BENTHIC HABITATS OF A SUB-ARCTIC FIARD - THE CASE STUDY OF OKAK BAY, LABRADOR

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by

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ABSTRACT

The objective of this thesis is to classify and map the nature and distribution of benthic marine habitats of Okak Bay. Okak Bay is an irregularly shaped, generally shallow, low elevation estuary best described as a fiard, on the central Labrador coast. Supervised classification of multibeam sonar bathymetry and backscatter data ground-truthed with substrate and biotic samples were used to map the seafloor. Cluster analysis of grain size data from 123 substrate samples indicated 7 classes: mud, sandy mud, sandy, gravelly mud, gravelly sand, kelp and bedrock/boulder. Analysis of similarity and similarity percentage analysis show that the 7 substrates support 5 statistically distinct habitats, divided into soft-bottom: mud, sandy mud, and gravelly sandy mud; and hard-bottom: kelp and bedrock/boulder. Key species comprising the soft-bottom habitats are deposit-feeding bivalves and polychaete, whereas encrusting epifauna dominates the hard-bottom habitats. The accuracy of the substrate and habitat maps was assessed at 71% and 82%, respectively. A sensitivity analysis of habitats to potential stressors suggests that kelp and gravelly sandy mud are most vulnerable to a variety of impacts including the majority of fishing activities and physical environment changes such as increases in turbidity and sedimentation, and steps should be taken to protect representative areas. The distribution and nature of habitats within Okak Bay differed significantly from others Labrador fiords, supporting the hypothesis that fiards are distinct marine estuarine systems, both physically and oceanographically, and developing a better understanding of these habitats will contribute to resource management initiatives within the central Labrador region as a whole.

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Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

1.1 Introduction

Within the coastal environment of Labrador, there has recently been an increase in coastal resource use and changes in traditional harvesting patterns (Davies 2007; Reschny 2007). Pressures from mineral and oil exploration and extraction activities such as the Voisey's Bay Nickel Mine have placed commercial value on a previously pristine environment, and have altered the ecosystem in ways that have impacted the local people (Davies 2007). In the northern community of Nain, the winter shipping activities of the mine have caused issues with ice safety and harvesting routes, forcing local hunters and fishers to move north in order to participate in the activities previously associated with the area around the mine (Davies 2007). In order to better predict the long-term environmental impacts of anthropogenic activities such as resource harvesting of fish and other marine mammals, and to identify habitats sensitive to current changes, it is necessary to identify and understand the benthic habitats within the central Labrador coastal environment.

The coastal inlets differ from the classic fiord landscapes of northern Labrador, where deep muddy basins are separated by rocky sills and flanked by tall, steep sidewalls and from the more subdued, boreal landscape of southern Labrador. In contrast, the glacially formed inlets may be better referred to as fiards; shallow, irregularly shaped inlets with gently sloping sidewalls and large intertidal zones (ABPmer and Wallingford 2007; Pritchard 1967; Syvitski *et al.* 1987). To date, research has focused on mapping the nature, distribution and biodiversity of benthic habitats of Labrador fiords (Copeland *et al.* 2011a; Copeland *et al.* 2011b) as part of the ArcticNet Nunatsiavut Nuluak project. This project seeks to establish baseline inventory conditions of benthic habitats within coastal Labrador, and has expanded its focus to include several inlets in central Labrador.

Okak Bay is one area at risk of receiving more attention from traditional harvesting activities, putting pressure on the marine ecosystem. As well, it is an area which shares physical characteristics with much of the central Labrador coast. Marine habitats in Okak Bay may be representative of habitats in areas with similar physical and oceanographic characteristics.

Completion of benthic habitat mapping in the area is an accurate and efficient way by which to gather baseline information about the marine environment, in comparison to previously used methods such as grab samples and single beam sonar. The use of biodiversity and sensitivity indices in connection with benthic mapping may show areas of particular importance for the fiard ecosystem (Diaz *et al.* 2004). Additionally, it may help to identify areas at risk from certain harvesting techniques such as bottom trawling and gill netting. Harvesting activities such as these are likely to become more common as traditional subsistence and commercial activities move to the area (Reschny 2007).

The purpose of this thesis is to better understand the spatial variability of habitats within a central Labrador fiard, and how they differ from those in northern Labrador fiords. The differences in bathymetry and oceanographic characteristics between fiords and fiards are likely to create similar differences in habitat distribution. Specifically, habitats in fiards may be more heterogeneous and less repetitive due to a wider variety of depth and substrate combinations. This study intends to create substrate and benthic habitat maps of Okak Bay, in order to determine patterns of biodiversity and identify habitats which may be sensitive to anthropogenic activities. Understanding these processes within this fiard may help to better understand these patterns throughout similar inlets and fiard features along the Labrador coastline.

1.2 Fiords vs. Fiards

We have classified Okak Bay as a fiard using several coastal classification schemes developed for estuaries. The development of classification schemes for coastal estuaries and landforms in the past has made it easier for coastal resource managers to understand the interactions and physical characteristics of coastal areas, and to better predict the biological processes which may occur within. The classifications are based on geomorphology, topography, origin, Holocene sediment influence, relative sea level trends and oceanographic characteristics, and attempt to identify specific geomorphological elements unique to estuarine class (Wallingford 2007; Dyer 1997).

The Labrador coast has been heavily impacted by glaciations, and many of the embayments and inlets are estuarine (regions where salt water from the ocean and freshwater from the land mix) in nature (Dyer 2002; Ives 1976). These characteristics place large portions of the Labrador coast into the estuaries of glacial origin classification, one of four categories of estuaries developed by Pritchard (1967). They are defined as drowned glacial valleys, and are prone to complex mixing, salinity and temperature gradients due to characteristic bathymetry which often includes sill-basin bathymetry. Sill-basin bathymetry consists of deep basins, divided by shallow sills which restrict water flow throughout the estuary, preventing the mixing of the freshwater and saltwater inputs. This creates distinct stratification in both temperature and salinity, with cool, highly saline water becoming trapped in the deep basins, and warmer less saline water forming layers at the surface.

Coastal classification work by Davidson (1991), Hume and Herdendorf (1988), Finkl (2004), Townend *et al.* (2000), and compiled by ABPmer and Wallingford (2007) has subdivided estuaries of glacial origin into fiords and fiards, with the key distinguishing factors being topography, relief, depth, and bathymetry (Doody 2001;Dyer 1997; Fairbridge 1968). The characteristics used to separate fiords and fiards in the literature are listed in Table 1.1.

Table 1.1 Defining characteristics of fiords and fiards

Characteristic	Fiord	Fiard	Reference
Relief and Topography	High relief, steep slopes	Moderate to low relief, low slopes	Dyer 1997
Bathymetry	Deep basins, inter-basin sills	Shallow to deep basins, irregular water depths	Fairbridge 1968
Valley width and shape	Uniform, structurally controlled	Irregular, islands and skerries common	Doody, 2001
Depth to width ratio	Approximately 1:10	Irregular, less than 1:10	Dyer 1997

A fiord is the classic coastal glacial landform, located in areas covered by Pleistocene continental ice sheets e.g. Canada and Northern Europe (Dyer 1997), and in areas of alpine glaciations e.g. Southern Chile, New Zealand (Perillo 1995). It is typically formed by glacial erosion of a pre-existing river valley. The glacier erodes the valley into the classic U-shape profile associated with fiords. The erosion is influenced by the underlying geology, and the overdeepening is constrained by the resistance of the bedrock. Particularly resistant bedrock may remain as inter-basin sills that impact circulation and sedimentation. Sills usually are formed by deposition of glacial debris in moraines. Sills may be very shallow (2m or less), or deep (>100m), and are considered a defining feature of fiords.

Biota in fiords is characterized by predictable habitats that correspond with the basin-sill bathymetry. These habitats are set against gradients in salinity and temperature, causing distinct vertical stratification where sills exist and horizontal gradients from the head of the fiord to the mouth at the surface. This can cause corresponding gradients in biodiversity and biomass.

The definition of a fiard emerged from observations of glacially formed embayments in southern Sweden (Fairbridge 1967; Embleton and King 1968). The definition states that a fiard is a shallow, temperate zone estuary formed by the glaciations of a lowland coast. Other definitions refer to the lower relief, gently undulating topography and irregular shape, including many islands and skerries, and the potential lack of classic sill-basin bathymetry. It is argued that fiards tend to be the result of unconfined glacial erosion, unlike the selective linear erosion associated with fiords (Finkl 2004). This results in a smooth topography, in comparison with the high, sharp topography typical of fiords, with lower relief and low slopes that extend underwater to incorporate shallow depths and bathymetry. Tidal flats, mud flats and spits may be present and islands are common. A characteristic of the fiard landscape and of Okak

Bay is the large drainage area, in which the surficial geology is fine grained and glaciomarine in origin, and the land forested.

Although there are abundant publications on the nature and distribution of benthic habitats in fiords worldwide (Aitken and Fournier 1993; Cochrane *et al.* 2011; Copeland *et al.* 2011a, 2011b), research on fiard habitats is much less common. This may be a product of terminology in that fiards is a seldom-used term, and many regions that may fit this classification have not been defined as such.

Fiard landscapes in central Labrador have the potential to contain more distinct habitats and distributions than those regions which have already been mapped in Labrador. Irregular bathymetry in combination with shallow environments is likely to contribute to a highly heterogeneous coastal environment, with less of the repetition seen in fiord habitats. These areas are also experiencing an increased level of pressure from resource harvesting activities. Developing an understanding of these coastal regions is necessary to ensure that changes can be monitored, and important habitats protected. Therefore, the primary objective of this study is to use benthic habitat mapping methodologies to create substrate and habitat maps, which will illustrate the nature and distribution of the habitats of this region. It will determine whether the fiards may exhibit more complex habitat interactions and biodiversity distributions in comparison to the known habitat distributions of fiords. Additionally, the thesis will determine whether Okak Bay is representative of additional unstudied fiard-like inlets along the central Labrador coast. Both the substrate and biotic information will be used to determine the sensitivity of the habitats within Okak Bay, and to identify those habitats which may be of particular importance for conservation purposes.

1.3 Habitat Mapping

1.3.1 Defining Habitat and Benthic Habitat Characteristics

The concept of habitat is important in benthic habitat mapping studies, but there is still a lack of agreement among the scientific community on a single view of what habitat is. The most basic definition of habitat includes all the abiotic and biotic characteristics of an area; physical and chemical environments dictate what biota will have the ability to exist in a given space and in turn, the biota can impact physical and chemical environments through processes such as bioturbation and bioerosion (Levinton, 1995).

This definition has been adapted by Kostylev *et al.* (2001) for use with habitat mapping, stating that a habitat is "a spatially defined area where the physical, chemical and biological environment is distinctly different from the surrounding area." This definition can be narrowed for our purposes, specifying that the benthic habitat is considered the top 15-20 cm of substrate and the adjacent water layer, and includes the epifauna (organisms which live attached to the substratum), infauna (organisms which live below the sediment-water interface), and semi-infauna (organisms which live both above and below the sediment water interface).

It is this dependence of benthic biota on environmental characteristics, especially bathymetry and bottom type that enable the habitats to be mapped using geophysical and acoustic methods: more specifically it is assumed that certain characteristics of the environment influence the distribution of benthic biota, and these characteristics can be mapped with sonar technology. Relationships between depth, grain size, and topography have been previously established (Brown and Collier 2008; Levinton 1995; Kostylev 2001), but other factors such as salinity, temperature, current flow, and organic content of bottom sediment may also impart some influence, particularly in coastal regions.

It is generally understood that benthic biota undergo a sequential, non-recurring change with depth (Levinton 1995), and that certain species are confined to specific depth ranges. Depth can also relate to other limiting factors such as light, salinity, and temperature, and is of particular importance in fiord and fiard environments where highly irregular bathymetry can leads to abrupt changes in depth (Levinton 1995).

Substrate type influences both the biota (e.g. encrusting vs. burrowing vs. boring), and the complexity of habitat structure in a region. Evolution has dictated whether an organism is better suited to hard or soft substrates, and each carries with it unique adaptations to sediment type, current strength and water chemistry in the form of a specific morphology for feeding and lifestyle (Levinton 1995).

The characteristics of substrates which influence benthic organisms include the percentages of organic and inorganic particles in bottom sediment, the average grain size, sediment sorting and the amount of pore water. Physiological traits that encourage settling in soft sediments include burrowing and deposit feeding. Grain size can also be indicative of organic content and current strength (Levinton 1995). A larger median grain size is also commonly linked with a stronger current – a high energy area can move and deposit larger particles (Dyer 1973). Hard substrates such as bedrock, boulders and large cobbles are more suitable for organisms with adaptations for strong or complex currents: they are inaccessible to infauna except for rock-borers.

The complexity of the environment and topography also impact benthic distributions and are of particular importance in coastal environments (Dunn and Halpin 2009; Henry *et al.* 2010). On micro- and mesoscales, changes in slope, depth and specific seabed features such as sand ripples can create specialized habitats, and can influence habitat distributions at a larger scale (McArthur *et al.* 2010). For example, fine grained sediments with a large percentage of organic material will temporarily accumulate in the troughs of sand ripples, attracting deposit feeding organisms, while the crests are sites of localized erosion, and organic content is low. On a larger scale, coastal features such as sills can provide localized areas of hard, shallow substrate in a high energy environment, providing habitat for encrusting epifauna and depth-limited species that are unable to thrive in the soft-deep basins that the sills separate. On both scales, organism themselves can impact the environment through activities such as burrowing and feeding, a process known as bioturbation (Baretta-Baker *et al.* 1998). Bioturbation mixes the surface substrate, reworking the distribution of grain sizes, and impacting organic matter content, oxygen levels and pore water. These processes can have a localized effect on the distribution of benthos. Topographic features and substrate type are easily discernable in multibeam sonar and therefore can be easily mapped.

1.3.2 Benthic Habitat Mapping

Benthic habitat mapping is situated as a tool within the larger context of marine and coastal research, and is supplying products in support of ecosystem-based approaches to ocean management (Anderson *et al.* 2008; Cogan *et al.* 2009). The basis of habitat mapping is related both to the ability to use acoustic remote sensing to collect depth and backscatter data over a large area of the sea floor and the ability to derive topographic characteristics (depth, slope, rugosity) from that data. As sound penetrates the substrate and basement materials of the ocean floor, the returning echo can be measured in terms of its strength. This can provide information on the type of substrate in a given area. A hard substrate such as bedrock will cause a stronger but thin return signal, whereas soft sediment such as sand will absorb and scatter more of the energy returning a weaker but wider signal to the transducer. In this way, multibeam echo sounders can be used to classify surficial sediments and with some amount of additional data (substrate and biotic samples) the associated marine habitats.

The ability to accurately map marine habitats through the use of multibeam sonar is dependent on two major assumptions. The first is that substrate heavily influences the distribution of benthic biota, and the second is that there is a consistent relationship between substrate and multibeam sonar derived data products such as depth, slope and backscatter. In assuming these two things we can perform a supervised classification of the multibeam data set, which allows interpolation of the substrate between ground-truthed sampling points (Kostylev *et al.* 2001).

1.3.3 Uses of Habitat Maps

Habitat mapping is an accurate and cost-effective way of gathering baseline information about marine systems for a variety of uses. Many coastal and ocean management initiatives are beginning to address issues in an ecosystem based manner, especially pertaining to the development of marine protected areas. Benthic habitat maps are a natural starting point for this method of management, providing large amounts of information about distribution and biodiversity at the benthic level (Cogan *et al.* 2009; Diaz *et al.* 2004).

This baseline information can also be used at several different scales. Species-specific information, including physiology can be used to deduce information about life history while the broader habitat classification can be used to determine representative habitats or identify specific resources such as scallop beds.

Monitoring natural and anthropogenic disturbances such as fishing activities is necessary in order to maintain ecosystem integrity in areas where marine resource exploitation activities may threaten systems. In the future, these methods will help to develop products for use in policy creation, marine protected areas and fisheries closures (McArthur 2010).

An example of the use of benthic habitat mapping for management purposes in Atlantic Canada is that of the Brown's Bank scallop fishery (Kostylev *et al.* 2003). In the late 1990s the area around Brown's Bank was mapped through a partnership of Clearwater Fine Foods, the Canadian Hydrographic Service, and the Geological Survey of Canada. The resultant maps were classified according to surface sediment cover and benthic habitat, and fishing charts were produced to show optimum scallop habitat. With the use of these maps, the amount of seabed being dragged annually was decreased by 75%, the amount of fishing time/ton was reduced, and by-catch was reduced (Kostylev *et al.* 2003).

1.3.4 Benthic Habitats in Fiards

Few marine inlets have been identified as fiards in the literature and most of these are located in Europe. One area in which habitat and species specific research has been completed is Somes Sound in Acadia National Park, Maine, USA (Bank *et al.* 2007; Roman *et al.* 2000). Research was initiated in this region due to mercury contamination concerns and degrading water quality from excess nitrogen and phosphorus loading in the larger Gulf of Maine. Habitat mapping activities were performed as part of the protocol for monitoring "Estuarine Nutrient Enrichment" in the National Parks of the Northeast and were focused on eelgrass habitats in the area. Additional work has been completed in Europe where the term firth is commonly used in place of fiard, particularly in Scotland. As part of several estuarine and coastal marine ecosystem reviews (Barne *et al.* 1997; Connor *et al.* 1998; MERC 2008) bathymetry, basic habitats and characteristic species were identified. Fiards were the most commonly identified estuarine feature in North-west Scotland (Barne *et al.* 1997), with 9 of the 11 inlets being identified as such. Large varieties of habitats were described as typical of "fiardic coasts" and were found to be unusually high biological diversity. The diversity of both habitats and species was attributed to a range of substrates, depths and exposures (Barne *et al.* 1997).

1.3.5 Habitat Maps and Benthic Ecological Indicators

As new techniques allow for larger areas of the seabed to be mapped, the incorporation of additional information into habitat maps provides for a more useful tool for coastal management. Interpreting maps to determine the sensitivity of marine environments is an important method by which habitat maps can be included in conservation and monitoring efforts. Biodiversity indicators are a method of presenting a quantitative summary of an ecosystem, combining numerous factors into a single value that is easier for managers to understand and employ (Marques *et al*. 2009). Incorporating them into benthic habitat mapping allows for the assessment of the baseline state to be enhanced and predictions of potential change and impacts to be made.

The pursuit of coastal resources for anthropogenic use will likely lead to changes in marine habitats, making it necessary to identify which areas are particularly sensitive to impacts and in what ways, so that important habitats can be protected. Long-term, repetitive disturbances lead to shifts in benthic communities from long-lived species to more motile, quick-recruiting species. The longer the time frame over which the disturbance occurs, the more likely it is that changes in habitats will become permanent (MacDonald *et al.* 1998). In particular, studies have focused on the implications of repeated disturbance of the seafloor by fishing activities, specifically trawling and dredging. Kaiser *et al.* (2000) found that heavily trawled areas demonstrated reduced biomass and abundance due to the removal of large-bodied sessile organisms, and the recolonization of the regions by smaller-bodied, damage-resistant organisms. Similarly, Tillin *et al.* (2006) found that large-scale functional shift of ecosystems occurred in repeatedly trawled areas. Areas which experienced frequent fishing activities experienced a switch to scavenging, mobile organisms. Regions which were lightly fished experienced only a minor shift in key organisms with an increase in filter feeders.

The recognition of this potential impact with implications for marine food chains has led to the development of sensitivity and vulnerability indexes, management tools whose dependence on spatial aspects of the environment make them ideal candidates for integration into marine mapping activities.

Several studies have provided basic definitions of sensitivity. Hiscock and Tyler-Walters (2006) stated that a sensitive habitat is one which may be easily impacted by external factors, and which will not recover quickly to a pre-impacted state. This definition incorporates two important concepts of sensitivity. The first is that of intolerance (Hiscock and Tyler-Walters, 2006) or resistance (Bax and Williams 2001) wherein part of a habitat's or species' sensitivity to a specified impact is determined by the level of environmental change that occurs once exposed. The second component of sensitivity is that of recoverability (Hiscock and Tyler-Walters 2006) or resilience (Bax and Williams 2001). This is the length of time that the species or habitat will take to return to the pre-impacted state determines its sensitivity. For example, a habitat that is impacted severely, but rapidly and fully recovers to the pre-impact state is placed in a low sensitivity class. A habitat that is minimally impacted but recovers slowly is considered high risk or highly sensitive.

To apply this approach to previously established habitats, several physiographic and biological characteristics, including geology, oceanography, life history and distribution of biota are determined. A decision tree can then be used to assess what level of sensitivity (from very low to very high) a habitat may have to a specified impact.

To determine which impacts may be relevant for what parts of a marine ecosystem, a sensitivity matrix such as the Valued Ecological Features (VEF) methodology developed by Zacharias and Gregr (2005) can be used. This approach determines which physical, biological or oceanographic characteristics of a marine environment have environmental, economic or social value (and are therefore valued ecological features), and so are in need of recognition and potential conservation. Such a list is then compared with potential natural and anthropogenic impacts in the region.

The second component of sensitivity studies is that of vulnerability – the likelihood that a particular stressor will impact a particular habitat. Lists of potential marine stressors and impacts, both natural and anthropogenic have been developed by several organizations (Hiscock and Tyler-Walters 2006; Moss *et al.* 2006), and studies (Hall *et al.* 2008; Zacharias and Gregr, 2005). The most common categories of stressors include oceanographic changes (salinity, temperature, wave and exposure regime), substrate and sedimentation changes (increase/decrease in sedimentation, turbidity, potential mass wasting), and fishing impacts (various fishing gear types).

1.3.6 Environmental Change in Okak Bay

Table 1.2 lists the stressors which were chosen from the broader lists in three categories as applicable to Okak Bay – those selected reflect both natural occurrences in marine environments (mass wasting and ice scour), anticipated changes in ocean conditions due to future climate change, and potential side effects of increasing industrial activity in the area. Stressors were selected based on currently available data, which tends to be general in regards to the study area. Additional inclusions or exclusions may be necessary in the future as research is conducted within the region.

Table 1.2 List of potential stressors that may impact Okak Bay

Physical Factors	Climate Change	Anthropogenic Stressors
Substratum Loss	Temperature increase	Mobile gear fishing activities
Increased sedimentation	Salinity Changes	Fixed gear fishing activities
Changes in exposure	Changes in oxygenation	Pollution from anthropogenic sources, e.g. oil spills, PCBs, heavy metal contamination
Displacement (Scour)	Changes in nutrient levels	
Changes in turbidity, light and irradiance	Introduction of non-native species	

While each stressor may not fit discretely into a category (for example, scour could be caused by sea ice, or by mobile fishing equipment), physical factors reflect changes which may occur naturally in marine coastal environments, and mainly pertain to changes in sedimentation. Substratum loss may occur as a result of scour from sea or land-fast ice, or by increased wave action through storm surge etc. The opposite effect, that of increased sedimentation may be linked to mass wasting, or increases in delivery of terrestrial based sediment via fresh-water input. Changes in exposure apply mainly to the outer fiard, where increased frequency of storm events and a longer ice-free season may cause increased erosion or similar effects. Changes in turbidity, light and irradiance are linked to the previous four stressors.

Climate change has been widely acknowledged as having an impact on the oceanographic characteristics of the marine environment among other issues. Stressors selected for inclusion in this category reflect the broader changes expected n marine environments and the arctic region as research specific to the study area is not yet available (Loeng 2004). Increases in temperature are linked to increases in atmospheric temperature and decreased sea-ice extent are expected throughout the arctic. Decreased overall salinity due to increased freshwater run-off from terrestrial sources and melting of glaciers. Dissolved oxygen changes may be linked to increases in primary productivity and phytoplankton levels caused by increased temperatures (Loeng 2004). Changing wind patterns may cause increased upwelling and additional nutrient delivery to coastal regions (Harley *et al.* 2006). Finally, warmer ocean temperatures may encourage the expansion of the range of more southern species. It is unknown how many of these species may interact with current biotic assemblages.

As previously mentioned, the Labrador coast is a region of increasing industrial development (Davies 2007; Reschny 2007). Stressors selected reflect the likely impacts from anthropogenic activities already occurring in the region, and those which may expand into the area in the future. Fishing is the most immediate threat to coast environments and biodiversity (Harris 2008). Fishing for both commercial and subsistence purposes currently occurs in the area, with views to expand north into coastal regions such as Okak Bay. Greenland halibut (turbot), northern shrimp, and snow crab are among the currently harvested species (Vilhjálmsson and Hoel 2004), all of which are chiefly bottom-dwelling species. Both turbot and northern shrimp fisheries employ mobile gear fishing activities, such as otter and bottom trawls, methods which not only capture the goal species but also damage other bottom structures and invertebrates in the trawl's path. Mobile fishing gear as a stressor can also contribute to substratum loss and displacement. Snow crab employs the use of pots, or fixed gear equipment. These methods are less destructive on a large scale, however anchors and ropes used in the setting of the gear can cause impacts in rugose environments such as the kelp beds which are found in Okak Bay.

Pollution from anthropogenic sources encompasses a range of contaminants that are possible from mineral and oil and gas exploration and extraction. While no industrial activities are currently occurring in the study area, they are occurring in the region at large (Voisey's Bay nickel mine), and an area of interest (Umiakovik Lake) has been identified in the Okak Bay area (Jones and Garcia 2003).

1.4 Approach

In order to determine how the habitat and biodiversity distribution of Okak Bay differs from previously mapped areas, a supervised classification of multibeam data was first used to determine the existing substrates and habitats. Ground-truthing activities, consisting of box core and video samples of substrate and biota determined substrate types and associated biota. This information was used to generate substrate and habitat classes and associated acoustic signatures for classification of the multibeam sonar data. The classification creates maps that interpolate between the sample points and present continuous coverage of the nature of the seafloor.

The completed maps illustrate both the nature and distribution of the benthic habitats in Okak Bay and were easily compared to similar studies in Arctic fiords (Aitken and Fournier 1993; Copeland *et al.* 2007; Dale *et al.* 1989; Syvitski *et al.* 1989). Additional information on the sensitivity of benthic habitats was generated using the sensitivity matrix approach (Zacharias and Gregr 2005) and when included in the habitat maps allow for the identification of habitats sensitive to specific physical, climate related and anthropogenic stressors.

An overview of the physical and cultural characteristics of the study area is presented in section 2, followed by a detailed description of the methods used for the collection, identification and classification of the substrates and habitats of Okak Bay. Section 3 contains the results of the study including the completed substrate, habitat and sensitivity maps. Discussion of the nature and distribution of the study in addition to a comparison between Okak Bay and Arctic fiords is found in section 4 in addition to a map illustrating specific habitat which have been identified as particularly sensitive, or deserving of conservation. Finally, section 5 contains conclusions and a discussion of potential future work.

2.0 Methods and Materials

2.1 Study Area

2.1.1 Introduction

Okak Bay is a fiard in central Labrador (Figure 2.1). It is located approximately 100 km north of the community of Nain, which is the nearest populated area. It is quite irregular in shape, with a long, narrow head opening into a wide mouth area which is intersected by two small and one large islands. This large island, known as Okak Island divides the mouth of the inlet in two parts, creating two narrow, shallow entrances to the inner fiard. The land around Okak Bay is low lying and smoothed in comparison to the northern coast, with average elevations of 100-200 m, with several points reaching heights of up to over 400 m. The region contains a large intertidal zone, and average depth is between 40-80 m. Only in the mouth of the bay, north of Okak Islands, does the bathymetry reach depths of over 200 m.

Although the area surrounding the fiard is covered in small lakes and brooks, there are three major freshwater inputs, Siorak Brook located midway from the head to the mouth on the north side of the inlet, and North River and Saputit River which flow into the head of the fiard and share a large drainage area containing several large sand flats, and several small islands where sand deposits have broken the surface.

