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IDENTIFICATION OF MONITORING INDICATORS, PROTOCOLS, AND STRATEGIES FOR FIVE MARINE REFUGES IN THE NEWFOUNDLAND AND LABRADOR REGION

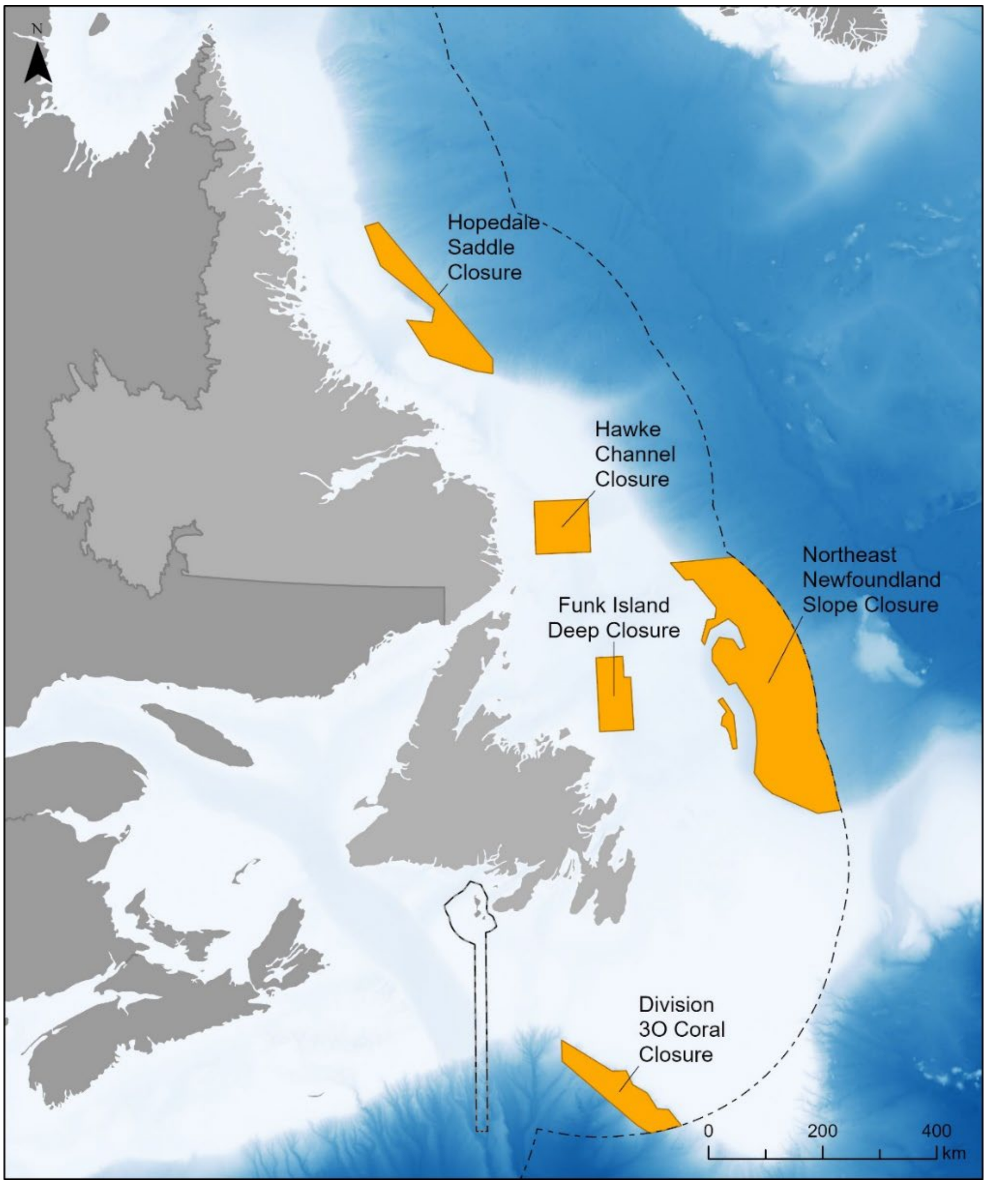

Figure 1. Five Marine Refuges in the Newfoundland and Labrador Region that meet the criteria for Other Effective Area-Based Conservation Measures (OECM) status.

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Canada

CONTEXT

National guidance for Other Effective Area-Based Conservation Measures (OECM), which includes Marine Refuges (MRs), states that monitoring plans must address OECM biodiversity conservation benefits (BCBs), including particular species, habitats, or other ecosystem components to be protected by the OECM. Science advice has been requested to identify monitoring indicators, protocols, and strategies for five MRs in the Newfoundland and Labrador (NL) Region. These five MRs and their associated conservation species or habitats are:

- Division 3O Coral Closure (Corals and Sponges)
- Funk Island Deep Closure (Benthic Habitat and Atlantic Cod (*Gadus morhua)*)
- Hawke Channel Closure (Benthic Habitat and Atlantic Cod)
- Hopedale Saddle Closure (Corals, Sponges, and Biodiversity)
- Northeast Newfoundland Slope Closure (Corals, Sponges, and Biodiversity)

Assessing changes inside the MR boundaries may allow for the identification of benefits or other biodiversity outcomes and/or conservation species/ecosystem components of interest based on the protection measures of each area.

This Science Advisory Report is from the regional peer review of November 26–28, 2024, on the Identification of Monitoring Indicators, Protocols, and Strategies for Five Marine Refuges in the Newfoundland and Labrador Region. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Fisheries and Oceans Canada (DFO) has recognized five large offshore *Fisheries Act* Marine Refuges (MRs) in the NL Region that meet the criteria for Other Effective Area Based Conservation Measures (OECMs) and contribute 97,297 km^2 to Canada's marine conservation targets.
- The five MRs (Hopedale Saddle, Hawke Channel, Funk Island Deep, Northeast Newfoundland Slope, and Division 3O Coral Closure) differ in size, distance from shore, and depth ranges, but can be grouped by their biodiversity conservation benefits (BCBs) –
    - Atlantic Cod and benthic habitat, and
    - corals, sponges and biodiversity.

  DFO has developed a scientific monitoring approach to report on the status and trends of the BCBs in the five MRs.
- The scientific monitoring approach is based on Core and Complementary Monitoring that will be supplemented as needed by Targeted Research. Core Monitoring uses a set of standardized survey methods and protocols across all five MRs. Complementary Monitoring leverages data collected for purposes other than monitoring MRs. Targeted Research addresses methodological and ecological knowledge gaps relevant to the MRs.
- Indicators for Atlantic Cod, corals, sponges, biodiversity, indirect Biodiversity Conservation Benefits (BCBs), oceanography, and human pressures have been identified, but these will be further assessed and prioritized for the purposes of data collection, analysis, and reporting.

- Limit reference levels or target levels for each indicator should be identified as early as possible for the purposes of monitoring and reporting and to inform adaptive management.
- Core Monitoring survey methods and protocols may be refined, particularly during the early years of the program, with a goal of adopting consistent approaches which will generate time series that can be used to assess status and trends of the BCBs.
- Sampling sites within MRs were selected according to BCB groupings. Reference sites have also been identified outside coral and sponge MRs as part of Targeted Research. Additional sites should be sampled in deep areas (i.e., >1,500 m) of coral and sponge MRs to characterize baseline conditions.
- Power analyses showed low statistical power of multispecies trawl survey data to detect changes in Atlantic Cod abundances within the Funk Island Deep and Hawke Channel MRs. Nevertheless, multispecies trawl survey data are important for collecting biological samples and other data relating to biodiversity indicators that are not provided by Core Monitoring methods.
- Power analyses showed adequate statistical power of drop camera data to detect changes in coral and sponge abundances collected in Hopedale Saddle.
- While DFO should ensure that it has the ability to deliver the Core Monitoring program independently, leveraging capacity and expertise from other internal and external groups through collaborations is important for delivering the monitoring program as it has been designed.
- Given the large volume and diversity of data generated by the program, a data management plan has been developed that provides management strategies for all stages of the data lifecycle, including data storage (e.g., cloud) and sharing. Tools developed for data processing, analysis, and reporting should be stable, reliable, and easy to maintain, and include automated processes (e.g., Artificial Intelligence), where applicable.
- The establishment of a relevant and effective monitoring program would benefit from ongoing dialogue with management on the information that would be required to inform potential adaptive management actions.

INTRODUCTION

Canada has committed to conserving 30% of coastal and marine waters by 2030. As part of that commitment, the Department of Fisheries and Oceans Canada (DFO) is responsible for establishing new sites and monitoring those that already exist. Monitoring these conserved areas for potential benefits, or outcomes, is a departmental priority and is considered an essential pillar of effective management. This includes assessing whether Biodiversity Conservation Benefits (BCBs) are being met and determining if adaptive management is needed (e.g., modifying closure boundaries, conservation objectives, etc.). It is important to note that monitoring has value beyond the data it generates, as it also builds capacity and fosters advocacy for environmental concerns. Long-term monitoring can also lead to better understanding of impacts such as climate change and other long-term environmental changes beyond protected area boundaries (Department of Conservation 2022). The two main marine conservation tools that DFO has available to establish Marine Conservation Areas (MCAs) are Marine Protected Areas (MPAs) under the *Oceans Act* and fisheries closures established under the *Fisheries Act* that can be recognized as Marine Refuges (MRs). MRs that meet the criteria for Other Effective Area-based Conservation Measures (OECMs), along with MPAs, count towards reaching the governments conservation targets (DFO 2016; Government of Canada 2022).

Within the NL Region there are five MRs that were officially assessed as meeting the OECM criteria and were formally established as of January 1, 2018: Hopedale Saddle, Northeast Newfoundland Slope, Hawke Channel, Funk Island Deep, and the Division 3O Coral closures (Figure 1). A scientific monitoring approach, including indicators, protocols, and strategies, along with reference sites where possible, are outlined in this document. This approach builds on previous work done for other Canadian Science Advisory Secretariat (CSAS) processes such as the National Monitoring Framework for Coral and Sponge Areas Identified as OECMs (DFO 2021) and the Identification of Reference Sites and a Scientific Monitoring Approach for the Laurentian Channel MPA (DFO 2024; Warren et al. In press). The main objectives here are to

1. use the scientific monitoring approach described in DFO (2024) to identify indicators, protocols, and strategies that can be used to monitor the status and trends of conservation species/taxa, habitats, and/or biodiversity in each of the five MRs, and
2. undertake power analyses to investigate the ability to assess change in scientific monitoring indicators using existing multispecies trawl and seafloor imagery data.

Marine Refuges

The five MRs in the NL Region can be characterized as relatively large offshore areas compared to other MRs across Canada and range in size from 7,274 km^2 to 55,353 km^2 (see Table 1). The two smaller areas, the Hawke Channel and Funk Island Deep closures, are located on the continental shelf, whereas the three larger ones, Hopedale Saddle, Northeast Newfoundland Slope, and Division 3O Coral closure, are found on the shelf edge and slope. The BCBs are consistent with these groupings. The Hawke Channel and Funk Island Deep closures are focused on conservation of Atlantic Cod and benthic habitat, and the other three closures have coral and sponge BCBs. These general groupings of cod vs. coral and sponge will carry on through much of this document. Based on the national guidance, the main purpose of OECMs is to protect marine biodiversity through the provision of long-term BCBs. BCBs are defined as the positive change in, or preventing the loss of, biodiversity resulting from the implementation of an area-based management measure (DFO 2016; Government of Canada 2022). A BCB in an OECM is analogous to a Conservation Object (CO) for an MPA, however, MPAs can also provide BCBs, and OECMs can have COs (Government of Canada 2022). It will be important to not only monitor these areas for the direct BCB (i.e., the main species or taxa) but also for general biodiversity indicators and any indirect BCB (i.e., other species that may benefit from the management measures in place). For the five MRs considered here, the listed COs are the same as the direct BCBs and will be referred to BCBs throughout the document.

