BENTHIC HABITAT MAPPING WITH MULTIBEAM SONAR IN NEWMAN SOUND, TERRA NOVA NATIONAL PARK, NEWFOUNDLAND

ALISON COPELAND

Benthic Habitat Mapping with Multibeam Sonar in Newman Sound, Terra Nova National Park, Newfoundland

By

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Abstract

The objective of this thesis is to characterise and map the benthic habitats of Newman Sound, a fjord in Terra Nova National Park, eastern Newfoundland. A multibeam sonar system was used to collect bathymetric and acoustic backscatter data. As backscatter is a function of seafloor substrate, interpretations were made about the distribution of substrates, and these were tested by groundtruthing. Benthic sediments were collected using a Peterson grab and video images were collected with a tethered drop camera, SCUBA divers, and a remotely operated vehicle. A seismic sub-bottom profiler was also used. Nine substrates were identified, and each supported a distinct assemblage of invertebrates and algae, which were classified into eleven habitats. The distribution of substrates and habitats were mapped in a Geographic Information System (GIS). The results indicate that this methodology can effectively map fjord habitats and successfully identifies areas of conservation value.

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Analysis of the samples was a major component of this project and required me to learn a lot of new techniques. Thanks especially to Helen Gillespie in the Earth Sciences Department, Memorial University for her patience when teaching me to prepare sedigraph samples. Also thanks to Rodolphe Devillers for his assistance with mapping, particularly in MapInfo.

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Chapter 1: Introduction

1.1 Introduction

The purpose of this thesis is to classify and map benthic habitats in Newman Sound, a boreal fjord in northeast Newfoundland. Methods exist for habitat mapping in other marine environments, but these have not been used extensively in fjords. One such methodology is to use multibeam sonar and acoustic sub-bottom profiling, groundtruthed with seabed samples and images. This methodology was applied in Newman Sound, and is the first application of multibeam sonar for habitat mapping in a Newfoundland fjord. The scope of this study was constrained by the use of an existing multibeam sonar data set collected for purposes other than habitat mapping, and by limited groundtruthing opportunities.

Previous benthic habitat and substrate maps were created using single beam echo sounders which only cover narrow survey tracks, making this method costly and time consuming as multiple closely spaced lines must be surveyed. The spaces between the survey tracks are filled by interpolation, resulting in gaps and reduced accuracy. Multibeam sonar technology offers a more efficient method for benthic mapping, as it offers complete coverage of the seafloor with fewer passes. It is therefore important at the present time to develop a methodology for creating benthic habitat maps from multibeam sonar data. Such a map has not previously been created anywhere in Newfoundland or Labrador.

Knowledge of the benthic habitats found in Newfoundland fjords has been limited until recently. Recent studies of fjord biota suggest that Newfoundland fjords are potential hotspots of biodiversity (Quijón 2004; Ramey 2001; Haedrich and Gagnon

1991). The potential for endemism is high in fjords, which characteristically have reduced water circulation and narrow connections to the sea. For example the population of Atlantic cod (*Gadus morhua)* in Gilbert Bay, Labrador remain in the bay year-round, and are genetically distinct from adjacent offshore cod stocks (Morris and Green 2002).

The attributes of fjords which make them biologically diverse, namely steep slopes, deep depths and patchy habitats, also make them difficult environments to study. Consequently the physical dynamics which contribute to biodiversity in fjords are poorly understood, as are the likely impacts of human activities on the benthos. Newfoundland fjords are becoming increasingly developed, particularly as they provide sheltered locations for aquaculture, an activity with documented impacts on the benthos (Tlusty et al. 2000). Hence there is a recognised need for conservation measures in fjords in Newfoundland and Labrador to protect biodiversity and unique coastal habitats.

Multibeam sonar technology and its applications to marine mapping will be discussed below. Newman Sound fjord is described in Chapter 2, along with the methods used to sample the fjord and map the results. Chapter 3 contains interpretations of the acoustic data sets, the results of groundtruthing, and maps of classified substrates and benthic habitats. Finally an assessment of the methodology used and the implications of this work are discussed in Chapter 4.

1.2 Introduction to Habitat Mapping

1.2.1 Defining Habitat

One of the greatest challenges in habitat mapping is defining what is meant by 'habitat.' Kostylev et al. (2001) define habitats as "spatially recognisable areas where the physical, chemical, and biological environment is distinctly different from surrounding environments." This definition was specifically designed for the purpose of habitat mapping. Thus it recognises the spatial nature of habitat investigation, and also that the physical and biological patterns which define a habitat must be continuous to the extent that they are recognised by the map maker. Scale therefore is of critical importance in defining habitats. In this study, habitat is defined at the scale of several 10s of metres, the 'mesohabitat' scale of Greene et al. (1999).

1.2.2 Uses of Benthic Habitat Maps

Benthic habitat maps produced from multibeam acoustic data provide high quality information for decision making and marine management. Such maps are useful to ascertain the impacts that petroleum exploration, fishing, aquaculture and other activities have on the benthos. Over most of the Canadian seabed, basic information about the benthos is not available, so baseline information must be gathered if changes and impacts are to be monitored. In Canada most benthic mapping is undertaken as a collaborative effort by industry, government, and academia (Geological Survey of Canada (Atlantic) et al. 1999).

Fisheries managers are becoming increasingly aware of the importance of benthic habitat mapping, particularly in identifying spawning and nursery grounds. Detailed maps of benthic communities also allow for targeted fishing effort, which reduces the financial costs of fishing and increases profits. Targeted fishing reduces the environmental costs associated with fishing techniques, such as trawling, by reducing the amount of seafloor that needs to be disturbed for fishermen to collect quotas (Marine Affairs Research and Education 2002b). Habitat maps can also be used to define buffers around fragile and vulnerable habitats, such as deep-water corals, to reduce impacts from fishing and industrial activity.

1.2.3 Benthic Habitat Criteria

At the 'mesohabitat' scale, the most influential physical variables that characterise benthic habitats are depth, substrate texture and hardness, and topography (Kostylev et al. 2001; Pickrill and Todd 2003; Hargrave et al. 2004; Tyrrell 2005). Depth controls other factors including light penetration (Tyrrell 2005), temperature and salinity. Light penetration limits the distribution of marine plants and algae which influences the distribution of herbivores and organisms that use vegetated habitat for protection. Water depth also determines the extent to which the seabed will be influenced by wind and wave energy and the currents they create, which disturb benthic habitats and influence their physical structure and biological communities (Valentine et al 2005).

Substrate texture influences habitat complexity, and complexity has been linked to biodiversity (Snelgrove 1998; Kamenos et al. 2004; Tyrrell 2005). A substrate such as a boulder field presents a very rough surface with many microhabitats, whereas a fine-grained sand or mud bottom generally has a lower surface roughness and complexity. Fine-grained substrates, and even coarse gravels, can be worked into larger bedforms, such as ripples, waves and dunes, which further increase the complexity of the substrate. Very fine-grained sediments (i.e. silts and clays) are likely to have a lower porosity than coarse sediments, which limits oxygen availability below the sediment surface and therefore the burrowing depth of infauna (Tyrrell 2005). In general habitats with a diversity of grain sizes will likely also support diverse biological communities (Snelgrove 1998).

The distribution of flora and fauna on the seafloor reflects their preferences for substrate texture for ecological reasons. For many invertebrates, especially sessile forms, substrate affinity is based on behaviour and life history traits. Tube-building polychaete annelids, for example, are found associated with specific sizes of sand and gravel, which they cement to build tubes (Ramey 2001).

The other attribute of substrate that characterises a habitat is hardness. Again, behaviour and life history traits play a key role in habitat selection for hardness as it is inconsequential to some organisms, and vital to others. Burrowing infauna, such as bivalves and polychaetes, will only be found in soft substrates into which they can successfully dig. Similarly, marine plants and algae can only exist where the substrate is suitable for attachment (Tyrrell 2005). If a sedentary organism settles on an unsuitable habitat, such as a soft, fine-grained bottom to which it cannot attach, it will die. The species will, therefore, only be distributed in habitats which are favourable to growth and survival, making sedentary taxa important habitat-specific biological indicators.

Topography is the third key habitat component. Topography controls habitat complexity at a larger scale than substrate texture. Components of topography include the slope angle of the seabed and structures such as depressions, hummocks and steep fjord side walls. Seabed slope is an important variable for habitat classification in fjords such as Newman Sound, and in many respects differentiates the fjord from the adjacent continental shelf off Bonavista Bay. The advent of increasingly sophisticated acoustic seabed detection equipment allows precise examination of depth, substrate texture and topography for habitat mapping.

1.3 Introduction to Multibeam Echo Sounders

Multibeam sonar systems have become the tool of choice for ocean mapping. Dartnell and Gardner (2004) note that multibeam echo sounders are currently being employed world wide by navies, marine surveyors and hydrographic services, as well as research scientists. The benefits of multibeam sonar to ocean mapping have been widely accepted by scientists, managers and policy makers. Improvements in data handling and global positioning systems have also made multibeam sounders more usable (Hughes Clarke et al. 1996). The use of multibeam sonar systems in Canada began when the Canadian Hydrographic Service invested in high resolution multibeam sonar for surveying the continental shelf in the late 1980s (Courtney and Shaw 2000).

A multibeam echo sounder works in a similar fashion to other sonar devices by sending out beams of sound which contact a target, and are reflected back to a receiver. However, most sonar systems used for mapping only emit a single beam which contacts the seabed directly beneath the sounder (a single beam, normal incidence sonar). Multibeam echo sounders emit many beams of sound simultaneously, each of which contacts the seabed at a slightly different grazing angle creating a cone of sound covering a swath of the seabed (Figure 1.1). For further discussion of multibeam acoustics and other sonar methods see Lurton (2002).

For mapping in shallow water the multibeam system (both the transmitter and receiver) are mounted on the hull of a survey ship. For mapping in deep water the system may be mounted on a remotely-operated vehicle or other platform, which can be towed

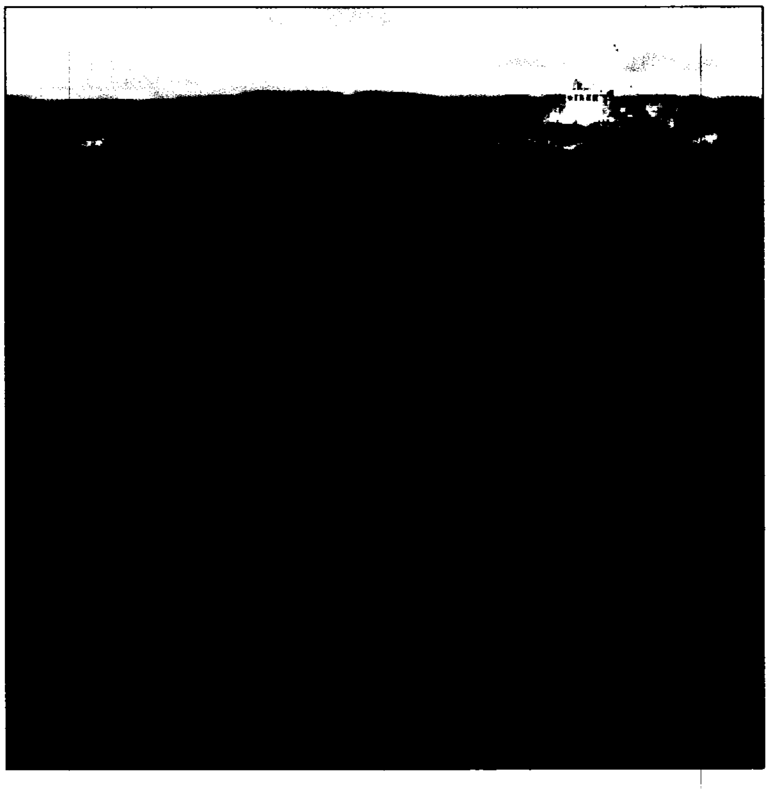


Figure 1.1 Multibeam echo sounder insonifying the seabed (Kongsberg Maritime AS 2005)

near the seabed. As water depth increases the area of seafloor covered by the sonar swath increases and resolution decreases. Signal attenuation in deep water can be unpredictable, as different water masses with different acoustical properties may be encountered (Hughes Clarke et al. 1996). This is why the platform and settings of the multibeam system are changed for surveying in deep water. The exact number of beams and dimensions of the swath are determined by the capabilities and settings of the multibeam system being used, and may be changed depending on the users needs.

1.3.1 Multibeam Bathymetry

During a bathymetric survey the multibeam echo sounder uses the travel time of the emitted sound through the water column to the target (the seabed) and back to calculate the water depth below the transducer. The multibeam system records the two-way travel time of the signal, which is used to calculate water depth as the speed of sound through water is known. A sound speed profile can be calculated by measuring salinity and temperature through the water column at the time of the multibeam survey. An existing profile for surface waters in the North Atlantic shows the speed of sound through water as 1524 m/s (Medwin and Clay 1998).

