SPATIAL DISTRIBUTION OF BENTHIC FLORA AND FAUNA OF COASTAL PLACENTIA BAY, AN ECOLOGICALLY AND BIOLOGICALLY SIGNIFICANT AREA OF THE ISLAND OF NEWFOUNDLAND, ATLANTIC CANADA.

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Abstract

Coastal habitats are not only hotspots of biodiversity and ecosystem services, but are also hotspots for human development and exploitation, causing stress that threatens their sustainability. Overlap of coastal ecosystems with regions of high anthropogenic impacts requires developing a baseline that captures the present benthic composition with inclusion of the fundamental ecology of organisms interacting with their environment. This study establishes a baseline describing benthic organisms present along the western coast of Placentia Bay, a declared Ecologically and Biologically Significant Area (EBSA) of the Island of Newfoundland, Canada. The interactions of the four identified epifaunal assemblages and two dominant macrophyte species with their physical environment were modelled with a new modelling technique: Light Gradient Boosting Machine (LightGBM). Each developed model determined the inclusion of fine-scale (< 1 m) substrate % coverage as crucial to understanding the distribution of both epifauna and flora. This study also found that the epifaunal assemblage with the greatest coverage contains the highest species richness and that there is extensive coverage by the two target macrophytes. This baseline can be used to inform future monitoring of Placentia Bay's coastal ecosystem and observe changes that may occur.

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Chapter 1 - Introduction

1.1. Context

1.1.1. The importance of Establishing Baselines along Marine Coasts

Marine coasts are invaluable in their high productivity and as hotspots of biodiversity (Costanza et al 1998, Jackson 2001, Halpern et al 2008). Across the world, coasts play a critical role in ecosystem functions including, but not limited to, providing nursery habitats, filtering and detoxifying waters, and bolstering viable commercial fisheries (Worm et al 2006, Barbier et al 2011). Coasts historically have been the target of human settlement, resulting in high functioning ecosystems threatened by negative human impacts (Lotze et al 2006). Overexploitation, pollution, and transformation of coasts has resulted in the loss of their diversity and functioning (Jackson et al 2001, Halpern et al 2008).

Growing reliance on the ocean has prompted the need for proper management and stewardship of resources for industrial, economic, and social purposes (Silver et al 2015, Bennet et al 2019). Establishing monitoring programs of coastal areas are critical for effective management and conservation efforts to mitigate anthropogenic consequences and ensure sustainability. The success of these monitoring programs requires a solid understanding of the present biological and ecological state of the target area (Neilson & Costello 1999, Brown et al 2011, Lee et al 2015). This baseline provides a comparable foundation to observe changes over time or as consequence of a catastrophic event, such as an oil spill (Giering et al 2018). Using best available knowledge at a discrete point in time, a baseline is therefore built with the purpose of understanding the current presence and distribution of biota and abiotic resources, with the understanding that baselines shift (Foster-Smith et al 2007, Schumchenia & King 2010). It is key that changes observed in coastal diversity and their ecological function over time are represented accurately and are not a reflection of different survey or analytical methods having been employed to build the baseline. Therefore, investigating the robustness of the methods employed is an important step in developing a baseline. Once established, ecosystem-based management and conservation efforts can be developed using holistic considerations of ecosystem processes instead of single-species analyses. Thus, ecological integrity is more successful while achieving human socioeconomic needs (De Young et al 2008, Cogan et al 2009).

1.1.2. The Use of Benthic Fauna as Indicators of Change

Benthic invertebrates are invaluable in the development of a baseline. They are key players in both the physical structure and dynamic function of the marine environment (Brey 2012, Oug et al 2012, Alexandridis et al 2017). They form the basis for trophic food webs (Iken et al 2010) and influence both the benthic and pelagic zone via cycling of energy, nutrients, and materials, (Sandnes 2000, Hajializadeh et al 2020, Lam-Gordillo et al 2021) and act as ecosystem engineers (Reise 1985, Meadows et al 2012). The majority of species spend their adult life stage, if not completely sessile (Bilyard 1987), relatively immobile. In addition, benthic invertebrates are long-lived, resulting in their prolonged exposure to detrimental stressors and disturbances (Wei et al 2019, Meng et al 2021). Marine benthic invertebrates represent a trophically diverse group with varying species-specific thresholds for environmental stressors (Pearson & Rosenberg 1978, Borja et al 2000, Shojaei et al 2016). These characteristics make benthic invertebrates' ideal candidates as bioindicators of ocean health for simple, repetitive, and diverse biological quantification strategies that can be used to monitor ecosystem health (Dauer 1993, Borja et al 2000, Borja et al 2008, Van Hoey et al 2010, Jayachandran et al 2020).

1.1.3 Benthic Macroalgae of Placentia Bay

Macroalgae of the northwest Atlantic include fields of kelp beds primarily made up of brown algae of the order *Laminariales* (Steneck et al 2002, Krumhansl et al 2016), with region-specific species (Mann 1982). Kelp beds act as primary producers and provide the framework for a heterotrophic system of secondary producers (Velimirov et al 1977, Linley et al 1981, Duggins et al 1989, Babcock et al 1999). Demersal fishes such as cod, pollock, tomcod, and white hake associate with Atlantic kelp beds for shelter, predator-avoidance, and as nursery grounds for young recruits (Dean et al 2000, Hamilton & Konar 2007, Lazzari 2012, Shaffer et al 2020). Kelp forests sequester carbon with the potential to act as a carbon sink (Hill et al 2015, Chung et al 2017, Filbee-Dexter & Wernberg 2020). Their provision of a physical structure directly influences the local environment and increases local 3D habitat complexity (Duggins et al 1990, Gaylord et al 2007, Layton et al 2020). These roles result in a rich association of biota from marine mammals to epibiota (Mann 1973), with representation from more phyla than what is associated with terrestrial forests (Steneck et al 2002).

However, for decades, kelp beds in temperate and sub-polar coastal regions of the northwest Atlantic are subject to periodic deterioration by the herbivorous green sea urchin (*Strongylocentrotus droebachiensis*), resulting in coastal barrens with extents of over 1000s of km (Figure 1.1) (Filbee-Dexter & Scheibling 2014). Thus, beds are reduced to a less-productive, less structurally-complex barren state characterized by coralligenous algae and aggregations of urchins. In eastern Canada, the development of urchin barrens has been attributed to changes in top-down pressure from urchin predators, such as fishes, crabs, and lobsters (Wharton & Mann 1981, Filbee-Dexter & Scheibling). Barrens can then persist for decades (Himmelman et al 1983, Norderhaug & Christie 2009), with shifts between kelp beds and urchin barrens catalyzed by additional factors such as urchin mass mortality, wave-action, and sea temperature (Tamaki et al 2009, Lauzon-Guay et al 2009, Filbee-Dexter et al 2014).

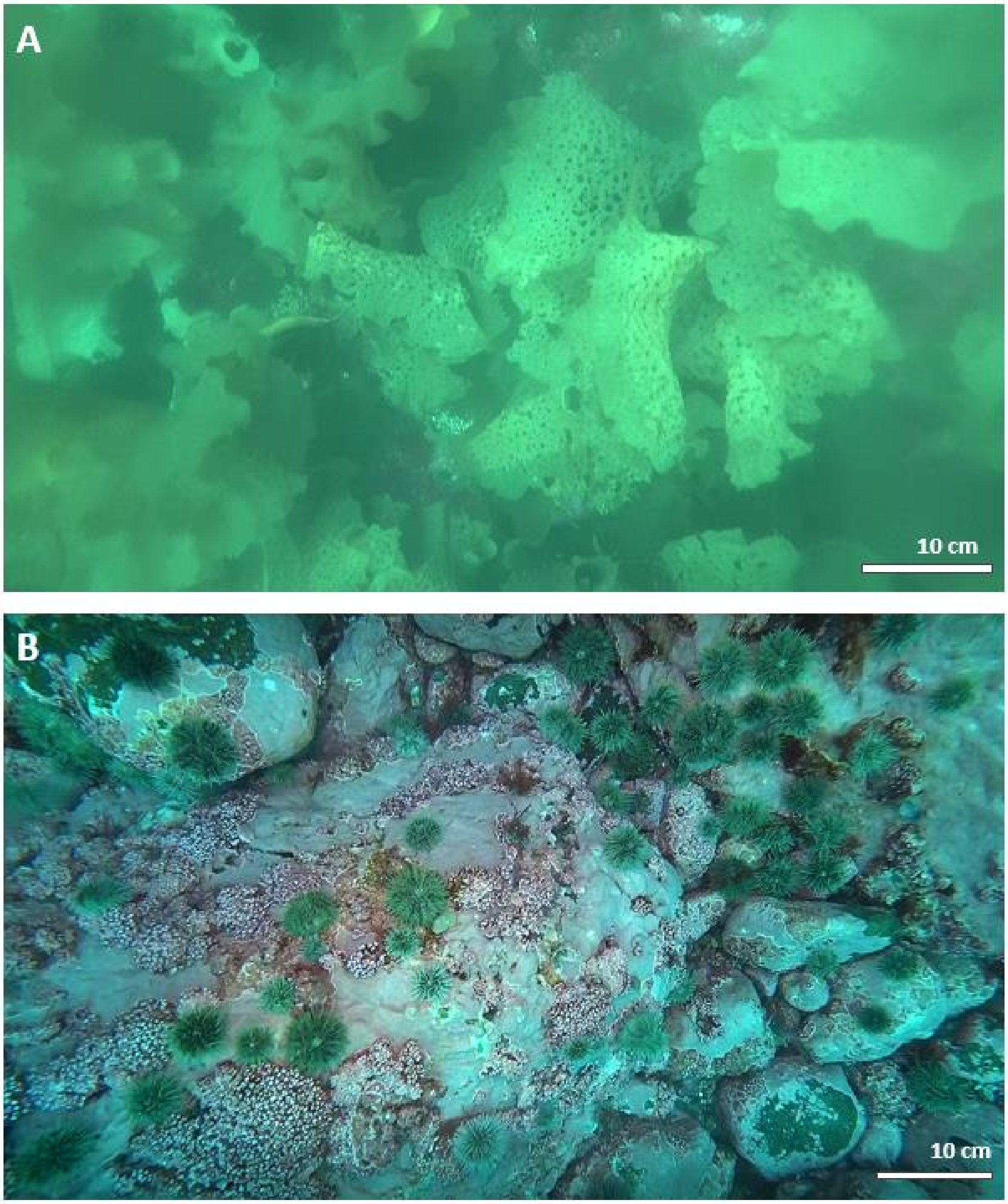

Figure 1.1. A comparison between A) a kelp bed with sugar kelp (*Saccharina latissima*) and *Agarum clathratum* and B) an urchin barren populated by the green sea urchin (*Strongylocentrotus droebachiensis*). Both images were taken from towed underwater camera footage within the surveyed areas of coastal Placentia Bay, NL.

1.1.3.1 **Agarum clathratum** ***(Dumortier 1822)***

Agarum clathratum, a species of kelp of the order Laminariales, is easily identified by holes perforating the blade's entire surface (Figure 1.1). The blade itself reaches 90 cm long and 50 cm wide, has a smooth and rounded stipe, and ends with a branching holdfast attached to a hard foundation. *A. clathratum* is perennial; sexually reproductive sporophytes grow during seasons when water temperatures are at their lowest (fall, winter, early spring) (Vadas 1968), forming dense, prostrate canopies on the seafloor.

A. clathratum canopies can persist even under grazing pressure by urchins. There are multiple theories as to what contributes to their resilience, including 1) integrated chemical deterrents (phenolics) (Himmelman & Nédélec 1990), 2) deeper depth range than typical urchin aggregations (Himmelman 1986, Krause-Jensen et al 2019), and 3) reduced competition from other kelp species following grazing (Vadas 1968).

These more resistant *A. clathratum* forests may be important contributors of local biodiversity when urchins are abundant; previously, Blain & Gagnon (2014) had found around 40 invertebrate and fish taxa across a spectrum of life stages associated with *A. clathratum* beds in the shallow (2 – 8 m) waters of Bay Bulls, Newfoundland.

1.1.3.2. Non-geniculate crustose coralline algae

Coralline algae are a group of red macroalgae (Rhodophyta) under the order Corallinales. They are the widest distributed algae group (Woelkerling 1988), spanning the photic zone to the mesophotic zone of most coastal communities from polar waters to the tropics (Johansen 1981, Steneck 1986). Different species come in wildly varying forms. Some are geniculate (articulated) with extensive branches. Others are non-geniculate, existing as free-living rhodolith (maërl) beds or as crusts on hard substrates. Crusts are the "pink paint" often seen growing either on hard substrates such as boulders or bottles, or as epibionts on other organisms, like molluscs (Figure 1.2). Coralline algae are characterized by magnesium carbonate ($MgCO_3$), a form of calcium carbonate ($CaCO_3$) precipitation within their cell walls that provides their rigid structure and light pink to red hue (Le Gall & Saunders 2007, Adey et al 2013).

Figure 1.2. Example of non-geniculate crustose coralline algae covering bedrock, with green sea urchins to the left and *Agarum clathratum* to the right. Photo taken using towed underwater camera in Placentia Bay, NL.

Similar to kelp, the presence of coralline algae may increase habitat availability for epifauna, particularly when the presence of branches increases its complex three-dimensional structure (Nelson 2009). Coralline algae are major producers of carbonate, and, considering their high abundance and extent, play an important role in the oceanic carbon cycle (Kamenos et al 2016). Because $CaCO_3$ deposits are difficult for *S. droebachiensis* to consume, coralline algae usually survive high urchin densities and become a characteristic feature of barrens. At higher latitudes, coralline algae exhibit increased build ups, sometimes forming networks of nodules and branches that increase local habitat complexity (Freiwald & Henrich 1994). The extensive coverage of coralline algae fields in barrens can lead to increased local biodiversity as numerous epifauna taxa (e.g. chitons, gastropods, limpets, bryozoans, polychaetes, and tunicates) associate with the structural complexity (Ojeda & Dearborn 1989, Chenelot et al 2011, Adey et al 2013).

1.1.4. Quantifying Seafloor Topography and its Linkage with Benthic Biota.

Physical characteristics of the seafloor exert significant influence on the distribution of benthic flora and fauna (Auster & Langton 1999, Kostylev et al 2001), and when these relationships are better understood, this information on species' ecological requirements can be applied to management and conservation efforts. Acoustic sonars, such as multibeam echosounder (MBES), are commonly used instruments to collect spatially-continuous bathymetric layer representing depth across a surveyed area (Pickrill & Todd 2003, Lamarche et al 2016, Ilich et al 2021). Sound waves travel from the sensor to the seafloor and back again, forming a swath of depth soundings across the path of the vessel. However, the area covered is reduced in shallower depths as the swath width narrows, resulting in more effort being required to cover an area. Higher frequencies can be used in shallower waters which lead to higher resolution datasets (i.e. smaller pixel size allowing finer objects to be identified) (Dowdeswell et al 2016, Wölfl et al 2019). During surveying, as sound waves echo back from the seafloor, the strength of their return is also measured. This backscatter can be indicative of substrate types: harder substrates like bedrock or boulder fields return a higher backscatter signal, while soft sediments like mud or sand will produce a weaker signal (Lamarche et al 2011, Lurton & Lamarche 2015, Calvert et al 2015).

Bathymetry and backscatter may not directly affect the fundamental niche of a species, but both can serve as indirect proxies for other more difficult variables to measure (McArthur et al 2010, Sutcliffe et al 2015, McHenry et al 2017). For example, it may not be depth itself that controls macroalgae extent, but the light availability which correlates with depth. The bathymetry and backscatter layers can also be used to derive additional terrain attributes, creating additional proxies (Lecours et al 2016). Slope, a common terrain attribute derived from a bathymetric layer, can be linked with sediment grain size (Henkel & Gilbane 2020), the local acceleration of currents (Levin & Gooday 2001), and ecological processes such as food supply (Dolan 2012, Jones et al 2013).

1.1.4.1. Spatial Scale

Organisms interact with their environment over a range of scales, but our understanding of these processes can change depending on the spatial context that they are analyzed at (Anderson et al 2008, Lecours et al 2015). The literature has reinforced the need to consider scale when examining species-environment relationships (Greene et al 2007, Brown et al 2011, Harris & Baker 2020, Lecours et al 2015, Porskamp et al 2018, Misiuk 2021). In the context of this thesis, scale is adjusted by changing the window size at which relevant terrain attributes are analyzed and used to contextualize how organisms interact with their surroundings. The broader the range of window sizes employed, the better the chance that more ecological processes are captured (Lecours et al 2015, Reiss et al 2015, Misiuk et al 2018, Misiuk et al 2021).

While it can be challenging to build full-coverage maps that incorporate fine-scale (< 1 m) substrate compositions (e.g. drop stones, bedrock with patches of infilled sediment, mixed sediments resulting from unconsolidated glacial material), the highly localized structural heterogeneity of the seafloor has been linked with benthic diversity (Robert et al 2014, Gallucci et al 2020). Price et al (2021) found benthic organisms associated with geomorphic features that were < 1 m, including those resultants of reef structure (i.e. reef rugosity). Therefore, it is of interest to understand how much of the biological variability is due to fine-scale heterogeneity of substrate characteristics. For example, the presence of small, interspersed sediment patches or hard substrata in the form of a drop stone (Jones et al 2007) is not captured by our current modelling approaches (Robert et al 2014, Stortini et al 2020).

1.1.4.2 Predictive Modelling

Machine-learning techniques can be employed to model the intricate relationships between biota and explanatory variables such as derived terrain attributes (Guisan & Zimmermann 2000, Elith & Leathwick, Brown et al 2011). As these terrain attributes represent full-coverage layers, when combined with spatially limited biological datasets, the relationships modelled can be used to build predictive maps showing biological spatial patterns (Brown et al 2011). However, even at high resolutions these terrain attributes can still struggle to capture fine-scale (< 1 m) substrate composition and heterogeneity (Robert et al 2014, Strotini et al 2020) that may be important to understand the benthic diversity and composition (Meyer et al 2016, Gallucci et al 2020) of specific environments.

There exists a fast-evolving suite of different modelling techniques, each with their own advantages and disadvantages (Ierodiaconou et al 2011, Martín-García et al 2013, Diesing et al 2014 Robert et al 2015, Trzcinska et al 2020). One technique that has repetitively been found to outcompete others is Random Forest (RF) (Turner et al 2018, Bayyana et al 2020, Zhang et al 2021). A newly developed method, Light Gradient Boosting Machine (LightGBM), has been promising. LightGBM is characterized by high precision, little memory use, and fast computational time, and has been successfully applied in a variety of disciplines (Ma et al 2018, Chen et al 2020, Kopitar et al 2020, Tan et al 2021), including ecology (Zhang et al 2022) and oceanography (Su et al 2021). Comparing the performance of different modelling techniques is important to identify the approaches that provide not only accurate predictions, but that is robust enough to enable the identification of changes over time.

1.2. Study Areas

Canada has the longest coastline of any country in the world (202,080 km); Newfoundland and Labrador have a coastline length of 17,000 km. Conserving the natural and socioeconomic health of an expanse of marine resources of this magnitude requires highly effective ecosystem-based management. A fact recognized in the Oceans Act (1997), which aims to employ this approach for the preservation of biodiversity and functionality of the marine environment. To achieve this goal, Fisheries and Oceans Canada (DFO) developed the Coastal Environmental Baseline Program to increase our knowledge of specific marine areas at risk of high or increasing vessel traffic and coastal development. This program sponsored projects in six different regions along Canada's coastline, one of which being the target of this thesis, Placentia Bay, Newfoundland and Labrador.

Placentia Bay is a deep-water embayment located on the southern side of the Island of Newfoundland, in the province of Newfoundland and Labrador, along Atlantic Canada (Figure 1.3). The narrow northern head is characterized by troughs with depths up to 350 m, punctuated by elongated islands (Shaw et al 2013). The outer bay has a shallow and rugged western coast of bedrock ridges and an eastern coast with fringing shallow margins covered in glaciomarine mud (Shaw & Potter 2016). Dominant currents are cyclonic and wind driven (deYoung & Rose 1993). O average, currents enter the bay on the eastern side and exit out of the western side (Ma et al 2012). Upwelling occurs along the western coast due to southwesterly winds in winter (Ma et al 2012), providing nutrient rich water.

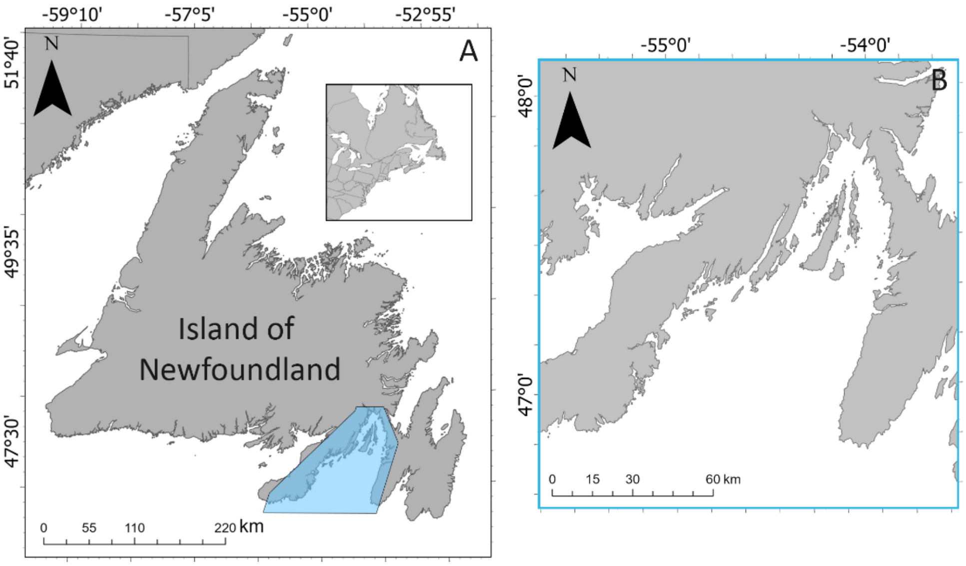

Figure 1.3. The A) location of the Island of Newfoundland in relation to North America (Placentia Bay highlighted in blue), and B) a close up of Placentia Bay.

Placentia Bay was designated an Ecologically and Biologically Significant Area (EBSA) following the overview of its ecosystem status, fish distribution/spawning, and assessment of single species presence (Templeman 2007, DFO 2016/032). An EBSA is defined by the fact that any severe disturbance would be of greater ecological consequences within the EBSA boundary than if the same perturbation occurred beyond the EBSA extent (DFO 2004/006). Not only does Placentia Bay host important capelin spawning beaches, eelgrass habitat, seabird colonies, and herring aggregations (Sjare et al 2013), but the EBSA's seaward extent encompasses important areas for large gorgonian corals and sponges (DFO 2019/040). Charismatic megafauna are frequent visitors, including leatherback turtles (DFO 2012/036) and blue whales (DFO 2018/003).

Historically, Placentia Bay hosts an Atlantic cod fishery, with key coastal habitat for cod spawning (Rose et al 2008, DFO 2019/009). There is one of the few remaining Atlantic cod stocks fishers continue to rely on for landings (Robichaud & Rose 2006, DFO 2019/009). As groundfish stocks decreased, commercial fisheries have shifted to shellfish, including northern shrimp, snow crab, and American lobster (DFO 2012), all of which are benthic species whose biomass increased within Placentia Bay in the early 1990s (DFO 2012). Aquaculture of finfish and shellfish is also growing along the coastal regions of the northern half of Placentia Bay (Ralph 2000, LGL 2018), which has the potential to impact sediment chemistry and benthic community structure (Giles 2008, LGL 2018, Sanz-Lazaro et al 2021).

The marine traffic in Placentia Bay includes tankers that transport oil along the main channel of the bay. Transport Canada identified Placentia Bay as a top high-risk region for oil spills. A spill with a volume of 10,000 barrels (1,590 tonnes) is estimated to occur once every 27 – 33 years (TP 2010, DFO 2007/1292). Placentia Bay's ecosystem overlaps with the industrial waste of oil refineries (i.e. Come By Chance refinery), naval yards, and wharfs. These areas can introduce oil, polychlorinated Biphenyls (PCBs), and grease into the local environment, potentially disrupting benthic fauna (Khan 2003, Khan 2011). Considering the harmful influence oil has on marine life (Schlacher et al 2011, Buskey et al 2016), and the reliance of human activities occurring in Placentia Bay on a healthy benthos, a thorough baseline was required.

In 2004 through 2006, Placentia Bay was mapped by the Geological Survey of Canada and the Canadian Hydrographic Service (Shaw et al 2006, Shaw et al 2007). While extensive bathymetric coverage of Placentia Bay was achieved, a critical portion was missed along the western coast due to its shallow nature. This data-deficient region, colloquially known as the "white-ribbon", represents an important overlap between hotspots of human activity and potential benthic biodiversity. This research focuses on collecting high-resolution (5x5 meter) multibeam bathymetric data of four survey areas within the "white-ribbon" (Figure 1.4): Rushoon, D'Argent Bay, Burin, and St. Lawrence.

Each of the four survey areas were selected because of their known ecological importance to Placentia Bay. The northernmost site surveyed was Rushoon, which is likely one of the most pristine sites of the four, due to its remote nature. This may be subject to change, as salmon aquaculture has recently been introduced within this site, and will likely impact the immediate environment (LGL 2018). To the southwest of Rushoon, D'Argent Bay was selected for its capelin spawning sites, herring aggregations, and high occurrence of whales (Sjare et al 2003). Continuing down the coast, Burin is situated near one of the larger population centers of Placentia Bay, near the towns of Burin and Marystown. Finally, closest to the mouth of Placentia Bay, St. Lawrence was selected for its capelin spawning sites, as well as its role as an important seabird habitat (White 2018). Nearby is the Lawn Bay Ecological Reserve, which was established to protect the only known colony of Manx shearwater in North America, as well as other breeding seabird species including storm petrels, gulls, guillemots, kittiwakes, murres, and terns.

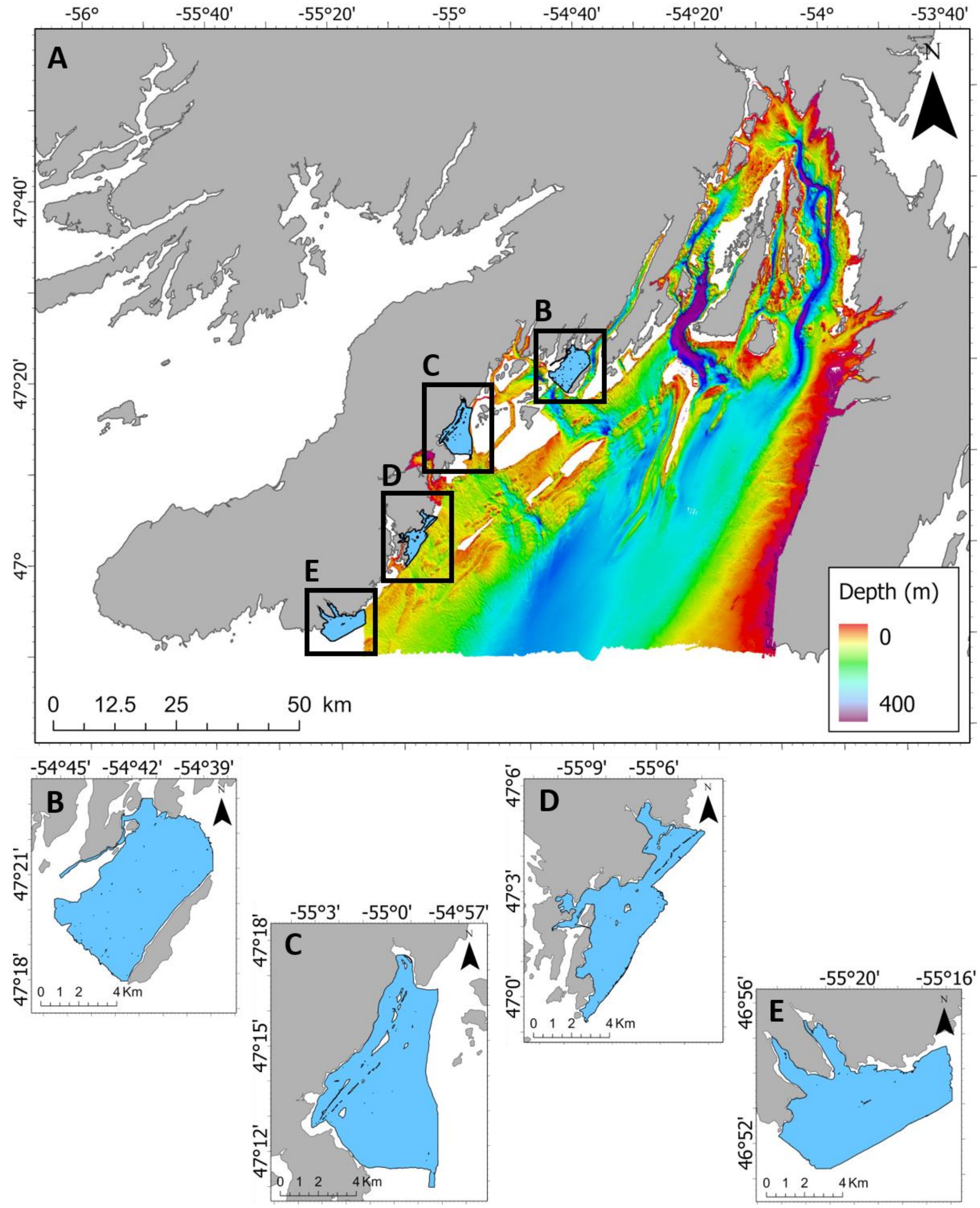

Figure 1.4. A) Bathymetry of Placentia Bay derived from the acoustic survey completed between 2004 – 2006 by the Geological Survey of Canada and the Canadian Hydrological Survey. The spatial location of the four survey areas along the west coast: B) Rushoon, C) D'Argent Bay, D) Burin, and E) St. Lawrence.

1.3 Research Objectives

Considering the threats to the ecosystem(s) of Placentia Bay and the lack of detailed information on its benthic faunal and floral species distributions, this study aims to answer the following research questions:

1. What are the dominant benthic epifaunal assemblages located along the western coast of Placentia Bay, NL?
    a. How does the seafloor topography influence the identified epifaunal assemblages across multiple scales?
    b. How important is the inclusion of fine-scale details on the heterogeneity of the substrate in understanding epifaunal distribution?
    c. How does the novel machine-learning algorithm LightGBM compare to RF in understanding the relationship between faunal assemblages and the environmental factors associated with their distribution?
2. What is the distribution of *A. clathratum* and non-geniculate crustose coralline algae across the western coast of Placentia Bay?
    a. How are *A. clathratum* and non-geniculate crustose coralline algae associated with the structure of the seafloor across multiple scales?

1.4 Thesis Organization

Following this introduction, the thesis is divided into two manuscript-style chapters and ends with a conclusion chapter summarizing the main findings.

Chapter 2 focuses on dominant epifaunal assemblages composed of epibenthic fauna and demersal fish (> 2 cm), existing within the four introduced survey areas of Placentia Bay's western coast. This study will improve upon the currently limited knowledge of epifaunal composition, considering both those associated with soft sediment (mud, sand) and hard substrata (bedrock, boulder, gravel) (Question 1a). In addition, this chapter emphasizes the need for the inclusion of fine-scale substrate data to capture the heterogeneity of the seafloor and help explain the spatial patterns of epifaunal assemblages (Question 1b). This chapter also compares the results of both the RF and LightGBM modelling techniques in a practical sense by looking at predictive maps derived from both model types (Question 1c).

Chapter 3 focuses on the previously introduced benthic macroalgae targets: *A. clathratum* and non-geniculate crustose coralline algae. This chapter works to understand how each target species is distributed across the same four areas of Placentia Bay, while investigating the species-environmental relationships (Question 2a). It highlights Burin as a location particularly suitable for *A. clathratum* growth and provides reasons as to why this occurs, highlighting the fact that it coincides with an area of higher human activity.

An R package was developed that allows the user to reproduce the results of this research. This R package is available by request. Please contact either the author (Julia Mackin-McLaughlin; julia.mm95@outlook.com) or the author's supervisor (Dr. Katleen Robert; katleen.robert@mi.mun.ca).

The main findings of the conducted research are summarized in the concluding chapter of this thesis. The inclusion of fine-scale substrate composition was identified as important in all models developed and, in each case, its inclusion boosted prediction accuracy. Placentia Bay hosts a variety of distinct epifaunal assemblages and has prominent coverage by both *A. clathratum* and non-geniculate crustose coralline algae, which all contribute to the local diversity relied on for ecological and socio-economic functioning.

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Chapter 2. From hard substrates to soft bottoms – modelling faunal assemblages of coastal Placentia Bay, Newfoundland, Canada.