Okak Bay is located near the latitudinal tree line, with mainly shrub vegetation and small patches of coniferous trees located in low lying, sheltered areas. Vegetation is

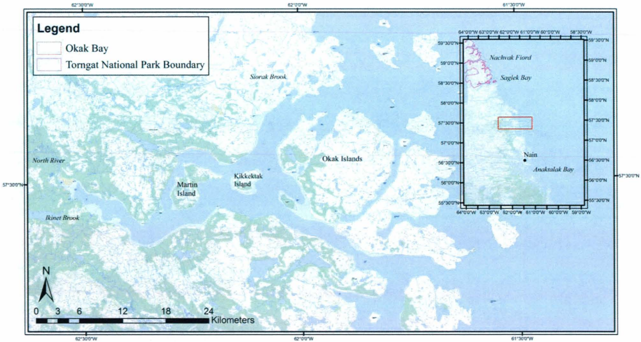

Figure 2.1 Location of Okak Bay, central Labrador coast. Base imagery: Toporama 2011

larger and more common towards the head of the fiard with shorelines being mostly forested. The islands towards the mouth of the fiard are barren or have tundra type vegetation. Marshy conditions are found along the mudflats at the drainage points mentioned previously, as well as in Okak Harbour on Okak Island.

2.1.2 Geology

Okak Bay is located within the Archaean Nain Province, in the Saglek block, an archean craton which contains some of the oldest rocks in Labrador, dated to > 3.9 Ga in some areas (Wilton 1996). It is composed of mostly layered, complex gneisses, metaplutonic rocks, and migimatite, with amphibolites and ultramafic intrusions. Okak Bay is part of the area known as the Nutak-North river transect, to which particular attention has been paid as a result of mineral exploration activities. Local bedrock is composed of igneous and metamorphic rocks of greater than 2.5 billion years in age.

2.1.3 Shoreline Geology

The shoreline and surficial geology has been extensively mapped by Ermanovics, and Van Kranendonk (1998). It is composed mostly of unconsolidated quaternary deposits, mainly drift covered areas comprised of sand. This is particularly true around Sipukat Bay, and Siorak Brook, Siorak brook estuary having the largest deposit of sand in the Nutak-North River area. As common in other areas of the Labrador coast (Rosen 1979), ice-boulder barricades are found along the shallow coasts. These barricades are formed when boulders are deposited on low-slope inter-tidal sand flats by land-flat ice that has rafted material upon melting.

2.1.4 Glacial History

The majority of research into the glacial history of Okak Bay and the surrounding area was completed in the 1960s and 1970s by Andrews (1963), Johnson (1969) and Ives (1976), and focused on the area known as the Nain-Okak region of Labrador. The work focused on a series of glacial erratics in the Kaumajet mountains, and a moraine complex just south of Okak Bay. The glacial history was linked to two glacial events, the Koroksoak and Saglek glaciations – a theory which has since been disproven by modern work (Dyke *et al.* 2002).

Current glacial theory suggests that during the Late Wisconsinan Glaciation, the central Labrador coast was inundated by glaciers advancing in a north-eastern direction from the central Labrador/Ungava region (Dyke *et al.* 2002). The exact location of the north-eastern margin of the Labrador section of the Laurentide ice sheet has yet to be determined.

2.1.5 Oceanography

The oceanography of Okak Bay is influenced by the Labrador current, which flows south from the Arctic along the Labrador coast (Lazier 1973; Mertz *et al.* 1993). The current originates in Hudson Strait as an extension of the West Greenland Current – a mix of the warmer west Greenland waters, and the cool, low salinity waters of Hudson Bay. The resulting current is cool and exhibits low salinity with high nutrient content which contributes to extensive phytoplankton productivity in the shallow areas offshore, and in the coastal region. Within Okak Bay, this cool, low salinity water mixes with the freshwater input of two large rivers – North and Siorak Rivers, and a large brook – Ikinet

Brook, as well as many smaller drainage features. The oceanography within the fiard has not been studied extensively.

Tides in the area average 2 m throughout the fiard. Currents and water circulation have not been studied, but the irregular shape of the inlet, and the shallow, narrow channels to the north and the south of Okak Island in the mouth likely create strong tidally driven currents.

2.1.6 Cultural History

Culturally, Okak Bay has a history important to the Inuit of northern and central Labrador. There have been numerous settlements in the area, and Okak was designated a National Historic Site in 1978 as it includes archaeological sites which show use of the area by Inuit from approximately 6000 years ago to modern times (Kaplan and Wollett 2000). Over 60 sites have been identified. Uivak Point 1 (referred to as HjCl 9 in the literature) is one of the more studied sites, and is located on the North side of the mouth of Okak Bay (Kaplan and Wollett 2000). It is a significant area of 18th century Inuit use, and finds in the area of housing, whale bones, and other small tools have been used to identify the area as an Inuit winter settlement and whale hunting camp, and to reconstruct climate in the region (Kaplan and Wollett 2000).

Okak Harbour is a settlement founded by Moravian missionaries in 1776; it was the second mission founded after the Nain location. It was continuously occupied until 1918 when the Spanish influenza killed 207 of the 263 occupants. All Inuit men and nearly all Inuit women died, and the majority of the survivors were children. It is believed that the disease was brought up the coast by the missionary ship *Harmony*, which went on to

Hebron and devastated populations there as well (Budgell 1994). After the disease had passed, the Moravians sold the land to the Hudson Bay Trading company. It was used as a trading and storage location until 1956 when it was completely abandoned. The community is still visible in the form of stone house foundations, the remnants of a wharf, and a cannon that overlooked the Harbour. A documentary was made (Budgell 1985) about the epidemic, called "The Last Days of Okak: the life and death of a Labrador town." Many of the surviving inhabitants were moved to the community of Nutak, also on Okak Island, and also a Moravian mission. The population of that community was resettled with the population of Hebron to Nain in 1956. The area is still being used by modern Inuit from Nain for summer harvesting of char and salmon, and winter caribou hunts. There are several camps located in Siorak Bay (Figure 2.1).

2.1.7 Previous Research

There has been no research into benthic habitats done in Okak Bay, however the Labrador shelf marine environment was studied in the 1980's (Gilbert *et al.* 1984; McLaren 1980) for the purpose of assessing the marine environment's sensitivity to potential oil spills. Particular attention was paid to the intertidal region in the vicinity of Nain. It is suggested that the key influence on near-shore biota in the central Labrador region is that of sea ice, and that the biota is dominated by kelp species and burrowing molluscs.

Previous research specifically in the Okak Bay area has been in terms of geology and fish populations. Ermanovics and Van Kranendonk (1995) have done extensive shoreline geology mapping, in particular from Nutak to North River, and the site was investigated as a potential soapstone harvesting region by Meyer and Montague (1993). More research has been conducted on Char populations and dynamics along the Labrador coast at large (Dempson *et al.* 2008), with Okak Bay functioning as a comparison site for the more impacted areas of Nain and Saglek (Kuzyk *et al.* 2005).

As previously mentioned in section 1.1 this study is part of the ArcticNet Nunatsiavut Nuluak project, which also included the habitat mapping work in Nachvak Fiord and Saglek Bay. Additional work on marine ecosystems includes data collection on water column nutrients, PCB monitoring, ringed seal health and modeling of sedimentation rates within the fiords.

2.2 Multibeam Bathymetric Data Collection

Multibeam bathymetry was collected for the area in 2003 and 2009 by the Canadian Hydrographic Service (CHS) on three platforms, the *CCGS Matthew*, *CSL Pipit* and *CSL Plover*. The *CCGS Matthew* uses a hull mounted Kongsberg EM710® multibeam echo sounder, which is used for deep-water surveying. Minimum depth of the sounder is approximately 3 m below the transducer, to a maximum depth of 2000 meters. Swath width is approximately 5.5 times the water depth. The sounder operates at a frequency rates ranging from 70 to 100 kHz.

The two *CCGS Matthew* launches, the *CSL Pipit* and *Plover*, are equipped with EM 3002® multibeam echo sounders, which are used for shallower depth surveying. Minimum operational depth of the sounder is 0.5 m below the transducer, and maximum is 150 m. Swath width is 10 times water depth, with a frequency of 300 kHz, and a vertical accuracy of 5 cm. While the *CCGS Matthew* conducts mapping of the deeper area, the launches allow mapping shallower waters in which the *Matthew* could not safely navigate.

Multibeam data coverage in Okak Bay is centered around the inner islands, with a minimum depth recovered of 1 m, and maximum depth of 201 m. Due to the large intertidal zone in Okak, there is a large littoral gap between the edge of the multibeam data coverage and the shoreline, and this holds true for much of the fiard. Coverage is most complete in areas of deep-water.

The data were processed and cleaned in CARIS HIPS-SIPS 7.0©. Data were imported into ArcMap 10© as a raster file with a 5m pixel resolution. The biggest challenge associated with the multibeam data was the use of multiple sensors for data collection. While bathymetric data collected by different systems can be easily merged, integrating backscatter data collected from different systems is a much greater challenge. Kongsberg sensors use a data reduction scheme in order to determine the backscatter strength from the average backscatter intensity. The scheme is limited by the discrepancies between the hardware performance, and the software design, including the sonar source levels, pulse lengths, and receiver sensitivity, and environmental assumptions including ocean attenuations and local seabed slopes (Hughes-Clarke 2008) which may vary from sensor to sensor and location to location. The use of three different sensors causes uncertainty in the estimate of backscatter strength, causing issues with the delineation of substrates with minor variations in backscatter strength.

Hughes-Clarke *et al.* (2008) suggests the use of backscatter strength shifts based on the use of an EM 1000 sensor as representative of the "truth," and recommended adjusting other sensors recordings based the average difference in backscatter values. The difference is calculated using overlap in previously collected data. Table 2.1 represents the currently used backscatter shifts, as applied to the specific sensors used for Okak Data collection.

Table 2.1 Average backscatter strength offset necessary to mosaic multiple sensor data

Platform	Sensor	Frequency	dB offset
Matthew	EM 710	71-97 kHz	0 dB (Reference)
Pipit	EM3002	300 kHz	+4.5 dB
Plover	EM3002	300 kHz	+2.5 dB

The files were adjusted for differences using the raster calculator of ArcGIS, mosaiced and projected over a nautical chart of the area using a 5 metre grid resolution.

2.3 Sampling Activities

2.3.1 Sample Site Selection

Sample sites were selected in order to best represent a range of depth, slope and backscatter values, as well as to ensure that large geomorphic features were sampled. Available time and distance to be travelled between sites were also taken into account. The focus of the first field season (2009) was the inner fiard, from the head of the fiard to the eastern and southern shores of Okak Island. In 2010, the sampling efforts were focused on the outer fiard, and on regions which had not been thoroughly sampled the previous year.

2.3.2 Box Core Samples

Box core samples were collected using a GOMEX® box core with a 25 x 25 x 50 cm sample box weighted with 25 kg lead weights to ensure maximum substrate penetration. Three replicate box cores were collected at each sample station. A sediment sample was taken from the top ~10 cm of each box core before the remaining sediment was sieved through 0.5 mm mesh. All biota were collected from the empty sieve, identified to lowest possible taxonomic level in the field (Appy *et al.* 1980; Gosner 1971; Gosner 1978; Pettibone 1963), counted and one example of each species was preserved in 95% ethanol for transport back to the laboratory.

The location of each box core was recorded using a handheld GPS once the box core touched the seafloor. Of the 27 sites sampled in 2009, 1 has only 1 grab and 2 have only 2 grabs due to difficulty obtaining adequate samples in areas of high kelp coverage. 16 sites were sampled in 2010, of which two have only one box core. Due to the presence of bedrock at the site there was no fine matrix to be retrieved at 2 sites. Locations of the sampled sites are illustrated in Figure 2.2.

2.3.3 Video Transects

Three minute video transects were recorded at each sample site using a SplashCam Deep Blue Pro® video camera with a 600 ft. cable reel. The video was recorded onto a Sony DCRHC96 MiniDV® handcam. A Garmin GPSMap 60CSx® GPS was used to mark the beginning and end points of the video transect once the seabed was visible.

While box cores allow for the collection of physical samples, videos can sample areas that the box core cannot, due to unfavorable conditions. It can also be used to sample coarse substrates and megafauna that the box core is not capable of retrieving. For example in the case of Okak, the video was particularly helpful in sampling beds of *Agarum* kelp, where the cover was too thick for the box core to penetrate. Twenty-nine sites were sampled in 2009, including all box core sampling sites, plus 2 areas that were sampled only by video, due to their occurrence on high slope environments. Figure 2.3 shows the locations of the camera sampled sites.

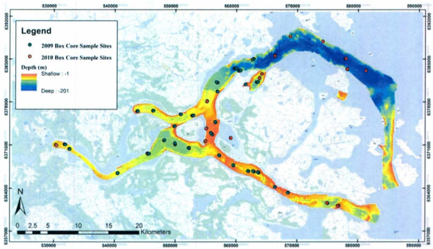

Figure 2.2 Locations of box core sample sites taken during the 2009 and 2010 field sampling seasons in Okak Bay

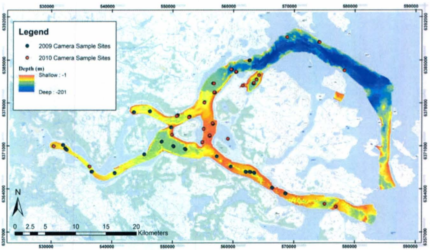

Figure 2.3 Locations of drop video transect sites from the 2009 and 2010 field sampling seasons in Okak Bay

2.3.4 Remotely Operated Vehicle Transects

A Saab-Seaeye Falcon® remotely operated vehicle (ROV) was used to complete transects and sampling in areas of high slope, providing continuous, smooth video transects across areas of heterogeneous slope and depth. The ROV allows for more control and a greater area to be sampled than the drop camera, and was of particular use when sampling two sills (Okak Harbour and Kikkektak sill), and the trench feature found in the southern entrance to the fiard. Four areas were sampled with the ROV, with an average length of the video of 1 hour and 20 minutes. Starting and ending points of the transect were recorded with a Garmin GPSMap 60CSx® GPS, as the subsea positioning systems were not functioning correctly. Figure 2.4 shows the locations at which sampling took place.

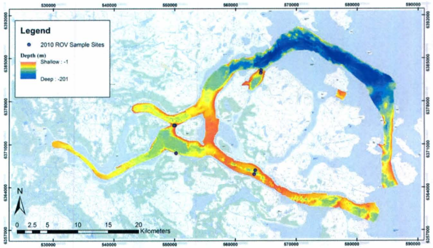

Figure 2.4 Locations of ROV sample transect sites from the 2010 field sampling season in Okak Bay

2.4 Sample Processing

2.4.1 Textural Analysis

Substrate type heavily influences the distribution of biota within marine environments, grain size being a defining feature of benthic habitats. Grain size analysis was conducted to determine the sediment type according to the grain size descriptions on the Wentworth scale (Wentworth 1922). The Wentworth scale quantitatively differentiates sediment based on grain size in mm, from clay sized particles to coarser cobble type sediments. The complete list is found in Appendix A.

2.4.2 Sieving

Sediment samples were subsampled prior to processing. A minimum of 50g was kept for grain size analysis, and the remainder of the sample split for loss on ignition and archiving. Each sample was oven dried and soaked in a 4% sodium hexametaphosphate (Calgon) solution for a minimum of 12 hours. This process serves to separate and disperse clay particles before wet sieving (Larson *et al.* 1997) to ensure accurate estimate of fine material. To remove the silt and clay fractions, the sample was wet sieved through a 4ϕ (0.0625mm) sieve. The remaining sample was dried, weighed, and subtracted from the weight of the total sample before sieving to determine the proportion of the fine fraction. Sedigraph analysis was not undertaken to further determine the grain size distribution of the silt and clay because the fine portion of the sample was lumped together as "mud".

The remaining sample was oven dried for a minimum of 12 hours, and ground with mortar and pestle before further sieving. It was placed in a stack of sieves with sizes -2ϕ, -1ϕ, 0ϕ, 1ϕ, 2ϕ, 3ϕ and 4ϕ to represent the boundaries of grain sizes as described on the Wentworth scale in Table 2.1. The sieves were placed in a mechanical shaker for 30 minutes. After shaking was complete, each sieve was weighed and the weight of the contents subtracted from the weight of the total sample to determine the proportion of the sample within each phi class on the scale.

2.4.3 Sediment Organic Content

The loss on ignition (LOI) method was used to determine the organic content of sediments available to biota within a habitat (Dean, 1974; Santisteban *et al.* 2004). The amount of organic content within the sediment will impact the abundance and type of species present in an area, and is therefore an important component of habitat.

A subsample of sediment (~ 10g) was taken before textural analysis and kept frozen to preserve organic content until LOI could be completed. The subsample was dried in an oven at 200°C for a minimum of 8 hours before being ground with a mortar and pestle. Crucibles were placed in a muffle furnace at 550°C for one hour and then placed in a desiccator to cool before being weighed. The dried sample and cooled crucible were weighed together to determine the starting sample weight.

The sample is covered with a lid to prevent sediment loss, and is heated in a muffle furnace for 2 hours at 550°C. The samples were removed and cooled and weighed again. The weight lost on ignition can be calculated by subtracting the weight of the empty crucible from both weights, and then subtracting the ash weight from the dry weight, and dividing by the dry weight. It can then be displayed as a percentage by multiplying the final number by 100.

$$\frac{\text{Dry weight (g)} - \text{Ash weight (g)}}{\text{Dry weight (g)}} = \text{Loss on ignition (g)} \times 100 = \text{Organic content (\%)}$$

2.5 Processing of Biological Samples

The biological samples collected using box cores were identified to the lowest possible taxonomic level in the field and counted for abundance. One specimen of each species, as well as any species that could not be identified, was preserved in 95% ethanol and brought back to the laboratory.

In the laboratory, all sampled biota were identified to the genus and species level if possible with use of appropriate taxonomic keys (Appy *et al.* 1980; Gosner 1971; Gosner 1978; Pettibone 1963).

2.5.1 Video Sample Processing

The video data were processed through a series of viewings in which all biota were identified to the lowest possible taxonomic level for presence/absence purposes. The video is also used to determine major patterns of biotic distribution, substrate preferences, and the presence of other organic material such as shell hash. The video analysis is well suited for the identification of megafauna and epibenthos as well as coarse substrates and those with boulders and cobbles. Often the box core will not retrieve these elements while sampling.

2.6 Statistical Analysis of Ground-Truth Data

2.6.1 Cluster Analysis

Cluster analysis was applied to sediment texture data to group grab samples with similar characteristics in the distribution of grain size (Xu and Wunsch 2008). Characteristics are determined as the percentage of total weight of the sample that falls within each previously mentioned phi (ϕ) class on the Wentworth scale. The Wards-Linkage method in Minitab ver. 16© displays similarity in clusters as Euclidean distance.

2.6.2 Non-Metric Multidimensional Scaling

Non-metric multidimensional scaling (MDS) was used with grab sampled biota to visualize the ecological similarity of the sampled biota. It uses PRIMER 6© software to create a Bray-Curtis similarity matrix from the presence/absence data for ground-truthed samples. The samples are treated in three dimensional space and associated stress values within the plot are a reflection of how well the plot distance represents real-world distance. A stress level of less than 0.2 suggests that the clustering is a reliable illustration of real-world distance, however as NMDS is a method to visualize data higher values can still be useful for interpretation (Clarke and Warwick 2001). The plots show the relationships between samples with closer samples being more similar than further samples. The samples were coloured according to substrate class in order to illustrate the relationship between biotic assemblage and substrate.

2.6.3 Analysis of Similarity

Analysis of Similarity (ANOSIM) tests for significant differences in biotic composition of within defined substrate classes. Also using the PRIMER 6© software, it uses the previous absence/presence data on a Bray-Curtis similarity index to calculate an R value. The R value represents the test for similarity between each substrate classes. An R value greater than 0 represents dissimilarity between the two classes being tested. A negative R value suggests that dissimilarity within the class being tested is greater than between the classes (Clarke and Warwick 2001). A significance level of less than 0.05

was used to select those pair-wise tests in which the difference or similarity indicated distinct habitats.

2.6.4 Similarity Percentage Analysis

Similarity percentage analysis (SIMPER) was used to determine the characteristic biota of each substrate class and to ultimately define habitats. It uses presence/absence data to determine which species and taxa contribute most to the similarity of samples within a specific substrate class.

2.7 Mapping

Mapping of substrates and habitats was done in ArcGIS 10©. Acoustic signatures for classifying the multibeam sonar were created through an iterative process. Initially the ranges of depth, backscatter and slope for each substrate and habitat class were determined by collecting the values of each pixel, at each sample station (Appendix C). As pixels are 5m x 5m, only one pixel was included per each box core. Box and whisker plots were used to visualize the range overlap of the depth, backscatter and slope values of each class. The final signatures were adjusted to minimize overlap of the three variables.

The raster calculator was used to apply the signatures to the depth, backscatter and slope layers in ArcMap, creating binary rasters for each substrate and habitat class. The order in which the rasters were overlain for the final map was determined by the most likely distribution of the substrates.

2.7.1 Accuracy Assessment

Before creating the acoustic signatures, 25 percent of the sample stations in each class were removed from the data set in order to create a "test sample set" for use in an accuracy assessment. Once the classification was complete, these test samples were overlaid on the map in order to determine how many of the samples were accurately classified. Ambiguity was measured by determining how many pixels were placed into more than one habitat class as done in Copeland *et al.* (2011a).

2.8 Sensitivity

The list of stressors to be applied to Okak Bay was presented in Chapter 1 (Table 2.1). This list was compared to a list of the predicted habitats using a combination of the sensitivity matrix approach as developed by Zacharias and Gregr (2005), and a decision tree as developed by Hiscock and Tyler-Walters (2006). The methodology used in the development of the sensitivity matrix was compiled from various sources including Zacharias and Gregr (2006), Hiscock and Walters (2006), and most recently used in the DEFRA reports on the development of Marine Protected Areas (DEFRA 2010). The matrix compares the sensitivity of valued ecological features, in this case the defined habitats, to previously identified pressures or stressors.

Steps taken to compile the matrix include: determination of key characteristics of valued ecological features. Key biota were selected for each habitat based on abundance. Additional characteristics which were unique to a habitat in terms of biota or substrate were also included. A decision tree, such as the one used in Hiscock and Walters (2006), is used to assess both the intolerance and resilience of a feature. Tables 2.2 – 2.3 define categories of both intolerance and resilience.

Table 2.2 Scale of intolerance of features/key species

Level of Intolerance	Rationale
Low	No, or low impacts to key species abundance or assemblage composition. 0-25% of surface area affected.
Medium	Some change to species composition or abundance. 25-75% surface area affected.
High	High levels of species mortality, changes to species composition. 75%-100% of surface area affected.

Table 2.3 Scale of resilience of features/key species

Level of Resilience	Rationale
Low	No recovery or recovery in longer than 10 years.
Medium	Recovery within 1-10 years.
High	Full recovery within 12 months.

Table 2.4 demonstrates how the final sensitivity ratings are determined through the combination of intolerance and resilience. Habitats were given a rating on a scale of 1-3 to each stressor (representing low to high levels of sensitivity), and ratings were averaged to determine final level of sensitivity to each category of stressor. Literature (Gagnon *et al.* 2005; Hall *et al.*, 2008; Hiscock and Tyler-Walters 2006), was used to determine the sensitivity of both the substrate, and of key species to each stressor.

Table 2.4 Scale of sensitivity of features/key species

Intolerance	Resilience	Low	Medium	High
High		High	High	Medium
Medium		High	Medium	Low
Low		Medium	Low	Low

2.8.1 Sensitivity Surface Mapping

Maps were produced to illustrate how the sensitivity values were distributed within the fiard. Coverages were created using the raster calculator for each stressor, wherein the pixel value (1-3) represented the level of sensitivity (Low-High) as previously determined using the matrix. The 21 coverages were then overlain using the weighted sum tool in ArcMap 10 to determine those areas with the combined highest levels of sensitivity to all stressors.

3.0 Results

3.1 Introduction

The overall goal of this study is to document the nature and distribution of benthic habitats in a central Labrador fiard, and determine how they compare to those habitats previously mapped along the Labrador coast. The results of the bathymetric surveying are presented by geomorphic region of the fiard. The ground-truthing activities are described, and the samples presented as classified substrates and habitats. The distribution and characteristics of each habitat are discussed in detail as are sensitivity values and maps.

3.2 Multibeam Sonar Survey

The multibeam sonar survey was completed in 2003 and 2009 by three vessels and two sonar systems. All of the *deep-water* portions of the fiard, and much of the shallow areas around the inner islands and the mouth were mapped for a total coverage of 274 km^2 (Fig. 3.1). Areas too shallow to be mapped efficiently (< 10 m) due either to the small footprint of the multibeam in the shallow water or danger to the vessel, were not completed. Coverage of the deeper areas of the fiard to the north of Okak Islands was limited by logistics, and data are available for a 3 km wide strip over the deep basins. Coverage extended past the mouth of the fiard into the shallow areas east of Okak Islands.

The acoustic backscatter intensity data collected in Okak Bay ranged from 0 to -53 decibels (dB) in value. Low values were found throughout the majority of the fiard

(< 0 dB) with areas of higher values found on the multiple sills and rock sidewalls. Shallow areas also resulted in generally higher backscatter of > -15 dB.

3.3 Bathymetry

The fiard is divided into four distinct regions and two smaller features, defined by depth, slope and morphology. Each of the regions is described separately and in more detail in the following sections.

3.3.1 Bathymetry of Fiard Head

The head of the fiard is a narrow, flat channel running NW-SE, with a sharp turn midway towards the northeast; it is approximately 21 km in length (Figure 3.2). Water depths range between 45 – 50 m throughout the region, with shallower areas (16-20 m) closer to the head and the margins of the channel. The deepest point is found at the eastern end of the channel (75 m) where it is separated from the central fiard by a small, deep (70 m) sill southwest of Martin Island. Slope in the region is low (<1°), increasing on the deltas at the head, and at the margins (to approximately 20° or less) (Figure 3.3). There are two sources of freshwater input near the head, Ikinet Brook, and North River, which enter the fiard from the south and east, respectively. While the North River has formed a broad, gently sloping tidal flat and delta, the Ikinet Brook forms a narrow channel through which sediment has built up on the north side, forming a skerry, which appears at low tide.

3.3.2 Backscatter Distribution of Head of Fiard

The head of the fiard is characterized by homogenous backscatter in the range of -14 to -17 dB (Figure 4.9). Areas of slightly lower values (- 18 to -20 dB) are found near

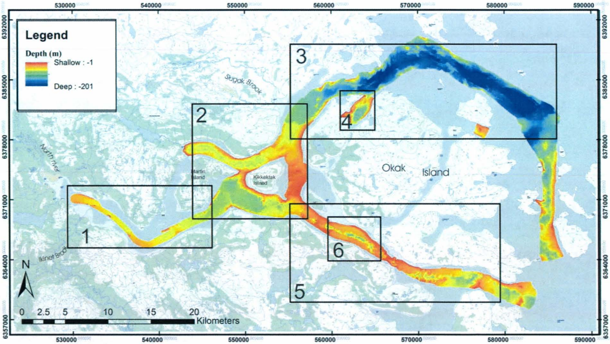

Figure 3.1 Multibeam bathymetry data coverage in Okak Bay, Labrador. 1) Head of fiard, 2) Central fiard, 3) Northern Entrance, 4) Okak Harbour, 5) Southern entrance, 6) Trench feature

the shallow areas of sediment accumulation around Ikinet Brook. Towards the eastern end of the region small patches of slightly higher backscatter (-11 to -13 dB) can be found running north to south (Figure 3.4).

3.3.3 Bathymetry of Central Fiard

The central fiard encompasses the region around the inner islands and is characterized by basins of intermediate depth, shallow sills and steep sidewalls (Figures 3.5). Average water depth is 70-80 m, with several shallow sills less than 20 m. To the east of Allavik sill is the deepest point of this region at >80 m depth. To the north is Kikkektak sill (~ 17 m), the largest sill in the fiard, connecting the two inner islands and separating the central fiard basin from shallower (~60 m) basins to the north.

