An adaptive ecological monitoring approach for the Scallop Buffer Zone Marine Refuges: indicators and strategies

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ABSTRACT

Bringloe, T., Dinn, C., Joseph, V., Bourque, D., Burbank, J., Arseneault, T. 2026. An adaptive ecological monitoring approach for the Scallop Buffer Zone Marine Refuges: indicators and strategies. Can. Manuscr. Rep. Fish. Aquat. Sci. 3352: viii + 50 p. https://doi.org/10.60825/8xct-3f92

The Scallop Buffer Zones (SBZs) fishery closures were introduced progressively from 1999–2006 along shorelines of the southern Gulf of St. Lawrence as a measure to reduce gear conflicts between scallop and lobster fishing. Today, the SBZs are recognized as marine refuges which aim to protect juvenile American Lobster and its habitat, along with other conservation benefits including Atlantic Herring spawning grounds, Winter Skate, and Lady Crab. This report details the first ecological monitoring approach for the SBZs, and seeks to establish the best currently available indicators for the status and health of its associated species and ecosystem, along with any gaps in knowledge. In this document, conservation objectives are operationalized, and key surveys and sources of data are categorized into core monitoring, complementary data and targeted research. Indicators primarily consist of yearly density data for important species and community composition derived from DFO Science Northumberland Multi-Species Trawl, SCUBA, Bio-Collector, and Atlantic Herring Acoustic Surveys. By leveraging existing inter-disciplinary programs we were able to establish a common monitoring framework for the SBZs and establish grounds to further improve and operationalize monitoring within the DFO Gulf Region’s most geographically expansive conservation areas.

RÉSUMÉ

Bringloe, T., Dinn, C., Joseph, V., Bourque, D., Burbank, J., Arseneault, T. 2026. An adaptive ecological monitoring approach for the Scallop Buffer Zone Marine Refuges: indicators and strategies. Can. Manuscr. Rep. Fish. Aquat. Sci. 3352: viii + 50 p. https://doi.org/10.60825/8xct-3f92

Les zones tampons pour la pêche du pétoncle (ZTPP) ont été instaurés de 1999 à 2006 le long des côtes du sud du golfe du Saint-Laurent afin de réduire les conflits d'engins de pêche entre la pêche au pétoncle et celle au homard. Actuellement, les ZTPP sont reconnus comme des refuges marins et visent à protéger le homard juvénile et son habitat, ainsi que d'autres bénéfices pour la conservation : les frayères du hareng de l'Atlantique, la raie tachetée, et le crabe demoiselle. Ce rapport détaille la première approche de surveillance écologique des ZTPP et vise à établir des indicateurs de l'état et de la santé des espèces et de l'écosystème, basé sur les données actuellement disponibles, tout en soulignant les lacunes. Dans ce document, les objectifs de conservation sont opérationnalisés, et les principaux relevés et sources de données sont classés en surveillance principale, données complémentaires et recherche ciblée. Les indicateurs consistent principalement en des données annuelles sur la densité des espèces d'intérêt et la composition des communautés, tirées des relevés multi-espèces au chalut de fond du détroit de Northumberland, du relevé par plongée sous-marine, des Bio-Collecteurs et des relevés acoustiques du hareng de l'Atlantique du MPO. En tirant parti des programmes interdisciplinaires existants, nous avons pu établir un système de surveillance commun pour les ZTPPs, et nous établissons les bases pour améliorer et opérationnaliser davantage la surveillance dans les zones de conservation les plus étendues géographiquement de la région du Golfe du MPO.

LIST OF ABBREVIATIONS

AIS	Aquatic Invasive Species
BCB	Biodiversity Conservation Benefit
CL	Carapace Length
CO	Conservation Objective
CSAS	Canadian Science Advisory Secretariat
DFO	Department of Fisheries and Oceans
eDNA	Environmental DNA
MCT	Marine Conservation Target(s)
MPA	Marine Protected Area
MR	Marine Refuge
NS Survey	Northumberland Strait Multi-Species Trawl Survey
OECM	Other Effective Area-Based Conservation Measures
SBZ	Scallop Buffer Zone
sGSL	southern Gulf of St. Lawrence
SFA	Scallop Fishing Area
SST	Sea Surface Temperature

GLOSSARY

The definitions provided here are intended to clarify the terminology and abbreviations used within the current document, and do not necessarily represent broad definitions upheld by DFO.

Biodiversity Conservation Benefit (BCB): the net positive change in, or preventing the loss of, biodiversity resulting from the implementation of an area-based management measure (DFO 2016). BCBs may either be a direct result of an other effective area-based conservation measure (OECM), or an indirect benefit provided by an area-based measure established for another purpose.

Conserved area: Lands and waters that are managed in ways that achieve positive long-term outcomes for the conservation of biodiversity. These include protected areas as well as OECMs. (Government of Canada 2025a)

(Strategic) Conservation Objective (CO): Reflects the species, habitat, or features that the area has been put in place to conserve. Every conserved area has a conservation objective. Certain activities may be allowed to take place within a conserved area provided they do not interfere with the conservation objective (CCFAM 2018).

Canadian Science Advisory Secretariat (CSAS): Coordinates scientific peer-review and science advice for the Department of Fisheries and Oceans (DFO 2020).

Department of Fisheries and Oceans (DFO): A federal institution of the Canadian Government responsible or safeguarding the nation's waters and managing fisheries and ocean resources (DFO 2026).

Indicator: Measurable variables used to evaluate the state of a particular species/ecological system with respect to achieving a particular objective (ECCC 2025; DFO 2013).

Marine Conservation Targets (MCT): A percentage of Canada's marine and coastal waters that must be recognized as conserved. This target is 30 % by 2030 for marine and coastal regions (Government of Canada 2025b). Federal MCT funding aims to establish new protected sites and develop monitoring and management plans in existing sites.

Marine Protected Area (MPA): A clearly defined geographical space recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Government of Canada 2011).

Marine Refuge (MR): A marine refuge is a fisheries-area closure established under the *Fisheries Act* that meets specific criteria in Canada's OECM guidance and is recognized as an OECM by the Minister of DFO (Government of Canada 2022).

Operational Objective: An objective that is more specific and measurable as compared to the (strategic) conservation objective. Specifies a parameter or indicator used for ecological monitoring, including reference points where available (DFO 2013).

Other Effective Area-Based Conservation Measures (OECM): A geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the *in situ* conservation of biodiversity (either directly or indirectly through BCBs) with associated ecosystem functions and services and, where applicable, cultural, spiritual, socio-economic, and other locally relevant values (Government of Canada 2022). Among the criteria for OECMs, sites must provide a benefit for an important species, an important habitat, and an additional benefit.

1. INTRODUCTION

The Government of Canada has committed to meeting international biodiversity protection goals, as outlined in the Kunming-Montréal Global Biodiversity Framework (Government of Canada 2025a). In support of these global objectives, Canada has set national targets to protect 30% of its marine environment by 2030 (Government of Canada 2025b) and has, as of 2026, conserved 15.54% of its marine territory. The Department of Fisheries and Oceans (DFO) is working towards Marine Conservation Targets (MCT) through Marine Protected Areas (MPAs) created under the *Oceans Act* (S.C. 2024, c. 30) and other effective area-based conservation measures (OECMs), also known as marine refuges (MRs). These MRs safeguard critical species and habitats from fishing activities through closures enacted under the *Fisheries Act* (S.C. 2024, c. 30), and they contribute to Canada's national MCT program by providing Biodiversity Conservation Benefits (BCB; Government of Canada 2022).

The purpose of this document is to detail the first adaptive ecological monitoring approach for the Scallop Buffer Zones (SBZ) MRs (Figure 1; Government of Canada 2024) for 2026–2031. To achieve this goal, we first provide a general overview of the proposed monitoring approach in the context of the Guidance on the Formulation of Conservation Objectives and Identification of Indicators, Monitoring Protocols and Strategies for Bioregional Marine Protected Area Networks (DFO 2013). We then provide a general overview of the SBZ MRs and their Conservation Objectives (COs), propose indicators for monitoring those COs, identify ongoing surveys/existing datasets that can be used to measure those indicators, outline the proposed strategies for reporting and managing data, and identify gaps in knowledge. This document will help to operationalize ecological monitoring of the SBZ MRs over the next five years, establishing a foundation for refining and expanding the approach into a long-term monitoring plan after 2030.

2. MONITORING APPROACH

2.1. Unpacking conservation objectives

The ecological monitoring framework detailed in this document, to be applied across all of Gulf Region's conservation areas, follows the advice produced via a formal scientific peer-review process coordinated by the Canadian Science Advisory Secretariat (CSAS), namely the Guidance on the Formulation of Conservation Objectives and Identification of Indicators, Monitoring Protocols and Strategies for Bioregional Marine Protected Area Networks (DFO 2013). According to the National Framework for Canada's Network of Marine Protected Areas (Government of Canada 2011), the overarching conservation goals of Canada's MPAs are to: (1) Provide long-term protection for marine biodiversity, ecosystem function and special features; (2) support conservation and management of marine resources, including socio-economic and ecosystem services; and (3) enhance public awareness and appreciation for marine environments and associated history and culture. For each conserved area, these goals are developed into strategic COs that detail the desired state of the conserved area and contribute to the conservation goals (Figure 2A). For the ecological monitoring framework

described here, these COs are unpacked into operational objectives (Figure 2A), which are more specific and tied to measurable indicators. While this guidance was intended for MPAs specifically, it is being used and adapted here for the development of ecological monitoring approaches for MRs to streamline efforts. For MRs specifically, important species, habitat, and other conservation benefits (Government of Canada 2022) will be unpacked into operational objectives to guide indicator selection.

The ecological monitoring is meant to assess, as simply and as accurately as possible, the status, trends, and health of various biological and ecological components of interest in each conservation area. This information can then be integrated with other sources, including socio-economic and non-ecological factors, to inform management plans and decision-making. Any thresholds included in the ecological monitoring plan are based solely on the biology and ecology of the conservation area, such as limits related to stress, mortality, or the collapse of ecological functions. These thresholds should, where feasible, be linked to management actions.

2.2. Developing indicators

DFO (2013) provided further guidance on suitability of indicators. An indicator is defined as a variable or index that reflects changes in a system, and the position or trend of an indicator relative to reference data points indicates the present state of a given system. DFO (2013) provides guidance on selection criteria for indicators, which include:

- sound theoretical basis
- ease and accuracy of measurement
- availability of historical data (10–20 years)
- suitable sensitivity (correspondence between change in indicator and pressure)
- suitable responsiveness (signal to noise ratio)
- suitable specificity (ability to disentangle multiple pressures)
- suitable public awareness (ease of comprehension to non-specialists)
- reasonable cost-effectiveness.

When specifically considering indicators for the monitoring of marine conservation areas, other guiding principles can be used to aid in selection. When possible, minimally invasive methods (e.g., environmental DNA [eDNA], imagery, etc.) should be preferred for monitoring, quantitative thresholds should be prioritized over qualitative ones, and indicators that can be used to assess similar objectives across many conservation areas should be standardized.

The approach to identifying and testing indicators for ecological monitoring of conservation areas is staged and iterative. First, potential indicators are identified by reviewing literature relevant to COs (Stage 1; Figure 2B). Once a potential indicator is identified, data are gathered and analyzed to establish its baseline status (Stage 2; Figure 2B). At Stage 2, relevant gaps in knowledge may be identified and iteratively addressed with new research and data. Once the baseline status for an indicator is sufficiently established, new data building off the baseline are collected by leveraging existing surveys, where possible, or by developing new monitoring protocols. At Stage 3, the validity and feasibility of the indicator is tested, specifically whether the indicator can reflect changes in operational objectives (Stage 3; Figure 2B). Once an indicator passes implementation testing, it can be fully integrated into a scientifically peer-reviewed (i.e., through a CSAS process) monitoring plan to inform on health and status updates

in a given conservation area (Stage 4; Figure 2B) through various reporting channels (e.g., scientific, management, and public facing documents). The indicator should also be periodically re-evaluated to ensure it remains valid and feasible to inform on the status of priority species and overall ecosystem health. This will be done through updates to the ecological monitoring approaches specific to each Gulf Region conservation area, optimally on a 5-year basis and in line with overall management plans (see Data Management and Reporting). Any scientific evidence suggesting that a better indicator or metric exists (e.g., a new technology or method is developed), or that a current indicator is not adequate, should result in an update to a given ecological monitoring approach and published as soon as feasible, even when falling outside the regular update cycle.

2.3. Data types

Ecological monitoring indicators and activities will be organized and prioritized by assigning them to one of three categories (modified from DFO 2024a): core monitoring, complementary data, and targeted research (Figure 2C). Core monitoring includes priority indicators that are assessed frequently (i.e., yearly when feasible) and are considered essential for building long-term datasets directly addressing conservation objectives for each conservation area. In marine conservation areas within the Gulf Region, core monitoring is carried out using scientifically validated protocols either by DFO Science or partners. Since core monitoring is critical to informing on the status and trends related to the COs, the quality of data coming from multiple sources must be evaluated prior to incorporation into reports. In order to optimize feasibility and cost effectiveness, monitoring will often leverage existing DFO surveys that can provide adequate data. Complementary data includes surveys or datasets that provide additional information that can help with interpretations of the status, health, and trends of marine conservation areas and associated operational objectives. Targeted research represents short-term projects that could help inform and fill knowledge gaps related to core monitoring, address observed changes in the operational objectives, test new methods, or refine existing protocols.

3. SCALLOP BUFFER ZONES MARINE REFUGES

3.1. Monitoring approach context

3.1.1. Scallop Buffer Zone Marine Refuges and its conservation species

The Sea Scallop (*Placopecten magellanicus*, hereafter scallop) fishery in the southern Gulf of St. Lawrence (sGSL) is one of three major coastal fisheries in the region, along with American Lobster (*Homarus americanus*, hereafter lobster) and Atlantic Herring (*Clupea harengus,* hereafter herring). The SBZ MRs, located in the coastal portions starting 300 m offshore of Scallop Fishing Areas (SFAs) 21, 22, and 24 (Figure 1), were introduced as scallop fishing closures to reduce gear conflicts between scallop harvesting and lobster fishing (which is permitted within the SBZ MRs), and to protect juvenile lobster and its habitat (DFO 1999). Scallop are distributed throughout the sGSL with preferred depths between 15 and 37 m (Figure S1; Niles et al. 2021), and fishing is aggregated into three beds occurring in the middle of the Strait (Niles et al. 2024). The use of scallop fishing gear can be destructive to benthic habitats that provide shelter to crustaceans, demersal fish, and other benthic fauna (Davidson et al. 2007; Hinz et al. 2011; Boulcott et al. 2014; Niles et al. 2021). The ability to detect and quantify disturbance vary widely (Stewart and Howarth 2016) and the impact to adult lobsters specifically may be low compared to natural perturbations (LeBlanc et al. 2015) and given the small degree

of spatial overlap in habitat. The prohibition on scallop fishing is therefore presumed to provide protection to 1) juvenile lobster (important species), 2) juvenile lobster habitat (important habitat), and 3) other stated benthic species and habitat (other benefits), which led to the SBZs to be recognized as MRs in 2017 (DFO 2017a; Figure 1). The SBZs qualify as OECMs and contribute to Canada's conservation targets (Government of Canada 2022).

