Fisheries and Oceans Canada | Pêches et Océans Canada
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Canadian Science Advisory Secretariat (CSAS)

Research Document 2020/007

Quebec and Gulf Regions

An assessment to support decisions on authorizing scientific surveys with bottom-contacting gears in protected areas in the Estuary and Gulf of St. Lawrence

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April 2020

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.

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:

Benoît, H.P., Asselin, N.C., Surette, T., and Juillet, C. 2020. An assessment to support decisions on authorizing scientific surveys with bottom-contacting gears in protected areas in the Estuary and Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/007. xi + 80 p.

Aussi disponible en français :

Benoît, H.P., Asselin, N.C., Surette, T., et Juillet, C. 2020. Évaluation visant à soutenir les décisions liées à l'autorisation des relevés scientifiques avec des engins entrant en contact avec le fond dans des zones benthiques protégées dans l'estuaire et le golfe du Saint-Laurent. Secr. can. de consult. sci. du MPO, Doc. de rech. 2020/007. xii + 86 p.

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ABSTRACT

Canada is rapidly increasing the number of protected areas in its coastal and marine waters to meet international conservation targets. This has created an urgent need for approaches to determine which human activities will be allowed within these areas in light of site-specific conservation objectives and monitoring requirements. Scientific activities contribute information that can support conservation-related management decision-making within protected areas and in the broader ecosystem (e.g., advice for sustainable fisheries, species recovery, and ecosystem status). However, these same scientific activities can harm organisms, populations, assemblages and habitats within protected areas and therefore can hinder the achievement of conservation objectives. Fisheries and Oceans Canada's (DFO) national *Framework to support decisions on authorizing scientific surveys with bottom-contacting gears in protected areas with defined benthic conservation objectives* guides the evaluation of ongoing recurrent scientific activities (surveys), within protected areas. The Framework evaluates four main elements: 1) the potential impact of recurring survey activities within protected areas, 2) potential mitigation measures to reduce their impact, 3) benefits of survey activities to the management of protected areas and 4) potential consequences to the scientific understanding and management of species and communities in the broader ecosystem caused by excluding sampling in protected areas. In this report we apply the Framework to the protected areas and recurring marine resource and ecosystem surveys of the Gulf of St. Lawrence. Specifically we consider eight surveys employing bottom-contacting gear and 15 protected areas: the Banc-des-Américains Marine Protected Area (MPA), three Scallop Buffer Zone marine refuges (SBZMR) and eleven Coral and/or Sponge Conservation Areas. Fishing with bottom-contacting gear is prohibited in the most sensitive portion of the Banc-des-Américains MPA (Zone 1), where survey activities are infrequent and their removal inconsequential to broader scale scientific understanding and management. The evaluation indicates that recurring surveys are unlikely to hinder the achievement of benthic and demersal conservation objectives in the less sensitive portion of the Banc-des-Américains MPA (Zone 2), in the SBZMR and in the Coral Conservation Areas. The evaluation is less certain for survey activities in the Sponge Conservation Areas given gaps in the available information. A number of mitigation measures that could be applied are discussed, though some could take several years to implement to avoid compromising existing survey standardized time series. Exclusion of some surveys from either Zone 2 of the MPA, the SBZMR or the Coral/Sponge Conservation Areas would likely compromise the broader scale monitoring of certain taxa, including species of conservation concern. Meanwhile all multi-species surveys collect some information that could support scientific understanding and evidence-based decision making within the protected areas at least in the short term. This information is presented in support of a DFO Canadian Science Advisory Science Response process that took place on September 12, 2019. This report and the advisory process do not provide decisions on authorizing survey activities in the protected areas of the Gulf of St. Lawrence, only the background information necessary to support these decisions. These decisions will be made by DFO Oceans and Resource Management sectors, in consultation and collaboration with DFO's Science Branch.

1. INTRODUCTION

Canada is rapidly increasing the number of protected areas in its coastal and marine waters to meet international conservation targets. This has created an urgent need for approaches to determine which human activities will be allowed within these areas in light of site-specific conservation objectives and monitoring requirements. Scientific activities contribute information that can support conservation-related management decision making within protected areas and in the broader ecosystem (e.g., advice for sustainable fisheries, species recovery, and ecosystem status). However, these same scientific activities can harm organisms, populations, assemblages and habitats within protected areas and therefore can hinder the achievement of conservation objectives. This is particularly true for areas with ecologically sensitive benthic taxa and features, which can be harmed by bottom-contacting sampling gear such as bottom-trawls used in multi-species surveys. On the other hand, excluding protected areas from established survey sampling areas (survey domains) may preclude information gathering that could aid in managing the protected areas and that often forms the basis of advice for the management of populations and communities in the broader ecosystem.

Fisheries and Oceans Canada (DFO) has produced a National Framework to guide the evaluation of ongoing recurrent scientific activities (surveys), within protected areas (DFO 2018; see Benoît et al. 2020 for more details). Briefly, this advice comprises the following elements.

1. An evaluation of the potential impact of survey activities within protected areas.

   Scientific activities should not compromise achieving the area-wide conservation objectives established for the protected areas. This evaluation is most reliably achieved through direct before-after-control-impact (BACI) type experiments. Oftentimes, such experiments have not yet occurred in the area of interest, and proxies of impact and the potential of benthic communities to recover from impacts are required. The national framework recommends the proportion of a protected area swept by sampling gear annually across all surveys as an important metric of impact on benthic habitat, as well as benthic and demersal taxa. The inverse of this metric is the recurrence time interval of impacts, i.e., the average number of years between two sampling events at a particular location. A measure of the potential for long term harm caused by sampling is the recurrence time interval of the activity relative to the expected recovery time (resilience) of the biological components of interest. A proxy for the expected recovery time is the longevity of the benthic or demersal ecological components of interest. Activity recurrence time intervals that are at least one order of magnitude greater than the longevity of the least resilient taxon or benthic feature are assumed to not result in long-term harm and therefore should not compromise achievement of protected area conservation objectives. In the absence of information on longevity, other factors such as reproductive patterns and the breadth of distribution and environmental tolerance can provide an indication of resilience.

2. An evaluation of potential mitigation measures that could reduce the impact of scientific activities in the protected areas.

   These include using lower-impact gear, modifying sampling procedures to reduce benthic impacts, reducing the swept area of individual survey hauls, and reducing the sampling density, including by reducing the number of surveys that operate in an area.

3. An evaluation of the benefits of survey activities to the management of protected areas.

   This is of particular importance for the permitting of scientific activities in Marine Protected Areas under the *Oceans Act*, where such benefits are a requirement. These benefits could include sampling within and outside protected areas that allows for a determination of the efficacy of protected areas for the conservation of key taxa (e.g., Kerr et al. 2019), sampling to better understand the distribution of taxa and diversity within protected areas, or the collection of samples to better understand the identity and biology of taxa in the areas.

4. An evaluation of the potential consequences of excluding survey sampling in protected areas.

   These consequences include the generation of biases in abundance indices for taxa in the broader ecosystem, which are used to produce scientific advice for the management of fishery resources and depleted species, including species at risk, and for ecosystem monitoring and reporting. A particular concern is that exclusion could lead to time-varying biases in abundance indices. The main method for evaluating the likelihood of this outcome is via retrospective simulation, in which original abundance indices are compared to recalculated indices in which data for sampling sets with geographic coordinates occurring within the boundaries of the protected area(s) are excluded.

The present report applies the National Framework (DFO 2018) to recurring bottom-contacting scientific survey activities in the Gulf of St. Lawrence (GSL), Canada that are either undertaken by, or in collaboration with, DFO. The results are intended to facilitate a dialogue between DFO scientists and managers responsible for marine refuges under the *Fisheries Act* (DFO Resource Management sector) and for Marine Protected Areas (MPAs) designated under the *Oceans Act* (DFO Oceans Management sector). The eventual outcomes are decisions on which recurring scientific activities will be permitted in the various protected areas of the Gulf. The report deals only with recurrent activities undertaken by, or in collaboration with DFO. One-off DFO scientific activities or research undertaken independently by other stakeholders will require individual assessments to support permitting decisions.

1.1 PROTECTED AREAS IN THE GULF OF ST. LAWRENCE

In the Estuary and Gulf of St. Lawrence (EGSL) bioregion, there are currently 19 fisheries area closures created under the *Fisheries Act* that qualify as Other Effective Area-Based Conservation Measures (marine refuge) (Table 1) and two MPAs, Basin Head MPA and the Banc-des-Américains MPA, created under the *Oceans Act*.

Five marine refuges and one MPA were excluded from this analysis as they either do not have defined conservations objectives aimed at protecting benthic species, assemblages or features or there are no recurring scientific surveys employing bottom-trawls within their boundaries. The Miramichi Bay closure (New Brunswick) aims to protect migrating Atlantic salmon by prohibiting the use of groundfish gillnets. Similarly, the Bay of Islands Salmon Migration closure (Newfoundland and Labrador) also aims to protect migrating Atlantic salmon by prohibiting all pelagic fixed-gear fisheries. The Saguenay Fjord Upstream closure (Quebec) aims to protect habitat for the beluga whale, a mammal designated as endangered and listed as threatened in the *Species at Risk Act*, and excludes the use of bottom-trawls to avoid stirring up contaminants contained in the river's sediments. There are no recurring scientific surveys employing bottom-trawls in the closure area. The Magdalen Islands Lagoons closures, the fisheries closure in the Les Demoiselles nursery, Plaisance Bay, Magdalen Islands and the Basin Head MPA were similarly excluded as they do not overlap with the domains of any current recurring surveys employing bottom-contacting gear.

A map of the 14 marine refuges relevant to this report and the Banc-des-Américains MPA is presented in Figure 1. The following acronyms are used with respect to the marine refuges:

- SFA – scallop fishing areas;
- CCA – coral conservation area;

- SCA – sponge conservation area; and
- CSCA – coral and sponge conservation area

The conservation objectives (normally termed 'ecological components of interest' for refuges) and prohibitions for all the marine refuges in the Gulf are summarized in Table 1. Some additional details are available on the web (accessed 2019-09-30).

The Banc-des-Américains MPA comprises two zones, 1 and 2 (Figure 1). Zone 2 is divided into two parts: 2a, which is northeast of zone 1, and 2b, which is southwest. Zones 2a and 2b are not distinguished in this report and are collectively referred to as zone 2. The purpose of the MPA is to promote the productivity and diversity of fishery resources on the Banc-des-Américains and the plains adjacent to it, as well as the recovery of species at risk. To achieve these goals, three broad conservation objectives have been established:

- Conserve and protect benthic (seabed) habitats;
- Conserve and protect pelagic (water column) habitats and forage species (prey);
- Promote the recovery of at-risk whales and wolffish

Of relevance to the present report, article 10(1) of the Banc-des-Américains MPA regulations (SOR/2019-50) requires Ministerial approval for scientific research or monitoring activities in the MPA. The completion of a research plan for activities in an MPA, the elements of which are defined by regulation, is required. The information provided to complete the evaluation in this report using the National Framework will be useful for the development of the MPA research plans but it does not cover all the elements required for consideration of authorization of research activities in the MPA.

Contrary to MPAs, there is presently no requirement for a formal activity plan for planned scientific activities in marine refuges. Permitting inside and outside marine refuges is done under section 52 of the Fishery (General) Regulations (SOR/93-53), led by DFO's Fisheries and Aquaculture Management Branch. Permitting decisions for marine refuges will be informed by evaluations like the one presented in this report.

1.2 SURVEYS IN THE GULF OF ST. LAWRENCE

1.2.1 Surveys relevant to the current evaluation

There are eight recurring surveys employing bottom-contacting gears that occur in one or more of the protected areas in the GSL. A summary of the main characteristics of these surveys is presented in Table 2.

1.2.1.1 Gulf of St. Lawrence halibut longline survey

The Gulf halibut longline survey (halibut survey hereafter) was initiated in 2017 to provide annual abundance indices for medium and large sized halibut and other species that may be caught as bycatch in the fishery. The survey is undertaken by members of the fishing industry in collaboration with DFO. The survey employs a stratified random design, with a series of shallow (20-50 m) and deep (100-250 m) strata (Figure 2). A total of 125 sites are fished annually, using a standardized soak time of 5 hours, and 500 hooks on 1,000-3,500 m lines. Based on the method in DFO (2018), the estimated swept area for individual hauls is 0.225 km^2.

1.2.1.2 Southern Gulf of St. Lawrence (sGSL) snow crab bottom-trawl survey

The southern Gulf snow crab bottom-trawl survey (sGSL snow crab trawl survey hereafter) has been conducted annually since 1988, though the survey area expanded considerably up to 1999 and again slightly in 2012, to cover waters between 20 and 200 fathoms (37-366 m;

Figure 3). The current annual sampling design involves 355 hauls at fixed stations that were chosen on a grid in 2012. Though the stations are fixed, inter-annual differences in location arise due to sampling variability as well as displacement of some 10-15% of regular stations to alternative ones when trawling problems are encountered. The survey employs a Bigouden Nephrops (Norway lobster trawl). Trawl hauls are on bottom for around 6 minutes and result in an area swept between the trawl doors that averages 0.0083 km^2. Further details on the survey are available in Moriyasu et al. (2008). Abundance indices are estimated using kriging with external drift (Hebert et al. 2016). This survey is the key source of information on the abundance and distribution of multiple life stages of sGSL snow crab and provides the data used to advise on the annual total allowable catch. It also collects information on a suite of demersal fish and benthic invertebrates (Wade et al. 2018).

1.2.1.3 Northumberland Strait multi-species bottom-trawl survey

The Northumberland Strait multi-species survey began in 2001 as a random stratified survey and now employs a random selection of sampling sites within the study area (Figure 4). The survey samples approximately 110 stations annually. The survey has employed a 286 rockhopper trawl in all years, except in 2010 and 2011 when a Nephrops trawl was used. Due to a lack of inter-calibration between the two different trawls, data from 2010 and 2011 are generally excluded from abundance indices. All calculations presented here are based on the current sampling equipment (i.e. a 286 rockhopper trawl). The swept area between the doors for a standard 15 minute tow averages 0.0347 km^2. The Northumberland Strait multi-species survey provides information on the abundance and distribution of a wide range of coastal fish and invertebrate species (e.g., Chabot et al. 2007; Voutier and Hanson 2008; Bosman et al. 2011) and is used in lobster stock assessments (Rondeau et al. 2015).

1.2.1.4 Southern Gulf of St. Lawrence scallop dredge survey

The sGSL scallop dredge survey was initiated in 2012 and uses a rotational design, changing areas each year over five years (Figure 5). Since its inception there has only been one rotation for the survey, with 100 stations typically sampled annually. The survey employs a stratified-random design and samples using a Digby dredge. Standard 10 minute dredge hauls have an average swept area of 0.0004 km^2. The survey provides data on the abundance of recruiting and adult sea scallop, as well as associated coastal benthic species. The series is presently too short to provide indices of abundance. The survey was last completed in 2016, but there are plans to resume survey activities in 2019 with a modified sampling design that will focus exclusively on scallop beds. In the absence of information on this modified design, this report contains the evaluation of the potential impacts and benefits of this survey based on the existing design and may need to be revisited once the new design is established.

1.2.1.5 Southern Gulf of St. Lawrence multi-species bottom-trawl survey

The sGSL multi-species bottom-trawl survey (sGSL multi-species survey hereafter) has been conducted annually since 1971. It employs a stratified-random design, with strata based on depth and area (Figure 6). In the past decade the survey has sampled approximately 160 stations annually. Since 1985, the swept area for a standard 30 minute haul using a Western IIA trawl is 0.1402 km^2. Details on trawl construction are provided in Hurlbut and Clay (1990). The survey provides abundance indices for a wide variety of demersal and small pelagic fish species (e.g., Benoît and Swain 2008; Hurlbut et al. 2010; Surette 2016), as well as a diversity of benthic invertebrates (e.g., Benoît et al. 2003).

1.2.1.6 Northern Gulf of St. Lawrence (nGSL) snow crab post-season trap survey

The nGSL post-season snow crab trap survey (nGSL snow crab trap survey hereafter) was initiated in 1994 in some sub-zones of the nGSL, and later in others. The survey employs a fixed station design (Figure 7), and is undertaken by industry in collaboration with DFO. It employs standard traps and experimental traps with reduced mesh size to sample smaller crab. The survey employs traps with a 6 or 7 foot diameter, fished singly following a standard soak time. Further details are available in Lambert and Dallaire (2016). Based on the results of Doherty et al. (2018), for a 7 foot diameter conical trap fished singly, the swept area caused by dragging of the pot during hauling was assumed to be 36 times the static footprint, resulting in a swept area of 0.00013 km^2. The nGSL snow crab trap survey is essentially a single species survey that provides a key input on the abundance of different life stages of snow crab.

1.2.1.7 Northern Gulf of St. Lawrence and Estuary multi-species bottom-trawl survey

The nGSL and Estuary multi-species survey (nGSL multi-species survey hereafter) was initiated in 1984. The survey area was expanded considerably to shallower waters (<100 m) in 1990 and in 1991, and again in the Estuary in 2008 to cover waters between 37 and 183 m of depth (strata 851, 852, 854, and 855). The survey employs a random stratified design, with strata based on depth and area (Figure 8). In the past decade the survey has sampled an average of 180 stations annually. Since 2004, the swept area for a standard 15 minute haul using the Campellen trawl is 0.0684 km^2. The survey provides abundance indices for a wide variety of demersal fish species and benthic invertebrates (e.g., Chabot et al. 2007; Bourdages et al. 2018). This survey, along with the sGSL multi-species survey, was key to identifying the aggregations of coral and sponges that eventually led to the selection of the conservation areas in the GSL (Kenchington et al. 2016). In particular, the nGSL multi-species survey identified a large number of areas of concentration and therefore there is a particularly elevated degree of overlap between the conservation areas and the survey area.

1.2.1.8 Northern Gulf of St. Lawrence Sentinel bottom-trawl survey

The nGSL Sentinel bottom-trawl survey (nGSL Sentinel trawl survey hereafter) was initiated in 1995 and revised slightly in 2003. The survey is undertaken by industry, in collaboration with DFO. The survey employs a stratified- random design, using the same strata as the nGSL and Estuary multi-species survey (Figure 8), with the exceptions that it does not sample strata in the Estuary and that it samples some additional coastal strata and strata in NAFO area 3Pn (Figure 9). The survey samples an average of 290 sets per year. The survey trawl is a Star Balloon trawl that employs restrictor cables to keep the trawl opening constant. The average standard 30 minute survey haul has a sept area of 0.1085 km^2. Though the survey is mainly used to provide abundance indices for commercially-important species, such as cod and Greenland halibut, it samples a diversity of fish species. The abundance indices are based on stratified-random estimation.

1.2.2 Surveys excluded from the current evaluation

The following ten additional recurring surveys employ bottom-contacting gear but were excluded from the evaluation as they do not, or will no longer as of 2019, occur in any of the protected areas:

- sGSL Sentinel longline survey (Gulf Region)
- nGSL Sentinel gillnet survey (Quebec Region)
- nGSL Sentinel longline survey (Quebec Region)
- Magdalen Islands lobster trawl survey (Quebec Region)
- Magdalen Islands and Minganie scallop dredge surveys (Quebec Region)
- Northern Gulf snow crab beam-trawl surveys (Quebec Region)

- North shore whelk survey (Quebec Region)

A herring multi-mesh index gillnet survey takes place in parts of the Miramichi and Scallop Buffer Zone marine refuges. However, this survey employs gillnets, which is not prohibited in these refuges, and takes place on commercial herring gillnet fishing grounds during the commercial fishery.

A groundfish gillnet survey is conducted in the Saguenay fjord to support advice for the winter recreational fishery. Though the survey takes place in the Saguenay Fjord Upstream closure, it does not employ a prohibited gear.

Lastly, from 2003 to 2018, the sGSL Sentinel bottom-trawl survey followed the same sampling design as the annual multi-species bottom-trawl survey (Figure 6). As of 2019, to reduce the impacts of the Sentinel survey in the marine refuges and the American Bank MPA, all survey sets that would normally be allocated to these areas will be re-distributed within the pertinent strata.

2. METHODS

The National Framework provides a methodology and check-list of factors to consider to help support decision making on permitting survey activities in protected areas. Appendix I reproduces this checklist and indicates the locations in this document where the relevant information can be found. In this section we focus only on particular analytical methods and approaches required to apply the Framework.

2.1 SWEPT AREA AND PROPORTION OF AREAS IMPACTED CALCULATIONS

Individual haul swept area calculations follow the recommendation in DFO (2018):

- the area swept between trawl doors, assuming complete contact, for bottom trawls,
- the dredge width multiplied by tow length for scallop dredge, and
- the length of longline gear multiplied by an assumed 0.1 km lateral sweep.

The only exception was for the nGSL post-season snow crab trap survey where we used new information on swept area that was not available at the time the National Framework was produced (Doherty et al. 2018; described briefly in section 1.2.1.6).

We estimated the average proportion of a site that is impacted by survey activities on a spatial grid of 0.005 degrees of latitude and longitude, which is approximately square for the latitude of the GSL. At each grid node *i*, the average proportion impacted by a given survey *s* was calculated as:

$$Proportion\ impact_{s,i} = \frac{haul\ swept\ area_{s,i} * frequency_{s,i} * mean\ number\ sets_{s,i}}{survey\ or\ stratum\ area_{s,i}}$$

and the average proportion impacted by all surveys as:

$$Proportion\ impact_{i} = \sum_{s} \frac{haul\ swept\ area_{s,i} * frequency_{s,i} * mean\ number\ sets_{s,i}}{survey\ or\ stratum\ area_{s,i}}$$

In other words, the proportion impacted is the product of the mean area swept by a haul in survey *s,* the frequency of the survey (e.g., 1 for annual; 0.2 for every 5 years), the mean number of sets in survey s in the survey area or the particular survey stratum that contains that node, whichever the case may be, divided by the surface area for the survey area or stratum. The average proportion impacted for a protected area is the average of the values for individual nodes that fall in that area. We estimated two such averages; one across all nodes that occur in a protected area, and one that averages values only for those nodes where one or more surveys occur. We term this latter value impact density.

2.2 RECURRENCE TIME CALCULATIONS

Recurrence time is the average number of years between two sampling events at a particular location, i.e., the average time between disturbance events. It is the inverse of the annual average proportion impacted.

We calculated recurrence times over all surveys for each node and plotted these values on maps to illustrate the spatial heterogeneity in survey recurrence times within individual protected areas. We also calculated averages for each protected area based on the inverse of impact density values at each node in the area. The resulting mean recurrence values represent those for locations in the protected areas where one or more surveys occur. Recurrence times for the remaining areas are infinite by definition, in that there would not be survey activities there unless survey procedures are modified or new surveys are added.

The recurrence time calculations are pertinent for random and stratified-random sampling designs. For fixed survey designs the recurrence time at sampling sites is the inverse of survey frequency and is infinite elsewhere, i.e. will never occur there as long as the survey operates in the same manner. In practice, fixed surveys do contain spatial variation in where sampling actually occurs in addition to ad hoc changes in survey design and sampling. To simplify calculations, we assumed that all surveys employed a random or stratified-random sampling design. For the sGSL snow crab trawl survey and the nGSL snow crab trap survey this calculation will not be exact. In reality recurrence times will be shorter in and around planned sampling locations and may be very long and potentially infinite in other areas.

2.3 EVALUATION OF THE CONSEQUENCES OF EXCLUDING SURVEY ACTIVITIES FROM PROTECTED AREAS.

To simulate the potential impacts of excluding survey sampling in protected areas, we re-calculated relevant time series for various species using all available data from appropriate surveys but excluding data collected from sites that fall within protected areas. We employed the same estimation methods presently used in the surveys: kriging with external drift for the sGSL snow crab trawl survey (Hébert et al. 2016), model-based estimation for the Northumberland Strait multi-species survey (Rondeau et al. 2015), standardized mean for the nGSL snow crab trap survey (Lambert and Dallaire 2016), and stratified means for the remaining surveys (e.g., Hurlbut et al. 2010; Bourdages et al. 2018). For the sGSL snow crab trawl survey and the Northumberland Strait surveys, values for the exclusion areas were effectively interpolated or extrapolated using the estimation methods. For the other areas, we assumed that species densities in the exclusion areas were equal to mean densities in the same stratum outside the protected area, or in the case of the nGSL snow crab trap survey, equal to overall mean densities in the sub-zone.

Potential impacts of exclusion were evaluated by comparing the two time series, with and without exclusion, and by examining trends in the annual log of the ratio of the series with exclusions to the series without. This provides a measure of potential bias. We were particularly interested in the potential for time-varying biases as these may compromise the scientific advice produced from the surveys (details in Benoît et al. 2020). To that end, we fit a generalized additive model (GAM) to the time series of log-ratio values. Significant results for the smoother for the covariate ‘year’ indicated the potential for a significant time varying bias.

It was impractical to consider the potential exclusion of every survey from every permutation of single and combinations of protected areas that overlap with that survey. Instead, we considered permutations for groups of protected areas that share ecological components of interest, reasoning that there would be little justification for excluding surveys in only a subset of areas that comprise a group. Specifically we considered the following groups:

- Scallop buffer zone marine refuges, which all have as a primary objective to protect juvenile lobster;
- Coral conservation areas, which all have as a primary objective the conservation of cold-water corals; and
- Sponge conservation areas, which all have as a primary objective the conservation of cold-water sponges.

Only the Banc-des-Américains MPA was considered singly, given its unique status (protection under the *Oceans Act*), and unique set of conservation objectives. For the exclusions, we considered all relevant single and multi-group permutations for the groups listed above and the MPA.

3. POTENTIAL IMPACTS OF SURVEYS IN THE PROTECTED AREAS

The National framework (DFO 2018) recommends that the evaluation of potential impacts of surveys should ideally be based on direct studies. These will typically be before-after-control-impact (BACI) type studies in which the response of benthic and demersal species to the passage of bottom-contacting fishing gear is quantified. The more the experimental conditions reflect the ecosystem of the protected areas, and the actions of gear employed reflect those of the scientific gear, the more the results will reflect the potential impact of given survey activities. For the GSL there are two such pertinent studies, one relevant for mobile gear in scallop buffer zone (LeBlanc et al. 2015), and a second relevant for the impact of trawls on sea pens (B. Sainte-Marie, DFO Quebec region, unpublished data). These are described in section 3.1.

In the absence of direct studies, the National Framework recommends that metrics of potential disturbance and harm be evaluated with respect to the potential resilience of the ecological components of interest that are the focus of conservation objectives. Metrics of harm include the proportion of the protected area that is covered by a survey, the average annual proportion of the area that is impacted by individual surveys and by all co-occurring surveys, and the mean recurrence time for survey activities at a particular location. The relative magnitude of recurrence time and the longevity of the least resilient taxon or feature in a protected area provides a measure of the risk of potential long-term degradation caused by survey activities (DFO 2018). Survey recurrence times that are longer than longevity by an order of magnitude or more are assumed to not result in long-term impact (DFO 2018; Benoît et al. 2020). In the absence of information on longevity, other factors such as reproductive patterns and the breadth of distribution and environmental tolerance can provide an indication of resilience. These considerations are described for each protected area in section 3.2.

3.1 DIRECT STUDIES OF POTENTIAL IMPACT

3.1.1 Scallop buffer zones

LeBlanc et al. (2015) conducted a study of the impact of scallop dredging on benthic taxa in two study sites: one within the SFA 21 scallop buffer zone and one just outside the SFA 22 scallop buffer zone. While the species relevant to the objectives for this marine refuge (Table 1) were not directly addressed in the study, the endo- and epi-benthic organisms in habitat used by these species were sampled immediately after and a year after dredging. Few taxa were significantly affected by the dredging both immediately and a year following. In contrast, short-term natural abundance fluctuations across experimental plots were much more prevalent and were of a magnitude similar to that estimated to be produced by fairly intense fishing, i.e., by the commercial fishery. The authors concluded that the lack of severe impact caused by scallop dredges reflects the resilient nature of the taxa that occur in the buffer zone areas which are adapted to living in these high energy habitats exposed to currents, storms, potentially rapid changes in temperature, and ice scour during the winter.

The results of the LeBlanc et al. (2015) study suggest that limited scientific sampling using a scallop dredge would not result in large impacts to benthic habitat in the scallop buffer zone marine refuges. Furthermore, because scallop dredges are generally considered to be more harmful to benthic habitats than bottom trawls (Collie et al. 2000; Hiddink et al. 2017; Sciberras et al. 2018), the impacts of scientific bottom trawling in these marine refuges with high energy habitats are also expected to be minor.

3.1.2 Sea pen coral conservation areas

Trawling experiments combined with benthic imagery surveys were conducted in sea pen fields just north of the Gaspe peninsula in August 2015, with follow-up monitoring in October 2015, August 2016 and October 2016 (B. Sainte-Marie, DFO Quebec Region, unpublished data). The four species of sea pens of the EGSL occur in this area, though the study area is most densely populated by *Pennatula aculeata*. The experiments involved four passes of a commercial shrimp trawl in three replicated corridors.