The system also records the angle from which the return signal arrives, which gives the location of the beam across the survey track. This ability to locate signal returns in space is critical, as survey data are not useful if not georeferenced (Hughes Clarke et al. 1996). Water depth is calculated for each beam and later combined to give a continuous record of water depth (Lurton 2002). When these data are mapped, topographic features such as depressions and cliffs can be observed due to changes in water depth, and hence elevation, across the seabed.

1.3.2 Multibeam Backscatter

A second data set can be processed from the signal return - acoustic backscatter. By comparing the strengths of the returned and emitted signals the amount of sound energy lost can be calculated. This loss is due to the acoustic properties of the seabed, and can be used to predict some physical properties of seafloor substrates. An acoustically low reflectance seabed is one which has a low backscatter value, expressed in negative decibels (−dB). Low backscatter substrates are likely to be fine grained, with high porosity, allowing sound energy to be absorbed. Acoustically reflective (high backscatter) substrates tend to be denser and usually harder surfaces such as bedrock, which reflect most of the signal back to the receiver, in contrast to absorptive seabeds like silt. Lurton (2002) notes that additional scattering of the acoustic signal occurs when other sources of scattering are found in the sediment or on the surface of the seabed; for example, shells and other living organisms, minerals, plants and algae, and gas bubbles.

The roughness of a seabed also affects the backscattered signal, as a rough seabed will reflect beams in all directions. This is especially true towards the edge of the insonified arc, as these edge beams are contacting the seabed at small grazing angles. Therefore smooth surfaces have higher acoustic backscatter than rough, complex ones. The acoustic parameters of seafloor sediments and their effect on backscatter signals are discussed further in Lurton (2002).

1.4 Multibeam Sonar as a Habitat Mapping Technique

Through the use of multibeam echo sounders it is possible to achieve 100% seafloor coverage at metre-scale horizontal resolution and centimetre-scale vertical resolution (Dartnell and Gardner 2004). This resolution provides seabed mapping opportunities which have not been possible until now. Courtney and Shaw (2000) noted that the use of multibeam systems has changed the scale at which geological mapping is now done on the Canadian continental shelf from greater than 1:250 000 to around 1:1000.

This revolution in marine geological mapping is important because an improved ability to map seabed geology allows us to indirectly map habitat characteristics related to substrate. However, as important as they are, geologic attributes alone are not sufficient to differentiate benthic habitats; biological groundtruthing must also be carried out (Kenny et al. 2003). Multibeam data must therefore be combined with additional seabed sampling to produce a benthic habitat classification, which in turn must be groundtruthed to ensure accuracy. The combination of methods employed to groundtruth multibeam data depends on the purpose of the habitat mapping, the target species, the size of the area to be covered and the level of detail required.

Multibeam sonar and associated groundtruthing methods form the foundation of a number of large, international, interdisciplinary efforts to map geology and benthic habitats. The Geological Survey of Ireland has recently completed a 7-year, €32-million project to map the Irish Exclusive Economic Zone. This project, the Irish National Seabed Survey (INSS), is the first of its kind in the world (Geological Survey of Ireland 2006). This type of large project is currently being undertaken elsewhere, such as the MAREANO project in Norway which began in October 2005 (Geological Survey of Norway 2006) and the HERMES project in the EU (Hermes Consortium 2004).

The Canadian Seabed Resource Mapping Program (SeaMap) led by the Canadian government, is the first proposed large, integrative seabed mapping project in Canada.

The main objective of SeaMap is to map the Canadian Exclusive Economic Zone (EEZ) out to the 200 nautical mile limit, so that Canada's Oceans Act (1997) can be implemented within this zone. Mapping is also proposed in waters adjacent to the EEZ, so that Canada can claim additional marine territory under the United Nations Convention on the Law of the Sea (Geological Survey of Canada (Atlantic) et al. 1999). Currently funding for the habitat mapping component of the SeaMap programme is still being sought.

1.5 Multibeam Mapping in Atlantic Canada

In Atlantic Canada much multibeam mapping work has been undertaken for mapping marine geology and geomorphology. This work has been primarily focused on the offshore banks, particularly those on the Scotian Shelf (Todd et al.1999; Todd 2005).

A number of multidisciplinary projects related to benthic habitat have also been undertaken, again primarily in Nova Scotia. For example Kostylev et al. (2001) used multibeam sonar to map benthic habitats on Brown's Bank. The Geological Survey of Canada (Atlantic) and the Canadian Hydrographic Service collaborated with the Canadian Offshore Scallop Industry Mapping Group to map scallop fishing grounds on Brown's and German banks (Kostylev et al. 2003). In that study multibeam sonar was used in concert with groundtruthing to determine scallop (*Placopecten magellanicus*) abundance.

Multibeam technology has also been utilised successfully for conservation purposes in Atlantic Canada. The Sable Island Gully was surveyed to assess habitat and biological communities before the area was officially designated as a federal marine protected area in 2004 (Hargrave et al. 2004). The sites of other proposed marine protected areas have also been surveyed using multibeam, including the Race Rocks in

British Columbia and the Musquash Estuary in New Brunswick (Marine Affairs Research and Education 2002a).

1.6 Multibeam Mapping Efforts in Newfoundland

A number of projects employing multibeam technologies have been undertaken in coastal Newfoundland and Labrador. A multibeam bathymetric survey was conducted in St. George's Bay in southwestern Newfoundland in 1995 to refine the results of previous Quaternary geology and coastal mapping (Shaw et al.1997; Shaw and Courtney 1997). A multibeam system was also used to map the Bay of Islands fjord in western Newfoundland in 1997 to interpret Quaternary sediments and examine seabed morphology (Shaw et al. 2000). Tlusty et al. (2000) used multibeam sonar to examine the effects of salmonid aquaculture on the benthos of Bay d'Espoir, a fjord on the south coast of Newfoundland. No literature was found on previous application of multibeam sonar specifically to habitat mapping in Newfoundland, making this thesis the first attempt to do so. Multibeam sonar has previously been applied to habitat mapping in fjordic environments in Alaska (Harney et al. 2006).

In 2001 the Canadian Hydrographic Service conducted a multibeam survey in the Leading Tickles area of Notre Dame Bay, which is an area of interest for a marine protected area under Canada's Oceans Act (1997). In 2002 a similar multibeam acoustic assessment was carried out in Gilbert Bay, Labrador; which has since been designated as a marine protected area (Morris and Power 2004). Therefore multibeam acoustics appear to be a recognised method of assessing marine habitats for conservation purposes in this province.

1.7 Fjords in Newfoundland

The island of Newfoundland has around 100 fjords of varying morphologies, more than any other region of Eastern Canada (Syvitski et al. 1987). Newfoundland's coast is considered to be a fjordic coast because its inlets are glacially carved and usually contain one, if not several, sills separating them into basins.

Newfoundland fjords are primarily wave-dominated, with only a few containing major rivers, therefore inputs of fluvial sediment are generally low. Benthic substrates characteristic of wave-dominated fjords are produced by wave action along the coastline and turbation of glacial sediments on the seabed (Syvitski et al. 1987). Unlike other parts of Canada, none of Newfoundland's fjords contain glaciers or permanent ice; however icebergs transported from the Arctic occasionally enter fjords and may disturb the seabed.

Some fjords in Newfoundland have experienced economic development in recent years. Tourism is increasing within the province and visits to fjords in all parts of the island are now possible, with some acting as major recreation areas. These fjords such as Bonne Bay near Gros Morne National Park and Newman Sound in Terra Nova National Park receive numerous visitors. Fjords also provide effective locations for aquaculture operations. For example, Bay d'Espoir on the south coast of the island has been the site of year-round salmonid aquaculture for over ten years (Tlusty et al. 2000).

1.8 Approach

The potential for coldwater boreal fjords in Newfoundland to be biodiversity hotspots is accepted but documentation requires that a methodology for successfully mapping benthic habitats of fjords be developed. Hence the primary objective of this thesis is to investigate the usefulness of multibeam data collected in a fjord environment for creating a benthic habitat map. Fjord bathymetry and backscatter are predicted to be more spatially heterogeneous and to have a greater range of values than the continental shelves where multibeam technology has previously been applied. Fjords also display more complex topography, different sedimentation rates and nutrient cycles, and are likely less disturbed than the previously mapped continental shelves. Thus fjords present a greater challenge for this mapping strategy.

In this thesis multibeam backscatter will be interpreted with the aid of shallow seismic profiles, grab samples and video imagery to classify substrates within Newman Sound. Since backscatter responds to select substrate characteristics, this approach relies on the close association between substrate and benthic habitat. The bathymetric setting of these substrates will also be considered as bathymetrically controlled variables such as slope, light availability, and seabed disturbance, influence substrate and habitat distribution. The approach therefore also relies on close associations between water depth, seabed morphology and benthic habitat.

Biological diversity was quantified by collection of flora and fauna. Physical variables that contribute to biodiversity within habitats will be noted, and an attempt will be made to delimit habitats with high biodiversity. The ways in which a benthic habitat map of Newman Sound can be used to enhance existing conservation measures, or contribute to new ones will also be discussed.

Chapter 2: Study Area and Methods

2.1 Newman Sound Study Area

2.1.1 Introduction

Newman Sound is a fjord in Bonavista Bay, eastern Newfoundland (Fig. 2.1). The fjord is 34 km long and 2 to 3.5 km wide. Its shoreline is indented with numerous coves, some of which contain gravel beaches. The land around Newman Sound is low-lying and contains numerous ponds and bogs as well as isolated hills up to 228 m high. Many small islands are found in the outer part of the fjord, the largest of which is Swale Island (11 km^2). Freshwater flows into the inner part of Newman Sound via Big Brook, Terra Nova Brook and Salton's Brook and there are several other small streams along the length of the fjord (Canadian Hydrographic Service 1997). The Big Brook estuary at the head of the fjord contains mudflats with salt marsh vegetation and seagrass. Big Brook cuts through glaciofluvial deposits, carrying fine sand into the estuary. Here the modern delta extends 1.5 km past the river mouth, and much of it is exposed at low tide. Terra Nova Brook, Salton's Brook, and Minchin Brook are also currently forming minor deltas (Sommerville 1997).

2.1.2 Geologic Setting

Terra Nova National Park is within the Avalon geologic zone and thus shares geologic features with the Bonavista Peninsula and vicinity. The Avalon zone is composed of a volcanic basement overlain by subaqueously deposited sedimentary rocks (Rogerson 1983). The regional structural geologic trend in the vicinity of Terra Nova National Park is along a southwest-northeast orientation which is reflected by coastal features such as the Eastport Peninsula, Swale Island, Clode Sound and Newman Sound (Jenness 1963).

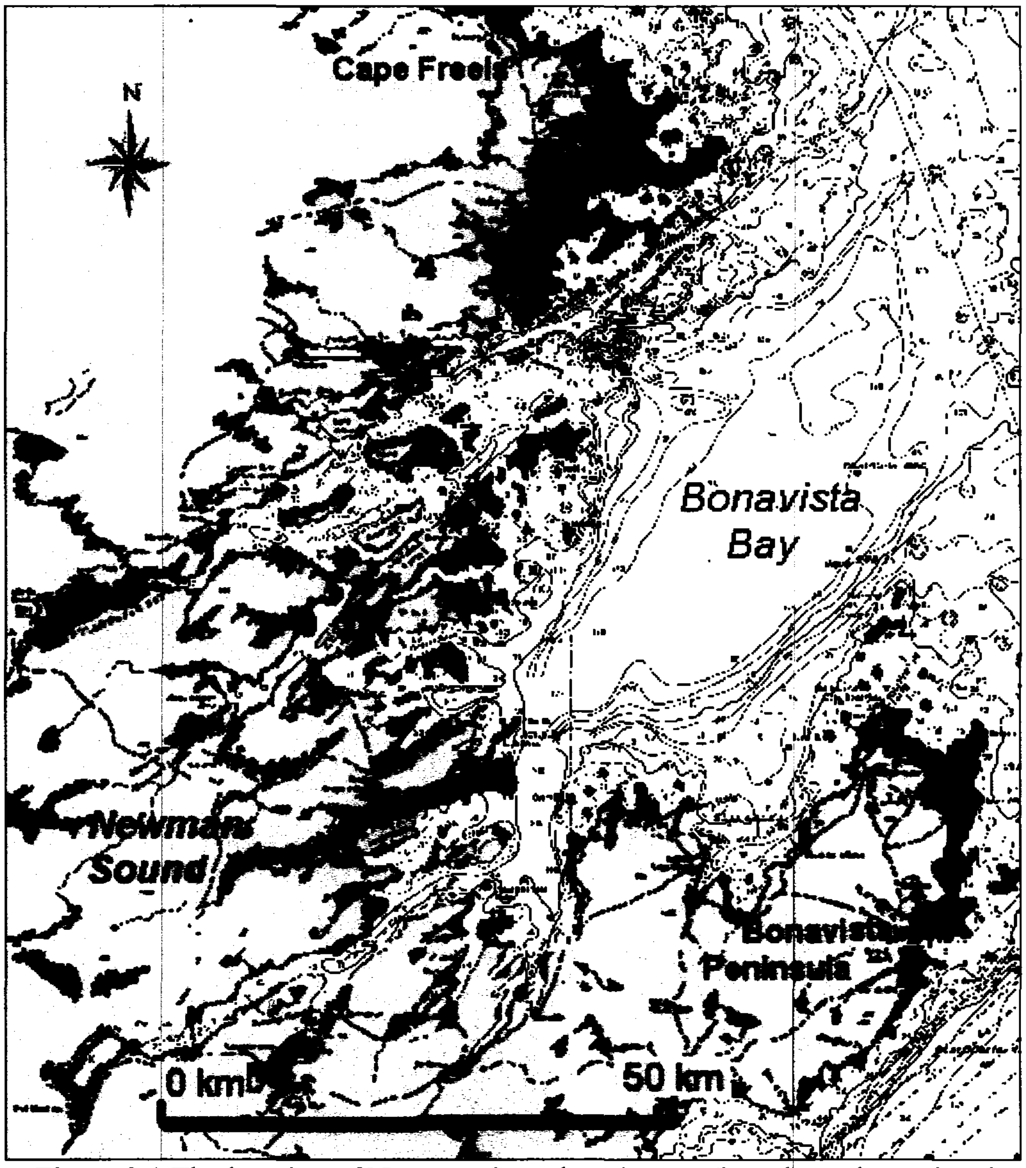


Figure 2.1 The location of Newman Sound study area (in red) on the regional nautical chart of Bonavista Bay.

