Mapping potential juvenile American Lobster habitat in the southern Gulf of St. Lawrence Scallop Buffer Zones (SFA 21, 22 and 24) Marine Refuges

Venitia Joseph, Eva Dickson, Jeffrey Barrell, Thomas Guyondet, and Tanya Arseneault

Fisheries and Oceans Canada
Gulf Fisheries Centre
343 University Avenue
Moncton, New Brunswick
E1C 9B6

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Fisheries and Oceans Canada
Gulf Fisheries Centre
343 University Avenue
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E1C 9B6

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Abstract

Joseph, V., Dickson, E., Barrell, J., Guyondet, T., and Arseneault, T. 2026. Mapping potential juvenile American Lobster habitat in the southern Gulf of St. Lawrence Scallop Buffer Zones (SFA 21, 22 and 24) Marine Refuges. Can. Manuscr. Rep. Fish. Aquat. Sci. 3307: vi + 38 p. https://doi.org/10.60825/95vj-7f21

The Scallop Buffer Zones (SBZs) Marine Refuges are located in the southern Gulf of St. Lawrence (sGSL), in coastal portions of Scallop Fishing Areas (SFAs) 21, 22, 24. The SBZs 21, 22 and 24 fishing closures were recognized as Marine Refuges in 2017. These conservation areas provide protection to juvenile American Lobster (*Homarus americanus*) and its benthic habitat through the prohibition of scallop dragging. This report aims to identify areas of potentially optimal juvenile lobster habitat that could be monitored to assess the status of the Marine Refuges. Potential habitat was identified by layering available geospatial data representing substrate, depth, and temperatures suitable for juvenile lobsters, which have a strong preference for rocky/cobble bottoms, waters less than 10 m deep and bottom temperatures of at least 12°C for post-larval settlement. Despite the substrate data not providing sufficient resolution for identification of cobble habitat, broad-scale areas for potential habitat were identified using sediment > 2 mm in diameter. Temperature data shows that most of the Northumberland Strait has temperatures suitable for juvenile lobster settlement, and sea surface temperatures could be a good proxy for bottom temperatures in these shallow coastal waters. Identified gaps providing opportunities for further research include better substrate and habitat characterization using video ground-truthing and modelling efforts in the SBZs. Studies on these methods can determine if they are an efficient way of better defining optimal juvenile lobster habitat in order to focus our ecological monitoring efforts.

Résumé

Joseph, V., Dickson, E., Barrell, J., Guyondet, T., and Arseneault, T. 2026. Mapping potential juvenile American Lobster habitat in the southern Gulf of St. Lawrence Scallop Buffer Zones (SFA 21, 22 and 24) Marine Refuges. Can. Manuscr. Rep. Fish. Aquat. Sci. 3307: vi + 38 p. https://doi.org/10.60825/95vj-7f21

Les refuges marins des zones tampons de pêche du pétoncle (ZTPP) sont situé dans le sud du golfe du Saint-Laurent (sGSL), dans les parties côtières des zones de pêche du pétoncle 21, 22, 24. Les ZTPP sont des zones de fermeture de pêche qui ont été désignées comme refuges marins en 2017. Ces zones de conservation assurent la protection des homards juvéniles (*Homarus americanus*) et de leur habitat grâce à l'interdiction de la pêche à la drague des pétoncles par contact avec le fond. Ce rapport vise à identifier les zones d'habitat potentiellement optimal du homard juvénile qui pourraient être suivies afin évaluer l'état des refuges marins. L'habitat potentiel a été identifié en superposant les données géospatiales disponibles sur le substrat, la profondeur et les températures convenant aux homards juvéniles, qui ont une forte préférence pour les fonds rocheux et de galets, les eaux de moins de 10 m de profondeur et les températures d'au moins 12°C. Bien que les données sur le substrat n'aient pas une résolution suffisante pour permettre d'identifier les habitats de galets, des zones d'habitat potentiel à grande échelle ont été identifiées en se basant sur les sédiments d'un diamètre supérieur à 2 mm. Les données montrent qu'au niveau de la température, la majorité du détroit de Northumberland a des températures adéquates pour les homards juvéniles, et que la température de surface peut servir d'indicateur de la température de fond dans ces eaux côtières peu profondes. Certaines lacunes identifiées lors de l'analyse des données présentent des opportunités de recherche, incluant une meilleure caractérisation du substrat et de l'habitat dans les zones tampons du pétoncle en utilisant des méthodes de collectes vidéos et de modélisation. Des études de ce type permettront de déterminer si ces méthodes représentent une façon efficace de délimiter des habitats optimaux pour le homard juvénile et concentrer nos efforts de suivi écologique.

1. Introduction and Overview

As part of Canada’s commitment to international biodiversity protection targets, the Government of Canada is committed to conserving 30% of our coastal and marine areas by 2030 (Fisheries and Oceans Canada 2025). For the Department of Fisheries and Oceans (DFO), this occurs through the implementation and management of Marine Protected Areas (MPAs) and other effective area-based conservation measures (OECMs), also known as Marine Refuges (MRs). There are currently over 60 MRs across Canada (Fisheries and Oceans Canada 2025) which aim to protect important species and their habitats from human impacts such as fishing. In the southern Gulf of St. Lawrence (sGSL), the Scallop Buffer Zones (SBZs) Marine Refuges were established in 2017 in the coastal portions of Scallop Fishing Areas (SFAs) 21a, 22, and 24 (Figure 1). The main conservation objective of the SBZs is to protect juvenile American Lobster (*Homarus americanus*; hereafter lobster) and its habitat through the prohibition of scallop dragging activities within the refuges (DFO 2019a). Ecological monitoring is a critical component of the ongoing management of conservation areas. It provides data on the condition and trends of key species and habitats and assesses the effectiveness of management actions in achieving defined conservation objectives. Developing a strong monitoring plan begins with compiling existing data and identifying gaps to guide future data collection.

This report aims to map potentially optimal juvenile lobster habitat within the SBZ 21, 22, and 24 MRs using currently available data. Habitat suitability is assessed by identifying key environmental preferences based on a review of recent scientific literature and integrating available geospatial data layers that reflect these conditions. This mapping exercise will be used to identify gaps in data, guide research, and contribute to the identification of monitoring sites that will be incorporated into the ecological monitoring plan for these conservation areas.

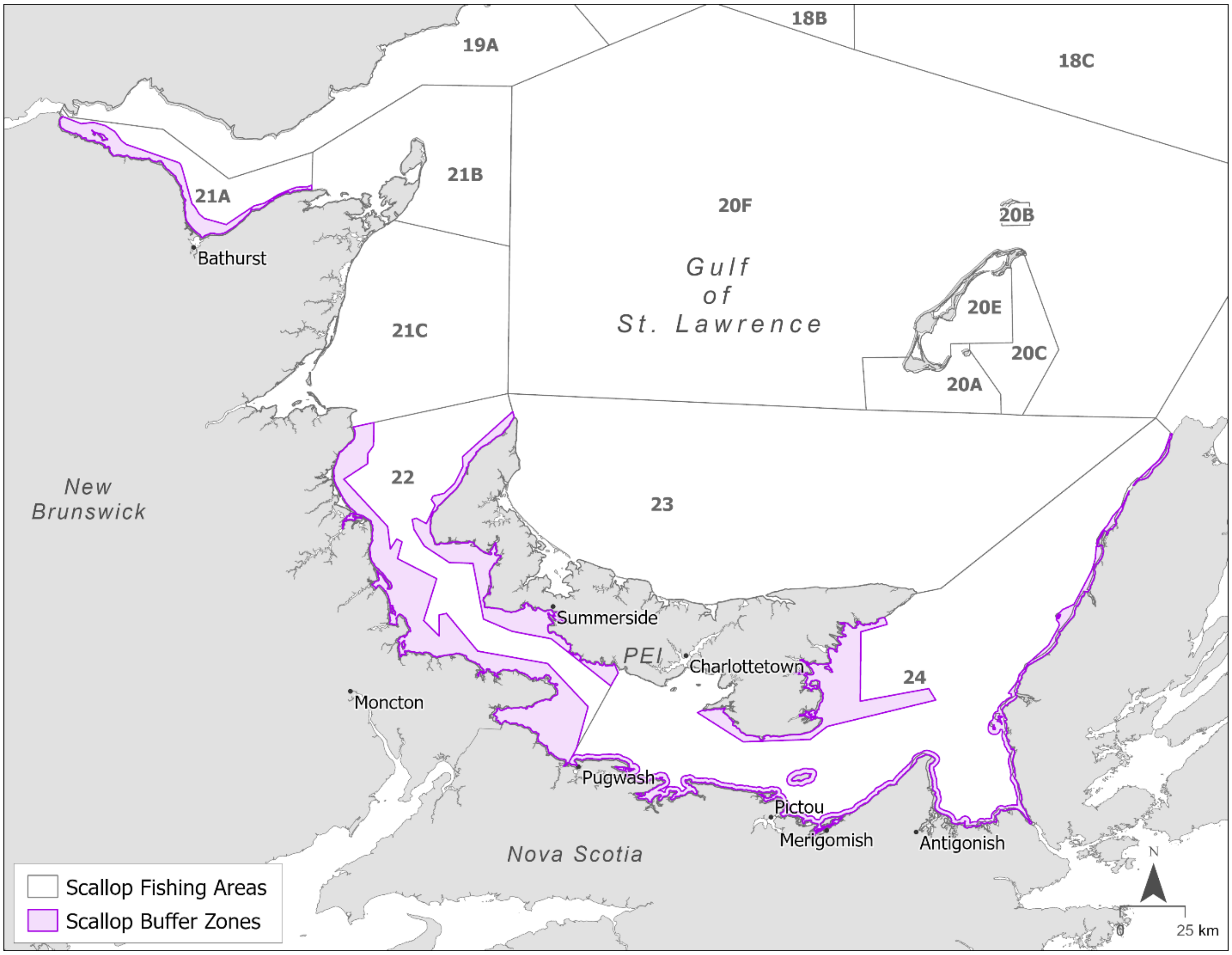

Figure 1. Map of Scallop Buffer Zones marine refuges in SFA 21a, 22, 24 in the southern Gulf of St. Lawrence.

1.1 Background on the Scallop Buffer Zones (SBZs)

Bottom contact fishing gear associated with Sea Scallop fisheries (i.e. Scallop drags/dredges) are 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). Scallop dragging is prohibited in the buffer zones of SFAs 21, 22, and 24 primarily to protect juvenile lobster (Niles et al. 2024). The bounds of SBZs Marine Refuges are based on these established fishing closures within SFAs 21a, 22, and 24 (Fisheries and Oceans Canada 2019). Although SBZs were initially delineated based on depth criteria (Niles et al. 2021), they are now formally defined by GPS coordinates. An exception exists for portions of SBZ 24 along the Nova Scotia coast, which extends 1 nautical mile from shore. These spatial boundaries are specified as conditions within the scallop fishery license. The SBZs cover an area of approximately 5,400 km^2 as listed in the Canadian Protected and Conserved Areas Database (Environment and Natural Resources 2025).

SBZ 22 covers the largest area of the three zones and was established in 2005 as a fishing closure along the coast of New Brunswick (NB) and western Prince Edward

Island (PEI). The SBZ 21a fishing closure was established in 1999 (Davidson et al. 2012) and further extended in 2013. The SBZ 24 fishing closure was established in 1996 within a distance of one nautical mile (1.852 km) from the Nova Scotia (NS) shore (Niles et al. 2021). In 1999, this SBZ was expanded to include waters along the Prince Edward Island (PEI) shore, up to a depth of 27.4 m. In 2006, the SBZ area was again expanded to include waters along the western Cape Breton shore, up to a depth of 27 m, and represents approximately a third of the total area represented by these SBZs. Henceforth, we use the term SBZs to reference the Marine Refuges and not specifically the fishing closures.

The main conservation objective of the three SBZs is to protect juvenile lobster and its associated habitat. These closures also provide indirect benefits to the ecosystem by offering protection to several other important species and benthic habitats in the sGSL. The SBZ 22 contains the last remaining area in which the Winter Skate (*Leucoraja ocellata*) southern Gulf population (listed as endangered by The Committee on the Status of Endangered Wildlife in Canada) is found during the summer (COSEWIC 2015; Swain and Benoît 2007). The SBZ 22 also includes a Lady Crab (*Ovalipes ocellatus*) population isolated from its southern range (Rondeau et al. 2016; Voutier and Hanson 2008). There are also coastal habitats within all three of the SBZs that are suitable spawning grounds for Atlantic Herring (*Clupea harengus*), which are an important forage species (Messieh 1987).

