# Mapping lobster habitat in the Northumberland Strait using multibeam echosounders to assess juvenile lobster conservation zone placement.

By

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ABSTRACT

The Northumberland Strait, located in the southern Gulf of Saint Lawrence, is an important area for scallop and lobster fishing. To mitigate the negative ecological effects of fishing, marine management strategies in the form of scallop fishing buffer zones are in place, and informed through dive surveys and fishing data aim to protect juvenile lobster habitat. Current scallop fishing buffer zone locations (shoreline to 1km offshore) align with where hard bottom is expected to be. There are multibeam datasets covering this area, but our understanding of the benthic ecosystem composition and marine conservation strategies could be greatly improved by creating benthic habitat maps of the area using multibeam echosounder (MBES) technology. Using a combination of bathymetry and backscatter collected by MBES, and drop camera footage, substrate distribution maps and habitat suitability maps for adult lobster were created using Random Forest and Maximum Entropy modelling respectively. The sediment was classified into three substrate categories using a modified Folk 5 classification: mud to muddy sand and sand, mixed sediment, and rock & boulders. The placement of the scallop fishing buffer zones from a species conservation standpoint is discussed based on the modelled habitat suitability and distribution of bottom type. Patterns of habitat suitability for adult lobster were spatially compared against the various bottom types. The sediment distribution results showed that there was a higher proportion of rock & boulder and mixed sediment within the scallop fishing buffer zones than outside of the protected zones. From the observed higher proportion of rock & boulders and mixed sediment inside the buffer zones, it can be inferred that substrate distribution inside the buffer zones is suitable for adult lobster conservation. There is however suitable habitat outside of the conservation zones that

could be further protected. The observed adult lobster habitat preference can then inform juvenile lobster juvenile lobster habitat preference from what is known about juvenile lobster and adult lobster behaviour. Increased understanding of the distribution of bottom type and of adult lobster habitat suitability will allow for more informed juvenile lobster conservation decisions in the Northumberland Strait based on relationships that have been observed in order studies to work towards meeting Canada's 2030 marine conservation goals.

Key words: benthic habitat mapping, juvenile lobster, habitat suitability, sediment distribution, multibeam sonar.

## LIST OF ABBREVIATIONS

| | |
|---|---|
| CHS | Canadian Hydrographic Service |
| DFO | Fisheries and Oceans Canada |
| MBES | Multibeam echosounder |
| NONNA | Non navigational |

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# CHAPTER I: INTRODUCTION

## Marine Conservation

### Sustainability and conservation goals

Mitigation of anthropogenic pressures on marine environments, such as fishing, is essential for the conservation of marine habitats and benthic biodiversity. Anthropogenic pressure in one marine environment will affect other marine ecosystems, therefore policy and conservation focused marine management strategies are necessary to reduce observed human impacts on seafloor ecosystems (Brown, 2012). Fisheries and Oceans Canada (DFO) is the federal institution that manages fisheries and enforces policy which protects ocean ecosystems (DFO, 2022). DFO works to protect the largest area of the ocean possible to maintain healthy and sustainable ocean environments and facilitate effective ocean management that supports the wellbeing and livelihoods of Canadians, while also protecting Canada's marine ecosystems (DFO, 2021). This management addresses the federal goal of balancing ecological, social, and economic considerations through supporting marine ecosystems in several ways including managing marine protected areas, fisheries management, and abiding by a series of legal frameworks such as the Oceans Act (Government of Canada, 2023; Fisheries and Oceans Canada, 2002).

As stated in the mandate letter written by the Prime Minister to the Minister of Fisheries and Oceans and the Canadian Coast Guard in 2019, Canada has made a federal commitment to conserve and protect 25% of oceans by 2025 and 30% by 2030 aligning with goal 14 on Canada's Departmental Sustainable Development Strategy (Government of Canada, 2019). To meet this sustainability goal, and follow the guiding principles of the organization, DFO utilizes marine conservation strategies such as *Marine Protected Areas*, *The Sustainable Fisheries Framework*, *The Policy of Managing the Impacts of Fishing on Sensitive Benthic Areas*, more commonly referred to as the SBA policy, and *Marine Spatial Planning* (Branch, 2019; Canada, 2023; Government of Canada, 2023).

DFO policy outlines that an ecosystem-based precautionary approach is the most important consideration when looking at management of marine ecosystems (DFO, 2014). The marine conservation strategy that manages fishing pressure in the Northumberland

Strait is scallop fishing buffer zones. Scallop fishing buffer zones target the conservation of vulnerable benthic species such as juvenile lobster, rock crab, and winter skate (DFO, 2019). It does so via prohibiting all human activity in specific areas deemed vulnerable or important habitat that would compromise the integrity of the benthic habitat (DFO, 2019).

To contribute to Canada's marine conservation targets, fisheries management areas need to be split into clearly defined geographic locations, requiring the scallop fishing areas to be delineated into various management zones (DFO, 2017). Scallop fishing buffer zone management area 24 located in the Northumberland Strait is primarily concerned with maintaining juvenile lobster populations through juvenile lobster habitat conservation (DFO, 2019). Scallop fishing buffer zones in scallop fishing area 24 prohibit all bottom contact scallop fishing or disruptive activity within the designated area (DFO, 2019).

## Spatial information to inform marine conservation

In addition to clearly defined geographic areas, Canada's marine conservation target also requires conservations areas to be created with a clear goal that aims to address an important or at-risk species and/or habitat and protect the target species/habitat in the long term (DFO, 2019). To create and maintain these conservation goals long term, there must first be a clear understanding of the composition of the benthic ecosystem (Coggan & Diesing, 2011; Kostylev et al., 2001). Acoustic remote sensing provides information about spatial patterns in benthic ecosystems which can be used to model change and contribute to more effective monitoring to reach sustainability and conservation goals (Misiuk & Brown, 2024).

Applying spatial information to marine management initiatives provides a multi-component view of habitats which allows for analyzing habitat disturbances, both natural and anthropogenic, while considering environmental variables (Misiuk and Brown, 2024). Incorporating spatial information into conservation and management questions allows for an ecosystem-based conservation and management approach (Anderson et al., 2008).

## Seafloor mapping

Seafloor bathymetry (i.e. the depth of the ocean floor) has been recorded and mapped for hundreds of years, with the earliest known measurement conducted using lead lines and later using echosounder technology following its development in the early-mid 20$^{th}$ century (Brown et al., 2011). These depth measurements were first used to provide information for vessel safety and navigation, particularly in shallow waters surrounding shipping hazards (Brown et al., 2011; Finkl, 2016), but more recently the same information has been used for other applications such as seafloor geological and habitat mapping (Misiuk and Brown, 2024).

Globally, there is a limitation in the area of ocean that is covered with fine resolution seafloor mapping (Mayer, 2018; Wolfl, 2019). The area of ocean mapped at fine spatial resolution under 1km resolution is only approximately 9%, and the area that is mapped at 1km resolution covers approximately 19% (Mayer et. al., 2018; Wolfl, 2019). In recent years, the focus on fine resolution benthic mapping has increased with projects such as seabed 2030 (Mayer, 2018). Projects such as seabed 2030 emphasize the importance of building a more robust global bathymetric datasets, which has led to increases in data coverage, however there is still a lack of spatial information and a strong need to continue to map marine areas at fine resolutions (Wolfl, 2019).

Echosounder technology collects information using the two-way time travel of sound and the density of water to identify characteristics of the seabed such as depth and substrate characteristics (Brown, Smith, et al., 2011; Kostylev et al., 2001; Lecours et al., 2016; Martí et al., 2022). Multibeam emits these signals on a swath which provides larger area data coverage of the return signal at high resolution (Misiuk and Brown, 2024; Wolfl, 2019).

Bathymetry, one of the measurements acquired from the multibeam echosounder technology, is the measurement of depth (Wolfl, 2019). From the depth measurement, bathymetric derivatives can be calculated, such as seabed slope, orientation, aspect, and curvature, which help to further describe the seabed morphology (Lecours, 2019; Wilson, 2006; Wolfl, 2019). Backscatter is the second variable measured with multibeam echosounders and is the measured intensity of the return sound signal (Kostylev et al., 2001; Misiuk et al., 2020). Backscatter can be used as a proxy for substrate due to its ability to detect the difference in response strength based on differing substrate types (Misiuk et al., 2020). A stronger response would indicate a harder substrate such as rock, whereas a weaker response, where the signal is absorbed, would indicate a softer substrate such as sand or silt (Brown et al., 2019; Haar et al., 2023).

The combination of bathymetry and backscatter is important for the creation of benthic habitat maps as they increase the accuracy of predicting large areas of substrate and habitat (Xu et al., 2021). Differentiating between seafloor substrate composition can then help to define ecological niches used to create benthic habitat maps (Brown et al., 2011; Lacharité et al., 2018).

The use of multibeam echosounders for benthic habitat mapping allows for the visualization of biotic and abiotic benthic habitat components and thus there has been large technological advancement in the field in recent years (Brown et al., 2011; Misiuk and Brown, 2024). This advancement has led to the development of various habitat visualization techniques such as machine learning methods for seabed classification, species distribution modelling and habitat suitability modelling (Brown, 2012; Misiuk and Brown, 2024). Two methods that have increased in usage are the Random Forest and Maximum Entropy models (Misiuk and Brown, 2024).

The availability of benthic habitat maps created in the Northumberland Strait however are still limited. Although there are MBES datasets collected for the Northumberland Strait, there are no current habitat maps that have been created for this area. The availability of sediment distribution maps is also limited. There has been one sediment distribution map created for this area however it was created in 1972 therefore is outdated, and resolution and detail on the map is limited (Kranck, 1972). Broadscale maps for the greater Gulf of St Lawrence have been created by Loring and Nota in 1973 and Sklar in 2024 however the lower resolution remains a limitation.

There have not been any species distribution or habitat suitability maps created for lobster at any life stage in this area, but there have been studies completed in other areas surrounding Nova Scotia for lobster for marine spatial planning (McKee, 2021). McKee notes that although lobster species distribution modelling is successful in informing marine spatial planning, there is an overall lack of models currently created (McKee, 2021).

## Fisheries in the Northumberland Strait

### Fishing pressures

The Northumberland Strait is the area of ocean in the southern Gulf of Saint Lawrence that separates Nova Scotia and Prince Edward Island. This area is home to an abundance of juvenile organisms, thus making it an important area for feeding and fishing, and an important location to monitor when targeting species conservation (Bosman et al., 2011; Hanson, 2009; Harding et al., 1983; Savenkoff et al., 2007). Due to the high levels of anthropogenic activity such as fishing, the ecosystem has experienced significant species population change through fishing exploitation (Hanson, 2009; Savenkoff et al., 2007).

