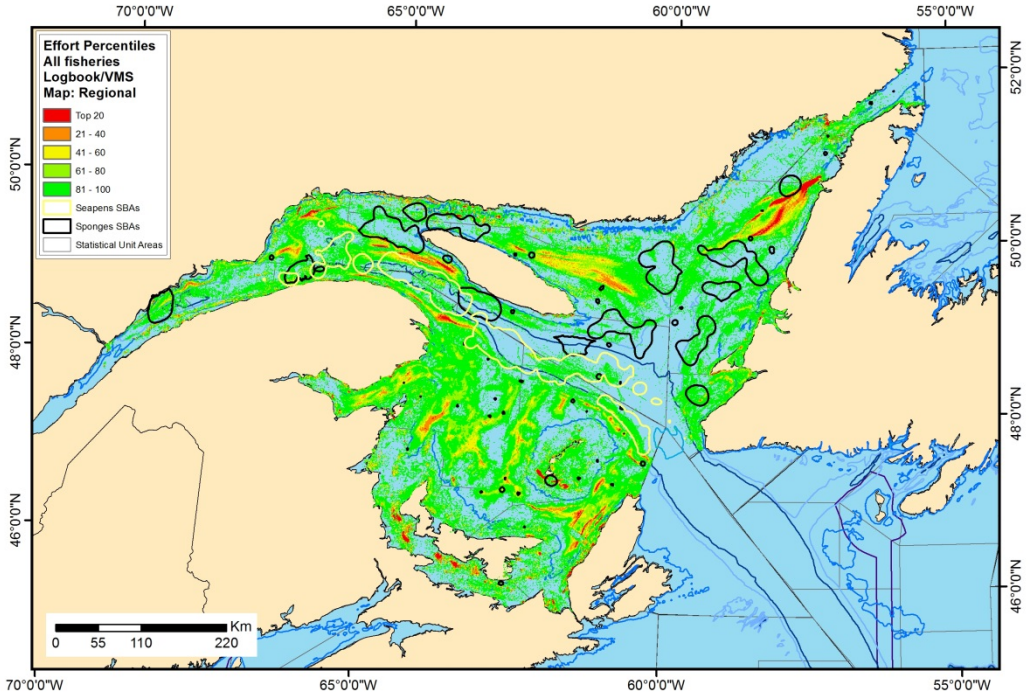

Figure A3 - 33. All fisheries, regional map.

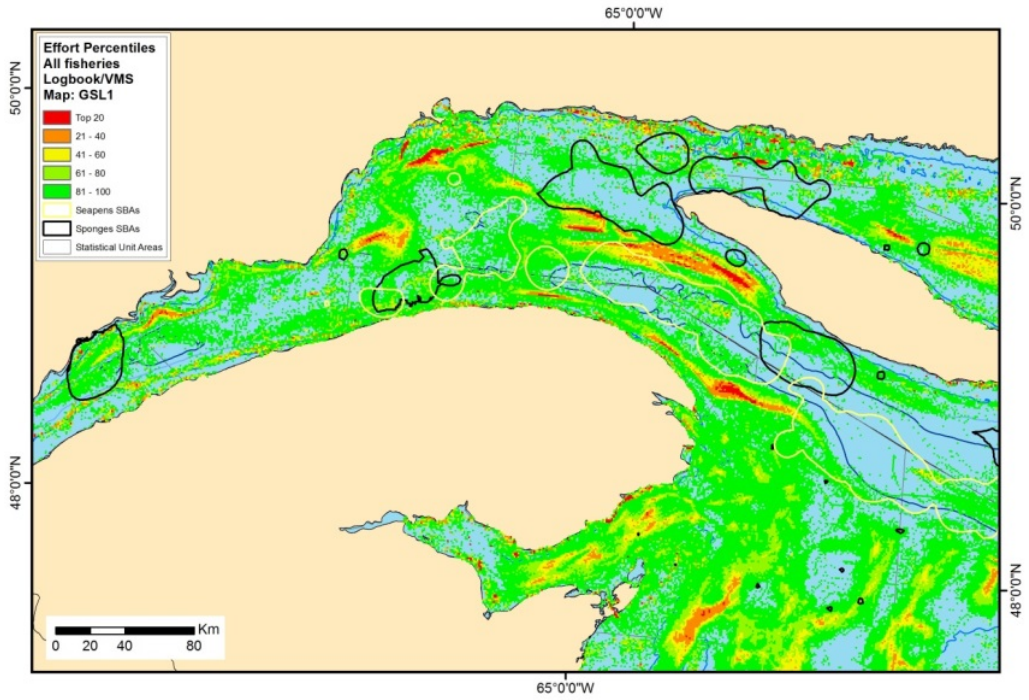

Figure A3 - 34. All fisheries, inset GSL1.

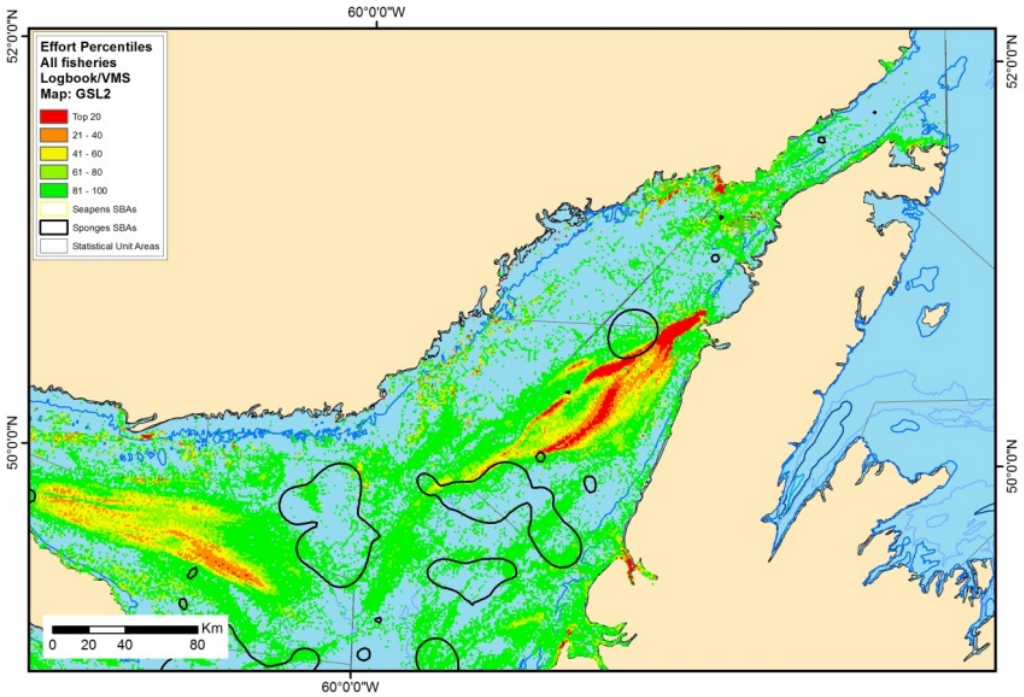

Figure A3 - 35. All fisheries, inset GSL2.

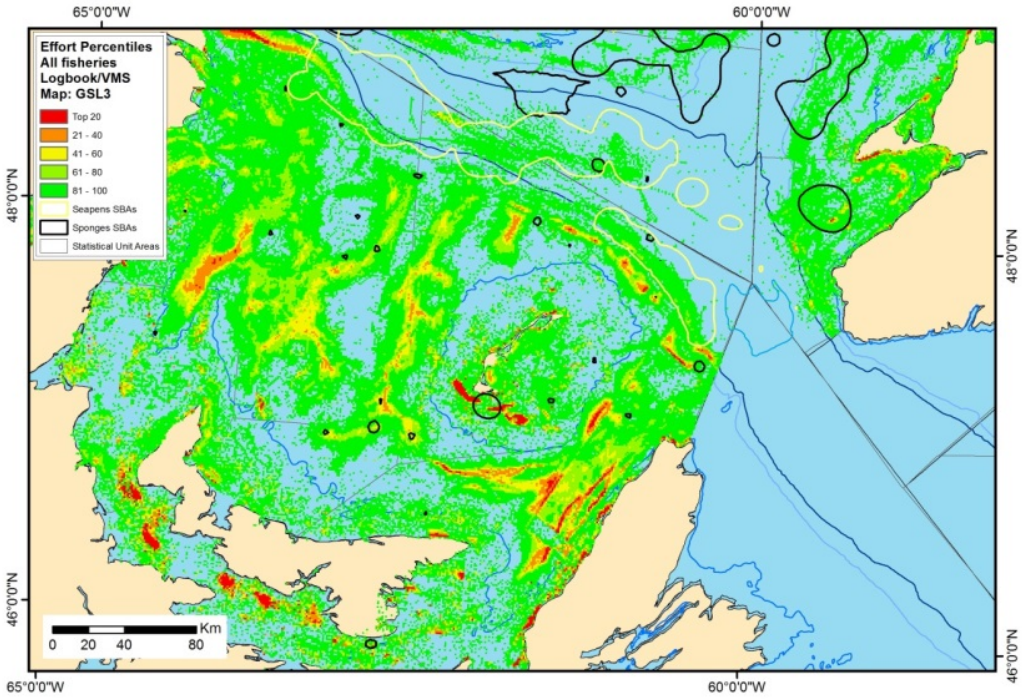

Figure A3 - 36. All fisheries, inset GSL3.

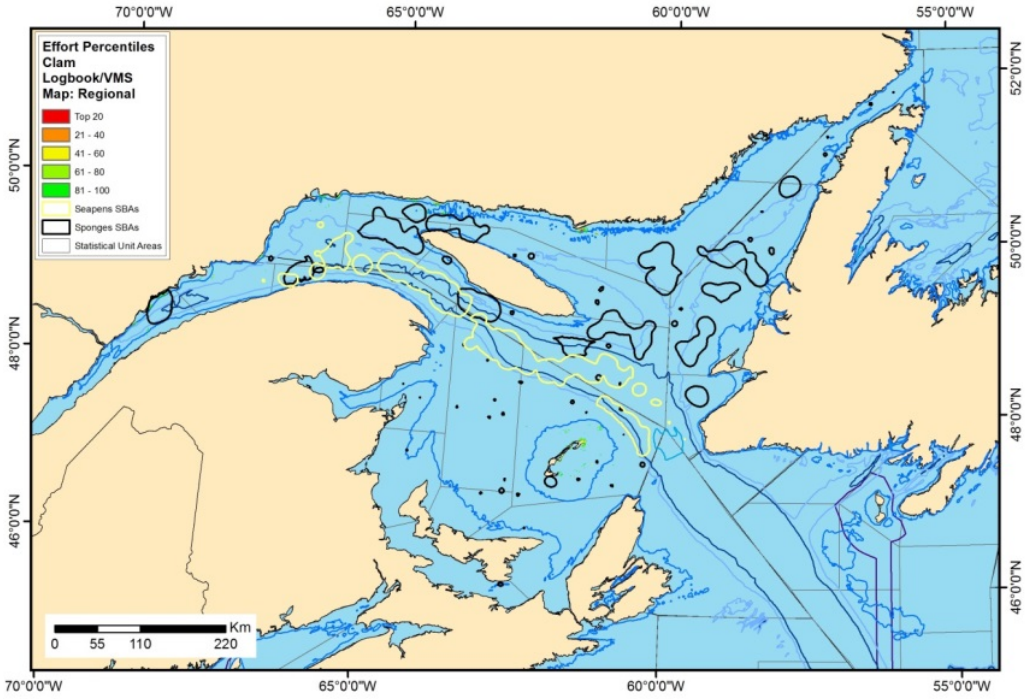

Figure A3 - 37. Clam, regional map.

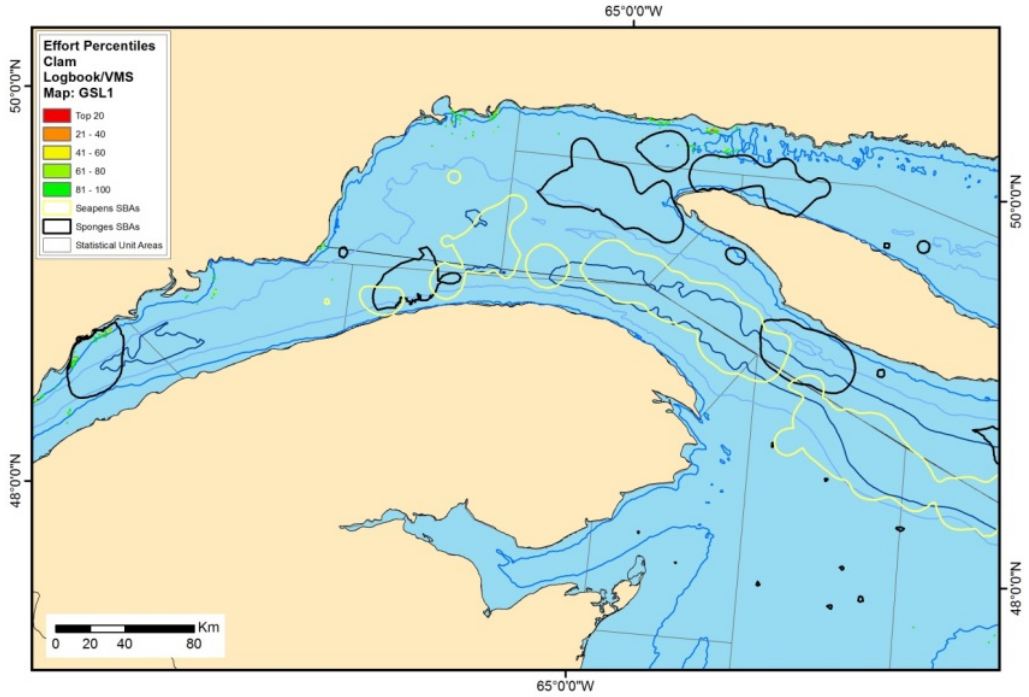

Figure A3 - 38. Clam, inset GSL1.

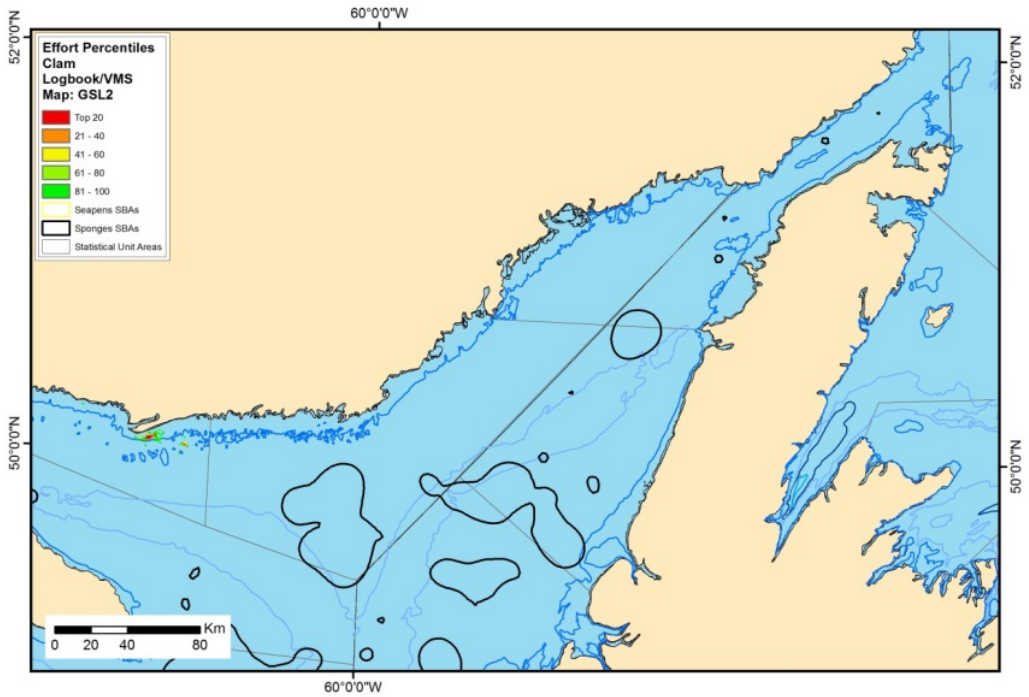

Figure A3 - 39. Clam, inset GSL2.

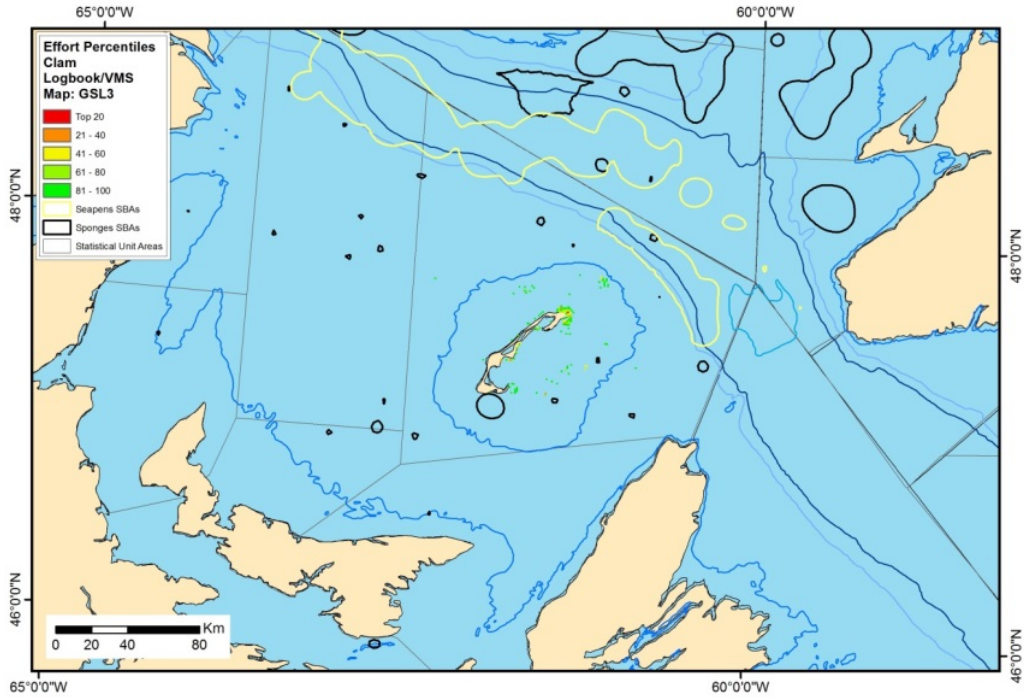

Figure A3 - 40. Clam, inset GSL3.

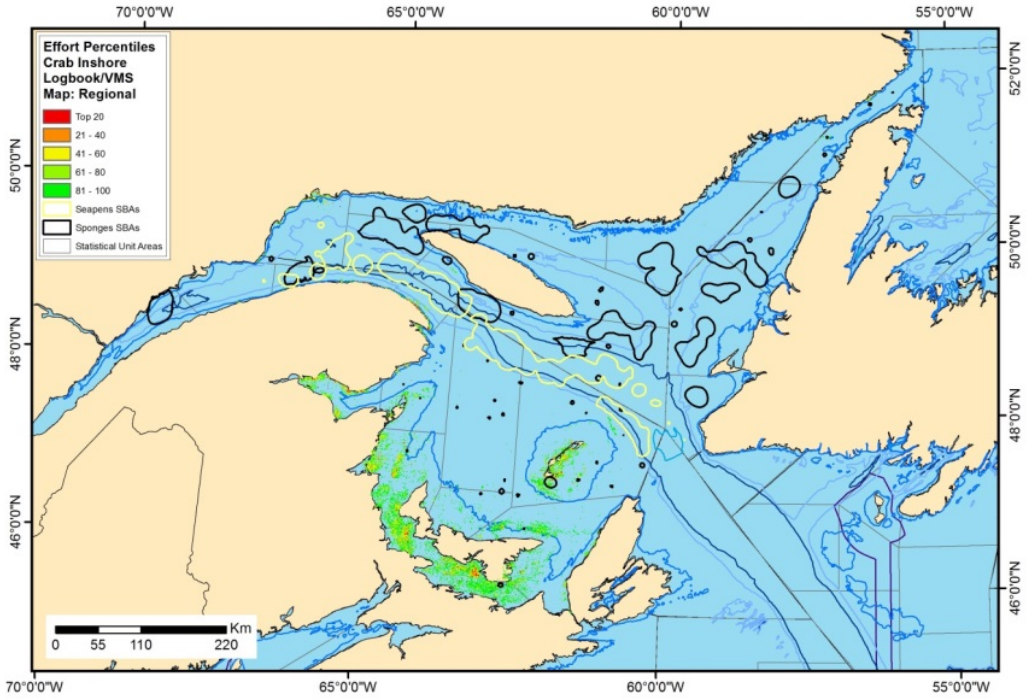

Figure A3 - 41. Crab Inshore, regional map.

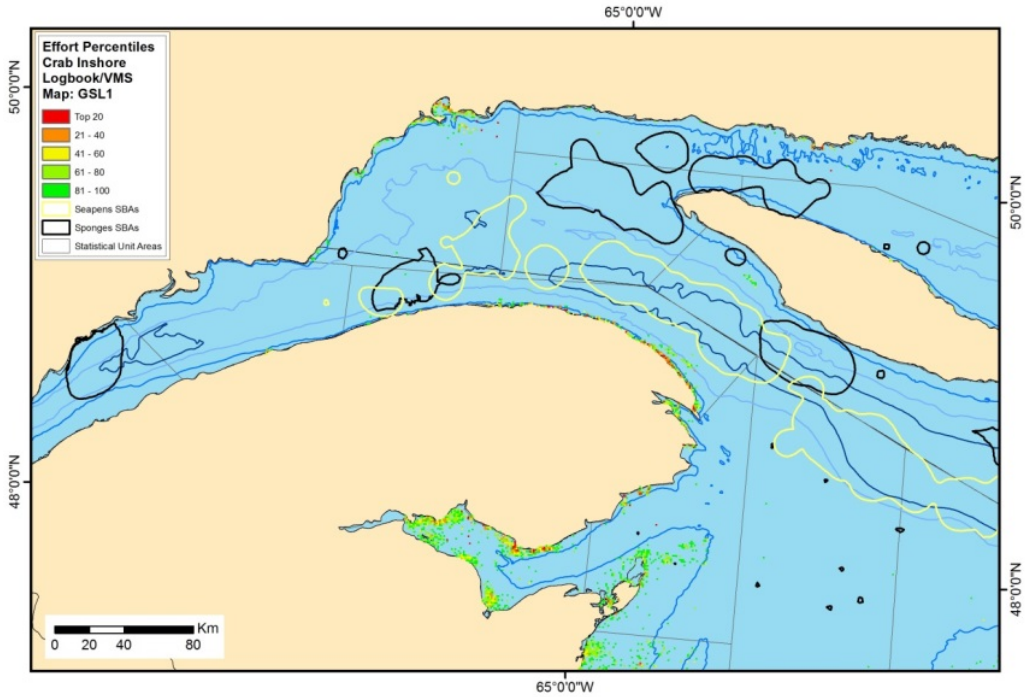

Figure A3 - 42. Crab Inshore, inset GSL1.

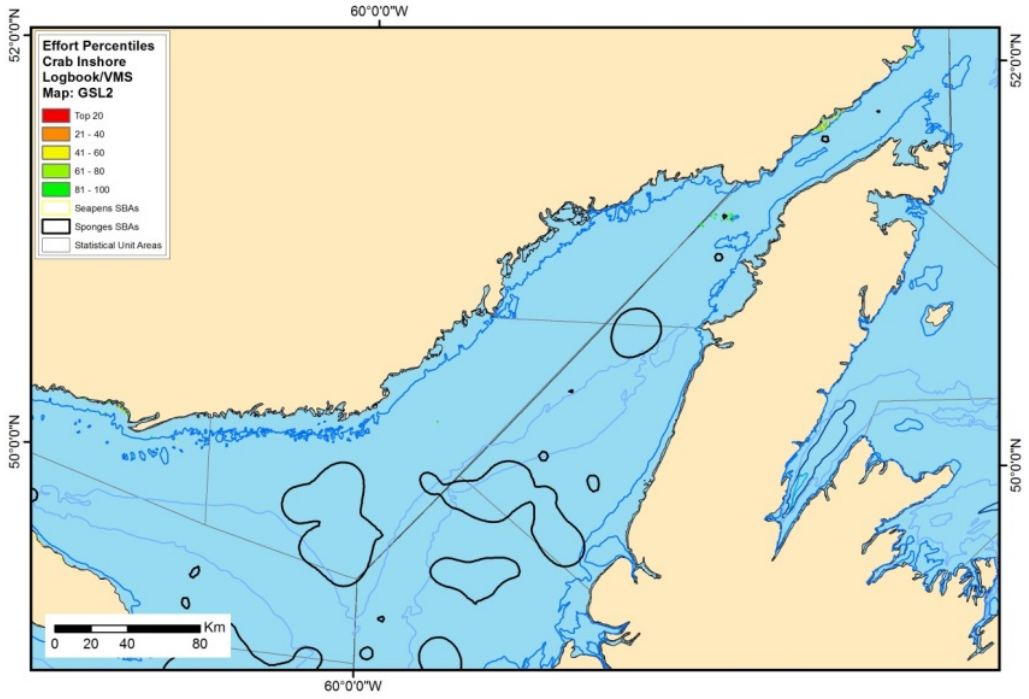

Figure A3 - 43. Crab Inshore, inset GSL2.

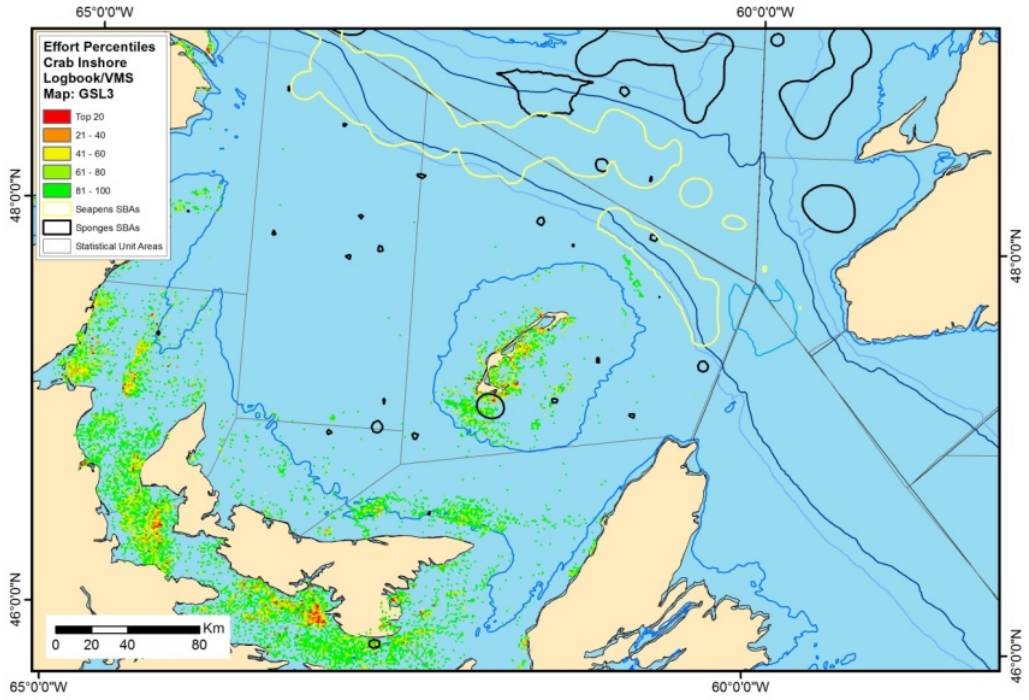

Figure A3 - 44. Crab Inshore, inset GSL3.

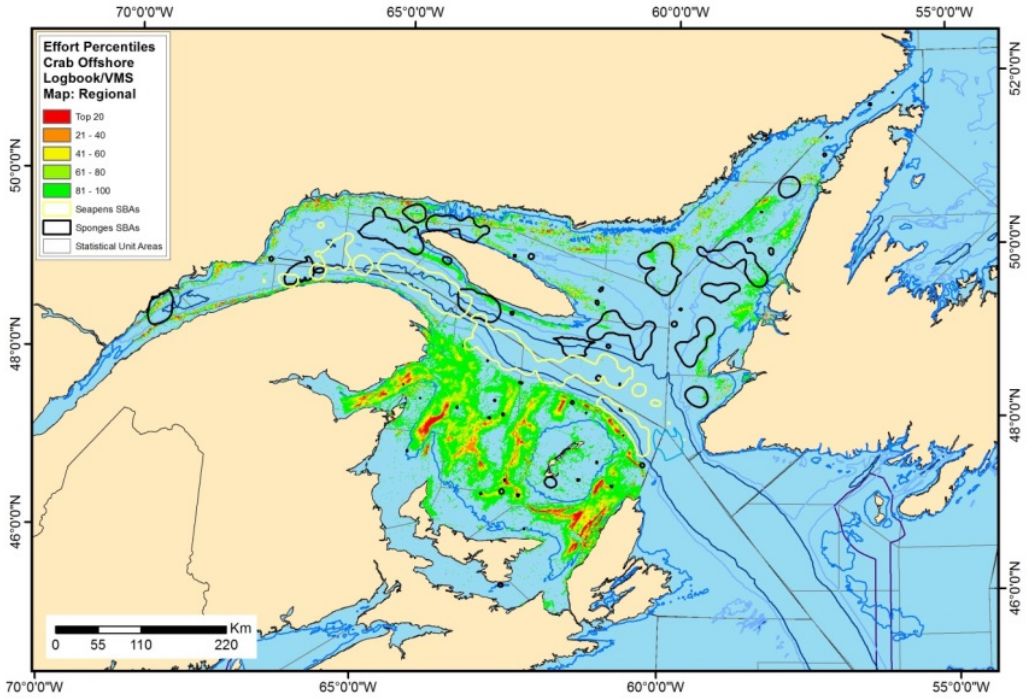

Figure A3 - 45. Crab Offshore, regional map.

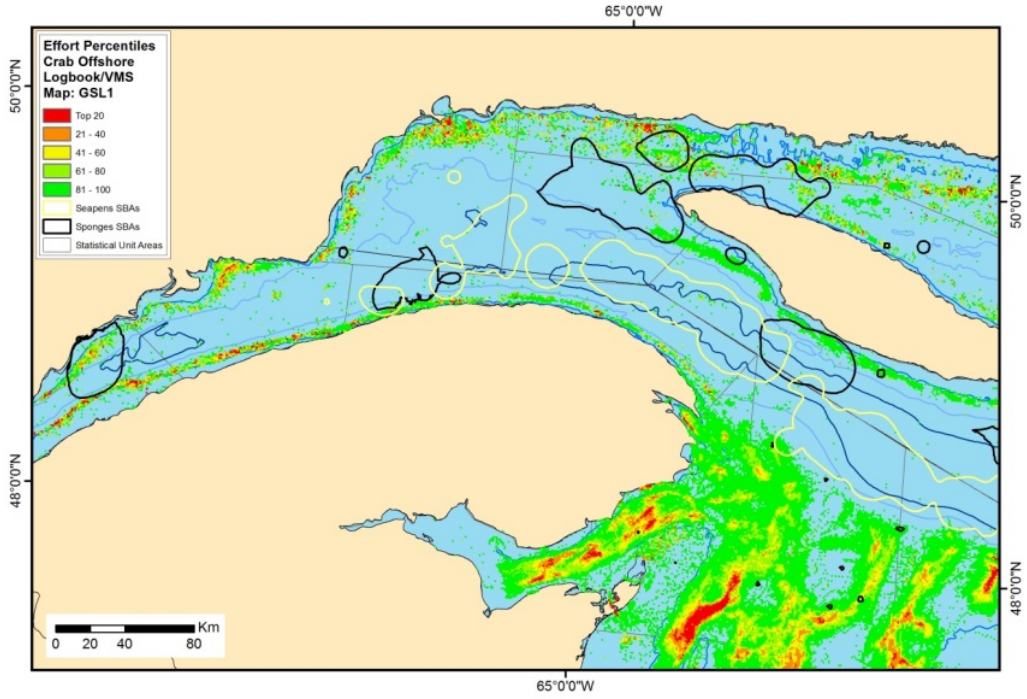

Figure A3 - 46. Crab Offshore inset GSL1.

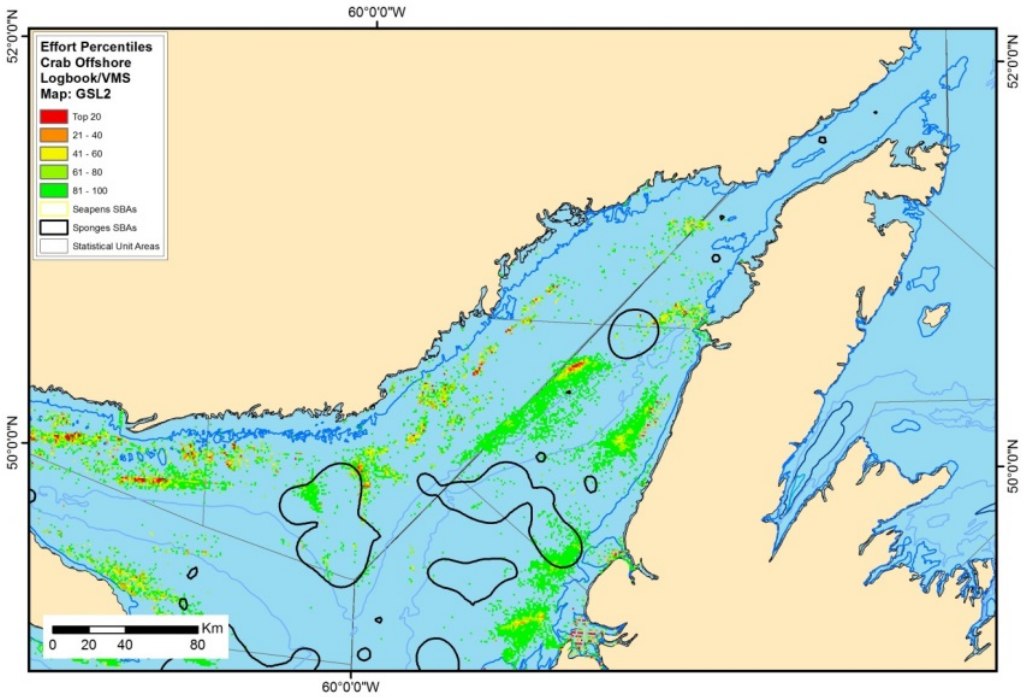

Figure A3 - 47. Crab Offshore, inset GSL2.

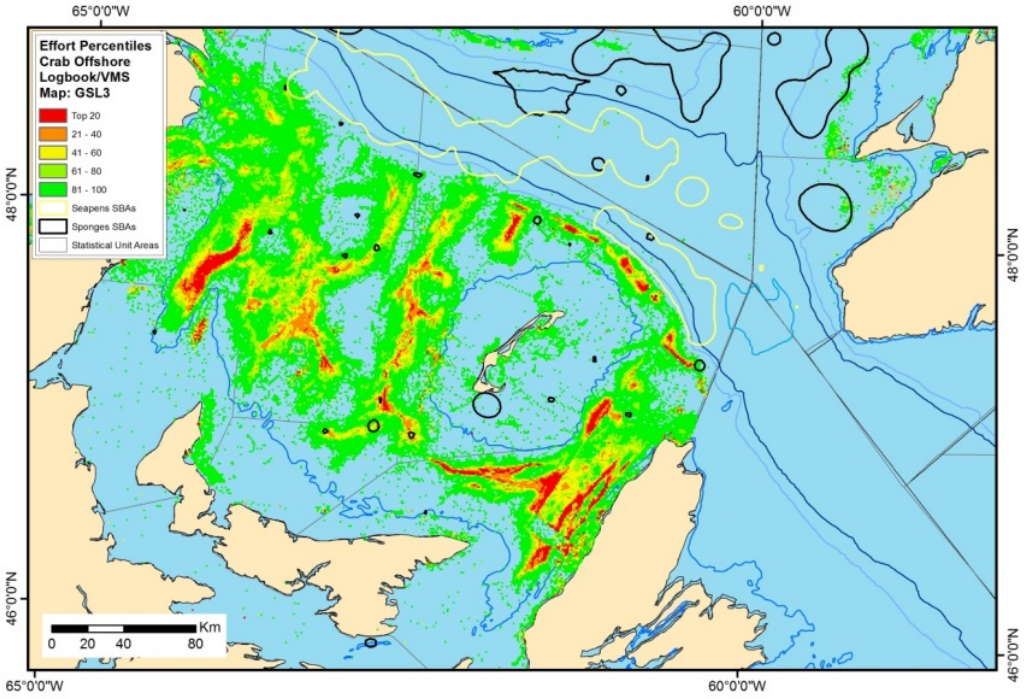

Figure A3 - 48. Crab Offshore, inset GSL3.

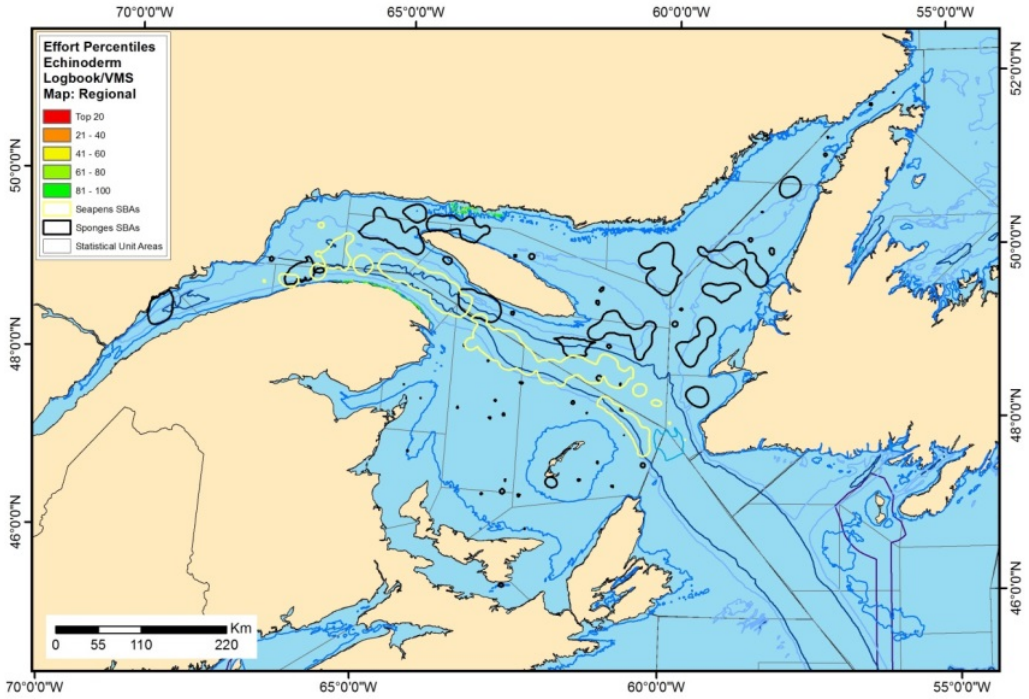

Figure A3 - 49. Echinoderm, regional map.

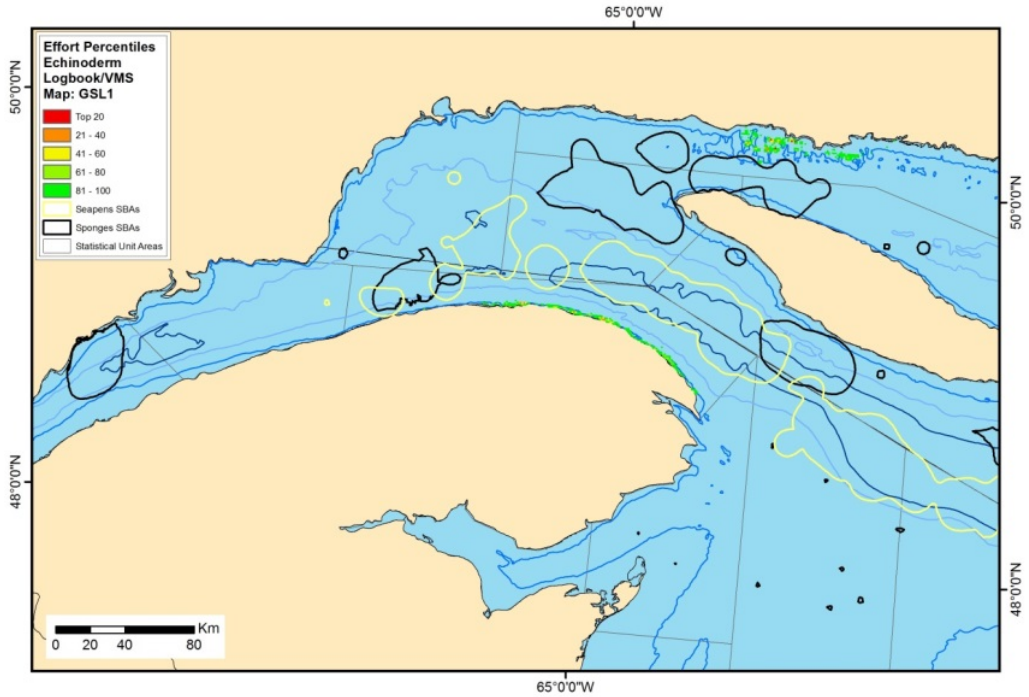

Figure A3 - 50. Echinoderm inset GSL1.

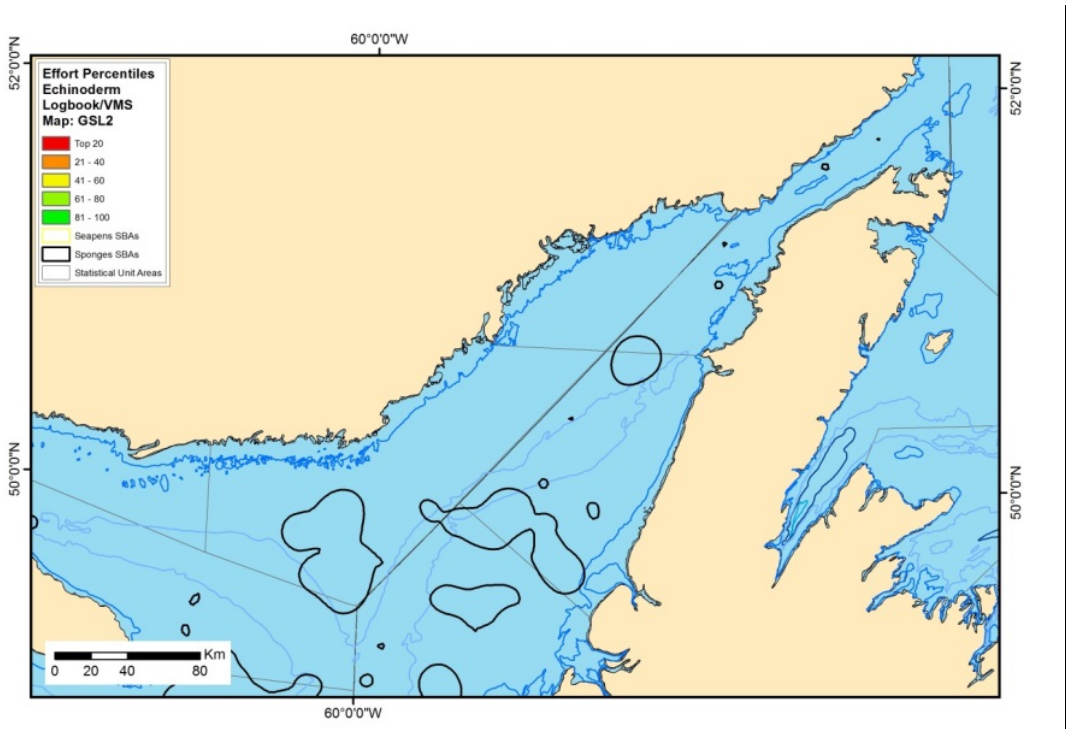

Figure A3 - 51. Echinoderm, inset GSL2.

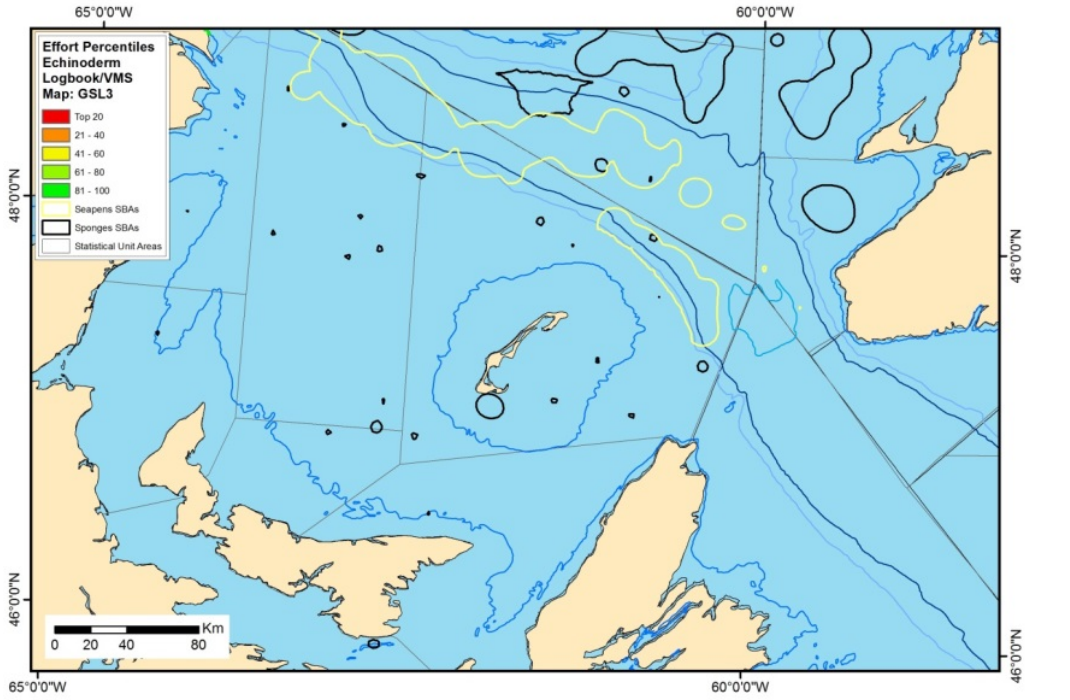

Figure A3 - 52. Echinoderm, inset GSL3.

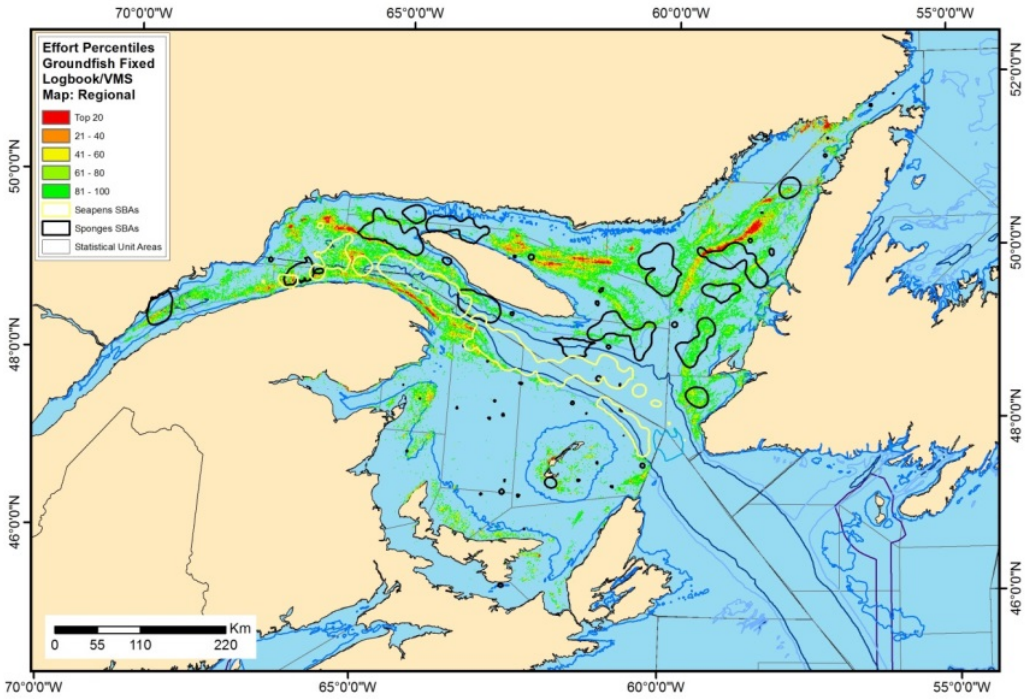

Figure A3 - 53. Groundfish Fixed, regional map.