2.1 Abstract

Placentia Bay is a southern embayment of the Island of Newfoundland, Canada, that has been recognized as an Ecologically and Biologically Significant Area (EBSA) for its ecological and socio-economic value. Little is known about the benthic epifauna inhabiting the coast, and how they may be affected by anthropogenic threats such as increasing shipping and aquaculture. An accurate baseline of coastal assemblages was required, and this study takes the opportunity to compare the already established machine learning technique of Random Forest (RF) with the newer Light Gradient Boosted Machine (LightGBM). Four dominant epifaunal assemblages were identified, with unique associations to depth, distance from the coast, seafloor rugosity, and the % coverage by fine sediment (mud/sand) and boulders. Both models highlighted the importance of including fine-scale details on the heterogeneity of the substrate as extracted from the benthic videos. Both models performed well, but RF marginally outperformed LightGBM. This study finds that the heterogeneous nature of Placentia Bay allows multiple benthic assemblages to exist.

2.2. Introduction

The reliance of anthropogenic activities on coastal zones places stress on coastal habitats and biodiversity (Lotze et al 2006) and ecosystem services (Costanza et al 1997, Barbier et al 2011, Barbier 2012), and careful management is required to ensure a balance between human use and coastal functioning. Considering the increased utilization of ocean resources (Bennet et al 2019), it is imperative to establish a baseline of the current environmental conditions of coastal ecosystems. This baseline provides discrete information on the present state of the benthos against which to monitor change over time (Shumechenia & King 2010, Siwabessy et al 2018). Benthic invertebrates are invaluable in their roles along coastal systems (Snelgrove et al 1997, Wahl 2009), but their relatively sedentary lifestyle and extended life-span results in their prolonged exposure to stressors with little mode of escape (Bilyard 1987, Dauvin 2007), making them especially susceptible to human influence. However, these two traits are also why benthic invertebrates are advantageous as bioindicators of ocean health in management and conservation programs (Van Hoey 2010, Borja et al 2008, Wei et al 2019).

Traditional monitoring programs often focus on infauna species (Gray & Elliot 2009, Buhl-Mortensen et al 2015), especially in temperate regions where soft sediments are the predominant substrate type (Ramey & Snelgrove 2003, Rossong 2016, Beisiegel et al 2017). This excludes the associated biota of temperate hard-substrates (e.g. boulders, bedrock) and associated biogenic structures (i.e. sponges, corals, kelps, crustose algae), all of which boost local epifaunal diversity (Sañé et al 2016, Palafox-Juárez & Liceaga

2017, Serrano et al 2017, Teagle et al 2017). The composition of epifauna of hard-substrates varies greatly from the epifauna of neighboring soft-sediment habitats (Buhl-Mortensen 2015). The inclusion of both in monitoring efforts better provides the context of a region's habitat heterogeneity and diversity (Palafox-Juárez & Liceaga 2017, Hemery & Henkel 2015).

Hard-bottom communities cannot be sampled using the same techniques as for the infauna of soft sediment bottoms (i.e. grabs and cores) (Rees 2009, Van Rein et al 2009), but imaging techniques (e.g. underwater cameras) have been established as an effective surveying technique for these substrata (Rees 2009, Beiseigel et al 2017). Imagery of epifaunal species can be collected on both soft sediment and hard substrate and associated with a suite of distinct structural characteristics of seafloor topography, obtained through multibeam echosounder surveys, using a range of modelling approaches to understand spatial patterns (Brown et al 2011).

The quantified seafloor terrain characteristics derived from the bathymetry can directly influence species' distributions, but may also represent proxies for other harder to measure environmental variables influencing biota distribution. For example, slope oftentimes correlates with current flow (Palardy & Witman 2011) and sedimentation (Jones et al 2013), with potential impact on nutrient availability (Ribó et al 2021). Concurrent with bathymetry, backscatter is collected as the returning acoustic energy and is often used as a proxy for substrate hardness (Brown & Blondel 2009, Misiuk et al

2019) as hard substrates return higher values while softer sediments return lower values (Brown & Collier 2008, Blondel & Gómez Sichi 2009). By identifying the links between seafloor substrate and topography with benthic invertebrate distribution (Snelgrove 1998, Boswarva et al 2018, Beaman et al 2005, Kostylev et al 2001), management and conservation efforts become more efficient and do not require the same level of exhaustive sampling (McArthur et al 2010, Pickrill & Todd 2003, Proudfoot et al 2020).

Placentia Bay is one region where a coastline overlaps with a relatively high concentration of human activities. Yet there is limited local biological data available for the assessment of potential risks. Located on the southside of the Island of Newfoundland, Canada, Placentia Bay hosts eelgrass beds (Morris et al 2010), capelin spawning beaches (Sjare et al 2003), cod nurseries (DFO 2007/042), seabird nesting grounds (DFO 2012), and often sees visiting megafauna such as blue whales (DFO 2018/003), porbeagle sharks (Campana et al 2012), and leatherback turtles (DFO 2012/036). These exist alongside oil and gas shipping routes, developing aquaculture sites, and established traditional and commercial fisheries. For its role in benefiting the local ecosystem health, Placentia Bay has been deemed an Ecologically and Biologically Significant Area (EBSA) by Fisheries and Oceans Canada (DFO) (Templeman 2007, DFO 2016/032).

Though infauna compositions within the deeper (184 m average) sedimented areas of Placentia Bay have been described (Ramey & Snelgrove 2003), shallower coastal soft sediment and hard substrate areas still represent an under-sampled habitat. As Placentia Bay is expected to experience a significant increase in aquaculture (LGL 2018), there is a need to understand the general composition of benthic fauna along the coast before it was further impacted.

In order for accurate monitoring of change to take place, it is crucial that the methods employed to establish the baseline be as robust, repeatable, and accurate as possible. Oftentimes, machine-learning algorithms are employed in developing benthic distribution and habitat models (Wicaksona et al 2019). These methods for relating a target class (e.g. substrates, faunal assemblages, habitats) with abiotic or biotic environmental predictors are constantly developing, with some algorithms being better suited than others (Reiss et al 2011, Melo-Merina et al 2020). For example, the capability of an algorithm in producing accurate models based on low sample sizes is often a necessary consideration (Wisz et al 2008), as obtaining biological samples is expensive and time-consuming (Stockwell & Peterson 2002, van Proosdij et al 2016).

This chapter will identify the dominant epifaunal assemblages of four areas along the west coast of Placentia Bay, and describe the interaction between each assemblage and various seafloor and substrate characteristics. Concurrently, the accuracy and predictive capability of one established and one novel machine-learning algorithm will be compared.

2.3 Methods

2.3.1 Survey Areas

Figure 2.1 visualizes the workflow for the entirety of methods employed for Chapter 2. Four survey areas along the west coast of Placentia Bay were selected for surveying: Rushoon, D'Argent Bay, Burin, and St-Lawrence (Figure 2.2). These sites are notable in their ecological importance to Placentia Bay but were inaccessible to previous MBES surveys by the Geological Survey of Canada due to their shallow nature. Rushoon is characterized by a combination of bedrock seascapes, with two deep (200 m) muddy channels running through the southwestern end of the survey boundary (Shaw et al 2011). D'Argent Bay and Burin are both topographically complex and relatively shallow, with the latter located near the relatively large population centers of Burin and Marystown. St. Lawrence is on the southern edge of the Burin peninsula, and exhibits less structural complexity and a gradual shift in depth across the survey area's boundary from coast to the mouth of Placentia Bay.

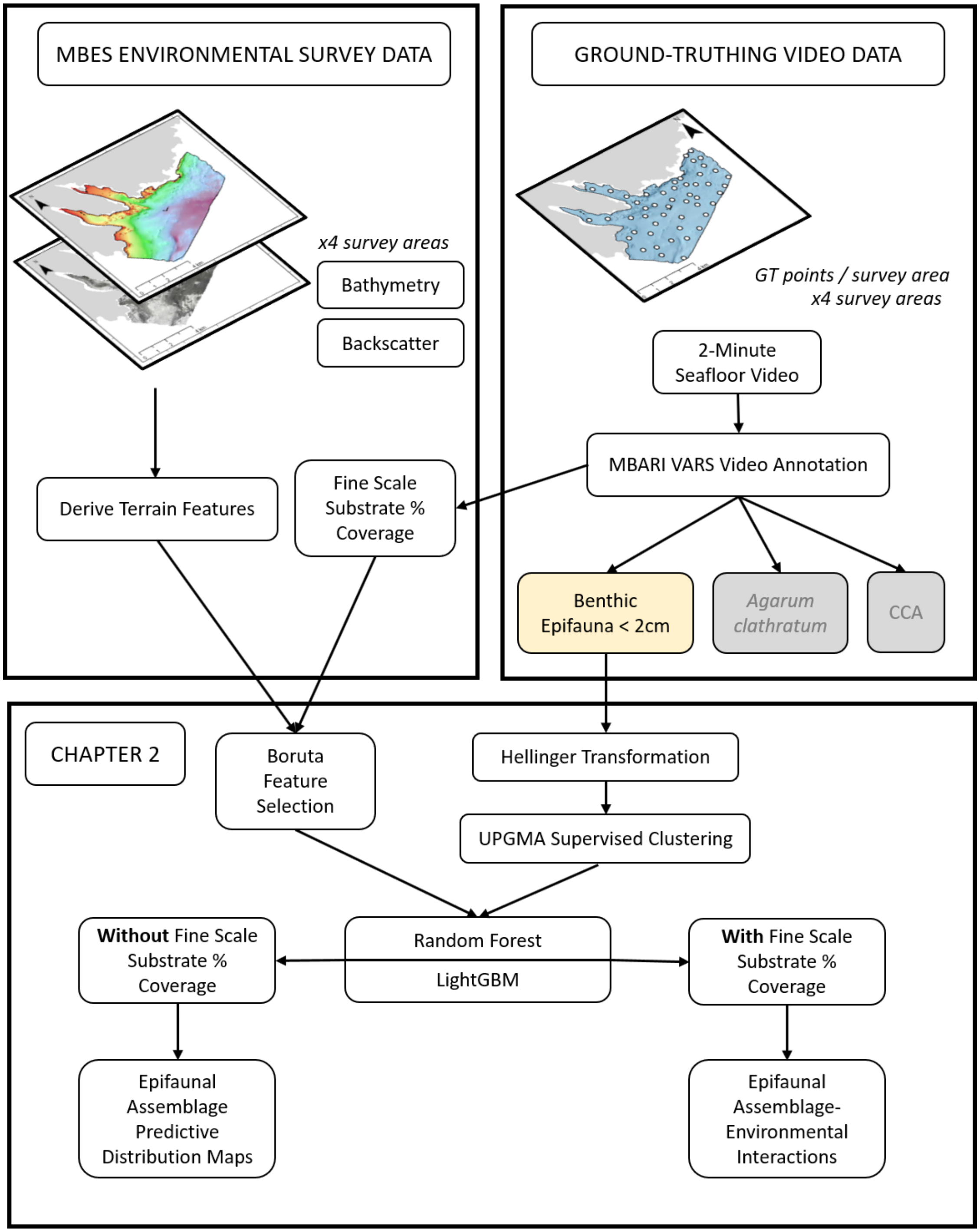

Figure 2.1. A methodological diagram of the workflow employed in Chapter 2 of this thesis. This included multibeam echosounder (MBES) acoustic surveying to collect environmental data and derived benthic epifauna species matrices from underwater video footage of the seafloor at specific ground-truthing (GT) sites. Epifaunal assemblages were determined using an Unweighted Pair Group Method with Arithmetic mean. Predictive distribution maps of dominant epifaunal assemblages were built using both Random Forest and Light Gradient Boosting Machine (LightGBM) techniques.

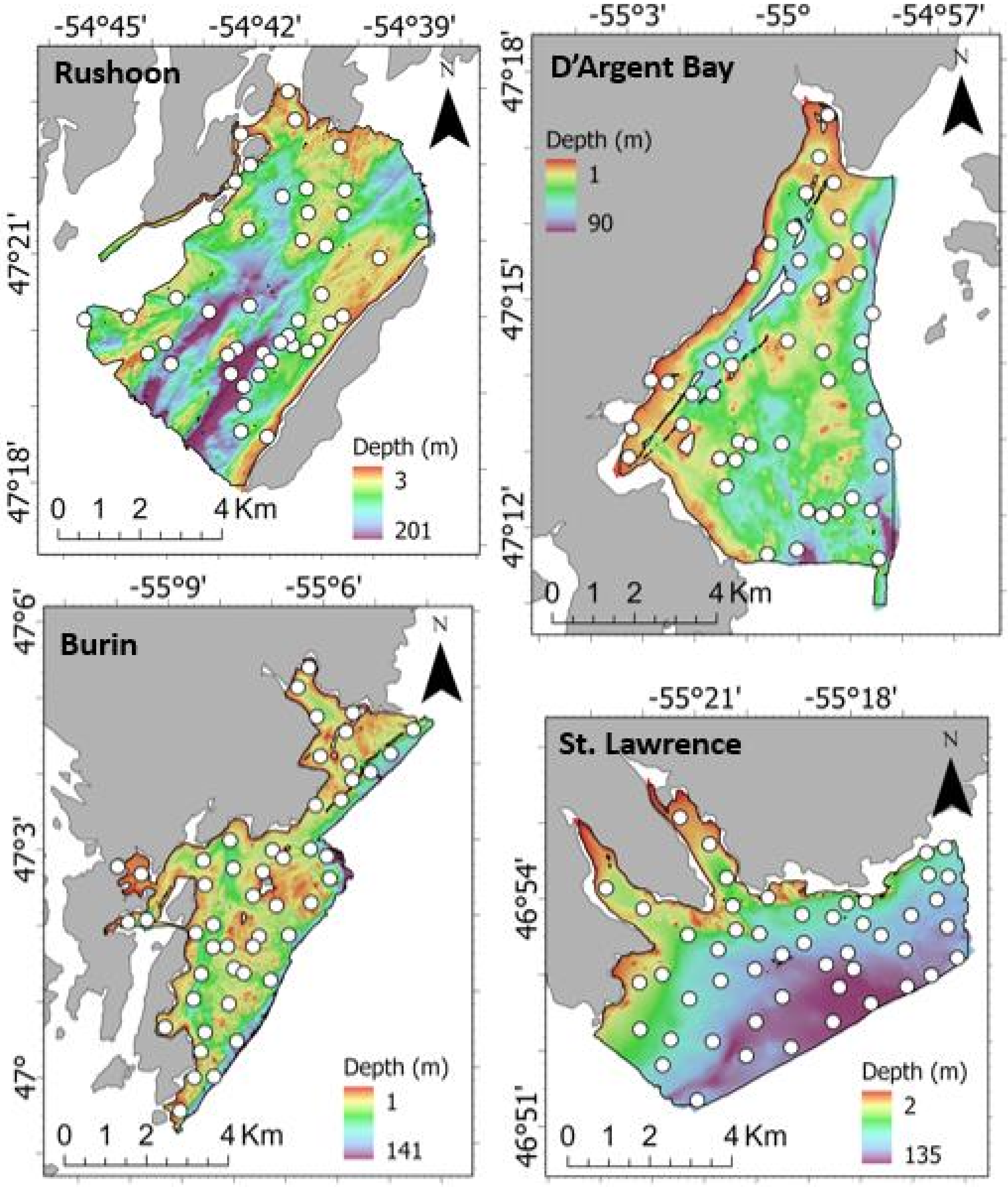

Figure 2.1. Location of ground-truthing sites (white circles), overlaid on the acquired bathymetry (5 x 5 m resolution).

2.3.2 Environmental Surveys

The raw bathymetric and backscatter data were collected first for this research. Multibeam echosounder (MBES) surveying was carried out between Winter 2018 and

Summer 2020 (Table 2.1) onboard the Fisheries and Marine Institute's research vessel *D. Cartwright*, a 27' aluminum vessel. Bathymetry and backscatter were collected using a Kongsberg EM 2040P, operating at 400 kHz. Positioning data were obtained using a Fugro 3610 differential GPS with a Seastar subscription that provided spatial accuracy of up to 8 cm. Sound Velocity Profiles (SVP) between the transducer and seafloor were obtained using an AML BaseX sound velocity profiler. Sound velocity measurements at the MBES transducer head were obtained by an AML Micro SV sound speed sensor.

Table 2.1. Acquisition dates and surveyed area for multibeam surveys.

Site	Dates	Survey Area (km^2)
Rushoon	June – July 2019	39
D'Argent Bay	December, February 2018, April 2019	43
Burin	May 2019	24
St. Lawrence	July – August 2020	37

Raw sonar files for each site were imported into the Quality Positioning Services (QPS) Qimera v2.0.3 software. Tidal fluctuations were adjusted using observations from Argentia, NL tide station (Station #835) for Rushoon and D'Argent Bay. Tidal fluctuations were adjusted using observations from St. Lawrence, NL (Station #755) for Burin and St. Lawrence. SVPs were imported into each respective Qimera project: 25 for D'Argent Bay, 19 for Rushoon, 19 for Burin, and 17 for St. Lawrence. Spline filters were employed to automatically remove outliers, and once processing was completed, a surface of each area was exported as a Floating Point GeoTIFF Grid at 5x5 m resolution. In addition, processed files were exported as .GSF files, and were imported into QPS Fledermaus Geocoder Toolbox (FMGT) v.7.8.4. 64 bit for backscatter processing. The backscatter mosaics were exported at 5x5 m resolution, and the UTM Zone 21 projection was employed for all environmental datasets.

The bathymetric surfaces were used to derive terrain attributes that have been found to influence epifaunal distribution. A plethora of derivable attributes exist, but Lecours et al (2017) identified a set of six that encompassed 70% of the topographic variation observed in the author's independent study. These six attributes were calculated in ESRI ArcGIS using the Terrain Attribute Selection for Spatial Ecology (TASSE) (Lecours 2017) toolbox and included slope (change in elevation), eastness and northness (orientation, calculated as the sine and cosine of slope), relative difference to the mean value (RDMV) (relative position), and standard deviation (SD) (a measure of rugosity) of bathymetry.

The TASSE-derived terrain features optimized the inclusion of topographic information, but additional features may still contribute to the understanding of specific faunal assemblages. For this research, fine and broad Bathymetric Position Index (BPI) and Vector Ruggedness Measure (VRM) were included. BPI is an adaptation of the terrestrial-orientated Topographic Position Index (TPI) (Weiss 2001) that measures relative position of an area to the surrounding seabed and is common in marine science (Lecours et al 2016). Positive and negative values represent peaks and troughs, respectively. VRM incorporates both slope and aspect as a single measure of surface roughness (Hobson 1972), and can provide a different perspective of habitat choice independent of slope (Sappington et al 2007, Martín-García et al 2012). BPI and VRM were derived from the bathymetric surfaces using the Benthic Terrain Modeller (BTM) Version 1.0 (Wright et al 2005).

Additional features were derived from backscatter mosaics based on the spatial distribution of the varying shades of grey (Haralick et al 1973). Three features were calculated using a grey-level co-occurrence matrix via the R package ‘GLCM’ (Zvoleff 2020): contrast (local variation), homogeneity (closeness of distribution), and entropy (randomness) (Haralick et al 1973). These features were selected for their common application in previous studies of similar systems (Blondel & Gómez Sichi 2009, Blondel et al 2015, Samsudin & Hasan 2017, Shang et al 2021).

No single scale can account for all ecological functions of a benthic ecosystem, so it is therefore necessary to include features representing multiple scales to capture as many processes as possible (Dolan 2012, Lecours et al 2015). All features (except for BPIs) were derived using a 3x3 window size (15x15 m), with additional scales obtained using the calculate-average approach outlined by Misiuk et al (2021): the 3x3 m derivatives were then averaged using increasing window sizes (3x3, 13x13, and 35x35 window size) (Table 2.2). BPI values were calculated using a range of outer (and inner) radii: 60 (3), 260 (13), and 700 (35), and 150 (45), 630 (195), and 1750 (525).

In addition, a layer measuring distance from the coast was calculated as it has been found previously to correlate with benthic assemblage distribution (Degraer 2008, Vassallo et al

2018, Richmond & Stevens 2014). Using a shapefile of Placentia as reference for the coastline (Natural Resources Canada), the tool 'Euclidean Distance' in ESRI ArcGIS was applied and distance from the coast calculated within the boundary of each survey area.

Preliminary modelling using the derived features indicated that crucial fine-scale (< 1 m) information was missing. As such, it was decided to include substrate heterogeneity information extracted from videos of the seafloor, to see if model performance improved. Substrate observations were obtained from underwater video of the seafloor that were collected for biological analysis (described in Section 2.3.3). An image was extracted every 10 seconds from each video using Blender v.2.8.2. Each image was then inputted into the ImageJ software (Image processing and analysis in Java) where a 50-square grid was overlaid and a designation of one of seven classes given: bedrock, boulder, gravel-mix, fine sediment (includes both mud and sand as these cannot be reliably distinguished visually), red algae (excluding coralligenous algae), *Agarum clathratum*, and *Saccharina latissima* (Figure 2.3).These classes were selected due to their prevalence in the initial annotation stage. Biogenic substrates were considered with the substrates because observing the substrate underneath was often not possible. Algae presence was also likely to influence the epifauna present. The number of occurrences of each class was divided by the total number of grids for a site, giving the fine-scale (< 1 m) percent coverage (%) of each substrate class for each ground-truthing site.

Table 2.2. Multiscale environmental features calculated at each site.

Feature	**Scale (m)**	**Unit**	**Software**	**Software Source**
Bathymetry (m)	-	meters	-	-
Slope	15, 45, 175	degrees	TASSE[a]	Lecours 2017
Eastness	15, 45, 175	unitless	TASSE	Lecours 2017
Northness	15, 45, 175	unitless	TASSE	Lecours 2017
RDMV[b]	15, 45, 175	unitless	TASSE	Lecours 2017
SD[c]	15, 45, 175	meters	TASSE	Lecours 2017
Fine BPI[d]	15, 45, 175	meters	BTM	Wright 2012
Broad BPI	15, 45, 175	meters	BTM	Wright 2012
VRM[e]	15, 45, 175	unitless	BTM	Wright 2012
Backscatter	-	Value (dB)	-	
Contrast	15, 45, 175	unitless	GLCM[f]	Zvoleff 2020
Entropy	15, 45, 175	unitless	GLCM	Zvoleff 2020
Homogeneity	15, 45, 175	unitless	GLCM	Zvoleff 2020
Distance to Coast (km)	10	meters	‘Euclidean Distance’	
Bedrock (%)		%	ImageJ	
Boulder (%)		%	ImageJ	
Gravel (%)		%	ImageJ	
Fine sediment (%)		%	ImageJ	
Red Algae (%)		%	ImageJ	
Agarum clathratum (%)		%	ImageJ	
Saccharina latissima (%)		%	ImageJ	

[a] Terrain Attribute Selection for Spatial Ecology (TASSE) (Lecours 2017)

[b] Relative Difference to the Mean Value

[c] Standard Deviantion

[d] Benthic Position Index

[e] Vector Ruggedness Measure

[f] Gray-Level Co-occurrence Matices

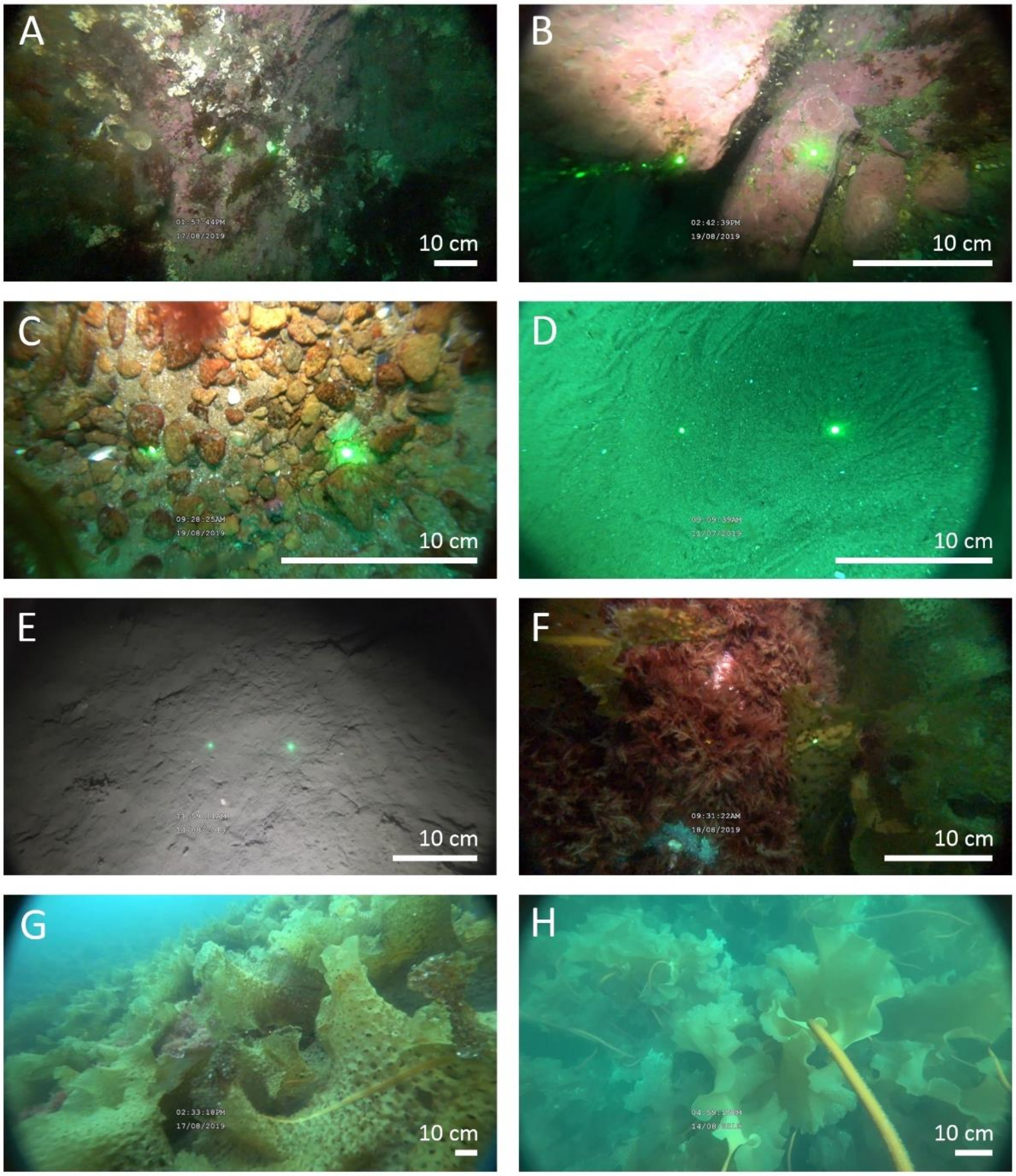

Figure 2.3. Images of the different substrate classes identified during video annotation: A) bedrock, B) boulder, C) gravel mix, D) fine-sediment (sand), E) fine-sediment (mud), F) filamentous red algae (excludes all coralline algae), G) *Agarum clathratum*, and H) sugar kelp (*Saccharina latissima).* All images were taken from towed underwater camera footage within the surveyed areas of coastal Placentia Bay, NL.

2.3.3 Ground-Truthing Surveys

Underwater video was taken at specific point-wise ground-truthing to collect biological and substrate ground-truthing data. The collected videos were annotated for substrate classifications and raw species counts for subsequent cluster analysis. To select ground-truthing points, a Generalized Random Tessellation Stratified (GRTS) survey design (Stevens & Olsen 2004) was run based on bathymetry and backscatter, ensuring that samples across their range were collected. When MBES data was unavailable, bathymetry was interpolated from depth soundings from a nautical chart (e.g. Great St. Lawrence Harbour, Marine Chart CA4642_2). A total of 192 ground-truthing points were sampled using videos (Table A1A, Table A1B).

Two separate underwater camera systems were used. First, a Sony camera FDR-X3000 Action Cam (1920 x 1080, 60 frames/sec), contained in a Deep Blue Abysso waterproof housing, paired with two 3500 lumen neutral white light Cree LED bulbs and two green lasers spaced 10 cm apart. Later, a Deep Trekker DTPod (1920 x 1080, 30 frames/sec). The Deep Trekker DTPod had an integrated light and two red lasers spaced 2.5 cm apart. Non-metric multidimensional scaling was applied to the two epifauna abundance datasets obtained by each camera system to compare their dissimilarity, finding no evidence of differences between the datasets (Figure A1).

For both systems, a live feed back to the boat was available to adjust the height of the camera above the seabed. Boat positioning at the start and end of each transect was obtained using the onboard Garmin GPS 16x, and the midpoint of each transect was used to extract values for each of the terrain attributes previously described.

Table 2.3. Acquisition dates of ground-truthing sites, including the number of sites per survey area and the camera system used.

Site	Time	Number of Sites	Camera System
Rushoon	August 2019	44	FDR-X300
D'Argent Bay	July – August 2019	48	
Burin	July 2020	50	Deep Trekker
St. Lawrence	August 2020	50	

Two-minute long segments were annotated using the Monterey Bay Aquarium Research Institute's (MBARI) Video Annotation and Reference System (VARS) (Schlining & Stout 2006). All organisms larger than 2 cm (size estimated using lasers) were counted and identified to the lowest taxonomic level. When species-level identification was not feasible, a morphotype approach was employed (Howell et al 2019) based on the production of an image catalogue specific to Placentia Bay, Newfoundland (Table A2). Species identification was conducted based on expert knowledge and published species guides (Gosner 1979, Harvey-Clark 1997, Fox et al 2014, Salvo et al 2018). The total number of morphotype/species per transect was calculated and converted to densities by estimating the total area imaged for each transect. Using the software Blender v.2.8.2, 12 frames at 10 second intervals were extracted. Using ImageJ, the distance between the two reference lasers was measured and used to estimate transect width, which was then averaged and multiplied by the total length of the transect as obtained based on the GPS coordinates. Organisms and morphotypes that had an abundance of < 5 individuals across all four survey areas were removed to reduce the influence of low-abundance species. Following this, ground-truthing sites with < 5 counts of epifauna were removed as it would be too few to characterize dominant assemblages (de la Torriente et al 2018).

2.3.4. Developing Faunal Assemblages

The biological data obtained was then analyzed to identify dominant epifaunal assemblages. To reduce the importance of larger abundances of individual species/morphotypes, the species matrix was Hellinger transformed (Legendre & Gallagher 2001, Borcard et al 2011). Doing so is necessary in order for the analysis to focus on relative species composition, without the order of magnitude of the abundances dominating. Epifaunal assemblages were clustered using an average hierarchical clustering method – 'Unweighted Pair-Group Method using arithmetic Averages' (UPGMA) (Sokal & Michener 1958), with hierarchical relationships plotted as a dendrogram. The UPGMA approach was selected as it is fast, simple, and has been found to outperform other clustering algorithms (Kreft & Jetz 2010).

To determine the optimal number of epifaunal assemblages, the dissimilarity values between two branches of the derived dendrogram, or fusion levels, were plotted. In doing so, potential fusion levels at which to cut the dendrogram were identified (Borcard et al 2011). In addition, silhouette widths were calculated and plotted for each fusion level, providing a metric for how distinguishable identified assemblages are from each other. Silhouette widths range from -1 to 1, with 1 representing assemblages that are clearly distinguished, zero (0) representing assemblages that could be misidentified, and -1 is an assemblage likely misidentified. Once epifaunal assemblages were identified, the indicative taxa characterizing each assemblage were identified with an IndVal procedure. An indicator number is assigned to each species that contextualizes its necessity and sufficiency in a cluster (Borcard et al 2011, Legendre 2013). A species accumulation curve was developed for each assemblage to identify if species richness was effectively captured (Ugland et al 2003, Bevilacqua et al 2018).

2.3.5 Modelling of Assemblage-Environment Relationships

As a large number of environmental layers were derived from the bathymetry and backscatter, the suite of environmental features was filtered to remove those deemed uninformative in explaining the spatial patterns of the species assemblages. To reduce the number of environmental features considered, a Boruta Feature Selection (Kursa & Rudnick 2010) algorithm was run separately on sets of features grouped by scale (window of analysis: 3x3, 13x13, 35x35) (Nemani et al 2022). The goal of a Boruta wrapper is to derive z-scores for each feature and its shadow feature, the latter of which contains the same distribution of values but randomly shuffled for each iteration. A feature with a greater z-score than the respective shadow feature was included as important and used for model training (Kursa & Rudnicki 2010).

Feature reduction is advantageous for reducing noise and including only relevant features in a model, which becomes especially important when the aim is to understand species-environment interactions. Degenhardt et al (2019) found the Boruta algorithm to have the greatest potential over other feature selection methods. Previous studies have used this method successfully in marine modelling (Li 2016, Diesing 2017, Nemani et al 2022). Features deemed important or tentative were selected for model training. Further feature reduction took place by removing features that had a correlation with another that exceeded ± 0.7, as determined with the function 'corrplot' (Wei 2013). Multiclass classification models were trained with a dataset that included 2/3 of observations of each faunal assemblage. The remaining 1/3 was reserved as testing data to assess model performance (Diesing et al 2016).

2.2.5.1 Random Forest Model

A random forest (RF) model was employed to identify the environmental features influencing the distribution of the defined faunal assemblages. RF is an ensemble machine-learning algorithm that builds a 'forest' of classification trees from which predictions are obtained through majority voting, and is a common technique employed in the habitat mapping literature (Misiuk et al 2018, Upadhyay et al 2020, Adyin et al 2022). It employs a 'bagging' technique, in which the data set is repeatedly subsampled to build different trees (Quinlan 1986). A distinction of RF is that the developed trees are decorrelated; each split relies on only a random subset of features, instead of the entire available selection. Building random forests was carried out using the R package ‘randomForest’ (Liaw & Wiener 2002). The number of variables included in each split (‘mtry’) was kept as the default value (mtry = 4).