When there is an absence of a certain species it affects the entire food chain of the area and impacts other species populations thus negatively affecting biodiversity and reducing fishing yields (Savenkoff et al., 2007). Marine trophic structures are impacted through overfishing which can lead to large changes in the ecosystem especially in this area where so many species rely on the ecosystem in their beginning stages of life (Savenkoff et al., 2007). The high fishing pressures in the Northumberland Strait particularly affect the lobster population in the area.

In addition to ecological considerations, maintaining lobster populations in Nova Scotia waters has a large impact on the economy in the east coast (DFO, 2021). In 2019, an estimated half of the national revenue from lobster fishing came from Nova Scotia lobster fishing areas (LFA) (Horricks, 2022). The industry supports socioeconomic development which relies on the maintenance of health and size of lobster populations (Horricks, 2022).

### Habitat preference for juvenile lobster and scallop

Scallop and lobster share ideal habitat in the Northumberland Strait. Both species prefer mixed sediment with scallop favouring the smaller cobble areas, and lobster preferring the larger mixed sediment with boulders (McDonald, 2023). Scallop are primarily sedentary species which remain on the mixed substrate at depths of generally

15-110m (Tanaka, 2020). Lobster are migratory species and favour the mixed cobbly substrate throughout their lifecycle (Tanaka, 2020). Although there are slight differences in the preferred habitat, the Northumberland Strait contains varied sediment distribution therefore many of these preferred areas overlap (Loring and Nota, 1972).

Maintaining juvenile lobster populations heavily on conditionsduring the post larval stage thus increasing the importance of maintaining early life cycle habitats (Tanaka, 2020). Juvenile lobsters are highly reliant on environmental factors, such as temperature and substrate type, which affect growth patterns and predation (Haarr et al., 2018; Hovel & Wahle, 2010). Post-larval settlement is high in the Gulf of St Lawrence because of the shallow depths and sediment structure, therefore making this area an important habitat for juvenile lobster (Wahle et al., 2013).

## Challenges with scallop fishing and juvenile lobster habitat disruption

The presence of scallop and lobster fishing in the same area as juvenile lobster habitat in the Northumberland Strait cause adverse effects of juvenile lobster populations (Jamieson et al., 1985). Although scallop fishing and lobster fishing are temporally separate, scallop fishing in the Northumberland Strait has minimal requirements surrounding gear (Poirier et al., 2021) and bottom contact scallop fishing gear negatively affects juvenile lobster habitat (Jamieson et al., 1985). Scallop fishing requires bottom contact dragging, which affects benthic ecosystems, in this case juvenile lobster habitat. Damage to juvenile lobster habitat via scallop fishing thus has potential impacts on lobster populations through increased juvenile lobster mortality.

## Aims and objectives

Guiding this study there was one main question: *how can multibeam echosounders be used to map sediment distribution and lobster habitat suitability in the Northumberland Strait?* and a sub question: *how can these maps help to inform the placement of juvenile lobster conservation zones?*

These questions guide the project to test the application of multibeam echosounder data to map the sediment distribution and model lobster habitat suitability in the Northumberland Strait. The patterns observed in sediment distribution and lobster habitat suitability are then compared against the placement of the scallop fishing buffer zones to evaluate the effective placement of juvenile lobster habitat conservation zones.

## CHAPTER II: METHODS

### Study area

The Northumberland Strait is located in the offshore Nova Scotian region of the Southern Gulf of Saint Lawrence (figure 01). The study extent was determined by the availability of bathymetry and backscatter data collected with MBES for this area and the drop camera drift locations. This area of the Northumberland Strait has been designated as scallop fishing area 24 (DFO, 2019). Scallop fishing buffer zones in scallop fishing area 24 are placed along the shorelines around Nova Scotia and Pictou Island 1.5 km offshore (figure 02).

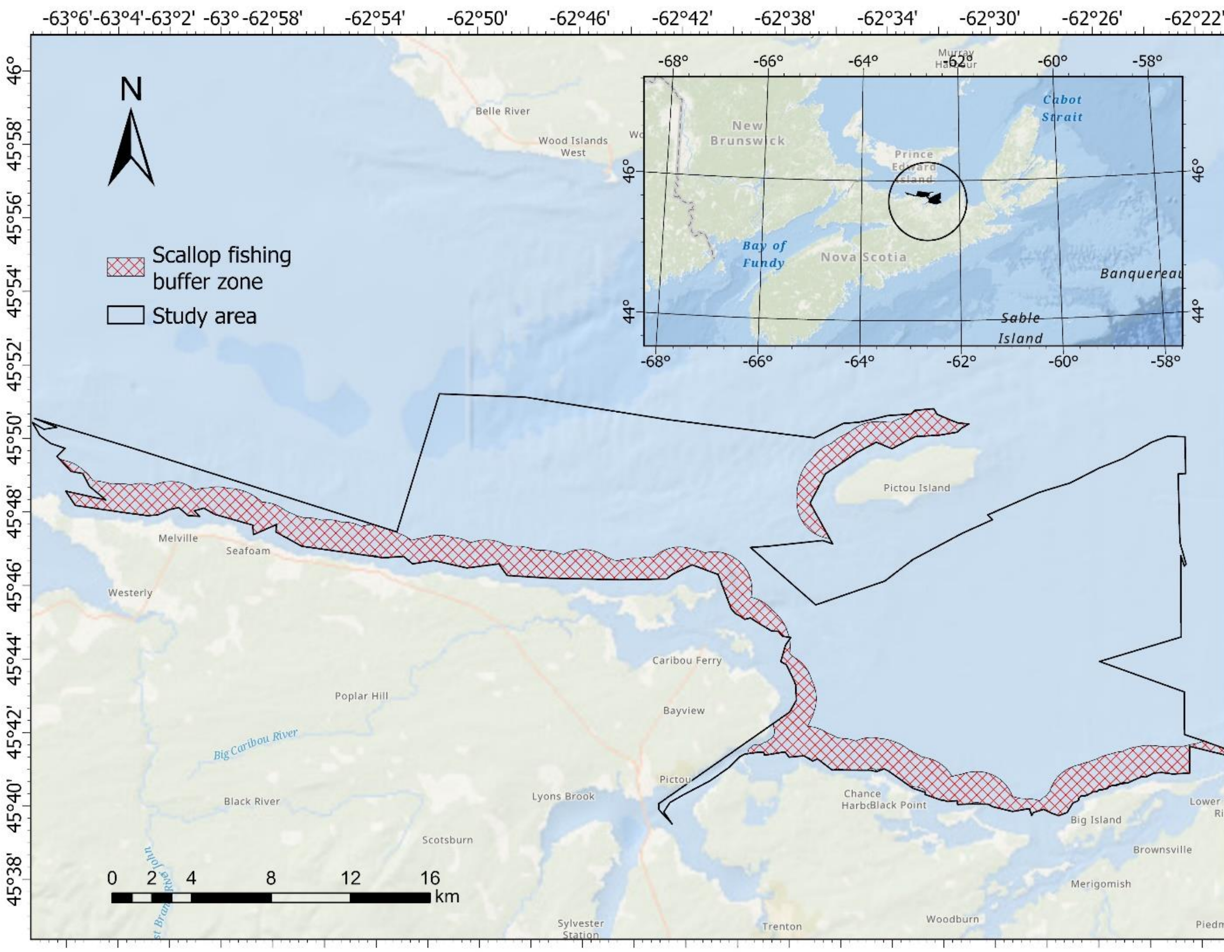


*Figure 1: Study extent showing scallop fishing buffer zones in red cross hatching within the extent of the backscatter and the bathymetry data.*

Multibeam datasets

This study utilized bathymetry and backscatter multibeam echosounder datasets collected by the Canadian Hydrographic Service (CHS) (Figure 2 and 3). The original bathymetry data layer covered a larger area than the backscatter data layer, therefore the bathymetry layer was clipped to fit the extent of the backscatter. From the bathymetry layer, environmental predictor variables were calculated to create layers which further informed subsequent modeling (see section 3.0). Selection of six environmental predictor variables calculated from the bathymetric dataset were chosen to provide explanatory variables for the models as seen in table 01 (Wilson et al., 2006). The environmental predictor variables chosen were slope, vector ruggedness measure, broad benthic position index, fine benthic position index, cosine, and sine (Appendix A).

*Table 1*: Echosounder data layers, their resolution, and units of measure.

| Environmental variable | Description | Resolution | Units |
|---|---|---|---|
| Bathymetry | Depth measurement. | 10x10 | metres |
| Backscatter | Intensity of the sonar return. | 5x5 | decibels |
| Slope | The steepness of the incline between two features. | 9x9 | degrees |
| Vector Ruggedness Measure | The measure of benthic terrain rugosity (Wilson, 2006) | 9x9 | metres |
| Broad Benthic Position Index | A measure of curvature describing the relative position of benthic terrain features at a wide spatial scale (Wilson, 2006) | 9x9 | - |
| Fine Benthic Position Index | The measure of curvature describing the relative position of | 9x9 | - |

| | | | |
|---|---|---|---|
| | benthic terrain features at a fine spatial scale (Wilson, 2006) | | |
| Cosine | Represents the orientation of the seabed at a particular location. Represents north-ness (Wilson, 2006). | 9x9 | degrees |
| Sine | Represents the orientation of the seabed at a particular location. Represents east-ness (Wilson, 2006). | 9x9 | degrees |