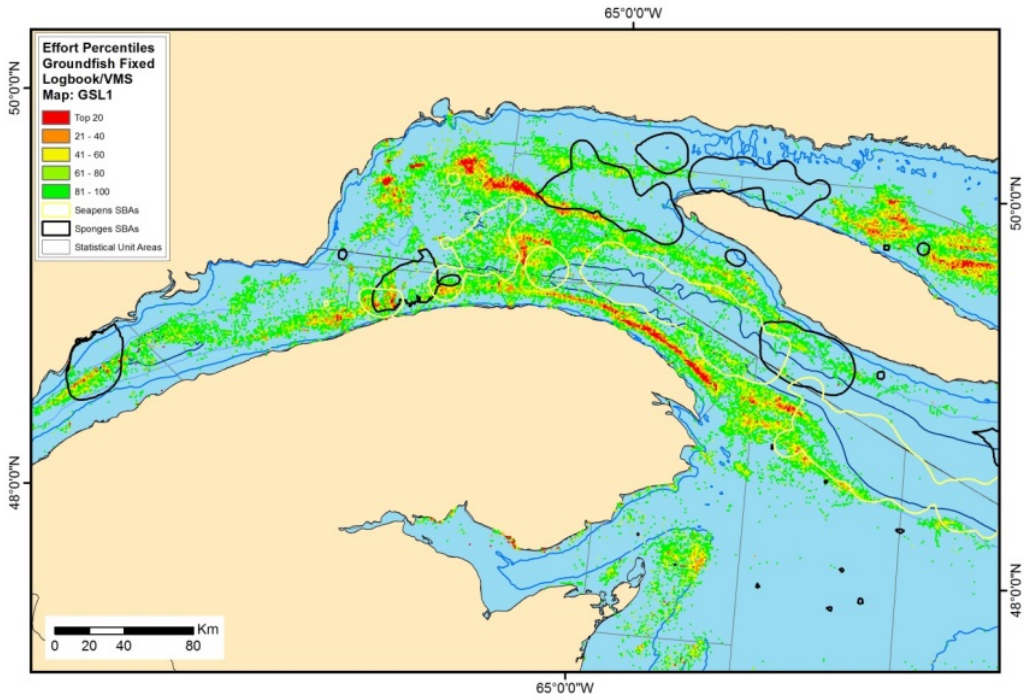

Figure A3 - 54. Groundfish Fixed, inset GSL1.

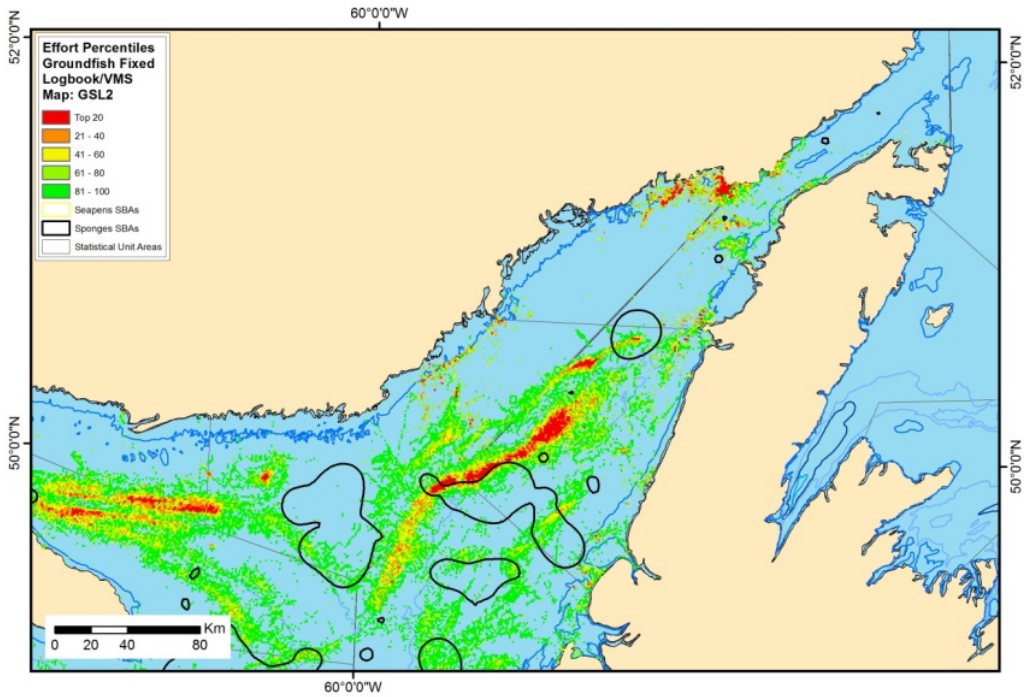

Figure A3 - 55. Groundfish Fixed, inset GSL2.

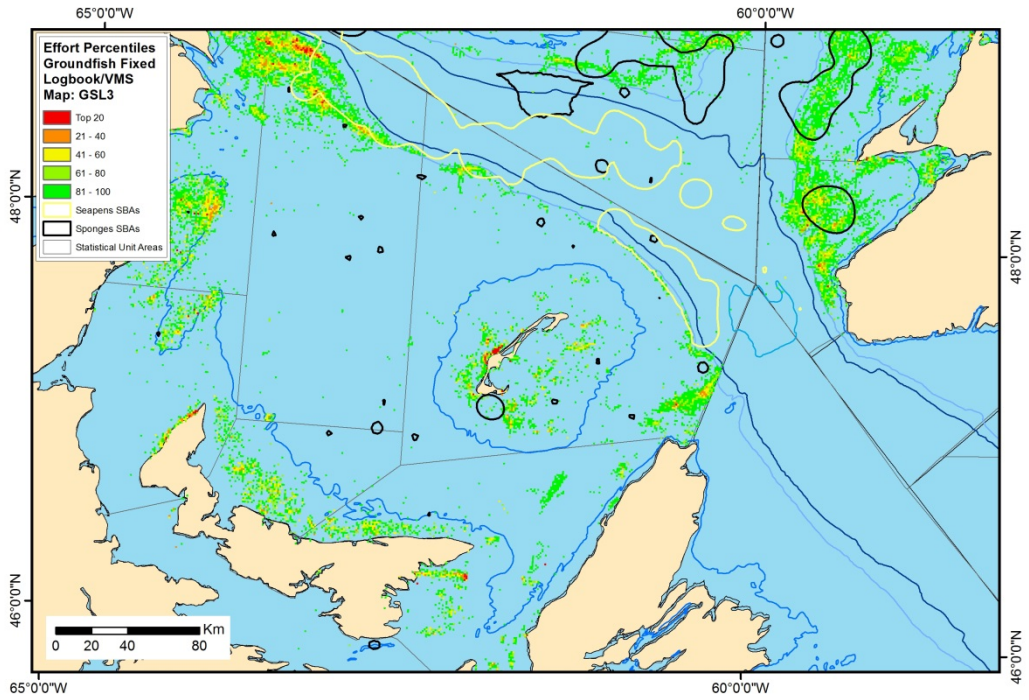

Figure A3 - 56. Groundfish Fixed, inset GSL3.

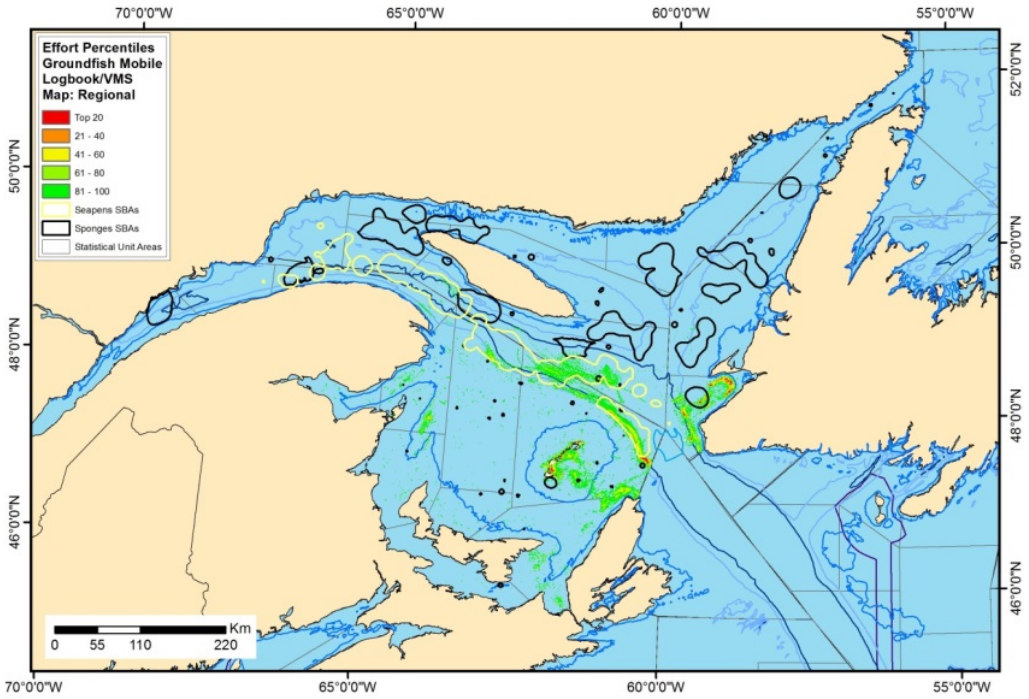

Figure A3 - 57. Groundfish Mobile, regional map.

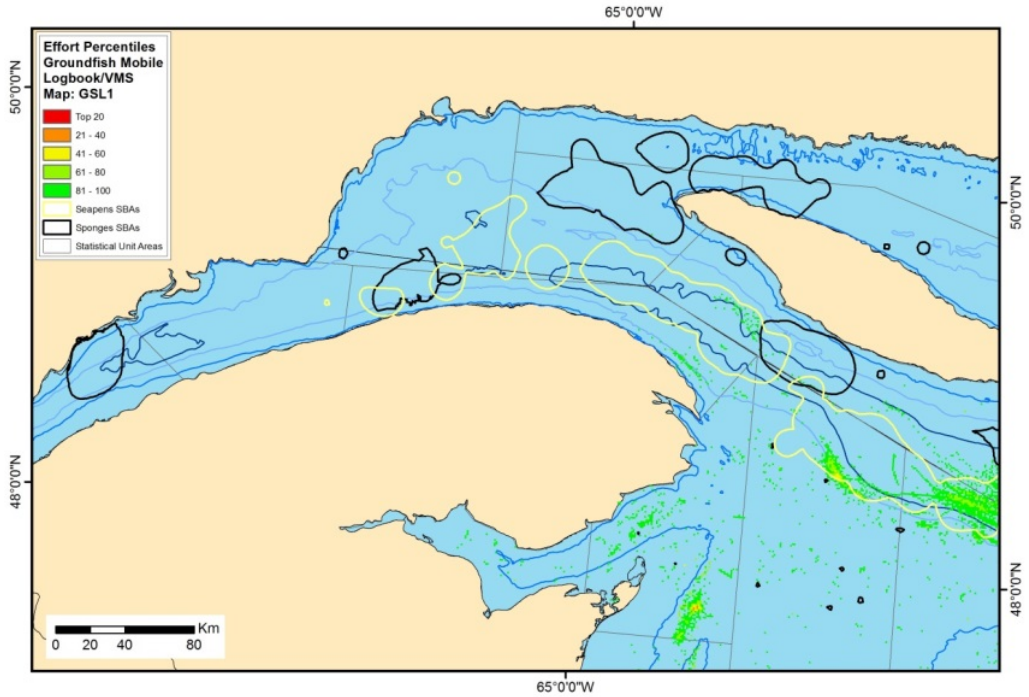

Figure A3 - 58. Groundfish Mobile, inset GSL1.

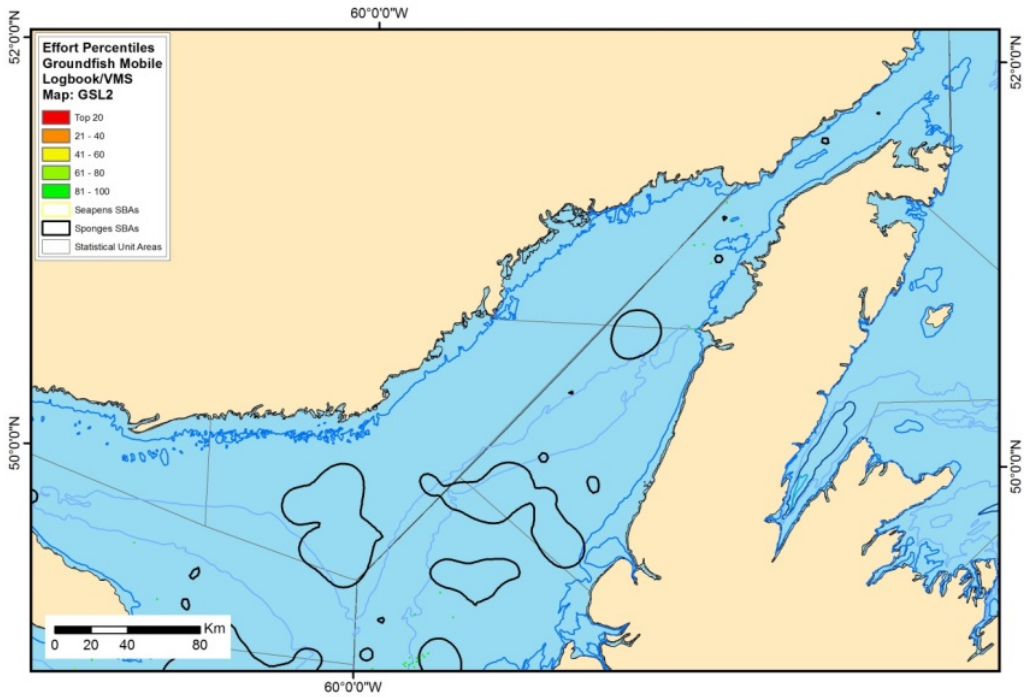

Figure A3 - 59. Groundfish Mobile, inset GSL2.

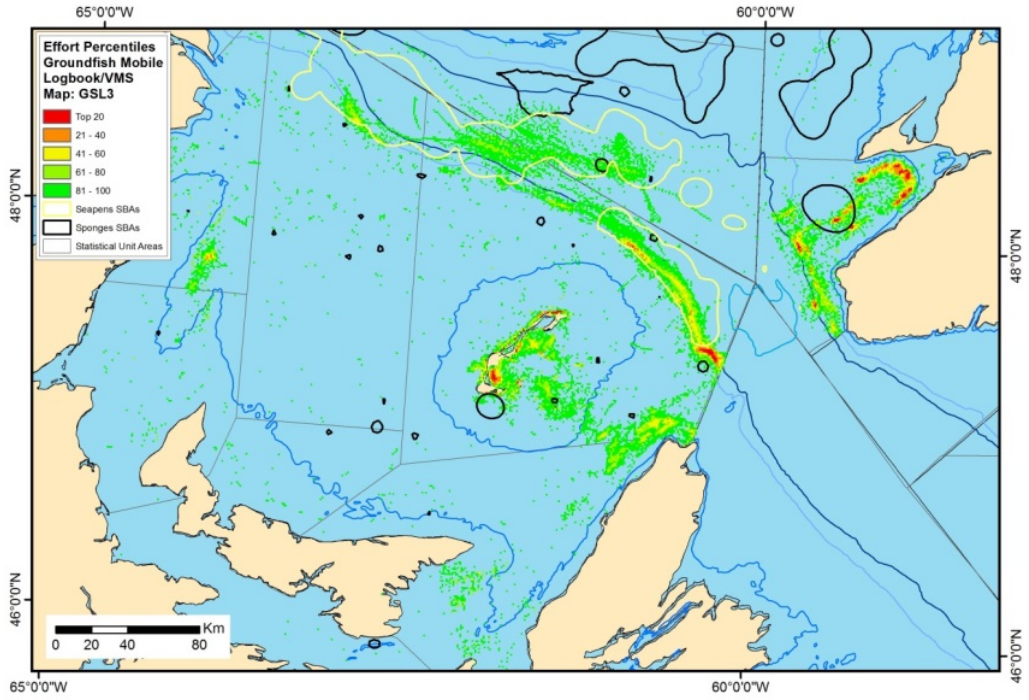

Figure A3 - 60. Groundfish Mobile, inset GSL3.

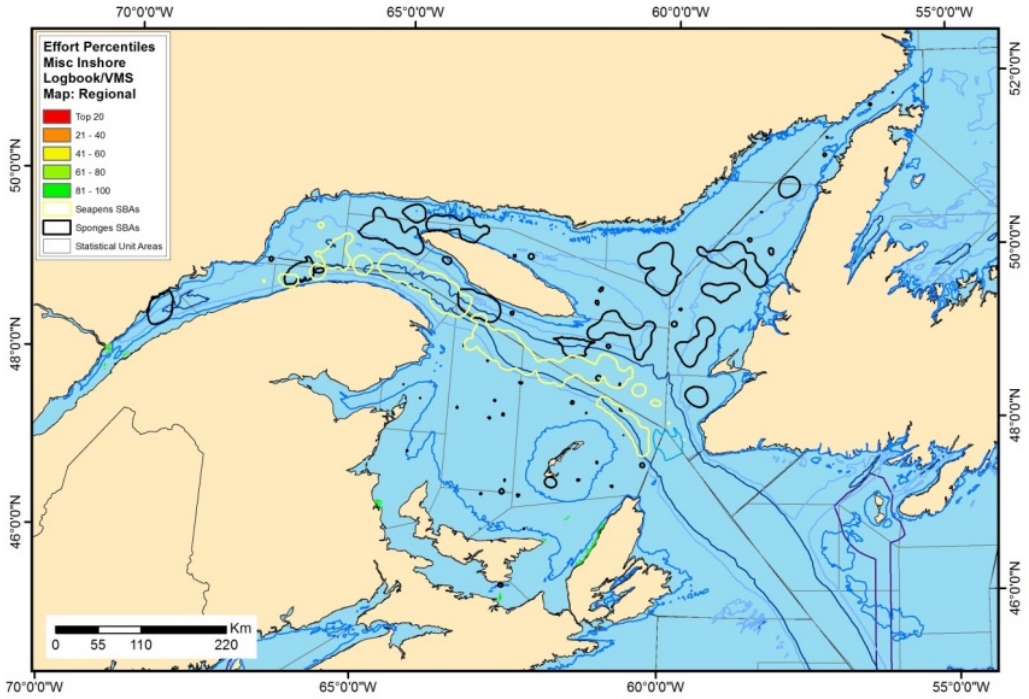

Figure A3 - 61. Miscellaneous Inshore, regional map.

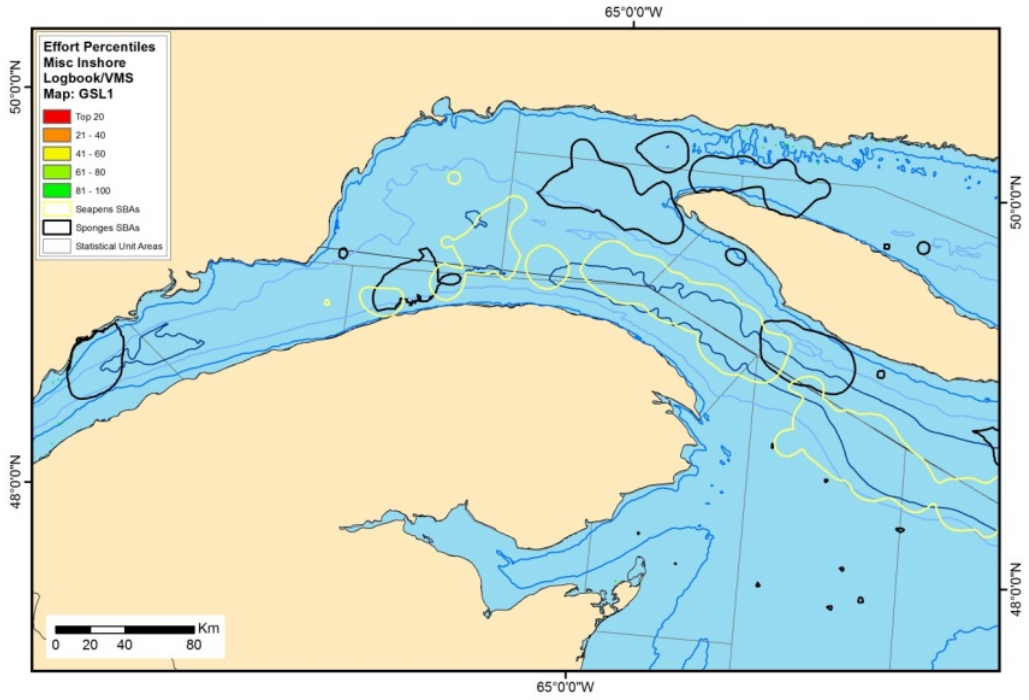

Figure A3 - 62. Miscellaneous Inshore, inset GSL1.

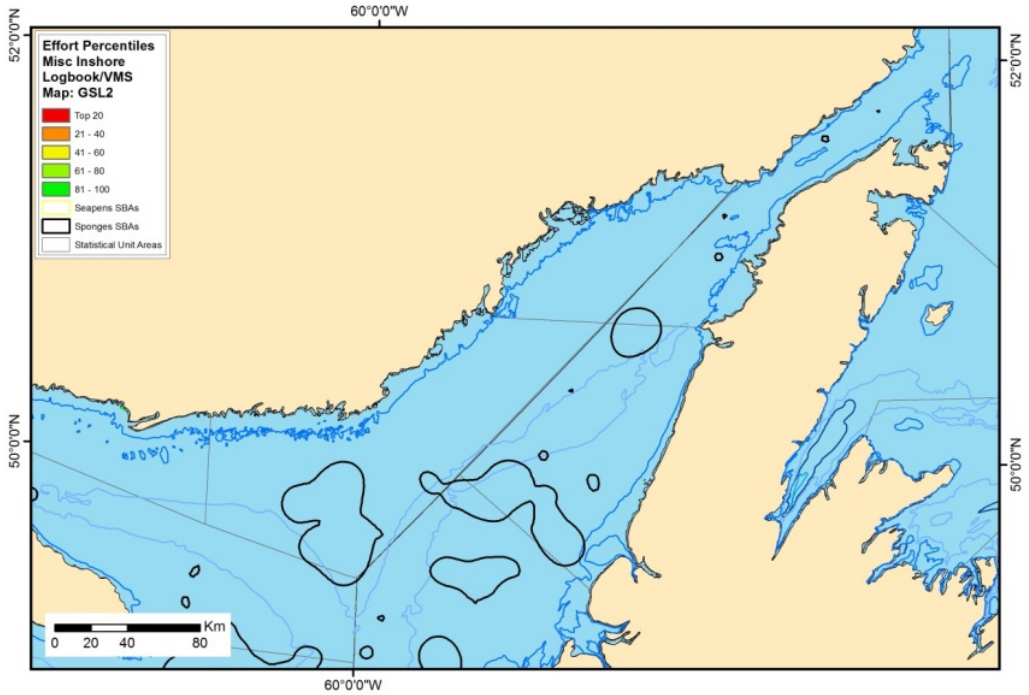

Figure A3 - 63. Miscellaneous Inshore, inset GSL2.

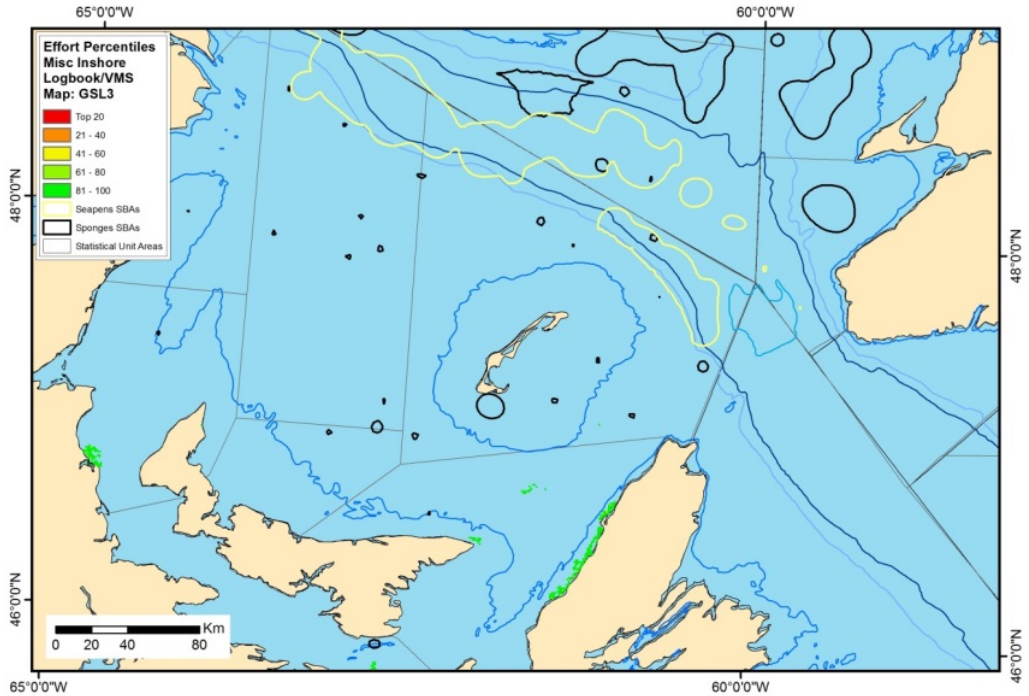

Figure A3 - 64. Miscellaneous Inshore, inset GSL3.

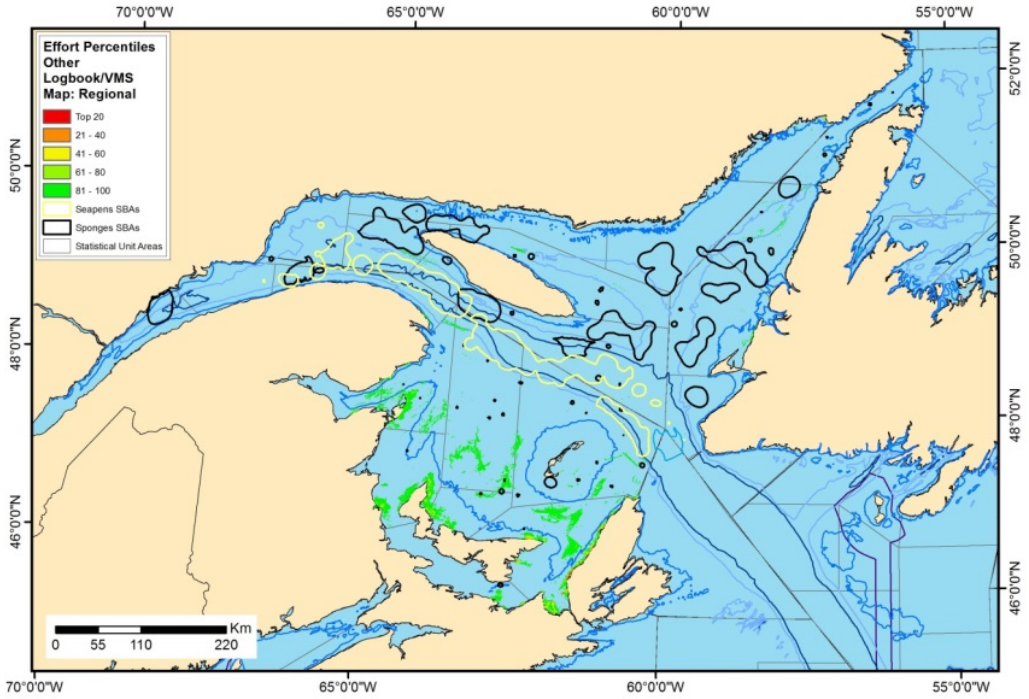

Figure A3 - 65. Other, regional map.

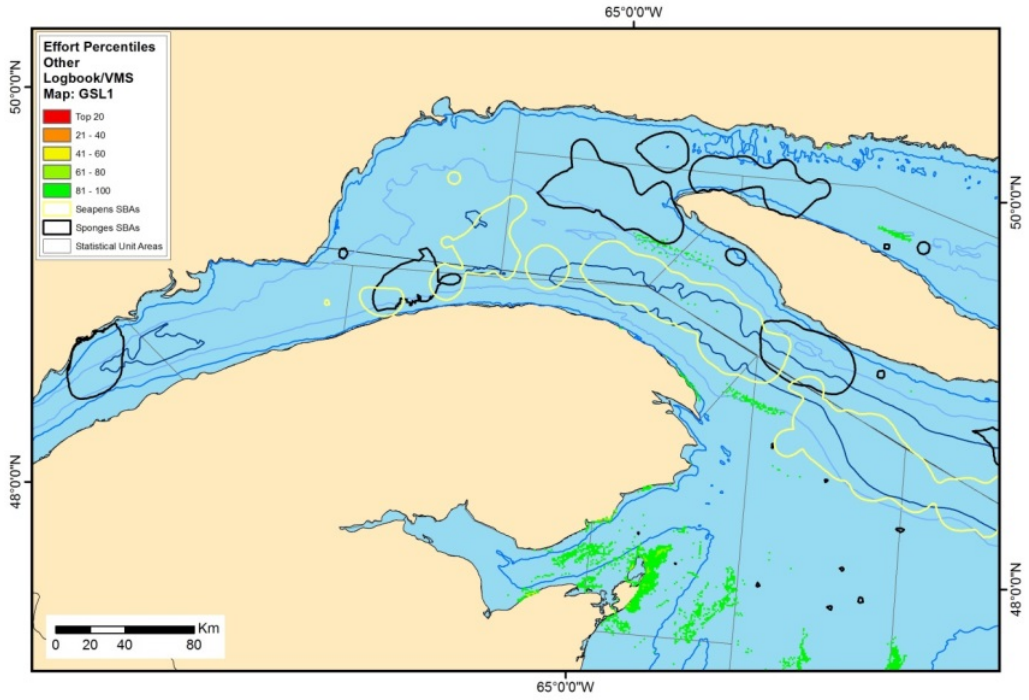

Figure A3 - 66. Other, inset GSL1.

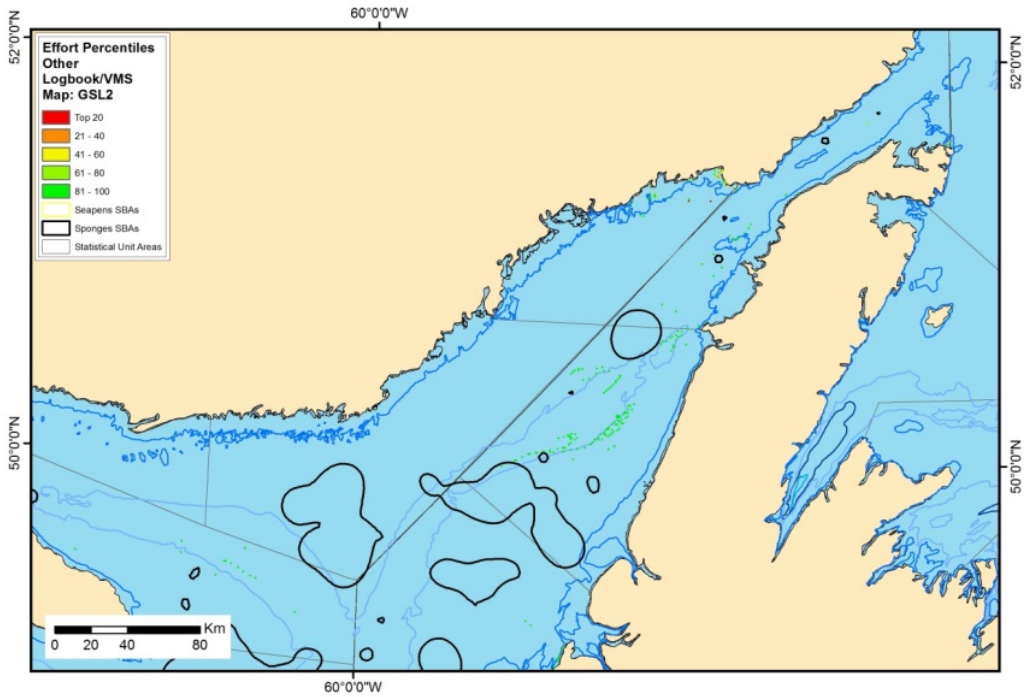

Figure A3 - 67. Other, inset GSL2.

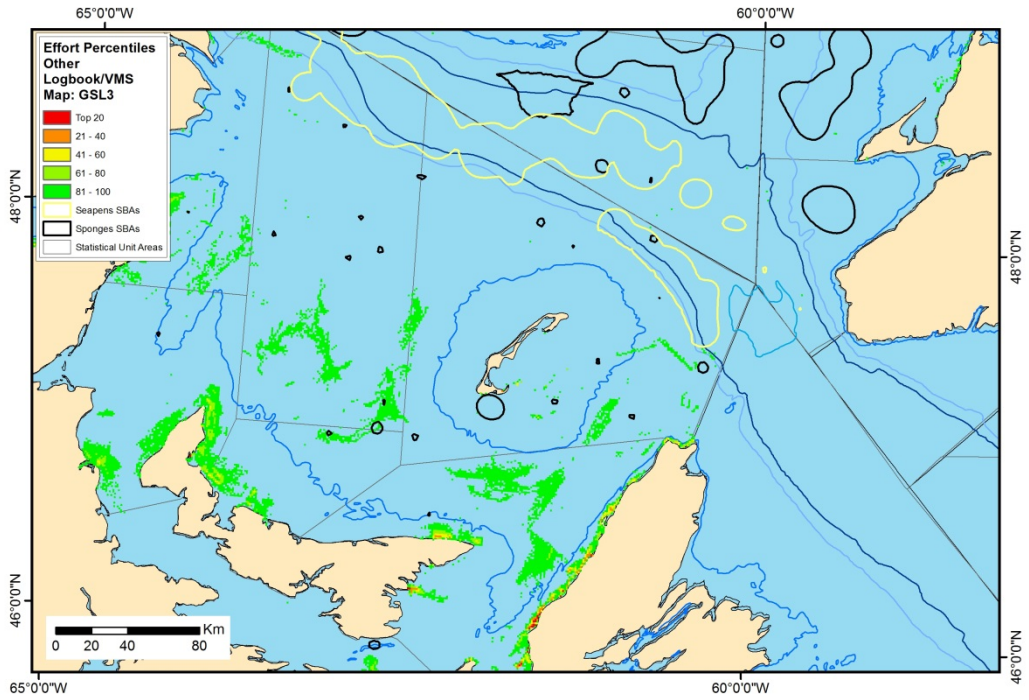

Figure A3 - 68. Other, inset GSL3.

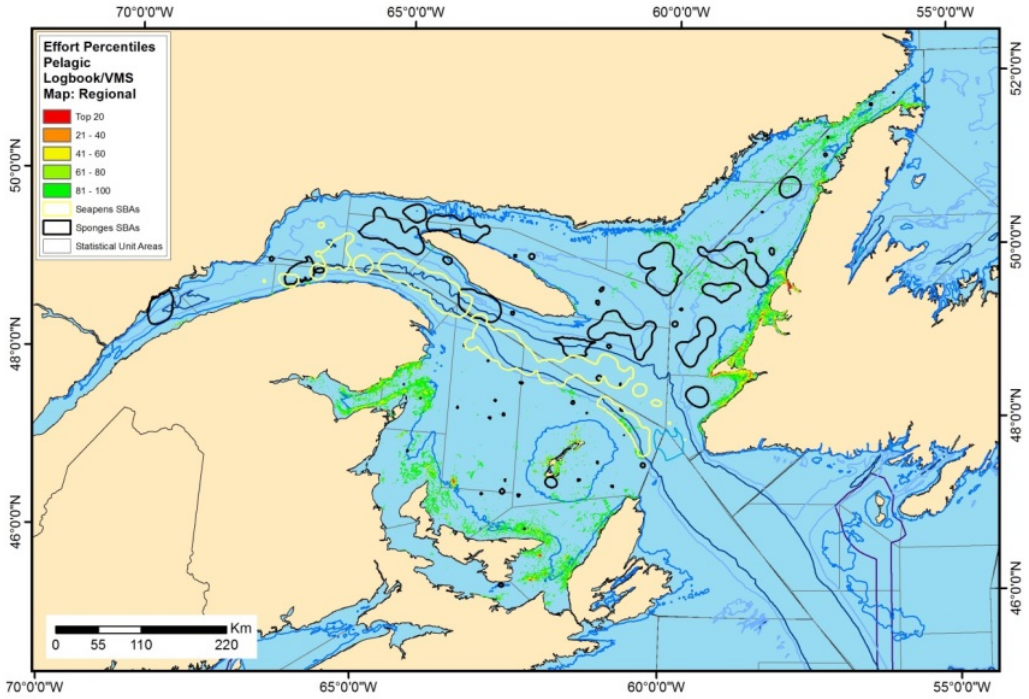

Figure A3 - 69. Pelagic, regional map.

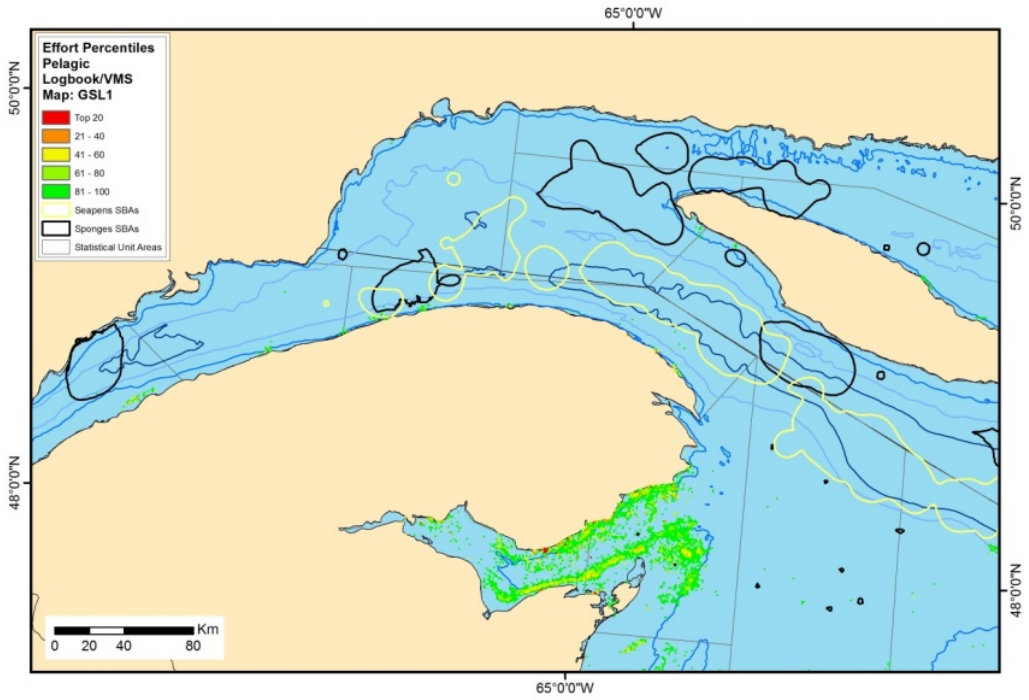

Figure A3 - 70. Pelagic, inset GSL1.

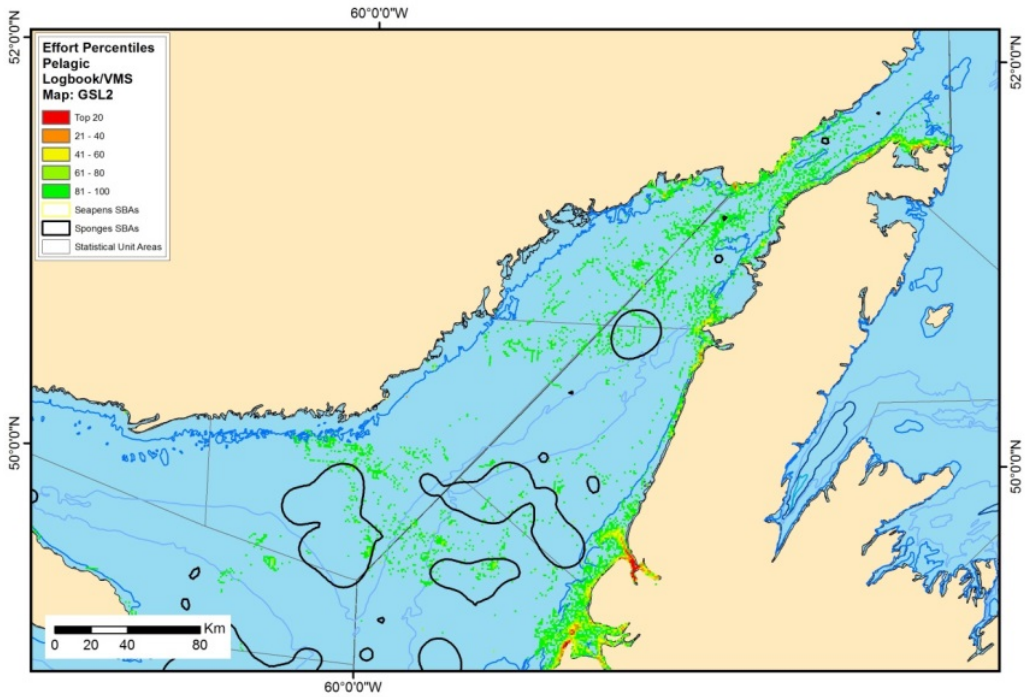

Figure A3 - 71. Pelagic, inset GSL2.

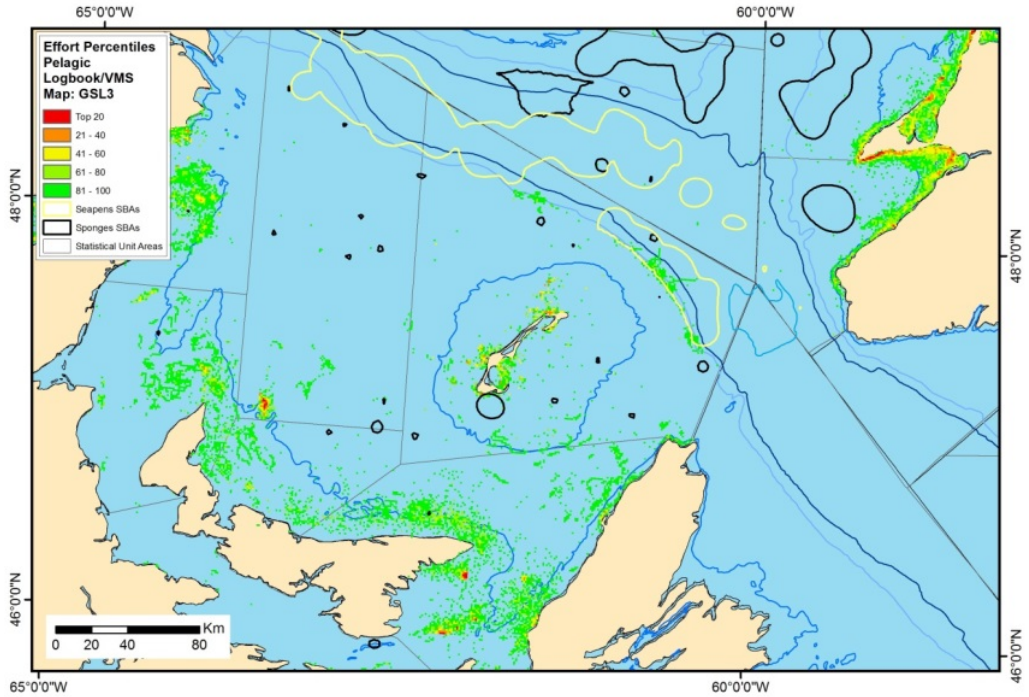

Figure A3 - 72. Pelagic, inset GSL3.

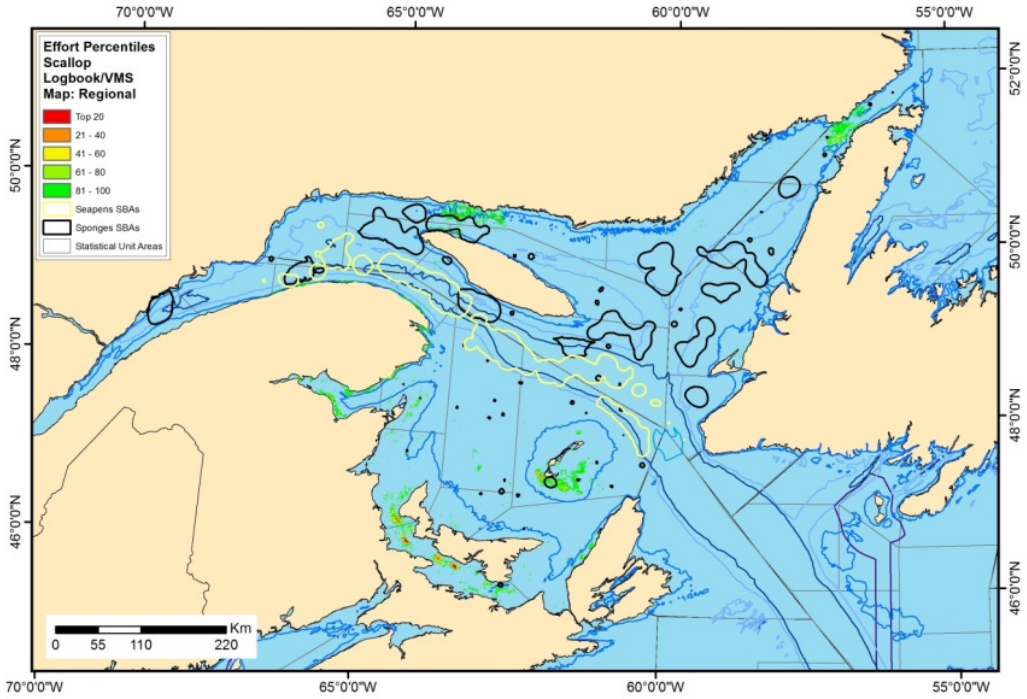

Figure A3 - 73. Scallop, regional map.

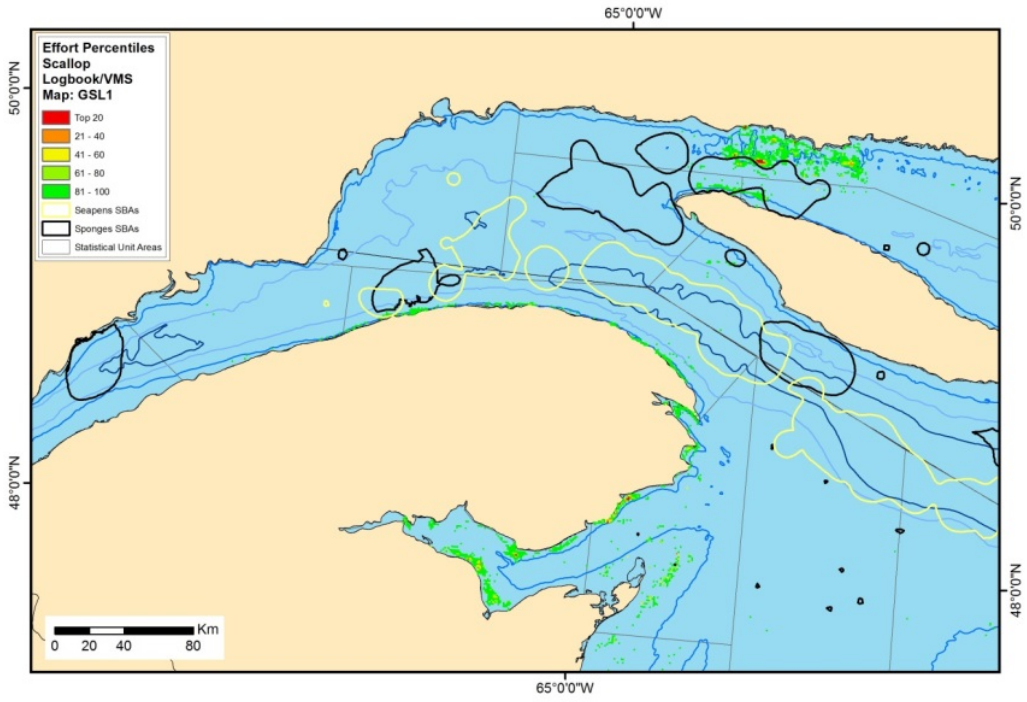

Figure A3 - 74. Scallop, inset GSL1.