Table 1. Marine Refuges in the NL Region.

Marine Refuge	**Area (km²)**	**Prohibitions**	**Conservation Objective/Direct Biodiversity Conservation Benefit**	**Indirect Biodiversity Conservation Benefits**
Funk Island Deep Closure	7,274	Bottom trawl, gillnet, and longline	Conserve **benthic habitat** and **Atlantic Cod**	Northern shrimp, Smooth Skate
Hawke Channel Closure	8,837	Bottom trawl, gillnet, and longline	Conserve **benthic habitat** and **Atlantic Cod**	Northern Shrimp, Northern Wolffish, Greenland Halibut
Division 3O Coral Closure	10,422	All bottom contact fishing activities	Protect **corals and sponges**	Atlantic Cod, Redfish spawning
Hopedale Saddle Closure	15,411	All bottom contact fishing activities	Protect **corals and sponges** and contribute to the long-term conservation of **biodiversity**.	Roundnose Grenadier, Atlantic Cod, Greenland Halibut, Northern and Spotted Wolffish
Northeast Newfoundland Slope Closure	55,353	All bottom contact fishing activities	Protect **corals and sponges** and contribute to the long-term conservation of **biodiversity**.	Northern Wolffish, Atlantic Wolffish, Greenland Halibut, Redfish spawning

For each of the MRs, indirect BCBs have also been identified (Table 1). Indirect BCBs may be provided by OECMs that do not have explicit biodiversity BCBs. For example, fisheries-area closures may be established to protect coral and sponge concentrations in areas identified through DFO's Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas. These fisheries-area closures may provide indirect benefits for the species that use this habitat, as well as direct BCBs to the coral and sponge concentrations themselves (Government of Canada 2022). For example, if a fisheries closure was put in place to protect Atlantic Cod by prohibiting bottom trawling activity and there was an increase in abundance of Greenland Halibut, it follows that Greenland Halibut is an indirect BCB for the closure. Scientific monitoring of these MRs is generally focused on the main BCBs for each area and general biodiversity, however, monitoring of the indirect BCBs will be done opportunistically.

Regional Scientific Monitoring Approach

The DFO-NL Region has developed a regional approach to scientific monitoring of MCAs, including both MPAs and MRs. The overall approach is outlined in DFO (2024) and Warren et al. (In press) and describes the three ways in which information is gathered for the purposes of monitoring:

1. Core Monitoring,
2. Targeted Research, and
3. Complementary Monitoring.

Core Monitoring focuses on minimally-invasive, efficient, co-located measurements of key indicators to generate long-term datasets. Targeted Research consists of short-term research-oriented projects that can be used to inform Core Monitoring, answer questions in response to observed changes in the BCB species/taxa, test survey methods, and identify other indirect BCBs. Complementary Monitoring includes surveys or data collected for purposes other than MCA monitoring which can be used for MR reporting, broad contextual information, or to aid in the interpretation of status and trends of the BCBs. Where possible, common monitoring methods are applied to protected areas to facilitate monitoring roll-ups across protected area networks, and achieve efficiencies in equipment, analytical approaches, and technical requirements. However, due to some conservation area-specific BCBs, some aspects of the monitoring program will differ between conservation areas.

ASSESSMENT

The five MRs discussed in this document can be grouped by the main BCBs: Atlantic Cod and benthic habitat, and corals and sponges.

Indicators

Indicators refer to the measurements used to assess changes or impacts to an ecosystem. They can be qualitative or quantitative and must be relevant to the COs or BCBs for the area. The NL regional monitoring working group developed a list of indicators for each CO and BCB, not only for the Laurentian Channel MPA but for all MCAs in the NL Region (see DFO 2024). The approach used to select indicators for each site was based on steps outlined in DFO (2013). The steps include:

1. identifying the operational COs,
2. identifying suitable indicators,
3. identifying selection criteria,
4. evaluation of indicators,
5. assessing for redundancy,
6. agreeing on final indicators, and
7. estimating limit reference levels and target levels.

The initial proposed indicators were selected in early 2022, at the beginning of the monitoring program, and three years of field work have been completed since then. This CSAS process therefore provides an opportunity to reassess the suitability of some of the indicators. The proposed indicators are itemized in Table 2. Physical and biological oceanography indicators are included to provide context for larger scale changes in the environment (Table 2). Indicators for indirect BCBs are also included, where possible, from opportunistic sampling. Lastly, human pressures monitoring indicators are included to ensure we have a complete understanding of the ecosystem and its stressors (Dunham et al. 2020). Step seven of the selection process above, estimating limit reference levels or target levels, was not completed for any of the indicators as it was outside the scope of this CSAS process. However, some recommendations on how to do this are provided as part of this advice with the intent to work towards limit reference levels for each indicator within the first five years of data collection for the regional monitoring program. This will allow for clear recommendations for adaptive management to DFO management.

Corals and Sponges

Potential indicators and their rationale for the monitoring of corals and sponges in Canadian OECMs have been extensively detailed in DFO (2021) and will not be repeated here. But in the context of NL Region's MRs, coral and sponge abundance/density from seafloor imagery surveys have been selected as the main metric for assessing trends in these taxa. The regional multispecies trawl surveys do not collect coral and sponge abundance data consistently and therefore are not reliable for that purpose.

We propose the following be reported for the monitoring of corals and sponges:

1. Coral and sponge diversity, richness, abundance and density collected through drop camera surveys.
2. Coral data extracted from seafloor imagery will be collected at the lowest possible taxonomic level but might be analyzed and reported at the functional group level (e.g., large gorgonian, small gorgonian, sea pen, black coral, cup coral, soft coral, *sensu* DFO [2021]). The taxonomic resolution of these analyses will be assessed on a case-by-case basis. For instance, if the number of records is too low at the species level, then analysis might be conducted at the group level (see Power Analysis section).
3. Sponge data extracted from seafloor imagery will be collected at the lowest possible taxonomic level for large, easily identifiable and habitat forming taxa (e.g., *Geodia*, *Asconema* spp.) but might be analyzed and reported at the group level (e.g., sponges, astrophorid sponges, mixed sponges, *sensu* DFO [2021]). Sponges are notably difficult to identify from imagery and can be easily confused amongst different sponge and non-sponge taxa (e.g., ascidians; [Command et al. 2024]). Small, sparse, and encrusting sponges will be noted but might not be analyzed or reported, given the challenges with properly visualizing and accounting for them from video.
4. Highly abundant taxa (e.g., sea pens when forming fields where thousands of specimens are observed during a video survey) might not be counted in their entirety (due to time constraints) until Artificial Intelligence (AI) methods have been integrated in our seafloor imagery annotation program (see Survey Methods and Protocols section). This is generally the case for continuous video (e.g., remote operated vehicle [ROV]), and it might not be an issue for the drop camera data used here. ROV data can be used to complement the drop camera data but is considered part of Targeted Research. Refer to DFO (2024) and Warren et al. (In press) for further details.

Indicators such as coral and sponge size distribution are expected to be only opportunistically collected as part of our Targeted Research. Determining size from imagery is challenging and would require considerable effort. Should this change, size could become a valuable metric to include in the monitoring program as it would give some idea of recruitment.

Atlantic Cod

Hawke Channel and Funk Island Deep MRs have BCBs protecting Atlantic Cod. Monitoring indicators for Atlantic Cod were selected using the same six indicator selection criteria (refer to DFO 2013); however, they have not been previously described in either the Laurentian Channel MPA CSAS process (DFO 2024) or the national framework for monitoring coral and sponge CSAS (DFO 2021). The multispecies trawl survey collects several indicators for this species as it is one of the key species targeted by the bottom otter trawl and is used for carrying out stock assessments for the species. Biomass and abundance are calculated for each trawl set. Both the Funk Island Deep and Hawke Channel closures are sampled by this survey in the fall. Size distributions of the population are tracked with the multispecies trawl surveys and otoliths are collected for ageing fish. Spatial distribution of the species can be derived from the multispecies trawl survey data as well, as illustrated by the average relative density maps of Atlantic Cod in Wells et al. (2021). A key advantage of the multispecies trawl survey is the long time series, with data going back to the 1970's for some BCB taxa such as Atlantic Cod.

There are less invasive alternatives to multispecies trawl surveys that can be used to monitor Atlantic Cod. For example, Baited Remote Underwater Video (BRUV) cameras can be used to monitor indices of abundance for demersal fish species like Atlantic Cod (Dalley et al. 2017) and have been applied to deepwater environments to characterize fish communities in the NL Region (Cote et al. 2019) and beyond (Sutton et al. in prep[1]). Similarly, environmental DNA (eDNA) has emerged as a non-invasive tool to assess the presence of a variety of species, including members of the Family Gadidae (McClenaghan et al. 2020; He et al. 2022; Cote et al. 2023) and, like BRUVs, is adaptable to sampling a variety of habitats (bottom types, depth zones, etc.). However, both of these minimally-invasive methods suffer from a lack of baseline data and can be limited in their ability to assess some metrics that require physical samples (e.g., age, reproductive status). We propose the following for reporting on Atlantic Cod:

1. Biomass and abundance will be collected annually from the DFO multispecies trawl survey, which has a long time series.
2. Index of abundance from BRUVs as a less invasive method for monitoring.

Benthic Habitat

Benthic habitat is listed as a BCB for two of the MRs: the Hawke Channel and Funk Island Deep closures. Characterizing the benthic habitat in each closure will be important for baseline knowledge of these areas. There are existing data layers that show large-scale benthic features (i.e., banks, bays, channels), depth (General Bathymetric Chart of the Oceans (GEBCO) data or multibeam sonar), and other oceanographic features like currents, temperature and salinity (described below) that can be used in the development of benthic habitat models. Some of these are more static features that do not require ongoing monitoring, however, advances in technology like multibeam may allow for better resolution of benthic features over time. Further to this, characterization and monitoring of trends in the biotic communities associated with the benthic habitat will be included in the monitoring approach.

Proposed indicators for benthic habitat are as follows:

1. Oceanographic indicators such as temperature, salinity, chlorophyll-a, or primary production
2. Multibeam bathymetry – can be used for both high resolution bathymetry or for backscatter analysis (bottom hardness or softness)
3. Infaunal and epifaunal diversity

Biodiversity

Preserving the world's biodiversity is the driving force behind the global conservation target to protect 30% of coastal and marine areas by 2030. Biodiversity is a catch-all term for many aspects that collectively represent variation in biological communities across spatial scales and habitats, and account for variation in genetics and function, etc. According to the officially

[1] Sutton, J., D. Cote, J. Fisher, I.G. Priede. In prep. The distribution of deep-sea demersal fish assemblages across environmental gradients of the Atlantic Ocean. TBD.

adopted definition by the Convention on Biological Diversity, biodiversity is “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (Secretariat of the Convention on Biological Diversity 2005). As the term biodiversity covers many things, it leaves considerable flexibility in how we might measure it within a monitoring program.

There are several methods that provide data on multiple species simultaneously, from which diversity information can be derived. Examples include Core Monitoring survey methods such as eDNA, BRUVs, and drop cameras, and Complementary Monitoring survey methods like the multispecies trawl survey. Perhaps the simplest metric is taxonomic richness, which is determined from the number of taxa detected in the sample. While simple to communicate, species richness is not always biologically meaningful when looking at trends in biodiversity, since the metric is insensitive to changes in species assemblage structure and can only detect severe declines in populations (Aune et al. 2024).