2.1.2.1 Shoreline Geology

Two geologic groups occur along the shoreline of Newman Sound; the Musgravetown Group and Connecting Point Group. The Connecting Point Group consists of green and black greywacke, cherty quartzite, and slate with some sandstone and conglomerate which underlie the Musgravetown Group (Jenness 1963). Musgravetown Group rocks are red and green, coarse grained conglomerates with subgreywackes, and interbedded volcanic rocks (Jenness 1963). Sommerville (1997) describes the Musgravetown group as terrestrial sedimentary and volcanic rocks, and the Connecting Point Group as altered marine clastic sedimentary rocks.

The Musgravetown Group trends north-northeast along the western edge of inner Newman Sound (Fig. 2.2). At Big Brook a fault on the eastern side of the estuary separates the siliclastic sediments of the Musgravetown Group from the mafic and felsic volcanic rocks of the Connecting Point Group (Jenness 1963; Davenport et al. 1994). These volcanic rocks of the Connecting Point Group are found along the eastern shore of the inner sound as well as the northwestern shore between Salton's Brook and the Narrows (Fig. 2.3). The shoreline of Newman Sound seaward of the Narrows, including the Eastport Peninsula and Swale Island, are recorded as turbidites (Davenport et al. 1994) belonging to the Connecting Point Group (Jenness 1963).

2.1.2.2 Faults

The Clode Sound Fault is thought to cross Newman Sound perpendicular to the long axis of the fjord and continue north-eastward to Eastport Bay (Fig. 2.2). Jenness identifies this fault as "maybe one of the most important structural elements in the entire Bonavista Bay area" (Jenness 1963). The exact location of the fault on the seabed is unknown, but a

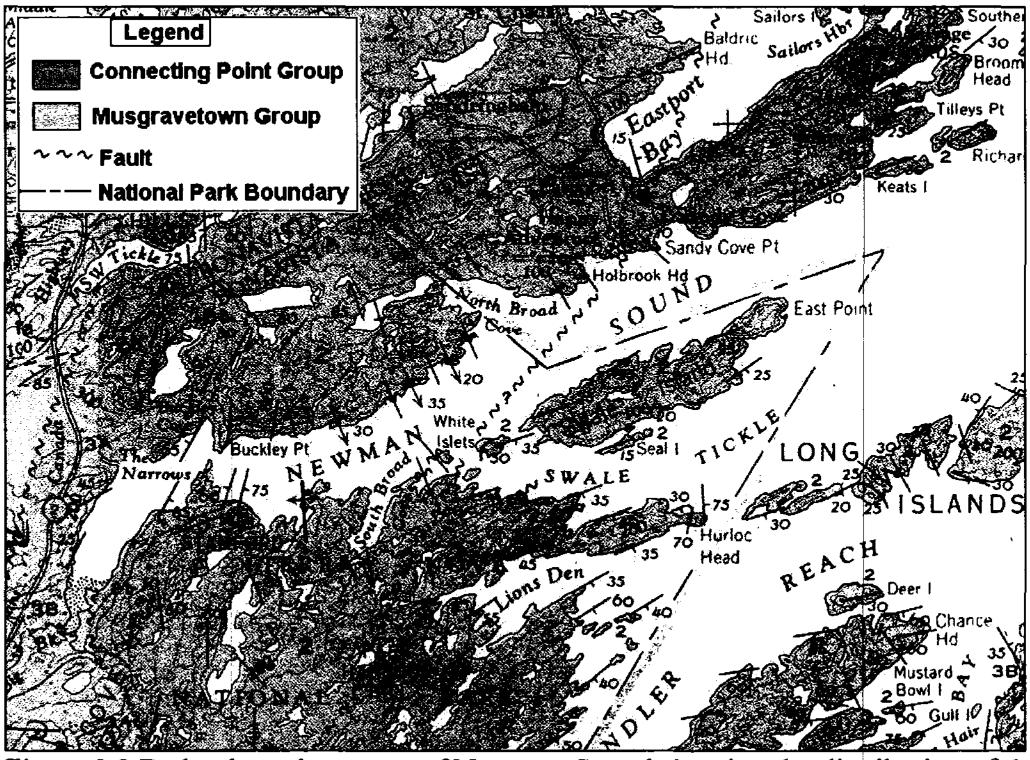


Figure 2.2 Bedrock geology map of Newman Sound showing the distribution of the Connecting Point Group and Musgravetown Group. From Jenness 1963.

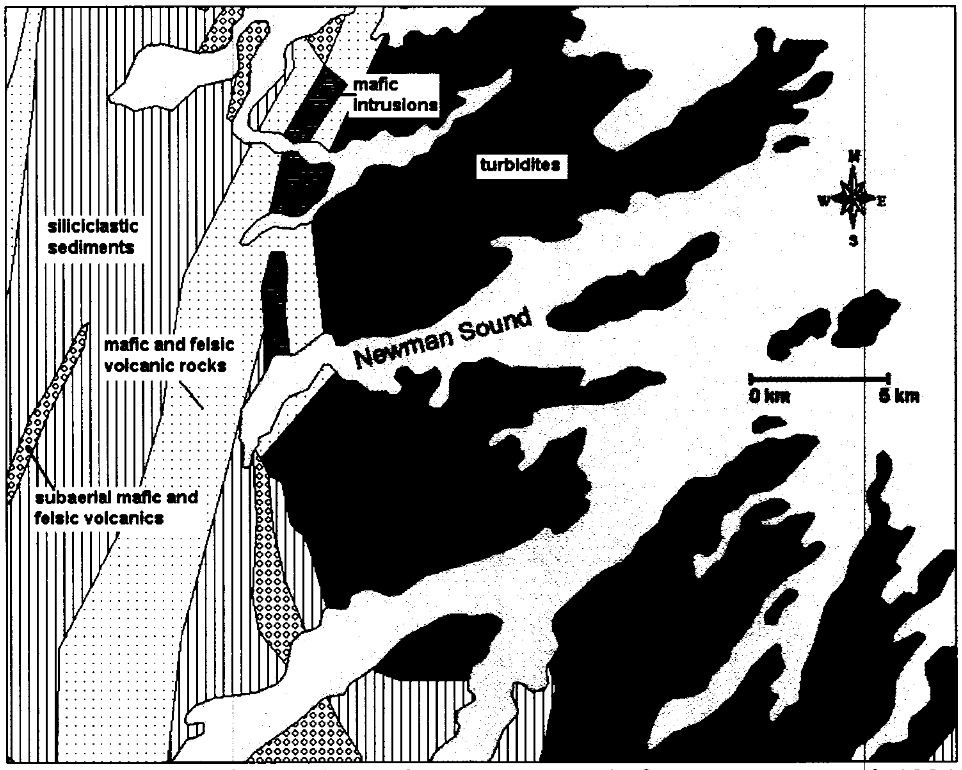


Figure 2.3 Shoreline geology of Newman Sound after Davenport et al. 1994.

channel found during the bathymetric survey may be evidence of the influence of this fault on the seabed morphology (see section 3.2.1.2).

2.1.3 Glacial History

During the Late Wisconsinan (~ 20,000 years before present) glaciers advanced from the southwest into Bonavista Bay. Subglacial depositional features found near Newman Sound, such as drumlins and till ridges, follow a southwest-northeast orientation providing evidence for the direction of ice movement (Sommerville 1997). Further evidence is provided by the sub-rounded clasts and boulders of distinctive Terra Nova granite that are common on the shore of Newman Sound. The Terra Nova granite intrusion is southwest of Terra Nova National Park, near the village of Terra Nova. These boulders therefore were moved by glacial ice in a northeasterly direction to be deposited in Newman Sound (Sommerville 1997). The ice retreated up Newman Sound during deglaciation, and reached the present coast 13,000 years before present, leaving the fjord valley to be flooded by the deglacial high sea level (Sommerville 1997).

2.1.4 Holocene Sea Level History

The elevations of raised deltas at Traytown and Eastport indicate that the marine limit for Terra Nova National Park was 39 m above sea level (asl) during deglaciation. Dating of marine shells from St. Chad's indicates that this maximum sea level occurred between 12,800 and 12,400 years before present (Sommerville 1997). During this time a number of deltas formed around Newman Sound which can now be seen as raised marine features marking the limit of Holocene sea level rise. These include the delta at Sandy Cove (30 m asl) and Happy Adventure (31 m asl), as well as unmeasured deltas at Buckley Cove, Salton's Brook and Big Brook (Jenness 1963; Sommerville 1997).

Isostatic rebound of the coast following deglaciation caused sea level to fall to a minimum of 17 m below present sea level prior to 8,600 years ago. Thereafter sea level rose again, and present sea level was reached around 2,000 years before present (Sommerville 1997).

2.1.5 Tides and Currents

The tidal range in Newman Sound is around 1 m throughout the fjord. The water circulation of the fjord has not been studied however, due to the shape of the fjord tidally-driven circulation is expected. There is also evidence of significant tidal current movement across the shallow sill at the Narrows.

2.1.6 Hydrography and Oceanography

The southward flow of the Labrador Current brings cold water to the east coast of Newfoundland, consequently it is colder than the west and south coasts, and provides a different benthic environment (Hooper et al. 2002). Conductivity, temperature and depth (CTD) data have been collected in Newman Sound by Fisheries and Oceans Canada since 1983. They vary seasonally, indicating that the water column in the fjord is well mixed in the winter and stratified in the summer.