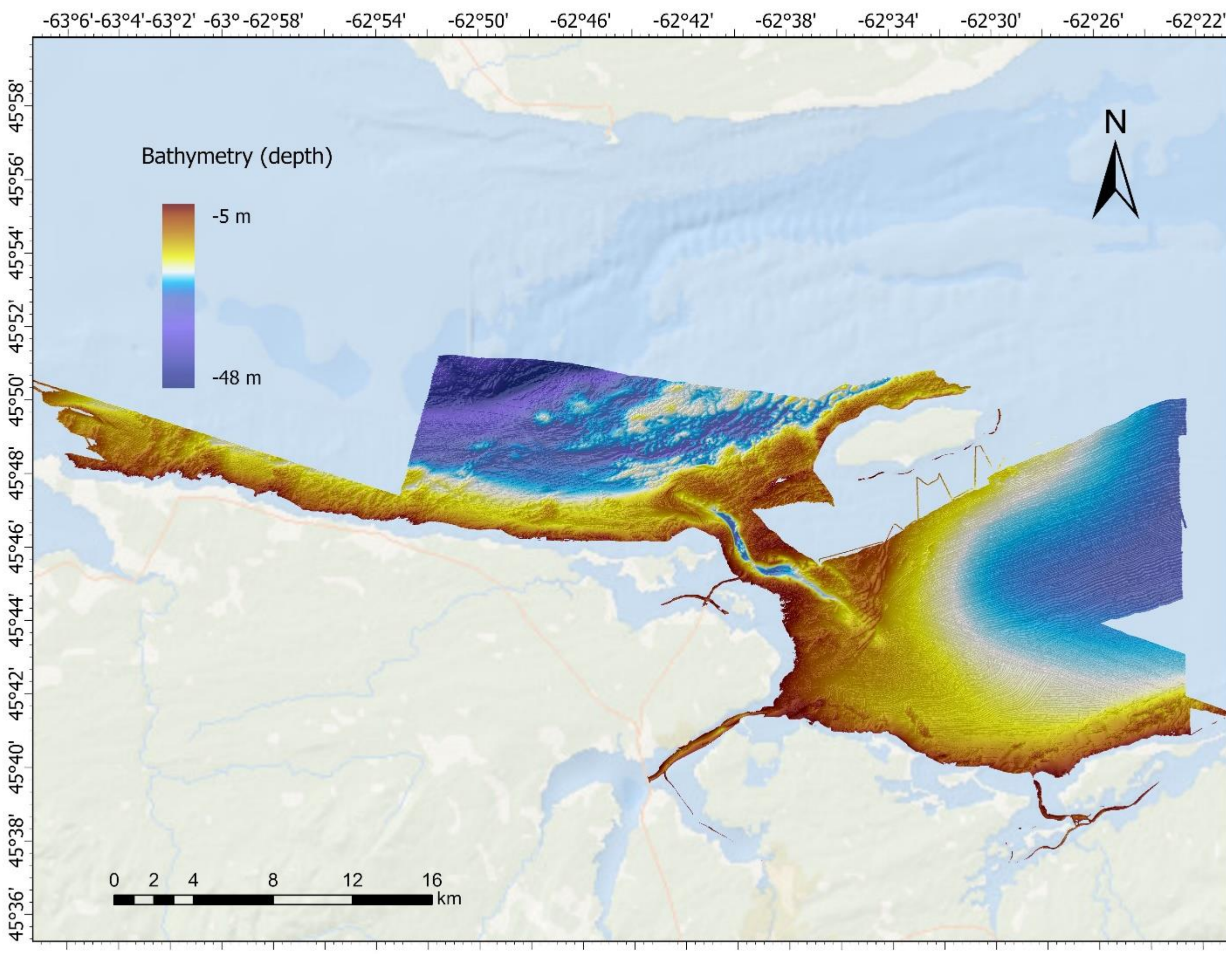

*Figure 2*: *Bathymetric dataset coverage for the Northumberland Strait used in the study. Data from Canadian Hydrographic Service. Basemap from ArcGIS Pro.*

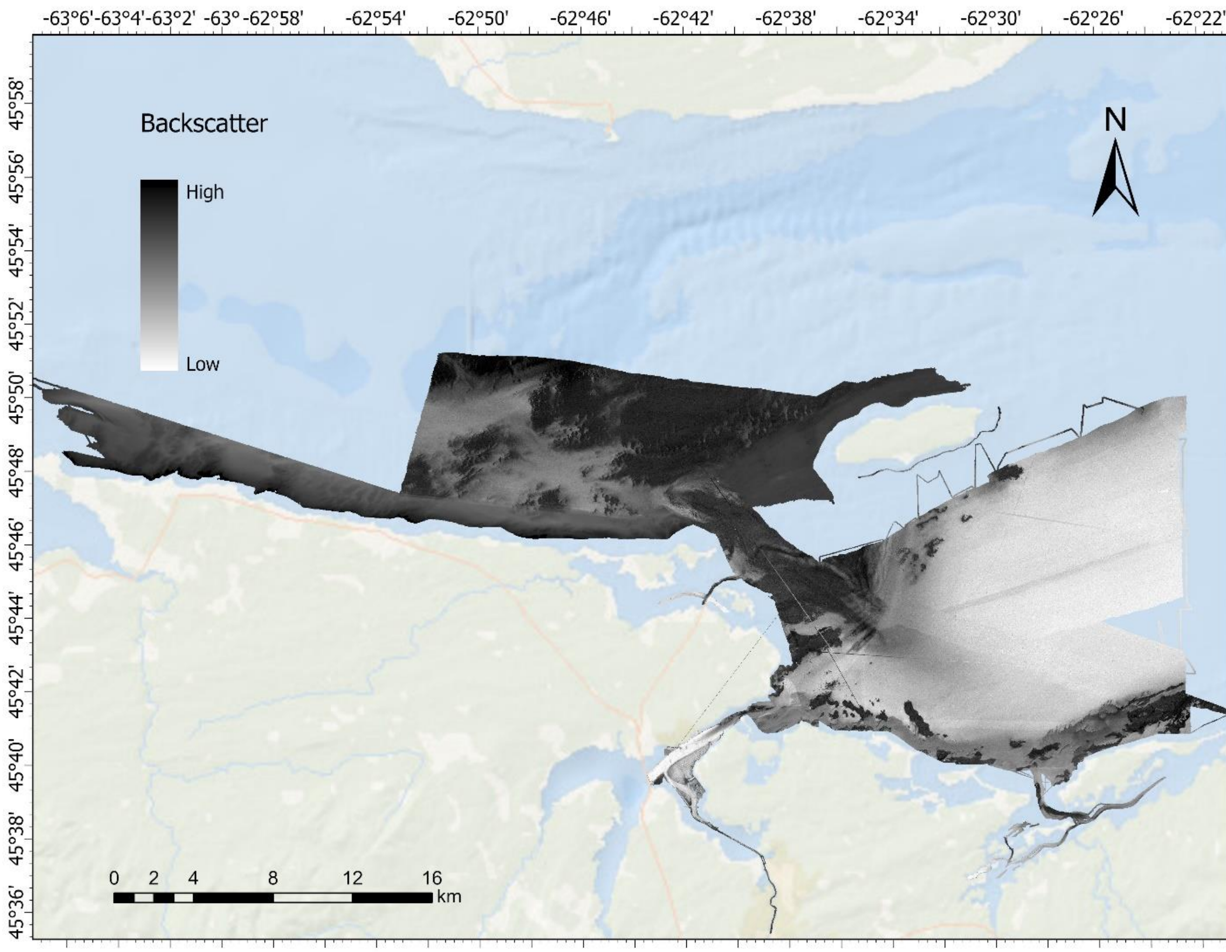


*Figure 3*: *Backscatter dataset coverage for the Northumberland Strait used in the study. Data from Canadian Hydrographic Service. Basemap from ArcGIS Pro.*

## Ground truthing

Ground truthing observations were extracted from drop camera video footage. The video footage was collected at 51 drop sites within the study area in October of 2023 on a 43-foot cape islander boat. The sites were determined through a stratified random design based on the backscatter dataset to represent imagery over the different backscatter intensities. The video was collected on a drop camera system designed by the Dalhousie University SEAM lab which consisted of two cameras; one that recorded in 1080p and a GoPro which was mounted to the drop camera system and collected video in 4k (Figure 5).

The position of the system was recorded using the vessel navigation system (DGPS). The 4k video from the GoPro provided a clearer and brighter image than the 1080p did and was therefore used to extract points for all subsequent analyses.

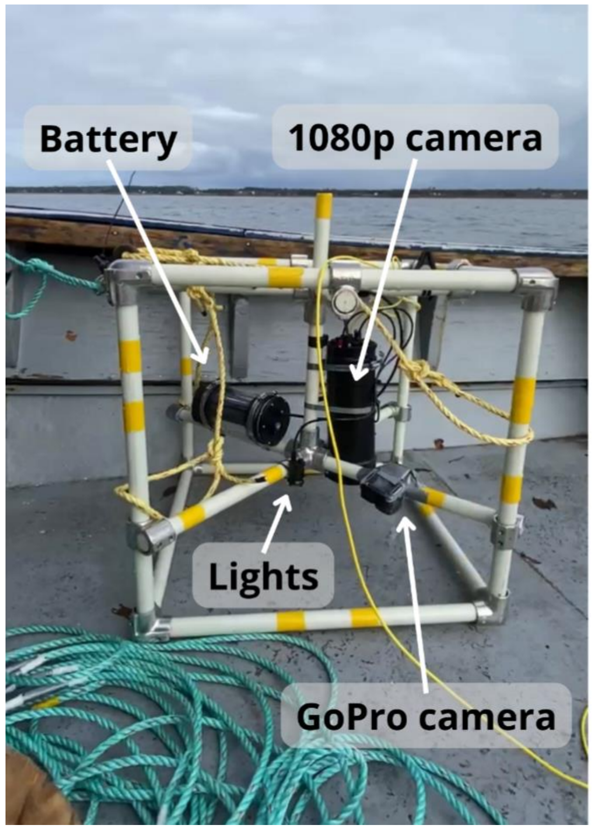


*Figure 4*: *Drop camera system used to collect the video footage. Photo taken by Peter Porskamp, October 2023.*

At each of the 51 stations, the camera was lowered to the seafloor, and the vessel drifted and was recorded for approximately eight minutes with the camera 0.5 – 1m above the seabed. The recorded drift tracks were used to geo-reference the observed points from the drop camera video for use in the distribution and suitability models. The videos were analyzed through continuous video footage to extract the lobster and sediment observations. This method involved playing the videos at a slow speed and recording all lobster occurrences and sediment observations in an excel spreadsheet which was then turned into a point shapefile for use in the models as seen in Figure 6 and Figure 8.

The lobster observations were recorded at each occurrence to account for differentiation in drifts where they were more abundant. The lobsters that were observed were all classified as adults as seen in Figure 5. This was due to the small size of juvenile lobster and their tendency to hide under rocks and cobble making juvenile lobster observations difficult (Tanaka, 2020).