2.2.5.2. LightGBM Model

Light Gradient Boosting Machine (LightGBM) is a recently developed Gradient Boosting Decision Tree machine learning algorithm (Ke et al 2017). Key distinctions between LightGBM and RF include LightGBM’s utilization of ‘boosting’. Unlike in bagging where models are built separately, boosting uses previously built models to influence successive models during learning (Vaghela et al 2009). LightGBM also includes a suite of tunable parameters that adjusts model accuracy by controlling how trees are grown. The parameters recommended in the LightGBM release 3.2.1.99 guide (Zhang et al 2018) were chosen to tune the developed model, and are described and listed in Table 2.4.

Table 2.4. Parameters selected for Light Gradient Boosting Machine model tuning.

Parameter	**Description**	**Range Tested**
‘objective’	Sets the model as regression or classification	‘multi_class’[a]
‘metric’	How the model performance is evaluated	‘multi_error’[b]
‘num_class’	Number of classes predicted	number of faunal assemblages*
‘is_unbalance’	Algorithm automatically balances weights of classes	TRUE, FALSE
‘force_col_wise’	Manages model instability when there is a large number of columns (features)	TRUE, FALSE
‘max_depth’	Controls the maximum distance between a tree’s root node and each leaf node	10, 20, 40, 80
‘num_leaves’	Maximum number of leaves for each learner; manages complexity; adjust with ‘max_depth’	(2^max_depth)
‘learning_rate’	Boosting learning rate	0.05, 0.1, 0.25, 0.5
‘num_iterations’	Number of trees to build; with larger values, adjust with smaller ‘learning_rate’	100, 200, 300, 400
‘feature_fraction’	Sets % of features selected as a subset for each iteration (tree)	0.8, 0.9, 0.95
‘lambda_l1’	L1 regularization	0.2, 0.4
‘lambda_l2’	L2 regularization	0.2, 0.4
‘min_gain_to_split’	Sets the minimum improvement value when evaluating gains at a split	0.2, 0.4
‘early_stopping_rounds’	Stops training when validation metric does not improve; adjust with ‘num_iterations’	10 % of ‘num_iterations’

[a] This sets the model to multiclass classification.

[b] The error rate for multi_class classification.

2.2.5.3. Feature Importance

A feature importance plot was derived from each model type, ranking features based on their predictive importance on the distribution of faunal assemblages. The RF model used Gini Importance, or Mean Decrease in Impurity (MDI), which measures the total decrease in node impurity by calculating the sum over the number of splits including a feature, across all trees (Friedman et al 2001). LightGBM implements “gain”, a gain-based method that is similar to the Gini Importance used by RF (Lundberg et al 2020).

2.2.5.4. Model Performance

The reserved testing data was used to compute a confusion matrix representing the predicted versus observed faunal assemblages (Congalton 1991), from which overall accuracy, Cohen’s kappa, precision, and recall were derived. Overall accuracy is the number of accurately predicted classifications divided by the total number of observations. The kappa statistic provides more detail on how agreement between observed and predicted classifications may be the result of chance (Cohen 1960, Hagen 2002, Allouche et al 2006). Precision measures the proportion of observations predicted that are truly that specified classification (true positive), and how many are supposed to be a different classification (false positive). Recall identifies how many observations of a classification were correctly identified (true positive), and how many were misidentified as something different (false negative) (Deng et al 2016). Both the RF and LightGBM models were run with and without fine-scale (< 1 m) substrate % coverage, to understand how these features impact model performance. To compare their practical application, both models developed without substrate % coverage features were used to predict the occurrence of identified assemblages across all four survey areas. Substrate % coverage could not be included as these features are not spatially-continuous layers. Univariate partial dependence plots were derived from the RF model to visualize the relationship between an individual environmental feature and a specified faunal assemblage (Hastie et al 2001, Vassallo et al 2018).

2.4 Results

2.4.1 Faunal Assemblages

From the original 192 sites surveyed during ground-truthing, 74 sites were dropped for the following reasons: 49 were removed for having low abundance (< 5 individual epifauna counted), 14 for lacking transect length, 10 for issues with extracting point-wise environmental data, and 1 was dropped for being its own cluster. One site (Rushoon 53) was split into two as it exhibited two distinct epifaunal assemblages and a stark change in substrate: the first third of the transect was primarily bedrock with an abundance of green sea urchins (*Strongylocentrotus droebachiensis*) but transitioned to 100 % coverage of fine sediment with a high presence of sand dollars (*Echinarachnius parma*).

A total of 12,096 individuals were counted across the ground-truthing sites. Fifty-five morphotypes were identified, with 14 identified to species level (25.5%) (Table A2). The morphotype 'Ophiuroidea spp.', or brittle stars, had the highest overall abundance, with a count of 6,693 individuals (55.3% of all individuals counted). 'Hormathia sp.1' was the second most abundant morphotype (1,631 individuals; 13.5%), followed by *S. droebachiensis* (766 individuals, 6.33%) and *E. parma* (627 individuals; 5.18%). The phylum Porifera had the most diverse range of morphotypes, with 14 representatives. Echinodermata was second in richness (7 morphotypes and 6 species), followed by Cnidaria (8 morphotypes and 2 species).

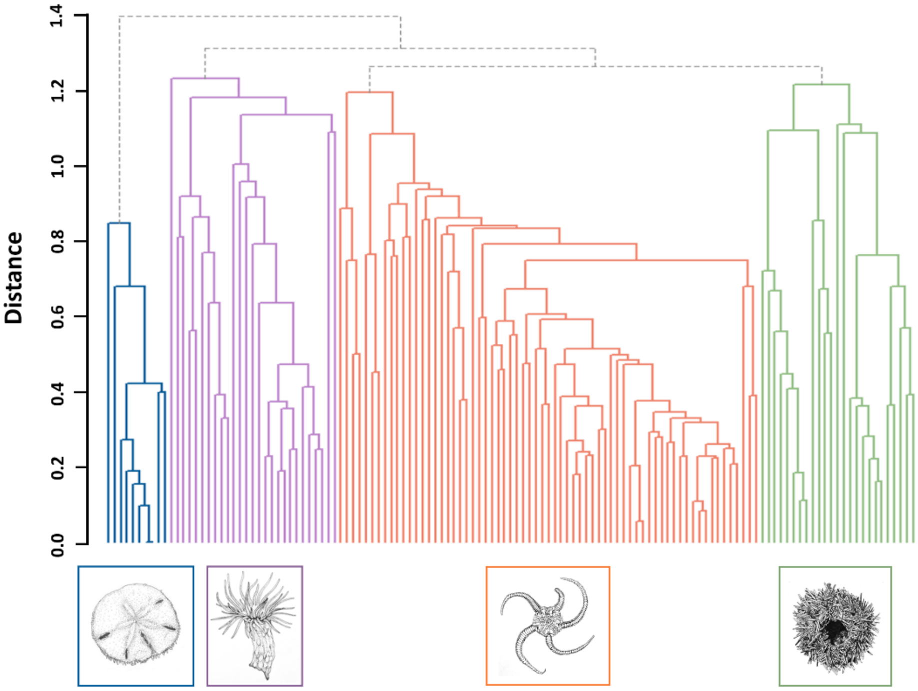

Figure 2.4. Derived dendrogram of the four dominant epifaunal assemblages identified across Placentia Bay's west coast: OPH (orange) is typified by 'Ophiuroidea spp.', 'Porifera sp.5', and 'Hydrozoa sp.1'; SDR (green) is typified by *Strongylocentrotus droebachiensis* and 'Stauromedusae sp.2'; MIX (purple) is typified by '*Hormathia* sp.1', 'Cerianthidae sp.3', 'Cnidaria sp.1', and 'Sagittidae sp.1'; EPA (blue) is typified *Echinarachnius parma* and *Pseudopleuronectes Americanus*. Illustrations included were done by the author.

Four faunal assemblages were identified (Figure 2.4, Table 2.5). 64 of 119 sites (53.8%) were identified as OPH, therefore making it the most prevalent assemblage. OPH was typified by 'Ophiuroidea spp.', 'Porifera sp.5', and 'Hydrozoa sp.1' as determined by the IndVal analysis. Aggregations of 'Ophiuroidea spp.' were found with sometimes 100s to 1000s of individuals at a OPH site. No aggregation included greater than 25 individuals in any other identified assemblage. OPH contained the highest taxa richness (total of 51: 39 morphotypes, 12 species) (Table A3), as well as the most fauna specific to a single assemblage (8 taxa). OPH had the largest depth extent, from a 14 m minimum to a maximum depth of 138 m. The faunal assemblage SDR represented 21 of 119 sites (17.6%) and was typified by *S. droebachiensis* and the morphotype 'Stauromedusae sp.2'. There were 21 different morphotypes/species within the assemblage (14 morphotypes, 7 species), none being unique to this assemblage. SDR had the narrowest depth range, mainly found between 10 m to 41 m, but with 2 outliers (as determined through box and whisker plots) existing at depths of 67 m and 100 m. The MIX assemblage represented 26 of 119 sites (21.8%) and was typified by four morphotypes: 'Hormathia sp.1', 'Cerianthidae sp.3', 'Cnidaria sp.1', and 'Sagittidae sp.1'. MIX had the second highest species richness, with 42 in total (30 morphotypes, 12 species). The only unique species to this assemblage was the morphotype 'Leptasterias sp.1'. MIX had a depth range of 35 m to 114 m, with 2 outliers at 139 and 148 m. The final assemblage, EPA was the rarest with only 8 of 119 representative sites (6.7%). EPA had the lowest species richness, with only 15 different representatives (8 morphotypes, 7 species). EPA was typified by two species: *E. parma* and the winter flounder *Pseudopleuronectes americanus*, with the former unique to this assemblage. Aside from one outlier at 91 m, EPA mainly occurred at a depth range between 12 m and 53 m.

OPH and MIX exhibited higher species richness than SDR and EPA (Figure 2.5). Accumulation curves representing species richness of individual assemblages did not taper into an asymptote, which indicates that further sampling would be beneficial (Gray et al 2004). However, a taper was evident when including the species richness across all sampling.

Table 2.5. Indicator species identified by IndVal analysis of faunal assemblages.

Name	Number of sites	Indicator Morphotype/Species	Species Present	Unique to this cluster	Images*
OPH	*64*	Ophiuroidea spp. Porifera sp.5 Hydrozoa sp.1	51	8	
SDR	*21*	*Strongylocentrotus droebachiensis* Stauromedusae sp.2	20	none	
MIX	*26*	Hormathia sp.1 Cerianthidae sp.3 Cnidaria sp.1 Sagittidae sp.1	42	1	
EPA	*8*	*Echinarachnius parma* *Pseudopleuronectes americanus*	15	1	

*Images follow the order listed under the 'Indicator Species' column for each faunal assemblage.

The assemblages OPH, SDR, and MIX occurred on heterogeneous seabed, with OPH and MIX predominantly associated with boulders and gravel mix (Figure 2.6). SDR had the largest % occurrence of *A. clathratum* (26.5%), with additional characterization by fine sediment (25.9%) and red algae (15.1%). OPH had a 20% coverage of filamentous red algae and 8.8% of *A. clathratum*, while MIX and EPA had < 2.0% coverage of either macrophyte substrate (Figure 2.6). EPA was predominately characterized (93.7%) by fine sediment.

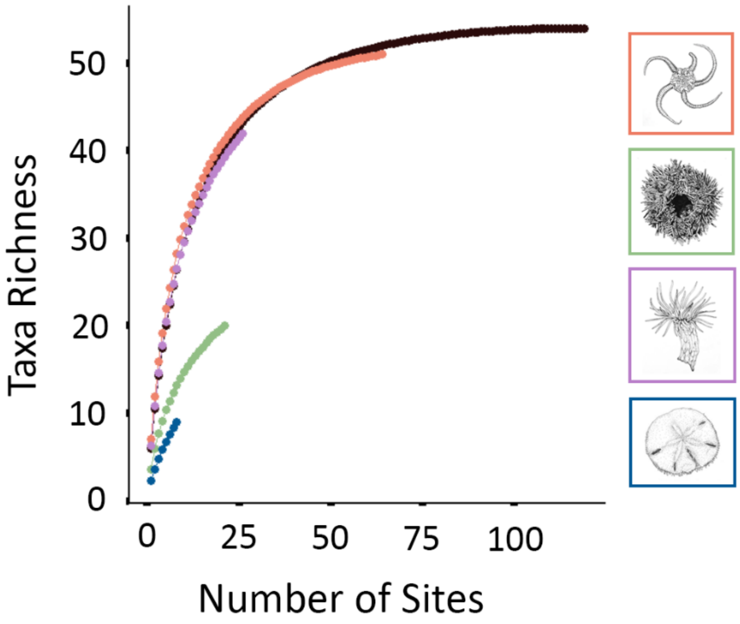

Figure 2.2. Species accumulation curves were developed for all sites included in the analysis as well as individual faunal assemblages: OPH (orange), SDR (green), MIX (purple), EPA (blue), and all sites (black).

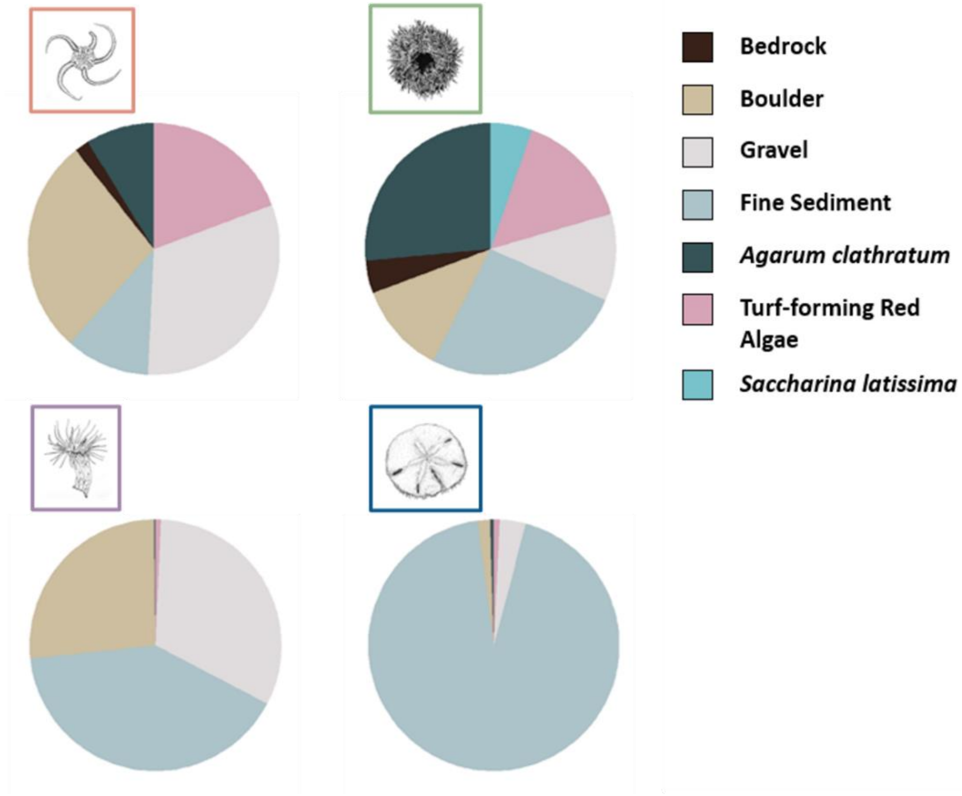

Figure 2.3. Substrate percent coverage for each epifaunal assemblage based on image analysis of ground-truthing sites.

OPH was relatively evenly distributed (20 – 31%) across all four survey areas, and made up the majority of ground-truthing sites within each survey area (Figure 2.7). MIX was most prevalent in St. Lawrence, occurring as a narrow band running parallel to the coast. In Rushoon, MIX was found spatially clustered within one of the deep (> 100 m) channels. The majority of SDR occurred within Burin. 62.5% of these sites identified as EPA occurred within St. Lawrence, with only one occurrence in each of the other three survey areas (Figure 2.7).

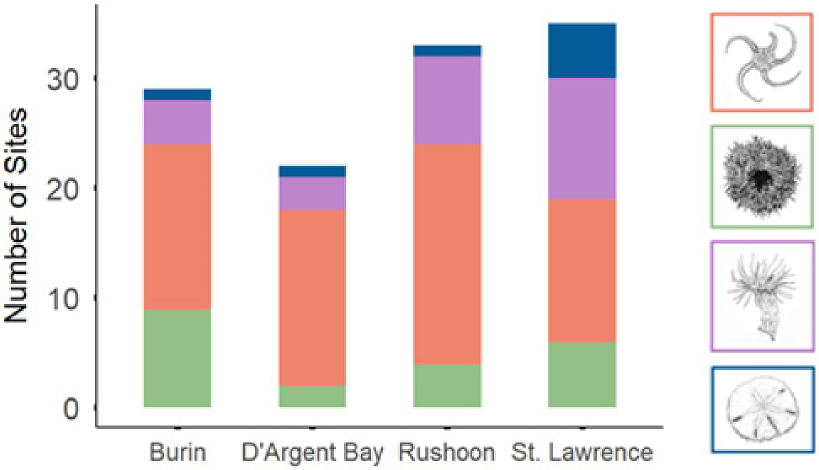

Figure 2.4. The occurrence of each assemblage within each survey area, based off of the number of ground-truthing sites identified as each assemblage.

2.4.2 Spatial Prediction

The Boruta feature selection identified 11 features as important or tentative to the model (Figure A4). Three features (VRM 3x3, Slope 13x13, Homogeneity 35x35) were removed due to their high collinearity (≤ -0.7, ≥ 0.7) to another feature that was to be included instead (Figure A5A). Ten features were automatically included for model development, as these features were only considered at a single scale. In total, 18 features were selected for the training of both the RF and LightGBM models (Table 2.6).

Table 2.6. Environmental features used in model training, including those deemed important or tentative by the Boruta feature selection algorithm.

Environmental Feature	Boruta Feature Selection
Bathymetry (m)	not applicable
Backscatter	
Distance to Coast (km)	
Bedrock % Coverage	
Boulder % Coverage	
Gravel % Coverage	
Fine Sediment % Coverage	
Red Algae % Coverage	
Agarum clathratum % Coverage	
Saccharina latissima % Coverage	
RDMV (3x3)	tentative
VRM (13x13)	important
Contrast (13x13)	tentative
Slope (35x35)	important
Fine BPI (35x35)	important
Broad (525x525)	important
Contrast (35x35)	important
Entropy (35x35)	important

2.4.3 Model Performance

The RF confusion matrix derived from the test data indicated an accuracy of 78.1% and a kappa of 0.62. The RF model overestimated the occurrence of OPH, indicated by the precision rate of 75%; a quarter of the model's predicted OPH observations were not actually OPH observations. There were few missed OPH observations, so recall was higher with a rate of 95.4%. As a result of this overestimation, however, a large number of SDR and MIX observations were incorrectly classified as OPH, and their recall rates were 33.3% and 60%, respectively. The model did well in identifying the observations of the rare EPA assemblage: 100% of EPA observations were correctly identified (Table 2.7).

The LightGBM model produced an accuracy of 75.6% (kappa = 0.59). Details regarding parameter tuning can be found in Table A6. The LightGBM model exhibited a tendency to overpredict the OPH assemblage. Recall indicated that 90% of true OPH observations were correctly identified; however, the model overestimated OPH occurrence as only 80 % of those identified as OPH were truly OPH. The LightGBM model did only slightly better when identifying true SDR and MIX; precision rates were 57% and 77.8%, respectively. LightGBM was unable to correctly predict any of the EPA assemblages, with both precision and recall rates of 0%, and one observation identified as EPA when it was actually SDR (Table 2.7). Both models performed worse when fine-scale substrate % coverage features were removed. The RF model dropped to an accuracy of 61% (kappa = 0.3087) and the tuned LightGBM model dropped to an accuracy of 68.29% (kappa = 0.467).

Table 2.7. Confusion matrix output derived from the reserved test data for both the Random Forest and Light Gradient Boosting Machine (LightGBM) models that included fine-scale (< 1 m) substrate % coverage features. Ground-truthing observations (*References*) are on top. Red indicates an incorrect assemblage assignment.

Random Forest		*Reference*				
		OPH	SDR	MIX	EPA	*Precision*
Prediction	OPH	**21**	3	4	0	75 %
	SDR	0	**2**	0	0	100 %
	MIX	1	0	**6**	0	85.7 %
	EPA	0	1	0	**3**	75 %
	Recall	95.5 %	33.3 %	60 %	100 %	

LightGBM		*Reference*				
		OPH	SDR	MIX	EPA	*Precision*
Prediction	OPH	**20**	2	2	1	80 %
	SDR	0	**4**	0	2	66.7 %
	MIX	2	0	**7**	0	77.8 %
	EPA	0	1	0	**0**	0 %
	Recall	90.9 %	57.1 %	77.8 %	0 %	

Maps built from both models reinforced the dominance of OPH across the four survey areas (Figure 2.8, Figure 2.9). However, the LightGBM model underestimated the occurrence of the rarer assemblages. This was particularly apparent for the MIX assemblage which was predicted by the RF model to occur in D'Argent Bay (1.75 km^2), Burin (0.43 km^2), and St. Lawrence (6.62 km km^2), but was underestimated or deemed absent by the LightGBM model, even in areas where it had been observed during ground-truthing (Figure 2.9, Table A7). The LightGBM model also predicted less coverage of SDR along the coast of D'Argent Bay and St. Lawrence, and determined EPA to be absent from all survey areas aside from D’Argent Bay, albeit having been observed four survey areas (Figure 2.9).

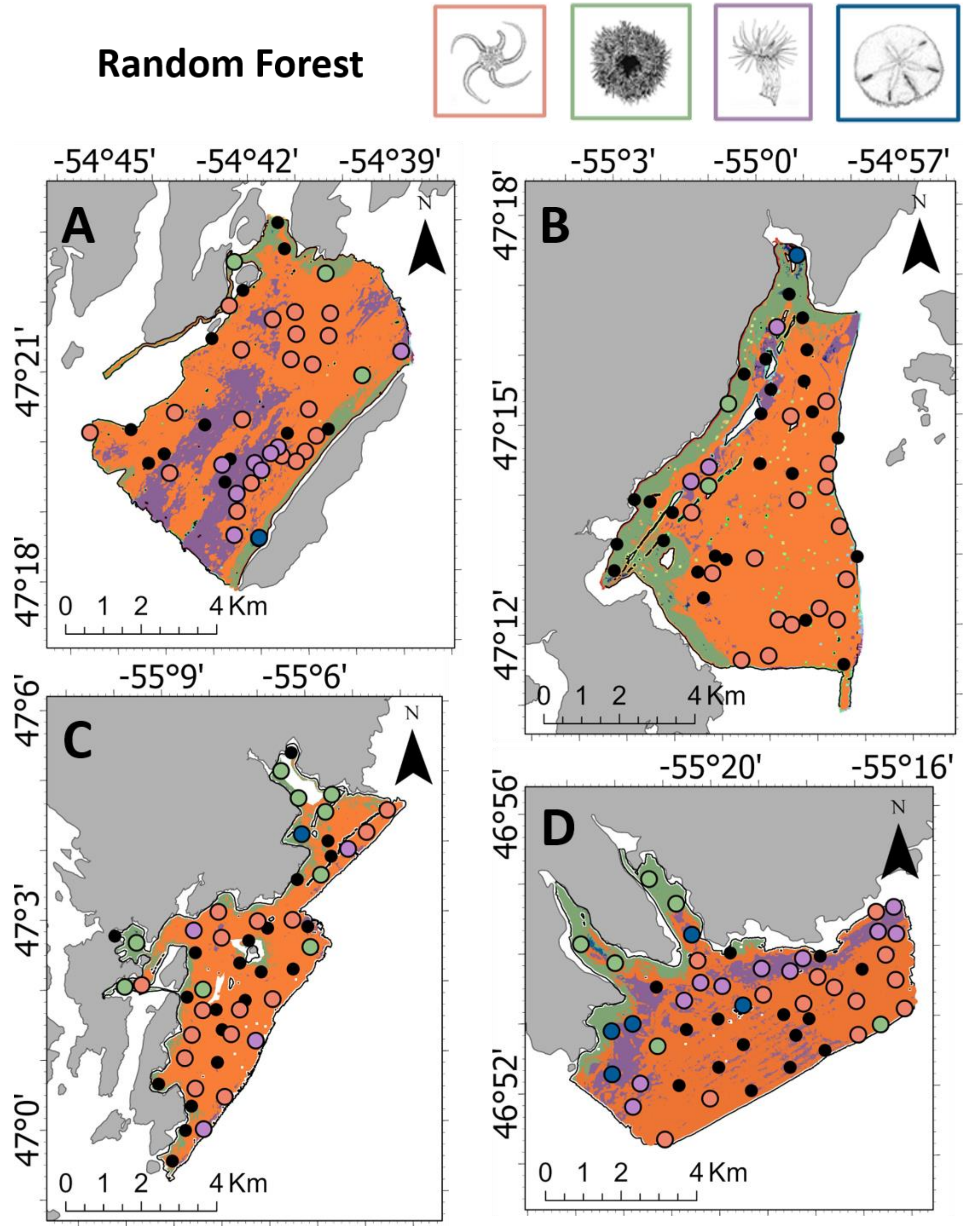

Figure 2.8. Spatial predictions by the Random Forest model for the four epifaunal assemblages (OPH (orange), SDR (green), MIX (purple), and EPA (blue)) across the four survey areas located along the west coast of Placentia Bay: Rushoon (A), D'Argent Bay (B), Burin (C), and St. Lawrence (D). Circles are ground-truthing sites with their assigned assemblage; black indicates a site removed before analysis. Spatial prediction does not include fine-scale (< 1 m) substrate % coverage. Refer to Figure 1.4 for the spatial orientation of the listed survey areas within Placentia Bay.

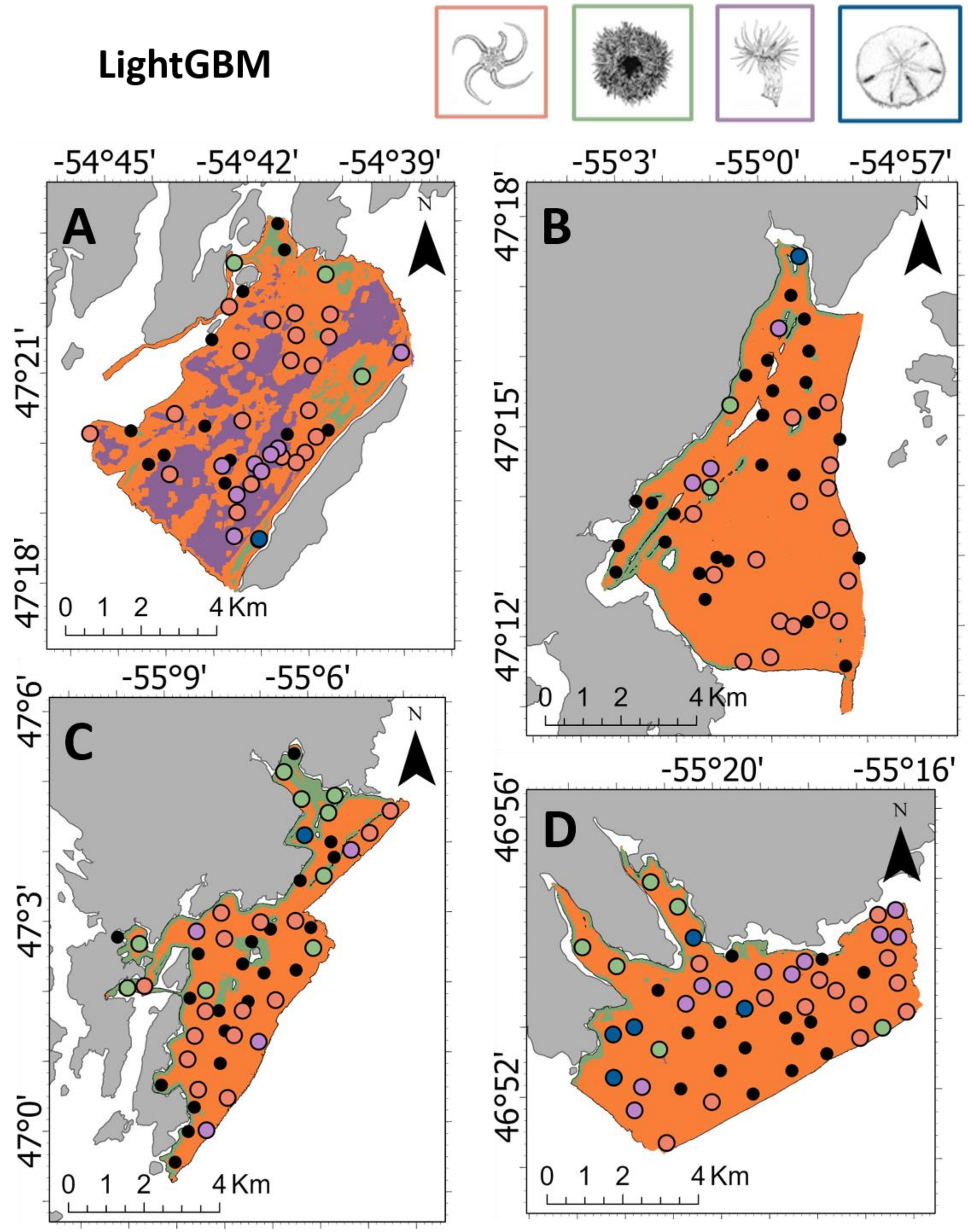

Figure 2.5. Spatial predictions by the Light Gradient Boosting Machine (LightGBM) model for the four epifaunal assemblages (OPH (orange), SDR (green), MIX (purple), and EPA (blue)) across the four survey areas located along the west coast of Placentia Bay: Rushoon (A), D'Argent Bay (B), Burin (C), and St. Lawrence (D). Circles are ground-truthing sites with their assigned assemblage; black indicates a site removed before analysis. Spatial prediction does not include fine-scale (< 1 m) substrate % coverage. Refer to Figure 1.4 for the spatial orientation of the listed survey areas within Placentia Bay.

Both models agreed on the three most important features explaining faunal assemblages' spatial patterns: 'Bathymetry (m)', 'Distance to Coast (km)', and 'Fine Sediment % Coverage'. However, the RF model identified 'Bathymetry' as the most important, while the LightGBM model identified 'Distance to Coast (km)' as the most important feature. The RF model gave emphasis to 'VRM 13x13' while the LightGBM model emphasized 'Backscatter' (Figure 2.10).

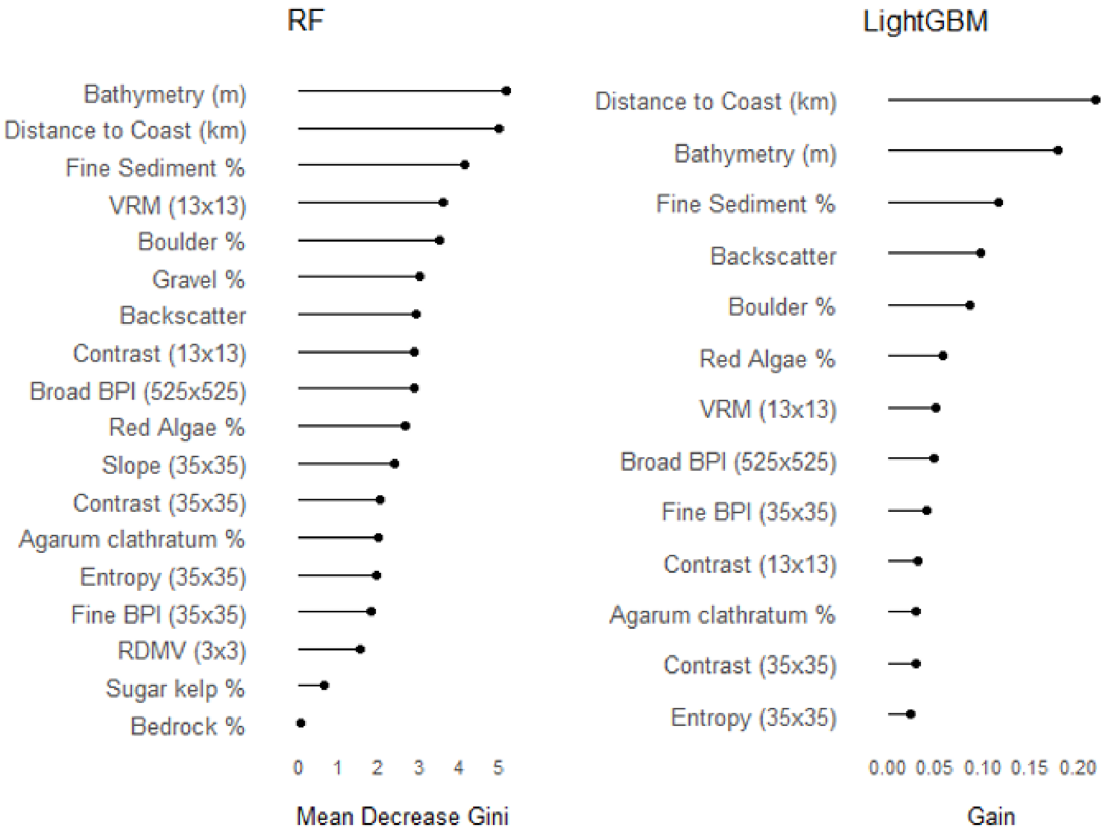

Figure 2.10. Feature importance as determined by Random Forest (left) or Light Gradient Boosting Machine (LightGBM, right) model via their respective method. The LightGBM did not include all features in model development, excluding those with too low a 'Gain'.