Presence-absence data can also be used within multivariate frameworks that can assess differences between test and reference conditions (Reynoldson et al. 1995; Clarke et al. 2014). More quantitative data on biodiversity can be assembled across communities using metrics like frequency of occurrence, counts, or biomass. These data can be applied to biodiversity metrics that assess evenness across the community, a combination of evenness and richness (e.g., Shannon-Weiner), or be applied to similar multivariate analyses (Reynoldson et al. 1995).

Food web metrics, or trophic structure, have the potential to detect changes in structure and component relationships but will lack the ability to understand changing species (Higashi et al. 1989; Kato et al. 2018). To ensure protected areas reflect their ongoing ecological value in climate change scenarios, it may be practical to consider species turnover and ecological replacement as an acceptable outcome.

Another important aspect of biodiversity is ecosystem function and productivity. Measures of the total biomass are a useful metric for ecosystems High biomass within a system is linked to higher consumption or predation, with higher biomasses of predatory species consuming more prey. Shifting systems can be detected through increases in predator or prey biomass (Hatton et al. 2015). Indices like predator/prey biomass require long term datasets and estimates of biomass which can be derived from tools like the multispecies trawl survey.

We propose the following be reported for MR biodiversity monitoring:

1. Trends in species richness collected via eDNA and drop camera surveys (epifauna only) and of fish taxa from the multispecies trawl survey (currently, the invertebrate data is much less reliable due to lack of quality control and poor species identification). BRUVs capture a much more limited segment of the existing species assemblage and therefore those data will not be used for biodiversity reporting.
2. Species abundance/density collected via drop camera surveys. Epifaunal species taxonomic information (including identification of corals and sponges) will be collected following the DFO annotation protocol.
3. Food web diversity metrics (e.g., Kato et al. 2018) using eDNA data supported by a predator-prey relationship database. Relative reads from a general biodiversity marker (e.g., 18S) could be used to provide an index of abundance to incorporate into food web biodiversity calculations. Multispecies trawl survey data could also generate valuable food web diversity time series data but only for a subset of taxa (i.e., fish and consistently

sampled invertebrates). Further investigation into this indicator will need to occur before making decisions on using eDNA or the multispecies trawl survey data.

4. Biomass from the multispecies trawl survey to estimate ecosystem function at higher trophic levels. Total biomass of the fish and shellfish community as a measure of productivity at higher trophic levels, predator and prey biomass using fish functional groups within stock assessments and other ecosystem-based analyses.

Oceanography

The NL Bioregion is characterized by a wide range of oceanographic conditions that are changing on seasonal, interannual and longer timescales (Cyr and Galbraith 2021). North of Flemish Cap and the Grand Banks, the southward flowing Labrador Current system floods the NL shelf with relatively cold and fresh Arctic and sub-arctic waters. In the southern portion of the bioregion, the North Atlantic Current – the eastern extension of the Gulf Stream – brings warmer and saltier subtropical waters north towards the southern part of the Grand Banks and past the Flemish Pass/Cap. This interaction between arctic/subarctic and subtropical waters creates large temperature differences (from freezing to more than 25°C at times at the surface). These current interactions are also responsible for a wide range of thermal fronts generally associated with steep bathymetric slopes and strong currents (Cyr and Larouche 2015). These strong currents are also associated with diversity in bottom habitat and high sponge biomass (de Froe et al. 2024).

The NL shelf has been monitored as part of the Atlantic Zone Monitoring Program (AZMP) since 1998 (Therriault et al. 1998). Physical and biogeochemical parameters are regularly collected at many stations distributed along standard hydrographic sections. Many of these stations are located within or adjacent to the MRs discussed in this document (Figure 2). At these stations, a series of physical (temperature, salinity, currents), biological (chlorophyll-a, plankton) and chemical (nutrients, oxygen, carbonate system) indicators are collected up to three times a year. Overviews of the current state of the ocean in relation to long-term conditions are presented annually in AZMP regional (e.g., Maillet et al. 2022; Cyr et al. 2024) and zonal (e.g., Galbraith et al. 2024) reports. Satellite imagery can also be used to measure sea surface chlorophyll-a concentration and other indicators that provides a more continuous data layer to extract information where there are no AZMP stations located nearby.

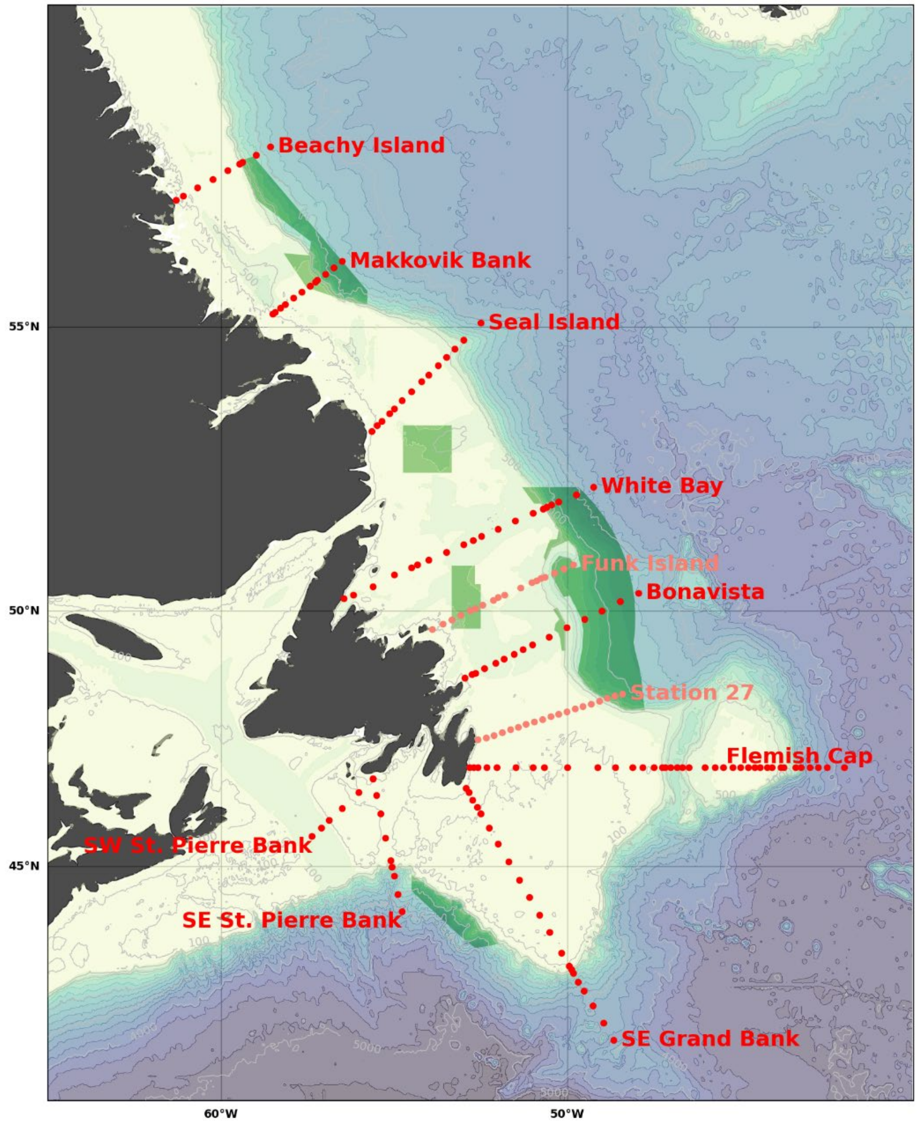

Figure 2. Map of the Atlantic Zone Monitoring Program stations along standardized sections (name at the end of the lines). The core stations are drawn in red and the optional lines in light pink. The marine refuges considered in this study are highlighted in green.

Another indicator, the NL Climate Index (NLCI), uses 10 components, or subindices, to represent the large-scale climate conditions and state of the physical environment on the NL shelf and the Northwest Atlantic in general (Cyr and Galbraith 2021). This climate index is calculated annually and dates back to 1951 which provides a long time series and will be useful for interpretation of shifts or changes in other indicators in the scientific monitoring program. It incorporates anomaly data on the North Atlantic Oscillation (NAO), air temperature, sea ice, iceberg count, sea surface temperature, Station 27 data (one of the longest hydrographic time series in Canada), summer cold intermediate layer (CIL; the water below 0°C), and bottom temperature. The NLCI can be used as a metric to evaluate changes in ocean climate happening over the entire bioregion. This index can also be used to inform on climate-related human pressures on the ecosystem, although it was not specifically designed for this.

We propose the following be reported for oceanographic monitoring:

1. Key metrics like temperature, salinity and chlorophyll-a or primary productivity using data from AZMP or modelled data will be useful for general context of the environmental conditions.
2. NL Climate Index – this indicator will provide a good frame of reference for interpreting changes in other indicators of the monitoring program and integrates multiple data sources.

Indirect BCBs

The indirect BCBs that were identified for each MR are listed in Table 1. It was recommended by Marine Planning and Conservation branch in the NL Region and nationally that the main focus for monitoring activities be on the direct BCBs and that the indirect BCBs be monitored opportunistically. Therefore, Core Monitoring and Targeted Research will not be directed at any of the indirect BCBs (although some may be collected incidentally) rather, any indicators for these species will come from Complementary Monitoring data.

Several fish species are listed as indirect BCBs due to their commercial fishing importance, *Species At Risk Act* (SARA) status, or Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status. This includes three wolffish species (Northern, Spotted, and Atlantic), Roundnose Grenadier, Smooth Skate, Greenland Halibut, and Atlantic Cod (see Table 1 for complete list). The indicators for these species include biomass, abundance, size distribution, occurrence and frequency, spatial distribution, and fisheries catch weights and length frequencies which are further described in DFO (2024) and Warren et al. (In press). Most of these indicators are being collected as part of Complementary Monitoring and have not yet been investigated for their power to detect significant changes as described by Morris et al. (2024). These species may also be detected with Core Monitoring methods like the BRUV or eDNA but potentially with limited statistical power to detect changes over time.

Redfish spawning was identified as an indirect BCB for the Division 3O Coral closure and also potentially for the Northeast Newfoundland Slope closure. This was based on maps from Ollerhead et al. (2004) showing the distribution of female redfish with hydrated eggs that were captured during the multispecies trawl survey from 1995 – 2002. The data is limited to only those areas sampled during the spring and early summer months (April-July) and has limited coverage in certain areas. The distribution of redfish in the surveys has remained relatively unchanged since the Ollerhead et al. (2004) study, suggesting that the spawning areas for redfish are unchanged. However, relative abundance of redfish has changed across the NL Bioregion, with declines noted across 3LNO and increases observed elsewhere.

Northern shrimp is listed as an indirect BCB for the Hawke Channel and Funk Island Deep MRs. During the DFO multispecies trawl survey, stations are sampled both inside and outside the two closures. The data from these surveys provide biomass estimates, abundance and density indices, size distributions, maturity stages, occurrence and frequency, as well as the spatial distribution of northern shrimp. All of this information is used to assess the stock. Surveys in these regions occur during the fall of each year and provide only a snapshot of the conditions at that time although processes and patterns may vary throughout the year. Another source of northern shrimp data comes from commercial fisheries. Shrimp fishing activity does not occur inside the Hawke Channel and Funk Island Deep MRs but does take place just outside the boundaries of these areas. Large vessel fleet (>500 t class) at-sea observer data from commercial fisheries provide both sexed and unsexed length frequency data, which also include the maturity stages of shrimp. Fishery catch weight and catch per unit effort (CPUE) are also calculated using the observer data set. Due to low coverage of at-sea observers on small vessels, logbooks are used to provide CPUE and fishery catch weights.