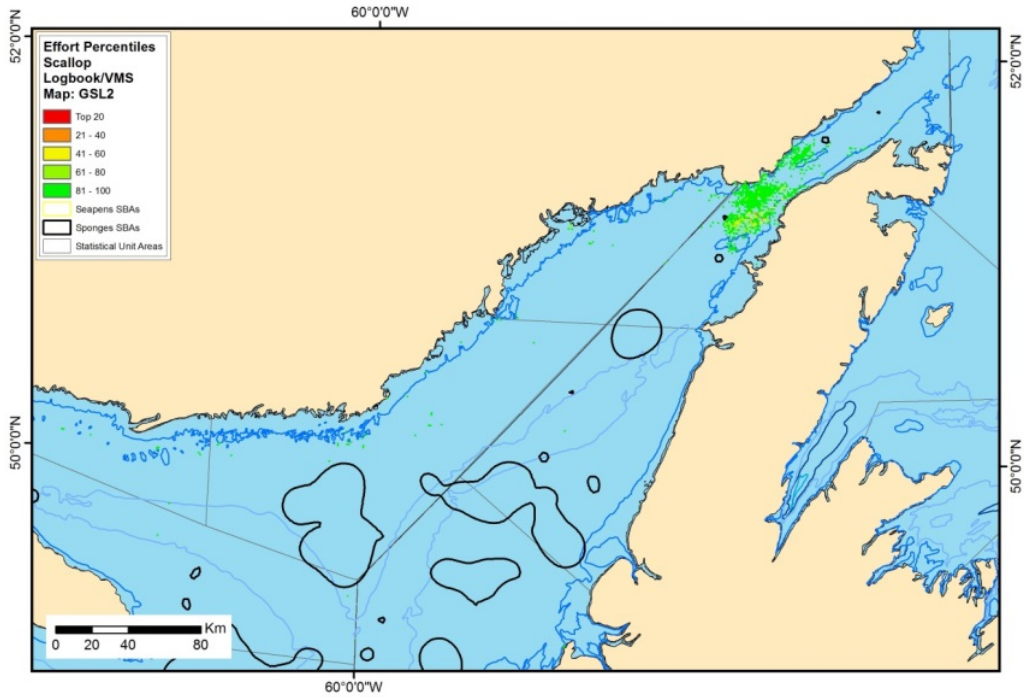

Figure A3 - 75. Scallop, inset GSL2.

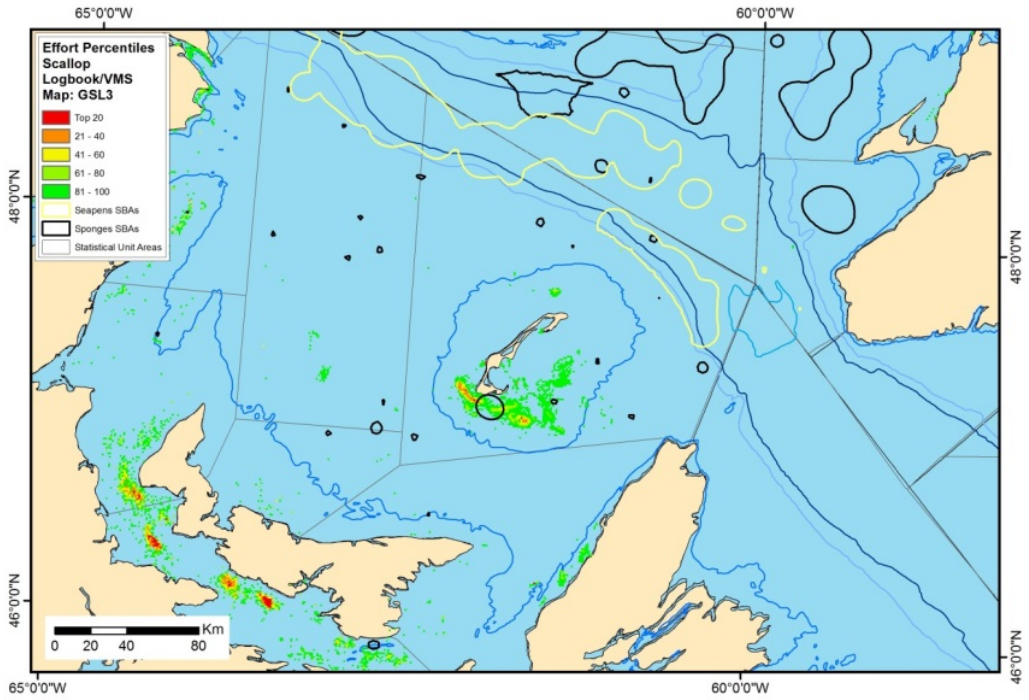

Figure A3 - 76. Scallop, inset GSL3.

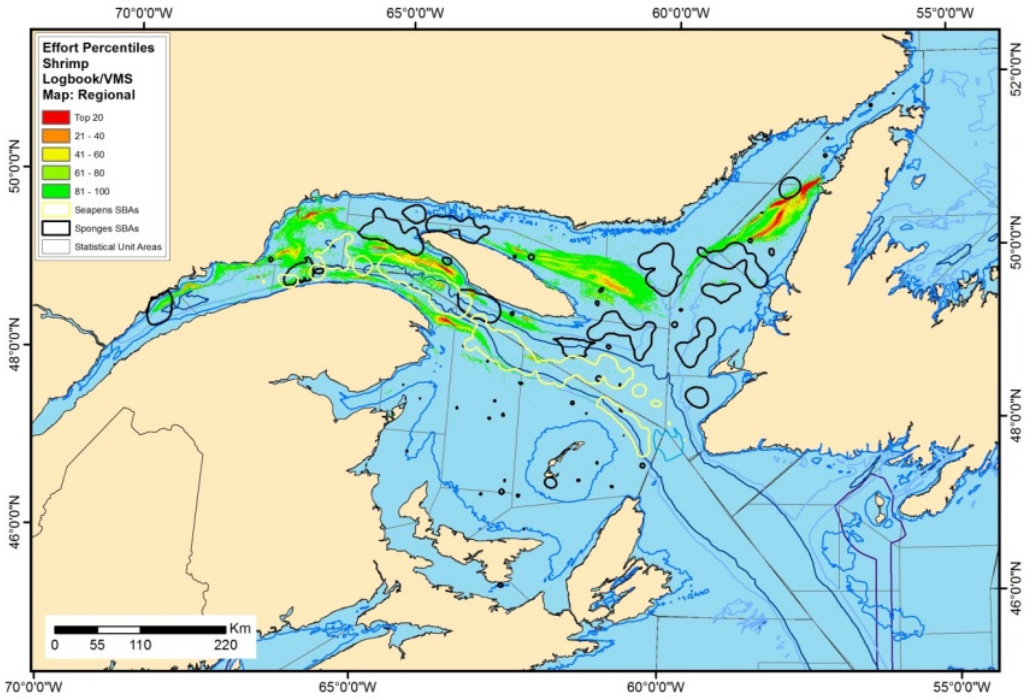

Figure A3 - 77. Shrimp, regional map.

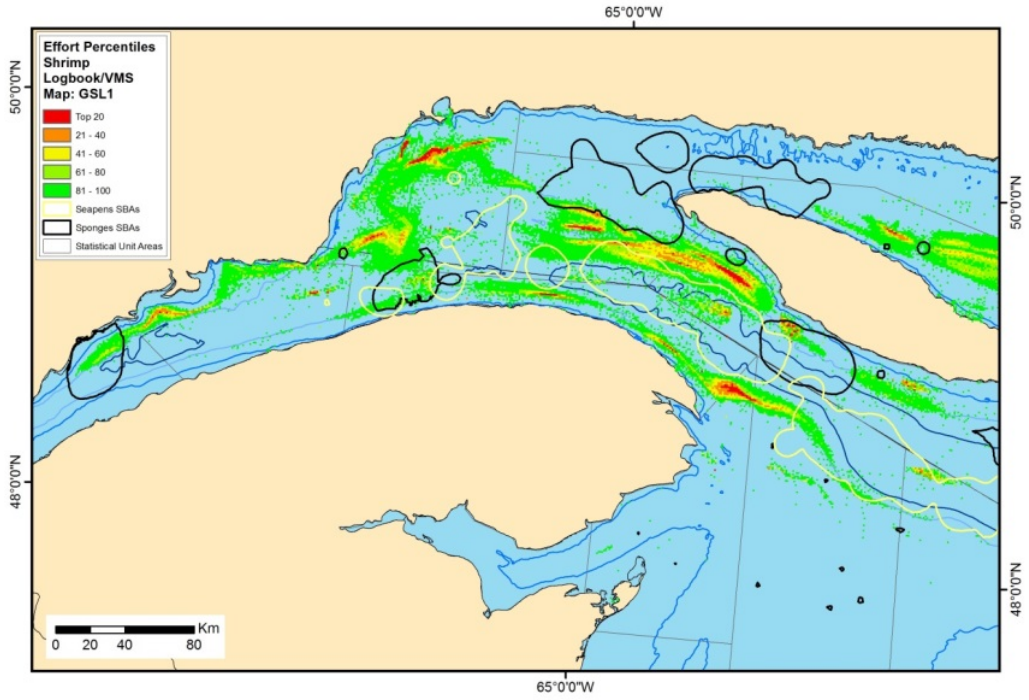

Figure A3 - 78. Shrimp, inset GSL1.

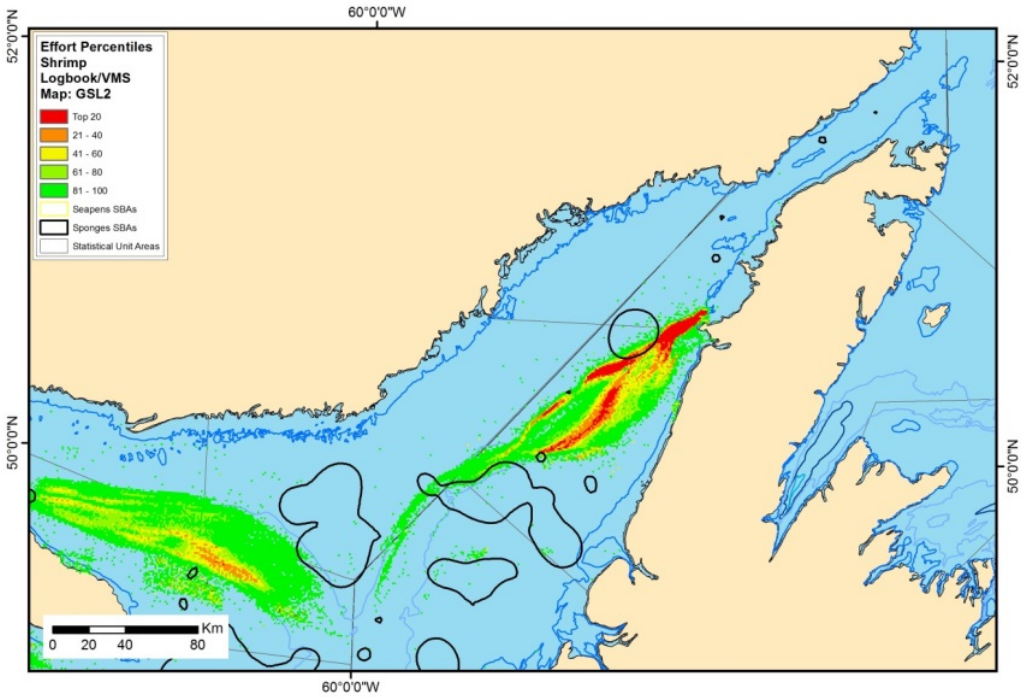

Figure A3 - 79. Shrimp, inset GSL2.

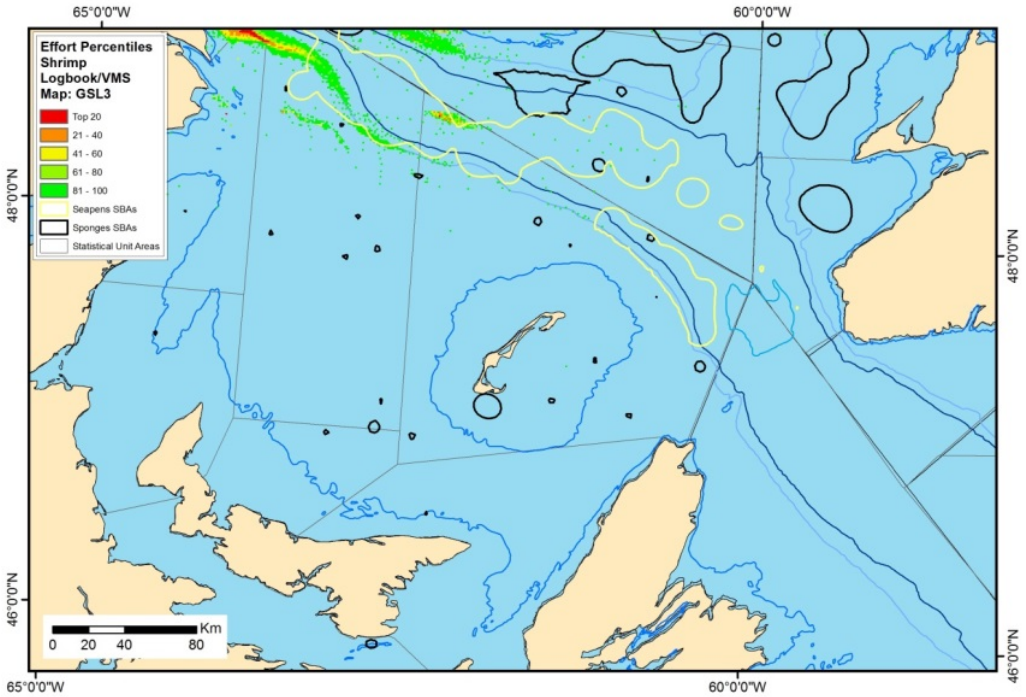

Figure A3 - 80. Shrimp, inset GSL3.

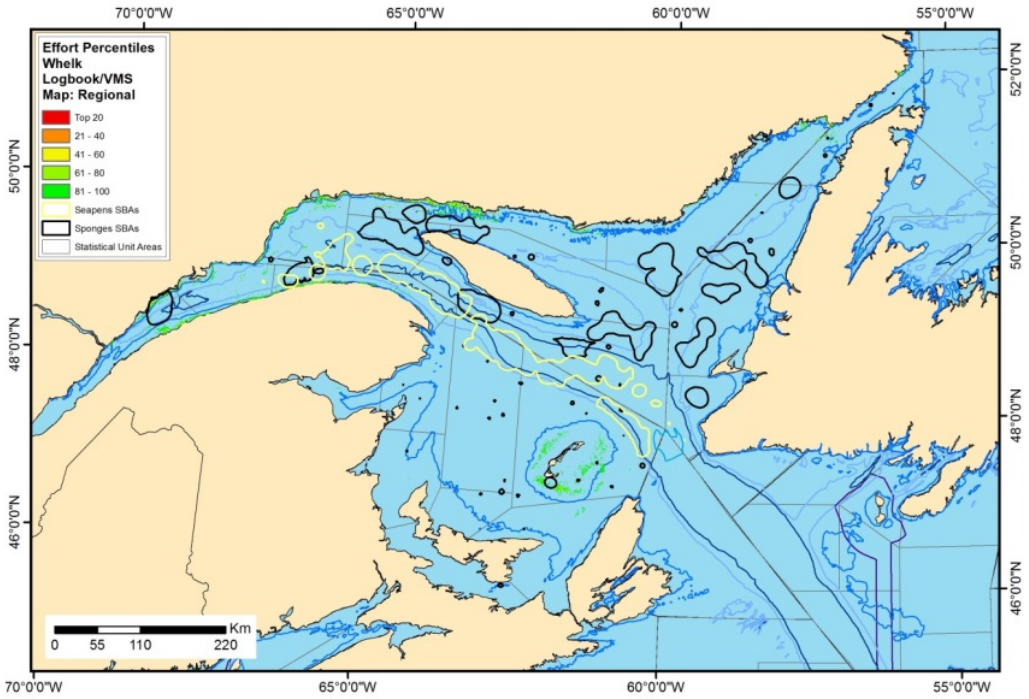

Figure A3 - 81. Whelk, regional map.

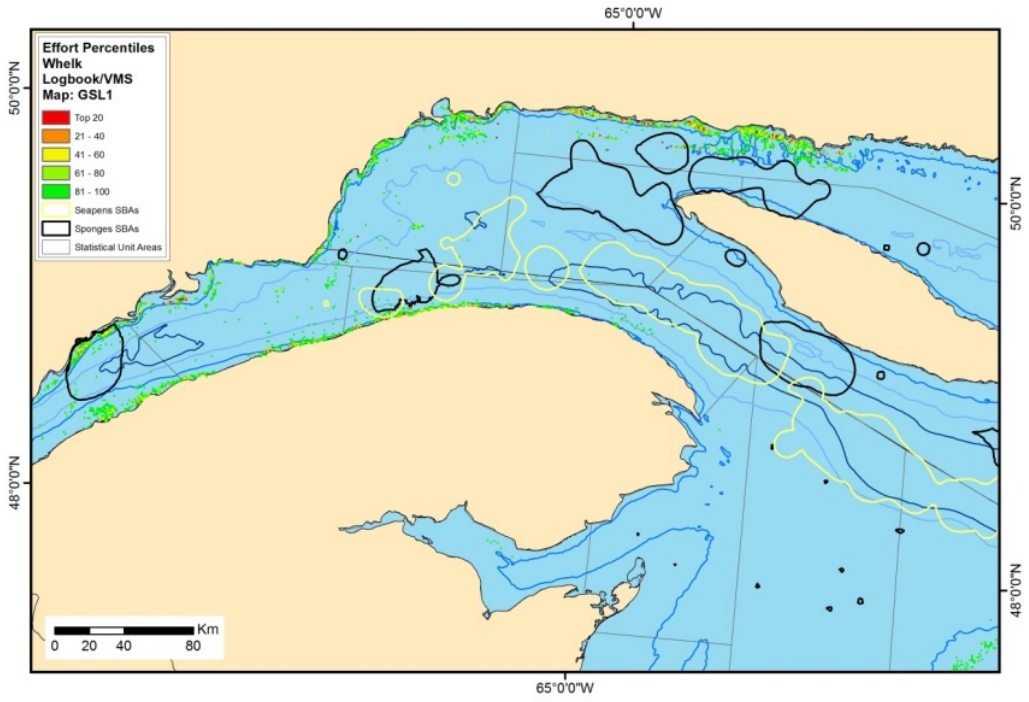

Figure A3 - 82. Whelk, inset GSL1.

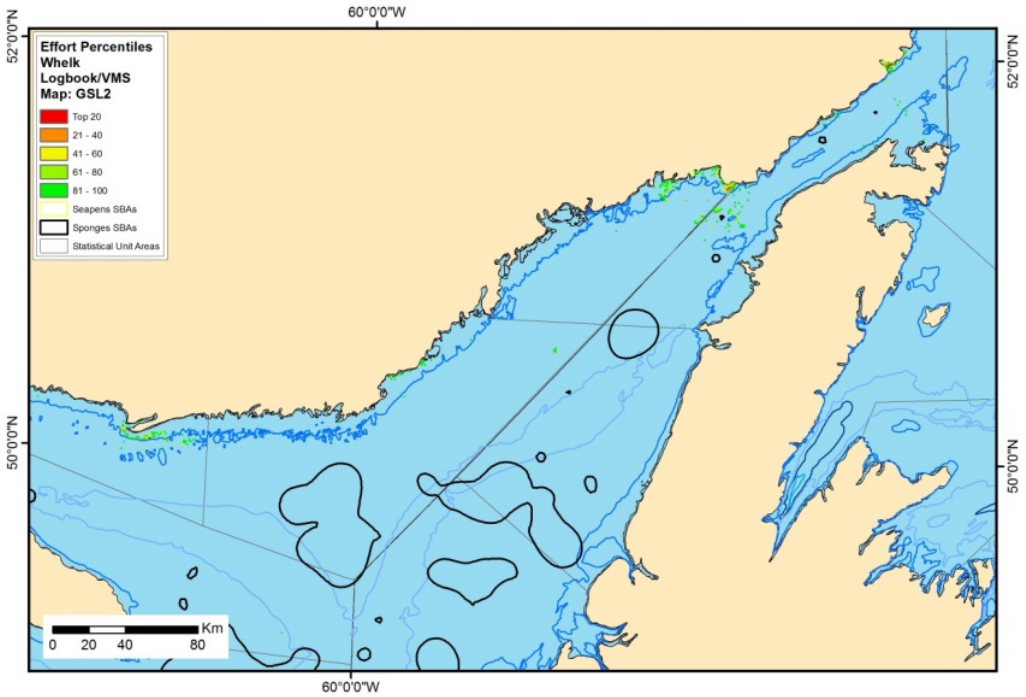

Figure A3 - 83. Whelk, inset GSL2.

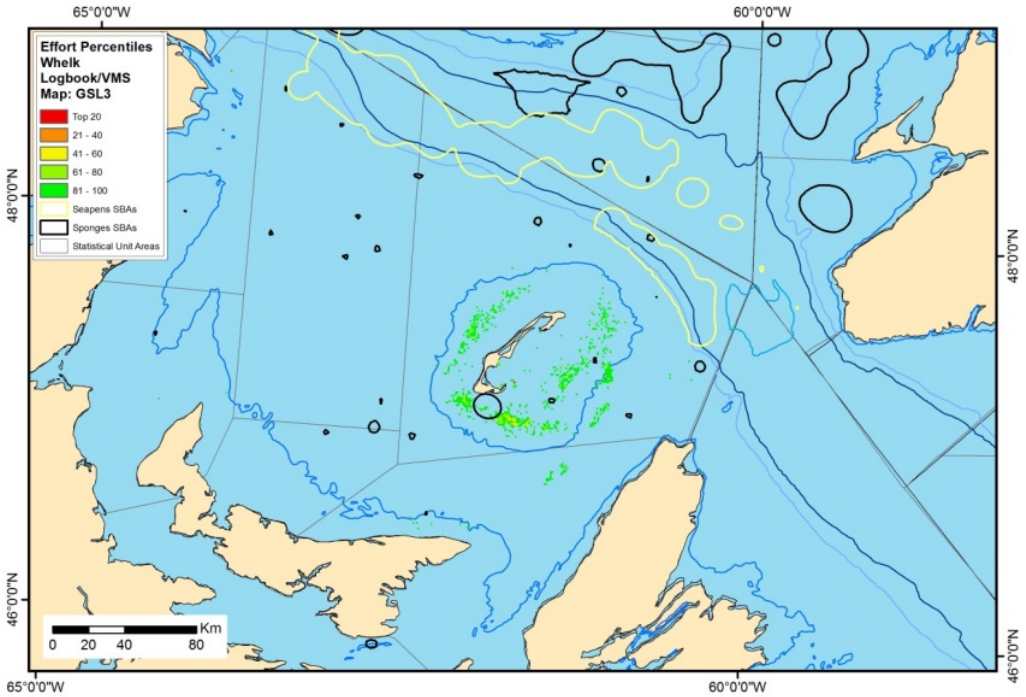

Figure A3 - 84. Whelk, inset GSL3.

NEWFOUNDLAND AND LABRADOR (NL)

In the Newfoundland and Labrador, there are four types of Significant Benthic Areas: small gorgonian, large gorgonian, sponge and sea pen. The first map within this section shows the Significant Benthic Areas without any fishing effort, followed by fisheries class-specific maps for the following fisheries classes in the Newfoundland and Labrador bioregion:

- All fisheries combined
- Crab offshore
- Echinoderm
- Groundfish fixed
- Groundfish mobile
- Other
- Pelagic
- Shrimp
- Scallop
- Whelk

Due to either privacy regulations or data deficiency, maps are not displayed for the following fisheries classes: crab inshore, clam, lobster, miscellaneous inshore, and miscellaneous offshore.

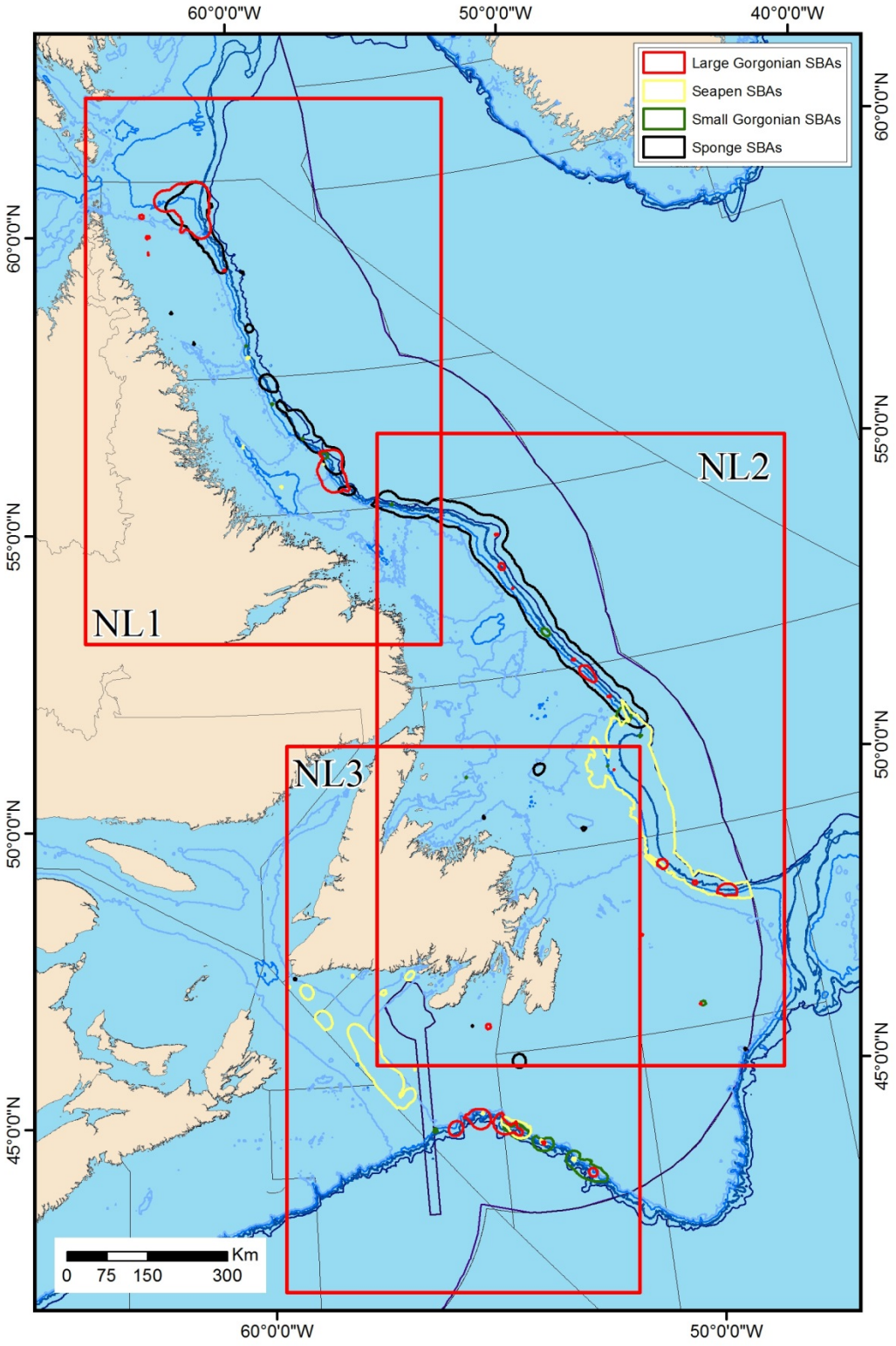

Figure A3 - 85. Inset Index.

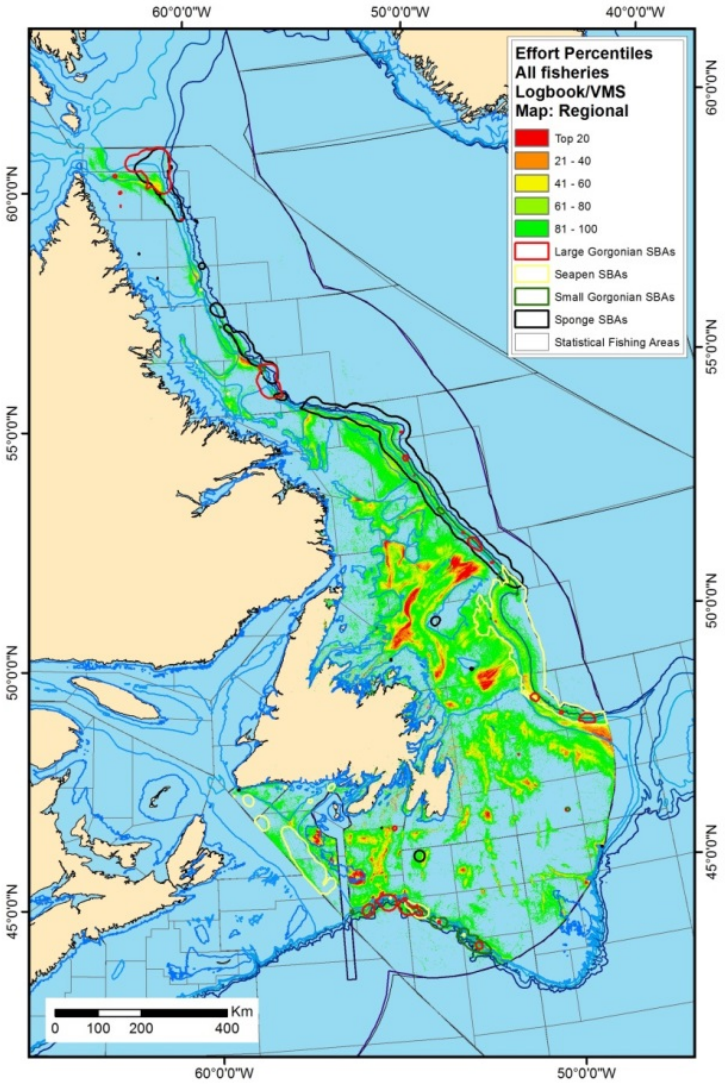

Figure A3 - 86. All fisheries, regional map.

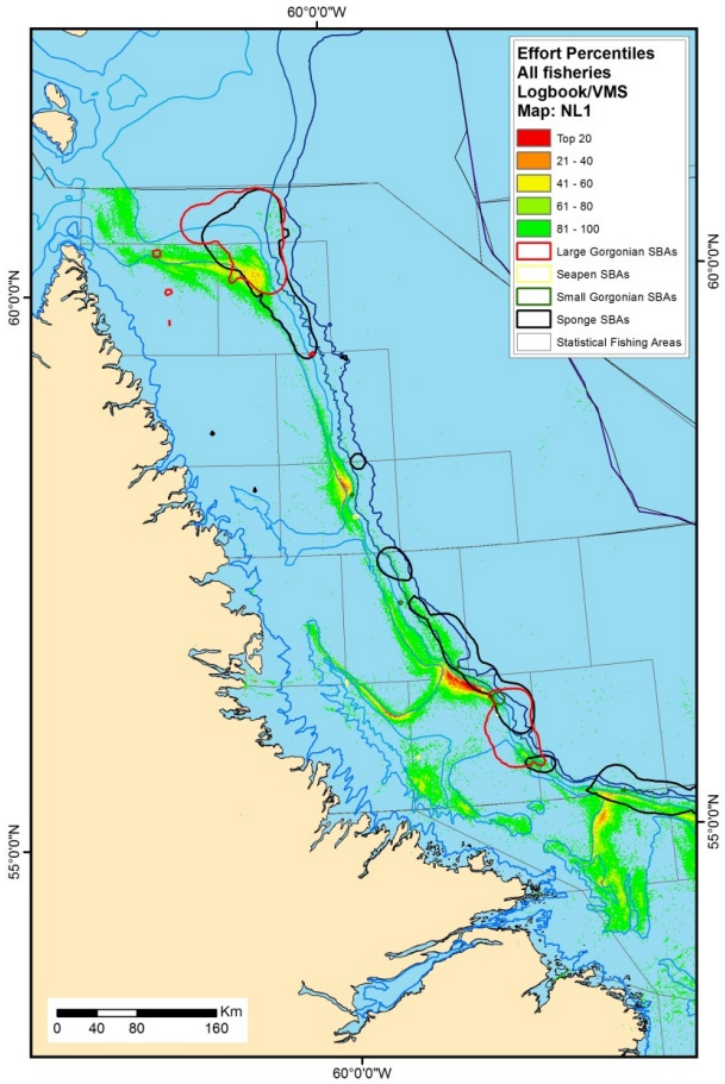

Figure A3 - 87. All fisheries, inset NL1

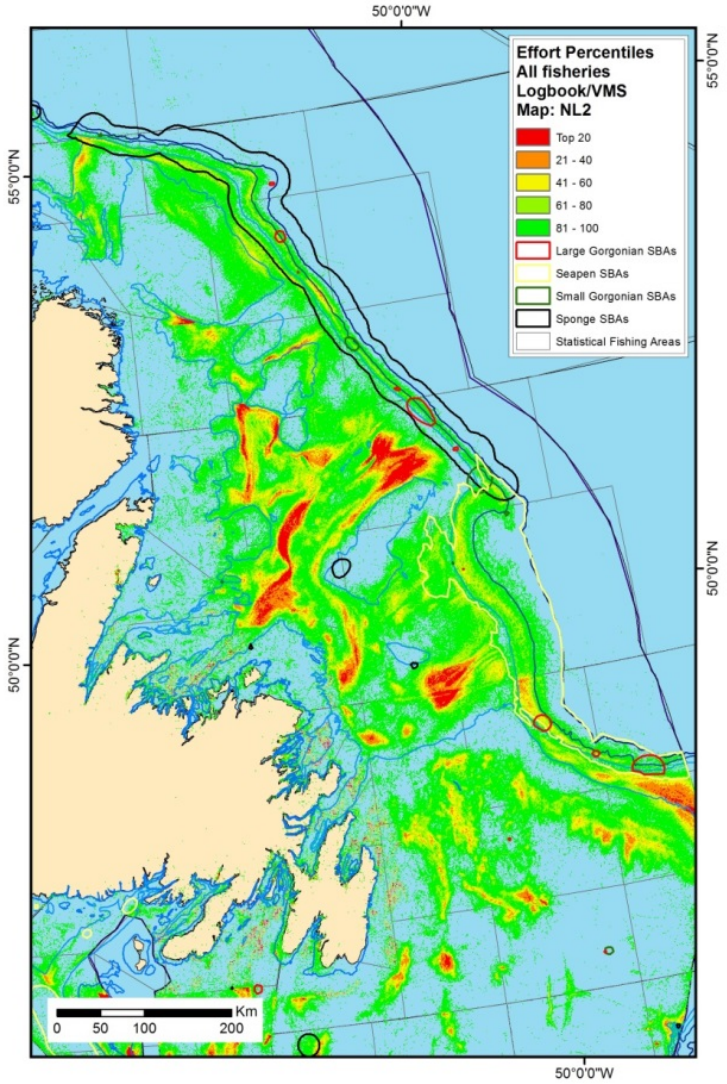

Figure A3 - 88. All fisheries, inset NL2.

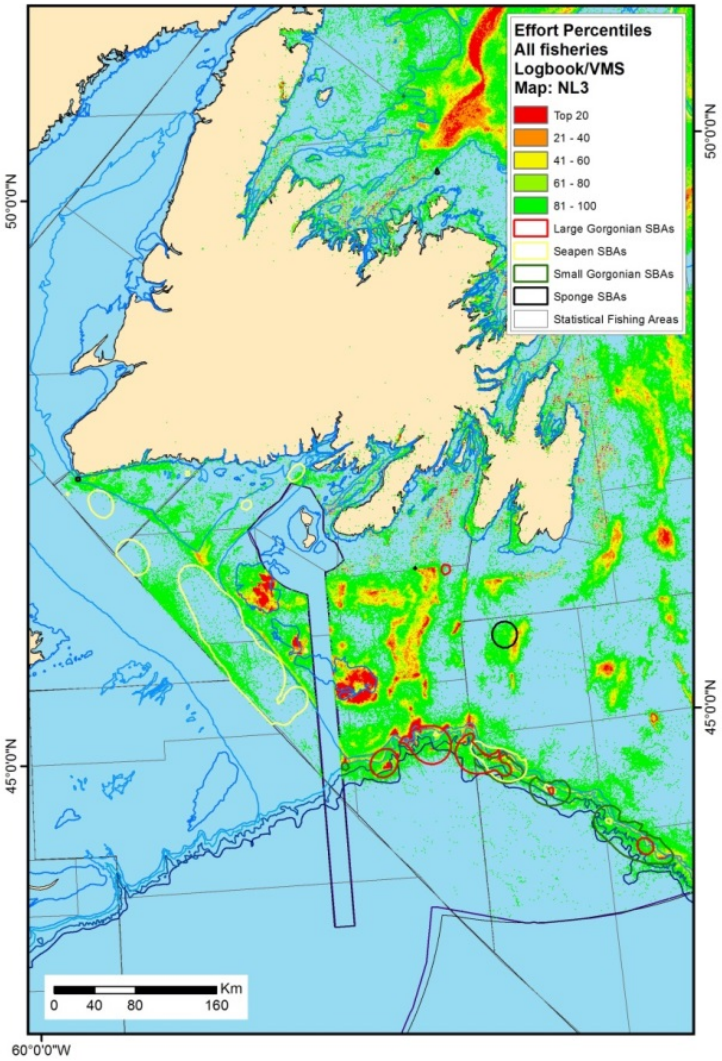

Figure A3 - 89. All fisheries, inset NL3.

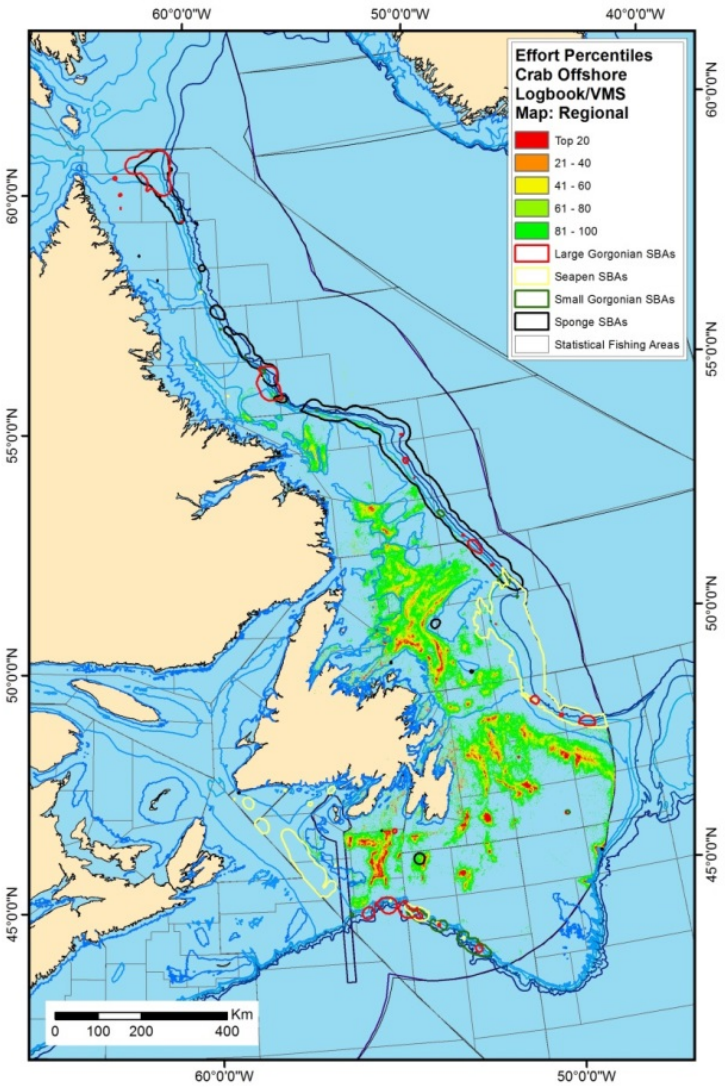

Figure A3 - 90. Crab Offshore, regional map.

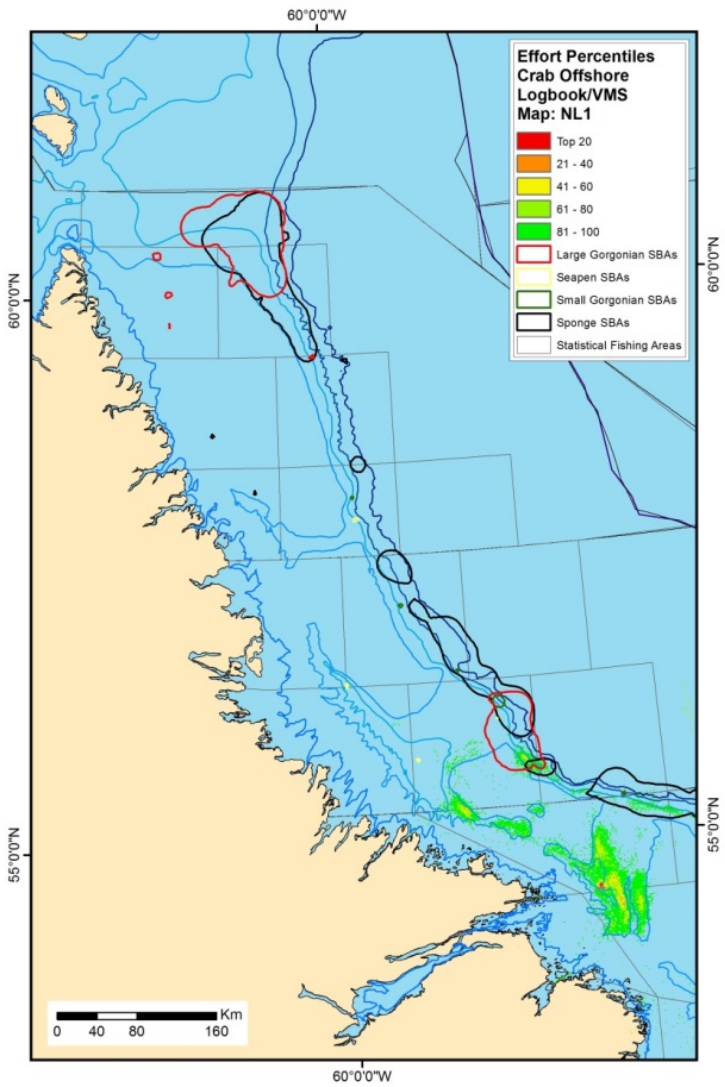

Figure A3 - 91. Crab Offshore, inset NL1.

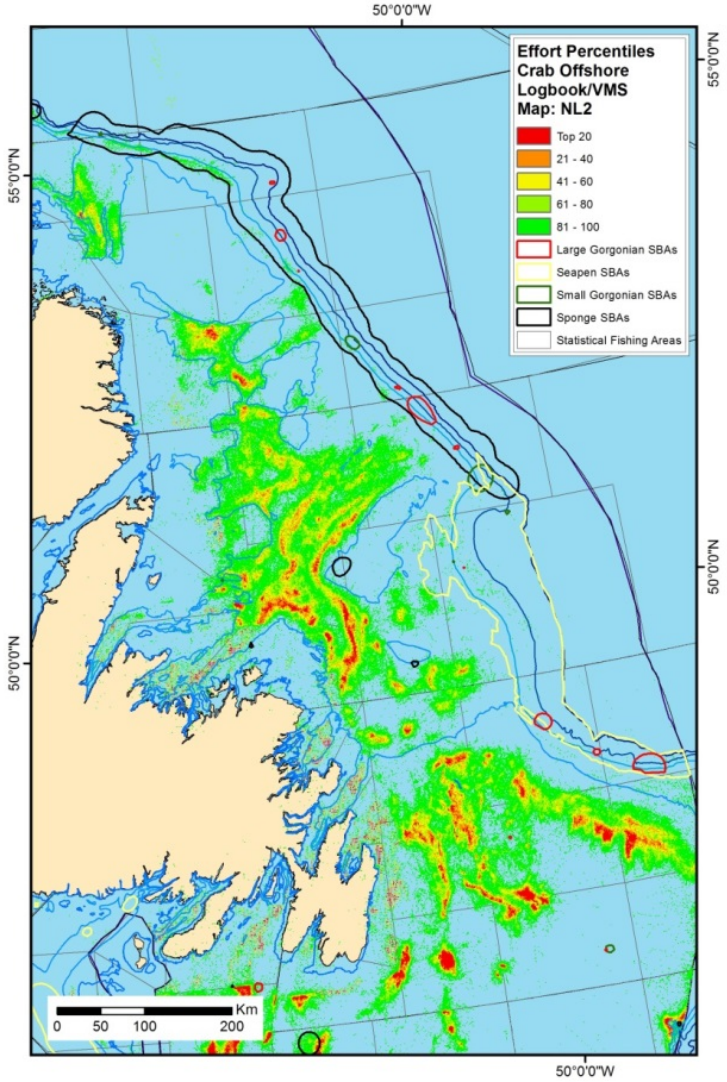

Figure A3 - 92. Crab Offshore, inset NL2.

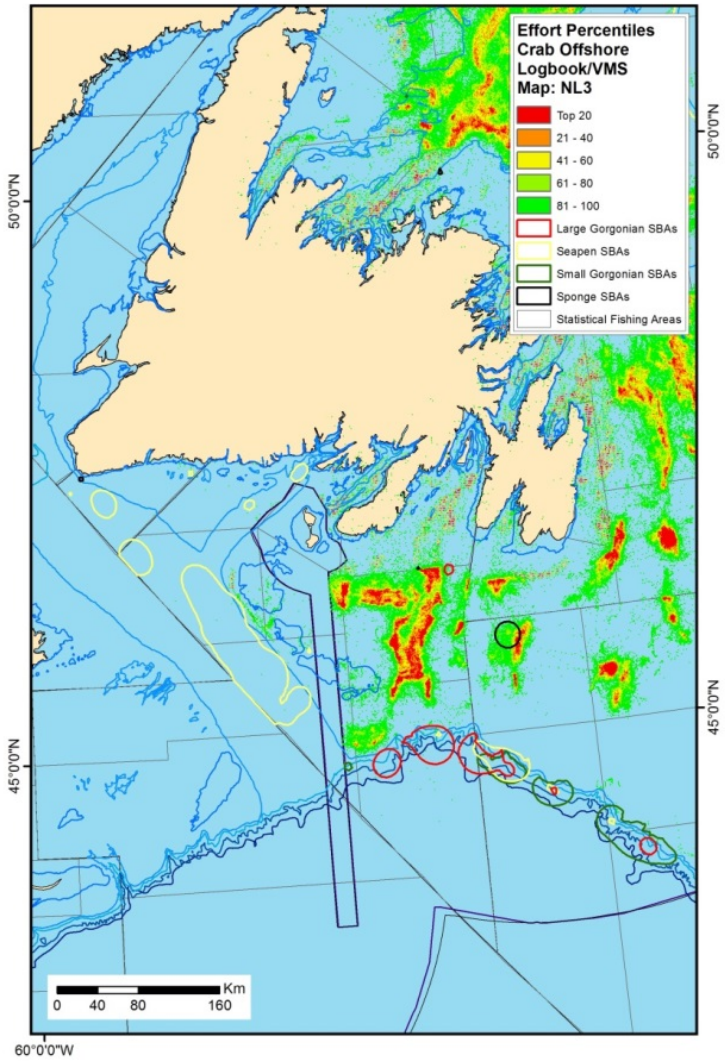

Figure A3 - 93. Crab Offshore, inset NL3.

