Scallop Buffer Zones (SFA 21, 22, 24) Marine Refuges in the southern Gulf of St. Lawrence, Canada: a scientific overview of the environment and ecosystem

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SCALLOP BUFFER ZONES (SFA 21, 22, 24) MARINE REFUGES IN THE SOUTHERN GULF OF ST. LAWRENCE, CANADA: A SCIENTIFIC REVIEW OF THE ENVIRONMENT AND ECOSYSTEM

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BCB	Biodiversity Conservation Benefit
CANOPA	CANadian Océan PArallélisé
CL	Carapace Length
DFO	Department of Fisheries and Oceans
EBSA	Ecologically and Biologically Significant Area
eDNA	Environmental DNA
LFA	Lobster Fishing Area
MCT	Marine Conservation Targets
MPA	Marine Protected Area
MR	Marine Refuge
NAFO	Northwest Atlantic Fisheries Organization
NB	New Brunswick
NS	Nova Scotia
OECM	Other Effective Area-Based Conservation Measures
PEI	Prince Edward Island
ROV	Remote Operated Vehicle
SBZ	Scallop Buffer Zone
sGSL	Southern Gulf of St. Lawrence
SFA	Scallop Fishing Area

ABSTRACT

Balbar, A.C., Bringloe, T., Shaw-McDonald, S., Joseph, V., Dinn, C., Bourque, D., Burbank, J., Asselin, N.C., Chassé, J., Blais, M., Dickson, E., and Arseneault, T. 2025. Scallop Buffer Zones (SFA 21, 22, 24) Marine Refuges in the southern Gulf of St. Lawrence, Canada: a scientific overview of the environment and ecosystem. Can. Tech. Rep. Fish. Aquat. Sci. 3746: ix + 57 p. https://doi.org/10.60825/e91z-1097

The Scallop Buffer Zones (SBZs) marine refuges, located within Scallop Fishing Areas 21, 22, and 24, were recognized as marine conservation areas in 2017 to protect juvenile American Lobster (*Homarus americanus*) and its habitat in the southern Gulf of St. Lawrence. The SBZs are also important habitat for additional biodiversity conservation benefit species of interest such as spawning Atlantic Herring (*Clupea harengus),* while SBZ 22 contains a Lady Crab (*Ovalipes ocellatus*) population isolated from its southern range, and one of the only remaining summering areas for an endangered population of Winter Skate (*Leucoraja ocellata*) in the Gulf of St. Lawrence. This document provides an overview of the physical features and ecology of the fish and benthic invertebrate populations found within the SBZs, and provides a summary of previous research conducted within the marine refuges as well as uncovered data gaps.

RÉSUMÉ

Balbar, A.C., Bringloe, T., Shaw-McDonald, S., Joseph, V., Dinn, C., Bourque, D., Burbank, J., Asselin, N.C., Chassé, J., Blais, M., Dickson, E., and Arseneault, T. 2025. Scallop Buffer Zones (SFA 21, 22, 24) Marine Refuges in the southern Gulf of St. Lawrence, Canada: a scientific overview of the environment and ecosystem. Can. Tech. Rep. Fish. Aquat. Sci. 3746: ix + 57 p. https://doi.org/10.60825/e91z-1097

Les refuges marins des zones tampons pour la pêche du pétoncle (ZTPPs), situés à l'intérieur des zones de pêche du pétoncle 21, 22 et 24, ont été reconnus comme aires de conservation marine en 2017 pour protéger le homard (*Homarus americanus*) juvénile et son habitat dans le sud du golfe du Saint-Laurent. Les ZTPPs constituent également un habitat important pour d'autres espèces d'avantage pour la conservation de la biodiversité, incluant : le hareng de l'Atlantique (*Clupea harengus*) en reproduction, et exclusif à la ZTPP 22, une population de crabes à ocelles (*Ovalipes ocellatus*) isolée de son aire de répartition plus au sud, ainsi que les seuls habitats d'été restants de la population de raie tachetée (*Leucoraja ocellata*) du golfe du Saint-Laurent, qui est menacée. Le présent document donne un aperçu des caractéristiques physiques et de la écologique des populations de poissons et d'invertébrés benthiques que l'on trouve dans les ZTPPs, et fournit également un résumé des recherches antérieures menées dans les refuges marins ainsi que des lacunes observées dans les données.

INTRODUCTION

The Government of Canada has agreed to international biodiversity protection targets (CBD 2022) and adopted complementary domestic targets for coastal and marine areas with the intent to protect 25% of Canada's marine environment by 2025, and 30% by 2030 (DFO 2021a; 2021b). Part of the Department of Fisheries and Oceans' (DFO) national strategy to contribute to these Marine Conservation Targets (MCT) includes the designation of Other Effective Area-Based Conservation Measures (OECMs). Marine OECMs recognized by DFO, also known as Marine Refuges (MR), protect important species and habitats from the impacts of fishing through the Fisheries Act, and complement Marine Protected Areas (MPAs), governed by the Oceans Act. OECMs contribute to Canada's national conservation targets because they provide in-situ biodiversity conservation benefits (IUCN-WCPA 2019).

The Sea Scallop (*Placopecten magellanicus*) fishery in the southern Gulf of St. Lawrence (sGSL) is a major coastal fishery, in addition to Lobster and Herring. Landing statistics for Sea Scallop date back to the early 1900s, but standardized reporting began in 1984 when landings began to be recorded by weight, by landing type (meat, live, or roe), sale slip type and commercial fishing vessel, permitting the calculation of catch per unit effort (CPUE) (Lanteigne and Davidson 1991). Buffer zones were introduced in the coastal portions of Scallop Fishing Areas (SFAs) starting in 1999 to protect sensitive benthic habitat. Bottom contact fishing gear associated with Sea Scallop fisheries (i.e. Scallop drags/dredges) have been prohibited in buffer zones of SFAs 21, 22, and 24 since 1999, 2005, and 2006, respectively. Each buffer zone was delineated according to either water depth and/or distance from shore (Niles et al. 2021). The closures were originally instated to reduce conflicts between Scallop and Lobster fishing gear and to protect nursery habitat for juvenile American Lobster (*Homarus americanus*; DFO 1999). Commercial Scallop bottom contact fishing gear is destructive to benthic habitats (gravel, cobble, boulders) that provide shelter to crustaceans and demersal fish (Davidson et al. 2007; Hinz et al. 2011; Niles et al. 2021).

Since 2017, these Scallop Buffer Zones (SBZ) fishing closures were recognized as MRs and contribute to Canada's MCT (Figure 1; DFO 2017a). They aim to provide protection to juvenile Lobster and their habitat, and overall benthic biodiversity in the sGSL. Segments of the SBZ MRs also intersect with identified Ecologically and Biologically Significant Areas (EBSAs) in the Gulf of St. Lawrence and may provide some protection for the identified features in these areas (DFO 2007). EBSAs are selected for having special biological or ecological significance when compared with the surrounding marine ecosystem and are identified through formal scientific assessments (DFO 2016a). These SBZ MRs in SFAs 21, 22 and 24 will henceforth be described as the SBZ MRs (each separate zone being referred to as SBZ 21, SBZ 22 and SBZ 24 in this document).

Overview Context

As part of the ongoing management of the SBZ MRs, it is the responsibility of DFO Science to provide information on the ecological status of biodiversity conservation benefits (BCBs), defined as a "net positive change in biodiversity or prevention of loss resulting from governance decisions and management actions within an area" (Government of Canada 2022). As such, the objectives of this scientific overview of the environment and ecosystem are to:

1. describe the physical setting of the SBZ MRs and review the biology and ecology of these areas, which include: juvenile American Lobster, the benthic habitat important for its development (direct BCBs), spawning areas important for Atlantic Herring (*Clupea harengus)*, a Lady Crab (*Ovalipes ocellatus*) population isolated from its southern range, and some of the only remaining summering areas for an endangered population of Winter Skate (*Leucoraja ocellata*) (other or indirect BCBs).
2. describe existing and ongoing research activities within or otherwise relevant to the SBZ MRs;
3. describe environmental threats that pertain to the identified BCBs;
4. identify key sources of uncertainty and knowledge gaps within the SBZ MRs.

PHYSICAL SETTING

Locations of the Scallop Buffer Zones Marine Refuges

SBZ 21 is located on the southern coastline of Chaleur Bay, which is part of the south-western coast of the Gulf EBSA (Figure 1; DFO 2007; Swain and Benoît 2007). Chaleur Bay is an area of rich biodiversity, providing estuarine habitat for American Lobster, Atlantic Herring, Threespine Stickleback (*Gasterosteus aculeatus*), Winter Flounder (*Pseudopleuronectes americanus*) and many other demersal fishes and invertebrates (Swain and Benoît 2007). SFA 21 consists of three sub-areas (21A, 21B and 21C) delineated in 1996 based on management recommendations from the Scallop Advisory Committee and Maritimes Fisherman's Union (DFO 1999). The MR extends from Dalhousie to Grand-Anse, New Brunswick (NB), extending through SFA 21A (Figure 1). The buffer zone management measure prohibiting commercial Scallop bottom contact fishing gear was first introduced in SFA 21A in 1999 and included areas with water depths less than 15 m (SFAs 21B and 21C were not included in the buffer zone; DFO 1999). The water depth was increased to 18.6 m in 2013 after Scallop harvesters requested the boundaries be modified (Davidson et al. 2012).

SBZ 22 runs along part of the western Northumberland Strait, intersecting with parts of the south-western Coast of the Gulf and western Northumberland Strait EBSAs (Figure 1; Swain and Benoît 2007). The western Northumberland Strait EBSA is a high priority for DFO Science due to its inclusion of some of the only remaining summering areas where an endangered population of Winter Skate are found within the sGSL (Swain and Benoît 2007; COSEWIC 2015) as well as the presence of a disjunct population of Lady Crab (Voutier and Hanson 2008). The MR is located along the coastline of SFA 22, including the coasts of NB, Nova Scotia (NS), and Prince Edward Island (PEI; Figure 1). On the southern coast of the Northumberland Strait, the area starts at Baie-Sainte-Anne, NB, and extends southeast towards Pugwash, NS. On the northern coast, SBZ 22 starts at North Cape and extends southeast towards Hampton, PEI. The SBZ in SFA 22 was established in 2005 with a prescribed depth of less than 11 m (Davidson et al. 2007; Niles et al. 2021).

SBZ 24 covers the southeast portion of the Northumberland Strait including St. George's Bay and a portion of the Cape Breton Trough (Figure 1), both of which are EBSAs of high importance as they are home to demersal fish spawning grounds and summer foraging habitat (Swain and Benoît 2007). The MR begins on the southern coast by Pugwash, Nova Scotia, up to the tip of Cape Breton Island, and includes a section from Hampton along the coast to Bothwell, PEI (Figure 1). The first buffer zone prohibiting commercial Scallop bottom contact fishing gear in SFA 24 was established in 1996 and included waters within a distance of one nautical mile (1.852 km) from the NS shore (Niles et al. 2021). In 1999 this buffer zone was expanded to include waters along the PEI shore, up to a depth of 27.4 m. In 2006, the buffer area was again expanded to include waters along the western Cape Breton shore, up to a depth of 27 m.

Coastal and Seabed Geology

The bedrock underlying the Northumberland Strait is made of two notable rock formations. The first is made up of faulted and folded rocks that characterize the eastern Northumberland Strait, including George's Bay and the Cape Breton highlands (Kranck 1971). The second is made up of soft, well-stratified sandstone and shale, characterizing the western and central Northumberland Strait (Kranck 1971). While a majority of the underlying bedrock are gently sloping, there are two prominent trending ridges on the eastern end of the Northumberland strait, forming Pictou Island and Fisherman's Bank. The latter forms an underwater shoal, about 20 m deep, and is an important fall spawning ground for Herring. On top of the bedrock are sediments that have been deposited in the Northumberland Strait for the past 2.5 million years. These sediments consist of glacial deposits, gravel, sand, and mud, the latter two being actively deposited today (Kranck 1971).

Sediment classification by Loring and Nota (1973) show that the area is predominantly gravelly fine sand (

Figure 2). Most of SBZ 22 is composed of sand and gravel. Coarse sediments are found here because it is an area with strong tidal currents, such that fine sand and mud are not deposited onto the seafloor. However, the eastern edge of SBZ 22, past Cape Tormentine and into Baie Verte, includes finer sediments. In SBZ 24, exposed sediments are a mix of both sand and gravel along the edges of the coast and limited areas of mud in parts of St. Georges Bay and along the eastern coast of PEI (except Fisherman Bank shoal). Along the coast of Cape Breton, sediment is mixed, consisting of all three sediment types.

Artificial reefs

Since the early 2000s, various types of artificial reefs have been deployed in the sGSL in an effort to increase available habitat for species such as Lobster, crab, and macrophytes. These structures modify the seafloor bottom and must be considered in future studies for their impact on sediment classification and local biodiversity. Locally, artificial reefs have been deployed with the intention to serve multiple purposes, including the offsetting of harmful impacts to fish and fish habitat (harmful alteration, disruption or destruction in past years), supporting habitat restoration projects, and enhancing Lobster fishing grounds. Through a review of multiple internal DFO documents, 104 artificial reef sites were identified across the sGSL, with over half located within specific SBZ MRs. It is likely that additional sites exist beyond those identified, more specifically older sites for which records may have been misplaced or lost. Each site contains varying numbers of deployed reef structures (from several hundred to several thousand), all made from concrete, and include the Blanchard/Comeau, Home'ster's Type U, U-180 and Type S, and Reefballs (see Table 1 for reef type descriptions). The number of sites located inside and outside each SBZ MRs for each reef type are summarized in Table 2. For each identified location, detailed information such as number of structures and reef type was not always available. The gathered information indicates a total of more than 278,114 reef structures deployed over the years. From these identified structures 55,743, 83,563 and 3,616 were deployed in SBZ 21, SBZ 22 and SBZ 24 respectively. Long term ecological impacts of these reefs have not been thoroughly studied.

Physical Oceanography

The sGSL is a semi-enclosed sea, with inflow of cold water from the Labrador current through the Strait of Belle-Isle and brackish water from the St. Lawrence River that predominantly flows southeasterly through the Cabot Strait to the Atlantic Ocean (Koutitonsky and Bugden 1991). Circulation in the sGSL is forced by tides, seasonality, freshwater runoff, and heat flux (Koutitonsky and Bugden 1991). In the Northumberland Strait, depth is shallower than the central Gulf of St. Lawrence, and currents flow from west to east, due to westerly winds. Current velocities are strongest at the east and west entrances to the strait, impacting the distribution of surficial sediments. The mean depth in the SBZ MRs is 10.5 m in SBZ 21, 8.6 m in SBZ 22, and 15.9 m in SBZ 24, with the deepest depths generally corresponding to areas farthest from shore (Figure 3).

In the Northumberland Strait and in the sGSL in general, the water column is stratified in the summer and ice-covered in the winter months (Galbraith et al. 2023). Sea surface temperature in the SBZ MRs ranges from -1°C in the winter to over 20°C in the summer months (Galbraith et al. 2023). Average bottom water temperatures from 1971 to 2010 ranged between <1°C to >17°C and in September reaching >23°C in some coastal regions (Kelly and Hanson 2013; Chassé et al. 2014). Air and water temperatures have increased over the past 100 years by an average of 1.5 ± 0.3 °C (Galbraith et al. 2022). In the summer months, the water column becomes stratified into a warm surface layer and cold intermediate layer. The surface layer averages 15 – 20 °C from the surface to 30 m in depth and the cold intermediate layer is > 1.0 °C at 100 – 120 m depth (Hanson 2009; Chassé et al. 2014). The position of the thermocline and halocline, particularly the 12°C isocline, have prominent impacts for the settlement of juvenile Lobster in the sGSL (Joseph et al submitted). In the fall, the water column becomes fully mixed and is ice-covered from January to mid-April (Galbraith et al. 2023). From 1969 to 2022, the duration of the ice-covered season in the Northumberland strait was 107 ± 21 days with an average maximum ice cover of 4.5 ± 2.0 km^3 (Galbraith et al. 2023).

Biogeochemical Oceanography

In the Northumberland Strait, and in the sGSL in general, the oxygen saturation levels near the bottom were above 80% on average over the 2002-2020 period (Blais et al. 2025). In Chaleur Bay, the average decreased to approximately 60% in the deepest part of the Bay, while remaining near or above 80% in the shallowest coastal parts (Blais et al. 2024). These levels are far above hypoxia thresholds generally set to 30% (Plante et al. 1998; Chabot et Dutil 1999; Chabot et Claireaux 2008; Brennan et al. 2016).

The highest saturation state for both aragonite ($\Omega_{arg} \approx 1$) and calcite ($\Omega_{cal} > 1$) across the Gulf of St. Lawrence bottom waters are found in the Northumberland Strait (Galbraith et al. 2024). The impact of acidification on the metabolism and external structures of marine calcifying organisms increases as the saturation state decreases, particularly when it is below the saturation horizon ($\Omega = 1$) (Waldbusser et al. 2015). In the Northumberland Strait, pH levels are generally above 7.8, somewhat similar to levels observed in the greater sGSL. In recent years, Chaleur Bay has exhibited aragonite undersaturated state ($\Omega_{arg} < 1$) while calcite saturation state has been around 1. Bottom pH levels are generally above 7.6 and, overall, acidification parameters in Chaleur Bay are more alike to those encountered in the northwestern Gulf (Galbraith et al. 2024).

Nutrient inventories in the surface layer (0-50 m) of the Northumberland Strait are the lowest across the Gulf year-round. This region is particularly nitrate depleted, leading to a very low

Nitrogen:Phosphorous ratio and a high Silicon:Nitrogen ratio, which may suggest a plankton community composed mainly of smaller-sized organisms (Tremblay et al. 2012; Svensen et al. 2019). While no phytoplankton taxonomic data is available for this region, chlorophyll *a* measurements and zooplankton biomass tend to confirm this hypothesis with relatively low phytoplankton biomass during summer and lower zooplankton biomass in September compared to the adjacent Magdalen Shallows (Blais et al. 2025). The abundance of common copepod taxa (*Calanus finmarchicus*, *C. hyperboreus* and *Pseudocalanus* spp.) is lower than on the Magdalen Shallows (Blais et al. 2024).

In Chaleur Bay, the surface layer is relatively nutrient-rich, bearing the nutrient signature of the St. Lawrence outflow, although local processes like river runoff may seasonally modify nutrient ratios (Blais et al. 2024). Phytoplankton biomass in the bay is low year-round. Similarly to the Northumberland Strait, the Chaleur Bay tends to have lower zooplankton biomass and abundances than in adjacent waters. Although variable from year to year, the size structure of the zooplankton community also tends to be dominated by smaller copepods (Blais et al. 2024).

BIOLOGICAL DESCRIPTION

DIRECT BIODIVERSITY CONSERVATION BENEFITS

The main BCB listed in the OECM assessment profile of the SBZs for recognition as MRs is the protection of juvenile American Lobster and its nursery habitat.

American Lobster

Biology

The American Lobster (*Homarus americanus*; hereafter Lobster) (Figure 4) occupies coastal waters from southern Labrador, Canada to New Jersey, USA, with the major fisheries concentrated in the Gulf of St. Lawrence and the Gulf of Maine (Miller 1995). Lobsters have a complex life cycle that includes several phases: egg, larval, juvenile and adult. Generally, females have a two-year reproductive cycle, mating within 48 hours after moulting (Cobb 1976) while the shell is still soft (Atema et al. 1979) and extruding eggs the following summer. Using catch rates and size distributions of berried females from at-sea sampling of commercial catch, Chassé and Miller (2010) estimated that egg production in the Northumberland Strait was higher than in the rest of the sGSL. Asselin et al. (2024) reported similar findings from an estimate of egg production based on both at-sea sampling data and trawl survey data (Figure 5), with Lobster Fishing Area (LFA) 25 in the western Northumberland Strait having the highest estimated egg production of the LFAs in the sGSL.