2.1.6.1 Temperature

Cote et al. (2001) noted strong horizontal temperature stratification at their Buckley Cove study site in late summer and early autumn. August appears to be when the water column is the most stratified as the temperature range within each station is the greatest, with cold water near the bottom. The lowest water temperature in the data set (−1.276°C) was recorded in August at station 6 at 47 m water depth in the inner sound near Salton's wharf (Fig. 2.4). Of the 11 stations which had temperatures of 0°C or less at the seabed, 8 were

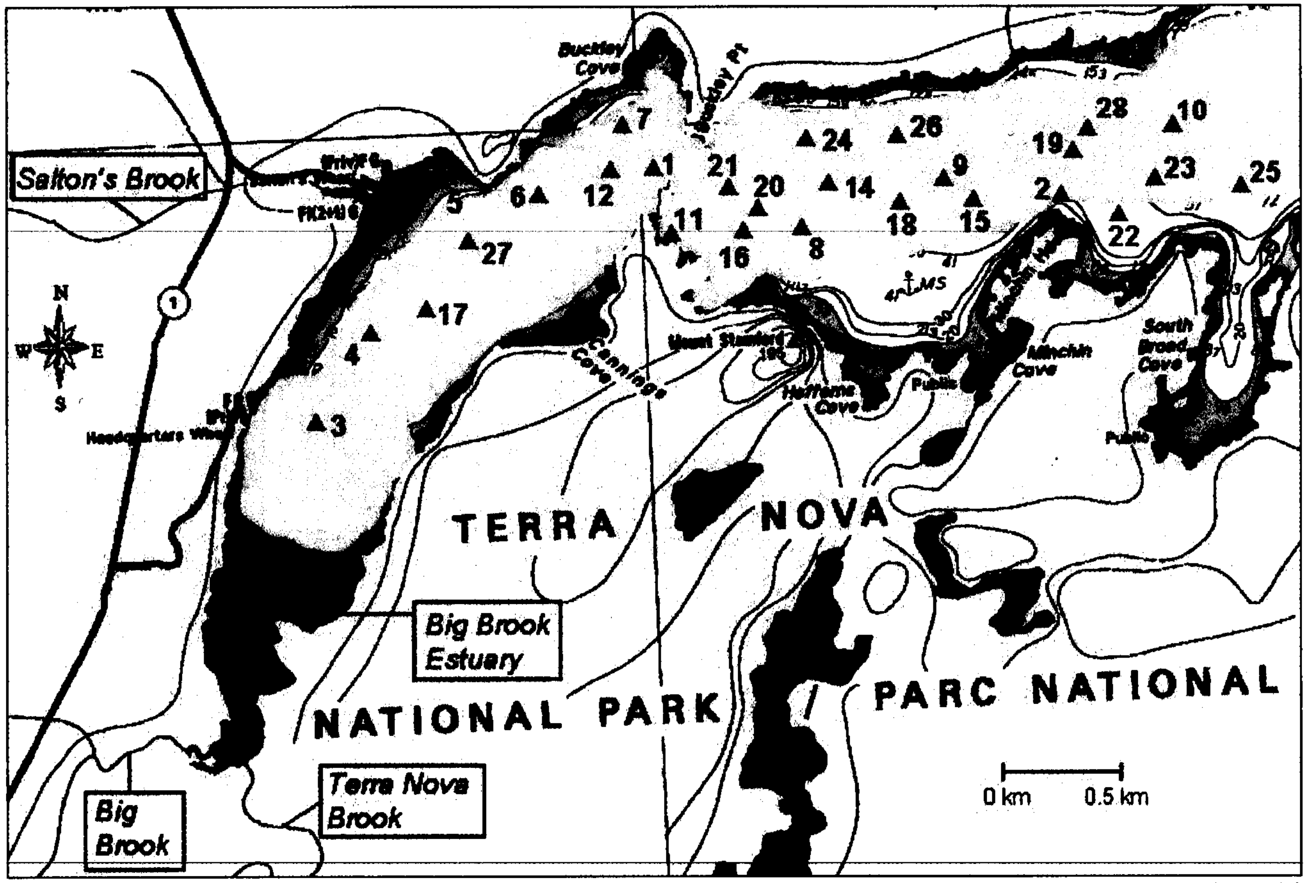


Figure 2.4 Conductivity, Temperature and Depth (CTD) stations from Fisheries and Oceans Canada archive on survey area (grey) and Newman Sound chart. Original station numbers are found in Appendix D.

in inner Newman Sound. This suggests that cold oceanic water is entering the inner sound, and therefore that the sill at the Narrows is not restricting water exchange.

2.1.6.2 Salinity

Inputs of freshwater from Big Brook, Salton's Brook and Terra Nova Brook (Fig. 2.4) into the inner sound would be expected to reduce its salinity as the inner sound is an enclosed basin. However, the CTD stations in the inner sound did not appear to be less saline than those outside the sill. In fact the maximum salinity recorded in the dataset (32.7 ‰) was in Buckley Cove, whereas the lowest (30.8 ‰) was off Minchin Head. This also indicates that the sill across the Narrows does not restrict water circulation. A table of CTD data ranges for stations in Fig. 2.4 can be found in Appendix D.

2.1.7 Conservation History

Newman Sound is surrounded on three sides by Terra Nova National Park, which was established in 1957 (Fig. 2.5). No development is permitted on the coast landward of the mean low water mark under Canada's National Parks Act (1930) however, marine habitats below this mark are unprotected (Beardmore 1985).

Efforts by Parks Canada to protect shorebirds and seabirds outside the park boundaries led to the establishment of the Terra Nova Migratory Bird Sanctuary in 1967 (Anderson et al. 2000). The sanctuary protects birds from hunting and other harmful activities and includes 8.6 km^2 of inner Newman Sound.

2.1.7.1 Marine Protected Areas in Bonavista Bay and Newman Sound

The marine habitats of Newman Sound are currently of conservation interest to a variety of stakeholders. In 1997 the Eastport Peninsula Lobster Protection Committee contacted the Department of Fisheries and Oceans to request that only traditional users be allowed

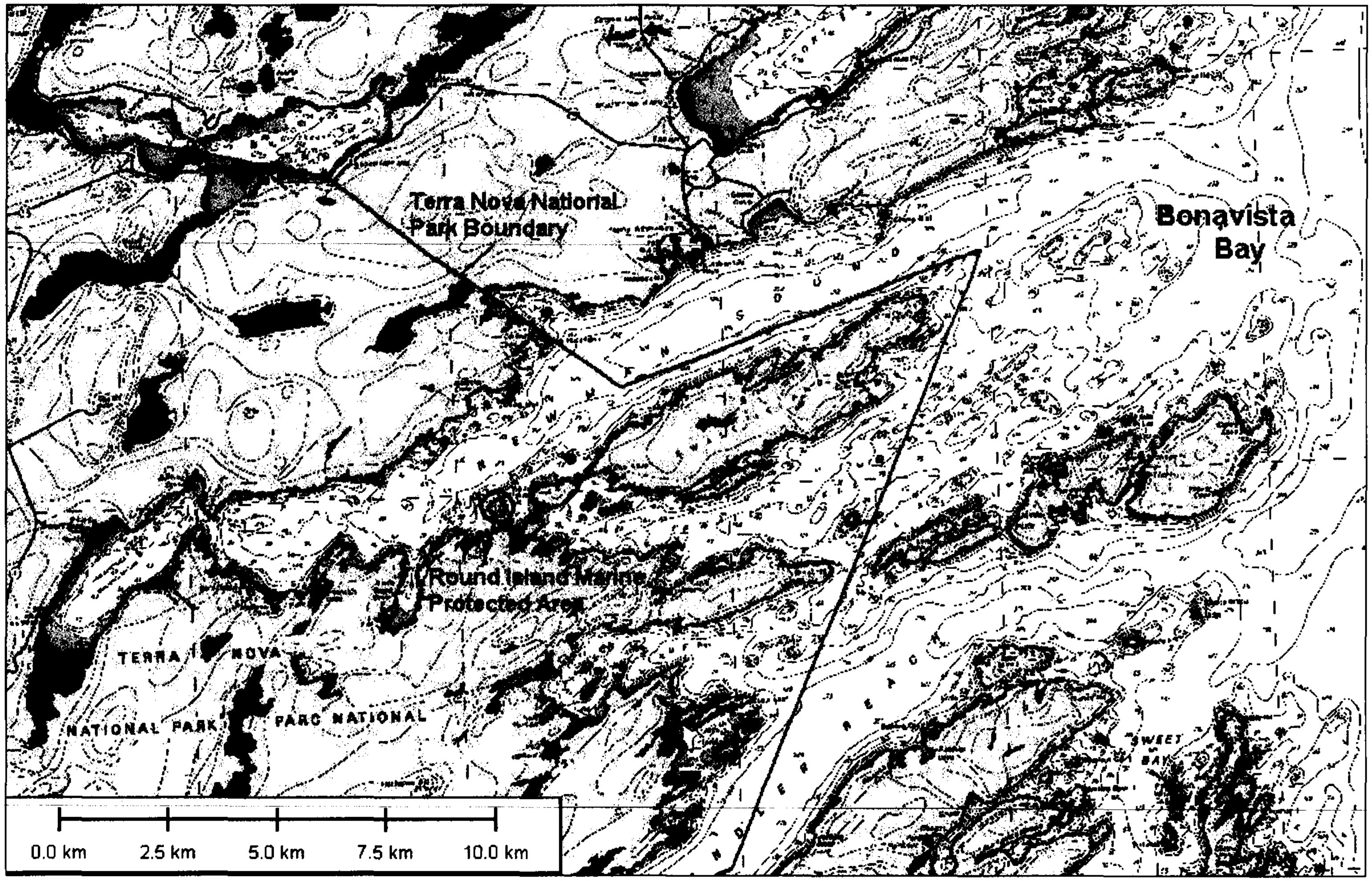


Figure 2.5 Nautical chart of Newman Sound showing the Terra Nova National Park Boundary and the location of the Eastport-Round Island Marine Protected Area.

to harvest lobster around the Eastport Peninsula, in what became known as the Eastport Peninsula Lobster Management Area. They also suggested that the waters around Round Island in the White Islets of Newman Sound and the Duck Islands, Bonavista Bay be closed to all lobster fishing. As a result, the Round Island no-take zone became the first marine protected area in Newman Sound.

As a result of the demonstrated success of these two small no-take areas, the Eastport Peninsula Lobster Protection Committee approached the Department of Fisheries and Oceans in 1999 to establish a marine protected area (MPA) at Eastport under Canada's Oceans Act (1997). The proposed MPA would protect habitat for commercially valuable species such as lobster, as well as endangered or threatened species such as the wolfish. The Eastport-Round Island Marine Protected Area was formally gazetted in June 2005, making it illegal to remove organisms or damage habitats within 198.12 m (650 ft.) of the low-water line around the island (Fig. 2.5). Regulations for the protected area were drawn up by the Eastport MPA Steering Committee and are currently enforced by the Department of Fisheries and Oceans (Government of Canada 2005).

2.1.8 Previous Research in Newman Sound

2.1.8.1 Mapping

Acoustic mapping of the benthos of Newman Sound has previously been carried out to characterise the substrate and examine fish habitat. In 1997 benthic habitats in part of Newman Sound were investigated by Anderson (2001) using the QTC View seabed classification system to determine substrate from normal incidence acoustic data. This classification was groundtruthed during two submersible transects. The most common substrate along these two transects was bedrock (78% of total), followed by gravel (12%) and cobble (9%). Sparse, moderate and dense algae were also recorded (Anderson 2001).

Anderson et al. (2002) reported the acoustic properties of four simplified seabed types encountered in coastal Newfoundland. They described mud as low relief, soft and with smooth surfaces. Gravel had low relief, was harder and had a rougher surface. Rock bottoms were the hardest, with higher relief, but a relatively smooth surface. Areas of rock with attached macroalgae were hard with variable relief and high surface roughness. These observations of Newfoundland habitats and their acoustic properties were valuable during interpretation of the multibeam data in this study.

Cote et al. (2004) produced a map of benthic habitats used by juvenile Atlantic cod (*Gadus morhua*) in inner Newman Sound. This map was produced using a tethered video camera, lowered at points on a grid, to characterise the benthos. Benthic substrates were classified as sand, gravel or boulder/cobble and the presence of eelgrass and kelp was noted. These existing maps show benthic substrate and juvenile fish habitat; however no comprehensive benthic habitat map exists for Newman Sound. This thesis aims to fill this knowledge gap.

2.1.8.2 Other work

Other than mapping, most of the existing research in Newman Sound relates to juvenile fish, particularly Atlantic cod, and eelgrass. Newman Sound is known to be a nursery for juvenile cod and investigations into their ecology are ongoing (Gregory et al.1997; Cote et al. 2001, 2004). Small juveniles rely on eelgrass habitats in shallow water, which were previously mapped from the air (Forsyth and Borstad 1999).

2.2 Methods

2.2.1 Acoustic Surveys

2.2.1.1 Multibeam Sonar Survey

The multibeam survey of Newman Sound was conducted in July 2003 by the Canadian Hydrographic Service under a joint project agreement with Dr. Trevor Bell, Geography Department, Memorial University of Newfoundland. A Simrad EM 1002 multibeam echo sounder, hull mounted on the *CCGS Matthew*, was used for the deep water component of the survey. A hydrographic launch deployed from the *Matthew* carried out surveys in selected shallow-water bays and the fjord head estuary. The launch was equipped with a Simrad EM 3000 system.

The EM 1002 system has 111 beams, which cover an arc of 150°. This system is used for mapping in deep water and is usable to 600 m depth or more. The across-track coverage of the swath for the EM 1002 is advertised as 7.4 times water depth in shallow water, and up to 1500 m in deeper water. The frequency of the EM 1002 is 95 kHz (Kongsberg Simrad AS 2005).

The EM 3000 system is designed to work in water as shallow as 1 m and provides good data to about 150 m water depth. It has a swath capability of ten times water depth, but only up to a swath width of 200 m (Kongsberg Maritime AS 2005). Therefore to get 100% bottom coverage in shallow water a larger number of survey lines must be run close together, making shallow-water surveys more time consuming. The frequency of this system is 300 kHz (Kongsberg Maritime AS 2005).