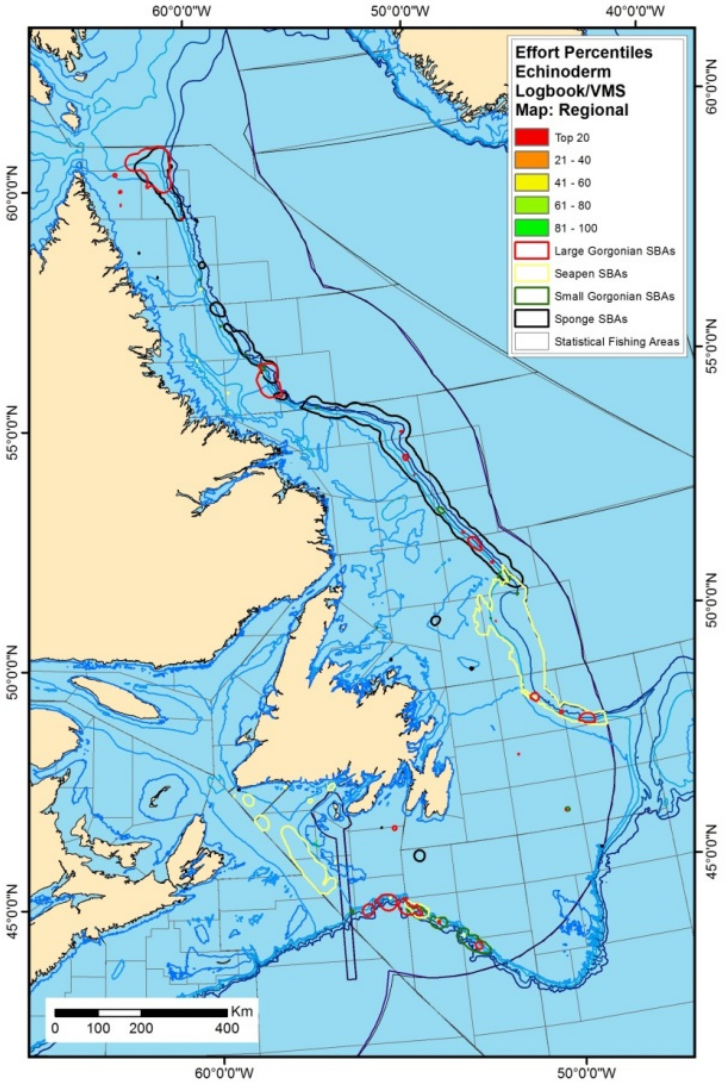

Figure A3 - 94. Echinoderm, regional map.

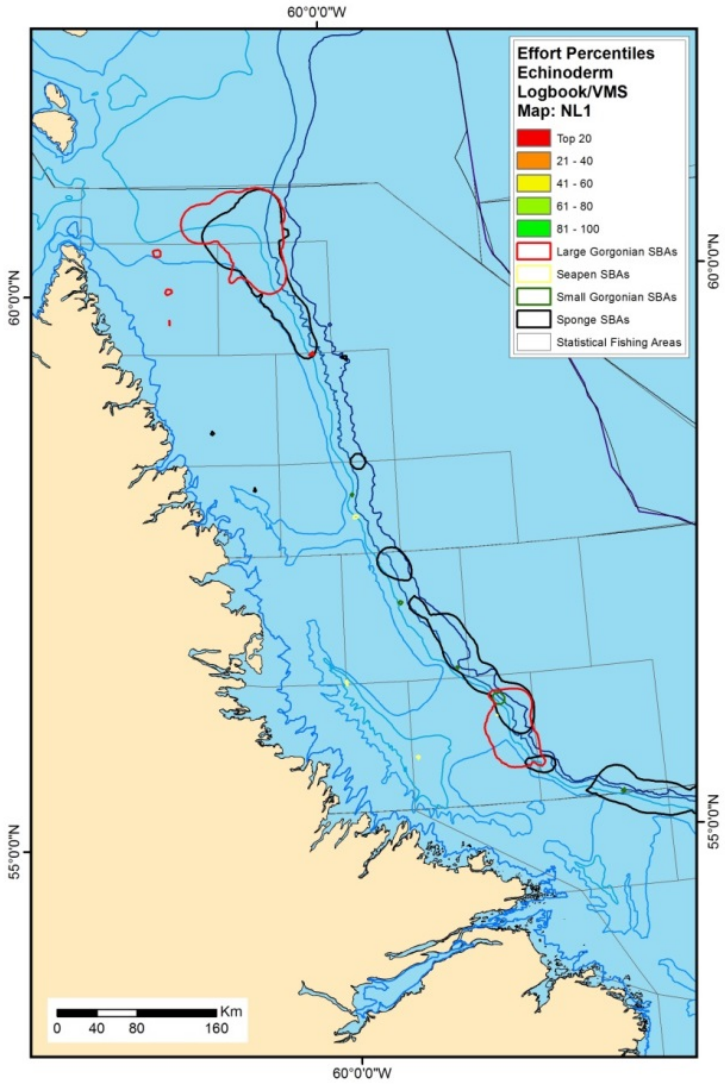

Figure A3 - 95. Echinoderm, inset NL1.

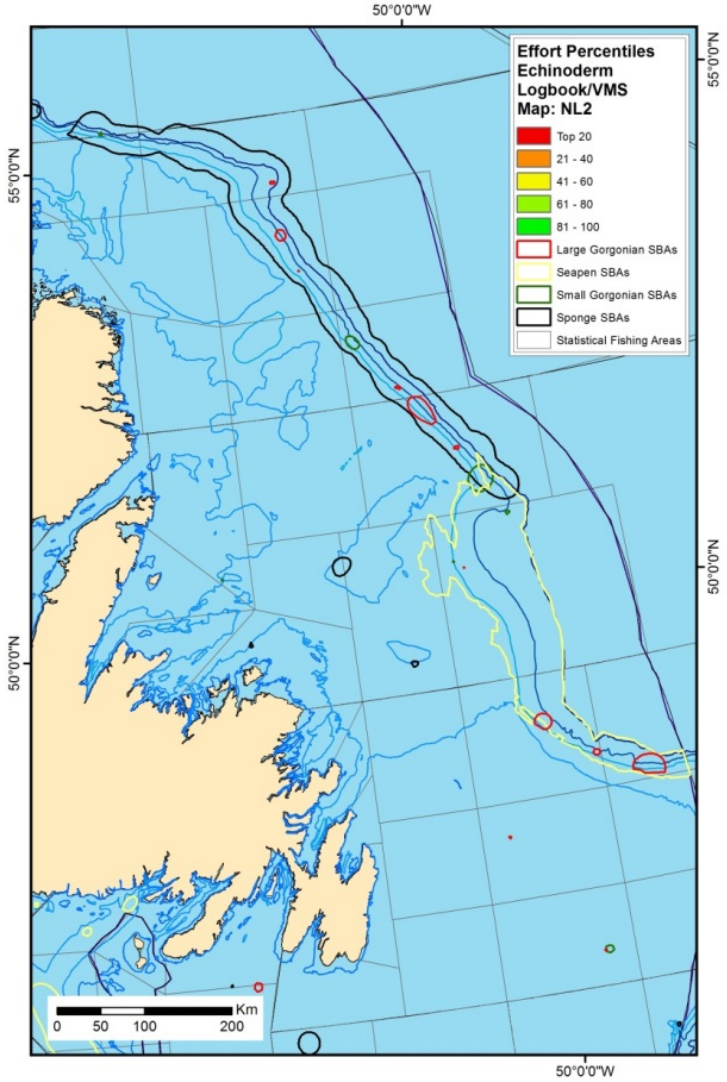

Figure A3 - 96. Echinoderm, inset NL2.

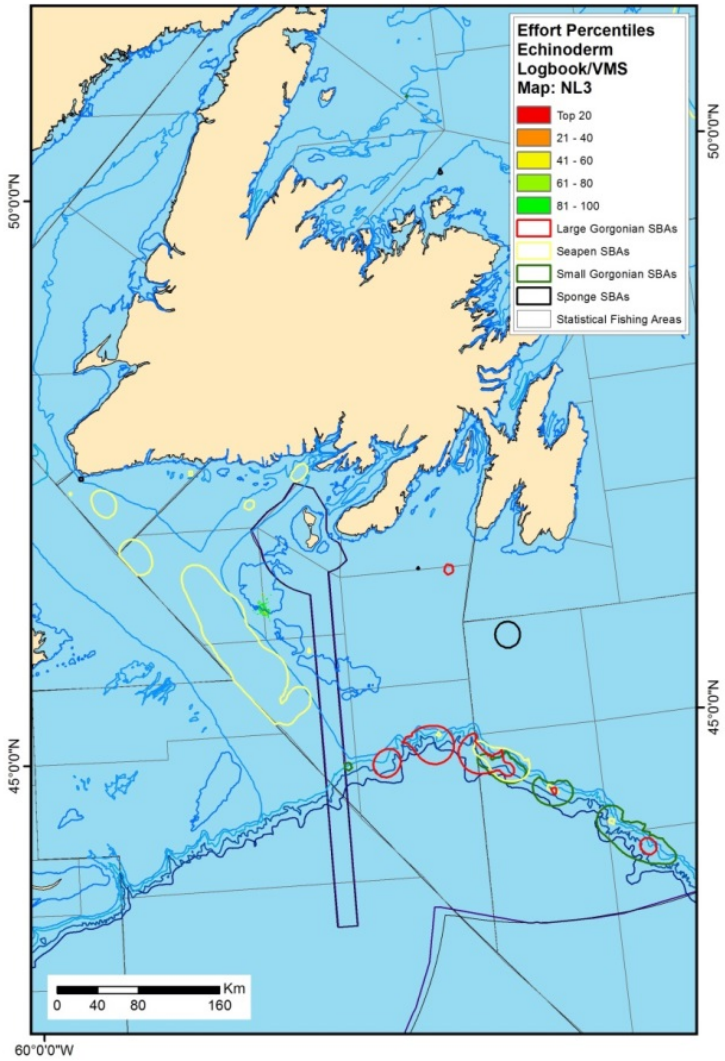

Figure A3 - 97. Echinoderm, inset NL3.

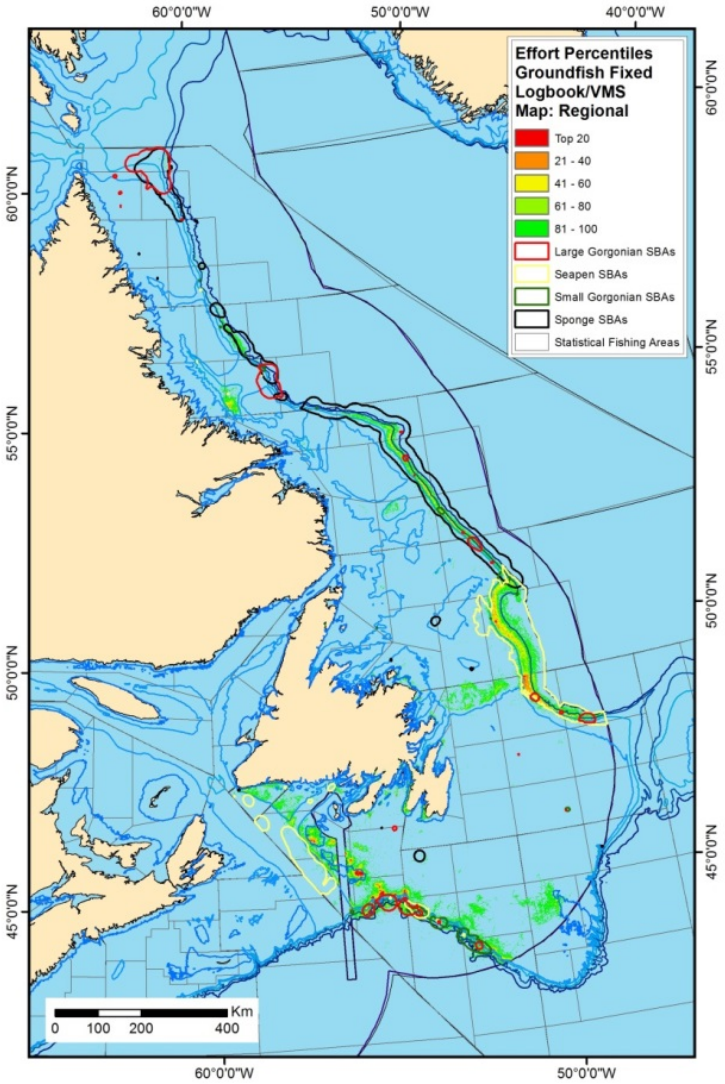

Figure A3 - 98. Groundfish Fixed, regional map.

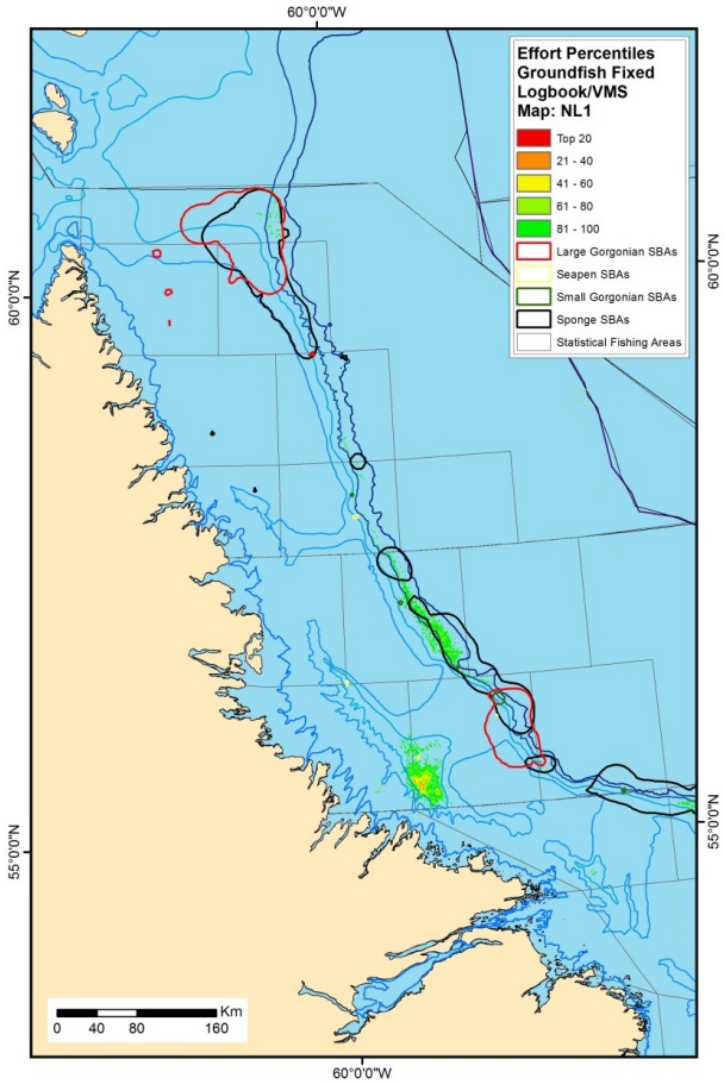

Figure A3 - 99. Groundfish Fixed, inset NL1.

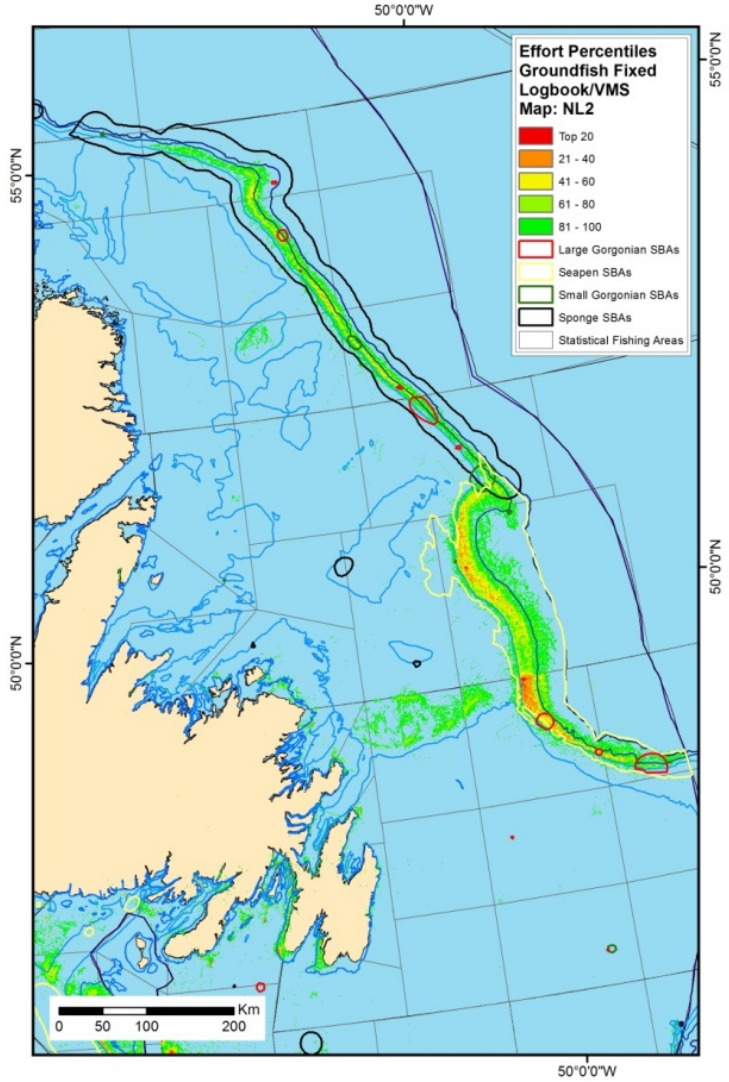

Figure A3 - 100. Groundfish Fixed, inset NL2.

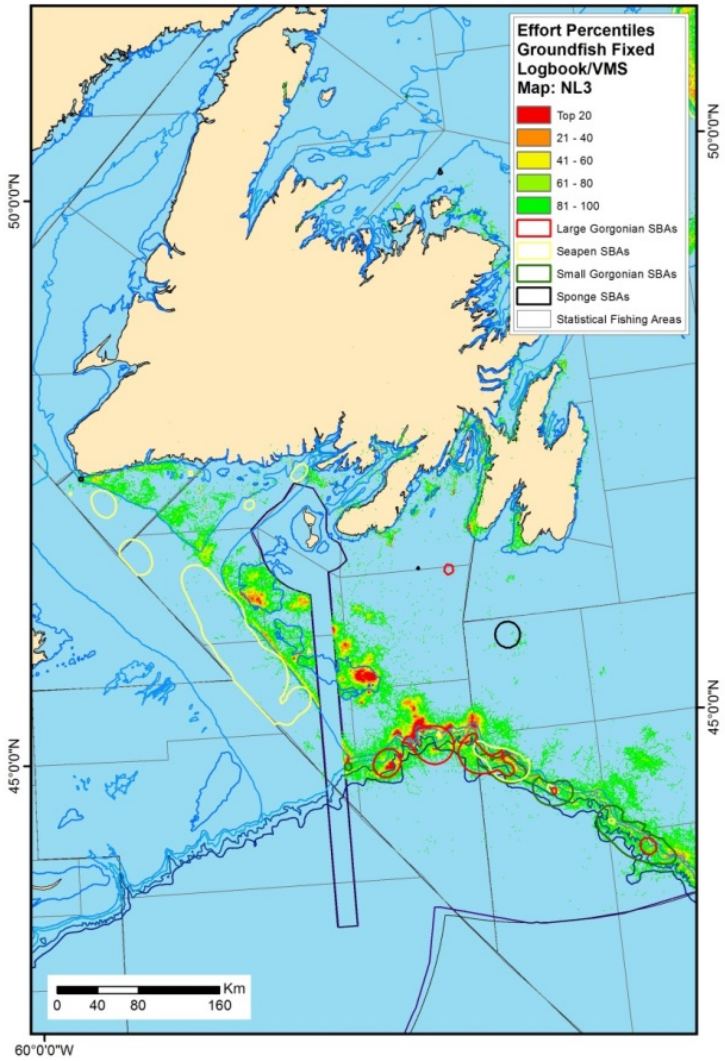

Figure A3 - 101. Groundfish Fixed, inset NL3.

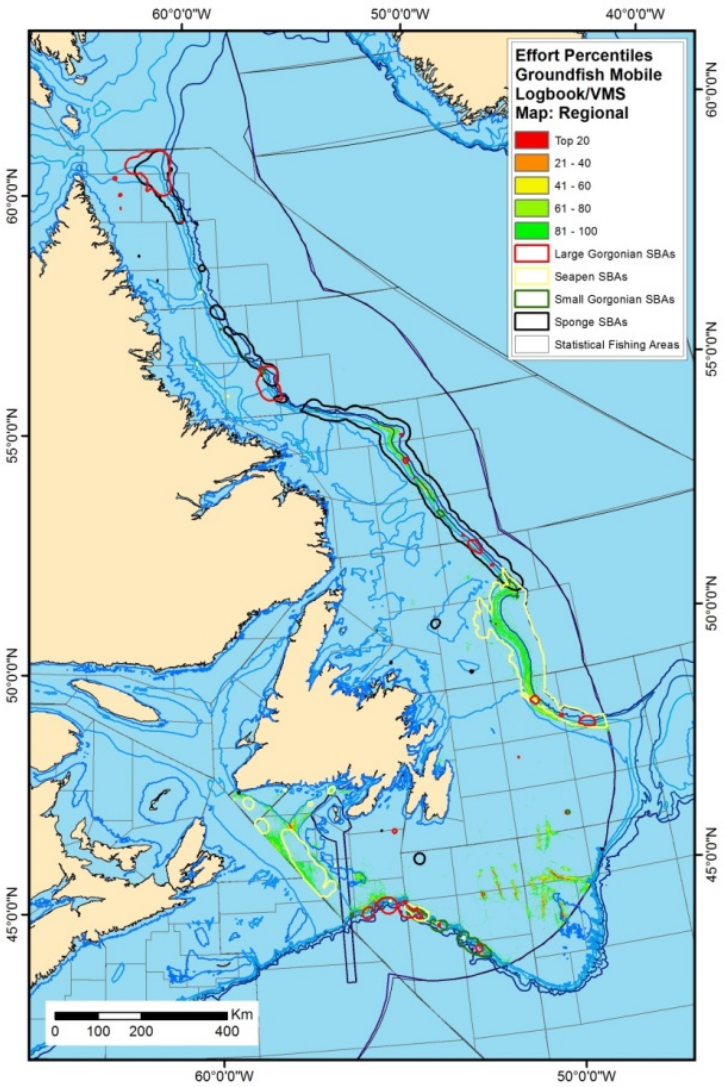

Figure A3 - 102. Groundfish Mobile, regional map.

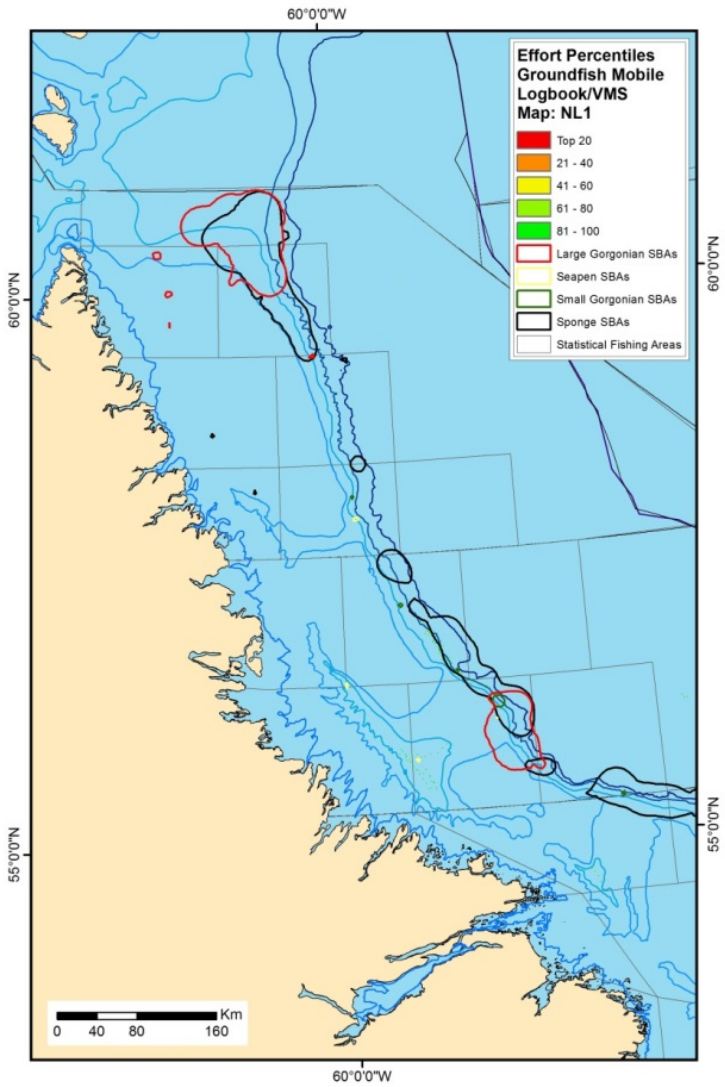

Figure A3 - 103. Groundfish Mobile, inset NL1.

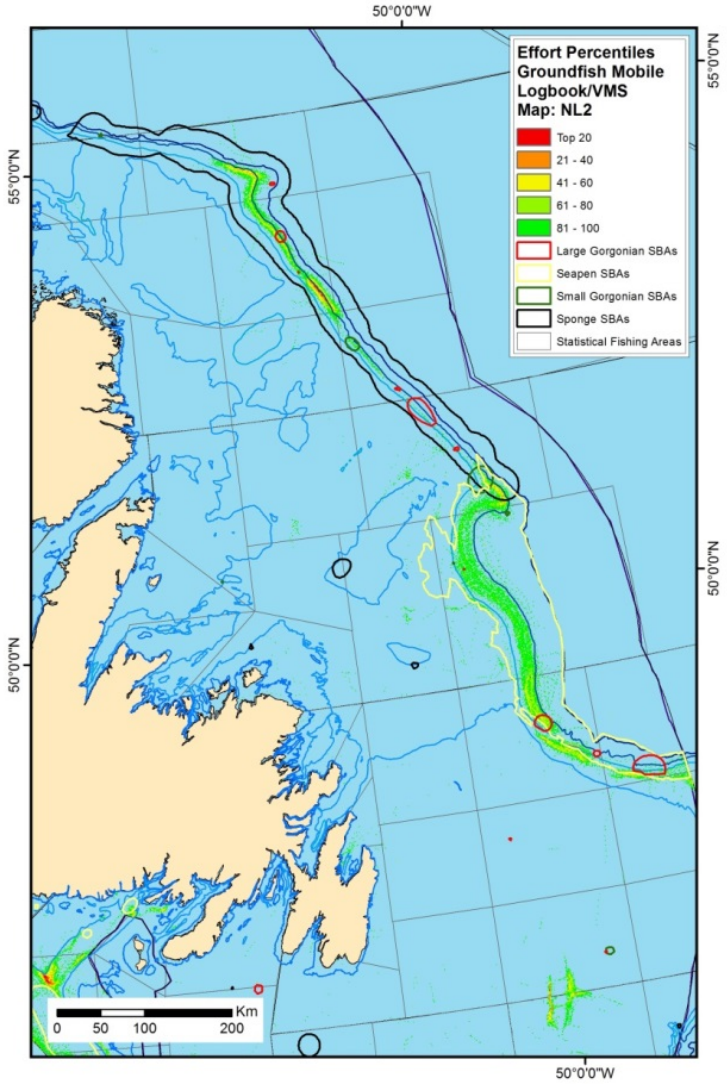

Figure A3 - 104. Groundfish Mobile, inset NL2.

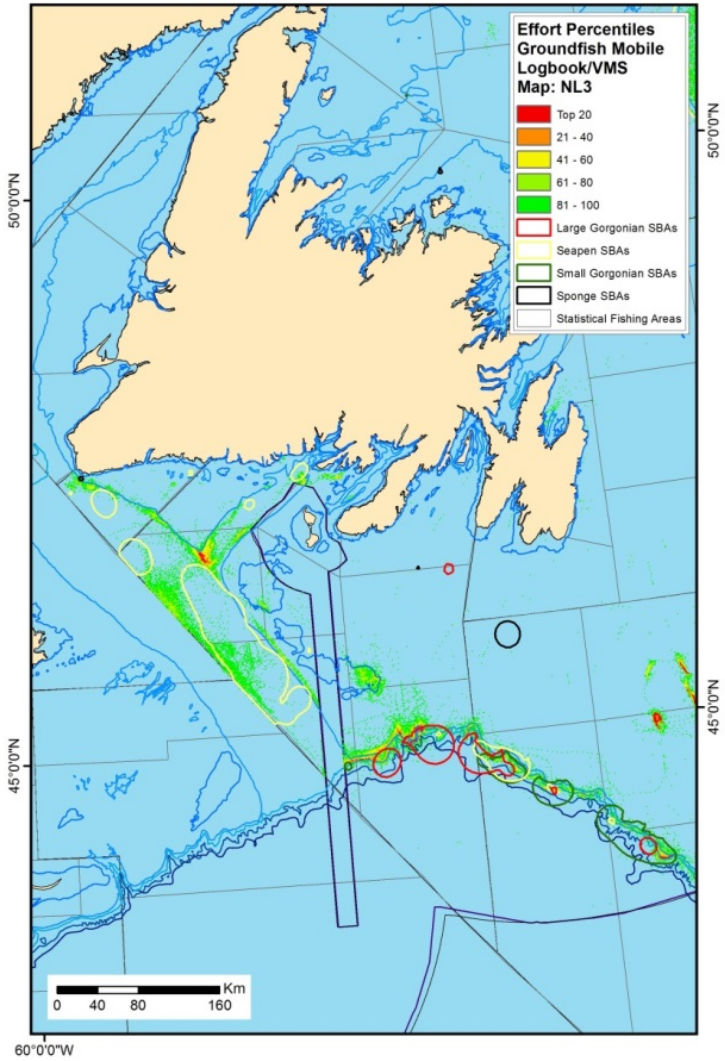

Figure A3 - 105. Groundfish Mobile, inset NL3.

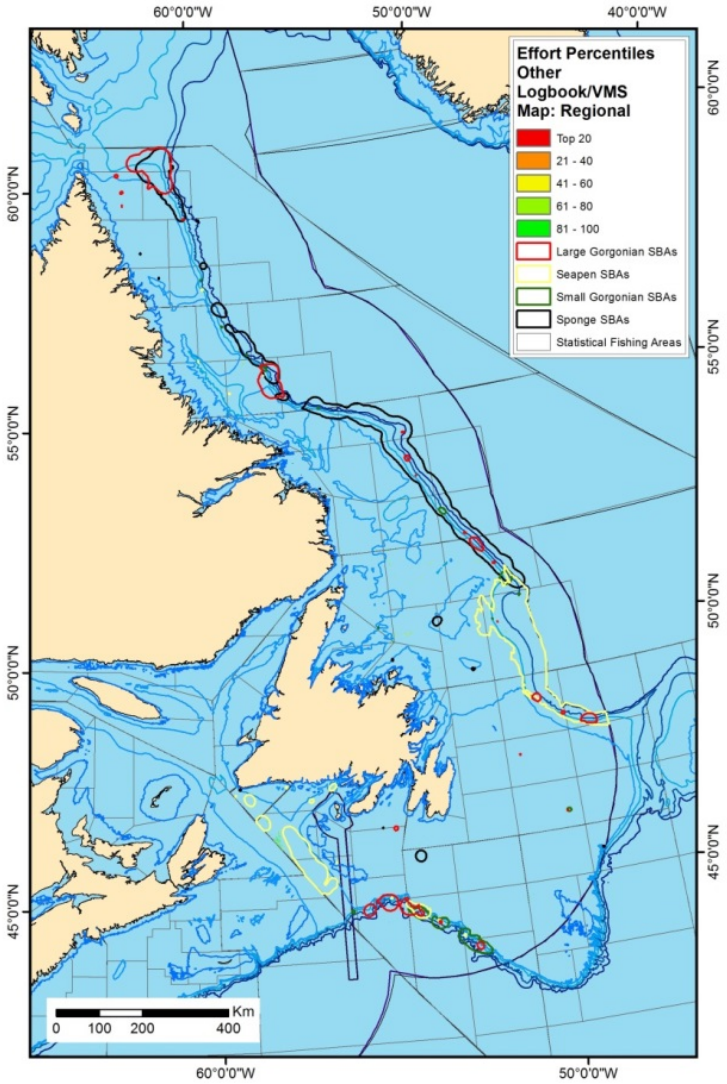

Figure A3 - 106. Other, regional map.

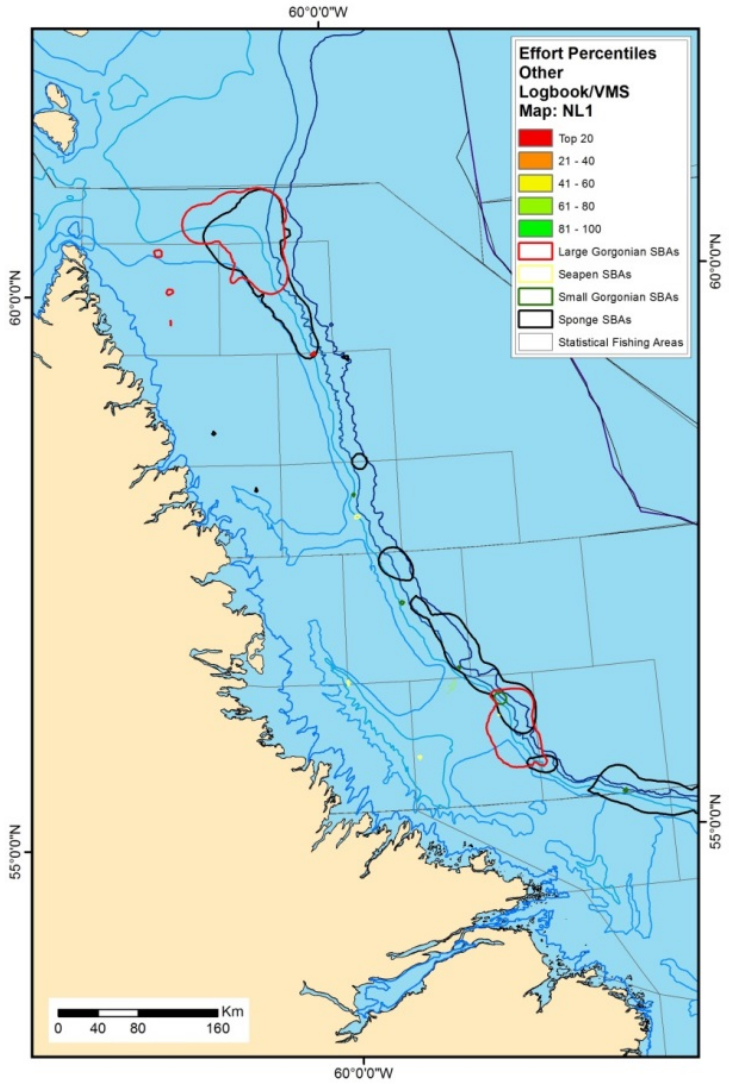

Figure A3 - 107. Other, inset NL1.

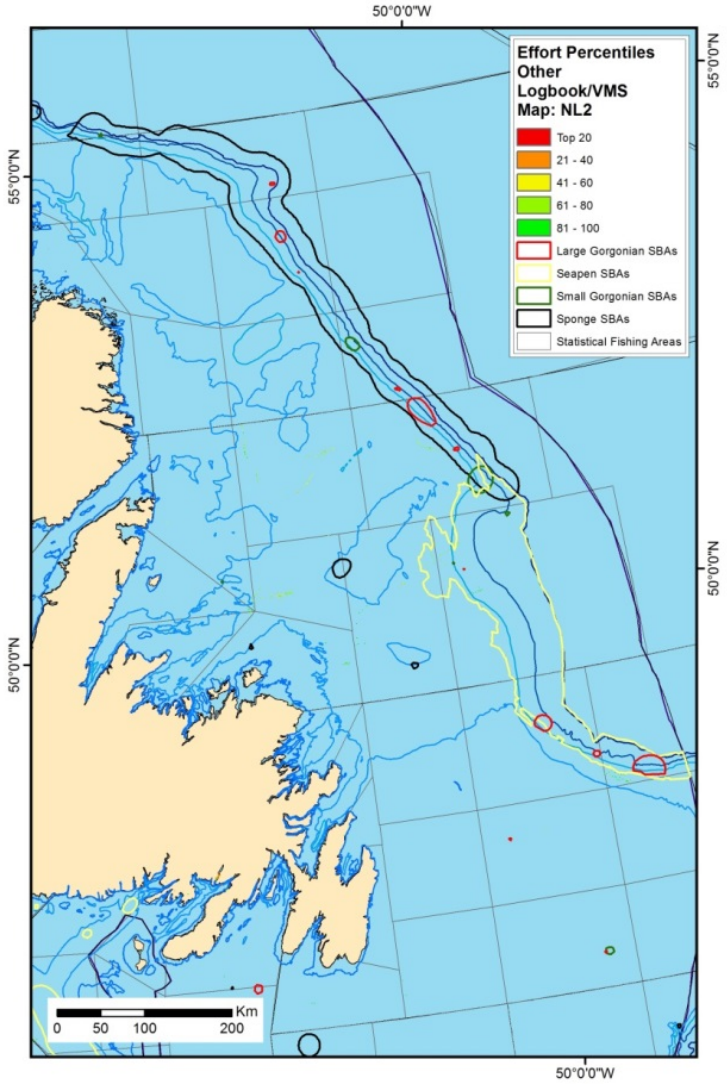

Figure A3 - 108. Other, inset NL2.

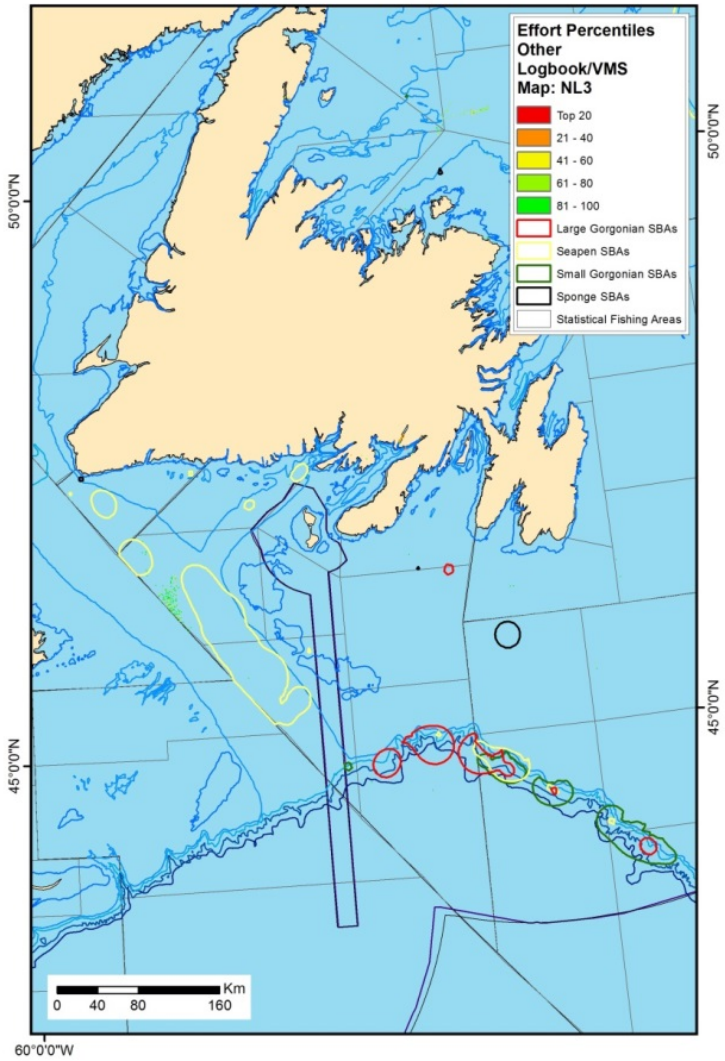

Figure A3 - 109. Other, inset NL3.

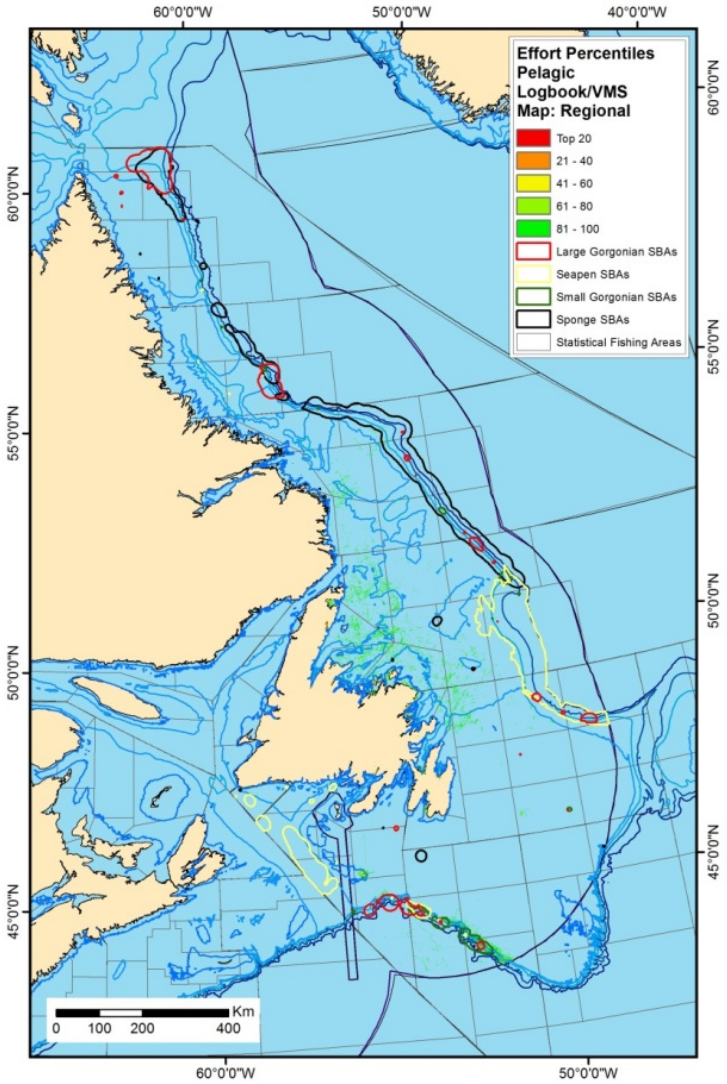

Figure A3 - 110. Pelagic, regional map.

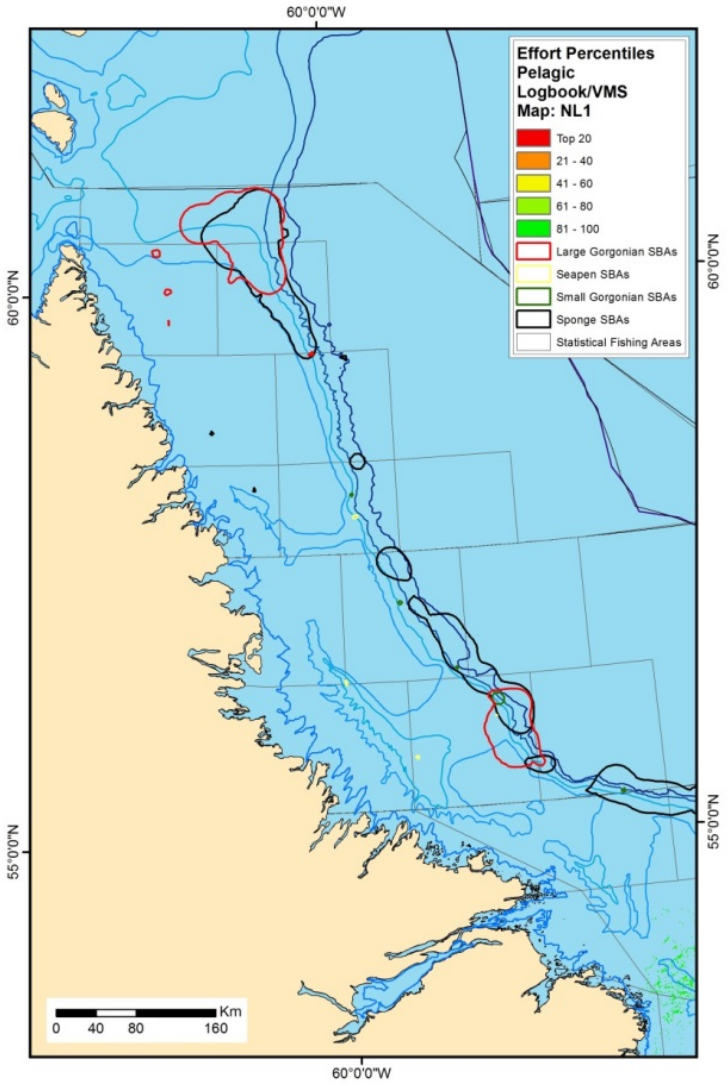

Figure A3 - 111. Pelagic, inset NL1.

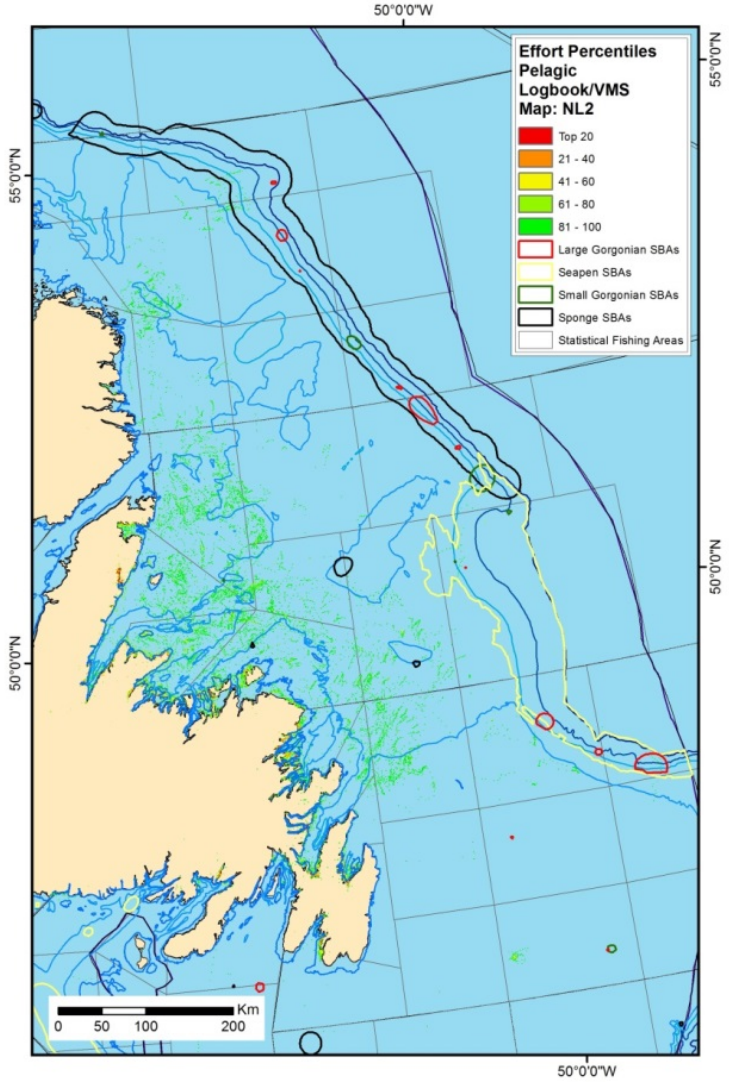

Figure A3 - 112. Pelagic, inset NL2.

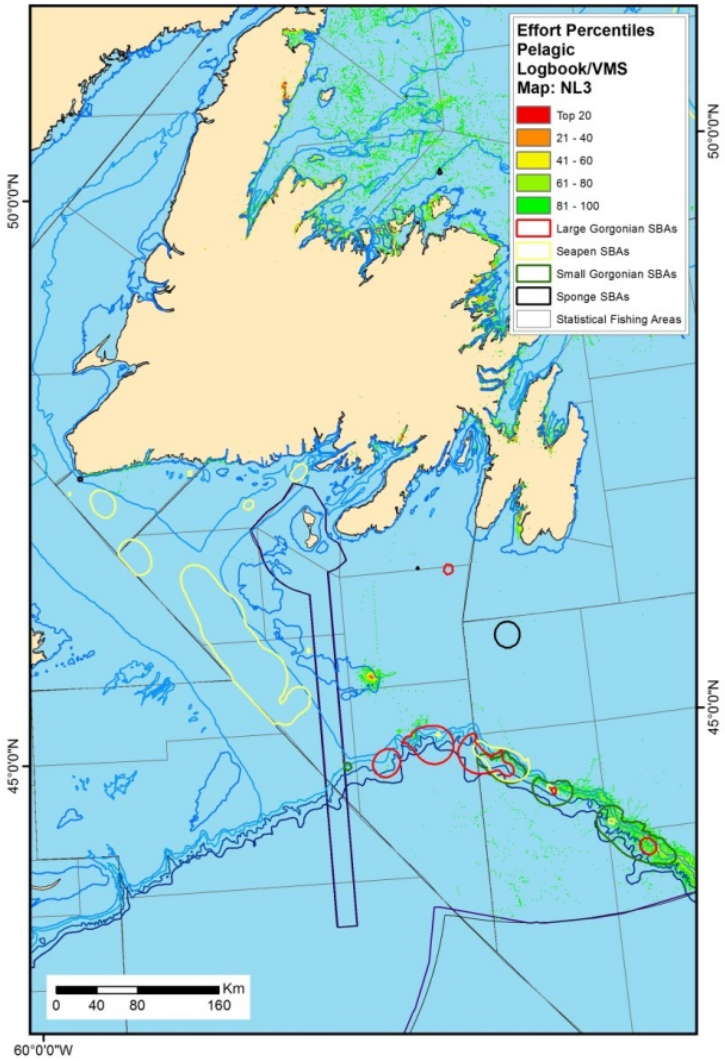

Figure A3 - 113. Pelagic, inset NL3.