Ovarian maturation is triggered by warming water temperatures and a longer photoperiod in spring (Nelson et al. 1983; Quackenbush 2013). Female Lobsters will then carry the eggs to development in their swimmerets for 11 months (Waddy and Aiken 1992). Warmer waters in the sGSL result in earlier hatching (mid-June) than in the Bay of Fundy (mid-July), and hatching in the sGSL has advanced by about five weeks between 1989 and 2014 (Haarr et al. 2020). Once the eggs hatch, larvae become pelagic and free-swimming for six to eight weeks (Cowan et al. 2001), while they undergo three moults (stages I-III). Water currents affect dispersal, colonization, and settlement of larvae into different habitats within their biological range. In their larval stage, Lobsters are pelagic and are carried with ocean currents, but are able to swim vertically in the water column (Chassé and Miller 2010). Lobster settlement tends to be greater in areas where eddies are present, where diverging currents promote settlement and retention of Lobster larvae in the circular current (Cetina-Heredia et al. 2015). With their movement driven by ocean currents, larval Lobster will seek out nearby areas that have suitable habitat before settling and starting the benthic stage of their life cycle (Cetina-Heredia et al. 2015).

The duration of the larval stages is highly influenced by temperature. In laboratory experiments, MacKenzie (1988) found that stage-specific development was faster at higher temperatures for all stages. Stage IV post-larvae were particularly sensitive to temperature changes with 82.5% survival at 12.3°C and only 18.9 % survival at 9.8°C. In the field, stage IV spend 95% of their time in the top 4.5 m, with occasional sounding behaviours (i.e. diving to the seafloor) to look for suitable benthic habitat (Annis 2005). Sounding events predominantly occurred above the 12°C isotherm, further supporting this temperature threshold for benthic settlement (Annis 2005; Wahle et al. 2013).

Post-larval Lobsters employ searching behaviours and are selective in suitable habitat with a preference for shallow, warm waters with cobble substrate for protection from predators (Ball et al. 2001; Lillis and Snelgrove 2010). Near bottom current flows also increase the frequency that post-larvae encounter the seafloor, further increasing settlement potential (Lillis and Snelgrove 2010). Substrate types that are best suited for post-larval settlement include abundant bedrock ledge, boulders, and embedded cobble (Wahle et al. 2013).

After settlement, juvenile Lobsters are cryptic and largely shelter-restricted, relying on cobble and gravel habitat for shelter from predators (Wahle and Steneck 1991; Lawton and Lavalli 1995, Barshaw and Lavalli 1988). However, when densities are high, juveniles may burrow in muddy substrate (Dinning and Rochette 2019), but juvenile Lobster density tends to be low in more sandy habitats (Lillis and Snelgrove 2010; Davidson et al. 2012). As their carapace length (CL) increases from 5 to 40 mm, they gradually move to deeper water and softer substrate (Wahle and Steneck 1991). Early settlers prefer shallower depths often between 0.4 and 5 m (Cowan 1999) with about 80% of Lobsters < 50 mm CL found shallower than 15 m (Hanson 2009).

Limited mobility in juvenile Lobsters results in opportunistic feeding behavior, whereas adults exhibit greater mobility and actively pursue prey (Hudon and Lamarche 1989). As Lobsters grow, they spend more time outside of their shelter foraging (Dinning and Rochette 2019; Lawton and Lavalli 1995). Medium and large size classes of Lobster rely heavily on Rock Crab (*Cancer irroratus*) as a prey source, with smaller amounts of sea stars, mussels, sea urchins, tunicates and fish remains supplementing their diets (Hudon and Lamarche 1989). Cannibalism also occurs in Lobster, where smaller individuals are targeted and discarded carapaces are scavenged during the molting seasons (Hanson 2009; Hanson et al. 2014).

Lobsters grow by moulting; typically in the sGSL (for Lobsters 86-154 CL) this period occurs largely from early July to early September (Comeau and Savoie 2001). Moult frequency decreases over their lifespan, with Lobsters moulting up to ten times their first year (Cobb 1976) and adult Lobsters moulting once a year or less (Aiken and Waddy 1980). Additionally, moult timing and frequency is impacted by temperature, density, and diet (Waddy et al. 1995).

Lobster size at maturity varies across its range and is impacted by local environmental conditions, mainly temperature, (Aiken and Waddy 1980; Campbell and Robinson 1983; Comeau and Savoie 2002; Comeau et al. 2025) and, to some extent, fishing pressure (Haarr et al. 2018). Female Lobsters in the sGSL mature at smaller sizes than those in regions with cooler summer temperatures (Waddy and Aiken 1990), with 50% of females in the sGSL reaching maturity by 69-77 mm CL (Comeau and Savoie 2002; Comeau 2003; DFO 2016b; Comeau et al. 2025).

In July and August in the Northumberland Strait, adult Lobsters are typically distributed unevenly with respect to temperature and depth (Figure 5), with 50% found in waters warmer than 15°C, coinciding with a depth shallower than 30 m (Hanson 2009). In the sGSL, Asselin et al. (2024) found that, in June (1983-2021), 95% of Lobsters were caught in areas with bottom temperatures between 0.4 and 14.0 °C. In September, the range was 3.3 to 18.0 °C. Performance and survival of Lobsters are negatively impacted when water temperatures are consistently above 26°C (Quinn 2017).

Fishery

There are 5 LFAs in the sGSL, assessed and managed by DFO (DFO 2019). There is an overlap between SFAs and LFAs (SFA 21/LFA 23; SFA 22/LFA 25; SFA 24/LFA 26A and 26B; Figure 1). The Lobster fishery is managed through a limited number of fishing licences, maximum individual trap allocations, restrictions on gear characteristics, defined fishing seasons, minimum legal size, the release of egg-bearing females and the release of large females (i.e. window-size or maximum size) (DFO 2023; Asselin et al. 2024). In the most recent assessment, reported Lobster landings were 39,313 t in 2021, approximately three times the upper stock reference of 13,798 t, which places the stock within the healthy zone of the precautionary approach (DFO 2023; Asselin et al. 2024; Figure 6). Within the Northumberland Strait, Lobster abundance, biomass and density have increased, and Lobsters have expanded their distribution into deeper waters (Asselin et al. 2024). While juvenile and young-of-year densities are stable at high levels or increasing (DFO 2023; Asselin et al. 2024) the availability of juvenile Lobster habitat will remain an important factor in the continued recruitment of new individuals into the local Lobster population.

Chassé and Miller (2010) developed an ocean circulation model of Lobster larval drift to simulate development and survival in relation to environmental conditions in the sGSL. Their study found areas along the NB coast (LFA 23 and 25) to be important source areas of larval production as they supplied a greater proportion of modelled settlers to all areas in the southern Gulf (Chassé and Miller, 2010). Chasse and Miller (2010) also found northern PEI (LFA 24) made only minor contributions to settlement likely due to larval drift into deep areas with colder bottom temperatures. Similar analyses across the entire species range of Lobster show self-recruitment is high (50%+ regardless of whether larval mortality is assumed) in the Northumberland Strait (LFAs 25, 26A, and 26B) (Quinn et al. 2017). LFAs in the northern Gulf of St. Lawrence (LFAs 18, 19, 20A, 20B) also contributed recruits into the Northumberland Strait. In Chaleur Bay, the northern shore LFAs (20B, 21) contributed high recruitment into LFA 23, while a large proportion of larvae were also predicted to disperse from LFA 23 into the Northumberland Strait (LFA25) and northern shore of PEI (LFA24; Quinn et al. 2017).

Prior research assessing the effect of commercial Scallop harvesting on Lobster habitat indicate that there is minimal overlap between the two species due to their differing preferred habitat types (Pringle and Jones 1980; Roddick and Miller 1992). Roddick and Miller (1992) found that Lobster >50 mm CL were rarely occupying habitats targeted by commercial Scallop harvesting activities and noted that Lobsters smaller than 50 mm often passed unharmed through the rings of Scallop drags. A study in the SFAs was also conducted by LeBlanc et al. (2015) to look at the impacts of Scallop dredging. The study used a Before-After-Control-Impact (BACI) design where experimental plots were treated with different intensities of harvesting activity using a four-meter Digby-type rock dredge. This study identified short-term fluctuations in abundance of benthic species due to Scallop dredging activities but showed little long-term (one-year post) impacts on benthic organisms (LeBlanc et al. 2015). There is also evidence that the negative effects of Scallop dredges on other organisms can vary seasonally, particularly for crustaceans during their molting periods (Auster et al. 1996).

Population enhancement

In reaction to decreasing Lobster landings in some areas of the sGSL in 2000-2001, fishers became interested in Lobster population enhancement. Inspired by Maine hatcheries, a hatchery and seeding program was developed in the region. The program consists of collecting berried females at the site where Lobster seeding will occur and bringing them to the hatchery for egg hatching. Once the eggs hatch the larvae are hatchery-raised for 12-14 days until they reach stage IV, which is the first benthic stage of the Lobster's life cycle. At this point they are released directly onto the bottom in the general location where the berried females were collected. A DFO Science study conducted using BACI method (Comeau 2006), showed that seeding significantly influenced juvenile density in the following years. Enhancement effects seem to be localized to within 200-500 meters from the release site. Seeding has been ongoing since 2002, with just over 8.4 million stage IV Lobster being released at 37 different areas.

Enhancement efforts conducted within the last 5 years have the potential to influence juvenile Lobster populations. From 2020 to 2024 a total of 1,092,900 stage IV Lobster were released inside or within 115 meters of one of the SBZ MRs (Table 3). The number of stage IV Lobster released over that period in SBZ 21a, SBZ 22 and SBZ 24 are 550,400, 237,500 and 305,000 respectively. No Lobster enhancement was conducted in the PEI sections of the SBZ MRs. See Figure 7 for approximate release locations (data provided by Homarus Inc.).

INDIRECT BIODIVERSITY CONSERVATION BENEFITS

There are other benefits to the ecosystem provided by the SBZ MRs. The absence of commercial Scallop harvesting could offer protection to other ecologically or biologically significant species in the southern Gulf of St. Lawrence (Rondeau et al. 2016) and can have an impact on general benthic biodiversity. The coastal regions of the sGSL are home to many species that are distinct from those in offshore areas (Hanson 2018). Large populations of diadromous fish, demersal species, benthic invertebrates, and macrophytes inhabit the warmer water and varied substrates of the coastal regions in the sGSL, both seasonally foraging or for particular life cycle stages (Wahle and Steneck, 1991; Hanson 2009, 2018; Bosman et al. 2011; DFO 2017b,c; Rondeau et al. 2016; Asselin et al. 2021).

Three particular species that inhabit the SBZ MRs are noteworthy due to recent population declines or geographically restricted populations (COSEWIC 2015; Surette and Rolland 2019; DFO 2020, 2022) (Figure 4): the protection of Atlantic Herring eggs in all three SBZ MRs (SFA 21, 22 and 24), as well as Winter Skate and Lady Crab within SBZ 22.

Atlantic Herring spawning areas

Atlantic Herring is an ecologically, economically and culturally important small pelagic fish species. Within the sGSL it serves as an important prey source for many higher-level trophic predators, including but not limited to Grey Seal (*Halichoerus grypus*), Atlantic Cod (*Gadus morhua*), White Hake (*Urophycis tenuis*), and Atlantic Bluefin Tuna (*Thunnus thynnus*) (Benoît and Rail 2016). Atlantic Herring is used as bait in several lucrative fisheries including American Lobster and Snow Crab. Atlantic Herring in the sGSL consist of two genetically distinct spawning components: spring spawners, which spawn between March-June, and fall spawners, which spawn between July- October (Messieh 1987; Lamichhaney et al. 2017). In the sGSL, spring spawning Atlantic Herring experienced substantial declines in the mid-1990s and have since remained at low spawning stock biomass over the past two decades. The stock has been in the critical zone of the Precautionary Approach Framework since the early 2000s and has shown little sign of recovery (DFO 2024a; Turcotte and McDermid 2024). Fall spawning Atlantic Herring experienced more recent declines beginning around 2010 and have been in the cautious zone of the Precautionary Approach Framework since 2017 (Figure 8; DFO 2024). These declines have been associated with a combination of fishing mortality, high predation-driven natural mortality, and low recruitment associated with unfavourable environmental conditions. Particularly, within the sGSL, temperature regimes have been altered due to climate change, with warming waters resulting in negative implications for overall habitat suitability and both prey (zooplankton) density and phenology, during the spring and fall spawning season (Turcotte 2022; Burbank et al. 2023a). Furthermore, research has shown the size-at-age and fecundity of both spring and fall spawning Atlantic Herring has been declining for the past three decades, which has negative implications for overall reproductive output (Burbank et al. 2023b; Burbank et al. 2024).

Both sGSL spring and fall spawning Atlantic Herring reproduce in shallow coastal habitats, with the majority of spawning activity likely occurring within the SBZ MRs (Messieh 1987). Public reports of spawning events from pilots, fishers and the general public have been collected and compiled by DFO Science since 2022, and 83.3% of spawning locations reported have been within or immediately adjacent to the SBZ MRs (Figure 9). Historically, spring spawners have been observed to deposit eggs at depths of 0.8 m to 5 m on rocky and sandy substrates covered in thick carpets of Irish moss (*Chondrus crispus*), rockweeds (*Fucus* sp.), and leafweeds (*Phyllophora sp.*), all of which are present in the SBZ MRs, whereas eggs deposited by fall spawners were found at depths between 15 and 20 m over relatively bare bedrock and rubble (Messieh 1987). More recent characterizations of contemporary spawning events have also observed spring spawners deposit eggs all the way to shore and over eelgrass beds and red algae species such as *Furcellaria lumbricalis* (Burbank, pers. comm.). Fisherman's bank, off the east coast of PEI, is a particularly important historical spawning ground for fall spawning Atlantic Herring (Cairns et al. 1995), which is offered protection by SBZ 24. In the northeastern Atlantic both spawning substrate complexity and vegetation cover quantity and quality have been shown to be important for the successful spawning and hatching of Atlantic Herring eggs (Kanstinger et al. 2018; von Nordheim et al. 2018). Furthermore, recent egg hatching experiments of sGSL spring and fall spawning Atlantic Herring have shown vegetation type has significant impact on egg survival (Burbank, unpublished). Therefore, protection of benthic habitat from commercial Scallop bottom contact fishing gear offered by the SBZ MRs likely has important positive impacts on the spawning and hatching success of sGSL Atlantic Herring by providing protection for important spawning habitat features. In addition to the spawning and egg stage, other early life stages of Atlantic Herring from the larval to the juvenile stage require suitable nursery habitat close to spawn locations that consist of high-quality zooplankton prey to facilitate growth and provide protection from predation. Specific larval and juvenile nursery locations are not currently well understood in the sGSL, but they are thought to be in coastal environments in close proximity to spawning beds and are thus likely offered some protection by the SBZ MRs given the large proportion of spawning events observed within or immediately adjacent to the SBZ MRs. Currently, poor recruitment, for which the first step is successful spawning and egg hatching (Burbank et al. 2023c), is a major factor restricting the rebuilding of spring spawning Atlantic Herring (Turcotte and McDermid 2024). Therefore, any protection of habitat that enhances early life survival is valuable for the population.

Winter Skate

Winter Skate (*Leucoraja ocellata*) is a cartilaginous fish that was commercially fished in the 1970s and 1980s (DFO 2017b). Overexploitation, increased bycatch in Scallop and groundfish fisheries, increased natural mortality, and their slow maturation rate led to the species being classified as endangered in 2015 in the Gulf of St. Lawrence and the eastern Scotian Shelf/Newfoundland waters (COSEWIC 2015). The Gulf of St. Lawrence population of Winter Skate, which matures quicker but grows smaller compared to other populations, has seen up to

99% population declines since 1980 (COSEWIC 2015; DFO 2017b). Winter Skate produce few offspring, which increases the risk of population decline when individuals are removed from the breeding population due to fishing (Kelly and Hanson 2013).

Winter Skate in the sGSL have experienced a decline in coastal habitat range and are now only found to occupy a small region of the western Northumberland Strait in SFA 22 (Figure 10) likely due to a 15 fold increase in their main predator, the Grey Seal, since 1960 (Swain and Benoît 2015). Winter Skate inhabit coastal waters less than 40 m deep in the summer and early fall, before moving into the deeper waters of the Laurentian Channel and Magdalen Shallows in the winter (DFO 2017b). They have been found living on both sand and gravel substrates (Kelly and Hanson 2013). Commercial Scallop harvesting activities have been found to overlap with the habitat of the Winter Skate outside the SBZ MRs, resulting in bycatch (Benoît et al. 2010). Therefore, limiting commercial Scallop harvesting ensures nearshore protection of Winter Skate occupying SFA 22.

Lady Crab

Northern Lady Crab (*Ovalipes ocellatus*) are found along the Atlantic coast of North America (Voutier and Hanson 2008). In Canadian waters, Lady Crab are found in two distinct populations: one in the Bay of Fundy and one in the Northumberland Strait (Voutier and Hanson 2008). Occupying sandy coastlines, Lady Crab play a key role in estuary ecosystems by regulating prey populations of molluscs, shrimps and other macrobenthic animals (Burchsted and Burchsted 2006). Lady Crab are known to eat smaller Rock Crab and fish remains (Voutier and Hanson 2008) and have also been found to prey on small amounts of Lobster, particularly in the summer months when molting occurs (Hanson 2009).

In the sGSL, the Lady Crab population has a restricted range (Voutier and Hanson 2008), appearing to occupy a 2,500 km^2 area along the coastlines of the center of the Northumberland Strait (Figure 11). This region is found within SFA 22 where the shelter of the strait in combination with the warm summer temperatures, sandy substrate and salinity likely create an ideal environment for Lady Crab. Water temperatures in this coastal region of the Northumberland Strait reach above 18°C throughout the summer and early fall, potentially explaining the isolated occurrence of this population (Voutier and Hanson 2008). Monitoring and protection of the SBZ MRs directly benefits Lady Crab given much of the nearshore habitat occurs within SBZ 22.

Aquatic Macrophytes

Seagrass occur predominantly in embayments that do not overlap with the SBZ MRs (Joseph et al. 2006; van den Heuvel et al. 2019), for which the inner boundaries do not extend all the way to the coast. Seaweeds/macrophytes, however, are abundant up to a depth of ca. 20 m, but depending on water clarity can reach depths of 60 m or more in the north Atlantic (Dorte et al. 2019). Seaweeds are ecosystem engineers, providing underwater habitat, nursery grounds (see Atlantic Herring above), and a food source for marine fauna in coastal waters (Bringloe et al. 2020). Seaweeds represent three major lineages, including the red and green seaweeds, and the more distantly related brown seaweeds, the latter of which include important habitat forming species present in the Northumberland Strait such as Fucales (e.g. *Ascophyllum nodosum*, *Fucus* spp.) and kelp (e.g. *Saccharina latissima*).

Several factors limit the abundance and diversity of seaweeds in the SBZ MRs. The primary limitation is substrate type, given seaweeds generally require stable cobble and rock to adhere to. Ice scour can also limit some species by physically removing individuals from substrate, particularly in the intertidal to shallow subtidal zones during winter. Aside from commercially important species, there are no recent formal surveys specific to Northumberland Strait species, abundances, and distributions. Multi-species trawling survey data are uninformative, with coarse level identifications left as red or brown seaweeds (e.g. Asselin et al. 2021); note, species identifications often require molecular (DNA) confirmation in seaweeds.