Some overlap between adjacent survey lines is always necessary to account for beam loss at the edges of the arc. The area of seafloor insonified by each beam in a multibeam system depends on the position of the beam in the arc and therefore the angle at which it will contact the seabed. The beams nearer to the point directly below the ship (nadir) will travel straight from the sonar head, through the water column to the bed, and back to the sonar receiver. Beams on the outer edges of the arc will travel to the seabed at an angle so the return echo from these beams must be corrected for ray bending (Lurton 2002). The EM 3000 multibeam system compensates for ray bending (Maritime AS 2005).

Another factor that must be compensated for is vessel movement. Due to the centimetre-scale resolution of some multibeam systems (Dartnell and Gardner 2004) the vertical movement of a ship in heavy seas, a change in the tide or changes in the forward speed of the ship all effect the accuracy of the water depths obtained from a multibeam sounder. For further discussion of sources of error in multibeam surveys and their potential impacts on the data set, see Hughes Clarke et al. (1996).

The survey data were processed by the Geological Survey of Canada (Atlantic) at the Bedford Institute of Oceanography in Bedford, Nova Scotia. The raw bathymetric data were manually cleaned in HIPS (Hydrographic Information Processing System) software to remove erroneous depth values. The cleaned bathymetric data, (in HDCS format) were imported into a GRASS (Geographic Resources Analysis Support System) GIS system and gridded at a 10 m resolution. In GRASS the bathymetric data were colour shaded by depth and artificially illuminated to produce a bathymetric image. The raw backscatter data were imported into a backscatter routine run in the GRASS GIS. The data were again gridded into 10 m cells and normalised to 45 degrees using a 200 ping running average.

For this thesis, text files containing multibeam bathymetry and backscatter values, provided by the Geological Survey of Canada (Atlantic), were projected in Global Mapper as separate raster layers. The multibeam data sets were overlain on a commercially available digital nautical chart of Newman Sound and projected in UTM zone 21 using the NAD 83 datum.

2.2.1.2 Shallow Seismic Survey

Sub-bottom profilers were suggested by Kenny et al. (2003) as an appropriate method for measuring sediment thickness - and potentially infauna - in order to construct habitat maps. Sub-bottom profilers were also used by Kostylev et al. (2001) in construction of benthic habitat maps for Brown's Bank on the Scotian Shelf.

The shallow seismic survey of Newman Sound was conducted November 17-18 2003 aboard the Memorial University Marine Institute vessel *Louis M. Lauzier*. Sub-bottom profiles were collected using an IKB Seistec sub-bottom profiler operated by IKB Technologies Limited. The results were printed by an EPC grey scale recorder (Simpkin 2003). The Seistec system employs a seismic boomer and a line-in-cone receiver as described by Simpkin and Davis (1993). The boomer was towed on a catamaran sled equipped with a Trimble GPS unit. The catamaran was maintained at a speed between 4.2 and 4.5 knots during the Newman Sound survey. The Seistec boomer provided high resolution coverage of the seabed, but did not allow deep penetration of the sediment package; however, this was sufficient for benthic habitat mapping.

The inbound leg of the seismic survey followed the long axis of the fjord from Bonavista Bay to the head of the inner basin. The outbound survey crossed the fjord from side to side and proceeded from the head of the inner sound to the mouth of the fjord (Fig.

2.6). The survey lines from both legs covered 64.5 km. Water depths covered by the seismic survey ranged from over 300 metres to about 10 metres. Because of this range and the fact that depth changes occurred sharply in the fjord, the acoustic delay and the sweep were changed frequently during the survey to provide the best quality output (Simpkin 2003). The thickness of each sediment layer identified from the seismic record was calculated based on the sweep rate. Time markers on the seismic record sheet were plotted in Global Mapper using the positions recorded by the Seistec at the time of the survey. These points were overlain on the multibeam sonar data and depth (m) and backscatter (−dB) were determined to aid in interpretation of the surface units.

2.2.2 Groundtruthing

Directly sampling the seafloor allows verification of the interpretation of the acoustic and geophysical data collected. Direct sampling also provides both qualitative and quantitative information regarding the seafloor substrate and associated biotic community. In this project two types of groundtruth samples were collected; benthic grabs and video. Each of these groundtruthing methods had its own strengths and weaknesses, so distribution of sampling effort was designed with this in mind.

Grab sampling is a widely used method for collecting both benthic sediments (Larsen 1997; Todd et al. 1999; Kostylev et al. 2001) and invertebrate fauna (Larsen 1997; Holte and Gulliksen 1998; Sejr et al. 2000; Oug 2000). Grab sampling was also mentioned in the literature as a useful method for groundtruthing multibeam sonar (Todd et al. 1999; Kostylev et al. 2001; Kenny et al. 2003). The advantage of grab sampling is that a physical sample is recovered which allows detailed description, grain size analysis, chemical and organic content analysis. Grab sampling also recovers any invertebrates

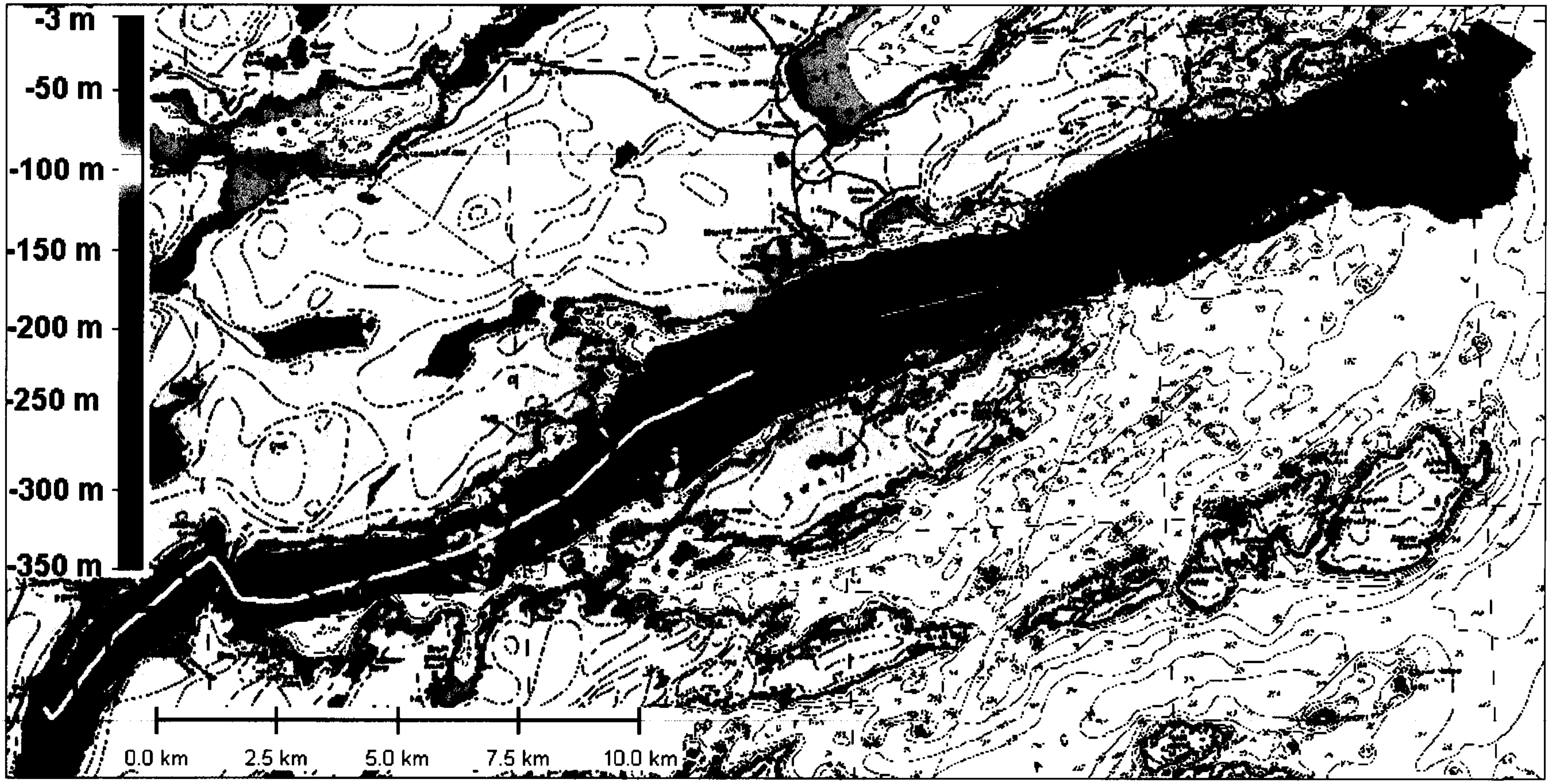


Figure 2.6 Survey track for inbound (white) and outbound (black) legs of the shallow seismic survey overlain on multibeam bathymetry data and Newman Sound chart.

present so that they can be counted and identified using a microscope where necessary. Grab samplers penetrate the upper surface of the sediment (the depth depends on the sampler) so subsurface sediments and shallow burrowing fauna can be sampled.

The main drawback to using grab sampling to examine the benthos is that it provides a very detailed look at a very small area and cannot show biota or substrates in context. For example, topographic features and species associations with them cannot be seen in a grab. Similarly species associations with other biota are not often seen as the contents of the grab are mixed together. Also, grab samplers are unlikely to sample mobile fauna or large species, and cannot sample large substrates like boulders.

Video provides a broader view of the underwater landscape than grab sampling by capturing the types of substrates and bedforms present. Hard substrates, steep slopes and large material that would be missed by a grab can be seen by video. Video is also capable of sampling large, mobile organisms and the associations of species with each other and with the substrate. Most importantly it does so without disturbing the substrate or biota. The drawback of using video is that only the surface of the substrate is sampled, giving little or no indication of the infauna. Also organisms are more difficult to identify and count on a screen than from specimens, and most small or cryptic species would be missed entirely. Detailed grain size descriptions are also impossible from video samples. Video was an asset to this project as it provided data over a larger area than grab sampling.

2.2.2.1 Benthic Grab Samples

In order to effectively groundtruth the multibeam data set, grab sample locations were chosen to cover as wide a range of water depths and backscatter intensity values as possible. For this project a Peterson grab sampler was used. This type of sampler is deployed open and closes under its own weight when it contacts the bottom and tension on the cable is released. The valves of the grab were weighted to improve bottom penetration.

Grab sampling was carried out in November 2003, July and September 2004 and May 2005 at 78 sampling locations in Newman Sound. During this time 89 attempts were made to collect benthic grabs and gravity cores, of which 67 were successful. Of the 67 collected samples, 4 were collected by gravity coring. As only a small amount of surface material was collected in the cores (with one exception), they were processed in the same manner as grab samples.

In November 2003, grabs and cores were collected in water depths ranging from 4 to 315 m in both the inner and outer sound aboard the MUN Marine Institute vessel *Louis M. Lauzier*. All subsequent grab sampling trips were conducted aboard *Lucky I*, a boat owned by Fisheries and Oceans Canada. On these trips sampling was limited to less than 100 m water depth and samples were only collected west of the White Islets. Samples collected on the later trips ranged from 7 to 95 m water depth.

The grab samples taken in 2003 were collected before data from the multibeam survey had been mapped. Therefore 9 of the 78 grab sampling stations are in shallow water not included in the multibeam coverage. These samples were still useful and are included with the other grab data, but their backscatter values are missing.

Backscatter values successfully sampled by grabs ranged from −58.5 dB to −2 dB however, grab sampling success was limited on substrates with backscatter higher than −10 dB. At 19 stations the grab sampler was recovered closed, but contained no sample. Each time no recovery was made, a second attempt was made at the same location, and at 5 of the 19 stations a recovery was made on the second attempt. No second attempt was made at station 108 due to mechanical failure of the winch used to deploy the sampler. A second attempt at 13 other stations provided no sample. In these cases the substrate was assumed to be too hard, too large or too compacted for the sampler to collect.

Grab sampling targeted features of interest that were seen from the shallow seismic survey and the multibeam sonar survey. Therefore clusters of grabs were collected in the Narrows, at the White Islets, at the head of the inner basin and near Hefferns Cove (Figs. 2.7 to 2.11).

When a grab sample was recovered a sub-sample of the sediment was collected in a numbered plastic bag. An attempt was made to not disturb the sample so the fine sediment matrix would not be lost. The sediment bags were frozen within a few hours of collection. The bulk of the sample was sieved in seawater through a 1 mm mesh to wash out the remaining matrix so that biota could be located. Invertebrates and algae were collected with forceps and placed in numbered jars containing 95% ethanol mixed with seawater. Fragile organisms such as small polychaetes were placed in separate jars to avoid damaging them. In most cases all the organisms were kept, but when a species was very abundant only a few individuals were taken and abundance was noted. The biological samples in ethanol were kept in a cooler until they could be refrigerated.