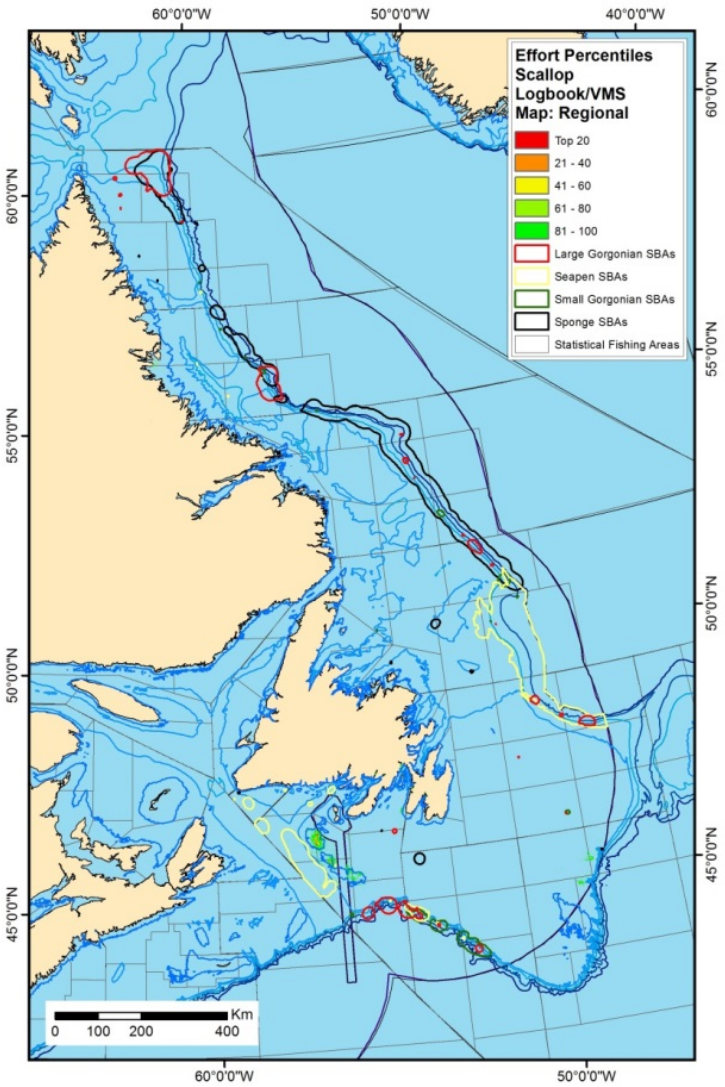

Figure A3 - 114. Scallop, regional map.

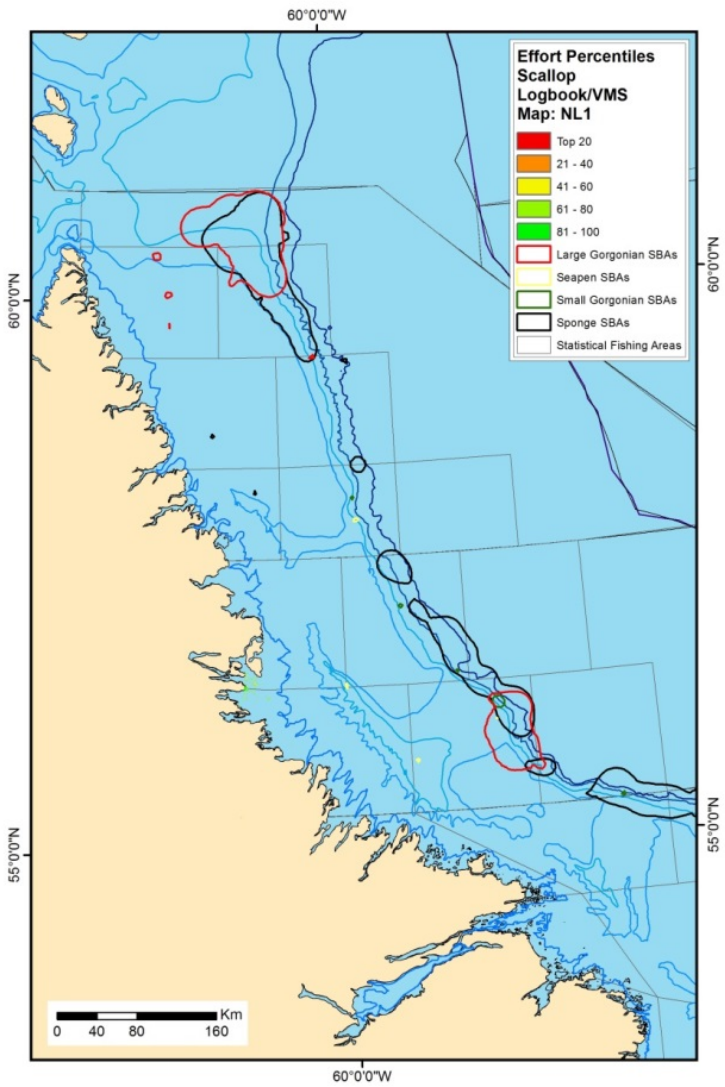

Figure A3 - 115. Scallop, inset NL1.

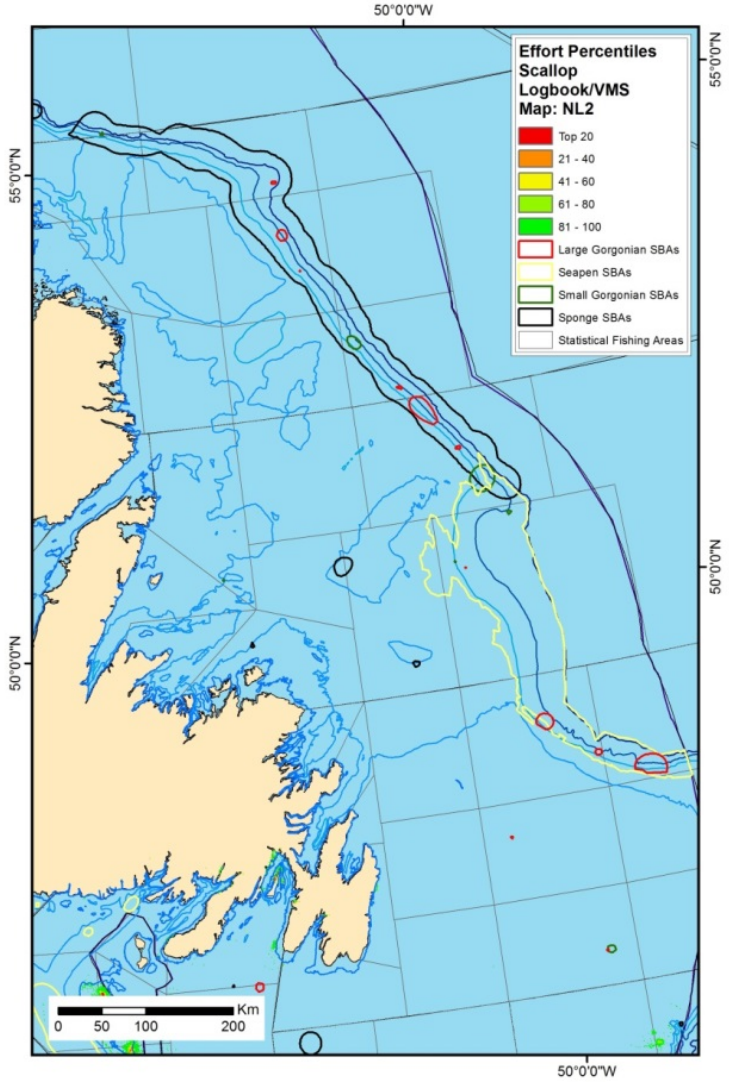

Figure A3 - 116. Scallop, inset NL2.

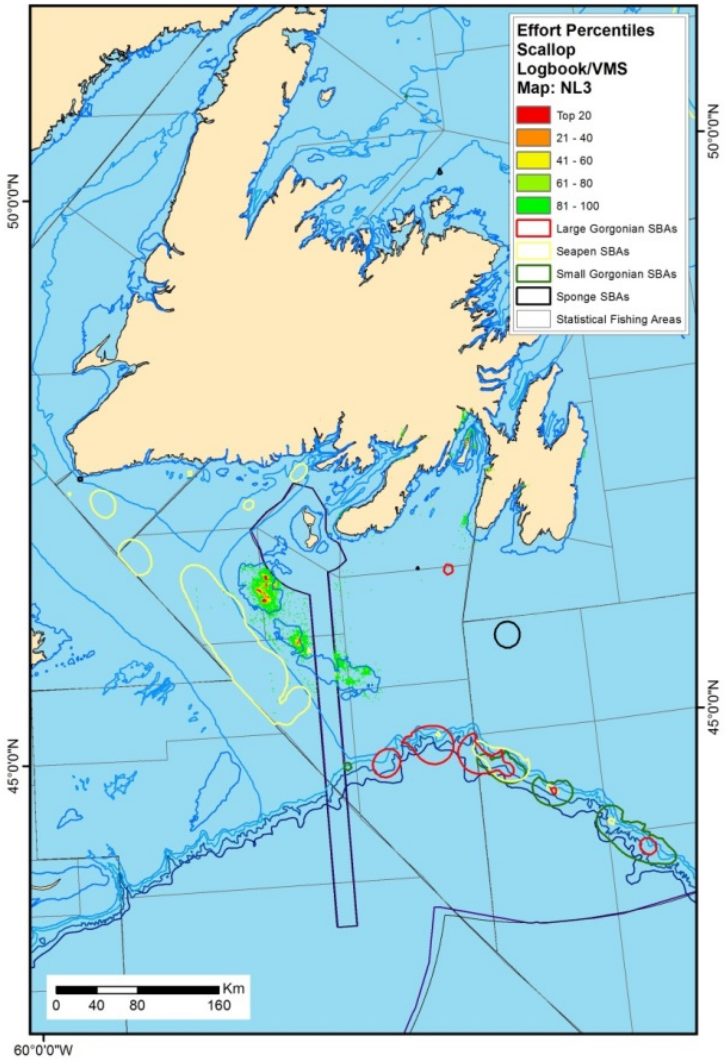

Figure A3 - 117. Scallop, inset NL3.

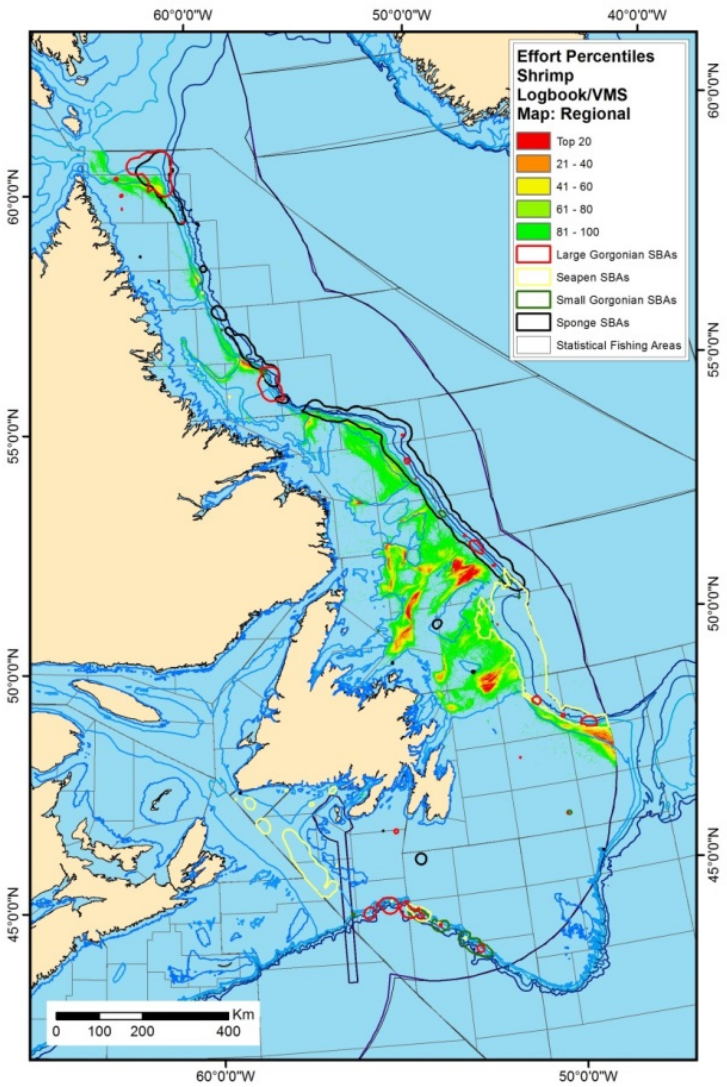

Figure A3 - 118. Shrimp, regional map.

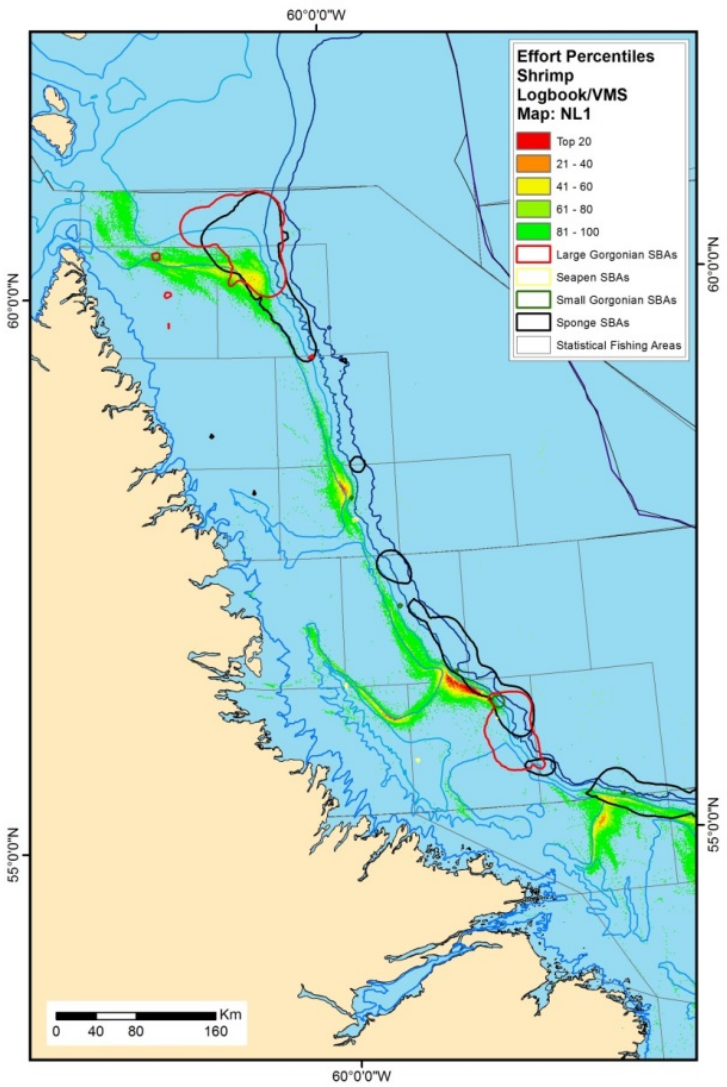

Figure A3 - 119. Shrimp, inset NL1.

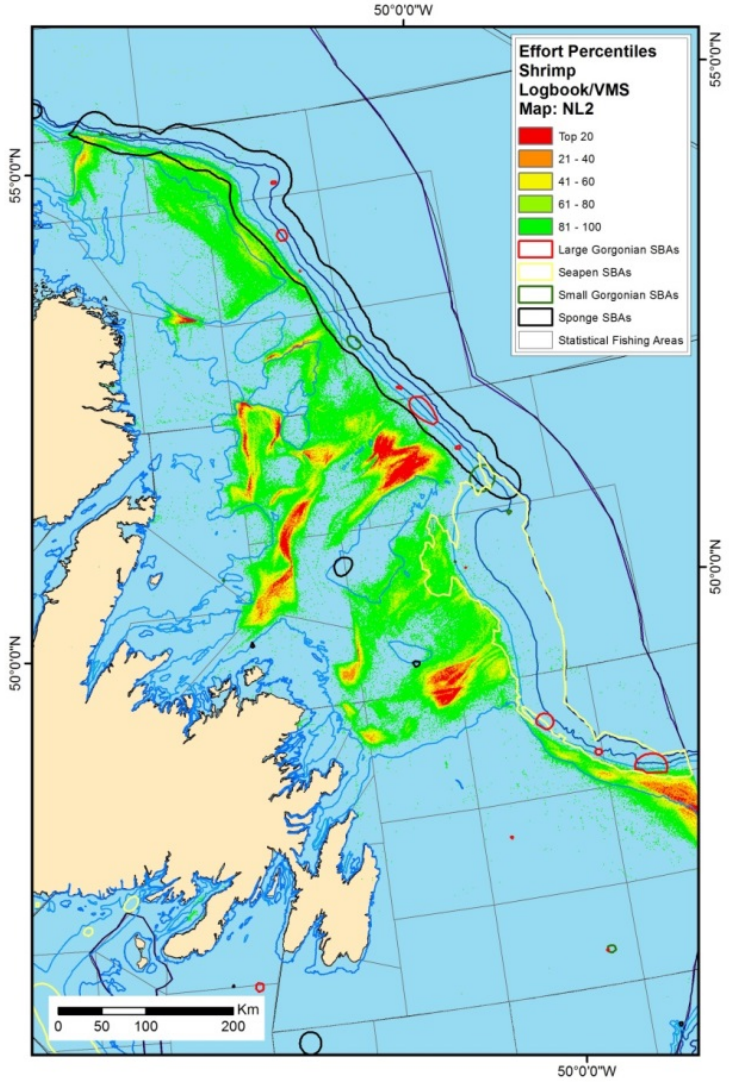

Figure A3 - 120. Shrimp, inset NL2.

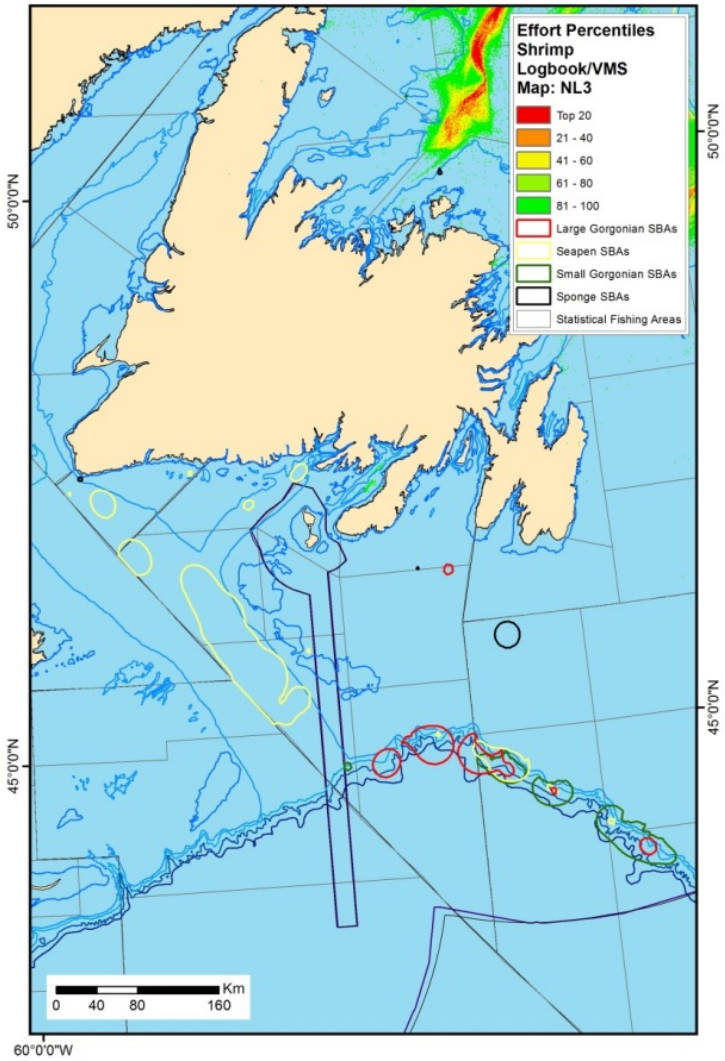

Figure A3 - 121. Shrimp, inset NL3.

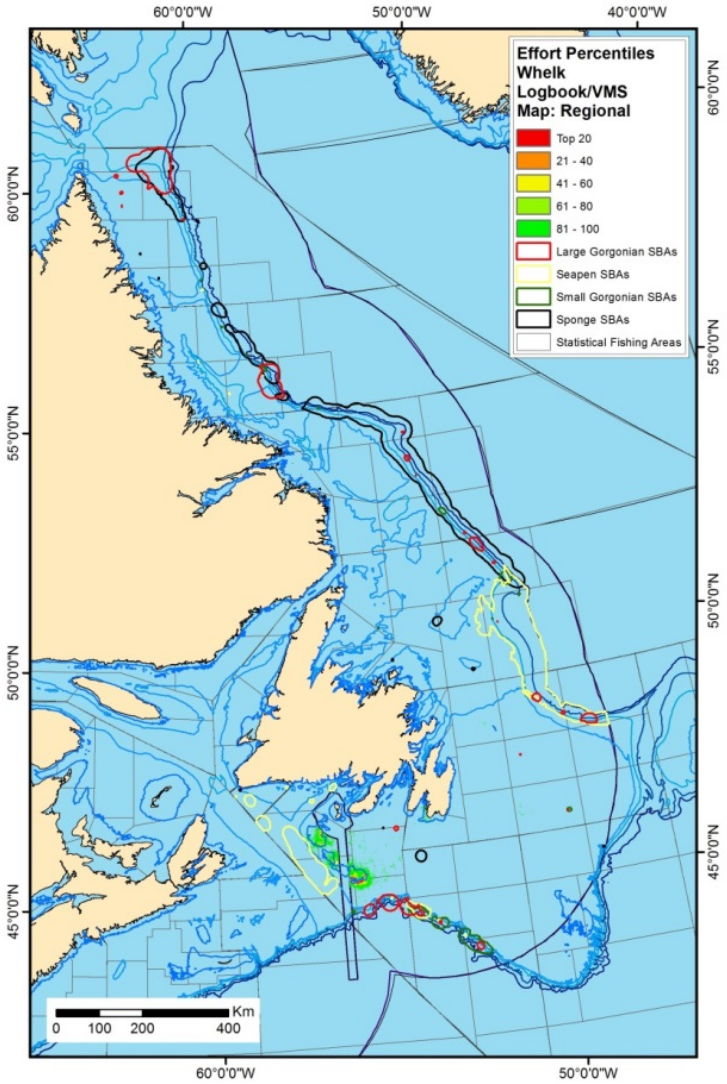

Figure A3 - 122. Whelk, regional map.

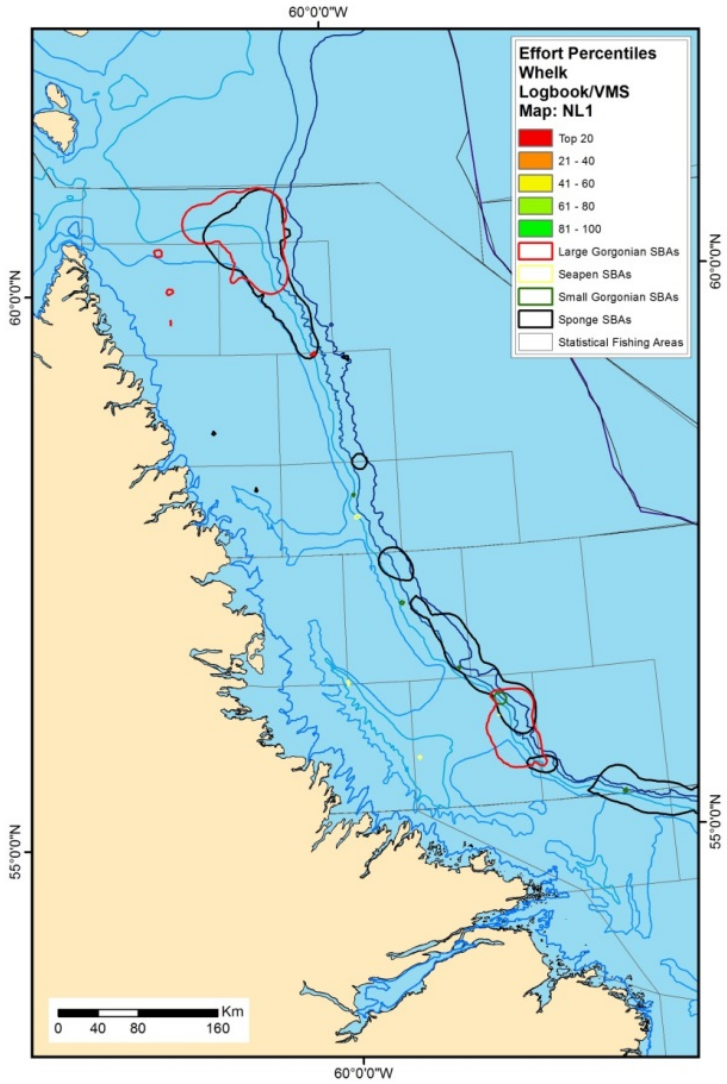

Figure A3 - 123. Whelk, inset NL1.

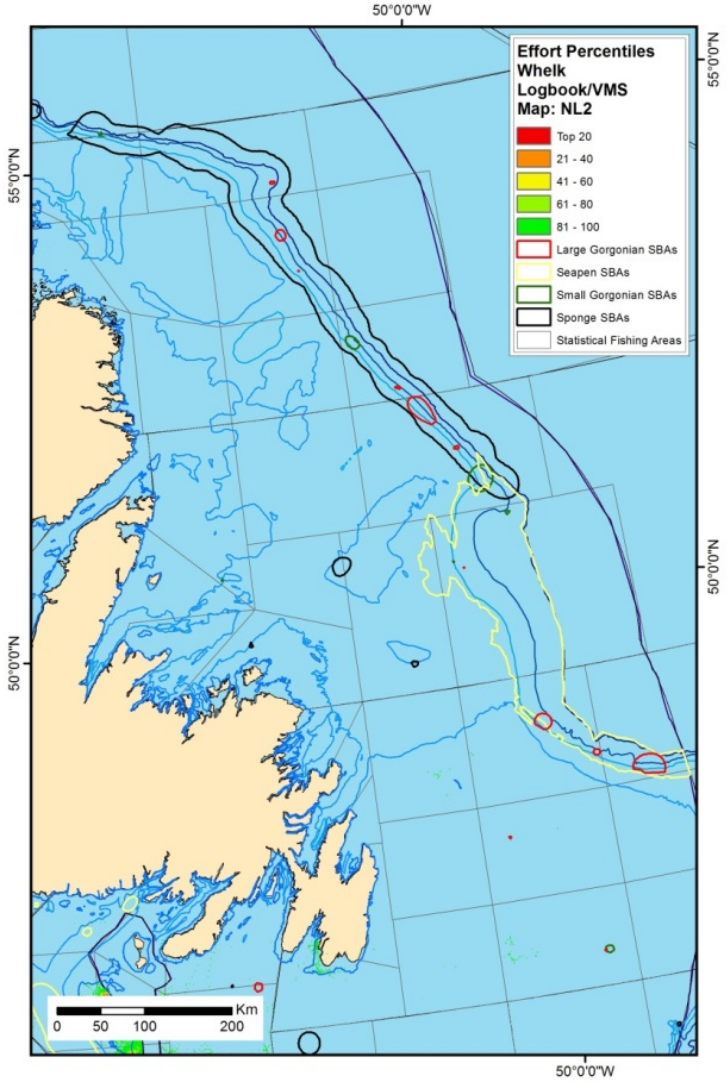

Figure A3 - 124. Whelk, inset NL2.

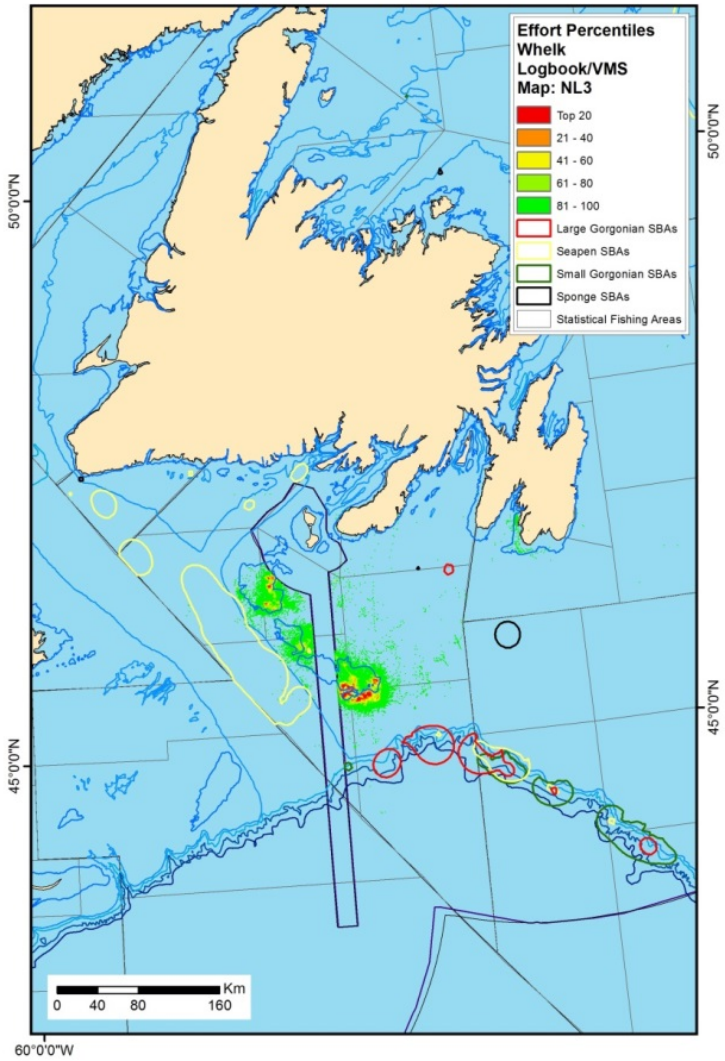

Figure A3 - 125. Whelk, inset NL3.

EASTERN ARCTIC (EA)

In the Eastern Arctic, there are four types of Significant Benthic Areas: small gorgonian, large gorgonian, sponge and sea pen. The first map within this section shows the Significant Benthic Areas without any fishing effort, followed by fisheries class-specific maps for the following fisheries classes in the Eastern Arctic bioregion:

- All fisheries combined
- Groundfish fixed
- Groundfish mobile
- Shrimp

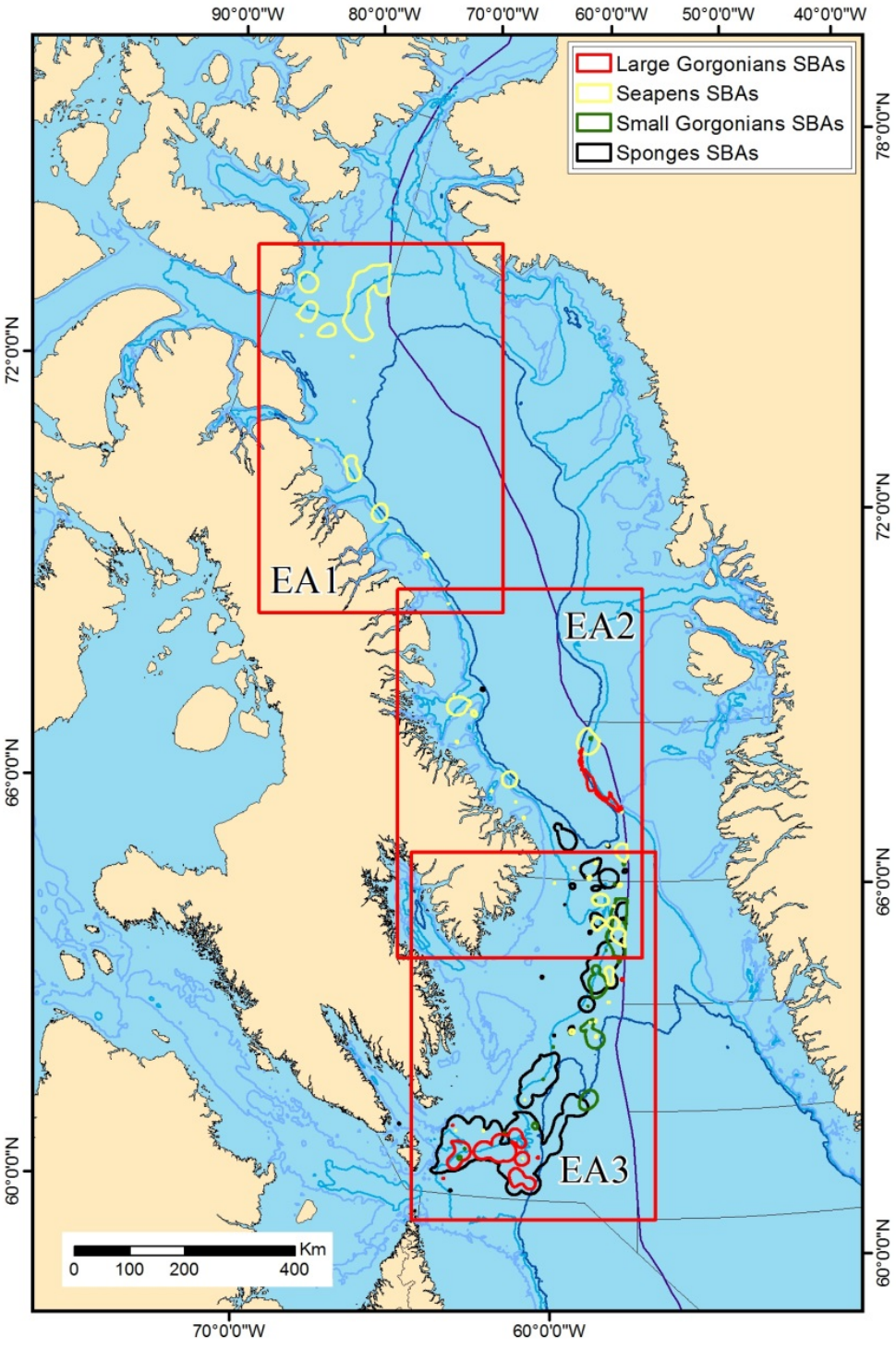

Figure A3 - 126. Inset Index.

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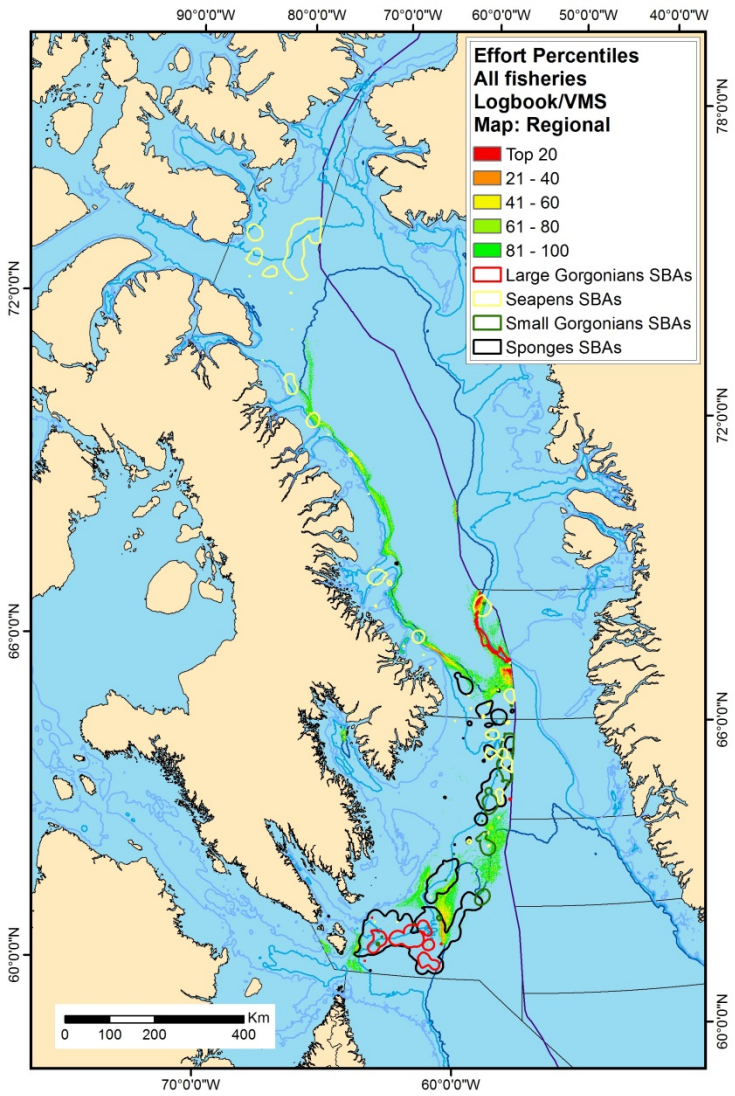

Figure A3 - 127. All fisheries, regional map.

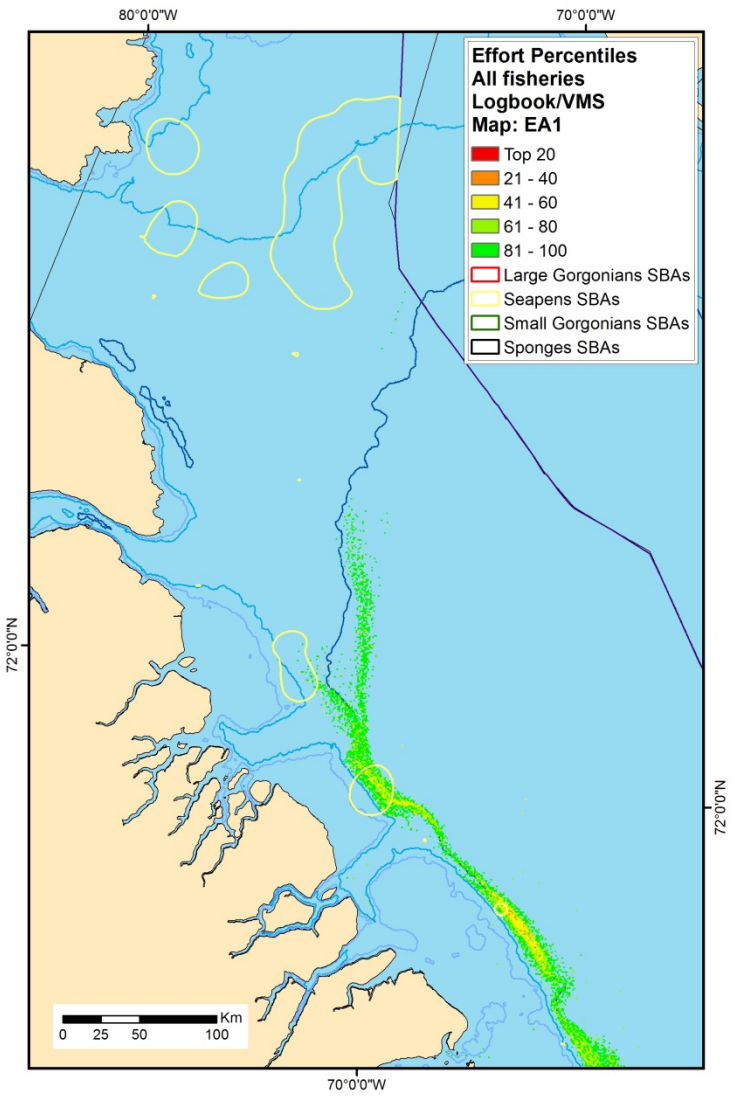

Figure A3 - 128. All fisheries, inset EA1.

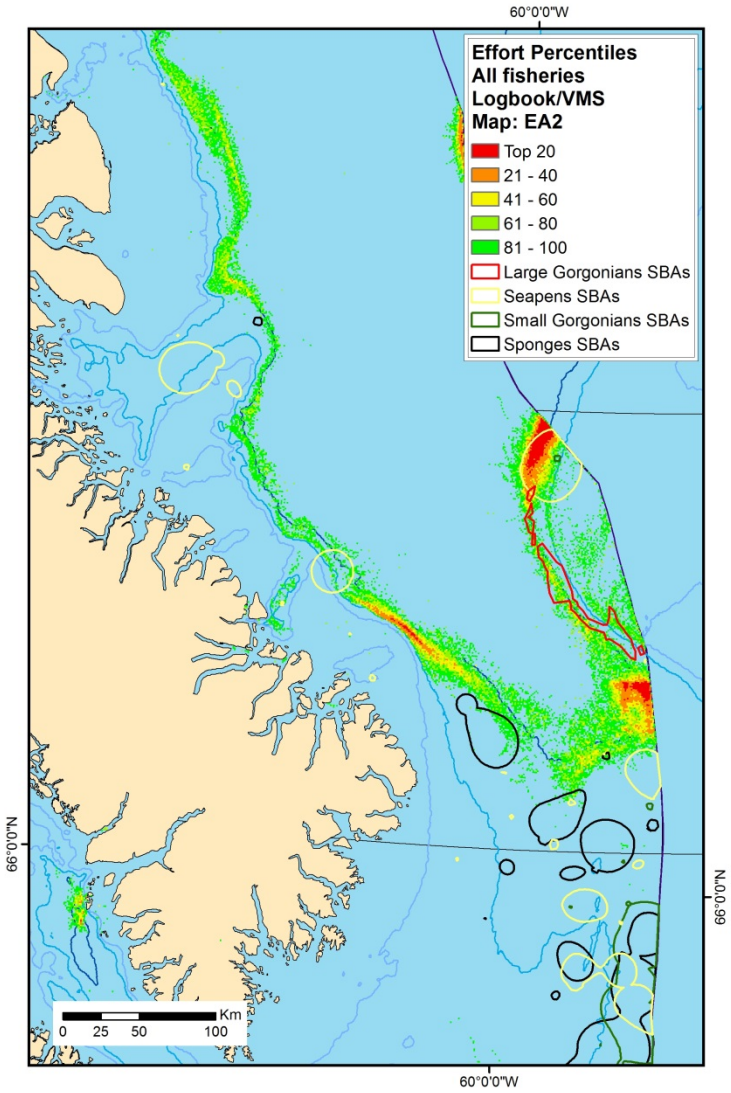

Figure A3 - 129. All fisheries, inset EA2.

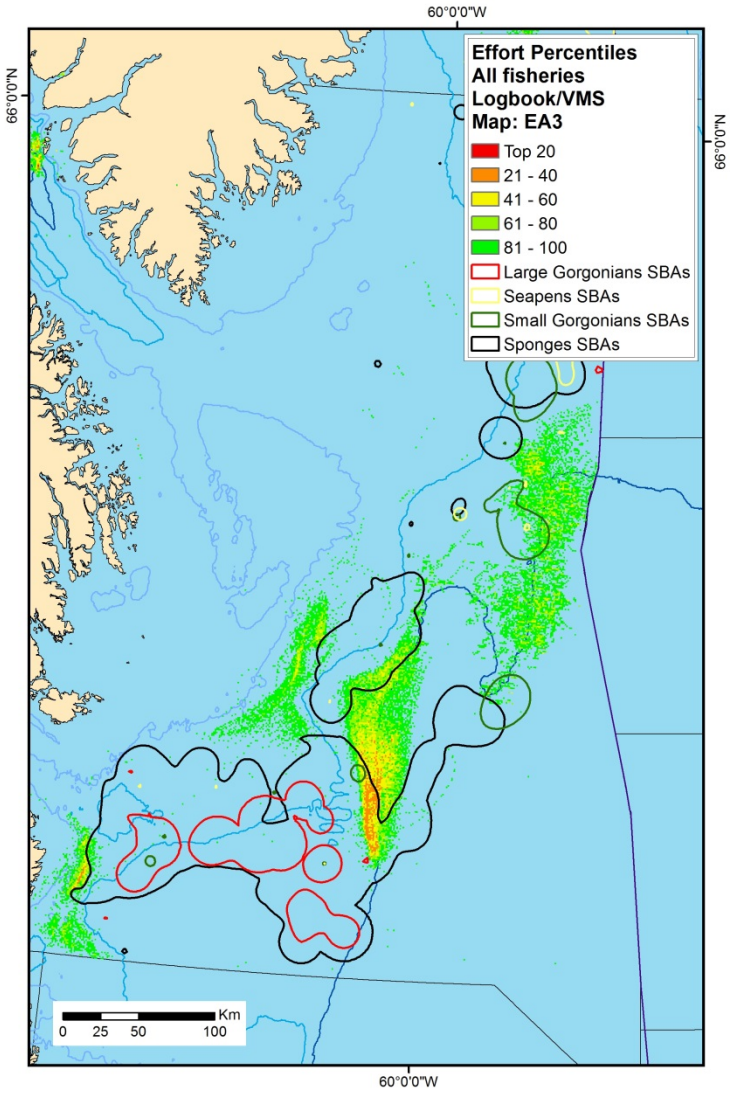

Figure A3 - 130. All fisheries, inset EA3.

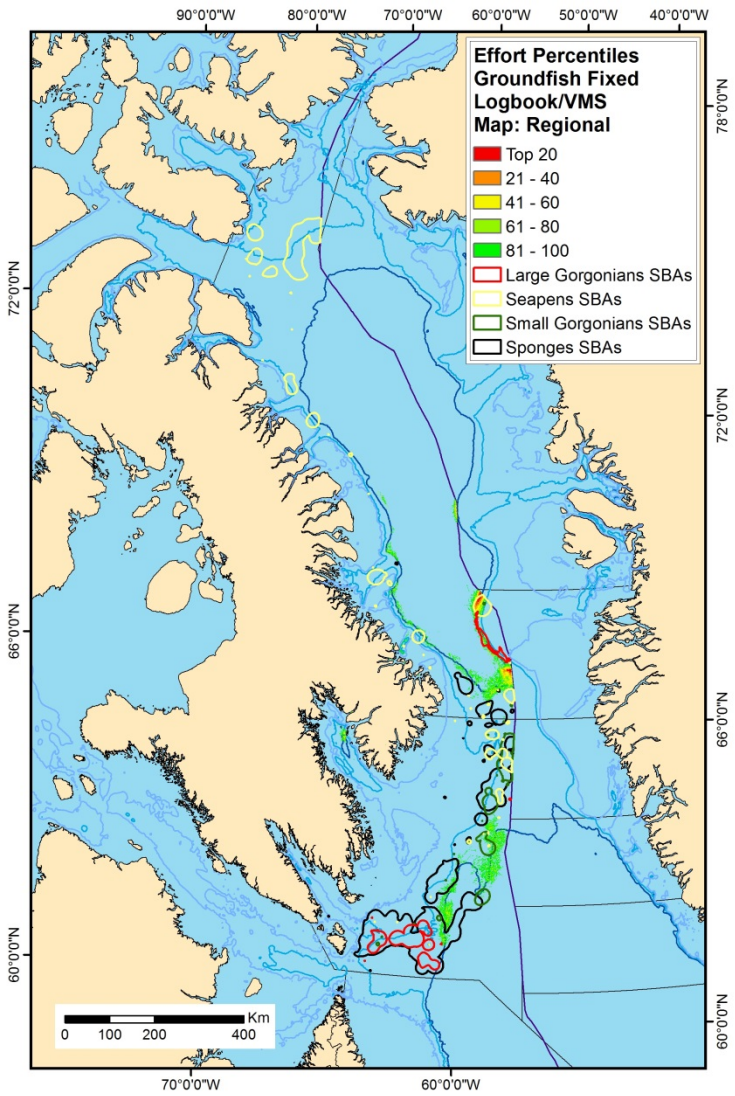

Figure A3 - 131. Groundfish Fixed, regional map.