Preliminary results of the experiment indicate that although many *P. aculeata* appeared to pass under the trawl footgear undamaged during the first pass, which replicates survey-like conditions, nearly all were removed or had burrowed in the sediment after four passes. Following the disturbance, the site was repopulated rapidly by some *P. aculeata*, which may have reemerged from the sediment or have crawled along the bottom, an ability lacking in the other sea pen species. In 2016, the site was found to be at least partially recolonized by both small, presumably recruiting, and large, presumably crawling, *P. aculeata*. The recovery of the other species has yet to be established since analyses of the experiment are ongoing. However, *P. aculeata* is undoubtedly much less vulnerable to trawling than the three other sea pen species due to its small size and known burrowing behavior, which make it much less catchable and possibly less susceptible to injury.

The trawling intensity employed in this study was greater than that produced by a survey haul using a trawl since surveys employ a single pass. The removal of and damage to individual sea pens may therefore be less for a survey haul. Partial recovery within a short time frame suggests that *P. aculeata* is likely to be resilient to disturbances such as by scientific sampling that recur every hundred or thousand years.

3.2 METRICS OF POTENTIAL IMPACT AND RESILIENCE

Available information that can be used to assess the resilience of demersal and benthic ecological components of interest is summarized in Table 3. The taxa in this table and their pertinence to particular protected areas can be cross-referenced to Table 2.

The potential impact of the surveys is summarized in four general tables (Tables 4 to 7), with finer scale survey-specific summaries in subsequent individual tables (Tables 8 to 15).

Table 4 presents a summary of the proportion of the surface area of each protected area that overlaps with the sampling area (domain) of each of the eight surveys evaluated. This measurement is based strictly on the overlap of the polygons for the protected areas and survey domains and does not take into account the density of survey sampling.

Table 5 provides a summary of the average proportion of each protected areas that is impacted by each individual survey and the average impact cumulated over all co-occurring surveys. This measurement takes into account survey sampling density and the swept area of individual survey hauls.

Table 6 provides a metric similar to that presented in Table 5 except that it measures the proportion impacted for only those portions of the protected areas where one or more surveys occur. Hereafter we will refer to this measure as proportion impact density.

Table 7 summarizes the average recurrence times (years) of survey activities at any particular location in each protected area, by survey where the survey occurs and overall across all co-occurring surveys. Note that Table 7 reports the average of recurrence times at the nodes on the fine scale grid. This result will differ from that obtained by simply taking the inverse of the average proportion impact values in Table 6.

Spatially resolved recurrence times are presented in maps for each protected area (Figures 11 to 25). Because recurrence times at a particular location are the inverse of the proportion of areas impacted (which is also the probability of an impact in a given year), we do not provide maps for this latter measure. However, Figure 10 provides a depiction of how to interpret proportion impacted from maps of recurrence times.

3.2.1 Banc-des-Américains MPA

Wolffish species are the only demersal taxa specifically noted in the conservation objectives for the MPA. The surveys are unlikely to exceed allowable harm to these species given the high potential for successful live release (Table 3). While survey activities might alter or destroy specific dens used by these fish, the impact density (see below) is sufficiently low that it seems unlikely that surveys would cause a long-term loss of potential den sites. Likewise, long-term harm caused by disruption of autumn egg-guarding by male wolffish (Keats et al. 1985) or destruction of eggs is not expected.

One of the three main conservation objectives of this MPA is to conserve and protect benthic habitats. Three ecosystem features had been detailed for the monitoring of this objective: epibenthic communities, demersal communities, and benthic and demersal commercial species (Faille et al. 2019). We do not consider the latter group here as they are all mobile and likely affected much more by commercial fisheries and broad scale ecosystem factors than survey activities in the MPA. For benthic species, among other things, fixed and erected species were targeted as potentially important species (e.g., rhodophyta, sponges, some larger bryozoans and hydrozoans, two species of soft-corals, anemones, and tunicates). Other selected dominant or indicator species include brittle stars and sea stars. For specifically identified species identified in Faille et al. (2019), as opposed to general species groups, their respective life histories or characteristics are such that they are not expected to be vulnerable to disturbances that recur on the order of 1,000 years or more (Table 3).

3.2.1.1 Zone 1

Zone 1 of the Banc-des-Américains MPA is completely overlapped by the sGSL snow crab trawl survey, while the halibut (stratum D19) and sGSL multi-species (stratum 416) surveys each overlap the area by about 20% (Tables 4, 8, and 12). While there have been on average 1.5 halibut longline sets in stratum D19, none occurred in Zone 1 (Table 8). Similarly, while there have been an average of 7.1 multi-species survey sets annually in stratum 416, none occurred in Zone 1 in the past decade (Table 12). There has generally been one set per year of the snow crab survey in Zone 1 (Table 9).

The average proportion of the area that is impacted annually is similar across the three surveys 5.24E-05 to 6.26E-05, resulting in an overall spatial average of 1.68E-04 (Table 5). Impact density is greater for the halibut and sGSL multi-species survey given that they occur only in a small portion of the area (Table 6). Recurrence time is around 19,000 years for the snow crab survey and over 3,000 years for the other two surveys, resulting in an overall average of around 14,600 years (Table 7). The majority of Zone 1 (73%) is associated with a recurrence time of over 19,000 years, with the remainder associated with recurrence times of 1,600 (12%), 2,600 (7%) or 3,000 (8%) years (Figure 11).

3.2.1.2 Zone 2

Zone 2 of the Banc-des-Américains MPA is almost completely overlapped by the sGSL snow crab trawl survey, and the halibut survey (strata C19, D16, D19) and sGSL multi-species survey (stratum 416 and a very small portion of stratum 417) each overlap the area by about 80% (Tables 4, 8, and 12). Halibut survey stratum C19 overlaps little with Zone 2, while strata D16 and D19 overlap by 5% and 37% respectively (Table 8). Once in two survey years, there was one halibut survey set in each of these strata that fell in Zone 2. There have been on average almost five sGSL snow crab survey sets annually in Zone 2 (Table 9), On average there have been 7.1 sGSL multi-species survey sets per year in stratum 417 of which an average of 1.6 fell in Zone 2 (Table 12).

The average proportion of the area that is impacted annually by the halibut and sGSL multi-species surveys is similar, around 2.3E-04, and greater than for the sGSL snow crab trawl survey (Table 5). Impact density is similar to the average proportion impacted given the high level of overlap for the three surveys (Table 6). Recurrence time is around 19,000 years for the sGSL snow crab trawl survey and over 3,000 years for the other two surveys, resulting in an overall average of around 4,500 years (Table 7). The average recurrence time value is smaller than in Zone 1 because the halibut and sGSL multi-species surveys occupy a greater proportion of the area of Zone 2 compared to Zone 1. The majority of Zone 2 (76%) is associated with a recurrence time of 1,600 years, with an additional 16.4% associated with a time of >19,000 year (Figure 11). Recurrence times in remaining areas are all ≥2,600 year.

3.2.2 Scallop buffer zones (SFA 21, 22 and 24)

Based on the study summarized in section 3.1.1, bottom-contacting survey activities are not expected to result in long-term harm to the habitat of the ecological components of interest in all three buffer zone marine refuges (Table 1). Notwithstanding section 3.1.1, the life-histories and productivity of both primary and secondary ecological components in the refuges are such that long-term harm caused by survey activities that recur on the scale of centuries or more is not expected (Table 3).

3.2.2.1 SFA 21 marine refuge

Scallop buffer zone SFA 21 is overlapped by the halibut survey (9.4%; strata C18, C19), the sGSL scallop dredge survey (45%; strata 2013.1, 2013.2, 2016.2, 2016.4) and the sGSL multi-species survey (2%; strata 418, 419) (Tables 4, 8, 11 and 12). The elevated degree of overlap between all scallop buffer zone marine refuges and the scallop dredge survey is not surprising as that survey was designed to sample both the original scallop buffer zones and the areas that are fished commercially. There is only one set annually in each of strata C18 and C19 of the halibut survey, none of which fell in the protected area (Table 8). There have been several sets in each stratum of the sGSL scallop dredge survey that fell in the protected area (Table 11).

There have been no sGSL multi-species survey sets in the protected area since 2009 (Table 12).

The average proportion of the area that is impacted annually is 2.78E-05 for the halibut survey and an order of magnitude smaller for the other two surveys (Table 5). Impact density is similar for the halibut and sGSL multi-species survey (approximately 3E-04) and about two orders of magnitude smaller for the sGSL scallop survey (Table 6). The latter result reflects the very small swept area of the scallop dredge survey (Table 2). The small swept area combined with small sampling density resulting in part from the rotational nature of the survey, results in very long recurrence times for the sGSL scallop survey in all three scallop buffer zone marine refuges (approximately 500,000 years; Table 7). Recurrence times for the other two surveys are over 3,000 years, and overall average recurrence time where one or more surveys occur is almost 400,000 years. There are no survey activities in just over half the protected area (i.e., infinite recurrence time) (Figure 12). Where survey activities occur, recurrence times are mainly >19,000 years or 3,200 years.

3.2.2.2 SFA 22 marine refuge

Scallop buffer zone SFA 22 is overlapped by the halibut survey (0.4%; strata C14, C17), the Northumberland Strait multi-species survey (64%), the sGSL scallop dredge survey (72%; 2012.4, 2012.5, 2014.4) and the sGSL multi-species survey (6%; strata 402, 421) (Tables 4, 8, 11, and 12). The overlap with the halibut survey is very small and there have been no sets in the refuge (Table 8). The refuge overlaps with about 17% of the Northumberland Strait multi-species survey domain and on average 25.2 sets have occurred in the refuge area annually (Table 10), which constitutes a large proportion of the approximately 110 sets made in that survey annually (Table 2). There have been several sets in each overlapping stratum of the sGSL scallop dredge survey that fell in the protected area (Table 11). There have been no sGSL multi-species survey sets in the protected area since 2009 (Table 12).

The average proportion of the area that is impacted annually is greatest for the Northumberland Strait multi-species survey (2.28E-04), followed by the sGSL multi-species survey (1.57E-05) and the remaining two surveys (just over 1.0E-6), resulting in an overall average of 2.46E-04 (Table 5). Impact densities for the halibut, Northumberland Strait multi-species and sGSL multi-species surveys are of similar magnitude, ~1E-04 (Table 6), resulting in recurrence times of between 2,000 and 3,800 years (Table 7). The average recurrence time is about 150,000 years. The majority of the area is associated with a recurrence time of 2,800 years, while the remainder is generally associated with a time of >19,000 years (21.5%), 1,600 years (5.7%) or no activity (14.3%) (Figure 13).

3.2.2.3 SFA 24 marine refuge

Scallop buffer zone SFA 24 is overlapped by the halibut survey (34%; strata C13, C14), the Northumberland Strait multi-species survey (38%), the sGSL snow crab trawl survey (4%), the sGSL scallop dredge survey (57%; 2015.1 to 2015.5) and the sGSL multi-species survey (25%; strata 403, 432, 433, 434) (Tables 4, 8, 11 and 12). For the halibut survey, the overlap is greatest for stratum C13, in which there are 6 sets annually of which an average of 1.5 have fallen in the refuge over the past two years (Table 8). While the refuge overlaps with only 0.1% of the sGSL snow crab survey domain, an average of 1.4 sets per year occur in the refuge (Table 9). The refuge overlaps about 8% of the Northumberland Strait multi-species survey domain and on average 7.9 sets have occurred in the refuge area annually (Table 10). Although all five of the 2015 sGSL scallop dredge survey strata overlapped with the refuge, stratum 2015.5 is the only one for which sets occurred in the refuge, specifically all but one of the 23 sets (Table 11). Stratum 433 is the main sGSL multi-species survey stratum that overlaps with the refuge (13% of the stratum area). There are on average 8.2 sets annually in this stratum of which an average of 0.6 has fallen in the refuge (Table 12). Approximately 1.4% of stratum 432 overlaps the refuge. This stratum is sampled by typically 3 or 4 sets per year, of which an average of 0.2 have occurred in the refuge. The refuge overlaps very little of the remaining two strata, 403 and 434.

The average proportion of the area that is impacted annually is greatest for the Northumberland Strait multi-species survey (1.34E-04), followed by the sGSL multi-species survey (7.17E-05), the halibut survey (8.58E-05) and the remaining two surveys (over 1.10E-6), resulting in an overall average of 2.95E-04 (Table 5). Impact densities for the halibut, Northumberland Strait multi-species and sGSL multi-species survey were of similar magnitude (approx. 2E-04) and greater than for the sGSL snow crab trawl survey (5.24E-05) and the sGSL scallop dredge survey (2.01E-06) (Table 6). Average recurrence times where surveys occurred were similar for the halibut, Northumberland Strait and multi-species survey, with values between 2,800-3,900 years, and were much longer for the remaining surveys (Table 7).

Almost half (38.2%) of the protected area is associated with no survey activity or with very long recurrence times (11.6% of the area), while the remainder is generally associated with recurrence times between 1,000 and 4,000 years (Figure 14).

3.2.3 Eastern Gulf of St. Lawrence CCA

The Eastern Gulf of St. Lawrence Coral Conservation Area is completely overlapped by the nGSL multi-species and nGSL Sentinel trawl surveys (stratum 407 in both cases; Tables 4, 14, and 15). Both surveys average 3 sets per year in stratum 407, of which an average of around 0.3 sets per year fall in the refuge. The average proportion of the refuge that is impacted by each survey is approximately the same, resulting in an overall average of 1.98E-04 (Table 5). The impact density of each survey is around 1E-04, resulting in an overall average recurrence time of around 5,000 years (Table 7), which is spatially uniform over the protected area (Figure 15).

The specific ecological components of interest for this refuge are *P. grandis* and *Anthoptilum grandiflorum* (Table 1). The observed (*A. grandiflorum*) and presumed (*P. grandis*) longevity of these taxa is two orders or magnitude smaller than the recurrence time (Table 3).

3.2.4 Slope of Magdalen Shallows CCA

The Slope of the Magdalen Shallow Coral Conservation Area is completely overlapped by the nGSL multi-species and nGSL Sentinel trawl surveys (strata 404, 407, 803 in both cases), and partially overlapped by the sGSL snow crab survey (21%) and the sGSL multi-species survey (36%; strata 425 and 439) (Tables 4, 12, 14, and 15). The nGSL multi-species survey averaged around 0.35 sets in each of strata 404 and 407 in the protected area annually, while there have only been 0.2 sets on average in stratum 407 in the nGSL Sentinel survey (Tables 14 and 15). There were 0.2 sets in stratum 425 and 0.4 sets in stratum 439 of the sGSL multi-species survey on average that fell in the protected area, reflecting the small proportion of the strata (3-4%) covered by the protected area (Table 12). On average there is around one set per year of the sGSL snow crab survey that fell in the area (Table 9).

The average proportion of the area that is impacted annually is smallest for the sGSL snow crab trawl survey (1.10E-05) and of similar general magnitude for the other surveys (>1.0E-04), resulting in an overall average of 3.87E-04 (Table 5). The impact density follows a similar pattern (Table 6). Recurrence times were smallest for the sGSL multi-species survey (3,250 years) and largest for the nGSL multi-species survey (11,176 years) and the sGSL snow crab survey (19,000 years), resulting in an overall average of 3,753 years for locations where one or more surveys occur (Table 7).The shortest recurrence times (1,000-2,000 years) occur where all four surveys overlap, along the southwestern portion of the protected area. The longest recurrence times (4,000-5,000) occur in the northeastern portion where only the nGSL multi-species and Sentinel surveys overlap.

The specific ecological components of interest for this refuge are *P. grandis* and *A. grandiflorum* (Table 1). The observed (*A. grandiflorum*) and presumed (*P. grandis*) longevity of these taxa is two orders or magnitude smaller than the recurrence time (Table 3).

3.2.5 Central Gulf of St. Lawrence CCA

The Central Gulf of St. Lawrence Coral Conservation Area is completely overlapped by the nGSL multi-species and nGSL Sentinel trawl surveys (stratum 803 in both cases; Tables 4, 14, and 15). The nGSL multi-species survey averages around 6.5 sets per year in stratum 803, of which an average of around one set per year falls in the refuge. The nGSL Sentinel survey averages around 12 sets per year in stratum 803, of which an average of around 3 sets per year falls in the refuge. It is worth noting that stratum 803 also overlaps with the Slope of the Magdalen Shallows CCA and the South-East of Anticosti Island CCA.

The average proportion of the refuge that is impacted is 6.37E-05 by the nGSL multi-species survey and 1.84E-04 by the nGSL Sentinel survey, resulting in an overall average of 2.47E-04 (Table 5). Because both surveys completely overlap the zone, impact density is the same as the proportion impacted (Table 6). The average recurrence times for the nGSL multi-species and nGSL Sentinel surveys are over 15,000 and 5,400 years, respectively, resulting in a spatially uniform average of around 4,000 years (Table 7; Figure 17).

The specific ecological component of interest for this refuge is *A. grandiflorum*, though some secondary taxa have been identified: *Flabellum alabastrum* hard corals, *Duva florida* soft corals, the presence of the large structure-providing *Asconema foliatum* sponge, and at least three species of skates and wolffish (Table 1). The longevity, life history or productivity of *A. grandiflorum*, *F. alabastrum*, *D. florida*, the skates and the wolffishes are such that survey activity recurrence times >1,000 years are unlikely to result in long-term harm (Table 3). The longevity of *A. foliatum* is not known.

3.2.6 South-East of Anticosti Island SCA

The South-East of Anticosti Island Sponge Conservation Area is almost completely overlapped by the nGSL multi-species and nGSL Sentinel trawl surveys (strata 803, 807 and 819 in both cases) and partly overlapped by the halibut survey (9%; stratum D6) (Tables 4, 8, 14, and 15). Stratum 803 receives around 6.5 sets per year in the nGSL multi-species survey, while the other two strata receive around 3 sets per year (Table 14). Of these, there have been on average 0.8 and 0.2 sets per year in strata 807 and 803 respectively that fell in the refuge area. Stratum 803 receives around 12 sets per year in the nGSL Sentinel survey, while the other two receive around 3 or 4 sets (Table 15). Of these, there have been on average 0.3 and 1 set per year in strata 803 and 807, respectively, that fell in the refuge area. Halibut survey stratum D6 is allocated an average of 5.5 sets per year and none have fallen in the refuge area to date (Table 8).

The average proportion of the refuge that is impacted is 8.40E-05 by the nGSL multi-species survey, 1.84E-04 by the nGSL Sentinel survey, and 2.06E-05 by the halibut survey, resulting in an overall average of 2.89E-04 (Table 5). Impact density values are the same for the first two surveys given their complete overlap of the refuge, while the value for the halibut survey is 2.38E-04 (Table 6). Average recurrence times for locations where a survey occurs are around 4,200 years for the halibut survey, 5,400 years for the nGSL Sentinel survey and 12,400 years for the nGSL multi-species survey, resulting in an overall average of 3,615 years (Table 7).

Spatially, the shortest recurrence times (1,800-2,200 years) occur in the northeastern portion of the refuge where all three surveys overlap (7.0% of the area) (Figure 18). Recurrence times are ≥3,600 years in the remainder of the area.

The specific ecological components of interest for this refuge are sponges, though some secondary taxa have been identified: *D. florida* soft corals*, A. grandiflorum*, the presence of the large structure-providing *A. foliatum* sponge, and at least three species of skates and wolffish (Table 1). For this refuge and all the other sponge conservation areas below, it is not possible to make any definitive statement about the longevity or vulnerability for unidentified sponges.

The presence of sponge aggregations at sites where intensive shrimp fishing activities occurred during the 1980s but where few activities have occurred since (e.g., west of Anticosti Island) suggest that those sponge communities can exhibit some recovery after disturbance (DFO 2012). However, the extent of recovery and the identification of the species involved are not presently known. The longevity, life history or productivity of *A. grandiflorum, D. florida,* the skates and the wolffishes are such that survey activity recurrence times >1,000 years are unlikely to result in long-term harm (Table 3). The longevity of *A. foliatum* is not known.

3.2.7 East of Anticosti Island SCA

The East of Anticosti Island Sponge Conservation Area is almost completely overlapped by the nGSL multi-species and nGSL Sentinel trawl surveys (strata 819, 829 and 830 in both cases) and largely overlapped by the halibut survey (85%; stratum D6 and D9) (Tables 4, 8, 14, and 15). All three nGSL multi-species survey strata receive between 2.4 and 3.0 sets per year, of which there are 0.1 in stratum 819, 0.2 in stratum 829, and 0.7 in stratum 830 which has about a third of its surface area covered by the refuge (Table 14). The pattern is similar for the nGSL Sentinel survey, though station allocations are a little higher (Table 15). Halibut survey stratum D6 receives on average 5.5 sets annually of which one has fallen in the protected area, while stratum D9 receives 11.5 sets per year and none have fallen in the refuge area to date (Table 8).

The average proportion of the refuge that is impacted is 9.07E-05 by the nGSL multi-species survey, 1.95E-04 by the nGSL Sentinel survey, and 2.05E-05 by the halibut survey, resulting in an overall average of 4.91E-04 (Table 5). Impact density values are almost the same for the first two surveys given their near complete overlap of the refuge, while the value for the halibut survey is 2.41E-04 (Table 6). Average recurrence times for locations where a survey occurs are around 4,150 years for the halibut survey, 8,000 years for the nGSL Sentinel survey, and 11,500 years for the nGSL multi-species survey, resulting in an overall average of around 2,100 years (Table 7). Most of the refuge is associated with recurrence times ranging between 1,800 and 2,200 years, concentrated in the central and eastern portion of the area where all three surveys co-occur (Figure 19). Recurrence times are greater in most of the western portions of the area, including the western-most portion (4.3%) in which no survey activities occur.

The specific ecological component of interest for this refuge are sponges, though some secondary taxa have been identified: *D. florida* and *Gersemia rubiformis* soft corals, and at least three species of skates and wolffish (Table 1). The considerations for unidentified sponges listed in section 3.2.6 are not repeated here. The longevity, life history or productivity of *D. florida, G. rubiformis* and the skates and the wolffishes are such that survey activity recurrence times >1,000 years are unlikely to result in long-term harm (Table 3).

3.2.8 Beaugé Bank SCA

The Beaugé Bank Sponge Conservation Area is completely overlapped by the nGSL multi-species and nGSL Sentinel bottom-trawl surveys (strata 827 and 833 in both cases) and partly overlapped by the halibut survey (5%; stratum D7) and the nGSL snow crab trap survey in snow crab fishing sub-zone 12A (Tables 4, 8, 13, 14, and 15). In the nGSL multi-species survey, stratum 827 receives an average of 2.8 sets annually of which 0.1 fell in the refuge, while stratum 833 receives 2.3 sets per year of which one per year on average has fallen in the refuge (Table 14). Patterns are similar for the nGSL Sentinel survey, though the numbers are slightly higher (Table 15). Halibut survey stratum D7 is allocated an average of 10.5 sets per year and none have fallen in the refuge area to date (Table 8). There have been six sets per year on average in the nGSL snow crab trap survey that have been in the refuge (Table 13).

The average proportion of the refuge that is impacted by the surveys is 2.44E-04 by the nGSL multi-species, 5.13E-04 by the nGSL Sentinel survey, 1.21E-05 by the halibut survey, and 3.59E-0.6 by the nGSL snow crab trap survey, resulting in an overall average of 7.73E-04 (Table 5). Impact density values are the same for the first two surveys given their complete overlap of the refuge, while the value is 2.51E-04 for the halibut survey and 8.94E-05 for the snow crab trap survey (Table 6). Average recurrence times for locations where a survey occurs are around 2,400 years for the nGSL Sentinel survey, 4,000 years for the halibut survey, 5,800 years for the nGSL multi-species survey, and 11,299 years for the snow crab trap survey, resulting in an average of 1,573 years, the smallest value of any of the protected areas considered (Table 7). Spatially, the shortest recurrence times (1,000-1,200 years) cover the majority of the area (81.3%) (Figure 20). The longest recurrence times (4,200 years) occur in the northern and southern portions of the area, representing about 12% of the refuge area.

The specific ecological component of interest for this refuge are sponges, though some secondary taxa have been identified: *D. florida* and *G. rubiformis* soft corals*, H. arcofer* sponge, and at least four species of skates and wolffish (Table 1). The considerations for unidentified sponges listed in section 3.2.6 are not repeated here. The longevity, life history or productivity of *D. florida, G.* rubiformis and the skates and the wolffishes are such that survey activity recurrence times >1,000 years are unlikely to result in long-term harm (Table 3). The longevity of *H. arcofer* is not known.

3.2.9 North of Bennett Bank CCA

The North of Bennett Bank Coral Conservation Area is completely overlapped by the nGSL multi-species and nGSL Sentinel bottom-trawl surveys (strata 804, 405 and 408 in both cases) and partly overlapped by the sGSL multi-species (20%; stratum 425) and sGSL snow crab surveys (12%) (Tables 4, 12, 14, and 15). In the nGSL multi-species survey, the three strata have been allocated between 2.6 and 3.4 sets annually of which 0.1 set in stratum 405 and 0.8 set in stratum 408 fell in the refuge (Table 14). Set allocations are slightly higher in the nGSL Sentinel survey, and on average there were 0.1, 0.5 and 1.2 sets annually in strata 804, 405 and 408, respectively, that fell in the refuge (Table 15). In the sGSL multi-species survey, stratum 425 has been allocated an average of around 4 sets per year, of which 0.5 fell within the refuge boundaries (Table 12). In the sGSL snow crab trawl survey, an average of 0.7 sets fell annually in the refuge.

The average proportion of the refuge that is impacted is 8.74E-04 by the nGSL multi-species survey, 1.26E-04 by the nGSL Sentinel survey, 5.28E-05 by the sGSL multi-species survey and 6.09E-0.6 by the sGSL snow crab trawl survey, resulting in an average of 2.73E-04 (Table 5). Impact density values are higher for all four surveys (Table 6). Average recurrence times for locations where a survey occurs are around 3,700 years for the sGSL multi-species survey, 8,100 years for the nGSL Sentinel survey, 11,500 years for the nGSL multi-species survey and 19,000 years for the sGSL snow crab trawl survey, resulting in an average of 4,300 years (Table 7). Spatially, the shortest recurrence times (1,600-2,200 years) occur along the southern margin of the refuge where all four surveys co-occur, covering about 20% of the refuge (Figure 21). The majority of the area (79%) of the refuge is associated with a recurrence time of 4,800 years.

The specific ecological component of interest for this refuge is *A. grandiflorum* and the other three species of sea pens, though some secondary taxa have been identified including at least three species of skates and wolffish (Table 1). The longevity, life history or productivity of *A. grandiflorum* and the other sea pens, the skates and the wolffishes are such that survey activity recurrence times >1,000 years are unlikely to result in long-term harm (Table 3).

3.2.10 Eastern Honguedo Strait CCA

The Eastern Honguedo Strait Coral Conservation Area is almost completely overlapped by the nGSL multi-species and nGSL Sentinel bottom-trawl surveys (strata 405, 406, 804, 807, 408, 818, and 806 in both cases) and partly overlapped by the sGSL multi-species survey (15%; stratum 415), the halibut survey (1%; stratum D6) and sGSL snow crab trawl survey (15%) (Tables 4, 8, 12, 14 and 15). The nGSL multi-species survey strata typically receive 2.5 to 4 sets each per year; on average 3.5 sets across these strata fell in the refuge area annually (Table 14). Set allocation is slightly higher in the nGSL Sentinel survey (3 to 5 sets), and on average 4.2 sets across the strata fell in the refuge area annually (Table 15). Stratum 415 in the sGSL multi-species survey is allocated an average of 4.1 sets per year of which 0.5 fell within the refuge boundaries (Table 12). In the sGSL snow crab survey, an average of 2 sets annually were in the refuge.

The average proportion of the refuge that is impacted is 9.44E-05 by the nGSL multi-species survey, 1.79E-04 by the nGSL Sentinel survey, 4.13E-05 by the sGSL multi-species survey, 2.41E-06 by the halibut survey and 7.77E-0.6 by the sGSL snow crab trawl survey, resulting in an average of 3.25E-04 (Table 5). Impact density values were almost the same for the nGSL surveys and higher for the sGSL surveys (Table 6). Average recurrence times for locations where a survey occurs are around 3,500 years for the sGSL multi-species survey, 4,200 for the halibut survey, 5,900 years for the nGSL Sentinel survey, 10,600 years for the nGSL multi-species survey and 19,000 years for the sGSL snow crab trawl survey, resulting in an average of 3,400 years (Table 7). Spatially, the shortest recurrence times (1,400-2,600 years) occur along the southwestern margin of the refuge where all four surveys co-occur, covering about 20% of the refuge (Figure 22). The central part of the refuge is associated with recurrence times ≥4,600 years (23% of the area), including some locations where no survey activities take place. The northern portion of the area is typically associated with recurrence times around 3,400 years.