2.4.4 Assemblage Environment Relations

Based on partial dependence plots (PDPs) derived from the better performing RF model, OPH and MIX were associated with the deeper portion of the surveyed area, while SDR and EPA favored depths shallower than 50 m. EPA showed different associations as compared with all three other assemblages with respect to the five most important features: ‘Bathymetry (m)’, ‘Distance to Coast (km)’, ‘Fine Sediment % Coverage’, ‘VRM (13x13)’, and ‘Boulder % Coverage’. EPA was associated with distances within 2 km of the coast. OPH, in contrast, preferred habitat that was farther than 2 km, up to the farthest extent of the surveyed area (5 km). EPA was the only assemblage that benefitted from increased coverage of fine sediment, while all other assemblages were less likely to associate with sediment dominated areas. OPH, SDR, and MIX were less influenced by flat and even seafloor, as indicated by ‘VRM (13x13)’. EPA was the opposite, with a sharp decline when ruggedness, and ‘Boulder % Coverage’, were greater than 0 % (Figure 2.11).

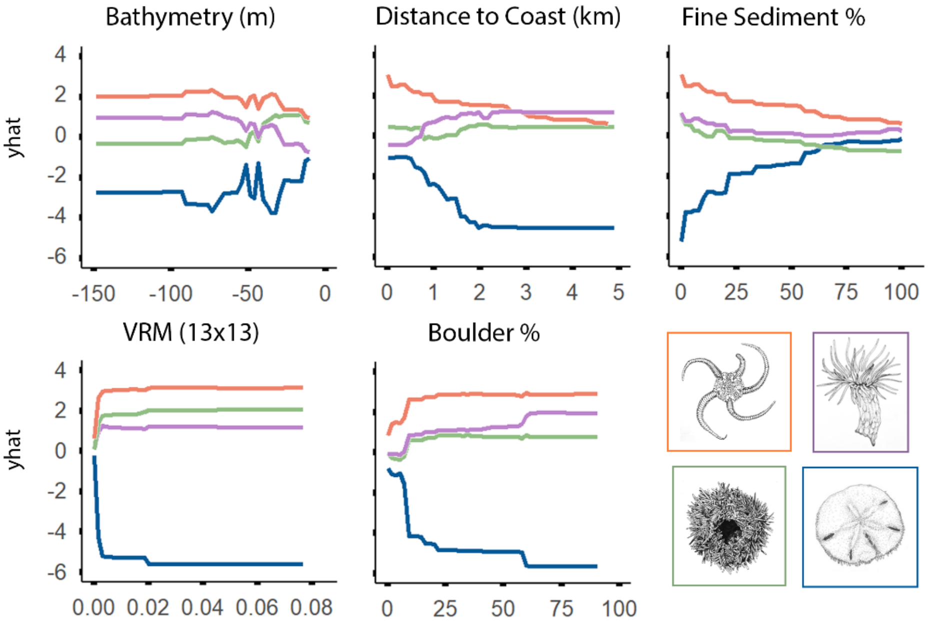

Figure 2.6. Univariate partial dependence plots derived from the Random Forest classification model for the top five most important explanatory environmental features. The 'yhat' axis refers to the value of partial dependence function. The lines indicate how each individual assemblage responds to the value of specific feature of interest. A PDP for every feature included in model training, with the association of that feature and each assemblage, can be found in Figure A8.

2.5. Discussion

The present study identified four distinct epifaunal assemblages within the boundaries of four ecologically important areas along the west coast of Placentia Bay: OPH (typified by 'Ophiuroidea spp.', 'Porifera sp.5', and 'Hydrozoa sp.1', with the highest abundance and occurrence), SDR (typified by *S. droebachiensis* and 'Stauromedusae sp.2"), MIX (typified by 'Hormathia sp.1', 'Cerianthidae sp.3', 'Cnidaria sp.1', and 'Sagittidae sp.1'), and EPA (typified by *E. parma* and *P. americanus*). The spatial distribution of these assemblages is primarily influenced by depth, the distance from the coast, seafloor rugosity, as well as fine-scale (< 1 m) substrate composition, specifically the proportion of fine-sediment (mud/sand) and boulder. This study also found that the LightGBM model had high model accuracy, but was unable to predict the rarer assemblages, making it less useful than the RF model in this context.

2.5.1 Assemblage-Environment Relationships

Depth is often found as an important variable explaining the distribution of benthic epifaunal assemblages (Neves et al 2014, Schückel et al 2015), however, depth is often acting as a proxy for other co-varying features not included in the model, such as light availability, temperature, salinity, wave action, or ice scouring (Elith & Leathwick 2003, Nyström Sandman et al 2013). Most observations of SDR were restricted to depths of up to 40 m, likely due to the association SDR had with *A. clathratum*. *A. clathratum* is a relatively deep-penetrating kelp species (Krause-Jensen et al 2019), with observed limits in this study of up to 60 m, which align with the drop-off in the presence of this assemblage at depths of ~50 m. EPA was found at shallower depths as adult *E. parma* migrate from greater depths to shallower regions as they grow larger in order to take advantage of the greater abundance of food, such as benthic diatoms (Cabanac & Himmelman 1996, Cabanac & Himmelman 1998).

In contrast, OPH and MIX were found across most of the depth range of surveyed sites. The dominant epifauna of these assemblages included porifera and cnidarians, with dense ophiuroid beds in OPH and abundant '*Hormathia* sp.1' aggregations in MIX. As these epifauna are reliant on filter- and suspension-feeding techniques, a major constraint on their survival would be food availability coming from the euphotic zone to the benthos (Maldonado et al 2017), a factor dependent on hydrography more than depth in coastal areas (Grebmeier & Barry 1991, Graf 1992). Placentia Bay's west coast is subject to upwelling currents (Ma et al 2012) that may be beneficial to filter- and suspension-feeders, though the strength of water flow may be interrupted, deflected, or accelerated by the complex topography and shoreline found in the small embayments that were the focus of this research (Largier et al 2020). This is reinforced by Hogg et al (2010) finding sponge aggregations settling where currents deliver a constant food supply, as well as *Hormathia digitata* being found to populate areas with faster velocity currents (Dunlop et al 2020).

This feeding strategy may also be why OPH and MIX prefer being further from shore. Distance from the coast may be an indicator for distance from a sediment source via coastal erosion (Stephens & Diesing 2015, Misiuk et al 2018). Sessile organisms can be overwhelmed by sediment load inhibiting feeding strategies (Kutti et al 2015, Dunlop et al 2020). Deeper water (≥ 100 m) may provide more stable sediments (Rosellon-Druker & Stokesbury 2019), as well as the potential for less pressure from predators such as seastars (Aronson 1992, Haedrich et al 1980, Howell et al 2002), the latter of which exerts top-down pressure inhibiting the formation of ophiuroid aggregations (Aronson & Sues 1987). *E. parma*, the main indicator species of EPA, inhabit areas characterized by coarse sand (Stanley & James 1971, Sisson et al 2002) which is necessary not only to filter for food (where coarse sands trap particulate matter for consumption, without excess fouling (Bland et al 2019)), but also for shelter as *E. parma* buries into the sediment to avoid predation (Manderson et al 1999, Pappal et al 2012) and damaging storm surge (O'Neill 1978).

All three other assemblages, OPH, MIX, and SDR, mostly occurred in areas characterized by the presence of harder substrate and high seafloor rugosity. Owing to the highly heterogeneous nature of the seafloor in Placentia Bay, fine-scale (< 1 m) substrate information (i.e. visually assessed % coverage of substrate classes) increased model performance by ~ 25%. The ability to capture increased structural complexity allows for identification of potential 'keystone structures', defined as a structure that directly bolsters species richness (Tews et al 2004). As an example, *Hormathia* sp.1 was often seen attached to the sporadic boulders scattered across the silt-covered seafloor in the deep channels within Rushoon while ‘Stauromedusae sp.1’ was only seen attached to a *A. clathratum* blade.

2.5.2 Diversity

The boulder fields and bedrock outcrops within Placentia Bay may represent rocky reefs, an ecologically important habitat characterized as a subtidal natural hard substrate (Gavazzi et al 2021). These are structurally heterogenous habitats, which are often associated with increased species abundance and diversity (Barry & Dayton 1991, Bracewell et al 2018, MacArthur & Wilson 1967, Bazzaz 1975). However, rocky reefs are severely impacted by human activities, facing growing impacts due to improved bottom gear technology (Halpern et al 2008, Hemery & Henkel 2016). There is also a lack of understanding of the associated diversity specific to rocky reefs of the subtidal (Gallucci et al 2020).

This research identified the increased diversity associated with rocky reefs within the surveyed areas of Placentia Bay’s subtidal. The assumed rocky reefs in the present study were associated with a higher presence of arcto-boreal species, such as the different morphotypes of porifera and anthozoan as well as species of echinoderms and crustaceans. This includes biogenic structures such as sponges, cnidarians, and macroalgae. OPH and MIX were colonized by a greater abundance and richness of morphotypes from the Phylum Porifera (1,064 individuals, 25 representatives) (Table A3), which would further increase habitat complexity.

Sponges and cnidarians are worthwhile organisms to consider for careful monitoring, with rocky reefs a good target for conservation efforts. Both groups serve to further increase local diversity in the Placentia Bay rocky reef habitats. Their complex body structures increase the local small-scale heterogeneity, and therefore niches for organisms to take advantage of (Ribeiro et al 2003, Fiore & Jutte 2010, Gallucci et al 2020).
In addition, rocky reefs from temperate zones to the Arctic are often covered with canopy-forming kelp species. Likely, the dense coverage by *A. clathratum* in SDR would also increase habitat complexity. Kelp forests are recognized for their role as primary and secondary producers, refuge from predators, nursery grounds, and as increased habitat for utilization by fauna (Teagle et al 2017). Although kelp forests are known to be a productive ecosystem, fewer species than expected were observed in this habitat in Placentia Bay. However, this likely results from the fact that seabed visibility was strongly limited by the presence of kelp blades.

2.5.3 LightGBM vs RF

The present study employed the new LightGBM machine learning technique to examine spatial patterns in species assemblages. Owing to the class imbalance, the performance between the RF and LightGBM models was comparable in terms of model accuracy and variable importance, but LightGBM could not adequately predict the rarer assemblages.

LightGBM is a powerful modelling technique, but it was developed to manage large datasets (i.e. 100,000 observations) (Ke at al 2017), a magnitude not yet common in benthic habitat mapping.

For larger datasets, LightGBM advantages include its potential for higher accuracy than other boosting algorithms, fast training speed, low memory usage (Ke et al 2017, McCarty et al 2020) and in-depth control over the model learning via parameter tuning. This latter point requires the user to be confident in their understanding of each parameter. In contrast, RF has only two parameters, making it a more user-friendly algorithm (Liaw & Wiener 2002, Brieman 2001), which has shown continual success in benthic habitat mapping studies (Lucieer et al 2013, Robert el al 2015, Rooper et al 2017, Misiuk et al 2019, Pillay et al 2020, Shang et al 2021). The findings from comparing the two different machine learning algorithms supports the continued use of RF as a modelling technique which can perform well with the limited amount of data that characterize many marine studies. It will be of future interest to determine whether the newer LightGBM algorithm shows better performance when informed with larger datasets.

The current study identified important ecological habitats such as rocky reef substrates and kelp beds. This study also predicted the spatial patterns of species assemblages across four areas of Placentia Bay where industrial development and increased vessel traffic are expected to lead to higher anthropogenic impacts. This provides a snapshot reference from which managers can make informed decisions to try and mitigate potential negative impacts from these activities.

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Chapter 3. Secret gardens of coastal Placentia Bay: spatial patterns of two macrophytes and the physical variables that influence their distribution.

3.1 Abstract

Highly productive kelp forests populate the rocky subtidal of temperate to sub-arctic coasts (Steneck et al 2002), but they are subject to phase-shifts with ‘urchin-barrens’ (Lawrence 1975, Filbee-Dexter et al 2016), a state of reduced vegetative coverage caused by herbivorous pressure that results in an ecosystem with stunted productivity and diversity (Filbee-Dexter et al 2014). However, Placentia Bay’s subtidal is host to beds of the brown kelp *Agarum clathratum* and fields of non-geniculate crustose coralline algae (CCA), which can also provide habitat for epifauna. This research identifies the influential seafloor characteristics associated with both target macrophytes, and establishes a baseline for their distribution across the four surveyed sites. Rocky terrain, such as boulders, are associated with their distribution at a fine scale (< 1 m). Depth has a prominent role in explaining the distribution of *A. clathratum*, but is less influential on the low-light tolerant CCA group. Excluding St. Lawrence, both macrophytes occurred in more than half of the ground-truthing sites of each survey area. This level of abundance may change with climate and anthropogenic stressors expected to occur in Placentia Bay. Therefore, a baseline would benefit management and conservation efforts by describing the spatial distribution of these two distinct macrophyte groups.

3.2 Introduction

Kelp forests are one of the world's most productive marine ecosystems on Earth (Mann 1973, Brady-Campbell et al 1984), one which provides ecosystem services such as supporting fishes like pollock, plaice, cunner, and cod, (Witman & Lamb 2018) and boosting local biodiversity (Beaumont et al 2008, Hynes et al 2021). A diverse range of kelps historically populated the rocky subtidal of temperate to sub-arctic coasts (Steneck et al 2002); however, phase-shifts from highly productive forests of kelps (order Laminariales) to an 'urchin-barren' stable-state have been reported along thousands of kilometers of coastline across the northwest Atlantic (Lawrence 1975, Harrold & Reed 1985, Gagnon et al 2004, Filbee-Dexter et al 2014). These 'urchin-barrens' are the result of herbivorous pressure by the green sea urchin, *Strongylocentrotus droebachiensis*, which consumes kelps, leading to reduced primary productivity and habitat complexity (Filbee-Dexter et al 2014). Remaining macrophyte taxa within barrens are the kelp *Agarum clathratum* and non-geniculate, crustose coralline algae (CCA). *Agarum clathratum* is believed to deter urchins via integrated phenolic compounds that render them unpalatable (Vadas 1977, Larson et al 1980). CCA differs from free-living rhodoliths in that they are found encrusting hard surfaces. When compared to fleshy macrophytes, CCA are a poor nutritional substitute for urchins (Agatsuma 2000, Kelly et al 2008), and may benefit from reduced competition once other kelps have been consumed (Johnson & Paine 2016).

A. clathratum and CCA are associated with their own unique epifaunal diversity. The physical structure of *A. clathratum* hosts a stable suite of specific invertebrates at varying life stages, such as polychaetes, copepods, and gastropod eggs (Bégin et al 2004, Blain & Gagnon 2014). CCA provides substrate, refuge, and food for epifauna (Freiwald 1993, Jørgensbye & Halfar 2016), with some larvae using chemical cues from CCA to signal invertebrate larval settlement (Swanson et al 2006, Tebben et al 2015). A high abundance of horse mussels (*Modiolus modiolus*), northern red chitons (*Tonicella ruber*), and daisy brittle stars (*Ophiopholis aculeate*) and a rich collection of other invertebrate fauna that echoes kelp forest species richness (Ojeda & Dearborn 1989, Chenelot et al 2011) have been found on CCA in the Northwest Atlantic (Adey et al 2013).

Both of these macroalgae are common along the western coast of Placentia Bay, an embayment on the southern side of the Island of Newfoundland that has been identified as an Ecologically and Biologically Significant Area (EBSA). This EBSA status has prompted Placentia Bay's inclusion in the Government of Canada's Coastal Environment Baseline Program, which seeks to establish a baseline knowledge of the current environmental status to understand changes over time. As biological samples are time consuming and expensive to obtain, spatially continuous environmental (e.g. topographic and oceanographic) conditions, which are easier to obtain, can be statistically linked to the spatial patterns of target species. The resultant species-environment relationships are then applied to predict the spatial distribution of the target species across the entire area for which environmental conditions are available (Brown et al 2011). This allows for a faster development of monitoring and management tools, including increasing our understanding of the environmental variables influencing the distribution of species.

Species-environmental modelling was first employed for terrestrial work, but has found applications in different marine disciplines such as conservation (Greathead et al 2015, Novaczek et al 2017), management (Sahri et al 2021), invasive species mitigation (Báez et al 2010), and climate change (Gormley et al 2015). Seafloor structures influence the distribution of benthic flora and fauna, with different physical attributes of the seafloor being more or less suitable depending on a species' niche (Bekbby et al 2009, Robert et al 2015). Acoustic surveys of the seafloor can provide high-resolution, spatially-continuous layers quantifying depth (bathymetry), backscatter (seafloor hardness), and a suite of secondary features derived from the former layers (e.g. slope, terrain variability (Wille 2005, Collier & Brown 2005, Brown et al 2008, Brown et al 2011, Lecours et al 2016). Different seafloor characteristics have the potential to influence the distribution of both *A. clathratum* and CCA. For example, slope, as derived from bathymetry, can act as a proxy for harder to measure variables such as sediment transport (Tong et al 2016, Misiuk et al 2018) and influence the availability of light or attachment capability of kelps (Vassallo et al 2018, Bekkby et al 2019).

With other kelp species currently subject to intense urchin grazing, this study focused on examining the spatial patterns associated with *A. clathratum* and CCA along the western coast of Placentia Bay. In particular, this research will focus on discerning the physical characteristics of the seafloor that influence both of these ecologically important taxa.

3.3 Methods

3.3.1 Survey Sites

Figure 3.1 visualizes the workflow for the entirety of methods employed for Chapter 3. Spatially-continuous layers of acoustic data were surveyed using MBES across the four survey areas selected due to their ecological or socio-economic importance to Placentia Bay. Raw sonar data were processed into both bathymetric and backscatter layers, from which additional terrain attributes were derived for model development. Details have been outlined in Section 2.2.1.

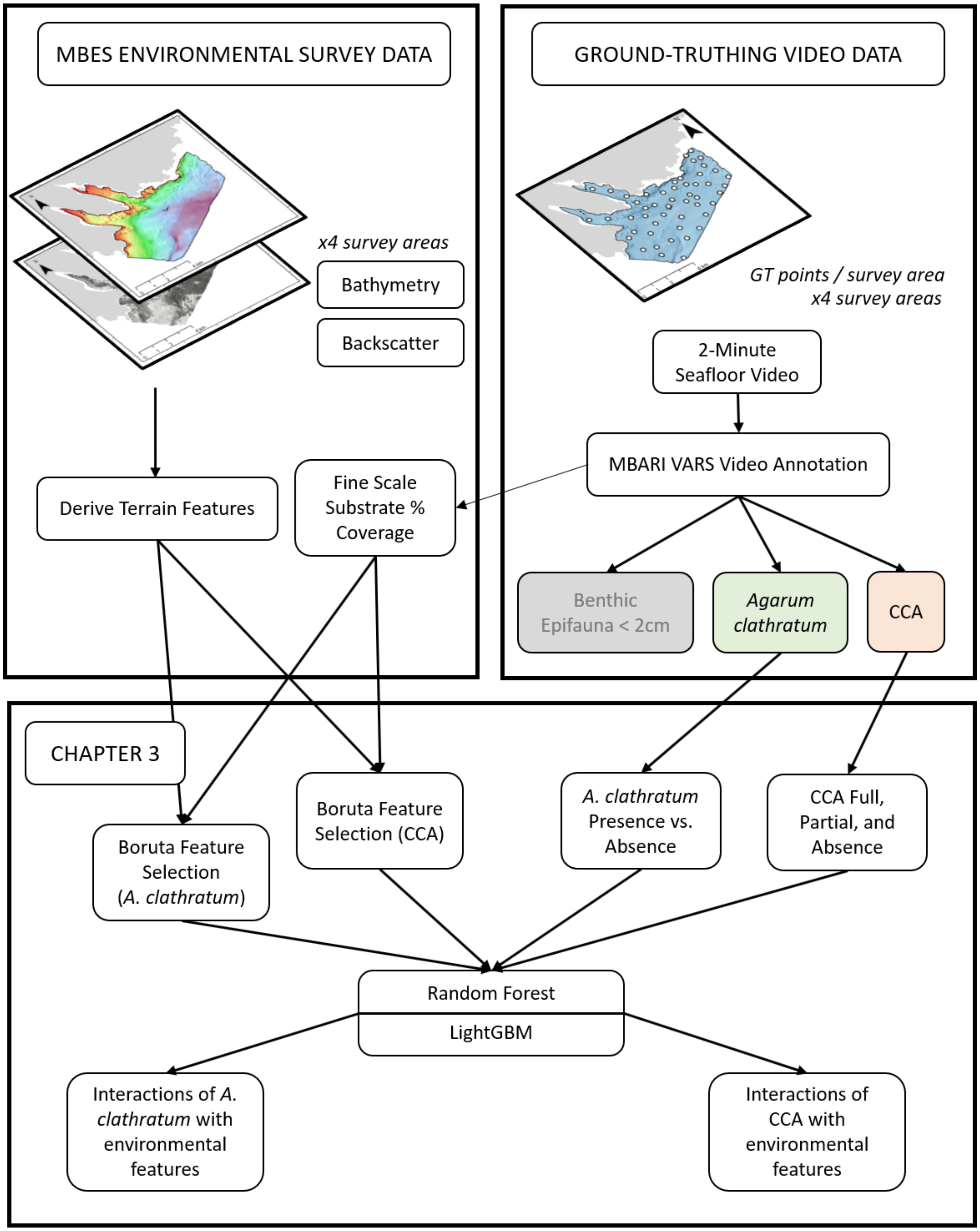

Figure 3.1. A methodological diagram of the workflow employed in Chapter 3 of this thesis. This includes multibeam echosounder (MBES) acoustic surveying to collect environmental data. In addition, the derived presence/absence data of *A. clathratum* and full, partial or absent coverage of non-geniculate, crustose coralline algae (CCA) from underwater video footage of the seafloor at specific ground-truthing (GT) sites. The environmental interactions with both target flora were assessed and interpreted using both Random Forest and Light Gradient Boosting Machine (LightGBM) techniques.

3.3.2 Ground-Truthing Surveys

The same underwater ground-truthing footage that was collected for use in Chapter 2 was used to collect biological data in this chapter. Ground-truthing sites were spatially-balanced across each survey area where MBES sonar data was obtained. An underwater camera was deployed at each site so it recorded two continuous minutes of useable footage at ~ 1 meter above the seafloor. Further detail on the methods used for obtaining biological data has been outlined in Section 2.3.3. However, footage was annotated not for epifaunal occurrence, but instead was annotated for the presence or absence of *A. clathratum* and full, partial or absent coverage of CCA (Figure 3.2). While *A. clathratum* abundance data was available as percentage cover, presence/absence was selected for the *A. clathratum* models due to its simplicity in repeating field techniques in future surveys. Considering this work is to establish a baseline that will be repeated over time and/or after events with severe consequences (e.g. oil spill), an efficient, yet effective, way to monitor changes over a broad and difficult to sample area is beneficial (Joseph et al 2006). Presence/absence methods have shown acceptable success when directly compared to abundance data, so its selection does not sacrifice quality (Rooper et al 2014).

CCA were divided into three classes: full coverage, partial coverage, and absent. Full-coverage was given when most (visually estimating >90% across the entire video) of the substrate had a coating of CCA, with or without prominent nodules that existed on the CCA's surface. Partial coverage was given when at least half of the substrate was covered, but was not enough to be full coverage. If little (visually estimating < 10% across the entire video) to no CCA was present, the site was marked as absent. In addition, raw count data were obtained for *S. droebachiensis* at each site. This was included to examine whether the occurrence of urchins affected macrophyte presence and absence.

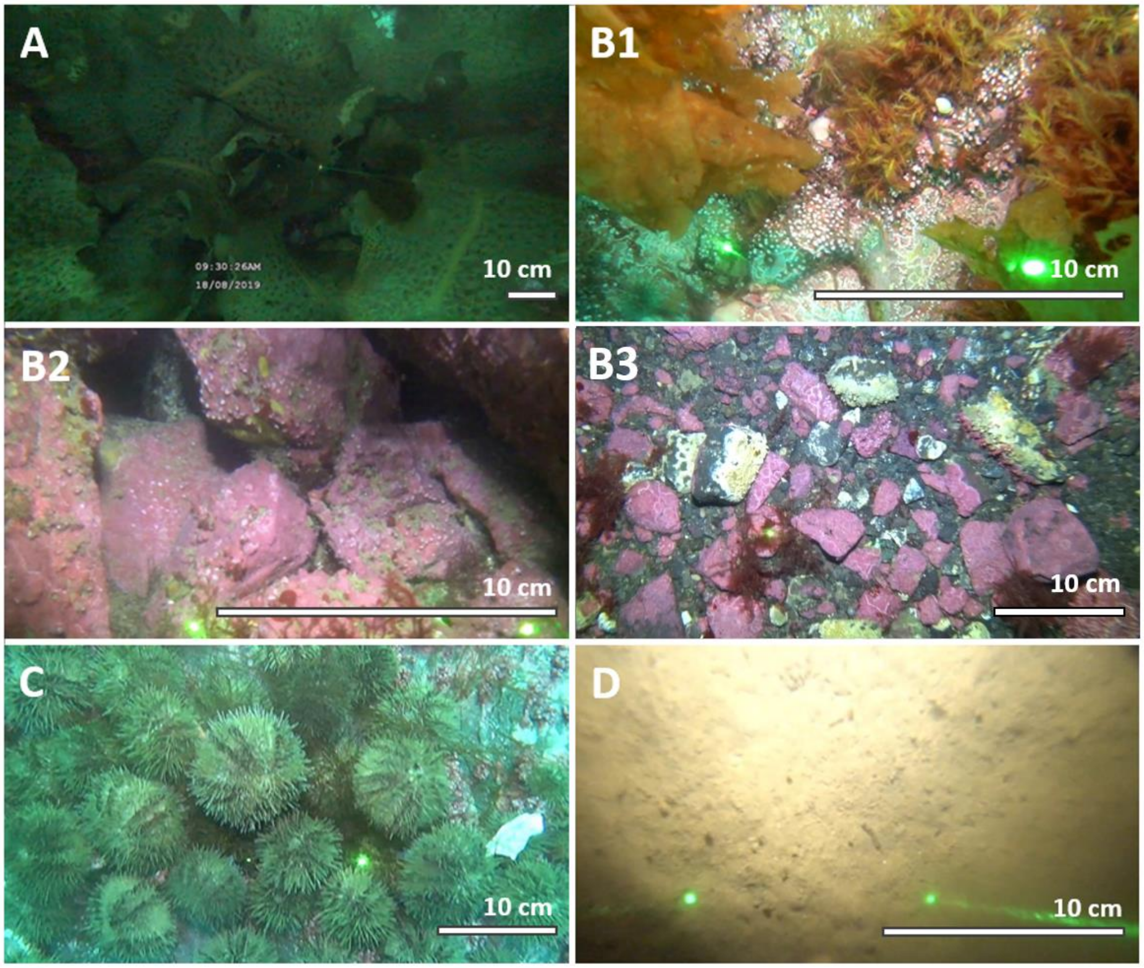

Figure 3.1. Examples of A) *Agarum clathratum* full coverage, B1) non-geniculate crustose coralline algae (CCA) with prominent nodules, B2) CCA full coverage without prominent nodules, B3) CCA partial coverage, C) *Strongylocentrotus droebachiensis*, and D) absence of *A. clathratum*, CCA, or *S. droebachiensis.* All images were taken from towed underwater camera footage within the surveyed areas of coastal Placentia Bay, NL.

3.3.3 Environmental Survey

Terrain derivatives are the same as those outlined in Section 2.3.2. The natural log-transformed *S. droebachiensis* count data from each ground-truthing site was included to understand how the occurrence of urchins affected macrophyte presence or absence.

3.3.4 Model Building and Evaluation

A Boruta Feature Selection (Kursa & Rudnicki 2010) algorithm was used to reduce the number of features, or attributes. This reduces complexity and increases model parsimony and performance of representative features (Stephens & Diesing 2014, Diesing & Stephens 2015, Montereale-Gavazzi et al 2018). A different selection of important features was determined for *A. clathratum* and CCA. Following this, high collinearity between each attribute was assessed using a correlation plot. When two attributes had a correlation value greater than 0.7 or less than -0.7, the attribute with the smaller influence on model output was removed.

A separate model was made for *A. clathratum* and CCA using a categorical Random Forest (RF) algorithm (Liaw & Wiener 2002), based off of its observed success in Chapter 2. The number of features randomly selected at each iteration (mtry) was kept as default. For each model, observations were removed that were deeper than the maximum depth where the target macrophyte was observed: *A. clathratum* was found at depths up to 66 m and CCA (partial coverage) penetrated to 78 m. The remaining data were split into training and testing datasets; training data contained 2/3 observations of each class to be modelled, with the testing data containing the remaining 1/3 observations. Variable importance and model performance were both evaluated following those methods outlined in Section 2.3.5.3 and Section 2.3.5.4, respectively.

3.4 Results

3.4.1 Agarum clathratum

3.4.2.1 Occurrences

For model development, 115 sites were found within the observed depth range of *A. clathratum* (15 to 66 meters): 21 from Rushoon, 36 from D'Argent Bay, 42 from Burin, and 16 from St. Lawrence.

Within the selected 115 ground-truthing sites, 60 sites contained *A. clathratum*, with Burin having the most ground-truthing sites with *A. clathratum* (25 out of 60 sites; 41.7 %). *A. clathratum* was present in the majority of ground-truthing sites across each survey area, except for St. Lawrence: Rushoon with eight positive occurrences out of 13 (61.9 %) sites, D'Argent Bay with 18 out of 36 sites (50 %), and Burin with 25 out of 42 sites (59.5 %) sites. In St. Lawrence, *A. clathratum* only occurred in 4 out of 12 ground-truthing sites (25 %).

Areas of high coverage of *A. clathratum* were found across the entirety of Burin, except for the sheltered, inner sections along the western side of the survey area. These areas were characterized by low backscatter and high % coverage of fine sediment. Pockets of dense *A. clathratum* coverage (≥ 75 % coverage) were restricted to Rushoon's outer extent and a small patch to the north and middle of D'Argent Bay. In contrast, St. Lawrence had no *A. clathratum* growth outside of the two harbours in the northwest section of the survey area (Figure 3.3).

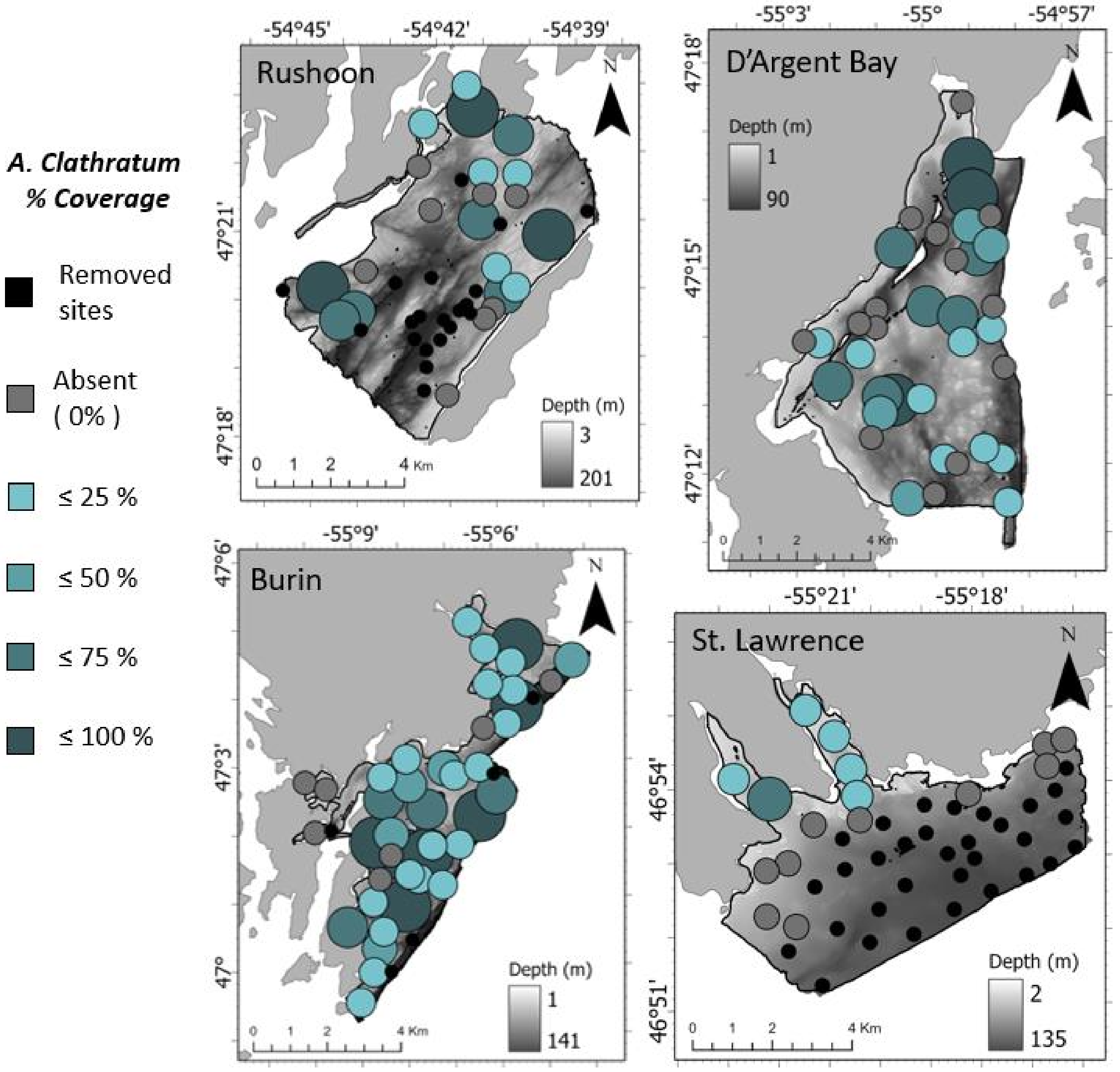

Figure 3.2. Spatial distribution of the measured percentage coverage of *Agarum clathratum* at each ground-truthing site across the four survey areas: Rushoon, D'Argent Bay, Burin, and St. Lawrence. Refer to Figure 1.4 for the spatial orientation of the listed survey areas within Placentia Bay.