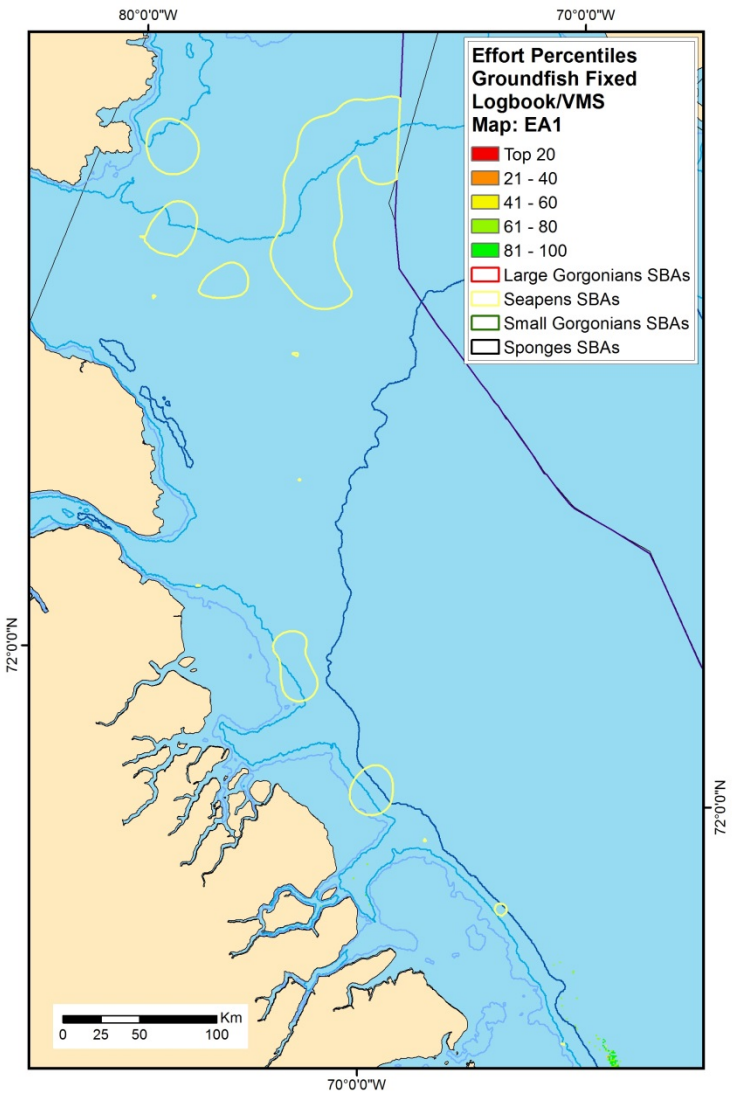

Figure A3 - 132. Groundfish Fixed, inset EA1.

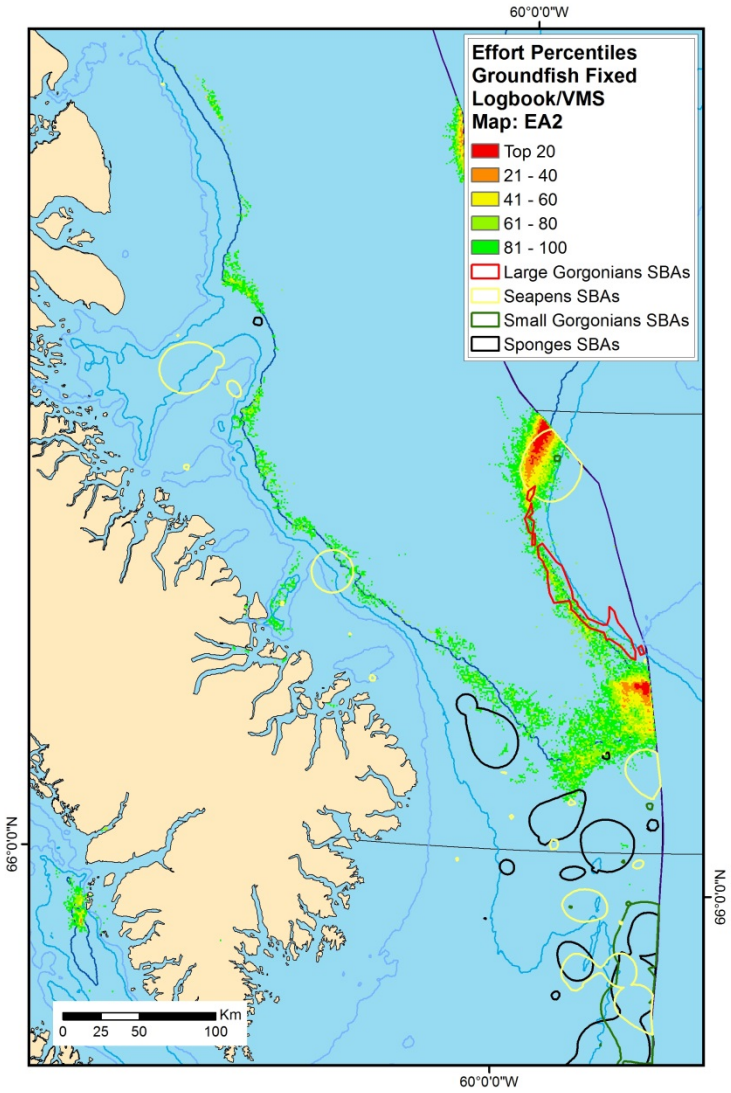

Figure A3 - 133. Groundfish Fixed, inset EA2.

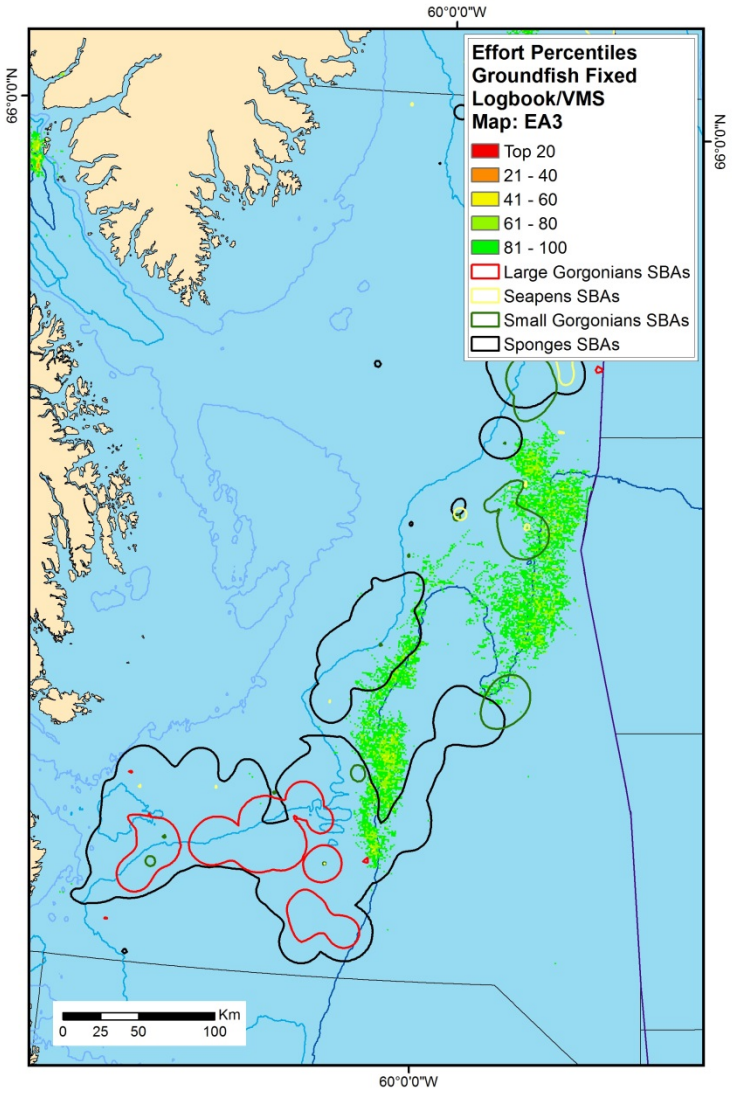

Figure A3 - 134. Groundfish Fixed, inset EA3.

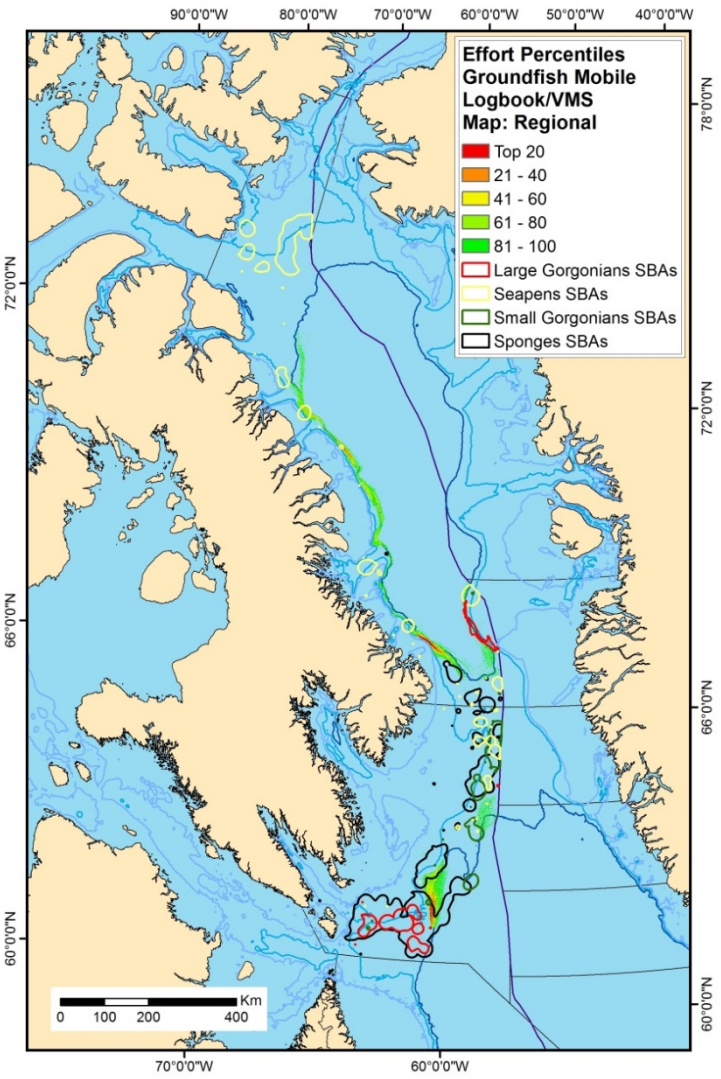

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Figure A3 - 135. Groundfish Mobile, regional map.

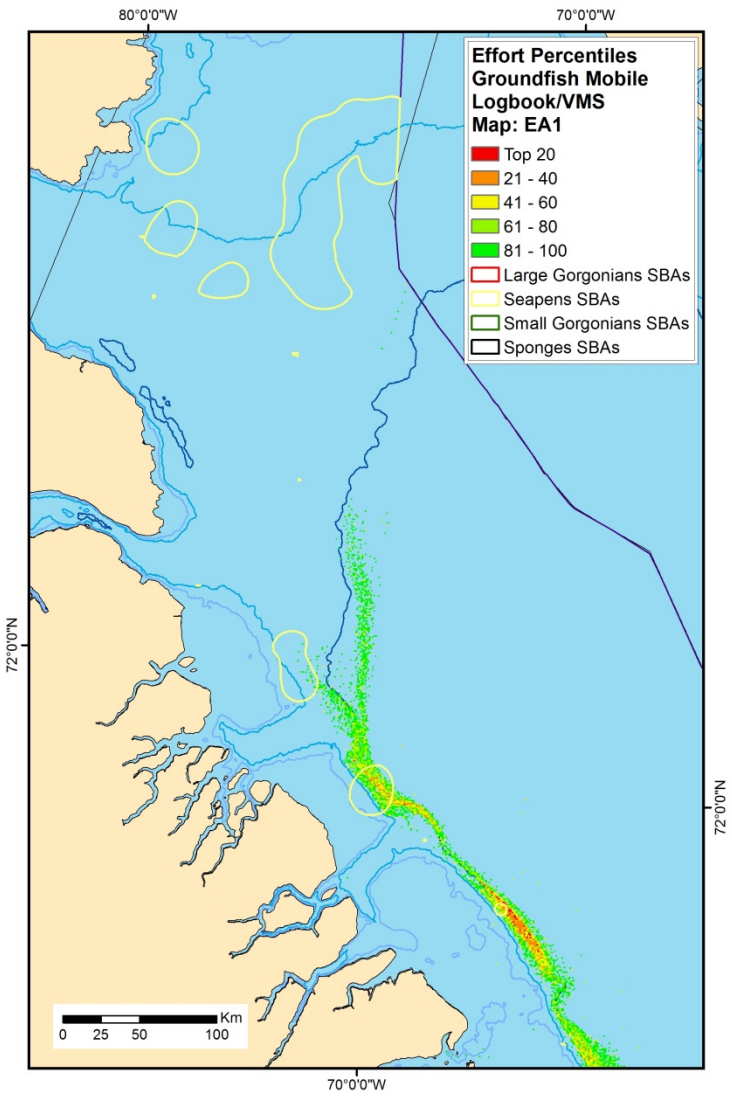

Figure A3 - 136. Groundfish Mobile, inset EA1.

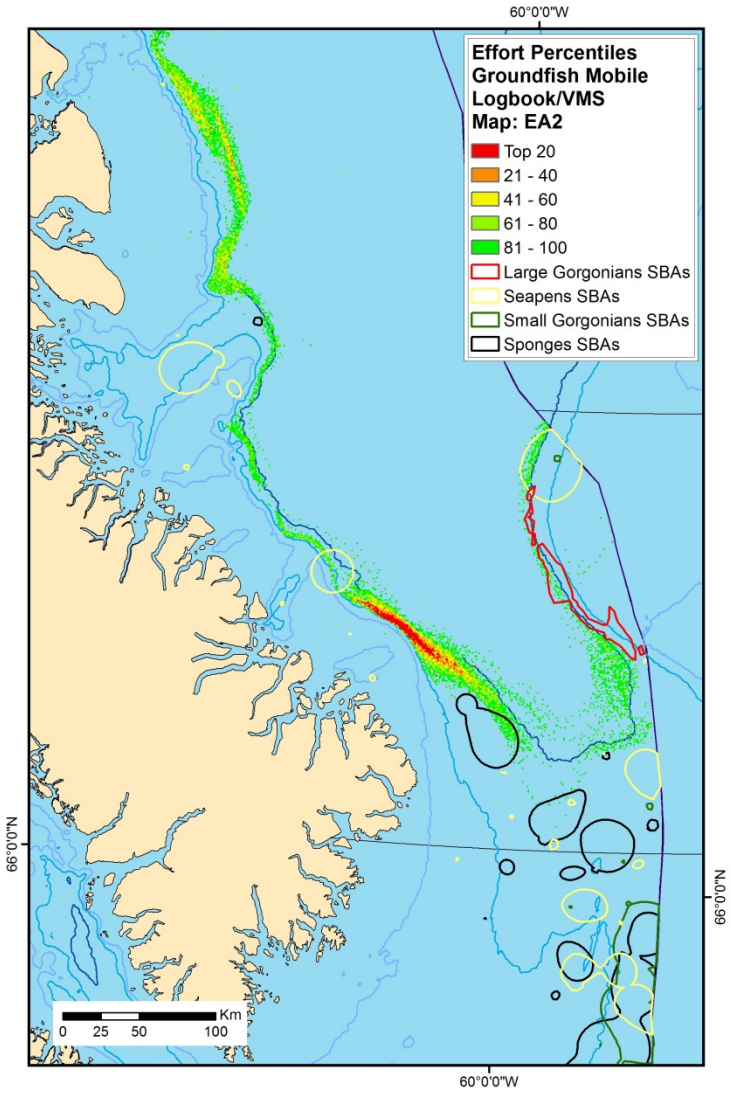

Figure A3 - 137. Groundfish Mobile, inset EA2.

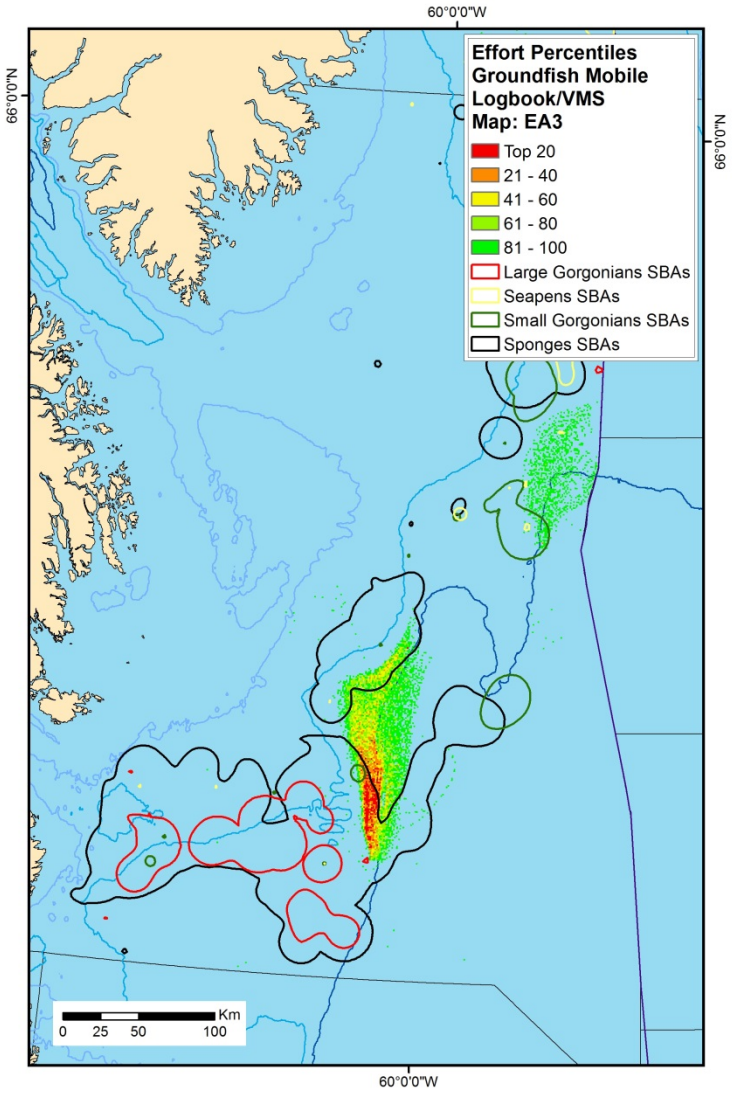

Figure A3 - 138. Groundfish Mobile, inset EA3.

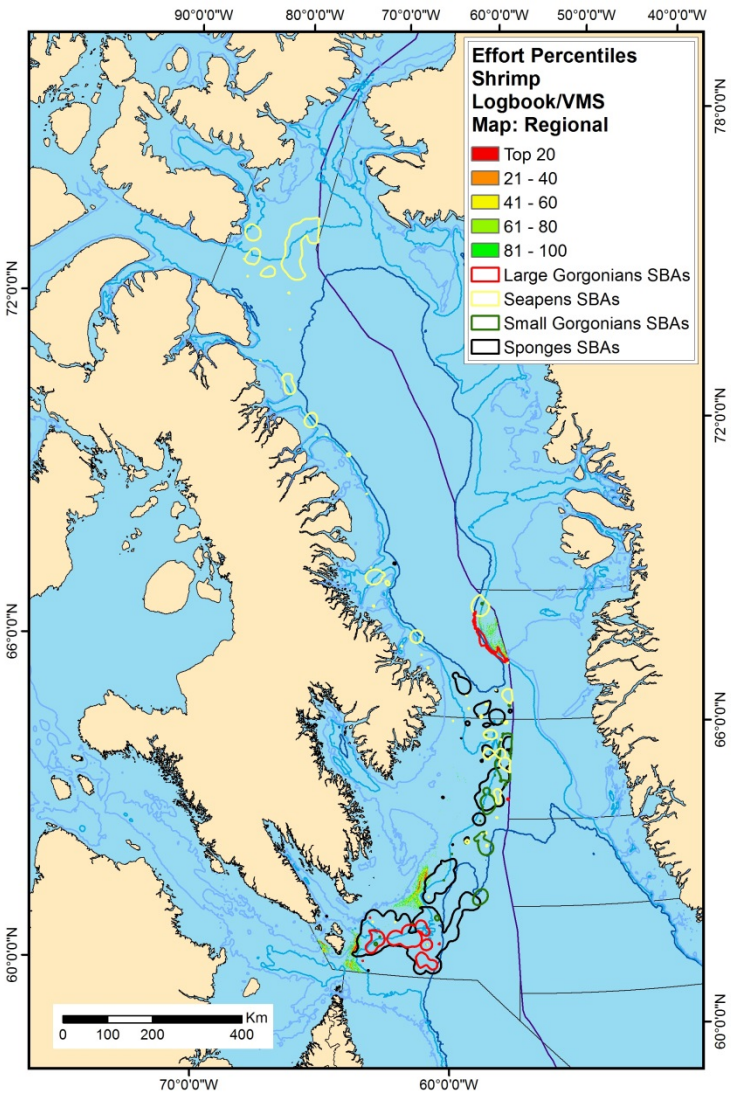

Figure A3 - 139. Shrimp, regional map.

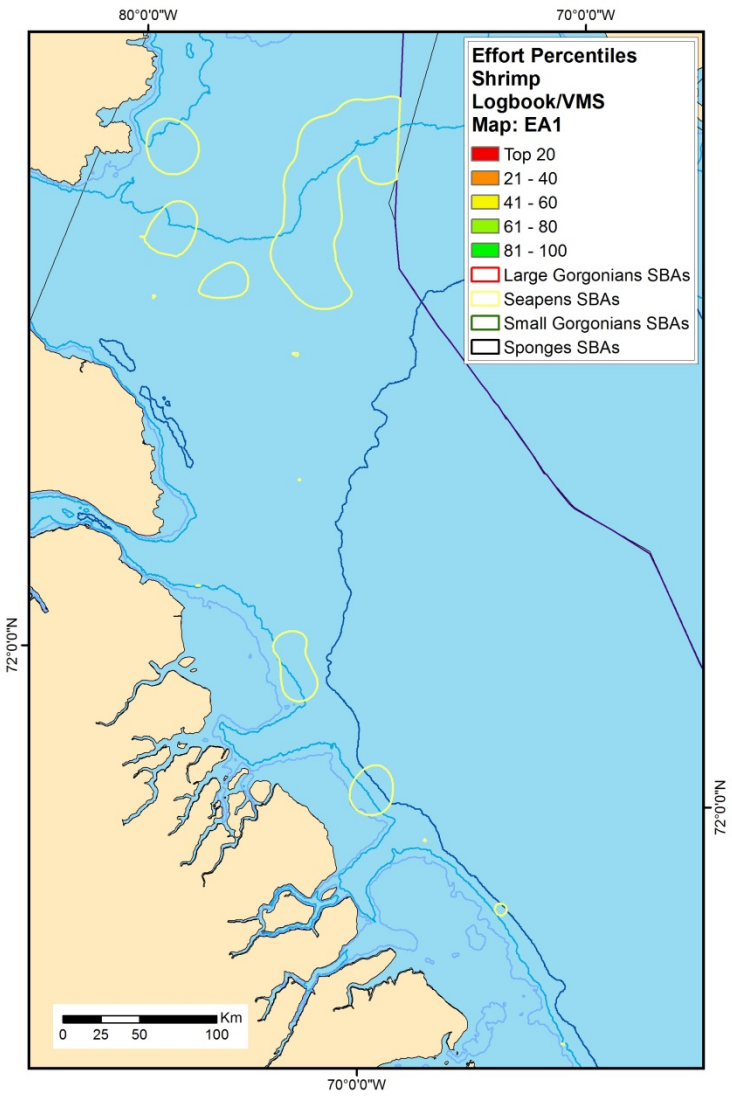

Figure A3 - 140. Shrimp, inset EA1.

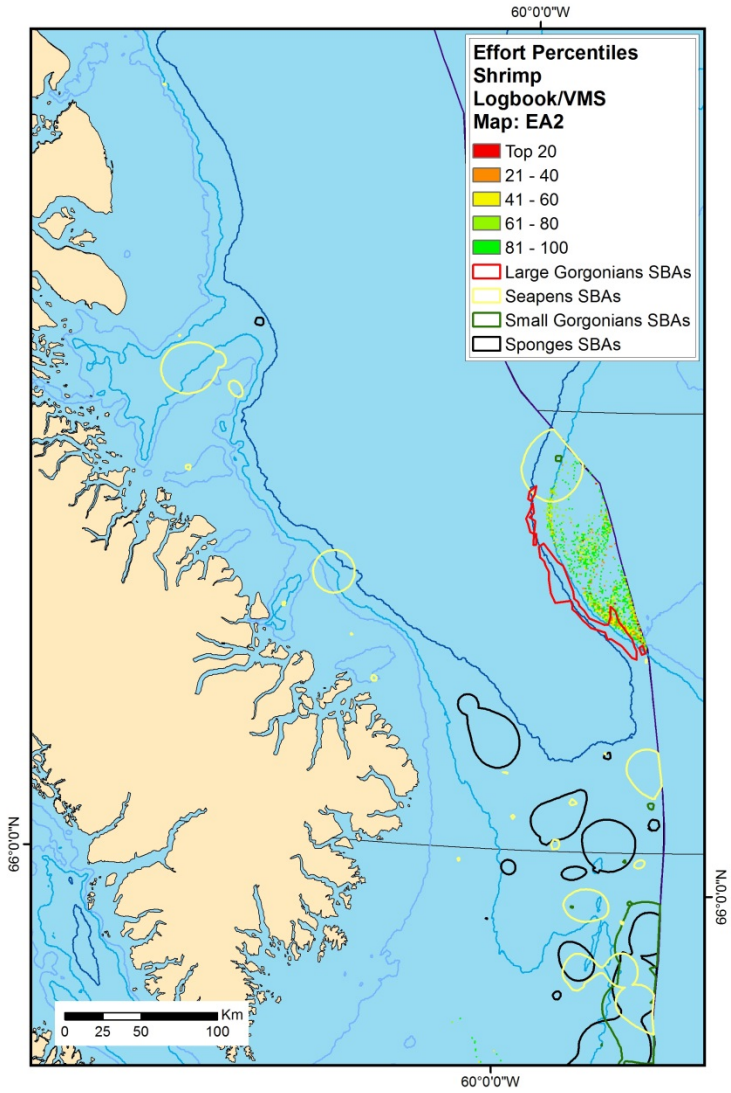

Figure A3 - 141. Shrimp, inset EA2.

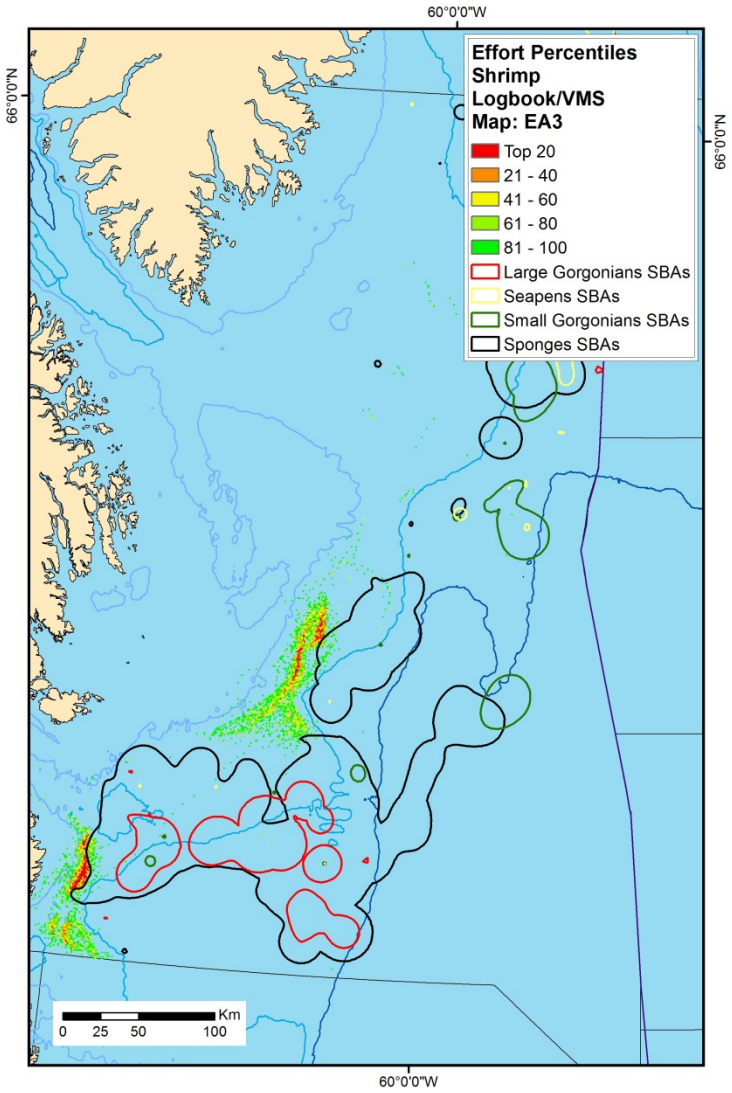

Figure A3 - 142. Shrimp, inset EA3.

APPENDIX 4. AGGREGATED FISHERIES CLASSES

This appendix shows combined effort layers (merged effort from logbooks and VMS data) for aggregates of fisheries classes overlaid with Significant Benthic Area outlines. The aggregates of fisheries classes are: all fisheries excluding the pelagic fisheries class, fixed gears, and mobile gears. See Table 2 in main text for more information on how specific fisheries are classified. Note that fixed gear and mobile gear categories do not include the “Other” category.

Significant Benthic Areas of each type present in a bioregion (small gorgonian, large gorgonian, sea pen or sponge) are all included together on maps marked with different colours.

For each bioregion, the first map shows the distribution of Significant Benthic Areas without fishing effort. Extent indicators for more detailed maps of effort and sensitive benthic areas are marked on the full size map. The “zoomed-in” maps (insets) are shown below the full extent map to allow a closer look at the effort within a Significant Benthic Area. Maps of fishing effort and Significant Benthic Areas within each bioregion are shown alphabetically by fishery category.

SCOTIAN SHELF (SS)

In the Scotian Shelf, there are three types of Significant Benthic Areas: large gorgonian, sea pen and sponge. The first map within this section shows the Significant Benthic Areas without any fishing effort, followed by fishing effort from all fisheries classes excluding the pelagic fisheries class, fixed gears fisheries classes, and mobile gears fisheries classes.

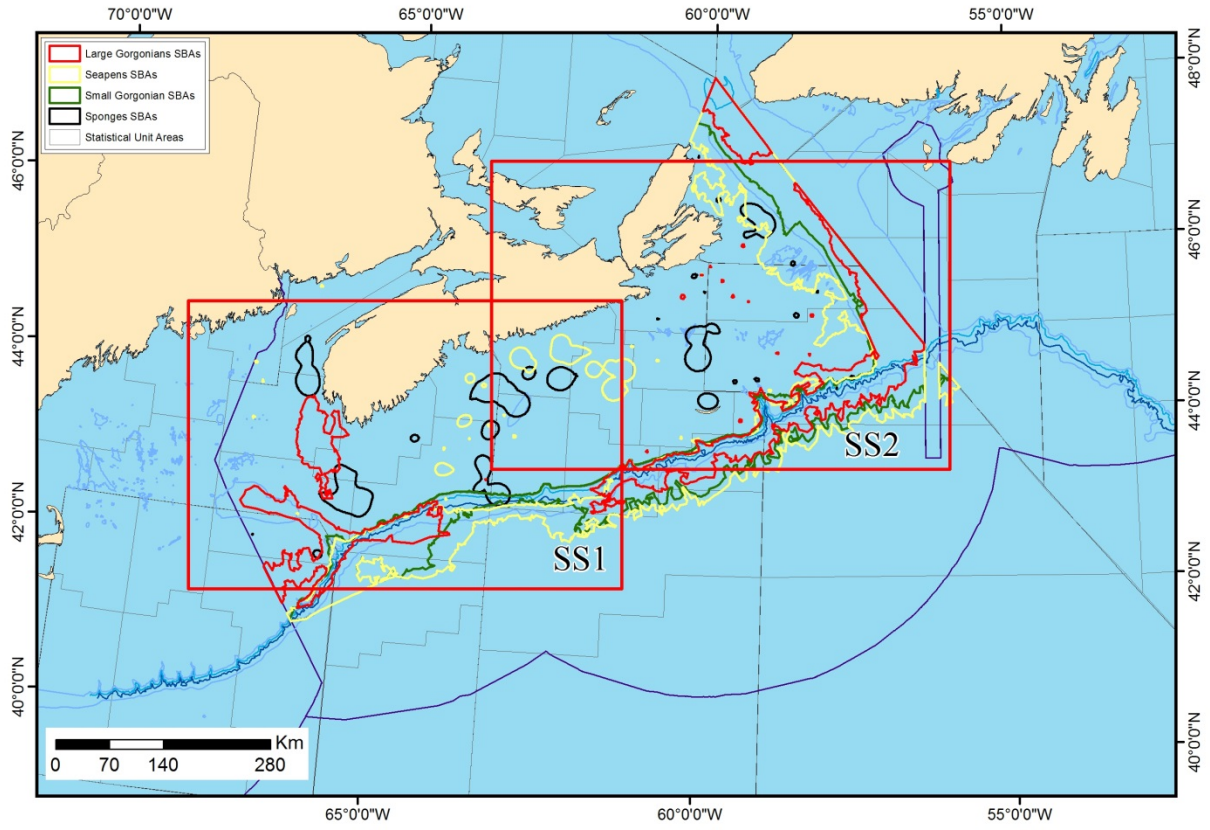

Figure A4 - 1. Inset Index.

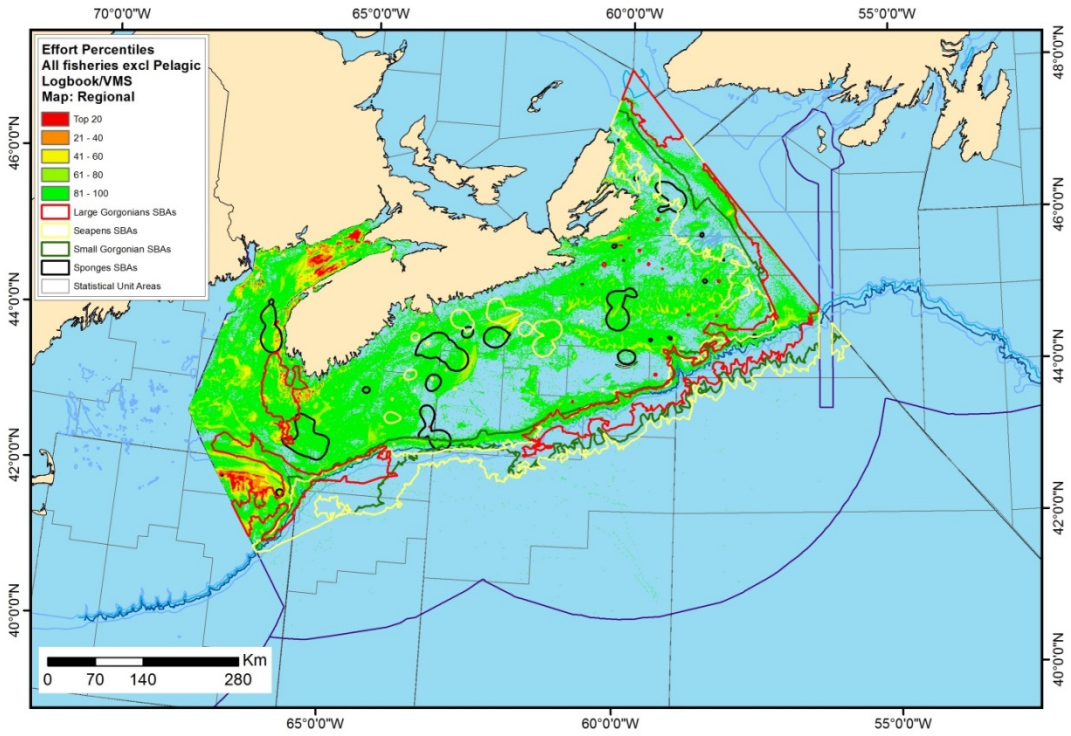

Figure A4 - 2. All fisheries excluding pelagic, regional map.

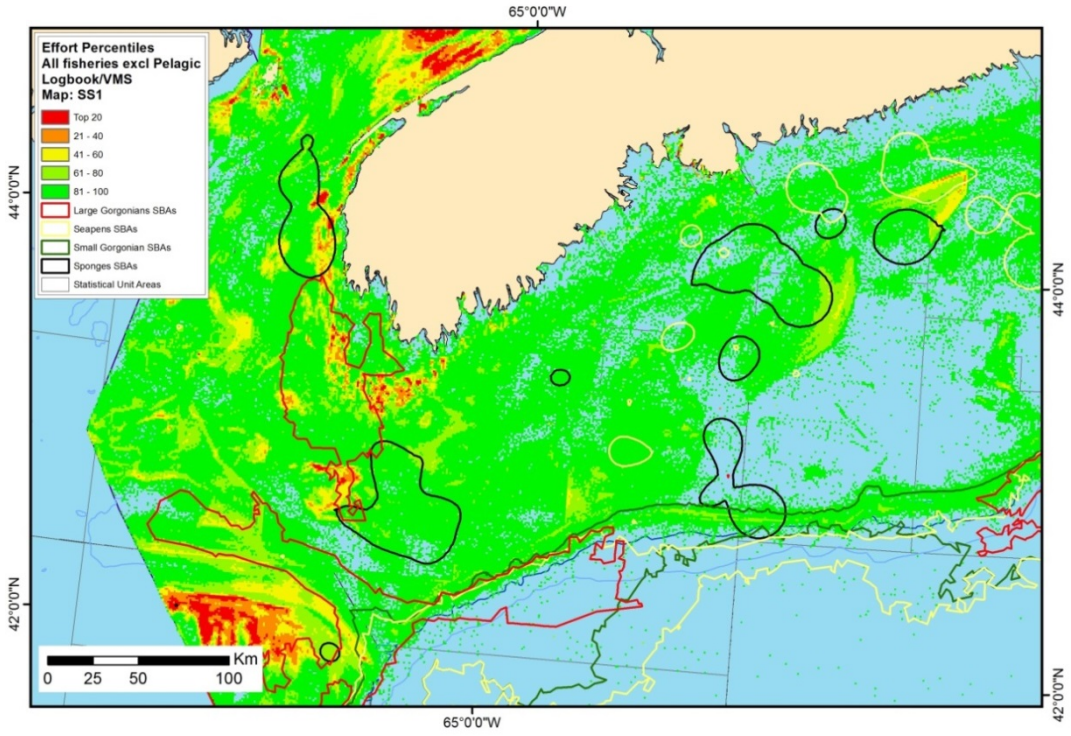

Figure A4 - 3. All fisheries excluding pelagic, inset SS1.

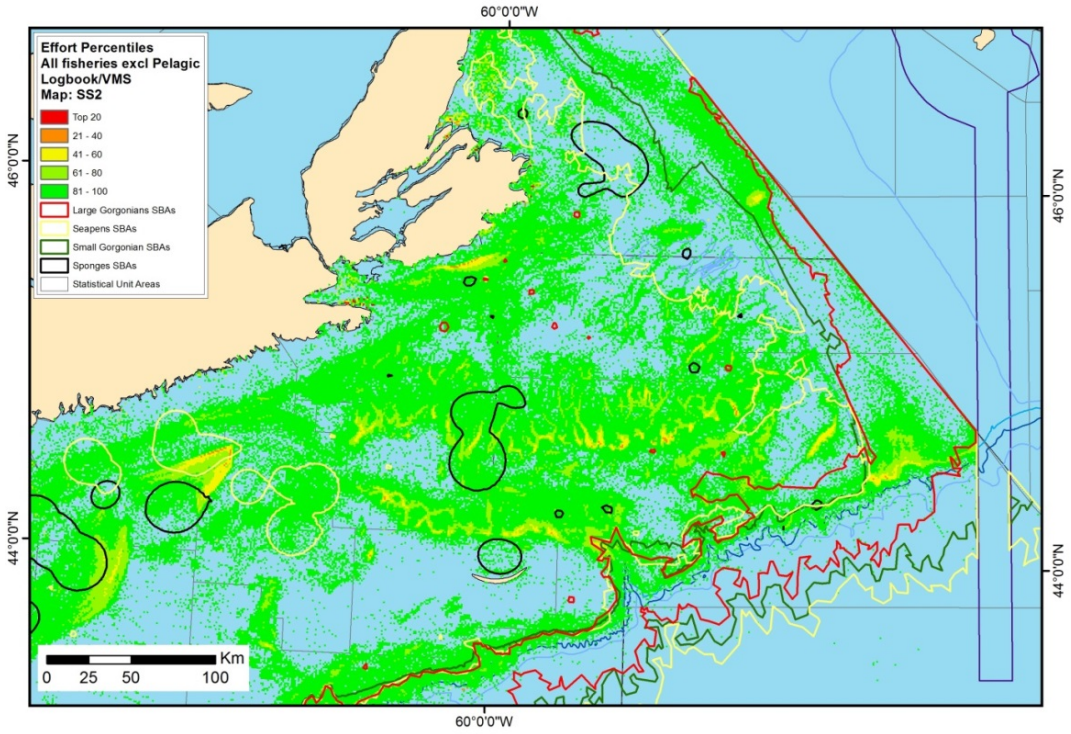

Figure A4 - 4. All fisheries excluding pelagic, inset SS2.

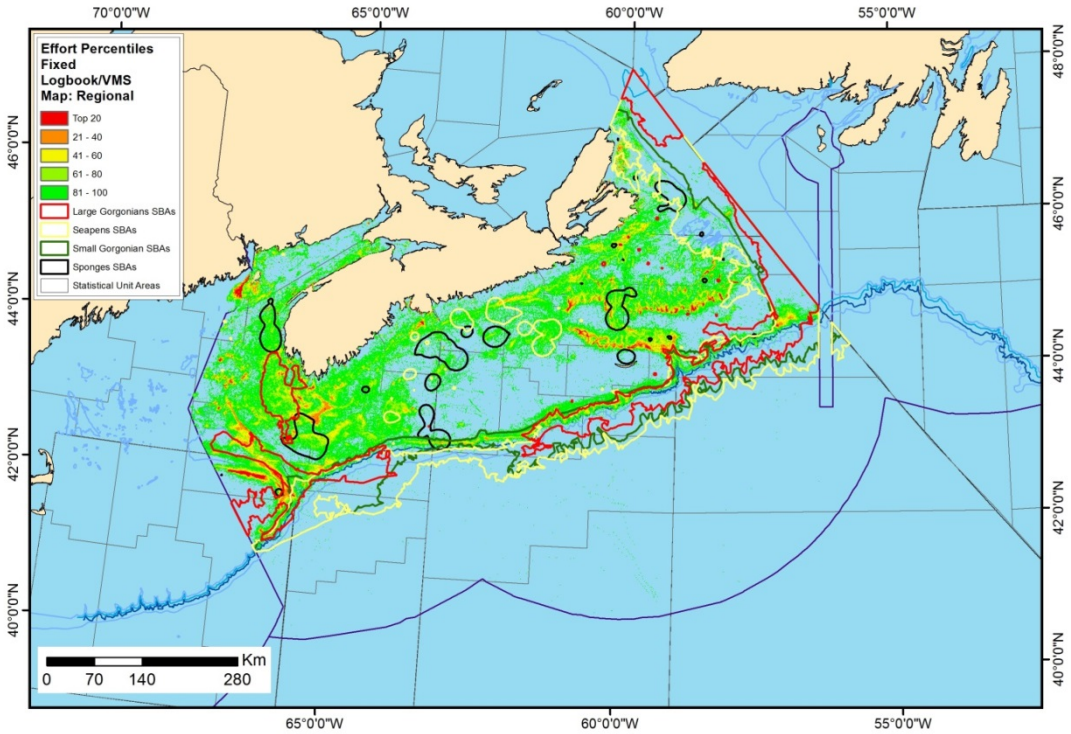

Figure A4 - 5. Fixed, regional map.

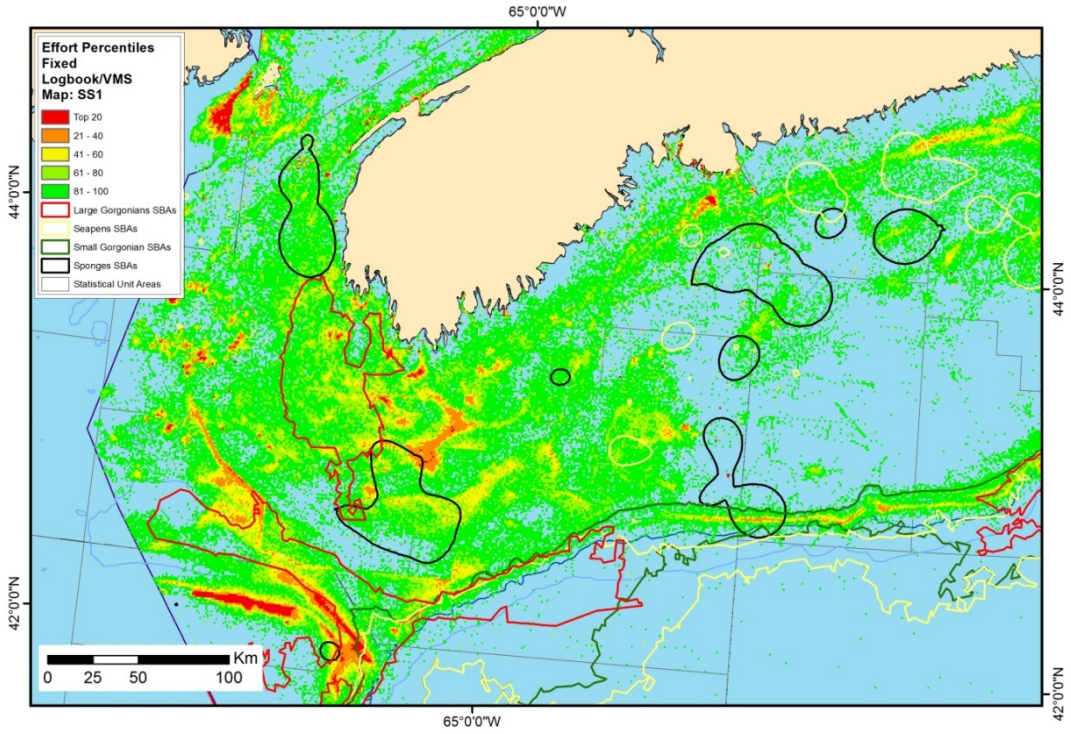

Figure A4 - 6. Fixed, inset SS1.

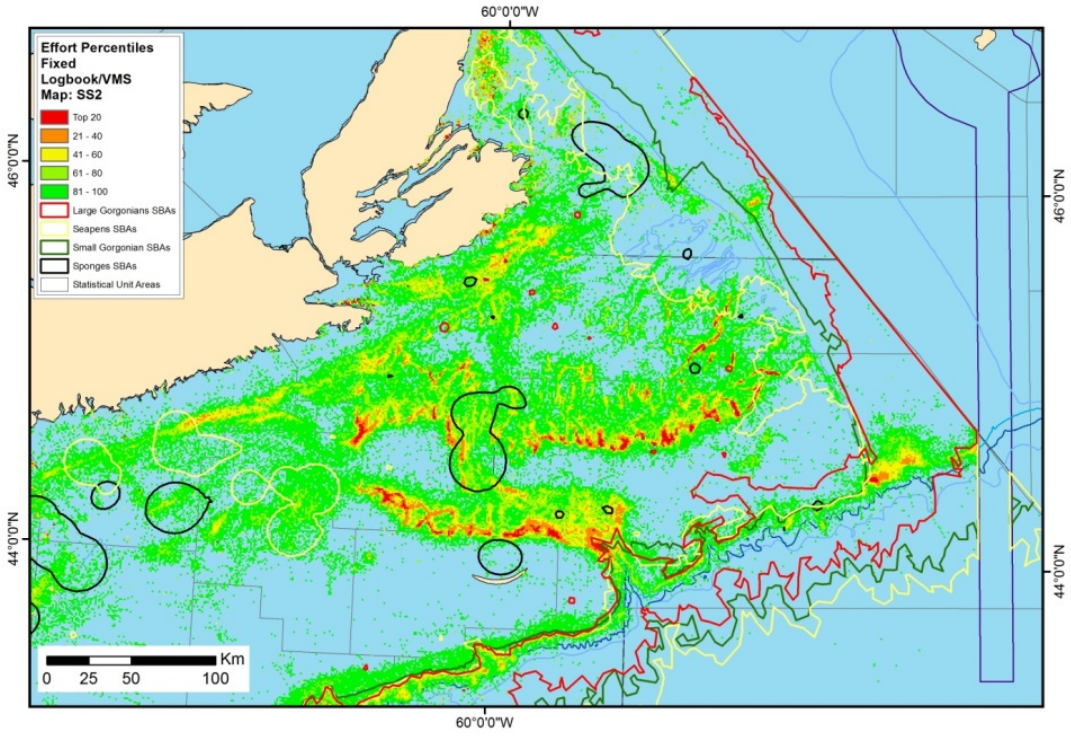

Figure A4 - 7. Fixed, inset SS2.