1.2 Juvenile American Lobster

The American Lobster is distributed in coastal waters from southern Labrador, Canada to New Jersey, USA, with major fisheries concentrated in the Gulf of St. Lawrence and the Gulf of Maine (DFO 2014). Lobsters have pelagic and benthic phases as part of their life cycle. Once the eggs hatch during the summer months, larvae become pelagic and free-swimming for 3-10 weeks, after which they settle onto the benthos (DFO 2014). After post-larval settlement, lobsters enter the juvenile stages at approximately 4-5 mm carapace length (CL) (Lavalli and Lawton 1996). Different life history terminology exists in the literature, but here we adopt the terminology proposed in the review by Lavalli and Lawton (1996), which differentiates three phases of juveniles, which are ecologically and behaviorally distinct from larger lobsters (Wahle and Steneck 1991). Shelter-restricted juveniles (approximately 4 to 14mm CL) are cryptic and remain covered, primarily in cobble substrate habitats in coastal waters (Wahle and Steneck 1991; Lawton and Lavalli 1995; Cobb et al. 1983; Rondeau et al. 2014). Emergent juveniles (15 to 25 mm CL) begin venturing outside their shelter but remain very close to it, while vagile juveniles (25 to 40 mm CL) have more extensive movements outside their shelter to search for food (Lavalli and Lawton 1996). It is estimated that juvenile lobsters spend the first 5 to 6 years of their lives in and near their initial shelters (Kilada et al. 2012), whereas adult lobsters are not cryptic, venture deeper and select different types of habitats (Lawton and Lavalli, 1995).

1.3 Habitat characteristics

Based on available data layers within the SBZs and known factors involved in juvenile's habitat selection, the key environmental characteristics that were considered for the mapping of juvenile lobster habitat were sediment type, depth, and water temperature. There are other localized factors that can affect juvenile lobster distribution and selection of suitable habitat, such as predation pressure, size-specific aggression (Wahle and Steneck 1991), food availability (Haarr et al. 2020), disease, ocean circulation (McManus et al. 2023), odor plumes (Boudreau et al. 1993) and presence of marine plants providing additional cover (Lawton and Lavalli 1995; DFO 1996). These factors have not been examined on a broad scale (i.e., cannot be mapped due to inherent spatial and temporal variability) and are outside the scope of this report. Water chemistry (pH, dissolved oxygen and salinity) was not considered in this analysis as these variables are not expected to limit the lobster habitat in the SBZs (Lavoie et al. 2021 and Dutil et al. 2012).

1.4 Substrate

The main environmental predictor of larval settlement is the bottom substrate type. Larval lobster dive to the seafloor repeatedly to test the substrate before choosing where to settle (Sigurdsson et al. 2015). Once settled, juveniles have a strong association with structurally complex habitats, especially cobble substrates (Hudon 1987; Wahle and Steneck, 1991; Wahle and Incze 1997; Hanson 2009; Dinning 2014). High abundances of juveniles are observed in cobble and boulder substrates (Wahle and Steneck 1991) and rock on sand (particle size not specified; Hudon 1987). Cobbles naturally provide ready-made shelter in the interstices that offer protection without expending energy to dig and maintain tunnels in secondary habitats such as mud (Dinning 2014).

Wahle and Steneck (1991) found that biotic habitats (e.g., macroalgae and mussels) influenced juvenile abundance on bedrock and that the juveniles were not found on exposed bedrock or sand substrates. In a controlled tank environment, juvenile lobsters collected from the wild that were given a choice of substrate for a 5-minute period were most abundant on cobble substratum (80 - 110 mm diameter) but were very rare on featureless soft or bedrock substrata (Wahle and Steneck 1992). It is likely that this association to cobble substrate is reinforced by predation pressure (Wahle and Steneck 1992; Sigurdsson and Rochette 2013). Experiments exposing tethered juveniles (attached to a platform by nylon harnesses) in the field to predators (demersal fish and crabs) showed that lack of cobble substrate resulted in higher mortality, and this vulnerability to predation decreases as individual body size increases (Wahle and Steneck 1992).

1.5 Depth

It has been reported that smaller sized juvenile lobsters (i.e., < 25-30 mm CL) typically inhabit water less than 10 m deep (Lawton and Lavalli 1995) and juveniles tend to occupy shallow subtidal habitats (Lawton et al. 2001). In the sGSL, most lobsters are found in waters < 30 m deep during the ice-free season (Hanson and Lanteigne 2000) and juvenile lobsters are mainly found in the shallowest part of the species' depth distribution (Hanson 2009). In the Northumberland Strait, July-August bottom-trawl surveys between 2001 and 2006 showed that 50% of lobsters (< 50 mm CL) were found below 8.5 m, while distributions of lobster over 70 mm CL extended to deeper waters (Hanson 2009).

1.6 Water Temperature

The hatching of lobster eggs is temperature-dependent and normally occurs in July and August in the sGSL (Ouellette et al. 2016; Sainte-Marie 2006; Haarr et al. 2020). Water temperature also influences larval settlement (Quinn et al. 2013), which occurs 3-10 weeks after hatching (DFO 2014). In laboratory experiments (Annis 2005) lobster larvae stayed in the water column if bottom water temperatures were below 12 °C, which could indicate that it is a threshold for larval settlement. Annis et al. (2013) also tested this thermal limit in the field (Gulf of Maine) and found sites with temperatures above 12 °C had higher post-larval settlement. In the laboratory, they found that post-larval mortality increased at temperatures below 12 °C.

2. Methods

Habitat identified to be important for the settlement of pelagic lobster larvae and the protection of juvenile lobsters, which remain very close to their burrows during their first years of life, is characterized as shallow (≤ 10 m deep) and warm (≥ 12°C) waters with rocky substrates. These are the areas we will aim to identify to estimate the coverage of potential habitat for juvenile lobster in the SBZs. To achieve this, we identified and selected the most relevant GIS layers (detailed in 2.1 below). The datasets that covered the entire SBZ area were assembled and mapped using ArcGIS Pro (ESRI version 3.3.2). This allowed us to characterize the area within the SBZs to describe the coverage of hard substrate (gravel and sand), depth, and sea bottom and surface temperature. We compared more recent DFO survey data including catches of juvenile lobsters with the habitat descriptor layers to confirm expected suitable habitat. Finally, we combined all habitat variables into an overlap analysis with all data layers combined to identify potential juvenile lobster habitat.

2.1 GIS Layer Selection

We explored various available public and internal data sources from research documents and consulted experts for datasets to display key habitat variables: substrate type, water depth, and water temperature in the SBZs (Appendix 1). Geographic datasets were downloaded when openly available or obtained from DFO survey leads or subject matter experts upon request. The data types were mainly polygon and point and where possible, point data were converted to polygon to allow easier overlap and comparison of coverage. In the case of dense points in a regular pattern, this meant converting to a raster format based on spacing between points and then to polygon using ArcGIS Pro. Where points were sparse, it was not statistically valid to do interpolation to create a grid format, so the exact location of the point was spatially overlaid onto the polygon layer in ArcGIS Pro and was compared to that specific polygon value.

2.1.1 Substrate

To understand the existing data and substrate classifications in the GSL, two key reports and their datasets were identified. The most complete substrate data available is a map of the entire Gulf of St. Lawrence from Loring and Nota (1973) depicting sediment types ranging from fine (pelite) to coarse (gravel) based on 500 surficial sediment samples collected throughout the Gulf and Estuary (150 from the Laurentian Trough and 350 from the Magdalen Shelf) and separate data from the Bedford Institute in the Northumberland Strait (provided by Kranck 1971). Loring and Nota (1973) defined gravel as grains coarser than 2 mm in diameter (with no distinction between pebbles, cobbles, and boulders), sand as grains 0.05-2 mm, and pelite (mud, silt) as grains < 0.05 mm. Components representing < 5% of the sediment weight were not considered in the assigning of type; those comprising 5-30% were indicated by adjectives (e.g., sandy) while components comprising 30% or more of the sediment weight were described qualitatively (e.g., sand).

Data gaps in coastal areas were identified by Dutil et al. (2012). They used 2.5 km resolution grid cells to map areas < 30 m deep in the Estuary and the Gulf of St. Lawrence, creating a spatial database of relevant variables including, depth, temperature, salinity, and surficial sediment, which were used to classify shallow coastal habitats. Dutil et al. (2012) bridged the gap of sediment data from Loring and Nota (1973) to the coast by assigning the nearest adjacent corresponding map value.

Though there is not a more recent and comprehensive primary source of sediment data in the region, Sklar et al. (2024) conducted sediment modelling using updated bathymetry and hydrological data with the legacy sediment data from Loring and Nota (1973). The predictor variables used included bathymetry, aspect, slope, current direction and magnitude, wave power, and proximity to land (Sklar et al. 2024). Three grain size fractions (mud, sand, and gravel) were modelled separately as continuous quantitative variables, and predicted proportions of each were then classified into grain size categories (Folk 1954). It should be noted that only a small subset of the original 1,500 samples were used (223) and that the gravel class had the highest number of null samples (i.e., samples containing no gravel); therefore, the model explained only 19.5% of the variance of that class, compared to 79.4% of the mud observations (Sklar et al. 2024). Despite the legacy status of the raw sediment data and the limitations of predicting the gravel class (likely to provide habitat for cryptic juvenile lobsters), this modelled dataset represents the most modern and robust estimate of the sediment in the Gulf of St. Lawrence. It does not include predictions for shallower coastal waters and therefore much of the SBZs, but it may still serve as a useful initial tool to infer nearby areas containing juvenile lobster habitat in the sGSL.

2.1.2 Depth

A comprehensive GIS dataset comprised of CHS and DFO acoustic data was interpolated using the natural neighbor method covering the Gulf Region (see Appendix 1). These datasets were compiled previously by DFO Gulf Region for internal use and analyses and are not for navigational purposes.

To look at the correlation of juvenile lobsters with this depth layer, we used more recent DFO bottom trawl survey data collected in the Northumberland Strait between 2010 and 2021 (Asselin et al. 2021, Appendix 1).

2.1.3 Water Temperature

To map the potential juvenile lobster thermal habitat (bottom temperatures > 12°C), DFO monitoring stations and other surveys with data occurring in the SBZs were explored. These bottom temperature point measurement data were collected by the Northumberland Strait Multi-species Bottom Trawl Survey, research vessel surveys, and the Coastal Temperature Monitoring Stations between 2010 and 2020 (Asselin et al. 2021, Hurlbut et al. 2006, Ouellet and Gagnon 2019, Appendix 1 for details).

The overlap of the bottom temperature point records with the SBZs was examined including a comparison in the shallow (< 10 m deep) zone. To see if juvenile lobsters in this region also prefer temperatures above 12°C, bottom temperature data (from CTD casts) from the DFO Northumberland Strait Multi-Species Bottom Trawl survey data for 2010-2021 were compiled where juveniles were detected at the same location.

Since this point data did not evenly cover the SBZs, it was not comprehensive enough to create a continuous surface layer to use in overlay, so average daily sea surface temperature (SST) data derived from satellite imagery (National Oceanic and Atmospheric Administration satellites, Advanced Very High Resolution Radiometer instruments) were mapped as a potential alternative for the overlay (Galbraith et al 2021, Appendix 1). These data were extracted for the summer months of July, August, and September across the years 2010-2020. All three months were explored because juvenile lobster settlement could occur within those months after egg hatching in July or August and accounting for a 3–10-week pre-settlement period (DFO 2014). The SST data were averaged across the 10 years each month to give an average value for points spaced 1 km apart. Then natural neighbor interpolation was used to create spatial layers for each month.

To better determine if SST is a good proxy for bottom temperature in the SBZs, we compared bottom temperature values (combined research vessels survey data and coastal monitoring stations) in the SBZs with the corresponding day’s average SST at the nearest location.

2.2 Overlap Analyses: Identification of Potential Juvenile Lobster Habitat

Because the modelled sediment layers do not fully cover the SBZs, a straightforward overlay cannot be done to identify key areas of shallow, rocky, warm waters that would be good potential habitat for juvenile lobsters within the SBZs. As discussed in the section on sediment, the coverage of the SBZs is mainly mixed sediment and gravel so we could presume that characteristic carries to the remainder of the SBZs and is not a limiting factor for juvenile lobsters. An overlap analysis typically is done by giving different layers classes of value from high to low (e.g. suitability index), and then layers are mapped on top of each other, adding the values together by location. Areas with the highest sum would, in this case, be the most suitable.

2.3 Biological Dataset Overlay

Survey datasets that collect juvenile lobsters deliberately or as by-catch could indicate potential habitat or show data gaps or inaccuracies to address. Two DFO surveys with juvenile lobster catches were overlaid with potential habitat.

2.3.1 DFO Northumberland Strait Multi-Species Bottom Trawl Survey

The Northumberland Strait multi-species bottom trawl survey is performed annually in July and August in waters > 4 m deep with a primary goal of obtaining an index of the abundance of American Lobster (for detailed survey methods, see Asselin et al. 2021; Rondeau et al. 2015). Though the trawl mesh sizes do not allow for targeted juvenile lobster capture, incidental captures of larger juveniles are still useful as detection data. Lobster catch data from 2010-2021 of this survey were examined to look at lobster size by depth. The counts of juvenile lobsters (≤ 40 mm CL) per location were then overlaid to show the survey's extent and where juveniles were concentrated.

2.3.2 DFO SCUBA Survey Data

DFO visual line-transect SCUBA surveys from 2019 and 2021 had been carried out to look at lobster density at specific locations, measure lengths, and monitor temporal change. Sites were selected based on fishers' knowledge, mapping surveys and ground-truthing to locate rocky bottom, about 4.5-10 m deep (see Rondeau et al. 2015, Asselin et al. 2024 for more detail). Seafloor substrate was categorized by divers according to size classification developed by Wentworth (1922) with modifications from Pettijohn (1949) where mud was defined as fine silt, clay or sand < 0.0625 mm, sand was 0.0625-2 mm, pebble was 2-4 mm, gravel was 4-64 mm, cobble was 64-256 mm, and boulder was > 256 mm. An approximate percentage was given for each of those categories as well as hard (barren) substrate.