The majority of the region has a low slope (<1°), including the basins to the south and north of the inner islands (Figure 3.6). Coastal margins and the sills provide areas of higher slope (>20°). The areas of the coast directly to the north of Kikkek Island, and to the south of Kikketak sill are the regions of highest slope (>50°).

The central fiard region is separated from those to the north and south by abrupt changes in bathymetry: deeper to the northeast and the northern entrance and shallower to the southeast and the southern entrance.

3.3.4 Backscatter Distribution of Central Fiard

Backscatter values in the central fiard area differ between the basins and sill/sidewall areas, and range between -5 and -23 dB (Figure 3.7). The basins to the north and south of Martin and Kikkektak Islands differ by an average of -5 dB. To the northwest of the islands, backscatter within the basin range from -18 to -22 dB, with a

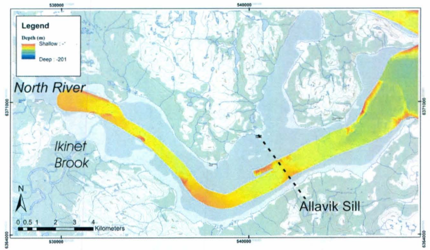

Figure 3.2 Multibeam bathymetry coverage of fiard head region

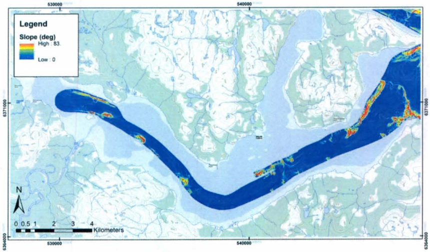

Figure 3.3 Distribution of slope values in fiard head region

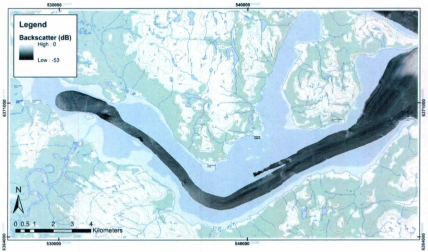

Figure 3.4 Multibeam backscatter coverage of fiard head region. Hard bottoms are light backscatter, and soft bottoms are dark

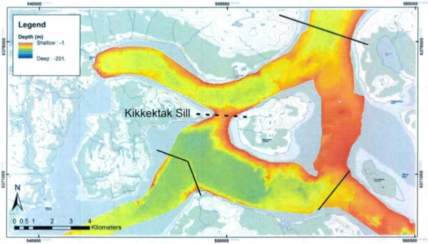

Figure 3.5 Multibeam bathymetry coverage of central fiard region. Lines indicate boundaries of region

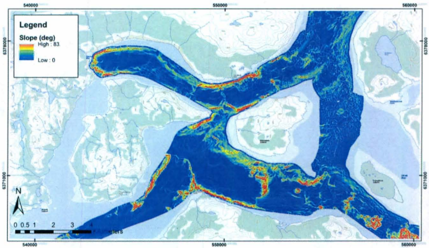

Figure 3.6 Distribution of slope values in central fiard region

Figure 3.7 Multibeam backscatter coverage of central fiard region. Hard bottoms are light backscatter, and soft bottoms are dark

small patch of higher values (-6 dB) at the southwest end. The relatively homogenous basin transitions into an area of slightly higher backscatter range (-12 to -17 dB) in the northeast basin, separated by the much higher values (-7 to -9 dB) of the Kikkektak sill. This region of high backscatter values extends over the sill, and over a distance of 3.5 km². The basin to the south of the sill averages -15 to -18 dB. It is relatively homogenous, with a small area of higher values off the southern point of the island. The highest backscatter values are found in the region between Kikkektak and Okak Islands. This patch, covering an area of 8 km², averages -6 dB.

3.3.5 Bathymetry of Northern Entrance

The northern entrance to the fiard contains the deepest areas of Okak Bay, characterized by three deep basins and sills with steep sidewalls (Figure 3.8). Total area covered by the deep basins (>100 m) is 44.5 km². The depth of the basins is between 175 and 200 m, while the sills separating the basins average 100-120 m. The deepest point is located just to the north of Coffin Island, at 201 m depth. The coastal areas consist of a series of small islands, and the northern shore of Okak Islands. In these areas the seabed is flat and shallow (40 m or less), before dramatically dropping to the basin depth. The bottom of the basins is flat, with an average slope of less than 1° (Figure 3.9). The basin sidewalls of the northern entrance are among the steepest in the fiard, averaging >30°, with a maximum of 79°, located along Uivak Point, across from Okak Harbour.

3.3.6 Backscatter Distribution of Northern Entrance

The northern entrance, with the largest range of slope and depth values within the fiard, also has a large range of backscatter values (Figure 3.10). In general the lower values (<-20 dB) are concentrated in the basins, while the steep sloped sidewalls and deep sills have higher values (>-10 dB). The lowest values are found in the basin to the north of Coffin Island – as are the greatest depths in the fiard. Values range from – 20 dB to -50 dB in this region. The steep sloped sidewalls have values between -17 dB and -12 dB, and taper off to the highest values of the regions (>-6 dB), found in the coastal regions and around the islands. Higher backscatter values at higher depths are found on the sills, between -7 and -9 DB.

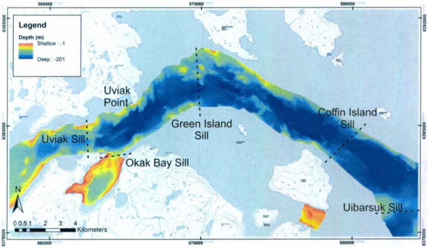

Figure 3.8 Multibeam bathymetry coverage of northern entrance region

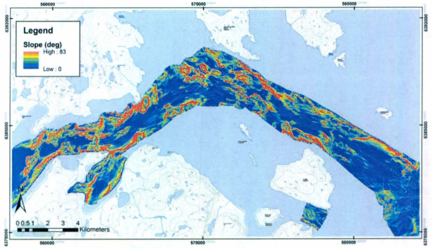

Figure 3.9 Distribution of slope values in the northern entrance region

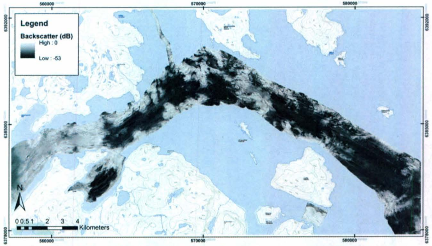

Figure 3.10 Multibeam backscatter of northern entrance region. Hard bottoms exhibit light backscatter, and soft bottoms are dark

3.3.7 Bathymetry of Southern Entrance

The southern entrance to the fiard is 30 km in length, and consists of a narrow, channel bordered by the Ubilik Peninsula to the south, and the southern coast of the Okak Islands to the north (Figure 3.11). It is 800 m wide at its narrowest point – beside Makkah Hill, and increases to 2.7 km at the mouth. It is shallow and flat, and encompasses the trench feature as described below, as well as several very shallow sills. .

Average depth is 30 m, rising to <15 m on the three sills located in its middle and either end of the channel. The shallowest point is located on the central sill (Makkak sill) at 3 m. There are a series of deeper scours (down to 60 m) on the eastern side of the outer two sills. Slope is low (<2°), increasing to >6° along the sides of the channel (Figure 3.12). Areas of steeper slope are found within the scours and the sides of the sills.

The trench feature is located within the southern entrance channel to the fiard (Figure 3.14). It runs approximately 6 km, and is broken at the beginning and end by the inner two sills. It averages 400 m in width from the top of the slope on either side. Maximum depth is 90 m. Average slope is > 20°. A series of depth profiles (Figures 3.15 through 3.18) illustrates that the trench contains a ridge in the centre with deeper points on either side, and has a depth range of approximately 40 m from top to bottom. Steep slope areas are confined to the sides of the feature (Figure 3.19).

3.3.8 Backscatter Distribution of Southern Entrance

The southern entrance also has a wide range of backscatter values. Higher values are concentrated at the three sills, at either end, and in the centre of the channel

(Figure 3.13). On these sills, values average -8 to -10 dB, while closer to shore, the values rise to < -5 dB. Between the two inner sills the values are still high, between -13 and -18 dB. Unlike most areas, values decrease closer to shore, particularly on the northern side of the channel, reaching values of -23 dB. The lowest values of the region are found between the two outer sills, at between -31 and -27 dB.

Backscatter values within the trench are slightly lower than those surrounding it (Figure 3.20). Within the trench itself, backscatter is -18 to -20 dB, with no change reflected in the values at greater depth. Around the trench, the values are on average higher, with a range of -12 to -17 dB.

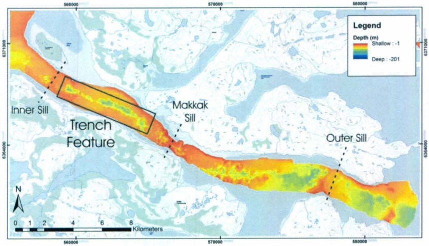

Figure 3.11 Multibeam bathymetry coverage of southern entrance region

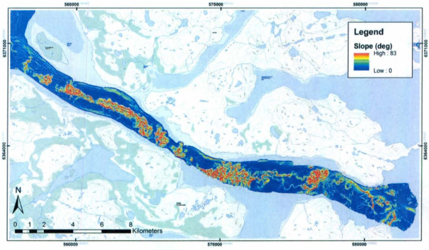

Figure 3.12 Distribution of slope values in southern entrance region

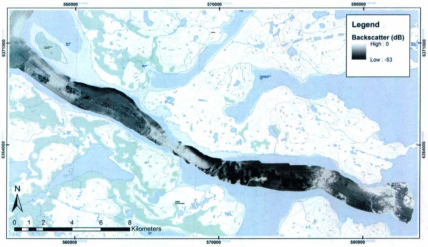

Figure 3.13 Multibeam backscatter of southern entrance. Hard bottoms exhibit light backscatter, and soft bottoms are dark

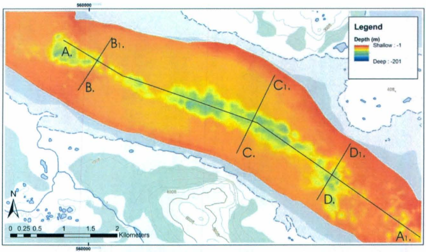

Figure 3.14 Multibeam bathymetry coverage of trench features. Letters indicate position of following profiles

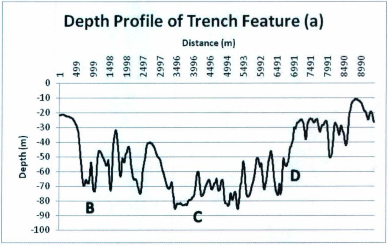

Figure 3.15 Depth profile (A) of trench feature located in southern entrance, letters indicate locations of perpendicular profiles. Vertical exaggeration 33.

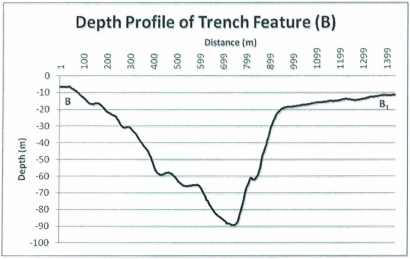

Figure 3.16 Depth profile (B) of trench feature located in southern entrance. Vertical exaggeration 7.5.

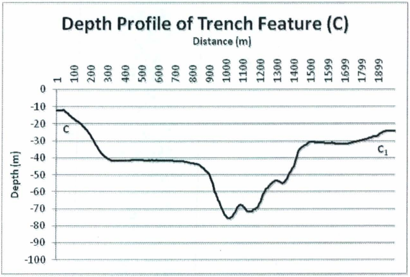

Figure 3.17 Depth profile (C) of trench feature located in southern entrance. Vertical exaggeration 10.

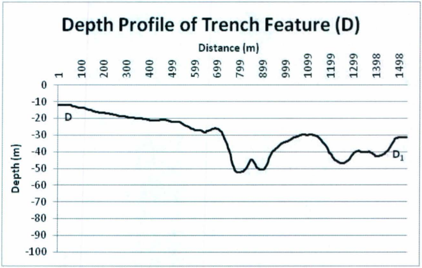

Figure 3.18 Depth profile (D) of trench feature located in southern entrance. Vertical exaggeration 7.5.

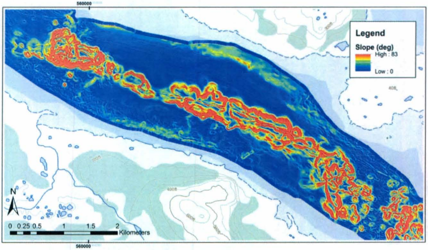

Figure 3.19 Distribution of slope values in trench feature

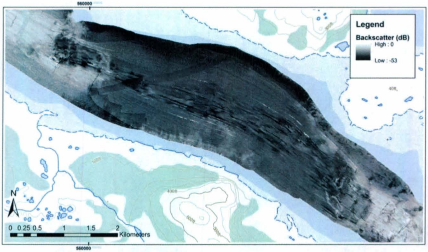

Figure 3.20 Multibeam backscatter of trench feature. Hard bottoms are light backscatter, and soft bottoms are dark

3.3.9 Bathymetry of Okak Harbour

Okak Harbour is located on the northwestern shore of Okak Islands. It is approximately 6.5 km^2 in size, nearly all of which was mapped by multibeam (Figure 3.21). It is defined by a deep basin of approximately 100 m water depth, and is separated from the rest of the fiard by a shallow sill of 20 to 30 m water depth. The edges of the harbour are shallow (20-40 m), and the area gently slopes to the central basin at an angle of approximately 12-13°. The slope around the entrance sill is steeper, at approximately 40°.

3.3.10 Backscatter Distribution of Okak Harbour

Okak Harbour has a wide range of backscatter values, with lower values found in the central basin, transitioning to higher values along the sidewalls and across the sill at the mouth (Figure 4.14). The deepest part of the harbour contains the lowest values

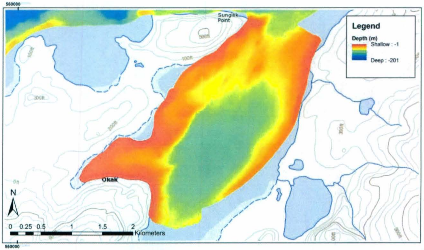

Figure 3.21 Multibeam bathymetry coverage of Okak Harbour

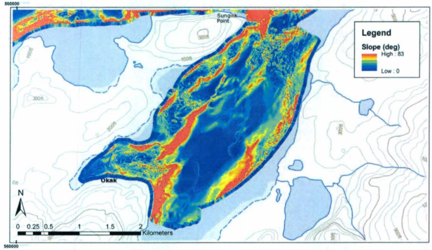

Figure 3.22 Distribution of slope values in the Okak harbour region

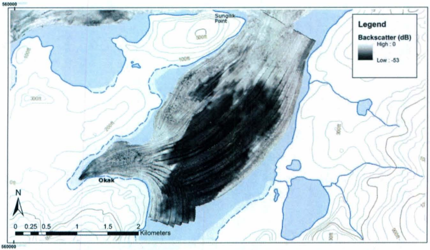

Figure 3.23 Multibeam backscatter coverage of Okak Harbour region. Hard bottoms exhibit light backscatter, and soft bottoms are dark

(<-25 dB). There is a gradual transition to the highest values (> -5 dB), found adjacent to the coastline, and across the shallow sill. Low values of less than -15 dB extend closer into the coastal area in the small area in which the community of Okak once was located.

3.4 Substrate Classification Development

The sediments collected with the box core were analyzed through sieving, to determine percentage grain sizes for each sample. Cluster analysis carried out at 50% similarity resulted in 14 clusters (Figure 3.24). The majority of sediment samples contained over 30% mud (<4ϕ), with an average value of 50% for all samples. As such, mud is the defining content for the majority of the clusters, with varying degrees of sand (0 ϕ -4 ϕ) characterizing them further. Only two clusters are defined by the granule and pebble (-1 ϕ - 2 ϕ) grain size. The two larger clusters are broadly divided into mud and muddy sand. The clusters can then be further named by the ratio of grain sizes. Cluster 1 contained 9 samples comprised of mud (<4 ϕ) and very coarse sand (2 ϕ). It is closely related to clusters 9 (containing 9 samples) and 4 (containing 3 samples), both of which contain approximately 30% mud and varying degrees of coarse sand, very coarse sand, and gravel. Cluster 4 contains the highest percentage of gravel (>20% on average). The other branch of the dendrogram within the larger mud cluster contains 6 clusters, composed of mostly grain size percentages of less than 1 φ (medium sand). Cluster 2 contains 7 samples and is comprised of mostly grain sizes > 3 ϕ – fine sand and mud. Clusters 3, 10 and 13 are composed of mostly fine sand and mud with small amounts of medium sand. Cluster 8 is the only cluster within this branch of the dendrogram to contain coarse sand. On average, the 10 samples found within this cluster contain 40% mud, and 30% medium to coarse sands.

The second branch of the dendrogram contains higher percentages of sand to mud, classifying it as sandy mud as a whole. The second branch has 5 clusters and 62 samples. Cluster 5 contains 7 samples, and contains a majority of mud (<4 ϕ), with a small amount of both fine sand and coarse sand (4 ϕ and 1 ϕ respectively). It is closely related to cluster 6, containing 14 samples, and a similar ratio of mud and fine sand with the remaining portion of the sample skewed towards smaller grain sizes (2 ϕ). Clusters 11 and 12 both contain large amounts of medium sand. Cluster 11, with 12 samples has a high content of mud (>40%), with medium and coarse sand. Cluster 12 has one of the lowest average percentages of mud (<12%), and highest percentages of medium and coarse sand (26%).

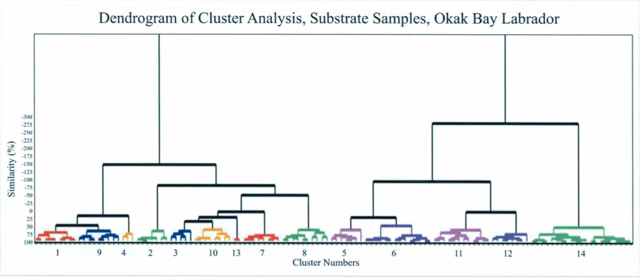

Figure 3.24 Sediment grain size analysis dendrogram, grouping sediments by similar grain size characteristics. Sample numbers associated with clusters are found in Appendix B. Y-axis reprsents percent similarity between samples.

Cluster 14 contains the largest number of samples (21). It is composed of a high percentage of mud and very fine sand – similar to cluster 5. A summary of the clusters and associated names is given in Table 3.2.

Table 3.1 Summary of sediment classification clusters

Cluster ID	Cluster Name	# of Samples	% Mud	% Sand	% Gravel	Final classification
14	Very fine sandy mud	21	88	12	0	Mud
13	Mud	2	89	10	1	Muddy Sand
10	Very Fine Sandy Mud with Coarse Sand	8	68	31	2	Muddy Sand
8	Coarse Muddy Sand	10	37	55	7	Muddy Sand
7	Medium muddy sand	8	35	60	5	Muddy Sand
2	Fine muddy sand	7	33	67	0	Muddy Sand
3	Muddy fine Sand	5	14	85	1	Muddy Sand
6	Fine Sandy Mud with Medium Sand	14	70	28	1	Sandy Mud
5	Coarse Sandy Mud with Fine Sand	7	63	29	8	Sandy Mud
11	Medium Muddy sand with Very Coarse Sand	12	43	53	4	Sandy Mud
12	Medium Sand	8	14	77	9	Sandy Mud
1	Very Coarse Muddy Sand	9	36	46	18	Gravelly Sandy Mud
9	Muddy Sand	9	33	63	4	Gravelly Muddy Sand
4	Muddy Gravel	3	28	37	35	Gravelly Sandy Mud

3.4.1 Development of Substrate Classes

The final classification of substrates must be equally applicable to both video and grab sampling methods - therefore the sediment classifications must be visually identifiable on the video, as well as significant for habitat purposes. Classes which could not be distinguished on video were merged. The 14 clusters from the video were condensed into 4: mud, sandy mud, muddy sand and gravelly sand.

Cluster 14 was the most statistically different of all the clusters. This cluster also contains the largest number of samples of all the clusters. It was retained and named "mud" as the majority of the samples contained nearly 90% mud with the remainder of the sample was composed of very fine sand. Several samples contained 100% mud, including Samples 2009-17B and 2009-6C.

Clusters 5, 6, 11 and 12 were combined to create the substrate class called sandy mud. Mud composed the majority of each of the samples (50-84% mud) but to a lesser degree than samples in class "mud", with the remainder of the samples composed of medium to very fine sand. Only two of the samples contained material with a grain size superior to -1 ϕ, 2009-9C and 2010-16A. Although difficult to distinguish from mud on video, the addition of sand may be important for habitat purposes as it reduces cohesion of the sediment.

Clusters 2, 3, 10, 13, 7 and 8 were merged into a cluster "muddy sand". While there were still small amounts of mud in each of the samples (<35% with the exception of 2009-24A which contained 39%), the remainder of each sample was composed of very fine to very coarse sand. Several of the samples contained < 10% of gravel.

The remaining samples, clusters 1, 4 and 9 were combined into gravelly sand. Again, a small amount of mud was common in the samples; however, the majority of the material (>60%) was composed of very coarse sand, gravel, and cobble. The coarse nature of this substrate class and the presence of cobbles made it distinctive on video.

Several of the samples returned too little sediment to be processed or no sediment at all. Large amounts of sea colander (*Agarum clathratum)* were retrieved using the box core but were visible on the video. Although the few samples that were retrieved from this area were identified as part of the muddy sand class, they were included in a fifth substrate class – kelp. Kelp acts as a substrate for those organisms which inhabit the fronds, and typically covers rocky/hard substrates. It is included as a fifth substrate here as the large amount of coverage will impact heavily the habitat of the region, as well as the physical characteristics of the seabed.

In summary, the 5 classes which were identified through sediment sampling techniques were mud, sandy mud, muddy sand, gravelly sand, and kelp.

3.4.2 Development of Substrate Classes from Video

Two methods of video were used to ground-truth the multibeam data, making use of a drop video camera and a remotely operated vehicle (ROV). The video was used to provide additional information about the substrate in areas where the box core had failed to sample the seabed (e.g. the inner kelp beds), and in areas that could not be sampled due to physical constraints (e.g. areas of high slope).

3.4.3 Drop Video Camera

A drop video camera was deployed at 42 sample stations (Figure 2.3). At four stations the camera was deployed but video quality was too low to be successfully processed. At two stations the tidal current was too strong to successfully deploy the camera. The remaining 38 stations were used to gather additional information about substrates including grain size and distribution, and about large or motile biota.

3.4.4 Remotely Operated Vehicle (ROV)

Four transects (Figure 2.4) were completed with the ROV, each in an area expected to represent a different habitat, and which was difficult to sample with the box core and drop video camera. The ROV allowed for more detailed sampling efforts and greater precision than the drop video camera in areas where depth or slope changed rapidly. In cases such as location 3 (trench in southern entrance to fiard), it allowed for continuous video to be captured from the base to the top of the muddy slope, in order to assess how the biota changed with depth in an area of continuous substrate. The ROV was of similar use in transect 4 (talus slope in southern fiard), where the substrate was different from transect 3, but covered a similar depth range (20-80 m).

Transects 1 and 2 were used to cover sills on which the substrate was heterogeneous and depth was relatively stable and shallow, both of them on sills and in shallow areas. In these regions, biota was surveyed for distribution with changing substrates, and how the biota differed in the centre of the sill (area of high disturbance/current), and the ends of the sill (close to shore, high sedimentation).

3.4.5 Classification of Video Samples

The video collected with the drop video camera and the ROV were classified according to the previously established substrate classes, and several new classes were developed. Videos were assigned to a class based on the percentage of substrate which was visible on the transect.

The only new substrate class identified from the video analysis is "bedrock/boulder". This substrate could not be successfully sampled by box core as there is no fine-grained material to be recovered – initial attempts at sampling this substrate returned a deployed, but empty sampler. As evidenced on the video at three locations, this substrate covers 90-100% of the transects, with only small amounts of sand/gravel matrix found in crevices and depressions.

The second substrate class which was identified by box core and verified by drop video camera is that of the kelp beds located in the central fiard. They are visible at three sample sites, and cover at least 75% of the seabed in those areas.

Drop video camera sampling was completed at the majority of the grab sampling sites. In some of these cases, cobbles or pebbles were visible on the video that were not sampled with the box core, and therefore included in the grain size analysis. Samples were placed in either the previously established substrate "gravelly sand", or if the fine-grained matrix was composed of mud, placed in a newly created substrate class "gravelly mud". Photographs of grab samples were used to confirm the presence of cobbles in several of these cases. Table 3.3 summarizes the video classifications for both the drop video and ROV samples.

Table 3.2 Classification of video samples

Substrate Class	# of Samples
Mud	15
Sandy Mud	2
Muddy sand	1
Gravelly Mud	5
Gravelly Sand	12
Kelp	3
Bedrock/boulder	2

3.4.6 Summary of Substrate Classes

One hundred and sixty-nine grab, video and ROV samples were placed into a total of seven substrate classes. The final substrate classifications for each sample site was determined through a combination of grain size analysis, video analysis and on-site sample photographs. The seven final substrate classes, as determined via grain size analysis and video analysis are as follows: mud, sandy mud, muddy sand, gravelly mud, gravelly sand, kelp and bedrock/boulder. Table 3.4 summarizes the number of samples placed into each class in the final classification.

Table 3.3 Substrate classification of grab and video samples

Substrate Class	# of Samples
Mud	26
Sandy Mud	52
Muddy sand	22
Gravelly Mud	10
Gravelly Sand	43
Kelp	11
Bedrock/boulder	4

3.5 Organic Content

Organic content was measured on 82 of the sediment samples collected by box core to determine organic content. Sample sites being classified as bedrock/boulder or containing only biological material (i.e. rhodoliths or kelp), contained no substrate material to process. This is regrettable as kelp fronds are often a source of high organic content in substrate. Therefore, the five substrate classes from which the organic content was processed are mud, sandy mud, muddy sand, gravelly mud, and gravelly sand.

Organic content ranged from 0.3 to 10.5% with a mean content of 3.8%. Only seven of the 82 samples have an organic content of over 5% and only two over 10%.

Gravelly sand had the highest average organic content of the substrate classes with 4.4%, followed closely by muddy sand (4.1%), and then mud (4%). Gravelly mud had the lowest average organic content (3.2%) (Figure 3.25).

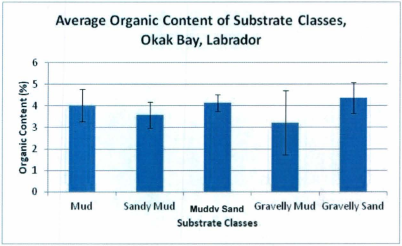

Figure 3.25 Average organic content of substrate classes, Okak Bay. Error bars represent 95% confidence intervals

A one-tailed ANOVA (Table 3.4) performed on the square-root transformed data with α=0.05 suggests that differences in organic content between substrates is not significant. Data was square-root transformed in order to ensure it fit the assumptions of normality required for the use of the ANOVA test.

Table 3.4 ANOVA organic content by substrate

	sum of squares	df	mean square	Fs	p
among groups	1.17	4	0.293	1.388	0.244
within groups	20.245	96	0.211		
total	21.415	100			

On average, the majority of the samples containing organic material were retrieved from less than 100 m water depth. Areas of the fiard deeper than 100 m are located in the outer northern entrance, approximately 2 km distance from both shallow coastal margins, and any freshwater input, which may act as a source of terrestrial organics. Marine sources of organic content such the decomposition of plant life (the kelp beds), and water column production (phytoplankton and zooplankton) appear to be minimal. Similar to the organic content of terrestrial origin, organic content produced via water column processes including phytoplankton and zooplankton production is likely not to be deposited in the high exposure environment of the outer basins. The kelp beds are located in a low-exposure region of the fiard, much of the material produced in this region is unlikely to be transported out of the shallow basin. Particularly high values (>8%), are found in the area directly south of Moore's Island Tickle, a body of water that divides Okak Islands. High values are also found in Okak Harbour. The lowest values are found in the outer fiard – the deep muddy basins at the north of Okak Islands and to the east of the outer sill in the southern entrance.