Human Pressures

To understand the context for any changes to the indicators listed for the BCB species, it is necessary to include some human pressures monitoring. According to Dunham et al. (2020) a monitoring program without any consideration for human pressures falls in the ambient monitoring category (i.e., general environmental and stock status monitoring) and will fail to be able to attribute observed ecological outcomes to protection measures. For these indicators, Complementary Monitoring will be the main approach for gathering this information since many of the human pressures indicators are outside the ability of DFO Science branch to monitor. Information on commercial fishing effort is available from sources such as logbooks and Vessel Monitoring Systems (VMS) and these data are updated annually and published on the Government of Canada Open Data website (Koen-Alonso et al. 2018). The total biomass removals from commercial fishing should also be included here from commercial fishing logbooks. Measurements of ocean noise or underwater soundscape models could be used once coverage for the MCAs increases and models improve (Miksis-Olds et al. 2018). All of these human pressure indicators are included here (Table 2) for consideration however, making a link between these pressures and the conservation benefits of a given area will be difficult. It is recommended that further work on linking these indicators to the BCBs and determining the level of impact be explored before implementing them fully into the monitoring program. There may also be other human pressures that need to be monitored as they arise in the future (e.g., oil and gas exploration or drilling, offshore wind development etc.).

Table 2. Recommended scientific monitoring indicators for Marine Refuges in the NL Region.

Indicator	Coral and Sponge	Atlantic Cod	Biodiversity	Benthic Habitat	Oceanography	Indirect BCBs (G. Halibut, N., S., and A. Wolffish, Rn. Grenadier, N. Shrimp)	Human Pressures
Biomass	X	X	-	-	-	X	-
Abundance/Density	X	X	-	-	-	X	-
Species/Taxa Diversity	X	-	X	-	-	-	-
Species/Taxa Richness	X	-	X	-	-	-	-
Age	-	X	-	-	-	-	-
Size Distribution	X	X	-	-	-	X	-
Growth rate	-	X	-	-	-	-	-
Occurrence/Frequency	-	X	-	-	-	X	-
Distribution	X	X	-	-	-	X	-
Habitat maps/habitat suitability	X	-	-	X	-	-	-
Fisheries Catch Weight	-	-	-	-	-	X	X
Length Frequencies	-	-	-	-	-	X	-
Temperature	-	-	-	X	X	-	-
Chlorophyll-a	-	-	-	-	X	-	-
Salinity	-	-	-	X	X	-	-
Oxygen Concentration	-	-	-	-	X	-	-
Ocean Acidification (alkalinity, pH, DIC, PCO2)	-	-	-	-	X	-	-
Soundscape/Acoustic Features	-	-	X	-	X	-	X
Nutrient Flux (movement of water masses)	-	-	-	-	X	-	-
Currents	-	-	-	-	X	-	-
Infaunal and Epifaunal Composition	X	-	X	X	-	-	-
Trophic Flows/ Foodweb Diversity	-	-	X	-	-	-	-
Energy Flows	-	-	X	-	-	-	-

Indicator	Coral and Sponge	Atlantic Cod	Biodiversity	Benthic Habitat	Oceanography	Indirect BCBs (G. Halibut, N., S., and A. Wolffish, Rn. Grenadier, N. Shrimp)	Human Pressures
Predator/Prey Biomass	-	-	X	-	-	-	-
Primary Productivity	-	-	-	-	X	-	-
Zooplankton Variability	-	-	X	-	X	-	-
Commercial Fishing Effort	-	-	-	-	-	-	X
NL Climate Index	-	-	-	-	X	-	X

Survey Methods and Protocols

The survey methods and protocols used in the NL Region have been outlined in several other documents (refer to Lewis et al. 2016; DFO 2021; Warren et al. In press). Survey methods refer to the practices used to gather data, whereas the protocols are a set of instructions for conducting a survey. Those survey methods that are relevant to MRs in the region are outlined in Table 3 below.

Table 3. Survey methods used for monitoring Marine Refuges in the NL Region. Table modified from DFO (2024).

Survey Methods	**Sampling** (Core/ Complementary/ Targeted)	**Frequency**
DFO multispecies trawl surveys	Complementary	Annual (spring and/or fall)
Aerial surveys (turtle, cetacean, jellyfish)	Complementary	Annual
Satellite imagery	Complementary	Annual (continuous)
Observer Data	Complementary	Annual
Atlantic Zonal Monitoring Program (AZMP)	Complementary	Annual (spring and fall)
Sightings (opportunistic)	Complementary	Annual
Vessel Monitoring System (VMS) or logbooks	Complementary	Annual
Dockside Monitoring	Complementary	Annual
Oceanographic mooring	Complementary / Core	Annual (continuous)
CTD cast	Complementary / Core	every 2-3 years (Core)
eDNA (water/sediment)	Core	every 2-3 years
Drop and drift/tow camera (non-ROV camera systems)	Core	every 2-3 years
Baited Remote Underwater Video (BRUV)	Core	every 2-3 years
Underwater Vision Profiler (UVP)	Core	every 2-3 years
Zooplankton Nets	Targeted	no current plans
Satellite Tags (PATs)	Targeted	no current plans
Acoustic Telemetry (receivers and tagging)	Targeted	no current plans
Passive and Active Acoustics (moorings and mobile)	Targeted	no current plans
Multibeam/sidescan sonar	Targeted	no current plans
Sediment corer (benthic grab/ box core)	Targeted	no current plans
Remote Operated Vehicle (ROV)	Targeted	~every 5–10 years

Core Monitoring

One of the main objectives of the Core Monitoring component of the regional scientific monitoring approach is to conduct minimally invasive sampling protocols. This includes the use of drop cameras, BRUV cameras, eDNA, CTDs, and moorings, often as dedicated missions rather that leveraging other sampling platforms (i.e., Multispecies or AZMP surveys). These techniques allow for less destructive sampling, particularly in areas that are designated to protect species and habitats that are fragile and long-lived, such as cold-water corals and sponges (McGeady et al. 2023). Since 2021, when directed monitoring was initiated for the five offshore MRs in the region, there has been a focus on using these minimally invasive sampling protocols. To be efficient in our use of ship time and personnel resources these operations are typically carried out at the same monitoring station/location before moving on. This way of co-locating operations will enhance interpretation of data and minimize transit time. The frequency for visiting each of the MRs is dependent on the amount of personnel and operational resources available each year. Based on current resources, Core Monitoring would occur in each MR on a two to three year rotation, which can be achieved by prioritizing at least two sites per year (typically restricted to ice-free months in the spring, summer and fall).

One of the seafloor video surveys utilizes a drop camera system consisting of downward and forward-facing cameras, lights, batteries, and laser points, mounted on a stable frame designed for deep-sea deployments. The system, weighing about 200 kg, is attached to a winch cable and lowered to the seafloor, where controlled sequences of touch-downs and raises are performed while recording video. Activities and ship positions are logged via a customized ArcGIS Survey123 application, with collected video data saved and backed up on MS Azure. Post-collection, still images are extracted during seafloor contact, annotated for metrics like substrate type and epifauna abundance, and processed using the BIIGLE annotation tool and R Statistical Software. While manual annotation is the current standard, AI techniques are being explored to enhance efficiency and address challenges like variability in substrate types.

BRUV systems are used in the NL Region to monitor demersal fish populations. Two methods have been employed: single landers equipped with deep-ocean-rated cameras, lights, lasers, and bait arms, deployed at depths over 3,000 m, and fleets of modified crab traps outfitted with cost-effective cameras and lights, primarily for shallower areas below 200 m. Deployed for hours at a time, these systems record footage for species identification and data metrics like MaxN (maximum individuals observed in a frame) and Time of First Arrival. While current methods rely on manual video review, efforts are underway to integrate AI for annotation. The fleet approach holds promise for increased replication at reduced costs, particularly in shallower habitats, while single landers remain essential for deeper coral and sponge monitoring areas, pending advancements in depth-rated housing.

eDNA is a versatile and evolving method for monitoring biodiversity by isolating free-floating DNA from water or sediment and assigning it to various taxa using genetic databases. In the NL Region, current protocols involve collecting water samples at different depths using CTD-Rosettes, filtering through sterivex or self-preserving filters, and extracting DNA with optimized methods, such as the Qiagen Blood and Tissue Extraction kit. Genetic markers like a 18S general biodiversity marker and a 12S MiFish fish specific marker are used for analysis, enabling assessments of biodiversity and food web diversity, with a focus on benthic samples while considering pelagic data as a secondary priority. Efforts are underway to standardize eDNA monitoring methods regionally and nationally. With advances in methods and analysis techniques, it will be important to consider the comparability of data over time when making changes to these standard protocols. Additionally, ancillary data from oceanographic instruments and plankton imaging tools (e.g., Underwater Vision Profiler) complement eDNA insights, providing valuable context for understanding BCBs.

Targeted Research

Targeted Research can utilize tools like acoustic and satellite tags (i.e., telemetry) to track species movements and habitat use, with applications such as studying Greenland sharks in MRs. Acoustic receivers capture sound data to assess noise impacts and identify vocalizing marine mammals. Multibeam and sidescan sonar help characterize seafloor features, guiding research on species linked to specific habitats. Minimally-invasive ROVs can be used for surveying coral and sponge habitats, while sediment corers analyze benthic biodiversity and ecosystem changes. Zooplankton sampling with bongo nets provides data on ecosystem health. Although these Targeted Research protocols are not being currently deployed in all MRs for monitoring, they are commonly used in the region and would be available to address Targeted Research questions should the need arise. Further development of the proposed indicators and questions would need to occur before these are used as part of the monitoring program. For further details on these protocols and their potential application to ecological monitoring of MRs, refer to DFO (2024) and Warren et al. (In press).

Complementary Monitoring

Complementary Monitoring protocols are surveys or other data collection methods that are being carried out for purposes other than MCA monitoring. Multispecies trawl surveys provide fishery-independent sampling to analyze trends in commercial and non-commercial species, with seasonal data coverage influencing applicability for specific MRs. The AZMP employs tools to gather oceanographic data along core transects that intersect certain MRs, offering valuable context for monitoring. Multi-instrument moorings collect baseline environmental data but are limited by logistical challenges and instrument availability. Similarly, CTD casts support core monitoring while supplementing complementary efforts.

Satellite imagery is a cost-effective option for observing remote MRs, tracking sea surface temperature and chlorophyll-a concentrations to assess environmental changes. Opportunistic marine mammal sightings contribute data for habitat suitability models but face limitations due to non-standardized collection methods. Commercial logbooks and dockside monitoring programs offer insights into fisheries catches outside MRs, while VMS provide spatial information on fishing effort. Fisheries observer data may include by-catch of coral and sponges, relevant for MRs with specific BCBs, though observer coverage and species identification accuracy remain challenges. Together, these protocols complement Targeted and Core Monitoring efforts to provide a comprehensive picture of MR ecosystems.

Strategies

Site Selection Criteria

The criteria for site selection varies depending on the direct BCB type of the MR (Figure 3). MRs with the same direct BCB type follow the same criteria.

Hawke Channel and Funk Island Deep MRs prioritize the conservation of Atlantic Cod and are situated on the shelf with limited depth ranges. The sampling design for these MRs, developed by the Marine Institute, focuses on depth range coverage and proximity between stations (<10 nautical miles), enabling efficient daily sampling. Hawke Channel has 64 and Funk Island Deep has 24 sampling sites (Figure 4).