Knowing that this survey was completed in shallow areas known to have juvenile lobsters, we took a closer look at the sediment data by depth and the lobster carapace length (i.e., size) by depth within the SCUBA data itself.

These SCUBA survey data near or within SBZs in 2019 and 2021 were then overlaid with the modelled sediment layer from Sklar et al. (2024) to see if there was 1) a relationship between modelled substrate and juvenile lobsters (≤ 40 mm CL) and 2) a difference in modelled sediment type and diver observation in sediment types.

3. Results

3.1 GIS Layer Selection

3.1.1 Substrate

To examine sediment suitability for juvenile lobsters in the SBZs we initially combined the maps of Loring and Nota (1973) of the GSL with the Dutil et al. (2012) of the coastal zones, filling that gap. Inconsistencies in expected patterns of species distribution and the sediment in areas adjacent to the SBZs were identified. Critically, the sediment data mapped by Loring and Nota does not differentiate between gravel, cobble, and boulder, with the latter two considered preferred substrate for juvenile lobster.

For the purposes of defining potentially optimal juvenile lobster habitat, we assumed that sediment with a finer composition (i.e., more sand or mud, < 2 mm particles) is less suitable for juvenile lobsters than sediment with a higher percentage of coarser sediment (i.e., gravel, > 2 mm diameter particles). Most of the SBZ has a predicted sediment gravel percentage between 10 and 30% (Figure 2), though the northwest portion of SBZ 22 along the NB coastline and the portion of SBZ 24 located southeast of PEI have a lower percentage of gravel. The composite sediment map (Figure 3) shows that most of the Northumberland Strait (and the SBZs) contains a predicted mixed sediment with gravel, sand, and mud present. The mainly gravel class references Folk’s (1954) sandy gravel class (where 30-80% of the sample is gravel, and at least 90% of the remainder is sand), gravel-sand-mud mix references gravelly sand (where 5-30% of the sample is gravel, and the remaining portion is at least 90% sand), and mainly sand references slightly gravelly sand (0.01-5% gravel with the remainder being at least 90% sand). If at least some coarser substrate is necessary for juvenile lobsters to shelter, it would follow that most of the region represents potential habitat for them, at least at a broad scale. Extrapolating the sediment layer to shore was outside of the scope of the present study but most of the SBZs are directly adjacent to mainly gravel or mixed sediment cells, indicating the likelihood that the SBZs would also primarily contain those sediments (Figure 3). Because of the gap and the uniformity of the predicted sediment in the SBZs, it may not be a reliable predictor. However, this is still the most up-to date and comprehensive sediment layer.

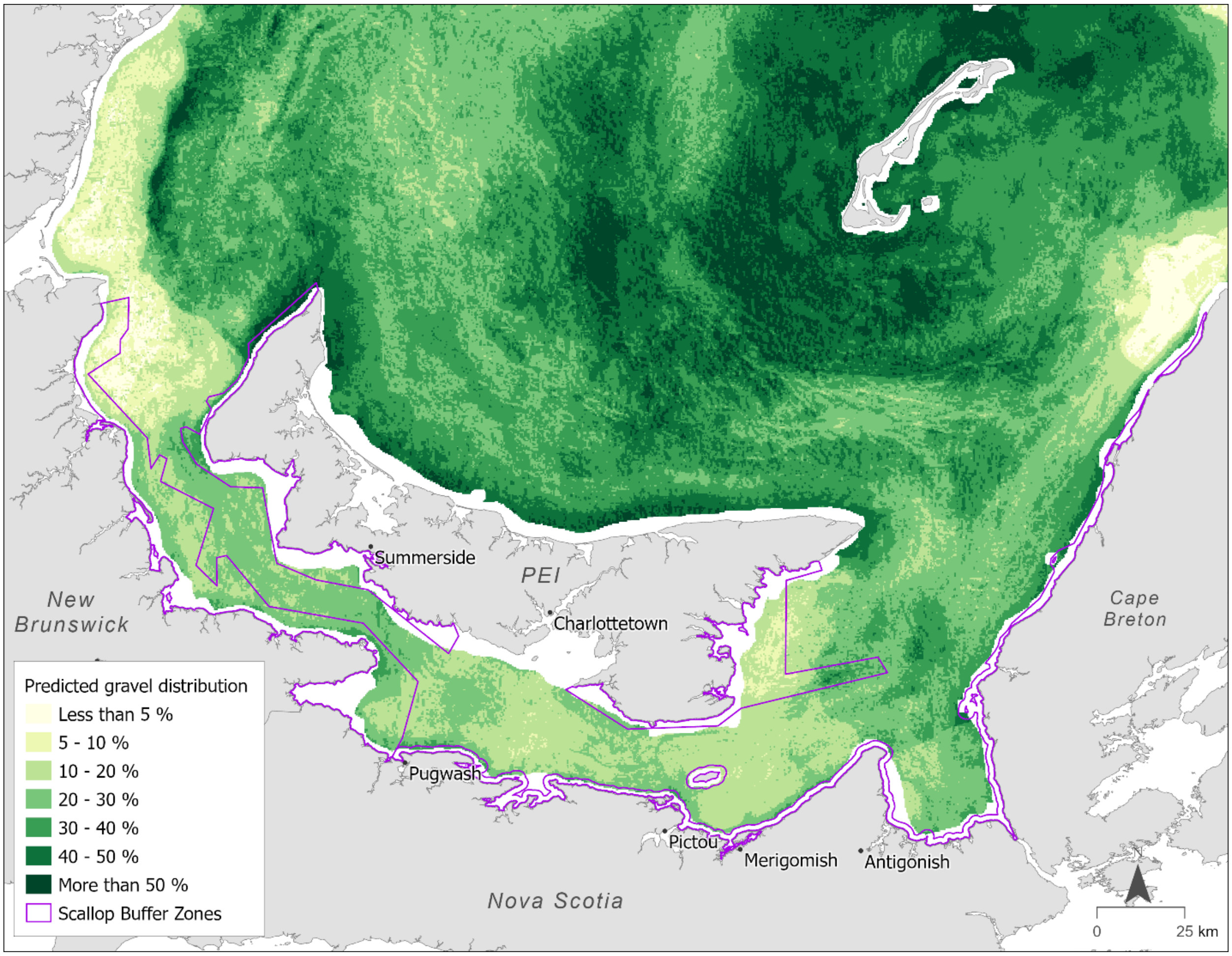

Figure 2. Surface sediment prediction map for gravel. Areas covered by a given colour are likely to have the associated percentage of gravel in the sediment. Darker colours of green indicate areas with more gravel. (data from Sklar et al. 2024).

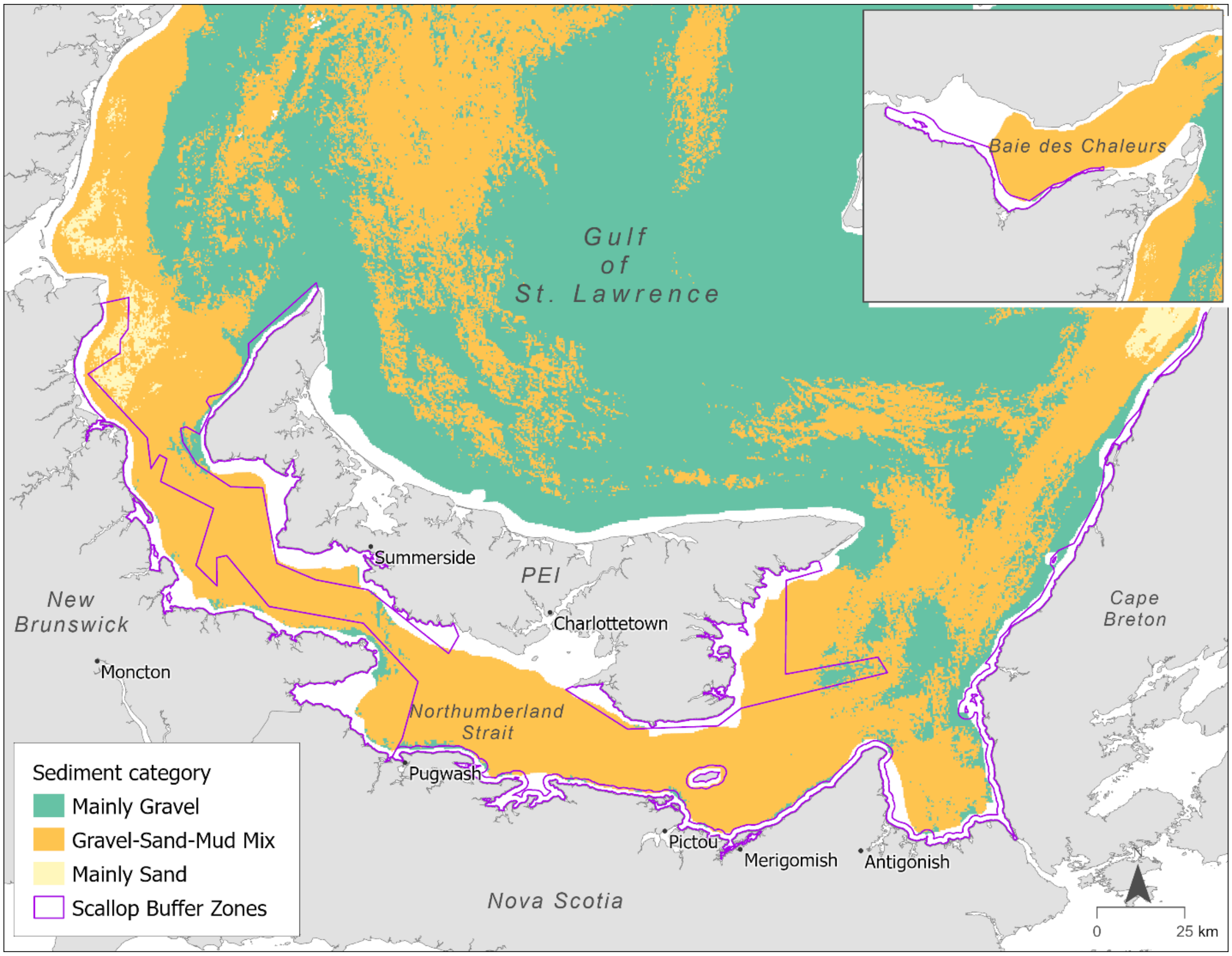

Figure 3. Surficial sediment map of the Gulf region. (data from Sklar et al. 2024).

3.1.2 Depth

The CHS/DFO modelled bathymetry covered the SBZs and the 10 m depth contour was used as the threshold for identifying the shallow region most suitable for juvenile lobsters within the SBZs (Figures 4-5). Within the SBZ, most of the 10 m habitat by depth is found in the western part of the Northumberland Strait (Table 1).

Table 1. Scallop Buffer Zone overlap with shallow waters.

	Total Area (km^2)	Area (km^2) < 10 m deep	% < 10 m deep	% < 5 m deep	% < 1 m deep
SBZ 21 Baie des Chaleurs	408.81	254.91	62.4	13.1	0.0
SBZ 24 Overall	1,677.84	580.24	34.6	15.0	1.3
NS & Cape Breton coast	774.01	382.72	49.5	20.4	1.2
Pictou Island	44.75	24.08	53.8	20.2	0.7
SE PEI	859.08	173.44	20.2	9.9	1.5
SBZ 22 Overall	2,530.40	1,549.62	61.2	19.9	4.1
SNB	1,798.53	1,039.71	57.8	17.5	3.4
SW PEI	731.87	509.91	69.7	25.6	5.8

The distribution of lobsters of carapace lengths smaller than 30 mm, 40 mm, and 50 mm from the trawl data were overlapped with the depth layer. We found that 66%, 44% and 30% of those lobsters respectively were found in shallow waters (≤ 10 m deep). This supports the idea that smaller juveniles favor shallower waters. Even considering that the survey does not specifically target juvenile lobster due to equipment design (mesh size) and survey sampling design (limited coverage of shallow areas) and is unable to detect smaller shelter-restricted (up to 14mm CL) and most of the emergent juveniles (15-25 mm CL), it still is apparent that juveniles are found more often in shallow waters (e.g. 10 m or less in depth).