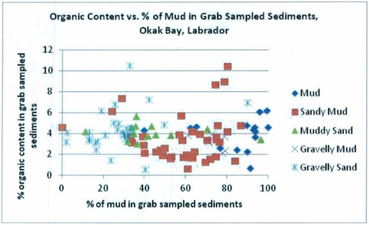

Figure 3.26 Organic content vs. % mud of grab sampled sediments, Okak Bay

As Figure 3.26 demonstrates, there is no clear relationship between percentage of fine grains in the samples and organic content. As high levels of silt and clay are typically associated with high percentages of organic content, this is surprising. The series of sills which lie between these areas and the inner fiard restrict the movement of organic material outwards, and high wave and tidal energy likely prevent deposition.

Gravelly sand was generally restricted to depths above 100 m and typically contained low values of between 2 and 5% organic content. This substrate class is commonly found in shallow areas of high disturbance such as exposure to waves, ice scour and mass wasting – promoting the removal of fine grained organic material by currents and the deposition in the finer-grained basins to the north and south of the sills.

3.6 Biological Data

Biological samples were collected from 123 box cores and identified from 42 video sites. Biota were classified into 118 taxa. Samples were identified to the species level where possible, with the exception of the polychaete class which was identified at the family level. Appendix C contains detailed taxonomic information for all sampled biota. Within the grab sampled biota, polychaetes and bivalves were the most frequently sampled taxa: 244 individuals from 30 polychaete families and 293 individual bivalves from 18 species. Gastropoda and crustacea were also commonly sampled taxa, with 71 and 57 samples, respectively. The only flora class that was sampled was Florideophyceae, encrusting coralline algae.

Grab sampled biota tended towards sampling of infauna, specifically infauna, while the video was used for sampling epifauna, flora, and large, motile organisms. Forty taxa were sampled from 20 classes on video; with Ophiuroidea and Anthozoa the two most commonly sampled classes. Two flora classes were sampled Phaeophyceae and Florideophyceae.

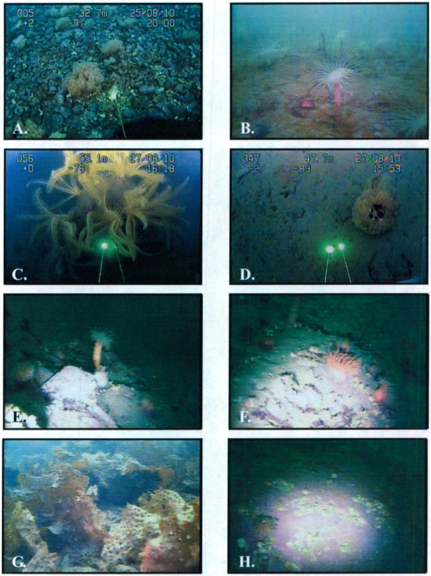

Figure 3.27 Epifaunal species identified in Okak Bay using video data analysis, A. *Gersemia spp.* B. *Pachycerianthus borealis* , C. *Heliometra glacialis*, D. *Suberites carnosus*, E. *Hormathia nodosa*, F. *Urticina felina*, G. *Agarum clathratum*, H. *Lithothamnion glaciale*

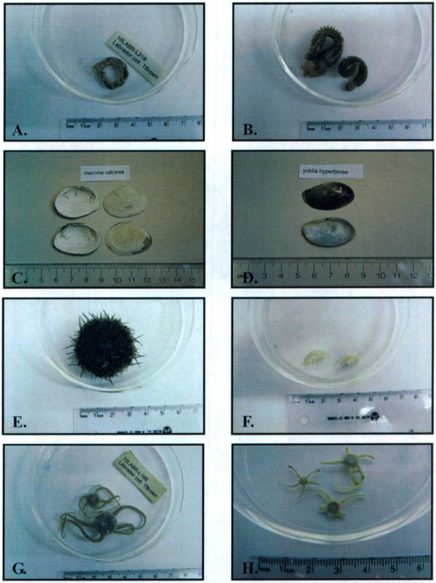

Figure 3.28 Common species found in Okak Bay using box core, A. *Fm. Maldanidae*, B. *Fm. Nephtyidae*, C. *Macoma calcarea*, D. *Yoldia hyperborea*, E. *Strongylocentrotus droebachiensis*, F. *Haustorius canadensis*, G. *Ophiura sarsii*, H. *Stegophiura nodosa*

3.6.1 Species Richness

Species richness was determined for the four habitats sampled via box core, and the six habitats sampled via video. Values were determined using PRIMER-E, the Margalef Index calculates species richness taking into account both number of taxa and abundance. Gravelly sandy mud has the highest species richness for the grab samples, and the second highest only to bedrock for the videos. Lowest species richness was found in the kelp class. Difficulty sampling this substrate likely accounts for this – kelp obscures the seabed in the video making biotic identification difficult, and the robust nature of the *Agarum* species prevents sampling via the box core. The second lowest species richness is found in mud, followed by sandy mud.

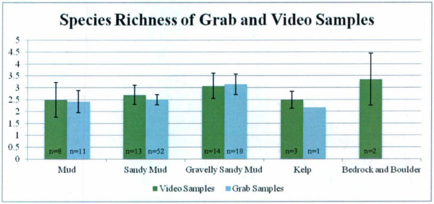

Figure 3.29 Species richness of grab and video sampled biota. Error bars illustrate 95% confidence intervals, and habitats are labeled with number of samples in each class

Table 3.5 ANOVA species richness by habitat class

	sum of squares	df	mean square	Fs	p
among groups	2.225	4	0.556	1.039	0.405
within groups	14.448	27	0.535		
total	16.673	31			

A one tailed ANOVA test (Table 3.5) performed on square root transformed data suggests that species richness is not significantly different between the habitat classes. High levels of biodiversity may be indicative of representative habitats, or of those which may be of importance for ecosystem functioning. Incorporation of this information with potential stressors can provide additional habitat map data for use in monitoring and conservation efforts.

3.6.2 Non-metric Multi-Dimensional Scaling (NMDS)

NMDS plots were used to visualize how biological assemblages differed between substrate classes. General patterns suggest that there is a clear distinction in biota between hard and soft substrates biological assemblages.

The stress value of the grab sample plot is low (0.16) (Figure 4.17) suggesting that the plot is a fair interpretation of the predicted distances. Interpretation of the plot suggests that substrate classes 1-3 (mud, sandy mud, muddy sand) are clustered together, towards one side of the plot (the upper right), while 4 through 5 (gravelly mud, gravelly sand) tend to be distributed towards the centre and lower left of the plot. Gravelly sand and gravelly mud share the common bivalve species (*Macoma calcarea, Yoldia* *hyperborea*) and several species of echinoderms with the softer substrates, contributing to the similarity of the softer substrates within the plot.

Only one grab sample station was classified as kelp, being close to several gravelly sand classified samples (2009-26C, 2009-26B, 2009-28B and 2009-13C). As the kelp beds are located on a gravelly-sand base, it is likely that the presence of sand is the cause of the similarity.

The inclusion of bedrock/boulder to the video sample NMDS plot adds another hard substrate (Figure 3.29). The division between soft and hard substrates is more easily distinguishable in the video plot, and the lower stress level (0.12) indicates an excellent representation. Soft substrate classes 1-3 (mud, sandy mud and muddy sand) plot close together on the right of the plot, while the four hard substrates occupy the space to the left. Bedrock/boulder and kelp are also clustered in the upper left, as biota in these classes is restricted to shared set of epifauna, causing a high level of similarity. Sample 2009-18, a hard substrate (gravelly sand), plots within the soft substrate cluster and within a group of mud samples (2009-17, 2009-19) in particular. Geographically, these samples are located together within the outer basin, suggesting that certain common species may be shared among regions as well as substrates. Analysis of similarity (ANOSIM) was performed on the datasets to confirm NMDS analysis.

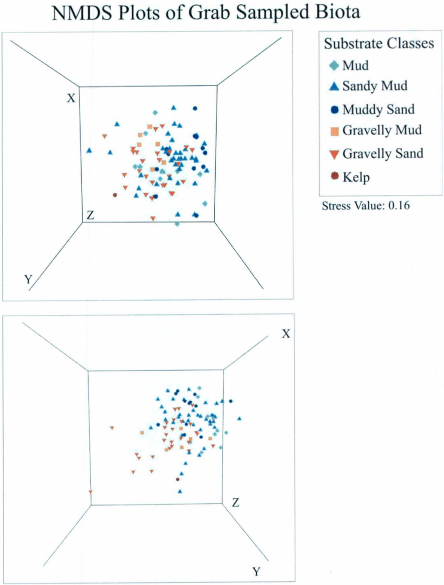

Figure 3.30 Two views of three dimensional NMDS plot of grab sampled presence/absence biota.

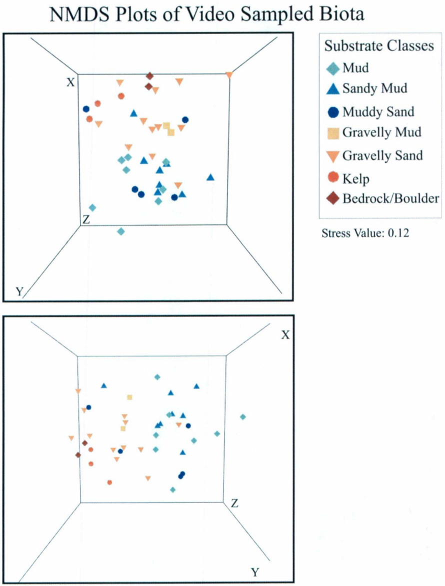

Figure 3.31 Two views of three dimensional NMDS plot of video sampled presence/absence biota

3.6.3 Analysis of Similarity (ANOSIM)

Analysis of similarity was used to determine if each substrate class had a distinct biological assemblage. Grab and video sampled substrates were tested separately to determine whether between-class or within-class similarity was higher.

Within the grab sampled biota (Table 3.6), the majority of the pairs displayed a high correlation (high R values) and low significance values, indicating that the biological assemblages differ between substrates, and therefore that each substrate provides a unique habitat. The sandy mud/muddy sand pair had an R value of –0.049, indicating that habitats are not distinct, and suggesting that the presence of sand may be important for the preference of infauna. Similarly, gravelly mud and gravelly sand had an R value of -0.035.

Table 3.6 Analysis of similarity of grab sampled biota. Bold values indicated statistically distinct habitats

	Mud	Sandy Mud	Muddy sand	Gravelly Mud	Gravelly Sand	Kelp
Mud						
Sandy Mud	0.1(p<0.09)					
Muddy sand	**0.2(p<0.03)**	-0.1(p<0.68)				
Gravelly Mud	**0.3(p<0.01)**	0.2(p<0.10)	0.3 (p<0.07)			
Gravelly Sand	**0.2(p<0.03)**	**0.2 (p<0.01)**	0.1(p<0.08)	-0.1 (p<0.56)		
Kelp	0.6 (p<0.09)	**0.7 (p<0.02)**	0.7(p<0.07)	0.7 (p<0.14)	0.2(p<0.21)	

*R value (Significance Level)

ANOSIM values for video sampled biota (Table 3.7) indicate similar separation of habitats as the grab sampled biota. Bedrock was included for testing and was found to be a distinct habitat compared to all the other classes, except for gravelly sand with an R value of -0.07. Other classes that were found to be indistinguishable were gravelly mud and gravelly sand (-0.248) and gravelly sand and kelp (-0.015). Several anemone and echinoderm species are shared between the harder substrates. Within the video samples, the tendency to sample exclusively these epifauna contributes to the similarity of the gravelly sand, kelp and bedrock substrates.

Table 3.7 Analysis of similarity of video sampled biota. Bold values indicate statistically distinct habitats.

	Mud	Sandy Mud	Muddy sand	Gravelly Mud	Gravelly Sand	Kelp	Bedrock/ boulder
Mud							
Sandy Mud	0.109 (p<0.08)						
Muddy sand	0.057 (p<0.32)	**0.281 (p<0.02)**					
Gravelly Mud	0.319 (p<0.08)	0.106 (p<0.31)	0.027 (p<0.57)				
Gravelly Sand	0.257 (p<0.06)	**0.283 (p<0.04)**	0.146 (p<0.12)	-0.248 (p<0.84)			
Kelp	0.565 (p<0.06)	0.706 (p<0.06)	0.405 (p<0.08)	1 (p<0.10)	-0.015 (p<0.48)		
Bedrock/ boulder	**0.668 (p<0.02)**	**0.636 (p<0.02)**	0.345 (p<0.14)	1 (p<0.33)	-0.07 (p<0.58)	0.75 (p<0.2)	

*R value (Significance Level)

The ANOSIM results suggest that the seven substrate classes can be condensed into five habitat classes, merging the muddy sand class and the two gravelly substrates into a single class, as the biota is indistinguishable between them.

3.7 Summary of Habitat Classes

Five habitat classes with distinct substrate and biotic assemblages were identified using NMDS ordination plots and ANOSIM. Classes were named according to description of bottom type, as mud, sandy mud, gravelly sandy mud, kelp and bedrock/boulder. Table 3.8 details the number of sites placed in each habitat class. Sandy mud and gravelly sandy mud composed the largest number of habitat classifications, at 43.5% and 31.4%. The bedrock/boulder class contains the fewest number of classified sample sites, at ~3%.

Table 3.8 Summary of habitat classifications for grab and video sampled biota

	Mud	**Sandy Mud**	**Gravelly Sandy Mud**	**Kelp**	**Bedrock/boulder**
Box core	18	58	37	8	2
Video Samples	14	32	28	6	4
Total	32	90	65	14	6
%	15.56	43.58	31.4	6.8	2.9

SIMPER classification was performed to determine characteristic biota for each habitat and to identify biota which most contributed to dissimilarity. Within the grab sampled data (Table 3.9), the bivalves *Macoma calcarea* and *Yoldia hyperborea* were the highest contributors to within-class similarity across the majority of substrates. Two species of brittle star (*Stegophiura nodosa* and *Ophiura sarsii*) were also common.

Within grab sampled data, *Agarum clathratum* and *Pachycerianthus borealis* were the top two contributors to within class similarity as they tend to dominate the biota in areas where they are found (Table 3.9). Species from the class Anthozoa were common across all classes, found in the top two contributing species with the exception of sandy mud and kelp. Detailed descriptions of the epi- and infauna contributing to each class follows.

Table 3.9 SIMPER results of grab sampled data, taxa contributing to within class similarity (numbers indicated percent contribution to similarity)

Mud	Sandy Mud	Muddy sand	Gravelly Mud	Gravelly Sand
Macoma calcarea (38.55)	*Macoma calcarea* (24.5)	*Stegophiura nodosa* (23.16)	*Haustorius canadensis* (23.22)	*Macoma calcarea* (23.25)
Ophiura sarsii (27.77)	*Yoldia hyperborea* (21.74)	*Clinocardium ciliatum* (20.4)	*Ophiura sarsii* (23.22)	*Astarte borealis* (9.82)
Nucula delpinodonta (8.53)	*Ophiura sarsii* (11.8)	*Yoldia hyperborea* (19.1)	*Nuculana pernula* (13.68)	*Ophiura sarsii* (9.32)
Yoldia hyperborea (3.94)	*Clinocardium ciliatum* (11.74)	*Macoma calcarea* (15.34)	*Macoma moesta* (7.32)	*Nuculana pernula* (8.79)
Saduria entomon (3.83)	*Nuculana pernula* (5.29)	*Ophiura sarsii* (11.04)	Formaminifera (7.3)	*Clinocardium ciliatum* (7.93)
Myriotrochus vitreus (3.83)	*Stegophiura nodosa* (4.19)	*Nucula delpinodonta* (1.73)	*Yoldia hyperborea* (6.58)	*Haustorius canadensis* (5.92)
Fm. Lumbrineridae (3.5)	*Fm. Lumbrineridae* (4.11)		*Clinocardium ciliatum* (3)	*Tachyrhynchus erosus* (4.04)
Fm. Flabelligeridae (1.62)	*Pachycerianthus borealis* (3.34)		*Cingula moerci* (2.65)	*Yoldia hyperborea* (3.4)
	Nucula delpinodonta (2.81)		*Macoma calcarea* (2.37)	*Tonicella rubra* (3.16)
	Gammarus sp. (1.49)		*Fm. Lumbrineridae* (2.25)	*Cyclocardia borealis* (2.03)
				Fm. Lumbrineridae (2.03)
				Foraminifera (2)
				Tectura testudinalis (1.62)
				Strongylocentrotus droebachiensis (1.57)
				Psolus fabricii (1.44)
				Mya Truncata (1.2)
				Hiatella arctica (1.02)
				Hemithiris psittacea (1.02)
				Nucula delpinodonta (0.99)

Table 3.10 SIMPER results of video sampled biota, taxa contributing to within class similarity (numbers indicated percent contribution to similarity)

Mud	Sandy Mud	Muddy sand	Gravelly Mud	Gravelly Sand	Kelp	Bedrock/boulder
F. Maldanidae (40.97)	*Stegophuria nodosa* (44.41)	*Pachyceriant hus borealis* (87.18)	*Agarum clathratu m* (25)	*Agarum clathratum* (22.61)	*Strongylocentro tus droebachiensis* (42.9)	*Hormathia nodosa* (16.67)
Pachyceriant hus borealis (30.77)	*Suberites carnosus* (14.82)	*Heliometra glacialis* (12.82)	*Gersemia rubiformi s* (25)	*Pachycerianthu s borealis* (21.03)	*Agarum clathratum* (42.9)	*Urticina felina* (16.67)
Stegophuria nodosa (7.06)	*Pachycerian thus borealis* (11.9)		*Balanus balanus* (25)	*Strongylocentro tus droebachiensis* (20.52)	*Coccotylus truncatus* (14.2)	*Strongylocentro tus droebachiensis* (16.67)
Ophiura sarsii (7.06)	*F. Maldanidae* (9.67)		*Drifa sp.*(25)	Bryozoan (4.93)		*Leptasterias polaris* (16.67)
Suberites carnosus (5.24)	*Heliometra glacialis* (9.31)			*Urticina felina* (4.67)		Encrusing coralline algae (16.67)
				Encrusing coralline algae (4.63)		*Balanus balanus* (16.67)
				Gersemia rubiformis (4.51)		
				Green Algae (4.51)		
				Balanus balanus (3.45)		

3.7.1 Mud

Figure 3.32 Images of the mud habitat class from the drop video camera, species shown include *Ophiura sarsii* (lower right and left corner) and *Suberites carnosus*

Average within class similarity for the mud substrate was 27.51% for grab samples and 25.34% for video samples. It is characterized by mostly infauna consisting of various bivalve and polychaete species including *Macoma calcarea, Nucula delphinodonta* and the *Maldanid* family, as well as two species of *Ophiuroidea*, *Ophiura sarsii* and *Stegophuria nodosa*. *Saduria entomon*, is the only species unique to the mud habitat, however abundance of the bivalve *Macoma calcarea* is significantly higher in pure mud environments than any other, and contributes nearly 40% of the within class similarity of mud as a class.

3.7.2 Sandy Mud

Figure 3.33 Images of the sandy mud habitat from the drop video camera, visible species include *Ophiura sarsii*

Sandy mud combines two substrate classes, sandy mud and muddy sand, and has comparable average similarity to mud, at 27% for grabs and 32% for video. Biotic assemblage was similar, with a higher number of epifauna, and of species in general. Although two of the top three contributors to similarity were the same (*Macoma calcarea, Ophiura sarsii*), the total contribution was more evenly distributed among a larger number of species including *Yoldia hyperborea, Suberites carnosus and Stegophuria nodosa*. In particular, *Suberites carnosus* was unique to this class, and contributes to 15% similarity of the video sampled biota. Other epifauna with a significant contribution not seen in the mud class include *Pachycerianthus borealis and Heliometra glacialis*, indicative of the higher sand concentration of this class.

3.7.3 Gravelly Sandy Mud

Figure 3.34 Images of the gravelly sandy mud habitat from the ROV, visible species include *Gersemia spp* (Examples circled).

This class combines gravelly mud and gravelly sand. Average similarity ranges from 22.19% (gravelly mud, grab samples) to 47.06% (gravelly sand, video samples). In terms of infauna, there was a large overlap with the soft sediments (*Macoma calcarea, Nuculana pernula, Astarte borealis),* however epifauna species such as *Agarum clathratum* and several species of soft coral (*Gersemia spp.*) reflect the gravel component of the class. Other species with a large contribution to similarity include *Haustorius canadensis, Pachycerianthus borealis* and *Strongylocentrotus droebachiensis*. The gravelly sand class contains the largest number of species overall.

3.7.4 Kelp Habitat

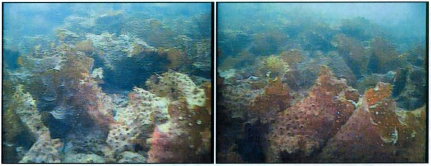

Figure 3.35 Images of the kelp habitat class from the drop video camera, visible species include *Agarum clathratum*

The low recovery of sediments in box cores in kelp habitat prevented the inclusion of the kelp class in the grab sample SIMPER results. However, average similarity was high for video results at 47%. Only three species, two flora and one fauna, contribute to within class similarity, as the nature of the substrate prevents the collection of all infauna, and obscures the surface for ready identification of the majority of epifauna. *Agarum clathratum* and *Strongylocentrotus droebachiensis* (green sea urchin), each contributes 43% of the similarity. *Coccotylus truncatus* contributes the remaining 14%. This was the only habitat in which the majority of within class similarity is provided by algal taxa.

3.7.5 Bedrock/ Boulder

Figure 3.36 Images of the bedrock/boulder habitat from the drop video camera, visible species include *Lithothamnion glaciale, Clathromorphum compactum, Hormathia nodosa* and *Strongylocentrotus droebachiensis*

Average similarity for bedrock/boulder was the highest for the video samples, at 75%, as this class is sampled only by video, and by less than 3 sites, this is rational. The class is defined by six species of epifauna, each contributing 12.67%, as there is no fine matrix for infauna. Several of the species are found exclusively within this habitat class, also contributing to between class dissimilarity, including *Hormathia nodosa*, and *Leptasterias polaris*.

3.8 Mapping

Substrate and biota were specifically sampled to allow using a supervised classification for producing substrate and habitat maps in Okak Bay. Data clustering visible in the 3D plot (Figure 3.37) of the depth, backscatter and slope values of the training samples indicate that habitat classes have well defined acoustic signatures. The largest overlap between the different habitat signatures appears to be between the hard substrate-based habitats, gravelly sandy mud, kelp and boulder and bedrock.

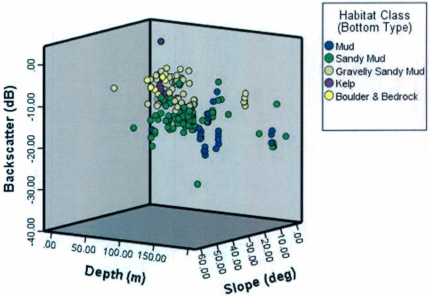

Figure 3.37 XYZ plot of backscatter, depth and slope values for training samples

3.8.1 Mapping of Substrates

3.8.1.1 Development of Acoustic Signatures

Visual analysis of the box and whisker plots generated for each variable suggest that there is a large amount of overlap between the depth slope and backscatter ranges of each substrate class. To reduce overlap between classes, and therefore classification ambiguity, initial signatures used the interquartile ranges of depth and backscatter. Initial examination of the slope ranges suggest that as the majority of Okak Bay has a slope value of <1°. Slope will hence not be very useful in the classification with the exception of the high slope class of bedrock/boulder. Table 3.13 in section 3.8.1.3 summarizes the classification iterations and accuracy.

As backscatter is indicative of substrate types, initial classification used the interquartile ranges of backscatter values. Although this resulted in large percentage of the fiard being classified (86%), ambiguity was high due to large overlap in the signatures with 35% of pixels being placed in two classes, and 29% in three. Depth was added to the second iteration in an attempt to better separate the classes.

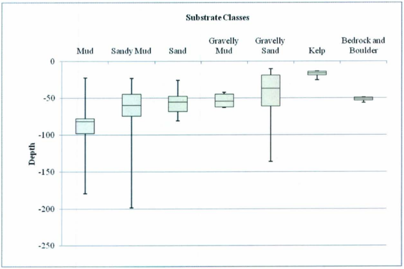

Figure 3.38 Box and whisker plot of depth ranges associated with substrate classes. Box represents interquartile range, whiskers full range of values

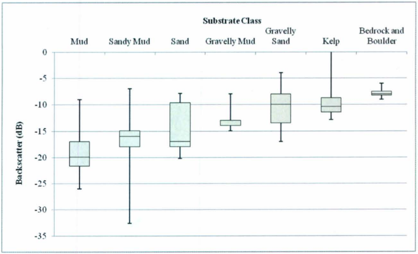

Figure 3.39 Box and whisker plot of backscatter ranges associated with substrate classes. Box represents interquartile range, whiskers full range of values

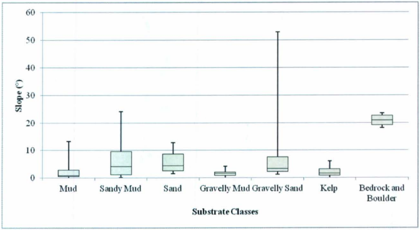

Figure 3.40 Box and whisker plot of slope ranges associated with substrate classes. Box represents interquartile range, whiskers full range of values

The use of the depth interquartile ranges resulted in lowered ambiguity, but higher levels of unclassified pixels. Restricting values to the inter-quartile ranges prevents the classification of the upper and lower values of each variable. The full depth ranges were used to eliminate this sampling bias. This resulted in lower values of unclassified pixels, but slightly higher ambiguity as the division between classes is less well defined. Final acoustic signatures were created by adjusting the signatures slightly where overlap was minimal, by splitting the overlap evenly between signatures. However the high levels of overlap between the sandy substrates and the gravelly substrates suggests that they are not acoustically distinct, and ambiguity may necessarily be high to result in an accurate classification. Table 3.11 contains the depth, backscatter and slope ranges used to define the classes for the final substrate maps.

The final substrate map was created by overlaying the classified substrate grids in order to best reflect the likely distribution of substrates based on ground truthing.

Table 3.11 Depth, backscatter and slope ranges for the creation of the substrate acoustic signatures

Substrate	**Depth (m)**	**Backscatter (dB)**	**Slope (°)**
Mud	<= -23	<= -17.60	Unlimited
Sandy Mud	<= -23	<= -15.00 >= -17.50	Unlimited
Muddy sand	<= -26	<= -10.00 >= -17.50	Unlimited
Gravelly Mud	<= -10	<= -13.00 >= -14.00	Unlimited
Gravelly Sand	<= -42	<= -8.00 >= -14.00	Unlimited
Kelp	<= -14 >= -25	<= -8.00 >= -12.00	Unlimited
Bedrock/boulder	Unlimited	>= -7.99	> 5

3.8.1.2 Substrate Maps

Final substrate map was generated by overlapping individual substrate class layers according to their likely distribution, as determined by previous ground-truthing activities (Figure 3.41). General patterns in distribution suggest that the substrate patterns differ between the previously described regions, and that unlike a typical fiord, the substrates are not repetitive from the head to the mouth. Total area statistics are found in Table 3.12.