*Figure 5: Adult lobster observations from the drop camera footage. The field of view is approximately half a meter.*

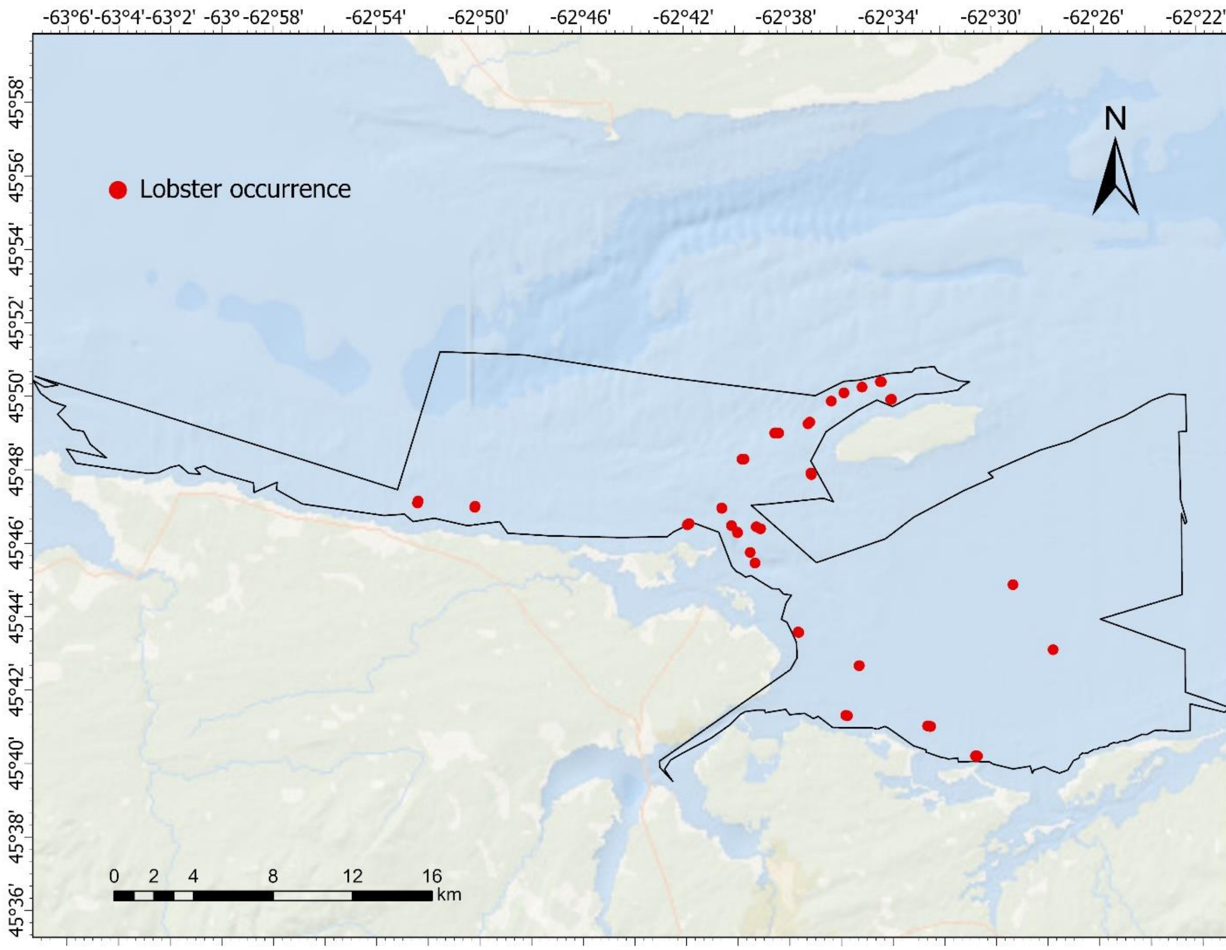


*Figure 6: Georeferenced lobster observation points from the drop camera footage along the drift camera tracks.*

The sediment was classified into three categories using a modified folk 5 scale (Figure 8); mud to muddy sand and sand, mixed sediment, and rock & boulders (Table 2). This classification was chosen due to limitations in measuring sediment size from the video. The substrate type with the most ground cover through the duration of the video drift was identified as the primary substrate class and the mid-point of the transect was used as the georeferenced ground truthing location in all subsequent analyses. If there was a change in substrate class during the camera drift (ex. mixed sediment to muddy sand), the track was split at the change point, and the mid-section of each segment was used as the observation point for the subsequent modelling. The observed sediment points were then transferred from the excel spreadsheet into ArcGIS Pro version 2.9.5 to create a point shapefile (Figure 9). The point shapefile was the occurrence information layer that informed the random forest sediment distribution model (see section 2.3).

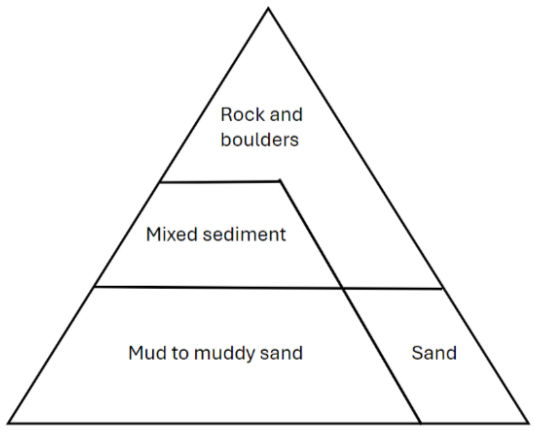


*Figure 7: Modified Folk 5 scale used to classify substrate. Categories include mud to muddy sand, sand, mixed sediment and rock and boulders.*

*Table 2*: Sediment classes observed through drop camera footage. Photos extracted from the drop camera footage. The field of view is approximately half a meter.

| Sediment classification | |
|---|---|
| Mud to muddy sand & sand |  |
| Mixed sediment |  |
| Rock and boulders |  |

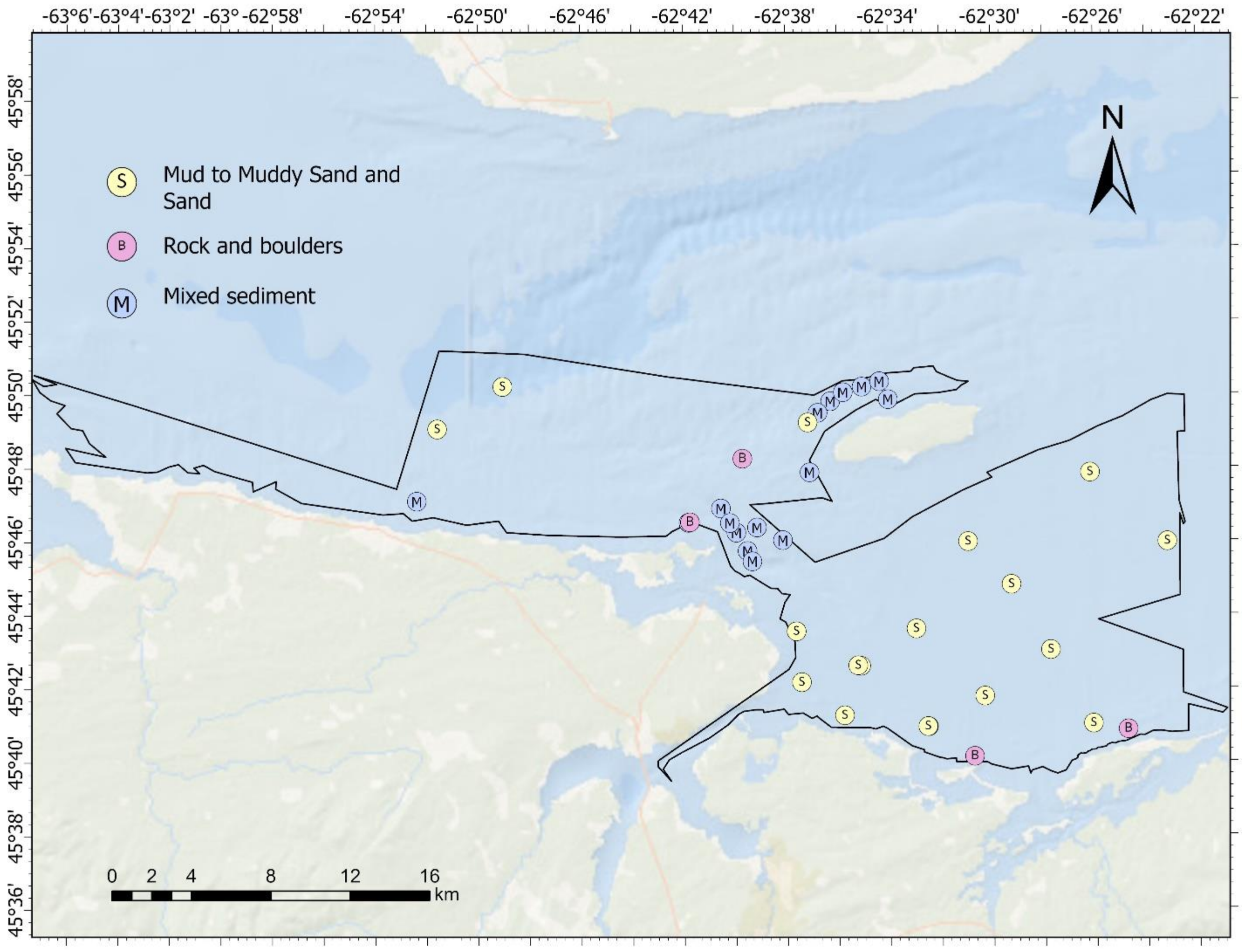


*Figure 8: Observed sediment classes* (using a modified folk 5 scale) from continuous drop camera footage.

## Modelling approaches

This study analyzed the distribution of substrate type and suitable adult lobster habitat throughout the study area using two machine learning approaches. Using the same set of environmental predictor data sets (Table 1, Figure 1, Figure 2, Figure 4), substrate type was modelled using a categorical Random Forest approach, and lobster habitat suitability was modelled using a presence only Maximum Entropy (MaxEnt) approach in Arc Pro version 2.9.5. The workflow for these analyses is shown in figure 09 and further details about statistical models are provided under sections 2.4.1 and 2.4.2.