Invertebrates

Many invertebrate species are present within the SBZ MRs, with a variety of crustaceans, molluscs and sponges inhabiting the area. In addition to Lobster, the Northumberland Strait multispecies trawl survey routinely captures Rock Crab (*Cancer irroratus*), Lady Crab (discussed above) as well as other invertebrates including sea stars, gastropods, and mussels (see Asselin et al. 2021 for a comprehensive species list).

Sponges

Several sponge species are common in the Northumberland Strait, and generally the species composition of the area differs from the rest of the Gulf of St. Lawrence (Dinn 2020). Sponges can have elaborate and diverse body forms, with many variations in shape and appearance (Hooper and Van Soest 2002). All of these growth forms can provide more complex benthic habitat than bare substrate alone (Bett and Rice 1992; Barthel 1992). This increase in habitat complexity and biogenic substrate provided by sponges can create shelter and nursery habitat and/or food for invertebrates (Larcombe and Russell 1971; Barthel and Gutt 1992; Freese and Wing 2003; Ryer et al. 2004; Amsler et al. 2009; Todt et al. 2009; Kenchington et al. 2013). Sponge species that are often encountered in the area include *Halichondria (Halichondria) panicea* , *Haliclona (Haliclona) oculata* , *Clathria (Clathria) prolifera* , *Amplilectus* sp., *Suberites ficus* , *Cliona celata* , and *Polymastia bartletti* (Dinn 2020). Additional species, specific physiology (growth rates, water filtering activity, etc.), and species interactions in the SBZ MRs warrant additional study.

Rock Crab

Rock Crab are the dominant prey source for adult Lobster in the Gulf of St. Lawrence (Hanson 2009; DFO 2017c). Rock Crab have been shown to make up approximately 80% of an adult Lobster's diet and contribute to increased energy reserves and muscle development when consumed by Lobster over their other prey species (Gendron et al. 2001).

Sharing many habitat preferences with Lobster, Rock Crab can be found living in both sandy and rocky substrate habitats within the SBZ MRs and coastal regions of the Gulf of St. Lawrence (Hudon and Lamarche 1989). Rock Crab tend to burrow in sandy substrates, while juvenile Lobster inhabit rockier habitats, preventing interspecific competition for space between the two crustaceans (Hudon and Lamarche 1989). As such, SBZ MRs can also contribute to protecting the habitat of an important prey source for Lobster. Rock Crab and Lobster share prey preferences such as mussels, other decapods, and algae, although Lobster have higher rates of cannibalism than Rock Crab. Rock Crab will also consume polychaetes and bryozoans in greater quantities than Lobster, however the largest dietary difference lies in overall prey selection trends. Rock Crab are more opportunistic feeders than Lobster and show greater variation in prey selection between different sample locations than Lobster (Hudon and Lamarche 1989).

Sea Scallop

Sea Scallop occurring within the SBZs benefit directly from prohibited commercial harvesting targeting the species. Moreover, juvenile Scallop are especially vulnerable to habitat disturbances (Niles et al. 2021), and benefit from dynamic substrate for establishment of spat (larvae settled on substrate), including adult shells (Bourgeois et al. 2006) and hydroids (in *Pecten maximus* and *Aequipecten opercularis*; Bradshaw et al. 2003). The preferred depths of Sea Scallop, which are between 15 and 37 m (Niles et al. 2021), largely do not overlap with the profile of the SBZ MRs (Figure 3). Moreover, three main beds are known from within the Northumberland Strait between PEI and NB in SFAs 22 and 24 (Niles et al. 2021), and historical knowledge indicates at least the Pictou bed pre-dates the SBZ (Chiasson 1952; Harbicht et al, 2024). Fisheries logbooks also suggest these beds have remained relatively stable from 2001 to 2016 (Niles et al. 2021). As such, the SBZ MRs likely offers limited overall protection for Sea Scallop.

Fish

The SBZ MRs are home to demersal and pelagic fish, including migratory species, that use coastal habitats for spawning and foraging. More comprehensive lists of species presence in trawlable areas can be found in the Northumberland Strait multi-species bottom trawl survey report (Asselin et al. 2021).

The SBZ MRs provide foraging habitat for migratory fish species such as the Striped Bass (*Morone saxatilis*) and Brook Trout (*Salvelinus Fontinalis*), which seasonally migrate through the estuaries of the Northumberland Strait (Rondeau et al. 2016). Other migratory fish species such as the American Eel (*Anguilla rostrata*), American Shad (*Alosa sapidissima*), Hickory Shad (*Alosa mediocris*), Spiny Dogfish (*Squalus acanthias*), Rainbow Smelt (*Osmerus mordax*), American Butterfish (*Peprilus triacanthus*) and Atlantic Saury (*Scomberesox saurus*) inhabit the coastal region of the Northumberland Strait for foraging and spawning (Rondeau et al. 2016; Asselin et al. 2021).

Coastal shallows provide seasonal habitat and foraging grounds for many demersal species. Economically valuable species such as Yellowtail Flounder (*Limanda ferruginea*), Cunner (*Tautogolabrus adspersus*) and Atlantic Cod (*Gadus morhua)* have been reported within the Northumberland Strait (Bosman et al. 2011). Windowpaine Flounder (*Scopthalmus aquosus*), Longhorn Sculpin (*Myoxocephalus octodecemspinosus*), Atlantic Tomcod (*Microgadus tomcod*), Ocean Pout (*Zoarces americanus*), American Plaice (*Hippoglossoides platessoides*) and White Hake (*Urophycis tenuis*) are other demersal fish that have also been recorded from trawl surveys in the sGSL in much smaller densities (Bosman et al. 2011; Asselin et al. 2021).

Winter Flounder

Winter Flounder inhabit most of the western Atlantic seaboard, ranging from Georgia, USA to the northeastern coast of Labrador (Surette and Rolland 2019). Within the Gulf of St. Lawrence, Winter Flounder can be found in the coastal regions of the Northumberland Strait as well as within the St. Lawrence River estuary, Chaleur Bay and the St. Georges Bay shallows. This flatfish species is unique in that it will overwinter within the Gulf of St. Lawrence, utilizing natural antifreeze properties and a wide tolerance for both temperature and salinity in order to occupy coastal regions before migrating into deeper waters in the summer. Rather than migrate to offshore areas during winter, Hanson and Courtenay (1996) found sGSL Winter Flounder aggregated within the Miramichi Estuary. The authors suggest estuaries throughout the sGSL provide refuge from freezing temperatures and ice scour given these are more accessible than offshore areas with suitable winter habitat. Uncertainty remains regarding the density of Winter Flounder at shallow depths in the sGSL, though Surette and Rolland (2019) suggest inshore areas might be important habitat for smaller, younger individuals, an observation confirmed in the Bay of Fundy (McCracken 1963) and the New England States (Pereira et al. 1999). Spawning also occurs in shallow waters in spring (May; <9 m), with mature fish moving to deeper waters during summer (June onwards; McCraken 1963). Eggs are also reported from cold (<10°C) shallow (<10 m) waters throughout the species southern range (Pereira et al. 1999).

Winter Flounder have been actively fished since the 1960s but landings have been declining in recent decades, in addition to declines in Winter Flounder size, growth and spawning stock biomass (Surette and Rolland 2019). Given these declines, the conservation of coastal habitats through efforts like the SBZ MR may help to protect nurseries for eggs and juveniles and consequently improve recruitment and fisheries stock, though this remains to be confirmed in the sGSL.

RESEARCH ACTIVITIES

Several DFO Science surveys occur throughout the Northumberland Strait and Chaleur Bay to assess the abundance and distribution of ecologically and economically important fish and invertebrate species, along with associated environmental variables. While the scientific surveys reviewed here do not occur solely within the boundaries of the SBZ MRs, surveys and data collection do overlap and are potentially important sources of information for ecological monitoring. Bottom-contacting survey activities conducted within these areas are not anticipated to cause long-term harm to the habitats supporting the ecological components of interest (Benoît et al. 2020). Removal of these types of surveys have been shown to reduce power to detect potential population declines (Anderson et al. 2024).

Northumberland Strait multi-species bottom trawl survey

The Northumberland Strait multi-species bottom trawl survey has been occurring since 1999, but was standardized in 2001 (Asselin et al. 2021) (Figure 12). Generally conducted in July and August, about 100 locations throughout LFAs 25 and 26A are sampled annually (Asselin et al. 2021). The survey originally targeted Lobster but, since 2005, the survey records catch weight, length frequencies, and counts for all fish, Lobster and crabs captured (Asselin et al. 2021). For Lobster, the data contribute to multiple stock status indicators of abundance (i.e. commercial biomass and commercial abundance) and productivity (i.e. pre-recruit abundance and egg production) (Asselin et al. 2024). In 2024, fin clip samples were collected from Winter Skates captured on the survey, and these samples were used for genetic analyses. Similar samples were collected on other surveys in the Gulf and Maritimes regions, to better characterize the population structure of Winter Skate on the Atlantic coast. The sGSL population was identified by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as endangered, and the genetic analyses aim to inform the assignment of designatable units for this species (COSEWIC 2015). As of the survey data reported for 2023, 26.2% of the data points occurred within the SBZ MRs (Figure 12). Of these data points, 0.2% occurred within SBZ 21, 81.8% occurred within SBZ 22, and 18.0% occurred within SBZ 24. Bottom-trawl surveys consistently capture adult-sized Lobsters but smaller Lobsters, species occurring at lower density, fast-swimming fish, and pelagic species are captured less consistently and catches may not be representative, including in some of the other BCB species listed here (i.e. Winter Skate; Figures 7 and 8).

September research vessel survey

This bottom-trawl survey has been operating every autumn since 1971 in the sGSL to evaluate the abundance indices and health of demersal fish and invertebrates (Hurlbut et al. 2006, Savoie et al. 2012). The survey has a random stratified sampling design, with strata defined according to depth and area. The survey covers Northwest Atlantic Fisheries Organization (NAFO) Area 4T in the sGSL (Ricard and Swain 2018). However, less than 0.5 % of the data points collected between 1971 and 2022 are within the boundaries of the SBZ MRs, with most sample sites targeting deeper waters off-shore north of PEI (Figures 3 and 13).

Coastal Temperature Monitoring Program in the sGSL

The coastal temperature monitoring program in the sGSL has been collecting data since 1995 with the intent of better understanding temperature fluctuations and its effect on coastal marine species. Monitoring program reports are published regularly with the most recent report for 2022 and 2023 monitoring published by Ouellet and Gagnon (2025). Bottom and surface temperatures are monitored using electronic recording devices attached to navigational buoys or moorings and are set to collect data every two hours. The dataset includes surface through to benthic recordings. Out of nearly 3 million observations to date, 32.4% occur within the SBZ MRs, with 1.6% within SBZ 21, 11.2% within SBZ 22, and 19.6% within SBZ 24. Forty three percent of the stations (n=121; 1995-2021) occurred within the SBZ MRs (Figure 14), making this a valuable resource for monitoring shifting temperature regimes within the MR. While there is considerable overlap in temperature profiles over the past three decades, more recent recordings do appear biased towards higher values in the Fall, particularly benthic readings for SBZ 24 (Figures 15 and 16).

American Lobster bio-collector project

In collaboration with industry groups and the PEI provincial government, DFO Science monitors the settlement of young-of-year Lobsters within the SBZ MRs and surrounding areas using vessel-deployed bio-collectors. Bio-collectors are rectangular metal cages filled with gravel and cobble and designed to mimic the preferred habitat of post-larval Lobsters (see additional details in Wahle et al. 2009 and Rondeau et al. 2015). There are eight sites that are surveyed every year, four of which have records falling within the SBZ MRs (Figure 17). At each site, thirty bio-collectors are deployed annually in July and retrieved in the fall, to capture the settlement period of young-of-year Lobster. For bio-collector sites within the SBZ MRs, the supply of post-larval Lobsters has been fairly consistent since 2010, except for Skinner's Pond, where the abundance of juveniles (<40 mm CL) was up to four times that of the other three sites (Figure 18). The highest recorded abundance of juvenile Lobsters was at Skinner's Pond in 2018 (Figure 18; Asselin et al. 2024). Data from the project are used with the sGSL Lobster stock assessment to estimate indices of the abundance of young-of-year Lobster and of prey availability (Asselin et al. 2024). The project also contributes to the American Lobster Settlement Index program, which includes sites from the Atlantic coast of New England, US to Newfoundland, Canada (McManus et al. 2023).

American Lobster SCUBA surveys

SCUBA surveys are completed annually in June and July by DFO Science at nine sites in the sGSL (Asselin et al. 2024). Initiated in 2000, the main objective of the project is to estimate the density of juvenile Lobsters (CL 21-40 mm) in rocky reef habitat, at water depths up to 10 m. Seven of the monitored sites are within the SBZ MRs boundaries (Figure 17). For all sites combined, juvenile Lobster predicted model densities increased in the region up to 2016, to 14.5 Lobsters per 100 m^2 (95% CI 3.6-57.6 Lobster per 100 m^2) and then stabilized or decreased slightly from 2016 to 2022 (Figure 19; Asselin et al. 2024).

Scallop surveys

A research vessel survey has been conducted in select SFAs to evaluate abundance, size, and natural mortality of Sea Scallops. One survey was conducted in 1997 in SFA 22 with an annual survey starting in 2012 (Niles et al. 2021). The annual survey would alternate between the different SFAs with the exception of SFA 23. Annual surveys were conducted using an eight-gang toothed Digby Scallop drag lined with 14 mm mesh to capture smaller specimens (Niles et al. 2021), though in more recent years (2019-2023) an eight-gang toothed Digby Scallop drag with 82.6 mm rings with two of the eight buckets lined with 18 mm mesh were used in the new survey to address limitations of previous surveys (Niles et al. 2024).These surveys contribute to understanding the regional Scallop population dynamics within the SFAs, in addition to recording occurrences of other benthic species caught in the drag nets. For the most recently updated dataset, only 6.1% of observations across all species occurred within the SBZ MRs (Figure 20).

Atlantic Herring Surveys

In 2022, DFO Science initiated a program to better understand the contemporary spawning locations and habitat of Atlantic Herring. DFO Science is requesting Transport Canada surveillance, private and flight school pilots, fishers, and the general public to report any observed spawning events and are compiling these observations. When a spawn event is reported, DFO Science staff visit the site to confirm spawning has occurred and take a small sample of eggs diameter measures, development staging, lipid analysis, and, in some cases, bring a small sample of eggs to the Homarus Centre in Shediac, NB, to rear eggs. The rearing portion of the project is being conducted to examine the impacts of spawning substrate type (i.e. different vegetation types) and environmental conditions on hatching success and duration of the yolk sac larval stage. In combination with lipid analysis of egg samples, this will inform on the habitat conditions that support successful hatching of Herring eggs. Overall, the project aims to quantify the benefit of the SBZ MRs for protecting these spawning habitats, and nursery grounds by calculating the proportion of the SBZ MRs that are suitable Herring habitat. Currently, a total of 18 spawn events have been reported from 2022-2024, of which 15 (83.3 %) fall within or immediately adjacent to the SBZ MRs (Figure 9).

DFO Science has also been conducting a spawning grounds acoustic survey with industry partners on six historically known major fall Herring spawning grounds, in a standardized manner since 2015 (Turcotte et al. 2022). For the survey, fishing boats equipped with echosounders collect hydroacoustic data along randomly generated pre-determined transects withing a fixed survey area up to five different times throughout the spawning season (August – October). Three of the six survey locations (Escuminac, Pictou and west PEI) are largely within the SBZ MRs. Experimental nets, which are multi-pane gill nets with 5 different mesh sizes designed to catch a wide range of fish sizes, are also deployed in the survey area to provide biological information that facilitates conversion of acoustic signal to biomass estimates (Turcotte et al. 2022). Therefore, an index of Herring biomass can be estimated and tracked from year to year in these locations within the SBZ MRs.

Since 1991, DFO Science has also been conducting an annual fishery-independent fall acoustic survey from mid-September to mid-October in the Chaleur Bay region of the SBZs. The acoustic survey uses a random stratified sampling design with parallel transects within predefined strata to collect acoustic data and estimate biomass of spring spawners, ages 4-8, who are thought to be congregating to forage in the area and fall spawners, ages 2-3, who may be using the area as a nursery (Rolland et al. 2022). When schools are detected, Herring are collected with a mid-water or bottom trawl to provide biological information and facilitate conversion of the acoustic signal to age-specific biomass estimates. Three of the 18 strata surveyed, each of which are located on the south shore of Chaleur Bay, enter the SBZ MRs and fish samples are often taken within the SBZ MRs depending on where fish are detected. This provides future opportunities to understand the age structure of Herring within the SBZ MRs. Furthermore, the use of Remote Operated Vehicle (ROV) footage to examine habitat where large schools were detected was piloted in 2024 and in future years this opportunistic video footage collection via ROV will continue when time allows, offering the opportunity to classify habitat features used by Herring schools within these areas.

Modelling and Forecasting

A hindcasting modeling system of the Gulf of St. Lawrence, Scotian Shelf and Gulf of Maine (named CANadian Océan PArallélisé '[CANOPA']) was first developed by Brickman and Drozdowski (2012) and used for several projects in the Gulf of St. Lawrence. The model is based on the Nucleus for European Modelling of the Ocean Océan PArallélisé circulation modeling system and includes ice cover, tides, oceanic surface momentum, heat and salt fluxes. A variant also includes biogeochemical modelling (Lavoie et al. 2021). Two versions of the physical modelling setup are available (1/12° and 1/24° horizontal resolution). In both cases, the vertical resolution is achieved by 46 vertical layers with vertical thickness resolutions varying from 6 m at the surface to 250 m at 5000 m depths. The model includes runoff from 78 main rivers to account for the freshwater fluxes into the domain. Several simulations were conducted using the CANOPA setup. Among them, a simulation for the 1948-2023 period using the updated atmospheric conditions obtained from the National Centers for Environmental Predictions was successfully compared to field data including temperature and salinity in the Gulf of St. Lawrence, Scotian Shelf and the Gulf of Maine (Brickman and Drozdowski 2012; Lavoie et al. 2015; Daigle et al. 2016; Lavoie et al. 2021). Another simulation, starting in May 2005, has been conducted using the Canadian Meteorological Center 3-hourly atmospheric forcing along with boundary conditions from GLobal Ocean ReanalYes and Simulations. The biogeochemical modelling simulation covers the 1997-2023 period. Recently, a north Atlantic Ocean-ice Downscaling System has been developed, which consists of a 1/12° model for the northwest Atlantic region nested to a 1/4° model for the north Atlantic. A hindcast simulation was carried out for the period from 1980 to 2021 (Han et al. 2021). All the simulations mentioned above cover the SBZ MRs and information could be taken from them when observation data is missing.

Recent advances in regional climate downscaling have improved the ability to project future environmental conditions in the Gulf of St. Lawrence, Scotian Shelf, and Gulf of Maine. Long et al. (2015) first developed a high-resolution regional climate downscaling system, which provided projections up to 2069. This modeling framework was later extended to 2100 and further refined by Lavoie et al. (2020) to simulate future physical and biogeochemical conditions under the Representative Concentration Pathway 8.5 climate scenario. These simulations incorporate output from multiple Earth System Models (CanESM2, MPI-ESM-LR, and HadGEM2-ES) and provide detailed forecasts of temperature, salinity, stratification, and carbonate chemistry. Han et al. (2025) also produced some downscaled climate projections that include the SBZ MRs. Such information is necessary for assessing future habitat suitability within SBZ MRs, particularly as climate-driven changes impact juvenile Lobster nursery areas and broader biodiversity.