Lobster larvae become juveniles after settling on the benthos, at approximately 4–5 mm carapace length (CL) (Lavalli and Lawton 1996). Lavalli and Lawton (1996) differentiates three phases of juveniles that are ecologically and behaviorally distinct from larger lobsters (Wahle and Steneck 1991): 1) shelter-restricted juveniles (approximately 4 to 14 mm CL) are cryptic and remain covered, primarily in cobble substrate habitats in coastal waters (Wahle and Steneck 1991; Lawton and Lavalli 1995, Rondeau et al. 2015); 2) emergent juveniles (15 to 25 mm CL) begin venturing outside their shelter but remain close to it; and 3) vagile juveniles (25 to 40 mm CL) which have more extensive movements outside their shelter to search for food (Lavalli and Lawton 1996). It is estimated that juvenile lobsters spend the first 5 to 8 years of their lives in or near their initial shelters while adult lobsters select different types of habitats and occupy deeper waters (Goldstein et al. 2026).

Habitat identified to be important for the settlement of pelagic lobster larvae and protection of juvenile lobsters is characterized as shallow (≤ 10 m deep) and warm (≥ 12 °C) bottom waters from mid-summer to early fall (latitude dependent; McManus et al. 2023). Juvenile lobsters are closely associated with habitats that exhibit high structural complexity, with cobble substrates being particularly important (Hudon 1987; Wahle and Steneck 1991; Wahle and Incze 1997; Hanson 2009; Dinning 2014). The natural interstices within cobble provide ready-made shelter, offering protection without requiring the energy investment needed to excavate and maintain burrows in less stable substrates like mud (Dinning 2014). A mapping exercise using available geospatial layers for depth, temperature and substrate was attempted in order to identify potentially optimal areas for juvenile lobsters within the SBZs (Joseph et al. 2026). Results from that analysis showed that temperatures are generally suitable throughout the SBZs, while substrate was poorly characterized, especially in coastal areas. As substrate is an essential factor in habitat selection for juveniles, this is a major data gap in terms of mapping specific areas of high suitability.

In addition to the important species and habitat that was targeted by management action, several other species and habitats have been identified that may also benefit from the same protection. Three species that inhabit the SBZ MRs are noteworthy due to recent population declines or geographically restricted ranges: the protection of herring spawning grounds in all three SBZ MRs, as well as Winter Skate (*Leucoraja ocellata*) and Lady Crab (*Ovalipes occelatus*) within SBZ SFA 22.

Herring is an important prey source for higher level trophic predators such as Grey Seal (*Halichoerus grypus*) and Bluefin Tuna (*Thunnus thynnus*; Benoît and Rail 2016), and is used as bait in several sGSL fisheries, including lobster and Snow Crab (*Chionoecetes opilio*). Two genetically distinct spawning populations of herring exist in the sGSL: spring (March-June) and fall (July-October) spawners (Messieh 1987; Lamichhaney et al. 2017), both of which have seen declines since the 1990s, and 2010, respectively (DFO 2024b; Turcotte and McDermid 2024). The two populations are assessed separately but they overlap in space and time, so biological samples are collected to partition surveyed fish into their spawning components. Both spring and fall spawners feed and overwinter in common areas and can be found feeding in close

proximity to spawning areas (Jac et al. 2025). Current knowledge on spawning locations and recent spawning observations indicate a substantial portion of sGSL herring spawning events likely occur within or adjacent to the SBZ MRs. Spring spawners deposit eggs at depths of 0.8 m to 5 m on rocky and sandy substrates covered in thick carpets of seaweeds, whereas eggs deposited by fall spawners are typically found at depths between 15 and 20 m over bare bedrock and rubble (Messieh 1987).

Winter Skate is a cartilaginous fish that was classified as endangered in 2015 in the Gulf of St. Lawrence and eastern Scotian Shelf/Newfoundland waters (COSEWIC 2015). The sGSL population is considered unique, with relatively quicker maturation and smaller overall size, now occupying only a small coastal region of the western Northumberland Strait in SBZ SFA 22 during the summer. Declines have likely been driven by a combination of predation by grey seal (Swain and Benoît 2015), overexploitation in the 1970s and 1980s (DFO 2017b), bycatch (Benoît et al. 2010), and overall slow maturation for the species.

Lady crab also occurs as a geographically distinct population in the Northumberland Strait , presumably isolated from populations in the Bay of Fundy and further south (Voutier and Hanson 2008). Much of its nearshore habitat occurs within SBZ SFA 22, where a combination of warm waters, sandy substrate, and salinity likely create ideal habitat. This species plays a key role regulating prey populations of macrobenthic animals (Burchsted and Burchsted 2006).

3.1.2. Threats

There are several threats to the ecological health of the SBZ MRs. Chief among these threats is climate change, which is bringing about shifting thermal regimes for some species, potential impacts of ocean acidification, and the introduction of novel invasive species (Figure 3). Rising water temperatures and lowered predation pressures have coincided with a northward shift in lobster densities in Maine (Steneck and Wahle 2013), with warming bottom temperatures in the sGSL also creating additional suitable habitat for lobster (Asselin et al. 2024). Despite these favorable shifts for adult lobsters, larval stages are vulnerable to changing temperatures. When exposed to temperatures exceeding 20 °C, lobster larvae experience reduced growth, slower development, limitations to settlement (Quinn et al. 2017), and reduced dispersal distances (Quinn et al. 2022). In addition, normal temperature extremes for benthic habitats have been altered, reducing the concentration of dissolved oxygen available for aquatic organisms (Brennan et al. 2016). Ocean acidification presents another climate-related threat that may negatively affect shell-producing species (Mucci et al. 2011; Tai et al. 2021) and influence biological functions in non-shelled organisms due to changing energy demands (DePasquale et al. 2015). Global surface ocean pH levels have dropped by 0.1 over the last 100 years, a decline also recorded in the deepest waters of the Gulf of St. Lawrence (Mucci et al. 2011; Brennan et al. 2016). Climate change could promote the establishment of aquatic invasive species in new environments (Kernan 2015), presenting a risk to the SBZ MRs. European Green Crab (*Carcinus maenas*), in particular, has become established throughout the sGSL, outcompeting lobster in certain habitats (Rayner and McGaw 2019). For a thorough biophysical overview, summary of ongoing research, environmental threats, and analysis of knowledge gaps within the SBZs, see Balbar et al. (2025).

3.1.3. Conservation objectives

Based on the guidance for recognizing marine OECMs (Government of Canada 2022), the purpose of an OECM is to protect marine biodiversity, including at minimum one important

species, one important habitat, and one other benefit, through the provision of long-term BCBs. In this guidance, a BCB is defined as the net positive change in biodiversity or prevention of its loss, resulting from the governance decisions and management actions within an area. We consider the following COs for the SBZ MRs, which are operationalized into ecological monitoring objectives through the current report (Table 1):

1. Protect juvenile American Lobster.
2. Protect juvenile American Lobster habitat and associated benthic environment
3. Protect species and habitat recognized as other benefits, specifically:
    a. spawning grounds for spring and fall Atlantic Herring (SBZ SFA 21, 22, 24),
    b. an endangered (COSEWIC assessed) winter skate population, where the last remaining summer refuge is located within the Northumberland Strait (SBZ SFA 22), and
    c. a disjunct northern population of Lady Crab (SBZ SFA 22).

The priority action for the SBZ MRs is to manage human activities so as to avoid or mitigate disturbance of benthic habitats and communities.

The purpose of this document is to summarize available indicators that could be suitable for core ecological monitoring of the SBZ MRs, as well as highlighting important gaps and other complementary data. The intent does not include evaluating the effectiveness of the MR in achieving the stated COs, which remains conceptually difficult given the timeline of establishment and perceived links of the fishery closure and stated BCBs. By establishing baseline monitoring, however, the impact of novel closures within the SBZ MRs could be evaluated moving forward. The selection of indicators was achieved by first reviewing the most recent biophysical overview of the SBZ MRs (Balbar et al. 2025) summarizing monitoring for the SBZs. Indicators were identified and qualitatively assessed for whether they met suitable criteria (Table S1). Indicators with 6/8 criteria were developed into the monitoring approach in order to balance feasibility (1-3 indicators per CO) with rigor of the indicator (majority of criteria apply). On some occasions, placeholder indicators (i.e., scoring 5/8 or lacking a sound theoretical basis) were selected with the caveat that stronger, more direct, indicators would be needed in the future. The draft monitoring approach was then reviewed by Subject Matter Experts (Table S2) and discussions were held during a workshop (December 2nd, 2025). Notes were taken and feedback was implemented prior to peer review. It is important to acknowledge that this document represents a conceptual exercise to identify the most adequate indicators for ecological monitoring based on currently available data, that this approach will be adapted as novel indicators are developed, and that implementation and operationalization towards a formal monitoring work plan depends on further peer review (i.e., CSAS) and additional factors such as funding, human resources, and regional priorities.

3.2. CO1. Protect juvenile American Lobster

3.2.1. Core monitoring and opportunities for targeted research

3.2.1.a. Juvenile lobster density

The protection of juvenile lobster is the primary conservation objective of the SBZ MRs. Scallop harvesting has the potential to destroy or otherwise disturb benthic habitat occupied by juvenile lobster and other species in areas where lobster and scallops overlap. Given that this fishery is prohibited within the SBZ MRs, the ecological impacts of this pressure cannot be monitored. Monitoring should therefore focus on the health and status of important species relevant to the COs of the SBZ MRs. For juvenile lobster, two existing and minimally invasive surveys for stock assessments can be leveraged for density indicators: SCUBA and Bio-Collector surveys (Figure 4). Given limitations linking these data to the conservation objective, these indicators are placeholders until an indicator with a stronger theoretical basis can be established (see below; Table S1). SCUBA surveys for juveniles were initiated in 2000 with the objective of estimating juvenile lobster density (CL 21–40 mm) from rocky shore habitat up to 10 m of depth (Asselin et al. 2024; Figure 5). Bio-Collector Surveys were established in 2008 in collaboration with industry groups and the Government of Prince Edward Island to monitor the settlement of young-of-year lobster on rectangular metal cages with cobble and gravel, mimicking their preferred habitat (Figure 6). Thirty bio-collectors are deployed annually at each site (Figure 4).

The SCUBA and Bio-Collector Survey were not designed to monitor the SBZs or the full size range of juveniles (~5–40 CL), and sites do not occur evenly across the SBZ area (Figure 4).

Direct measurements of juvenile lobster densities may not be a viable long term monitoring method due to the low coverage within the SBZ MRs and the difficulty in observing and quantifying this small and cryptic life stage of lobster. Targeted research to create a species distribution model using inputs from additional surveys within the Northumberland Strait with greater geographic coverage and amounts of data may be needed to derive meaningful density measurements inside the SBZ MRs. These projections would also be useful for estimating the density or abundance of other conservation benefits.

3.3. CO2. Protect juvenile American Lobster habitat

3.3.1. Core monitoring and opportunities for targeted research

3.3.1.a. Water temperature

Temperature is broadly used as a proxy for suitable habitat in a wide range of species. While we apply temperature as a juvenile lobster habitat indicator here, it also serves as important complementary data for the other COs. In Atlantic Canada, lobster have been known to inhabit water with a wide range of seasonal temperatures, between -1 and 26 °C (Lawton and Lavalli 1995, Quinn 2017). Information is available on the optimal temperatures for adult lobsters using laboratory studies, which indicated a preferred range between 12 and 18 °C (Crossin et al. 2018). In larvae particularly, temperatures above 20 °C and up to 26 °C have been shown to create stress and inhibit molting, growth, hatching, and settlement, whereas even short-term exposure to temperatures above 28 °C have resulted in mortality (Quinn 2017). Mean daily benthic temperature is the proposed indicator for suitability of juvenile lobster habitat. These data will be leveraged from DFO's Coastal Temperature Monitoring Program in the sGSL, which has been deploying temperature loggers using navigational buoys or moorings throughout the sGSL since 1995 (Ouellet and Gagnon 2025; DFO 2025). This monitoring program provides surface and benthic temperature readings for sites throughout the sGSL. Forty-three percent of stations (n=121) occur within the SBZ MRs, though there is a clear bias towards SBZ SFA 24, and little data for SBZ SFA 21. Yearly temperature profiles should be monitored for changes, paying special attention to the minimum optimal settling temperature of 12 °C and upper threshold for onset of various types of stress at 20 °C, along with the "window of settlement" (onset and termination of rolling 7-day mean temperature above 12 °C, and number of days above 12 °C; Figures 7 and 8). Maximum temperature thresholds, or ideal temperature ranges, should also be explored and specifically validated for juvenile lobsters (research is ongoing by Drolet et al. pers. comm.) in order to inform on long-term habitat suitability and possible species range shifts in light of climate change pressures. This is especially important since research has shown that adult lobsters' thermal tolerance can depend on the temperatures to which they are already acclimated (i.e., lobsters that are acclimated to warmer waters can tolerate higher temperatures; Horricks et al. 2024).

Monitoring for this CO would benefit from other proxies for suitable habitat. Benthic habitat mapping and species distribution modelling can address challenges with sampling coverage of the SBZ MRs by providing spatially continuous predictions for the presence of lobster or other conservation benefit species. These outputs would inform monitoring by 1) estimating the total amount of suitable habitat provided by the SBZ MRs and how this might fluctuate through time, and 2) identify high priority locations for monitoring where species of interest are expected to occur. The mapping of complex substrates ideal for juvenile lobsters would serve as a direct

indicator for habitat, and would be a good area of research to prioritize to better inform this CO (Table S1).

To achieve the desired outputs, species distribution modelling can be used to couple species occurrences with environmental data. Underwater imagery data collected in collaboration with Dalhousie University is currently being explored to profile species and substrate characteristics both within and outside the SBZ MRs, with initial results obtained in 2024. The annotations can be used for community level analyses (see 3.3.1.b. *Abundance and diversity of benthic fish and invertebrates*). These data could help close a major research gap by mapping suitable habitats for important and other conservation species within the SBZ MRs, not only by documenting species occurrences but also by associating them with specific substrate types. Additionally, the data could support the integration of artificial intelligence workflows to annotate imagery, offering a more efficient and streamlined approach to future biodiversity monitoring. However, preliminary data have shown that benthic habitat in the Northumberland Strait is highly dynamic and heterogeneous with regards to sediment type and transportation (e.g., Shaw et al. 2008). Further targeted research is needed to understand if mapping can provide a solid basis for habitat characterization or if the bottom type changes too quickly to provide reliable information that can be operationalized long-term (Balbar et al. 2025).

3.3.1.b. Diversity of benthic fish and crustaceans

Juvenile lobster live in an environment that includes many other species. Some are prey sources for lobster (e.g., Rock Crab; Hanson 2009) while others are direct competitors for space and resources (e.g., Green Crab; Rayner and McGaw 2019). Other species act as “sentinels” for benthic habitat condition, and with the appropriate workflow, sentinel species that are more sensitive to particular pressures can be identified against a background of typical species (Serrano et al. 2022). The health and status of conservation species and their habitat are intrinsically linked to the broader ecosystem. In recognition of this link, fisheries are moving from a single stock focus to an Ecosystem Approach to Fisheries Management in order to better inform on decisions making (Pepin et al. 2023), setting a precedence for the link we make here between biodiversity indicators and the conservation focus of lobster habitat.