The specific ecological component of interest for this refuge are cold-water corals and sponges, notably *H. finmarchica, A. grandiflorum, P. grandis* and *P. aculeata,* as well as secondary species *D. florida* soft corals, one structure-providing sponge, *Mycale sp.*, and at least three species of rays and wolffish. The considerations for unidentified sponges listed in section 3.2.6 are not repeated here. Estimated longevity of the sea pens does not appear to make them vulnerable to recurrence times >1,000 years. Similarly, the longevity, life history or productivity of the skates and the wolffishes are such that survey activity recurrence times >1,000 years are unlikely to result in long-term harm (Table 3). Recovery of the related *Mycale loveni* sponge following perturbation by a single trawl pass is likely much longer than a decade (Malecha and Heifetz 2017), although growth forms of this species are different from *Mycale* species in the Gulf and the results of this study may not accurately reflect recovery potential here (Curtis Dinn, DFO Science Gulf Region, personal communication).

3.2.11 Western Honguedo Strait CCA

The Western Honguedo Strait Coral Conservation Area is almost completely overlapped by the nGSL multi-species and nGSL Sentinel bottom-trawl surveys (strata 804, 406 and 806 in both cases) (Tables 14 and 15). The nGSL multi-species survey strata typically receive 3 to 4 sets each per year and an average of 0.1, 0.8 and 0.2 sets per year fell within refuge boundaries in strata 804, 406 and 806 respectively (Table 14). Set allocation is slightly higher in the nGSL Sentinel survey (3 to 5 sets), and an average of 0.6 and 0.1 sets per year fell within refuge boundaries in strata 406 and 806, respectively (Table 15).

The average proportion of the refuge that is impacted is 9.17E-05 by the nGSL multi-species survey and 1.51E-04 by the nGSL Sentinel survey, resulting in an average of 2.43E-04 (Table 5). Impact density values were almost the same (Table 6). Average recurrence times for locations where a survey occurs are around 6,900 years for the nGSL Sentinel survey and 10,900 years for the nGSL multi-species survey, resulting in an average of 4,200 years (Table 7). Spatially, the shortest recurrence times (3,400 years; 31% of the area) occur along the northern portion of the refuge and the longest ones (4,600 years; about 68% of the area) along the southern portion (Figure 23).

The specific ecological component of interest for this refuge are *P. aculeata, P. grandis* and *A. grandiflorum*. Results of the experiment for *P. aculeata* described in section 3.1.2, and the estimated longevity of the sea pens does not appear to make them vulnerable to recurrence times >1,000 years.

3.2.12 Parent Bank SCA

The Parent Bank Sponge Conservation Area is overlapped by the nGSL multi-species and nGSL Sentinel surveys (71%, strata 817 and 831, in both cases) and the halibut survey (59%, stratum D5) (Tables 4, 8, 14 and 15). There are typically an average of 4.5 and 2.4 sets annually in strata 817 and 831, respectively, of the nGSL multi-species survey (Table 14). In each stratum an average of 0.4 sets per year fell in the refuge. There are typically an average of 6.4 and 2.3 sets annually in strata 817 and 831, respectively, of the nGSL Sentinel survey (Table 15). In each stratum an average of 0.2 sets per year fell in the refuge. Stratum D5 of the halibut survey is allocated 5 sets annually, of which one has fallen annually within the refuge boundaries (Table 8).

The average proportion of the refuge that is impacted is 8.73E-05 by the nGSL multi-species survey, 1.44E-04 by the nGSL Sentinel survey and 1.39E-04 by the halibut survey, resulting in an average of 3.70E-04 (Table 5). Impact density values were greater for all three surveys (Table 6). Average recurrence times for locations where a survey occurs are around 4,200 for the halibut survey, 4,900 years for the nGSL Sentinel survey and 8,500 years for the nGSL multi-species survey, resulting in an average of 2,100 years (Table 7). Spatially, the shortest recurrence times (1,800-2,000 years) occur in the western and southwestern portion of the refuge (56% of the area) (Figure 24). There are no survey activities in much of the eastern portion of the area (27%).

The specific ecological component of interest for this refuge are sponges, though some secondary taxa have been identified: *D. florida* and *G. rubiformis* soft corals, *P. aculeata*, *Mycale sp.* sponge, and at least three species of skates and wolffish (Table 1). The considerations for unidentified sponges listed in section 3.2.6 are not repeated here. The longevity, life history or productivity of *P. aculeata, D. florida, G.* rubiformis and the skates and the wolffishes are such that survey activity recurrence times >1,000 years are unlikely to result in long-term harm (Table 3). Recovery of the related *Mycale loveni* sponge following perturbation by a single trawl pass is likely much longer than a decade (Malecha and Heifetz

2017), although growth forms of this species are different from *Mycale* species in the Gulf and the results of this study may not accurately reflect recovery potential here (Curtis Dinn, DFO Science Gulf Region, personal communication).

3.2.13 Jacques-Cartier Strait SCA

The Jacques-Cartier Sponge Conservation Area is completely overlapped by the nGSL multi-species and nGSL Sentinel surveys (strata 828, 832, 839 and 841, in both cases) and the nGSL snow crab trap survey in sub-zone 16, and is partly overlapped by the halibut survey (50%, strata D10, D5 and D9) (Tables 4, 8, 14 and 15). There are typically an average of 2.3 to 4.1 sets annually in strata 828, 832, 839 and 841 of the nGSL multi-species survey, with an average of 0.1 in strata 428 and 432, and 0.2 in 841, that occurred within refuge boundaries (Table 14). The set allocation to these strata is higher in the nGSL Sentinel survey, though only 0.1 and 0.2 sets on average, in strata 828 and 841 respectively, fell within refuge boundaries (Table 15). There are 6 sets annually that fell within refuge boundaries in the nGSL snow crab trap survey (Table 13). The halibut survey allocated around 4 sets annually to strata D10 and D5, and 11.5 sets to stratum D9, of which none fell within the refuge boundaries (Table 8).

The average proportion of the refuge that is impacted is 1.10E-04 by the nGSL multi-species survey, 1.65E-04 by the nGSL Sentinel survey, 2.60E-06 by the nGSL snow crab trap survey, and 1.29E-04 by the halibut survey, resulting in an average of 4.07E-04 (Table 5). Impact density values are the same for all three nGSL surveys and are 2.61E-04 for the halibut survey (Table 6). Average recurrence times for locations where a survey occurs are around 3,800 years for the halibut survey, 9,100 years for the nGSL Sentinel survey, 11,900 years for the nGSL multi-species survey, and almost 400,000 years for the nGSL snow crab trap survey, resulting in an overall average of 2,900 years (Table 7). Spatially, the shortest recurrence times (mainly 2,000-2,400 years) generally occur in the southern portion of the refuge (80% of the area) (Figure 25). The longest recurrence times (mainly 5,600-6,600 years) generally occur along the northern margin of the refuge, with some locations in the center.

The specific ecological components of interest for this refuge are sponges, though some secondary taxa have been identified: *G. rubiformis* soft corals and *H. arcofer* sponge (Table 1). The considerations for unidentified sponges listed in section 3.2.6 are not repeated here. The longevity, life history or productivity of *G. rubiformis* is such that survey activity recurrence times >1,000 years are unlikely to result in long-term harm (Table 3). The longevity of *H. arcofer* is unknown.

3.2.14 Summary

The shortest overall recurrence time (1,573 years) occurred in the Beaugé Bank SCA, while the other coral and/or sponge conservation areas and Zone 2 of the Banc-des-Américains MPA experience estimated recurrence times ranging from 2,000 to 5,000 years. Recurrence times were very long for the scallop buffer zone refuges as a result of the very small swept areas for the sGSL scallop dredge survey and the low to moderate degree of overlap by the other surveys that occur there. At finer spatial scales within protected areas, local recurrence times were all 1,000 years or more, with the exception of 0.2% of the overlapped area of the scallop buffer zone SFA 24 refuge, where recurrence times ranged between 600 and 1,000 years.

Biological and ecological characteristics of demersal and benthic ecological components of interest for the protected areas of the EGSL other than sponges are such that they should not be vulnerable to impacts by surveys associated with recurrence times >1,000 years (DFO 2018; Appendix Table 2). These characteristics include observed or predicted longevities less than 100 years, high likelihood of survival following capture and release, and elevated growth or reproductive rates. For example, longevities for the four species of sea pen corals of the EGSL are estimated to be on the scale of decades (Appendix Table 2), thus at least one order of magnitude less than surveys' recurrence times in EGSL protected areas.

The resilience of sponges in the EGSL is poorly known. The presence of sponge aggregations of unknown species composition at sites in the EGSL where intensive shrimp fishing activities occurred during the 1980s but where few activities have occurred since (e.g., west of Anticosti Island) suggests that sponge aggregations, can be established within decades following disturbance (DFO 2012), although the successional nature of sponge species recruitment in the region is unknown. In contrast, recovery periods much longer than a decade following perturbation by a single trawl pass have been inferred for *Mycale loveni* for example (Malecha and Heifetz 2017). This species, however, does not occur in the EGSL and exhibits growth forms that are different from *Mycale* species in the EGSL. The results of that study may not accurately reflect recovery potential for this bioregion (Curtis Dinn, DFO Science Gulf Region, personal communication).

4. POTENTIAL IMPACTS TO SURVEY SERIES IF SURVEY ACTIVITIES ARE RESTRICTED OR PROHIBITED IN THE PROTECTED AREAS

A decision to restrict or prohibit survey activities in protected areas could compromise monitoring results and have knock-on effects for the conservation of marine taxa in the broader ecosystem. Given that DFO's conservation mandate includes fishery resources, species at risk and ecological components of interest in protected areas, potential impacts on broader scale scientific monitoring and advice should be part of the considerations in the decision-making process for authorizing monitoring in protected areas.

In this section we consider the potential for such impacts by recalculating survey time-series using only data from outside the boundaries of individual or groups of protected areas. Of particular interest is the potential for time-varying biases in monitoring time series, which would result in a misinterpretation of population trends which could in turn reduce the efficacy of management actions (Benoît et al. 2020). Non-time varying biases are of much less concern given that all of the surveys of interest produce relative indices of abundance (i.e., already a bias with respect to true abundance), provided that the bias introduced by removing sampling stations is estimated and accounted for going forward.

The analyses did not cover an exhaustive list of species or populations, but rather focused on a small number of case studies. These include selected species of commercial interest, species of ecological (conservation) interest in protected areas, and species most susceptible to time-varying biases, resulting from for example temporal shifts in habitat selection and spatial distribution. The retrospective analyses were restricted to surveys with at least a five year history, thereby omitting the halibut longline and sGSL scallop dredge surveys

4.1 SGSL SNOW CRAB TRAWL SURVEY

Survey time series with and without sets that occurred in protected areas were estimated for the sGSL estimation polygon as a whole and for individual snow crab fishery management sub areas, zones 19, 12E, and 12F. We evaluated the consequence of removing sets from the American Bank MPA, from the coral conservation areas, and from all protected areas. The means for commercial male snow crab (*Chionocetes opilio*; mature males ≥95 mm) survey series with and without sets in protected areas were essentially the same for all permutations of set removals for years after 2011 in which the survey area has covered waters between 20 and 200 fathoms. Figure 26 shows the consequences of removing stations from all protected areas. Confidence intervals were generally a little wider, as expected for a reduced sample size. There were slight differences between series with and without protected area sets for years prior to 2012, reflecting the higher degree of extrapolation required in those years given that the survey did not fully cover deeper waters that have been well sampled since 2012. The lack of an effect of set removal on the snow crab time series likely reflects the small number of stations removed, the high sampling density for this survey, and the use of kriging to interpolate/extrapolate and estimate abundance.

4.2 NORTHUMBERLAND STRAIT MULTI-SPECIES SURVEY

About a quarter of the area and sets (33 of 110) of the Northumberland Strait multi-species survey fall within the boundaries of scallop buffer zones 22 and 24 (Tables 2 and 10). Removing these sets results in a large increase in annual variability and the potential for large time-varying biases in abundance indices for two key species, Winter Skate (*Leucoraja ocellata*), a population assessed as endangered by COSEWIC, and American lobster (*Homarus americanus*), an important fishery resource (Figure 27). The Northumberland Strait multi-species survey is the only survey that covers the majority of the current severely contracted range of sGSL Winter Skate and thus can be used to monitor the dynamics of this species (Swain et al. 2019).

4.3 SGSL MULTI-SPECIES BOTTOW-TRAWL SURVEY

Three series of potential exclusions were evaluated for the sGSL multi-species survey: from the Banc-des-Américains MPA, from coral conservation areas (Slope of Magdalen Shallows, North of Bennett Bank and Eastern Honguedo Strait, as an ensemble) and from scallop buffer zone refuges (SFAs 21, 22 and 24, as an ensemble). In each case we evaluated the potential impacts for three species with relative abundance time series having the greatest potential for being affected by exclusion from protected areas. In all cases we consider only fish of adult size given existing evidence of distribution shifts for these sizes in the sGSL (e.g., Swain et al. 2015): Atlantic Cod (*Gadus morhua*) ≥ 39 cm; American Plaice (*Hippoglossoides platessoides*) ≥ 30 cm; Thorny Skate (*Amblyraja radiata*) ≥ 51 cm; White Hake (*Urophycis tenuis*) ≥ 45 cm; Yellowtail Flounder (*Limanda ferruginea*) ≥ 25 cm; Winter Flounder (*Pseudopleuronectes americanus*) ≥ 25 cm; and Winter Skate ≥ 42 cm.

The time series with and without excluded sets in the Banc-des-Américains MPA for Atlantic Cod, American Plaice, and Thorny Skate, three currently or formerly broadly distributed species, were very similar in terms of trend and inter-annual variation (Figure 28). However, excluding survey sets in the MPA causes a time-varying bias for the American Plaice index, with a negative bias around 1980, when abundance was high, and a positive bias around 2010 during the current period of low abundance. There were no biases for the two other species times series.

The time series with and without sets excluded from the coral conservation areas were largely similar for Atlantic Cod, White Hake, and Thorny skate, although differences were more evident in recent years for the latter two species (Figure 29). These differences result in an increasingly positive bias for White Hake, and the potential for a negative, albeit more variable bias for Thorny Skate. The results for White Hake and Thorny Skate reflect a shift in the distribution of these two species into some of the areas that would now be excluded from the survey domain (see details in Benoît et al. 2020). For White Hake, densities just outside the CCAs have been increasing at a higher rate than those in the CCAs, while the imputation method assumes the changes would be the same, hence resulting in an increasing bias. Should the trend continue, failure to sample in the CCAs will overstate the ongoing declines of sGSL White Hake, a population assessed as endangered by COSEWIC and that is at high risk of extirpation (Swain et al. 2016).

The time series with and without sets excluded from the scallop buffer zone marine refuges were largely the same for three species with coastal summer distributions: Yellowtail Flounder Winter Flounder, and Winter Skate, although catches of the latter have been nil or very low in most years since 2011 (Figure 30). Exclusion of sets did not create a time-varying bias for any of these species.

4.4 NGSL SNOW CRAB TRAP SURVEY

Excluding the stations from the sub-zone 12C post-season survey that fell in the Beaugé Bank SCA increased the inter-annual variability in the abundance index for three snow crab stages (Figure 31). The differences do not appear systematic or increasing in time, therefore there does not appear to be a bias, time varying or otherwise, although the time series are short. In contrast, excluding stations from the sub-zone 16 survey that fell in the Jacques-Cartier Strait SCA results in a largely systematic stationary positive bias for the three snow crab stages (Figure 32). This occurs because the excluded sets are in deeper waters, where snow crab densities are much lower. Though the bias did not vary in time, there is potential for a time-varying bias in the future if bottom waters continue to warm and snow crab habitat contracts, resulting in densities that decline most rapidly at the deeper margins of the distribution (see details on this mechanism in Benoît et al. 2020). Based on the retrospective analysis only, excluding the stations in the Jacques-Cartier Strait SCA would not affect snow crab quotas set according to the present decision rule provided the overall bias is accounted for (C. Juillet, DFO Science Quebec Region, unpublished analyses).

4.5 NGSL MULTI-SPECIES BOTTOM-TRAWL SURVEY

For the nGSL multi-species survey and the nGSL Sentinel survey (section 4.6), we considered exclusion from the coral conservation areas as an ensemble, the sponge conservation areas as an ensemble, and all coral and sponge conservation areas. Because these areas are widespread, we selected a wide group of species for which to consider potential biases: Atlantic Cod, redfish (*Sebastes* spp.), Greenland Halibut (*Reinhardtius hippoglossoides*), Silver Hake (*Merluccius bilinearis*), White Hake, Long-fin Hake (*Urophycis chesteri*), Black Dogfish (*Centroscylilium fabricii*), Marlin-spike Grenadier (*Nezumia bairdi*), American Plaice, and northern shrimp (*Pandalus borealis*).

For cod in the nGSL multi-species survey, exclusion from the CCAs had little effect on the time series, while exclusion from the SCAs and to a greater extent from all conservation areas increased inter-annual variability but did not result in a bias, stationary or time-varying (Figure 33a). For redfish (Figure 33b), Greenland Halibut (Figure 33c), and White Hake (Figure 33e), exclusion resulted in a moderate increase in inter-annual variability in all cases, but no biases. For Silver Hake, exclusion of sets from all areas resulted in widely divergent values in some years, but no biases (Figure 33d). For Long-fin Hake, exclusions resulted in a moderate increase in inter-annual variability in all cases, with an overall slight positive bias (Figure 33f). A time-varying bias resulted when sets were excluded from all areas, with positive biases in the mid-2000s and late 2010s. For Black Dogfish, exclusion of sets resulted in a potentially large, though inter-annually variable, bias (Figure 33g). For Marlin-spike Grenadier, exclusions resulted in a moderate increase in inter-annual variability, with a time-varying bias when sets were excluded from all conservation areas (Figure 33h). The bias was such that abundance was underestimated during the early to mid-1990s, when abundance was relatively high. For American Plaice, exclusion from the CCAs did not affect inter-annual variability, while exclusion from SCAs and all areas resulted in a moderate increase (Figure 33i). Finally, for northern shrimp, exclusion from the SCAs and from all areas resulted in a stationary positive bias (Figure 33j).

4.6 NGSL SENTINEL BOTTOM-TRAWL SURVEY

Given the similarities in survey design of the nGSL multi-species survey and the nGSL Sentinel trawl survey, results were generally similar (Figure 34). We therefore focus on the differences when presenting results for the latter. For Silver Hake, exclusion from the CCAs and from all areas resulted in a positive bias early in the series when the abundance index was lower, declining to no bias since the early 2010s (Figure 34d). A similar effect was produced for White Hake when sets were excluded from the SCAs (Figure 34e). A time-varying bias for Long-fin Hake, similar to that produced in the time series for the nGSL Sentinel survey (Figure 33e), was generated when sets were excluded from the SCAs. For American Plaice, exclusion of sets from the CCAs and from all areas resulted in a time-varying bias characterized by a small, yet significant, negative bias in the years around 2010 (Figure 34i).

5. OTHER POTENTIAL MITIGATION MEASURES

Benoît et al (2020) review a number of potential measures to mitigate the impacts of survey activities in protected areas. These include a change in survey design, a change to less impactful gear, and a reduction in the footprint of individual sets. Furthermore, within protected areas, survey activities could be sited such as to avoid particularly sensitive geographically-restricted features. At a broader scale, particular attention should be paid to avoiding an insufficiently justified expansion of survey footprints, particularly in frontier areas (DFO 2018); though this consideration is generally not applicable in the EGSL.

In their review, Benoît et al. (2020) could not identify alternative survey methods that can replace trawling in a multi-species context involving mobile demersal species or when a broad range of sizes of organisms must be sampled (e.g., snow crab trawl survey, Hébert et al. 2016). The only potential exception is for sea scallops, where video surveys have the potential to replace dredge surveys (Stokesbury 2002; Stokesbury et al. 2004; Singh et al. 2014), though independent reviews have recommended against dropping dredge surveys completely because the latter are still considered superior for estimating length composition, distinguishing live and dead scallops, and obtaining information on physiological and life-history attributes of individual scallops, amongst other considerations (Cryer 2015). The cost to implement the video surveys, as has been done in the NE U.S.A, is quite elevated. Video-surveys might be able to replace the stations sampled in protected areas by the nGSL post-season snow crab trap survey given that only larger snow crab are sampled. However the cost of the surveys, the fact they are conducted by industry in collaboration with DFO with vessels that may not be adapted for camera deployment, and the need to calibrate with survey densities sampled by traps outside the protected areas (Benoît et al. 2020) render this option inviable presently.

It might be possible to shorten survey trawl hauls to reduce activity footprints in protected areas, though these reductions would have to remain within the boundaries of acceptable haul durations and distances, which tend to be no less than 70% of the values for a target standard tow (e.g., Hurlbut and Clay 1990). However, systematically reducing haul duration would require extensive calibration trials as catch rates likely do not scale linearly with haul length and may be species specific (e.g., Somerton et al. 2002). Forthcoming comparative fishing (calibration) experiments associated with a change in the vessels that undertake the sGSL and nGSL multi-species surveys provide an opportunity to also calibrate for a change to a bottom-trawl associated with a smaller swept area. In the sGSL, the change in vessel will be associated with a change to a smaller trawl that is fished at a lower speed (3.0 instead of 3.5 knots) and for a shorter time (20 rather than 30 minutes) resulting in a swept area footprint that is less than half the current haul footprint (0.062 km^2 rather than 0.1403 km^2). For a constant sampling (haul) density, this will more than double recurrence times for this survey.

The cumulative footprint of multiple, spatially overlapping surveys, could be reduced by limiting the number of surveys that sample the same areas. This is already being done voluntarily by DFO Science Gulf Region by removing sampling stations for all sGSL Sentinel survey hauls falling within protected area boundaries as of 2019. The greatest potential for further reduction is for the three southern-most CCAs (Slope of the Magdalen Shallows, North of Bennett Bank and Eastern Honguedo Strait CCAs), where four surveys (sGSL snow crab survey, sGSL multi-species survey, nGSL multi-species survey, and nGSL Sentinel survey) presently overlap along the southern margin of these areas. As in the sGSL, the nGSL Sentinel survey could also be excluded from protected areas. In all cases, it is important that the survey be intercalibrated for the suite of species monitored before activities can be dropped to avoid the biases identified in the previous section. Research is presently underway to intercalibrate these various surveys (e.g., see Benoît and Cadigan (2013) for snow crab) such that eventually there may not be a need to have them all sample the same areas. However, given a forthcoming change in survey vessel for the sGSL and nGSL multi-species surveys, and a change in survey gear for the former, it will be important to maintain the overlap for at least a few years to allow for the intercalibration.

Finally, with the exception of the Banc-des-Américains MPA (Savenkoff et al. 2017), there are presently no results available on the heterogeneity of ecological components of interest within the majority of the protected areas that would allow to confidently strategically site survey sampling stations to minimize impacts. Further research to that end could reduce harm in the future, however, it will be important to ensure that there are no species for which monitoring is required and that are highly associated with the ecological components of interest. Strategic placement of survey hauls would alias the sampling of these species.

6. POTENTIAL BENEFITS PROVIDED BY SURVEYS FOR THE UNDERSTANDING AND MANAGEMENT OF THE PROTECTED AREAS AND TAXA OF CONSERVATION IMPORTANCE

The bottom-trawl surveys of the EGSL can potentially provide information and data that can contribute to scientific understanding and efficacy monitoring for the protected areas. Details are provided in the subsections below. We could not identify similar benefit stemming from the sGSL scallop dredge and nGSL snow crab trap single species surveys. For the scallop dredge survey this is because the rotational nature of the survey is not conducive to monitoring abundance trends for many species. Even if the survey becomes more frequent, perhaps annual, a shift towards focussing on scallop beds will preclude reliably monitoring the abundance of other species, many of which will presumably have broader distributions. In the case of the nGSL snow crab trap survey, given that it samples mainly only snow crab and extends only into the margin of the protected areas, it is difficult to conceive that this information would be beneficial for monitoring and science knowledge associated with the protected areas.

6.1 SGSL SNOW CRAB BOTTOM-TRAWL SURVEY

A key advantage of this survey is that the Nephrops trawl gear is particularly suited to sampling soft bottom benthic species. Given high set density and small individual haul footprint (Table 2) this survey could provide data on benthic taxon density within and outside protected areas that is conducive to before-after-control-impact type of analysis for testing the efficacy of the protected areas. The most notable area for which this might be beneficial is the Banc-des-Américains MPA, Zone 2, which is completely circumscribed by the survey area and where a moderate number of sets are made annually within and just outside the areas (Table 9; Figure 3).

Refining the taxonomic resolution of non-crab benthic invertebrates sampled by the snow crab survey would greatly improve its potential benefits for the protected areas. Until recently, such taxa were identified at and above the genus level (Wade et al. 2018), although beginning in 2019 sponges and starfish have been identified at the lowest taxonomic level possible and additional efforts have been deployed to identify challenging species.

6.2 NORTHUMBERLAND STRAIT MULTI-SPECIES SURVEY

The Northumberland Strait multi-species survey is the only large scale coastal survey in Atlantic Canada (Table 10 in Benoît et al. 2020). It provides sampling within and just outside scallop buffer zone marine refuges SFA 22 and 24. It has the potential to provide monitoring data that could aid in gauging the efficacy of the refuges, particularly to monitoring the abundance and distribution of juvenile lobster, the main conservation objective for these refuges. Furthermore, it is the only remaining survey that can monitor abundance trends for sGSL Winter Skate, which is identified as a secondary ecological component of interest for the SFA 22 refuge and generally of heightened conservation concern for DFO given the poor and deteriorating status of this population (Swain and Benoît 2017; Swain et al. 2019).

6.3 LARGE SCALE MULTI-SPECIES BOTTOM-TRAWL SURVEYS

Compared to video-based methods, trawl surveys are unlikely to be the best means to monitor the efficacy of protected areas with respect to conservation objectives for sessile benthic species like coral and sponges. However, they are well suited to identifying areas of concentration of these taxa for follow-up monitoring and for the collection of biological material for biometric measurements and species identification (Chimienti et al. 2018; Murillo et al. 2018b). Notably, efforts at enhancing the taxonomic resolution for the identification of benthic invertebrates have increased considerably in both sGSL and nGSL surveys, and surveys in neighboring areas (e.g., Murillo et al. 2018b). The sGSL survey has carried a scientist with expertise in the identification of sponges for the past two years, while the nGSL has carried scientists with expertise in benthic ecology for several years. These efforts will improve knowledge on the species being protected by the marine refuges and provide broad-scale sampling to better understand the distribution of these species within protected areas and in the broader ecosystem.

The large scale multi-species surveys are particularly adapted to monitoring the abundance and distribution of mobile demersal species, including wolffish and skates, which are a focus of ecological interest for many of the marine refuges and of the Banc-des-Américains MPA (Table 3). These surveys provided population-wide sampling for many years in the past and are therefore well suited for monitoring changes in abundance and distribution in the EGSL ecosystem as well as within the protected areas. Video monitoring is presently unable to fulfill this role (Benoît et al. 2020).

7. CONCLUSIONS

Every protected area in the EGSL is substantially or completely overlapped by one or more survey study areas. The annual swept area by all surveys on average does not exceed 0.08% of the areas of overlap for any protected area. Average recurrence times for areas of overlap were all greater than or equal to 2,400 years for individual surveys. Concerning the cumulative impact over all surveys, the shortest overall recurrence time (1,573 years) was calculated for the Beaugé Bank SCA, while survey activities in the other coral or sponge conservation areas and Zone 2 of the Banc-des-Américains MPA have estimated average recurrence times of 2,000 to 5,000 years. At finer spatial scales, all locations of overlap between surveys and protected areas are associated with recurrence times >1,000 year, except for the scallop buffer zone of SFA 24 in which 0.2% of the zone of overlap is associated with a recurrence time of 600 to 1,000 years.

Based on before-and-after-impact (BACI) experiments in the EGSL, for certain species (*Pennatula aculeata)* and benthic communities in high energy benthic habitats such as the scallop buffer zones, the recovery times are likely or certainly on the order of a decade or less.

According to DFO (2018), activity recurrence time intervals that are at least an order of magnitude greater than the longevity of the least resilient taxon or benthic feature are assumed to not result in long-term harm and therefore should not compromise achievement of protected area conservation objectives. With the exception of sponges, the estimates of recurrence intervals of scientific surveys (> 1000 years) are one order of magnitude greater than the inferred recovery period of the defined benthic components in protected areas of the EGSL, based on longevity or other life-history characteristics that affect resilience.

The potential impacts of survey activities on sponges in SCAs are difficult to evaluate because information on longevity and resilience is lacking for sponge species which occur in the EGSL. The continuation of current scientific survey activities would improve knowledge on the species composition, distribution, and biological characteristics within and outside the conservation areas. BACI-type disturbance experiments, like those undertaken for sea pens in the GSL and for sponges elsewhere (e.g., Kahn et al. 2016, for experiments on Pacific glass sponge reefs), would provide information on the resilience of sponges to disturbance by scientific bottom-contact gears in the EGSL. Such experiments may need to be carried out in more than one location given different species compositions. They will also need to involve follow-up monitoring over a fairly prolonged period to quantify resilience or lack thereof, given the results of Malecha and Heifetz (2017), who found little if any recovery for some Pacific species even after 13 years post trawl disturbance. Given these considerations related to sponges, the assessment of the impacts of survey activities in the SCAs should be reviewed as new knowledge is accumulated.