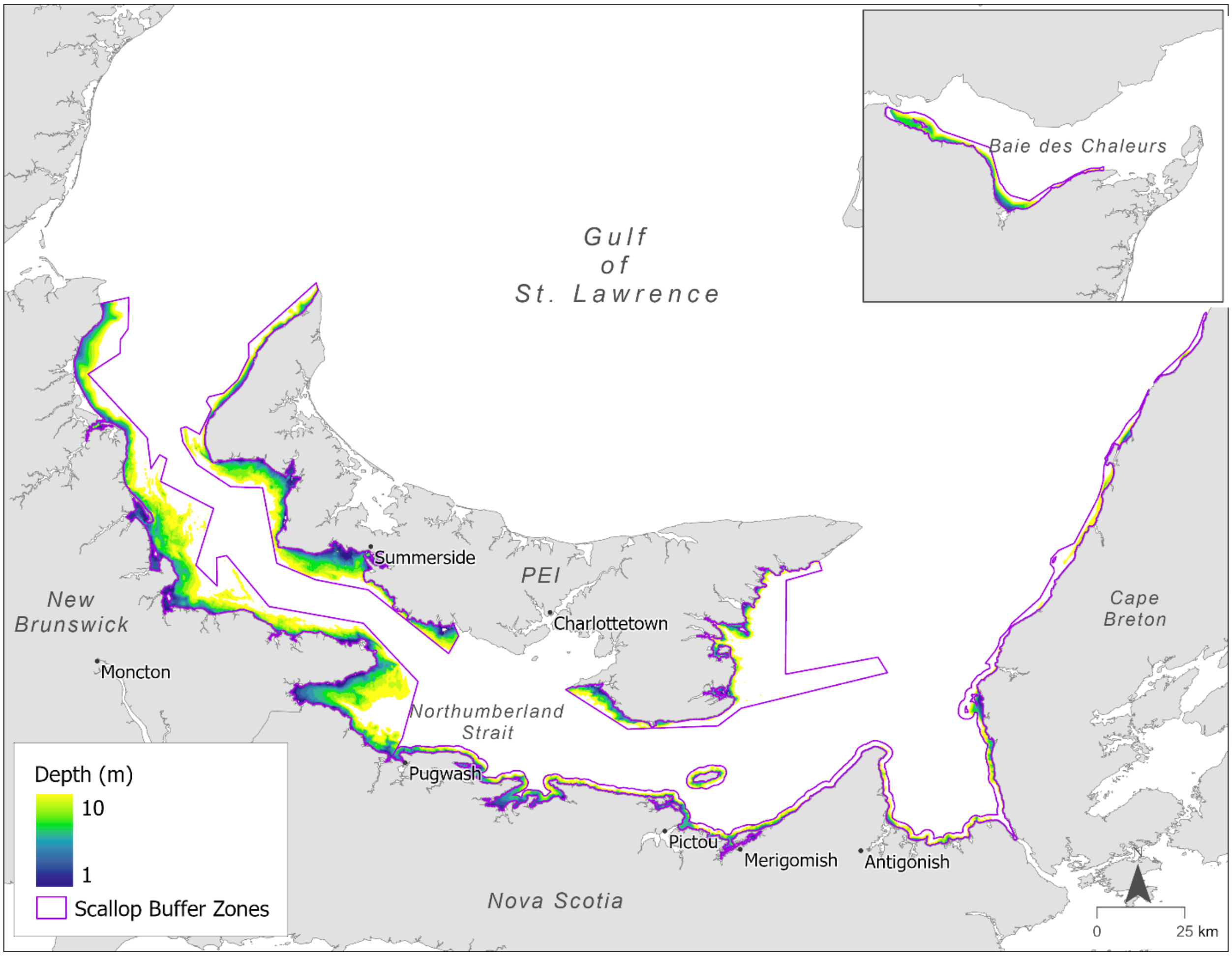

Figure 4. Bathymetry map within the SBZ Marine Refuges (≤ 10 m depth). (CHS/DFO, Appendix 1).

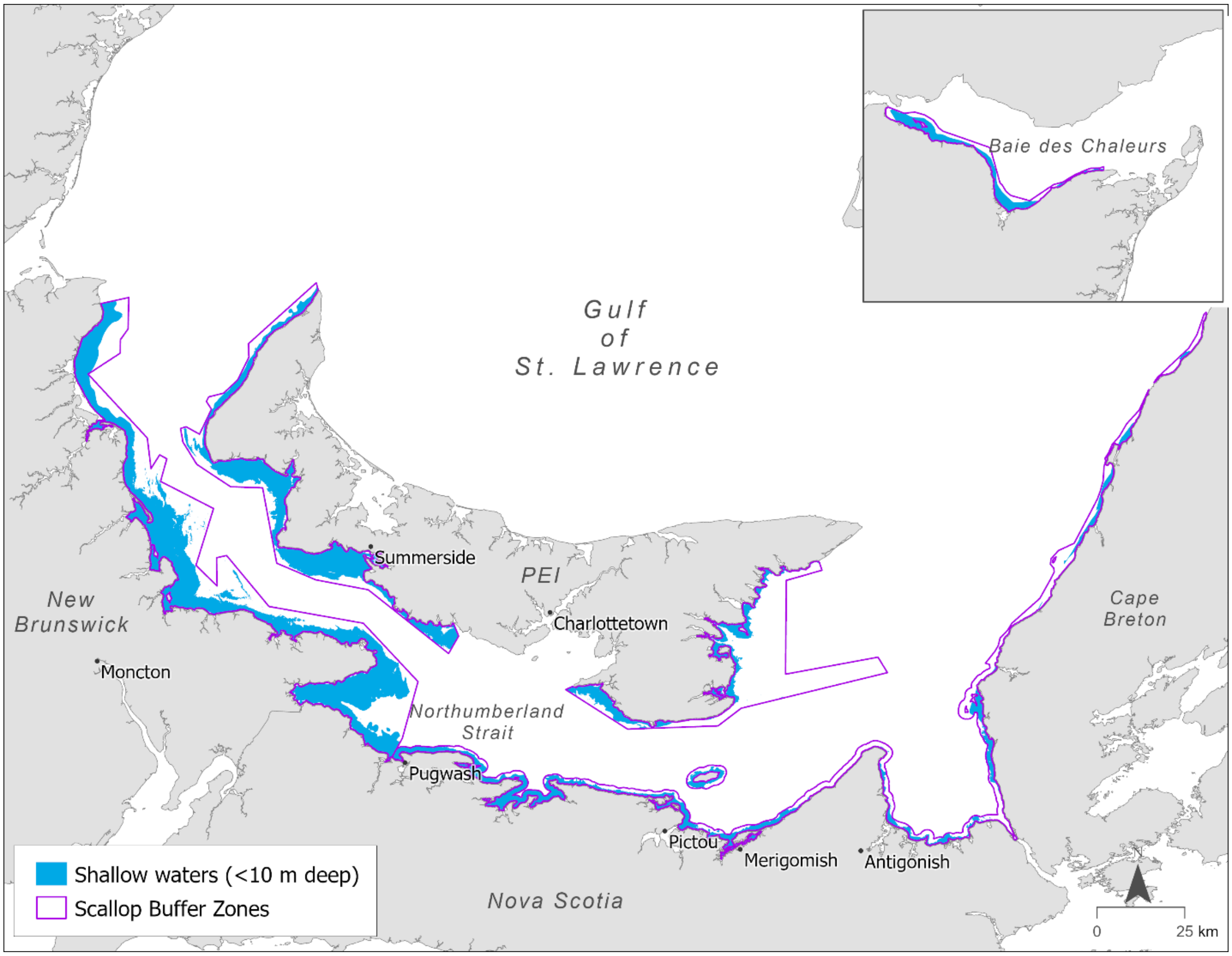

Figure 5. Shallow waters less than 10m deep within the SBZs.

3.1.3 Water Temperature

In July, 76.5% of bottom temperature point records falling in the SBZs polygons were greater than or equal to 12°C. In shallow waters 10 m deep or less, 89.9% of point records were 12°C or warmer (Figure 6, panel D). In August, 80% of SBZs bottom temperature records had values greater than 12°C, though the cooler values clustered mainly in the deeper waters off the East coast of PEI (Figure 6, panel E). When only a subset falling in the 10 m or shallower region was used, 95.7% had values > 12°C. In September, waters had warmed further and of the records in the SBZs, 93.3% were 12°C or warmer. In shallow waters, 98.7% of records were at least 12°C (Figure 6, panel F).

Of the DFO Northumberland Strait Multi-Species Bottom Trawl survey dataset for 2010-2021, only the years 2010-2016 had records with juvenile lobsters ≤ 40 mm CL and temperature data at the same sampling location. Of those, 73% had temperatures of at least 12°C. The highest bottom temperature with a juvenile lobster recorded was 21.1°C and the lowest was 3.1°C. Juveniles found where bottom temperatures were lower than 12°C does not necessarily mean that the temperature is unsuitable for the lobsters at the bottom, but it may not allow existing larvae in the water column to settle. Therefore, the limited coverage of bottom temperatures in the SBZs seems to confirm that those potential shallow-water habitats do have suitable temperatures for juvenile lobsters to settle and thrive.

The entirety of the SBZ Marine Refuge had an average surface temperature greater than 12°C in July and August (Figure 6, panels A and B), but in September (panel C), there were some areas (highlighted blue) where temperatures were slightly below 12°C. Therefore, water temperature does not appear to be a limiting factor for settling juvenile lobsters in the Marine Refuges in July and August, provided that SST is a decent proxy for bottom temperature. In September, there could be some areas where larval settlement is impacted by lower temperatures, but it is likely minimal given that the minimum averaged SST mapped is 9.97°C , and the total SBZ area with a SST less than 12°C is 59 km^2.

In summer, surface water temperatures are typically higher than bottom water temperatures, and we did find this pattern in our comparisons of SST and bottom temperatures. In July, the SST was on average 2.6°C warmer than the bottom temperature, and 1.5°C warmer than the bottom when only measurements in the 10 m or shallower zone were used. In August, the SST was on average 2.7°C warmer than the bottom temperature, and 1.1°C warmer when using shallow water points only. In September, the surface measurement was only 0.2°C warmer than the corresponding bottom temperature, while in the shallow zone, the bottom temperature was 0.4°C warmer than the surface. Even though this is a limited comparison, it does suggest that SST is not vastly different from bottom temperature in the shallow water regions of the SBZ and that it could serve as a decent proxy. This is an expected relationship, where typically shallow waters are well-mixed, while deeper waters are more stratified, meaning there are greater temperature differences through the water column. In the Northumberland shallow region of the sGSL, temperature profiles from 2022 and 2023 show little variation of temperature with depth in August and September (Galbraith et al. 2024). That same work showed that even in June, the Northumberland area had more temperature stratification with depth, but less than 2.5°C (Galbraith et al. 2024).

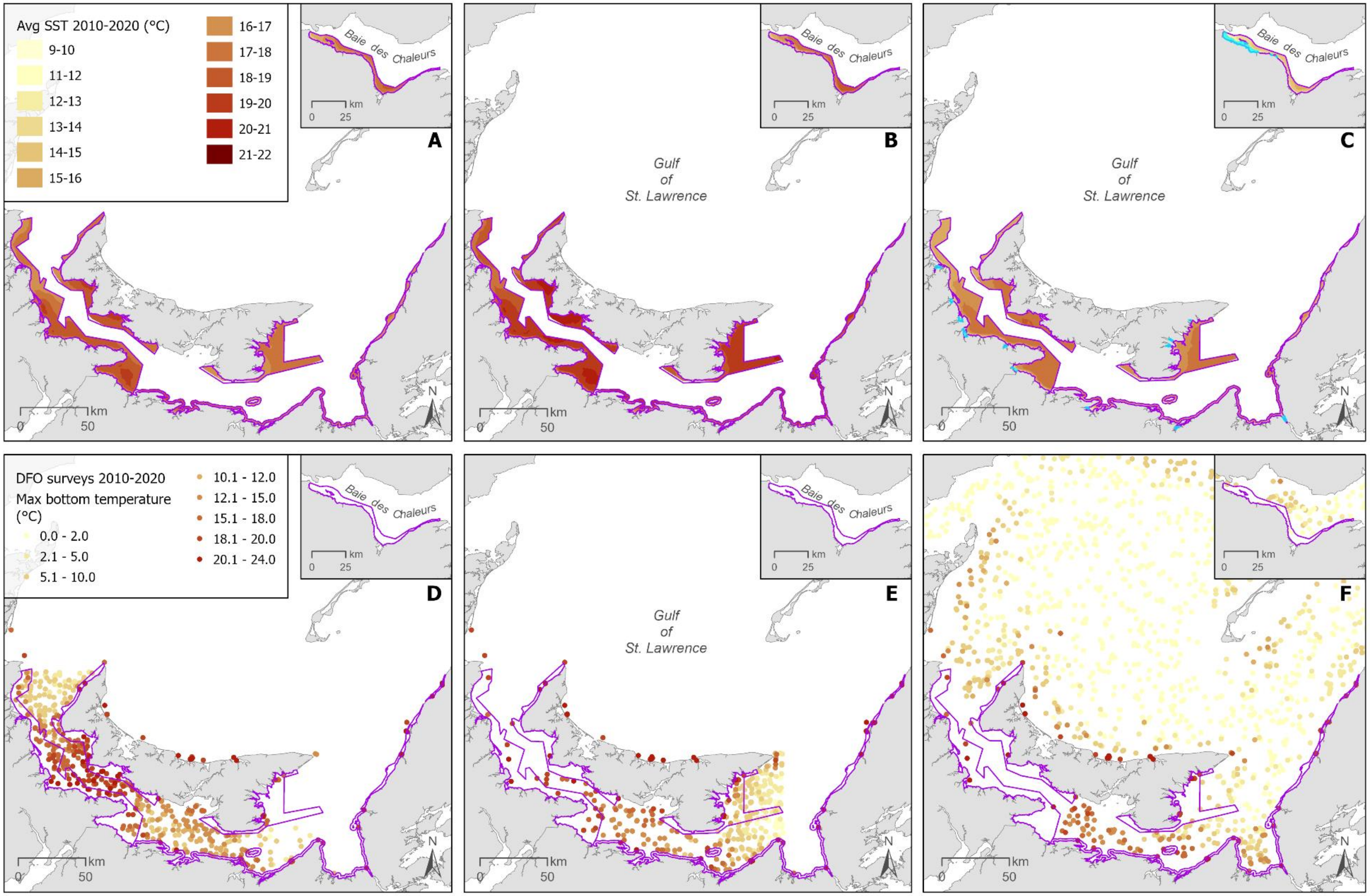

Figure 6. Average sea surface temperature (SST), satellite (top row) and bottom temperature data - DFO trawl surveys and coastal temperature monitoring stations (bottom row) for July (A,D), August (B,E), and September (C,F) from 2010-2020. SST for September shows areas less than 12°C highlighted in light blue.