Hopedale Saddle, Division 3O Coral closure, and Northeast Newfoundland Slope are large (>10,000 km²) MRs along the continental shelf edge, aimed at conserving corals and sponges. The sampling design focused on selecting monitoring sites within suitable habitats for coral functional groups (based on habitat suitability models) and sponge significant benthic areas (SiBAs; Kenchington et al. 2016). Spatially balanced designs (Hopedale Saddle, Northeast Newfoundland Slope) or randomized points (Division 3O) were used to identify “inside” sites, improving sampling efficiency and reducing spatial autocorrelation. Additional “outside” sites were identified with similar habitat suitability and, where possible, comparable fishing pressure.

In total, Hopedale Saddle has 16 sampling sites (10 inside, 6 outside), Division 3O has 20 (15 inside, 5 outside), and the Northeast Newfoundland Slope has 25 (20 inside, 5 outside; Figure 5).

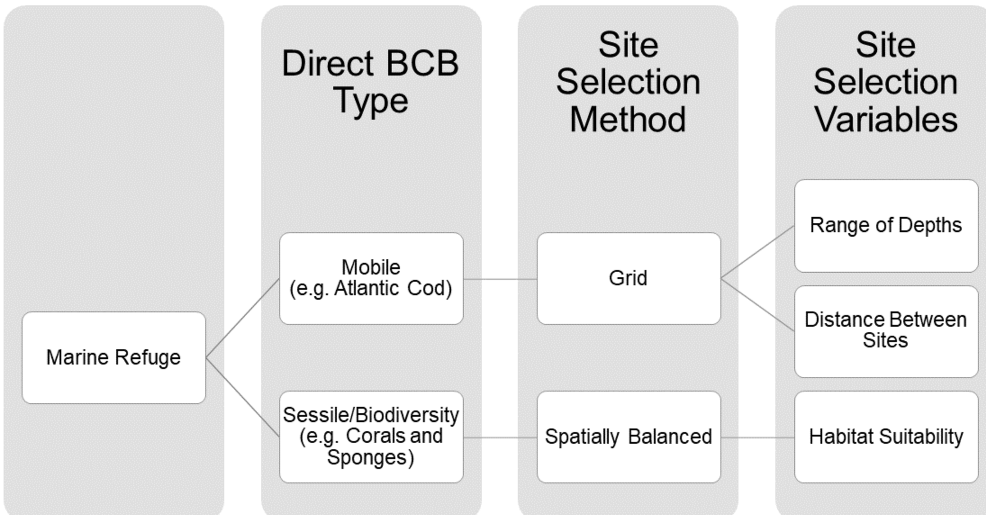

Figure 3. Flow chart showing site selection method and variables used depending on direct BCB type.

Deepwater Sites

As the habitat suitability models and SiBAs are limited by depth (generally <1,500 m), the deepwater portions of the Hopedale Saddle, Division 3O Coral, and Northeast Newfoundland Slope closures were excluded from the sampling frame. However, the deepwater areas make up a large proportion of these MRs. In general, little is known about these areas and baseline sampling is required to help characterize them. Therefore, in addition to the sampling sites described above, it is recommended that random sampling sites be developed for deepwater (i.e., >1,500 m) areas. This method can follow a split panel design that samples both permanent (<1,500 m) and random (>1,500 m) sites; while the permanent sites are useful for determining trends, random sites can be used to improve indicator estimates (Department of Conservation 2022) and in the case of NL Region's MRs, will be used to gather baseline data from areas that have not been previously surveyed.

Deepwater sites will require sampling methods (e.g., gear) that are depth rated appropriately as well as additional time considerations for travel and deployment/retrieval.

Outside/Reference Sites

The protected areas within the NL Region are largely in place to protect habitat and biodiversity (rather than enhance ecosystems beyond their boundaries through spillover effects). Therefore, it is reasonable to prioritize understanding trends for COs or BCBs within the protected area boundaries over inside-outside comparisons to reference sites over time (i.e., Before-After-Control-Impact study design). However, Targeted Research using reference sites can address whether long term changes observed within protected areas are in opposition to those outside the protected area and whether adaptive management of the protected area could reasonably be expected to enhance COs or BCBs. Some of the Complementary Monitoring data is collected both inside and outside of the protected areas and offers an opportunity for comparison, however, this sort of analysis should be done with caution. Based on the amount of fishing pressure in an area before it was closed, if relatively low, it would be unreasonable to expect significant impacts from fisheries closures, especially at the large scale of some of these MRs. The power of the data used (i.e., multispecies trawl survey) to detect these changes also needs to be considered (Morris et al. 2024).

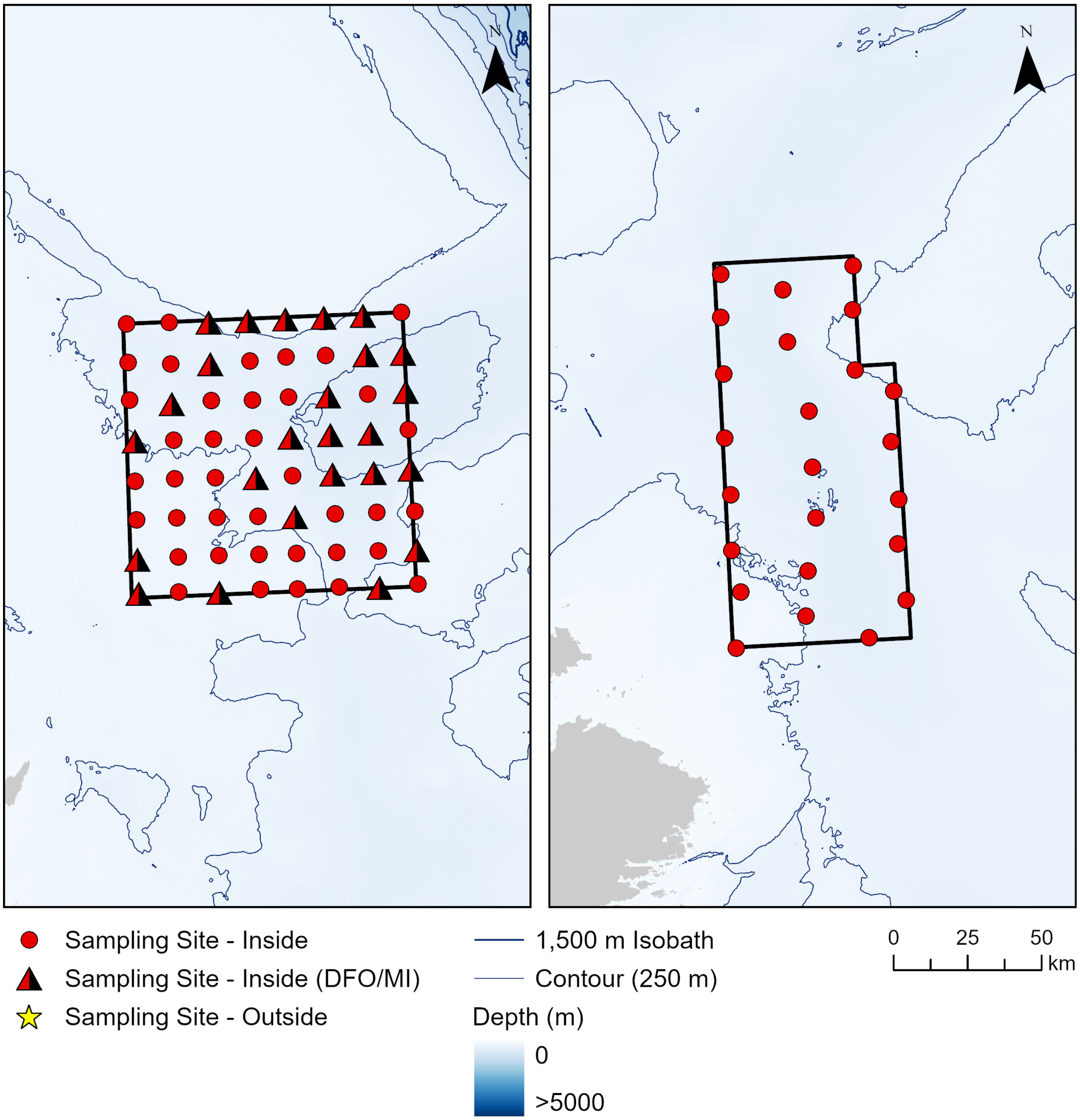

Figure 4. Sampling sites for Hawke Channel (left panel) and Funk Island Deep (right panel) marine refuges.

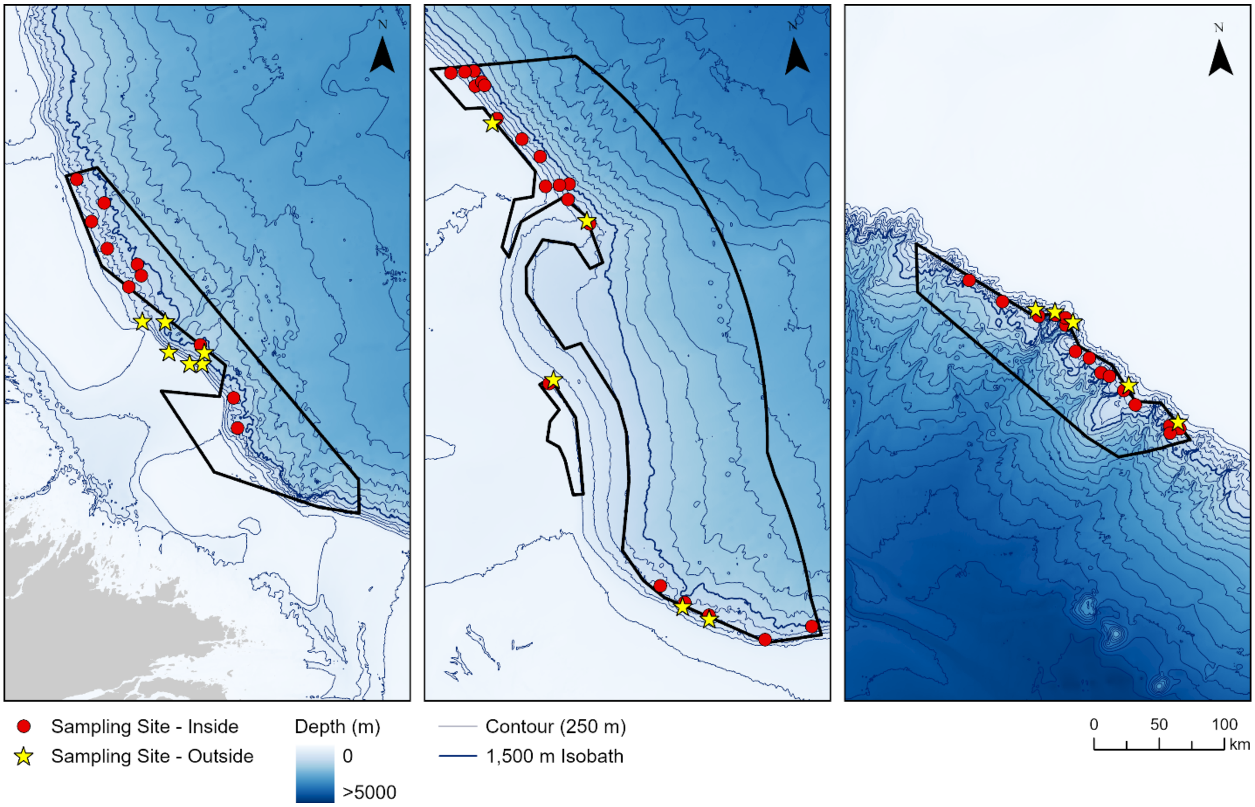

Figure 5. Sampling sites for Hopedale Saddle (left panel), Northeast Newfoundland Slope (centre panel), and Division 3O Coral Closure (right panel) marine refuges.