Retrospective analyses of survey data demonstrated the potential for time-varying biases in species trends of abundance should certain surveys be excluded from protected areas. This is of particular concern for those surveys that monitor the status of species that are at high risk of extinction, for example, the Northumberland Strait multi-species survey with respect to Winter Skate, and the sGSL multi-species survey with respect to White Hake and Thorny Skate. In the case of the Northumberland Strait multi-species survey, excluding survey activities from the scallop buffer zone marine refuges would compromise the ability to monitor the status of juvenile American lobster, the main ecological component of interest for these refuges, and American lobster in general, the target of a large commercial fishery in the sGSL.

Research aimed at inter-calibrating surveys and in data interpolation/extrapolation using other surveys as covariates should be continued in an effort to reduce the need for overlapping surveys. Not only does this survey duplication increase the impact of surveys in protected areas, it also potentially represents an inefficient use of resources. This is perhaps most feasible and appropriate for the Sentinel surveys which tend to only be used to provide advice based on monitoring of commercially important species (though the sampling is multi-species) and where there is high overlap with respective multi-species surveys allowing for inter-calibration. It may also be possible to avoid the duplication of sampling of the sGSL and nGSL multi-species surveys along the southern slope of the Laurentian Channel.

The forthcoming change in survey trawl for the sGSL multi-species survey will result in a swept area that is less than half, and a recurrence time that is more than double, compared to the present situation (section 5). There may be opportunities to reduce haul durations in protected areas in other surveys provided there is research on the potential consequences of making such a systematic change (section 5).

Research and policy consideration should be given to the acceptability of risks of fixed station versus random based survey designs in protected areas for ecologically-sensitive benthic species. Fixed station surveys will result in intensely disturbed sites with very little potential for local recovery, embedded in a landscape of less or unperturbed sites, while random-based surveys spread out perturbations in space and time, resulting in a landscape of varying degrees of recovery. A change from one design to the other could require considerable standardization depending on the number of stations involved, and the mobility and habitat dependency of the taxa that are the focus for monitoring.

Several benefits to continuing ongoing surveys in protected areas were identified. Collaboration between DFO Oceans and Science sectors will help to ensure that these benefits are realized and that others are identified.

Finally, the evaluation presented in this document should be valid until one or more of the following conditions occur:

- There are changes to benthic conservation objectives of protected areas;
- There are changes in the status of valued ecological components of interest that suggest that a change in the degree of precaution is warranted (more precaution with worsening status, less if status improves considerably);
- There are changes in survey design, procedures or gear that alter the area impacted by surveys and recurrence time in such a way that permitting decisions might change;
- There is new information that allows for a better evaluation of the resilience of ecological components of interest; and
- New protected areas are created that might further limit where scientific activities take place, thereby compromising the ability of surveys to monitor the broader ecosystem in support of evidence-based decision making by resource managers (DFO 2018).

Such changes could motivate a re-evaluation for one or more surveys in one or more protected areas.

8. ACKNOWLEDGEMENTS

We thank the following people for providing data and/or information that contributed to the analyses in this report: Rénald Belley, Hugo Bourdages, Claude Brassard, Benoît Bruneau, Sylvie Brulotte, Mathieu Desgagnés, Geneviève Faille, Isabelle Lévesque, Jean-François Lussier, Jenni McDermid, Denise Méthé, Monique Niles, Claude Nozère, Nicolas Rolland, and Doug Swain. We also thank the following people for constructive input and comments on the initial drafts of the report: Hugo Bourdages, Mathieu Desgagnés, Curtis Dinn, Geneviève Faille, Claude Nozère, Daniel Ricard, Monik Richard, Nicolas Rolland, Amélie Rondeau, and Bernard Sainte-Marie.

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10. TABLES

Table 1. List of marine refuges in the Gulf of St. Lawrence, along with their conservation objectives (ecological components of interest) and the associated prohibitions and restrictions. All refuges were defined on the basis of a primary ecological component of interest that is the aim of conservation efforts. For some refuges, additional secondary components of interest have been identified.

Refuge name	Conservation objectives (ecological components of interest)	Prohibitions and restrictions
Bay of Islands Salmon Migration closure	Protect Atlantic Salmon migratory area	All pelagic fixed gear fisheries
Scallop Buffer Zone SFA 21	Protect juvenile American lobster. Secondary: scallop and Winter Flounder	Scallop dredging
Scallop Buffer Zone SFA 22	Protect juvenile American lobster. Secondary: the last remaining area in which the Winter Skate (endangered designation by COSEWIC) is found during the summer, unique population of lady crab (suspected endemic), and rock crab.	Scallop dredging
Scallop Buffer Zone SFA 24	Protect juvenile American lobster. Secondary: scallop and Winter Flounder	Scallop dredging
Eastern Gulf of St. Lawrence Coral Conservation Area	Protect cold-water corals, notably *Pennatula grandis* and *Anthoptilum grandiflorum* sea pens.	All fishing that uses bottom-contacting gear
Slope of Magdalen Shallows Coral Conservation Area	Protect cold-water corals, notably *P. grandis* and *A. grandiflorum* sea pens.	All fishing that uses bottom-contacting gear
Central Gulf of St. Lawrence Coral Conservation Area	Protect cold-water corals, notably *A. grandiflorum* sea pen. Secondary: Protect *Flabellum alabastrum* hard corals, which have a restricted range. This conservation area also includes other biologically important features, such as a high concentration of *Duva florida* soft corals, the presence of the large structure-providing *Asconema foliatum* sponge, and at least three species of rays and wolffish.	All fishing that uses bottom-contacting gear
South-East of Anticosti Island Sponge Conservation Area	Protect cold-water sponges. Secondary: area also includes other biologically important features, such as high concentrations of *D. florida* soft corals and *A. grandiflorum* sea pens, the large structure-providing *A. foliatum* sponge, and at least three species of rays and wolffish	All fishing that uses bottom-contacting gear
East of Anticosti Island Sponge Conservation Area	Protect cold-water sponges. Secondary: The area also includes other biologically important features, such as a high concentration of *D. florida* and *Gersemia rubiformis* soft corals, the presence of the large structure-providing *Hemigellius arcofer* sponge, and at least three species of rays and wolffish.	All fishing that uses bottom-contacting gear

Refuge name	Conservation objectives (ecological components of interest)	Prohibitions and restrictions
Beaugé Bank Sponge Conservation Area	Protect cold-water sponges. Secondary: The area also includes other biologically significant features, such as a high concentration of *Duva* sp. and *G. rubiformis* soft corals, the presence of the large structure-providing *H. arcofer* sponge, and at least four species of rays and wolffish	All fishing that uses bottom-contacting gear
North of Bennett Bank Coral Conservation Area	Protect cold-water corals, notably *A. grandiflorum* sea pen and the three other species of sea pen : *Pennatula aculeata, P. grandis* and *Halipteris finmarchica*. Secondary: as at least three species of rays and wolffish.	All fishing that uses bottom-contacting gear
Eastern Honguedo Strait Coral and Sponge Conservation Area	Protect cold-water sponges and corals, notably *H. finmarchica, A. grandiflorum, P. grandis* and *P. aculeata.* Secondary: *D. florida* soft corals, the presence of one large structure-providing sponge species, *Mycale sp.*, and at least two species of rays.	All fishing that uses bottom-contacting gear
Western Honguedo Strait Coral Conservation Area	Protect cold-water corals, notably *P. aculeata, P. grandis* and *A. grandiflorum*. Secondary: at least two species of rays.	All fishing that uses bottom-contacting gear
Parent Bank Sponge Conservation Area	Protect cold-water sponges. Secondary: The area also includes other important biological features, such as a high concentration of *P. aculeata* sea pens, and *D. florida* and *G. rubiformis* soft corals. The area also contains the large structure-providing *Mycale sp.* sponge, and at least three species of rays and wolffish.	All fishing that uses bottom-contacting gear
Jacques-Cartier Strait Sponge Conservation Area	Protect cold-water sponges. Secondary: The area also includes other important biological features, such as a high concentration of *G. rubiformis* soft corals, and the presence of the large structure-providing *H. arcofer* sponge. This is an area known for its high biodiversity; it is home to many benthic species and used by birds and marine mammals.	All fishing that uses bottom-contacting gear
Magdalen Islands Lagoons closures	Protect American lobster and herring spawning habitat. Secondary: habitat for numerous other species and the closure contains eelgrass habitat which is an ecologically significant species (ESS) and a highly productive ecosystem that can support a wide variety of species in key life stages. Marshes, which are a unique coastal habitat, are also present in this area	Hydraulic dredge for Atlantic razor clam and Atlantic surf clam; Gill net and square net fishing for Winter Flounder; Gill net fishing for Atlantic Herring; trawl, Danish and Scottish seine for the Yellowtail Flounder and the Winter Flounder; lobster trap

Refuge name	Conservation objectives (ecological components of interest)	Prohibitions and restrictions
Fisheries closure in the Les Demoiselles nursery, Plaisance Bay, Magdalen Islands	Protect juvenile American lobster	Hydraulic dredge for Atlantic surf clam and Atlantic razor clam; Otter trawl, Danish and Scottish seine for flatfish.
Saguenay Fjord Upstream closure	Protect beluga whale habitat.	Otter trawl
Miramichi Bay closure	Protect Atlantic salmon migratory area	Commerical groundfish gillnets

Table 2. Ongoing bottom-contacting surveys undertaken in the Gulf of St. Lawrence (GSL) and Estuary that overlap with the protected areas retained for this report. Surveys are identified by the lead DFO region (GULF or QC- Quebec), survey name, targeted species, location, the initial year for the survey, the gear employed (OTB – otter trawl or bottom trawl, LLS – bottom set longline DRB – bottom dredge and pots), the sampling design employed in the survey (F- fixed station, R- random or SR- stratified random), the survey frequency (Freq: A-annual or R-rotational), the mean number of hauls per complete survey in recent years (Hauls), the estimated swept area per average haul (Haul swept area; km^2), the area of the survey study area (km^2), annual average total survey swept area (km^2) and the recurrence interval (years).

DFO Region	Survey	Spec.	Location	Initial year	Gear	Design	Freq	Hauls	Haul swept area (km^2)	Survey study area (km^2)	Survey swept area (km^2)	Recur. Interval (years)
GULF	Sea scallop dredge survey	Sea scallop	southern GSL	2012	DRB	SR	R: 5 yr	500 [1]	0.0004	23,520	0.20	534,545
GULF	Snow crab trawl survey	Snow crab	southern GSL	1988	OTB	F	A	355	0.0083	57,840	3.3	17,527 [2]
GULF	Multi-species trawl survey	Various	southern GSL	1971	OTB	SR	A	180	0.1402	73,182	25.2	2,900
GULF	Northumberland Strait multi-species survey	Various	Northumber-land Strait (southern GSL)	2001	OTB	SR/R	A	110	0.0347	11,925	3.8	3,122
QC	Atlantic Halibut survey	Atlantic Halibut	GSL	2017	LLS	SR	A	125	0.225	~115,000	28.1	4,089
QC	Post-season snow crab trap survey (zones 12C & 16)	Snow crab	Estuary & northern GSL	1994	POTS	F	A	335	0.0001	~15,000	0.04	376,250 [2]
QC	Sentinel bottom-trawl survey	Various	northern GSL	1995	OTB	SR	A	287	0.1085	129,221	31.1	4,149
QC	Multi-species trawl survey	Various	Estuary & northern GSL	1984	OTB	SR	A	180	0.0684	125,780	12.3	10,216

[1]Represents the total number of hauls for a complete five-year cycle of the rotational survey.
[2] For fixed design surveys, the recurrence interval is shown assuming the same calculation as for random and stratified-random surveys.

Table 3. Demersal and benthic ecological components of interest and their characteristics that help define their resilience to perturbation for the marine refuges and the Banc-des-Américains MPA in which scientific surveys recur. Secondary components of interest are noted when relevant.

Taxon	Marine refuges	Characteristics
Fish and decapod crustaceans		
American lobster (juvenile)	Scallop Buffer Zones	Based on growth rates estimated by Kilada et al. (2012) and contemporary sizes at maturity in the sGSL (between 70-80 mm; Haarr et al. 2017), lobster mature around 7-9 years of age, the 'longevity' of the juvenile stage. Furthermore, lobster in the sGSL are presently very productive and not limited by recruitment (DFO 2019; Gendron et al. 2019)
Giant scallop (secondary)	Scallop Buffer Zones SFA 21 & 24	In the sGSL, sea scallops reach maturity around 4-5 years of age and maximum observed ages are below 20 years (Davidson et al. 2012)
Lady crab (secondary)	Scallop Buffer Zone SFA 22	Information on growth and longevity could not be found. The species occupies very warm waters (Voutier and Hanson 2008) and is expected to be relatively fast growing and not particularly long-lived. Related species, *O. punctatus* and *O. catharus* develop to maximum size in <4 years at colder summer temperatures but warmer winter temperatures than in Northumberland Strait (Osborne 1987).
Rock crab (secondary)	Scallop Buffer Zone SFA 22	Longevity is around 8 years (DFO 2000)
Winter Flounder (secondary)	Scallop Buffer Zones SFA 21 & 24	Longevity is greater than 12 years. The sGSL stock is depleted and the main cause is elevated adult mortality (Surette and Rolland 2019). Individuals released alive after capture have a high likelihood of survival (Benoît et al. 2012).
Winter Skate (secondary)	Scallop Buffer Zone SFA 22	The sGSL population is designated as Endangered by COSEWIC. The main threat to the population is elevated natural morality among adults (Swain and Benoît 2017). Longevity in the sGSL is above 12 years. Individuals released alive after capture have a high likelihood of survival (Benoît et al. 2010, 2012).
Smooth Skate (secondary)	Central Gulf of St. Lawrence CCA, S-E of Anticosti Isl. SCA, East of Anticosti Isl. SCA, North of Bennett Bank CCA, Eastern Honguedo Strait CSCA, Parent Bank CCA	Designated as Special Concern by COSEWIC. Longevity is not known, but age at 50% maturity for this species was found to be 10 years and 12 years for females and males (Simpson et al. 2012). The main threat to the population is elevated natural morality among adults (Swain et al. 2012). Individuals released alive after capture have a high likelihood of survival (Benoît et al. 2012).
Thorny Skate (secondary)	Central Gulf of St. Lawrence CCA, S-E of Anticosti Isl. SCA, East of Anticosti Isl. SCA, North of Bennett Bank CCA, Eastern Honguedo Strait CSCA, Parent Bank CCA	Designated as Special Concern by COSEWIC. The main threat to the population is elevated natural morality among adults (Swain et al. 2012). Longevity is over 20 years (Simpson et al. 2011). Individuals released alive after capture have a high likelihood of survival (Benoît et al. 2012).

Taxon	Marine refuges	Characteristics
Wolffish (secondary, except Banc-des-Américains MPA) Atlantic Wolffish Spotted Wolffish Northern Wolffish	Central Gulf of St. Lawrence CCA, S-E of Anticosti Isl. SCA, East of Anticosti Isl. SCA, North of Bennett Bank CCA, , Parent Bank CCA, Beaugé Bank SCA , American Bank MPA (primary)	Designated as Special Concern (Atlantic Wolffish) or Threatened (Spotted Wolffish and Northern Wolffish) by COSEWIC. Fishing is considered a main threat. Although the allowable harm that these species can sustain cannot be quantified currently, current levels of harm appear sustainable (DFO 2015). Larger individuals released alive after capture have a high likelihood of survival (Grant and Hiscock 2014). Observed maximum ages for Atlantic Wolffish and Spotted Wolffish are around or above 20 years (Scott and Scott 1988; Collette and Klein-MacPhee 2002).
Cold-water corals		
Anthoptilum grandiflorum	Eastern Gulf of St. Lawrence CCA, Slope of Magdalen Shallows CCA, Central Gulf of St. Lawrence CCA, S-E of Anticosti Isl. SCA (secondary), North of Bennett Bank CCA, Eastern Honguedo Strait CSCA, Western Honguedo Strait CCA	Murillo et al. (2018a), estimated ages ranging from 5 and 28 years for *A. grandiflorum* colonies outside the Gulf. Based on mean lengths in colonies in the sGSL and nGSL multi-species surveys, this would correspond to colonies 15-16 and approximately 21 years old respectively. Estimated maximum ages fell within previously published ranges for pennatulids of between 15 and 50 years, though the authors cautioned that the age determination for the sea pens required additional validation.
Halipteris finmarchica	Eastern Honguedo Strait CSCA, North of Bennett Bank CCA	Estimated age at maturation and maximum observed age in the NW Atlantic at 4 and 22 years, respectively (Neves et al. 2015)
Pennatula aculeata	Eastern Honguedo Strait CSCA, North of Bennett Bank CCA, Western Honguedo Strait CCA, Parent Bank CCA (secondary)	Murillo et al. (2018a), estimated ages ranging between 2 and 21 years for *P. aculeata*. Mean colony lengths observed in the sGSL surveys by the authors correspond to *P. aculeata* colonies younger than 9 years old. Estimated maximum ages fell within previously published ranges for pennatulids of between 15 and 50 years, though the authors cautioned that the age determination for the sea pens required additional validation. Known to be able to burrow and crawl, which may afford some protection from trawling and potential for rapid recolonization of disturbed areas.
Pennatula grandis	Eastern Gulf of St. Lawrence CCA, Slope of Magdalen Shallows CCA, Eastern Honguedo Strait CSCA, Western Honguedo Strait CCA, North of Bennett Bank CCA	Not known. However, the published range of maximum ages for pennatulids is between 15 and 50 years (Murillo et al. 2018a)
Soft corals (secondary)		
Duva florida (secondary)	Central Gulf of St. Lawrence CCA, S-E of Anticosti Isl. SCA, East of Anticosti Isl. SCA, Eastern Honguedo Strait CSCA, Parent Bank CCA	Resilient to environmental variability, in that they survive and reproduce successfully under laboratory conditions. Studies suggest that when fertile colonies are damaged or torn by anthropogenic activities (e.g., bottom trawling), planulae that become free may grow into viable offspring. Nevertheless, growth of primary polyps is slow (Sun et al. 2011).
Gersemia rubiformis (secondary)	East of Anticosti Isl. SCA, Parent Bank CCA, Jacques-Cartier Strait SCA, Beaugé Bank SCA	Widespread. Colonies grow by vegetative budding and sexual reproduction. Generally not considered a vulnerable species.
Hard corals		
Flabellum alabastrum (secondary)	Central Gulf of St. Lawrence CCA	Growth is sensitive to environmental conditions. Estimates indicate that the largest individuals sampled along the southwest Grand Banks were at least 45 years old (Hamel et al. 2010).
Sponges		

Taxon	Marine refuges	Characteristics
Multiple species (identification pending)	S-E of Anticosti Isl. SCA, East of Anticosti Isl. SCA, Parent Bank SCA, Beaugé Bank SCA, Jacques-Cartier Strait SCA, Eastern Honguedo Strait CSCA	Measures of resiliency of the sponge species in the Gulf of St. Lawrence require further investigation.
Asconema foliatum (secondary)	Central Gulf of St. Lawrence CCA, S-E of Anticosti Isl. SCA,	Glass sponge (Class Hexactinellida) which grows as a complex bouquet of tubes. Measures of resiliency of this species requires further investigation.
Hemigellius arcofer (secondary)	Beaugé Bank SCA, Jacques-Cartier Strait SCA	Large, fan-shaped sponge with a coarse fibrous structure. Whole North Atlantic distribution. Measure of resiliency of this species requires further investigation.
Mycale sp. (secondary)	Eastern Honguedo Strait CSCA, Parent Bank CCA	Most *Mycale* specimens in the GSL have been identified as *Mycale lingua* (C. Dinn, DFO Science Gulf Region). Results from a single pass trawling experiment in the Gulf of Alaska suggest a reduction of 15% in the density of *Mycale loveni* sponge and incremental damage rate of around 32% of individuals that persisted at least 13 years post-trawling (Malecha and Heifetz 2017). However it is important to note that growth forms of *M. loveni* are different from those of *Mycale* species in the Gulf and the results of this study may not accurately reflect recovery potential here (Curtis Dinn, DFO Science Gulf Region, personal communication).
Other taxa		
Metridum senile (anemone; secondary)	Banc-des-Américains MPA	Can reproduce sexually and asexually (binary fission). Growth rate is rapid (Bucklin 1987). These factors suggest resilience to disturbance.
*Urticina feline (*anemone; secondary)	Banc-des-Américains MPA	Can reproduce sexually and asexually. Occurs in dynamic subtidal environments. These factors suggest resilience to disturbance.
Ophiopholis aculeata (brittle star; secondary)	Banc-des-Américains MPA	Ubiquitous broadcast-spawning species (Doyle et al. 2014).
Ophiacantha bidentata (brittle star; secondary)	Banc-des-Américains MPA	Widespread arctic-boreal ophiuroid with a circumpolar distribution
*Stomphia coccinea (*anemone; secondary)	Banc-des-Américains MPA	A widespread species that is able to detach itself, drift and reattach, suggesting resilience to benthic disturbance.
Boltenia ovifera (tunicate; secondary)	Banc-des-Américains MPA	Estimated to live an average of 3 years based on growth rates measured within the first year (Plough 1969), suggesting resilience to disturbance.
Halocynthia pyriformis (tunicate; secondary)	Banc-des-Américains MPA	Widespread in north Atlantic shallow waters suggesting resilience to disturbance.

Table 4. Summary of the proportion of each protected area that overlaps with the survey area of each of the eight relevant surveys and with all surveys. Surveys are as follows: Halibut – halibut survey, SCsGSL – snow crab bottom-trawl survey (sGSL), NSMS – Northumberland Strait multi-species survey, SCALsGSL – scallop dredge survey (sGSL), MSsGSL –multi-species bottom-trawl survey (sGSL), SCnGSL - snow crab post-season trap survey (nGSL), MSnGSL –multi-species bottom-trawl survey (nGSL & Estuary), and SENnGSL – Sentinel bottom-trawl survey (nGSL).

Protected area	Halibut	SCsGSL	NSMS	SCALsGSL	MSsGSL	SCnGSL	MSnGSL	SENnGSL	All surveys
Banc-des-Américains MPA (Zone 1)	0.190	1.000	0	0	0.196	0	0	0	1.000
Banc-des-Américains MPA (Zone 2)	0.781	0.995	0	0	0.816	0	0	0	0.999
Scallop Buffer Zone SFA 21	0.094	0	0	0.450	0.018	0	0	0	0.469
Scallop Buffer Zone SFA 22	0.004	0	0.639	0.719	0.056	0	0	0	0.857
Scallop Buffer Zone SFA 24	0.338	0.044	0.375	0.569	0.246	0	0	0	0.622
Eastern Gulf of St. Lawrence CCA	0	0	0	0	0	0	1.000	1.000	1.000
Slope of Magdalen Shallows CCA	0	0.211	0	0	0.355	0	1.000	1.000	1.000
Central Gulf of St. Lawrence CCA	0	0	0	0	0	0	1.000	1.000	1.000
South-East of Anticosti Isl. SCA	0.086	0	0	0	0	0	1.000	1.000	1.000
East of Anticosti Isl. SCA	0.851	0	0	0	0	0	0.953	0.953	0.957
Beaugé Bank SCA	0.048	0	0	0	0	0.040	1.000	1.000	1.000
North of Bennett Bank CCA	0	0.116	0	0	0.199	0	1.000	1.000	1.000
Eastern Honguedo Strait CSCA	0.010	0.148	0	0	0.146	0	0.997	0.997	0.997
Western Honguedo Strait CCA	0	0	0	0	0	0	0.998	0.998	0.998
Parent Bank SCA	0.591	0	0	0	0	0	0.710	0.710	0.733
Jacques-Cartier Strait SCA	0.495	0	0	0	0	1.000	1.000	1.000	1.000

Table 5. Summary of the average proportion of each protected area that is impacted annually by each of the eight relevant surveys and overall for all surveys combined: Halibut – halibut survey, SCsGSL – snow crab bottom-trawl survey (sGSL), NSMS – Northumberland Strait multi-species survey, SCALsGSL – scallop dredge survey (sGSL), MSsGSL –multi-species bottom-trawl survey (sGSL), snow crab post-season trap survey (nGSL), MSnGSL –multi-species bottom-trawl survey (nGSL & Estuary), and SENnGSL – Sentinel bottom-trawl survey (nGSL). The acronym "na" in the table means the survey does not overlap with the protected area.

Protected area	Halibut	SCsGSL	NSMS	SCALsGSL	MSsGSL	SCnGSL	MSnGSL	SENnGSL	Overall
Banc-des-Américains MPA (Zone 1)	6.26E-05	5.24E-05	na	na	5.33E-05	na	na	na	1.68E-04
Banc-des-Américains MPA (Zone 2)	2.49E-04	5.21E-05	na	na	2.22E-04	na	na	na	5.23E-04
Scallop Buffer Zone SFA 21	2.65E-05	na	na	1.73E-06	5.16E-06	na	na	na	3.34E-05
Scallop Buffer Zone SFA 22	7.42E-07	na	2.29E-04	1.28E-06	1.57E-05	na	na	na	2.46E-04
Scallop Buffer Zone SFA 24	8.64E-05	2.39E-06	1.34E-04	1.15E-06	7.26E-05	na	na	na	2.97E-04
Eastern Gulf of St. Lawrence CCA	na	na	na	na	na	na	8.20E-05	1.16E-04	1.98E-04
Slope of Magdalen Shallows CCA	na	1.06E-05	na	na	1.11E-04	0.00E+00	9.83E-05	1.59E-04	3.80E-04
Central Gulf of St. Lawrence CCA	na	na	na	na	na	na	6.37E-05	1.84E-04	2.47E-04
South-East of Anticosti Isl. SCA	1.67E-05	na	na	na	na	na	8.35E-05	1.84E-04	2.84E-04
East of Anticosti Isl. SCA	2.06E-04	na	na	na	na	na	9.05E-05	1.95E-04	4.91E-04
Beaugé Bank SCA	1.63E-05	na	na	na	na	3.41E-06	2.40E-04	5.06E-04	7.65E-04
North of Bennett Bank CCA	na	6.18E-06	na	na	5.27E-05	na	8.76E-05	1.27E-04	2.74E-04
Eastern Honguedo Strait CSCA	2.46E-06	7.75E-06	na	na	4.07E-05	na	9.45E-05	1.79E-04	3.25E-04
Western Honguedo Strait CCA	na	na	na	na	na	na	9.11E-05	1.50E-04	2.41E-04
Parent Bank SCA	1.38E-04	na	na	na	na	na	8.73E-05	1.44E-04	3.69E-04
Jacques-Cartier Strait SCA	1.26E-04	na	na	na	na	2.60E-06	1.10E-04	1.65E-04	4.05E-04

Table 6. Summary of the proportion impact density, the average proportion of each protected area that is impacted annually by each of the eight relevant surveys, and overall for all surveys combined, in the portions of the protected areas that overlap with the surveys: Halibut – halibut survey, SCsGSL – snow crab bottom-trawl survey (sGSL), NSMS – Northumberland Strait multi-species survey, SCALsGSL – scallop dredge survey (sGSL), MSsGSL –multi-species bottom-trawl survey (sGSL), snow crab post-season trap survey (nGSL), MSnGSL –multi-species bottom-trawl survey (nGSL & Estuary), and SENnGSL – Sentinel bottom-trawl survey (nGSL). The acronym "na" in the table means the survey does not overlap with the protected area.

Area	Halibut	SCsGSL	NSMS	SCALsGSL	MSsGSL	SCnGSL	MSnGSL	SENnGSL	Overall
Banc-des-Américains MPA (Zone 1)	3.30E-04	5.24E-05	na	na	2.72E-04	na	na	na	1.68E-04
Banc-des-Américains MPA (Zone 2)	3.19E-04	5.24E-05	na	na	2.72E-04	na	na	na	5.24E-04
Scallop Buffer Zone SFA 21	2.96E-04	na	na	3.85E-06	3.18E-04	na	na	na	7.11E-05
Scallop Buffer Zone SFA 22	2.71E-04	na	3.57E-04	1.78E-06	2.81E-04	na	na	na	2.87E-04
Scallop Buffer Zone SFA 24	2.54E-04	5.24E-05	3.57E-04	2.01E-06	2.92E-04	na	na	na	4.78E-04
Eastern Gulf of St. Lawrence CCA	na	na	na	na	na	na	8.20E-05	1.16E-04	1.98E-04
Slope of Magdalen Shallows CCA	na	5.24E-05	na	na	3.20E-04	na	9.83E-05	1.59E-04	3.80E-04
Central Gulf of St. Lawrence CCA	na	na	na	na	na	na	6.37E-05	1.84E-04	2.47E-04
South-East of Anticosti Isl. SCA	2.38E-04	na	na	na	na	na	8.35E-05	1.84E-04	2.84E-04
East of Anticosti Isl. SCA	2.41E-04	na	na	na	na	na	9.48E-05	2.04E-04	5.13E-04
Beaugé Bank SCA	2.51E-04	na	na	na	na	8.94E-05	2.40E-04	5.06E-04	7.65E-04
North of Bennett Bank CCA	na	5.24E-05	na	na	2.66E-04	na	8.76E-05	1.27E-04	2.74E-04
Eastern Honguedo Strait CSCA	2.38E-04	5.24E-05	na	na	2.83E-04	na	9.48E-05	1.80E-04	3.26E-04
Western Honguedo Strait CCA	na	na	na	na	na	na	9.18E-05	1.51E-04	2.43E-04
Parent Bank SCA	2.35E-04	na	na	na	na	na	1.23E-04	2.03E-04	5.03E-04
Jacques-Cartier Strait SCA	2.61E-04	na	na	na	na	2.60E-06	1.10E-04	1.65E-04	4.05E-04

Table 7. The average recurrence time (years) of survey activities at any particular location in each protected area, by survey where a survey occurs, and overall for all surveys combined, where one or more surveys occur: Halibut – halibut survey, SCsGSL – snow crab bottom-trawl survey (sGSL), NSMS – Northumberland Strait multi-species survey, SCALsGSL – scallop dredge survey (sGSL), MSsGSL –multi-species bottom-trawl survey (sGSL), snow crab post-season trap survey (nGSL), MSnGSL –multi-species bottom-trawl survey (nGSL & Estuary), and SENnGSL – Sentinel bottom-trawl survey (nGSL). The acronym "na" in the table means the survey does not overlap with the protected area.