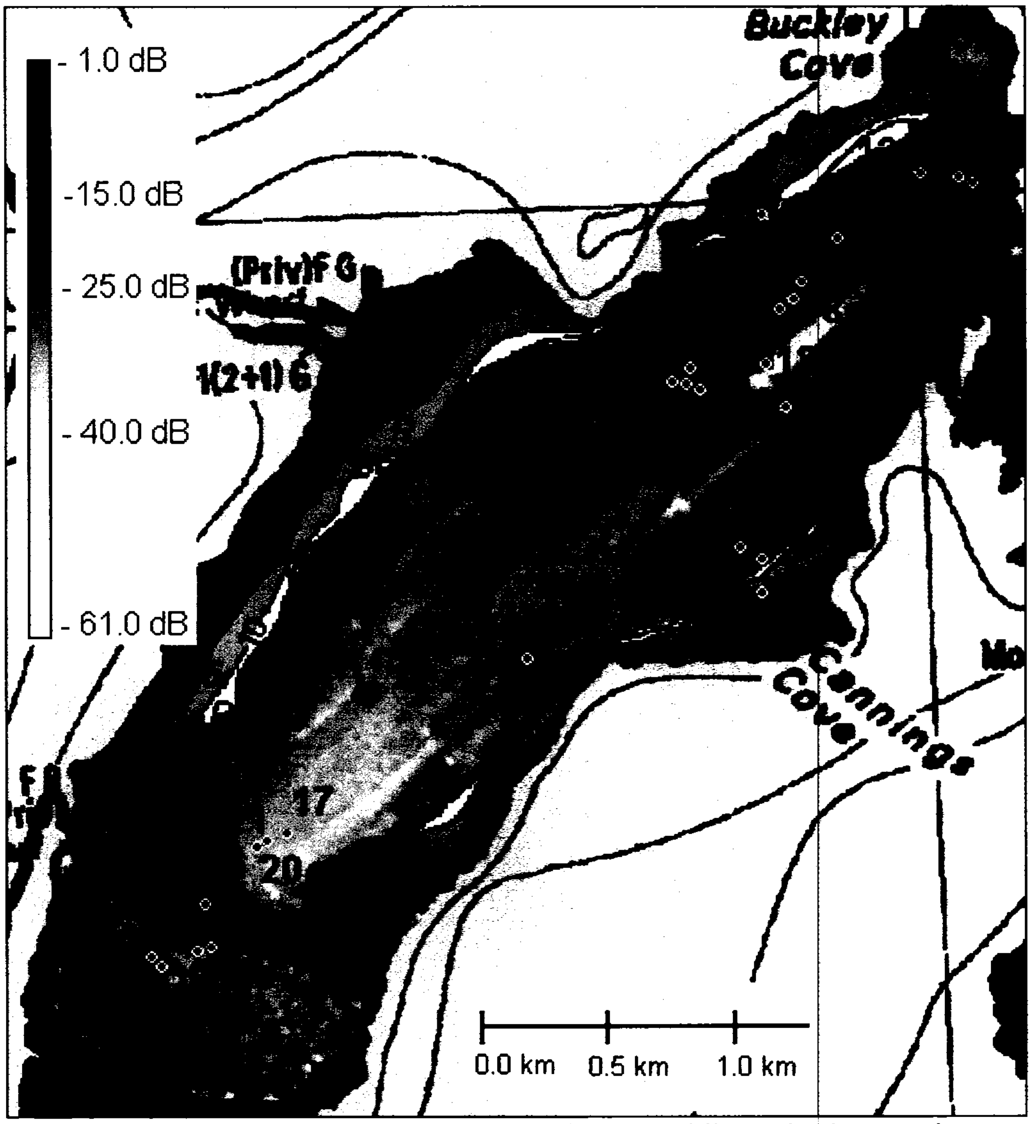


Figure 2.7 Location of inner basin grab samples on multibeam backscatter image and Newman Sound chart.

Figure 2.8 Location of grab samples in the Narrows and immediate area on multibeam backscatter image and Newman Sound chart.

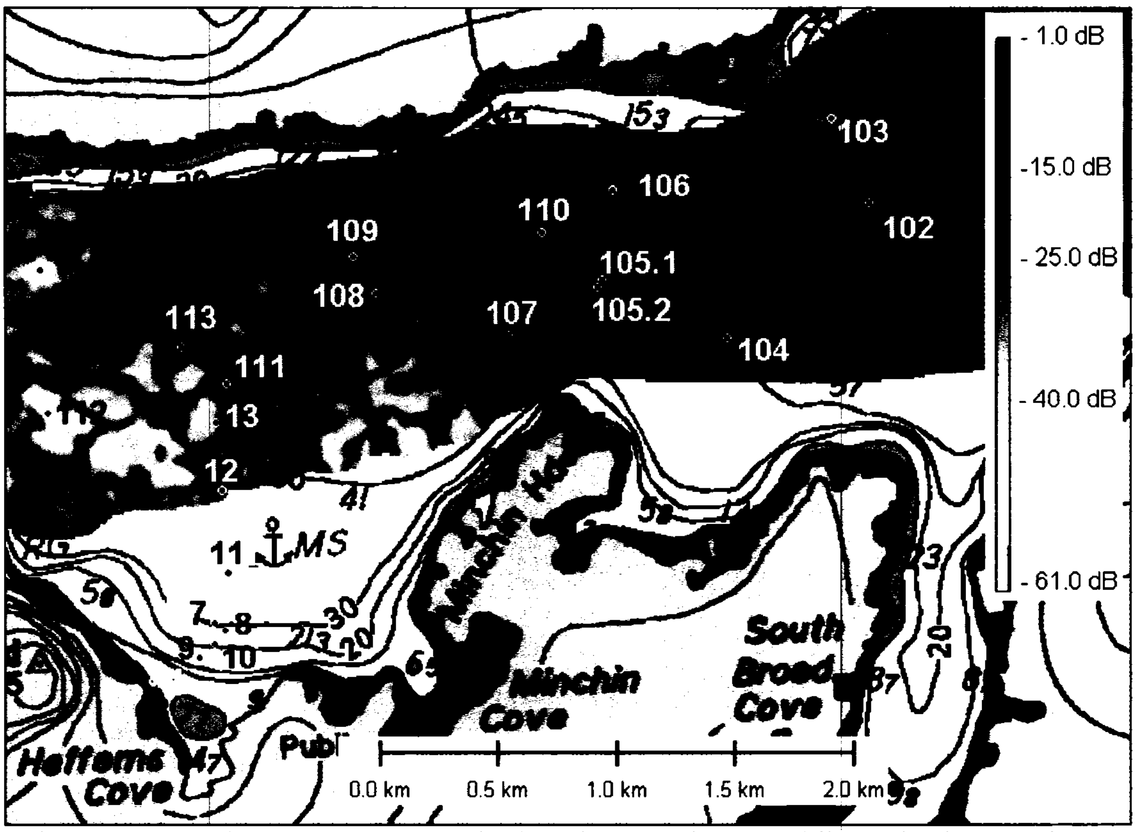


Figure 2.9 Location of grab samples in the middle basin on multibeam backscatter image and Newman Sound chart.

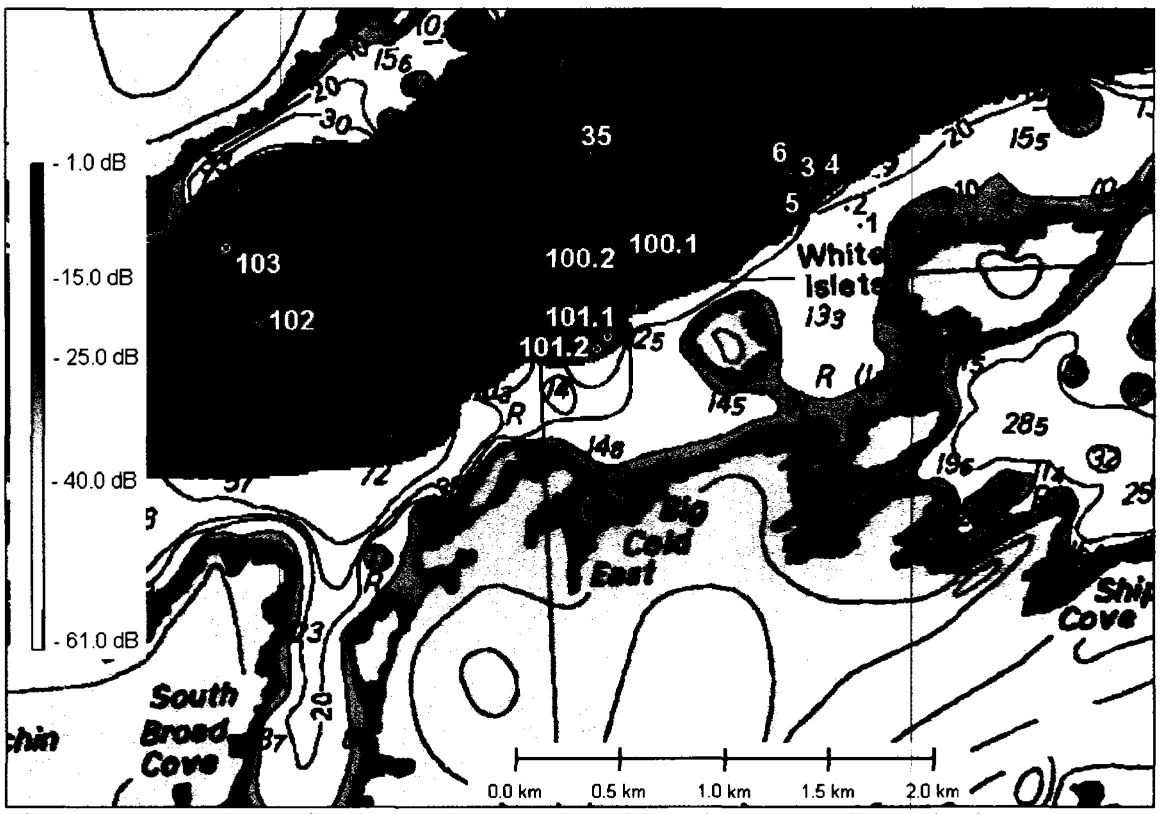


Figure 2.10 Locations of grab samples near the White Islets on multibeam backscatter image and Newman Sound chart

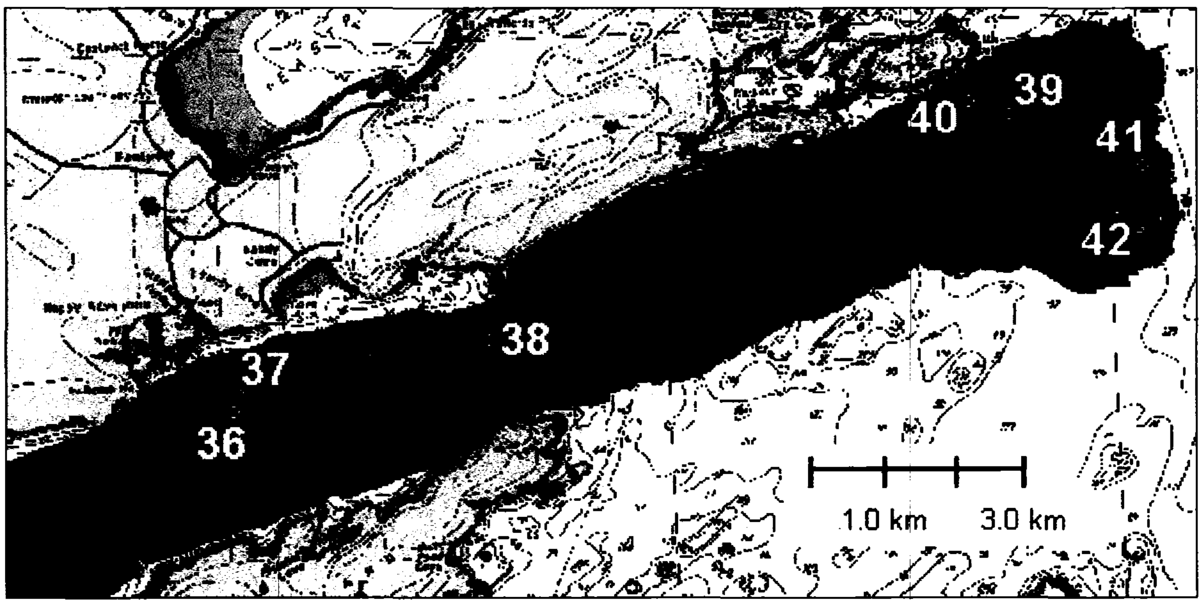


Figure 2.11 Locations of grab samples collected in the outer sound on multibeam backscatter and Newman Sound chart

2.2.2.2 SCUBA Diver Video Transects

Parts of Newman Sound that were covered by the multibeam survey were also shallow enough to be sampled by SCUBA divers. All dives were planned at depths shallower than 20 m (65 ft) in accordance with Memorial University of Newfoundland regulations for science divers in training. As much of the shallow water had not been covered by the multibeam, only 13 sites were chosen for diving (Fig 2.12). Dive sites were selected at Buckley Cove (n = 3), the eastern side of Buckley Point (n = 3), Mt. Stamford Cove (n = 3), southeast of the Narrows (n = 4) and one practice dive west of the island in the Narrows. Due to time constraints only 8 of the 13 sites were sampled using SCUBA. Dives were completed in water ranging from 6.6 to 12.8 m deep, on substrates with backscatter values between −7.68 and −58.71 dB.