The Northumberland Strait Multi-Species Trawl Survey (NS Survey) has been operating since 1999, and has seen various iterations in methodology and standardization (Asselin et al. 2021, 2024). Notably for the monitoring proposed here, different gear types and tow durations have been used throughout the history of the NS Survey. From 2001–2009 and 2012–2018, the survey was conducted using 15-minute tows and a number 286 otter trawl equipped with rubber “rockhopper” footgear and otter trawl doors. A Bigounden Nephrops trawl using 5-minute tows was used in 2010 and 2011; these data are excluded from analyses due to a lack of calibration standardizing the catch data to years before and after. In 2019, the Northumberland trawl was introduced using 10-minute tows. Comparative fishing analyses were conducted to calibrate previous catch data (using the no. 286 otter trawl) to the newly implemented Northumberland trawl (Asselin et al. 2021, 2024). The NS Survey operates during July-August and records catch weight, length frequencies, and counts for all fish species and crabs (Figure 9), as well as weight of all other organisms.

Biodiversity indicators directly linking to lobster habitat remain to be developed, however, placeholder indicators can be used in the meantime to leverage the existing datasets. Two indicators are proposed, each using species counts converted to presence-absence data (to partially address calibration limitations) from the NS Survey, assessing fish and crustacean

species identified from 2005 onwards (non-species level identifications and species with less than 10 reports in the dataset are removed to reduce noise). First, species richness will be measured across years for each of the SBZs SFAs 22 and 24 (insufficient data for SBZ SFA 21). Trends for increasing or decreasing biodiversity will be evaluated at the level of trawl samples (Figure 10). Second, community composition in the form of presence-absence data will be evaluated yearly, evaluating species composition for SBZs SFAs 22 and 24 separately (Figure 11; initial analyses indicated an effect of SBZ on community composition; Figure S2). Heatmaps will also inform on species driving differences across years (Figure S3 and S4).

DNA technology has emerged as a promising biodiversity monitoring technique that differs fundamentally from traditional approaches requiring physical specimen collection (e.g., trawl-based surveys). eDNA is genetic material left in the environment (water, soil, air) by organisms, which can be used to sequence taxonomically informative DNA markers that identify and delineate taxa (Çevik and Çevik 2025). eDNA is fast and cost efficient on a per sample, per ID basis, given it offers simultaneous information on a wide array of taxa (e.g., bacteria to fungi to fish) without the inherent need for taxonomic expertise (Beng and Corlett 2020). The simple and minimally invasive sampling protocols are especially amendable to MRs or MPAs that prohibit activities destructive to protected flora, fauna, and habitat. Moreover, eDNA is being widely adopted at DFO (e.g., Aquatic Invasive Species [AIS] detections: Abbott et al. 2021; targeted species detection: Wringe et al. 2023; inferring community structure: Trask et al. 2025), providing a link between efforts regionally and nationally. eDNA collection was initiated in the SBZ MRs in 2024. Initial results were promising, with eDNA detections for fish and invertebrates from both within and outside the SBZ MRs. It is expected that the eDNA approach could eventually complement the trawl-based datasets, providing a better overall picture of biodiversity (eDNA) and relative abundances of species (trawl-based surveys). eDNA will also provide opportunities to develop new community level indicators, such as phylogenetic diversity, and standardize species detection methods across geographic scales (for instance, comparing results at regional to national levels). Moving forward, the main priorities to onboarding eDNA for ecological monitoring within the SBZ MRs are to 1) ensure samples are representative of the local biological community (i.e., DNA transport and temporal integrity must be considered; Jo et al. 2025), 2) establish methods for sampling that are consistent and comparable across years, and 3) build up the dataset to establish a baseline for monitoring.

3.4. CO3. Protect other species and habitat recognized as other benefits

3.4.1 Core monitoring and opportunities for targeted research

3.4.1.a. Atlantic Herring biomass

The protection of benthic habitat can have several benefits to herring. The afforded protection against scallop harvesting within the SBZ MRs can help maintain structural complexity and vegetation cover, which are essential for successful herring spawning, hatching, and larval/juvenile survival (Messieh 1987, von Nordheim et al. 2018, Burbank et al. 2023, Burbank et al. 2025). A direct indicator for habitat is lacking at this time, though targeted research is underway (see below). For now, an indirect indicator of habitat use by herring can be developed from the spawning ground acoustic survey conducted in collaboration with industry since 2015, which provides relative biomass indices for fall spawning herring within some portions of the SBZ (near Escuminac, Pictou and Fisherman's Bank off East, Prince Edward Island; Figure 12). For the survey, a fisher follows randomly generated parallel transects ~400 meters apart in each

predetermined survey area once a week over 5 weeks during the fall spawning season, collecting acoustic data using a side mounted scientific echosounder on their fishing vessel. The echograms are then processed using the Echoview software, and acoustic biomass is estimated (See Turcotte et al. 2022 for details). This relative biomass is the proposed placeholder indicator for herring fall spawning within specific portions of the SBZs SFAs 22 and 24 until a more direct indicator can be developed. The fishery-independent acoustic survey in the Baie des Chaleurs region occurs each fall (mid September-mid October), with a portion of the survey conducted in SBZ SFA 21. During this time, fall spawners are found to be spawning and feeding (following spawning) and a substantial portion of spring spawners are also present and aggregating to feed in the survey area. The survey utilizes both a scientific acoustic vessel and a second vessel equipped with a trawl to collect biological samples to help determine the size composition and relative proportions of spring and fall spawners present. The acoustic vessel follows randomly generated parallel transects in 18 predetermined strata (LeBlanc and Dale 1996, Maynard et al. 2024). The survey estimates the relative biomass of both spring and fall spawners in the region, and expands the biomass indicator for both spring and fall spawning herring to a portion of SBZ SFA 21 (Figure 13).

Targeted research should prioritize the establishment of novel indicators more directly linked to habitat usage by herring. For spring spawning herring, a spawning event survey was initiated in 2022 and tracks the number and location of spawn events reported by fishers, pilots and the general public (Figure 14). When possible, spawning sites were visited and habitat information was collected including temperature, dissolved oxygen, and macrophyte type and cover (all potential indicators for herring). The continuation of this survey would allow the number of spawning events occurring in the SBZ to be tracked through time and coarse habitat evaluations to identify if suitable habitat is consistently available and being targeted by spring spawning herring for reproduction. Furthermore, targeted research on defining suitable spring herring spawning habitat in the sGSL is being conducted. Both observational and laboratory rearing are being used to examine the influence of aquatic vegetation type and quality on egg density to better elucidate the role of habitat features, particularly, aquatic vegetation on early life survival. Once spawning habitat is better understood, this information can be leveraged to develop a habitat suitability model for estimating the proportion of the SBZs that is suitable spring spawning Atlantic Herring.

3.4.1.b. Winter Skate density

Winter Skate, a species with a population largely unique to SBZ SFA 22 (COSEWIC 2015), is among the other BCB species identified for monitoring. Density (individuals per m²) is the chosen indicator, estimated from NS Survey data within the SBZ MRs to track annual changes (Figure 15). Trawl coverage in the MRs is limited (see 4. Knowledge gaps and opportunities), and no surveys currently target Winter Skate directly. Therefore, this indicator is provisional until more direct monitoring can be developed.

3.4.1.c. Lady Crab density

Lady Crab is another BCB species of interest for monitoring within the SBZs, with an isolated population in SBZ SFA 22 (Voutier and Hanson 2008). The chosen indicator is density (individuals per m^2) estimated from the NS Survey data (Figure 15). As with Winter Skate, this indicator is a placeholder until limitations associated with leveraging NS Survey data can be addressed with targeted research.

3.5. Complementary data

Complementary data provide potential context for interpreting the core indicators detailed above. Data are available through several existing surveys specifically designed to provide indices on the abundance and health of demersal fish and invertebrates (Table 2). Pre-fishery lobster (51–70 mm) provide context for understanding the density of juvenile lobster in the SBZ MRs; these data can be derived from the NS Survey data (Figure S5). Other noteworthy surveys include: the September Research Vessel (RV) Survey, which has been occurring annually in the sGSL since 1971, but only overlaps minimally with a portion of SBZ SFA 24 (Balbar et al. 2025); the historical Scallop Survey, which began in 2000 but was discontinued in 2020, and provides records for scallop and other benthic species (including lobster) caught in drag nets deployed within the Northumberland Strait but generally outside the SBZ MRs; and lobster landings data dating back to 1947, which provide longer term context for interpreting adult lobster densities. In terms of habitat indicators, benthic temperature is the focus given the link to juvenile lobster settlement, but Sea Surface Temperatures (SST) are also available through the Coastal Temperature Monitoring Program of the sGSL, providing context for dispersal of earlier life stages. SST could also provide a reliable indicator for benthic conditions in non-stratified bodies of water (Yang et al. 2026), as in the nearshore habitat targeted through the proposed monitoring for SBZ MRs. Modelled SST, such as those provided through the E.U. Copernicus Marine Service Information (https://doi.org/10.48670/moi-00021) could provide further coverage. The retention and export of lobster larvae, both within the SBZ MRs but also across the sGSL, would provide context for changes in juvenile lobster density (Chassé and Miller 2010, Quinn et. al. 2017). Current profiler data could be sourced to model sink-source dynamics. Information on thermal limits for larval stages can also be linked to temperatures in the SBZ MRs (Annis et al. 2026). Finally, the Gulf Region AIS Biofouling monitoring program provides data dating back to 2018 and throughout the SBZ MRs, and records settlement of species on PVC plates along with several environmental parameters. These data provide early warning detections for AIS that could disrupt ecological processes within the SBZ MRs.

4. KNOWLEDGE GAPS AND OPPORTUNITIES

This section describes priority gaps in terms of the scientific knowledge generated and how this can better inform core monitoring. Operationally, the next steps in implementing and further developing this ecological monitoring approach depend on several factors, including funding, regional priorities and human resources required to carry out the work.

Many biological thresholds for the indicators listed here (Table 1) remain unknown at this time. The indicators are primarily density estimates, and establishing critical density thresholds for a healthy ecosystem within the SBZ MRs is not realistic. Scoring indicators and reporting the magnitude of changes, such as in DFO (2023), could be considered for conceptualizing monitoring thresholds. Comparative analyses inside and outside the SBZ MRs could also provide context for thresholds and MR efficacy.

Leveraging existing surveys to inform monitoring of the SBZ MRs come with inherent limitations. Trawl surveys employ a randomized design over a broad spatial extent, so coverage within the SBZ MRs is inconsistent among years (Figure 9). In addition, portions of the seafloor are not

trawlable and trawl surveys are limited by the operational depths of the research vessels (e.g., the NS Survey is restricted to waters deeper than 5 m). Deriving density estimates for species from trawls within a subset of the larger survey may be insufficient to detect change. To address this limitation, a transition toward a model-based monitoring framework should be considered to interpolate or predict density of conservation species within the SBZ MRs.

Power analyses, the determination of sample sizes required to detect specified degrees of change, should be incorporated as soon as possible because the ability to detect statistically supported changes in the proposed monitoring of indicators remains unknown at this time. These should ideally be applied to each indicator and accompanying dataset. A critical step in these power analyses will be to determine what constitutes biologically meaningful change within the context of the proposed indicators. Once completed, these power analyses may help to determine if the current surveys have sufficient power to measure relevant change in the proposed indicators (Morris et al. 2024). This in turn will inform routine monitoring, either by increasing or decreasing sampling effort accordingly, or shifting an indicator to something more feasible if sampling effort cannot be scaled to address detection limitations.

Another major consideration here is the scalability of monitoring and the size of the SBZ MRs. There are persistent geographic gaps in sampling within the SBZ MRs, specifically within SBZ SFA 21 (Baie des Chaleurs), and portions of SBZ SFA 24 along the Cape Breton Coast (e.g. Figures 4 and 9). Evidently, the current monitoring approach is susceptible to missing crucial insights from these areas. New monitoring programs or collaborations would be needed to fill these spatial gaps in sampling. Knowledge gaps also center around suitable habitat mapping and the utility of these data long term given the dynamic nature of the benthos within the Northumberland Strait.

Core monitoring includes some data collection performed by stakeholders and agencies external to DFO using scientifically validated protocols. For monitoring to be successful long-term, the quality of data coming from multiple sources must be evaluated prior to incorporation into reports. The reliance on programs external to the DFO MCT program also leaves vulnerabilities in the core monitoring proposed here. While proposed monitoring relies on the continuance of non-MCT led monitoring programs, enhancing efficiencies by leveraging existing datasets bolsters the justification for these monitoring programs to continue moving forward.

5. DATA MANAGEMENT AND REPORTING

Informal reporting to management and other stakeholders should be performed on a yearly basis to prevent data backlog, ensure timely analysis, and provide up to date insights on emerging trends to be used in decision making. Automation must be considered to promote efficiency. Currently, the proposed indicators can be reanalyzed with established R code; assuming a reasonable timeframe to access data, the user would update the master datasheets for the proposed indicators and rerun the code. This can be further automated to produce a single workflow of all indicator datasets and publication into a standardized “report card” on the status and health of the conservation area. Interactive web applications are also being considered as data/result portals for internal and external stakeholders and to ensure DFO’s open data standards are being met.

Formal reporting should follow a regular publication cycle targeting a wider scientific audience. This can be achieved using DFO manuscript reports providing status and health updates on the conservation areas, acting as checkpoints on a 3 year cycle or earlier depending on whether notable and prescient trends emerge. Published status updates should be clear on the status of the monitoring approach and whether it has passed into a long term monitoring plan. In order to achieve and maintain a monitoring plan, a CSAS should be conducted as soon as feasible and then following a regular cycle (i.e. every 5 years) in order to review, validate, and update indicators. Note, the proposed reporting cycles are dependent on funding, human resources, and regional priorities.

6. CONCLUSIONS

Establishing long-term monitoring of validated core indicators is needed for the SBZ MRs to achieve their COs. This document represents the initial conceptual framework detailing proposed indicators and accompanying sources of currently available data for monitoring the SBZ MRs. The proposed indicators for monitoring are primarily in Stage 3 (validity and feasibility assessment through further data collection and analysis), however, several are placeholders until more direct indicators can be developed. Ongoing and new targeted research can be utilized to fill these knowledge gaps, particularly developing new indicators for suitable habitat area within the SBZ MRs for each conservation species, substrate profiles relevant to lobster habitat, and spawning events/habitat for herring. Targeted research is also addressing detection methods for conservation species outside DFO surveys identified here, including underwater video footage and eDNA. Several sources of complementary data have been identified, particularly lobster landings data and alternative surveys for benthic species. Several years of data collection and analysis are needed to pass all proposed indicators into stage 4 where they can be subjected to scientific peer-review (CSAS) and form the basis for a long-term monitoring plan. This monitoring approach is not meant to be prescriptive, but is intended to be adaptive as new data and better indicators become available dependent on funding, human resources, and regional priorities. Nonetheless, the monitoring approach presented here represents a significant checkpoint for the SBZ MRs, providing direction for monitoring moving forward.

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Table 1. Core ecological monitoring indicators for Scallop Buffer Zone Marine Refuges. See Figure 2 for status stage definitions.