One of the major findings from the above studies is that increasing ocean stratification and warming trends may alter key ecosystem dynamics in the Gulf of St. Lawrence. Additionally, ocean acidification, characterized by declining aragonite and calcite saturation states, poses a growing risk to calcifying organisms that form a critical part of the food web. Given these emerging threats, integrating biological and physical models is essential to better predict ecosystem shifts within SBZ MRs and develop effective conservation strategies under predicted climate scenarios.

ENVIRONMENTAL THREATS

Here we list environmental pressures and threats that are likely to have the most impact on the biological and ecological components of the SBZ MRs. However, we note that being a large coastal area that hosts a large variety of human activities (commercial, industrial and recreational), cumulative impacts not explicitly described could be observed during ecological monitoring. These should be addressed in the operational management plan for the SBZ MRs, while considering additional non-ecological factors.

Climate Change

Climate change can affect the marine environment though shifting thermal regimes and altered water chemistry, which can lead to various effects on biological processes ranging from positive to negative depending on the context. It is worth noting, however, that coastal systems are inherently dynamic, with daily and seasonal fluctuations in environmental conditions. If SBZ MRs species are generally adapted to a broader range of conditions, then we might expect greater resilience to climate change. Changes are also expected at the ecosystem level as species migrate into or out of the area with their ideal water temperatures. There is still a fair amount of uncertainty in how abiotic and biotic variables will shift and change under new climate regimes, as well as how benthic species such as Lobster will adapt when their optimal habitat conditions are altered (Tai et al. 2021). Regional climate downscaling and statistical downscaling (e.g. neural networks) are necessary to bring the large-scale climate change information to the scale of the SBZ MRs.

Changing Thermal Regimes

Water temperatures are changing in the Gulf of St. Lawrence. The range of temperatures of many marine and coastal habitats are expected to change drastically with projected increases in both surface and bottom temperatures (Greenan et al. 2019; Lavoie et al. 2021). In the Gulf of St. Lawrence, bottom water temperatures have increased by approximately 1.8°C between 2009 and 2022, altering the normal temperature extremes for those habitats and reducing the concentration of dissolved oxygen available for aquatic organisms (Brennan et al. 2016; Galbraith et al. 2023). As a result of these changes, the distributions of some species have been shifting, either to avoid biological thermal limits or to occupy new habitats that fit into their tolerances. This has been seen in Lobster populations, which are shifting northward in response to warmer temperatures (Steneck and Wahle 2013). Local changes in Lobster temperature habitat in the sGSL have also been documented by Asselin et al. (2024). Range shifts have also been observed in predator species of Lobster such as the Black Sea Bass (*Centropristis striata*) which has been observed moving its range northward towards the Gulf of Maine (McMahan et al. 2020), implying potential longer-term threats to the sGSL.

For the larval stage of Lobster, water temperature plays an important role in larval development, settlement, and distribution patterns (Quinn 2017; Quinn et al. 2022). Increases in water temperature will result in changes in ocean currents, altering the trajectory and transport of larval Lobsters within a region (Chassé and Miller 2010; Cetina-Heredia et al. 2015). Waller et al. (2017) also found that increases in temperature can affect larval development, with correlated increases in growth rate, oxygen consumption and a decrease in survival between the first and fourth larval stages. Since temperature plays a role in the time between each larval molt (Cobb 1976), warmer water temperatures will shorten the duration of the larval phase and reduce potential dispersal before settlement occurs (Cetina-Heredia et al. 2015).

Juvenile Lobster have limited mobility, therefore warming water temperatures above their tolerance threshold can lead to increased mortality (Greenan et al. 2019). Warming water temperatures can also result in long-term effects on fitness, reducing resilience of Lobster to stressors such as disease-causing bacteria which cause epizootic shell disease (Greenan et al. 2019). Recent studies have shown that larval Lobster can be affected by short-term exposure to temperatures above their thermal limits, and that these exposures can cause sub-lethal effects which can reduce the overall fitness and survival of the individual, even after the heat event has passed (Quinn 2017). Shifting temperature regimes can also result in “mismatches” for migratory species, where the biological timing of seasonal foraging events or habitat use is no longer synchronized with the resource availability or suitability (Greenan et al. 2019).

Seaweed distributions are also highly correlated with water temperatures (Lüning 1990). Coarse resolution spatial predictions exist for species occurrences under advanced climate change. The southern range edge of some Arctic and cold-temperate species such as kelp are predicted to shift northwards and lose suitable habitat in the sGSL (Assis et al. 2018; Wilson et al. 2019; Bringloe et al. 2022). Finer scale environmental data (i.e. substrate type and temperature) along with species occurrence data are needed to refine predictions for the SBZ MRs and the sGSL in general. Given the importance of macrophytes as ecosystem engineers, species and/or functional group abundances and distributions warrant attention in future monitoring.

Ocean acidification

Increased CO_2 in the atmosphere can lead to ocean acidification (Mucci et al. 2011). Global oceans have seen a drop in pH of 0.1 over the last 100 years, a decline that has also been seen in the deepest waters of the Gulf of St. Lawrence (Mucci et al. 2011; Brennan et al. 2016). Ocean acidification can have negative effects on aquatic organisms such as crustaceans, corals, and other shell-developing species due to the reduced availability of calcium and other minerals in more acidic water (Mucci et al. 2011; Tai et al. 2021). Lower pH environments can negatively affect non-shell developing organisms as well, due to the influence of pH on biological functions such as hatching success, growth rate and overall fitness due to changing energy demands (DePasquale et al. 2015).

For Lobster, ocean acidification can impact growth rates and size at maturity, with the juvenile life stage being the most vulnerable (Brennan et al. 2016). Juvenile Lobster have higher energy requirements for growth and in lower pH waters this energy demand increases, where the acidic environment makes it harder for calcium rich carapaces to form (Brennan et al. 2016; Tai et al. 2021). The intermoult interval length has also been found to be negatively affected by lowered water pH, reducing calcification rates during shell formation (Brennan et al. 2016).

Because ocean acidification is affecting the deeper waters of the sGSL, it is possible the SBZ MRs, which are generally restricted to the top 20-40 meters (Figure 3), will not see similar impacts. However, Gibb et al. 2023 have reported zones of aragonite and calcite undersaturation in the sGSL and it is not known if those areas can expand to SBZ MRs and affect species within.

Aquatic invasive species

European Green Crab

European Green Crab (*Carcinus maenas*) is an introduced species that has spread rapidly across the coastal regions of Canada. First detected in the United States in the late 1800's, Green Crab were reported off the coast of Prince Edward Island in 1997 (Audet et al. 2008). The species can tolerate a range of water quality and temperatures, and will prey upon a variety of coastal and estuarine species (Audet et al. 2008; De Rivera et al. 2011).

In the Gulf of St. Lawrence, European Green Crab have considerable overlap in habitat use with juvenile Lobster (Rossong et al. 2006). Green Crab often outcompete Lobster when introduced to an area, dominating food resources and shelter habitat (Rayner and McGaw 2019). In addition, Rossong et al. (2006) found that Green Crab prey on juvenile Lobster in experimental trials. Green Crab's influence on Lobster food availability can severely impact the juvenile life stage of Lobster and could affect Lobster abundance in the sGSL. The presence of Green Crabs can also reduce the catchability of Lobster by influencing their behaviours around traps (Rayner and McGaw 2019).

The introduction of invasive species can also introduce novel pathogens and diseases into native populations. European Green Crab are known to carry numerous disease-causing viruses, metazoan parasites, bacteria, and microbial eukaryotes (Bojko et al. 2018). Green crabs can also act as a sink for diseases already present in the introduced area, where they can function as an intermediate host for parasites which can then be transmitted to native crustacean, seabird, and bivalve species (Klassen and Locke 2007).

UNCERTAINTIES AND DATA GAPS

Several gaps in knowledge are described here, providing guidance on novel types of data and monitoring that could be developed for the SBZ MRs to meet conservation objectives. These will be important considerations in the upcoming development of an ecological monitoring approach (and associated indicators) that is required for the adaptive management of these MRs.

Spatial gaps in sampling

Among the key gaps in data is dedicated monitoring of the SBZ MRs. While several surveys provide important context on regional ecosystem health, these direct observations within the SBZ MRs are scant (e.g. Scallop surveys, September research vessel survey). Some surveys do overlap considerably with the SBZ MRs, and should be leveraged for long term observational data, in particular the Northumberland Strait multi-species bottom trawl survey (Figure 12) and the Coastal Temperature Monitoring Program in the sGSL (Figure 14). The bio-collector and SCUBA surveys for monitoring Lobster abundances could also provide a basis for long term monitoring sites within the SBZ MRs (Figure 17). Site selection for monitoring programs should strategically leverage these existing efforts to ensure historical observations are carried forward into management of the SBZ MRs.

Direct biogeochemical characterization of SBZ MRs is also lacking. Biogeochemical data of Northumberland Strait and Chaleur Bay have been acquired over the course of oceanographic surveys aimed at describing offshore conditions. Thus, only the deepest part of these two regions have been characterized. Conditions prevailing in the coastal zone where the SBZ MRs are located might differ from the conditions described here since localized environmental conditions or events, such as freshwater discharge or localized water mass circulation patterns, may alter oceanic patterns. In particular, deoxygenation and acidification are phenomena known to occur mostly in deep waters, where water renewal is infrequent. Dynamics occurring in the top 15 m of the water column might differ from what is described here.

A substantial geographic gap exists for SBZ 21, which is data poor relative to SBZ 22 and 24. Monitoring efforts will need to expand in the Chaleur Bay to help balance data outputs across the SBZ MRs. New dedicated monitoring sites should also be considered along the Cape Breton coast, as most of the biological observations for SBZ 24 are within western to central portions of the Northumberland Strait.

Benthic habitat mapping

A mapping exercise was undertaken to identify potential juvenile Lobster habitat in the SBZ MRs by layering currently available geospatial data representing substrate, depth and temperatures suitable for juvenile Lobsters. Broad scale areas for potential habitat were identified using sediment > 2 mm in diameter. A major gap identified was the lack of comprehensive and updated knowledge of substrate types and distribution in the SBZ MRs, particularly in the Northumberland Strait (Joseph et al. submitted). Additional data are needed to better characterize substrate in the SBZ MRs, particularly to refine details of coarser particle sizes (gravel, pebble, cobble, boulder) and better identify suitable habitat for juvenile Lobster and establish sites for ecological monitoring.

Benthic habitat mapping, defined as “spatially continuous prediction of biological patterns on the seafloor” (Misiuk and Brown 2024), represents a critical knowledge gap limiting monitoring efforts within the SBZ MRs. A prerequisite to habitat mapping is robust environmental data. Acoustic remote sensing can provide high resolution mapping data of the Northumberland Strait seabed, including substrate characteristics (mud vs. sand vs. rock). Challenges persist, however, to applying these data in the SBZ MRs. First, acoustic remote sensing is less efficient nearshore as acoustic beam width decreases in shallower waters, meaning more passes of a research vessel are needed to map the seabed. Second, the stability of substrate characteristics remains unclear, which can only be determined with temporal sampling. As such, mapping of the seabed within the SBZ MRs remains costly at this time.

Drop camera footage, wherein a camera is towed along transects by a vessel, is emerging as a promising approach for linking species distributions with benthic information. In 2024, drop camera video was collected by DFO Science for the Northumberland Strait both inside and outside the SBZ MRs. Exploring these data will provide insights on how drop camera footage can inform/validate habitat mapping, link species distributions with particular substrate, and could potentially yield novel indicators for monitoring.

Barring modelling of juvenile Lobster dispersal between LFAs (Chasse and Miller 2010; Quinn et al. 2017), the movement of BCB species within and between SBZ MRs remains unknown. Monitoring the movement of BCB species in the Northumberland Strait and Chaleur Bay using acoustic tags/receivers could help determine how the SBZ MRs are utilized throughout the year and prioritize key time frames for monitoring.

Modelling changes to benthic habitats under climate change would also help with anticipating potential shifts in how the SBZ MRs are occupied by BCB species. This analysis would ideally couple robust contemporary species distribution models with high resolution predicted environmental layers, though as stated above, there are limitations to these data. Model choice and spatial resolution for predicting environmental conditions under various climate change scenarios will be important considerations.

Detection of low density or sporadic BCB species and ecosystem indicators

Conservation objectives for the SBZ MRs are focused primarily on juvenile Lobster and its associated habitat, and dedicated monitoring currently exists to quantify the abundance of Lobster within and outside the SBZ MRs (Figures 13 and 18). Novel approaches targeting low density and pelagic species sporadically captured in the trawl surveys are needed.

Environmental DNA (eDNA) represents an alternative approach to the labour-intensive trawling and SCUBA surveys. Collecting and assessing eDNA involves the filtration of water for DNA shed by organisms, making it a highly desirable non-destructive approach. Moreover, eDNA can be further tailored for specific species (i.e. qPCR), making this a multi-pronged approach of value to community and species level indicators. In 2024, a annual survey for eDNA samples in the Northumberland Strait was initiated in conjunction with the Northumberland multi-species trawl and SCUBA surveys (Figure 21). Comparing these detections methods could help reduce taxonomically-biased gaps in sampling effort. Data transparency and standardization, particularly in conjunction with other DFO regions, will be paramount to onboarding eDNA surveys for the Gulf Region.

In addition to exploring these data for the detection of BCB species, a significant challenge will be the development of ecosystem level indicators that are relevant to the current conservation objectives. This would help address monitoring for general biodiversity, and ensure monitoring of the SBZ MRs are not exclusively tailored to a handful of species with commercial interests.

Other potential opportunities exist. Community led efforts could improve the coverage of recording efforts. In particular, the Atlantic Herring contemporary spawning ground survey leverages observations from pilots, fishers, and the public. Similar community led efforts could be extended into other BCB species. As stated above, drop camera footage is also being explored for species detections, including the BCB species listed here (Figure 4).

CONCLUSIONS

The SBZ fisheries closures were recognized as MRs in 2017 with prohibitions on commercial bottom contact Scallop harvesting gear in order to protect juvenile Lobster habitat and *in situ* biodiversity. While Lobster populations are not currently at risk in the sGSL, the continued protection of juvenile Lobster habitat ensures that young Lobster have ample opportunities to reach the adult sizes targeted by local fisheries. Protecting this vulnerable life stage will therefore contribute to the recruitment of new Lobster and promote a sustainable fishery. The SBZ MRs are also home to additional species of interest that can benefit from protection against benthic disruptions, particularly Winter Skate, Lady Crab, and Atlantic Herring.

Here, we highlighted key information that will be used for the development of an ecological monitoring plan of the SBZ MRs. The scientific overview of the environment and ecosystem of these MRs show that numerous research surveys occur within the sGSL, however dedicated monitoring tailored to the conservation objectives is needed, particularly in Chaleur Bay. Long term monitoring sites should leverage current sites of the SCUBA surveys for juvenile Lobster. While Lobster distributions and abundances are well characterized and serve as logical indicators for the health status of juvenile Lobster, new approaches are needed for the indirect BCB species and general biodiversity. Drop camera footage, ROV, eDNA, and other non-destructive tools are currently the most viable approaches to monitor marine conservation areas. Environmental data are also available, but nearshore conditions most relevant to the SBZ MRs are poorly characterized, including water chemistry and benthic substrate information. A monitoring plan focusing on the detection of BCB species and biodiversity indicators can be initially expanded from existing surveys, but the next step will be to build up and link abiotic and biotic observations to predict the distribution of key species throughout the SBZ MRs.

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TABLES

Table 1 . Description of artificial reef types deployed in southern Gulf of St. Lawrence.

Artificial reef type	Description
Blanchard/Comeau	Square concrete block measuring approximately 413mm x 413mm x 127mm with rope handle on top. The block also has a shallow cut out at the bottom. Each block weighs approximately 70 lbs.
Type U	Rectangular concrete block measuring approximately 500mm x 250mm x 140mm. There is a large longitudinal cut out and 2 transversal cut outs for adult and juvenile Lobster use. Each block weighs approximately 54 lbs.
U180	Rectangular concrete block measuring approximately 457mm x 279mm x 134mm. Has 180 degree design which allows for installation on either side. There are large and small longitudinal cut outs for both adult and juvenile Lobster use. Each block weighs approximately 57 lbs.
Type S	Rectangular concrete block measuring approximately 432mm x 225mm x 121mm. Has 180 degree design which allows for installation on either side. There are large and small transversal cut outs for both adult and juvenile Lobster use. Each block weighs approximately 40 lbs.
Reefball	Dome shaped concrete structure with several holes and cavities of various sizes in its surface. The model used was the Lo-Pro Ball which has a 610mm diameter at the base and a height of approximately 457mm. Each structure weighs between 100-200 lbs.

Table 2 . Number of artificial reef deployment sites categorized by reef structure type located inside and outside each Scallop Buffer Zone Marine Refuges.

	U-180	Reefball	Blanchard/ Comeau	Type U	Type S	Unknown	Total
SBZ 21	4					15	19
SBZ 22	9					18	27
SBZ 24	1	4				5	10
Outside SBZ MRs	17		2	1	10	18	48
Total	31	4	2	1	10	56	**104**

*Table 3. Lobster enhancement efforts via release of stage IV Lobster from 2020 to 2024 within each Scallop Buffer Zone Marine Refuge (SBZ MR). *Release of stage IV Lobster were outside of SBZ MRs but within 115 meters of the SBZ MRs boundaries.*

Marine Refuge	Location	Year	Stage IV Lobster
SBZ 21a	Anse-Bleue, NB	2020	37000
		2022	25000
		2023	25000
	Grande-Anse, NB	2020	25000
		2021*	21000
		2022	20000
		2024*	14000
	Millerbrook, NB	2021	25000
		2023	30000
	Petit-Rocher, NB	2020	25000
		2021	51500
	Pointe-Verte, NB	2020	25000
		2021	53000
		2022	30900
	Stonehaven, NB	2023	12000
		2024	96000
	New Mills, NB	2020	20000
		2021	15000
SBZ 22	Cap-Lumière, NB	2023	35000
	Cap-Saint-Louis, NB	2024	40000
	Cormierville, NB	2023	23000
	Shediac, NB	2021	10000
		2022	10000
		2023	10000
	Indian Island, NB	2023	15000
	Pointe-Sapin, NB	2020	44500
		2021	50000
SBZ 24	Ballantynes Cove, NS	2024	40000
	Cribbons Point, NS	2022*	40000
	Lismore, NS	2021	30000
		2023	30000
	Pictou Island, NS	2022	30000
	Pugwash, NS	2024	40000
	Sinclair Island, NS	2020	30000
		2023	30000
	Wallace, NS	2023	35000

FIGURES

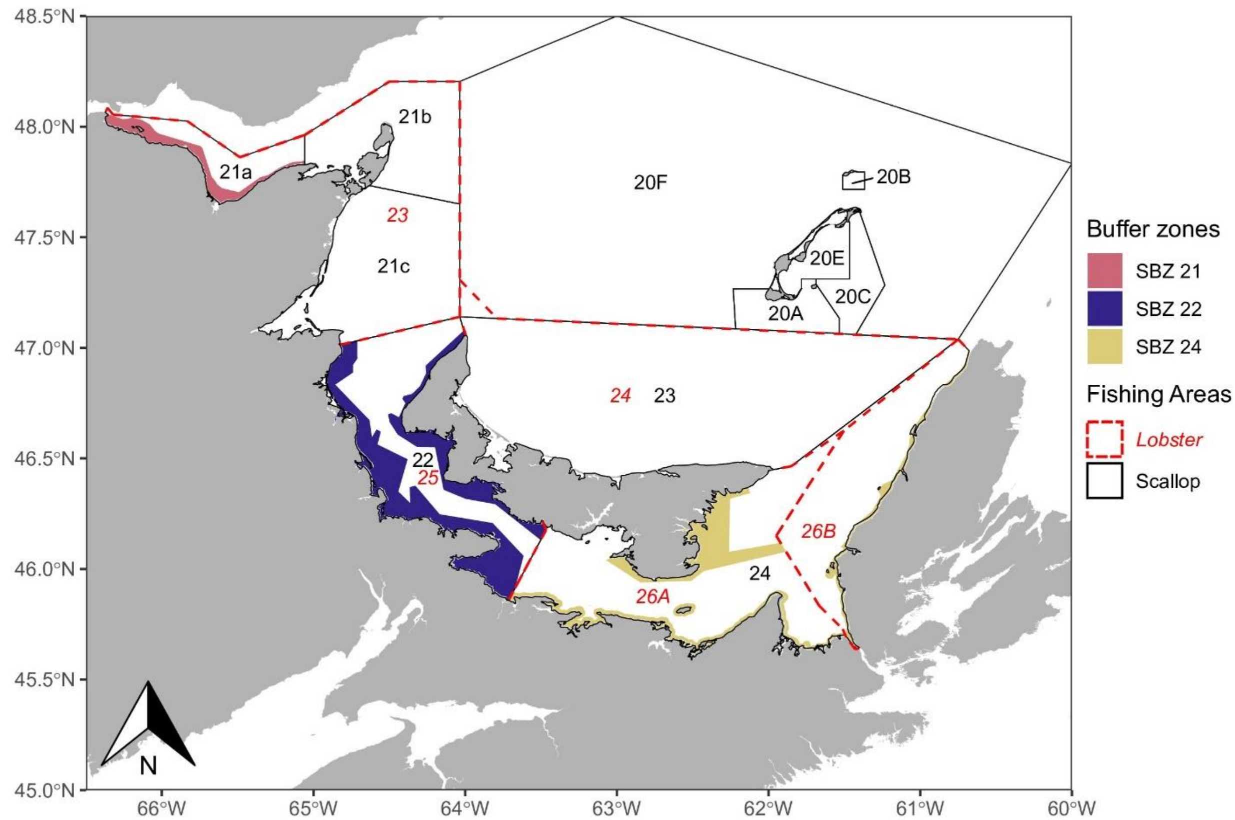

Figure 1. Scallop Buffer Zone Marine Refuges in the southern Gulf of St. Lawrence. Lobster (in red) and Scallop (in black) fishing areas are numbered.