Table 3.12 Summary of area statistics of substrate classifications

Substrate Class	**Mud**	**Sandy Mud**	**Muddy sand**	**Gravelly Mud**	**Gravelly Sand**	**Kelp**	**Bedrock/ boulder**	**Total**
Area (km^2)	62.38	63.69	125.78	10.23	62.41	8.96	11.03	344.48

The inner fiard area is composed mostly of muddy sand and sandy mud. Coarser substrates are found in small patches along the coastline, and a large deposit of mud is found at the entrance of one of the largest freshwater inputs. The fine head of the fiard extends up to the southern regions of the central fiard, where it transitions into coarser substrates – gravelly mud and gravelly sand. Small amounts of bedrock are found in areas of steep slope in the central fiard, but the majority of the class composes the sidewalls of the outer muddy basins. Kelp is confined to the region between Okak Islands and Kikkektak Island, and to small and shallow areas along the coast.

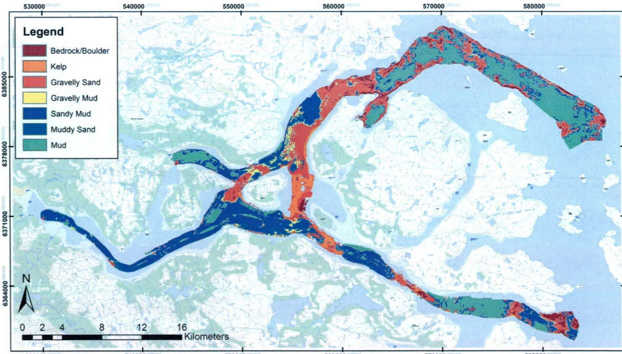

Figure 3.41 Substrate classification distribution in Okak Bay, Labrador

The westernmost part of the fiard, where North River enters the fiard is covered by a large portion of muddy sand and gravelly sand. This transitions into the finer sandy mud, however similar patterns of muddy sand with the gravel substrates are found in the shallow regions of the fiard head throughout. Mud is found along the low elevation northern coast, and a large area of mud is deposited by Ikinet Brook on the southern coast.

The central fiard contains a higher percentage of coarse substrates. Mud, sandy mud and muddy sand are found in the southern part of the central area, to the south and north of Martin's islands, and to a small extent in the region where Siugak Brook enters the fiard. The largest deposit of mud in the inner fiard is found in the basin to the north of Martin Island.

Gravelly mud and gravelly sand cover the central sill between Martin and Kikkektak Islands, and extend along the coastlines and into the northern fiard. Bedrock is predicted in small amounts on the central sill, and in some of the shallower, coastal regions of the area. The central fiard contains the largest region of kelp substrate, occupying the shallow areas between 15 and 25 m depth to the west of Okak Islands.

The northern entrance is composed of muddy basins, surrounded by small amounts of sandy mud and muddy sand. The sidewalls and shallow areas around the coast are composed of coarse substrates – trace amounts of gravelly mud, as well as gravelly sand and bedrock. The deep sills which divide the basins are gravelly sand and small amounts of gravelly mud.

The southern entrance contains the most heterogeneous mix of substrates. All seven are found within the narrow channel. Shallow basins of sandy mud (inner channel), and mud (outer channel), are separated by shallow sills of gravelly mud and gravelly sand. Bedrock is found on the high slope areas, with kelp predicted along the coastlines.

3.8.1.3 Accuracy Assessment

An accuracy assessment was performed to determine whether the substrate created corresponds to the ground-truthing data collected. Two techniques were used to assess the accuracy of the classification, the first of which is the ambiguity. Ideally, the acoustic classes should allow for the majority of pixels to be placed into one substrate class, while minimizing unclassified pixels and those placed in multiple substrate classes. Table 3.13 shows the classification iterations previously discussed in section 3.8.1, and how the addition of depth ranges helped to meet these goals.

Table 3.13 Ambiguity of substrate classifications

Iteration Description	Unclassified	Ambiguity		
		1	*2*	*3*
Backscatter Only	13.97%	21.88%	34.71%	29.44%
Backscatter and Depth, Interquartile Range	52.11%	31.41%	10.92%	5.56%
Backscatter and Full Depth Range	15.80%	59.60%	16.59%	8.01%
Adjusted Backscatter and Full Depth Range	4.14%	74.23%	21.63%	0.00%

In the final classification, 74.23% of pixels were allocated to a unique substrate class. 21.63% of pixels were placed in two substrate classes, and 4.14% were left unclassified. The geographic distribution of the ambiguity is illustrated in Figure 3.42.

The majority of the unclassified pixels are constricted to the shallow coastal regions, where sampling efforts were not possible. As previously mentioned there was a large overlap in backscatter and depth signatures in the sandy mud and muddy sand classes, and the gravelly mud and gravelly sand – therefore the majority of the pixels placed into two classes are located in the central fiard. As well, kelp is not acoustically distinct substrate, so areas in which kelp was found are placed into multiple classes.

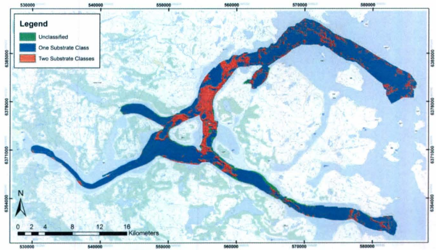

Figure 3.42 Ambiguity of substrate classes map, illustrating pixel classification

Although the majority of pixels are placed into one substrate class, it is still possible for these pixels to be incorrectly classified. Table 3.14 shows the number of the test samples and the number that were correctly classified.

71% of the 49 test samples were accurately classified, however some classes were better classified than others. The classes "mud" and "bedrock/boulder" were classified correctly 100% of the time. "Gravelly mud" was classified correctly 75% of the time, and "sandy mud", "muddy sand" and "gravelly sand" had accuracy percentages of between 60-70%. "Kelp" had the lowest classification accuracy at only 50% - suggesting that while kelp is an important and distinct substrate for habitat purposes, predictions of kelp distribution may not be accurate.

Table 3.14 Accuracy of test sample classifications

	Mud	Sandy Mud	Mud dy sand	Gravelly Mud	Gravelly Sand	Kelp	Bedrock/ boulder	Total
Total Samples	32	61	29	12	53	14	6	207
Number of Test Samples	7	16	8	4	14	4	2	55
Number Misclassified	0	5	3	1	4	2	0	15
Accuracy Percentage	100	69	63	75	64	50	100	71

3.8.2 Habitat Classes

A similar method was followed for the development of the habitat map. Habitat classes were predetermined via ANOSIM and SIMPER analysis, and box and whisker plots were generated to visualize the acoustic signatures within the multibeam data (Figures 3.43 through 3.45). Visual analysis of the plots for the habitat classifications suggests that division of inter-quartile ranges is better defined within the habitat classes, and a similar iteration as the one used in the substrate classification was used to create the final acoustic signatures. As with substrates, the overlap between the slope values was so high that they were excluded from the signatures. The only habitat class for which they are applicable is bedrock/boulder, as this class tends to occur at high slope values.

The initial acoustic signature (Table 3.15) is created with the use of only the backscatter ranges, resulting in high levels of unclassified pixels, and high levels of ambiguity. In order to reduce ambiguity, inter-quartile ranges of depth were added to the signatures, reducing ambiguity, and increasing unclassified pixels. The addition of depth eliminates all pixels placed into three classes. As with the substrate map, the use of the inter-quartile range causes the upper and lower depth ranges to be unclassified. With the exception of the kelp habitat class that is limited by depth to above 25 m (within the photic zone), sampling methodologies favour the shallower parts of the fiard.

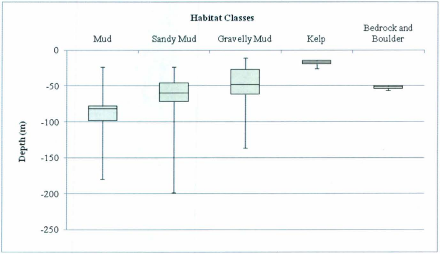

Figure 3.43 Box and whisker plot of depth ranges associated with habitat classes. Box represents interquartile range, whiskers full range of values

In order to decrease the number of unclassified pixels, the lower limit of the depth range was eliminated from the signatures, and the upper limit expanded to the full range.

While this greatly reduced unclassified pixels, it also increased classification ambiguity by increasing the number of pixels being placed into two habitat classes. In order to better define classes, the backscatter signatures were adjusted to split the majority of overlap where it was small, and the slope range was added to the bedrock/boulder habitat. To eliminate bias from the sampling methodology and increase the classified area, the lower limit of backscatter was removed from the mud class signature. Lower backscatter values are reflective of finer substrate, and mud is the finest substrate class in the fiard. Similarly, the upper backscatter limit of the bedrock class was eliminated. As well, as bedrock was only sampled by video, its ground-truthing was constrained by the ability to control the depth of the camera. Although the depth range of the bedrock sample station is narrow, it is safe to assume that the substrate exists outside of this area. For the final classification the depth range was removed from the bedrock class.

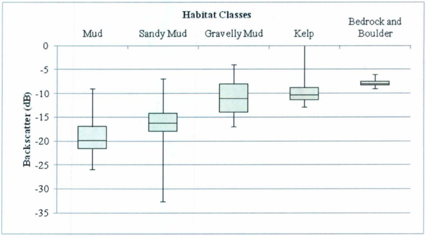

Figure 3.44 Box and whisker plot of backscatter ranges associated with habitat classes. Box represents interquartile range, whiskers full range of values

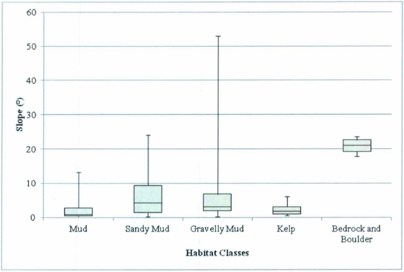

Figure 3.45 Box and whisker plot of slope ranges associated with habitat classes. Box represents interquartile range, whiskers full range of values

Although the kelp habitat is a distinct habitat in terms of biota, it is not acoustically distinct. Both its depth and backscatter ranges overlap with the gravelly sandy mud class. In order to include the class in habitat classifications, increased ambiguity is necessary. Table 3.15 contains the percentage of pixels which are unclassified and ambiguity values for the habitat classification iterations. Figure 3.53 demonstrates that the majority of unclassified pixels are found in the very shallow areas of the coastline – areas that were unable to be sampled via the box core or video. Areas of ambiguity are concentrated in kelp-covered regions – as expected due to the overlap in acoustic signatures. The depth, backscatter and slope values used in the final classification are found in Table 3.15.

Table 3.15 Final acoustic ranges for habitat class signatures

Habitat	Depth (m)	Backscatter (dB)	Slope (°)
Mud	<= -23	<= -17.60	Unlimited
Sandy Mud	<= -23	<= -14.01 >= -17.59	Unlimited
Gravelly Sandy Mud	<= -10	<= -8.00 >= -14.00	Unlimited
Kelp	<= -14 >= -25	<= -8.00 >= -12.00	Unlimited
Bedrock/boulder	Unlimited	>= -7.99	> 5

3.8.3 Habitat Map

As with the substrate maps, the habitat maps were created by overlapping the habitat layers in the order that they are most likely to be found (Figure 3.46) as determined by ground-truthing activities. In the case of the habitats, overlap was minimal with the exception of the kelp class.

The majority of the muddy bottom habitat is found in the outer basins – as well as in the inner basin to the north of Martin's Island, and to a lessor extent in the southern entrance. Other soft bottom habitats are mostly confined to the inner fiard. The seabed of the fiard head is exclusively sandy mud with only small patches of coarse bottom. Gravelly sandy mud habitat is extensively distributed throughout the central fiard. Kelp is, as with the substrate map, limited to the region between Okak Islands and Kikkektak Islands.

Habitat distribution within the previously determined bathymetric regions is discussed in more detail in the following sections.

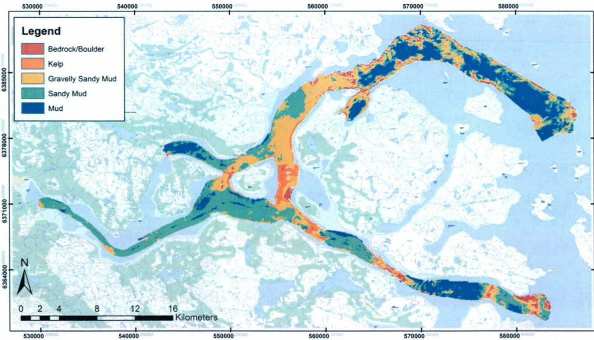

Figure 3.46 Predicted distribution of benthic habitats in Okak Bay, Labrador

3.8.3.1 Habitat Distribution of the Fiard Head

As previously stated, the seabed of the fiard head is composed of mostly of soft bottomed habitats – mud and sandy mud (Figure 3.47). It is the most homogenous of the regions in terms of habitat coverage, containing only three of the five habitats, and only one with extensive coverage - sandy mud. Mud is found in patches, particularly at the mouth of Ikinet Brook, and along the northern margins. The southern margins of the fiard head tend towards patches of coarser substrates, particularly across from Tikigatsiuk Point. Another large region of coarse substrate is found at the western most point of the fiard, where the North River empties into the fiard.

3.8.3.2 Habitat Distribution of the Central Fiard

The seabed of the central fiard is far more heterogeneous than the fiard head (Figure 3.48). The soft-bottom habitats extend into the south-western basins of the central fiard, and to the south of Kikkektak Island. There is also a significant region of muddy-bottom habitat in the shallow basin to the north of Martin Island – it is the largest region of mud substrates found within the inner fiard. The soft bottom habitats are broken up by the three coarser bottomed habitats. The sill between Martin and Kikkektak Islands is composed of the gravelly muddy sand habitat, with small amounts of bedrock in the high slope regions. This is the shallowest instance of gravelly sandy mud within the fiard, leading to a high incidence of the encrusting coralline algae, and soft corals *Gersemia spp*. (sample site 17), as seen on the third ROV transect. The hard bottom substrates extend through the north and south-eastern parts of the central fiard, broken by the large kelp beds in the shallow region between Kikkektak and Okak Islands.

3.8.3.3 Habitat Distribution of the Northern Entrance

The northern entrance of the fiard is characterized by muddy habitats within the basins, and coarse substrates on the margins, sidewalls and sills (Figure 3.49). This is the region in which the muddy habitat is most prevalent, as it is responsible for the majority of the basin floors. Several areas of less than $100m^2$ of sandy mud are found on the basin margins. The two hard bottom substrates, gravelly sandy mud and bedrock/boulder, make up the sidewalls and shallow areas of the region. This region contains the largest extent of exposed bedrock in the fiard.

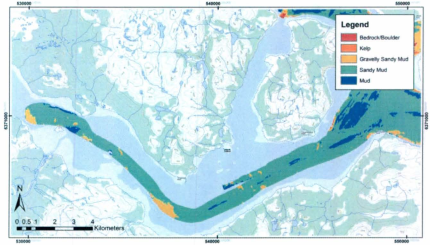

Figure 3.47 Habitat distribution of the fiard head

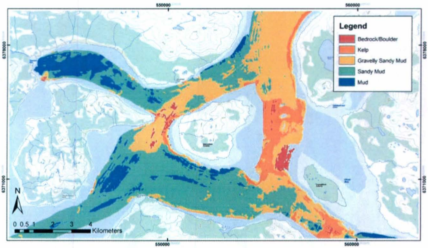

Figure 3.48 Benthic habitat distribution of the central fiard

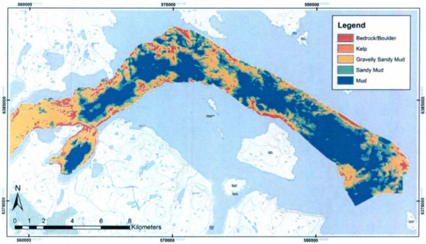

Figure 3.49 Benthic habitat distribution of the northern entrance of fiard

3.8.3.4 Habitat Distribution of Southern Entrance

The southern entrance also contains all five habitats, distributed between two shallow basins (inner and outer), and divided by several shallow hard-bottom sills (Figure 3.50). The inner soft-bottom basin is composed mainly of muddy sandy-bottom habitat with lessor amounts of mud found around the margins. The opposite is true of the outer basins – where the bottom is mainly muddy in nature with lessor amounts of sandy mud towards the sills. Sandy mud and mud are evenly distributed to the east of the outer sill. The inner sill is composed of a mix of the two hard-bottom habitats, gravelly sandy mud and bedrock/boulder. Kelp is predicted in the inner end of the channel, as well as to a certain extent on the inner sills, but not observed.

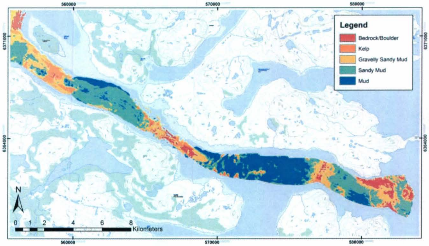

Figure 3.50 Habitat distribution of the southern entrance

3.8.3.5 Habitat Distribution of Okak Harbour

Okak harbour is a deep muddy basin, separated from the remainder of the fiard by a shallow sill composed of hard-bottom substrates (Figure 3.51). The basin is deep (~100m), and transitions from soft bottom habitats in the centre to hard bottom habitats around the margins. The muddy habitats here are among the lowest in terms of species richness – containing only a few polychaete species. The shallower, hard bottom regions occupy a large portion of the harbour. Bedrock/boulder habitats are found on the steep sides of the harbour and sill, in particular on the point close to the abandoned community. Small amounts of kelp are predicted along the harbour margins.

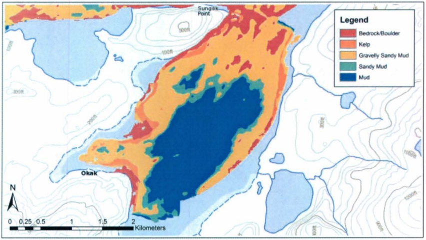

Figure 3.51 Habitat distribution of Okak Harbour

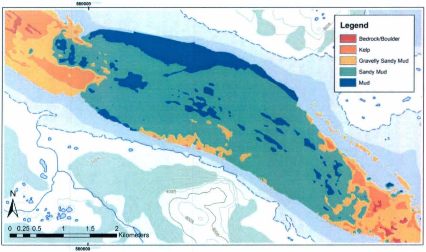

Figure 3.52 Habitat distribution of trench feature

3.8.3.6 Habitat Distribution of the Trench Feature

Habitat distribution within the trench feature is not markedly different than the surrounding shallow areas (Figure 3.52). The inner basin is composed of soft bottom habitats, sandy mud with lesser amounts of mud. There is no change in habitat with the increase in slope or depth. This corresponds with the ROV transect of the trench which showed that substrate and biota were consistent from the top to the bottom, and were composed of mainly brittle stars and sponges.

3.8.3.7 Accuracy Assessment

Two forms of accuracy assessment were performed, as with the substrate classification. The ambiguity table (Table 3.16) developed for the habitats shows that the number of pixels placed into a single habitat class is much higher than the substrate classes at 94%. Overlap between classes is much lower in the habitat classes, leading to low levels of pixels with multiple classifications (3.77%), and lower levels of unclassified pixels (2.08%).

Table 3.16 Acoustic signature creation iterations, habitat classification

Iteration Description	Unclassified	Ambiguity		
		1	*2*	*3*
Backscatter Only	31.41%	34.60%	20.68%	13.31%
Backscatter and Depth, Interquartile Range	48.64%	39.59%	11.77%	0.00%
Backscatter and Full Depth Range	7.63%	51.27%	41.09%	0.00%
Adjusted Backscatter, Depth	2.08%	94.15%	3.77%	0.00%

The geographic distribution of ambiguity is shown in Figure 3.53. Pixels placed in two substrate classes are confined to the areas in which kelp is predicted, as this is the only place where there is overlap in the backscatter signatures. Unclassified cells are found in the shallow regions around the coast, particularly in the southern entrance channel where the largest area of unclassified cells is found. These regions have low backscatter (<17 dB), and shallow depths. The shallow depths of these regions limit sampling activities, so although mud is suspected, these areas were left unclassified.

Although the acoustic classes are well defined, the same approach using test samples was used to determine the accuracy of the habitat classes. Table 3.17 shows the results of the accuracy assessment.

Overall classification of the test samples was higher than for substrate samples, at 82% - again mud and bedrock/boulder were classified accurately 100% of the time.

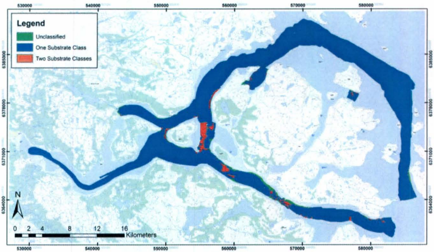

Figure 3.53 Distribution of ambiguity of habitat classification

Classification values for sandy mud and gravelly sandy mud are higher than for the corresponding substrate classes at 71% and 95% respectively. Kelp, again, has the lowest classification accuracy value at 50% - suggesting that predicted distributions may not be accurate.

Table 3.17 Accuracy classification of test samples

	Mud	**Sandy Mud**	**Gravelly Sandy Mud**	**Kelp**	**Bedrock/boulder**	**Total**
Total Samples	32	90	65	14	6	207
Number of Test Samples	8	24	17	4	2	55
Number misclassified	0	7	1	2	2	10
Accuracy Percentage	100%	71%	95%	50%	100%	82%

3.9 Sensitivity

The inclusion of sensitivity data into the habitat maps can help to paint a better picture of the distribution of vulnerable species and regions. The list of potential stressors in the Okak Area was previously developed from published lists of marine environmental stressors. The list includes several categories – including natural, biological, climate-change related and anthropogenic. The first step to determining sensitivity of each habitat to each stressor is to create a sensitivity matrix as seen in Zacharias (2005) and Hall *et al.* (2008).

Of the 105 possible combinations of stressors and habitats, 26 or approximately 25% were assessed as high sensitivity, 38 were medium sensitivity, and the remaining 41 were low sensitivity using a combination of literature and the sensitivity biotopes previously developed by the Marine Life Information Network (Hiscock and Tyler-Walters 2006). Kelp and gravelly sandy mud were assessed as the highest sensitivity – their complex surface substrate and variety of microhabitats are particularly sensitive to physical disturbances, both natural and anthropogenic due to the high numbers of sensitive characteristic biota, and encrusting epifauna.

Table 3.18 Sensitivity matrix of potential stressors vs. Okak Bay habitats. Bold numbers indicate cumulative sensitivity scores for each stressor category as determined by the average scores as function of the highest possible score.

	Mud	Sandy Mud	Gravelly Sandy Mud	Kelp	Bedrock and Boulder
Substratum Loss	3	3	3	3	1
Increased sedimentation	1	3	3	3	2
Changes in exposure	1	2	1	3	1
Displacement (Scour)	1	1	2	3	3
Changes in turbidity	1	2	2	3	2
Physical Factors	**0.47**	**0.73**	**0.73**	**1.00**	**0.60**
Temperature increase	1	1	2	2	1
Salinity Changes	1	1	2	2	1
Changes in oxygenation	1	1	2	2	1
Changes in nutrient levels	1	1	1	2	1
Introduction of non-native species	1	1	1	2	1
Climate Change	**0.33**	**0.30**	**0.50**	**0.67**	**0.30**
Dredging	2	2	3	3	1
Trawling	2	2	3	3	1
Scallop Dragging	2	2	3	3	1
Gill Nets	1	1	2	1	2
Bottom Contact Long Lines	1	1	2	1	2
Bottom Traps	1	1	2	1	2
Sampling Activities	2	2	2	2	2
Anchor Damage	2	2	2	2	1
Oil Spills	3	3	3	3	1
Introduction of accumulated metals	3	3	3	3	1
Fuel Spills	3	3	3	3	1
Anthropogenic Stressors	**0.76**	**0.80**	**0.88**	**0.69**	**0.48**
Cumulative Sensitivity	***1.56***	***1.83***	***2.11***	***2.36***	***1.38***
REFERENCES	Marlin (2011), Hall et al. (2008)			Hall *et al.* (2008), Gagnon *et al.* (2005),	Hall *et al.* (2008)

3.10 Mapping of Distribution of Sensitivity

Maps were created in ArcMap 10® to better illustrate the distribution of sensitivity within the fiard. Separate maps were created for each category of stressor and for the cumulative sensitivity of all stressors, illustrating that all habitats had different levels of sensitivity to different categories of stressors. For example – although kelp is assessed as having highest sensitivity to both physical and climate change stressors, gravelly sandy mud had the highest sensitivity to anthropogenic stressors.

3.10.1 Sensitivity to Physical Stressors

The most sensitive habitat to physical stressors was the kelp habitat due to a narrow preference for specified exposure and depth , followed by the gravelly sandy mud and sandy mud habitat. They are mostly found within the inner fiard, in particular the area surrounding the inner islands (Figure 4.37). The kelp habitat is restricted to this area, and the largest (and shallowest) sill is located between the two islands. Sensitive habitats extend into the head of the fiard. The outer fiard, which is primarily composed of mud and bedrock/boulder sidewalls, contained the lowest sensitivity values.

3.10.2 Sensitivity to Climate Change Based Stressors

The most sensitive habitat to climate change related stressors was again kelp, as the biota in this region is dominated by echinoderms, species which do not tolerate changes in salinity and temperature well – followed by gravelly sandy mud, however in this instance while kelp is considered to have relatively high sensitivity, the remainder of the habitats have low sensitivity. With the exception of the area in which kelp is restricted within the inner fiard, the rest of the region, including the fiard head and outer fiard is of low sensitivity (Figure 4.38).

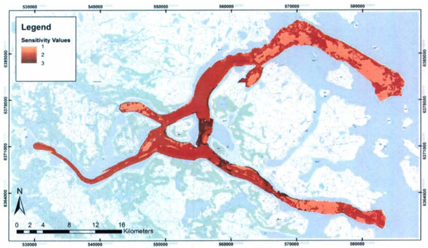

Figure 3.54 Distribution of the sensitivity of benthic habitats to physical stressors

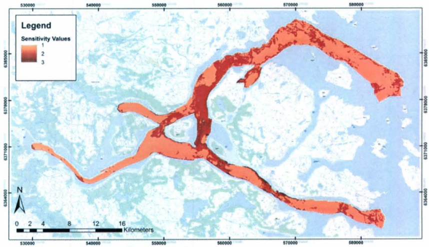

Figure 3.55 Distribution of the sensitivity of benthic habitats to climate change stressors

3.10.3 Sensitivity to Anthropogenic Stressors

With the exception of bedrock/boulder, all of the habitats were considered to be of medium to high sensitivity – they would be both heavily impacted by the initial stressor and would take an extended period of time to recover to pre-impacted levels if complete recovery occurs at all. Gravelly sandy mud had the highest sensitivity, followed closely by mud and sandy mud. Sensitivity was evenly distributed throughout the fiard, as gravelly sandy mud and sandy mud in particular cover the majority of the fiard sea bed.

3.10.4 Cumulative Sensitivity of Fiard Habitats

Overall sensitivity of the fiard habitats was determined by adding the sensitivity values determined for the previous three categories to find a final value on a scale from 1 to 3. The final values can be seen in table 3.18. Kelp had the highest overall sensitivity followed by gravelly sandy mud, sandy mud, mud and finally bedrock/boulder. The highest sensitivity values were concentrated around the inner fiard islands, particularly Kikkektak Island. High values were also found along coastal margins, particularly within the southern entrance. Lower sensitivity values are found in the outer fiard, where habitats are characterized by deep mud basins and bedrock/boulder sidewalls.