Conservation objective	Operational objective	Indicator	Starting reference point	Threshold	Survey(s)	Frequency	Stage
Protect juvenile American Lobster	*1. Monitor for changes in the density of **juvenile lobster***	Number of lobsters per transect; Juvenile lobster density (number per 100 or 1 m^2, respectively)	2010; 2000	TBD	Gulf SCUBA surveys; Bio-Collectors	Annual	3
Protect juvenile American Lobster habitat and associated benthic environment	*1. Monitor for changes in benthic **temperatures***	Mean daily temperature (^oC)	1995	Min 12^oC for juvenile settlement Max and optimal range for juveniles TBD	Coastal Temperature Monitoring Program in the sGSL	Annual	3
	*2. Monitor for changes to the **diversity** of fish and crustaceans year over year*	Species richness, non-Metric Multidimensional Scaling	2012	Any significant year on year shift in community composition	Gulf Northumberland Multi-Species Trawl Survey	Annual	2–3
Protect species and habitat recognized as other benefits, specifically (a) spawning grounds for spring and fall Atlantic herring (SBZ SFA 21, 22,	*1. Monitor for changes in spring and fall spawning **Atlantic Herring** biomass from SBZ SFA 21; biomass of fall Atlantic Herring on spawning ground from SBZs SFAs 22 and 24*	Relative Biomass (tonnes)	1994; 2015	TBD	Gulf Acoustic Surveys	Annual	3

24), (b) Winter Skate (SBZ SFA 22), and (c) Lady Crab (SBZ SFA 22)	*2. Monitor for changes in the density of **Winter Skate** from SBZ SFA 22*	Density (individuals per m^2)	2003	TBD	Gulf Northumberland Multi-Species Trawl Survey	Annual	3
	*3. Monitor for changes in the density of **Lady Crab** from SBZ SFA 22*	Density (individuals per m^2)	2001	TBD	Gulf Northumberland Multi-Species Trawl Survey	Annual	3

Table 2. Ongoing targeted research and complementary surveys relevant for ecological monitoring of the Scallop Buffer Zone Marine Refuges.

Organization	Survey/dataset	Monitoring type	Reference point	Potential indicator(s)	Frequency
DFO Science Gulf	DFO lobster landing data	Complementary	1947	Lobster landings (t)	Annual
DFO Science Gulf	Gulf Northumberland Multi-Species Trawl Survey	Complementary	2004	Species relative tow densities	Annual
Craig Brown, Dalhousie University	Suitable habitat mapping	Targeted	2024	Suitable habitat area (km^2) of species	TBD
Craig Brown, Dalhousie University	Drop camera surveys	Targeted	2024	Number of species per transect	TBD
DFO Science Gulf	Sea Scallop surveys	Complementary	2012	Species relative tow densities	Annual
DFO Science Gulf	eDNA surveys	Targeted	2024	Community composition (fish and invertebrates)	Annual
DFO Gulf Science	Spring herring spawning events and habitat	Targeted	2022	Number of spawning events in SBZ and habitat quality/suitability	Annual
DFO Science Gulf	September RV survey	Complementary	1971	Species relative tow densities	Annual
E.U. Copernicus Marine Service Information	Global Ocean Physics Reanalysis	Complementary	1993	SST	Daily

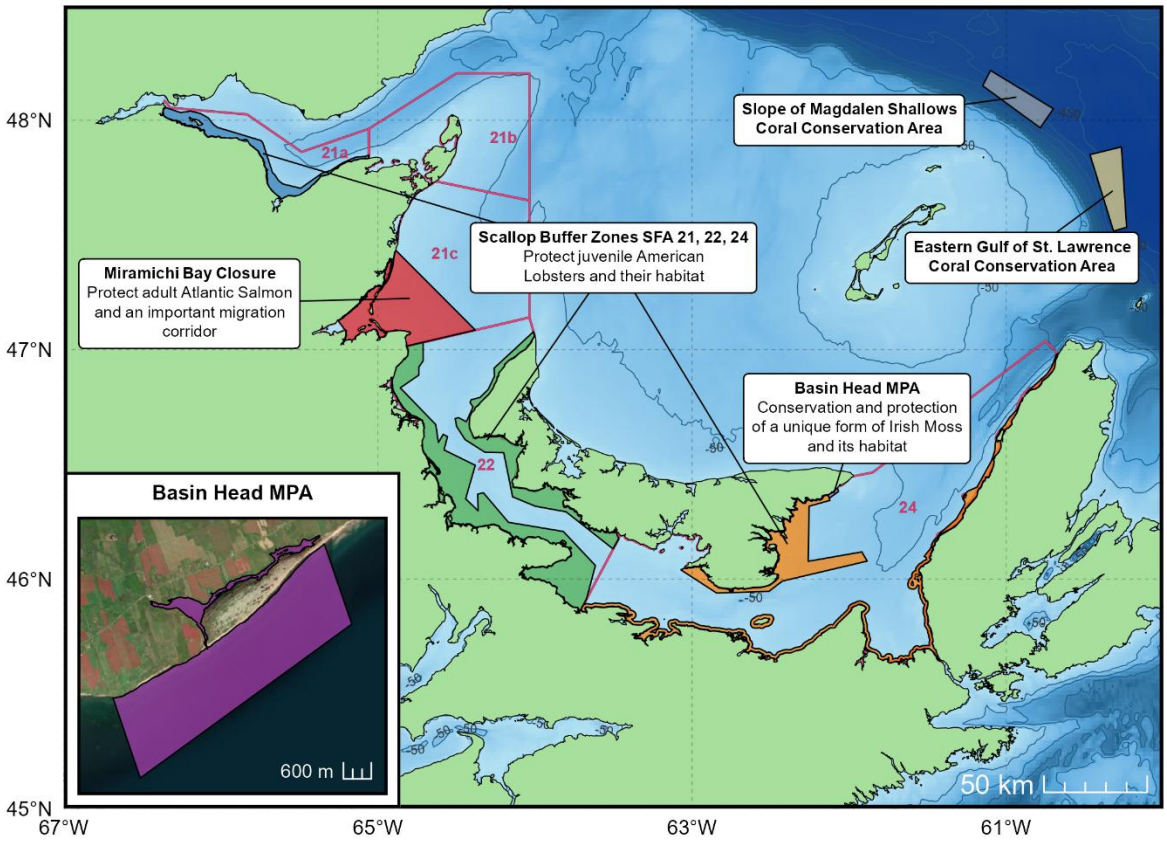


Figure. 1. Conservation areas in the southern Gulf of St. Lawrence managed by DFO Gulf Region. Area-based conservation measures are denoted by coloured polygons. Scallop Fishing Areas (SFAs) are labelled in pink.

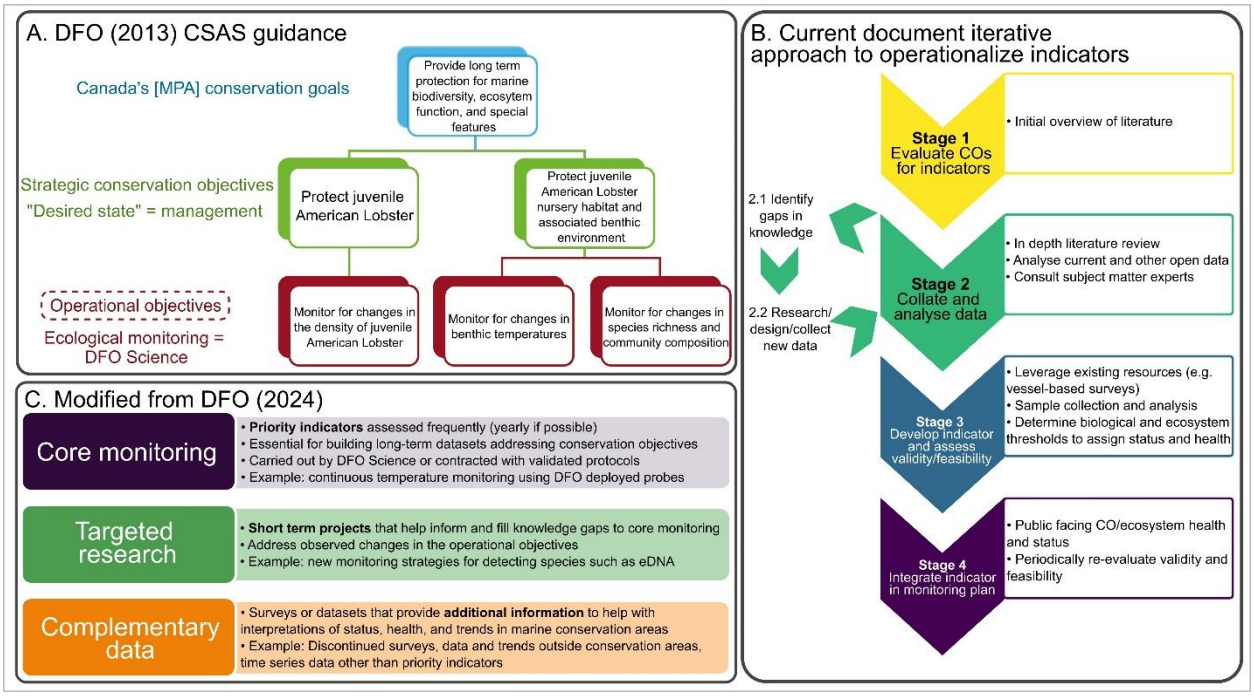


Figure 2. Conceptual approach to ecological monitoring, including A) how conservation objectives are unpacked from national to site level objectives, B) categories for data types used in monitoring, and 3) stages to developing indicators for ecological monitoring.

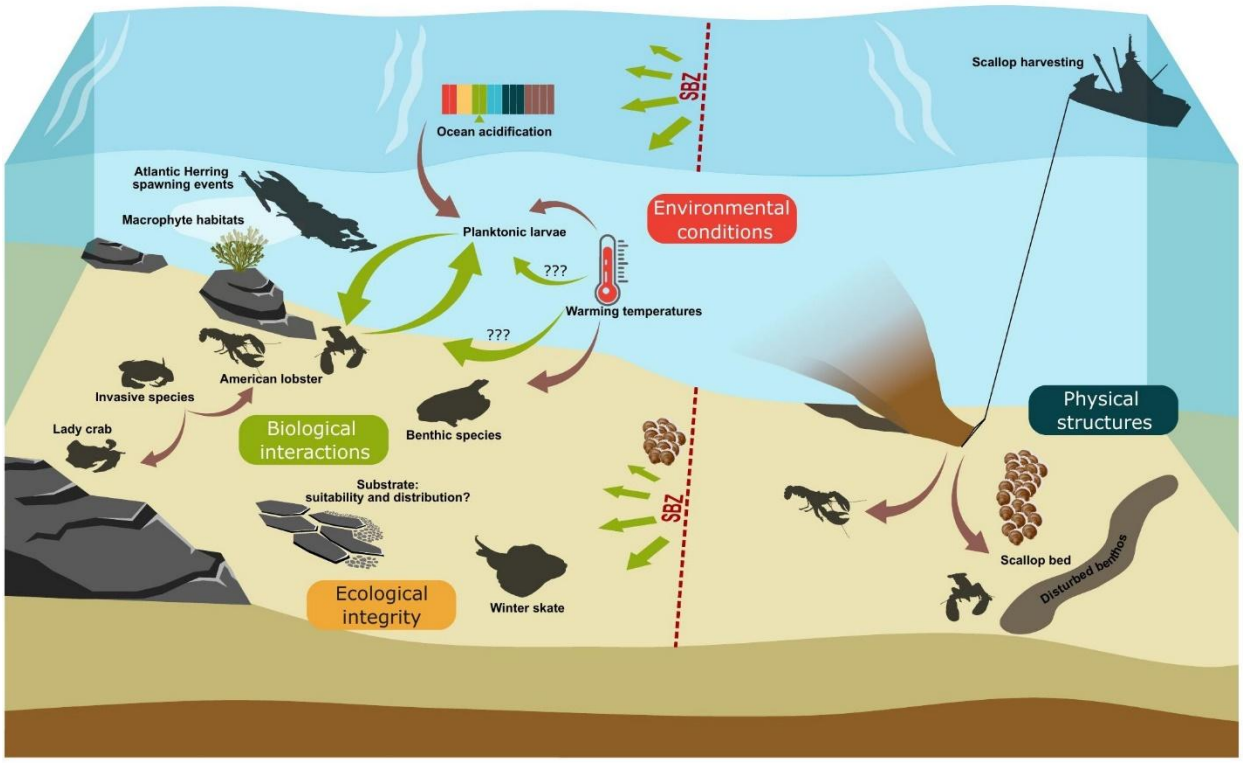


Figure 3. Conceptual diagram of ecological pressures within the Scallop Buffer Zone Marine Refuges.

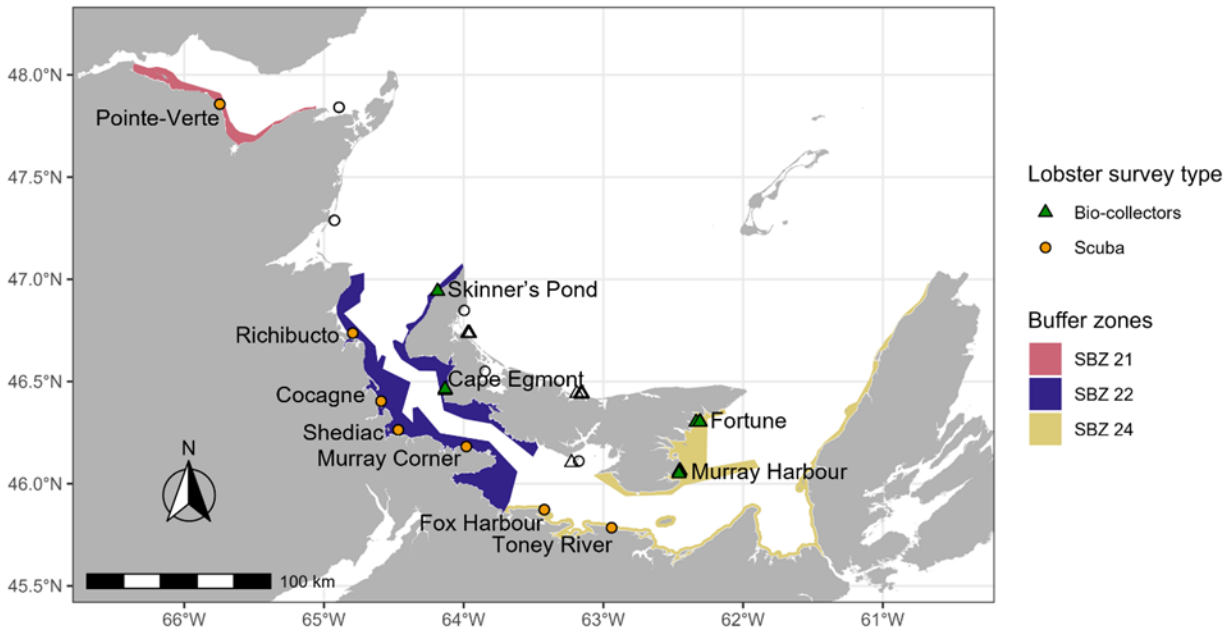


Figure 4. Map of bio-collector and SCUBA research sites by DFO science in the southern Gulf of St. Lawrence. Transparent points are not within the Scallop Buffer Zones.