Here, a hybrid approach is proposed in which outside reference sites are identified and visited to establish baseline conditions for a few priority indicators, but not regularly revisited or reported in the Core Monitoring program. Should within-protected area monitoring identify deteriorating integrity of BCBs, these sites can be revisited and used with baseline data to inform adaptive management (i.e., are within-protected area declines a function of broader regional trends [Targeted Research]).

Selecting true reference sites in complex marine environments is difficult, especially when protected areas are often selected for their unique characteristics. In the NL Region, two general approaches have been used: multivariate analyses (Laurentian Channel MPA) and habitat suitability models (coral and sponge MRs). Both approaches include additional constraints (e.g., proximity, depth, fishing history) to ensure comparability.

Power Analysis

A power analysis was conducted to determine how our capacity to detect significant shifts in the abundance of BCB taxa changes over time given different effect sizes and sample sizes. Existing data collected from multispecies trawl surveys and seafloor imagery surveys were used to inform the analysis and a range of scenarios were explored to aid in determining what level of sampling effort will balance statistical power and monitoring feasibility.

Models were developed for Atlantic Cod in Hawke Channel and Funk Island Deep closures using multispecies trawl survey data from 2010–19, standardizing abundance as CPUE. After 2019, there is a break in the time series due to COVID-19 (2020) and vessel changes.

Generalized linear mixed-effects model (GLMM) was applied for Hawke Channel to account for variability, using fixed effect of survey year and a random effect of strata. For Funk Island Deep, a generalized linear model was run to model CPUE with a fixed effect of survey year. A random effect of strata was not included in this model due to convergence issues. Simulated datasets evaluated the impact of sample size, effect size, and survey years on detecting abundance changes, with a focus on addressing significant decreases in abundance. Similarly, coral and sponge data from Hopedale Saddle MR were analyzed using a drop camera system, with species grouped into functional categories. GLMMs were fitted to count data for corals and sponges, using substrate classifications to understand sampling requirements and detect changes over time. A negative binomial error distribution was used for the Sponge and Small Gorgonian models whereas a Poisson distribution was used for Sea Pens. Power analysis simulations helped refine future survey designs for effective monitoring.

From 2010 – 19, an average of 10 trawls per year were conducted in the Hawke Channel closure, while 6 trawls per year were conducted in the Funk Island Deep closure. Atlantic Cod abundance (CPUE) in Hawke Channel increased by 810% during this period, with an annual proportional growth rate of 1.27 (based on fitted model predictions), while Funk Island Deep recorded a 219% increase, with an annual growth rate of 1.14 (Figure 6). Power analysis indicates that, at the current sampling levels, it would take five years of monitoring to detect significant changes in abundance in both closures, though greater sampling effort could accelerate this (Figures 7, 8). Conversely, reduced sampling would extend the timeline for detecting changes. Power is slightly higher for one-tailed tests than two-tailed tests.

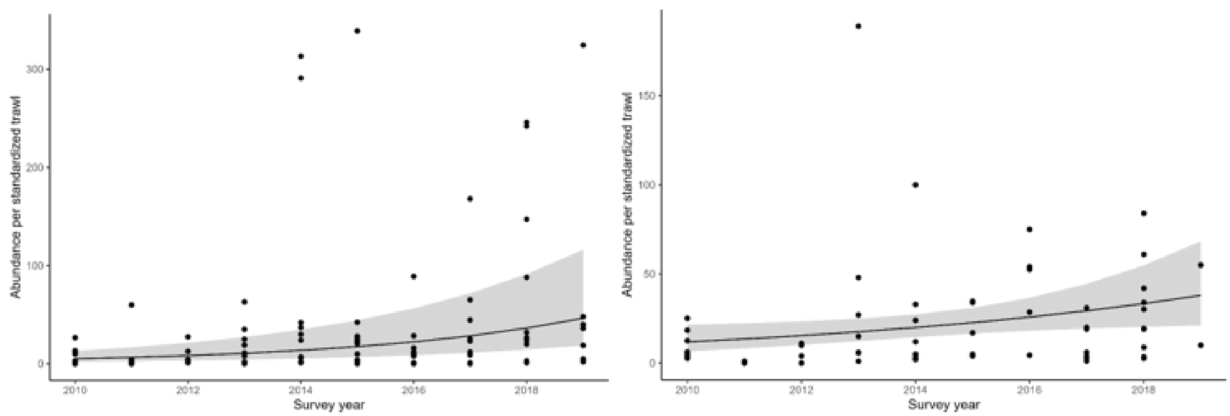

Figure 6. Catch per unit effort of Atlantic Cod in the Hawke Channel closure (left panel) and Funk Island Deep closure (right panel) by year. The black line and shaded area indicate the model prediction of CPUE and associated 95% confidence interval, respectively.

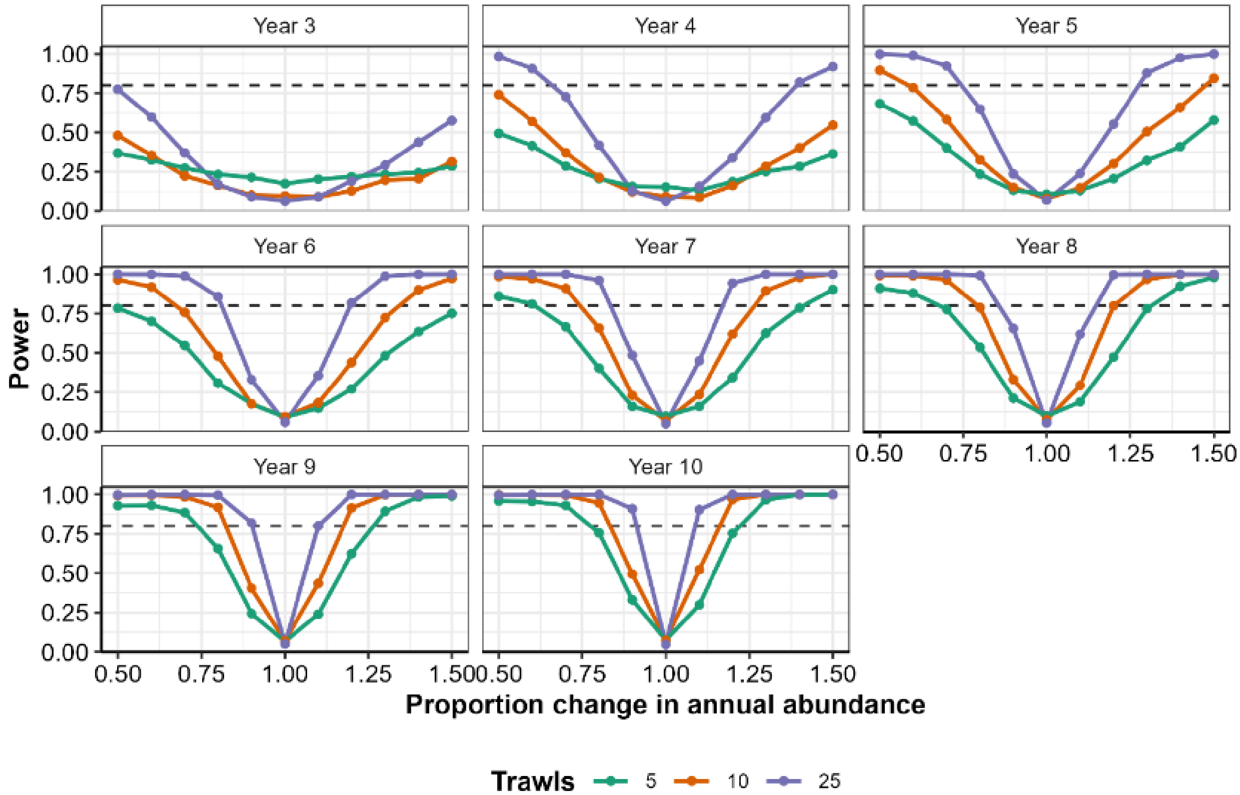

Figure 7. Statistical power to detect significant (two-tailed test, alpha = 0.05) changes in the abundance of Atlantic Cod within the Hawke Channel closure with various levels of trawling effort (trawls per year within the closure). Panels represent the number of years of simulated data included in the time series for the analysis. The dashed horizontal line indicates the target power of 80%.

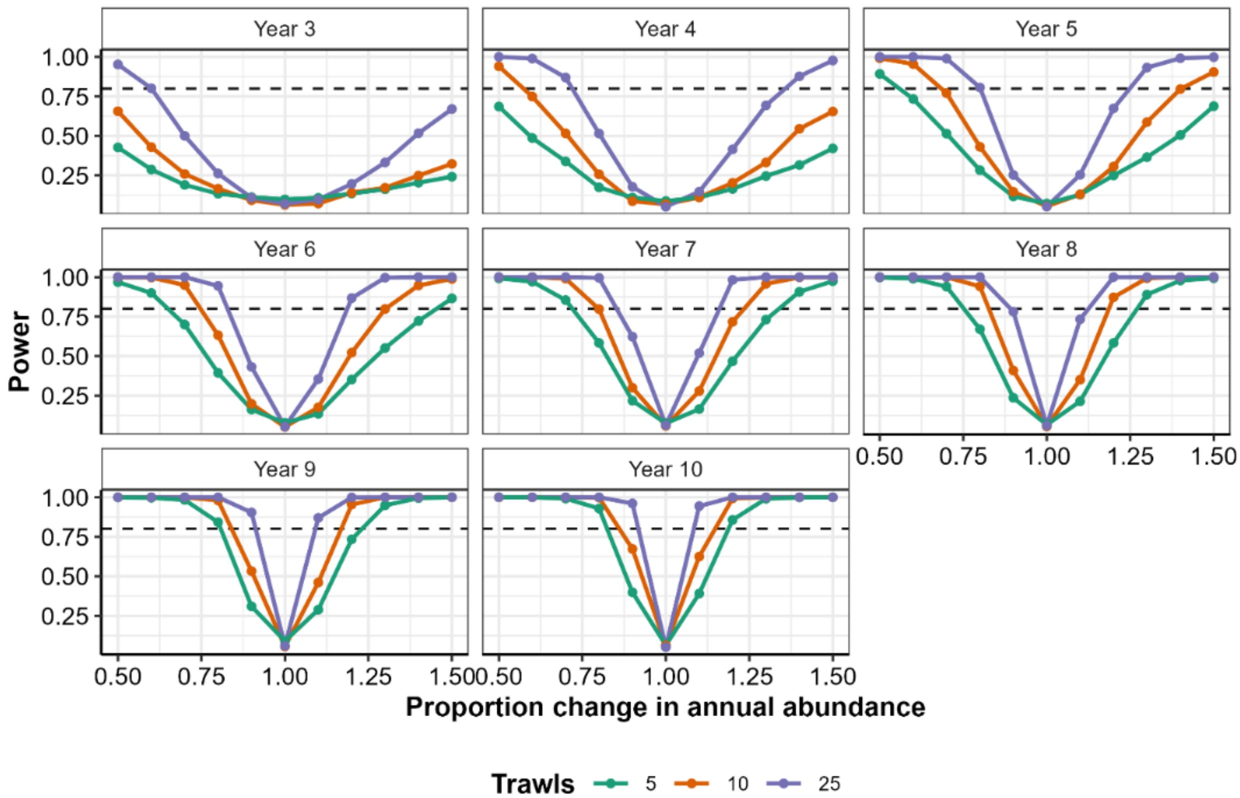

Figure 8. Statistical power to detect significant (two-tailed test, alpha = 0.05) changes in the abundance of Atlantic Cod within the Funk Island Deep closure with various levels of trawling effort (trawls per year within the closure). Panels represent the number of years of simulated data included in the time series for the analysis. The dashed horizontal line indicates the target power of 80%.