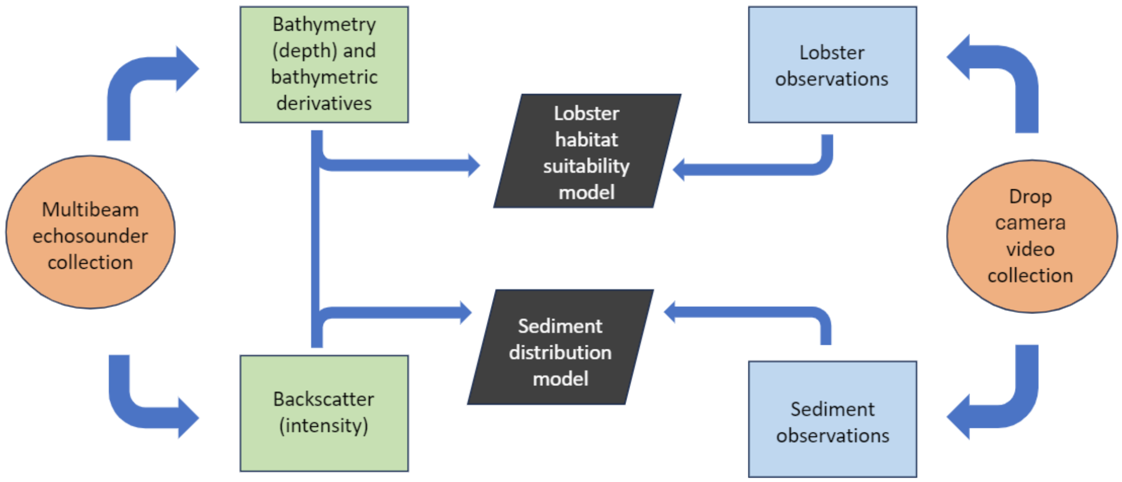


*Figure 9:* Workflow flow *chart of the creation of the sediment distribution model and the habitat suitability model which guided the process of the study.*

## Random Forest

Random Forest statistical modeling is a common machine learning method used to predict sediment distribution (Misiuk and Brown, 2024). It is a machine learning method that has gained momentum in benthic habitat mapping over the past ten years (Misiuk and Brown, 2024). The model operates through a series of decision trees to bin the data and create a prediction surface. It bags the individual results of regression and classification trees based on the point samples from the ground truth data (Misiuk, 2019). The error rate is determined through calculating out of bag data for each sample which provides an measure of model performance (Liaw and Wiener, 2002). The model also produces an input variable importance table which indicates the importance that each environmental predictor variable played in the creation of the prediction surface (Liaw and Wiener, 2002). The Random Forest model for this study was run with a 10% data omission rate which was used to validate the model.

## Maximum Entropy

MaxEnt presence-only prediction modelling uses environmental predictor variables and known point locations of the target species to build a prediction surface that estimates the suitability of the target species throughout an area (Cunze, 2015; Reiss, 2011). MaxEnt modelling can be done on a broad or fine scale making it a popular tool for analyzing distribution of species and understanding habitat niches (Smith, 2012). In ArcGIS Pro, the MaxEnt presence-only model can be run based on five basic functions which consider various phenomena when creating a model for a complex area; Linear, quadratic, product, threshold and hinge (ESRI, n.d.). For this study, the linear, quadratic, and product functions were applied. To validate the model, there was a data omission rate of 10% run five times with random resampling. The model accuracy is evaluated by the area under curve score. The higher the score the more accurate the model.

### Scallop Fishing buffer zone analysis

Once the sediment distribution and the lobster habitat suitability maps were created, the relationship between the distribution of sediment type and lobster habitat suitability and the placement of the scallop fishing buffer zones was analyzed. The proportion of each substrate class protected by the scallop fishing buffer zones was calculated using the raster information. Mean suitability within and outside of the fishing zones was calculated in ArcGIS Pro using raster to point information to create box and whiskers plots (Figure 13). This showed the distribution of suitability that was being protected by the fishing zones. The final relationship analyzed was the relationship between sediment type and habitat suitability throughout the entire study area which assessed which substrate type was the most suitable for lobster species in the area. This was also calculated using raster information in ArcGIS Pro to create explanatory box and whiskers plots (Figure 14).

# CHAPTER III: RESULTS

## Random Forest Model

The sediment distribution model predicted using the forest-based classification and regression tool shows the locations of the three substrate types that were classified using the modified folk 5 scale (Figure 8). The distribution map (Figure 10) shows a large amount of muddy sand to sand in the east and within the centre of the study area. Areas of rock and boulder are concentrated towards the shoreline on the south-western coast, and a large concentration of mixed sediment is in the north central section surrounding Pictou Island. There is also an area of mixed sediment in the centre of the study area. The overall breakdown of percentage of sediment type throughout the entire study area is 72.7% mud to muddy sand and sand, 23.3% mixed sediment and 5.6% rock and boulder. The dominant sediment within the study area is mud to muddy sand and sand. The random forest model showed that the predicted substrate distribution was calculated at 67% accuracy with a MSE of 29.6.

Most of the sediment in the buffer zone was found to be muddy sand to sand, with the highest concentrations around the coastline leading into the offshore area of the study area. Of the study area inside of the buffer zone, 58.7% was muddy sand to sand, 21.6% was mixed sediment and 19.7% was rock and boulders. In terms of protected sediment however, rock and boulder contained the highest percentage of protected area at 50.2% protected suitable habitat followed by mixed sediment with 39.5% protected suitable habitat (Table 4).

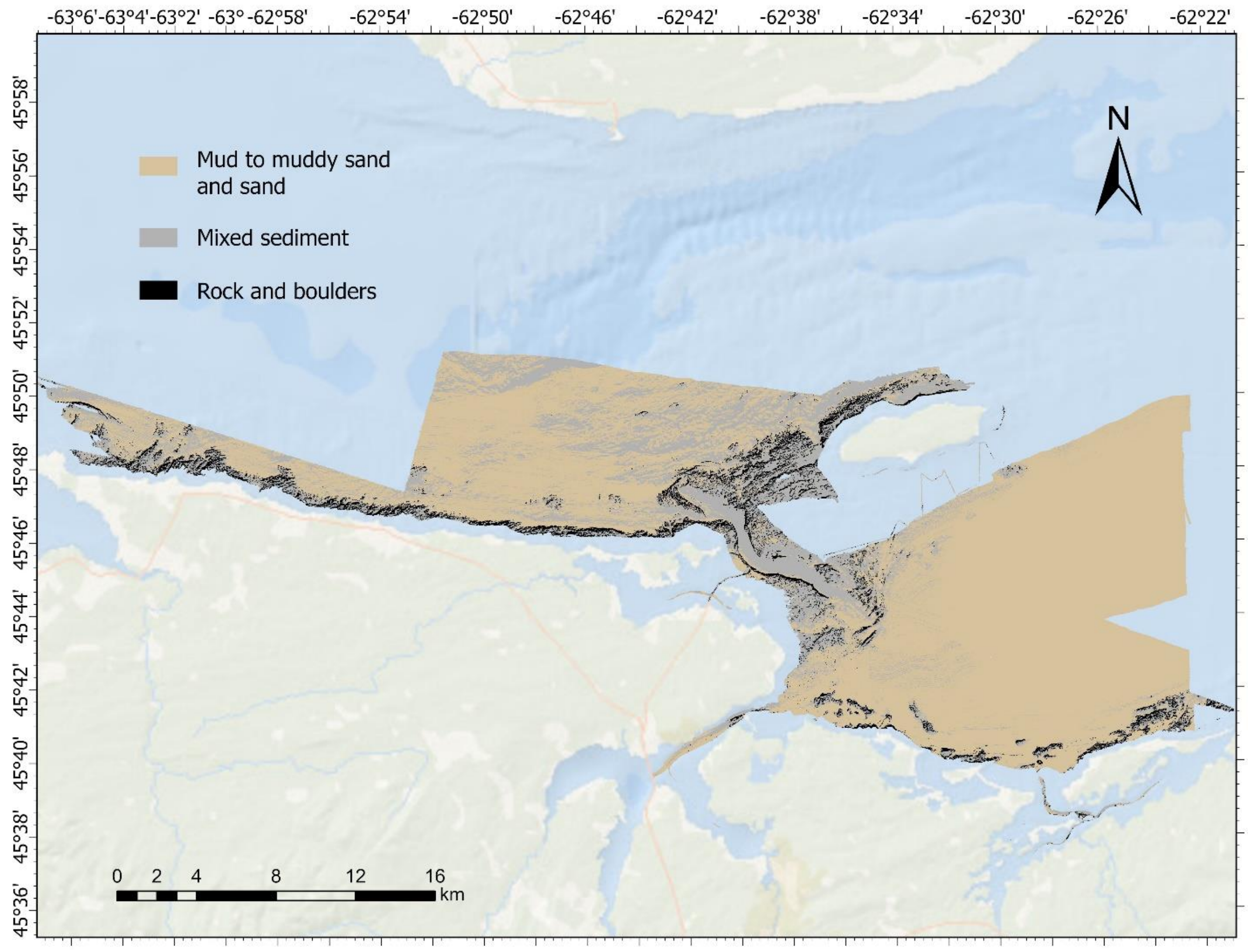


*Figure 10*: Sediment distribution *in the Northumberland Strait predicted using the forest-based classification and regression tool in ArcGIS Pro.*

## Variable importance for Random Forest model

The Random Forest sediment distribution model produced a variable importance table for the environmental predictor variables which indicated that cosine, broad benthic position index and backscatter were the most important variables for predicting the distribution of sediment type (table 03).

*Table 3:* Table of importance for environmental predictor variables which informed the Random Forest sediment distribution model.

| Variable | Importance | % |
|---|---|---|
| Backscatter | 0.30 | 12 |

| | | |
|---|---|---|
| Broad benthic position index | 0.34 | 14 |
| Cosine | 0.41 | 17 |
| Fine benthic position index | 0.39 | 16 |
| Sine | 0.23 | 9 |
| Slope | 0.23 | 9 |
| Vector ruggedness measure | 0.30 | 12 |
| Depth | 0.27 | 11 |

### Comparison of substrate inside and outside buffer zone

The composition of substrate type within the scallop fishing buffer zone was calculated from the raster values of the sediment distribution model. Sediment distribution proportions were calculated for within and outside of the scallop fishing buffer zones to assess the sediment type that is being protected by the conservation areas. It was found that the highest percentage of substrate type was muddy sand to sand both within and outside of the buffer zones. There was a higher percentage of rock and boulder and mixed sediment protected inside the buffer zone although mud to muddy sand and sand was the predominant substrate type (table 04).

*Table 4*: Substrate class coverage

| | **Percent of substrate area of the total study area** | **Of total substrate class coverage, percent of each substrate found in SBZ** | **Of total substrate class coverage, percent of each substrate found outside SBZ** |
|---|---|---|---|
| **Mud to muddy sand & sand** | 72.7% | 14.7% | 85.3% |
| **Mixed sediment** | 23.3% | 36.0% | 64.0% |
| **Rock & boulder** | 5.6% | 50.2% | 49.8% |

## Maximum Entropy Model

The habitat suitability model for adult lobster showed suitability on a continuous scale with 1 being the highest suitability and 0 being the lowest (Figure 11). The suitability map shows that the highest concentration of suitable habitat is located in the middle channel and along the northern coast. The southern coasts also show high habitat suitability with large areas toward the northwest and the northeast of the study that show significantly lower suitability for adult lobster habitat (Figure 11). The habitat suitability model had an area under curve score of 0.75 and an omission rate of 0.31.