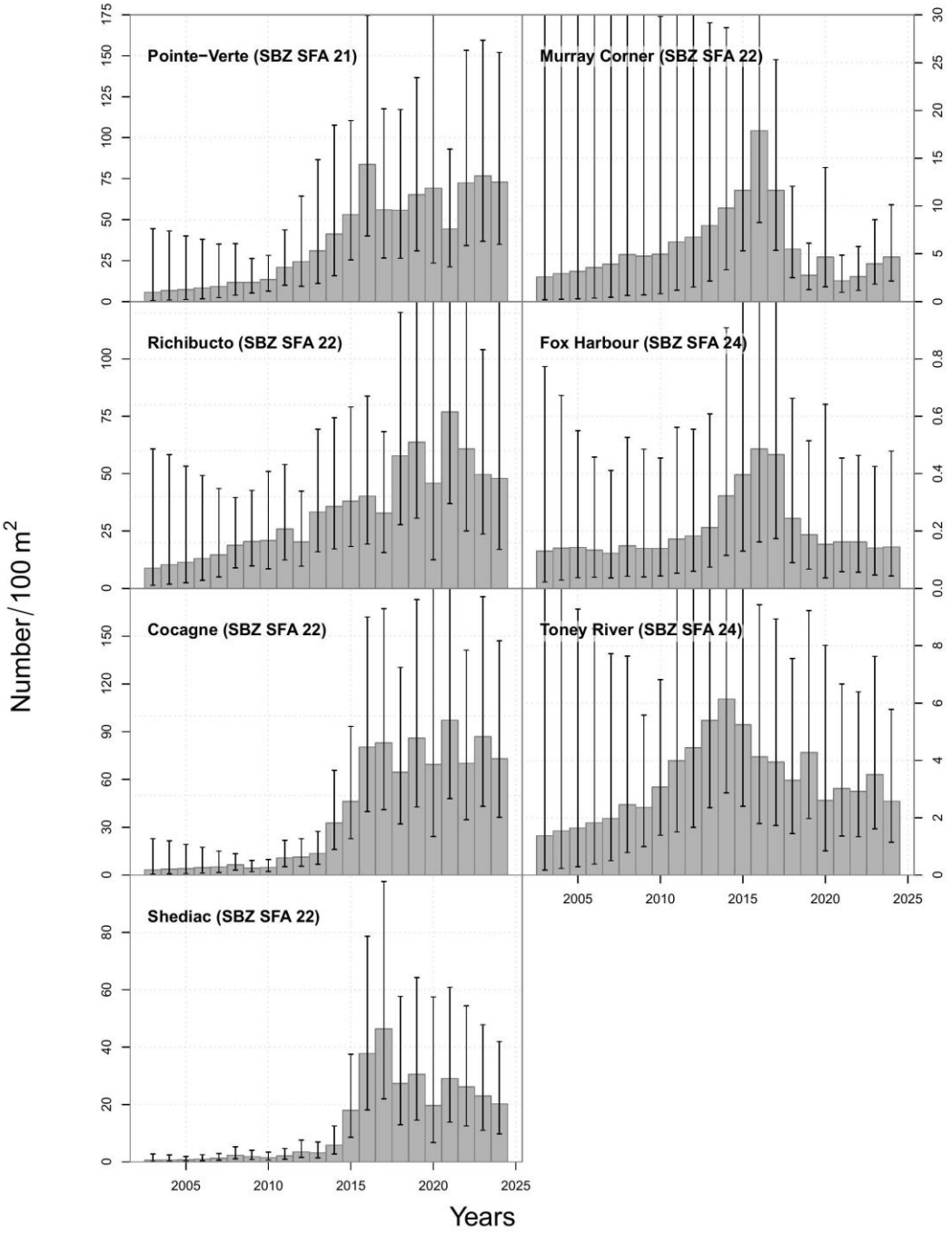


Figure 5. Time series of lobster recruitment indices (carapace length 21 – 40 mm) by study site from the SCUBA transect analysis, 2003 to 2024. Confidence intervals (95%) are shown as vertical black bars. Note: the range of values for the y-axis is defined for each study site.

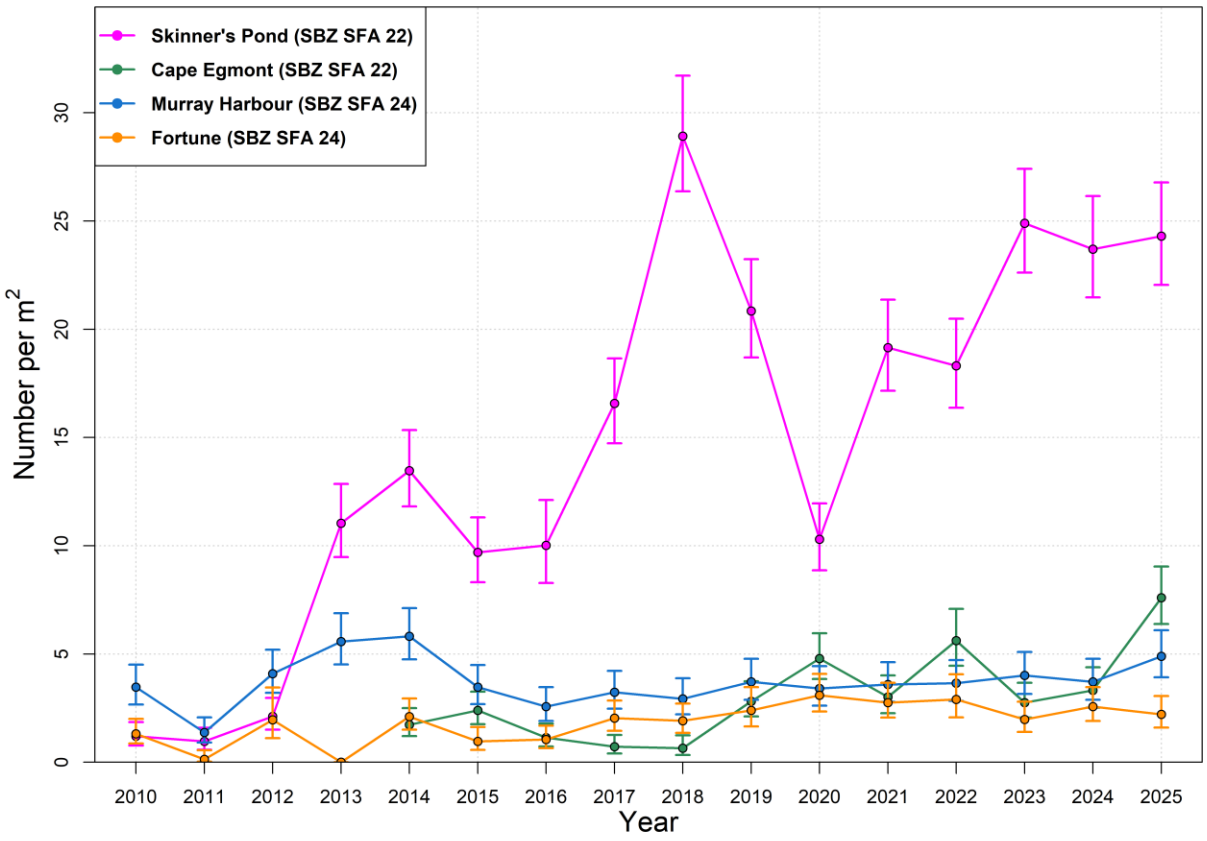


Figure 6. Density of juvenile lobsters with a carapace length less than 40 mm from bio-collectors at four locations within Scallop Buffer Zones in the southern Gulf of St. Lawrence. Prepared using bio-collector data analysis methods described in Asselin et al. 2024.

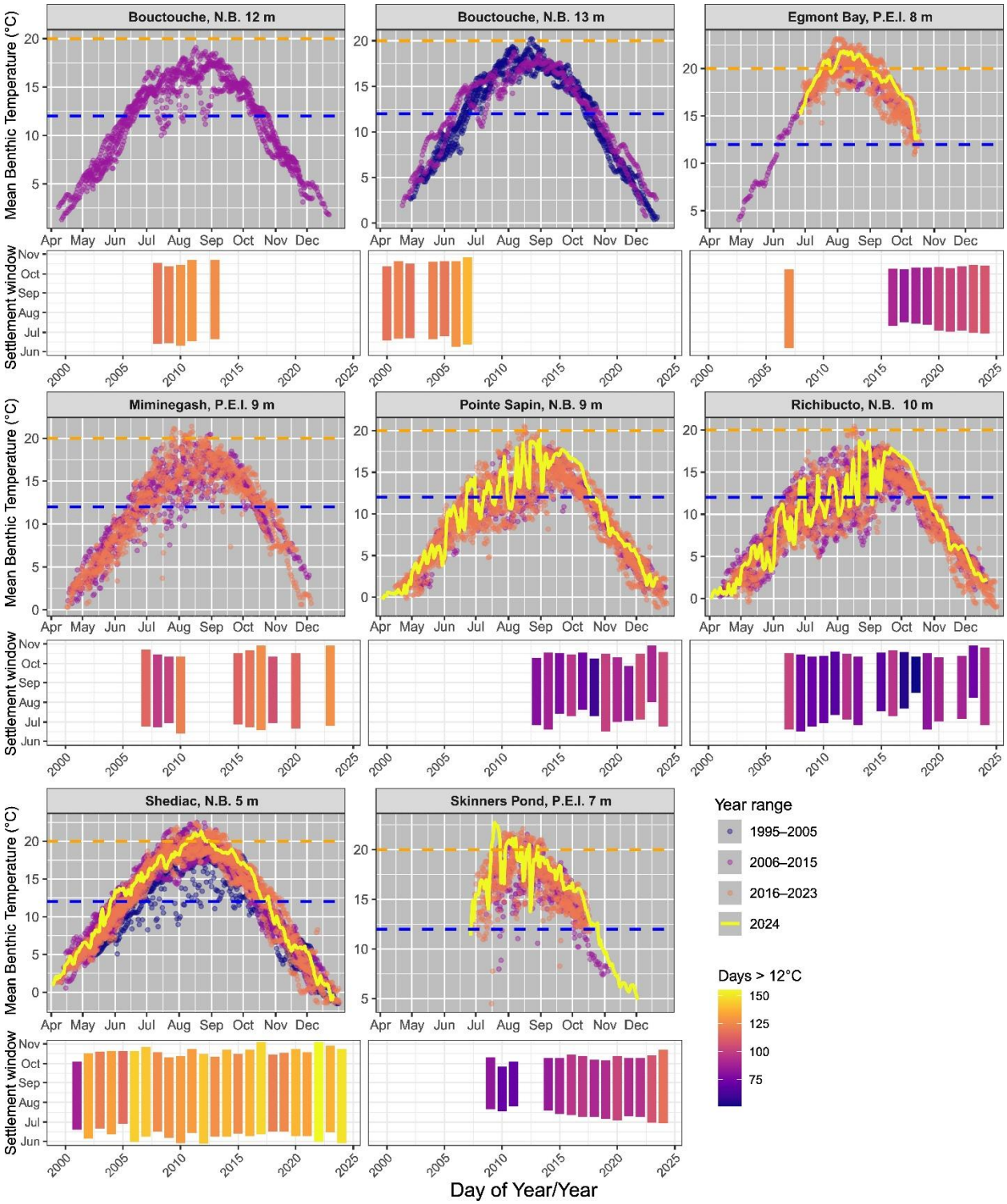


Figure 7. Daily mean benthic temperatures and settlement window (rolling mean above 12 °C) for juvenile lobster for various site-depth combinations in Scallop Buffer Zone Scallop Fishing Area 22 from the Coastal Temperature Monitoring Program in the Southern Gulf of St. Lawrence. The blue dashed line represents the minimum optimal temperature above which juvenile lobster settle onto the benthos (12 °C), the orange line (20 °C) represents onset of stress.

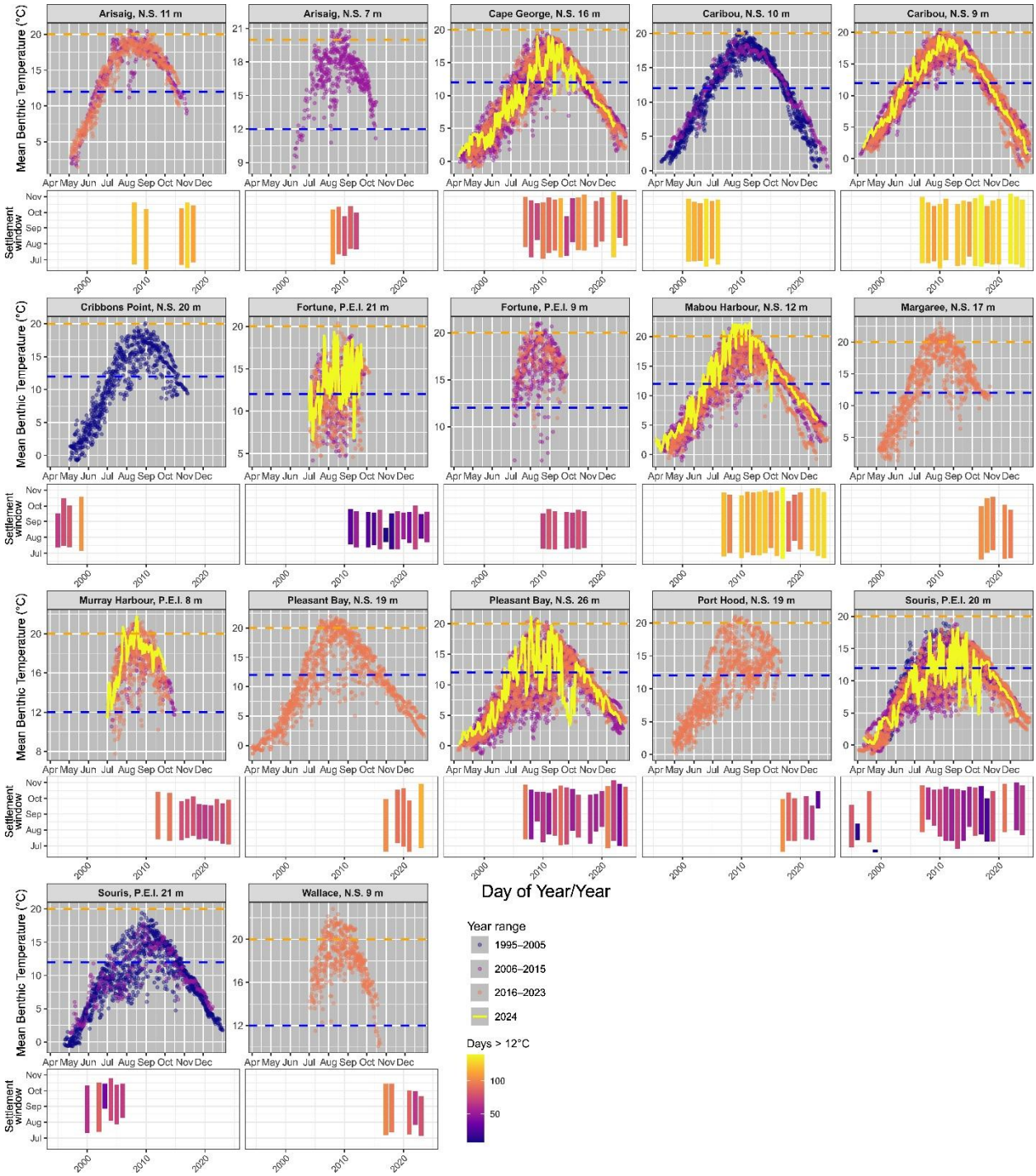


Figure 8. Daily mean benthic temperatures and settlement window (rolling mean above 12 °C) for juvenile lobster for various site-depth combinations in Scallop Buffer Zone Scallop Fishing Area 24 from the Coastal Temperature Monitoring Program in the Southern Gulf of St. Lawrence. The blue dashed line represents the minimum optimal temperature above which juvenile lobster settle onto the benthos (12 °C), the orange line (20 °C) represents onset of stress.