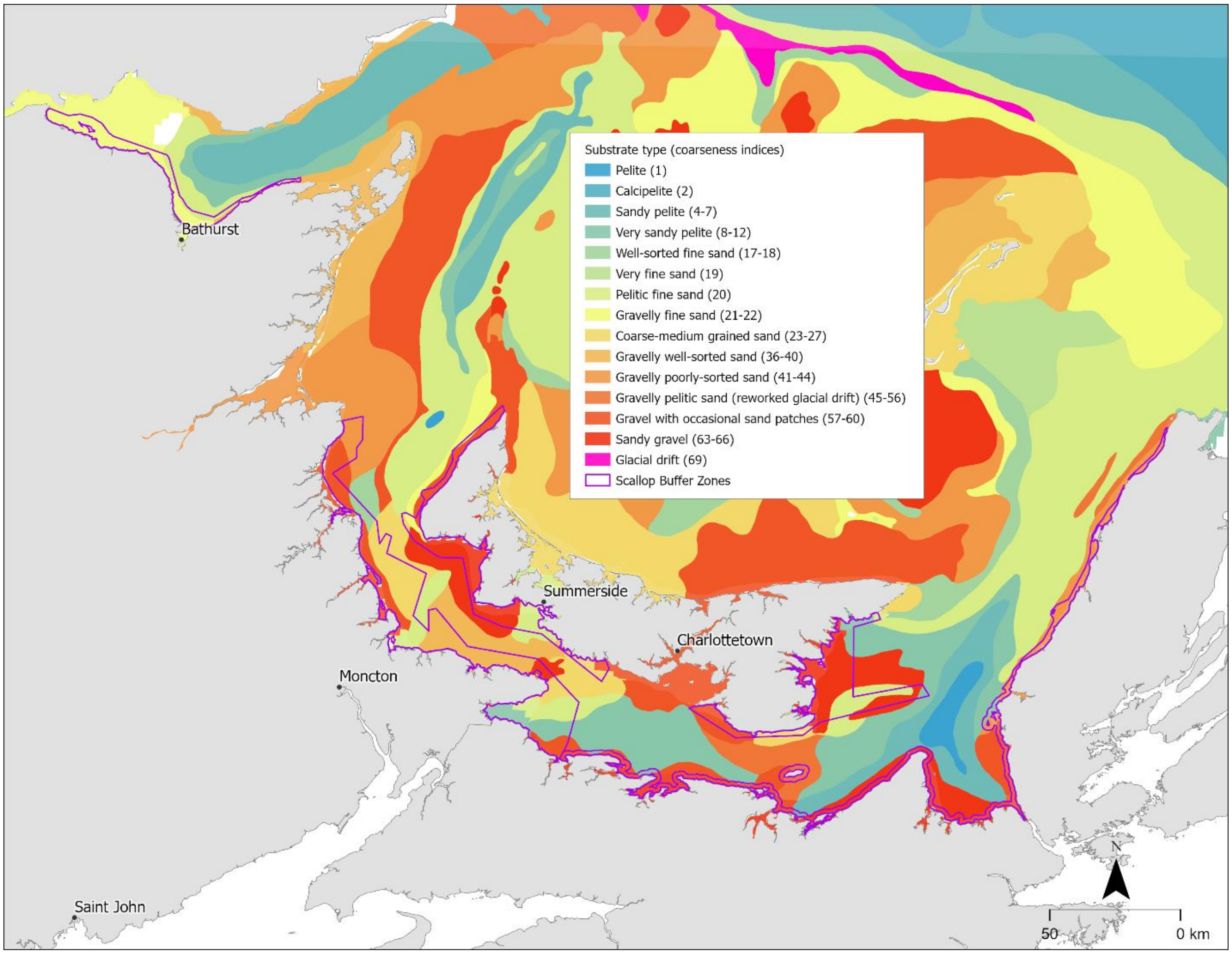

Figure 2. Sediment map for southern Gulf of St. Lawrence area from Dutil et al. (2011). Data based on Loring and Nota (1973).

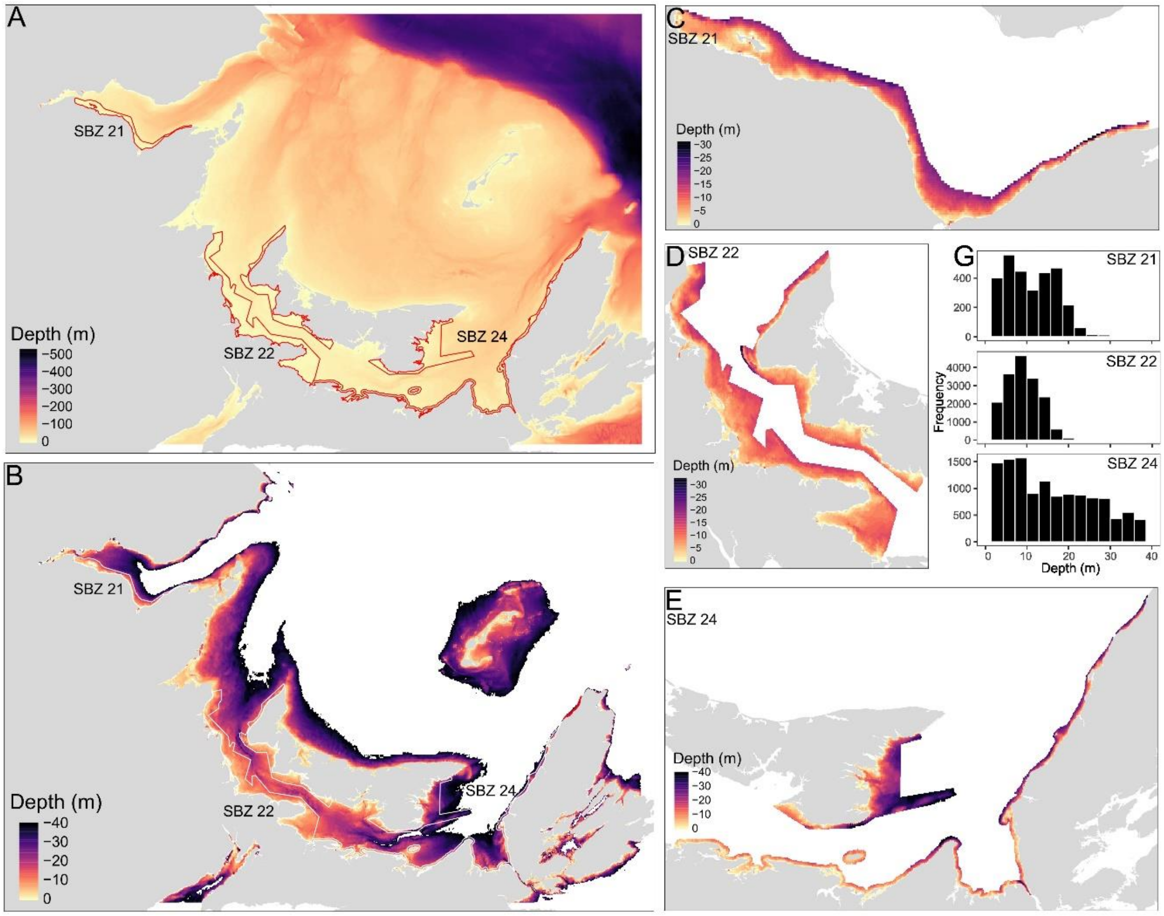

Figure 3. Depth profiles for Scallop Buffer Zone Marine Refuges 21, 22 and 24 and surrounding areas data based on GEBCO's global bathymetric grids (2023). Bathymetry of the Gulf Region to a depth of 500 m (A) and 40 m (B). Bathymetry of SBZ 21 (C), SBZ 22 (D), and SBZ 24 (E), including depth profiles (G). Note, the depth legends change between panels, and that depth profiles of the SBZ MRs delineations are intended to generally, not exactly, correspond to depth guidelines. For SBZ 24, depths greater than 40 m are not shown.

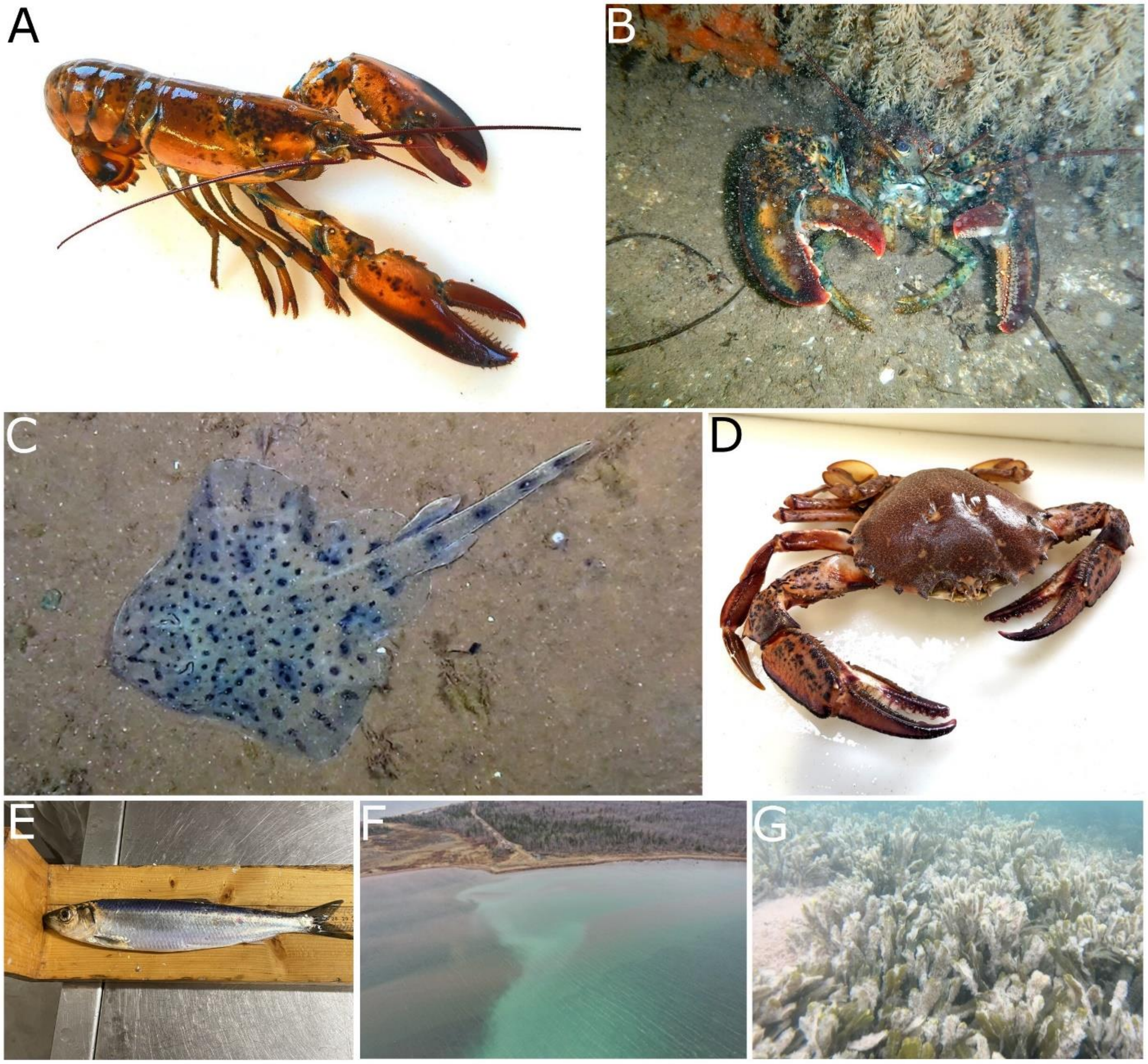

Figure 4. Scallop Buffer Zone Marine Refuges Biodiversity Conservation Benefits species. A) juvenile American Lobster (Homarus americanus), B) American Lobster (Shediac, New Brunswick); C) Winter Skate (Leucoraja ocellata), D) Lady Crab (Ovalipes ocellatus), E) Atlantic Herring (Clupea harengus), F) Atlantic Herring spawning (Cap-Pele, New Brunswick), and G) Atlantic Herring eggs on Fucus (Cape Tormentine, New Brunswick). Tormentine, New Brunswick).

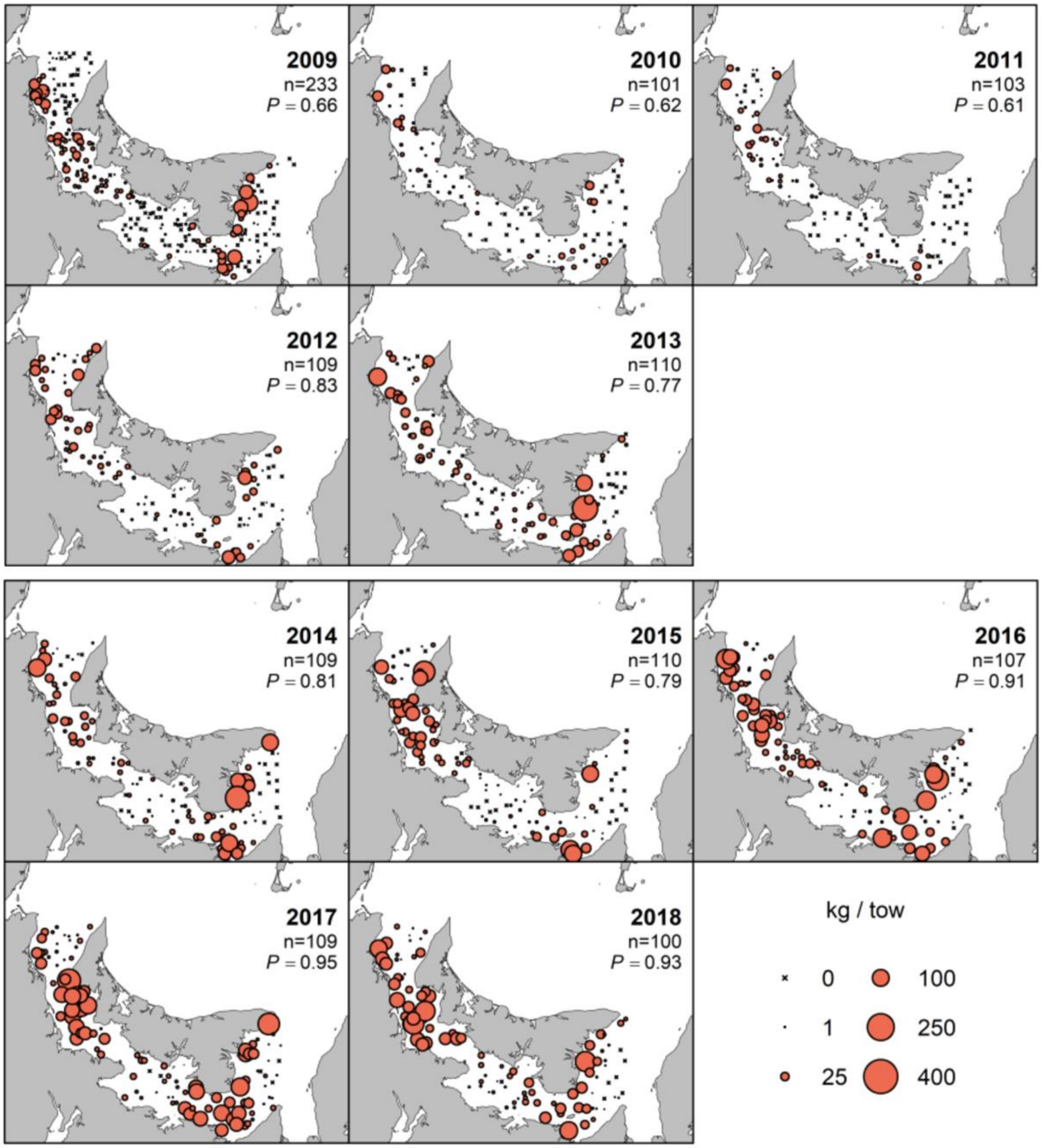

Figure 5. Relative density (kg/tow) of American Lobster (Homarus americanus) from the Northumberland Strait multi-species bottom trawl survey 2009-2013 compared with 2014-2018. The number of valid sets completed (n) and the probability of occurrence (P) are shown below the year label in each panel. From Asselin et al. (2021).