Each transect was 50 m in length and chosen to be representative of backscatter values found in shallow water. Dives were planned by selecting a target start point and determining a compass direction to be followed by the divers. All transects were aligned to follow depth contours on the bathymetric chart so that a relatively constant depth was maintained during the dive.

The SCUBA video transect surveys were carried out by two divers; one operated the video camera while the second rolled out a 50 m long measuring tape. All video was collected using a Sony digital video camera in an Amphibico housing. A Garmin 12 GPS was used to record the start and end points of each transect. Diving surveys were completed between July 16th and 19th 2004 from a Fisheries and Oceans Canada boat.

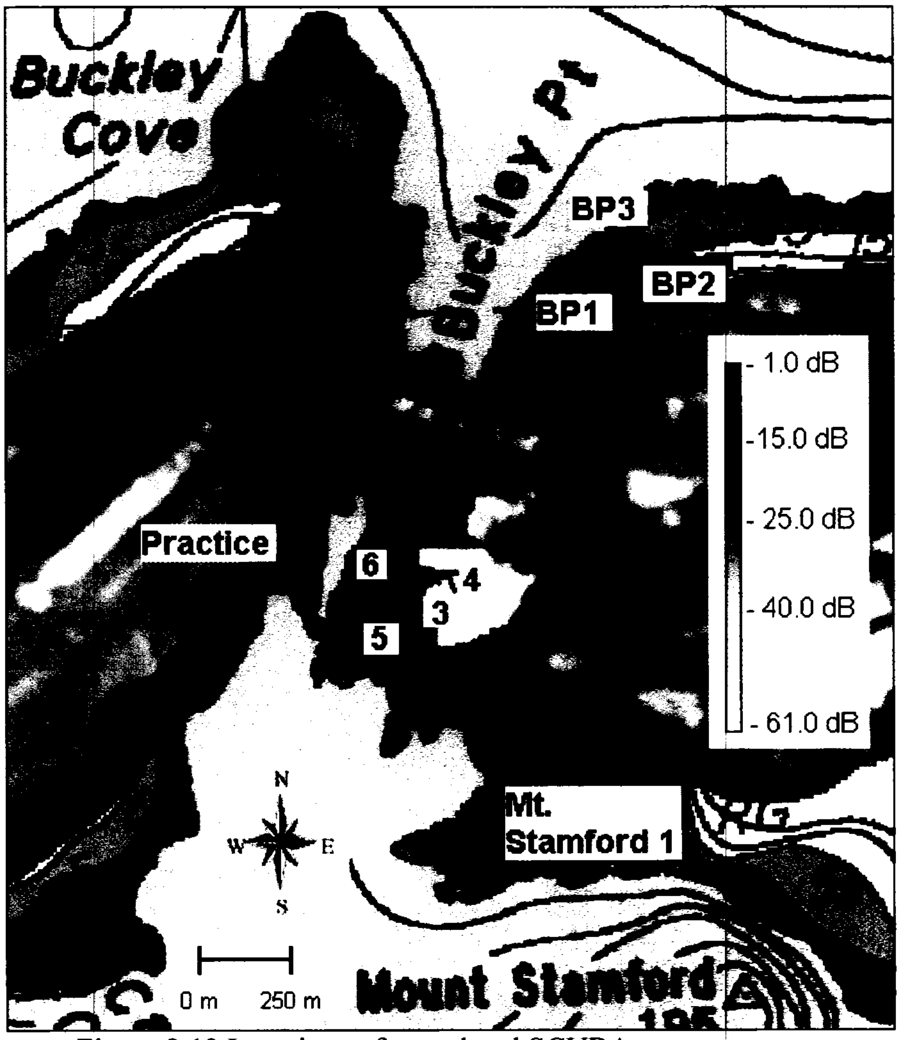


Figure 2.12 Locations of completed SCUBA transects on multibeam backscatter image and Newman Sound chart.

2.2.2.3 Drop Video Camera

A drop camera is a surface tethered video camera deployed from a stationary vessel. This method of video collection was employed because the camera can be deployed easily and quickly so many points can be sampled in a short time. This method was used previously in Newman Sound by Cote et al. (2004). Drop camera stations were chosen from the multibeam data to cover a range of depth and backscatter values. Particular attention was paid to locations with high backscatter and sites where grab sampling had failed. Drop camera stations were only planned in less than 100 m water depth due to the capabilities of the equipment.

A total of 30 drop camera stations had been planned but due to inclement weather only 19 were sampled from the inner basin, the Narrows and the north side of the mid-fjord as far east as South Broad Cove (Fig. 2.13). The camera used was a SeaView BW-150 owned by Parks Canada and deployed from a Parks Canada boat on November 30th 2004. The camera recorded black and white video imagery on VHS cassettes via a TV/VCR. A position was recorded with a GPS at the start of every station and at the end of most stations as drifting occurred; therefore 34 geo-referenced data points were collected. In some cases the substrate types at the start and end of a station were different, so the points were each treated as individual samples. Locations sampled with the video drop camera ranged in depth from 8 to 81 m. Backscatter values ranged from −7.4 to −56.6 dB. As one of the aims in planning drop camera stations was to cover places which had been unsuccessfully sampled with the grab, a larger proportion of high backscatter locations were sampled.

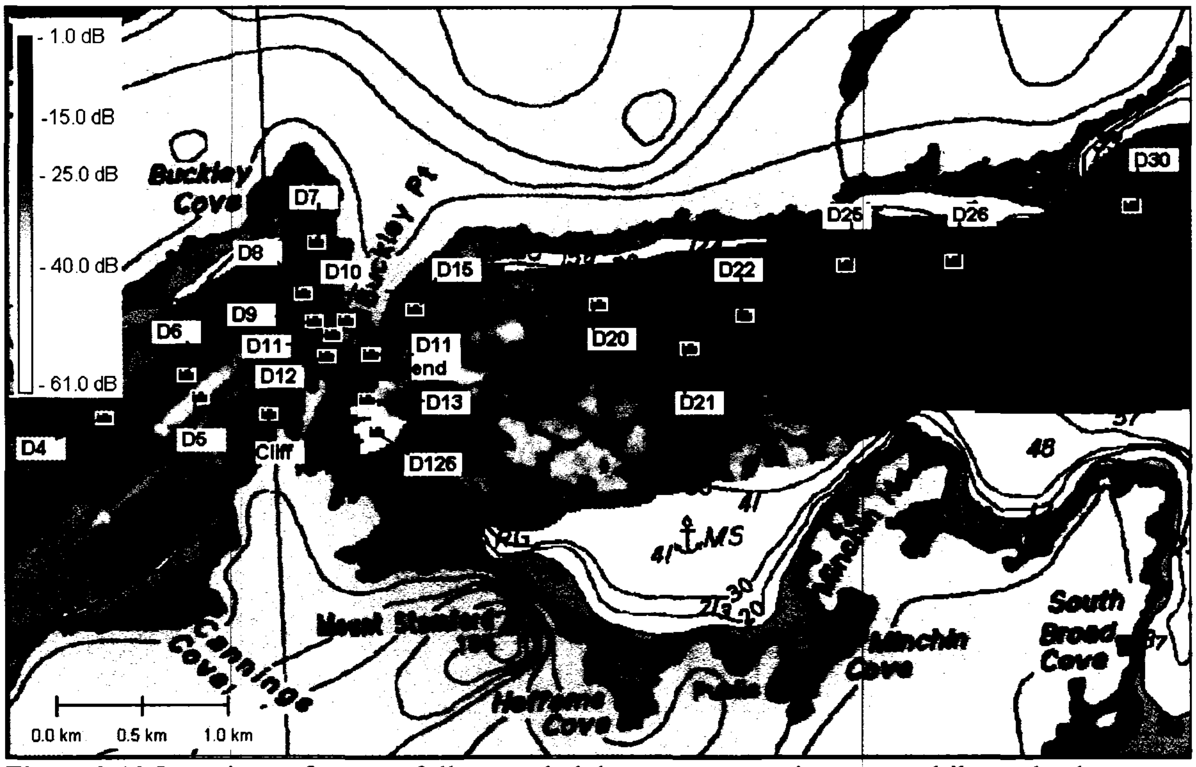


Figure 2.13 Locations of successfully sampled drop camera stations on multibeam backscatter and Newman Sound chart.

2.2.2.4 Remotely Operated Vehicle (ROV) Video

A VideoRay Remotely Operated Vehicle (ROV) owned by Fisheries and Oceans Canada was used to survey sites in Newman Sound. The ROV was deployed from the *CCGS Shamook* on December 2nd 2004. The vehicle was tethered to the surface and was piloted from aboard ship. The ROV provided real-time, colour video images of the seabed (with use of a light source) which were recorded on a Sony digital recorder.

Sampling with the ROV was planned for 8 sites in Newman Sound (Fig. 2.14). These locations were intended to represent distinctly different habitats, based on previous knowledge from grab sampling results as well as from the multibeam backscatter and bathymetry data, and sub-bottom profiles. Use of the *Shamook* allowed stations in exposed locations, such as the mouth of the fjord to be sampled. The tether on the ROV was 100 m long, so all stations were planned above 75 m depth. Stations A, B, D and E were successfully sampled, while attempts at G and H were unsuccessful (Fig. 2.14). Throughout the day the weather deteriorated so sampling at stations C and F were abandoned.

When target locations were reached the ships anchor was set to maintain position on the station. The ROV was deployed by hand from the port rail. Various combinations of neutrally buoyant cable and weights were used depending on the currents at each station. The video recorder was started when the bottom was reached, and written observations were taken of substrate and biota at regular intervals. The positions of observations were recorded from a computer screen slaved to the bridge computer, and depth readings were taken from the ROV. The navigation files from the bridge computer were downloaded into Global Mapper.

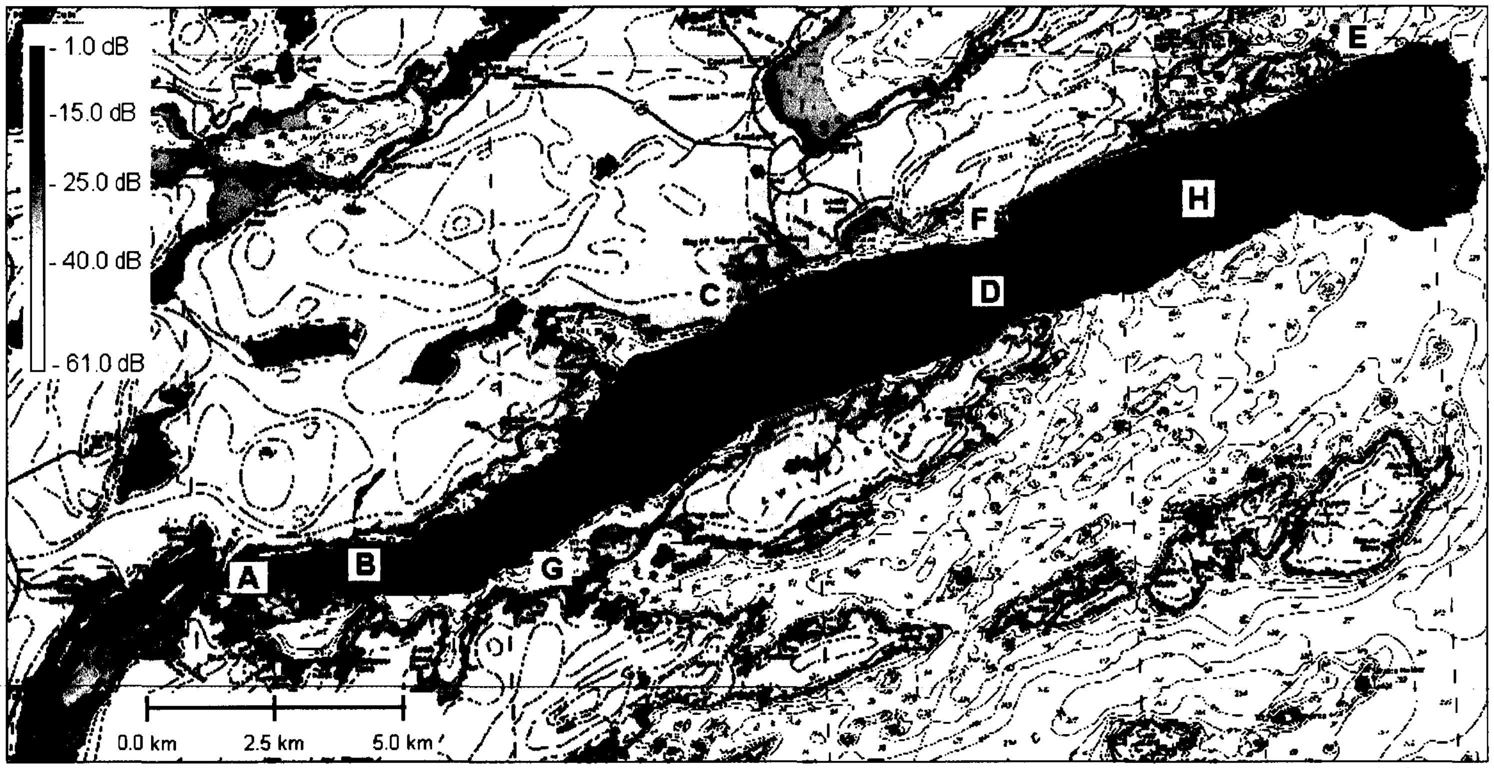


Figure 2.14 Locations of planned ROV stations on multibeam backscatter and Newman Sound chart.