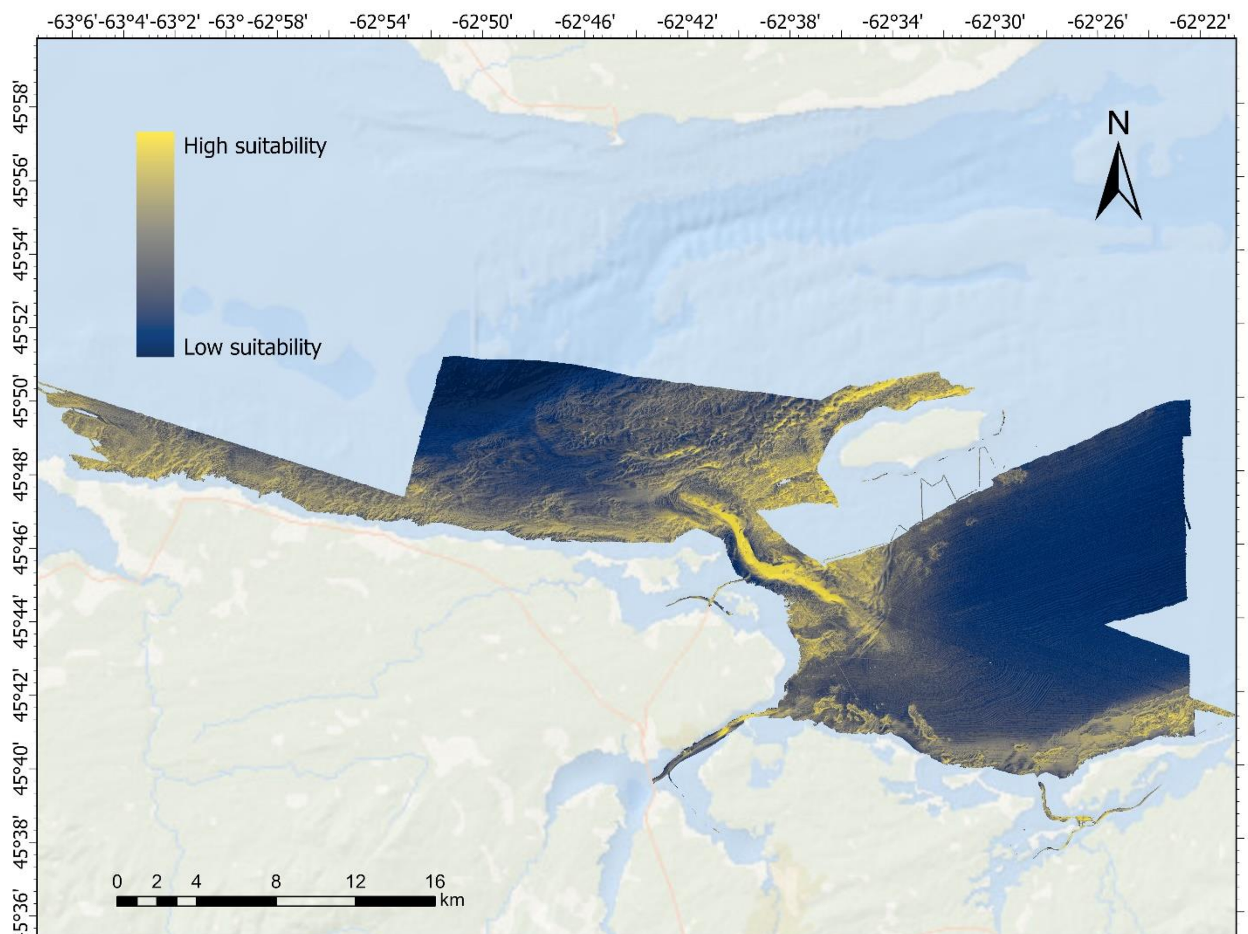


*Figure 11: Distribution of habitat suitability for lobster in the Northumberland Strait calculated using a presence only model.*

The suitability raster was applied to only the buffer zones within the study area to calculate the suitability for the regulated zones on their own. The mean suitability inside the buffer zones was 0.5 (Figure 12). The suitability was mixed and had a lot of variability between unsuitable and suitable on the southwestern buffer zones while it was more distinctly separated towards the southeastern area. The northern buffer zone area was also varied but contained higher concentrations of suitable habitat.

The suitability was also applied to the area outside the buffer zones but within the study area to compare the suitability within the zones. The mean suitability was 0.3 for the area outside the buffer zones within the study area (Figure 13). This comparison of mean suitability showed that despite the areas of high concentration, most of the area would not be suitable habitat.

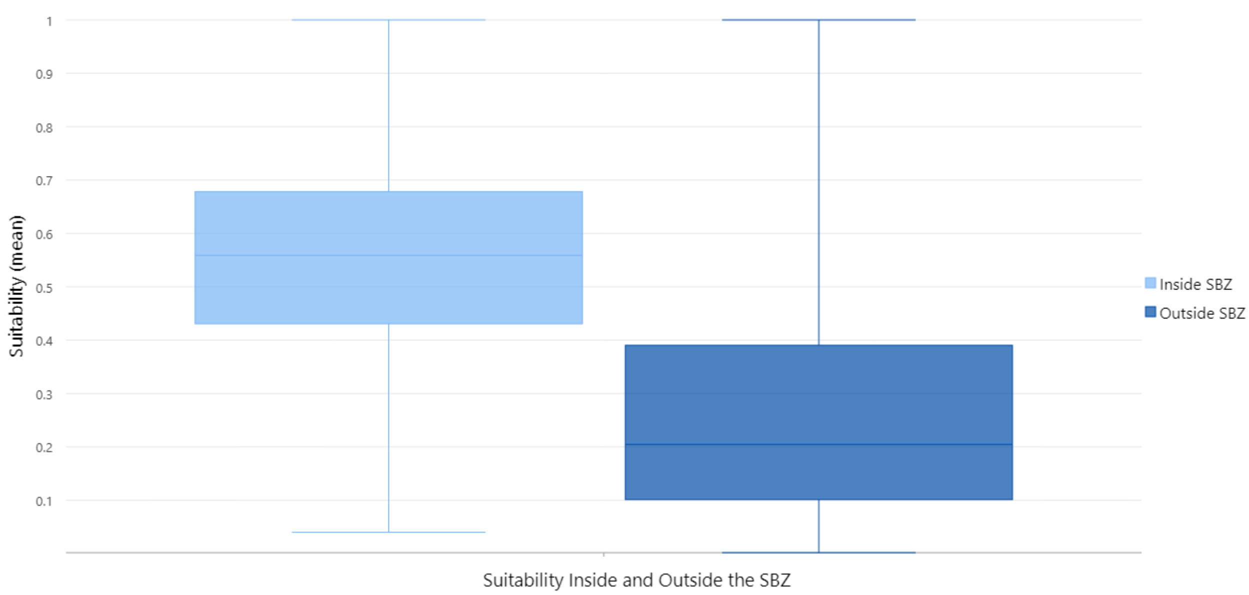


*Figure 12*: *Mean suitability inside and outside the buffer zones.*

## Comparing substrate distribution and habitat suitability distribution

The mean habitat suitability for each substrate type was then plotted to determine which substrate type was preferred lobster habitat. This showed that mean suitability for lobster habitat on mud to muddy sand & sand was 0.3, the mixed sediment 0.5, and rock and boulders 0.6 (Figure 13). Comparison of the mean suitability for each substrate type determined that rock and boulder was the preferred substrate type for lobster habitat in this area followed by mixed sediment.

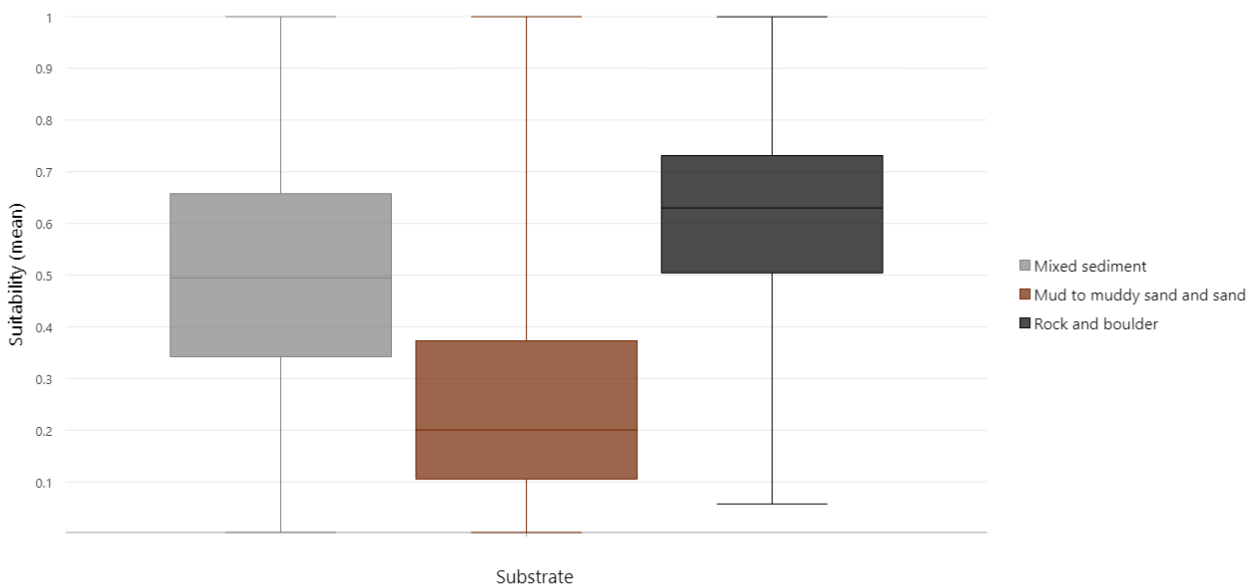


*Figure 13: Mean suitability for each substrate type throughout the entire study area.*

## CHAPTER IV: DISCUSSION

This study produced two main maps which outlined the distribution of sediment and the distribution of adult lobster habitat suitability throughout the study area and the scallop fishing buffer zones. The sediment distribution map and habitat suitability map indicated that the substrate within and outside of the scallop fishing buffer zones was primarily muddy sand to sand. The buffer zones however comprised a higher proportion of mixed sediment and rock & boulder located inside than outside of the buffer zones. The suitability analysis showed that higher lobster habitat suitability was on rock and boulder substrate. The findings surrounding adult lobster habitat suitability and the distribution of sediment in the area in this study can be used as a baseline to evaluate juvenile lobster population conservation based on the known relationship between behaviours and lobster life cycle characteristics (Morse, 2016).