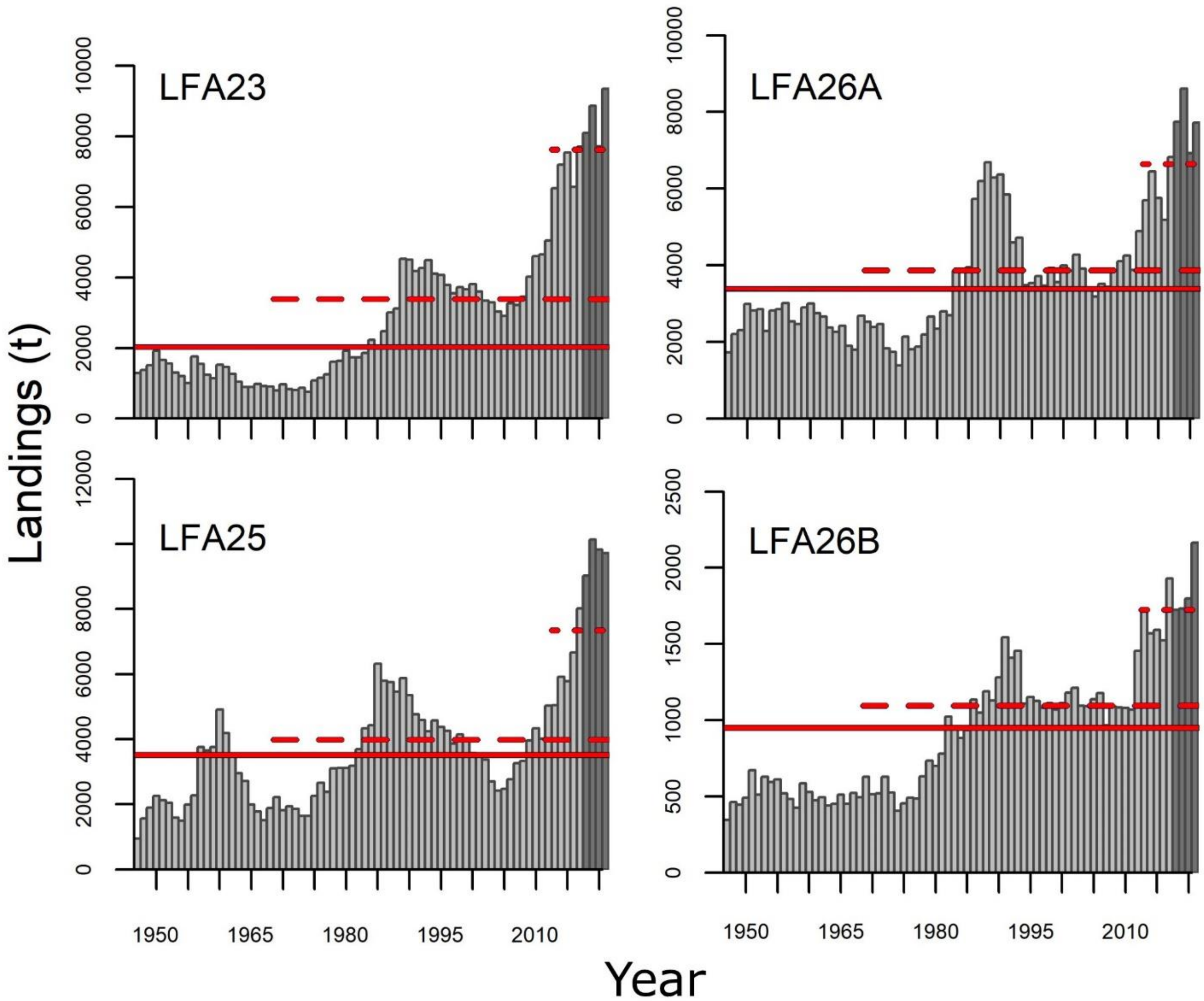

Figure 6. Reported Lobster landings (t) by Lobster Fishing Areas (23, 25, 26A, 26B) in the southern Gulf of St. Lawrence, 1947 to 2021. The solid line, the dashed line and the dotted line represent the median long-term (1947-2021), mid-term (1968-2021) and short-term (2012-2021) landings, respectively. Data added since the last assessment update (2018-2021) are in a darker grey shading. Data for 2021 are preliminary. Modified from Asselin et al. 2024, figure 13.

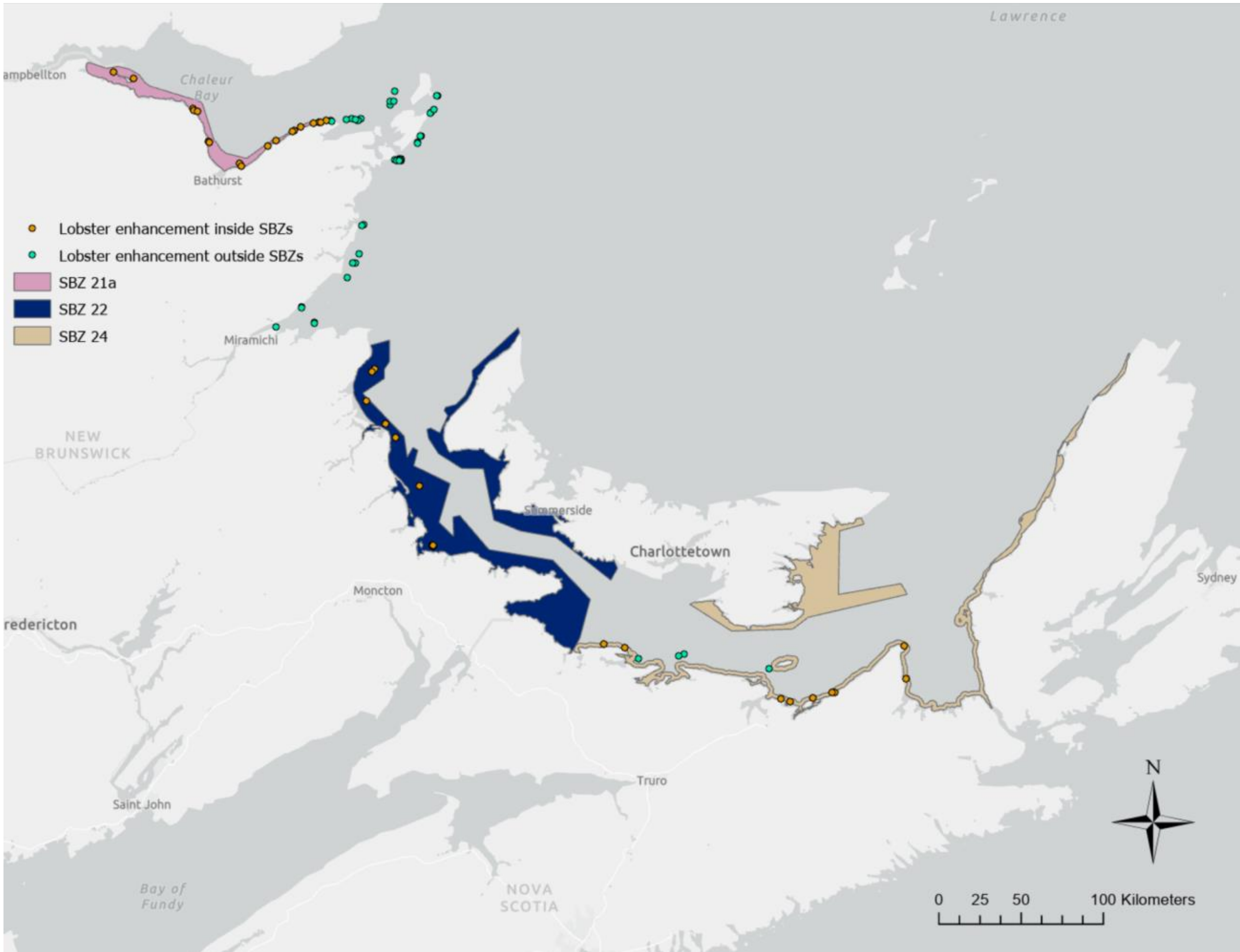

Figure 7. Lobster enhancement locations between 2020 and 2024 that fall inside and outside the Scallop Buffer Zone Marine Refuges (SBZ MRs). Locations within 115 meters of the boundary of the SBZ MRs were included as inside. Locations designate where stage IV Lobsters were released onto the bottom. Data provided by Homarus Inc.

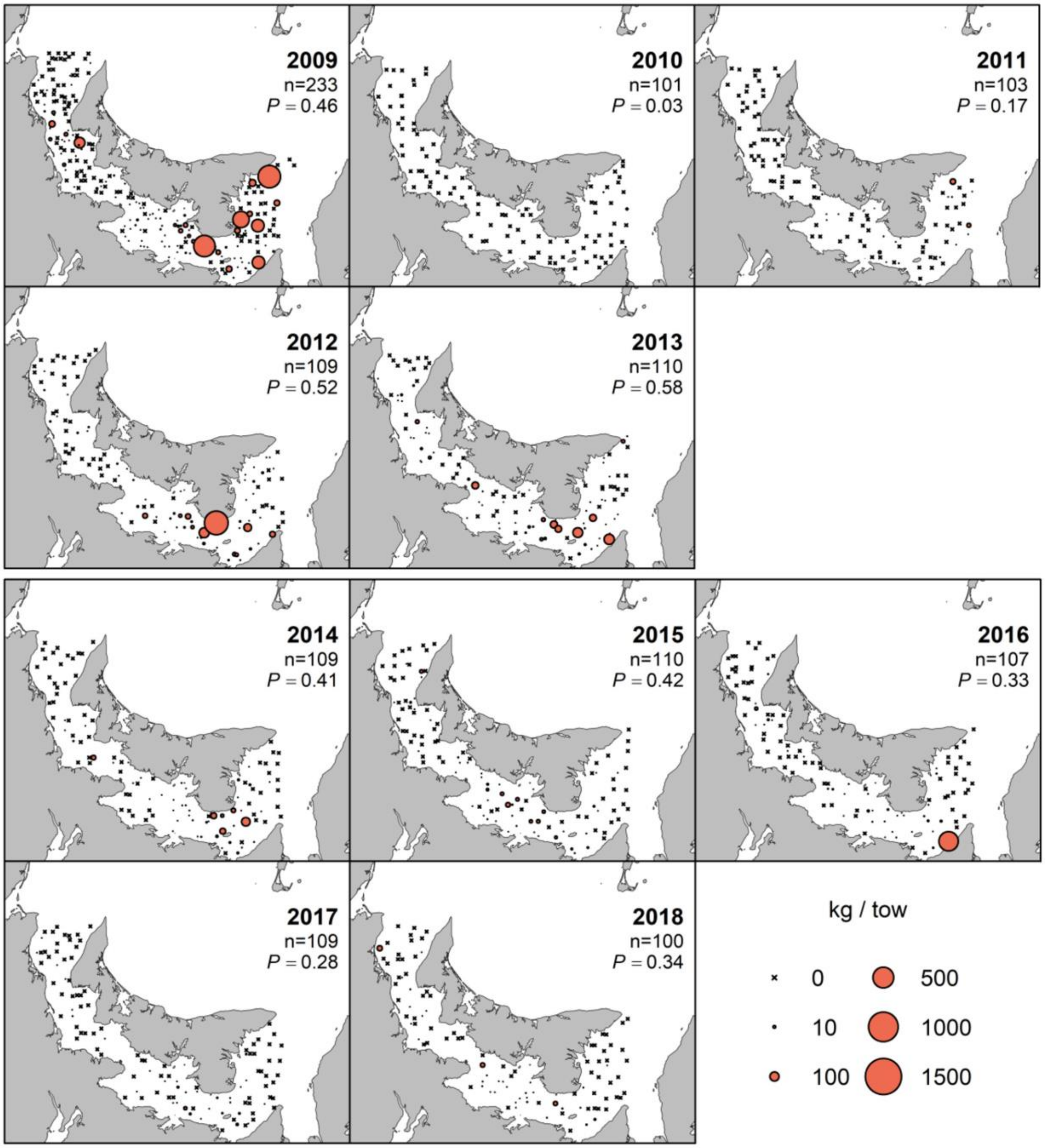

Figure 8. Relative density (kg/tow) of Atlantic Herring (Clupea harengus) from the Northumberland Strait multi-species bottom trawl survey 2009-2013 compared with 2014-2018. The number of valid sets completed (n) and the probability of occurrence (P) are shown below the year label in each panel. From Asselin et al. (2021).

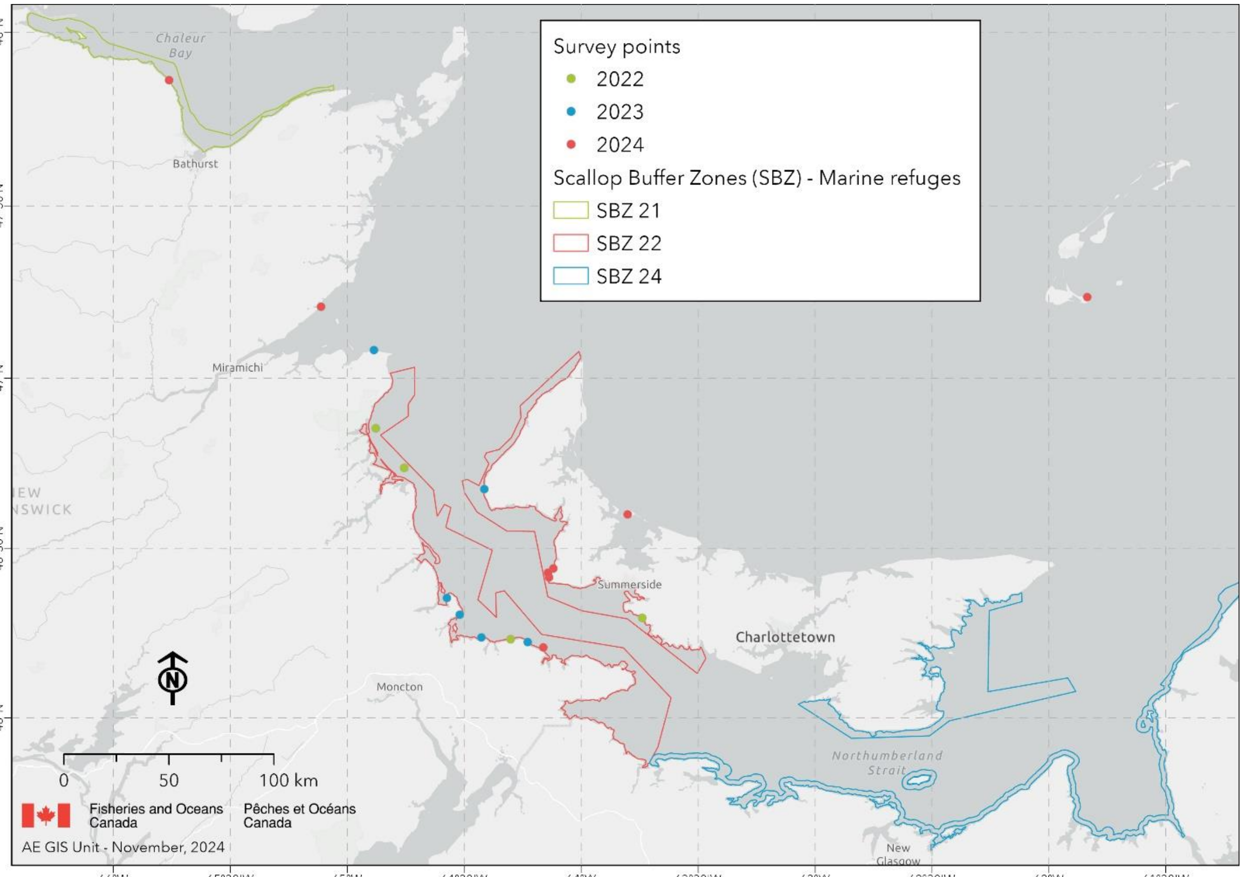

Figure 9. The location of Atlantic Herring (Clupea harengus) spawning events reported by pilots, fishers and the public during 2022 (green dots), 2023 (blue dots), and 2024 (red dots) in the southern Gulf of St. Lawrence along with the boundaries of Scallop Buffer Zone (SBZ) 21 (green outline), SBZ 22 (red outline) and SBZ 24 (blue outline).

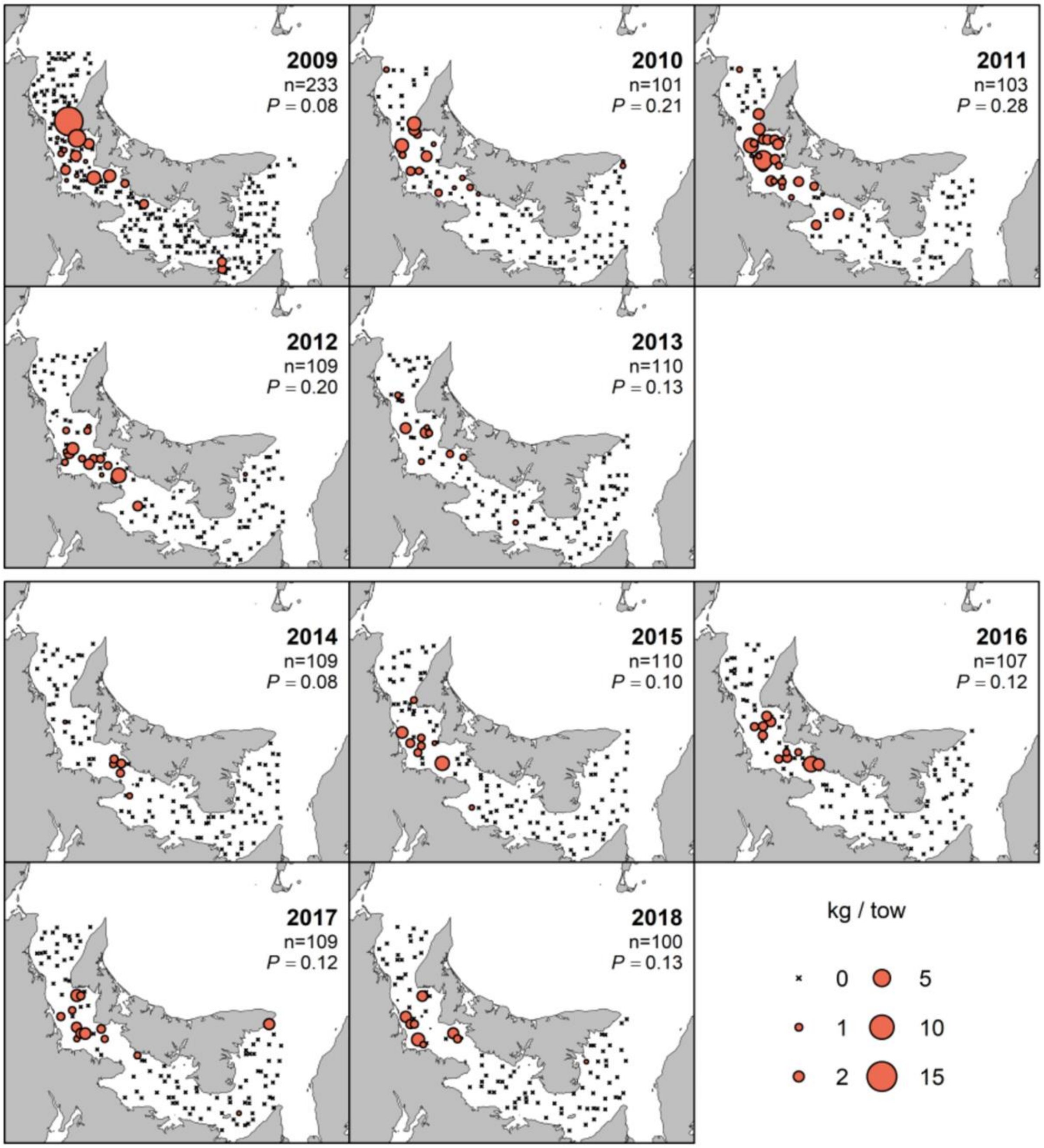

Figure 10. Relative density (kg/tow) of Winter Skate (Leucoraja ocellata) from the Northumberland Strait multi-species bottom trawl survey 2009-2013 compared with 2014-2018. The number of valid sets completed (n) and the probability of occurrence (P) are shown below the year label in each panel. From Asselin et al. (2021).