3.2 Overlay Analysis: Identification of Potential Juvenile Lobster Habitat

If all the area within the SBZs is considered to have a suitability rank of 1 (suitable) vs 0 (not suitable) for temperature and sediment, given the data layers and their limitations, overlaying those with the shallow 10 m or less area (also rank of 1) would result in potentially optimal habitat for juvenile lobster matching the shallow water zone (added value of 3) (Figure 7).

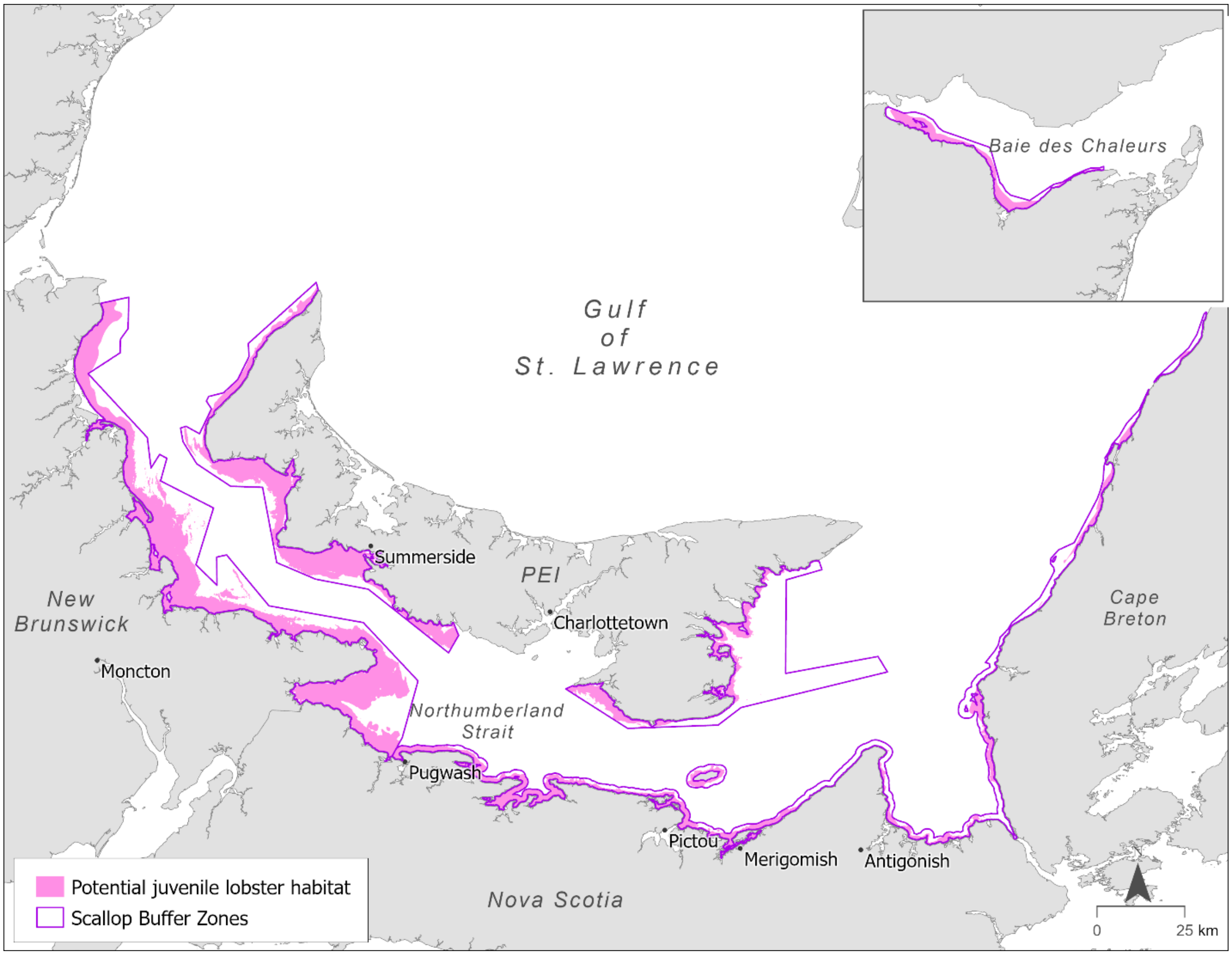

Figure 7. Potential juvenile lobster habitat less than 10 m deep in SBZ.

3.3 Biological Data Overlay

3.3.1 Northumberland Strait Multi-Species Overlay

Though the Northumberland Strait multi-species bottom trawls did not sample specifically for juvenile lobster sizes, Figure 8 shows that they were still caught at many depths, not just the waters less than 10 m deep.

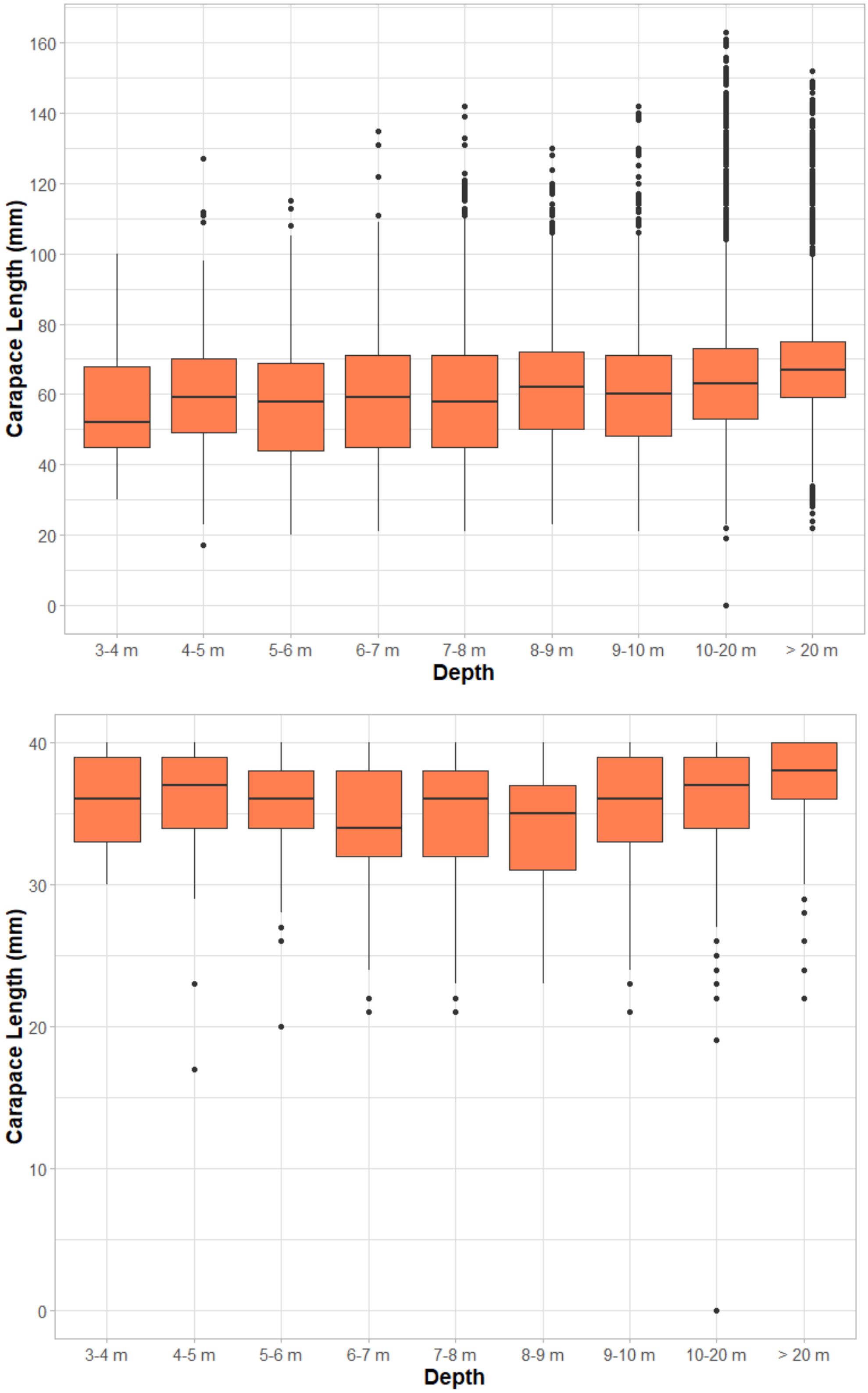

Figure 8. Boxplots of Northumberland Strait Multi-Species Trawl Survey carapace length (mm) by depth for all sizes (top) and for juveniles 40 mm or smaller in size (bottom).

Northumberland Strait multi-species bottom trawls did not cover the SBZ 21, and only cover a portion of the SBZ 24; this is reflected within the map extent (Figure 9). The mesh sizes for the trawls are not designed to catch juvenile lobsters, as indicated by the low capture rate (see Figure 80 in Asselin et al. 2021) so the results cannot be expected to show full distribution (pers. comm. Natalie Asselin DFO). Trawls and mesh sizes did vary throughout the 2010-2021 period, and beginning in 2019, the equipment allowed higher capture rate of small lobsters, down to about 30 mm CL (DFO, unpublished data), which represents older vagile juveniles. The survey also does not fully cover shallower coastal waters by design, as they are completed in waters > 4 m deep at lowest normal tide. Despite these limitations, this survey remains the most comprehensive source of large-scale juvenile lobster distribution data. Of the 391 juvenile lobster trawl records, 345 overlapped the sediment map from Sklar et. al. (2024). Those trawl records corresponded to 88% mixed sediment (gravelly sand), 3% mainly gravel (sandy gravel), and 8% mainly sand (slightly gravelly sand). Within the SBZs where there was sediment map coverage (142 records), similar distribution across sediment types was observed with 86% in mixed sediment, 5% in mainly gravel, and 9% in mainly sand. There was less coverage of the shallow zone of the SBZ with sediment coverage (25 records), of which 24 were in mixed sediment and one in mainly gravel.

Though the trawl survey did not sample below 10 m extensively, Figure 9 shows clustering of higher numbers of juvenile lobsters in the shallow portion of SBZ 22 Marine Refuge in the Western Northumberland strait. It is also evident that high numbers of these larger juvenile lobsters are found in waters deeper than 10 m in the Western Northumberland Strait. From this, it would appear that key habitat for juvenile lobsters is in the Western Northumberland Strait, while only low numbers are caught in the lower central strait.

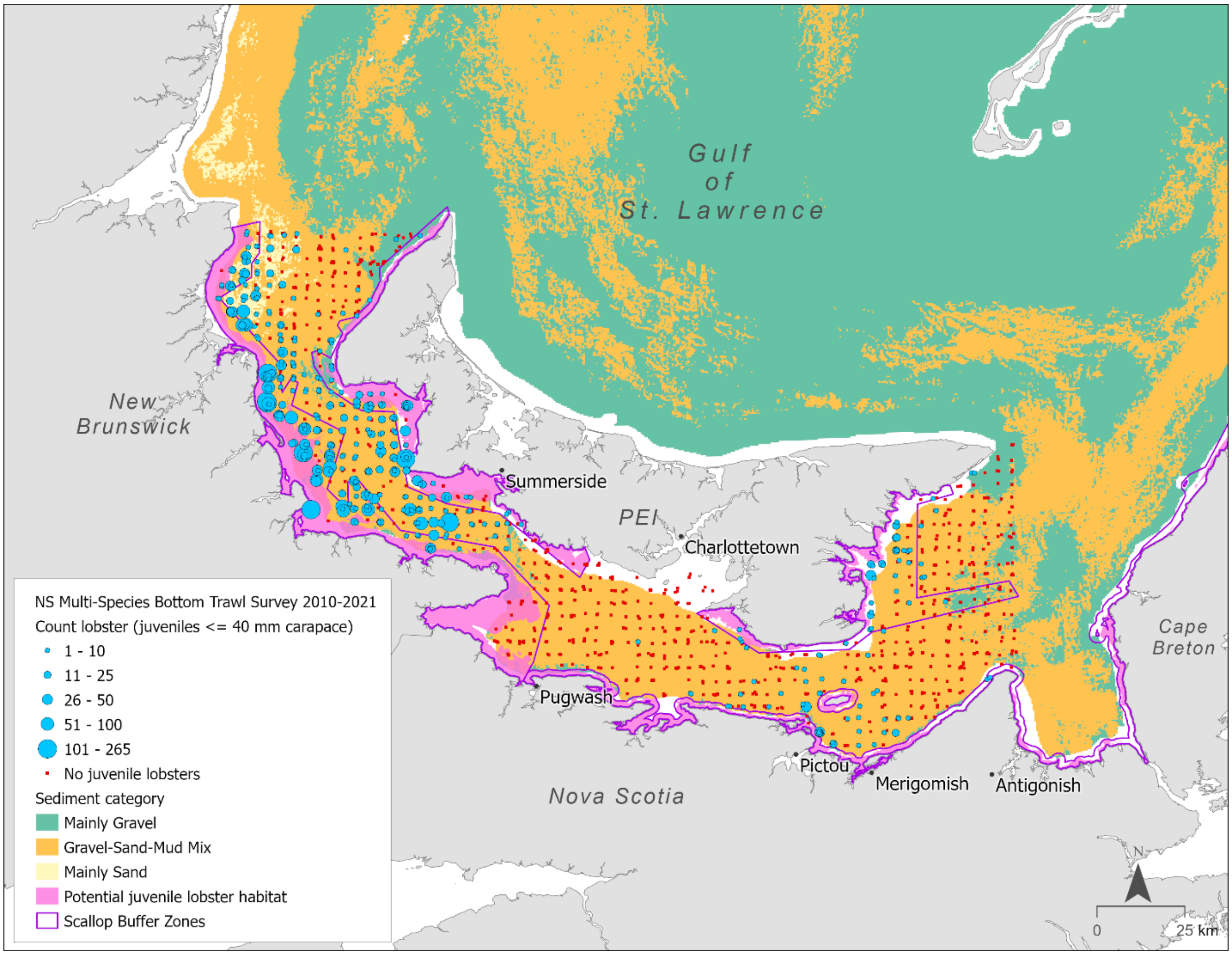

Figure 9. Potential juvenile lobster habitat and sediment map overlaid with juvenile lobster counts from the Northumberland Strait Multi-species Bottom Trawl Survey (2010-2021 records).