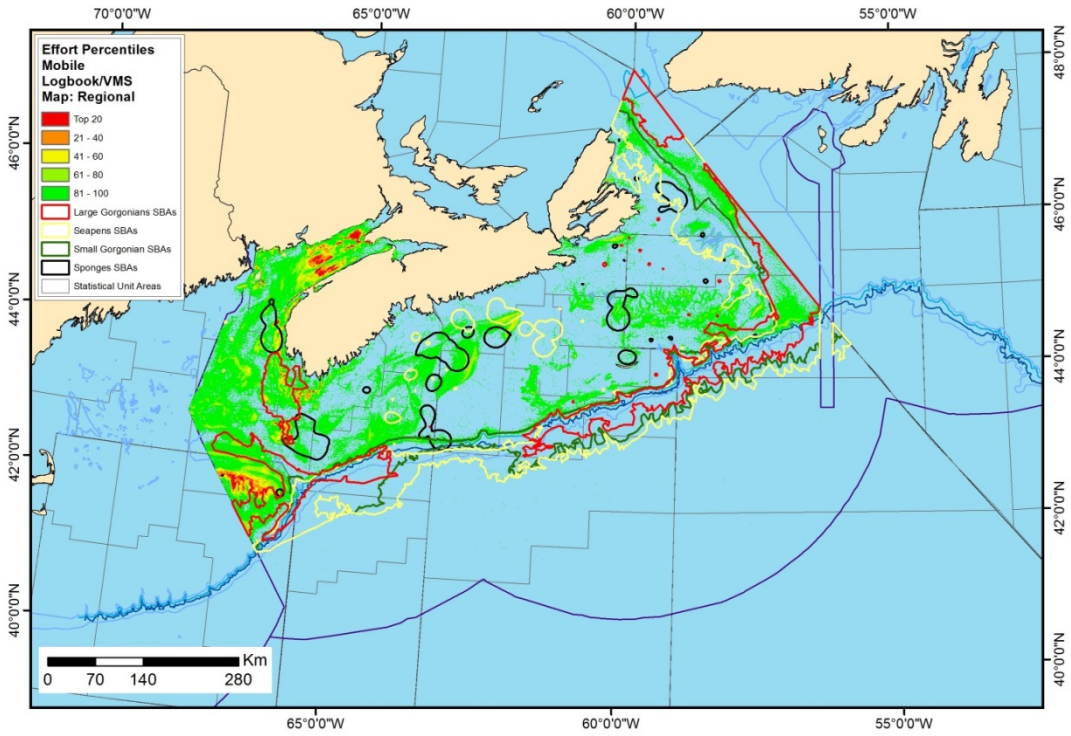

Figure A4 - 8. Mobile, regional map.

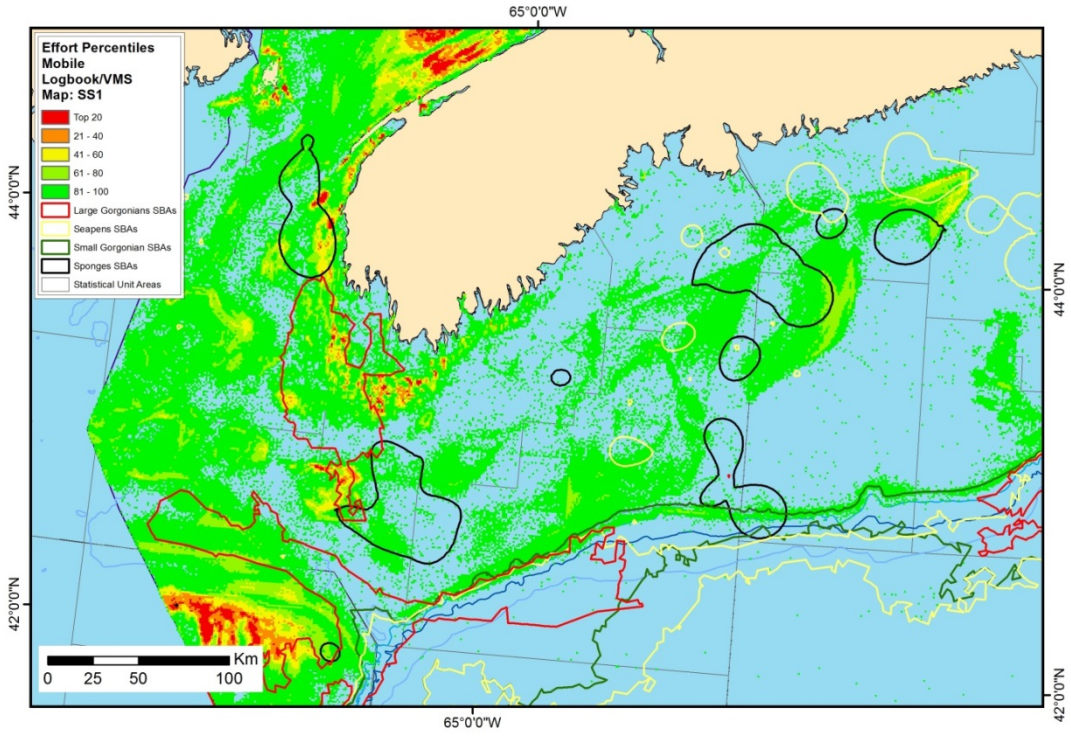

Figure A4 - 9. Mobile, inset SS1.

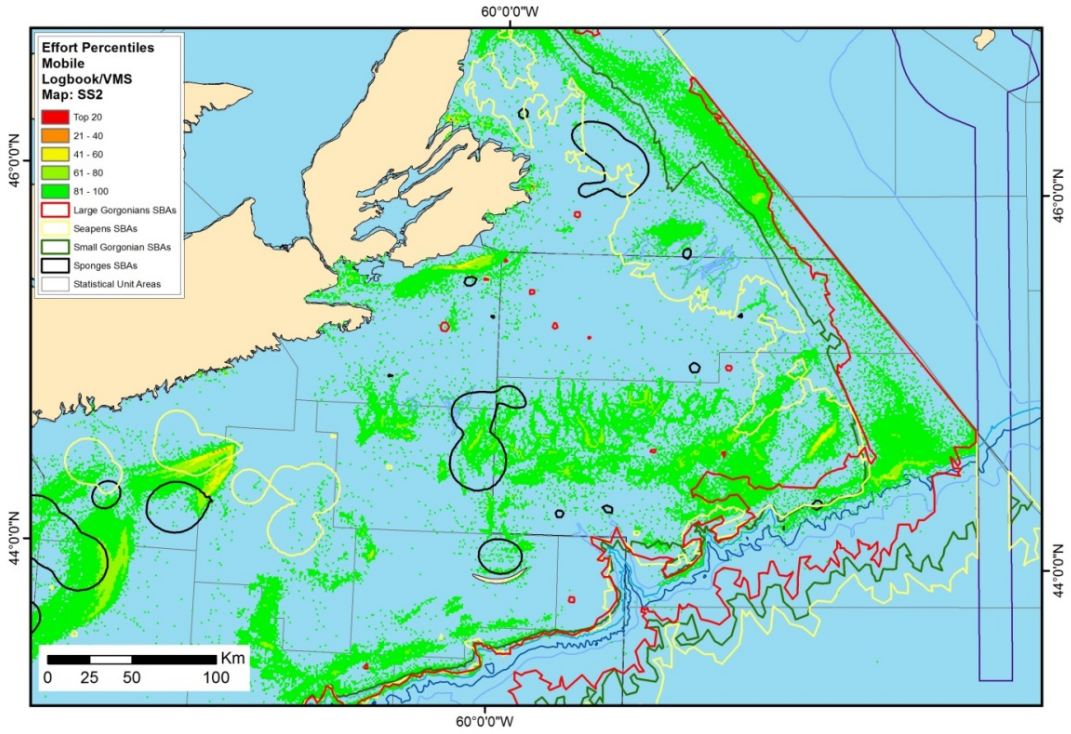

Figure A4 - 10. Mobile, inset SS2.

GULF OF ST. LAWRENCE (GSL)

In the Gulf of St. Lawrence, there are two types of Significant Benthic Areas: sea pen and sponge. The first map within this section shows the Significant Benthic Areas without any fishing effort, followed by fishing effort from all fisheries classes excluding the pelagic fisheries class, fixed gears fisheries class, and mobile gears fisheries class.

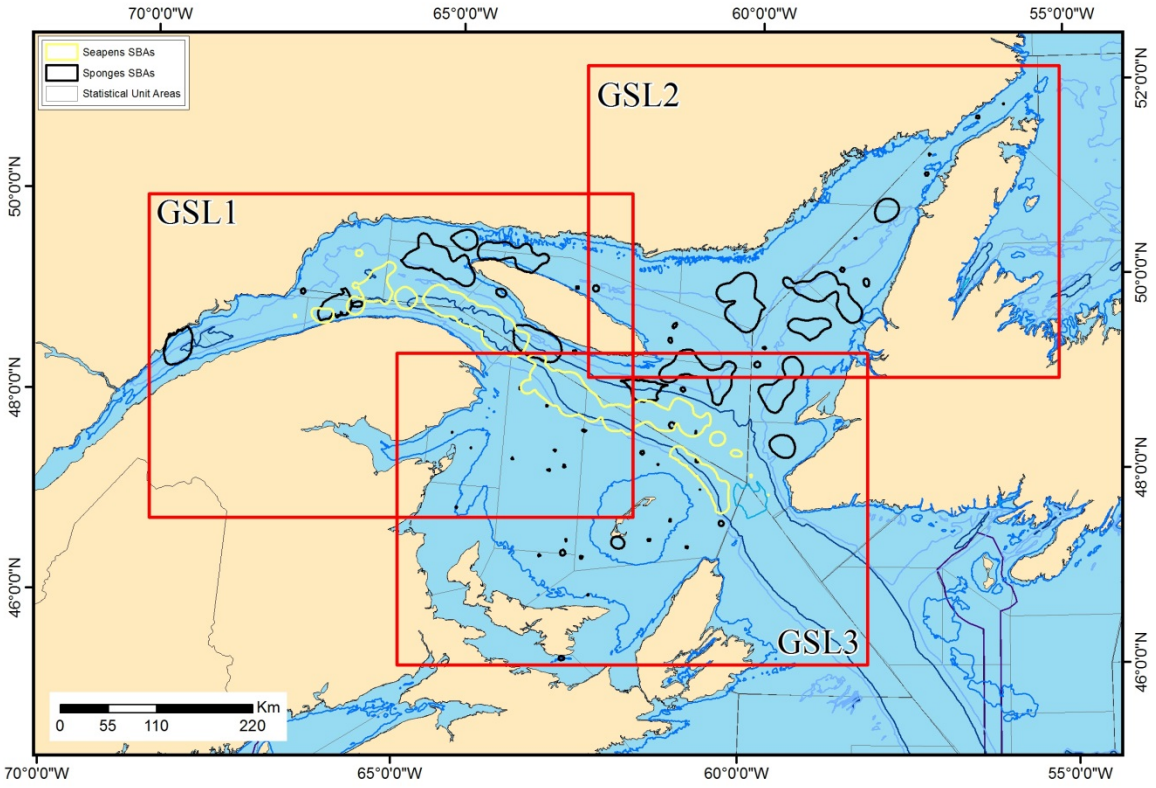

Figure A4 - 11. Inset Index.

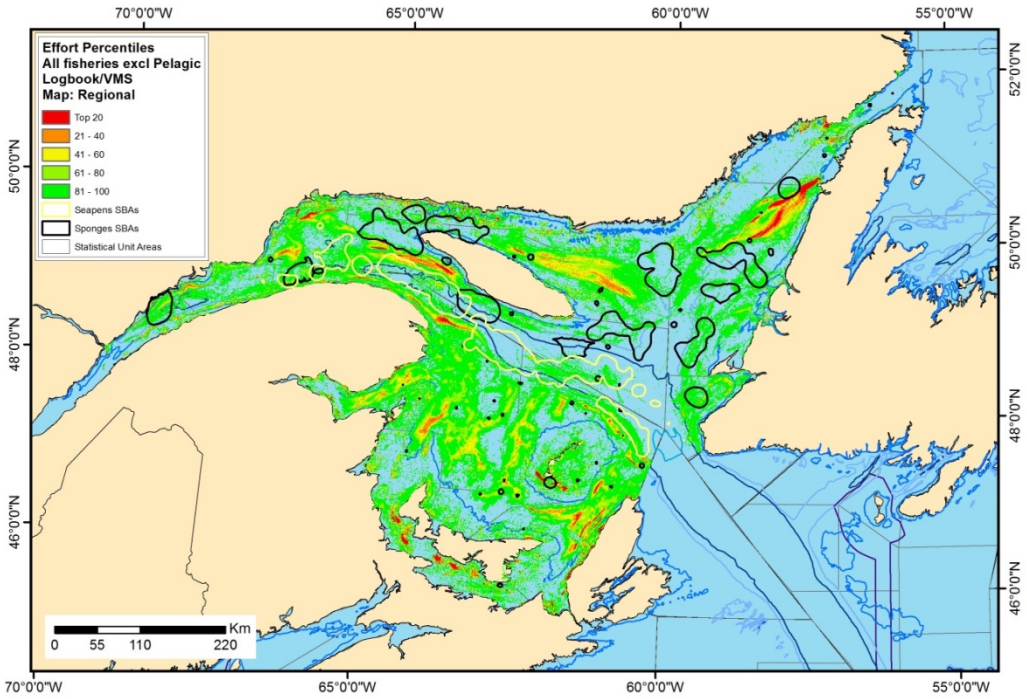

Figure A4 - 12. All fisheries excluding pelagic, regional map.

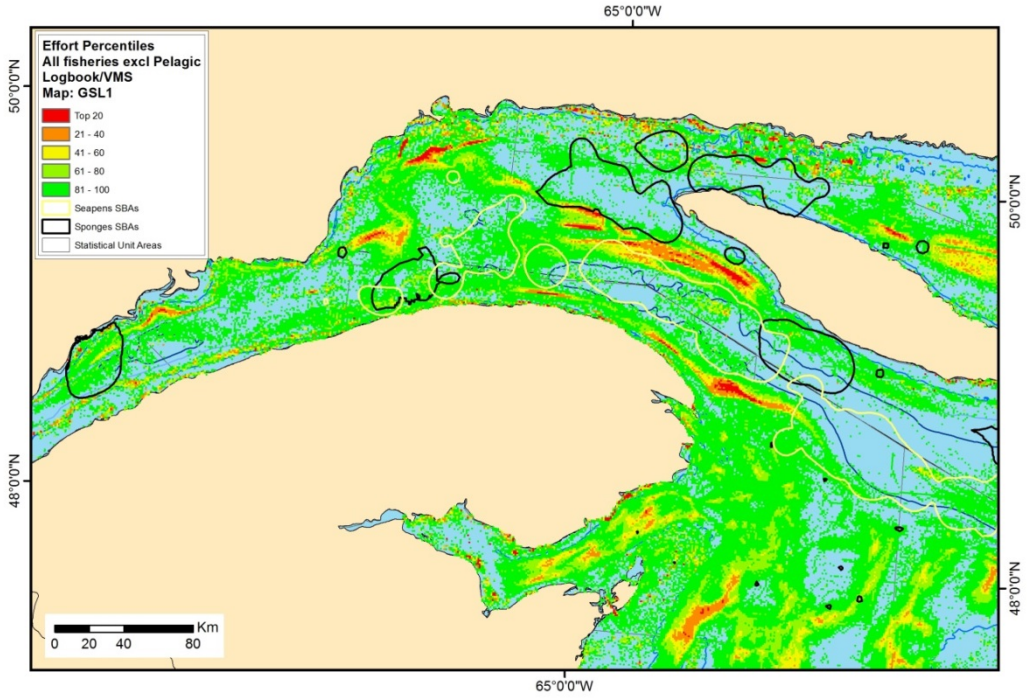

Figure A4 - 13. All fisheries excluding pelagic, inset GSL1.

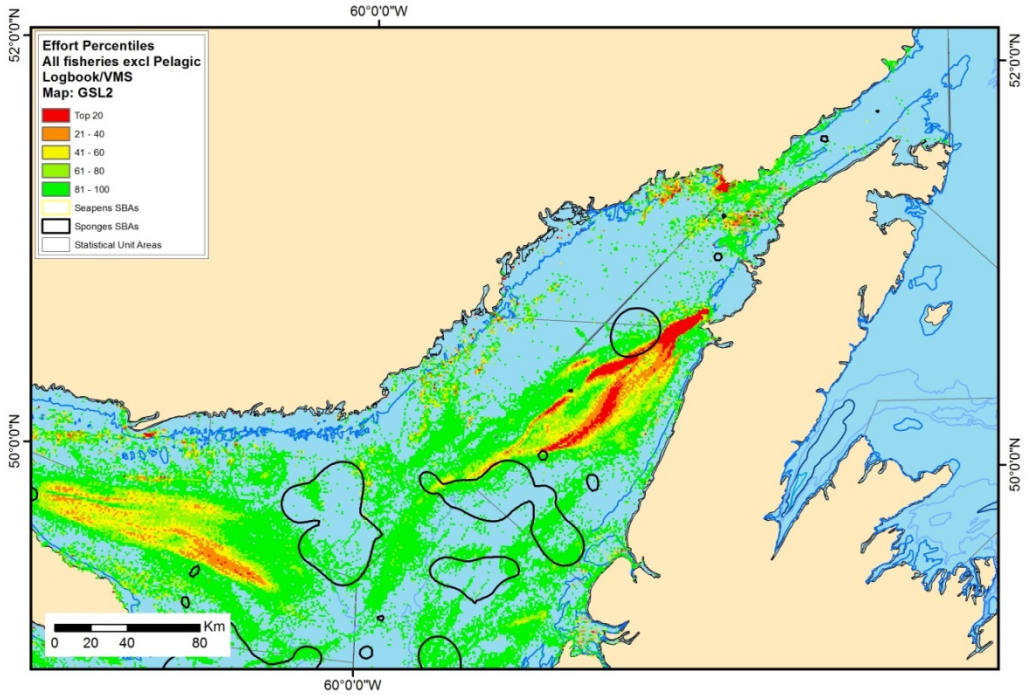

Figure A4 - 14. All fisheries excluding pelagic, inset GSL2.

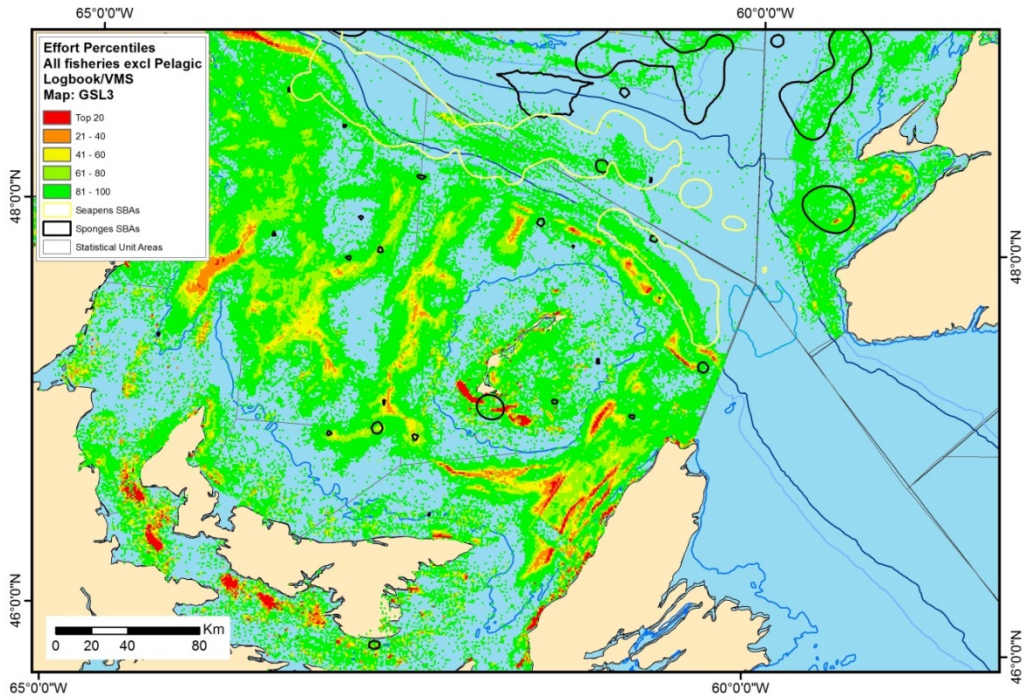

Figure A4 - 15. All fisheries excluding pelagic, inset GSL3.

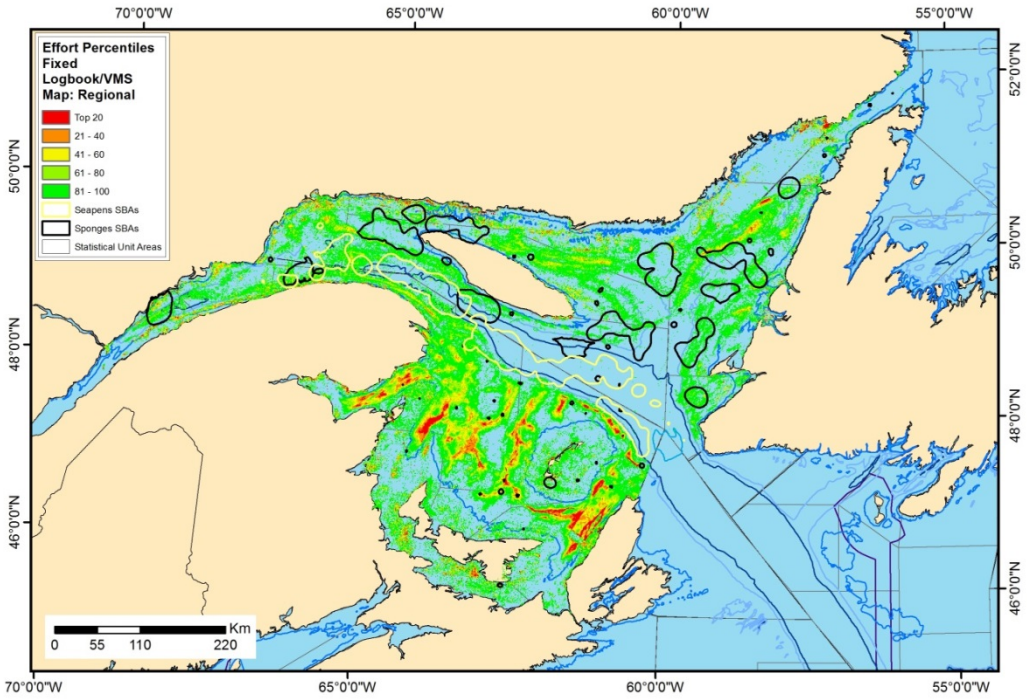

Figure A4 - 16. Fixed, regional map.

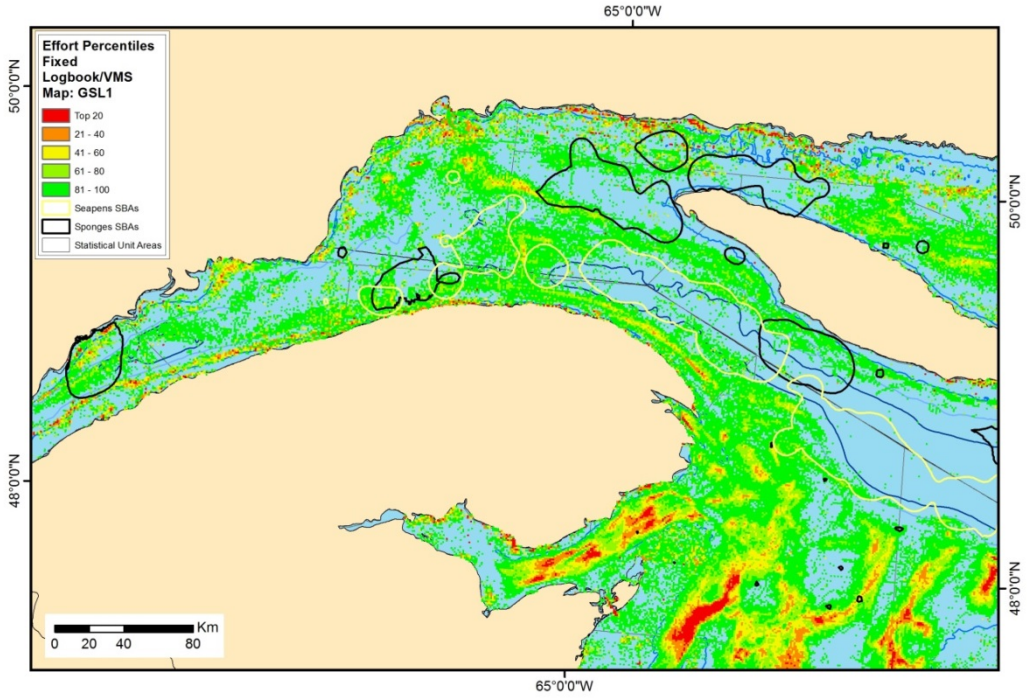

Figure A4 - 17. Fixed, inset GSL1.

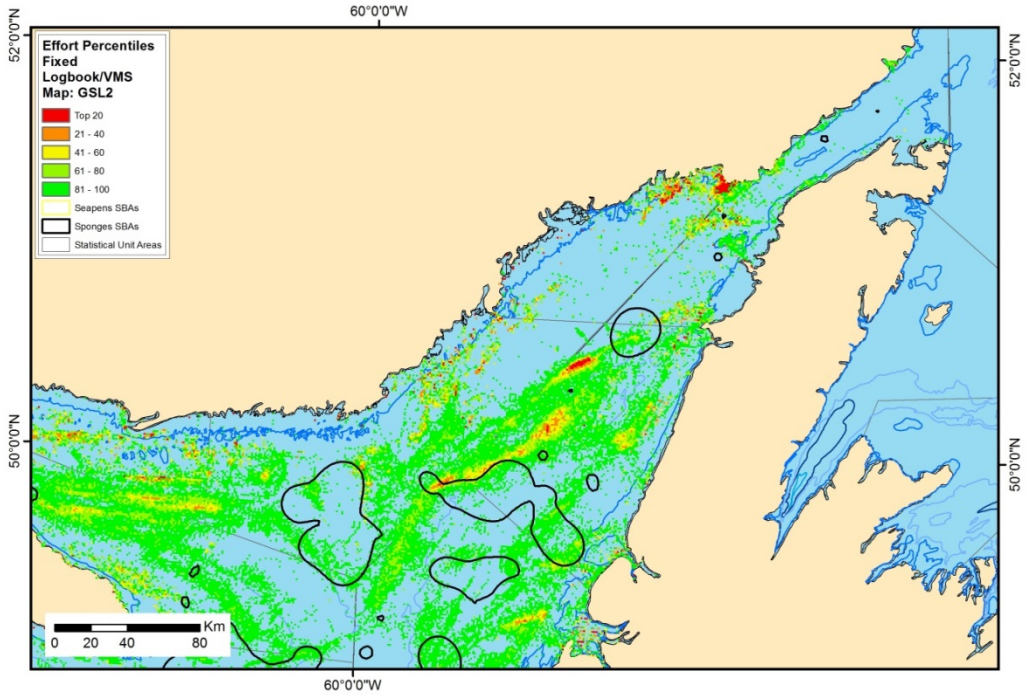

Figure A4 - 18. Fixed, inset GSL2.

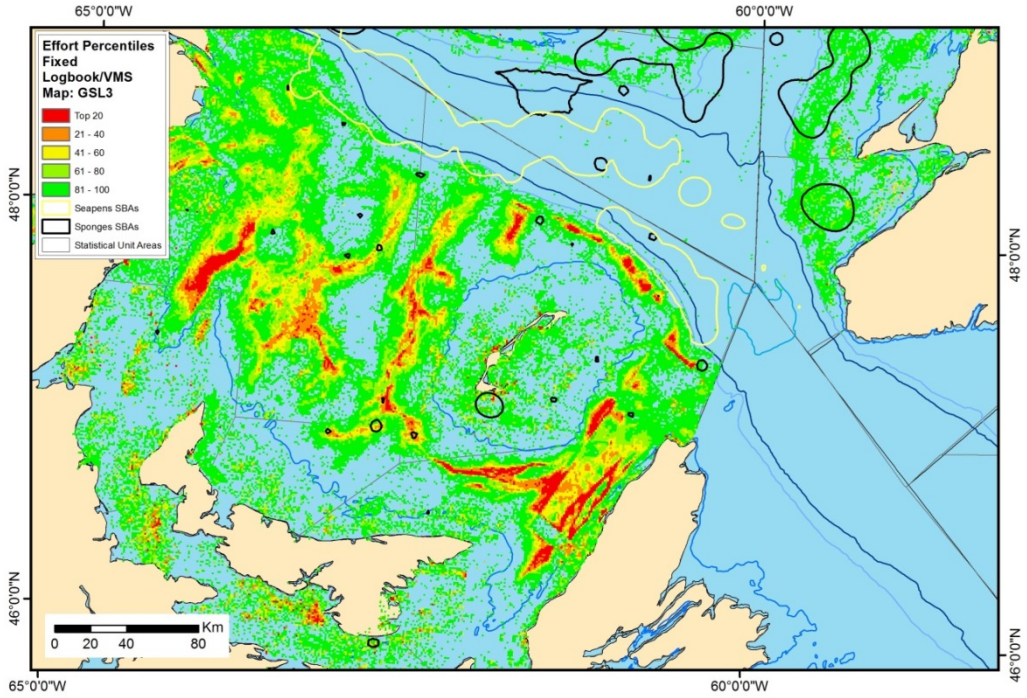

Figure A4 - 19. Fixed, inset GSL3.

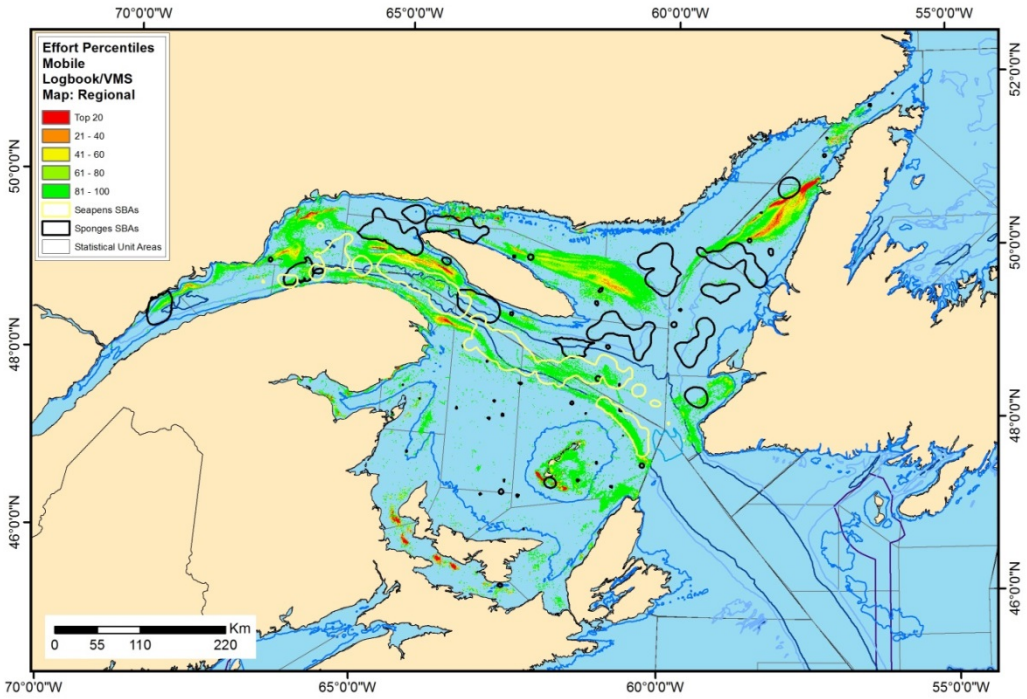

Figure A4 - 20. Mobile, regional map.

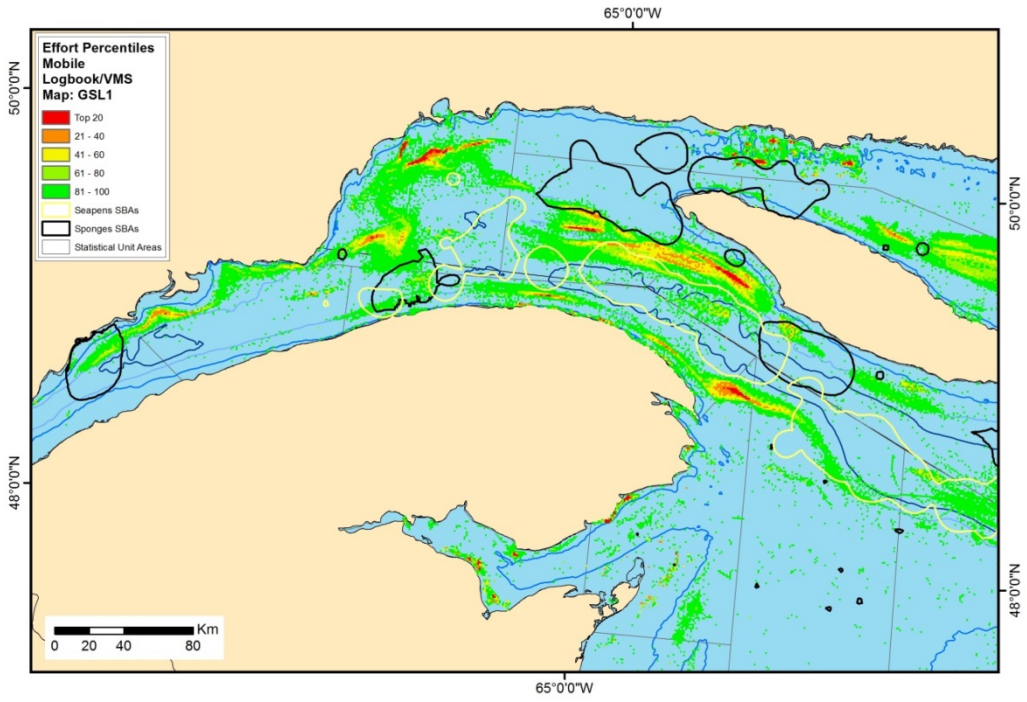

Figure A4 - 21. Mobile, inset GSL1.

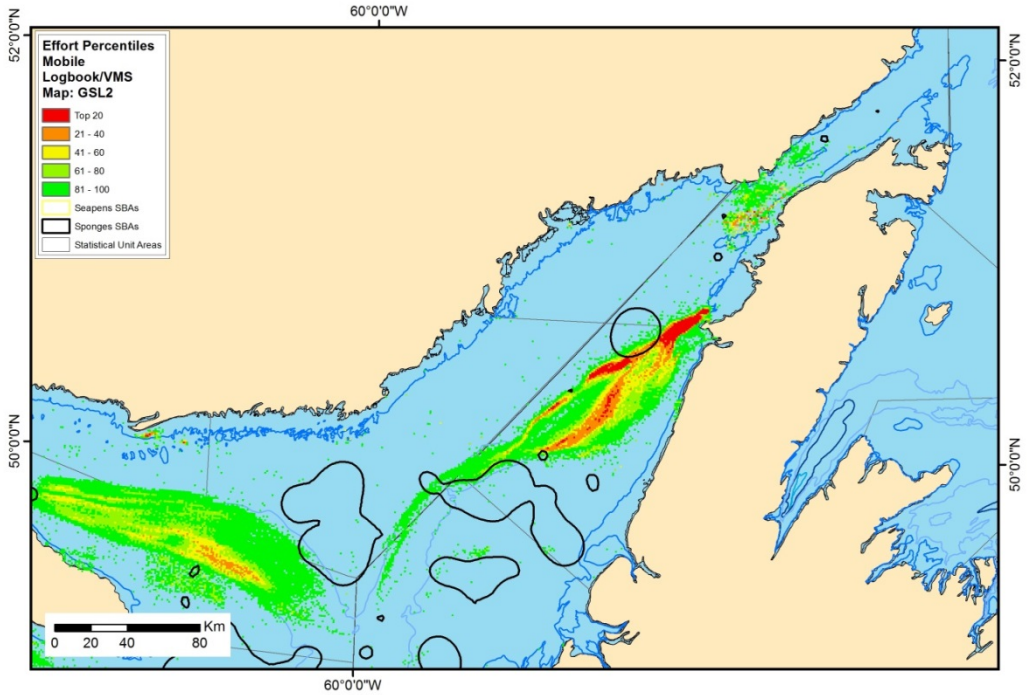

Figure A4 - 22. Mobile, inset GSL2.

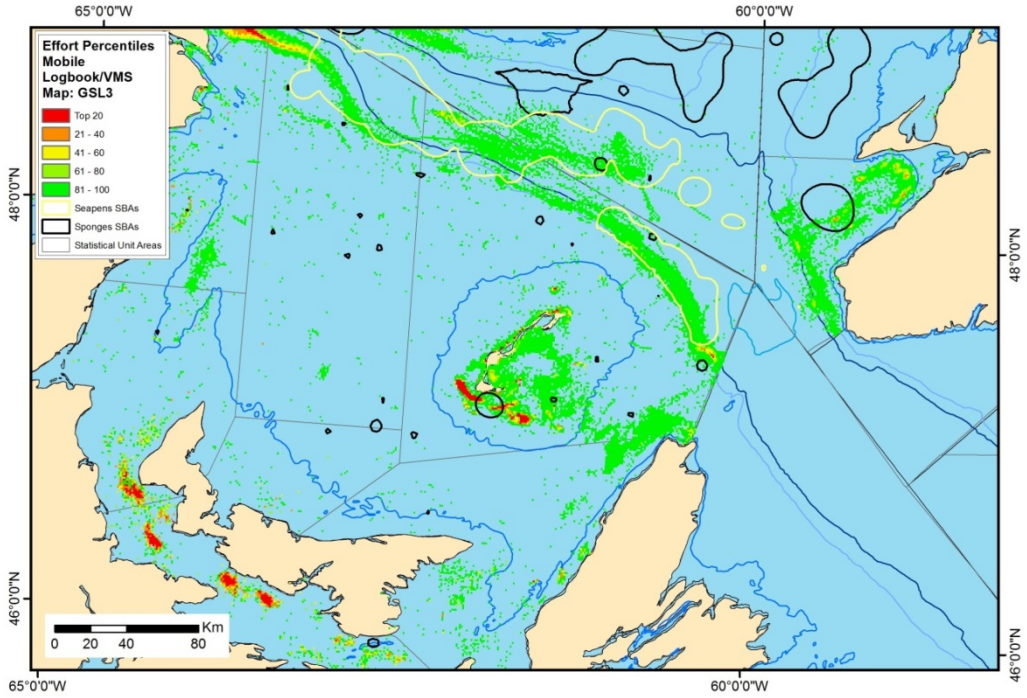

Figure A4 - 23. Mobile, inset GSL3.

NEWFOUNDLAND AND LABRADOR (NL)

In the Newfoundland and Labrador bioregion, there are four types of Significant Benthic Areas shown: small gorgonian, large gorgonian, sea pen and sponge. The first map within this section shows the Significant Benthic Areas without any fishing effort, followed by fishing effort from all fisheries classes excluding the pelagic fisheries class, fixed gears fisheries class, and mobile gears fisheries class.

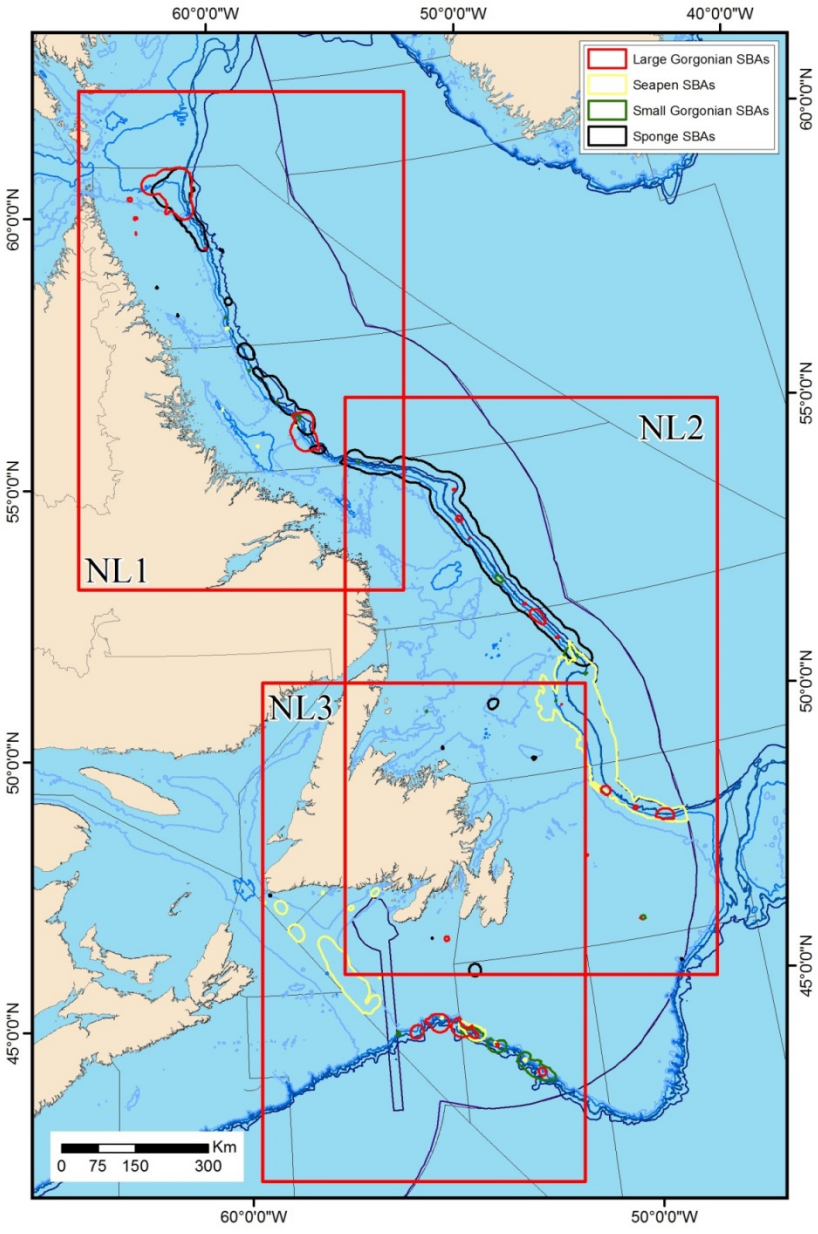

Figure A4 - 24. Inset Index.

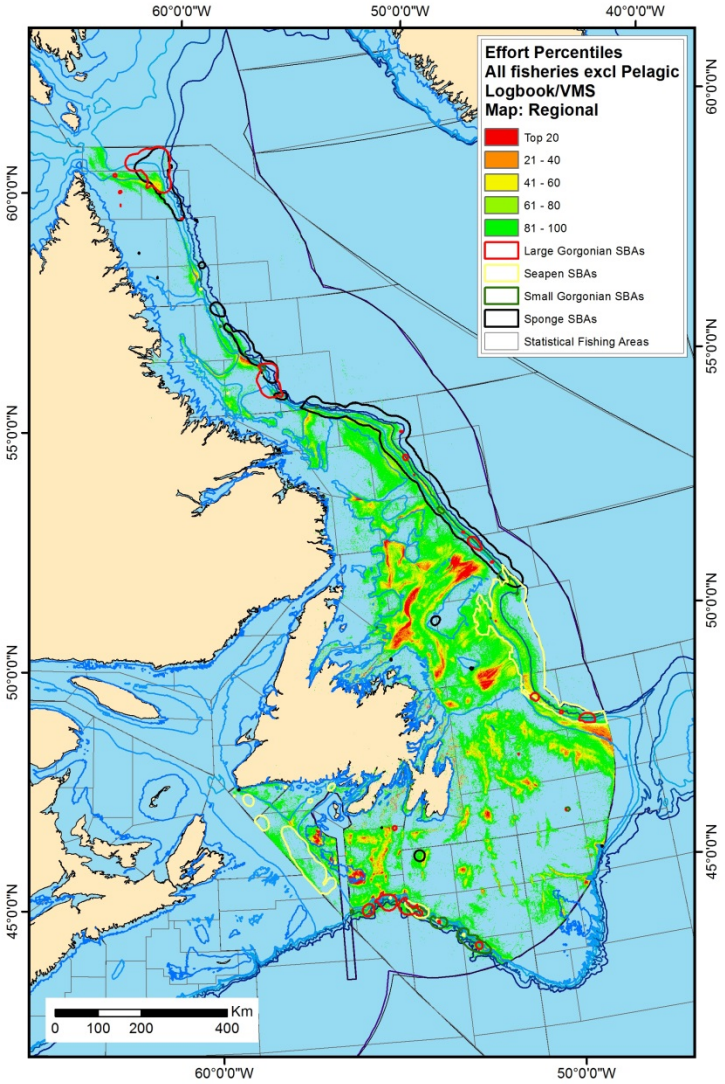

Figure A4 - 25. All fisheries excluding pelagic, regional map.

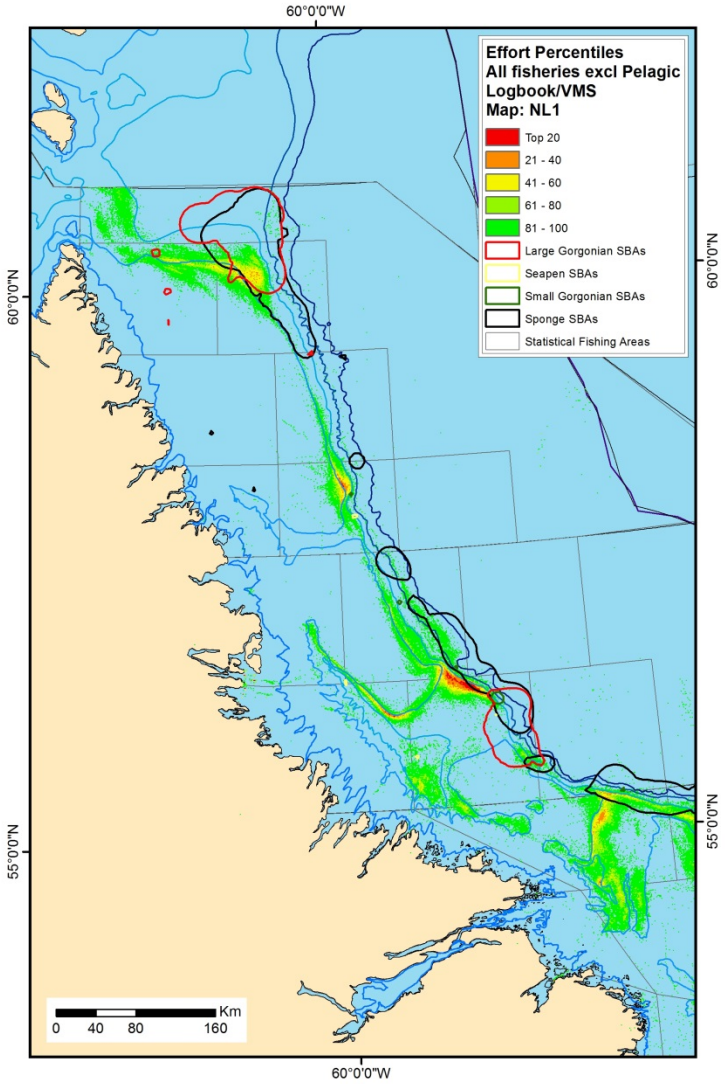

Figure A4 - 26. All fisheries excluding pelagic, inset NL1.