Area	Halibut	SCsGSL[1]	NSMS	SCALsGSL	MSsGSL	SCnGSL[1]	MSnGSL	SENnGSL	Overall
Banc-des-Américains MPA (Zone 1)	3,028	19,092	na	na	3,681	na	na	na	14,586
Banc-des-Américains MPA (Zone 2)	3,145	19,092	na	na	3,680	na	na	na	4,548
Scallop Buffer Zone SFA 21	3,411	na	na	480,011	3,161	na	na	na	381,627
Scallop Buffer Zone SFA 22	3,762	na	2,802	564,987	3,560	na	na	na	148,498
Scallop Buffer Zone SFA 24	3,949	19,092	2,802	574,701	3,507	na	na	na	115,427
Eastern Gulf of St. Lawrence CCA	na	na	na	na	na	na	12,196	8,611	5,047
Slope of Magdalen Shallows CCA	na	19,092	na	na	3,250	na	11,176	7,580	3,753
Central Gulf of St. Lawrence CCA	na	na	na	na	na	na	15,691	5,449	4,045
South-East of Anticosti Isl. SCA	4,193	na	na	na	na	na	12,404	5,431	3,615
East of Anticosti Isl. SCA	4,150	na	na	na	na	na	11,030	5,046	2,091
Beaugé Bank SCA	3,983	na	na	na	na	11,192	5,800	2,394	1,573
North of Bennett Bank CCA	na	19,092	na	na	3,763	na	11,528	8,114	4,278
Eastern Honguedo Strait CSCA	4,193	19,092	na	na	3,530	na	10,644	5,926	3,398
Western Honguedo Strait CCA	na	na	na	na	na	na	10,895	6,941	4,204
Parent Bank SCA	4,246	na	na	na	na	na	8,500	4,934	2,098
Jacques-Cartier Strait SCA	3,827	na	na	na	na	384,023	11,910	9,115	2,913

[1] The results in the table were obtained assuming a random or stratified random distribution of survey hauls in each survey. The surveys identified by the footnote are in fact fixed gear surveys for which, technically-speaking, recurrence time at and around the fixed station locations is annual or near annual, and the survey does not occur elsewhere. However because of annual variation in the exact placement of hauls and the potential for changes in station location as survey designs are modified, a random placement assumption is probably closer to what occurs in practice.

Table 8. Summary of the overlap between individual halibut survey strata and each protected area. Prop. of area is the proportion of the protected area that overlaps the survey stratum, Prop. of stratum is the proportion of the stratum area that overlaps the protected area, Sets Total is the average annual number of sets in the stratum and Sets In is the average annual number of sets in both the stratum and the protected area (2017-2018). Only protected areas and strata for which there was overlap are shown.

Area	Stratum	Prop. of area	Prop. of stratum	Sets Total	Sets In
Banc-des-Américains MPA (Zone 1)	D19	0.196	0.007	1.5	0
Banc-des-Américains MPA (Zone 2)	C19	0.814	0.210	1	0
Banc-des-Américains MPA (Zone 2)	D16	0.002	0.001	2.5	0.5
Banc-des-Américains MPA (Zone 2)	D19	0.015	0.006	1.5	0.5
Scallop Buffer Zone SFA 21	C18	0.002	0.001	1	0
Scallop Buffer Zone SFA 21	C19	0.056	0.073	1	0
Scallop Buffer Zone SFA 22	C14	0.000	0.001	1	0
Scallop Buffer Zone SFA 22	C17	0.236	0.131	5	0
Scallop Buffer Zone SFA 24	C13	0.005	0.003	6	1.5
Scallop Buffer Zone SFA 24	C14	0.002	0.007	1	0
South-East of Anticosti Isl. SCA	D6	0.006	0.014	5.5	0
East of Anticosti Isl. SCA	D6	0.200	0.030	5.5	1
East of Anticosti Isl. SCA	D9	0.148	0.044	11.5	0
Beaugé Bank SCA	D7	0.198	0.073	10.5	0
Eastern Honguedo Strait CSCA	D6	0.144	0.137	5.5	0
Parent Bank SCA	D5	0.196	0.007	4	1
Jacques-Cartier Strait SCA	D10	0.814	0.210	4.5	0
Jacques-Cartier Strait SCA	D5	0.002	0.001	4	0
Jacques-Cartier Strait SCA	D9	0.015	0.006	11.5	0

Table 9. Summary of the overlap between the sGSL snow crab bottom-trawl survey area and each protected area. Prop. of area is the proportion of the protected area that overlaps the survey area, Prop. of domain is the proportion of the survey domain that overlaps the protected area, and Sets In is the average annual number of sets in both the survey area and the protected area (2012-2018). Only protected areas for which there was overlap are shown.

Protected area	Prop. of area	Prop. of domain	Sets In
Banc-des-Américains MPA (Zone 1)	1.000	0.002	0.86
Banc-des-Américains MPA (Zone 2)	0.995	0.015	4.71
Scallop Buffer Zone SFA 24	0.046	0.002	1.43
Slope of Magdalen Shallows CCA	0.201	0.001	0.86
North of Bennett Bank CCA	0.118	0.002	0.71
Eastern Honguedo Strait CSCA	0.148	0.006	2.00

Table 10. Summary of the overlap between the Northumberland Strait multi-species survey area and each protected area. Prop. of area is the proportion of the protected area that overlaps the survey area, Prop. of domain is the proportion of the survey domain that overlaps the protected area, and Sets In is the average annual number of sets in both the survey area and the protected area (2013-2018). Only protected areas for which there was overlap are shown.

Protected area	Prop. of area	Prop. of domain	Sets In
Scallop Buffer Zone SFA 22	0.641	0.174	25.15
Scallop Buffer Zone SFA 24	0.376	0.079	7.92

Table 11. Summary of the overlap between individual sGSL scallop dredge survey strata and each protected area. Prop. of area is the proportion of the protected area that overlaps the survey stratum, Prop. of stratum is the proportion of the stratum area that overlaps the protected area, Sets Total is the number of sets in the stratum and Sets In is the number of sets in both the stratum and the protected area for the one cycle of this rotational survey. Proportion entries of 0.000 indicate values <0.001. Only protected areas and strata for which there was overlap are shown.

Protected area	Stratum	Prop. of area	Prop. of stratum	Sets Total	Sets In
Scallop Buffer Zone SFA 21	2013.1	0.271	0.700	16	5
Scallop Buffer Zone SFA 21	2013.2	0.001	0.009	39	2
Scallop Buffer Zone SFA 21	2016.2	0.001	0.000	56	9
Scallop Buffer Zone SFA 21	2016.4	0.175	0.057	12	8
Scallop Buffer Zone SFA 22	2012.4	0.378	1.000	18	18
Scallop Buffer Zone SFA 22	2012.5	0.123	1.000	6	6
Scallop Buffer Zone SFA 22	2014.4	0.217	1.000	12	12
Scallop Buffer Zone SFA 24	2015.1	0.054	0.397	48	0
Scallop Buffer Zone SFA 24	2015.2	0.006	0.016	18	0
Scallop Buffer Zone SFA 24	2015.3	0.004	0.597	18	0
Scallop Buffer Zone SFA 24	2015.4	0.009	0.115	12	0
Scallop Buffer Zone SFA 24	2015.5	0.494	1.000	17	17

Table 12. Summary of the overlap between individual sGSL multi-species bottom-trawl survey strata and each protected area. Prop. of area is the proportion of the protected area that overlaps the survey stratum, Prop. of stratum is the proportion of the stratum area that overlaps the protected area, Sets Total is the average annual number of sets in the stratum (2009-2018) and Sets In is the average annual number of sets in both the stratum and the protected area. Only protected areas and strata for which there was overlap are shown.

Protected area	Stratum	Prop. of area	Prop. of stratum	Sets Total	Sets In
Banc-des-Américains MPA (Zone 1)	416	0.196	0.007	7.1	0
Banc-des-Américains MPA (Zone 2)	416	0.814	0.210	7.1	1.6
Banc-des-Américains MPA (Zone 2)	417	0.002	0.001	3.7	0
Scallop Buffer Zone SFA 21	418	0.015	0.006	3.1	0
Scallop Buffer Zone SFA 21	419	0.002	0.001	3.1	0
Scallop Buffer Zone SFA 22	402	0.056	0.073	3.1	0
Scallop Buffer Zone SFA 22	421	0.000	0.001	3.1	0
Scallop Buffer Zone SFA 24	433	0.236	0.131	8.2	0.6
Scallop Buffer Zone SFA 24	434	0.005	0.003	7.7	0
Scallop Buffer Zone SFA 24	403	0.002	0.007	3.6	0
Scallop Buffer Zone SFA 24	432	0.006	0.014	3.2	0.2
Slope of Magdalen Shallows CCA	425	0.200	0.030	4.1	0.2
Slope of Magdalen Shallows CCA	439	0.148	0.044	3.4	0.4
North of Bennett Bank CCA	425	0.198	0.073	4.1	0.5
Eastern Honguedo Strait CSCA	415	0.144	0.137	5.3	0.6

Table 13. Summary of the overlap between the nGSL post-season snow crab trap survey areas (Zones) and each protected area. Prop. of area is the proportion of the protected area that overlaps the survey area, Prop. of domain is the proportion of the survey domain that overlaps the protected area, and Sets In is the average annual number of sets in both the survey area and the protected area (2009-2018). Only protected areas for which there was overlap are shown.

Area	Zone	Prop. of area	Prop. of domain	Sets In
Beaugé Bank SCA	12C	0.040	0.039	6.0
Jacques-Cartier Strait SCA	16	1.000	0.030	6.0

Table 14. Summary of the overlap between individual nGSL & Estuary multi-species bottom-trawl survey strata and each protected area. Prop. of area is the proportion of the protected area that overlaps the survey stratum, Prop. of stratum is the proportion of the stratum area that overlaps the protected area, Sets Total is the average annual number of sets in the stratum (2009-2018) and Sets In is the average annual number of sets in both the stratum and the protected area. Only protected areas and strata for which there was overlap are shown.

Protected area	Stratum	Prop. of area	Prop. of stratum	Sets Total	Sets In
Eastern Gulf of St. Lawrence CCA	407	1.000	0.182	2.8	0.3
Slope of Magdalen Shallows CCA	404	0.143	0.069	2.3	0.4
Slope of Magdalen Shallows CCA	407	0.838	0.122	2.8	0.3
Slope of Magdalen Shallows CCA	803	0.019	0.001	6.5	0
Central Gulf of St. Lawrence CCA	803	1.000	0.182	6.5	1.1
South-East of Anticosti Isl. SCA	803	0.392	0.047	6.5	0.2
South-East of Anticosti Isl. SCA	807	0.576	0.198	3.3	0.8
South-East of Anticosti Isl. SCA	819	0.032	0.018	2.4	0
East of Anticosti Isl. SCA	819	0.023	0.017	2.4	0.1
East of Anticosti Isl. SCA	829	0.290	0.093	2.6	0.2
East of Anticosti Isl. SCA	830	0.642	0.309	3	0.7
Beaugé Bank SCA	827	0.187	0.015	2.8	0.1
Beaugé Bank SCA	833	0.813	0.307	2.3	1
North of Bennett Bank CCA	804	0.016	0.006	3.4	0
North of Bennett Bank CCA	405	0.067	0.041	2.6	0.1
North of Bennett Bank CCA	408	0.918	0.280	3.4	0.8
Eastern Honguedo Strait CSCA	405	0.101	0.170	2.6	0.3
Eastern Honguedo Strait CSCA	406	0.142	0.139	3.4	0.4
Eastern Honguedo Strait CSCA	804	0.347	0.381	3.4	1.1
Eastern Honguedo Strait CSCA	807	0.006	0.006	3.3	0
Eastern Honguedo Strait CSCA	408	0.189	0.164	3.4	0.9
Eastern Honguedo Strait CSCA	818	0.005	0.005	3.9	0
Eastern Honguedo Strait CSCA	806	0.206	0.212	3	0.8
Western Honguedo Strait CCA	804	0.105	0.025	3.4	0.1
Western Honguedo Strait CCA	406	0.682	0.142	3.4	0.8
Western Honguedo Strait CCA	806	0.206	0.046	3	0.2
Parent Bank SCA	817	0.178	0.026	4.5	0.4
Parent Bank SCA	831	0.530	0.229	2.4	0.4
Jacques-Cartier Strait SCA	828	0.559	0.078	2.6	0.1
Jacques-Cartier Strait SCA	832	0.035	0.003	4.1	0.1
Jacques-Cartier Strait SCA	839	0.072	0.006	2.4	0
Jacques-Cartier Strait SCA	841	0.335	0.139	2.3	0.2

Table 15. Summary of the overlap between individual nGSL Sentinel bottom-trawl survey strata and each protected area. Prop. of area is the proportion of the protected area that overlaps the survey stratum, Prop. of stratum is the proportion of the stratum area that overlaps the protected area, Sets Total is the average annual number of sets in the stratum (2009-2018) and Sets In is the average annual number of sets in both the stratum and the protected area. Only protected areas and strata for which there was overlap are shown.

Protected area	Stratum	Prop. of area	Prop. of stratum	Sets Total	Sets In
Eastern Gulf of St. Lawrence CCA	407	1.000	0.182	2.5	0.4
Slope of Magdalen Shallows CCA	404	0.143	0.069	3	0
Slope of Magdalen Shallows CCA	407	0.838	0.122	2.5	0.2
Slope of Magdalen Shallows CCA	803	0.019	0.001	11.8	0
Central Gulf of St. Lawrence CCA	803	1.000	0.182	11.8	2.9
South-East of Anticosti Isl. SCA	803	0.392	0.047	11.8	0.3
South-East of Anticosti Isl. SCA	807	0.576	0.198	4	1
South-East of Anticosti Isl. SCA	819	0.032	0.018	2.8	0
East of Anticosti Isl. SCA	819	0.023	0.017	2.8	0
East of Anticosti Isl. SCA	829	0.290	0.093	3.8	0
East of Anticosti Isl. SCA	830	0.642	0.309	4	0.8
Beaugé Bank SCA	827	0.187	0.015	5.2	0.3
Beaugé Bank SCA	833	0.813	0.307	3	1.1
North of Bennett Bank CCA	804	0.014	0.006	4.8	0.1
North of Bennett Bank CCA	405	0.067	0.041	3	0.5
North of Bennett Bank CCA	408	0.920	0.280	3	1.2
Eastern Honguedo Strait CSCA	405	0.101	0.170	3	0.7
Eastern Honguedo Strait CSCA	406	0.142	0.139	3	0.2
Eastern Honguedo Strait CSCA	804	0.347	0.381	4.8	2.1
Eastern Honguedo Strait CSCA	807	0.006	0.006	4	0.1
Eastern Honguedo Strait CSCA	408	0.189	0.164	3	0.3
Eastern Honguedo Strait CSCA	818	0.005	0.005	4.8	0.1
Eastern Honguedo Strait CSCA	806	0.206	0.212	4	0.7
Western Honguedo Strait CCA	804	0.105	0.025	4.8	0
Western Honguedo Strait CCA	406	0.682	0.142	3	0.6
Western Honguedo Strait CCA	806	0.206	0.046	4	0.1
Parent Bank SCA	817	0.178	0.026	6.4	0.2
Parent Bank SCA	831	0.530	0.229	2.3	0.2
Jacques-Cartier Strait SCA	828	0.559	0.078	1.7	0.1
Jacques-Cartier Strait SCA	832	0.035	0.003	6.8	0
Jacques-Cartier Strait SCA	839	0.072	0.006	5.5	0
Jacques-Cartier Strait SCA	841	0.335	0.139	2.4	0.2

11. FIGURES

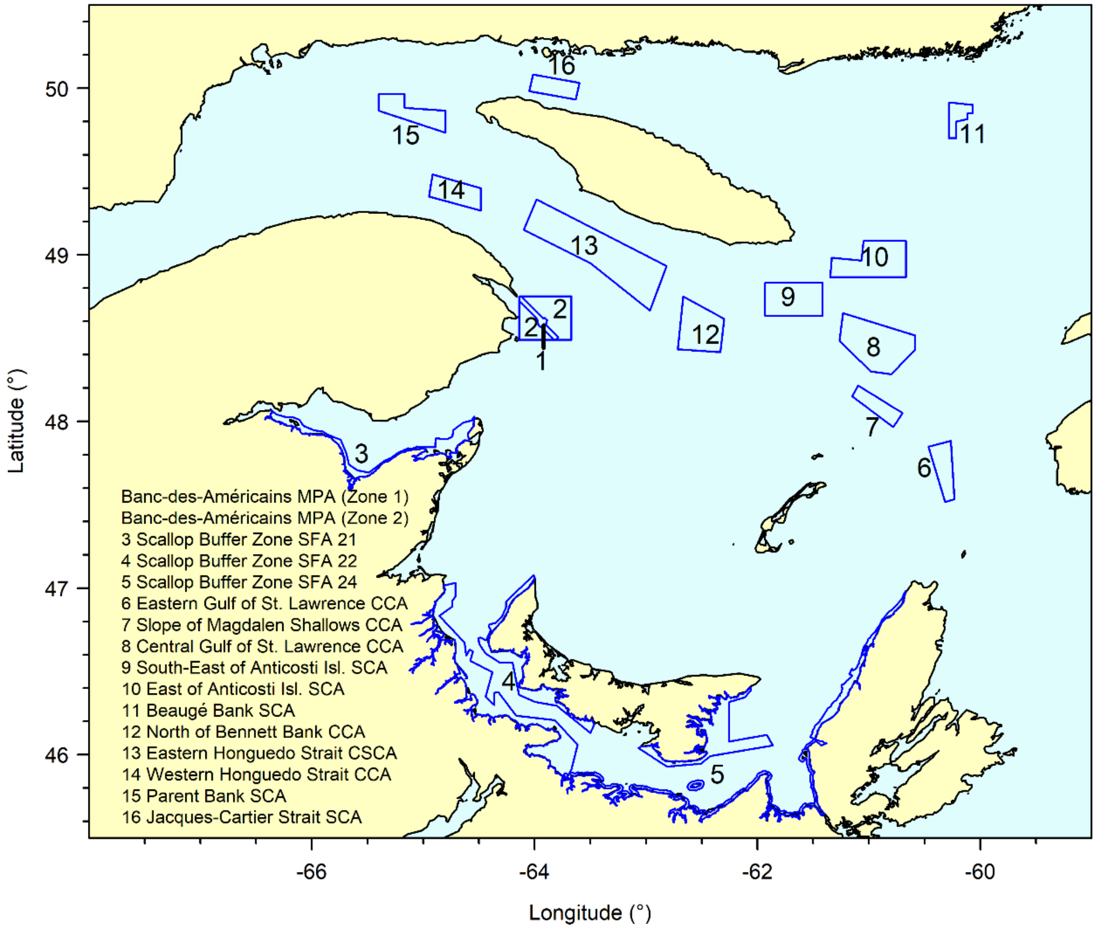

Figure 1. Map of the marine refuges and the Marine Protected Area (Banc-des-Américains MPA) with defined benthic conservation objectives and in which one or more ongoing scientific surveys employing bottom-contacting gear recur. The following acronyms are used in the legend to identify the refuges: SFA – scallop fishing areas, CCA – coral conservation area, SCA – sponge conservation area, and CSCA – coral and sponge conservation area.

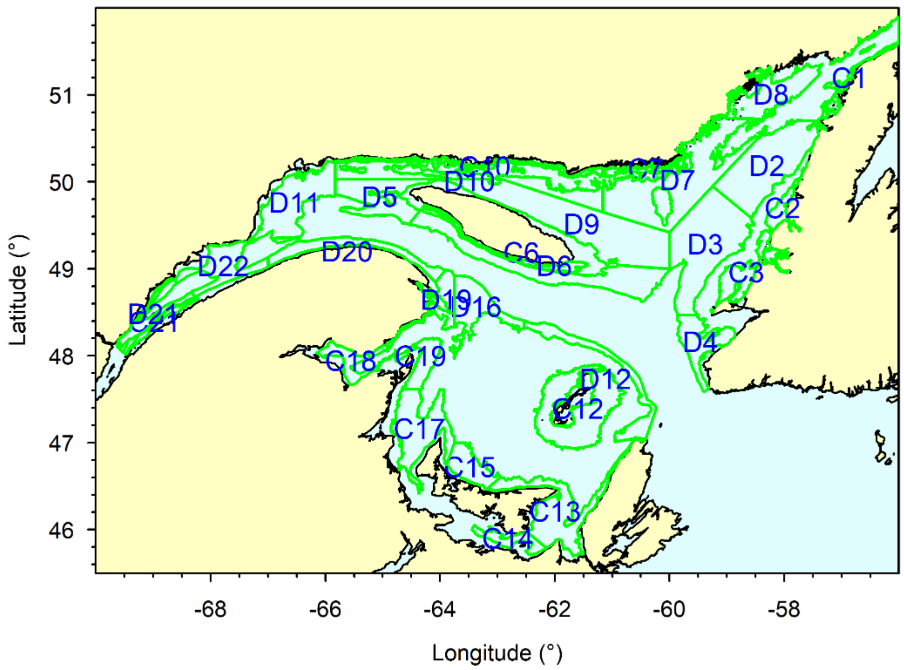

Figure 2. Stratification scheme for the Gulf of St. Lawrence Atlantic halibut survey. Strata are identified as being either coastal (C) or deep (D).

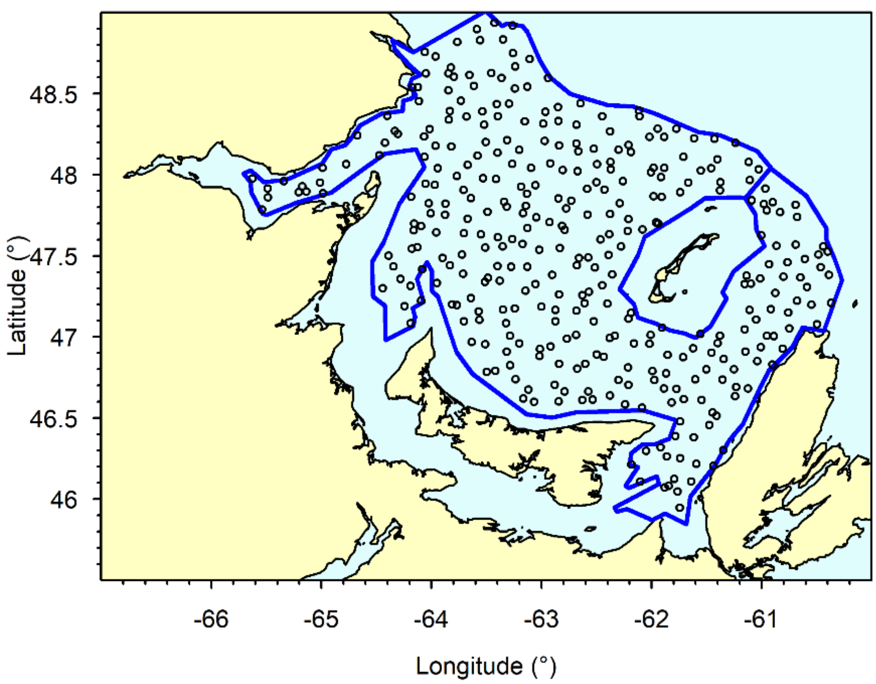

Figure 3. Survey polygon and fixed station locations (2018) for the southern Gulf of St. Lawrence snow crab bottom-trawl survey.

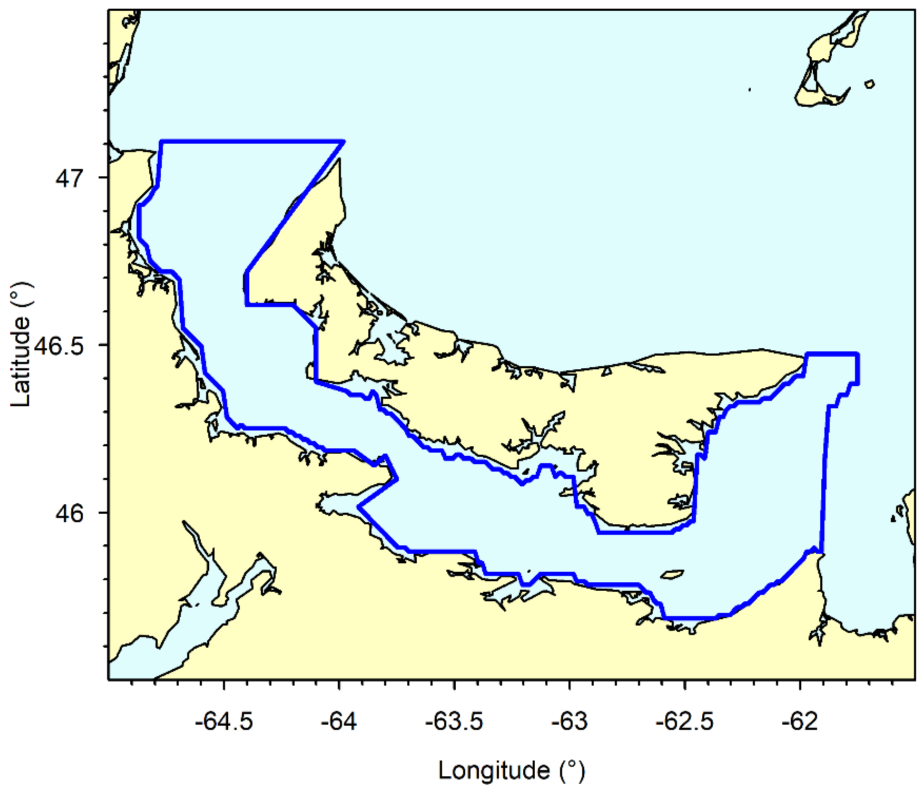

Figure 4. Approximate survey polygon for the Northumberland Strait multi-species survey. The polygon was defined based on the coordinates of the grid used for estimation of survey indices.

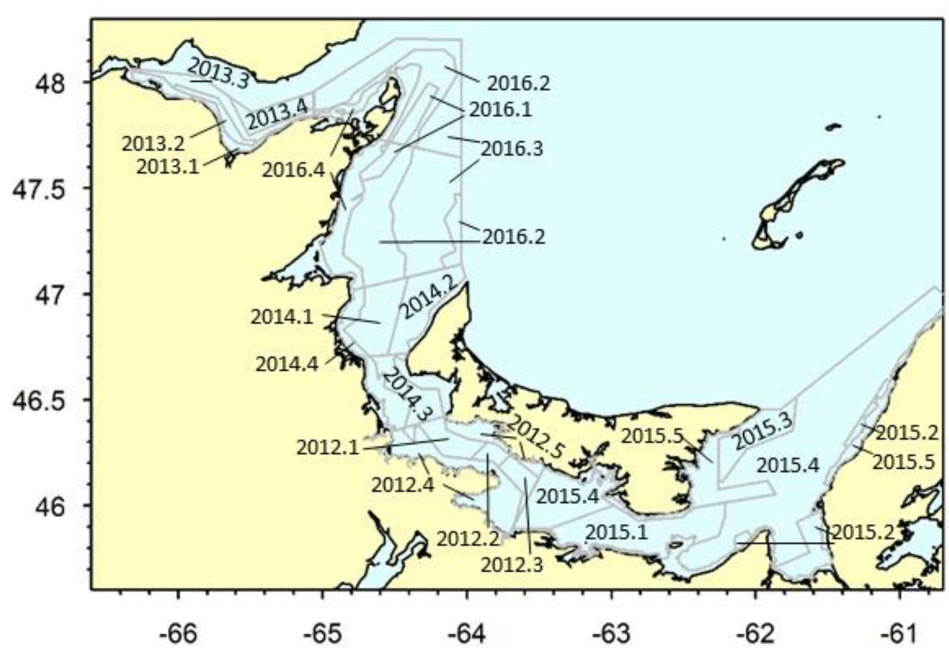

Figure 5. Stratification scheme for the southern Gulf of St. Lawrence scallop dredge survey. Strata are numbered sequentially for each year of the survey as shorthand for the actual strata place names.