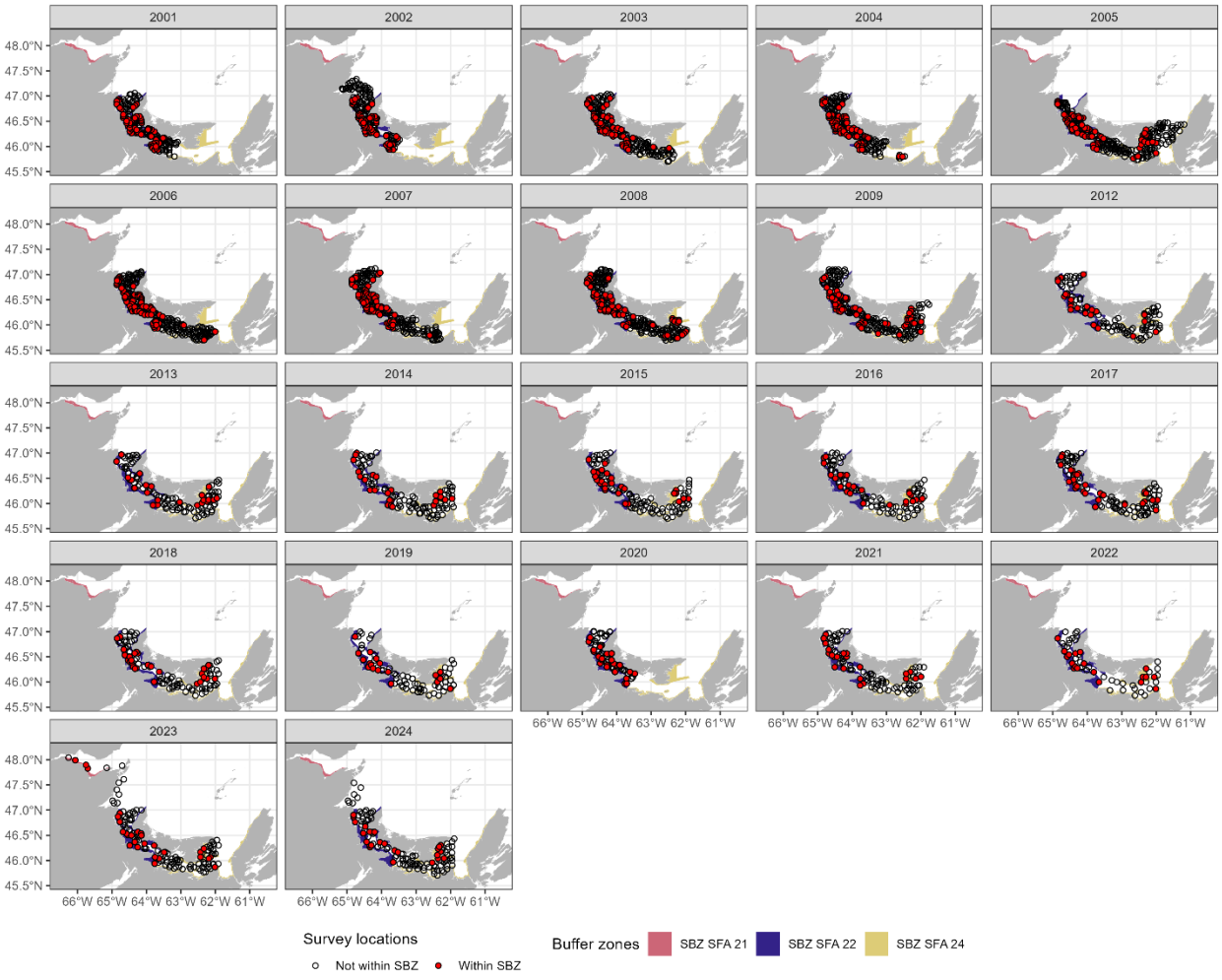


Figure 9. Locations of DFO Northumberland Strait Multi-Species Trawl Surveys from 2000–2024.

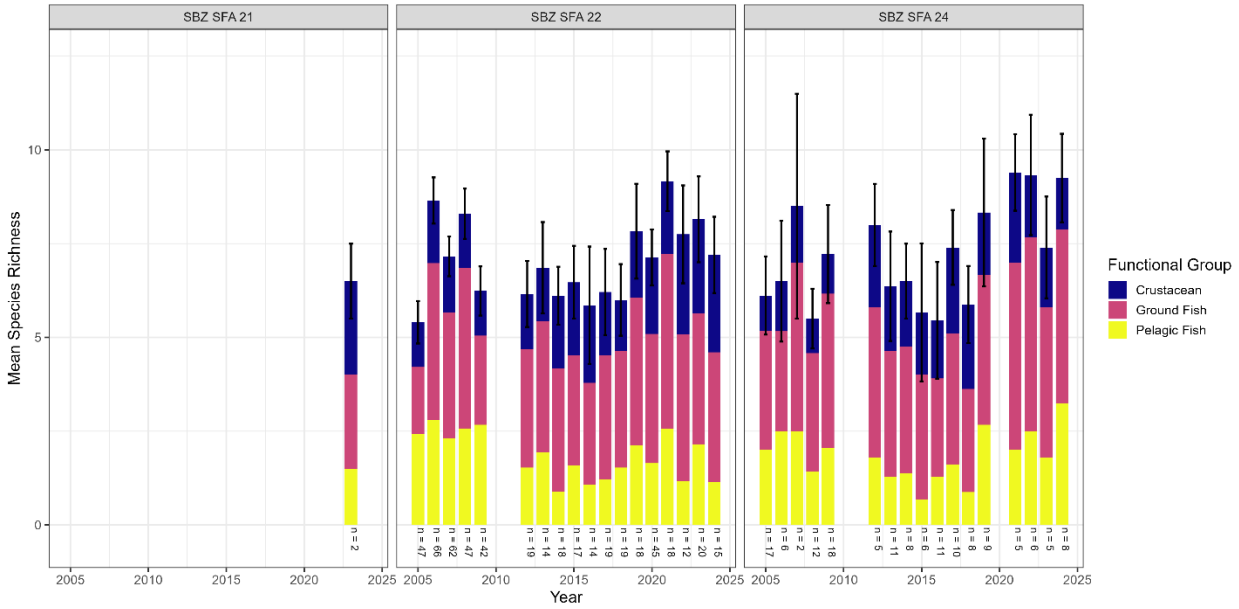


Figure 10. Species richness within the Scallop Buffer Zone Marine Refuges as recorded by the Northumberland Multi-Species Trawl surveys from 2005–2024. Scallop Buffer Zone Scallop Fishing Area 21 is depicted here to demonstrate only one year of data are available; these will not be used in routine monitoring unless a sufficient baseline is built up. Values above the bars represent sample sizes (i.e. number of trawls used in estimate). Error bars represent ±2 SE. Only records for fish (ground and pelagic) and crustaceans were analyzed.

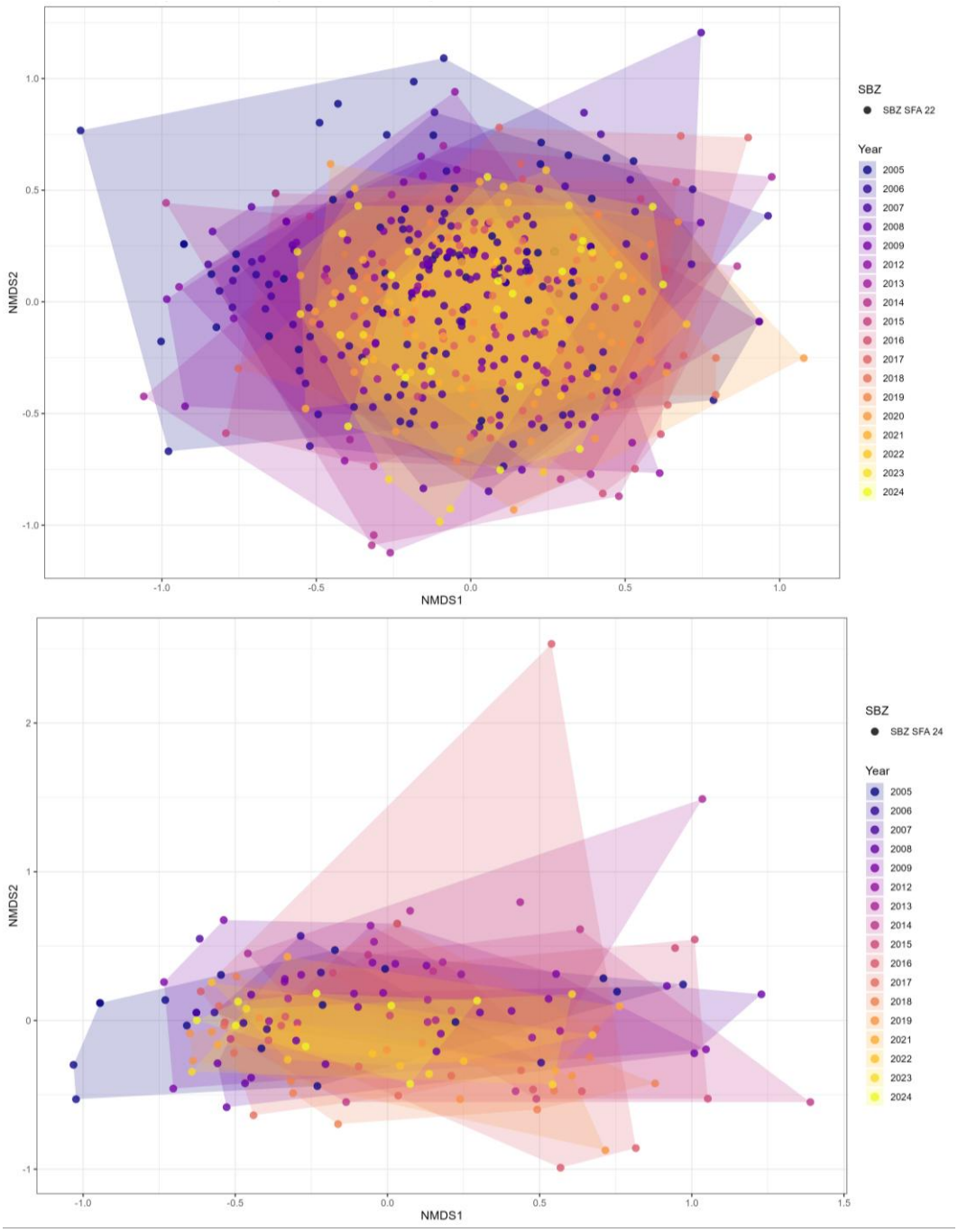


Figure 11. Non-Metric Multidimensional Scaling of species within the Scallop Buffer Zone Marine Refuges as recorded by the Northumberland Multi-Species Trawl surveys from 2005–2009, and 2012–2024. Scallop Buffer Zones Scallop Fishing Areas 22 and 24 are presented separately owing to differences in community composition between them (Figure S2). Only records for fish and crustaceans were analyzed.

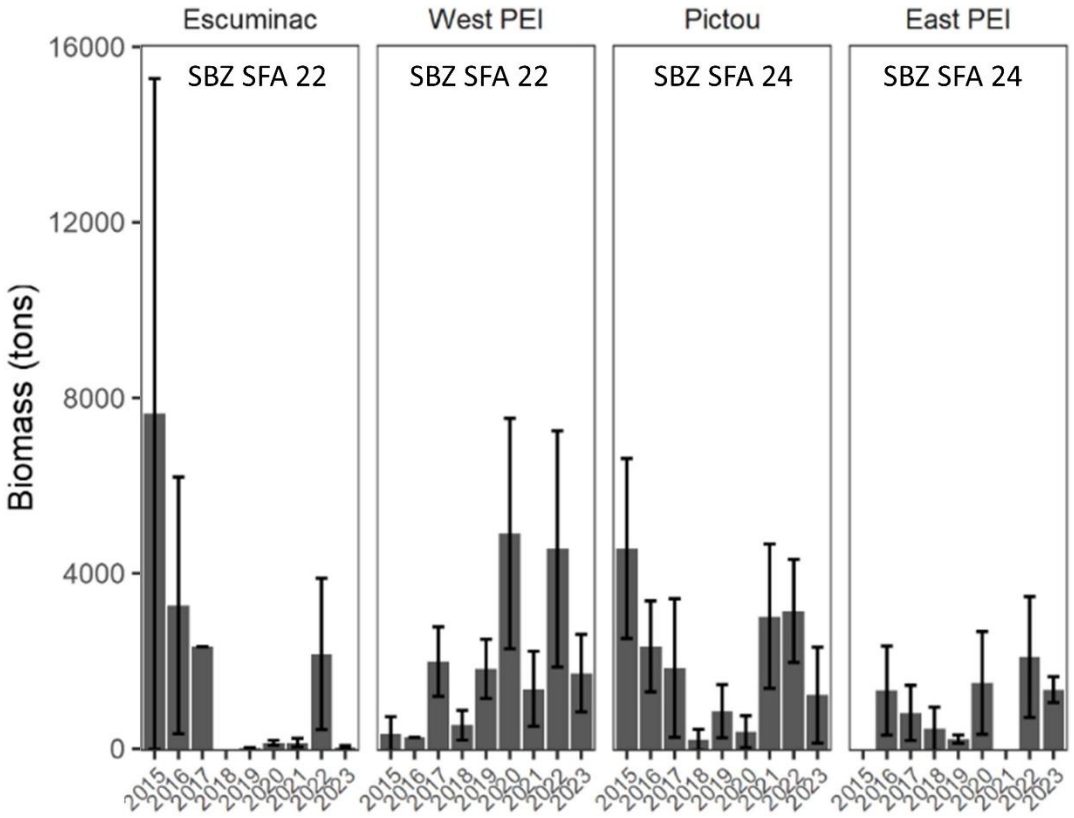


Figure 12. Nightly biomass of fall spawning Atlantic Herring estimated (mean ± SE) from industry spawning ground acoustic surveys which take place each fall on various spawning grounds. The Escuminac and Western Prince Edward Island spawning grounds overlap with Scallop Buffer Zone Scallop Fishing Area 22 and the Pictou and East Prince Edward Island spawning grounds overlap with Scallop Buffer Zone Scallop Fishing Area 24. This figure is adapted from Maynard et al. 2024.