3.4.2.2 Feature Selection and Model Output

Following the Boruta feature selection algorithm, a total of 21 features were selected for *A. clathratum* model development (Figure A4). Three additional features were removed as each exhibited collinearity with other features that were above 0.7 or below -0.7 (Figure A5B). Overall model accuracy based on the test data was 89.7% with a Kappa statistic of 0.80. The model was proficient at predicting both absences and presences. The model had precisions of 100 % for both absences and presences, and recalls of 80.0% and 100% for absence and presence, respectively.

The RF model indicated that 'Fine Sediment % Coverage' was the most important feature influencing *A. clathratum* distribution (Figure 3.4), with all but the lowest percentage of fine sediment coverage interacting positively with the absence of *A. clathratum*. Bathymetry was identified as the second most important feature. Most *A. clathratum* occurrences were limited to between 15 and 48 m depth, except for one outlier that was present in a deep channel near the southwest extent of the Burin survey area. This site, Burin-42, had a carpeting of turf-forming red algae (90% cover) with little pockets of *A. clathratum* (8.4% cover) and a mix of fine sediment with sporadic boulders where macroalgae were not observed. Even a low occurrence of fine sediment was influential on *A. clathratum* (Figure 3.5). The growth of *A. clathratum* was also dependent on the % coverage of harder substrates, with higher % coverage of gravel and boulder being more influential on the presence or absence of *A. clathratum*. Lower backscatter, indicative of fine sediments, had an influence regarding *A. clathratum*. Likely, fine sediments were inversely related to *A. clathratum* growth, as *A. clathratum* cannot grow without a hard substrate for its holdfast to attach to. In addition, the presence of red algae carpeting influenced the occurrence of *A. clathratum*. The final two substrate classes, bedrock and sugar kelp % coverage, were ranked the lowest in feature importance (Figure 3.4). In terms of terrain morphology, *A. clathratum* was dependent on broad, flat or slight crested regions that were characterized by a complex surface, with greater occurrences within 3000 m of the shore (Figure 3.4).

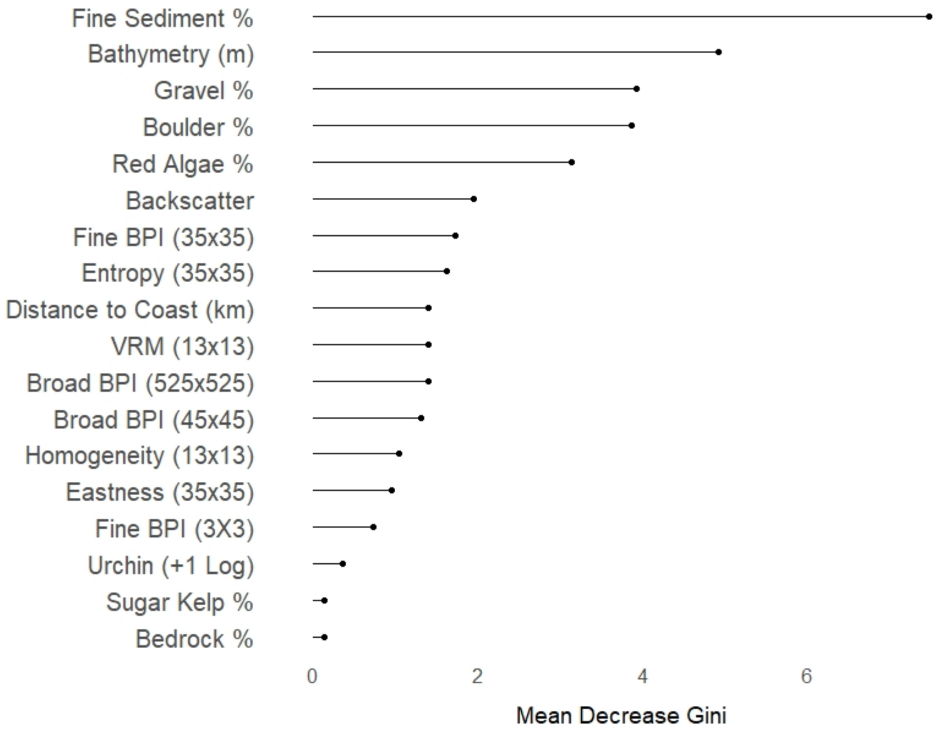

Figure 3.3. Importance of features included in the *Agarum clathratum* Random Forest Model, used the mean decrease in Gini Index.

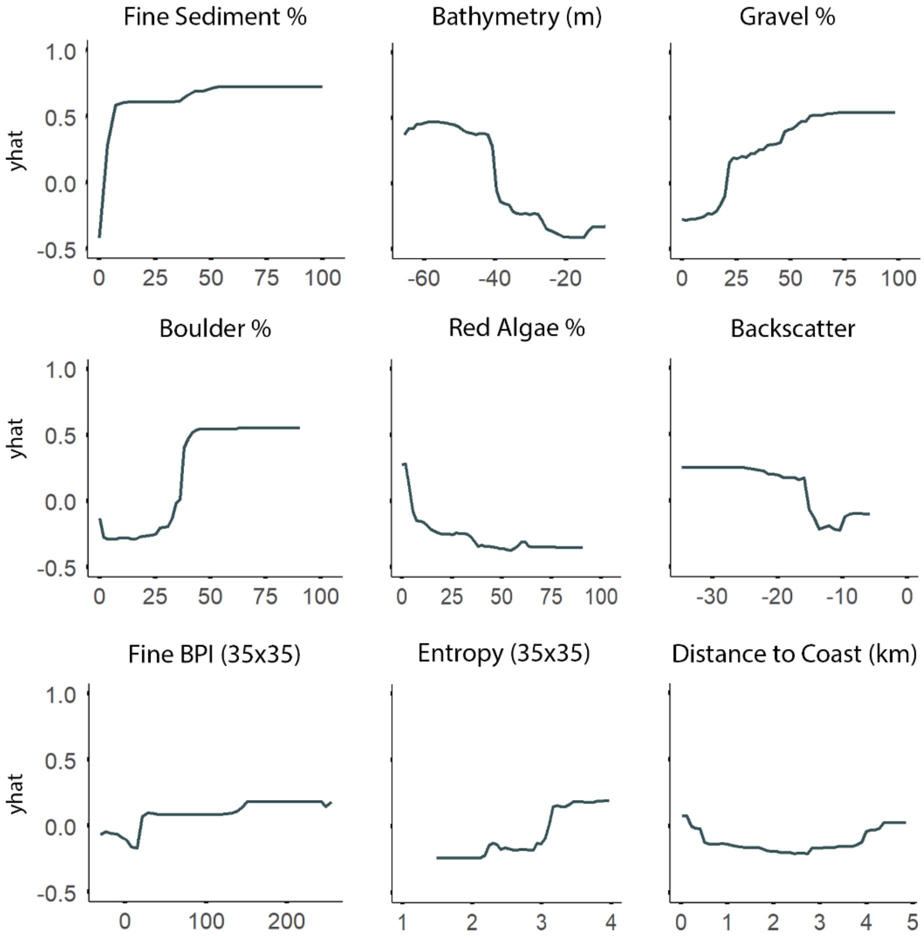

Figure 3.4. Partial dependence plots derived from the random forest model highlighting the dependency of *Agarum clathratum* on an individual terrain feature. Specifically, when *A. clathratum* is absent. Included are the first nine most influential features as indicated by the Random Forest model, with additional features available in Figure A9.

3.4.3 Non-geniculate Coralline Algae

3.4.3.1 Occurrences

Forty-two sites with full coverage and 31 sites with partial coverage of CCA were observed out of the 132 ground-truthing sites that were between the depths of 15 to 78 m.

Rushoon had the highest number of ground-truthing sites that exhibited a full coverage of CCA (15 out of 27), and was the only survey area where the majority of observations displayed full coverage. Those sites with CCA were distributed closer to the outer boundaries of the Rushoon survey area. No ground-truthing sites were included from the deeper channels located in the center of Rushoon, as these sites were often beyond CCA's depth range. Burin and D'Argent Bay exhibited mostly full or partial coverage of CCA, with 14 full coverage and 15 partial coverage sites in D'Argent Bay and 12 full coverage and 22 partial coverage sites in Burin. Full coverage occurrences within D'Argent Bay were mostly observed closer to the coast, while those in Burin were on the westward extent of the survey area, further from shore. St. Lawrence had only one site with full coverage, with the majority of sites located on the northeastern coast exhibiting only partial coverage (Figure 3.6).

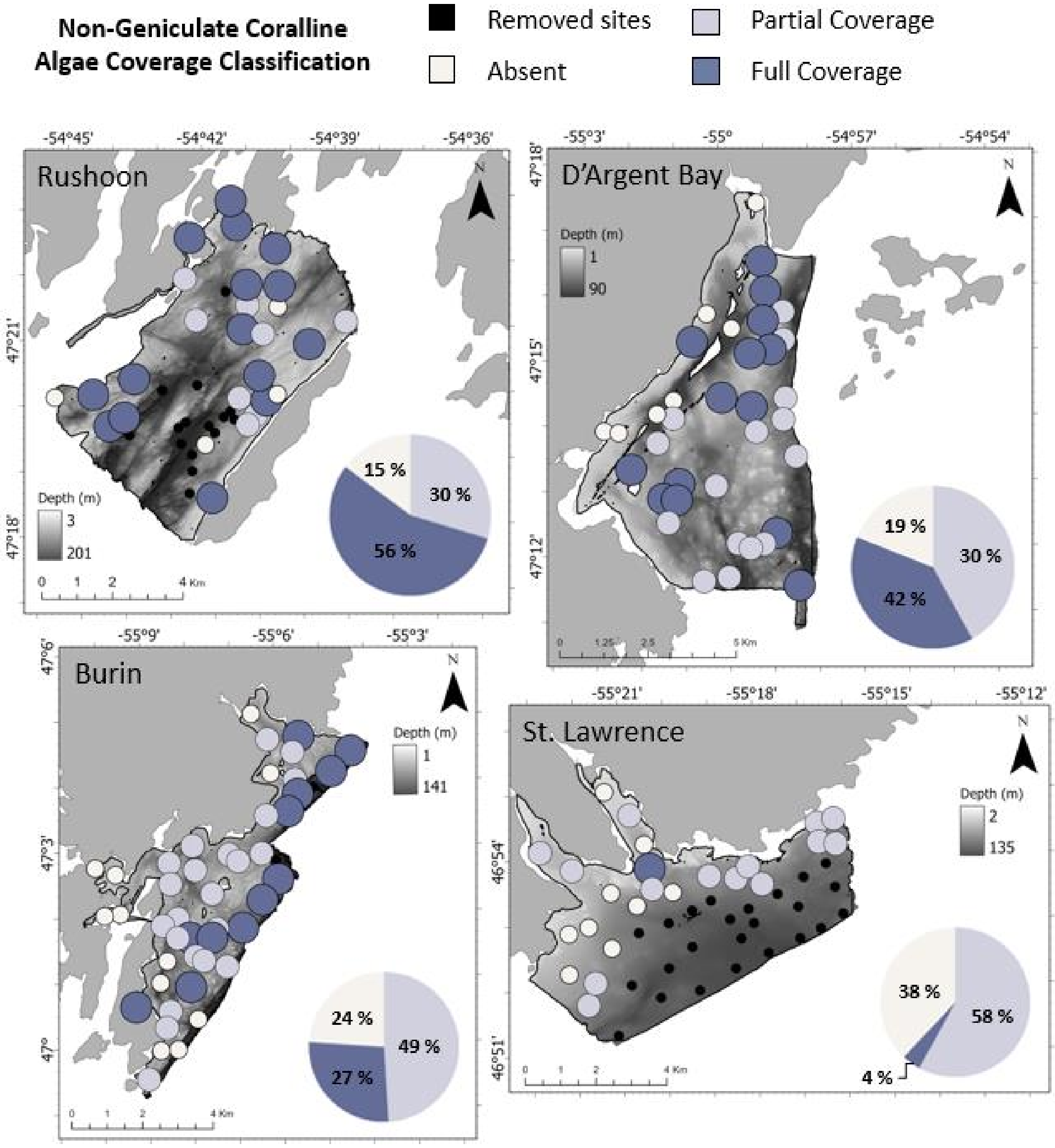

Figure 3.5. Spatial arrangement of absence, partial coverage, and full coverage of non-geniculate crustose coralline algae across the four survey areas: Rushoon, D'Argent Bay, Burin, and St. Lawrence. Proportion of each coverage class for each site is visualized in the bottom right. Refer to Figure 1.4 for the spatial orientation of the listed survey areas within Placentia Bay.

3.4.3.2 Feature Selection and Model Output

Following the Boruta feature selection algorithm process, 34 features were initially selected for model development (Figure A4). Of these, 10 were removed for correlation values either ≤ -0.7 or ≥ 0.7 (Figure A5C), with 24 included in the final model. None of the features removed impacted model performance. Model output had an accuracy of 82.2% with a kappa of 0.72. Model performance per class had a 100% precision for absences (recall of 75%), 82.3% for partial coverage (93.3% recall), and 88.9% for full coverage (88.9% recall).

Substrate composition was the primary driver for CCA presence or absence. The fine sediment and boulder % coverage features were deemed the most influential features controlling CCA distribution (Figure 3.7). Absences are associated with a high % coverage of fine sediment (Figure 3.8); in contrast, boulder substrate was often associated with full coverage CCA. Partial and full coverage often occurred in areas where red algae were present, while absences of both taxa tended to be co-located. Of note, bedrock % coverage was ranked the least influential feature in the model, but this may be because it was only infrequently observed. When present, bedrock was associated with a full coverage of CCA.

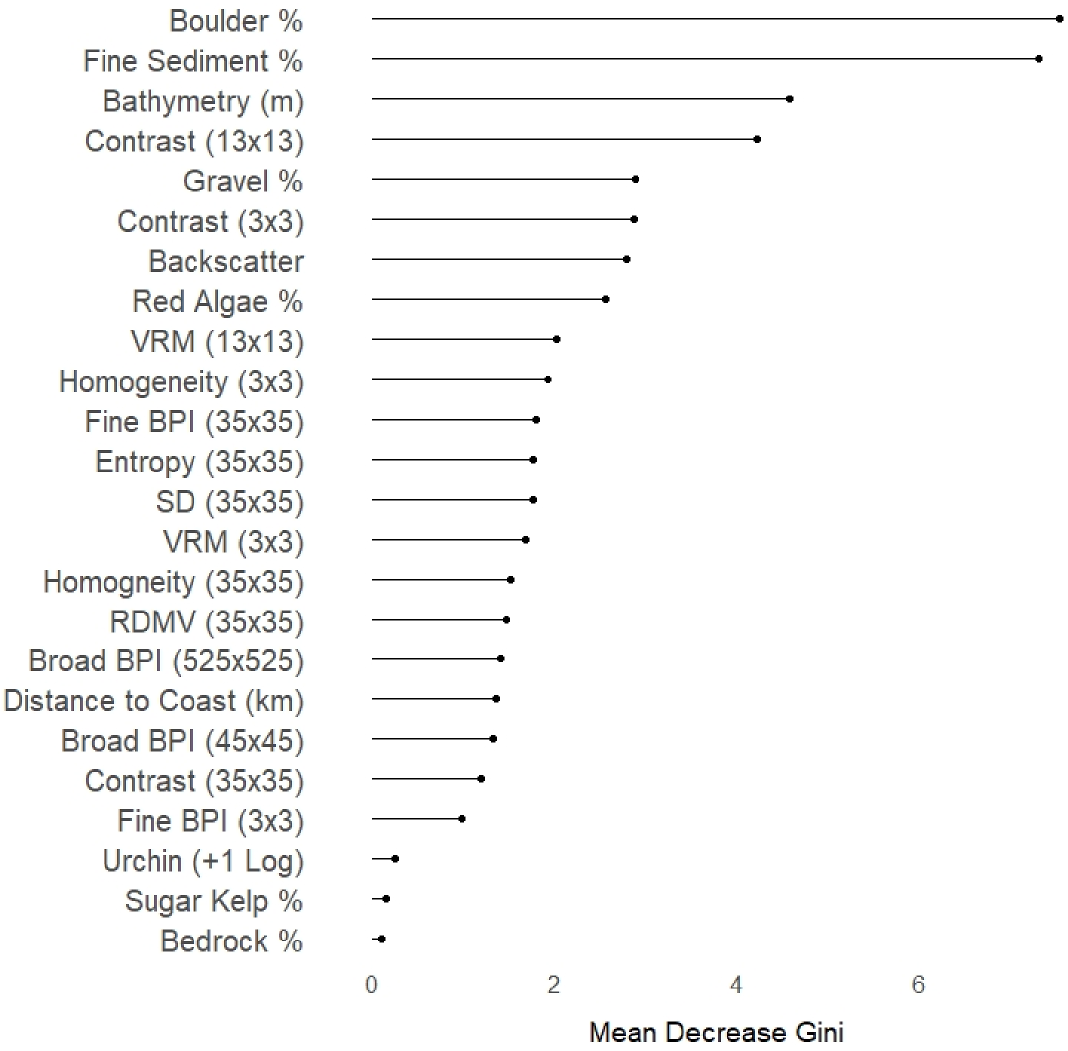

Figure 3.6. Order of variable importance as determined by the Random Forest model for non-geniculate coralline algae, using the mean decrease in Gini Index.

Bathymetry was also found by the RF model to be influential on CCA. Partial coverage penetrated from 22 m to a depth of 77 m, while full coverage was found to have a shallower limit of 10 m, with a bottom depth of 70 m. Absences were found throughout the entire depth range, from 6 m to 77 m.

Absences were associated with lower backscatter values, while partial and full coverage showed the opposite trend. CCA exhibited a preference for rugose and disordered substrate.

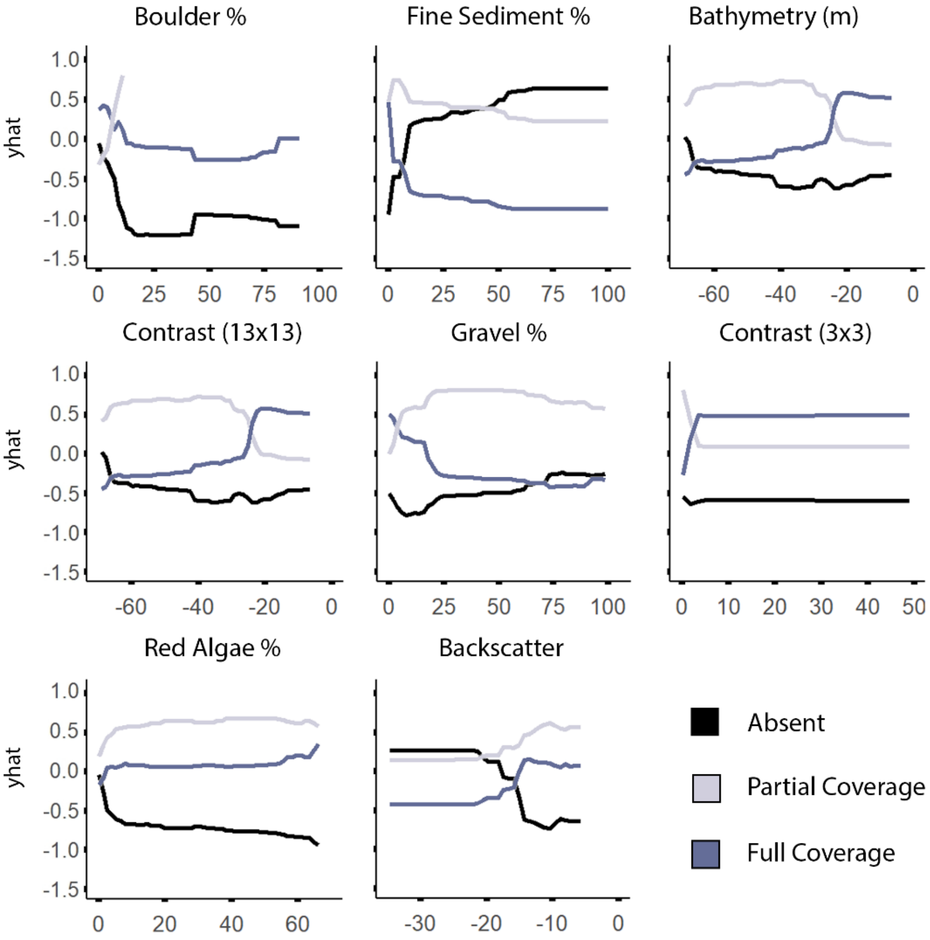

Figure 3.8. Partial dependence plots derived from the random forest model of selected terrain attributes influencing the absence or degree of presence of non-geniculate coralline algae. All partial dependence plots and boxplots representing each variable used in model training are available in Figure A10**.**

3.5 Discussion

This study found that three of the four ecologically important survey areas along the west coast of Placentia Bay had more than 50% of the sites where *A. clathratum* beds and CCA were present, with the exception being St. Lawrence. Burin had the highest proportion of *A. clathratum* and CCA. Both of the RF models developed for *A. clathratum* and CCA indicated the importance of fine-scale substrate % coverage and depth, over seabed morphology, in understanding the spatial distribution of macrophyte taxa.

3.5.1. Terrain Features

Although found to be an important predictor, depth likely did not directly influence the distribution of either macroalgae, but instead acted as a proxy for light attenuation (Bekkby et al 2009). It is common for increasing depth to lead to a decline in kelp species' presence (Sjøtun et al 1995) with Bekkby et al (2009) finding depth to be the most important feature determining the distribution of *Laminaria hyperborea*. They also found marked changes in population structures across depth gradients and attributed to light attenuation (Smith et al 2022). Canadian kelp beds made up of *S. latissima* and *Laminaria digitata* extend to depths of 20 – 30 m (Filbee-Dexter et al 2019). However, in Disko Bay, Greenland, *A. clathratum* penetrated depths upwards of 61 m (Krause-Jensen 2019) at sites further offshore, likely owing to a combined effect of *A. clathratum*'s shade tolerance (Vadas 1968, Wernberg et al 2019) and enhanced light availability due to reduced phytoplankton production and sediment load from coastal runoff (Murray et al 2015).

CCA, like most species of the order Corallinales, have a higher tolerance for low light conditions, even more so than *A. clathratum*, allowing for a deeper depth limit (Vadas & Steneck 1988, Stotz et al 2016). A similar pattern as to what was observed in Placentia Bay has been found along other cold-water coastlines, with distinct population structures associated with depth. Jørgensbye & Halfar (2015) found that from 25 to 40 m, CCA are covered in *A. clathratum* and red foliose algae, which are replaced by sessile invertebrates from 40 to 60 m with CCA becoming patchy and sparse beyond 60 m.

Flat basins are often composed of fine sediment and offer little for kelp growth (Bekkby et al. 2009). The seafloor of Placentia Bay was formed during glacial retreat, which produced scoured channels and deposits of glacio-marine sediments. Flat regions within Placentia Bay may also be punctuated by boulders and rocks from glacial debris not captured by full coverage terrain features, allowing for kelp survival (Shaw et al 2011). This fine-scale habitat heterogeneity might not have been adequately captured by acoustically derived terrain features, possibly explaining why video derived fine-scale substrate % coverage was the most important feature in the *A. clathratum* and CCA RF models.

For both *A. clathratum* and CCA, substrate % coverage was important in explaining their distribution. That is to be expected, as fine sediment does not encourage the growth of large kelps such as *A. clathratum* (Watanabe et al 2014). *A. clathratum* require a stable foundation for the holdfast to attach to and weather currents and storm surge (Morrison et al 2009, Masteller et al 2015). In the case of CCA, growth occurs only on hard substrate (Connell 2005, Gagnon et al 2012), with fine sediment reducing light availability for photosynthesis (Konar & Iken 2005, Jørgensbye & Halfar 2016). CCA was found to occur on smaller cobbles, an observation that would be influenced by local currents, as smaller grain sizes would be more likely to get overturned in a dynamic environment, affecting CCA survival (Foster 2001, Hetzinger et al 2006).

A. clathratum was often found to co-exist with red algae, which in the context of this research includes foliose, low-structured mats and excludes coralligenous red algae, such as CCA (Filbee-Dexter & Wernberg 2018). Following Connell et al (2014), the large patches of red algae observed fall under the qualitative categorization of turfs, or loosely to densely aggregated filamentous algae that are < 15 cm tall and cover an area greater than 1 m^2. As compared to the fleshy macrophytes that form kelp beds, turfs are a fast-growing and opportunistic group of stress-tolerant algae (Airoldi 1998, Filbee-Dexter & Wernberg 2018). Their high turnover rates and extensive coverage allow them to succeed kelp forests that have been weakened by thermal stress across broad spaces of coastal Atlantic Canada (Scheibling & Gagnon 2006, Filbee-Dexter et al 2016, Wernberg et al 2019). Filamentous red algae utilize hard substrates and create an environment that reduces oxygen and increases sediment accumulation (Gorgula & Connell 2004). High sediment loads limit kelp recruitment by blocking the settlement of spores, reducing germination and survival (Norton & Fetter 1981, Connell & Russell 2010). Significant areas of kelp biomass have been lost due to human impact on a global scale (Steneck et al 2002, Mineur et al 2015, Filbee-Dexter 2016), being superseded by turf-forming algae with no observations of turfs shifting back to kelp (Filbee-Dexter & Wernberg 2018). Even with the potential of *A. clathratum* to thwart consumption by *S. droebachiensis*, there exists a need to understand the dynamics of *A. clathratum* recruitment methods under the presence of turf-forming filamentous red algae.

Seafloor complexity, texture, and roughness are recognized for their influence on algal community structures (Sangil et al 2014). Grazer efficiency is affected by the level of roughness, though the direct relationship of whether it is due to consumption or dislodgement is unclear (Hutchinson et al 2006). Sangril et al (2014) found that substrate roughness and urchin density had opposite effects on algal community organization, with algae finding refuge from intense herbivory where irregularities in the substrate surface was greater. While *A. clathratum* has an integrated chemical defense that inhibits consumption, *S. droebachiensis* has been found to consume *A. clathratum* when no other food source is available (Keats et al 1982), and *A. clathratum* may find rocky terrain advantageous against herbivory (Bergey & Weaver 2004). Depressions in rock surface also passively accumulate algal propagules, with smooth surfaces less favorable for settlement (Norton & Fetter 1981).

Kelp beds do well in areas with moderate wave exposure (Gorman et al 2013, Bekkby et al 2019), as wave action boosts nutrient supply and uptake (Hurd et al 1996, Hepburn et al 2007). In addition, moderate wave action boosts photosynthetic rates by increasing the exposure of algal fronts to light (Lobban & Harrison 1994) and reducing the survivability of epiphytes (Strand & Weisner 1996). *A. clathratum* occurring further from the coast may result in greater exposure to wave action which ensures that algal fronds experience continuous light exposure (Bekkby et al 2019). However, excessive wave action can increase detachment and decrease recruitment success (Goldberg & Kendrick 2004). Mean current circulation in Placentia Bay is cyclical, with currents entering on the eastern coast and exiting on the west (Ma et al 2012). The association of *A. clathratum* to westward-facing substrate, as indicated by Eastness (35x35), likely results from the presence of south westerly currents along the west coast of Placentia Bay (Figure A9), providing the moderate wave action that encourages growth through boosted photosynthetic rates and nutrient uptake. In areas of excessive wave action, such as the southern end of the western coast, growth can become inhibited due to abrasion or the holdfast being pulled off from its connection (Foster 2001), a phenomenon identified along the eastern side of the Alaskan Archipelago (Sañé et al 2016).

3.5.2. Distribution and potential anthropogenic impacts within Placentia Bay

The depth range of both Burin and D'Argent Bay are almost completely within the depth range of which *A. clathratum* and CCA were found to occur in this study. These two survey areas also exhibited high coverage of boulder and gravel fields, with little fine sediment present. Rushoon was similar, with a predominant presence of boulder, gravel, and the only presence of bedrock (Figure A11). There were two deep channels in the southwest extent of Rushoon covered in fine glacio-marine sediments, with depths that extended far beyond either macrophytes' extent (range 100 – 200 m). The conditions found across the majority of the St. Lawrence survey area were not suitable for *A. clathratum* and CCA. St. Lawrence was the most exposed of the four surveyed sites and faced the greatest current exposure of Placentia Bay during winter-spring (Ma et al 2012), a period when algal recruitment occurs (Gagnon et al 2003). St. Lawrence has a deeper overall average depth, as well as a greater proportion of 'Fine Sediment % Coverage' paired with a lower proportion of 'Boulder % Coverage'. Even with CCA having a greater tolerance for a wider range of environmental conditions, only more sheltered Little St. Lawrence and Great St. Lawrence Harbours located in the northwest corner of the survey area appeared suitable.

Highest occurrence of *A. clathratum* and CCA occurred in the site with the highest level of human activity along the west coast of Placentia Bay. Burin is located just north of Mortier Bay, which acts as the service hub to the Burin peninsula and includes industrial activities associated with the Marystown Shipyard and Kiewit Offshore Services Cow Head Fabrication Facility. In future monitoring efforts, it would be interesting to see how *A. clathratum* and CCA are impacted by this population hub. It is possible that *A. clathratum* may be supported by potential nutrient loading from the human activities surrounding Burin. Williams et al (2020) found higher percent cover of the kelp *Ecklonia radiata* (laminariales) on reefs near higher nutrient loads. Shifts in *A. clathratum* distribution, and local subtidal kelp compositions as a whole, may instead be indicative of fluctuations in *S. droebachiensis* populations.

Rushoon is the focus of the Grieg NL Placentia Bay Atlantic Salmon Aquaculture Project, and cages for salmon aquaculture set within the survey area's extent were expected to receive fish in Summer 2022 (LGL 2018). Rushoon hosts sites with not only extensive *A. clathratum* coverage, but *S. latissima*, a canopy-forming kelp species that suffers from over-consumption by *S. droebachiensis* (Traiger 2019). Processes involved with salmon aquaculture, such as using hydrogen peroxide for lice removal, can have detrimental effects on *S. latissima* (Haugland et al 2019). However, kelp species such as *S. latissimi* may benefit from the increased nutrient load released by finfish as waste (Rugiu et al 2020).

3.5.3. Future Implications: Biodiversity, Baseline, and Conclusions

With coastlines facing instability of kelp beds due to local grazing pressure, anthropogenic effects and global-scale climate change, this research provides a first step in understanding the interaction of two resilient macroalgae groups with seafloor characteristics. Establishing an accurate baseline of current conditions will require an understanding of the associated biota of each respective macroalgae group. Blain &

Gagnon (2014) identified beds of *A. clathratum* as supporting a diverse group of invertebrate and fish taxa spanning multiple life history stages. For the purpose of an effective baseline, a fundamental understanding of species assemblages in *A. clathratum* forests is necessary, especially when considering the severe loss of other kelp beds found in ecologically important areas such as Placentia Bay. *A. clathratum* has shown resistance against *S. droebachiensis* herbivorous pressure from its presumed phenolic defenses (Witman & Lamb 2018, Krause-Jensen et al 2019).

The fauna co-located with CCA will require further attention, breaking the pattern of having CCA being overlooked as just “pink paint”. In the context of this study, the CCA observed often exhibited large patches of bulbous nodules that increased local 3D complexity. In Placentia Bay, dense aggregations of brittle stars (order Ophiuroidea) were often observed in the complex 3D structures created by these nodules. CCA of the North Atlantic have exhibited a role in providing food, refuge, and substrate for both infauna and epifaunal invertebrates (Ojeda & Dearborn 1989, Jørgensbye & Halfar 2016), but the details of associated fauna within Newfoundland subtidal CCA has not been described.