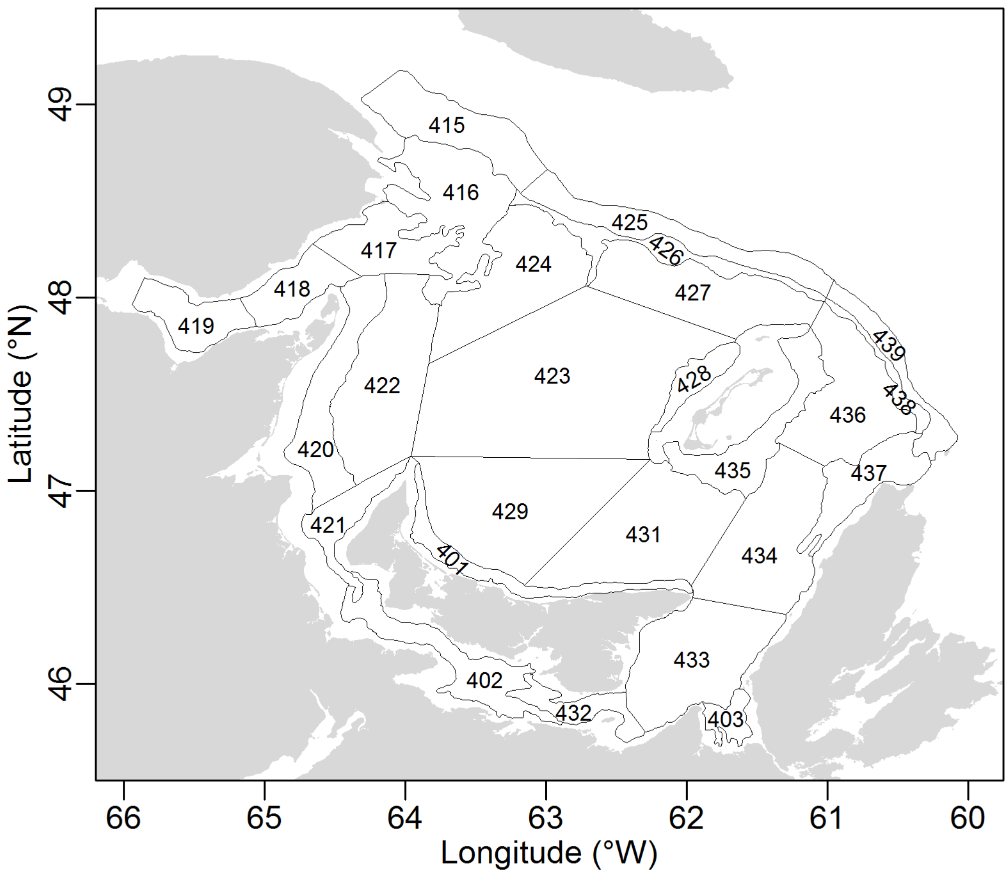

Figure 6. Stratification scheme for the southern Gulf of St. Lawrence multi-species bottom-trawl survey.

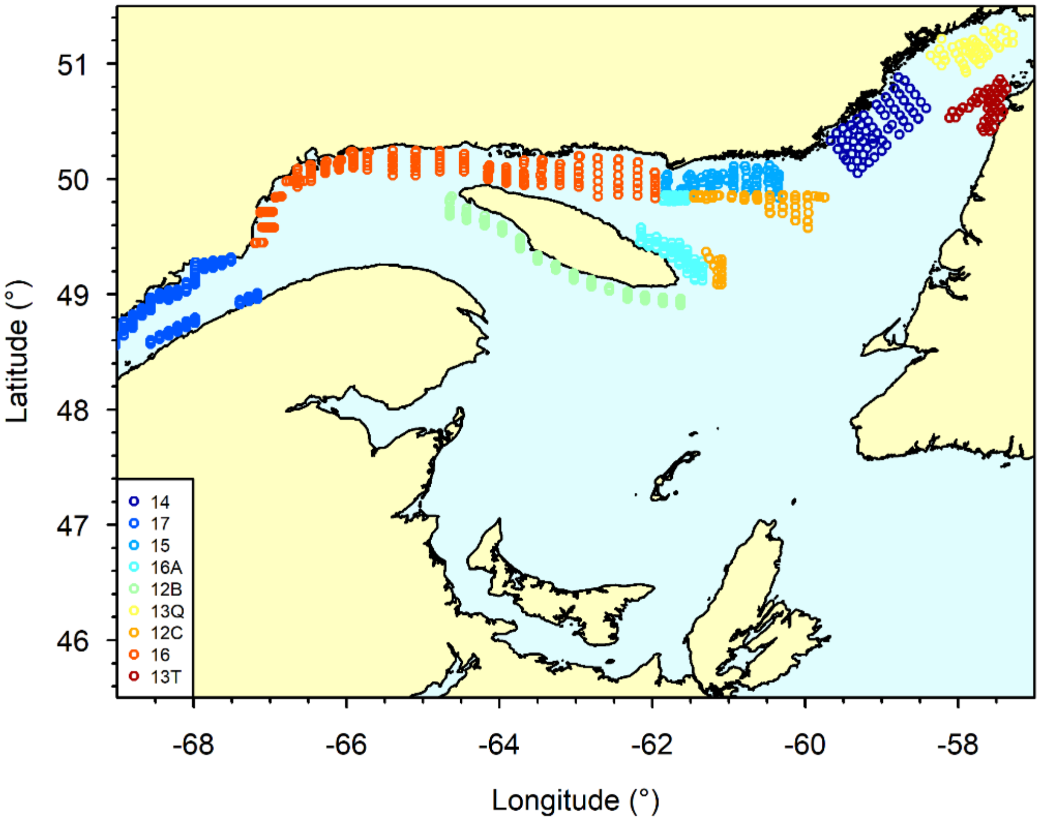

Figure 7. Fixed station locations for the northern Gulf of St. Lawrence post-season snow crab trap survey in each fishing sub-zone (distinguished by colour). The stations in sub-zones 12C (light orange) and 16 (dark orange) are pertinent for the present report.

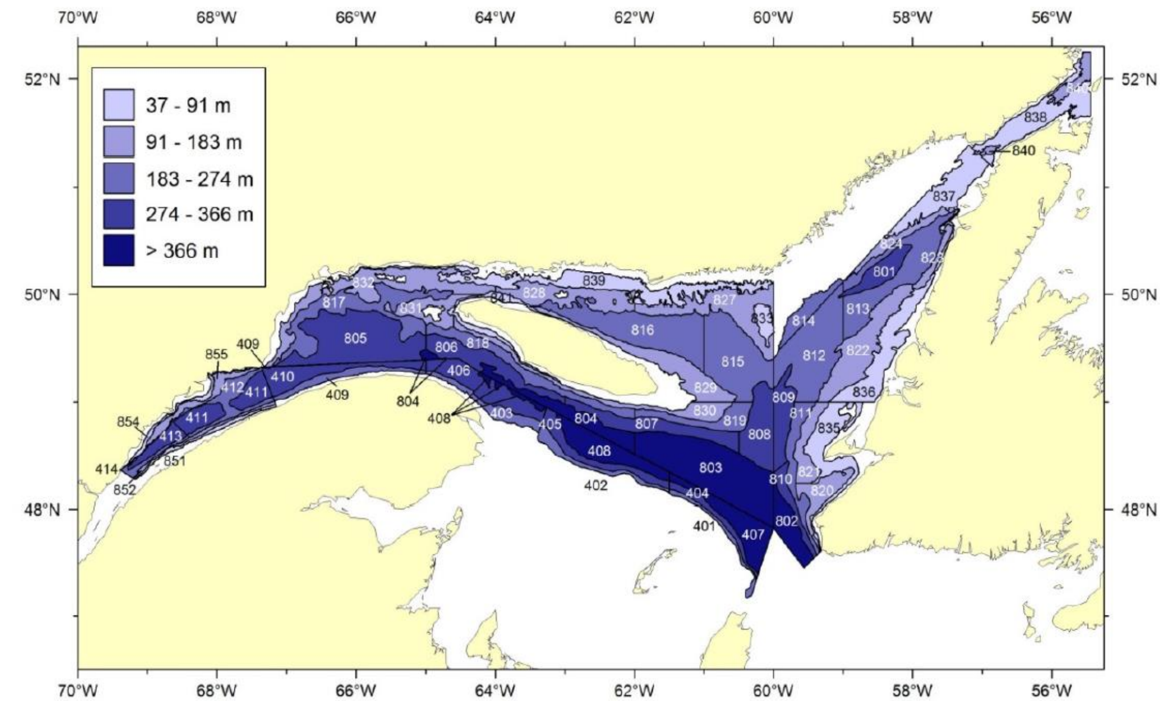

Figure 8. Stratification scheme for the multi-species bottom-trawl survey of the northern Gulf of St. Lawrence and Estuary.

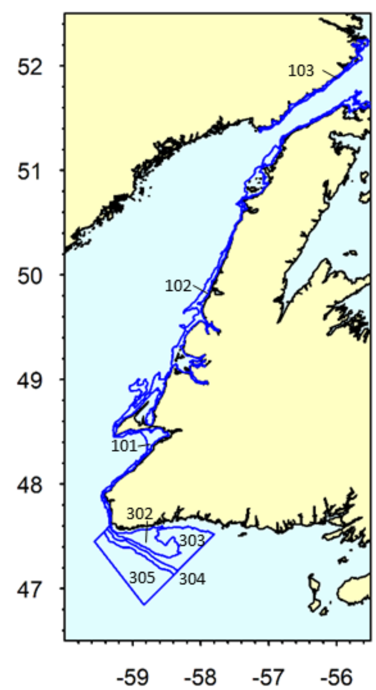

Figure 9. Coastal strata used in the northern Gulf of St. Lawrence Sentinel bottom-trawl survey in addition to the other strata employed in the nGSL multi-species survey (Figure 8, with the exception of strata in the Estuary).

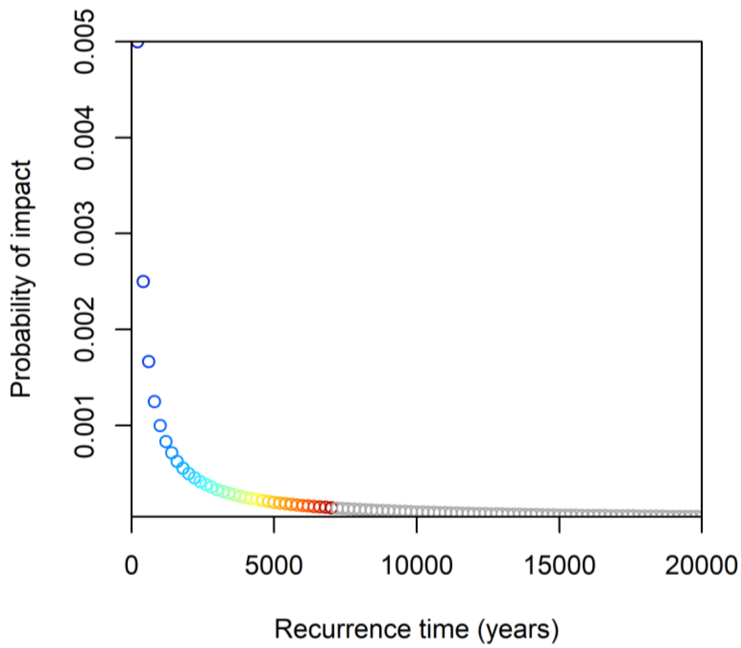

Figure 10. Summary of the relationship between recurrence time interval (years) and the annual proportion of a protected area that is impacted (which is the annual probability of an impact at a particular location). The colours employed in the plot correspond to those used in subsequent figures to summarize recurrence times. Recurrence times in Gulf of St. Lawrence areas were either <7,000 year, >19,000 year or infinite (i.e., survey activities do not recur at that location).

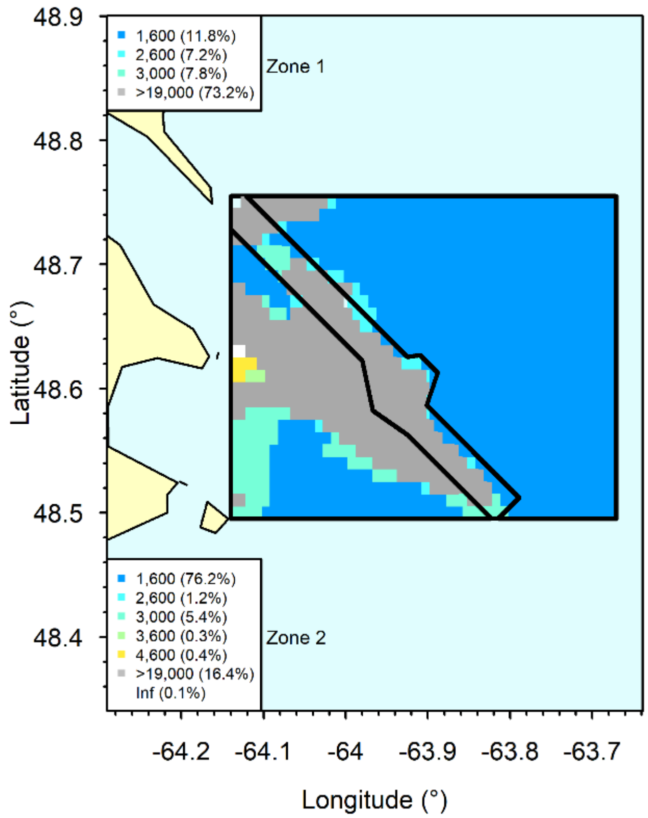

Figure 11. Map summarizing the mean recurrence time intervals (years) for particular locations in the Banc-des-Américains MPA. Recurrence times were rounded to the nearest 100 years for plotting.

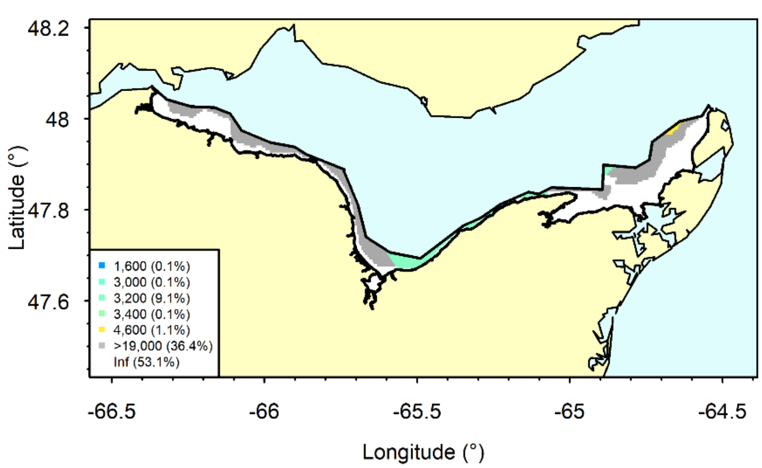

Figure 12. Map summarizing the mean recurrence time intervals (years) for particular locations in the Scallop Buffer Zone SFA 21 marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

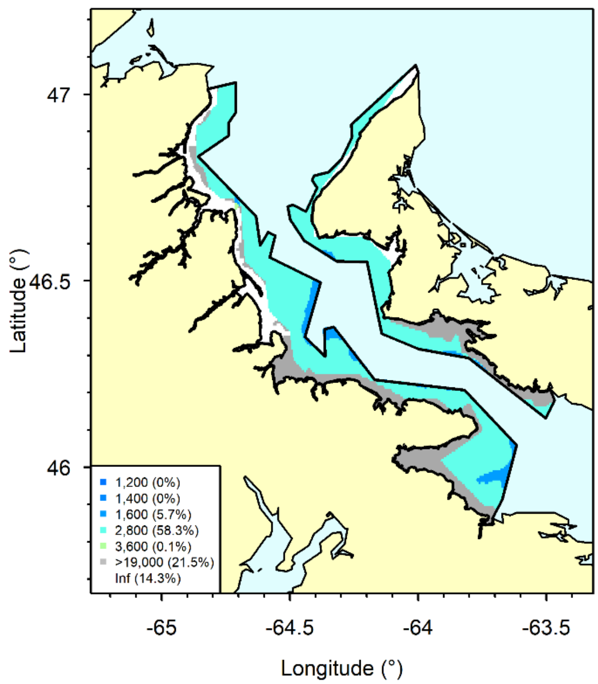

Figure 13. Map summarizing the mean recurrence time intervals (years) for particular locations in the Scallop Buffer Zone SFA 22 marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

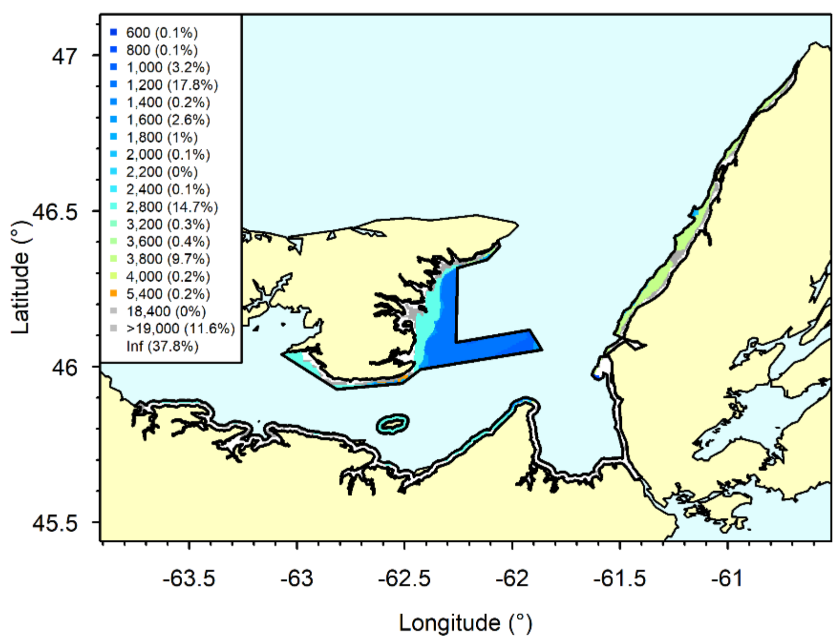

Figure 14. Map summarizing the mean recurrence time intervals (years) for particular locations in the Scallop Buffer Zone SFA 24 marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

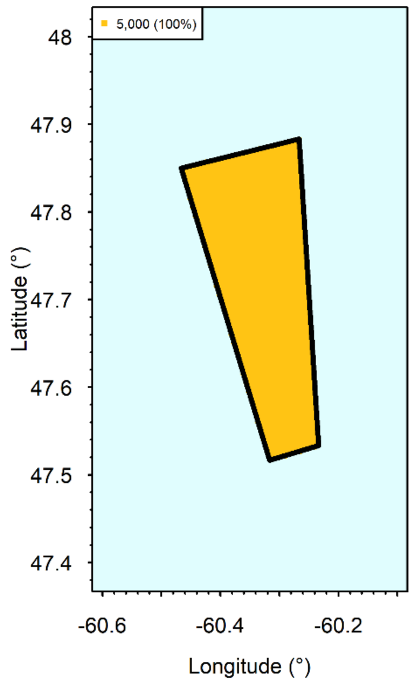

Figure 15. Map summarizing the mean recurrence time intervals (years) for particular locations in the Eastern Gulf of St. Lawrence CCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

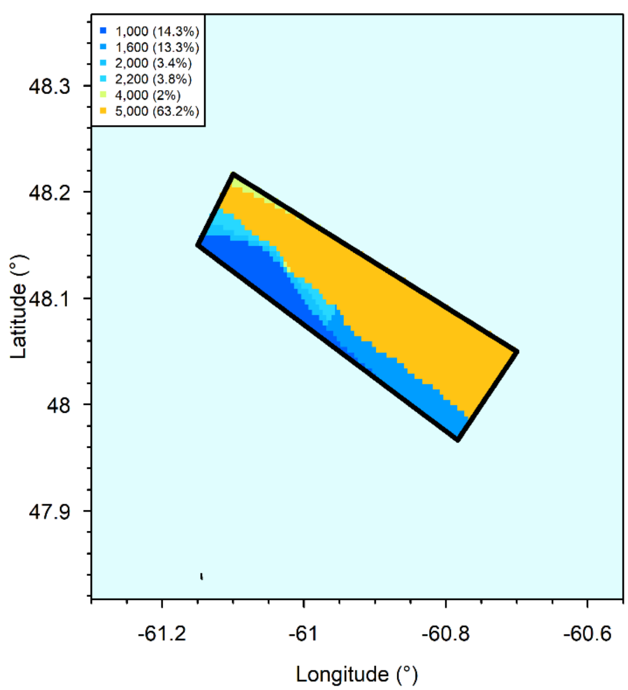

Figure 16. Map summarizing the mean recurrence time intervals (years) for particular locations in the Slope of Magdalen Shallows CCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

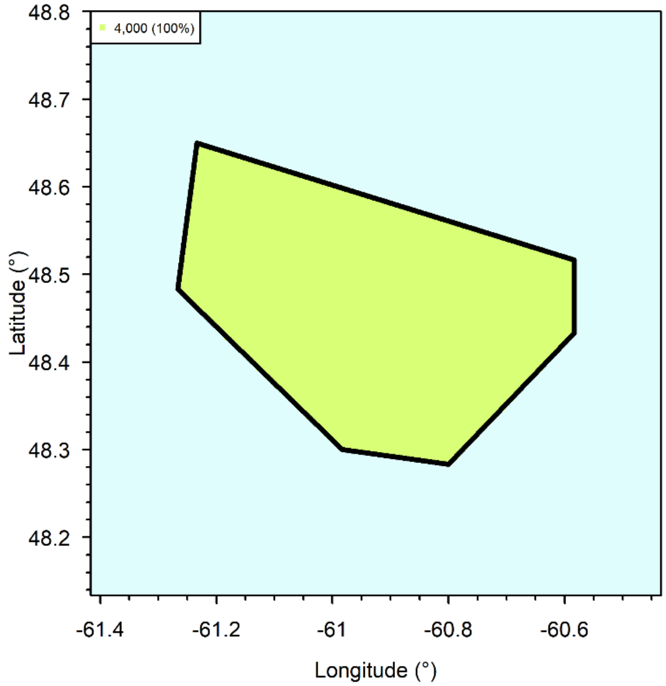

Figure 17. Map summarizing the mean recurrence time intervals (years) for particular locations in the Central Gulf of St. Lawrence CCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

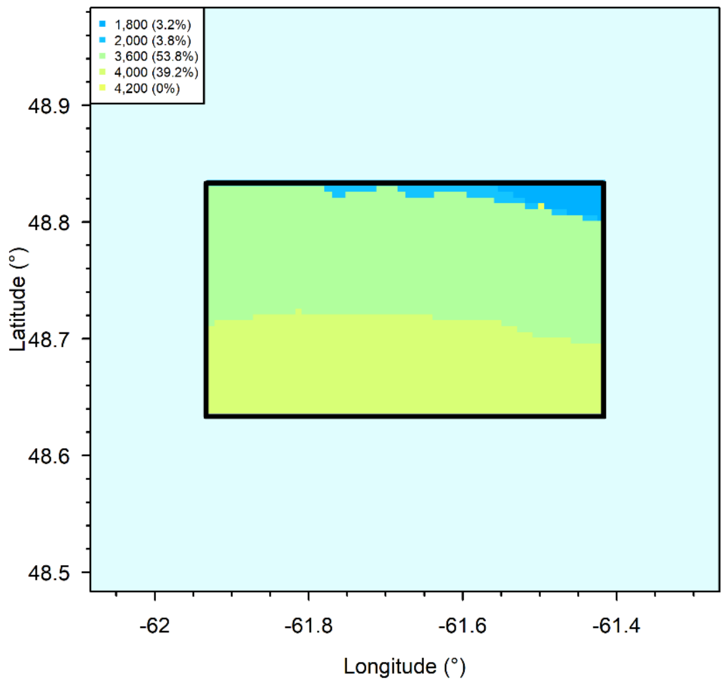

Figure 18. Map summarizing the mean recurrence time intervals (years) for particular locations in the South-East of Anticosti Island SCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

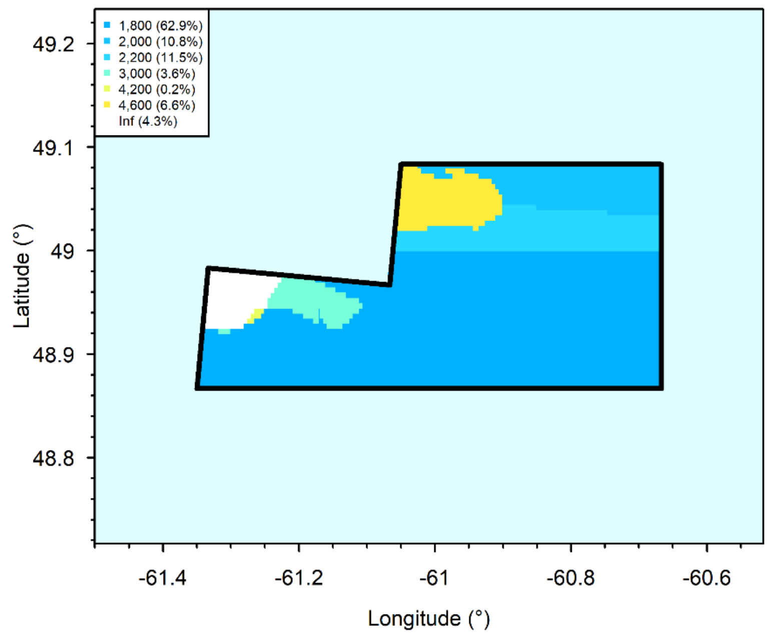

Figure 19. Map summarizing the mean recurrence time intervals (years) for particular locations in the East of Anticosti Island SCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

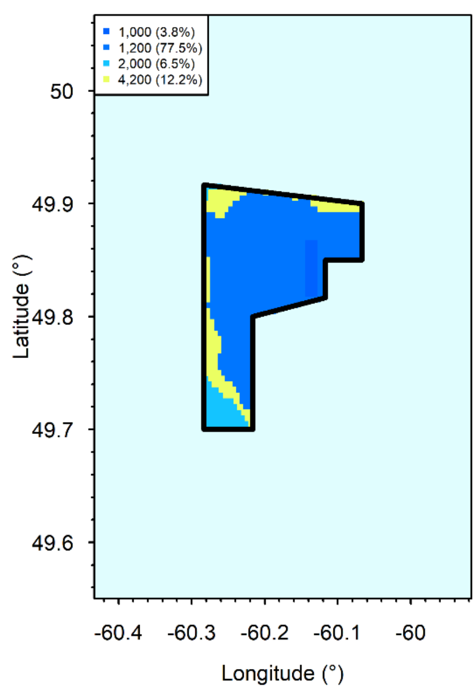

Figure 20. Map summarizing the mean recurrence time intervals (years) for particular locations in the Beaugé Bank SCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

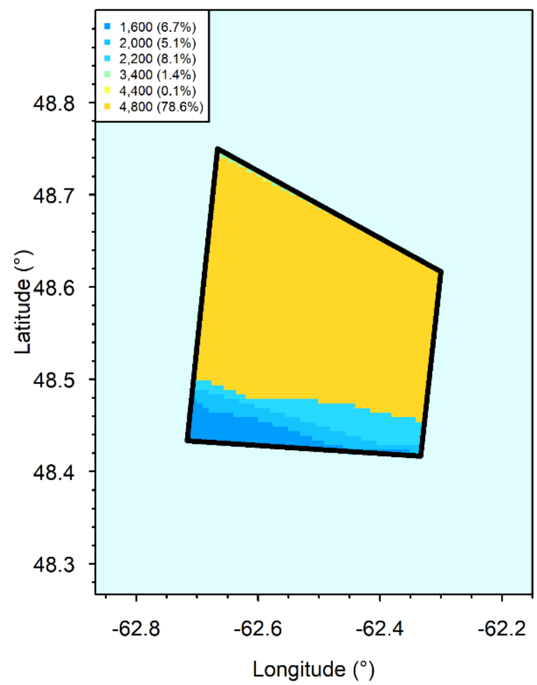

Figure 21. Map summarizing the mean recurrence time intervals (years) for particular locations in the North of Bennett Bank CCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