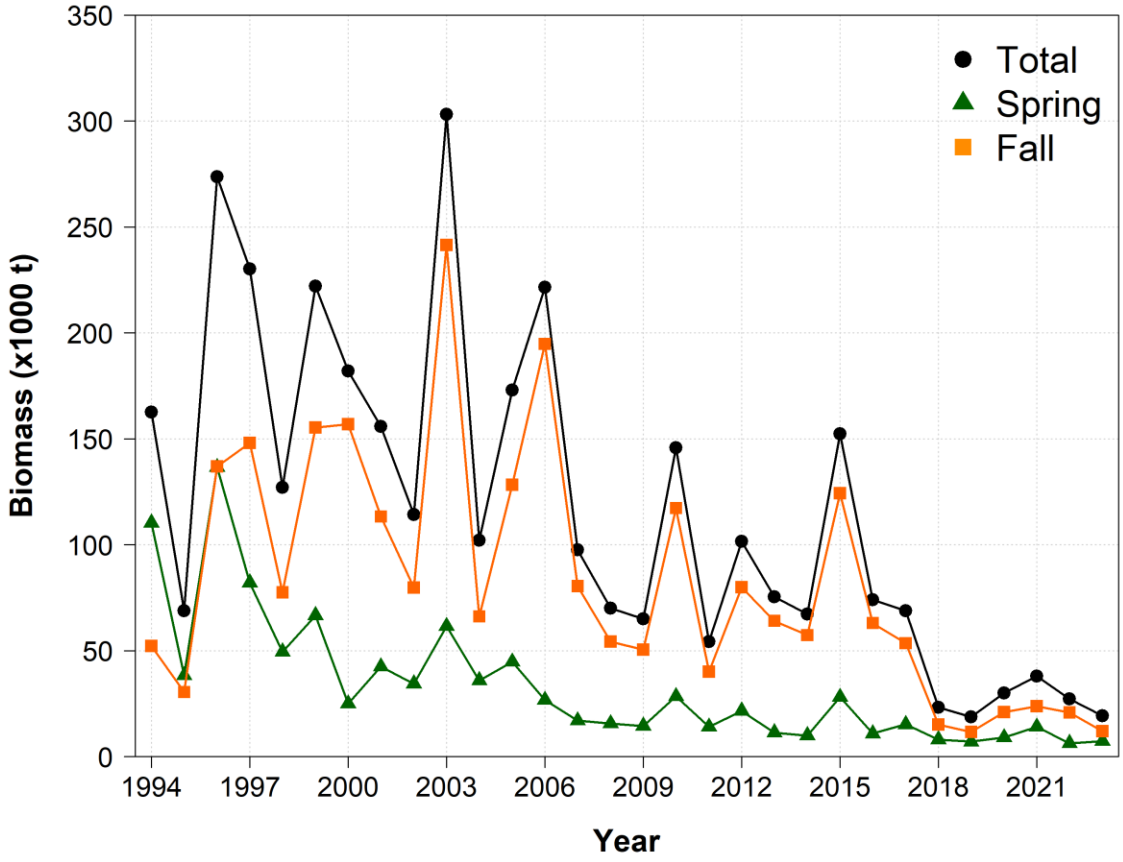


Figure 13. The total biomass of spring (green) and fall (orange) spawning Atlantic Herring and both spawning components combined (black) estimated during the fishery independent acoustic survey which occurs annually during mid-September to mid-October in the Baie des Chaleur region. A portion of the survey occurs within Scallop Buffer Zone Scallop Fishing Area 21. The figure is adapted from Maynard et al. 2024.

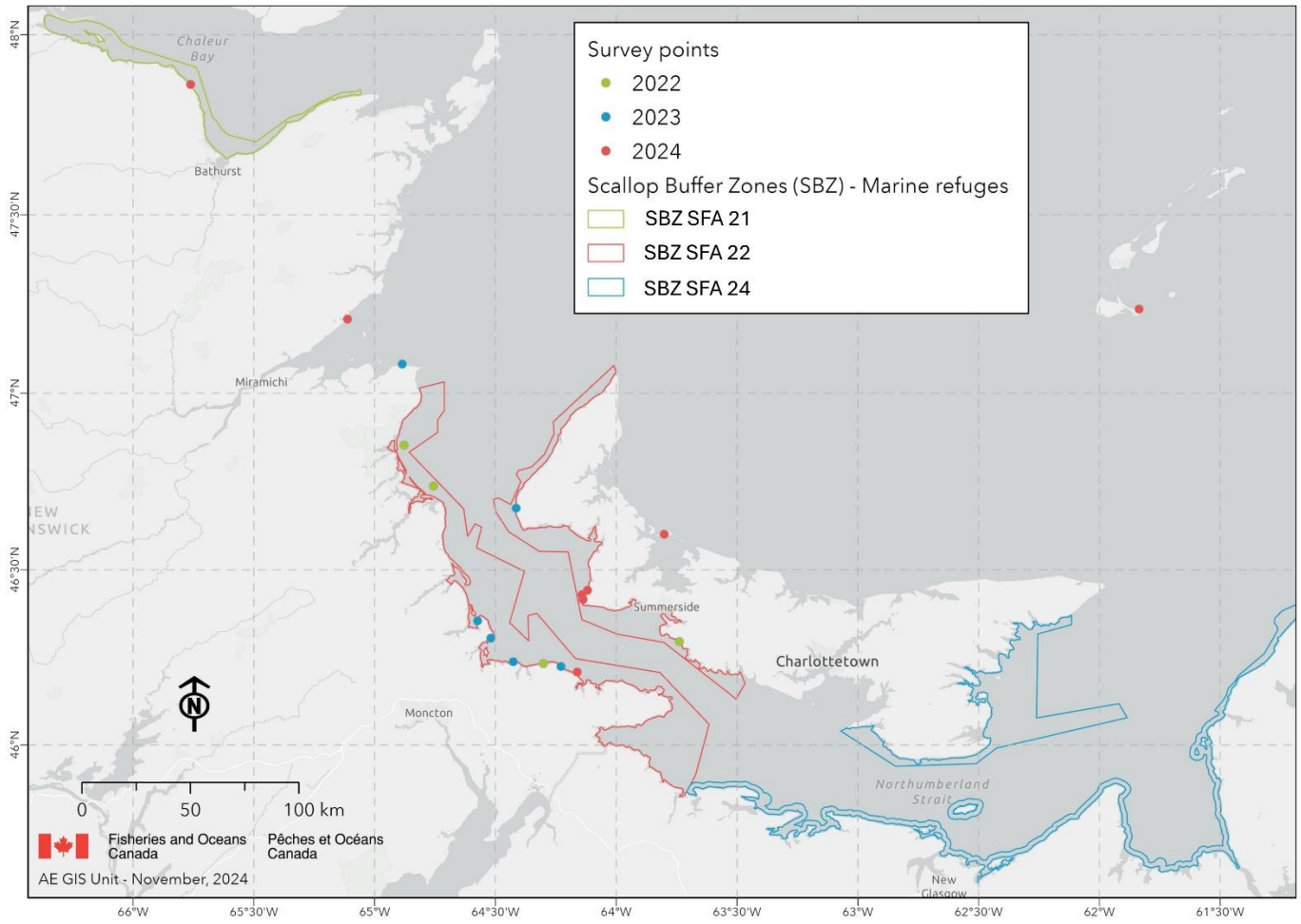


Figure 14. Atlantic Herring spring contemporary spawning based on public observations.

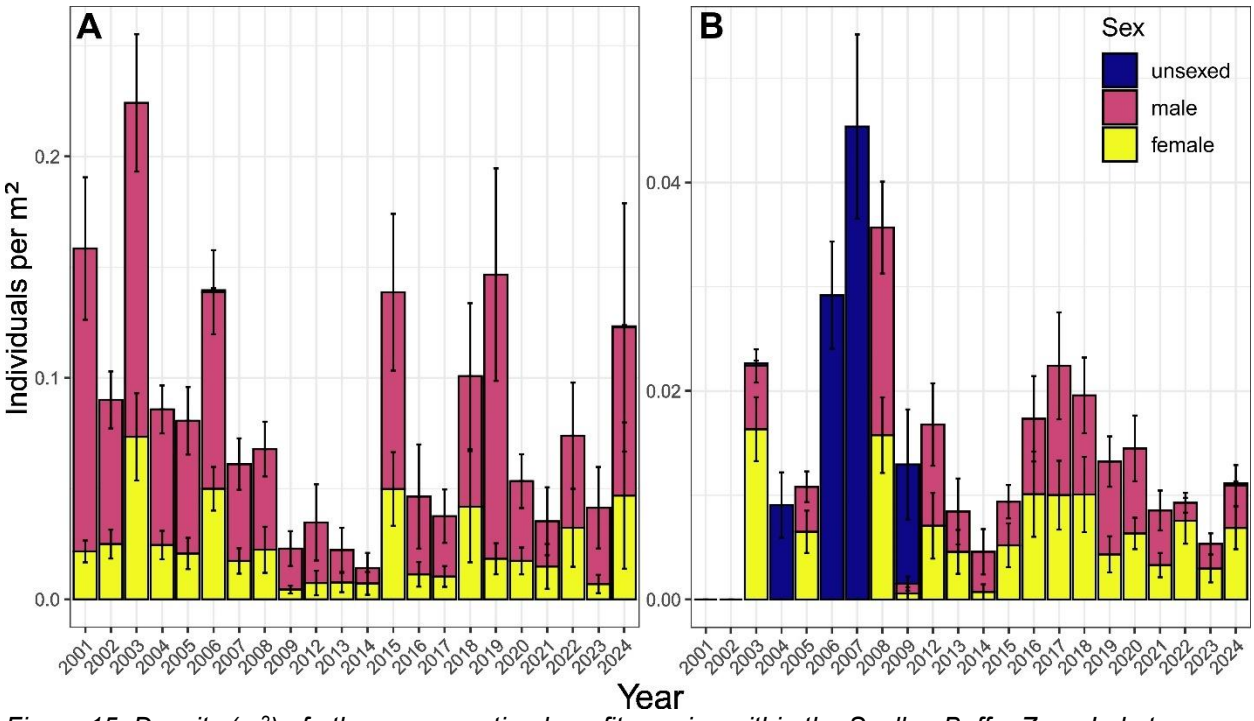


Figure 15. Density (m^2) of other conservation benefit species within the Scallop Buffer Zone Lobster Fishing Area 22, including (A) Lady Crab and (B) Winter Skate, as recorded by the Northumberland Multi-Species Trawl surveys from 2001–2024. Error bars represent ±1 SE.

9. APPENDICES

Table S1. List of potential indicators qualitatively evaluated. DFO (2013) provides guidance on selection criteria for indicators, which include sound theoretical basis, ease and accuracy of measurement (measurable), availability of historical data (10-20 years), suitable sensitivity (correspondence between change in indicator and pressure), suitable responsiveness (signal to noise ratio), suitable specificity (ability to disentangle multiple pressures), suitable public awareness (ease of comprehension to non-specialists), and reasonable cost-effectiveness. Each criteria was assessed using currently available information and methods for evaluating each indicator; this can change as research and new technologies evolve. Indicators with the highest scores for each CO (6 or greater) were selected for monitoring (in green) while some indicators below this threshold with scores less than 6 are used as placeholders (in yellow). na=not evaluated (at the time of this report).

	Criteria								Score
Indicator	Theoretical basis	Measurable	Historical data	Sensitivity	Responsive-ness	Specificity	Public awareness	Cost-benefit ratio	
CO1. Protect juvenile lobster									
Northumberland Multi Species Trawl survey density (individuals per m^2)		•	•	•	•		•	•	6
Bio-collector juvenile lobster density (number per m^2)		•	•	•	•		•	•	6
SCUBA lobsters counts (number per 100 m^2)		•	•	•	•		•	•	6
Modelled SBZ specific lobster density	•	•	•	•	na	•		•	6
Lobster landings (t)		•	•		•		•	•	5
CO2. Protect juvenile lobster habitat									
Benthic Temperature (°C)	•	•	•	•	•		•	•	7

Species richness/Shannon's diversity Index (NS Survey)		•	•		•		•	•	5
Community composition (NS Survey)		•	•		•		•	•	5
Substrate characteristics	•	na	•				•		3
Drop camera counts per transect	na	•			na		•	na	2
eDNA	na	•	na	na	na	na	na	na	1
CO3. Protect other benefits									
Northumberland Multi Species Trawl survey density (individuals per m2)		•	•	•	•		•	•	6
Relative tonnes (Atlantic Herring acoustic data)		•	•	•			•	•	5
Spawning event reports	•	•		na	na	na	•	•	4
Macrophyte coverage (km^2)	•			na	na	na	•	•	3

Table S2. List of workshop participants (DFO-Gulf Region), held at the Gulf Fisheries Centre in Moncton, New Brunswick, December 2nd, 2025.

Name	Section	Area of expertise
Trevor Bringloe	Marine Conservation Science	Genomics, phycology
Daniel Bourque	Marine Conservation Science	Ecosystem monitoring, conservation
Venitia Joseph	Marine Conservation Science	Ecosystem monitoring, conservation
Curtis Dinn	Marine Conservation Science	Ecosystem monitoring, conservation
Alain Mallet	Marine Planning and Conservation	Management, conservation
Joël Chassé	Oceanography Science	Environmental modelling
Jeff Clements	Aquaculture and Coastal Ecosystems	Molluscan biology
Jacob Burbank	Marine Fish and Mammals	Herring/fish biology
Natalie Asselin	Crustaceans Section	Crustacean biology
Eva Dickson	Aquaculture and Coastal Ecosystems	GIS and spatial analysis

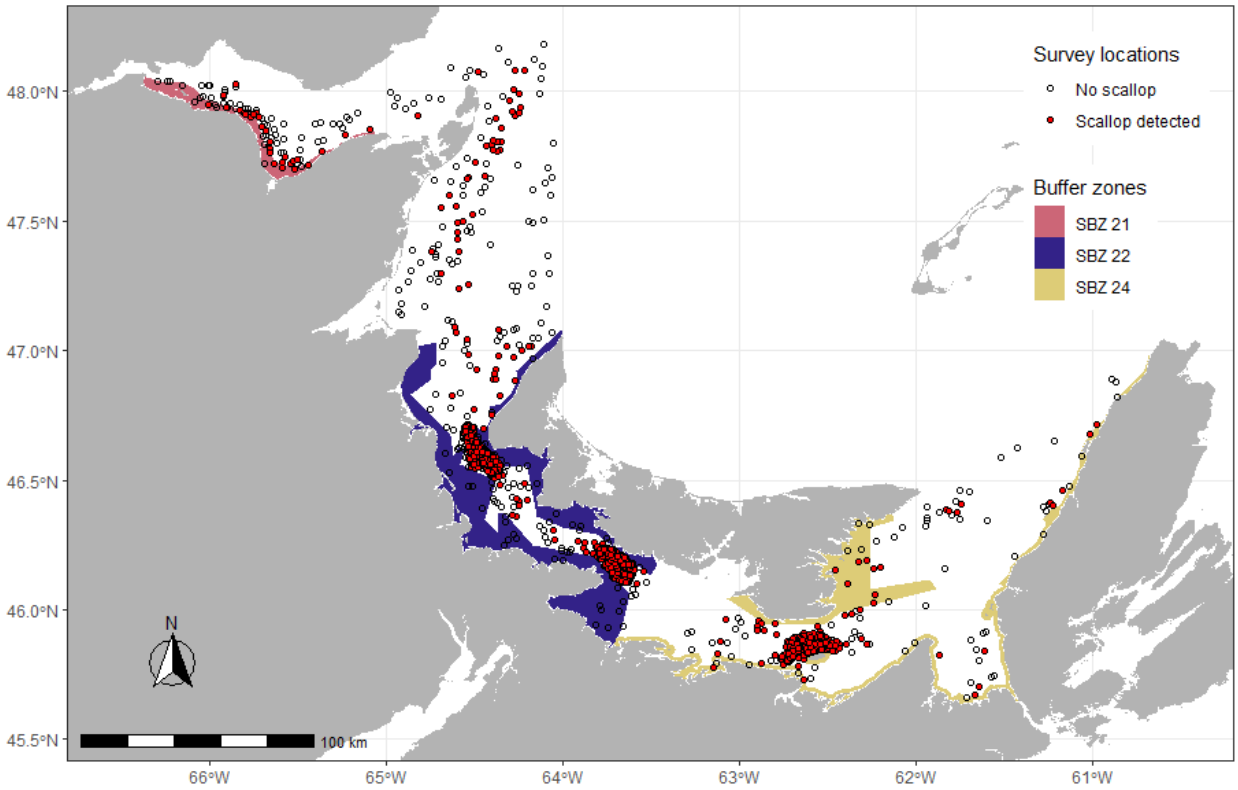


Figure S1. Distribution of Sea Scallop based on Gulf Region Sea Scallop survey samples (2012-2023).