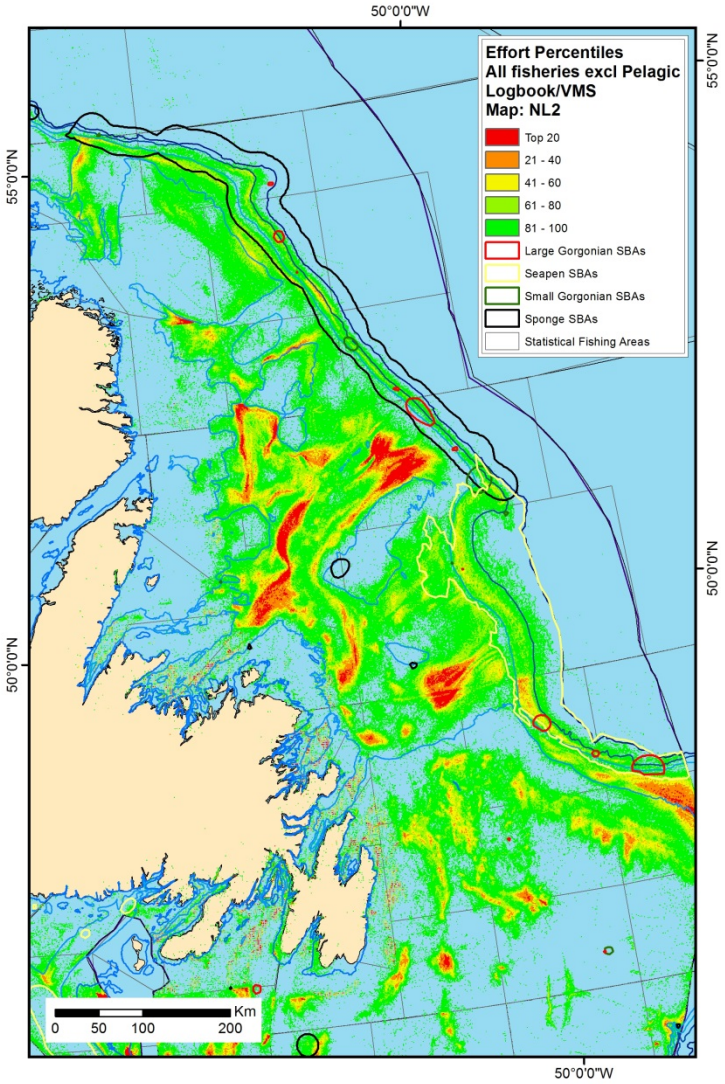

Figure A4 - 27. All fisheries excluding pelagic, inset NL2.

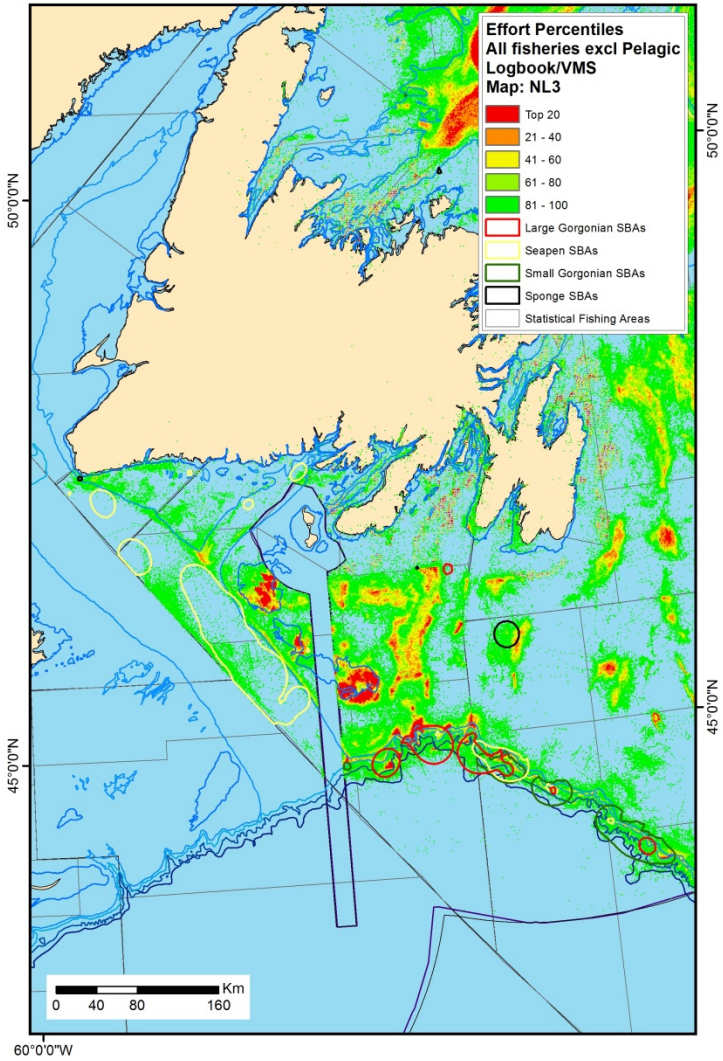

Figure A4 - 28. All fisheries excluding pelagic, inset NL3.

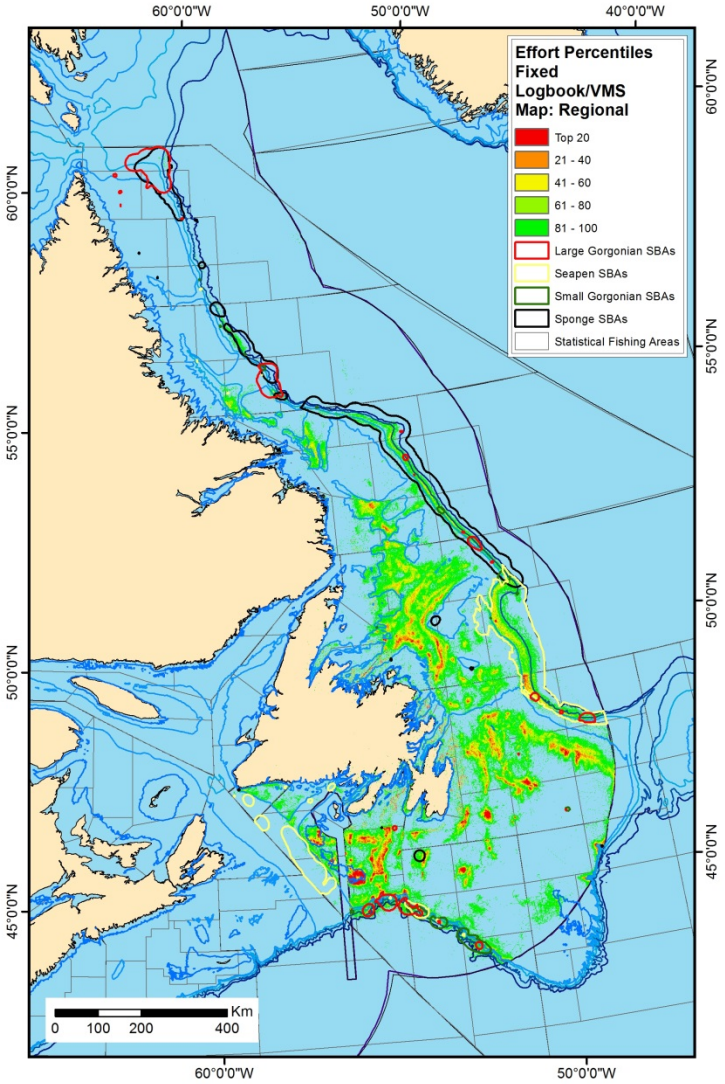

Figure A4 - 29. Fixed, regional map.

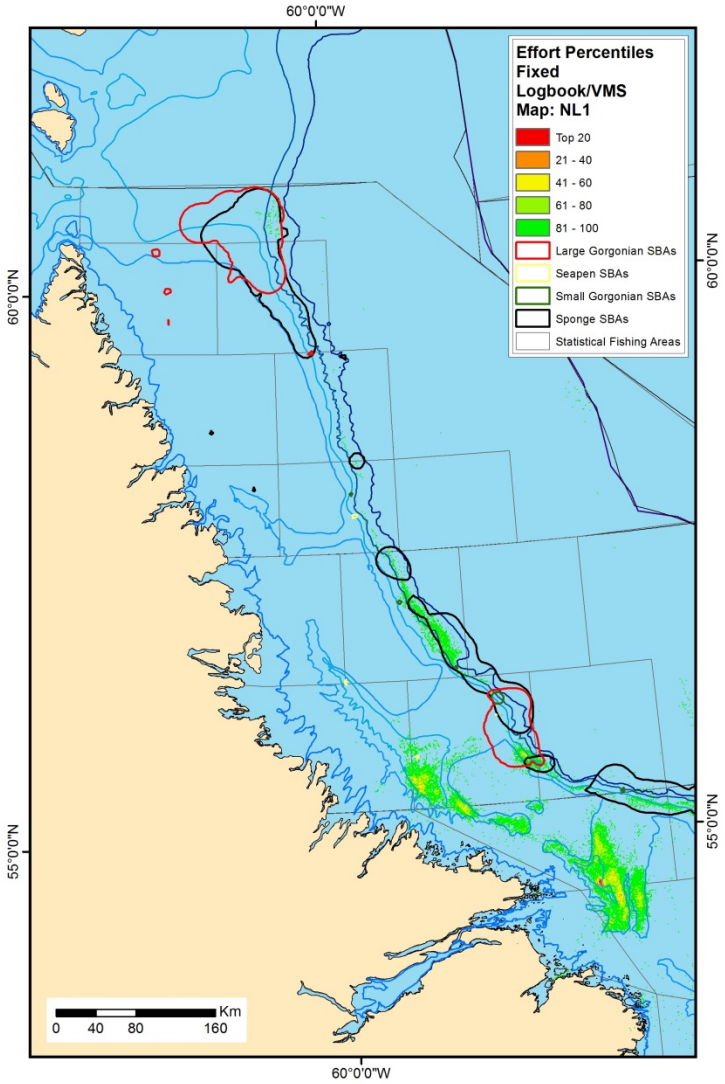

Figure A4 - 30. Fixed, inset NL1.

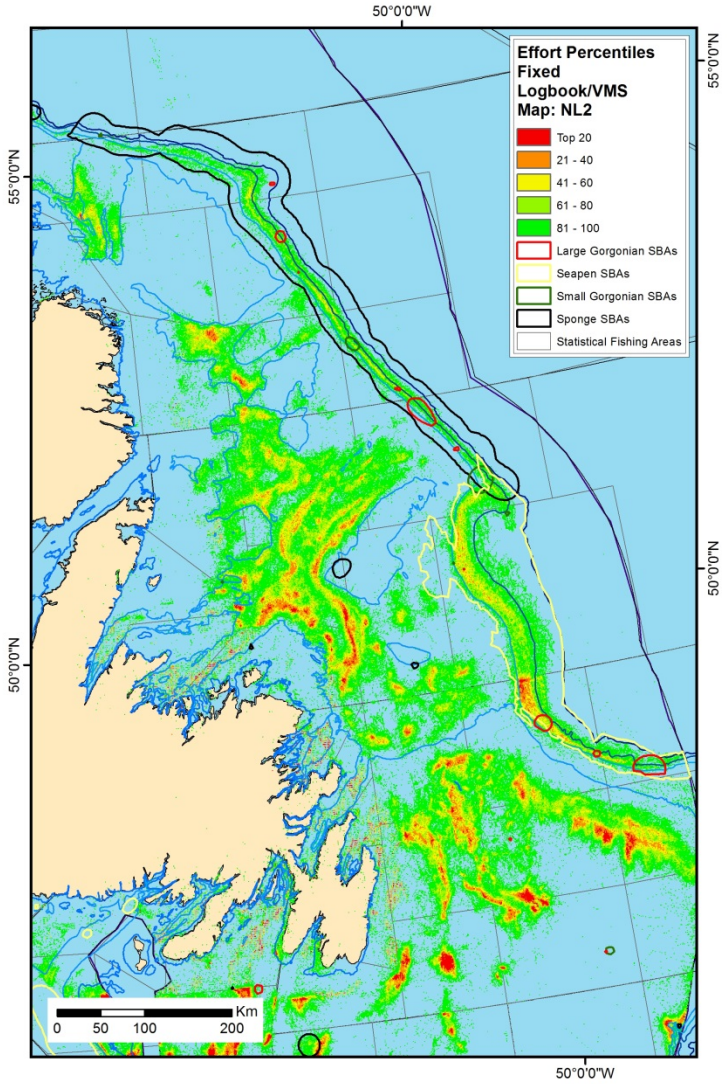

Figure A4 - 31. Fixed, inset NL2.

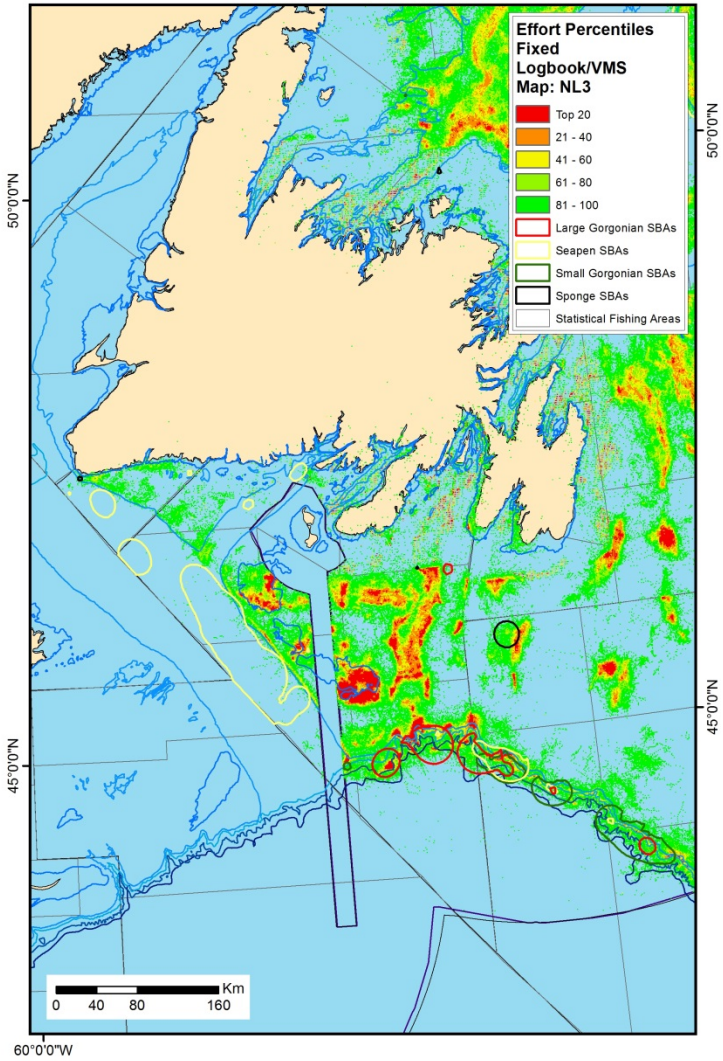

Figure A4 - 32. Fixed, inset NL3.

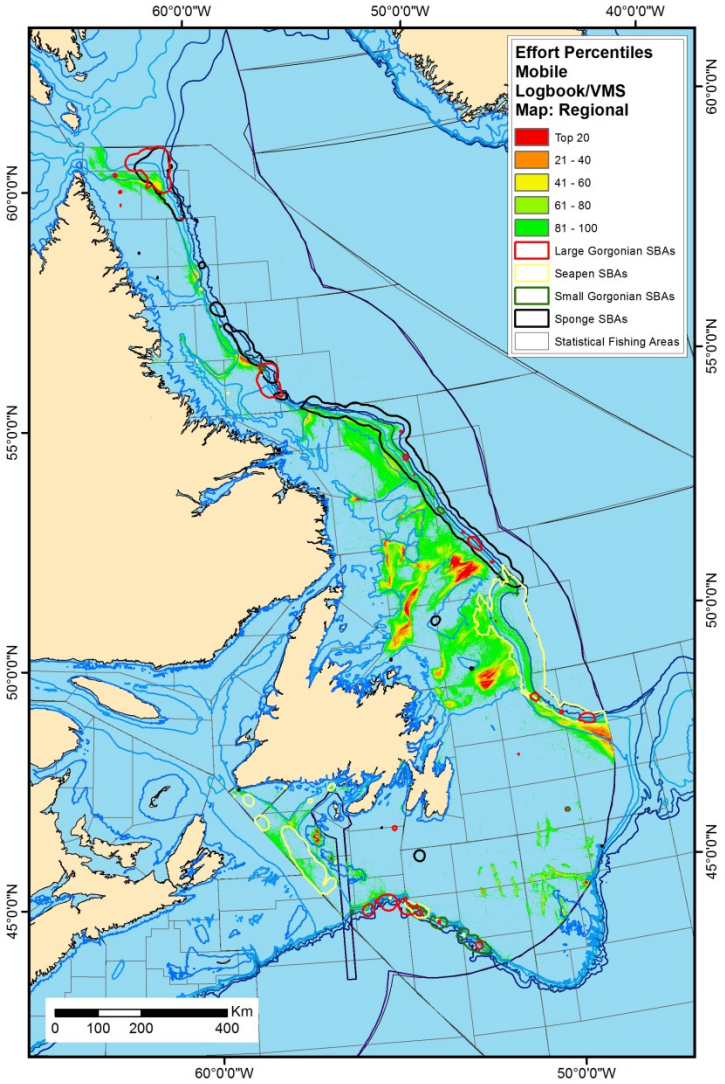

Figure A4 - 33. Mobile, regional map.

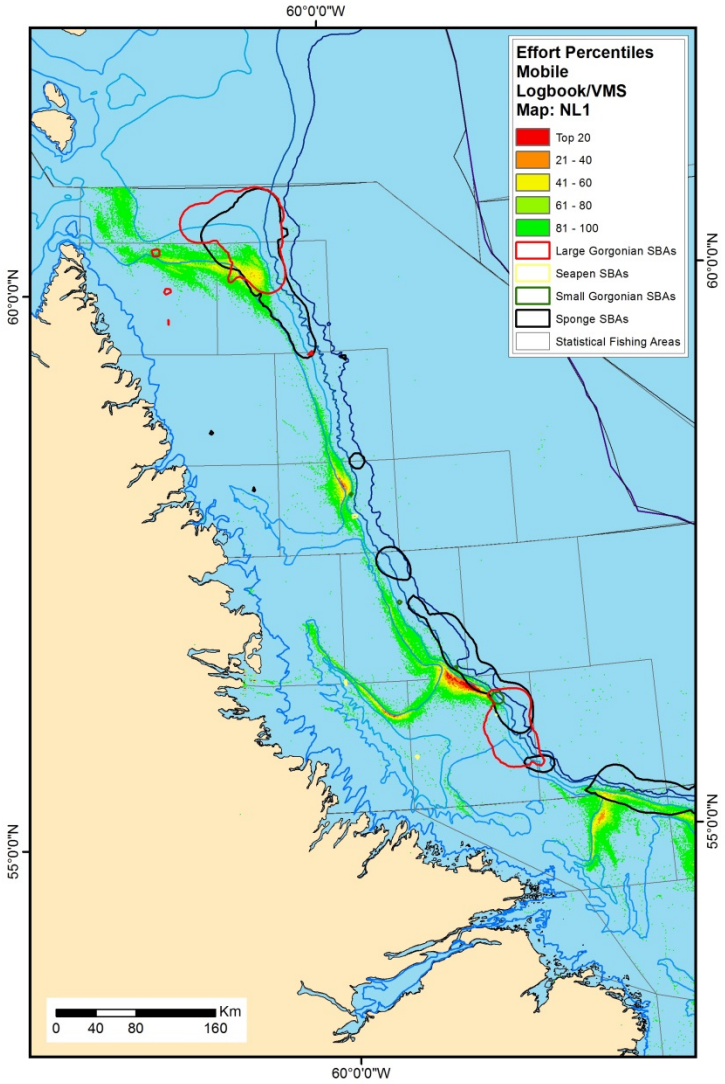

Figure A4 - 34. Mobile, inset NL1.

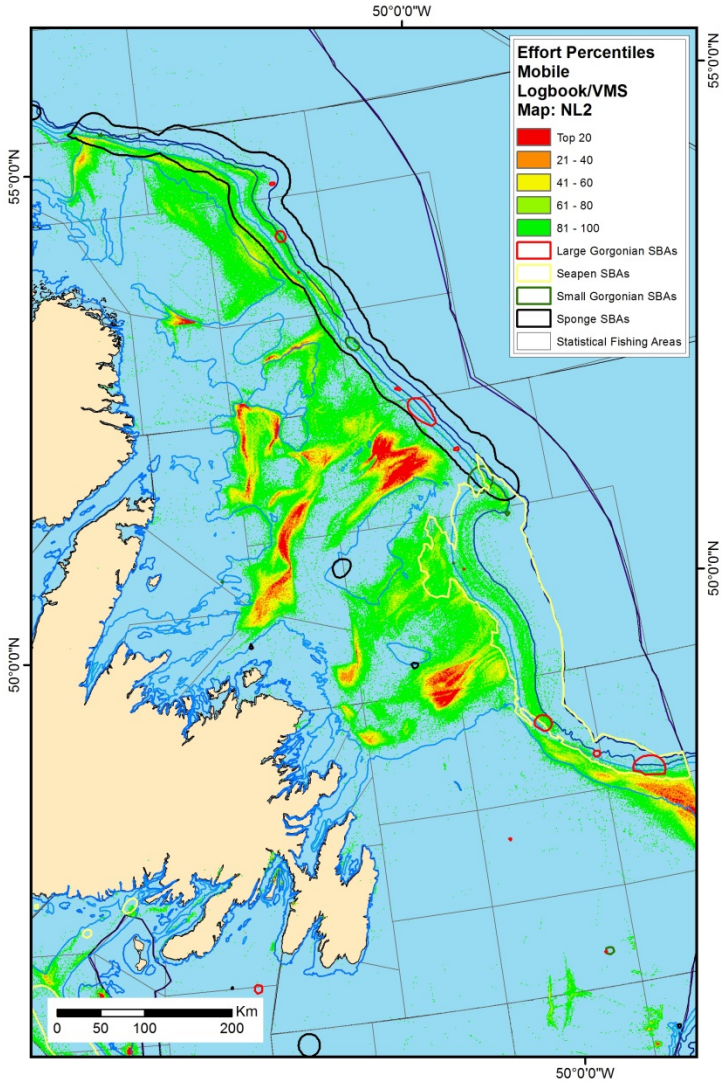

Figure A4 - 35. Mobile, inset NL2.

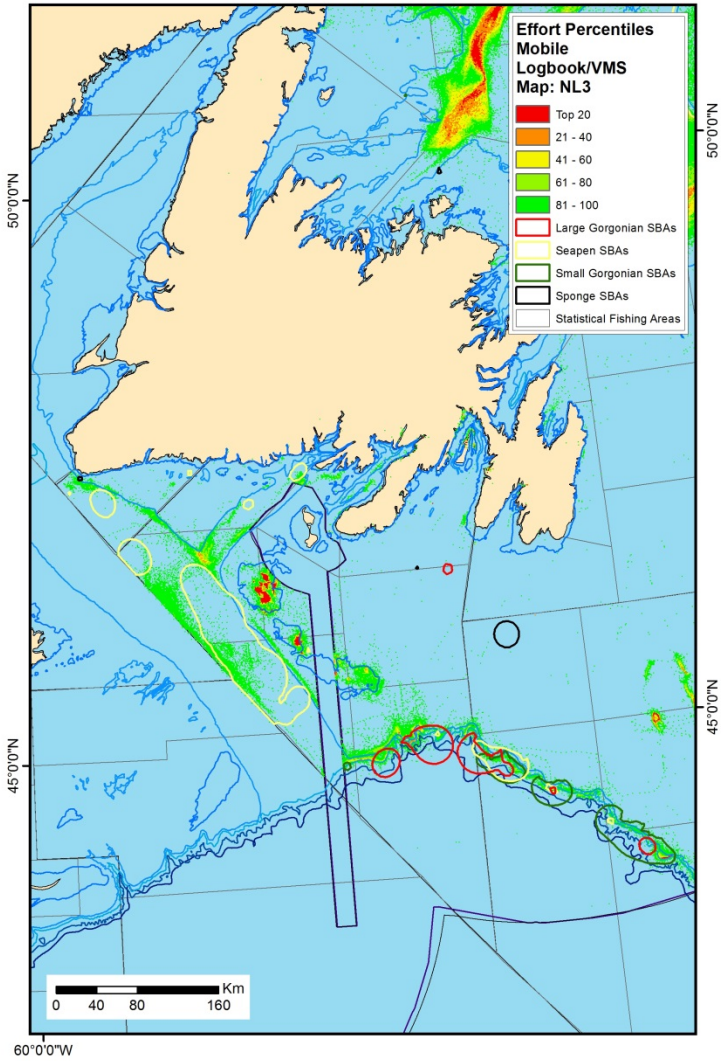

Figure A4 - 36. Mobile, inset NL3.

EASTERN ARCTIC (EA)

In the Eastern Arctic, there are four types of Significant Benthic Areas: small gorgonian, large gorgonian, sea pen and sponge. The first map within this section shows the Significant Benthic Areas without any fishing effort, followed by fishing effort from fixed gears and mobile gears fisheries classes. There is no category for “all fisheries excluding pelagic” because there are no pelagic fisheries class in the Eastern Arctic.

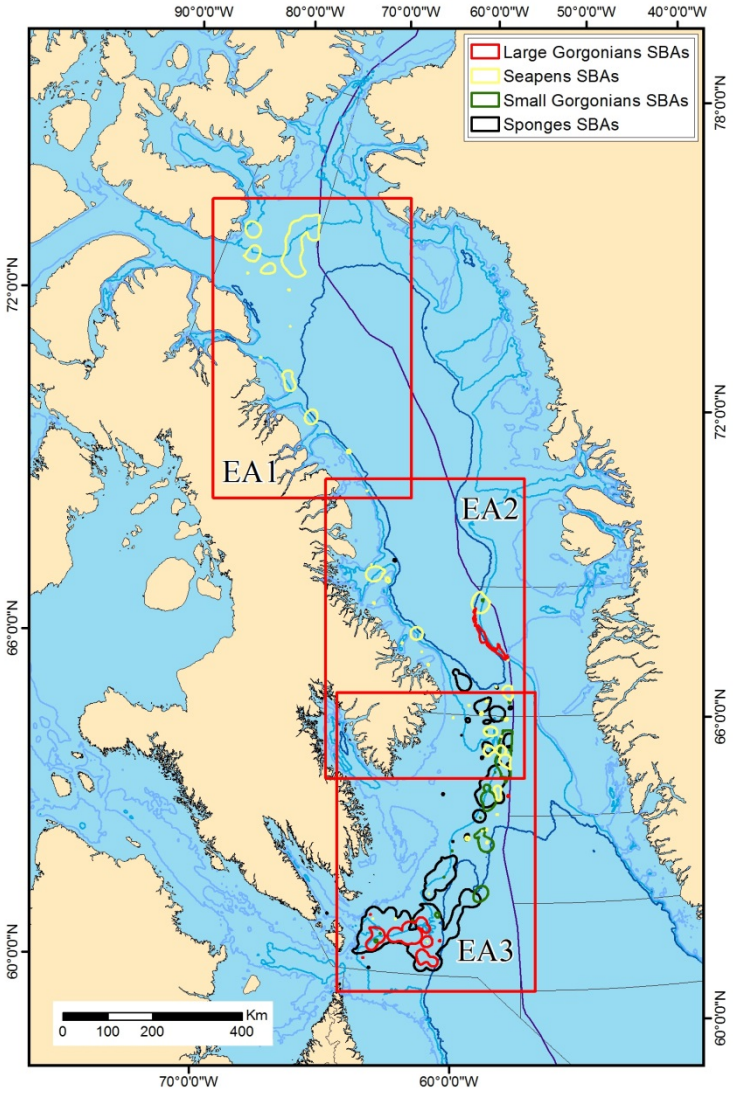

Figure A4 - 37. Inset Index.

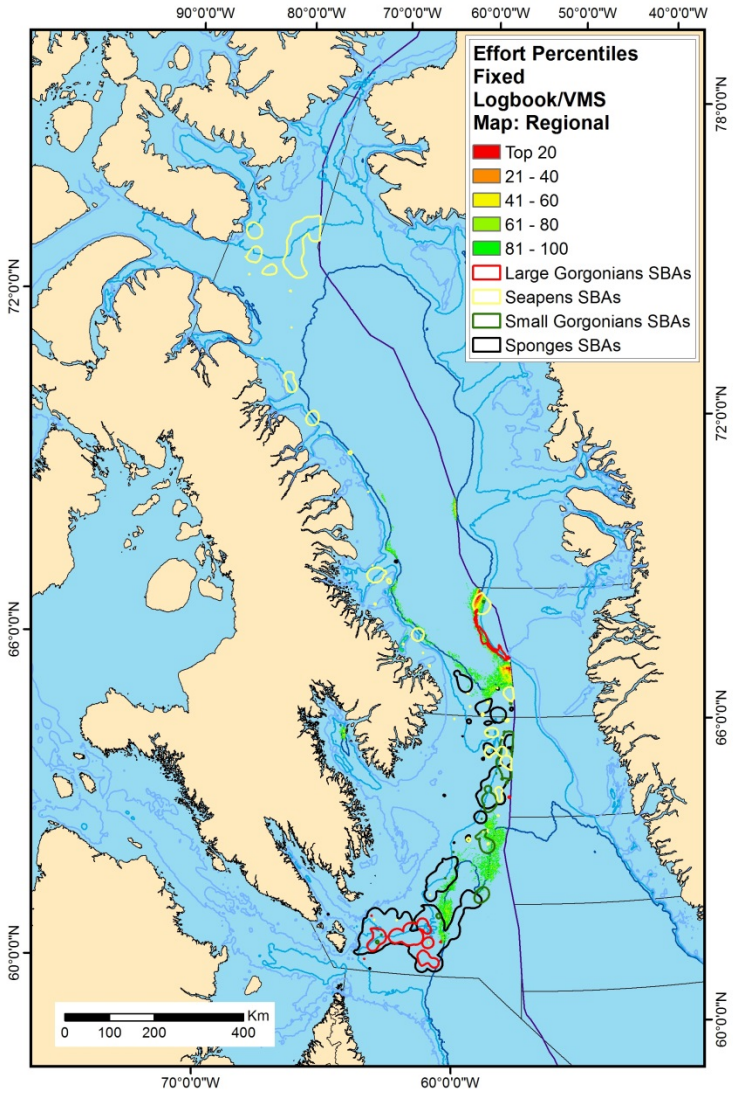

Figure A4 - 38. Fixed, regional map.

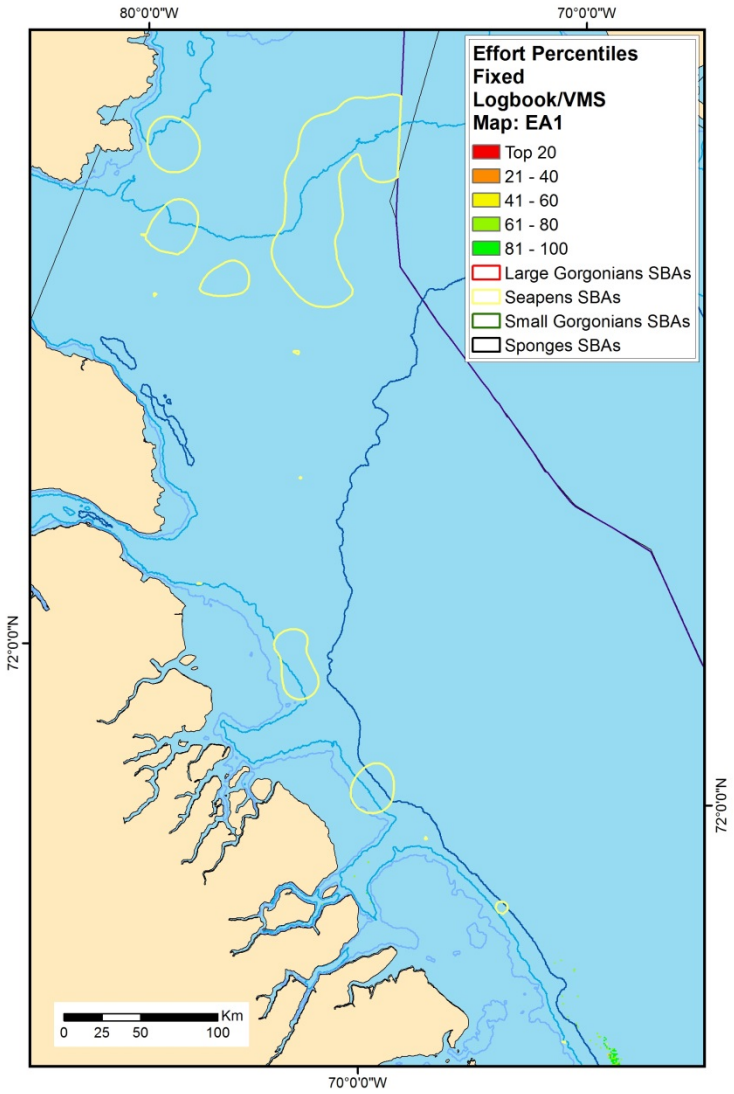

Figure A4 - 39. Fixed, inset EA1.

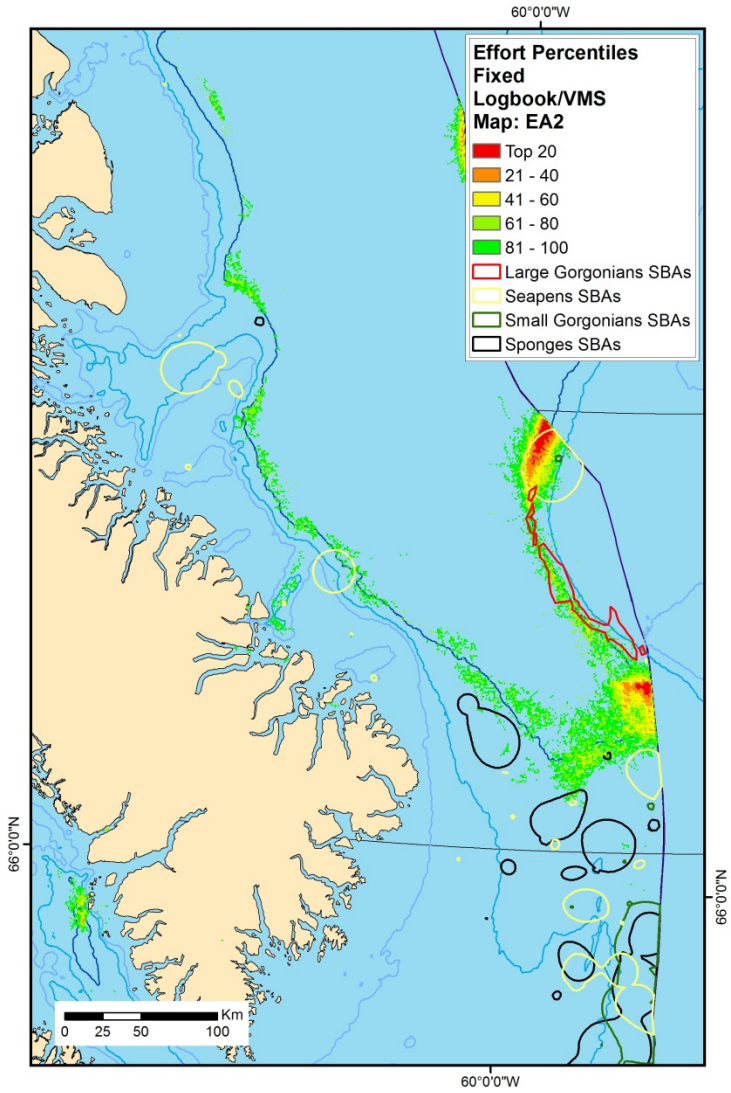

Figure A4 - 40. Fixed, inset EA2

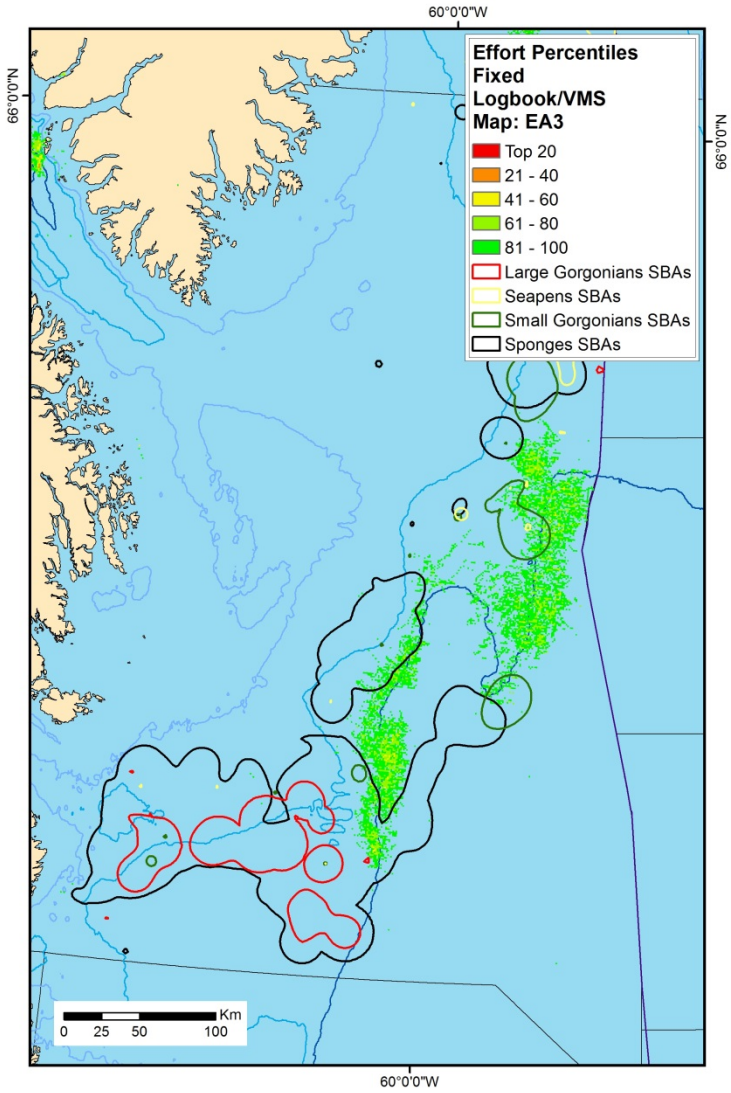

Figure A4 - 41. Fixed, inset EA3.

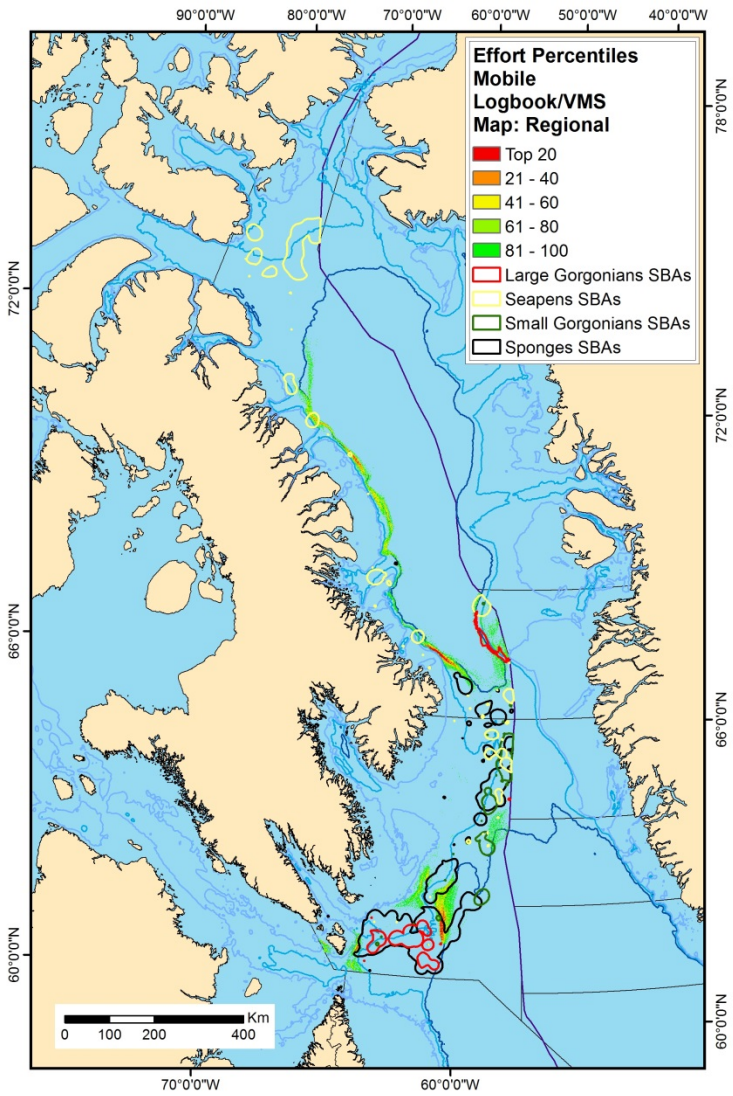

Figure A4 - 42. Mobile, regional map.

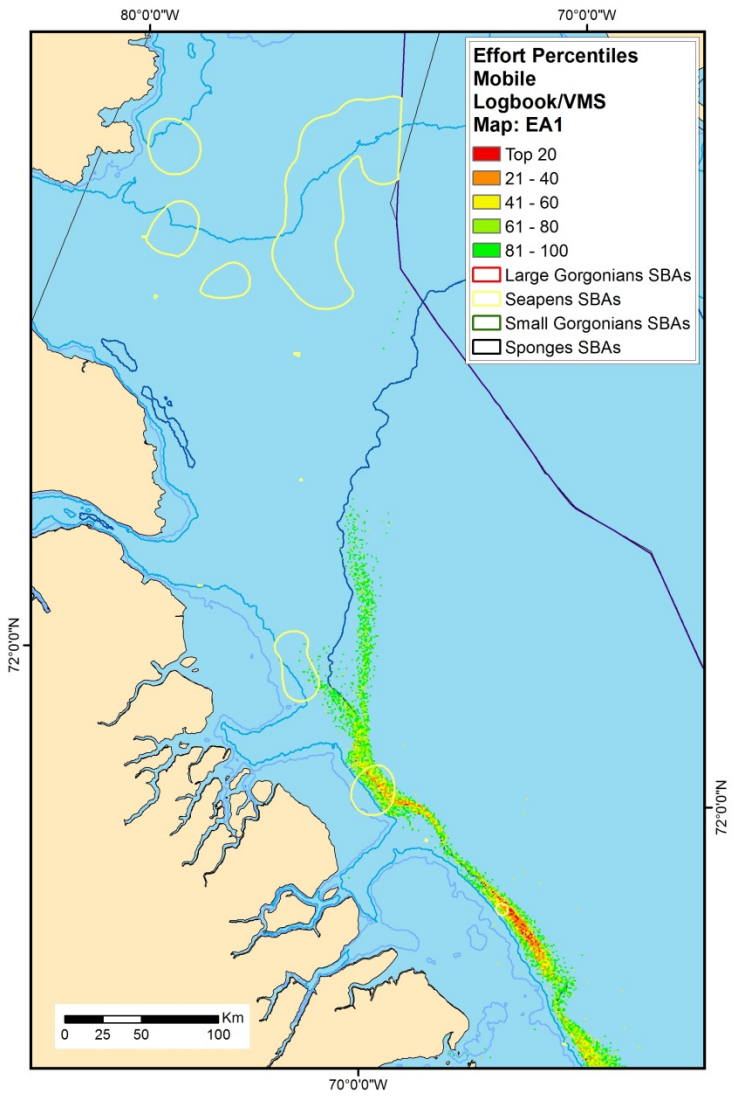

Figure A4 - 43. Mobile, inset EA1.

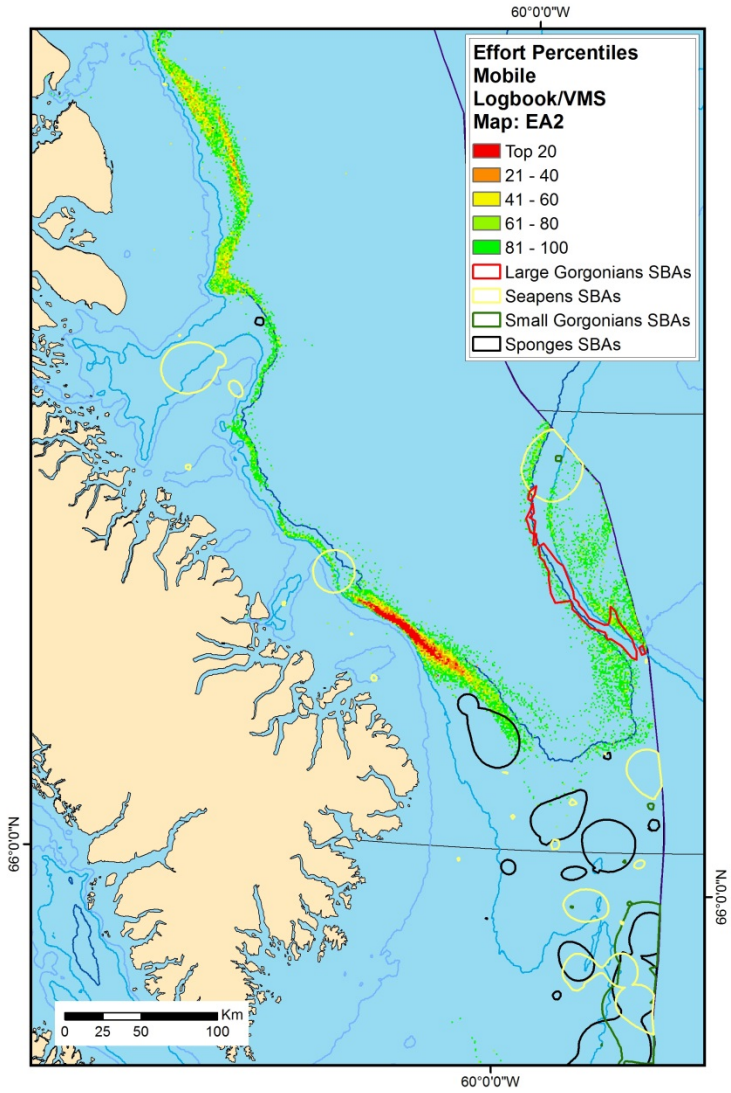

Figure A4 - 44. Mobile, inset EA2.

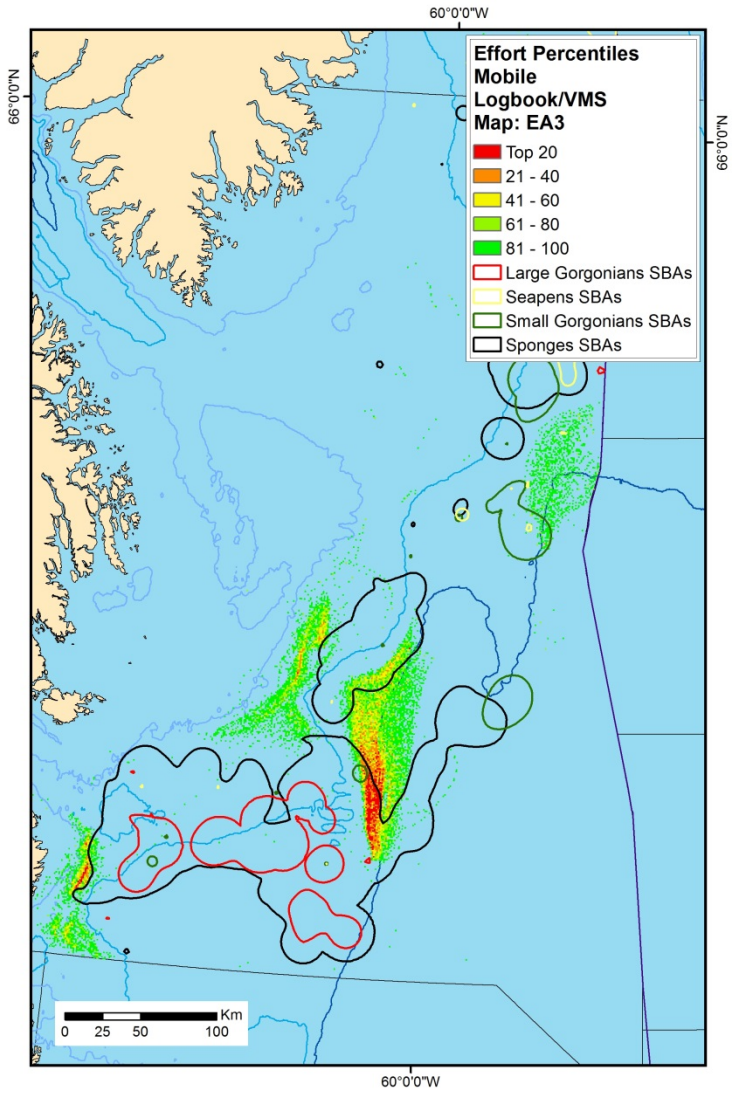

Figure A4 - 45. Mobile, inset EA3.