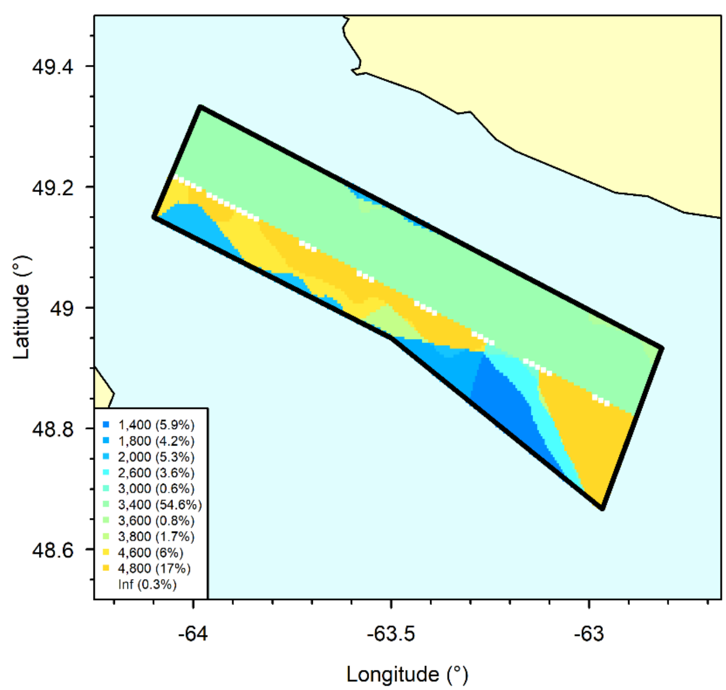

Figure 22. Map summarizing the mean recurrence time intervals (years) for particular locations in the Eastern Honguedo Strait CSCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

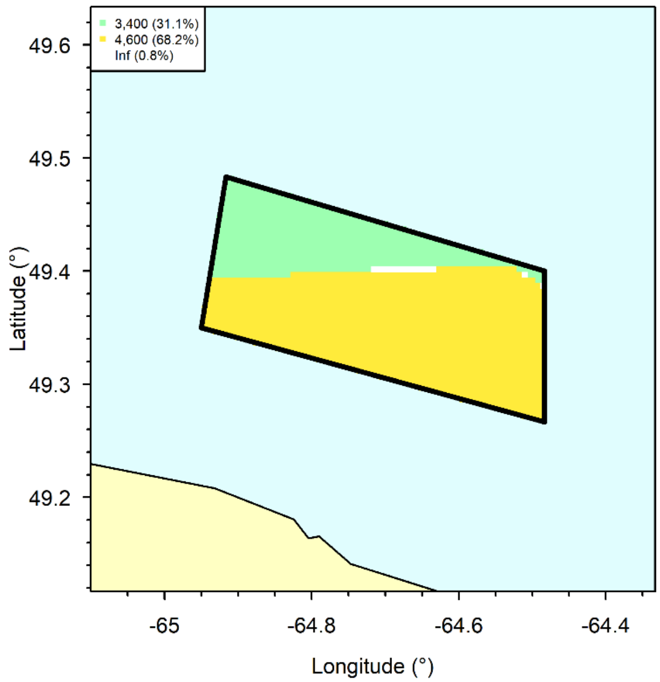

Figure 23. Map summarizing the mean recurrence time intervals (years) for particular locations in the Western Honguedo Strait CCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

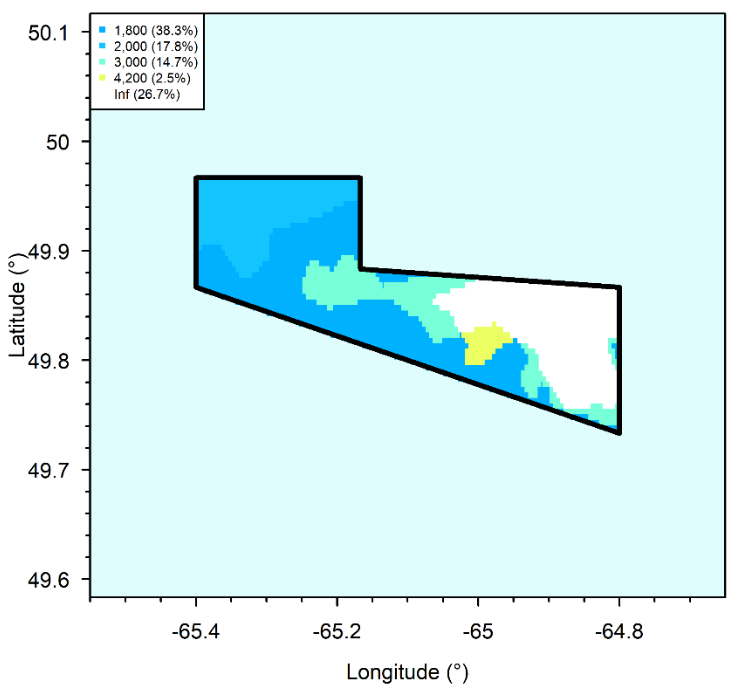

Figure 24. Map summarizing the mean recurrence time intervals (years) for particular locations in the Parent Bank SCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

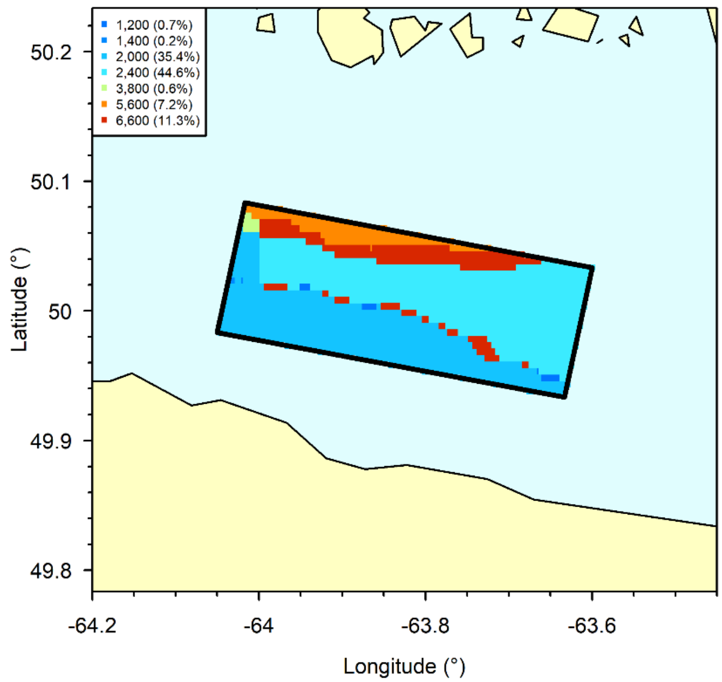

Figure 25. Map summarizing the mean recurrence time intervals (years) for particular locations in the Jacques-Cartier Strait SCA marine refuge. Recurrence times were rounded to the nearest 100 years for plotting.

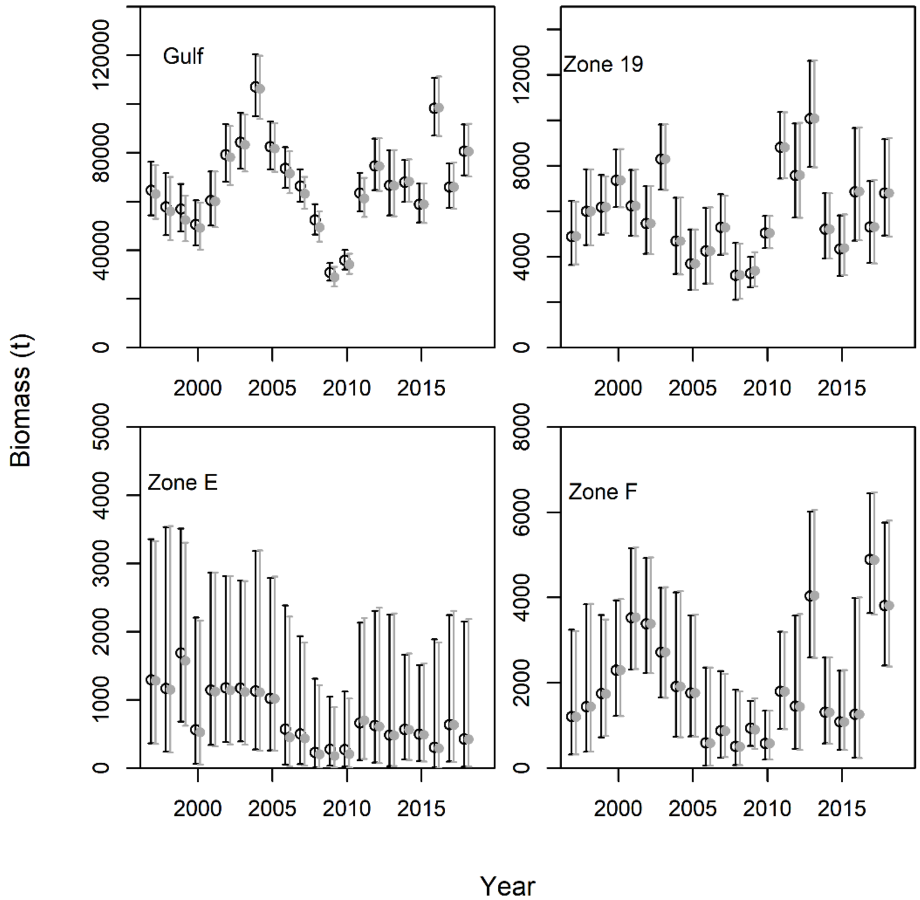

Figure 26. Summary of potential impacts to snow crab biomass estimate time series of excluding sGSL snow crab survey activities from all marine refuges. The data presented are time series of abundance indices including all sets (black points) and excluding sets occurring in the refuges (grey points), with 95% confidence intervals. The panels are for the southern Gulf (top-left) or different sub-zones.

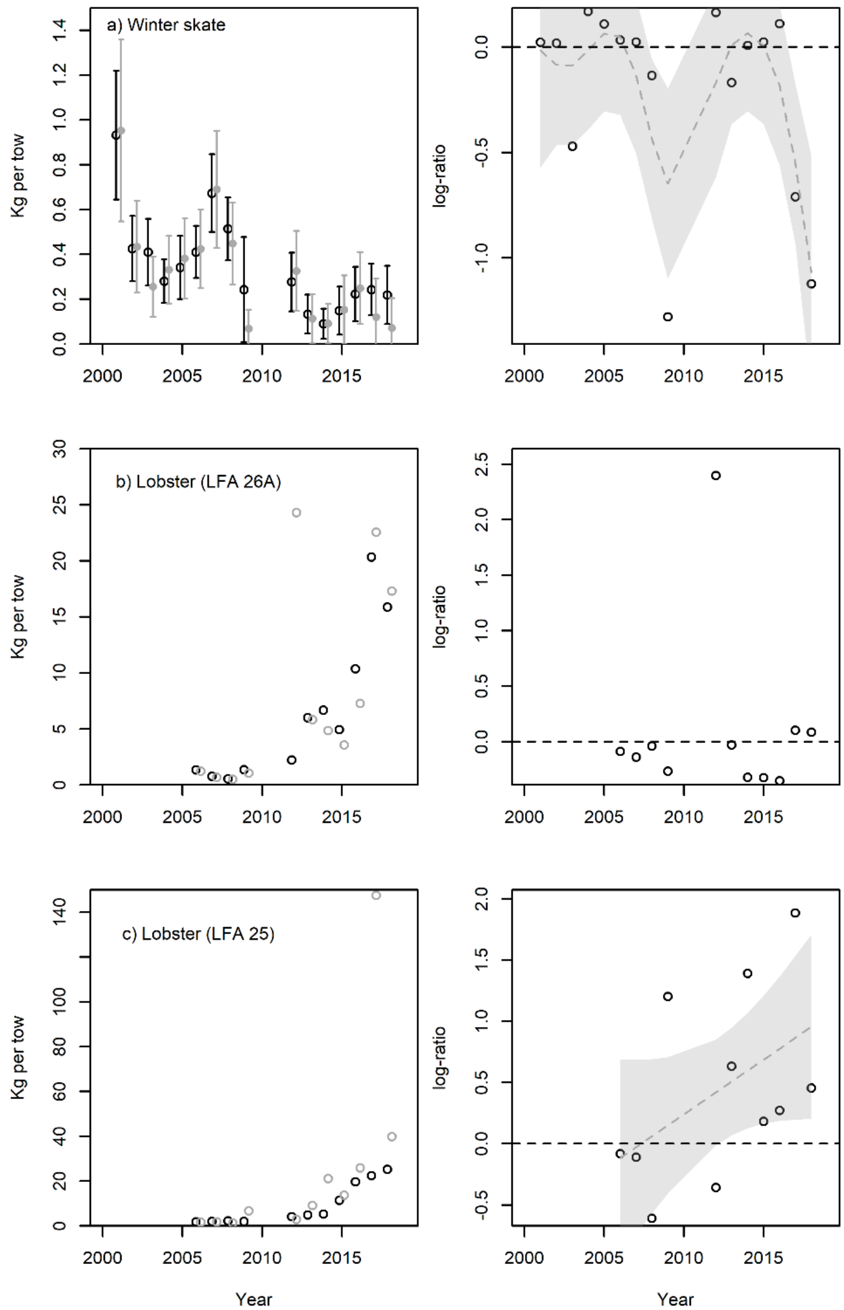

Figure 27. Summary of potential impacts to biomass index time series of excluding Northumberland Strait multi-species survey activities from the Scallop Buffer Zone marine refuges. The left column presents time series of abundance indices including all sets (black points) and excluding sets occurring in the refuges (grey points). The right column presents the time series for the relative bias (log-survey index ratio), where the points are the data values and the grey dashed line and grey band indicate the trend and 95% confidence interval for the smoother of a GAM through the points when that smoother was statistically significant. Each row presents the results for a different species or population, here a) Winter Skate (individuals ≥ 42 cm, representing adults), b) lobster in LFA 26A and c) lobster in LFA 25.

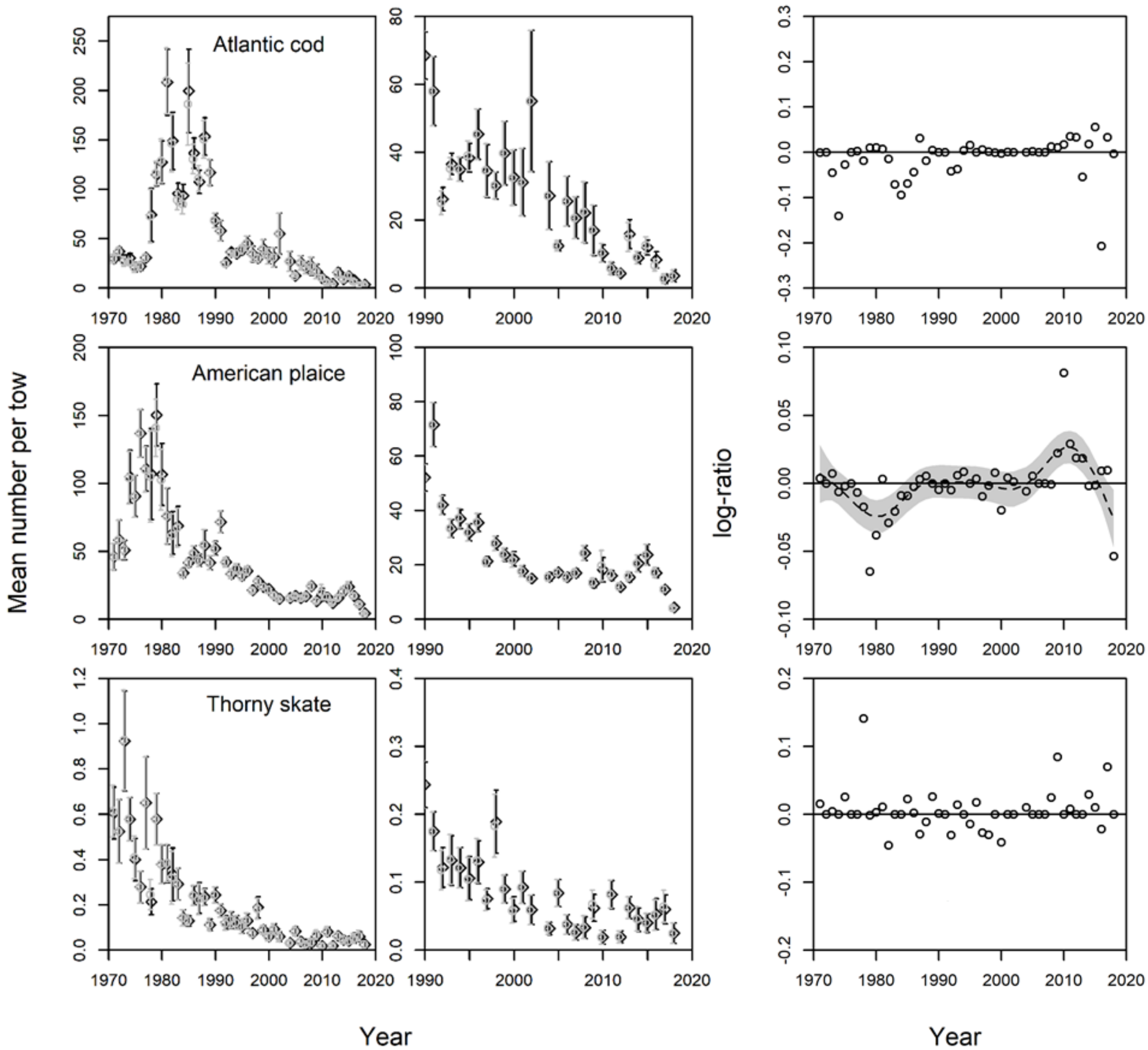

Figure 28. Summary of potential impacts to abundance index time series of excluding sGSL multi-species survey activities from the Banc-des-Américains MPA. The left and middle columns present time series of abundance indices including all sets (black points) and excluding sets occurring in the refuges (grey points), with 95% confidence intervals, for the entire time series (left) or only the most recent period (middle). The right column presents the time series for the relative bias (log-survey index ratio), where the points are the data values and the grey dashed line and grey band indicate the trend and 95% confidence interval for the smoother of a GAM through the points when that smoother was statistically significant. Each row presents series for adults of a different species, here Atlantic Cod (top), American Plaice (middle) and Thorny Skate (bottom).

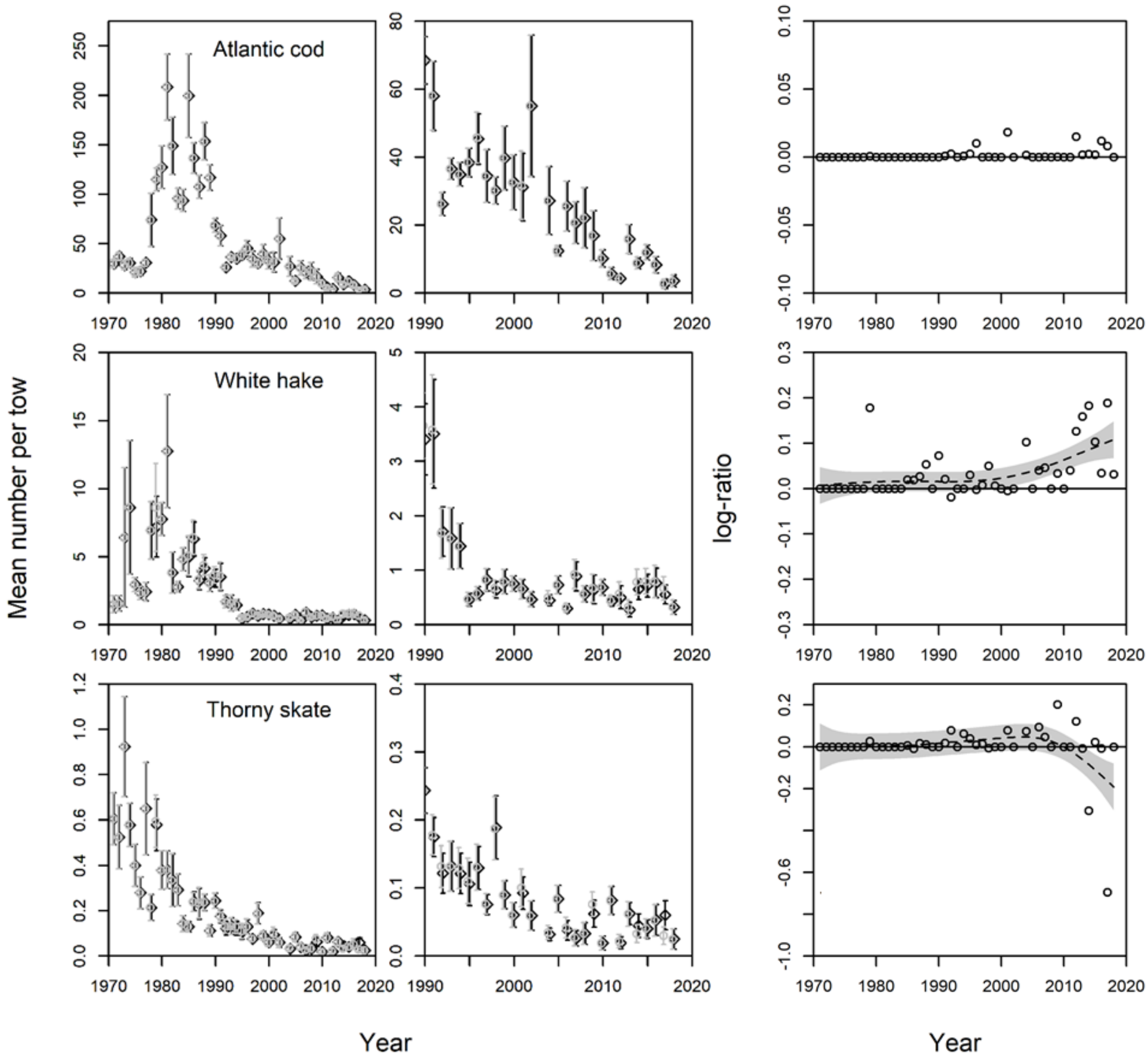

Figure 29. Summary of potential impacts to abundance index time series of excluding sGSL multi-species survey activities from the coral conservation areas. The left and middle columns present time series of abundance indices including all sets (black points) and excluding sets occurring in the refuges (grey points), with 95% confidence intervals, for the entire time series (left) or only the most recent period (middle). The right column presents the time series for the relative bias (log-survey index ratio), where the points are the data values and the grey dashed line and grey band indicate the trend and 95% confidence interval for the smoother of a GAM through the points when that smoother was statistically significant. Each row presents series for adults of a different species, here Atlantic Cod (top), White Hake (middle) and Thorny Skate (bottom).

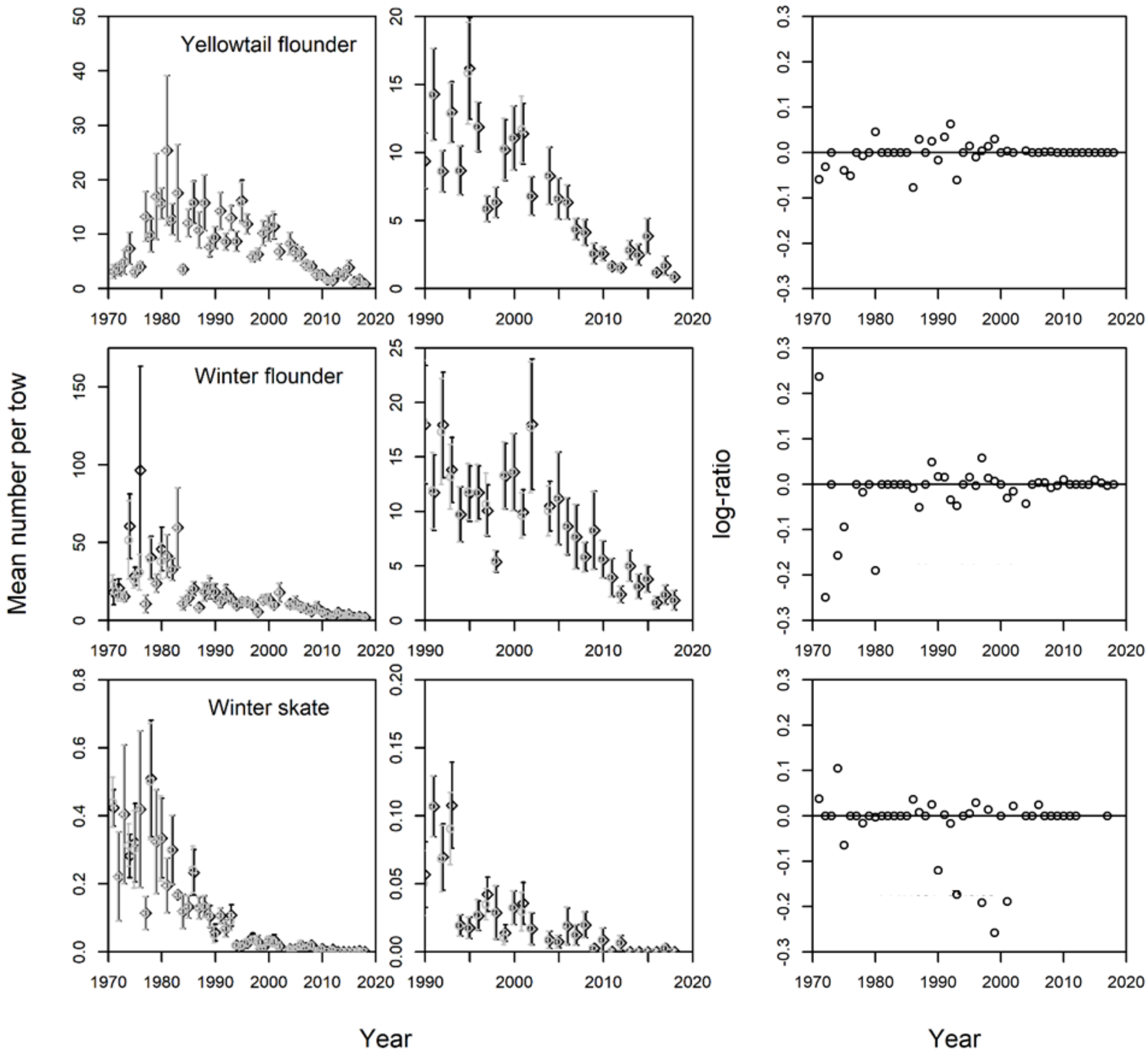

Figure 30. Summary of potential impacts to abundance index time series of excluding sGSL multi-species survey activities from the scallop buffer zone marine refuges. The left and middle columns present time series of abundance indices including all sets (black points) and excluding sets occurring in the refuges (grey points), with 95% confidence intervals, for the entire time series (left) or only the most recent period (middle). The right column presents the time series for the relative bias (log-survey index ratio), where the points are the data values and the grey dashed line and grey band indicate the trend and 95% confidence interval for the smoother of a GAM through the points when that smoother was statistically significant. Each row presents series for adults of a different species, here Yellowtail Flounder (top), Winter Flounder (middle) and Winter Skate (bottom).

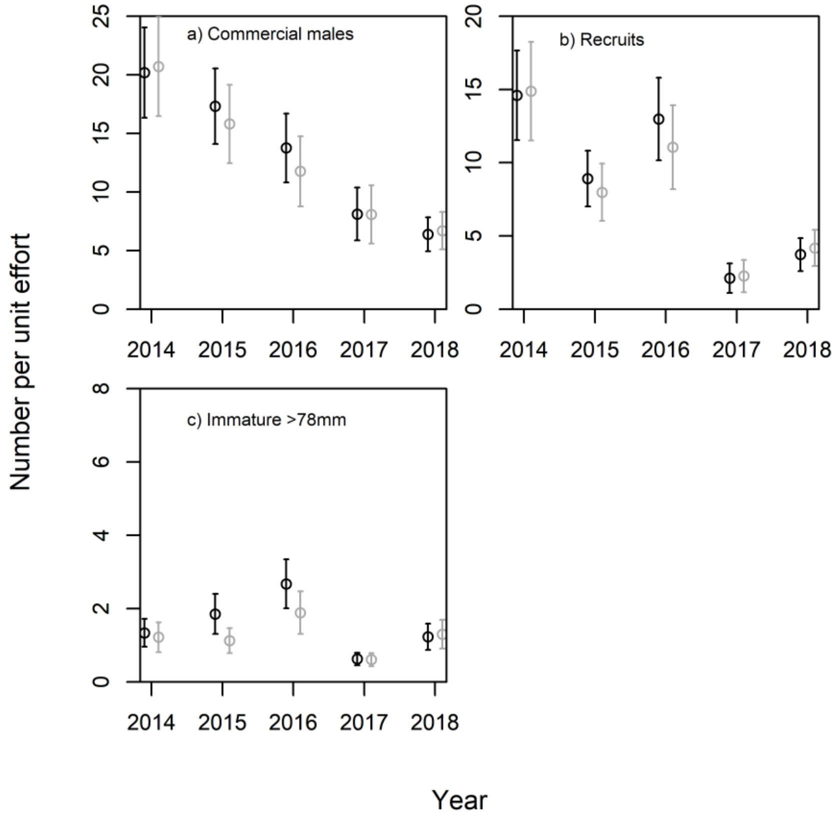

Figure 31. Summary of potential impacts to snow crab abundance index time series of excluding nGSL snow crab post-season trap survey activities in sub-zone 12C from the Beaugé Bank Sponge Conservation Area. The data presented are time series of abundance indices including all sets (black points) and excluding sets occurring in the refuges (grey points), with 95% confidence intervals. The panels are for a) commercial males (adult males ≥ 95mm), b) recruits (newly mature adult males) and immature males >78 mm.