Like *A. clathratum*, CCA are often not the focus of studies on coralligenous algae (Adey et al 2015), even though they have the potential for hosting species richness comparable to coral reefs (Adey et al 2013, Ingrassia et al 2019). This work examined their distribution in the Placentia Bay EBSA, an area that people continue to rely on for socio-economic gains. This study highlighted the importance of fine-scale substrate data, as both *A. clathratum* and CCA have intrinsic relations with fine sediment and 'Boulder % Coverage'. This study also observed an overlap with *A. clathratum* forest coverage with filamentous red algae, an ecological interaction that may be worthwhile to further investigate. The models developed provide a baseline on the present natural status of Placentia Bay's western coastline, allowing observation of change as global ocean conditions continue to shift.

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Chapter 4 Conclusions

4.1 Summary

To properly manage marine resources, there has been a gradual shift from the traditional single-species focus to the holistic approach of representing and maintaining a target ecosystem's dynamic ecology (Gavaris 2009, Long et al 2015). Management strategies should also be adaptive to the fundamental knowledge of an ecosystem (Pomeroy et al 2005, Long et al 2015), and should incorporate long-term studies (> 10 years (Lindenmayer et al 2012)) to monitor how a target ecosystem changes over time, and whether these changes are due to natural processes or anthropogenic impacts and stressors. Before any monitoring can begin, however, a critical first step is the establishment of a preliminary baseline that describes the present state of a coastal ecosystem (Lacharité & Brown 2019). Baselines that focus on benthic indicators take advantage of the high sensitivity that these biota have to anthropogenic effects (Clarke et al 2006, Van Hoey et al 2010, Wei et al 2019), making them an optimal choice for monitoring programs.

Placentia Bay is an economically important area of the Island of Newfoundland, where potentially damaging activities to the local coastal ecosystem occur. Developments in natural gas (Newfoundland LNG Ltd 2021), oil (DFO 2007/1292), and aquaculture (LGL 2018, Maxwell & Filgueira 2020), as well as traditional and commercial fishing (Healey et al 2014), all invoke the need for a monitoring program of the local benthic communities. People living along the western coast of Placentia Bay are deeply connected to the ocean, both socio-economically (DFO 2012) and, on a deeper psychological level, harkening a sense of home (Redmond 2021). People are connected to their ecosystem in a way that can nurture a need to protect its wellbeing. A baseline is one tool towards an effective monitoring program that works to maintain ecosystem health. This thesis addressed the development of this step.

4.2 Research Outcomes

This thesis developed baselines of biota occurrences along the west coast of Placentia Bay, linking each respective group to environmental drivers that influenced their distribution. First, epifaunal density data were used to identify dominant assemblages (Chapter 2). Second, presence/absence data were used to identify spatial patterns in two prevalent macrophyte species/morphotypes (Chapter 3).

In Chapter 2, four assemblages dominated the surveyed areas along the west coast of Placentia, ranging from depths of 14 to 140 meters. Most assemblages, aside from the fine-sediment dominated EPA assemblage, were highly heterogeneous in their substrate composition, as indicated by the high ranking of fine-scale (< 1 m) substrate % coverage features in modelling. This study highlights that including video-derived substrate features captures how species interact with their environment at a scale that traditional acoustic-based features are still not fully able to reproduce (Robert et al 2014). This study also was an opportunity to explore the use of a new machine learning technique, Light Gradient Boosting Machine (LightGBM). While the well-established Random Forest model was selected for further analysis of results, LightGBM could be revisited when larger quantities of data become available over time.

Chapter 3 took a similar approach, but instead described the relationship between a single species/morphotype with its respective physical habitat; specifically, *Agarum clathratum* and non-geniculate crustose coralline algae. *A. clathratum*'s distribution was unsurprisingly controlled primarily by depth, which likely acts as a proxy for light attenuation (Krause-Jensen et al 2019). Substrate % coverage features had a greater influence on crustose coralline algae distribution than depth, emphasizing the relationship this macrophyte has with seafloor structure (Nelson 2009).

Chapter 3 reported extensive distributions of both *A. clathratum* and crustose coralline algae across most of the survey areas, with the exception of St. Lawrence. Rushoon contained some notable sites with the largest observed 3D nodules on coralline algae crusts, supporting dense beds of both *A. clathratum* and *S. latissima*. Across the survey areas, dense forests of *A. clathratum* were punctuated by mosaics of turf-forming red algae (excluding coralline algae). As kelp beds face a suite of stressors such as species invasions, acidification, increased heat waves and storm action (Filbee-Dexter & Wernberg 2018), beds may risk being replaced by low-lying, structurally simple, carpets of red algae (Moy & Christie 2012). Now that a baseline for *A. clathratum* has been achieved, it will be possible to monitor future change in the proportion of *A. clathratum* beds and red algae carpets, looking for phase-shifts from one dominant species to another.

This chapter also introduced the need for identifying associated fauna with understudied macrophytes *A. clathratum* and crustose coralline algae, as well as continued monitoring to address shifts in their distribution with anthropogenic stressors, including changing ocean conditions.

4.3 Limitations

The role of a baseline is to provide a snapshot of the present ecological, social, and economic conditions of the target area (Barandiarán 2015), for the purpose of precautionary, preventative action in anticipation of negative future changes (Kriebel et al 2001). Conceptually a simple goal, developing an effective baseline includes significant challenges. Baselines face the challenge of accurately encompassing spatial and temporal variability in the ecosystem they were selected to characterize. So in the context of this research, were the baselines developed here an effective snapshot of the benthic epifauna and flora found along Placentia Bay's west coast?

Both chapters emphasize the importance of fine-scale substrate % coverage in boosting model accuracy and improving our understanding of the ecology of benthic ecosystems in Placentia Bay. However, the habitat maps predicting biota coverage in unsampled areas could not include these important features. Techniques that use point samples to build full coverage substrate maps have been developed with success (Lark et al 2012, Shang et al 2021), but still lack the fine-scale resolution (< 1 m) that was identified as critically important in understanding the distribution of both the epifauna and flora across the surveyed sites. Management efforts would benefit from these features being included in future predictive habitat maps. Fortunately, fine-scale substrate % coverage was included in the investigation of biota-environment interactions, and can be used to inform decisions (such as the identification of rocky regions that may support greater species richness and abundance).

Species accumulation curves (SACs) of individual assemblages showed all but OPH were underrepresenting the number of species and morphotypes. However, now that we understand the distribution of these assemblages, sampling efforts that target a full description of their biodiversity would be facilitated. In addition, a drawback of underwater camera footage is it can be difficult to identify smaller, cryptic species, with many taxa that cannot be identified to species level. Phyla such as porifera and cnidaria are particularly difficult to identify without a physical sample. Assemblages with high algal coverage were also particularly undersampled as fronds may have obscured present epifauna from the field of view.

While temperature and salinity data collection were attempted, instrument failure resulted in 45 sites from Rushoon and D’Argent Bay not having data. As neither temperature nor salinity ranked particularly high, it was determined that retaining these 45 sites was more useful than including these variables in the modelling process. Spatially-continuous environmental layers which quantify oceanographic data might also have had the potential to increase model performance as canopy-forming kelp are reliant on hydrodynamic conditions such as current speed (Bekkby et al 2019), but did not exist at sufficient resolution. Including oceanographic parameters, such as temperature, salinity, and pH, would allow for better monitoring of both macrophyte, as well as epifaunal, targets in the context of a changing ocean climate.

This study focused on epifaunal assemblage composition and macrophyte distribution during the summer season, with ground-truthing conducted between June through August. While this thesis considers a snapshot of each assemblage's distribution, it does not account for the natural seasonal temporal changes that occur along Placentia Bay's coastline. The epifaunal composition of assemblages will likely change with seasons (Bahrebar et al 2020); for example, the urchin-dominated 'SdS' assemblage was associated with the substrate *A. clathratum*, which experiences seasonal growth (Blain & Gagnon 2014).

In summary, this baseline suffers from data deficiencies. There is no temporal factor addressing how benthic epifaunal assemblages and flora coverage changes across seasons. There is potential for missed epifauna species in the less prevalent assemblages, though the SAC curve does indicate a satisfactory sampling effort for the entirety of the surveyed area (Figure 2.5). Nonetheless, it provides a necessary snapshot of the benthic ecology of an area of the Placentia Bay EBSA that was previously lacking a comprehensive understanding. This research provides a strong first step and is an effective tool for informing future decision-making within its boundaries.

To elevate this baseline, the inclusion of historical ecology encompassing the status of Placentia Bay's benthic ecosystem pre-human impact would improve the heading of management to set realistic goals. Historical ecology studies human-ecosystem interactions across decades or centuries (McClenachan et al 2012); by providing context of an ecosystem with the absence (or reduction) of human pressure, managers can set realistic goals for an improved environment that re-establishes its original functions (Thrush & Dayton 2010, McClenachan et al 2012). In doing so, this baseline would contribute to the development of a benchmark status managers should aim to achieve.

A benchmark is different from a baseline. A benchmark does not present an ecological state, but a standard to be reached. They require useful ecological indicators that serve as biological reference points (Arkema et al 2006). In addition, the development of a realistic benchmark requires the human societal pressures included in a baseline, a factor not considered in the development of this specific baseline (Atmore et al 2021). While the work here is argued as a satisfactory baseline, it is not a benchmark.

4.4 Applications

The baselines provided in this thesis can be used to inform managers and scientists while also contributing to the end-goal of ecosystem-based management. This research links the physical features of the seafloor to diverse species richness and structurally complex macroalgae habitats. This link is not exclusive to the survey areas included in this thesis. If the “white-ribbon” of missing data that exists along Placentia Bay’s west coast is surveyed using MBES, the distribution of epifaunal assemblages, *A. clathratum*, and CCA can be expanded by using the machine-learning models developed here.

Understanding the spatial distribution of benthic biota can be utilized by DFO in decision-making regarding projects that may affect benthic habitats. For example, at the time when this thesis was written, Grieg NL Seafarms Ltd. applied for licenses to increase the number of sea cages containing farmed salmon along the northwestern coast of Placentia Bay (DFO 2022/019). Their proposed sites all fall within the Placentia Bay EBSA. Salmon sea cages have potential to impact benthic habitats due to deposits of waste feed and feces from the cages. These deposits could impact sessile invertebrates identified in this research such as anemones, sponges, and soft corals, the latter of which is an indicator of vulnerable marine ecosystems (FAO 2020, Long et al 2020). The knowledge of where epifaunal assemblages that host these potentially susceptible organisms, such as OPH and MIX, is therefore applicable by government in mitigating risk.

Decision-makers can also use the information presented here regarding structurally complex habitats, such as areas of high rugosity, which are often linked with increased biodiversity (Buhl-Mortensen et al 2010). This is evidenced by the epifaunal assemblage OPH being characterized by features indicative of increased complexity, such as high boulder % coverage, concurrent with the highest species abundance and richness. Knowing this, greater conservation efforts could be focused on these regions, improving efficiency and effectiveness of management choices.

Alternatively, the baselines provide a look at specific organisms' populations. For example, there is an opportunity to monitor the distribution of *S. droebachiensis*, the primary herbivore of kelp species. This data can serve as a preliminary understanding of the present state of *S. droebachiensis* distribution, as it was a typifying species for the SDR epifaunal assemblage. Monitoring changes in *S. droebachiensis* abundance, as well as *A. clathratum* distribution, would inform whether the subtidal is dominated by urchin-barrens or if there is a shift towards kelps re-establishing themselves.

4.5 Conclusion

The purpose of this thesis was to establish an ecologically-informed baseline of the distribution of epifauna and flora of the Ecologically and Biologically Significant Area (EBSA) of Placentia Bay. The present study indicated that a heterogeneous benthic ecosystem presently exists within Placentia Bay. A diverse group of fauna, flora and people rely on the health of Placentia Bay, which is likely supported by the diverse benthic epifaunal assemblages and extensive macroalgal beds existing. As such, its designation as an EBSA is appropriate and care should be given to mitigate potential impacts as anthropogenic pressures continue to grow. With this baseline, changes can now be observed, informing adaptive management strategies support sustainability of ocean resources.

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Appendices

Appendix 1.

Ground-truthing was conducted by deploying an underwater camera over the starboard side of the *R/V Cartwright* and continuously filming until a total of two minutes of footage was collected. The *R/V Cartwright* was left to drift while the camera was deployed with the start and end time recorded in Coordinated Universal Time (UTC); depth (meters) was recorded at the start of each drift according to the *R/V Cartwright*'s depth finder (Table A1A). The start and end latitude and longitude were recorded and reported in decimal degrees (DD) for each site (Table A1B). Two camera systems were employed: a Sony FDR-X3000 for sites in Rushoon and D'Argent Bay and a Deep Trekker DTPod for sites in Burin and St. Lawrence. Non-metric multidimensional scaling (NMDS) was employed to measure the agreement in observable epifauna (Figure A1), with no difference due to camera systems found.

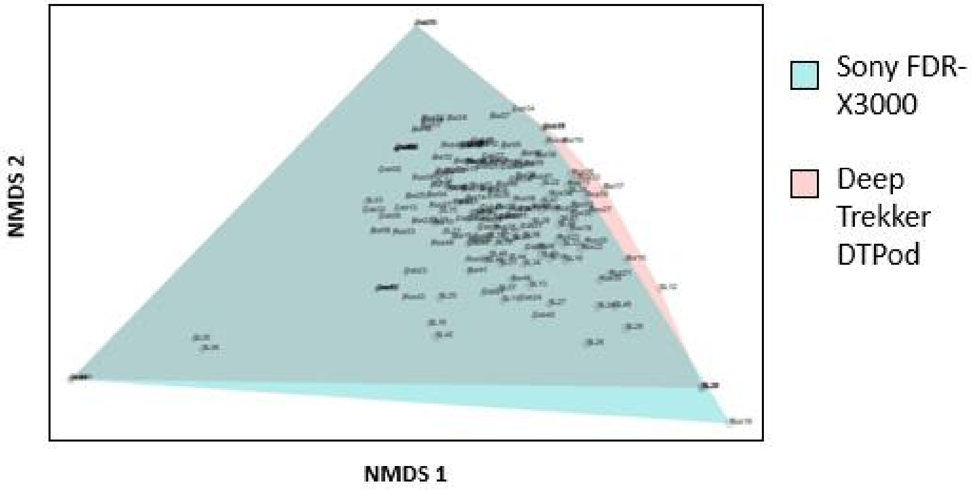


Figure A1 Non-metric multidimensional scaling (NMDS) plotting the dissimilarity in annotated species/morphotypes within each ground-truthing site.

Table A1A. Date when each ground-truthing site was surveyed and the start and end time of the transect, in Coordinated Universal Time (UTC). Also includes the depth read by the R/V Cartwright's depth sonar at the beginning, and when available the end, of the transect.

Site	**Site ID**	**Date**	**Start Time (UTC)**	**End Time (UTC)**	**Depth (m)**
D'Argent Bay	DB_06	2019-07-10	13:26:08	13:28:51	17.2
D'Argent Bay	DB_03	2019-07-10	13:41:34	13:43:27	17.7
D'Argent Bay	DB_05	2019-07-10	14:04:16	14:06:31	29.5
D'Argent Bay	DB_02	2019-07-10	14:27:02	14:29:11	24.5
D'Argent Bay	DB_13	2019-07-10	15:01:29	15:03:44	14.6
D'Argent Bay	DB_23	2019-07-10	15:30:04	15:32:13	39.9
D'Argent Bay	DB_32	2019-07-10	17:53:39	17:55:36	19
D'Argent Bay	DB_42	2019-07-10	18:11:09	18:13:28	45.8
D'Argent Bay	DB_34	2019-07-10	18:34:03	18:36:15	27.5
D'Argent Bay	DB_44	2019-07-10	19:02:55	19:05:34	56
D'Argent Bay	DB_22	2019-07-10	19:40:05	19:42:26	27.5
D'Argent Bay	DB_01	2019-07-11	11:39:53	11:42:07	12.7
D'Argent Bay	DB_07	2019-07-11	11:55:51	11:58:41	45.6
D'Argent Bay	DB_12	2019-07-11	12:17:19	12:19:31	56

D’Argent Bay	DB_11	2019-07-11	12:52:43	12:54:38	24.8
D’Argent Bay	DB_15	2019-07-11	13:09:21	13:11:29	22.3
D’Argent Bay	DB_16	2019-07-11	13:20:19	13:22:25	15.4
D’Argent Bay	DB_19	2019-07-11	13:33:11	13:35:27	20.7
D’Argent Bay	DB_27	2019-07-11	13:46:49	13:49:05	35
D’Argent Bay	DB_30	2019-07-11	14:02:53	14:04:59	41.6
D’Argent Bay	DB_40	2019-07-11	14:24:19	14:26:25	29
D’Argent Bay	DB_39	2019-07-11	14:37:45	14:39:57	21.9
D’Argent Bay	DB_45	2019-07-11	15:01:46	15:03:55	34.8
D’Argent Bay	DB_49	2019-07-11	15:13:09	15:15:21	36
D’Argent Bay	DB_48	2019-07-11	15:28:00	15:29:51	50.7
D’Argent Bay	DB_46	2019-07-11	15:49:07	15:51:23	42.2
D’Argent Bay	DB_50	2019-07-11	16:10:23	16:12:55	47
D’Argent Bay	DB_37	2019-07-11	16:47:57	16:50:29	26.1
D’Argent Bay	DB_29	2019-07-11	17:05:11	17:07:15	45.4
D’Argent Bay	DB_28	2019-07-11	17:17:27	17:19:59	18.4
D’Argent Bay	DB_26	2019-07-11	17:50:07	17:52:19	8.4
D’Argent Bay	DB_25	2019-07-11	18:27:21	18:29:27	48.7
D’Argent Bay	DB_10	2019-08-19	11:56:07	11:58:32	20.3-21.6
D’Argent Bay	DB_17	2019-08-19	12:46:45	12:49:28	17.5-18.3
D’Argent Bay	DB_31	2019-08-19	13:16:00	13:19:14	50.2-50.9
D’Argent Bay	DB_35	2019-08-19	13:39:14	13:42:00	50.1-51.9
D’Argent Bay	DB_41	2019-08-19	14:14:35	14:17:07	58.5-58.8
D’Argent Bay	DB_43	2019-08-19	14:36:55	14:40:00	37.1-44.1
D’Argent Bay	DB_47	2019-08-19	14:48:54	14:52:24	45.3-47.3
D’Argent Bay	DB_38	2019-08-19	15:08:08	15:10:34	17.8-18
D’Argent Bay	DB_33	2019-08-19	15:18:08	15:20:28	15.8-15.9
D’Argent Bay	DB_36	2019-08-19	15:44:29	15:46:51	33.5-39.7
D’Argent Bay	DB_24	2019-08-19	16:01:07	16:03:28	57.1-57.7
D’Argent Bay	DB_21	2019-08-19	16:29:39	16:32:01	57-59.3
D’Argent Bay	DB_20	2019-08-19	16:54:57	16:57:22	52.6-55.2
D’Argent Bay	DB_18	2019-08-19	17:11:14	17:13:44	47.3-48
D’Argent Bay	DB_14	2019-08-19	17:23:10	17:25:31	32.9-34.6

D’Argent Bay	DB_08	2019-08-19	17:36:01	17:38:26	47.6-49.8
Rushoon	RU_60	2019-08-14	13:01:00	13:04:50	78.8-91.9
Rushoon	RU_35	2019-08-14	13:32:50	13:35:06	73.7-72.5
Rushoon	RU_03	2019-08-14	13:45:05	13:50:05	63.3-65.8
Rushoon	RU_39	2019-08-14	14:06:10	14:09:22	42.2
Rushoon	RU_11	2019-08-14	14:25:05	14:32:20	110-113
Rushoon	RU_52	2019-08-14	15:02:00	15:07:08	18.4-36.7
Rushoon	RU_57	2019-08-14	15:16:10	15:20:11	11.5-13.5
Rushoon	RU_56	2019-08-14	15:57:00	16:00:41	6.9-12.2
Rushoon	RU_36	2019-08-14	16:32:30	16:36:33	59.4-63.3
Rushoon	RU_54	2019-08-14	11:37:01	11:41:38	112
Rushoon	RU_23	2019-08-15	12:13:32	nodata	94
Rushoon	RU_14	2019-08-15	12:56:14	13:01:25	201
Rushoon	RU_22	2019-08-15	13:58:30	14:05:53	133-137
Rushoon	RU_30	2019-08-15	14:29:10	14:33:32	90.4-91.9
Rushoon	RU_21	2019-08-15	14:53:01	14:58:13	124-130
Rushoon	RU_20	2019-08-15	15:19:21	15:23:53	99.4-98.1
Rushoon	RU_38	2019-08-15	15:49:21	nodata	66.6
Rushoon	RU_13	2019-08-15	16:22:54	16:26:39	76.9-79.7
Rushoon	RU_12	2019-08-15	16:45:04	16:47:57	77.7-78.3
Rushoon	RU_27	2019-08-15	17:22:41	17:27:48	120-125
Rushoon	RU_34	2019-08-15	17:51:02	17:57:07	81.4-82.4
Rushoon	RU_25	2019-08-15	18:19:21	18:23:58	137-140
Rushoon	RU_06	2019-08-15	16:23:58	16:29:06	19.6-21.1
Rushoon	RU_45	2019-08-17	17:01:29	17:04:44	16.8-23.2
Rushoon	RU_51	2019-08-17	17:17:29	17:20:08	28.3-28.9
Rushoon	RU_47	2019-08-17	17:31:54	17:34:39	10.2-24.9
Rushoon	RU_41	2019-08-17	18:25:53	18:28:38	57.4-59.3
Rushoon	RU_53	2019-08-17	18:46:31	18:49:09	18.0-18.4
Rushoon	RU_18	2019-08-17	19:04:40	19:08:42	92.6-93.2
Rushoon	RU_37	2019-08-17	11:28:50	11:31:43	75.2-77.8
Rushoon	RU_43	2019-08-18	11:59:52	12:03:05	22.4-24
Rushoon	RU_40	2019-08-18	12:19:28	12:21:51	39.5-43

Rushoon	RU_19	2019-08-18	12:50:46	12:53:42	120-140
Rushoon	RU_33	2019-08-18	13:20:56	13:24:05	102-104
Rushoon	RU_07	2019-08-18	14:29:47	14:32:33	13.6-18.6
Rushoon	RU_04	2019-08-18	14:44:48	14:47:34	50.7-57.6
Rushoon	RU_48	2019-08-18	15:38:40	15:41:32	27.5-32.4
Rushoon	RU_46	2019-08-18	15:53:51	15:56:35	33.7-41.4
Rushoon	RU_08	2019-08-18	16:23:21	16:26:32	71.2-71.7
Rushoon	RU_05	2019-08-18	16:50:32	16:53:42	23.0-28.4
Rushoon	RU_50	2019-08-18	17:09:35	17:12:08	34.1-35.6
Rushoon	RU_15	2019-08-18	17:37:36	17:41:41	54.5-55.2
Rushoon	RU_49	2019-08-18	18:18:40	18:21:23	24.1-31.1
Rushoon	RU_44	2019-08-18	18:44:17	18:47:07	23.8-24
Burin	BU_01	2020-07-20	13:06:00	13:09:00	19
Burin	BU_02	2020-07-20	13:25:00	13:27:00	31
Burin	BU_04	2020-07-20	13:34:00	13:37:00	31
Burin	BU_03	2020-07-20	13:46:00	13:48:00	17
Burin	BU_06	2020-07-20	13:52:00	13:55:00	34
Burin	BU_08	2020-07-20	14:01:00	14:03:00	28
Burin	BU_09	2020-07-20	14:10:00	14:12:00	36
Burin	BU_05	2020-07-20	14:20:00	14:23:00	40
Burin	BU_07	2020-07-20	14:30:00	14:33:00	62
Burin	BU_10	2020-07-20	14:44:00	14:47:00	81
Burin	BU_11	2020-07-20	14:53:00	14:56:00	20
Burin	BU_12	2020-07-20	15:05:00	15:07:00	25
Burin	BU_13	2020-07-20	15:21:00	15:24:00	25
Burin	BU_15	2020-07-20	15:32:00	15:34:00	55
Burin	BU_17	2020-07-20	15:41:00	15:43:00	93
Burin	BU_24	2020-07-20	15:51:00	15:53:18	31
Burin	BU_27	2020-07-20	16:00:00	16:03:00	20
Burin	BU_28	2020-07-20	16:11:00	16:14:00	17
Burin	BU_26	2020-07-20	16:20:00	16:22:00	25
Burin	BU_23	2020-07-20	16:30:00	16:32:00	20
Burin	BU_18	2020-07-20	16:38:00	16:40:00	30

Burin	BU_16	2020-07-20	16:45:00	16:47:00	29
Burin	BU_33	2020-07-20	17:13:00	17:16:58	38
Burin	BU_34	2020-07-20	17:24:00	17:26:30	32
Burin	BU_37	2020-07-20	17:33:00	17:36:00	15
Burin	BU_41	2020-07-20	17:43:00	17:45:00	60
Burin	BU_40	2020-07-20	17:53:00	17:55:00	31
Burin	BU_38	2020-07-20	18:01:00	18:03:00	36
Burin	BU_35	2020-07-20	18:08:00	18:10:00	24
Burin	BU_36	2020-07-20	18:15:00	18:17:00	33
Burin	BU_32	2020-07-20	18:21:00	18:23:00	22
Burin	BU_31	2020-07-20	18:28:00	18:31:00	46
Burin	BU_25	2020-07-20	18:37:00	18:39:00	27
Burin	BU_21	2020-07-20	18:44:00	18:46:00	40
Burin	BU_14	2020-07-20	18:49:00	18:53:00	39
Burin	BU_19	2020-07-20	19:01:00	19:04:00	42
Burin	BU_29	2020-07-20	19:12:00	19:15:00	62
Burin	BU_30	2020-07-20	19:22:00	19:24:00	28
Burin	BU_20	2020-07-21	11:55:00	11:57:00	28
Burin	BU_22	2020-07-21	12:07:00	12:10:00	17
Burin	BU_39	2020-07-22	11:56:00	11:59:00	56
Burin	BU_42	2020-07-22	12:06:00	12:08:00	67
Burin	BU_44	2020-07-22	12:16:00	12:18:00	32
Burin	BU_45	2020-07-22	12:26:00	12:28:00	50
Burin	BU_47	2020-07-22	12:34:00	12:37:00	21
Burin	BU_49	2020-07-22	12:43:00	12:46:00	26
Burin	BU_50	2020-07-22	12:52:00	12:54:00	40
Burin	BU_48	2020-07-22	13:02:00	13:04:00	72
Burin	BU_46	2020-07-22	13:13:00	13:15:00	85
Burin	BU_43	2020-07-22	13:25:00	13:29:00	32
Burin	BU_40	2020-07-22	13:36:00	13:38:00	39
Burin	BU_34	2020-07-22	13:45:00	13:47:00	35
Burin	BU_35	2020-07-22	13:53:00	13:56:00	24
Burin	BU_31	2020-07-22	14:02:00	14:04:00	37

Burin	BU_27	2020-07-22	14:11:00	14:14:00	22
Burin	BU_12	2020-07-22	14:25:00	14:27:00	30
Burin	BU_23	2020-07-22	14:39:00	14:41:00	22
Burin	BU_14	2020-07-22	14:50:00	14:52:00	30
St. Lawrence	SL_07	2020-08-01	16:20:28	16:22:56	72
St. Lawrence	SL_01	2020-08-02	12:45:04	12:47:20	30
St. Lawrence	SL_02	2020-08-02	12:54:10	12:57:10	35
St. Lawrence	SL_03	2020-08-02	13:04:05	13:06:18	50
St. Lawrence	SL_04	2020-08-02	13:13:26	13:15:48	44
St. Lawrence	SL_05	2020-08-02	13:21:42	13:23:52	40
St. Lawrence	SL_06	2020-08-02	13:33:58	13:36:04	50
St. Lawrence	SL_08	2020-08-02	13:44:18	13:46:52	65
St. Lawrence	SL_10	2020-08-02	13:59:50	14:01:50	85
St. Lawrence	SL_20	2020-08-02	14:12:06	14:15:12	101
St. Lawrence	SL_19	2020-08-02	14:24:22	14:27:44	96
St. Lawrence	SL_09	2020-08-02	14:37:14	14:39:44	91
St. Lawrence	SL_11	2020-08-02	16:30:18	16:32:38	65
St. Lawrence	SL_12	2020-08-02	16:42:06	16:45:16	80
St. Lawrence	SL_13	2020-08-02	16:53:12	16:55:30	76
St. Lawrence	SL_21	2020-08-02	17:03:10	17:05:32	95
St. Lawrence	SL_25	2020-08-02	17:12:10	17:14:26	92
St. Lawrence	SL_28	2020-08-02	17:19:54	17:22:26	80
St. Lawrence	SL_31	2020-08-02	17:28:28	17:30:58	66
St. Lawrence	SL_34	2020-08-02	17:36:30	17:38:42	64
St. Lawrence	SL_37	2020-08-02	17:44:52	17:47:12	47
St. Lawrence	SL_42	2020-08-02	17:55:08	17:57:24	90
St. Lawrence	SL_40	2020-08-02	18:05:28	18:07:38	89
St. Lawrence	SL_39	2020-08-02	18:15:32	18:18:00	83
St. Lawrence	SL_33	2020-08-02	18:24:40	18:26:58	93
St. Lawrence	SL_35	2020-08-02	18:32:48	18:35:14	104
St. Lawrence	SL_32	2020-08-02	18:40:54	18:43:24	107
St. Lawrence	SL_29	2020-08-02	18:50:26	18:52:46	102
St. Lawrence	SL_27	2020-08-02	19:00:06	19:02:22	65

St. Lawrence	SL_22	2020-08-02	19:08:24	19:10:36	70
St. Lawrence	SL_18	2020-08-02	19:16:00	19:18:08	55
St. Lawrence	SL_23	2020-08-02	19:23:22	19:25:10	23
St. Lawrence	SL_17	2020-08-02	19:30:16	19:32:16	38
St. Lawrence	SL_16	2020-08-02	19:36:38	19:38:38	53
St. Lawrence	SL_15	2020-08-02	19:43:48	19:46:12	31
St. Lawrence	SL_14	2020-08-02	19:49:46	19:51:40	20
St. Lawrence	SL_24	2020-08-02	12:24:28	12:26:50	99
St. Lawrence	SL_26	2020-08-02	12:35:24	12:38:04	100
St. Lawrence	SL_30	2020-08-02	12:45:20	12:47:34	110
St. Lawrence	SL_38	2020-08-02	12:54:16	12:56:48	108
St. Lawrence	SL_41	2020-08-02	13:05:08	13:07:20	105
St. Lawrence	SL_45	2020-08-02	13:13:22	13:16:02	101
St. Lawrence	SL_50	2020-08-02	13:22:24	13:24:36	92
St. Lawrence	SL_48	2020-08-02	13:31:48	13:33:24	95
St. Lawrence	SL_46	2020-08-02	13:43:04	13:45:28	83
St. Lawrence	SL_49	2020-08-02	13:50:46	13:53:46	69
St. Lawrence	SL_47	2020-08-02	14:00:28	14:02:58	61
St. Lawrence	SL_43	2020-08-02	14:08:10	14:10:32	43
St. Lawrence	SL_44	2020-08-02	14:16:30	14:18:50	64
St. Lawrence	SL_36	2020-08-02	14:27:38	14:29:56	77

Table A1B. The start and end latitude and longitude of each ground-truthing site, in decimal degrees (DD).