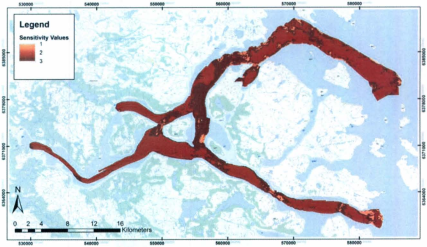

Figure 3.56 Distribution of the sensitivity of benthic habitats to anthropogenic stressors

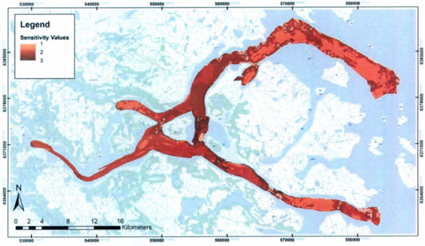

Figure 3.57 Distribution of cumulative sensitivity values

4.0 Discussion

4.1 Results Summary

The primary objective of this thesis was to determine the nature and distribution of the substrates and benthic habitats of Okak Bay. Secondary objectives were: 1) to determine whether the predicted distribution of habitats within Okak Bay may be typical of other fiard-like inlets along the Central Labrador coast, 2) to compare the predicted habitat distribution to the previously mapped fiords in Labrador, 3) to determine the sensitivity of the predicted habitats within Okak Bay, and 4) to identify areas that may be important for conservation or monitoring efforts. These objectives were set to address a lack of baseline information on benthic habitats in Okak Bay, an area that may in the future experience increased pressures from resource exploitation activities.

The fiard was successfully mapped via multibeam classification techniques, showing that there are seven substrate classes – mud, sandy mud, muddy sand, gravelly mud, gravelly sand, kelp, and bedrock/boulder, and five habitats – mud, sandy mud, gravelly sandy mud, bedrock/boulder, and kelp. Ambiguity and accuracy assessment measures show that test locations were classified correctly 71% and 82% of the time for substrate and habitat distributions, respectively. Sensitivity values were assigned to each habitat for a set of predetermined stressors, and showed that kelp and gravelly sandy mud were the most sensitive habitats to potential physical, climate change related, and anthropogenic stressors. The habitat distribution described within Okak Bay shows that fiard habitats are distinctly different from those found in a classic fiord environment with sills present, and that the habitat and sensitivity data collected have potential to be applicable to the central Labrador coast as a whole.

4.2 Habitat Distribution in Okak Bay

Okak Bay is characterised by a shallow, low-slope bathymetry that gradually deepens towards the outer fiard into a series of deep basins divided by deep sills (> 100 m water depth). The habitat distribution consists of broad homogenous regions and non-repetitive habitats. Habitats are more heterogeneous towards the coastal margins and in shallow areas. A conceptual model (Figure 4.1) constructed along a simplified transect of the fiard, like that developed by Post *et al.* (2006), illustrates the relationship between depth, substrate and habitats as well as major geomorphic features.

Perillo (1995) suggested five types of dominant-sediment producing processes for glacial estuaries, two of which are common in sub-arctic fiords (Howe *et al.* 2010). Okak Bay lacks the characteristic sills of a fiord landscape (with the exception of Kikkektak sill [Figure 3.5]) and possesses a large watershed. These characteristics likely classify the bay into the river-influenced sediment deposition model. In these models, the majority of sediment input is supplied by river discharge. In the case of Okak Bay, the freshwater input is the three large rivers located at the head and in the north-central part of the fiard. The outer fiard is influenced by sediment deposition from both wave and tidal reworking processes and fluvial input from up the bay.

The type of sediment input is dominated by the terrestrial nature of the watershed (Howe *et al.* 2010). Okak Bay has a large, forested watershed in which surficial sediment is mainly composed of sand and gravel, including the largest deposit of sand within the

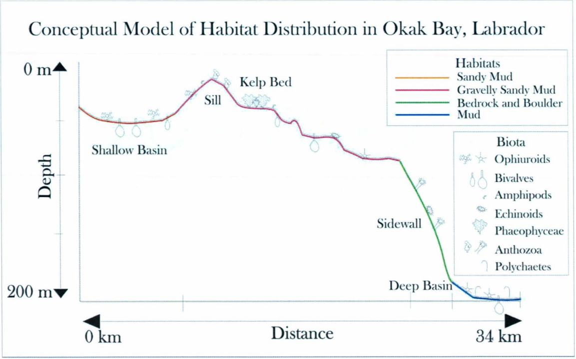

Figure 4.1 Conceptual model of habitat distributions within Okak Bay, illustrating the link between depth, substrate and major geomorphic feature

Nain-Nutak region, located at Siorak Brook (Ermanovics and Van Kranendonk 1998). Sedimentary inputs into the fiard consist of mostly sand and mud. The sand is rapidly deposited upon entering the fiard, while the finer-grained mud is carried farther into the fiard and deposited in low-exposure basins (Perillo 1995; Syvitski *et al.* 1987). The central fiard is dominated by gravelly habitats, suggesting that rapid tidal currents keep mud in suspension, preventing deposition, while failing to mobilize the coarser grained sediments (Noll *et al.* 2009). The presence of gravelly substrates and habitats around the margins of the fiard and at the head and bottom of the bedrock/boulder sidewalls suggest reworking of the substrates by wave and tidal processes (Perillo 1995). Barne *et al.* (1997) described a similar distribution of substrates within fiards of western Scotland where there are rocky, wave-swept outer shores and sediment-filled heads. Many of these fiards also drain large watersheds and have significant tidal flats composed of sand and sandy mud.

The connection between substrate type and benthic invertebrates is well established (Hargrave *et al.* 2004; Kostylev *et al.* 2001; Pickrill and Todd 2003), and the habitat distribution in Okak Bay is likely in most part influenced by substrate. CTD data collected by the CCGS Amundsen in 2009 and 2010 (T. Brown pers. comm. 2011) show that the estuary waters are well mixed, not surprising in the absence of a sill to promote formation of salinity and temperature gradients that are common in fiord environments.

The five habitats can be divided into two basic categories, soft bottom and hard bottom. The soft bottom habitats – mud and sandy mud classes – occur in distinctly different areas of the fiard. Sandy mud is found in higher-energy environments at the head of the fiard and at other river mouths within the central region. The narrow nature of the channel at the fiard head likely causes a rapid tidal current, promoting the occurrence of motile epifauna and suspension feeding infauna.

The habitat class mud was restricted to low exposure basins. An example of one is the basin to the north of Martin Island. A small freshwater point source and narrowing of the coastal margins to the east of the basin provide a source of sediment and shorten fetch, limiting the amount of exposure to wave action. A similar small basin is found in the southern entrance between the two outer sills. The extremely shallow sills restrict circulation and prevent mud from being re-suspended after deposition (Noll *et al.* 2009; Syvitski *et al.* 1987). As with sandy mud, deposit-feeding bivalves and polychaetes dominate, and there is a large overlap between characteristic species. Deposit feeding species are slightly more dominant here (such as Fm. Maldanidae), as are species that are known for being both suspension and deposit feeders (*Macoma calcarea, Nucula delphinodonta*) (McLusky and Elliot 2004). Soft-bottom habitats typically are smoothed with few microhabitats – although the abundance of particular species may be high at a given sample site (e.g. *Pachycerianthus borealis, Macoma calcarea*), the diversity of species is low.

The hard substrates – gravelly sandy mud, bedrock/boulder and kelp – are found within the central fiard and along the margins of the fiard and basins. Overlap between the species of the soft substrate habitats and the gravelly sandy mud class occurs; however, the addition of gravel and an increased incidence of cobbles increase rugosity (roughness of surface). This creates a variety of microhabitats and supports the greatest number of species within the fiard, a connection that has been previously established (Dunn and Halpin 2009; Henry *et al.* 2010). High richness values for the harder substrates are common. The centre sill is both the shallowest point of gravelly sandy mud, and is located in a high-energy area. Strong currents are generated in this area, likely by the restriction of tidal flow between the central islands. This provides an excellent habitat for several species of epifauna common to this habitat class, such as the soft coral *Gersemia spp.* and the anemone *Urticina felina*. Both of these species thrive in areas of shallow water depth (such as the sills that make up a portion of this habitat class) with strong currents, as they depend on these currents to deliver food (Reise 2001; Thurston and Barrett, 2011).

Light levels commonly restrict kelp forests in the western North Atlantic, constraining them to shallow depths (Steneck *et al.* 2002). Additionally, herbivory by sea urchins (*Strongylocentrotus droebachiensis*) can reduce the depth range that may otherwise be occupied by kelp forests (Gagnon *et al.* 2005; Steneck *et al.* 2002). The kelp class of substrate and habitat is composed of the species *Agarum clathratum*, a thick stalked prostrate canopy that is resistant to sea urchin grazing (Gagnon *et al.* 2005). The presence of *Agarum clathratum* and *Strongylocentrotus droebachiensis* explain the low taxonomic diversity of flora classes within Okak Bay. *Agarum* is at a competitive disadvantage with the other common kelp species found along the Labrador coast, such as the genus *Laminaria* and *Saccharina.* The high numbers of sea urchins within Okak Bay may prevent the establishment of those species that are more susceptible to herbivory, allowing for the expansion of the *Agarum* kelp forests (Gagnon *et al.* 2005, Steneck *et al.* 2002).

Previous studies of boreal kelp forest biodiversity suggest kelp beds should be a source of high levels of species richness (Graham *et al.* 2007; Steneck *et al.* 2002; Wlodarska-Kowalczuk *et al.* 2009). Kelp beds offer high levels of rugosity and the canopy provides protection from both large predators and wave exposure (Steneck *et al.* 2002). The low observed biodiversity can likely be explained by sampling bias – the kelp canopy was too thick to be sampled with a box core, and also prevented viewing of the seabed below. Previous studies that sampled kelp bed biodiversity (Gagnon *et al.* 2005; Graham *et al.* 2007; Wlodarska-Kowalczuk *et al.* 2009) used scuba divers to collect samples, allowing for the collection of both the kelp canopy and the associated understory biota.

Bedrock/boulder was the only substrate class classified by slope, and was only sampled in the outer entrance of the fiard. It comprises the sides of the basins, and while small pockets of fine matrix are found in indentations in the rocks, there is limited opportunity for infauna to settle. Key species – *Strongylocentrotus droebachiensis*, and the two anemones *Hormathia nodosa* and *Urcitina felina* – compose the majority of the biota. The abundance of the sea urchin species *Strongylocentrotus droebachiensis* once again restricts the growth of kelp species as would commonly be found in similar environments in fiords (Gagnon *et al.* 2005) and fiards (Barne *et al.* 1997; MERC 2008), although the herbivory resistant coralline algae species *Lithothamnion spp,* and *Clathromorphum spp.* are prevalent.

4.3 Comparison of Fiard and Fiord Habitats

Benthic habitat mapping of coastal regions has been completed in multiple areas along the Labrador coast, including Nachvak Fiord, Saglek Bay and Gilbert Bay (Copeland *et al.* 2008; Copeland *et al.* 2011a; Copeland *et al.* 2011b), and around Newfoundland, including Newman Sound (Copeland *et al.* 2007). Benthic habitat distributions have also been described in several areas of the Arctic (Aitken and Fournier 1993; Dale *et al.* 1989; Syvitski & Schafer, 1985; Syvitski *et al.* 1989). The majority of these regions can be classified as classic fiord landscape – glacially formed, with steep topography and basin-sill bathymetry (Syvitski *et al.* 1987). The distribution of benthic habitats is influenced by a variety of physical and oceanographic variables, including substrate, depth, slope, salinity and temperature, among others (Dethier & Schoch 2005; Levinton 1995). Differing characteristics of these embayments can greatly influence the habitats within, and the rapid changes in these variables within the coastal environment can lead to highly heterogeneous or patchy habitat distribution (Munguia *et al.* 2011).

Oceanographic and physical characteristics are similarly variable in a fiard such as Okak Bay; however, the ice-smoothed topography, irregular shape and bathymetry and poorly developed gradients in oceanographic variables cause a distinctly different habitat distribution (Inman and Jenkins 2005) from those commonly found in a fiord. Understanding how the differences in the physical environment may impact the distribution of habitats can help to predict how changing environmental variables along the latitudinal gradient can impact benthic habitats.

4.3.1 Comparison with Arctic Fiords

Examining previously mapped fiords in Labrador (Nachvak fiord, Saglek Bay) and the Eastern Arctic (Baffin Island) suggests that habitats may be similar (Aitken and Fournier 1993; Copeland *et al.* 2008; Dale *et al.* 1989). There is a large overlap between characteristic species (deposit feeding bivalves, ophiuroids, encrusting epifauna); however, the distribution of habitats is broadly different (Copeland *et al.* 2008).

Biota are also comparable, as seen in Table 4.1. Dominant biota are typically deposit feeding, and include taxa from the classes Bivalvia, Polychaeta and Ophiuroidea. Common species that are found within the Baffin Island fiords, Labrador fiords and Okak Bay include the bivalves *Macoma calcarea, Yoldia hyperborea, Hiatella arctica, Astarte borealis, Nuculana pernula*, the polychaete family *Maldanidae*, and certain anthozoan species including *Gersemia spp.* and the cerianthid anemones, among others (Aitken and Fournier1993; Dale *et al.*1989; Copeland *et al.* 2008). The bivalve *Portlandia arctica,* a common species in all of the fiords, was not found in Okak Bay.

The overlap in species suggests that the differences in habitats between fiord and fiard environments are mainly in terms of the habitat distribution. Within the fiord environment, habitats may be repetitive from the head to the mouth in terms of those found on shallow sills and in deep basins, with gradients in species richness and biomass created by changes in salinity and temperature (Perez-Ruzafa *et al.* 2010; Syvitsky *et al.* 1987). Sedimentary deposition creates soft substrate habitats within the basins separated by shallow, hard substrate habitats on the sills. High energy, sandy bottom habitats are commonly found at the head of the fiord, and at any freshwater point source. Bedrock

Table 4.1 Comparison chart of benthic biota in boreal fiards and arctic fiords

Gilbert Bay	*Okak Bay*	*Labrador Fiords*	*Arctic Fiords*
South	⟶		*North*
Admete viridula	*Admete viridula*		
Astarte borealis	*Astarte borealis*	*Astarte borealis*	*Astarte borealis*
Balanus balanus	*Balanus balanus*	*Balanus balanus*	*Balanus balanus*
Buccinum undatum	*Buccinum undatum*	*Buccinum sp.*	
	Bucinnum finmarkianum	*Buccinum finmarkianum*	
	Bucinnum hydrophanum	*Buccinum hydrophanum*	
	Cerianthus borealis	*Cerianthus borealis*	
Chlamys islandica	*Chlamys islandica*		
Clinocardium ciliatum	*Clinocardium ciliatum*	*Clinocardium ciliatum*	*Clinocardium ciliatum*
	Crossaster papposus	*Crossaster papposus*	
Ctenodiscus crispatus	*Ctenodiscus crispatus*		
	Cucumaria frondosa	*Cucumaria frondosa*	
	Cucumaria frondosa		*Cucumaria frondosa*
	Cyclocardia borealis	*Cyclocardia borealis*	
	Cylichna cylindracea	*Cylichna cylindracea*	
Escharella immersa	*Escarella sp.*		
	Fm. Capitellidae		*Capitella capitata*
	Fm. Nephtyidae	*Nephtys sp.*	*Nephtys ciliata*
	Fm. Oenonidae		*Oenopota cf. reticulata*
	Fm. Phyllodocida		*Phyllodoce groenlandica*
	Fm. Terrebelidae		*Amphitrite sp.*
Gammarid amphipod	*Gammarus scud*		
	Gersemia sp.		*Gersemia rubiformis*
	Heliometra glacialis		*Heliometra glacialis*
	Hemithiris psittacea	*Hernithyris psittacea*	*Hemithiris psittacea*
Hiatella arctica	*Hiatella arctica*	*Hiatella arctica*	*Hiatella arctica*
	Hormathia nodosa	*Hormathia nodosa*	
	Lumbrineris fragilis	*Lumbrineris fragilis*	*Lumbrineris fragilis*
	Lunatia heros	*Lunatia heros*	

Gilbert Bay	Okak Bay	Labrador Fiords	Arctic Fiords
	Lyonsia arenosa	*Lyonsia arenosa*	*Lyonsia arenosa*
Macoma calcarea	*Macoma calcarea*	*Macoma calcarea*	*Macoma calcarea*
	Macoma moesta	*Macoma moesta*	
bamboo worm	*Maldane sarsi*	*Maldane sarsi*	
	Musculus discors	*Musculus discors*	*Musculus discors*
	Musculus niger	*Musculus niger*	
	Mya Truncata	*Mya Truncata*	*Mya Truncata*
	Nuculana pernula	*Nuculana pernula*	*Nuculana pernula*
	Oenopota sp.		*Oenopota turricula*
	Ophiopholis aculeata	*Ophiopholis aculeata*	*Ophiopholis aculeata*
	Ophiura sarsi		*Ophiura sarsi*
Pectinaria granulata	*Pectinaria granulata*	*Pectinaria granulata*	*Pectinaria granulata*
Pherusa plumosa	*Pherusa plumosa*	*Pherusa plumosa*	
Priapulus caudatus	*Priapulus caudatus*	*Priapulus caudatus*	*Priapulus caudatus*
	Psolus fabricii	*Psolus fabricii*	*Psolus fabricii*
	Saduria entomon	*Saduria entomon*	
	Scalibregma inflatum		*Scalibregma inflatum*
	Serripes groenlandicus	*Serripes groenlandicus*	*Serripes groenlandicus*
	Stegophiura nodosa	*Stegophiura nodosa*	*Stegophiura nodosa*
	Strongylocentrotus droebachiensis	*Strongylocentrotus droebachiensis*	*Strongylocentrotus droebachiensis*
	Tachyrhynchus erosus	*Tachyrhynchus erosus*	
	Thyasira gouldi		*Thyasira gouldi*
Tonicella marmorea	*Tonicella marmorea*	*Tonicella marmorea*	*Tonicella marmorea*
	Trichotropis borealis		*Trichotropis borealis*
	Urticina felina		*Urticina felina*
	Yoldia hyperborea	*Yoldia hyperborea*	*Yoldia hyperborea*
		Portlandia arctica	*Portlandia arctica*

habitats characterized by encrusting epifauna are found on the sidewalls of the fiord and on steep slopes.

Within Okak Bay, habitats are non-repetitve. Sandy mud substrates and habitats are found at the head and near small freshwater inputs, gravelly habitats are found in the central fiard and on sills, and mud is found in the outer fiard. The irregular bathymetry of the fiard contributes to a greater variety of depth-substrate combinations. Depth and percentage of sand appear to differentiate these habitats, and they are homogenous with respect to their biota throughout the fiard – sandy mud at the head of the fiard contains the same biota as sandy mud in the central fiard. Gradients within the habitats caused by stratification of salinity and temperature, such as those commonly found in a fiord, are not exhibited in Okak Bay. CTD data (Brown 2011) collected over a period of 2 years suggests that multiple large freshwater inputs and open sea circulation allow tidal and wave mixing and prevent the formation of oceanographic gradients.

4.3.2 Comparison with Boreal Fiards

Gilbert Bay is an embayment in southern Labrador. Although recent literature has labeled it a "sub-arctic fiord" (Copeland *et al.* 2011a; Copeland *et al.* 2011b), it may better fit the fiard definition associated with Okak Bay. It is shallow with irregular bathymetry, low topography and a non-linear shape with several small islands. The exception is in the size of the watershed. While Okak Bay and fiards by definition have a large watershed and ample sediment supply, Gilbert Bay has a small watershed and is typically a sediment-starved environment. Additionally, the southern geographic location of Gilbert Bay contributes to significantly warmer water temperatures (Copeland *et al.* 2011a).

Depth distribution is similar to Okak Bay, with a shallow, narrow head that deepens gradually towards the mouth of the fiard. The majority of the bay is shallow

(> 30 m) and the deepest point is 163 m, less than the maximum water depth of 200 m in Okak Bay. Steep slopes are limited, the average slope is 10°.

Species overlap between Okak Bay and Gilbert Bay was less pronounced than those in Okak Bay and the northern fiords (Table 4.1). Although a few species such as *Strongylocentrotus droebachiensis, Hiatella arctica, Balanus balanus, Pectinaria granulata* and species of the Ophuiridae class were found in both regions, characteristic species in Gilbert bay included *Nucula tenuis*, several members of the genus *Spirorbis,* and the bivalve *Heteranomia squamula*.

Five habitats were identified in benthic habitat studies completed in 2008 (Copeland *et al.* 2011); however, only three had distinct acoustic signatures and were therefore mappeable. These five habitats were gravel bottom habitat, soft-bottom habitat, coralline algae habitat, current-swept gravel habitat and nearshore gravel habitat. The final map only included coralline-algae encrusted gravel, muddy or sandy gravel habitat and soft bottom habitat. Soft bottom habitats are found in shallow basins, while the hard-bottom habitats are found on margins and sills. Coralline-algae-encrusted gravel in particular is found only in shallow areas, particular in the southern arm of the fiard.

The key differences between Okak Bay and Gilbert Bay appear to be associated with latitude – while the physical characteristics, and habitat distribution suggest Okak Bay is more similar to the southern coast of Labrador, the biota are more similar to the northern fiords.

4.4 Is Okak Bay a Representative Fiard?

The characteristics of Okak Bay that define it as a fiard rather than a fiord are typical of many coastal inlets along the central Labrador coast. These include low topography, irregular and shallow bathymetry, large sources of freshwater input and a large watershed and the presence of many islands. According to topographic maps and nautical charts of the area, there are several regions that may be similarly classified as fiard landscapes – and therefore may have similar habitats and distributions.

Irregularly shaped inlets characterize the central Labrador coast as a whole with large numbers of islands along the outer coastline. Several resemble Okak Bay in form, with a narrow head that widens rapidly to include the channels created by islands. An example of this is Anaktalak Bay. The head of the bay is narrow (<1 km) and short (~6 km in length), wherein it widens to over 9 km and is divided by a series of small islands. (Satosoak Island, Palunitak Island). Multiple large freshwater inputs (e.g. Anaktalik Brook) and shallow irregular bathymetry promote mixing, preventing the formation of salinity and temperature gradients (an oceanographic characteristic similar to that found in Okak Bay). Topographic relief is low and the intertidal zone is wide.

Four other inlets within central Labrador that fit the description of a fiard are Nain Bay, Voisey's Bay, Merrifield Bay and Deep Inlet (Figure 4.4). In addition to Anaktalak Bay, Nain Bay and Voisey's Bay are of particular interest due to the extensive use for anthropogenic purposes (Davies 2007, Reschny 2007). Gilbert *et al.* (1984) describe the Labrador coast in the vicinity of Nain as a "classical skerry coast," dominated by raised marine features, with low topography and extensive intertidal zones. Additionally, well-developed boulder barricades similar to those found in the inner fiard of Okak Bay are common. Similar physical and oceanographic characteristics of these regions to Okak Bay suggest that the classification rules developed for multibeam classification may be equally applicable to the broader region. Further collection of multibeam data accompanied by substrate and biotic samples is necessary to determine whether this is correct.

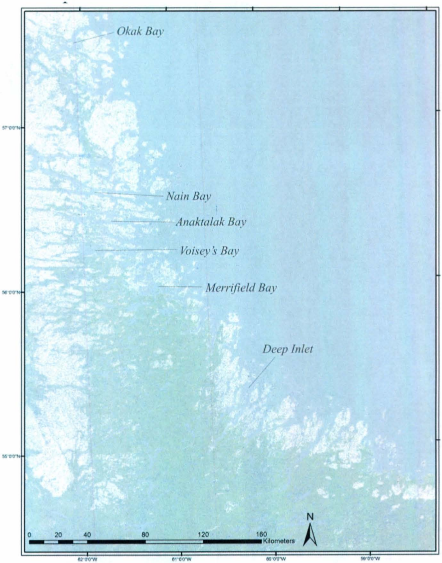

Figure 4.2 Coastal embayments along the Labrador coast which are representative of a fiard environment

4.5 Sensitivity and Potential for Conservation Efforts

In order to conserve marine biodiversity, it is necessary to identify and protect representative habitats and species and those important for the function of ecosystems (Day and Roff 2000; Roff and Taylor 2000; Salm *et al.* 2000). In order to better understand the impacts of both natural and anthropogenic stressors on the marine environment, baseline information is necessary (Lerodiaconou *et al.* 2007). Benthic habitat mapping activities allow for the collection of baseline information on the state of benthic habitats (Brown and Blondel 2009). With the addition of sensitivity surfaces for a range of stressors, specific areas within a region can be identified for protection and monitoring efforts (Zacharias and Gregr 2005). A preliminary sensitivity matrix (section 3.14) suggests that gravelly sandy mud and kelp are the areas of highest sensitivity due to their rugose substrates. The bedrock/boulder class has the lowest level of sensitivity as the majority of stressors are unlikely to impact the area, and only a portion of the biota was found to be sensitive. Mud and sandy mud are sensitive to many of the anthropogenic stressors, but less sensitive to the physical ones. The following sections further explore the sensitivity of each habitat class.

4.5.1 Mud

As muddy habitats tend to be located in low-energy and low deposition habitats in Okak Bay, they support infaunal biota as well as a wide range of epifauna. These habitats are most susceptible to impacts involving physical damage or stressors, and tend to be tolerant of oceanographic changes (Tyler-Walters *et al.* 2001). In terms of the physical factors, the removal of the substrate via dragging type fishing activities, or ice scour will also likely remove the majority of the infauna, causing severe damage and reducing habitat for recolonization (Tyler-Walters *et al.* 2001). Displacement type stressors may have similar effect; however, burrowing bivalves such as those from the genus Macoma are typically able to rebury themselves within 15-18 minutes (McGreer 1982). The potential for recovery is high; however, they will experience increased rates of predation during this time. The same infauna are commonly deposit-feeding type biota and as such will adjust to increased sedimentation and changes in turbidity. The muddy areas of Okak Bay are in deep and often protected bays; therefore changes in exposure are unlikely and excluded.

The key biota in the mud habitat (*Macoma calcarea, Ophiura sarsii, F. Maldanidae*) have a wide distribution including both boreal and arctic locations – suggesting that they are unlikely to be impacted by changes in temperature and salinity. *Macoma calcarea* in particular is well adapted to changes in oxygenation (Tyler-Walters *et al.* 2001). Species within the genus have been shown to extend their siphons beyond the substrate surface to access oxygen-rich water when exposed to lowered oxygen levels. Reduced dissolved oxygen level trends in the North Atlantic have been observed in response to atmospheric forcing (Joos 2003). In the area of Okak Harbour – where a shallow sill separates the muddy basin from the main fiard – there is a possibility for changing oxygen levels to have a higher impact, potentially resulting in a hypoxic environment.

Muddy habitats are sensitive to dragging type fishing activities – sensitivity is dependent on the weight of the gear and the depth of which the disturbance occurs at.

Lighter weight gear may only disturb the epifauna, while heavier gear such as scallop dredges and beam trawls will penetrate the surface further and disturb a large number of the infauna as well (Foden and Jones 2010; Kaiser 2006; MacDonald *et al.* 1996). Impact has been found to be negative in the short term, however the habitat will recover quickly (Foden and Jones 2010; Kaiser 2006). Potting-type gear, when set correctly should have minimal impact, as they will not penetrate the surface, and will impact only a small area (MacDonald *et al.* 1996).

Other anthropogenic impacts such as exposure to oil spills, fuel spills and high metal accumulations have the potential to be extremely damaging to mud-type habitats, as the majority of biota are deposit feeding. Studies show that ingestion of synthetic materials and high levels of metals are frequently fatal to infauna, particularly large bivalves of which there are several species of importance in Okak Bay (Suchanek 1993).

4.5.2 Sandy Mud

Many of the same stressors will impact the sandy mud habitats in similar ways (Tyler-Walters *et al.* 2001) – however, within Okak Bay, the sandy mud habitat tends to occur at shallower depths, and is host to a wider range of epifauna than the muddy habitats. As such, the potential for changes in exposure via increased storm surge or frequency to impact the habitat is higher, particularly in shallow regions such as those found in the southern channel. Increases in water flow or turbidity may remove a higher percentage of fine-grained sediments out of this area, resulting in reduced nutrients for the many deposit-feeding species.