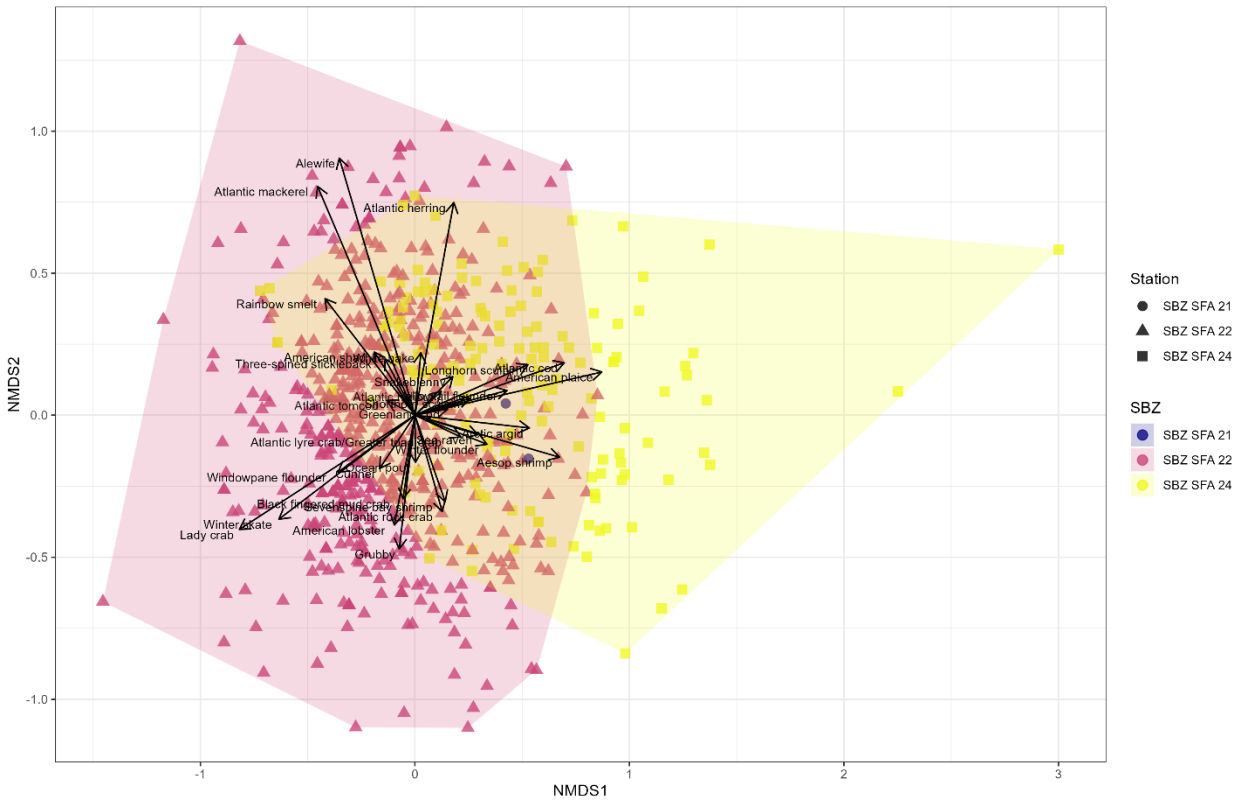


Figure S2. Non-Metric Multidimensional Scaling of species within the Scallop Buffer Zone Marine Refuges as recorded by the Northumberland Multi-Species Trawl surveys from 2005–2024. Arrows show species significantly affecting the direction and magnitude of results (faded species/arrows are not significant). Scallop Buffer Zone Scallop Fishing Areas 22 and 24 are significantly different in community composition, particularly due to Lady Crab and Winter Skate, among other species.

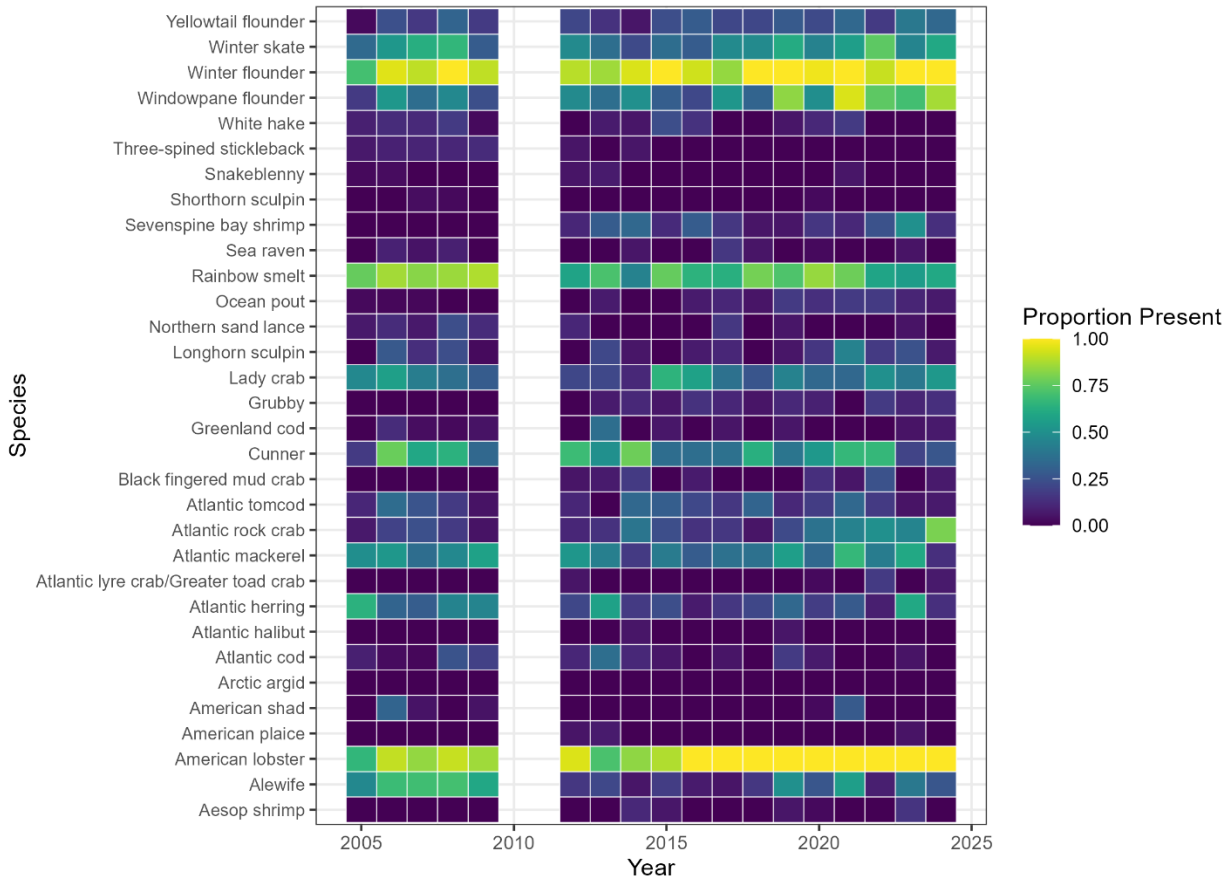


Figure S3. Heatmap of species within Scallop Buffer Zone Scallop Fishing Area 22 as recorded by the Northumberland Multi-Species Trawl surveys from 2005–2024. Only records for fish and crustaceans were analyzed.

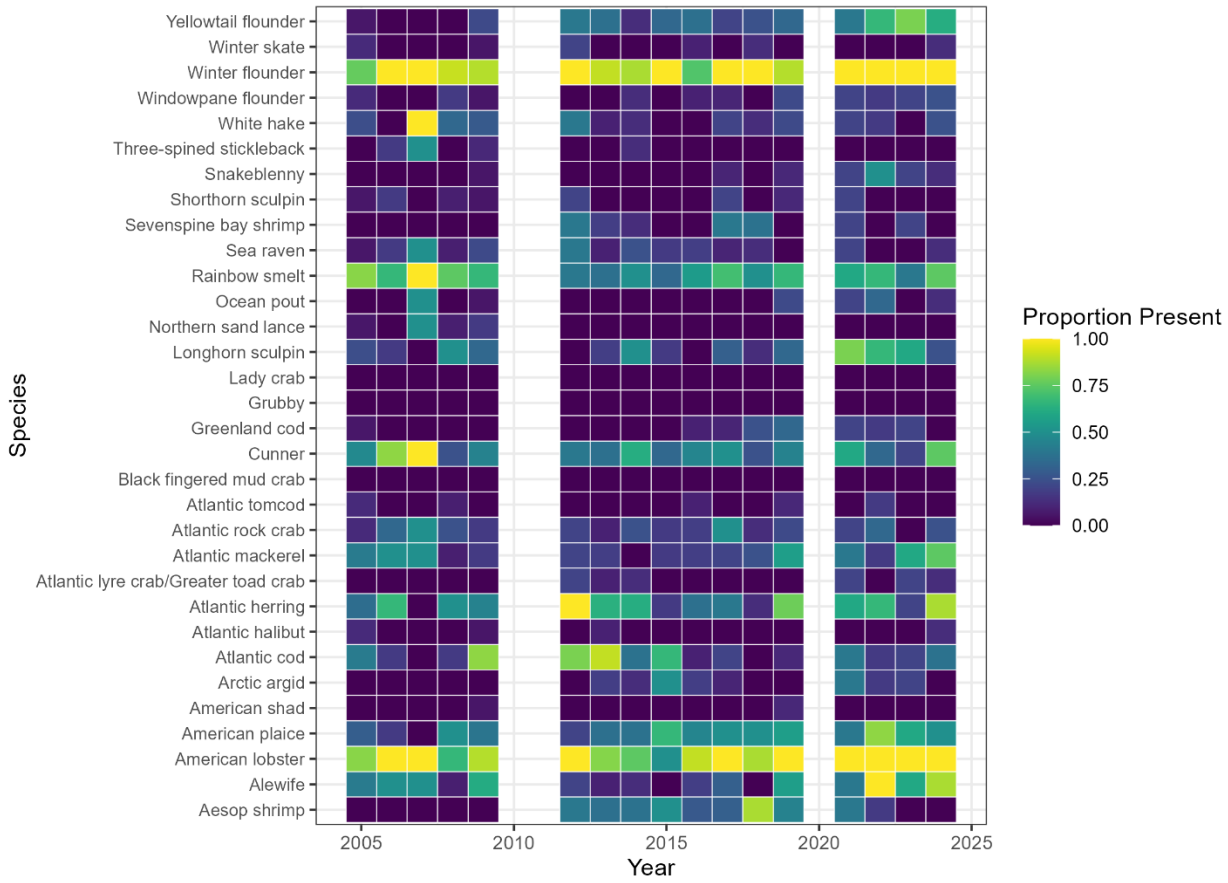


Figure S4. Heatmap of species within Scallop Buffer Zone Scallop Fishing Area 24 as recorded by the Northumberland Multi-Species Trawl surveys from 2005–2024. Only records for fish and crustaceans were analyzed.

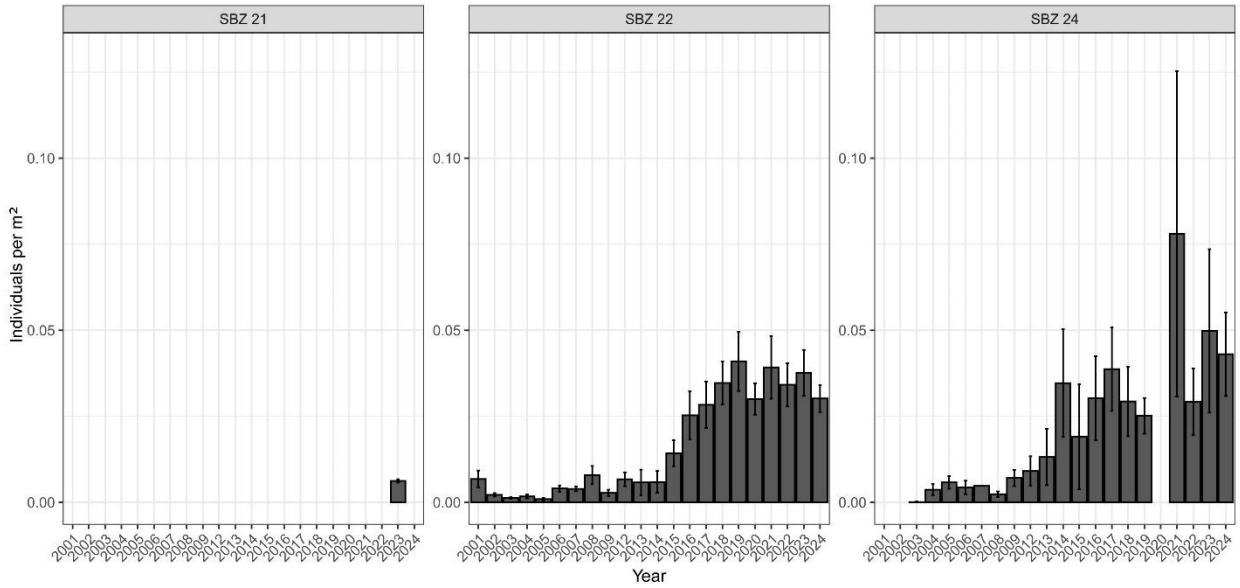


Figure S5. Density (m^2) of prefishery (51–70 mm) adult lobster within the Scallop Buffer Zone Marine Refuges as recorded by the Northumberland Multi-Species Trawl surveys from 2001–2024. Error bars represent ±1 SE.