3.3.2 DFO SCUBA Survey Data

Within the SCUBA survey data itself, cobble and gravel observations in particular were found consistently in the sediment at most depths, while pebble was mainly found in the mid range depths of 4-6 m (Figure 10). Finer sediments (e.g. sand, mud) were found in larger proportions in mid and deeper shallows. However, at all depths, there was a mix of sediment types reported and outliers show that there were some samples at all depths with high proportions of both coarse and fine sediments.

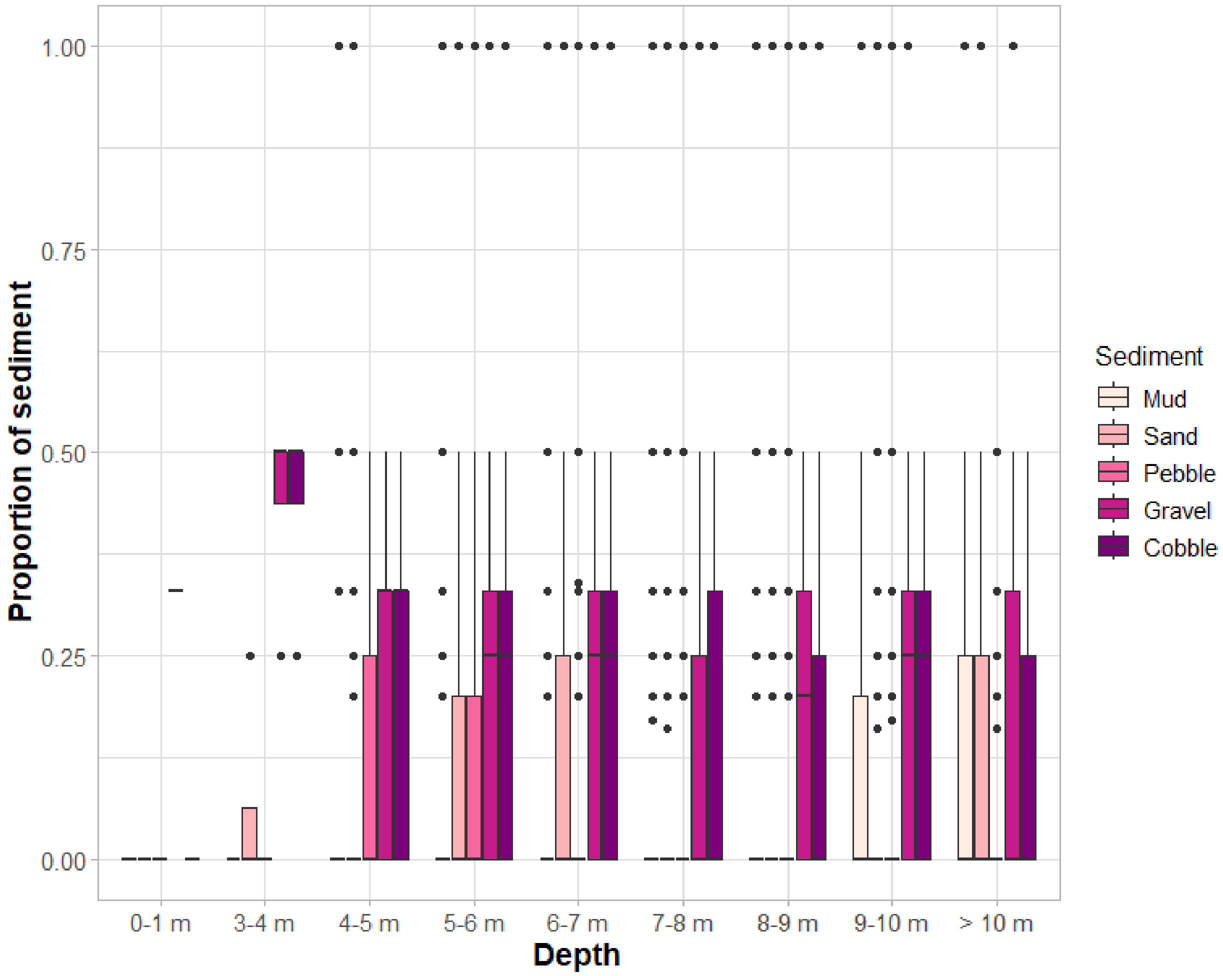

Figure 10. Boxplot of SCUBA transect sediment proportions by depth for 2019 and 2021.

Lobster carapace length was not significantly different across the shallow water depths in the SCUBA data (Figure 11). There is an increasingly larger variation in carapace lengths with increasing depth though, which is consistent with the rationale that smaller lobsters start in the shallower zone and move to deeper waters as they get larger.

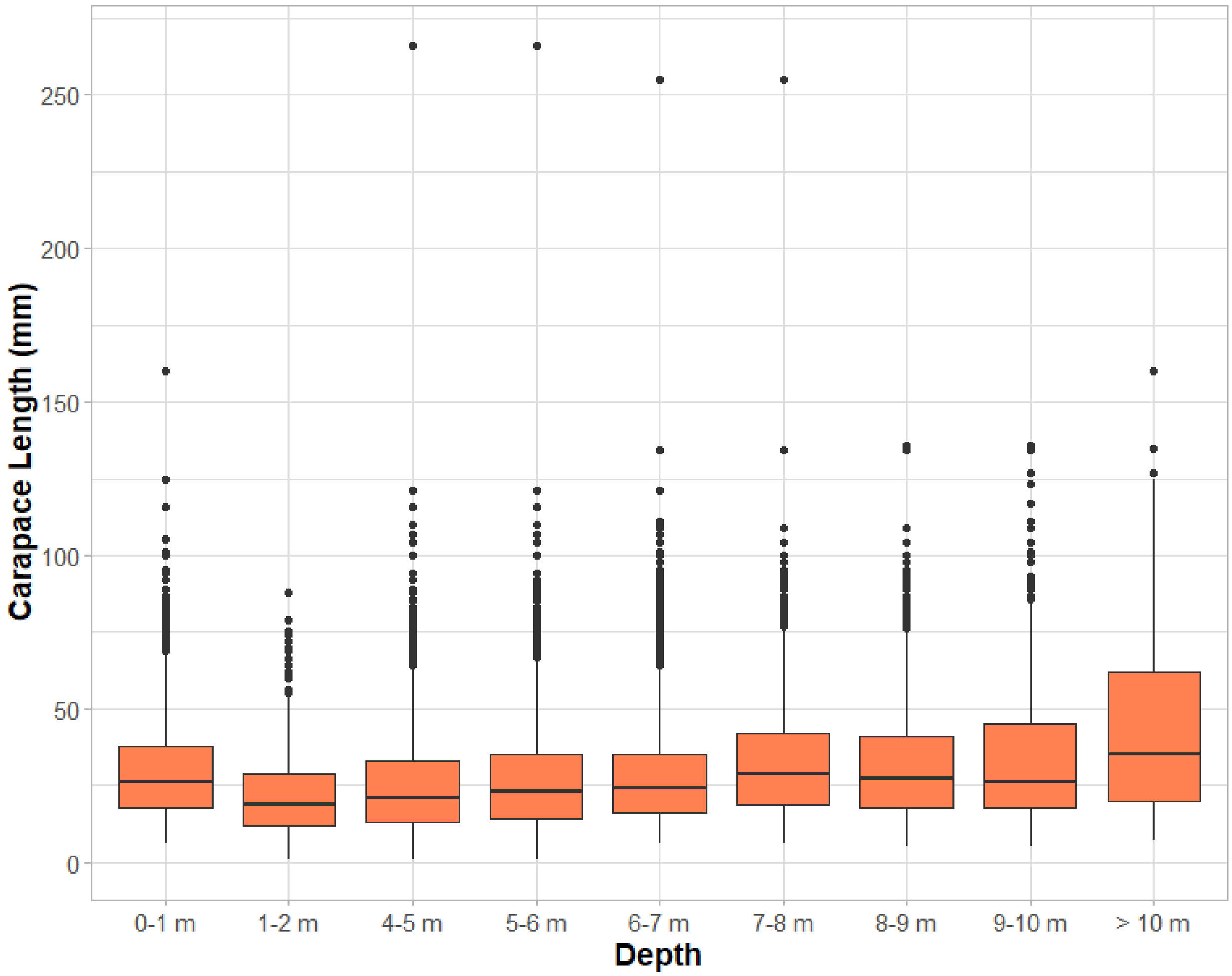

Figure 11. Boxplot of SCUBA transect lobster carapace length measurements by depth 2019 and 2021.

Only 8% of the SCUBA transect records overlapped the sediment map from Sklar et al. (2024) (Figure 12) and those were assessed to see if the sediment types noted by the divers matched the classification schema from the sediment map. The SCUBA sediment noted by divers was fine sediment (< 5% gravel, cobble or pebble combined) for 44% of the records, coarse sediment (> 30% gravel, cobble or pebble combined) for 54% of records, and mixed for the remainder. All these SCUBA records corresponded to the mixed sediment category on the modelled sediment map (gravelly sand, 5-30% gravel and 90% of the remainder, sand). This again highlights that detail is severely lacking in the modelled sediment dataset, in a number of ways. The spatial extent of the modelled layer does not extend to cover much of the coastal area of interest, and where specific information is needed, localized sampling should be utilized. The SCUBA data unequivocally shows more detail about the local sediment and habitat for juvenile lobsters, however this cannot be extrapolated to larger areas.

A closer examination of SCUBA records that contained juvenile lobster observations was done to compare bottom type observations during these dives. Eighty-nine percent (89%) of the juvenile lobster observations corresponded with at least one of the coarse sediment types being observed at the same interval on the transect (pebble, gravel, cobble). Thirty-four percent (34%) of the juvenile records corresponded to a pebble observation greater than zero percent, while that increased to 62% for gravel and 67% for cobble. This shows that more juveniles were found in sediments not just greater than 2 mm diameter particles, but greater than 4 mm and 64 mm, likely because they provide greater shelter for the juveniles. The modelled sediment does not give detail above a broad 2 mm “gravel” classification, which is likely not a biologically meaningful size division for juvenile lobsters.