Site	Site ID	Start Latitude (DD)	Start Longitude (DD)	End Latitude (DD)	End Longitude (DD)
D'Argent Bay	DB_06	47.26683333N	054.98455833W	47.26722500N	054.98478333W
D'Argent Bay	DB_03	47.27396667N	054.98510833W	47.27413333N	054.98525167W
D'Argent Bay	DB_05	47.27235833N	054.99466833W	47.27250833N	054.99466500W
D'Argent Bay	DB_02	47.28037333N	054.98919833W	47.28056333N	054.98918833W
D'Argent Bay	DB_13	47.25394333N	055.01170333W	47.25401000N	055.01184000W

D’Argent Bay	DB_23	47.23549167N	055.01945333W	47.23556833N	055.01945333W
D’Argent Bay	DB_32	47.22101667N	055.03446167W	47.22099833N	055.03433000W
D’Argent Bay	DB_42	47.20727000N	055.02177667W	47.20725500N	055.02147000W
D’Argent Bay	DB_34	47.21787667N	055.01727500W	47.21787000N	055.01714000W
D’Argent Bay	DB_44	47.20166667N	054.97464000W	47.20166500N	054.97436500W
D’Argent Bay	DB_22	47.23667833N	054.98976833W	47.23663833N	054.98993667W
D’Argent Bay	DB_01	47.28883333N	054.98621667W	47.28863333N	054.98626667W
D’Argent Bay	DB_07	47.26493333N	054.99750000W	47.26490000N	054.99768333W
D’Argent Bay	DB_12	47.25698333N	054.99683333W	47.25696667N	054.99700000W
D’Argent Bay	DB_11	47.25895000N	054.98486667W	47.25890000N	054.98491667W
D’Argent Bay	DB_15	47.25163333N	054.98268333W	47.25136667N	054.98290000W
D’Argent Bay	DB_16	47.25061667N	054.99026667W	47.25056667N	054.99048333W
D’Argent Bay	DB_19	47.23885000N	055.00180000W	47.23886667N	055.00158333W
D’Argent Bay	DB_27	47.23068333N	054.98833333W	47.23058333N	054.98838333W
D’Argent Bay	DB_30	47.22850000N	055.02503333W	47.22845000N	055.02508333W
D’Argent Bay	DB_40	47.21361667N	055.01891667W	47.21361667N	055.01891667W
D’Argent Bay	DB_39	47.21376667N	055.02385000W	47.21383333N	055.02396667W
D’Argent Bay	DB_45	47.20270000N	054.99673333W	47.20258333N	054.99685000W
D’Argent Bay	DB_49	47.19281667N	055.00953333W	47.19271667N	055.00975000W
D’Argent Bay	DB_48	47.19390000N	055.00050000W	47.19376667N	055.00058333W
D’Argent Bay	DB_46	47.20211667N	054.98641667W	47.20201667N	054.98655000W
D’Argent Bay	DB_50	47.19118333N	054.97386667W	47.19131667N	054.97376667W
D’Argent Bay	DB_37	47.21660000N	055.03076667W	47.21658333N	055.03080000W
D’Argent Bay	DB_29	47.22820000N	055.03198333W	47.22816667N	055.03185000W
D’Argent Bay	DB_28	47.23126667N	055.03961667W	47.23111667N	055.03973333W
D’Argent Bay	DB_26	47.23165000N	055.04516667W	47.23145000N	055.04510000W

D'Argent Bay	DB_25	47.23348333N	054.97785000W	47.23335000N	054.97790000W
D'Argent Bay	DB_10	47.26081667N	055.00608333W	47.26085000N	055.00570000W
D'Argent Bay	DB_17	47.25070000N	054.98928333W	47.25090000N	054.98895000W
D'Argent Bay	DB_31	47.22403333N	054.97346667W	47.22426667N	054.97335000W
D'Argent Bay	DB_35	47.21676667N	054.96818333W	47.21698333N	054.96810000W
D'Argent Bay	DB_41	47.21140000N	054.97195000W	47.21161667N	054.97186667W
D'Argent Bay	DB_43	47.20451667N	054.98158333W	47.20483333N	054.98151667W
D'Argent Bay	DB_47	47.20103333N	054.99211667W	47.20143333N	054.99215000W
D'Argent Bay	DB_38	47.21500000N	055.05261667W	47.21520000N	055.05283333W
D'Argent Bay	DB_33	47.22115000N	055.05198333W	47.22141667N	055.05228333W
D'Argent Bay	DB_36	47.21788333N	055.00361667W	47.21823333N	055.00356667W
D'Argent Bay	DB_24	47.23605000N	055.02495000W	47.23635000N	055.02515000W
D'Argent Bay	DB_21	47.23991667N	055.01881667W	47.24021667N	055.01910000W
D'Argent Bay	DB_20	47.23905000N	054.97728333W	47.23948333N	054.97728333W
D'Argent Bay	DB_18	47.24640000N	054.97268333W	47.24640000N	054.97268333W
D'Argent Bay	DB_14	47.25885000N	054.97638333W	47.25931667N	054.97621667W
D'Argent Bay	DB_08	47.26185000N	054.97666667W	47.26230000N	054.97660000W
Rushoon	RU_60	47.35273333N	054.64663333W	47.35320000N	054.64570000W
Rushoon	RU_35	47.35521667N	054.67276667W	47.35510000N	054.67250000W
Rushoon	RU_03	47.35590000N	054.67223333W	47.35608333N	054.67173333W
Rushoon	RU_39	47.36256667N	054.68351667W	47.33390000N	054.68303333W
Rushoon	RU_11	47.36003333N	054.69371667W	47.35983333N	054.69318333W
Rushoon	RU_52	47.37801667N	054.68775000W	47.37813333N	054.68673333W
Rushoon	RU_57	47.38391667N	054.68953333W	47.38376667N	054.68916667W
Rushoon	RU_56	47.37475000N	054.70553333W	47.37495000N	054.70533333W
Rushoon	RU_36	47.36516667N	054.70570000W	47.36541667N	054.70493333W
Rushoon	RU_54	47.32606667N	054.71218333W	47.32576667N	054.71271667W
Rushoon	RU_23	47.32775000N	054.71038333W	nodata	nodata

Rushoon	RU_14	47.32183333N	054.71198333W	47.32096667N	054.92694444W
Rushoon	RU_22	47.32643333N	054.70156667W	47.32620000N	054.70231667W
Rushoon	RU_30	47.32485000N	054.69890000W	47.32478333N	054.69961667W
Rushoon	RU_21	47.32958333N	054.69568333W	47.32963333N	054.69655000W
Rushoon	RU_20	47.33095000N	054.69210000W	47.33105000N	054.69268333W
Rushoon	RU_38	47.33400000N	054.68848333W	nodata	nodata
Rushoon	RU_13	47.32815000N	054.69143333W	47.32838333N	054.69170000W
Rushoon	RU_12	47.32213333N	054.70145000W	47.32238333N	054.70113333W
Rushoon	RU_27	47.31983333N	054.70625000W	47.32010000N	054.70585000W
Rushoon	RU_34	47.31570000N	054.70690000W	47.31580000N	054.70650000W
Rushoon	RU_25	47.32566667N	054.72970000W	47.32575000N	054.72928333W
Rushoon	RU_06	47.36776667N	054.70225000W	47.36775000N	054.70210000W
Rushoon	RU_45	47.34713333N	054.66203333W	47.34775000N	054.66181667W
Rushoon	RU_51	47.33490000N	054.67456667W	47.33521667N	054.66766667W
Rushoon	RU_47	47.3336666&N	054.67760000W	47.33390000N	054.67745000W
Rushoon	RU_41	47.32656667N	054.68585000W	47.32673333N	054.68543333W
Rushoon	RU_53	47.30890000N	054.69973333W	47.30906667N	054.69955000W
Rushoon	RU_18	47.31003333N	054.70843333W	47.31035000N	054.70816667W
Rushoon	RU_37	47.33621667N	054.75971667W	47.33630000N	054.75963333W
Rushoon	RU_43	47.33663333N	054.74230000W	47.33683333N	054.74211667W
Rushoon	RU_40	47.34040000N	054.72761667W	47.34058333N	054.72746667W
Rushoon	RU_19	47.33626667N	054.71726667W	47.33638333N	054.71721667W
Rushoon	RU_33	47.33753333N	054.70360000W	47.33780000N	054.70446667W
Rushoon	RU_07	47.35695000N	054.71420000W	47.35723333N	054.71405000W
Rushoon	RU_04	47.35448333N	054.70300000W	47.35491667N	054.70293333W
Rushoon	RU_48	47.37180000N	054.67278333W	47.37225000N	054.67223333W
Rushoon	RU_46	47.36226667N	054.67158333W	47.36250000N	054.67133333W
Rushoon	RU_08	47.34981667N	054.67935000W	47.35035000N	054.67870000W
Rushoon	RU_05	47.35155000N	054.68573333W	47.35200000N	054.68531667W
Rushoon	RU_50	47.33975000N	054.68020000W	47.34000000N	054.67968333W
Rushoon	RU_15	47.32940000N	054.68208333W	47.32983333N	054.68130000W
Rushoon	RU_49	47.32975000N	054.73238333W	47.33018333N	054.73205000W
Rushoon	RU_44	47.32800000N	054.73803333W	47.32856667N	054.73780000W

Burin	BU_01	47.08817667N	055.10571667W	47.08839000N	055.10583333W
Burin	BU_02	47.08393833N	055.10878333W	47.08380333N	055.10898333W
Burin	BU_04	47.07787667N	055.10246667W	47.07802667N	055.10191667W
Burin	BU_03	47.07799833N	055.09083333W	47.07790000N	055.09096667W
Burin	BU_06	47.07411833N	055.09328333W	47.07398833N	055.09338333W
Burin	BU_08	47.06881333N	055.10186667W	47.06855667N	055.10191667W
Burin	BU_09	47.06730167N	055.09291667W	47.06752167N	055.09258333W
Burin	BU_05	47.07435167N	055.07123333W	47.07457000N	055.07086667W
Burin	BU_07	47.06921667N	055.07931667W	47.06979667N	055.07886667W
Burin	BU_10	47.06572333N	055.08656667W	47.06616667N	055.08666667W
Burin	BU_11	47.06381167N	055.09165000W	47.06412667N	055.09203333W
Burin	BU_12	47.05863833N	055.09561667W	47.05988000N	055.09560000W
Burin	BU_13	47.05842167N	055.08781667W	47.10863333N	055.10395000W
Burin	BU_15	47.04871333N	055.10563333W	47.04866500N	055.10523333W
Burin	BU_17	47.04683333N	055.10003333W	47.04677667N	055.09975000W
Burin	BU_24	47.04263167N	055.09948333W	47.04276500N	055.09898333W
Burin	BU_27	47.03680500N	055.10596667W	47.03677167N	055.10548333W
Burin	BU_28	47.03632833N	055.11726667W	47.03623167N	055.11676667W
Burin	BU_26	47.03845500N	055.12490000W	47.03850333N	055.12441667W
Burin	BU_23	47.04393000N	055.12155000W	47.04399500N	055.12183333W
Burin	BU_18	47.04663500N	055.11421667W	47.04640167N	055.11398333W
Burin	BU_16	47.04838000N	055.11820000W	47.04838333N	055.11768333W
Burin	BU_33	47.03006833N	055.11350000W	47.03042500N	055.11300000W
Burin	BU_34	47.02984167N	055.12351667W	47.03005333N	055.12360000W
Burin	BU_37	47.02767833N	055.12538333W	47.02782333N	055.12566667W
Burin	BU_41	47.02023167N	055.12001667W	47.02040000N	055.11993333W
Burin	BU_40	47.02178833N	055.12820000W	47.02184000N	055.12786667W
Burin	BU_38	47.02336000N	055.13123333W	47.02356167N	055.13071667W
Burin	BU_35	47.02769500N	055.13360000W	47.02773667N	055.13288333W
Burin	BU_36	47.02775333N	055.13773333W	47.02790667N	055.13720000W
Burin	BU_32	47.03091000N	055.14356667W	47.03111000N	055.14283333W
Burin	BU_31	47.03290000N	055.13795000W	47.03326833N	055.13740000W
Burin	BU_25	47.04143333N	055.13968333W	47.04153500N	055.13915000W

Burin	BU_21	47.04419500N	055.13081667W	47.04409333N	055.13020000W
Burin	BU_14	47.04543000N	055.12980000W	47.05045500N	055.13111667W
Burin	BU_19	47.04639833N	055.13990000W	47.04615833N	055.13938333W
Burin	BU_29	47.03396333N	055.15976667W	47.03398500N	055.15901667W
Burin	BU_30	47.03351833N	055.16546667W	47.03358000N	055.16478333W
Burin	BU_20	47.04576667N	055.16881667W	47.04567167N	055.16913333W
Burin	BU_22	47.04358500N	055.16033333W	47.04318500N	055.15978333W
Burin	BU_39	47.02098167N	055.14198333W	47.02084333N	055.14176667W
Burin	BU_42	47.01599167N	055.14505000W	47.01593500N	055.14443333W
Burin	BU_44	47.01051833N	055.15346667W	47.01044667N	055.15298333W
Burin	BU_45	47.00853667N	055.14098333W	47.00807833N	055.14040000W
Burin	BU_47	47.00436333N	055.14273333W	47.00429333N	055.14238333W
Burin	BU_49	46.99855500N	055.14558167W	46.99811000N	055.14567000W
Burin	BU_50	46.99146000N	055.14991167W	46.99105000N	055.14950000W
Burin	BU_48	46.99904333N	055.13866833W	46.99860000N	055.13811000W
Burin	BU_46	47.00613333N	055.13061667W	47.00572833N	055.13041667W
Burin	BU_43	47.01452167N	055.13306667W	47.01425500N	055.13243333W
Burin	BU_40	47.02130667N	055.12856667W	47.02100833N	055.12826667W
Burin	BU_34	47.02923500N	055.12315000W	47.02873333N	055.12315000W
Burin	BU_35	47.02739833N	055.13310000W	47.02692500N	055.13270000W
Burin	BU_31	47.03239667N	055.13720000W	47.03199333N	055.13698333W
Burin	BU_27	47.03611667N	055.10641667W	47.03553500N	055.10838333W
Burin	BU_12	47.05756000N	055.09640000W	47.05711500N	055.09633333W
Burin	BU_23	47.04391500N	055.12220000W	47.04394833N	055.12240000W
Burin	BU_14	47.05061667N	055.13180000W	47.05031167N	055.13206667W
St. Lawrence	SL_07	46.86287500N	055.36345000W	46.86285167N	055.36424333W
St. Lawrence	SL_01	46.90152833N	055.37963333W	46.90106833N	055.37951667W
St. Lawrence	SL_02	46.89733333N	055.36806667W	46.89693500N	055.36785000W
St. Lawrence	SL_03	46.89202000N	055.35511667W	46.89169333N	055.35495000W
St. Lawrence	SL_04	46.88294333N	055.36195000W	46.88259667N	055.36185000W
St. Lawrence	SL_05	46.88120167N	055.36936667W	46.88081667N	055.36918333W
St. Lawrence	SL_06	46.87085167N	055.36996667W	46.87034500N	055.37001667W
St. Lawrence	SL_08	46.86846333N	055.35975000W	46.86789833N	055.35976667W

St. Lawrence	SL_10	46.86722167N	055.33901667W	46.86699167N	055.34720000W
St. Lawrence	SL_20	46.87163000N	055.33406667W	46.87130500N	055.33403333W
St. Lawrence	SL_19	46.86149000N	055.33665000W	46.86120667N	055.33686667W
St. Lawrence	SL_09	46.85490333N	055.35155000W	46.85455333N	055.35170000W
St. Lawrence	SL_11	46.87690000N	055.35350000W	46.87665667N	055.35343333W
St. Lawrence	SL_12	46.88079333N	055.34390000W	46.88063333N	055.34406667W
St. Lawrence	SL_13	46.88799667N	055.34386667W	46.88792667N	055.34383333W
St. Lawrence	SL_21	46.88359333N	055.33225000W	46.88383000N	055.33225000W
St. Lawrence	SL_25	46.88676000N	055.32381667W	46.88691500N	055.32381667W
St. Lawrence	SL_28	46.88897000N	055.31628333W	46.88916333N	055.31613333W
St. Lawrence	SL_31	46.89470000N	055.30738333W	46.89495167N	055.30738333W
St. Lawrence	SL_34	46.89748167N	055.30226667W	46.89764000N	055.30213333W
St. Lawrence	SL_37	46.89794833N	055.29613333W	46.89809833N	055.29603333W
St. Lawrence	SL_42	46.89463667N	055.28336667W	46.89479667N	055.28331667W
St. Lawrence	SL_40	46.88710833N	055.28480000W	46.88725500N	055.28490000W
St. Lawrence	SL_39	46.89040833N	055.29250000W	46.89055667N	055.29260000W
St. Lawrence	SL_33	46.88667667N	055.30280000W	46.88673333N	055.30300000W
St. Lawrence	SL_35	46.88303333N	055.30111667W	46.88318667N	055.30138333W
St. Lawrence	SL_32	46.87938500N	055.30595000W	46.87956500N	055.30615000W
St. Lawrence	SL_29	46.88409167N	055.30998333W	46.88414833N	055.31020000W
St. Lawrence	SL_27	46.89527500N	055.31733333W	46.89532833N	055.31745000W
St. Lawrence	SL_22	46.89146333N	055.33035000W	46.89158333N	055.33051667W
St. Lawrence	SL_18	46.89215167N	055.33828333W	46.89198833N	055.33816667W
St. Lawrence	SL_23	46.89922667N	055.32781667W	46.89880667N	055.32761667W
St. Lawrence	SL_17	46.89743500N	055.33923333W	46.89709667N	055.33916667W
St. Lawrence	SL_16	46.90322000N	055.34041667W	46.90286000N	055.34033333W
St. Lawrence	SL_15	46.91056667N	055.34593333W	46.91020500N	055.34573333W
St. Lawrence	SL_14	46.91690167N	055.35503333W	46.91652000N	055.35485000W
St. Lawrence	SL_24	46.87730167N	055.32308333W	46.87739333N	055.32293333W
St. Lawrence	SL_26	46.86581667N	055.32131667W	46.86595833N	055.32110000W
St. Lawrence	SL_30	46.87155333N	055.30780000W	46.87170833N	055.30756667W
St. Lawrence	SL_38	46.87527667N	055.29570000W	46.87542333N	055.29541667W
St. Lawrence	SL_41	46.87950000N	055.28361667W	46.87961667N	055.28330000W

St. Lawrence	SL_45	46.88134500N	055.27621667W	46.88151000N	055.27560000W
St. Lawrence	SL_50	46.88522833N	055.26720000W	46.88539667N	055.26696667W
St. Lawrence	SL_48	46.89193667N	055.27018333W	46.89191333N	055.26985000W
St. Lawrence	SL_46	46.89850500N	055.27275000W	46.89867667N	055.27223333W
St. Lawrence	SL_49	46.90271500N	055.27018333W	46.90261667N	055.26973333W
St. Lawrence	SL_47	46.90950167N	055.27045000W	46.90918833N	055.27051667W
St. Lawrence	SL_43	46.90823333N	055.27678333W	46.90805333N	055.27661667W
St. Lawrence	SL_44	46.90334667N	055.27661667W	46.90361833N	055.27686667W
St. Lawrence	SL_36	46.89290667N	055.29733333W	46.89273833N	055.29711667W

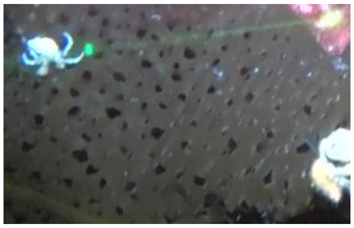
Appendix 2.

Following the video annotation process, a catalog was developed to outline all species/morphotypes identified and included in this study's analysis (Table A3). A combination of expert knowledge and published epifaunal identification guides were used during the identification process.

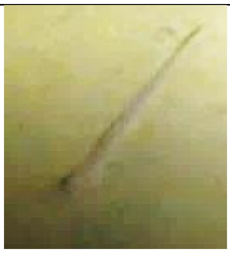
Table A2. Species catalogue of all epifauna taxa identified across the entirety of the four sites surveyed along the western coast of Placentia Bay of the Island of Newfoundland. Images are taken from videos collected during the ground-truthing portion of this research. Species/morphotypes are grouped together by phyla; within each group, species/morphotypes are in alphabetical order. Identifier refers to the demarcation for a species/morphotype used for annotation and for data analysis. Taxonomic information was taken from the World Register of Marine Species (WoRMS; https://www.marinespecies.org/index.php).

ARTHROPODA

IDENTIFER	TAXONOMY	IMAGE
Chionoecetes.opilio	**Phylum**: Athropoda **Class:** Malacostraca **Order:** Decapoda **Family:** Oregoniidae **Genus:** *Chionoecetes* **Species:** *opilio* **common name(s)**: snow crab	
Hyas.sp.1	**Phylum**: Athropoda **Class:** Malacostraca **Order:** Decapoda **Family:** Oregoniidae **Genus:** *Hyas* **common name(s)**: toad crab great spider crab	

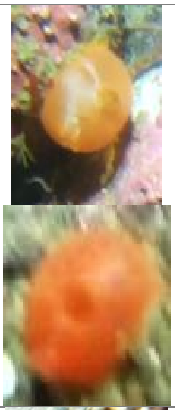
Pagurus.sp.1	**Phylum**: Athropoda **Class:** Malacostraca **Order:** Decapoda **Family:** Paguridae **Genus:** *Pagurus* **common name(s)**: hermit crab	
Pandalidae.sp.2	**Phylum**: Arthropoda **Class:** Malacostraca **Order:** Decapoda **Family:** Pandalidae	
Pandalus.sp.1	**Phylum**: Arthropoda **Class:** Malacostraca **Order:** Decapoda **Family:** Pandalidae **Genus:** *Pandalus* **common name(s)**: boreal shrimp	

CHAETOGNATHA

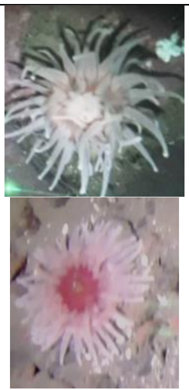
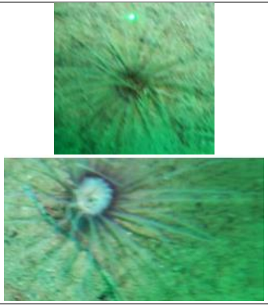
IDENTIFER	**TAXONOMY**	**IMAGE**
Sagittidae.sp.1	**Phylum:** Chaetognatha **Class:** Sagittoidea **Order:** Aphragmophora **Family:** Sagittidae	

CHORDATA

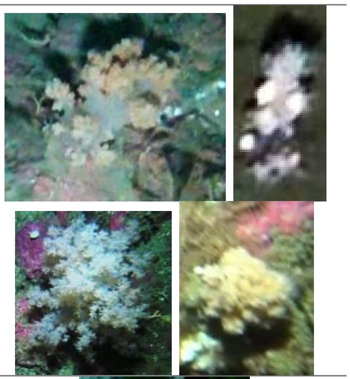
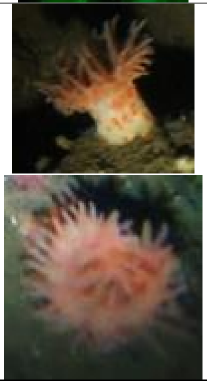
IDENTIFER	TAXONOMY	IMAGE
Botryllus.sp.1	**Phylum:** Chordata **Class:** Ascidiacea **Order:** Stolidobranchia **Family:** Styelidae **Genus:** *Botryllus*	
Hippoglossoides.platessoides	**Phylum**: Chordata **Class:** Actinopteri **Order:** Pleuronectiformes **Family:** Pleuronectidae **Genus:** *Hippoglossoides* **Species:** *platessoides* **common name(s):** sand-dab Canadian plaice American plaice	
Myoxocephalus.sp.1	**Phylum**: Chordata **Class:** Actinopteri **Order:** Perciformes **Family:** Cottidae **Genus:** *Myoxocephalus* **common name(s)**: sculpin	
Pseudopleuronectes.americanus	**Phylum:** Chordata **Class:** Actinopteri **Order:** Pleuronectiformes **Family:** Pleuronectidae **Genus:** *Pseudopleuronectes* **Species:** *americanus* **common name(s):** winter flounder lemon sole	

Tunicata.sp.1	**Phylum:** Chordata	
Tunicata.sp.2	**Phylum:** Chordata	

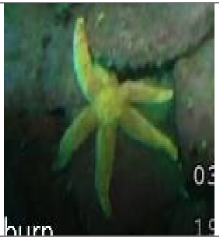
CNIDARIA

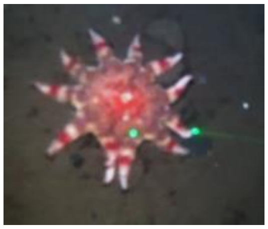
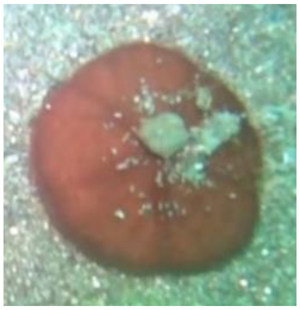
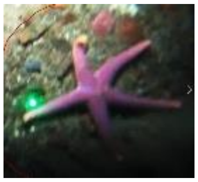
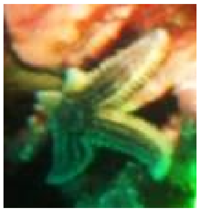
IDENTIFER	TAXONOMY	IMAGE
Actiniidae.spp.	**Phylum:** Cnidaria **Class:** Anthozoa **Order:** Actiniaria **Family:** Actiniidae	
Cerianthidae.sp.1	**Phylum:** Cnidaria **Class:** Anthozoa **Order:** Spirularia **Family:** Cerianthidae	

Cerianthidae.sp.3	**Phylum:** Cnidaria **Class:** Anthozoa **Order:** Spirularia **Family:** Cerianthidae	
Cnidaria.sp.1	**Phylum:** Cnidaria	
Hormathia.sp.1	**Phylum:** Cnidaria **Class:** Anthozoa **Order:** Actiniaria **Family:** Metridioidea **Genus:** *Hormathia*	 
Hydrozoa.sp.1	**Phylum**: Cnidaria **Class:** Hydrozoa **common name(s):** hydroids	
Metridium.senile	**Phylum:** Cnidaria **Class:** Anthozoa **Order:** Actiniaria **Family:** Metridioidea **Genus:** *Metridium* **Species:** *senile* **common name(s):** plumose sea anenome frilled anenome	

Nephtheidae.spp.	**Phylum:** Cnidaria **Class:** Anthozoa **Order:** Alcyonacea **Family:** Nephtheidae	
Stauromedusae.sp.2	**Phylum:** Cnidaria **Class:** Staurozoa **Order:** Stauromedusae	
Stomphia.coccinea	**Phylum:** Cnidaria **Class:** Anthozoa **Order:** Actiniaria **Family:** Actinostolidae **Genus:** *Stomphia* **Species:** *coccinea* **common name(s):** swimming anenome red stomphia	

ECHINODERMATA

IDENTIFER	**TAXONOMY**	**IMAGE**
Asterias.sp.1	**Phylum:** Echinodermata **Class:** Asteroidea **Order:** Forcipulatida **Family:** Asteriidae **Genus:** *Asterias*	
Asteroidea.sp.10	**Phylum**: Echinodermata **Class:** Asteroidea	

Crossaster.papposus	**Phylum:** Echinodermata **Class:** Asteroidea **Order:** Valvatida **Family:** Solasteridae **Genus:** *Crossaster* **Species**: *papposus* **common name(s):** rose star snowflake star common sun star	
Crossaster.sp.1	**Phylum:** Echinodermata **Class:** Asteroidea **Order:** Valvatida **Family:** Solasteridae **Genus:** *Crossaster*	
Echinarachnius.parma	**Phylum**: Echinodermata **Class:** Echinoidea **Order:** Echinolampadacea **Family:** Echinarachniidae **Genus:** *Echinarachnius* **Species:** *parma* **common name(s):** common sand dollar	
Henricia.sp.1	**Phylum:** Echinodermata **Class:** Asteroidea **Order:** Spinulosida **Family:** Echinasteridae **Genus:** *Henricia*	
Leptasterias.littoralis	**Phylum:** Echinodermata **Class:** Asteroidea **Order:** Forcipulatida **Family:** Asteriidae **Genus:** *Leptasterias* **Species:** *littoralis*	

Leptasterias.polaris	**Phylum:** Echinodermata **Class:** Asteroidea **Order:** Forcipulatida **Family:** Asteriidae **Genus:** *Leptasterias* **Species:** *polaris*	
Leptasterias.sp.1	**Phylum:** Echinodermata **Class:** Asteroidea **Order:** Forcipulatida **Family:** Asteriidae **Genus:** *Leptasterias*	
Ophiuroidea.spp	**Phylum**: Echinodermata **Class:** Ophiuroidea **common name(s):** brittle stars	
Psammechinus.miliaris	**Phylum**: Echinodermata **Class:** Echinoidea **Order:** Camarodonta **Family:** Parechinidae **Genus:** *Psammechinus* **Species:** *miliaris*	
Strongylocentrotus.droebachiensis	**Phylum:** Echinodermata **Class:** Echinoidea **Order:** Camarodonta **Family:** Strongylocentrotidae **Genus:** *Strongylocentrotus* **Species:** *droebachiensis* **common name(s):** green sea urchin northern sea urchin	

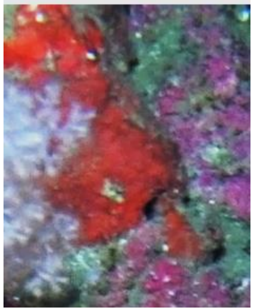
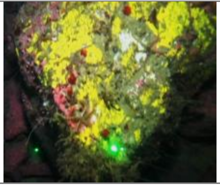
MOLLUSCA

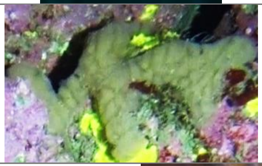
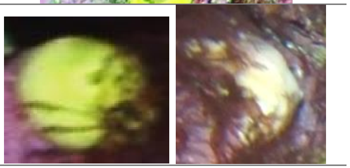
IDENTIFER	TAXONOMY	IMAGE

Arctica.islandica	**Phylum**: Mollusca **Class:** Bivalvia **Order:** Venerida **Family:** Arcticidae **Genus:** *Arctica* **Species:** *islandica* **common name(s):** ocean quahog icelandic cyprine	
Boreochiton.ruber	**Phylum**: Mollusca **Class:** Polyplacophora **Order:** Chitonida **Family:** Tonicellidae **Genus:** *Boreochiton* **Species:** *ruber* **common name(s):** red northern chiton	
Buccinum.undatum	**Phylum**: Mollusca **Class:** Gastropoda **Order:** Neogastropoda **Family:** Buccinidae **Genus:** *Buccinum* **Species:** *undatum* **common name(s):** common whelk buckie	
Chlamys.sp.1	**Phylum**: Mollusca **Class:** Hexanauplia **Order:** Siphonostomatoida **Family:** Pandaridae **Genus:** *Perissopus*	

PORIFERA

IDENTIFER	**TAXONOMY**	**IMAGE**

Geodia.sp.1	**Phylum:** Porifera **Class:** Demospongiae **Order:** Tetractinellida **Family:** Geodiidae **Genus:** *Geodia*	
Porifera.sp.1	**Phylum:** Porifera	
Porifera.sp.13	**Phylum:** Porifera	
Porifera.sp.14	**Phylum:** Porifera	
Porifera.sp.15	**Phylum:** Porifera	
Porifera.sp.17	**Phylum:** Porifera	
Porifera.sp.2	**Phylum:** Porifera	

Porifera.sp.28	**Phylum:** Porifera	
Porifera.sp.30	**Phylum:** Porifera	
Porifera.sp.5	**Phylum:** Porifera	
Porifera.sp.6	**Phylum:** Porifera	
Porifera.sp.7	**Phylum:** Porifera	
Porifera.sp.8	**Phylum:** Porifera	

Porifera.sp.9	**Phylum:** Porifera	
Tetillidae.sp.1	**Phylum:** Porifera **Class:** Demospongiae **Order:** Tetractinellida **Family:** Tetillidae	

Appendix 3.

Table A3. List of species/morphotypes identified in each faunal assemblage, listed in alphabetical order, with the counts of each in each epifaunal assemblage identified along the western coast of Placentia Bay. Numbers in bold and outlined are the typifying species of each assemblage, as determined by the IndVal analysis.

Species/Morphotype	**Assemblage**				**Total Count**
	OPH	SDR	MIX	EPA	
Actiniidae sp.1	58	9	9	19	95
Arctica islandica	4	0	1	0	5
Asterias sp.1	72	149	4	16	241
Asteroidea sp.10	2	0	3	0	5
Boreochiton ruber	26	0	4	0	30
Botryllus sp.1	15	0	0	0	15
Buccinum undatum	18	4	10	0	32
Cerianthidae sp.1	11	0	0	0	11
Cerianthidae sp.3	5	0	**190**	0	195
Chionoecetes opilio	4	4	3	1	12
Chlamys sp.1	4	0	0	0	4
Cnidaria sp.1	5	0	**22**	0	27
Cnidaria sp.5	5	0	1	0	6
Crossaster papposus	18	0	4	0	22
Crossaster sp.1	5	1	0	0	6
Echinarachnius parma	0	0	0	**627**	627
Geodia sp.1	14	0	9	0	23
Henricia sp.1	47	14	8	0	69
Hippoglossoides platessoides	0	1	1	0	2
Hormathia sp.1	163	1	**1467**	0	1631
Hyas sp.1	4	0	19	1	24
Hydrozoa sp.1	**42**	0	0	0	42
Leptasterias littoralis	7	0	0	0	7
Leptasterias polaris	26	4	12	1	43
Leptasterias sp.1	0	0	2	0	0
Metridium senile	54	2	4	0	60
Myoxocephalus sp.1	3	2	1	0	6
Neptheidae spp.	40	0	5	0	45
Ophiuroidea spp.	**6613**	33	47	9	6693
Pagurus sp.1	4	2	3	0	9
Pandalidae sp.2	8	0	0	0	8

Pandalus sp.1	38	0	11	0	49
Porifera sp.1	110	6	4	2	122
Porifera sp.13	64	4	3	0	71
Porifera sp.14	21	0	6	0	27
Porifera sp.15	9	0	6	0	15
Porifera sp.17	40	0	4	0	44
Porifera sp.2	192	18	2	0	212
Porifera sp.28	7	0	0	0	7
Porifera sp.30	33	0	17	0	50
Porifera sp.5	**475**	0	7	0	482
Porifera sp.6	3	0	5	0	8
Porifera sp.7	7	0	0	0	7
Porifera sp.8	14	0	1	0	15
Porifera sp.9	4	3	0	0	7
Pseudopleuronectes americanus	1	1	1	**2**	5
Pteraster militaris	16	0	10	0	26
Sagittidae sp.1	3	0	**20**	0	23
Stauromedusae sp.2	16	**70**	1	0	87
Stomphia coccinea	26	0	3	0	29
Strongylocentrotus droebachiensis	244	**410**	106	6	766
Porifera sp.25	2	0	5	0	7
Tunicata sp.1	14	0	11	0	25
Tunicata sp.2	15	0	0	0	15

Appendix 4.