4.5.3 Gravelly Sandy Mud

Gravelly sandy mud habitats are commonly composed of occasional gravel draped over sandy mud. Biota is comprised of large numbers of burrowing infauna (several bivalve species), as well as several species of large epifauna (*Gersemia rubiformis*, green sea urchin). Physical factors are likely to be an issue for this habitat, due to the balance between infauna and epifauna. Substratum loss would remove the top hard substrate impacting encrusting biota, and disturbing the burrowing biota below (Newell *et al.* 1998). Increased sedimentation may make it difficult for the many suspension feeding epifauna to feed (Maurer *et al.* 1986). This habitat is typically located in areas of high energy and exposure, such as coastal regions and shallow sills, so increases in exposure will likely have a negligible impact for the majority of species. Displacement via scour, however, is a threat, particularly in the southern channel where the bathymetry shallows dramatically.

This habitat has the highest number of taxa associated with it, the majority with large ranges that include both boreal and arctic affinities. As such, they are likely to be tolerant of changes in temperature and salinity. Species that may not tolerate changes well include several species of echinoderms and anthozoa. Echinoderms in particular have difficulty tolerating changes in salinity due to a lack of an excretory organ, inhibiting their ability to osmo-regulate (Budd, 2008). Therefore, this class is assessed moderate sensitivity to the majority of climate related changes, with the exception of changes in nutrient levels (Tyler-Walters *et al.* 2001).

Drag fishing activities tend to disturb the top layers of the substrates, moving or overturning cobbles and gravel with the potential for fauna to be crushed or removed. *Gersemia* spp. and other encrusting organisms (*Balanus balanus, Tonicella rubra*) are likely to be particularly susceptible to this type of impact (Foden and Jones 2010; Kaiser *et al.* 2006; MacDonald *et al.* 1998). As well, dragged equipment can typically have a "smoothing" effect on the surface, reducing rugosity and therefore potential habitat (Auster *et al.* 1996). Certain species are more likely to be susceptible to potting type fishing activities, and may not recover once disturbed; however, the majority have flex and can recover rapidly, placing them at only moderate risk (Eno *et al.* 2001). The potential for fisheries activity in the region has been assessed, with the likely expansion of crab and turbot fisheries into the area (T. Brown pers. comm. 2011).

Marine contamination by oil and fuel, and metal accumulation is a threat to the gravelly sandy mud habitat, as bivalves (deposit feeding), echinoderms (exposed epidermis), and amphipods are common classes of species for which marine pollution is frequently fatal (Jackson 2008; Stekoll *et al.* 1980; Suchanek 1993).

The gravelly sandy mud habitat is common on the shallow sills of Okak Bay, where the highest levels of biodiversity are found. These sites in particular may be sensitive to all impacts, in particular physical displacement and fishing activities, as the biota is highly dependent on the gravel and cobble cover found in this region. Disturbance of these habitats could result in greatly reduced species richness.

4.5.4 Kelp

Biogenic habitats such as the kelp beds provide robust and complex habitats for biota (Steneck 2002; Wlodarska-Kowalczuk *et al.* 2009). The kelp beds of Okak are comprised of *Agarum clathratum*, a relatively hardy and fast-growing kelp species (Gagnon 2005). They are located in a shallow, sheltered area. This area is likely to be susceptible to a range of physical stressors. The removal of the kelp would eliminate this habitat – as the kelp acts as a host for a variety of epifauna (Tyler-Walters *et al.*2001). *Agarum clathratum* is a kelp species that prefers low-energy environments. Increases in wave energy and exposure due to sea level rise or increase in storm surge will likely cause an inhospitable environment for this habitat. Displacement in this case will have a similar effect as substratum loss – eliminating potential habitat for kelp-dependent biota.

The green sea urchin and several species of brittle stars are common in the kelp beds. The urchin in particular has been shown to be particularly sensitive to changes in temperature and salinity. This habitat covers the smallest area of the fiard, and is depth and exposure limited. Changes in oceanographic variables, particularly salinity have the potential to have the highest impact on this habitat.

The kelp beds are sensitive to all types of fishing activities (Gagnon *et al.* 2005). Trawling and dragging activities will be particularly damaging, as the kelp will be displaced, removing the surface complexity and reducing habitat. *Agarum clathratum*, the kelp species responsible for the biogenic substrate in Okak Bay is a relatively quickly growing species and studies have shown that once displaced, it is able to recolonize relatively quickly (12-14 months; Gagnon *et al.* 2005). As such it is placed in the sensitive class to dragging-type fishing activities, and the low sensitivity to potting type-fishing activities, with the exception of multipotting activities in which connective strings may entangle and dislodge kelp plants.

Echinoderms as a class tend to be highly susceptible to various forms of marine pollution (Jackson 2008; Suchanek 1993), potentially due to their largely exposed epidermis, and relative lack of mobility. Due to the fact that echinoderms are common this habitat, it is placed as highly susceptible to various types of spills and metal accumulation.

4.5.5 Bedrock/boulder

Bedrock/boulder substrates tend to occur in steeply sloping, high-energy environments in the outer fiard and inner sills. As such they are unlikely to be susceptible to physical disturbances such as increased exposure. The biota are suspension feeding, encrusting epifauna for the most part, susceptible to displacement as they are slow growing and unable to recolonize rapidly once removed. Similarly, they may be susceptible to increased sedimentation or turbidity as additional sediment within the water column can make feeding activities difficult.

Bedrock/boulder substrates were found to be sensitive to damage from fishing activities (Hall *et al.* 2008). While dragging-type fishing gear would damage the habitat, it is unlikely to be used in these areas and so were excluded from consideration. However, the long-lived, slow growing biota typical of this habitat type are sensitive to damage from dragging ropes and potting type fishing activities. While some epifauna may be mobile (*Strongylocentrotus droebachiensis*) or have the ability to bend (*Urticina* *felina*) when in contact with gear, other species such as *Hormathia nodosa* lack mobility and are likely to be displaced or damaged and unable to recover. This habitat was assessed as sensitive to these types of stressors for these reasons.

To the best of our knowledge, there is no literature available to suggest the impacts of exposure to accumulated metals or synthetic materials on bedrock type environments; however, due to the low sediment accumulation and high energy of the environment, it is likely that accumulation would be low, and impacts minimal.

4.5.6 Identification of Sensitive Habitats and Areas of High Biodiversity

Certain regions within the broader sensitivity classifications may be identifiable as more deserving of protection for several reasons. Certain areas may function as representative habitats (sill), particularly sensitive ones (kelp) or for cultural reasons (Okak Harbour). Four areas within Okak Bay have been identified for the purposes of conservation, due to high sensitivity values or biodiversity.

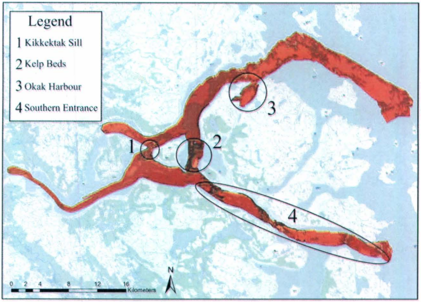

Figure 4.3 Regions that be of interest for conservation efforts

Region one is located between Martin and Kikkektak Islands and covers the sill. The rapid change in depth and slope creates a highly heterogeneous area, and the predominantly shallow depth allows for this region to contain some of the highest levels of biodiversity within the fiard (Copeland *et al.* 2011). The region contains three of the five habitat classes, bedrock/boulder, gravelly sandy mud and sandy mud, in particular this region is an excellent representation of the gravelly sandy mud class. Several species of epifauna (*Gersemia* spp., *Urcitina felina*), which may be particularly susceptible to anthropogenic impacts, are found in this area.

Region two covers the kelp beds, which were identified as having the highest level of sensitivity found within the fiard. This region is particularly sensitive to physical and climate change related impacts, and is restricted within the fiard to those areas with moderate or low exposure. Protection of this region ensures that the best example of this habitat will be maintained.

Region three covers the area of Okak Harbour. This region is representative of nearly all of the habitat classes. It consists of a deep muddy basin that transitions through sandy mud to gravelly sandy mud along the margins. Bedrock/boulder substrates are found in steep sloping areas on the sides of the shallow sill at the mouth. The region to the north of the western point has been shown to have the highest species richness within the sampled area. In addition, conservation of this region may have cultural value, as the abandoned community of Okak Harbour is located on the northwestern shore. Foundations of buildings, and pieces of ceramic are visible along the shoreline.

Region four covers the entirety of the southern entrance. The southern entrance is likely too shallow for the majority of boats to safely navigate (<17 m water depth), and contains several interesting features, including the previously discussed trench feature, and two sills. All five identified habitats are present within the channel and two areas have been identified as being of high sensitivity.

4.6 Assessment of Methodology

Supervised classification of multibeam sonar data used in this study was previously published successfully by Kostylev *et al.* (2001), and used by Copeland (2006) and Copeland *et al.* (2007, 2008, 2011), and Hargrave *et al.* (2004). It uses a classification of multibeam bathymetric data to produce a map illustrating the habitats and substrates of a given area. In the case of Okak Bay, the multibeam data were ground-truthed via three methods, substrate sampling via box core, drop video camera, and remotely operated vehicle. The methodology was used successfully to classify the habitats in Okak Bay (section 3.12.3), and the accuracy of the classification can be accessed through the ambiguity of the developed classes, and through a set of test samples collected via ground-truthing activities (sections 3.12.1.3, and 3.12.3.7).

4.6.1 Accuracy of Classification

Two methods were used to determine accuracy of the classification of substrates and habitats. The first is ambiguity – the number of substrate and habitat classes in which each pixel was placed. The second utilized a set of test samples excluded while the user-generated expressions were created. These samples were later placed back onto the map surface to determine if they had been accurately classified.

4.6.2 Ambiguity

Ideally the majority of pixels classified should be placed in a single class, suggesting that each substrate and habitat is acoustically distinct. Multiple classes per pixel occur when there is overlap in the depth and backscatter ranges for each class. Unclassified pixels occur when user generated expressions exclude a portion of the depth and backscatter ranges (generally the extreme ends as shallow or hard substrates may be difficult to sample).

The habitat classes were more acoustically distinct than the substrate classes. Several of the acoustic classes – muddy sand and sandy mud, gravelly mud and gravelly sand had large overlaps in both depth and backscatter. These classes were not found to be biologically distinct and so were merged for the habitat classification. This created a considerably reduced ambiguity between classes for the habitat maps.

The kelp beds of the inner fiard were identified as a statistically unique habitat by ANOSIM tests, but were not wholly acoustically distinct. There was overlap in both backscatter and depth values of the sampled regions, and the resulting expression for classification created overlap within the predicted habitat map. This overlap was the main source of ambiguity in pixel classification. Further sampling efforts would be necessary to determine if kelp beds occur in areas of the fiard other than those initially sampled and predictions of kelp other than in the sheltered central region should be addressed with caution.

Unclassified pixels were concentrated along the coasts and in extreme shallow regions. These regions were difficult to sample with box core and video due to the low maneuverability of the sampling vessel, and so the extreme ranges of depth (<10m) were left unsampled.

4.6.3 Test Samples

The 25% of sample sites that were set aside for accuracy assessment showed that 71% of substrate samples and 82% of habitat samples were classified correctly. Other benthic habitat studies making use of similar accuracy assessment reported comparable or lower accuracy percentages of between 28-85% accuracy (White 2003; Cochran-Marquez 2005). The majority of incorrectly classified samples were found in the sandy mud habitat class (7 out of 24). The incorrectly classified samples were typically placed in the mud class, along the boundaries of the habitat areas. This reflects the fact that in order to reduce ambiguity the difference was split between the backscatter ranges when developing the classification expressions, removing the one pixel overlap. Five of the misclassified pixels fall within this overlap.

5.0 Conclusions and Future Work

The results of this thesis show that not only is Okak Bay a distinct glacial landform in comparison to the previously mapped fiords of the Labrador coast, but it also contains a distinct set of habitats and substrates. Okak Bay is a fiard, an embayment characterized by smoothed, low relief topography, and irregular shape and bathymetry. Its habitat distribution differs from that of the classic fiords to the north, lacking the repetition in broad homogeneous regions from head to mouth. The habitat distribution more closely resembles that of Gilbert Bay, another fiard-type inlet mapped in southern Labrador.

Fiard topography is likely to be found throughout the central Labrador coast. Five additional embayments that share physical and oceanographic characteristics with Okak Bay were identified in the region. The habitat information and multibeam classification for Okak Bay may be applicable to these other regions and could be tested with additional sampling. Also applicable to other regions may be the sensitivity values developed for the Okak region. The two most sensitive habitats identified were kelp and gravelly sandy mud due to their complex substrates and particularly sensitive epifauna. Although conclusions drawn about habitat sensitivity in this thesis are preliminary and require more data and analysis, they demonstrate that the inclusion of habitat and sensitivity information in coastal management initiatives along the central Labrador coast is an important step for monitoring and conservation in the face of expanded resource harvesting activities.

Recommendations for future work include the addition of more oceanographic variables in the creation of the map. Benthic habitats are likely influenced by oceanographic characteristics above the sea floor, including temperature, salinity, and dissolved oxygen concentration. The inclusion of variables such as these can help to improve accuracy and help to develop a better picture of the variables that influence habitat distribution. Although a small amount of CTD data was available for Okak Bay, it was excluded from the mapping activities due to its limited coverage. Analysis of water masses may suggest more about which oceanographic characteristics influence biota. Additional variables that may be of use include wave exposure and current models.

The use of the ROV in the southern part of the fiard helped to better understand the changes in habitats with depth along a long transect. Additional transects with the ROV, including in the areas of bedrock/boulder would have been useful to better measure the full depth extent of this habitat class. Current sampling activities in this habitat area are limited by the drop video camera. The drifting of the boat controls this camera, and is depth limited. As the ROV can move independently of the vessel, the expansion of its use in the fiard would help to more thoroughly sample the harder substrates.

Sampling activities in the fiard were separated by field season. The inner fiard was sampled in 2009 and the outer fiard in 2010. Although separating the field seasons in this way allowed for a thorough sampling of a smaller area and reduced travelling time between stations, it may be advisable to attempt a more complete sampling program in the first field season in order to develop a rudimentary habitat map with which to plan the second field season. This would allow for the planned sampling of neglected habitats, and the ROV transect locations could be planned in advance. Additional sampling at different times of year will also help to determine baselines for biotic species populations.

The intertidal zone, an important region in the marine ecosystem, was also neglected in past sampling efforts. Future sampling should include this area, as it is potentially a region of high sensitivity.

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Appendix A - Wentworth Grain Size Descriptions (Wentworth 1992)

Phi Unit (ϕ)	Wentworth Grain Size Description	Grain Size (mm)
>-4	Cobble	63 – 256
>-2	Pebble	4 – 63
-1	Granule	2 – 4
0	Very coarse sand	1 – 2
1	Coarse sand	0.5 – 1
2	Medium sand	0.25 – 0.5
3	Fine sand	0.125 – 0.25
4	Very fine sand	0.0625 – 0.125
5	Coarse silt	0.031 – 0.0625
6	Medium silt	0.0156 – 0.031
7	Fine silt	0.0078 – 0.00156
8	Very fine silt	0.0039 – 0.0078
9 - >11	Clay	<0.0039

Appendix B – Substrate Sample and Associated Cluster ID

Sample Number	Cluster Number	Sample Number	ID Number	Sample Number	ID Number	Sample Number	ID Number
7A	1	11C	6	30C	11	19B	14
7B	1	11B	6	17A	11	19C	14
29A	1	11A	6	12A	6	14B	12
33C	1	3B	6	32A	6	14C	12
6B	1	3A	6	1B	11	14A	12
33A	1	1B	6	1B	6	9C	14
33B	1	1A	6	25B	11	8A	14
9B	1	26A	13	25C	11	9A	14
5A	9	18A	7	12C	11	9B	14
10C	4	8A	7	12B	11	8C	14
10A	2	20C	7	32C	11	6C	14
24A	2	18C	8	4A	84	6B	14
24B	2	26B	7	19B	85	8B	14
24C	2	13A	7	8C	12	6A	14
2C	2	7A	7	9A	12	1C	12
2A	2	22C	9	27B	88		
10B	2	19C	9	25A	12		
30A	3	29C	9	22B	11		
13B	3	4B	9	28C	8		
16B	3	5B	9	28B	10		
13C	3	18B	9	20B	10		
7C	9	1C	9	28A	10		
14B	4	16A	9	13A	10		
12C	4	22A	9	26C	10		
9C	8	20A	8	23A	10		
6A	14	7B	8	2B	10		
27C	5	28C	3	20B	10		
11B	5	18A	8	20A	13		
16A	8	8A	7	32B	12		
3C	5	8B	8	6C	14		
19A	5	18C	7	17B	14		
29B	6	13A	8	4C	6		
11C	6	26C	7	5C	14		
11A	5	14A	8	27A	5		
16C	5	17C	6	16C	12		
16B	6	30B	11	19A	14		

Appendix C – Physical Attributes of Box Core Samples

Site	Northing	Easting	Depth (m)	Backscatter (dB)	Slope (°)	Organic Content (%)	Substrate Class	Habitat Class
2009-1A	532556.6	6370378.3	30.6	-18.0	24.9	1.8	Sandy Mud	Sandy Mud
2009-1B	532576.2	6370362.7	23.4	-24.0	10.0	1.7	Sandy Mud	Sandy Mud
2009-1C	532601.9	6370346.9	24.8	-21.0	9.1	2.3	Sandy Mud	Sandy Mud
2009-10A	550854.3	6375984.7	54.3	-15.0	8.7	10.5	Gravelly Sand	Gravelly Sandy Mud
2009-10B	550874.8	6375991.3	56.5	-14.0	8.5	3.2	Gravelly Sand	Gravelly Sandy Mud
2009-10C	550910.0	6375984.3	63.7	-12.0	13.3	3.5	Gravelly Sand	Gravelly Sandy Mud
2009-11A	552764.1	6375780.1	42.6	-15.0	1.6	3.8	Gravelly Mud	Gravelly Sandy Mud
2009-11B	552864.1	6375790.2	42.7	-13.0	2.4	3.9	Gravelly Mud	Gravelly Sandy Mud
2009-11C	552958.4	6375805.7	47.1	-14.0	1.8	4.0	Gravelly Mud	Gravelly Sandy Mud
2009-12A	552263.2	6370461.9	67.0	-16.0	9.7	1.6	Sandy Mud	Sandy Mud
2009-12B	552179.3	6370523.4	47.7	-17.0	10.3	0.6	Sandy Mud	Sandy Mud
2009-12C	552255.0	6370547.9	63.5	-18.0	7.9	1.3	Sandy Mud	Sandy Mud
2009-13A	556055.2	6372694.0	11.6	-8.0	0.6	6.2	Gravelly Sand	Gravelly Sandy Mud
2009-13B	556014.5	6372740.3	12.2	-8.4	1.3	3.3	Gravelly Sand	Gravelly Sandy Mud
2009-13C	555835.2	6372962.9	14.5	-13.4	3.1	2.5	Gravelly Sand	Gravelly Sandy Mud
2009-14A	566356.0	6364214.4	13.9	-8.5	7.1	1.5	Gravelly Sand	Gravelly Sandy Mud
2009-16A	561512.3	6380857.7	16.4	-14.7	3.4	7.2	Gravelly Sand	Gravelly Sandy Mud
2009-16B	561512.3	6380857.7	16.4	-14.7	3.4	6.8	Gravelly Sand	Gravelly Sandy Mud
2009-16C	561512.3	6380857.7	16.4	-14.7	3.4	7.0	Gravelly Sand	Gravelly Sandy Mud
2009-17A	563309.2	6381226.5	98.4	-22.9	0.6	2.7	Mud	Mud
2009-17B	563392.9	6381231.2	98.1	-19.8	0.7	4.6	Mud	Mud
2009-17C	563585.1	6381267.3	98.5	-23.9	2.2	4.7	Mud	Mud
2009-18A	559653.5	6383446.5	136.4	-12.0	1.0	4.3	Gravelly Sand	Gravelly Sandy Mud

Site	Northing	Easting	Depth (m)	Backscatter (dB)	Slope (°)	Organic Content (%)	Substrate Class	Habitat Class
2009-18B	559801.2	6383469.8	137.1	-11.0	0.9	-0.6	Gravelly Sand	Gravelly Sandy Mud
2009-18C	559992.4	6383486.1	137.5	-10.0	0.5	5.1	Gravelly Sand	Gravelly Sandy Mud
2009-19A	556821.6	6381162.9	89.4	-15.5	0.4	3.5	Sandy Mud	Sandy Mud
2009-19B	556937.8	6381153.3	89.8	-16.5	0.6	3.4	Sandy Mud	Sandy Mud
2009-19C	556732.7	6381241.7	89.7	-15.5	0.8	2.5	Sandy Mud	Sandy Mud
2009-20A	556876.0	6379711.1	37.3	-11.3	5.4	4.4	Gravelly Sand	Gravelly Sandy Mud
2009-20B	556918.3	6379688.1	32.7	-11.8	3.2	3.3	Gravelly Sand	Gravelly Sandy Mud
2009-20C	556939.4	6379677.7	31.7	-11.2	3.0	5.0	Gravelly Sand	Gravelly Sandy Mud
2009-22A	540469.1	6366436.3	59.9	-16.0	0.5	2.0	Sandy Mud	Sandy Mud
2009-22B	540483.0	6366470.1	60.2	-17.0	0.2	1.8	Sandy Mud	Sandy Mud
2009-22C	540498.4	6366497.2	60.3	-19.0	1.0	1.6	Sandy Mud	Sandy Mud
2009-23A	556600.2	6374653.3	24.3	-11.2	5.3	1.7	Kelp	Kelp
2009-23B	556541.3	6374765.2	26.3	-11.9	3.2	~	Kelp	Kelp
2009-24A	568546.8	6363278.3	26.2	-19.0	1.0	3.3	Muddy sand	Sandy Mud
2009-24B	568494.1	6363308.4	25.2	-18.9	1.3	4.0	Muddy sand	Sandy Mud
2009-25A	557238.9	6369296.0	34.5	-13.0	3.4	2.6	Sandy Mud	Sandy Mud
2009-25B	557208.3	6369318.1	35.0	-14.0	3.8	4.2	Sandy Mud	Sandy Mud
2009-25C	557175.4	6369343.4	33.7	-14.0	2.7	3.2	Sandy Mud	Sandy Mud
2009-26A	562772.7	6385009.9	52.6	-8.0	7.2	3.9	Gravelly Sand	Gravelly Sandy Mud
2009-26B	562844.1	6385041.7	48.2	-9.0	5.8	4.6	Gravelly Sand	Gravelly Sandy Mud
2009-26C	562624.0	6384920.8	58.8	-9.0	2.0	4.2	Gravelly Sand	Gravelly Sandy Mud
2009-27A	559557.8	6367688.2	76.9	-32.6	4.6	2.0	Sandy Mud	Sandy Mud
2009-27B	559532.8	6367719.7	66.1	-14.0	8.4	1.7	Sandy Mud	Sandy Mud
2009-27C	559506.0	6367764.5	69.0	-10.0	24.1	1.7	Sandy Mud	Sandy Mud
2009-28A	560377.4	6383084.1	67.5	-5.0	53.0	3.5	Gravelly Sand	Gravelly Sandy Mud

Site	Northing	Easting	Depth (m)	Backscatter (dB)	Slope (°)	Organic Content (%)	Substrate Class	Habitat Class
2009-28B	560621.1	6383123.9	58.6	-6.0	22.4	3.9	Gravelly Sand	Gravelly Sandy Mud
2009-28C	560691.7	6383132.2	65.4	-8.0	11.3	4.2	Muddy sand	Sandy Mud
2009-29A	563691.3	6366518.4	53.4	-20.0	23.7	3.2	Sandy Mud	Sandy Mud
2009-29B	563652.8	6366562.3	50.6	-17.0	13.2	3.4	Sandy Mud	Sandy Mud
2009-29C	563567.0	6366618.8	40.9	-17.0	4.1	3.7	Sandy Mud	Sandy Mud
2009-30A	531765.4	6371112.1	47.5	-16.0	1.1	4.7	Sandy Mud	Sandy Mud
2009-30B	531830.1	6371087.1	45.4	-17.0	1.4	4.2	Sandy Mud	Sandy Mud
2009-30C	531886.7	6371073.2	45.3	-18.0	0.7	10.5	Sandy Mud	Sandy Mud
2009-32A	562019.4	6366785.6	74.1	-17.0	8.4	4.0	Sandy Mud	Sandy Mud
2009-32B	561964.9	6366792.0	74.2	-16.0	9.3	4.8	Sandy Mud	Sandy Mud
2009-32C	561929.5	6366808.4	82.0	-19.0	15.6	~	Sandy Mud	Sandy Mud
2009-33A	562931.3	6366692.8	67.2	-18.0	7.0	4.8	Muddy sand	Sandy Mud
2009-33B	562859.7	6366721.6	71.0	-16.5	7.6	3.1	Muddy sand	Sandy Mud
2009-33C	562772.3	6366768.7	72.0	-19.0	3.6	4.8	Muddy sand	Sandy Mud
2009-4A	545374.5	6369649.6	56.8	-18.0	8.6	3.9	Muddy sand	Sandy Mud
2009-4B	545448.3	6369544.7	55.9	-19.0	10.9	3.8	Muddy sand	Sandy Mud
2009-4C	545667.2	6369593.7	65.0	-16.5	4.2	4.5	Muddy sand	Sandy Mud
2009-5A	548111.5	6371737.4	77.7	-14.4	10.0	4.6	Muddy sand	Sandy Mud
2009-5B	548153.8	6371762.0	81.3	-17.7	0.7	3.9	Muddy sand	Sandy Mud
2009-5C	548204.4	6371781.7	81.4	-18.0	0.6	3.5	Muddy sand	Sandy Mud
2009-6A	549967.2	6371080.1	81.9	-18.0	0.2	4.6	Mud	Mud
2009-6B	549893.8	6371224.4	82.2	-17.0	0.4	4.3	Mud	Mud
2009-6C	549921.7	6371305.5	82.4	-16.0	0.2	6.2	Mud	Mud
2009-7A	549809.6	6374024.0	31.5	-8.0	2.8	4.0	Gravelly Sand	Gravelly Sandy Mud
2009-7B	549858.6	6374045.1	29.7	-7.9	2.9	3.8	Gravelly Sand	Gravelly Sandy Mud

Site	Northing	Easting	Depth (m)	Backscatter (dB)	Slope (°)	Organic Content (%)	Substrate Class	Habitat Class
2009-7C	549893.2	6374072.5	28.0	-7.2	3.9	4.7	Gravelly Sand	Gravelly Sandy Mud
2009-8A	543674.2	6376493.5	62.7	-14.0	3.0	4.5	Gravelly Sand	Gravelly Sandy Mud
2009-8B	543726.6	6376490.9	61.5	-17.0	2.4	4.1	Gravelly Sand	Gravelly Sandy Mud
2009-8C	543809.1	6376491.6	59.7	-18.0	0.9	4.9	Gravelly Sand	Gravelly Sandy Mud
2009-9A	546289.9	6376594.1	64.0	-19.0	3.0	2.2	Sandy Mud	Sandy Mud
2009-9B	546336.6	6376587.1	63.0	-18.0	2.9	2.9	Sandy Mud	Sandy Mud
2009-9C	546383.4	6376576.5	61.9	-18.0	3.5	3.9	Sandy Mud	Sandy Mud
2010-11A	555204.7	6378133.3	62.6	-13.0	0.9	2.1	Gravelly Mud	Gravelly Sandy Mud
2010-11B	555191.7	6378109.7	62.4	-14.0	0.7	3.2	Gravelly Mud	Gravelly Sandy Mud
2010-11C	555181.7	6378075.8	62.4	-14.0	0.4	2.4	Gravelly Mud	Gravelly Sandy Mud
2010-12A	555084.4	6373706.3	14.0	-11.1	0.6	~	Kelp	Kelp
2010-12B	555055.4	6373673.1	14.1	0.0	0.5	~	Kelp	Kelp
2010-12C	555055.2	6373670.7	14.1	0.0	0.8	3.3	Kelp	Kelp
2010-13A	554930.9	6371625.2	17.6	-10.2	3.2	4.0	Kelp	Kelp
2010-13B	554942.9	6371629.1	16.7	-8.7	2.9	~	Kelp	Kelp
2010-13C	554955.7	6371633.3	16.3	-9.1	2.4	~	Kelp	Kelp
2010-16A	530352.3	6370995.2	37.8	-16.0	0.2	2.3	Sandy Mud	Sandy Mud
2010-16B	530385.1	6370967.3	37.6	-15.0	0.2	3.7	Sandy Mud	Sandy Mud
2010-16C	530412.4	6370936.3	37.5	-14.0	0.4	4.8	Sandy Mud	Sandy Mud
2010-19A	575041.6	6361566.0	78.3	-24.0	0.6	6.1	Mud	Mud
2010-19B	575002.1	6361584.7	78.7	-26.0	0.6	0.7	Mud	Mud
2010-19C	574963.6	6361604.1	79.3	-25.0	1.0	2.5	Mud	Mud
2010-1A	581292.6	6383139.8	178.0	-22.0	0.2	1.4	Sandy Mud	Sandy Mud
2010-1B	581279.9	6383119.9	178.2	-21.0	0.7	~	Sandy Mud	Sandy Mud
2010-1C	581277.9	6383087.9	178.5	-22.0	1.1	~	Sandy Mud	Sandy Mud