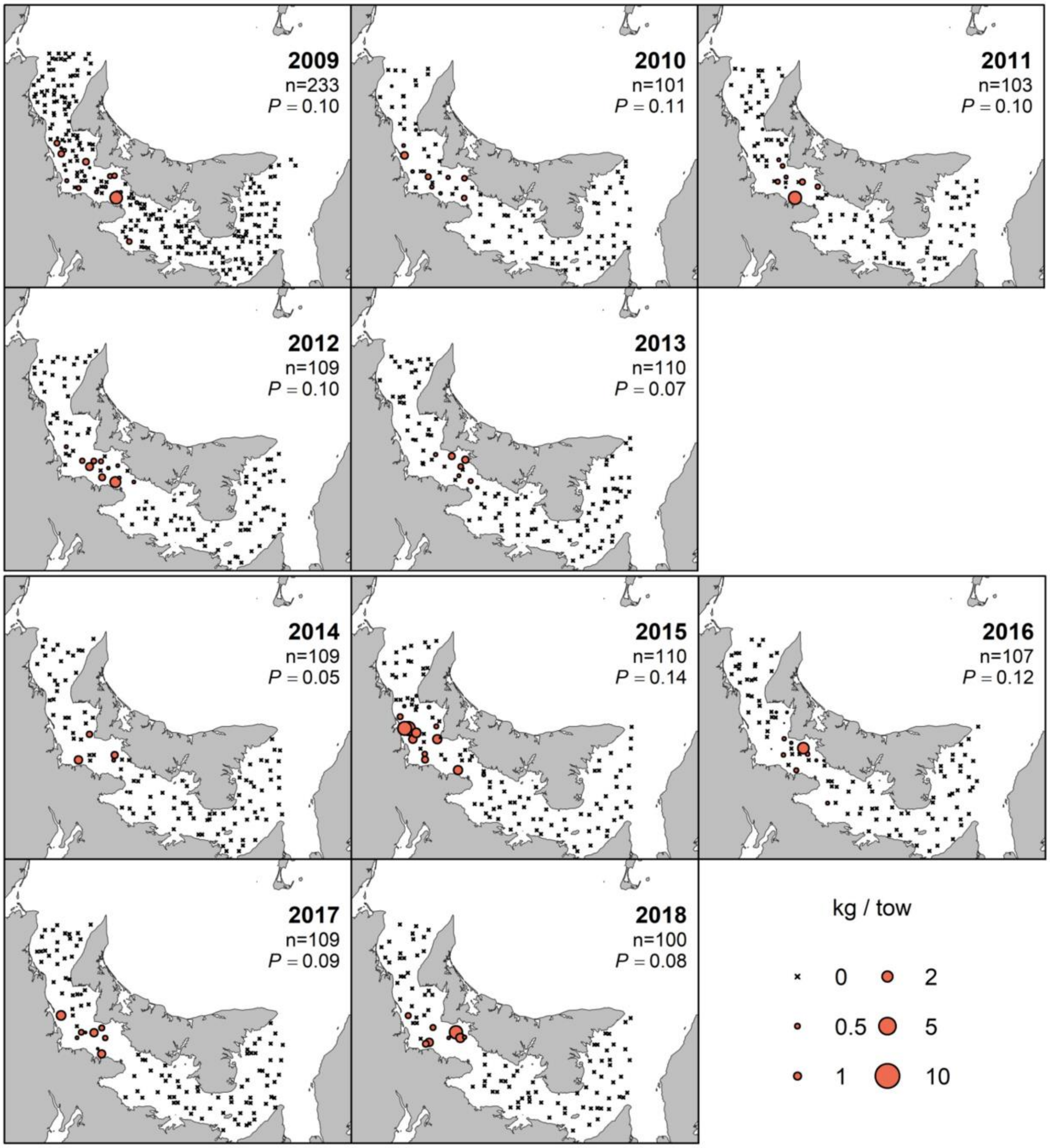

Figure 11. Relative density (kg/tow) of Lady Crab (Ovalipes ocellatus) from the Northumberland Strait multi-species bottom trawl survey 2009-2013 compared with 2014-2018. The number of valid sets completed (n) and the probability of occurrence (P) are shown below the year label in each panel. From Asselin et al. (2021).

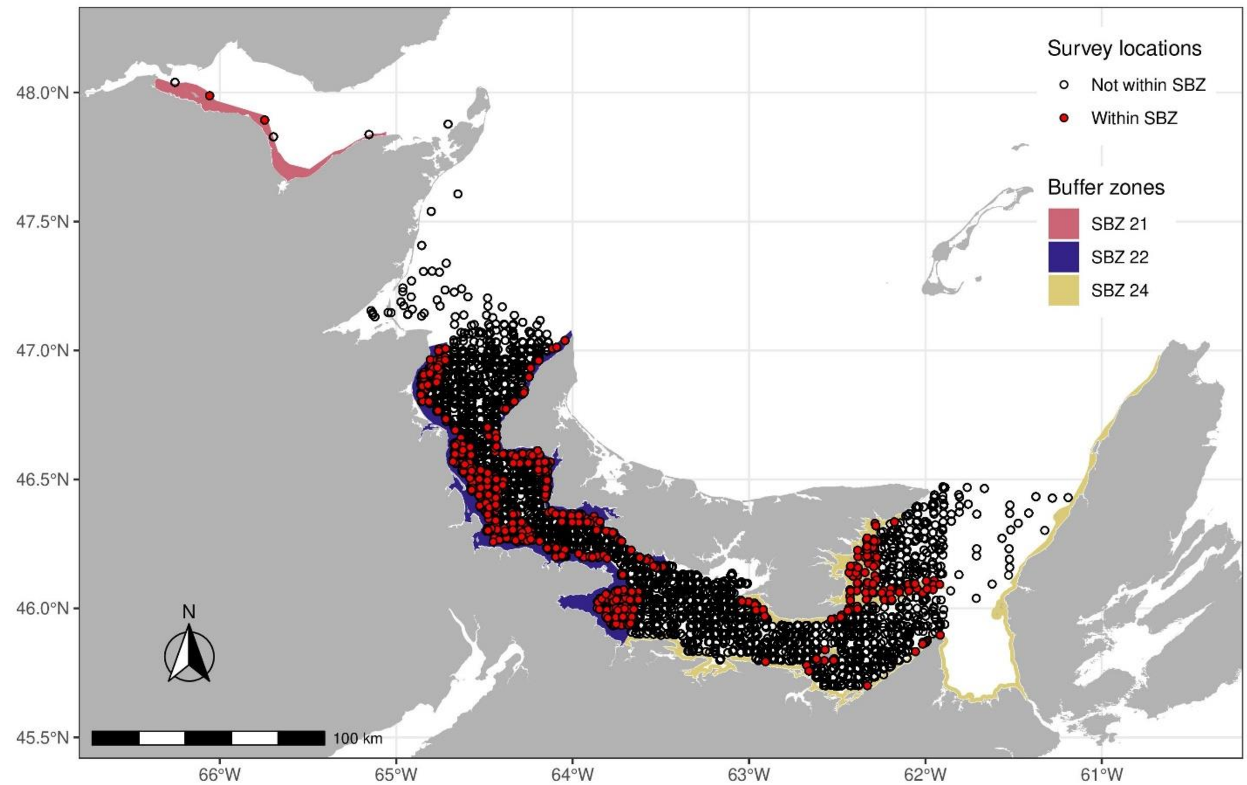

Figure 12. Locations of DFO Northumberland Strait multi-species bottom trawl Surveys from 2000-2023.

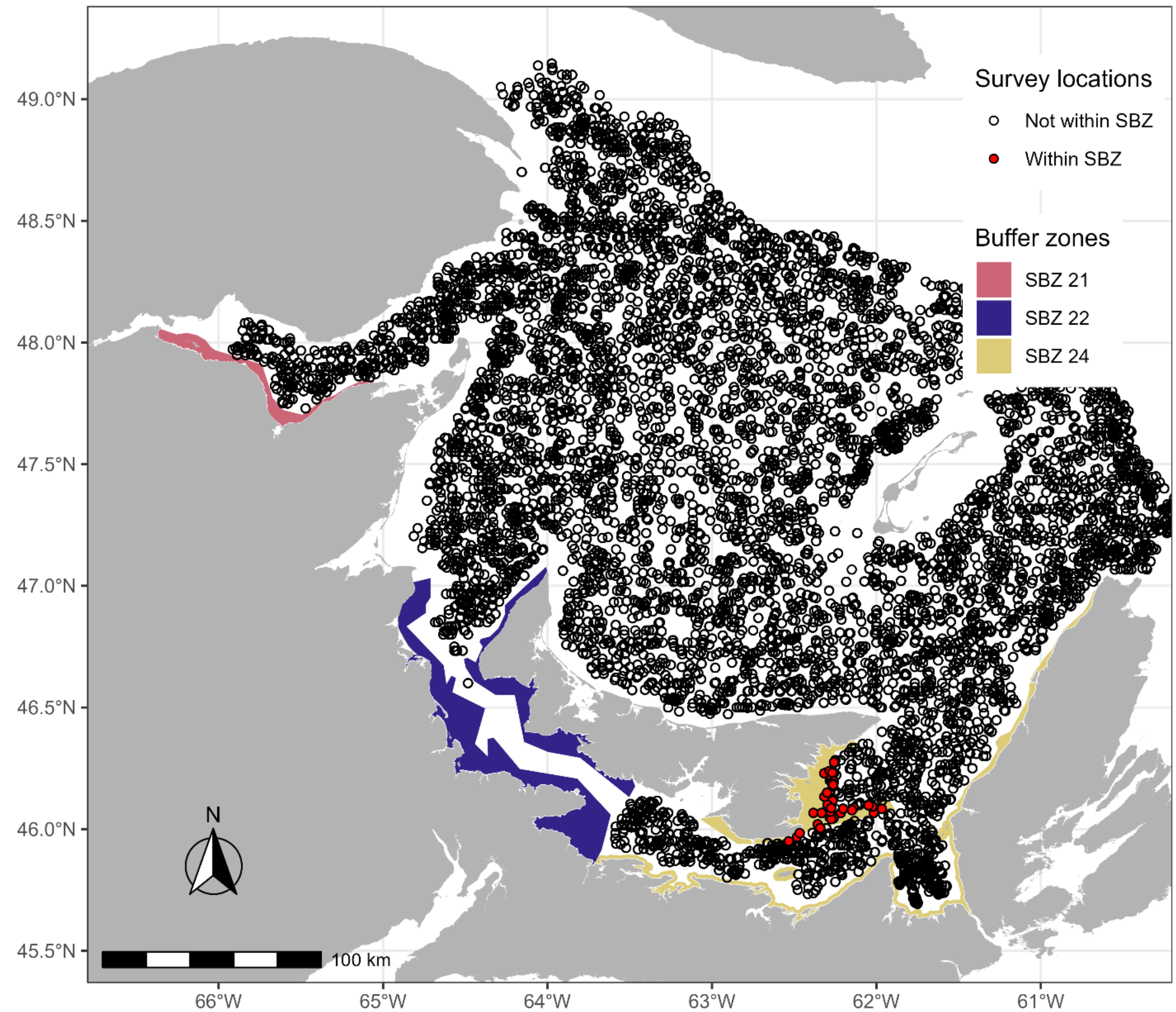

Figure 13. Survey locations for the September research vessel survey from 1971 to 2022. Red symbols indicate sample taken within the Scallop Buffer Zone Marine Refuges.

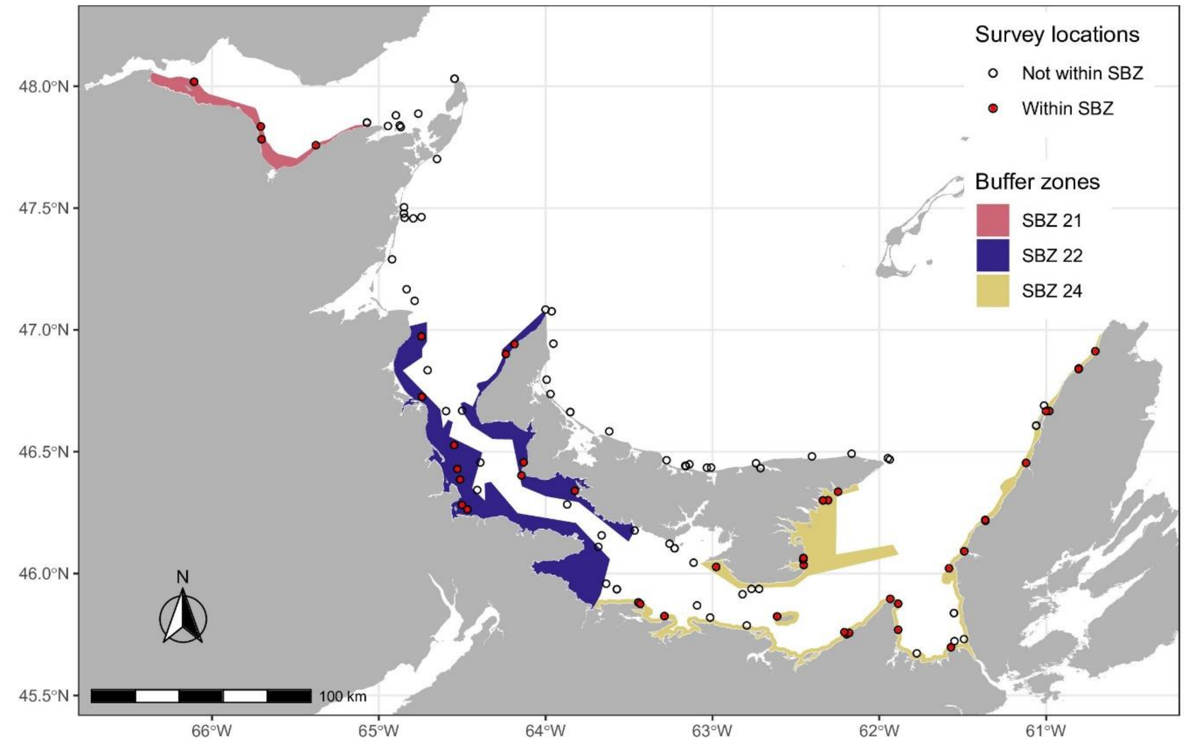

Figure 14. Sites for the coastal temperature monitoring program in the southern Gulf of St. Lawrence within and outside the Scallop Buffer Zone Marine Refuges.

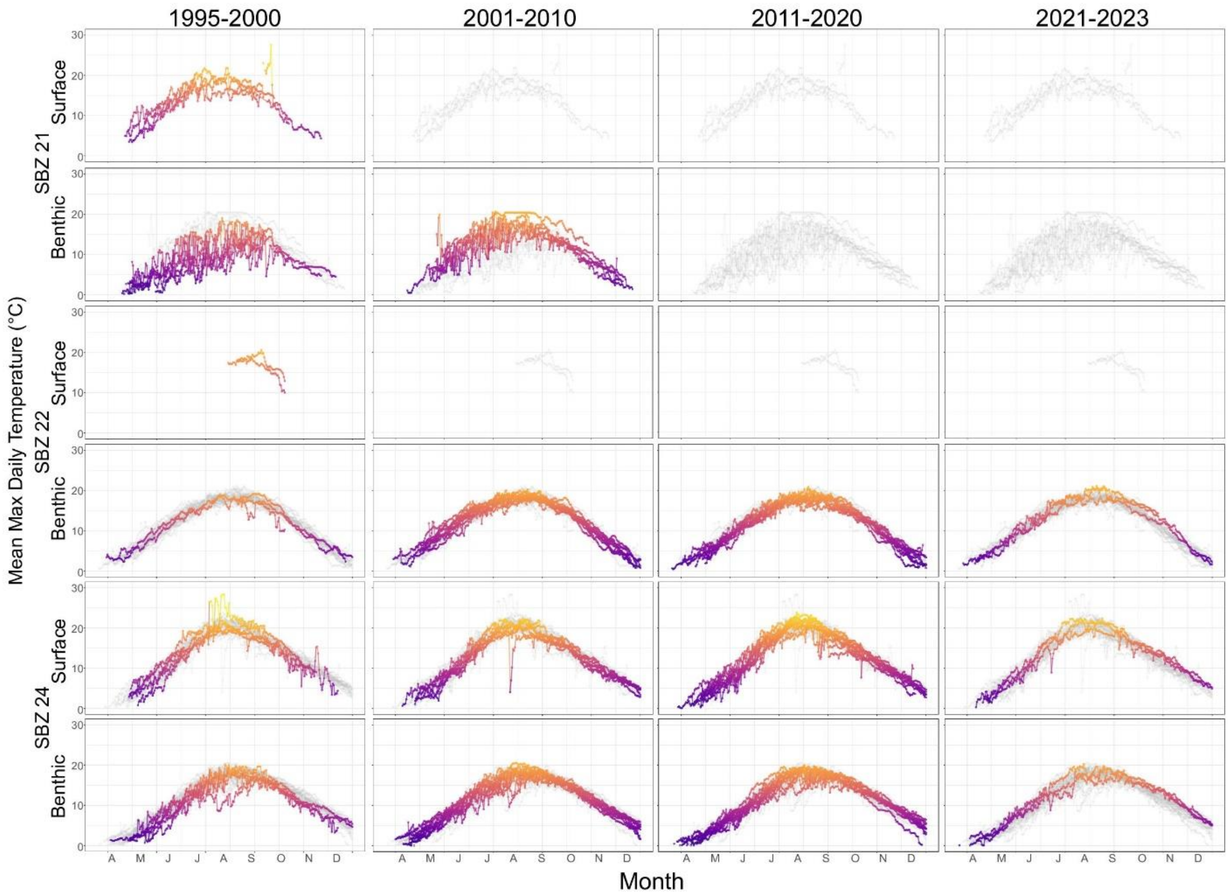

Figure 15. Surface and benthic mean daily max temperature profiles for Scallop Buffer Zone Marine Refuges 21, 22 and 24 based on data from the coastal temperature monitoring program in the southern Gulf of St. Lawrence for various time periods between 1995 and 2023.