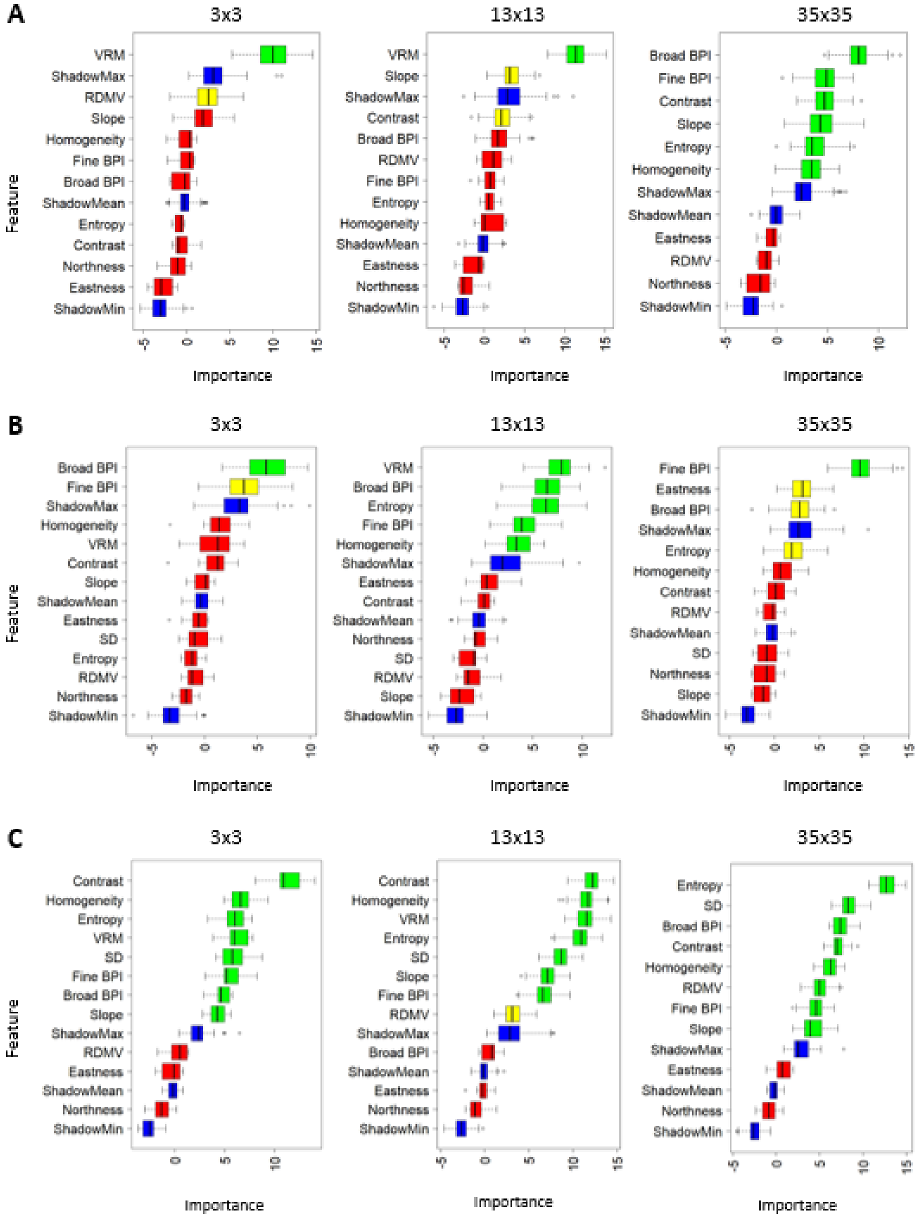


Figure A4. Results of Boruta feature selection across three separate scales. Green indicates a feature was deemed important by the Boruta algorithm; yellow is tentative, red is not important, and blue represents the shadow feature. The Boruta feature selections for the A) dominate epifaunal assemblages (Chapter 2), B) Agarum clathratum (Chapter 3), and C) non-geniculate crustose coralline algae (CCA) (Chapter 3) models are all listed

Appendix 5.

Correlation plots were developed to compare the correlation of each feature selected for model development, following Boruta feature selection and prior to removal of any features due to high correlation (≤ –0.7 or ≥ 0.7). Correlation plots were developed using the R package “corrplot”.

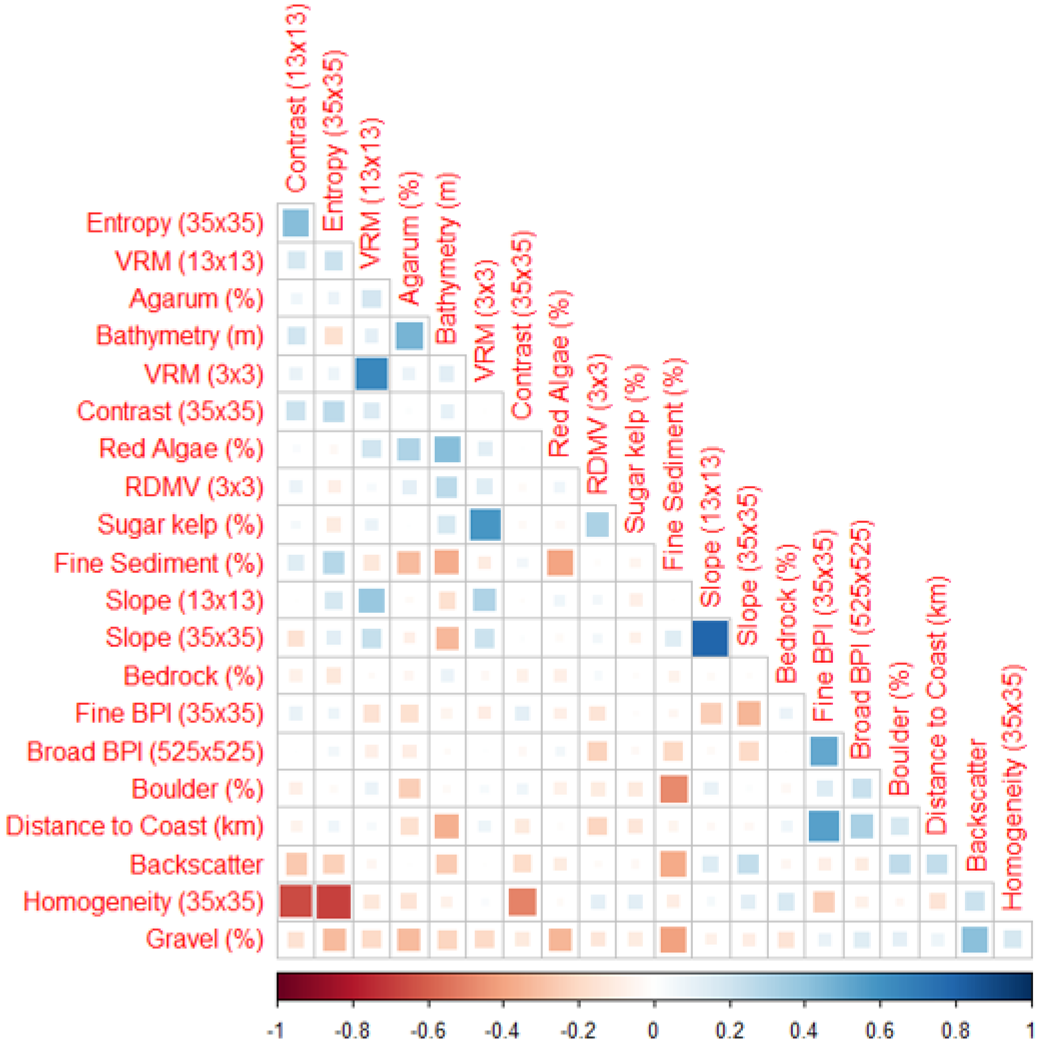


Figure A5A. Correlation plot for those features used in the Random Forest and Light Gradient Boosting Machine models developed using the epifauna assemblage data (Chapter 2).

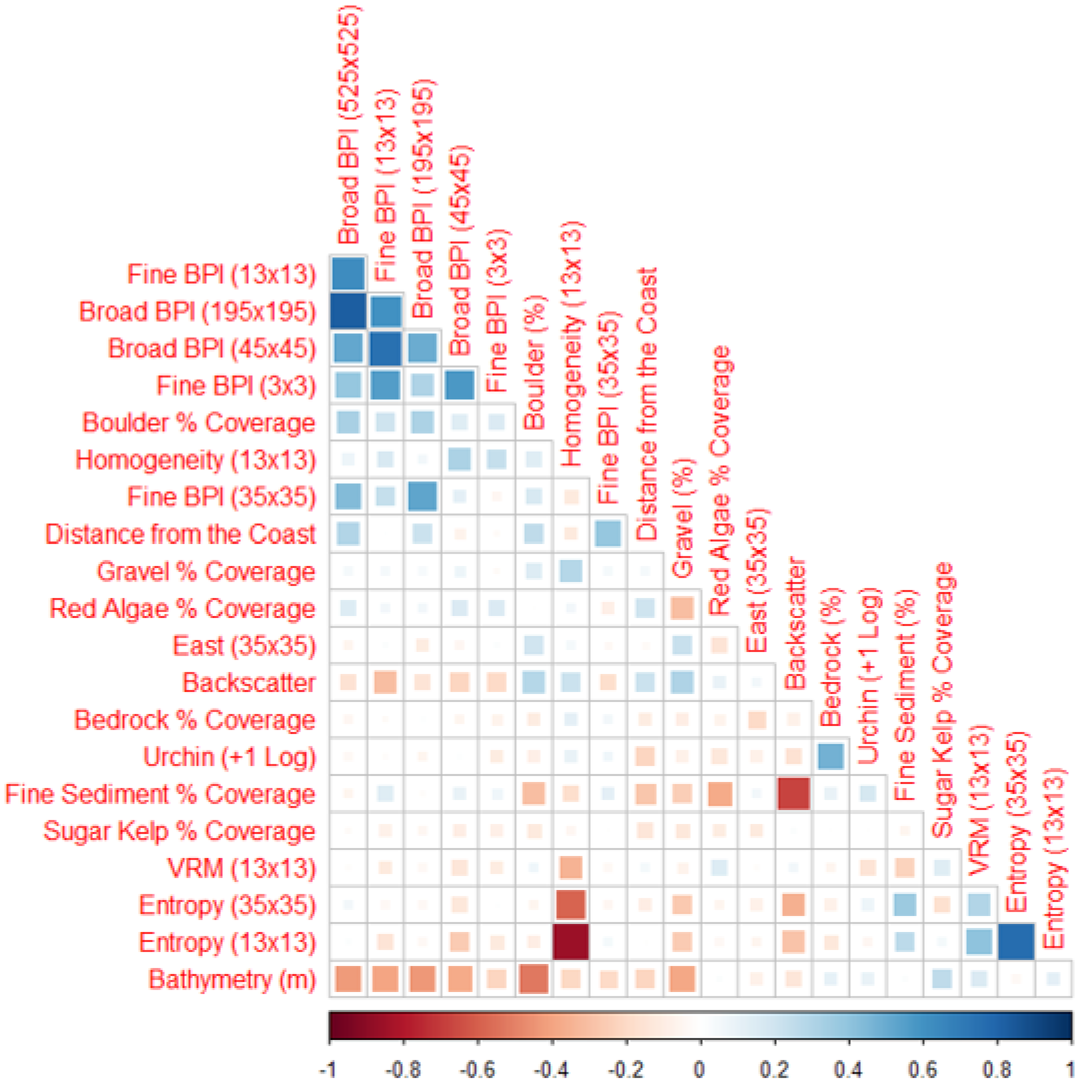


Figure A5B. Correlation plot for those features used in the Random Forest model developed using the *Agarum clathratum* presence and absence data (Chapter 3).

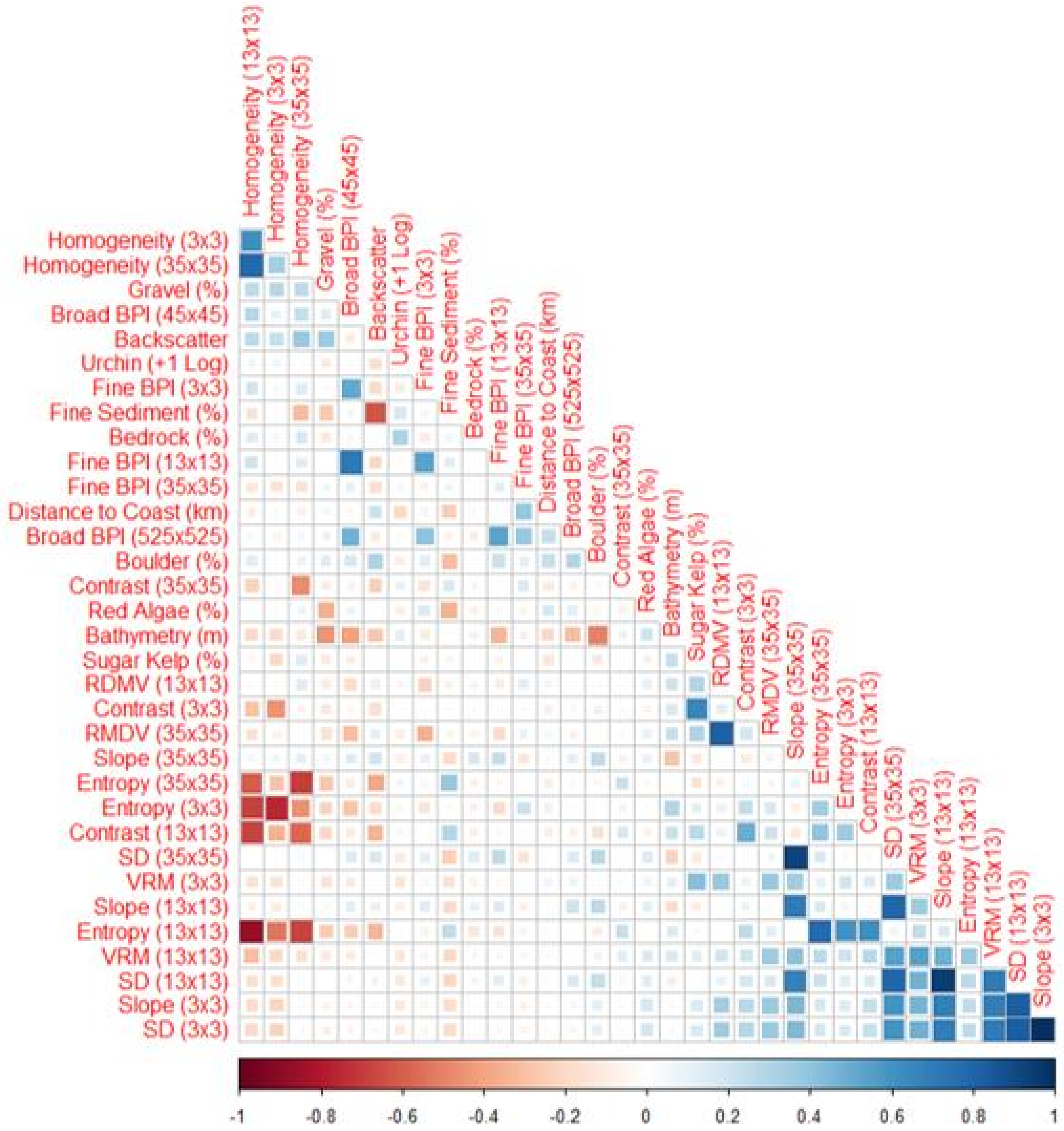


Figure A2C. Correlation plot for those features used in the Random Forest model developed using the non-geniculate crustose coralline algae data (Chapter 3).

Appendix 6.

Settings for each parameter utilized and tuned for the Light Gradient Boosting Machine (LightGBM). ‘objective’, ‘metric’, and ‘num_class’ were not changed throughout the modelling process. ‘is_unbalance’ and ‘force_col_wise’ were set to FALSE and TRUE, respectively, based off of the model’s own recommendations. All other settings were chosen based off of what combination produced the highest accuracy and precision/recall. Prior to tuning, model accuracy was 58.5 % with a 0.1942.

Table A6. Setting selected for tuning the Light Gradient Boosting Machine model.

Parameter	Setting
‘objective’	‘multiclass’
‘metric’	‘multi_error’
‘num_class’	4L
‘is_unbalance’	FALSE
‘force_col_wise’	TRUE
‘max_depth’	10
‘num_leaves’	1024
‘learning_rate’	0.5
‘num_iterations’	400
‘feature_fraction’	0.8
‘lambda_l1’	0.2
‘lambda_l2’	0.2
‘min_gain_to_split’	0.2
‘early_stopping_rounds’	20
‘bagging_freq’	2

Appendix 7.

Table A7. Coverage (km^2) of each assemblage across each survey area, as predicted by both the Random Forest and Light Gradient Boosting Machine (LightGBM) models.

		Rushoon	**D'Argent Bay**	**Burin**	**St. Lawrence**
Random Forest	OPH	25.19	30.61	17.32	24.11
	SDR	2.61	7.08	2.70	3.81
	Mix	9.53	1.75	0.43	6.62
	EpA	0.02	0.23	0.01	0.09
LightGBM	OPH	24.08	40.12	19.70	34.70
	SDR	2.22	3.36	4.65	2.02
	Mix	13.36	0.00	0.00	0.04
	EpA	0.00	0.01	0.00	0.00

Appendix 8.

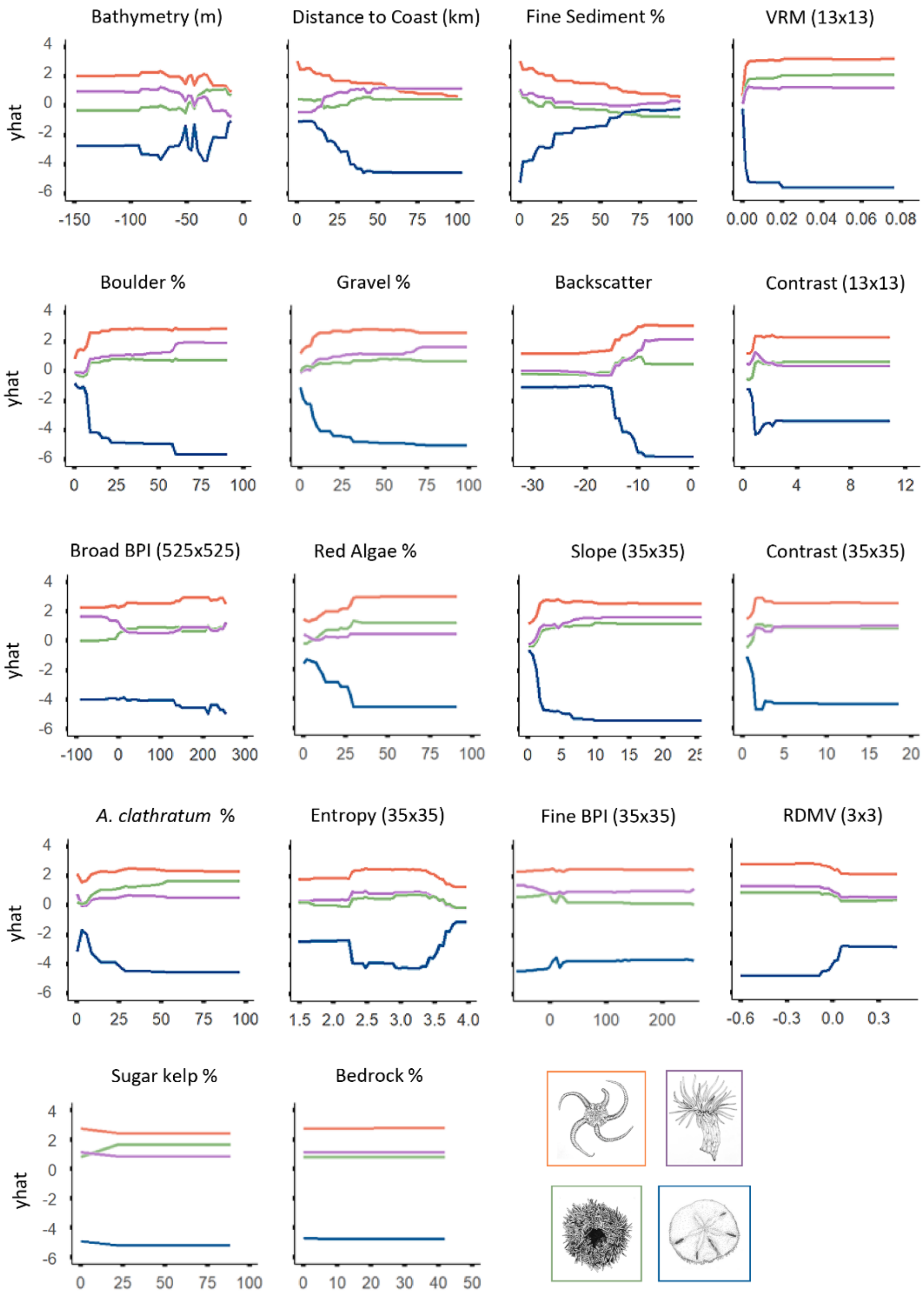


Figure A8. Partial dependence plots per epifaunal assemblage (Chapter 2) for all features included in training of the random forest model, in order of importance.

Appendix 9.

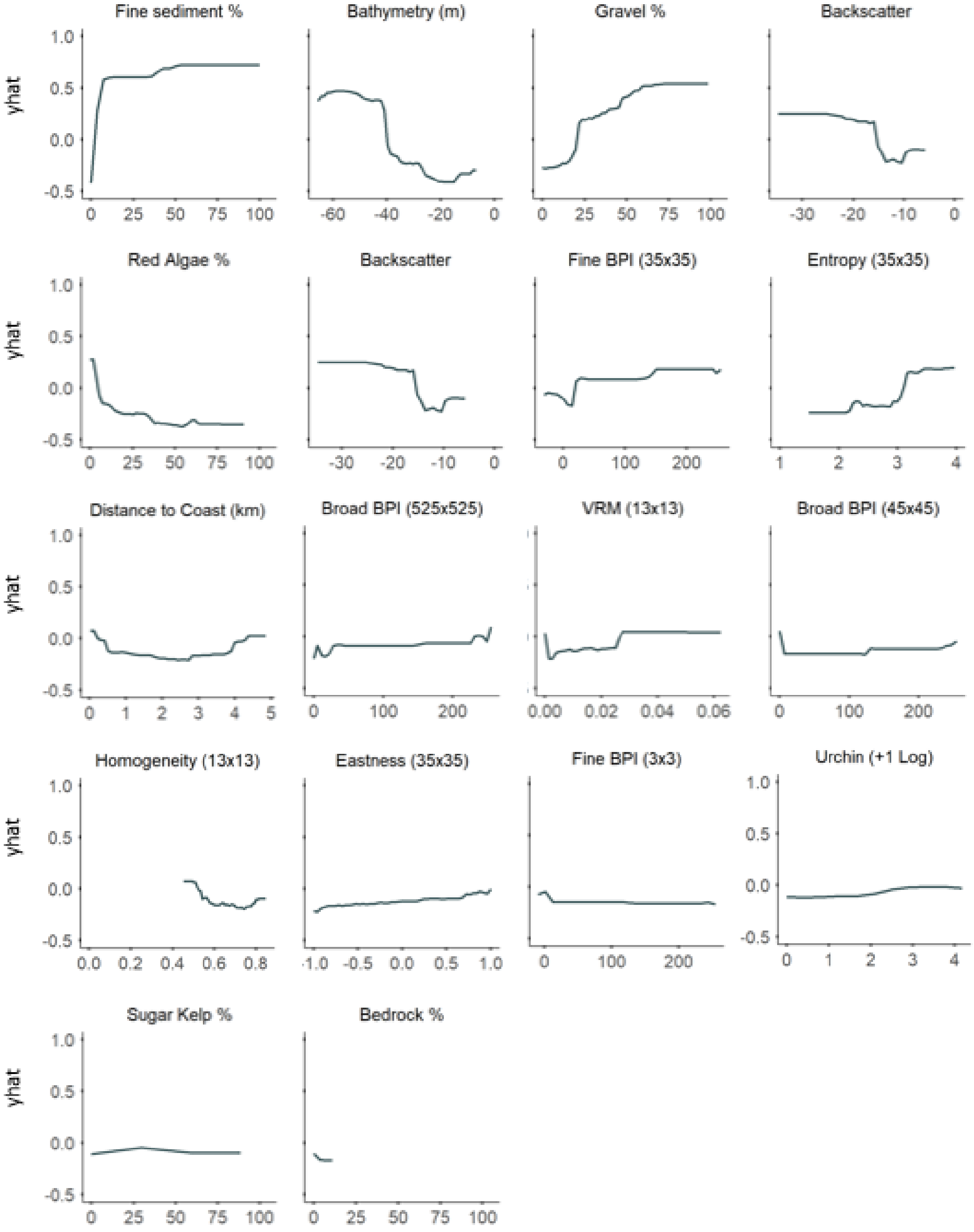


Figure A9. Partial dependence plots for all features included in training of the *Agarum clathratum* random forest model, in order of importance.

Appendix 10.

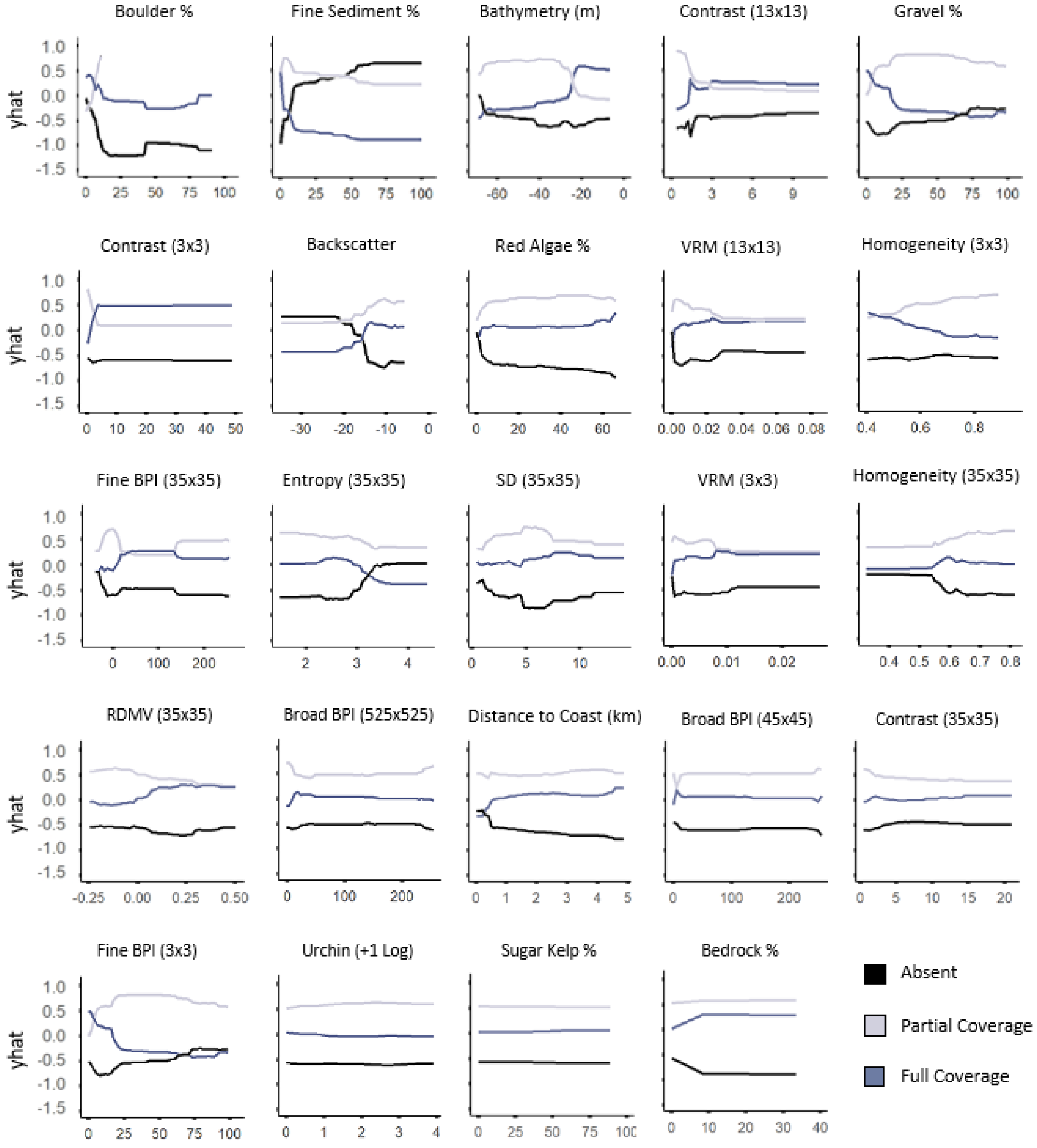


Figure A10. Partial dependence plots for all features included in the training of the non-geniculate coralline crustose algae random forest model, in order of importance.

Appendix 11.

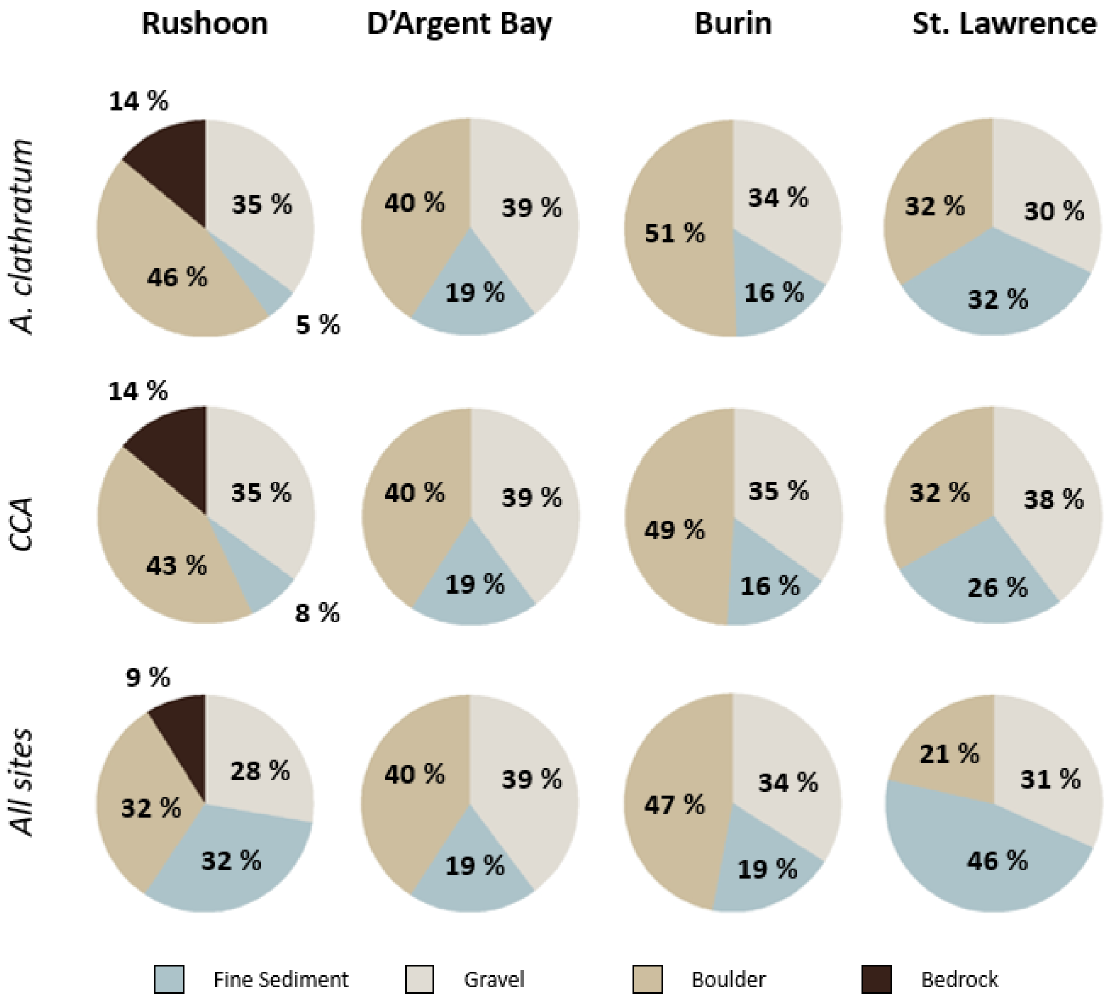


Figure A11. Average % coverage for each survey area of the west coast of Placentia Bay for sites included in the *Agarum clathratum* model, the non-geniculate crustose coralline algae (CCA), and all ground-truthing sites.