### Distribution of sediment

The sediment distribution model overall aligned with the map created by Kranck in 1972. The original map from 1972 was created at a coarser scale and used expert interpretation resulting in the detail being reduced (Kranck, 1972). Although detail was reduced, broad scale interpretation of sediment distribution in this study was similar to the distribution in this study. The areas of muddy sand to sand were the most obvious area of similarity with the inshore area similarities being harder to interpret due to the course scale and difference in sediment classification used between maps. Other studies completed by Sklar (2024) and Loring and Nota (1973) in the Gulf of Saint Lawrence find the same distribution of sediment consistent throughout the broader area of harder substrate towards the inshore areas and muddy sand and sand further offshore however the resolution is coarse.

Inshore areas where the scallop fishing buffer zones are located were predicted to contain higher proportion of harder substrate based on the backscatter response and the sediment distribution model overall aligned with this prediction. The high concentrations of mud to muddy sand and sand were found in the offshore areas and the inshore areas contained higher mixed sediment and rock and boulders. Although the highest proportion of substrate throughout the entire study area was mud and muddy sand, higher proportional coverage of rock and boulder as well as mixed sediment concentrations were found inside the buffer zones than outside (Table 4), which potentially provides positive benefits for lobster population conservation efforts. Although there is a large proportion of suitable habitat within the scallop fishing buffer zones, there are also areas of suitable habitat outside of the zones which contain suitable habitat that could be further protected. Further protection of these suitable habitats would potentially reduce juvenile lobster mortality rates leading to a greater lobster population in this area.

The sediment distribution model was created with an accuracy score of 67%. The lower model accuracy score indicates that the sediment composition in this area is varied and complex. Due to the variability and complexity of the sediment in the area, further sampling would be required to categorize the sediment into more specific classes. This might look like classifying sediment consistent with a true folk 5 or a folk 7 scale, to achieve a more detailed depiction of the distribution of the sediment throughout the study area. Physical grab samples can also be collected to more accurately categorize sediment types such as what Loring and Nota completed in 1973.

## Variable importance in the models

The variable importance table showed that the most important variables that were used to inform the Random Forest sediment distribution model were cosine and fine benthic position index at 17% and 16% importance (table 04). These variables as the most important were not the expected result of the variable importance table. Variables that were expected to be more important for the sediment distribution model were backscatter and VRM due to their ability to calculate the fine scale morphology of the seafloor.

The application of orientation as a predictor variable is important for understanding current and water movement for benthic habitat due to its ability to calculate areas on the seafloor which are exposed in various direction. This variable however is not as useful for determining sediment distribution and seabed morphology (Wilson, 2006). The increased importance of the cosine and fine BPI variables in this study could be due to the collection artefacts in the bathymetric non navigational (NONNA) data. Aspect calculation is sensitive to collection artefacts (Wilson, 2006) as it uses the slope to visualize the exposure of an area. Therefore, if there were large artefacts in the original dataset, it would amplify those changes in the created cosine layer giving it more weight in the Random Forest model. The same applies for benthic position index. This is a measure of position that evaluates the curvature of the surface based on the original raster of the collected multibeam (Lundblad, 2006). It provides information about the overall surface, however, would not have a large impact on the prediction of sediment types throughout the study area.

### Substrate distribution and habitat suitability

Although the sediment distribution showed error due to the limited substrate classes and mixed sediments, the general distribution of sediment around the buffer zones can be used to evaluate the placement of the buffer zones based on the distribution of sediment and the observed habitat suitability for each substrate class.

The rock and boulder substrate was found to be the most suitable habitat for lobster. This aligns with studies completed by Ouellette (2016) and Geraldi (2009) which outline that ideal lobster habitat is complex habitat with varying sizes of rock and boulder combined with softer sediments, with pure mud and sand being not ideal habitat. The varying sizes of rock and boulders with a foundation of softer sediment allow for more habitat for lobster to hide in which aligns with the conclusions of these past studies. The area of mud to muddy sand and sand throughout this study covered an extensive area which was also predicted to have low lobster habitat suitability.

The mean suitability scores for each substrate class also showed that mixed sediment had relatively high lobster habitat suitability (Figure 13). The sediment in the study area was very mixed and contained a wide variety of cobble sizes with varying levels of sand. This could be a result of high levels of sediment movement from hurricane activity in the area which had occurred before the collection of the video. The increased presence of suspended sand in the water at the time of video collection may have contributed to areas that are normally rock and boulder appearing as more mixed sediment. As the lobster get older, they also prefer a more complex habitat (Ouellette, 2016) which, combined with the increase in sandy substrate, would have also led to higher suitability on the mixed substrate.

## Conservation and policy applications

Overall, the distribution of highest concentration of rock and boulder substrate which had the highest suitability for adult lobster were found to align with the placement of the scallop fishing buffer zones. This was expected as the scallop fishing buffer zones are currently placed along the coastline of Nova Scotia and Pictou Island where the sediment is generally harder with more rock and boulder distribution which was reflected in the sediment distribution map (figure 10) (DFO, 2019). The scallop fishing buffer zones do not protect the majority of suitable habitat which means that there are areas that are currently not protected which could be to further target juvenile lobster conservation.

Although this study was completed for adult lobster, the findings can be applied to juvenile lobster population conservation efforts based on the known relationship between juveniles an adults. Based on a study completed by Morse (2016), juvenile lobster prefer mixed substrates where there are rocks that protect young lobster from predation (Ouellette 2016). The ideal depth for post larval lobster is shallow water less than 10m (Ouellette, 2016). A study completed by Chang in 2010 concluded that juvenile lobster are also found to be more abundant in in-shore areas and travel further offshore as they grow (Chang, 2010). From the distribution of adult lobster and where they were found in this study, it can be predicted that juvenile lobster will be found on similar substrate with even higher levels of rock and boulder and in shallower areas of water, for example around the coastlines.

Based on the results found in this study, and applying what has been observed in other studies concerning juvenile lobster behaviour, it can be determined that the scallop fishing zones are targeting the juvenile lobster habitat. The scallop fishing buffer zones contain a higher concentration of ideal habitat than areas outside the buffer zones.

Knowing where the distribution of sediment is and the predicted distribution of habitat suitability, the results can be used to compare future studies to understand how the environment and ideal suitability is changing or staying the same with increased sediment movement in the area due to climate events. If there are large changes seen in coming years regarding sediment movement and therefore habitat suitability, these findings could be compared to inform the movement of the buffer zones for more effective management. For example, if it is determined in the future that more mixed sediment needs to be protected to provide better habitat where lobster can shelter themselves (PM Johns, 1987), the sediment distribution map showed that there is a large concentration of mixed sediment in the middle channel of the study area. This area could be further examined for lobster suitability to determine if the zone placement could be altered to include this area.

## Limitations

The first limitation for this study surrounds the lack of grab samples taken in the study area. The ground truthing was completed using drop camera footage for sediment observation which provided some limitation in the ability to classify the substrate into sediment classes. Grain size cannot be determined from video alone, and the camera did not have lasers, therefore measuring the size of coarse substrata (e.g. pebbles, cobbles, and boulders) became difficult to narrow down into detailed sediment classes. The lack of lasers also made it difficult to measure lobster size from the video.

Another consideration is the temporal difference between the echosounder dataset collection and the video collection. The echosounder data set was collected in from before the video collection. Between the two collection times, there were significant extreme weather events including hurricane Lee, which would have caused sediment disturbance in the area. The observed sediment would have been observed post hurricane however the backscatter dataset used to inform the model was collected pre hurricane. This movement in the soft sediment could be a factor contributing to the lower accuracy score of the sediment distribution model.

## Areas for future work

Future work in the Northumberland Strait around analyzing scallop buffer zone placement for juvenile lobster population conservation includes completing ground truthing that targets juvenile lobster. In a study completed by Wahle et al., diver-based suction sampling and passive collectors were effectively used to ground-truth juvenile lobster populations (Wahle et al., 2011). This would allow for a more accurate account of the juvenile lobster population distribution in this area. These dive surveys could be completed in the spring when populations are more abundant due to the temperature differences in the area (Chang, 2010). Additionally, population information could also be determined through stock assessment as seen in George's Bank and the Gulf of Maine (Atlantic States Marine Fisheries Commission, 2024).

Grab samples for sediment classification should also be collected to contribute to a more accurate and detailed sediment classification system. Due to the limitations in resolving the observed sediment into the three substrate classes from the drop camera footage, the distribution model had a relatively low accuracy score. By collecting a wide distribution and variety of samples throughout the study area, the sediment distribution model would be more precise than the one created in this study and could better inform the placement of the zones based on sediment distribution. Collecting samples continuously, at regular time intervals would aid in assessing the movement of sediment throughout the area over time and how this affects the suitability of juvenile lobster habitat. Extreme weather events around the time of video collection led to cloudy sediment in the video therefore having multiple datasets from different time periods would also help to give a more complete and accurate prediction of the sediment distribution over the study area.

Further MBES data collection could also be completed for this study area. The MBES dataset used in this study contained some data gaps resulting in holes in the maps. Collecting MBES data at more regular intervals would also contribute to a better understanding of how the habitat is changing and contribute to more accurate habitat maps in the area.

# CHAPTER V: CONCLUSION

Distribution of sediment and lobster habitat suitability can be used to assess the placement of scallop fishing buffer zones aimed at addressing juvenile lobster population conservation. The area that is contained within the scallop fishing buffer zones is comprised of primarily mud to muddy sand and sand however contains a higher percentage of mixed sediment than the areas that surround it. This indicated that the zones are overall effective in targeting lobster conservation over the area outside the zones. More research should be done to model the benthic habitat in the Northumberland Strait over time to get a more accurate display of the sediment distribution and juvenile lobster habitat suitability surrounding the scallop fishing buffer zones.