In Hopedale Saddle MR, drop camera surveys at 10 stations captured an average of 60 images per transect, focusing on functional groups like sea pens, small gorgonians, and sponges. Sponges were most abundant, with counts ranging from 0 to 28 per image, while sea pens and small gorgonians showed lower numbers. Power analysis suggests that with current sampling efforts, significant changes in these groups could be detected by year four of monitoring at small effect sizes (Figures 9, 10, 11). Images with hard substrate classifications provided the highest power, indicating the importance of substrate in monitoring strategies. Increasing years of sampling improves sensitivity, though additional transects or images per transect show diminishing returns in power gains.

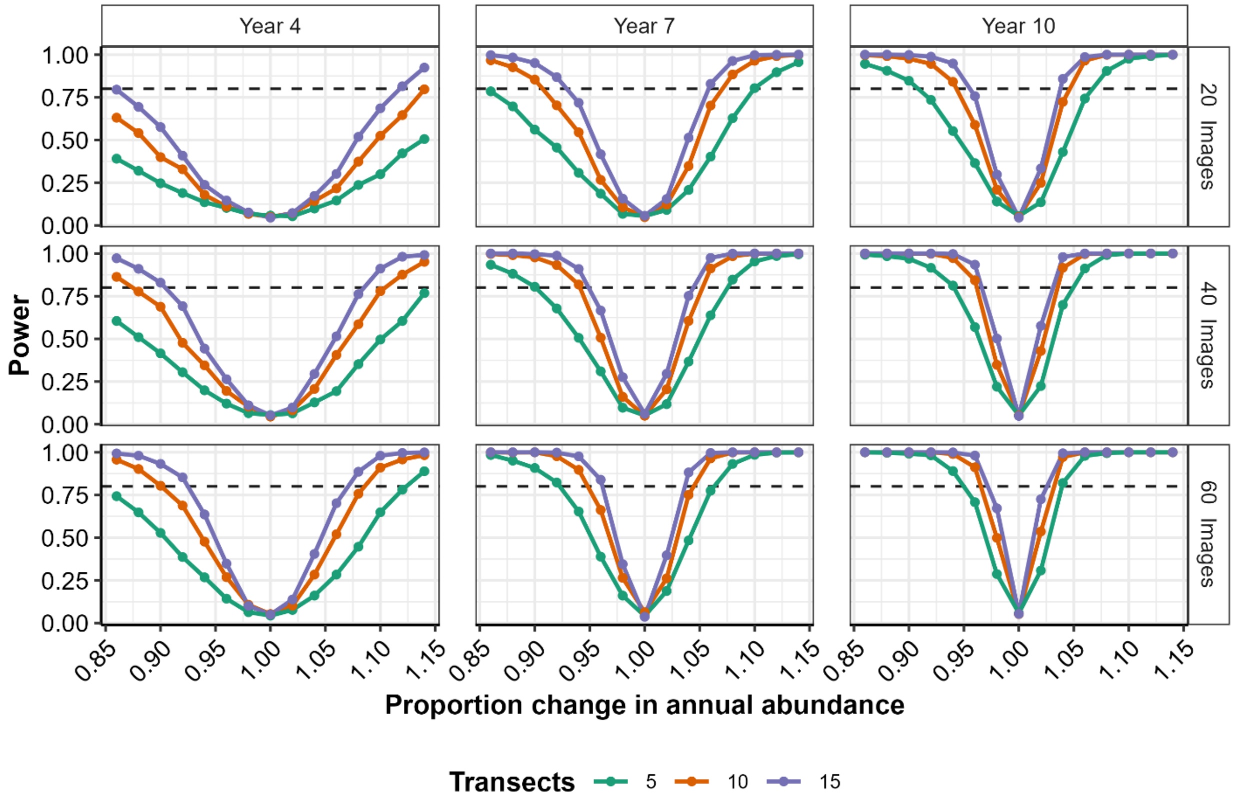

Figure 9. Statistical power to detect significant (two-tailed test, alpha = 0.05) changes in the abundance of Sea Pens within the Hopedale Saddle closure with various levels of sampling effort (transects per year within the closure and number of images per transect) by year of sampling program. The dashed horizontal line indicates the target power of 80%.

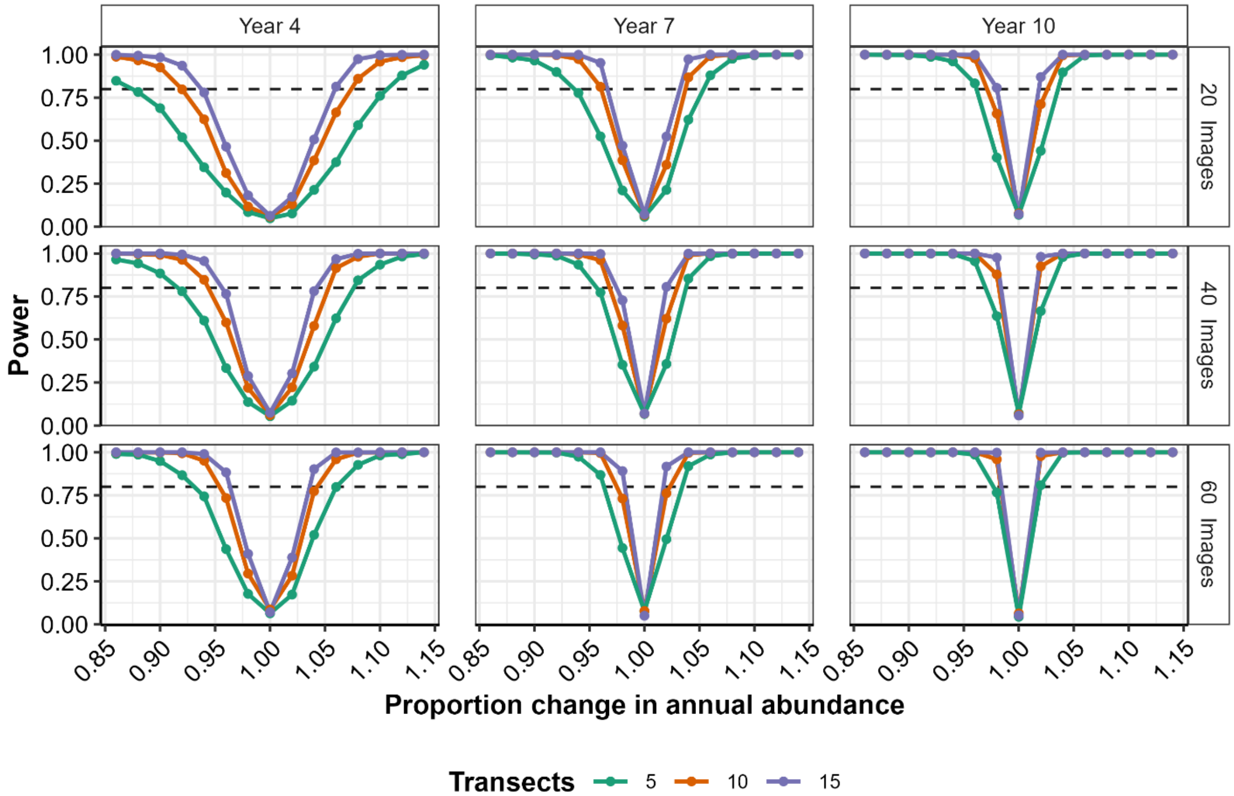

Figure 10. Statistical power to detect significant (two-tailed test, alpha = 0.05) changes in the abundance of Small Gorgonians within the Hopedale Saddle closure with various levels of sampling effort (transects per year within the closure and number of images per transect) by year of sampling program. The dashed horizontal line indicates the target power of 80%.

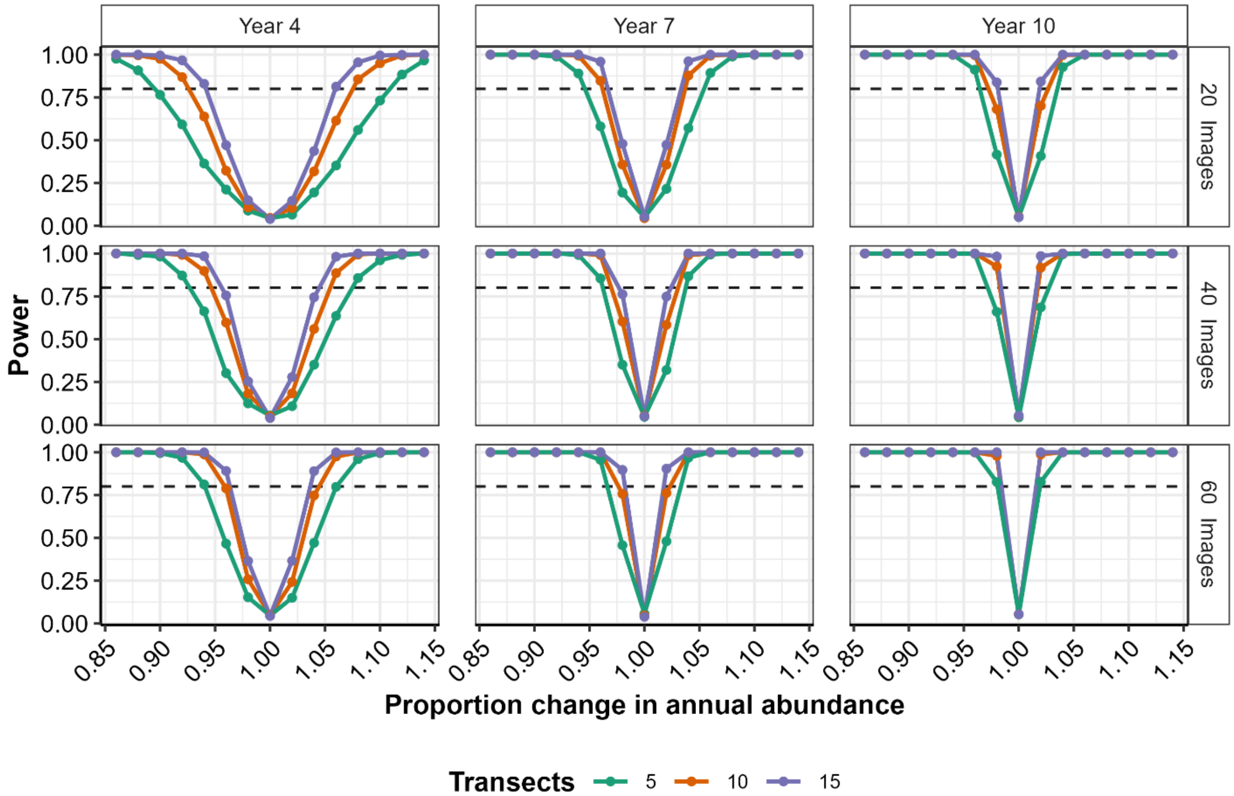

Figure 11. Statistical power to detect significant (two-tailed test, alpha = 0.05) changes in the abundance of Sponges within the Hopedale Saddle closure with various levels of sampling effort (transects per year within the closure and number of images per transect) by year of sampling program. The dashed horizontal line indicates the target power of 80%.

Collaborations

Collaborations play a vital role in monitoring programs by pooling resources, fostering engagement, and providing diverse expertise. The MR monitoring program involves partnerships with Indigenous and academic groups. While no MRs currently lie within Indigenous land claims, DFO collaborates with the Nunatsiavut Government to monitor the marine areas adjacent to their land claim zone to recognize ecological links across the boundary. This is conducted under Nunatsiavut scientific permits, sharing data accordingly. A potential MCA within Nunatsiavut waters (see McCarney et al. 2024), could further integrate these partnerships.