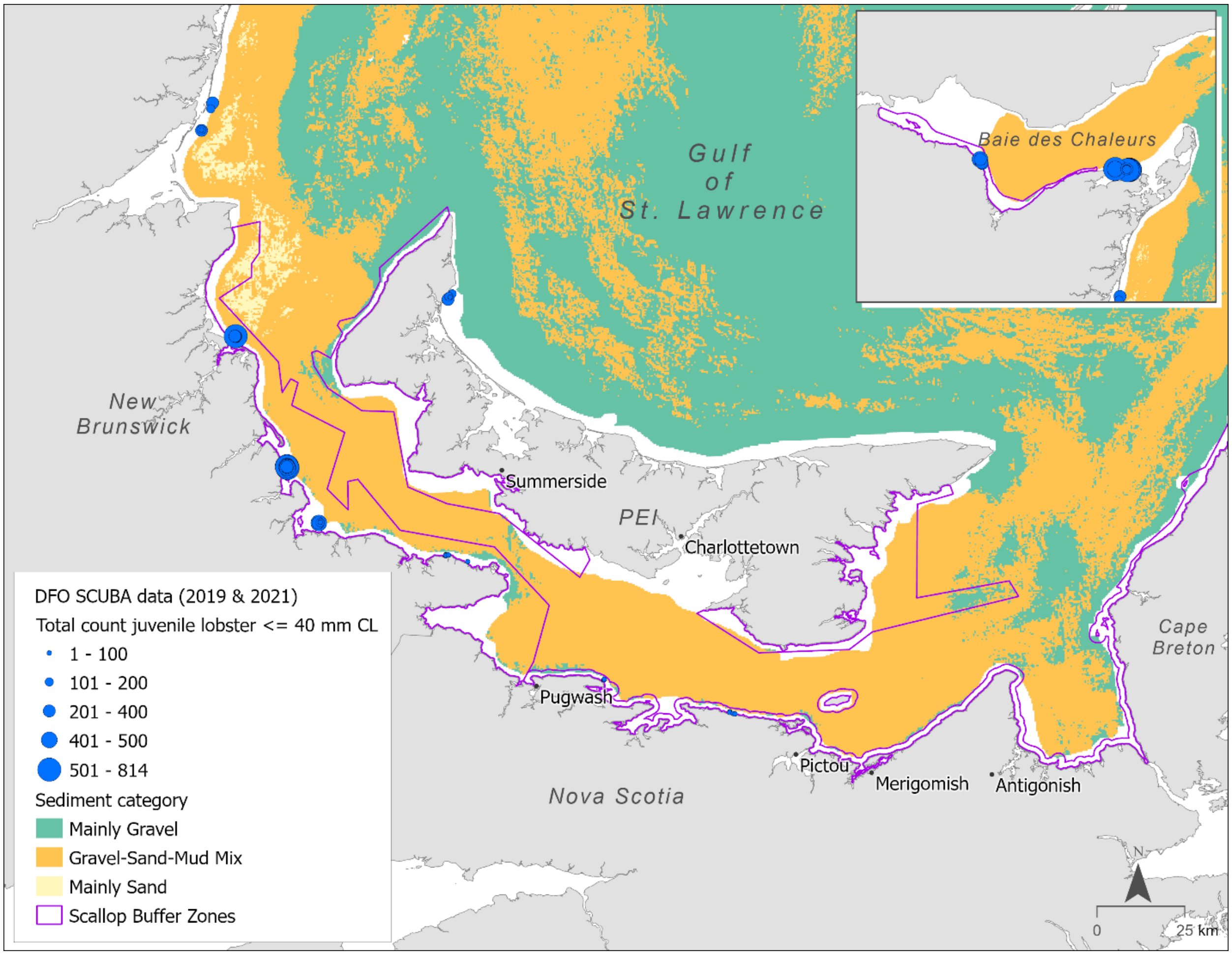

Figure 12. SCUBA transects with juvenile lobster (≤ 40 mm CL) for 2019 and 2021. The modelled sediment from Sklar et al. (2024) is overlaid.

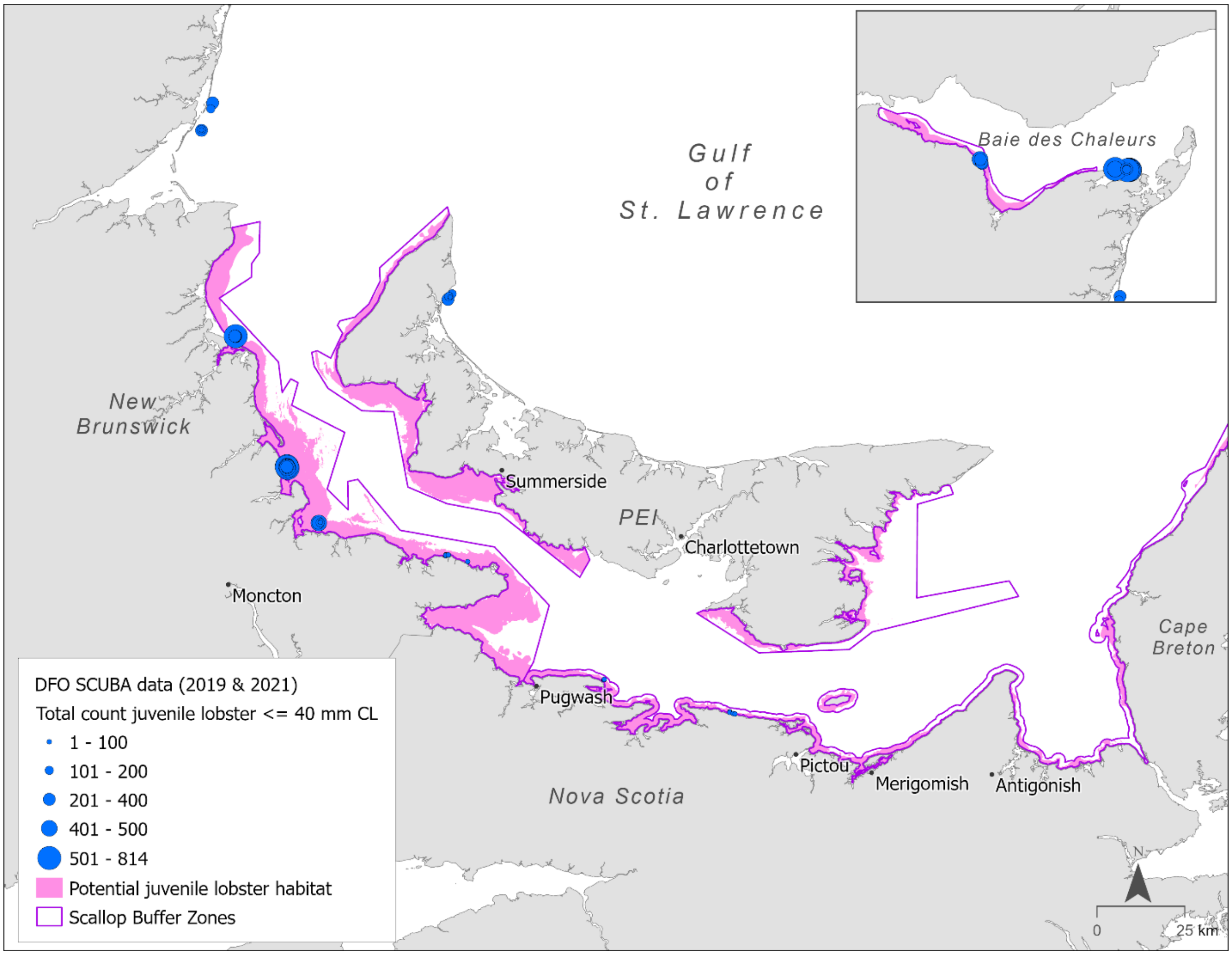

Figure 13. SCUBA transects with juvenile lobster (≤ 40 mm CL) for 2019 and 2021. Overlaid is the shallow water potential juvenile lobster habitat.

4. Discussion

As outlined in the literature, post-larval American Lobster settlement seems enhanced in shallow (< 10 m) rocky/cobble bottom with bottom temperatures above 12°C (Ouellette et al. 2016; Wahle and Stenbeck 1991;1992 and Anis 2005). Especially during the early shelter-restricted phases, juvenile lobsters live for the first several years of their lives in this benthic habitat (Wahle and Stenbeck 1991; Dinning 2014) and could benefit from the protection offered by the Marine Refuges, which restricts fishing activities that can disrupt the benthos. Data layers for bottom sediment type, depth and temperature were therefore overlaid to attempt to identify these preferential areas. The overlap analysis of these variables showed potentially optimal habitat for juvenile lobster within a large portion of the SBZs and the survey data, despite its limitations, confirmed the presence of juveniles in some areas of the SBZs and adjacent waters. Some assumptions were made using the sediment dataset when it did not fully cover the SBZs and had little detail about grain size distribution greater than 2 mm. We assumed that the sediment types in the SBZs extend inward to shore and that the gravel-sand-mud mix contains potential habitat throughout, from the preferred cobble and boulder substrates (Wahle and Steneck 1991) and rock on sand (particle size not specified; Hudon 1987) to other less preferred but viable substrate, such as mud (Dinning 2014). Knowing that the gravel-sand-mud mix seems to be the dominant substrate type in the Northumberland Strait and that it is inherently very heterogeneous, it is likely that lobster larvae in the process of selecting a settlement site will eventually succeed in finding an optimal substrate type if it perseveres and continues diving past less preferable substrates, making the vast majority of the SBZs potentially suitable. It was noted that the central portion of the Northumberland Strait did not show many juvenile lobsters in the bottom trawl survey compared to the clusters at each end of the strait (Figure 8). Hanson (2009) also found that lobster < 50 mm CL were found in the single area of high density along the mainland at each end of the strait and these lobsters were also absent from the central part of the strait. We hypothesize that more detailed substrate mapping may yield more information on why this is the case, in addition to considering other factors involved in lobster settlement.

With regards to substrate characterization, there are a variety of sediment classifications used in the literature, including, but not limited to, the widely accepted and used Wentworth (1922) method, which is used in DFO’s SCUBA survey with modifications from Pettijohn (1949) where mud (fine silt, clay or sand) was < 0.0625 mm, sand was 0.0625-2 mm, pebble was 2-4 mm, gravel was 4-64 mm, cobble was 64-256 mm, and boulder was > 256 mm. When comparing this classification method to the substrate data used here for mapping, it is obvious that detail is lacking at the rocky end of the spectrum. Since juvenile lobsters are reliant on shelter in rocky habitats, that detail is key and the conclusions we can make with no detail above 2 mm will not be specific in terms of suitability. The data presented indicates that the currently available substrate mapping is not accurate at a scale to pinpoint specific areas of optimal juvenile lobster habitat. Seafloor mapping and modelling are examples of methods that can refine and extend the potential habitat layer, keeping in mind that substrate maps do represent a snapshot in time, and that substrate distribution can evolve through time (Sklar et al. 2024), especially in dynamic coastal areas such as the Northumberland Strait. The operational feasibility of this type of characterization research would need to be considered in light of the unknown degree of temporal variability in the SBZ MRs substrate. Evolving technologies, such as aerial imagery for coastal habitat and biotope mapping (Monteiro et al, 2021) could provide some future opportunities for research in this area as well.

The temperature data layers showed that from July to September, the average sea surface temperature and bottom temperatures were mainly above the 12°C suitable for juvenile lobster settlement in the SBZs. Furthermore, the average difference between SST and bottom temperatures from July to September was less than 2°C in shallow waters less than 10 meters deep. Since thermal gradients above 4-5°C are known to negatively affect juvenile lobster settlement (Boudreau et al. 1992), these data show that the small gradient observed in the Northumberland Strait is unlikely to have an impact on settlement, even in deeper waters, where the average gradient is around 3°C in July and August, and decreases in September. This also highlights that temperature and depth are linked variables, and temperature gradients can be very different in various locations, depending on other environmental conditions, such as currents and winds.

With regards to depth, the trawl data shows that there are high counts of juvenile lobsters in waters deeper than 10 meters, outside the SBZs, likely due to the older juveniles (i.e., vagile juvenile phase) venturing into other territory further from the immediate vicinity of shelter (Lavalli and Lawton 1996). It is also possible that the increase in lobster abundance over the last few decades in the sGSL (DFO 2024) has driven juveniles to occupy other less preferable habitats, which may include deeper waters or less favorable substrate types. There is evidence that when cobble substrates are limited, or when there is competition or aggression between juveniles, there is spillover into secondary habitats such as mud (Dinning 2014; Dinning and Rochette 2019). In tanks lined with cobble, mud, or sand, post-larvae settled first onto cobble, second onto mud, and last onto sand which had resulted in a delayed settlement and smaller sized individuals (Dinning 2014). A recent study (Dinning et al. 2025) in the nearby Bay of Fundy also showed that juvenile lobsters have increased their use of mud habitat in the last 30 years in the face of increasing lobster populations and a decrease in predator abundance on mud bottoms. Although the data-limited model shows that large areas have coarse and mixed-coarse sediment coverage in the SBZs and surrounding region, secondary habitats in finer sediment (that contain mud, i.e., sediment mainly < 2 mm) should not be ruled out and could further contribute to the suitable habitat available for use by juveniles. Currently, there is no detailed classification of fine sediment to differentiate between mud and sand coverage in SBZs, but this information would be useful as it is known that juvenile lobsters seem to have a much stronger preference for mud over sand when creating shelter.

A major gap highlighted by the analysis of the trawl data available is that we have no widespread surveys that can reliably detect smaller, more shelter-restricted and emergent juvenile lobsters, which remain closer to their burrows. Developing a method of monitoring them is challenging as they remain hidden and very small (approximately 4-25 mm CL). DFO's existing SCUBA surveys do provide information on younger juveniles; however, they are not currently located in all SBZs and provide very localized information. They show high potential as fixed stations with long-term monitoring data and should be leveraged as initial monitoring sites. Bio-collector surveys by DFO also provide targeted information on post-larval lobster settlement and densities (Rondeau et al. 2015); however, these data are limited in geographic scope and do not necessarily provide information on natural substrate selection as the collectors themselves contain preferred substrate. Studies to develop shallow water surveys targeting juveniles in areas not covered by existing DFO surveys could provide more concrete data of lobster presence throughout the Marine Refuges. In addition to aiding in the ecological monitoring of the SBZs Marine Refuges, developing an indicator to locate areas with high populations of the smaller, shelter-restricted and emergent juvenile lobsters will aid in 1) identifying areas that are optimal for the settlement of juvenile lobsters within our ecosystem, 2) monitoring benthic recruitment densities, and 3) helping inform decisions about adult stocks and the lobster fishery (White et al 2024).