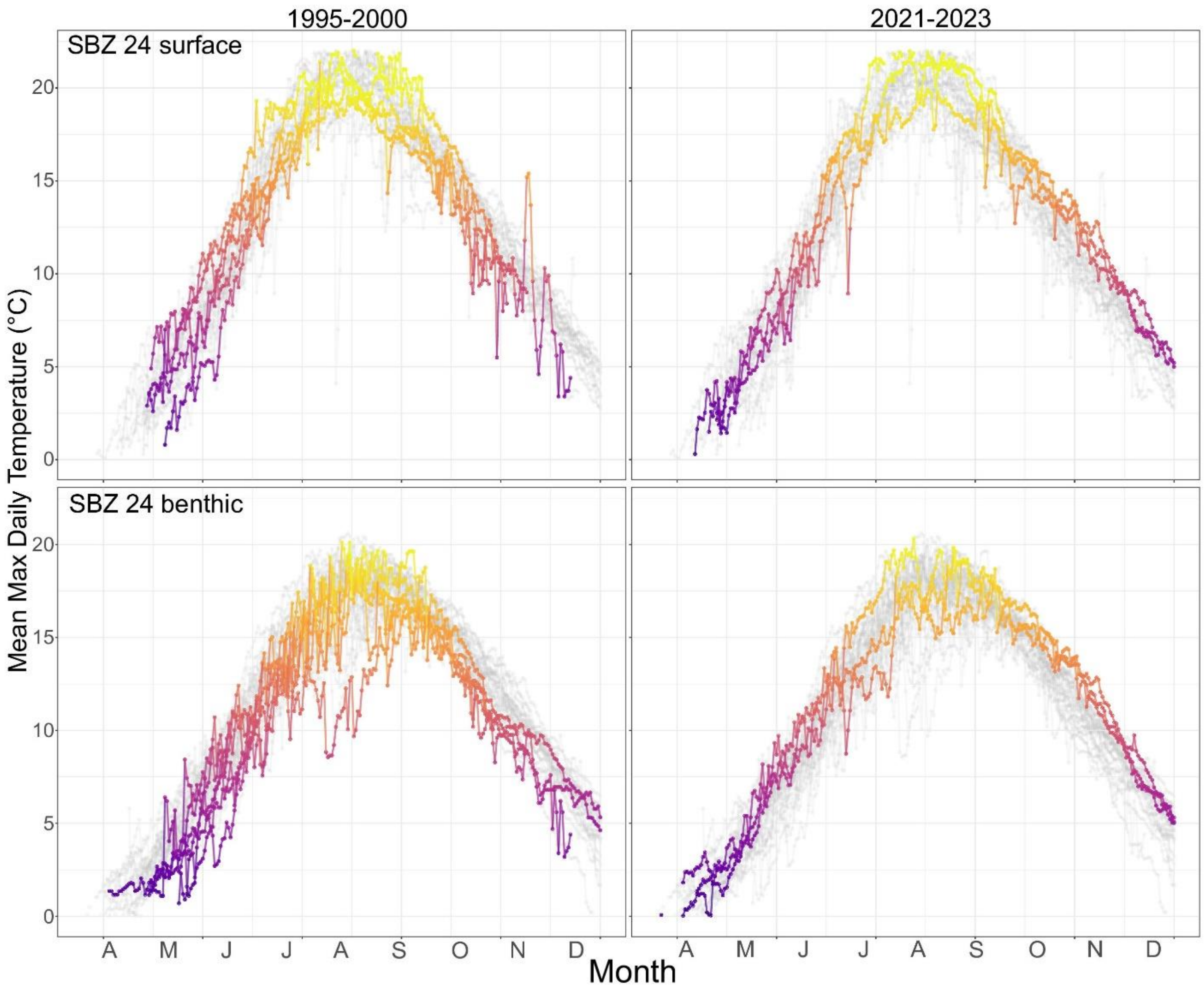

Figure 16. Surface and benthic mean daily max temperature profiles for Scallop Buffer Zone (SBZ) 24 based on data from the coastal temperature monitoring program in the southern Gulf St. Lawrence comparing recordings before 2001 and after 2020. The grey background depicts all recordings between 1995 and 2023. Note, recordings higher than 22°C are not depicted here (i.e. see SBZ 24 surface, Figure 15).

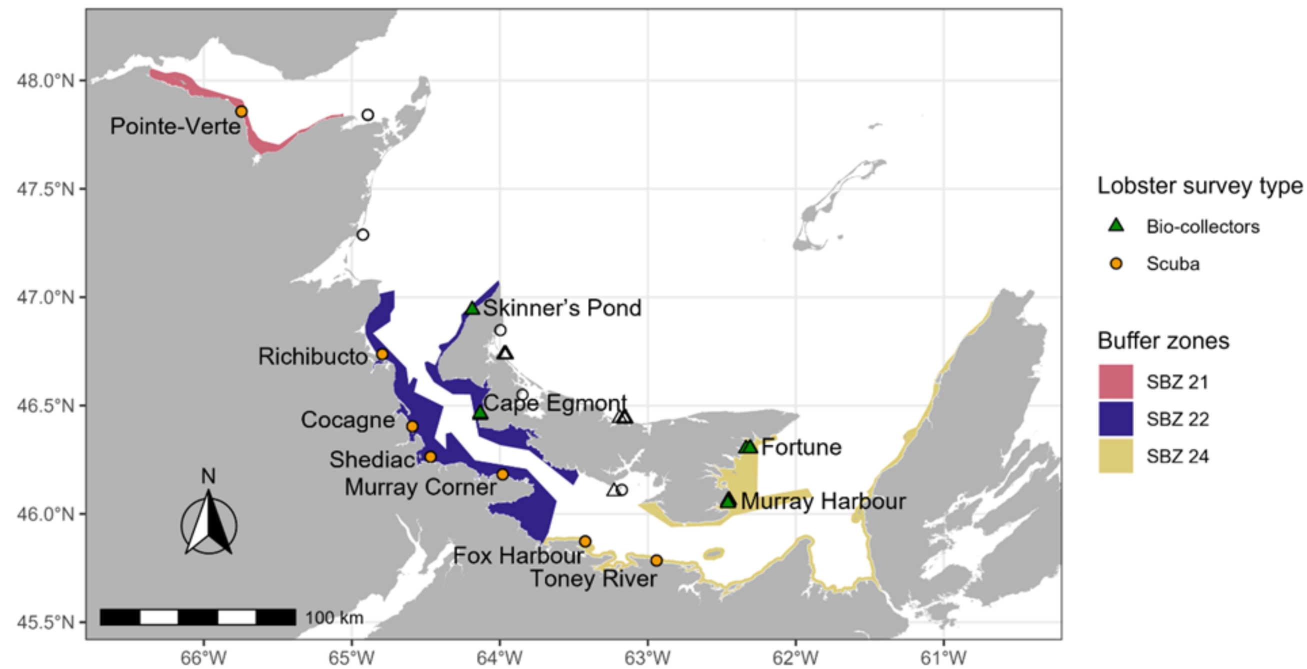

Figure 17. Map of bio-collector and SCUBA research sites in the southern Gulf of St. Lawrence.

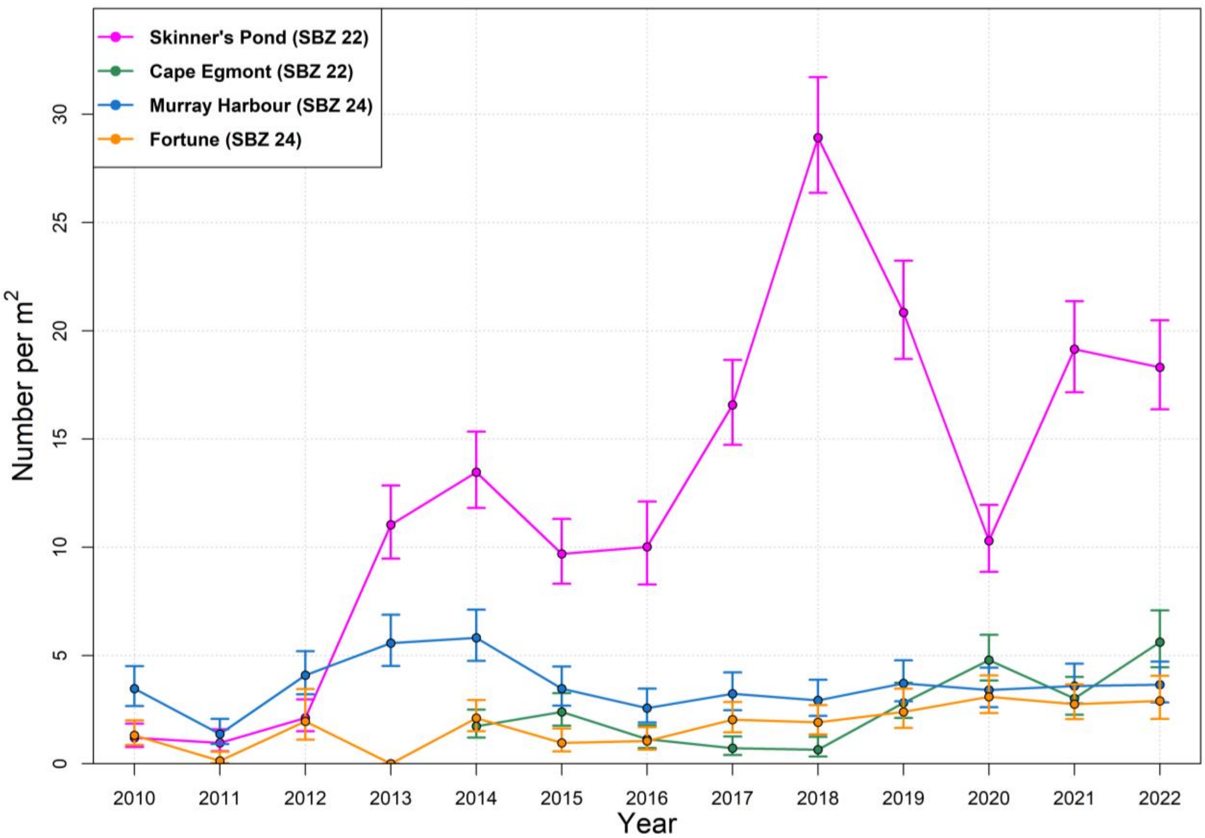

Figure 18. Density of juvenile Lobsters with a carapace length (CL) less than 40 mm from bio-collectors at four locations within Scallop Buffer Zone Marine Refuges in the southern Gulf of St. Lawrence. See Figure 17 for map of sites. Prepared using bio-collector data analysis methods described in Asselin et al. 2024.

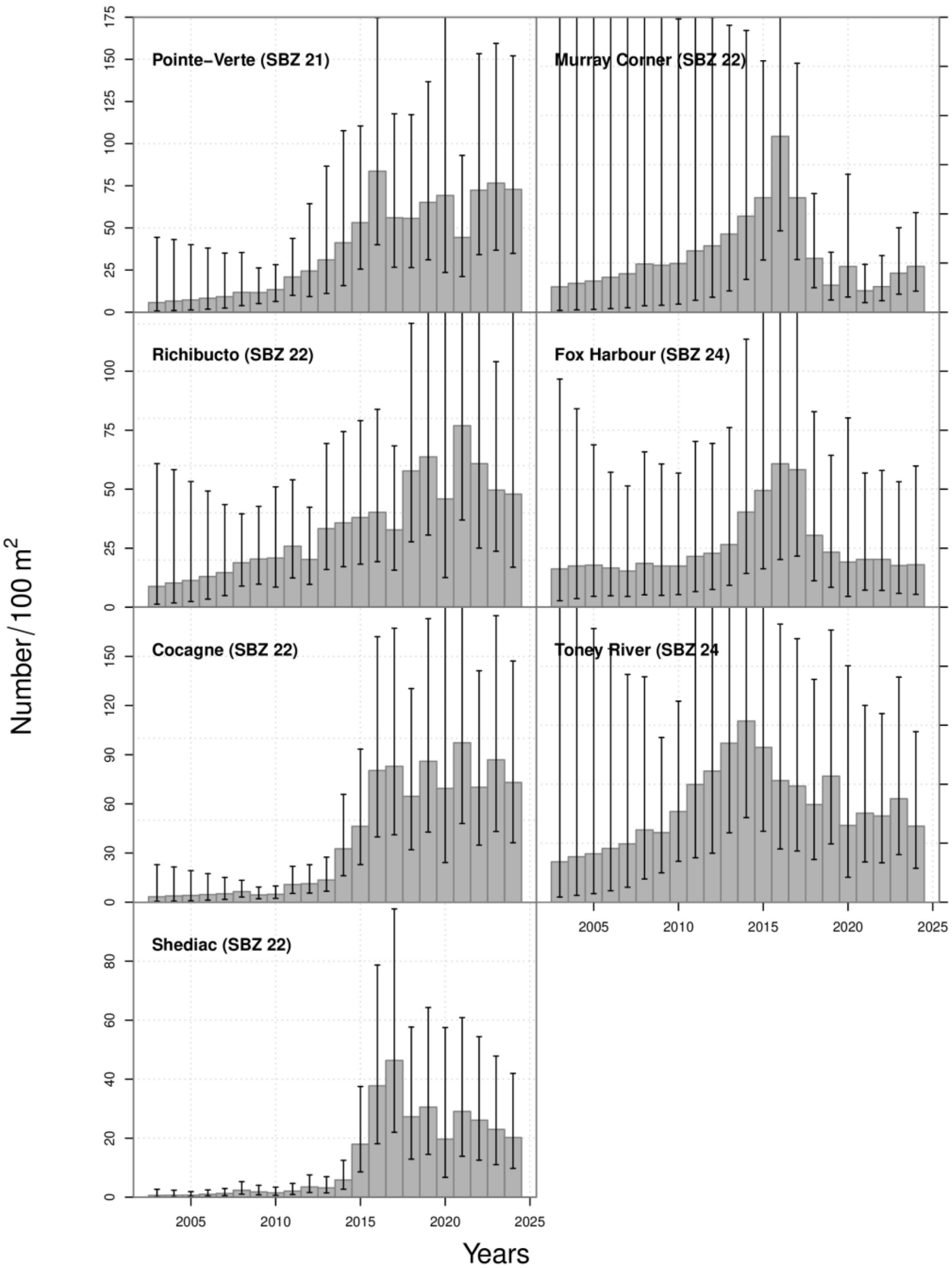

Figure 19. Count of Lobsters along SCUBA transects sampled yearly from 2001 to 2024 for sites within the Scallop Buffer Zone Marine Refuges. See Figure 17 for a map of survey locations.

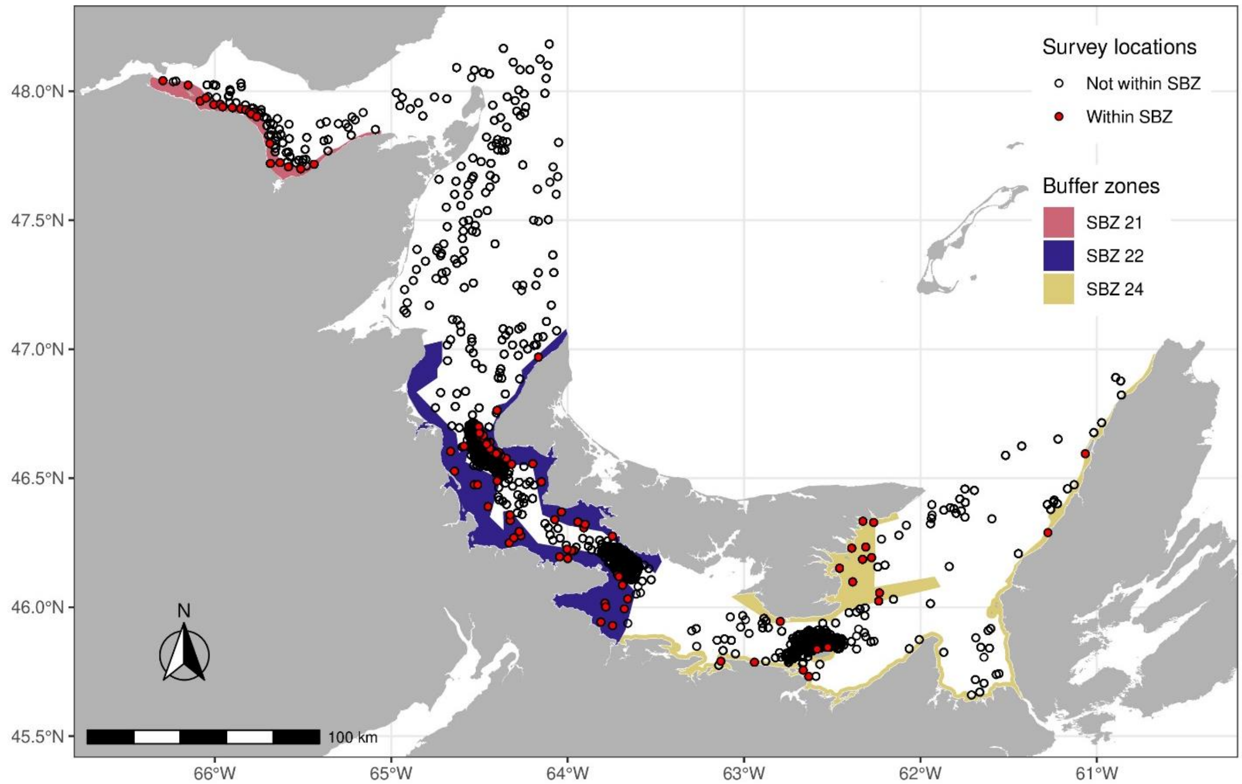

Figure 20. Gulf Region Sea Scallop (Placopecten magellanicus) survey locations.

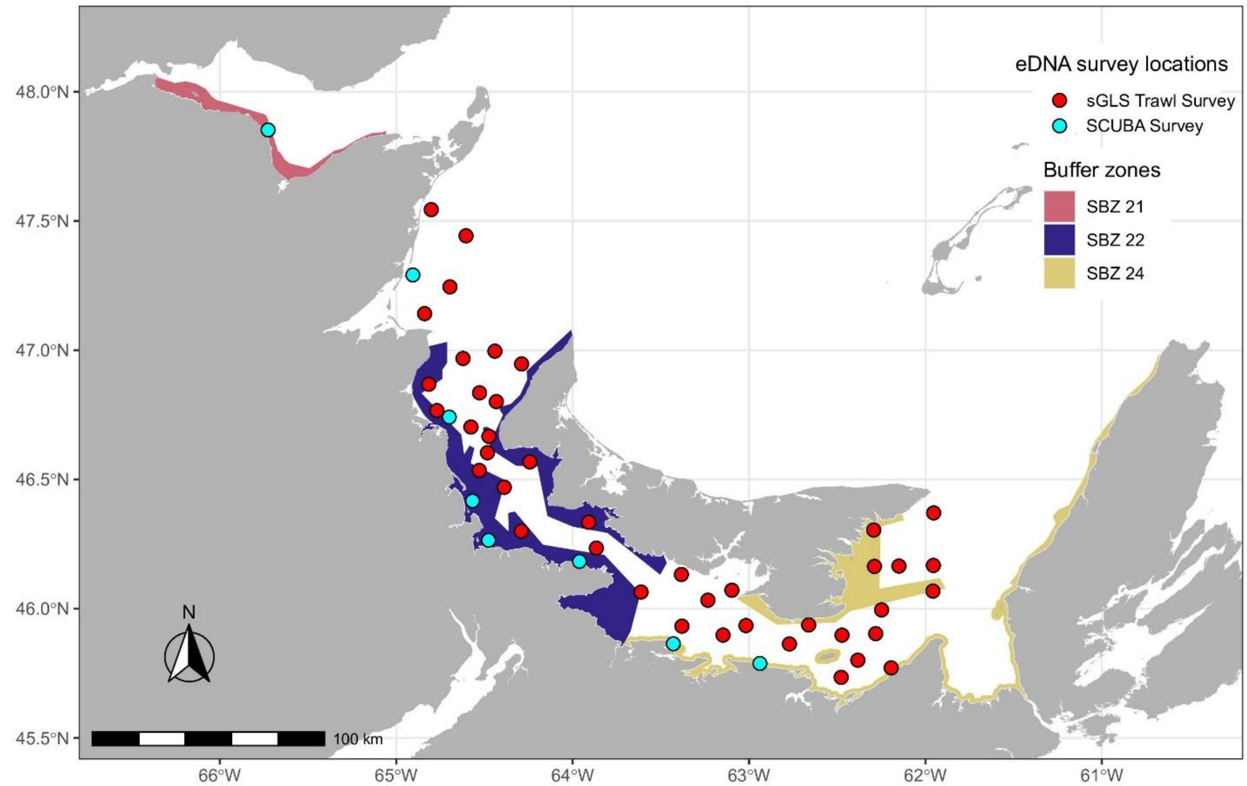

Figure 21. Locations of eDNA samples piloted during 2024 Northumberland Strait multi-species trawl and SCUBA surveys.