Further work is needed to ground truth sediment and juvenile lobster to get a more accurate model of the sediment distribution and the juvenile lobster habitat suitability throughout the scallop fishing buffer zones. Although this study mapped the adult lobster habitat suitability, it was still helpful in determining a baseline for the species and knowing the lifecycle characteristics of lobster, assumptions can then be made about the effective placement of the scallop fishing buffer zones for juvenile lobster conservation.

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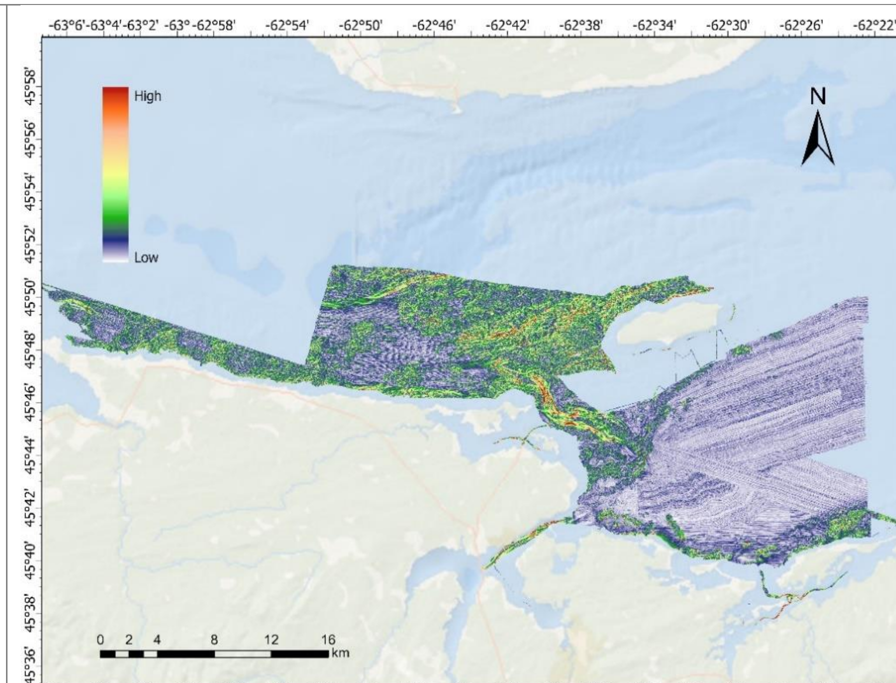
## APPENDICES

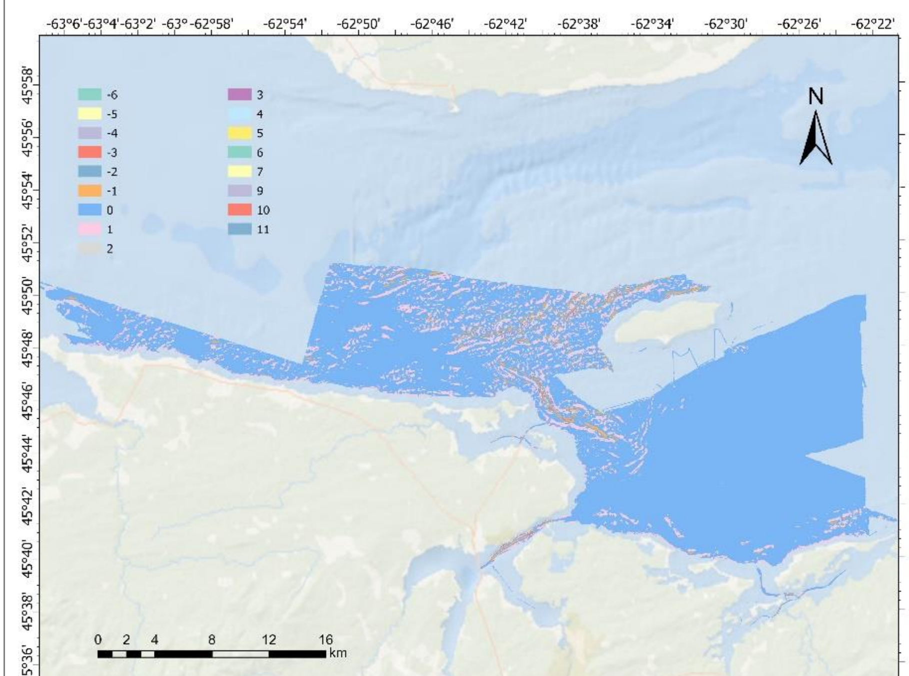
## Appendix A

**BATHYMETRIC DERIVATIVES**

**SLOPE**




**FINE BPI**



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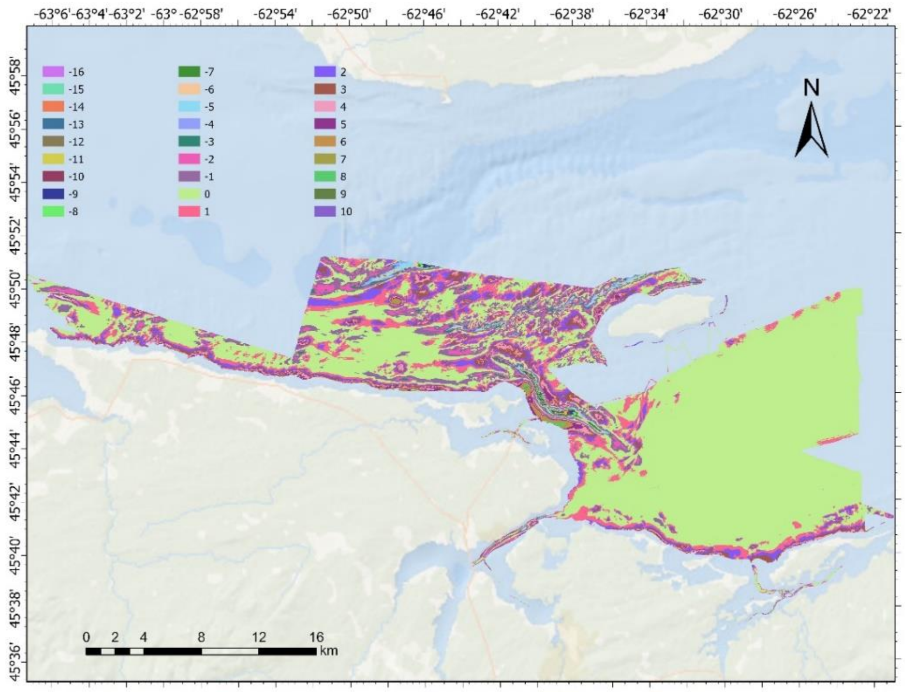


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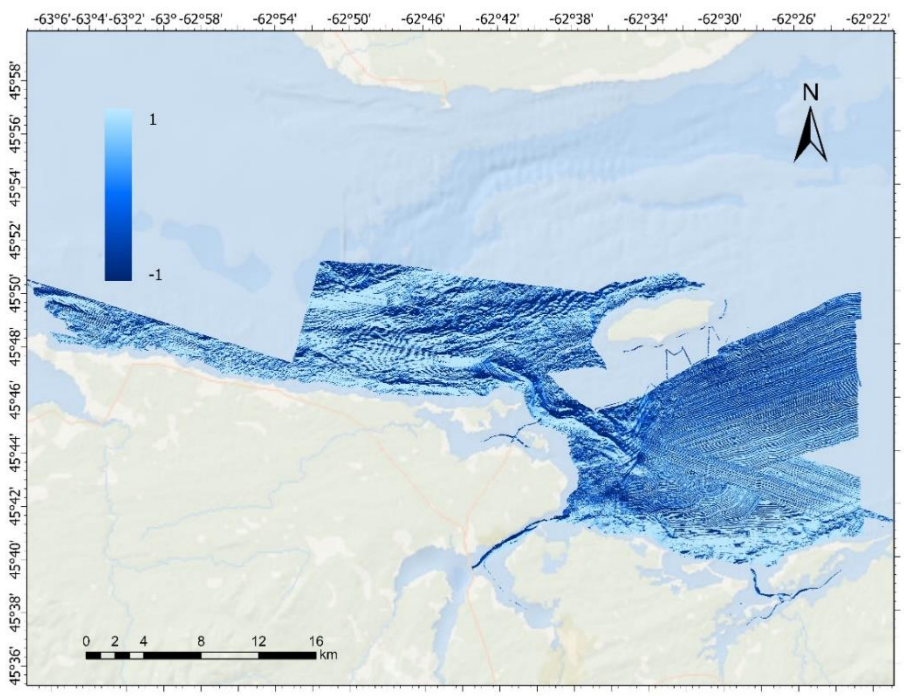

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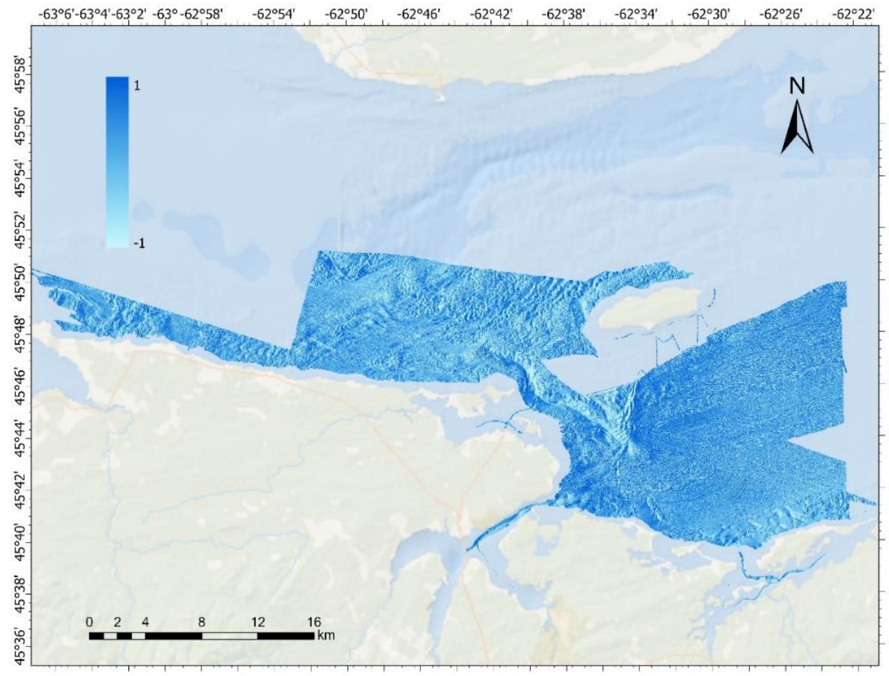


**VECTOR RUGGEDNESS MEASURE**