Site	Northing	Easting	Depth (m)	Backscatter (dB)	Slope (°)	Organic Content (%)	Substrate Class	Habitat Class
2010-20A	576845.2	6361134.6	20.6	-11.0	3.1	3.2	Gravelly Sand	Gravelly Sandy Mud
2010-20B	576757.7	6361151.7	25.1	-11.0	3.1	4.1	Gravelly Sand	Gravelly Sandy Mud
2010-20C	576698.9	6361158.6	32.1	-13.0	16.6	~	Gravelly Sand	Gravelly Sandy Mud
2010-20D	576720.5	6361109.4	26.0	-6.0	2.3	~	Gravelly Sand	Gravelly Sandy Mud
2010-2A	578266.9	6383344.6	120.7	-11.0	10.5	7.4	Sandy Mud	Sandy Mud
2010-2B	578203.2	6383359.7	120.8	-15.0	4.2	6.2	Sandy Mud	Sandy Mud
2010-2C	578233.7	6383320.2	114.9	-7.0	7.8	3.7	Sandy Mud	Sandy Mud
2010-2D	578238.9	6383358.1	120.4	-11.0	8.4	~	Sandy Mud	Sandy Mud
2010-3A	577828.4	6385032.2	198.7	-19.0	1.4	9.0	Sandy Mud	Sandy Mud
2010-3B	577902.8	6385059.3	193.6	-11.0	5.0	8.7	Sandy Mud	Sandy Mud
2010-3C	577990.9	6385087.9	178.1	-18.0	9.4	5.8	Sandy Mud	Sandy Mud
2010-4A	574205.6	6387880.3	56.6	-6.0	17.8	~	Bedrock/Boulder	Bedrock/Boulder
2010-5A	568839.5	6388701.5	55.6	-7.0	15.8	~	Bedrock/Boulder	Bedrock/Boulder
2010-6A	566354.8	6385540.6	177.7	-21.0	1.5	~	Mud	Mud
2010-6B	566345.2	6385615.8	179.5	-18.0	1.8	4.6	Mud	Mud
2010-6C	566319.0	6385508.5	177.6	-19.0	1.4	3.7	Mud	Mud
2010-7A	564192.5	6382580.2	47.9	-7.9	2.2	5.7	Muddy sand	Sandy Mud
2010-7B	564195.2	6382580.4	48.2	-9.0	3.2	~	Muddy sand	Sandy Mud
2010-7C	564194.5	6382579.3	48.2	-9.0	3.2	~	Muddy sand	Sandy Mud
2010-8A	563809.3	6381931.3	77.6	-20.1	2.7	4.4	Mud	Mud
2010-8B	563795.7	6381898.4	78.2	-21.6	3.0	4.8	Mud	Mud
2010-8C	563782.7	6381870.9	78.8	-21.8	3.9	4.2	Mud	Mud
2010-9A	536260.4	6367668.8	58.5	-15.0	0.5	~	Mud	Mud
2010-9B	536312.5	6367640.3	59.0	-17.0	0.6	~	Mud	Mud
2010-9C	536252.8	6367619.2	58.3	-17.0	0.2	~	Mud	Mud

Appendix D – Physical Characteristics of Video Transects

Site	Northing	Easting	Depth (m)	Backscatter (dB)	Slope (°)	Substrate Class	Habitat Class
2009-1 Start	532295.8	6370583.7	50.3	-15.0	0.5	Mud	Mud
2009-1 Stop	532551.9	6370356.7	23.1	-20.0	10.1	Mud	Mud
2009-3 Start	536627.1	6366796.9	23.6	-13.0	1.6	Muddy sand	Sandy Mud
2009-3 Stop	536712.9	6366791.3	37.9	-17.0	12.8	Muddy sand	Sandy Mud
2009-4 Start	545333.9	6369605.7	50.4	-16.0	11.5	Muddy sand	Sandy Mud
2009-4 Stop	545343.1	6369621.1	52.7	-17.0	8.2	Muddy sand	Sandy Mud
2009-5 Start	548172.4	6371679.8	80.3	-17.3	2.9	Muddy sand	Sandy Mud
2009-5 Stop	548227.5	6371697.0	81.0	-16.0	0.3	Muddy sand	Sandy Mud
2009-6 Start	550177.4	6370902.8	82.3	-16.0	0.1	Mud	Mud
2009-6 Stop	550086.9	6370989.2	82.0	-17.5	0.4	Mud	Mud
2009-7 Start	549720.3	6374016.1	34.2	-9.2	2.0	Gravelly Sand	Gravelly Sandy Mud
2009-7 Stop	549775.6	6374023.6	32.3	-8.0	1.6	Gravelly Sand	Gravelly Sandy Mud
2009-8 Start	543575.3	6376473.9	61.4	-17.0	9.3	Gravelly Sand	Gravelly Sandy Mud
2009-8 Stop	543615.7	6376476.6	61.5	-11.0	7.0	Gravelly Sand	Gravelly Sandy Mud
2009-9 Start	546226.5	6376612.2	63.3	-20.0	1.3	Sandy Mud	Sandy Mud
2009-9 Stop	546251.3	6376611.9	63.9	-20.0	2.5	Sandy Mud	Sandy Mud
2009-10 Start	550761.0	6375897.6	65.8	-14.0	4.9	Gravelly Sand	Gravelly Sandy Mud
2009-10 Stop	550653.1	6375853.4	61.0	-13.0	7.9	Gravelly Sand	Gravelly Sandy Mud
2009-11 Start	552737.6	6375708.8	43.4	-13.0	2.3	Gravelly Mud	Gravelly Sandy Mud
2009-11 Stop	552669.1	6375660.6	54.7	-8.0	4.2	Gravelly Mud	Gravelly Sandy Mud
2009-12 Start	552148.5	6370420.9	41.4	-14.0	9.3	Sandy Mud	Sandy Mud
2009-12 Stop	552019.3	6370522.9	71.5	-16.0	14.3	Sandy Mud	Sandy Mud
2009-13 Start	556085.8	6372702.0	10.8	-8.0	1.6	Gravelly Sand	Gravelly Sandy Mud
2009-13 Stop	556101.4	6372709.6	10.8	-8.0	0.7	Gravelly Sand	Gravelly Sandy Mud

Site	Northing	Easting	Depth (m)	Backscatter (dB)	Slope (°)	Substrate Class	Habitat Class
2009-14 Start	566421.4	6364151.3	11.4	-7.9	2.0	Gravelly Sand	Gravelly Sandy Mud
2009-14 Stop	566374.6	6364191.8	12.2	-8.4	2.5	Gravelly Sand	Gravelly Sandy Mud
2009-15 Start	549906.8	6372789.7	26.0	-16.4	5.8	Muddy sand	Sandy Mud
2009-15 Stop	549878.7	6372823.6	24.4	-14.2	3.1	Muddy sand	Sandy Mud
2009-16 Start	561533.8	6380868.5	19.0	-14.8	5.2	Gravelly Sand	Gravelly Sandy Mud
2009-16 Stop	561508.5	6380867.7	17.1	-13.2	2.6	Gravelly Sand	Gravelly Sandy Mud
2009-17 Start	563333.3	6381263.0	98.0	-21.8	0.7	Mud	Mud
2009-17 Stop	563350.5	6381312.6	97.5	-20.8	0.4	Mud	Mud
2009-18 Start	559646.9	6383479.7	136.3	-13.0	0.2	Gravelly Sand	Gravelly Sandy Mud
2009-18 Stop	559624.6	6383499.0	136.1	-12.0	0.5	Gravelly Sand	Gravelly Sandy Mud
2009-19 Start	556805.6	6381205.2	89.4	-15.0	0.6	Sandy Mud	Sandy Mud
2009-19 Stop	556784.5	6381200.4	89.3	-15.5	0.3	Sandy Mud	Sandy Mud
2009-20 Start	556841.3	6379675.3	36.2	-10.7	3.1	Gravelly Sand	Gravelly Sandy Mud
2009-20 Stop	556831.7	6379752.7	53.8	-10.0	19.4	Gravelly Sand	Gravelly Sandy Mud
2009-22 Start	540447.4	6366581.2	60.0	-19.0	0.4	Sandy Mud	Sandy Mud
2009-22 Stop	540453.9	6366547.2	60.1	-20.0	0.6	Sandy Mud	Sandy Mud
2009-23 Start	556593.0	6374683.6	25.2	-10.6	5.5	Kelp	Kelp
2009-23 Stop	556581.9	6374708.0	25.9	-11.3	6.2	Kelp	Kelp
2009-24 Start	568648.0	6363226.4	28.6	-20.7	1.3	Sand	Sandy Mud
2009-24 Stop	568576.6	6363265.0	26.9	-20.2	1.7	Sand	Sandy Mud
2009-26 Start	562619.1	6384931.8	58.3	-6.0	2.1	Gravelly Sand	Gravelly Sandy Mud
2009-26 Stop	562687.4	6384965.7	59.3	-5.0	7.9	Gravelly Sand	Gravelly Sandy Mud
2009-27 Start	557274.8	6369280.8	31.7	-13.0	6.7	Sandy Mud	Sandy Mud
2009-27 Stop	559591.9	6367623.8	52.9	-15.0	20.7	Sandy Mud	Sandy Mud
2009-28 Start	560417.8	6383124.9	76.3	-4.0	30.4	Gravelly Sand	Gravelly Sandy Mud
2009-28 Stop	560428.6	6383142.2	80.6	-5.0	19.2	Gravelly Sand	Gravelly Sandy Mud

Site	Northing	Easting	Depth (m)	Backscatter (dB)	Slope (°)	Substrate Class	Habitat Class
2009-29 Start	563475.7	6366576.1	49.9	-16.0	22.6	Sandy Mud	Sandy Mud
2009-29 Stop	563413.0	6366623.2	48.9	-19.0	19.3	Sandy Mud	Sandy Mud
2009-30 Start	531917.0	6371139.8	45.5	-16.0	1.6	Sandy Mud	Sandy Mud
2009-30 Stop	531967.1	6371133.8	44.3	-16.0	2.4	Sandy Mud	Sandy Mud
2009-32 Start	562109.8	6366751.7	79.5	-17.0	14.7	Sandy Mud	Sandy Mud
2009-32 Stop	562043.7	6366779.2	74.8	-18.0	9.6	Sandy Mud	Sandy Mud
2009-33 Start	562824.9	6366715.1	68.8	-18.5	8.7	Muddy sand	Sandy Mud
2009-33 Stop	562721.4	6366753.6	70.0	-17.5	4.4	Muddy sand	Sandy Mud
2010-2 Start	578261.1	6383336.8	118.5	-9.0	10.2	Gravelly Mud	Gravelly Sandy Mud
2010-2 Stop	578284.5	6383326.0	120.1	-11.0	13.3	Gravelly Mud	Gravelly Sandy Mud
2010-4 Start	574084.2	6387920.0	50.0	-8.0	22.3	Bedrock/Boulder	Bedrock/Boulder
2010-4 Stop	574188.7	6387887.4	53.1	-6.0	26.0	Bedrock/Boulder	Bedrock/Boulder
2010-5 Start	568805.0	6388703.3	49.5	-9.0	19.6	Bedrock/Boulder	Bedrock/Boulder
2010-5 Stop	568840.8	6388688.5	52.4	-8.0	23.5	Bedrock/Boulder	Bedrock/Boulder
2010-7 Start	564201.1	6382578.0	48.0	-8.5	6.3	Muddy sand	Sandy Mud
2010-7 Stop	564217.3	6382575.6	45.9	-9.6	2.5	Muddy sand	Sandy Mud
2010-8 Start	563783.5	6381880.4	78.4	-20.9	3.4	Mud	Mud
2010-8 Stop	563770.1	6381833.4	79.2	-19.1	4.7	Mud	Mud
2010-9 Start	536262.0	6367644.1	58.4	-16.0	0.4	Mud	Mud
2010-9 Stop	536310.2	6367638.6	59.0	-17.0	0.5	Mud	Mud
2010-11 Start	555234.2	6378107.2	63.1	-13.0	0.7	Gravelly Mud	Gravelly Sandy Mud
2010-11 Stop	555218.2	6378048.7	62.9	-14.0	1.2	Gravelly Mud	Gravelly Sandy Mud
2010-12 Start	555111.0	6373779.2	14.2	-11.4	1.0	Kelp	Kelp
2010-12 Stop	555099.0	6373744.7	14.3	-11.5	1.0	Kelp	Kelp
2010-13 Start	554879.7	6371576.8	19.9	-12.9	0.8	Kelp	Kelp
2010-13 Stop	554912.7	6371606.4	18.3	-11.2	1.8	Kelp	Kelp

Site	Northing	Easting	Depth (m)	Backscatter (dB)	Slope (°)	Substrate Class	Habitat Class
2010-14 Start	559112.7	6372147.1	0.0	0.0	0.0	Mud	Mud
2010-14 Stop	559101.3	6372158.4	0.0	0.0	0.0	Mud	Mud
2010-16 Start	530369.4	6370969.4	37.6	-15.0	0.2	Sandy Mud	Sandy Mud
2010-16 Stop	530417.6	6370933.2	37.5	-13.0	0.6	Sandy Mud	Sandy Mud
2010-19 Start	575065.3	6361551.0	78.0	-25.0	1.0	Mud	Mud
2010-19 Stop	575049.1	6361561.3	78.2	-25.0	0.5	Mud	Mud
2010-20 Start	576922.8	6361105.8	16.5	-7.0	1.5	Gravelly Sand	Gravelly Sandy Mud
2010-20 Stop	576869.2	6361133.2	19.4	-11.0	2.5	Gravelly Sand	Gravelly Sandy Mud

Appendix E – Biota Sampled by Box Core

Phyllum	Class	Family	Species	Feeding Mode	Reference
Annelida	Polychaeta	*Capitellidae*	*spp.*	Carnivore	1
Annelida	Polychaeta	*Flabelligeridae*	*spp.*	Suspension, Deposit	2
Annelida	Polychaeta	*Glyceridae*	*spp.*	Predator	3
Annelida	Polychaeta	*Goniadidae*	*spp.*	Predator	3
Annelida	Polychaeta	*Lumbrineridae*	*spp.*	Predator	4
Annelida	Polychaeta	*Maldanidae*	*spp.*	Deposit	4
Annelida	Polychaeta	*Nephtyidae*	*spp.*	Predator	3
Annelida	Polychaeta	*Nereididae*	*spp.*	Predator	3
Annelida	Polychaeta	*Oenonidae*	*spp.*	Omnivore, scavenger	3
Annelida	Polychaeta	*Onuphidae*	*spp.*	Suspension	3
Annelida	Polychaeta	*Opheliidae*	*spp.*	Suspension, Deposit	3
Annelida	Polychaeta	*Orbiniidae*	*spp.*	Deposit	3
Annelida	Polychaeta	*Pectinariidae*	*spp.*	Deposit	3
Annelida	Polychaeta	*Phyllodocidae*	*spp.*	Omnivore, scavenger	3
Annelida	Polychaeta	*Polynoidae*	*spp.*	Predator	3
Annelida	Polychaeta	*Scalibregmatidae*	*spp.*	Deposit	3
Annelida	Polychaeta	*Terrebelidae*	*spp.*	Deposit	3
Annelida	Polychaeta	*Unknown 1*	~	~	~
Annelida	Polychaeta	*Unknown 2*	~	~	~
Annelida	Polychaeta	*Unknown 3*	~	~	~
Annelida	Polychaeta	*Unknown 4*	~	~	~
Annelida	Polychaeta	*Unknown 5*	~	~	~

Phyllum	Class	Family	Species	Feeding Mode	Reference
Annelida	Polychaeta	*Unknown 6*	~	~	~
Annelida	Polychaeta	*Unknown 7*	~	~	~
Annelida	Polychaeta	*Unknown 8*	~	~	~
Annelida	Polychaeta	*Unknown 9*	~	~	~
Annelida	Polychaeta	*Uknown 10*	~	~	~
Annelida	Polychaeta	*Uknown 11*	~	~	~
Annelida	Polychaeta	*Uknown 12*	~	~	~
Arthropoda	Malacostraca	*Gammarus*	*spp.*	Scavenger	1
Arthropoda	Malacostraca	*Haustorius*	*canadensis*	Scavenger	2
Arthropoda	Malacostraca	*Hyas*	*spp.*	Omnivore, scavenger	2
Arthropoda	Malacostraca	*Leptocheirus*	*pinguis*	Suspension	2
Arthropoda	Malacostraca	*Pandalus*	*montagui*	Omnivore, scavenger	2
Arthropoda	Malacostraca	*Saduria*	*entomon*	Predator, scavenger	2
Arthropoda	Malacostraca	*Unknown 1*	~	~	~
Arthropoda	Malacostraca	*Unknown 2*	~	~	~
Arthropoda	Malacostraca	*Unknown 3*	~	~	~
Arthropoda	Maxillopoda	*Balanus*	*balanus*	Suspension	2
Brachiopoda	Rhynchonellata	*Hemithiris*	*psittacea*	Suspension	2
Bryozoa	Gymnolaemata	*Callopora*	*craticula*	Suspension	2
Bryozoa	Gymnolaemata	*Escarella*	*spp.*	Suspension	2
Bryozoa	Gymnolaemata	*Eucratea*	*loricata*	Suspension	1; 2
Bryozoa	Gymnolaemata	*Scrupocellaria*	*scabra*	Suspension	1; 2
Bryozoa	Gymnolaemata	*Smittina*	*spp.*	Suspension	2

Phyllum	Class	Family	Species	Feeding Mode	Reference
Bryozoa	Gymnolaemata	*Stomachetosella*	*sinuosa*	Suspension	2
Cephalorhynch a	Priapulida	*Priapulus*	*caudatus*	Omnivore, scavenger	2
Cnidaria	Anthozoa	*Gersemia*	*fruticosa*	Suspension	2
Cnidaria	Anthozoa	*Gersemia*	*spp.*	Suspension	2
Cnidaria	Anthozoa	*Hormathia*	*nodosa*	Suspension	2
Cnidaria	Anthozoa	*Pachycerianthus*	*borealis*	Suspension	1
Echinodermata	Asteroidea	*Crossaster*	*papposus*	Carnivore	5
Echinodermata	Asteroidea	*Ctenodiscus*	*crispatus*	Deposit	5, 6
Echinodermata	Asteroidea	*Leptasterias*	*spp.*	Omnivore, scavenger	5
Echinodermata	Crinoidea	*Heliometra*	*glacialis*	Suspension	1
Echinodermata	Echinoidea	*Strongylocentrotus*	*droebachiensis*	Deposit, Grazer	1; 2
Echinodermata	Holothuroidea	*Cucumaria*	*frondosa*	Suspension	6
Echinodermata	Holothuroidea	*Leptosynapta*	*spp.*	Deposit	1
Echinodermata	Holothuroidea	*Myriotrochus*	*vitreus*	Suspension, Deposit	6
Echinodermata	Holothuroidea	*Psolus*	*fabricii*	Deposit	2
Echinodermata	Ophiuroidea	*Ophiopholis*	*aculeata*	Suspension	1; 2
Echinodermata	Ophiuroidea	*Ophiura*	*sarsii*	Predator	6
Echinodermata	Ophiuroidea	*Stegophiura*	*nodosa*	~	2
Foraminifera	Foraminiferans	~	~	~	~
Mollusca	Bivalvia	*Astarte*	*borealis*	Suspension	1
Mollusca	Bivalvia	*Ciliatocardium*	*ciliatum ciliatum*	Suspension	7
Mollusca	Bivalvia	*Cyclocardia*	*borealis*	Suspension	7
Mollusca	Bivalvia	*Cylichna*	*cylindracea*	Carnivore	
Mollusca	Bivalvia	*Hiatella*	*arctica*	Suspension	6
Mollusca	Bivalvia	*Lyonsia*	*arenosa*	Suspension, Deposit	1; 8

Phyllum	Class	Family	Species	Feeding Mode	Reference
Mollusca	Bivalvia	*Lyonsia*	*hyalina*	Suspension, Deposit	1
Mollusca	Bivalvia	*Macoma*	*calcarea*	Suspension, Deposit	9
Mollusca	Bivalvia	*Macoma*	*moesta*	Deposit	2
Mollusca	Bivalvia	*Musculus*	*discors*	Suspension	2
Mollusca	Bivalvia	*Musculus*	*niger*	Suspension	2
Mollusca	Bivalvia	*Mya*	*truncata*	Suspension	1
Mollusca	Bivalvia	*Nucula*	*delphinodonta*	Suspension, Depost	1
Mollusca	Bivalvia	*Nuculana*	*pernula*	Deposit	2
Mollusca	Bivalvia	*Periploma*	*alueticum*	Suspension	8
Mollusca	Bivalvia	*Serripes*	*groenlandicus*	Suspension	2
Mollusca	Bivalvia	*Thyasira*	*spp.*	Deposit	1
Mollusca	Bivalvia	*Yoldia*	*hyperborea*	Deposit	2
Mollusca	Gastropoda	*Admete*	*viridula*		1
Mollusca	Gastropoda	*Buccinum*	*undatum*	Omnivore, scavenger	1
Mollusca	Gastropoda	*Cingula*	*moerchi*		
Mollusca	Gastropoda	*Lunatia*	*heros*	Predator	1; 2
Mollusca	Gastropoda	*Oenopota*	*spp.*	Omnivore, scavenger	1
Mollusca	Gastropoda	*Scabrotrophon*	*fabricii*		1
Mollusca	Gastropoda	*Tachyrhynchus*	*erosus*	Suspension	1
Mollusca	Gastropoda	*Tachyrhynchus*	*reticulatus*	Suspension	1
Mollusca	Gastropoda	*Testudinalia*	*testudinalis*	Browser, Grazer	2
Mollusca	Gastropoda	*Trichotropis*	*borealis*	Deposit	1
Mollusca	Gastropoda	*Unknown 1*	~	~	~
Mollusca	Gastropoda	*Unknown 2*	~	~	~
Mollusca	Gastropoda	*Unknown 3*	~	~	~

Phyllum	Class	Family	Species	Feeding Mode	Reference
Mollusca	Gastropoda	*Unknown 4*	~	~	~
Mollusca	Polyplacophora	*Tonicella*	*rubra*	Browser	2
Nemertea	Anopla	*Cerebratulus*	*lacteus*	Carnivore	1
Nemertea	Anopla	*Lineus*	*spp.*	Deposit	1
Porferia	Demospongiae	*Halichondria*	*panicea*	Suspension	6
Sipuncula	Sipunculidea	*Sipunculus*	~	Deposit	6
Unknown 1	~	~	~	~	~
Unknown 2	~	~	~	~	~
Unknown 3	~	~	~	~	~
Unknown 4	~	~	~	~	~
Unknown 5	~	~	~	~	~
Unknown 6	~	~	~	~	~
Unknown 7	~	~	~	~	~

** Reference codes: 1 (Gosner 1971), 2 (Brunel 1998), 3 (Appy 1980), 4 (Gosner 1978), 5 (Clark and Downey 1992), 6 (Gosner 1979), 7 (Harvey-Clarke 1977), 8 (Huber 2010), 9 (Gosner 1972).

Appendix F – Biota Sampled by Video

Phyllum	Class	Family	Species	Feeding Mode	Reference
Annelida	Polychaeta	*Maldanidae*	*spp.*	Deposit	6
Annelida	Polychaeta	*Pectinariidae*	*spp.*	Deposit	3
Arthropoda	Malacostraca	*Hyas*	*spp.*	Omnivore, scavenger	2
Arthropoda	Malacostraca	*Saduria*	*entomon*	Predator, scavenger	2
Arthropoda	Maxillopoda	*Balanus*	*balanus*	Suspension	2
Bryozoa	Gymnolaemata	*Callopora*	*craticula*	Suspension	2
Cnidaria	Anthozoa	*Drifa*	*spp.*	Suspension	1
Cnidaria	Anthozoa	*Gersemia*	*spp.*	Suspension	2
Cnidaria	Anthozoa	*Hormathia*	*nodosa*	Suspension	2
Cnidaria	Anthozoa	*Pachycerianthus*	*borealis*	Suspension	1
Cnidaria	Anthozoa	*Urticina*	*felina*	Suspension	1
Echinodermata	Asteroidea	*Crossaster*	*papposus*	Carnivore	5
Echinodermata	Asteroidea	*Leptasterias*	*polaris*	Omnivore, scavenger	5
Echinodermata	Asteroidea	*Solaster*	*endeca*	Carnivore	5
Echinodermata	Crinoidea	*Heliometra*	*glacialis*	Suspension	1
Echinodermata	Echinoidea	*Strongylocentrotus*	*droebachiensis*	Deposit, Grazer	1; 2
Echinodermata	Holothuroidea	*Myriotrochus*	*vitreus*	Suspension/ Deposit	6
Echinodermata	Holothuroidea	*Psolus*	*fabricii*	Deposit	2
Echinodermata	Ophiuroidea	*Gorgonocephalus*	*arcticus*	Predator/Suspension	2
Echinodermata	Ophiuroidea	*Ophiopholis*	*aculeata*	Suspension	1; 2
Echinodermata	Ophiuroidea	*Ophiura*	*sarsii*	Predator	6
Echinodermata	Ophiuroidea	*Stegophiura*	*nodosa*	~	2
Mollusca	Bivalvia	*Ciliatocardium*	*ciliatum ciliatum*	Suspension	7

Phyllum	Class	Family	Species	Feeding Mode	Reference
Mollusca	Bivalvia	*Macoma*	*calcarea*	Suspension/Deposit	1
Mollusca	Gastropoda	*Lunatia*	*heros*	Predator	1, 2
Mollusca	Polyplacophora	*Tonicella*	*rubra*	Deposit	2
Ochrophyta	Phaeophyceae	*Agarum*	*clathratum*	Photosynthetic	1
Porifera	Demospongiae	*Haliclona*	*oculata*	Suspension	1
Porifera	Demospongiae	*Suberites*	*carnosus*	Suspension	10
Poriferia	Demospongiae	*Halichondria*	*panicea*	Suspension	6
Rhodophyta	Florideophyceae	*Coccotylus*	*truncates*	Photosynthetic	11
Rhodophyta	Florideophyceae	*Lithothamnion*	*glaciale*	Photosynthetic	1

** Reference codes: 1 (Gosner 1971), 2 (Brunel 1998), 3 (Appy 1980), 4 (Gosner 1978), 5 (Clark and Downey 1992), 6 (Gosner 1979), 7 (Harvey-Clarke 1977), 8 (Huber 2010), 9 (Gosner 1972), 10 (Hooper 2002), 11 (Sears 1998).