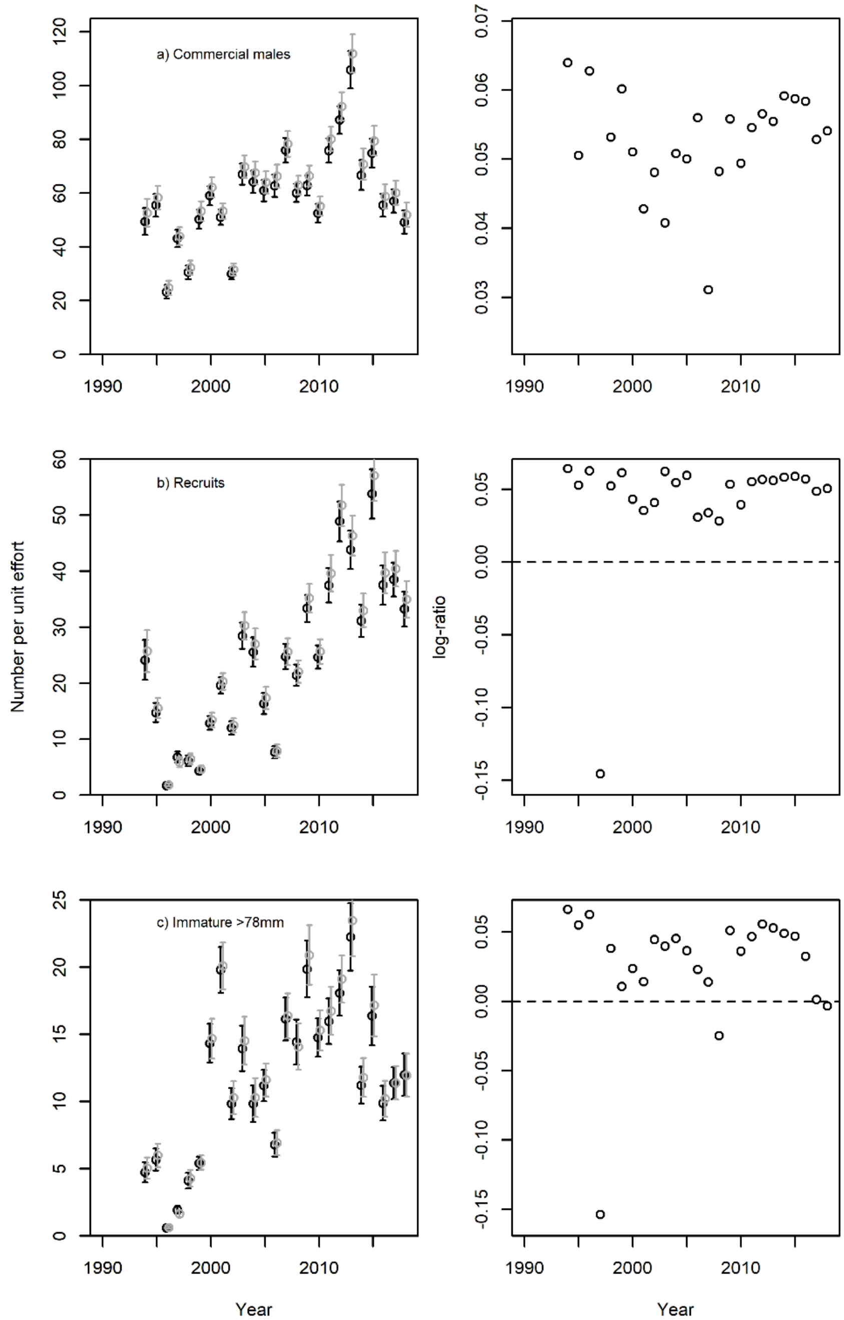

Figure 32. Summary of potential impacts to snow crab abundance index time series of excluding nGSL snow crab post-season trap survey activities in sub-zone 16 from the Jacques-Cartier Strait Sponge Conservation Area. The left column presents time series of abundance indices including all sets (black points) and excluding sets occurring in the refuges (grey points). The right column presents the time series for the relative bias (log-survey index ratio). None of the trends were statistically significant and therefore smoothers are not shown. Each row presents the results for a different portion of the population, commercial males (adult males ≥ 95mm), recruits (newly mature adult males) and immature males >78 mm.

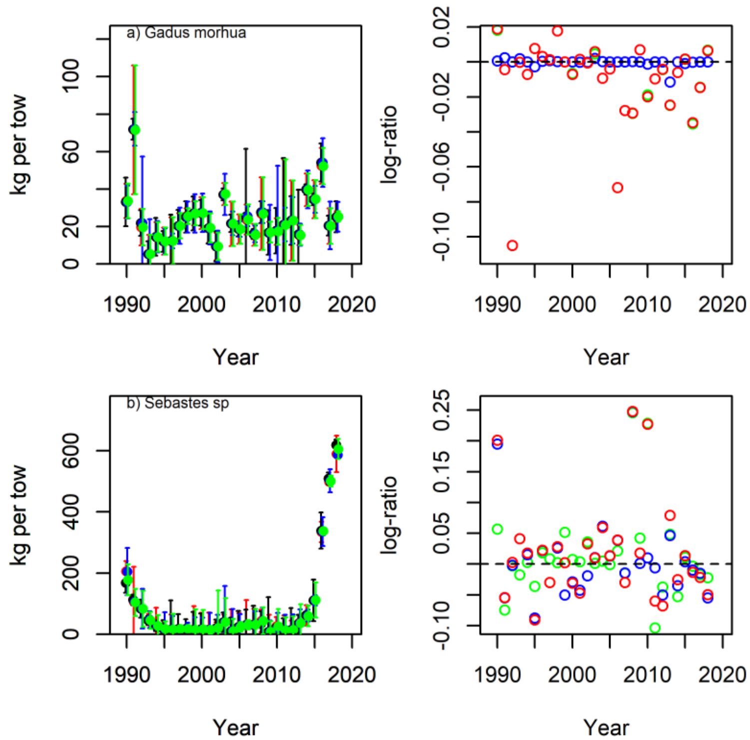

Figure 33. Summary of potential impacts to biomass index time series of excluding nGSL multi-species survey activities from different combinations of marine refuges (blue – exclusion from coral conservation areas, green- exclusion from sponge conservation areas, red- exclusion from all conservation areas). The left column presents time series of abundance indices including all sets (black points) and excluding sets occurring in the refuges (coloured points). The right column presents the time series for the relative bias (log-survey index ratio), where the points are the data values and the coloured dashed line and coloured band indicate the trend and 95% confidence interval for the smoother of a GAM through the points when that smoother was statistically significant. Each row presents the results for a different species or population, a) Atlantic Cod, b) redfish, c) Greenland Halibut, d) Silver Hake, e) White Hake, f) Long-fin Hake, g) Black Dogfish, h) Marlin-spike Grenadier, i) American Plaice, and j) northern shrimp.

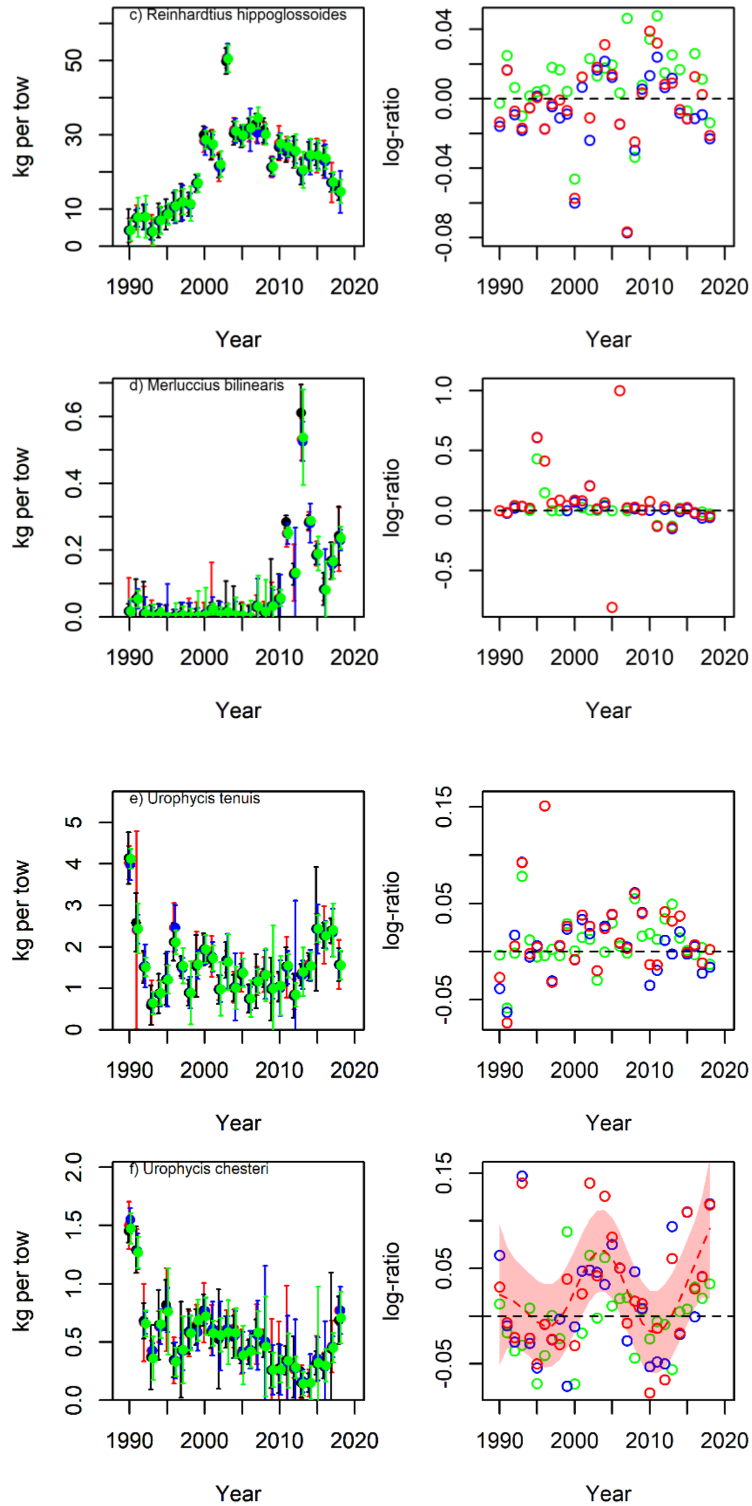

Figure 33 continued. Rows are c) Greenland Halibut, d) Silver Hake, e) White Hake, and f) Long-fin Hake.

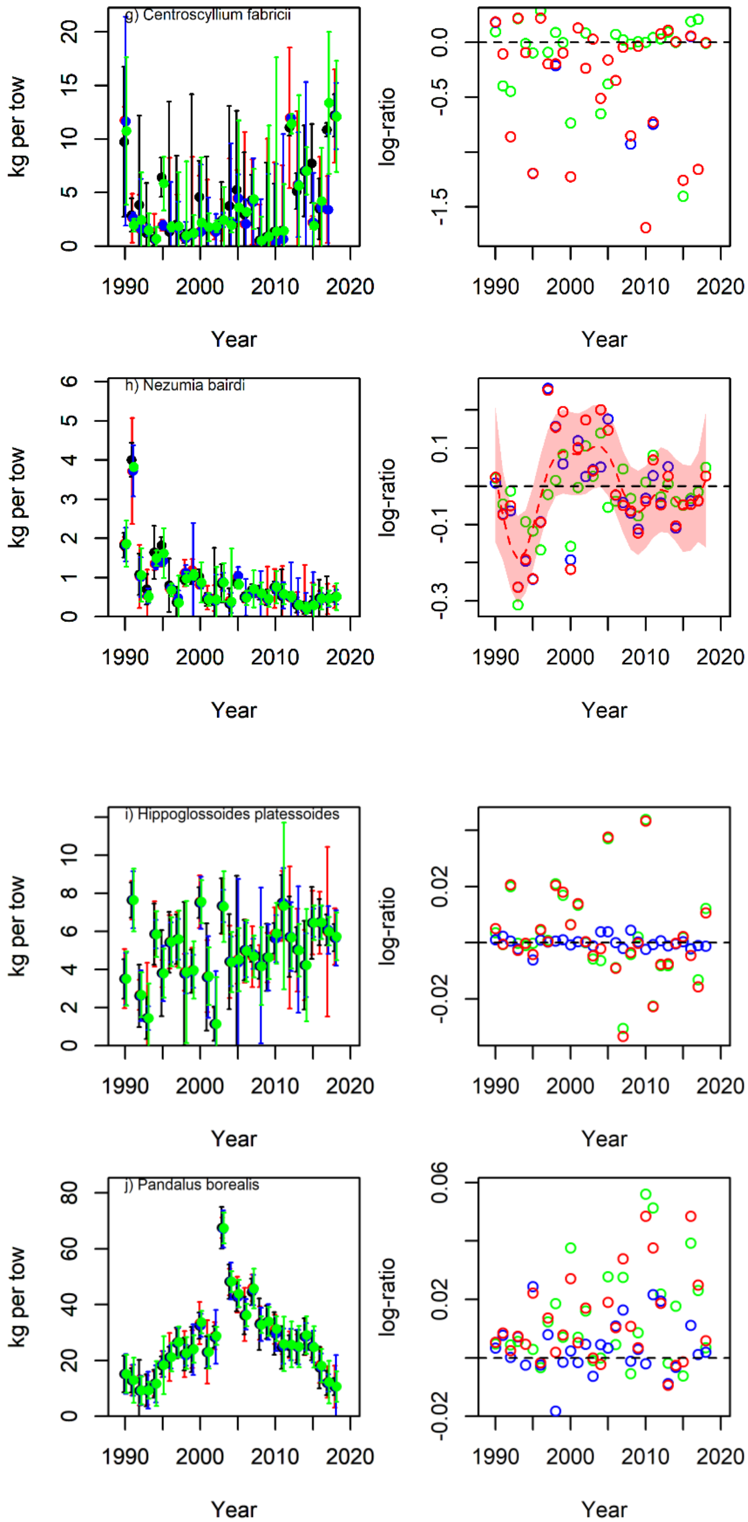

Figure 33 continued. Rows are g) Black Dogfish, h) Marlin-spike Grenadier, i) American Plaice, and j) northern shrimp.

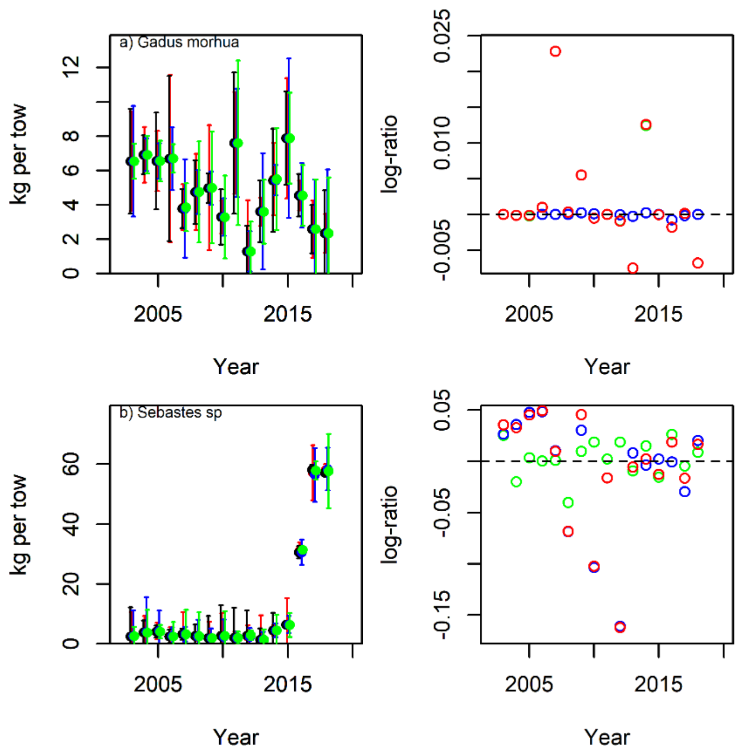

Figure 34. Summary of potential impacts to biomass index time series of excluding nGSL Sentinel survey activities from different combinations of marine refuges (blue – exclusion from coral conservation areas, green- exclusion from sponge conservation areas, red- exclusion from all conservation areas). The left column presents time series of abundance indices including all sets (black points) and excluding sets occurring in the refuges (coloured points). The right column presents the time series for the relative bias (log-survey index ratio), where the points are the data values and the coloured dashed line and coloured band indicate the trend and 95% confidence interval for the smoother of a GAM through the points when that smoother was statistically significant. Each row presents the results for a different species or population, a) Atlantic Cod b) redfish, c) Greenland Halibut, d) Silver Hake, e) White Hake, f) Long-fin Hake, g) Black Dogfish, h) Marlin-spike Grenadier, i) American Plaice, and j) northern shrimp.

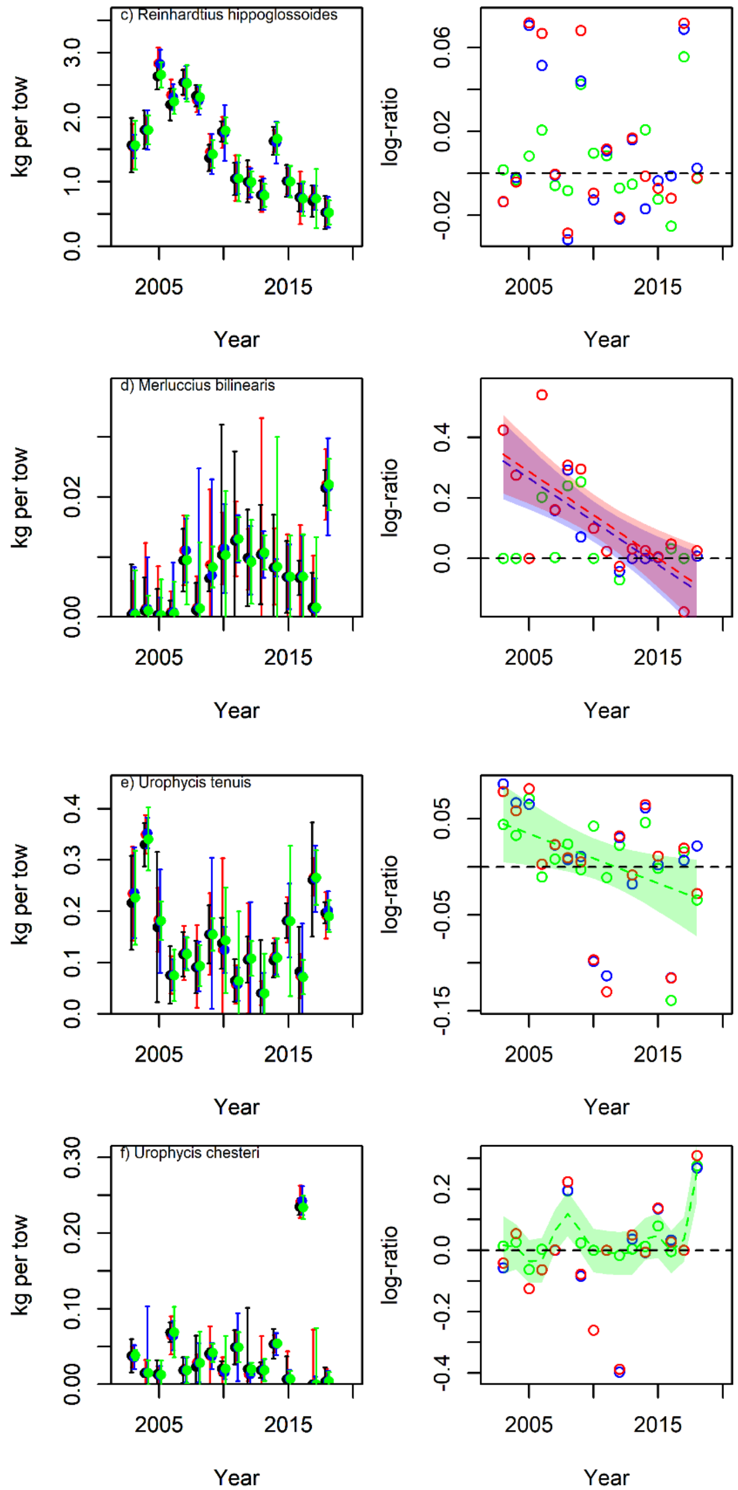

Figure 34 continued. Rows are c) Greenland Halibut, d) Silver Hake, e) White Hake, and f) Long-fin Hake.

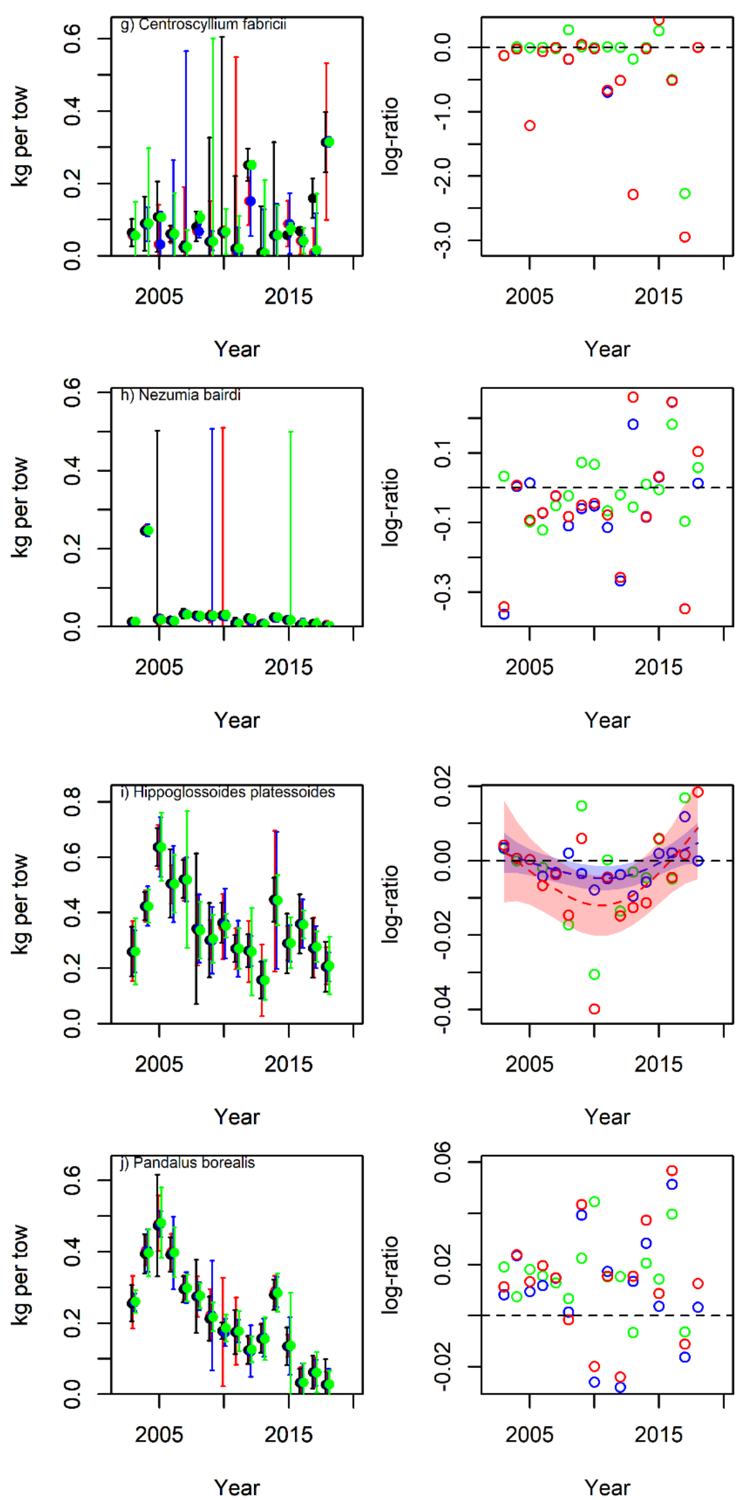

Figure 34 continued. Rows are g) Black Dogfish, h) Marlin-spike Grenadier, i) American Plaice, and j) northern shrimp

12. APPENDIX I

The five major elements of the National Framework to support decisions on the authorization of scientific survey activities with bottom-contacting gears in protected areas are presented below. Text in bold indicates the locations in the document in which the relevant information can be found.

1. A description of protected area(s) which is(are) within the survey domain(s) of the proposed scientific survey(s) and the benthic conservation objectives of the protected area(s), including:

- A separate description of each protected area. **[Table 1; Section 1.1]**
- A description of the type of closure(s) and related regulatory policy framework of the protected area(s) (including maps at the scale of the bioregion as well as at the scale of each protected area). **[Fig. 1; Section 1.1]**
- A description of the benthic species, assemblages, biogenic habitats or physical habitats and features that link to the conservation objectives of the protected area(s). It is expected that this information would be available in the documentation supporting the protected area designations. **[Tables 1, 3]**
- Information on the expected recovery times of the benthic components. Specific information on time for recovery of the benthic components following a benthic disturbance should be used when available. In the absence of such information, the known or expected lifespan of the most sensitive benthic species / community features or the age of biogenic structures or structuring components in a protected area is proposed as a proxy for recovery time. **[Table 3; Section 3]**

2. A description of the proposed scientific activity(ies) to be undertaken in the protected area including:

- The purpose of each survey (e.g. single species focus to support fisheries management; multi-species focus to support ecosystem considerations and fisheries management; monitoring specific to the protected area). **[Table 2; Section 1.2]**
- The history (first year) and frequency of survey (such as long term annual survey versus periodic, one-time, or new survey). **[Table 2; Section 1.2]**
- The type of proposed bottom-contacting gear to be used (mobile gear including trawl doors, footrope, and bottom contact construction; fixed gear including deployment plan). **[References where available are provided in Section 1.2]**
- An estimate of the average direct footprint area of the activity at each sampling location; the footprint area would ideally include the indirect impact from other factors as for example sediment plumes, if available. **[Table 2]**
- The best available estimate of the sediment resuspension, transportation and fate if warranted by case specific circumstances, for example trawl gear deployments on soft substrates near glass sponge reefs. **[this type of information is not available for the GSL]**
- For each protected area, the calculated proportion of its area potentially impacted by each proposed survey and for all surveys combined, when known. **[Tables 4 to 6; Section 3]**
- For each survey stratum or the entire survey area, the proportion that is overlapped by the protected area(s). **[Tables 8 to 15]**

- A calculated proportion of each survey's stratum or areas that have been removed in previous decisions to not survey in the protected area. **[presently there are none]**
- A description of the frequency of failed tows resulting from interactions with the seabed within the protected area (if it has occurred or is known) and particular locations that are not sampled due to features that are not conducive to the gear used. **[not addressed in this report but will be tabulated for surveys in the coming years]**
- A calculated recurrence time of the impact from sampling within each protected area encompassed by survey domain or strata and for the entire protected area, for all surveys. **[Table 7; Figs. 11 to 25; Section 3]**

3. An assessment of the susceptibility of the valued benthic components in the protected area(s) to the proposed scientific survey(s) activities **[generally summarized in section 3]**.

- A summary of recurrence times of each activity (individual survey) within each of the protected areas overlapped by the survey. **[Table 7; Figs. 11 to 25]**
- An assessment of impacts of multiple surveys in a specified protected area or areas. **[Table 7; Figs. 11 to 25]**
- A summary of expected recovery time of the benthic components within each protected area overlapped by the survey. **[Table 3 presents information on longevity and resilience; Results are interpreted for each protected area in section 3]**

4. Consideration of sampling options to mitigate impacts in protected areas. The review of options is intended to reduce potential impacts of scientific activities and could include:

- The exclusion of scientific activities from the specific locations or entire protected areas with known benthic features that have a very long recovery period.**[sections 3, 4 and 5]**
- Preventing benthic impacts of activities from expanding within a protected area (i.e., limiting the sampling footprint). **[not a relevant consideration for the GSL surveys]**
- Consideration of alternative sampling methods **[section 5]**.
- A combination of elements above.

5. An assessment of the consequences to integrity of time series or development of indicators that encompass areas extending outside the protected area and the potential benefits of benthic impacting scientific activities on conservation, protection and understanding of the protected area (if any) and to other management objectives outside the protected area:

- A consequences analysis, i.e. potential bias in the monitoring indices (including age structure, size structure, etc.) within the survey domain that extends beyond the protected area(s) introduced by excluding the scientific activities from the protected area(s). Biases are expected for species whose relative distribution over time has changed into or away from protected area features. The consequences of excluding the survey from multiple protected areas that overlap with the survey domain should be taken into consideration. **[Figs. 26 to 37; section 4]**
- The identification of additional information that could be collected from the scientific survey to augment knowledge in protected areas. **[section 6]**