There are also wider environmental and ecological aspects to consider that were not captured in this broadscale mapping exercise that could aid in better predictive modelling. One element impacting juvenile lobster densities is how ocean circulation affects lobster larval transport in the sGSL, and consequently the location of benthic settlement. Chassé and Miller (2010) developed an ocean circulation model around lobster larval drift to simulate lobster larval development and survival in relation to environmental conditions in the sGSL. The purpose was to identify important sources of larval production that may need protection, and if these sources contribute to the landings of lobster in the LFA management areas. Their study found areas along the NB coast (LFA 23 and 25 - which contains SBZ 22) to be important source areas as they supplied a greater proportion of settlers to all areas in the southern Gulf. In addition to high concentrations of larvae, other localized ecological variables can also impact where juvenile lobsters settle on the benthos. As reviewed by Lawton and Lavalli (1995), post-larval lobsters can use chemical cues to determine predation risk and survivability in light of conspecific competition. It seems that the presence of adult lobsters and macroalgae can signal favorable settlement habitat (Boudreau et al, 1993), while the presence of potentially significant predators, such as cunners (Wahle and Steneck, 1992), send negative cues and inhibits settlement. However, ablation studies (where these cues are removed) are needed to measure how important these chemical cues are in relation to other variables in habitat selection by post-larval lobsters (Lawton and Lavalli, 1995). Another aspect to consider is the presence of biogenic habitat, such as marine plants and mussels, among others, which can significantly contribute to habitat complexity and provide small shelter spaces (Wahle and Steneck, 1991). Further characterization of specific monitoring sites, using video or SCUBA, will allow us to better define the complex three-dimensional habitats utilized by juvenile lobsters. Even if wide-spread predictive modelling is currently out of scope, these types of targeted surveying could provide valuable data on juvenile lobster presence, along with local data on associated habitat.

In this mapping exercise, the overlaying of preferred substrate, depth, and temperature variables with the best available biological information of juvenile lobster densities (trawl data) has shown that we cannot utilize current data to make specific spatial predictions about juvenile lobster distributions or preferred habitat locations in the SBZs, but has shown that environmental conditions in the Northumberland Strait do not seem limiting for juvenile lobster settlement, and that their preferred depth is well covered by the Marine Refuges. A refinement of the sediment classification could increase the accuracy of our optimal habitat predictions, as well as other secondary or tertiary habitats that may be interesting to monitor for changes in juvenile lobster densities. Current studies at Dalhousie University (Metcalfe 2024) are working to model higher resolution sediment and lobster habitats. They utilized bathymetry and backscatter multibeam echosounder datasets collected by the Canadian Hydrographic Service along with ground-truthing video data to develop modelled substrate distribution maps and habitat suitability maps for adult lobster in SBZ 24. Studies like this can contribute to better identifying habitat and target sites for ecological monitoring.

5. Conclusion

This mapping exercise was intended to identify areas of optimal juvenile lobster habitat, based on available substrate, depth, and bottom temperature data, though results show that sediment and temperature layers were not particularly selective in identifying specific areas of juvenile lobster habitat within the SBZs. Temperature does not seem to be a limiting factor anywhere in the Northumberland Strait as the warm waters are widespread and suitable for lobsters. The depth layer has shown that the SBZs are indeed protecting the areas where juvenile lobsters are known to settle based on this parameter alone. These parameters were chosen based on a literature search and available data layers. However, even when these three parameters align to provide optimal habitat, other local factors such as food availability, competition, and predation can unpredictably influence post-larval settlement and survival. Therefore the results obtained are broad-scale areas that potentially hold suitable juvenile lobster habitat, and do not specifically or quantitatively inform about the location of optimal habitat. The overlay of available trawl data with these parameters has highlighted that large densities of older juvenile lobsters do not particularly align with known environmental conditions considered optimal in this exercise (i.e., shallower than 10 m). This could be related to the exploratory behavior of older vagile juveniles or the selection of varying habitats driven by other environmental or ecological factors not considered here, such as the increasing lobster population and competition that push juveniles to occupy a wider range of habitats.

This exercise highlights that the SBZs are relatively data-limited, particularly in terms of actual juvenile lobster distributions and substrate characterization. The development of methods to better monitor smaller juvenile lobster presence in the SBZs and Northumberland Strait could provide more spatial information about their habitat and the important variables that impact selection during post-larval settlement in our ecosystem. A well-designed benthic mapping survey, along with ground-truthing video collection and modelling, could contribute to better characterize habitat and substrate in the Northumberland Strait, particularly in relation to coarser particle sizes (gravel, pebble, cobble, boulder), but also in finer sediments to distinguish between mud and sand.

6. Acknowledgements

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Author Contributions: Venitia Joseph – conceptualization, project lead, writing (original draft); Eva Dickson – conceptualization, methodology, data analysis, writing (original draft); Jeffrey Barrell – conceptualization, writing (review and editing); Thomas Guyondet – validation, writing (review and editing); Tanya Arseneault – conceptualization, writing (review and editing), supervision.

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Appendix 1. Identified GIS datasets for mapping SBZ juvenile lobster habitat

Data Type	Format	Source	Area covered	Description	Links
Sediment	Shapefile, polygon	Loring and Nota 1973	Gulf of St. Lawrence	Submarine morphology and sediment characteristics from sampling and previous data (Kranck 1971) covering the Gulf of St. Lawrence region. Coastal areas not entirely covered. Attributes include particle size ranges (0.05-2.0 mm, < 0.05 mm, > 2.0 mm) and descriptions of sediment (e.g. gravelly fine sand, sandy pelite, gravel with occasional sand patches).	Report: https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/1493.pdf Dataset: https://open.canada.ca/data/en/dataset/8c269a91-d3a2-4f49-943d-6b2401c42cba
Sediment	PDF map, not georefrenced	Kranck 1971	Northumberland Strait	Surficial sediments of the Northumberland Strait based on bottom samples, acoustic, and seismic data.	Report: https://ostrnrcan-dostrncan.canada.ca/entities/publication/8128f4a5-6fd7-40ae-908d-7590de5c8126
Sediment	Shapefile, polygon	Dutil et al. 2012	Gulf of St. Lawrence	2.5 m x 2.5 m grid cells covering the coastal area about 30 m deep and shallower aggregating 103 individual variables to fill the gaps from the Loring and Nota 1973 sediment map and to identify epipelagic habitats. Used primarily for sediment mapping here, but sea surface temperature was also examined initially. Sediment categorization matched the classes from Loring and Nota (1973).	Report: https://www.publications.gc.ca/collections/collection_2012/mpo-dfo/Fs97-6-3009-eng.pdf Dataset: https://open.canada.ca/data/en/dataset/5edf2b99-1058-438a-a450-155e888a5390
Sediment	Raster (TIF)	Sklar et al. 2024	Gulf of St. Lawrence	Random forest sediment model including 17 predictor variables to update the Loring and Nota map using updated hydrodynamic data (current direction, magnitude, velocity, wave power), bathymetry data and associated products (slope, aspect), and distance to land. The Loring and Nota (1973) data was	Report: https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2024.1306396/full Dataset:

Data Type	Format	Source	Area covered	Description	Links
				used with predictor variables to model three grain size fractions (mud, sand, gravel) separately.	Contacted Emily Sklar directly
Depth	Feature class, contour polygons	CHS/NDI, DFO Aquatic Ecosystems, DFO PEI Aquaculture various years, internal use	Various portion of Gulf of St. Lawrence combined	This is an unpublished product of DFO and includes data provided by the Canadian Hydrographic Service (CHS, soundings for charts 4001, 4002, 4403, 4404, 4405, 4905, 4906). Also included for coastal bathymetry were DFO data from BioSonics surveys 2018-2021 (Marine Planning and Conservation / Aquaculture and Coastal Ecosystems, DFO Gulf Region in partnership with the Southern Gulf of St. Lawrence Coalition on Sustainability) and various acoustic surveys within estuaries with aquaculture leases (DFO Aquaculture, Charlottetown office). The incorporation of CHS data does not constitute an endorsement of this product by CHS or DFO. This product does not meet the requirements of the Navigation Safety Regulations, 2020 under the Canada Shipping Act, 2001 and must not be used for navigation. The product itself cannot be shared publicly due to licensing constraints (CHS) and unpublished data (DFO), but see links tab.	Datasets: Soundings: Canadian Hydrographic Charts, Various Scales, Nautical Data International (NDI). https://www.dfo-mpo.gc.ca/science/hydrography-hydrographie/data-acquisition-eng.html Soundings: DFO Gulf Region Aquaculture PEI, internal use within aquaculture leases. Soundings: Acoustic surveys within aquaculture bays and estuaries of interest for mapping eelgrass distribution and change over time (DFO Gulf Region Marine Planning and Conservation, Southern Gulf of St. Lawrence Coalition on Sustainability). Unpublished internal datasets.
Depth	GeoTIFF, ASCII++, Web Map Service (WMS)	Government of Canada; Fisheries and Oceans Canada; Canadian	Various locations along Canadian coast	The CHS NONNA-10 NONNA-100 and NONNA Package Bathymetric Data products represent a consolidation of digital bathymetric sources managed by the CHS in Canadian jurisdiction. Much of the SBZs is not covered by the data.	Dataset: https://open.canada.ca/data/dataset/d3881c4c-650d-4070-bf9b-1e00aabf0a1d Viewing: https://data.chs-shc.ca/dashboard/map

Data Type	Format	Source	Area covered	Description	Links
		Hydrographic Service			
Depth	WMS	Government of Canada; Fisheries and Oceans Canada; ; Canadian Hydrographic Service		Canadian Hydrographic Service (CHS) offers 500-metre bathymetric gridded data for users interested in the topography of the seafloor. These data provide seafloor depth in metres. These data are included in the NONNA datasets.	CHS bathymetric gridded data 500metre https://open.canada.ca/data/dataset/ad865d71-b644-4750-955d-37e542f3b92f WMS: https://egisp.dfo-mpo.gc.ca/arcgis/rest/services/open_data_donnees_ouvertes/chs_500m_gridded_bathymetry/MapServer/0
Temperature, juvenile lobster catches	CSV, point data	Asselin et al. 2021	Northumberland Strait	Northumberland strait multi-species bottom trawl survey, DFO Gulf Region (Natalie Asselin). Survey data from 2010-2021. Bottom temperature and juvenile lobster catches were used here.	Report: https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40960730.pdf Datasets: Contacted Natalie Asselin, Pablo Vergara, and Denis Gagnon directly (DFO Gulf Region)
Temperature	CSV, point data	DFO Gulf Region (e.g. Ouellet et al. 2019)	DFO Gulf Region (Southern Gulf of St. Lawrence)	Coastal temperature data from a long-term monitoring program along the coast of the Gulf of St. Lawrence using devices attached to buoys or moorings. 2010-2020 data extracted by DFO Gulf Region. See Ouellet et al. 2019 or for a sample report including details on methodology.	Report example: https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/4119021x.pdf Dataset: Contacted Maxime Ouellet and Denis Gagnon directly (DFO Gulf Region)

Data Type	Format	Source	Area covered	Description	Links
Temperature	CSV, point data	NAFO division 4T groundfish research vessel trawl survey (September survey), DFO Gulf Region		The research survey provides a fisheries-independent source of information about all marine living organisms that are captured by the fishing trawl used to obtain samples in the southern Gulf of St. Lawrence. A Vemco Minilog depth and temperature probe was mounted on the trawl during groundfish surveys. Only the bottom temperature records were extracted for use here.	See Hurlbut and Clay 1990: Protocols for research vessel cruises within the Gulf Region (demersal fish) (1970-1980) https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/115732.pdf and Hurlbut et al. 2006 (https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/324444.pdf) Dataset: Contacted Dan Ricard and Pablo Vergara directly (DFO Gulf Region) as only the catch data are provided openly (https://open.canada.ca/data/en/dataset/1989de32-bc5d-c696-879c-54d422438e64)

Data Type	Format	Source	Area covered	Description	Links
Temperature	Text, point data	Bedford Institute of Oceanography (BIO), National Oceanic and Atmospheric Administration (NOAA) , European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)	Extracted for SBZ areas	Extract from a composite SST database produced by Pierre Larouche derived from 1) BIO remote sensing group (1.5 km resolution, 1997-present) using NOAA and EUMETSAT and 2) NOAA Advanced Very High Resolution Radiometer (AVHRR) Pathfinder satellite data (4 km resolution, 1982-2020). BIO completed calculations and calibrations including the MCSST algorithm to create the SST values. Daytime values were averaged into a daily value. The composite result is a 1.1 km resolution grid, which was sent as spaced point values falling within the SBZ. These points were interpolated using the Natural Neighbor method in ArcGIS Pro to cover SBZs more completely. Note that the database also contains data from the Maurice Lamontagne Institute (MLI), but the date range used in this report was not covered by that subset.	Publication: Galbraith et al. 2021 (https://www.tandfonline.com/doi/full/10.1080/07038992.2021.1924645#d1e183) Dataset: Contacted author Joel Chassé for custom export of data for the SBZs NOAA Pathfinder data information: https://www.ncei.noaa.gov/products/avhrr-pathfinder-sst