Academic collaborations can also enhance monitoring programs by supporting methodological refinements, providing access to specialized equipment, and generating baseline knowledge. Coordination across strategic and technical working groups ensures methodological compatibility, while shared resources facilitate cost-effective and consistent data collection. The Fisheries and Marine Institute of Memorial University of Newfoundland, supported by DFO's Oceans Management Funding Program (2021–26), exemplifies successful collaboration through its project on monitoring and assessing MCAs in the NL Region. This initiative focuses on conducting at-sea monitoring, and training future ocean researchers. The program benefits from a dedicated Project Manager, efficient coordination via regular advisory meetings, and the ability to scale scientific capacity by engaging students, interns, and post-doctoral fellows. DFO's contributions, including expertise, shared resources, and personnel, and co-supervision of students, have strengthened this collaboration, fostering innovative research, knowledge sharing, and alignment towards shared goals.

The Marine Institute (MI) project has addressed indicators, protocols, site selection, and data management, guided by its goals and the expertise of collaborators at DFO and MI. Since its start in 2022, it has benefited from DFO's Marine Refuge Monitoring Approach and been involved in Core and Targeted Monitoring methods such as multibeam mapping, ROVs, fisheries acoustics, and zooplankton sampling. Priority site selection followed depth-transect approaches informed by international guidance and local expertise, with adjustments made to address multibeam mapping gaps and enhance alignment with coral and sponge conservation areas. Iterative collaboration has strengthened missions to key MRs in the region.

Data Management

The data management approach for the broader Marine Conservation Targets (MCT) program is structured to follow the general data lifecycle as shown in Figure 12. A standard data lifecycle typically begins with the planning stage and then moves through the logical steps of collection, processing, analysis, and then final datasets. Throughout the MCT program, data storage and sharing practices are tailored around these stages.

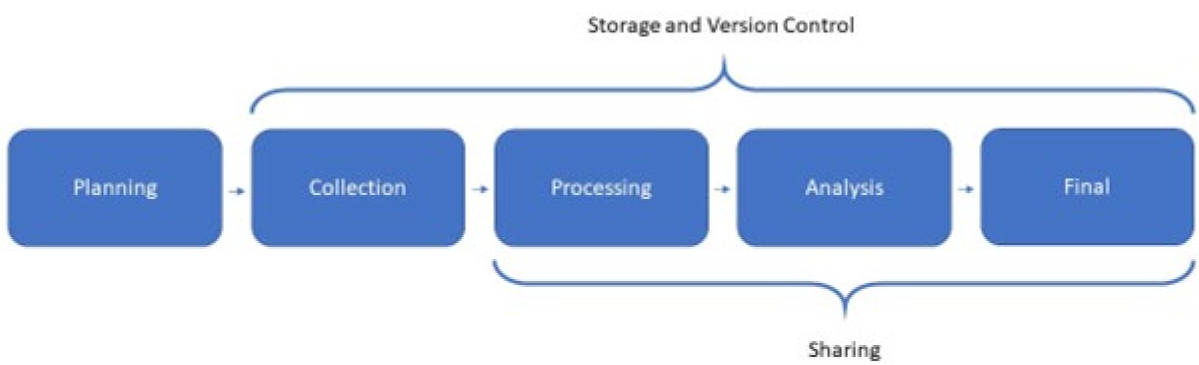

Figure 12. Data management stages that will be applied to the MCT program.

Raw data collected in the field serves as the foundation, progressing through quality control and calibration during processing, analysis through statistical or graphical methods, and eventual conversion to a preservation-friendly or standardized format for final storage. The directory structure and naming conventions (e.g., <site>*<stationID>*<method>*<gear>*<date>_<stage>) ensure organized and accessible data, with flexibility for specific data types like videos. Data are stored on Microsoft Azure cloud services for secure backup, complemented by hard drive storage to minimize costs.

Field data metadata, including coordinates and associated details, is collected using the ArcGIS Survey123 application, uploaded to the ArcGIS Online Portal, and stored securely via the eGIS platform. Relational databases are being developed for managing large datasets such as eDNA results, linking field metadata with processed outputs like taxonomic observations. This comprehensive system facilitates efficient data management, ensuring data integrity across all stages of the lifecycle.

Most datasets are stored in non-proprietary formats to enable easy sharing and require proper documentation and metadata for usability. While sharing among project collaborators is at the discretion of principal investigators, external sharing requires agreements or official requests. Confidential datasets must be flagged during data preparation to prevent improper storage or sharing. Per policy, DFO scientific data becomes a public resource after two years, allowing non-confidential data to be shared on Canada's Open Data website with coordination from relevant regional data groups. Metadata stored on ArcGIS Portal is displayed as interactive web maps and dashboards, accessible through a browser for viewing spatial and tabular data.

Reporting

The scientific monitoring program, though still in its early stages, has only just begun processing/analyzing data to establish a reporting framework for the region's MCAs. A regional monitoring dashboard has been proposed to present data from all MCAs in a standardized and user-friendly format, featuring interactive plots and maps for site-specific analysis (Figure 13). While national guidelines for monitoring and reporting are still under development, interim measures like dashboards and published reports will suffice. Looking ahead, a robust reporting structure is essential for efficient data management and sharing and should be further developed over the next 1–2 years. Additionally, understanding indicator trends in relation to COs or BCBs is crucial, with two assessment methods outlined by DFO (2023): anomaly and fixed-threshold. These methods, although yet to be applied, aim to enhance clarity and communication regarding the status and trends of BCBs for all MRs.

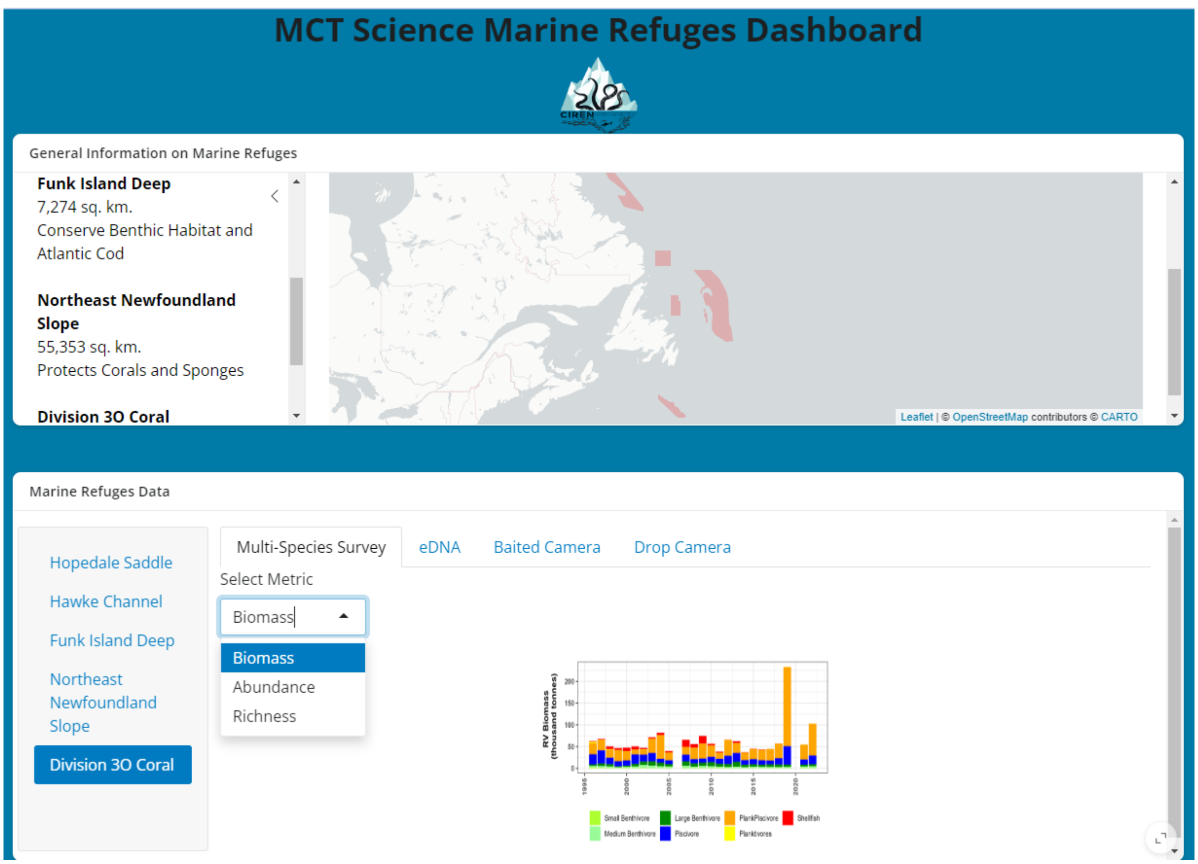

Figure 13. Screenshot of the draft monitoring dashboard showing various MRs, survey types, and indicators.

Sources of Uncertainty

Power Analysis

Statistical power analyses highlight variability across methods and taxonomic groups, with assumptions about variables, study design, and error rates shaping results. Multispecies trawl survey data showed low sensitivity for detecting changes in species like Atlantic Cod within MRs, requiring significant cod declines over a decade to confidently observe trends. Increasing survey effort yielded minimal gains in statistical power and posed ecological and operational challenges. Despite its low power for detecting changes in BCBs, maintaining multispecies trawl surveys in protected areas is vital for long-term fisheries management in the NL Region. Multispecies trawl survey data may also benefit broader monitoring efforts. For example, the survey may prove to be more effective for higher level biodiversity measures compared to single-species objectives, as demonstrated in the Laurentian Channel MPA. Further analyses will be required after finalizing study designs to refine monitoring program development.

Drop camera methods demonstrate higher effectiveness in detecting changes for conservation taxa, like sponges and certain corals, identifying <10% annual declines in abundance within 4 years. Increasing transects to 15 stations per MR per year and analyzing fewer images per transect (20) is recommended for logistical feasibility while maintaining deployment durations (30 minutes). However, challenges arise from year-to-year variability in transects, necessitating covariates to address inconsistencies. Functional group analysis enhances statistical power compared to single-species methods but may obscure individual trends, as seen with large gorgonians, which remain limited to presence and distribution monitoring due to low abundance. Further adjustments may be needed across different MRs based on species composition and environmental differences.

Future power analyses should explore remote sensing data (e.g., primary production), eDNA data, and validate BRUVs for detecting abundance changes, while also examining broader taxonomic groupings in the multispecies trawl survey. Rethinking the five-eighty convention (alpha = 0.05, power = 80%) is crucial for conservation, as its rigidity may hinder adaptive management by undervaluing the higher cost of Type II errors (failing to detect real effects) compared to Type I errors (concluding there is an effect when none exists; Di Stefano 2003). Adjusting thresholds to reflect conservation goals and the inherent uncertainties in species abundance trends may lead to more precautionary data interpretations (Leung and Gonzalez 2024). Though specific recommendations for power and significance thresholds are beyond the scope of this work, their refinement will be vital for advancing the monitoring program and ensuring effective conservation and adaptive management strategies.

CONCLUSION

The scientific monitoring approach described in this document provides several effective data streams for the regional monitoring of five Marine Refuges in the NL Region. These include more specific, cost-effective methods (Core Monitoring and Targeted Research) as well as leveraging of existing regional monitoring programs (Complementary Monitoring). Many unknowns remain and this program will require re-evaluation and refinement (particularly after field trials) to ensure the conservation objectives, or biodiversity conservation benefits can be assessed over the long term.

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