2.2.3 Sample Processing

2.2.3.1 Grain Size Analysis

Grain size analysis was conducted to define each substrate type recovered from the grab samples. Grain size is important to some invertebrates and will control their use of habitat. This analysis also gave a quantitative label to each sediment type using the phi scale and related grain size descriptions on the Wentworth scale (Wentworth 1922). The units used are as follows:

Table 2.1 Wentworth Grain Size Definitions

Phi unit (ø)	**Wentworth Grain Size Description**	**Grain Size (mm)**
> −2	cobble	63 to 256
> −2	pebble	4 to 63
−1	granule	2 to 4
0	very coarse sand	1 to 2
1	coarse sand	0.5 to 1
2	medium sand	0.25 to 0.5
3	fine sand	0.125 to 0.25
4	very fine sand	0.0625 to 0.125
5	coarse silt	0.031 to 0.0625
6	medium silt	0.0156 to 0.031
7	fine silt	0.0078 to 0.0156
8	very fine silt	0.0039 to 0.0078
9 to >11	clay	<0.0039

2.2.3.1.1 Sieving

A sub-sample was collected from the grab samples that contained pebble to clay sized material. As most samples were rich in silt and clay, they were wet sieved on a 4ø (0.0625 mm) sieve to remove as much of the mud fraction as possible, as this is the most appropriate way to remove silt and clay (Larsen 1997; Sheppard 2000; Holte 2001). The silt and clay which passed through the sieve was reserved for sedigraph analysis.

The rest of the sub-sample was dried at 100°C for 24 hours. The dried sample was weighed and ground with a mortar and pestle and put through a stack of seven sieves. The sieves used for this analysis were −2ø, −1ø, 0ø, 1ø, 2ø, 3ø and 4ø which were chosen to represent the boundaries between grain sizes on the Wentworth scale (Table 2.1). The sieves were shaken on an electric shaker for 30 minutes. After being shaken, each sieve was weighed, and the weight of its contents calculated by subtracting the weight of the empty sieve. Any silt or clay which had passed the 4ø sieve was collected in a pan, and added to the wet sieved silt and clay for sedigraph analysis.

2.2.3.1.2 Sedigraph Analysis

The silt and clay fraction (>4ø) of the sieved sample was placed in a beaker with 15% hydrogen peroxide and 0.05% Calgon (Sodium hexametaphosphate) solution to dissolve the organic material. The beakers were stirred frequently to accelerate the reaction. Once the reaction slowed, each beaker was heated to boil off the remaining peroxide solution. The silt and clay fraction was then dried in an oven overnight. The dry silt and clay were weighed then re-suspended in 0.05% Calgon solution. After the sediment had settled (about 48 hours) the Calgon was decanted. A 40 ml sub-sample was taken from the silt and clay solution for analysis in a Sedigraph 5100 Particle Size Analyser.

The Sedigraph uses Stokes Law to calculate the diameter of the silt and clay grains based on their settling velocities in a liquid with known physical properties (in this case Calgon). The Sedigraph passes X-rays through a solution of the silt and clay, and the rays are refracted by the sediment particles (Micrometrics Instrument Corp. 2005). The amount of energy refraction at each point in time is compared to a baseline of clear Calgon solution which is collected at the beginning of the analysis. The machine then calculates the grain size of the particles still in suspension and the percentage of the total sample that has settled out. When all the particles have settled there will be no refraction and the baseline value should be recorded.

The Sedigraph produced a measurement of the cumulative distribution of mass between 4.0ø and >11ø. The mass of sediment from the sample which fell into each silt and clay phi class could then be calculated using the known weight of the whole silt and clay fraction with the percentage mass distribution. These data are combined with the masses of the coarse fraction found through sieving to give the percentage (by weight) of each phi size class, between −2 ø and >11ø, in the sediment.

2.2.3.2 Organic Content by Loss on Ignition

The amount of organic material available to invertebrates within the sediment may determine which species occur there and the number of individuals a habitat can sustain. For example, it is predicted that deposit-feeding organisms would be abundant in substrates with easily ingested grain sizes (such as silt), and in sediments with large amounts of available organic matter (Holte 2001). The organic content of the sampled sediments was therefore determined to explore the links between this variable and the sampled biota.

The loss on ignition (LOI) method was used to determine the organic content of the fine sediments collected by grab sampling and coring. As the sediments from Newman Sound did not contain significant amounts of carbonate, ignition was the most appropriate method of determining the organic content (Luczak et al. 1997; Ramey and Snelgrove 2003). Sediments from 50 of the grab samples were analysed by loss on ignition to determine the organic content of the sediment. A further 12 duplicate samples were also processed, for a total of 62.

To begin loss on ignition analysis a sub-sample of the sediment matrix was dried in a drying oven overnight at 200°C. Six numbered ceramic crucibles with lids were heated in the muffle furnace for one hour at 550°C. The empty crucibles were removed from the furnace, cooled in a desiccator and weighed to determine the starting weight of the crucible. The sediment samples were removed from the drying oven one at a time and ground into a fine powder using a mortar and pestle. The ground sample was put into one of the previously weighed crucibles, then the crucible and its contents were weighed. This allowed the weight of the dry sample in the crucible to be determined by subtracting the weight of the empty crucible.

A lid was placed on the crucible to prevent any of the sediment from being lost while in the furnace. The crucibles were placed into the muffle furnace six at a time, and were heated at 550°C for 2 hours. After 2 hours the crucibles were removed and cooled in a desiccator. The cooled crucibles were weighed and the weight of the crucible and ash were recorded. By subtracting the weight of the empty crucible, the ash weight was found. The loss on ignition could then be calculated by subtracting the weight of the ash from the weight of the dry sample then dividing by the weight of the dry sample.

Organic content was then calculated by the following method:

1. $\frac{\text{Dry weight (g)} - \text{Ash weight (g)}}{\text{Dry weight (g)}}$ = Loss on Ignition in grams
2. Loss on Ignition (g) X 100 = Organic Content %

2.2.3.3 Biological Sample Analysis

Biological samples were collected using a Peterson grab sampler. Sampled invertebrates and algae were examined under a dissecting microscope and were identified to family level, and when possible genus and species, using a variety of keys (Bousfield 1960; Smith 1964; Gosner 1971; Gosner 1979; Harvey-Clark 1997; Sears 2002). In several cases the keys contained differing scientific names for the same species. In such cases the scientific name that was deemed the most commonly used or most recently adjusted was used.

Individuals that could not be identified were photographed using a Nikon Coolpix 900 digital camera mounted on the dissecting microscope. Representative individuals of frequently occurring species were also photographed. Notes were recorded about each organism such as feeding method, if known, associations with other biota in the sample and the condition of the specimen. Individuals of each species were counted to give an idea of abundance, but all individuals were not kept for every grab, so abundance was not included in analysis.

In some of the literature that was reviewed, specific taxa were systematically excluded from analysis. For example Larsen (1997) left out all colonial organisms such as Bryozoa, Foraminifera and colonial cnidarians. All such organisms were included in this study, however less effort was expended on identification of Bryozoa, Porifera, and Foraminifera as they are more significant as a group than individual species, and are difficult to identify.

2.2.3.4 Video Sample Processing

The video data collected from SCUBA surveys, the remotely operated vehicle video camera and the stationary drop video camera were processed in a similar fashion. The videos were viewed 5 times. During the first viewing all species of flora and fauna were identified to the lowest possible taxonomic level. During the second viewing notes on substrate were recorded, such as the presence of mud, sand, pebbles, cobbles, boulders, bedrock and rhodoliths. The video was then reviewed again to confirm the presence of each substrate type and estimates of the percentage of the seafloor covered by each type were recorded. During the fourth viewing of the video particular attention was paid to the substrate preferences of identified species, and small scale distributions of biota and their preferred substrates within each site. On the final viewing of the video final notes were made on the occurrence of shell hash, organic material, and wood at each site, as well as obvious water movement, light penetration and anything else of interest, also all previous notes were verified. Still photos were captured from the digital video data (ROV and SCUBA diver videos) from representative points in the video for reference.

2.2.4 Statistical Analysis

2.2.4.1 Cluster Analysis

Cluster analysis was used to group grab sampled sediments with similar characteristics. Samples were assigned to clusters using the percent of the total sample weight in the phi classes described from sieve and sedigraph analysis. Clusters measuring similarity as Euclidean distance were formed using the Wards linkage method in MiniTab 14 software. Clustering was carried out at 50% similarity, with the results displayed as a dendrogram.

2.2.4.2 Non-metric Multi-dimensional Scaling (NMDS)

Non-metric multi-dimensional scaling was used to test the inter-relationships of grab sampled biota (Sejr et al. 2000; Lindegarth et al. 2000). It does not assume linearity in the data, like Principle Components Analysis and other scaling methods (McGarigal et al. 2000; Quinn and Keough 2002). NMDS was performed in PRIMER software on a Bray-Curtis similarity matrix created from the species presence/ absence data for all grab and video samples. The resulting three-dimensional configurations gave the best representation of the similarity in the overall dataset, with a stress value of 0.11 for grabs and 0.07 for video.

The eigenvalues from the three-dimensional configuration were used to plot each grab or video sample in three-dimensional space. The resulting plots (Figs. 3.24 and 3.25) show the relationship between each sample and every other sample, based on their distance from each other on the plot, with similar samples being closer together. The factor "substrate class" was then used to colour code the points based on which substrate class it was assigned to however, substrate was not used in the analysis to determine where points would lie.

2.2.4.3 Analysis of Similarity (ANOSIM)

Analysis of Similarity was used to test for significant differences in the biological species assemblage between the substrate classes defined. Each substrate class was tested against every other substrate to produce an R value. R values can range between +1 and −1. If R is greater than 0, there is more dissimilarity between the two tested groups than within each group. If the resulting R value is negative, then there is more dissimilarity within the group than between the groups being tested. ANOSIM was carried out on a Bray-Curtis similarity matrix of the original species presence and absence data in PRIMER.

2.2.4.4 Similarity Percentage Analysis (SIMPER)

Similarity percentage analysis (SIMPER) was used to compare the similarity of biota sampled within a substrate class. The presence and absence of all identified invertebrates and algae were tested in PRIMER.

Characteristic taxa were determined for each substrate class by determining which taxa contributed most to the similarity of samples within a substrate class. Also pair-wise comparisons of substrate classes were carried out to determine which taxa contributed the most to dissimilarity between substrates. These characteristic biota were used as descriptors in defining the biotic assemblage of each substrate class and ultimately habitats.

2.2.5 Mapping

The maps of multibeam bathymetry and backscatter which were used to plan groundtruthing were created in Global Mapper (v. 6.0 and 7.2). The classified substrate and habitat maps were created in MapInfo using the Vertical Mapper extension. MapInfo utilises user-defined mathematical expressions to classify pixels within a raster grid, in this case the 10 m grid of the multibeam bathymetry and backscatter. An additional grid with slope values was created in MapInfo and overlain with the bathymetry and backscatter grids. Expressions were created for each substrate class, which included depth, backscatter and slope values or ranges. Binary grids were produced for each substrate class, showing the distribution of pixels which met all three criteria. The habitat map was created by renaming the grids used to produce the final substrate map, based on observed biological trends.

Chapter 3: Results

3.1 Introduction

The overall goal of this thesis is to demonstrate the usefulness of multibeam data, groundtruthed with grab samples and video, to the production of classified seafloor substrate and habitat maps in a fjord environment. The results of the multibeam survey are presented as a description of the spatial patterns in the bathymetry and backscatter data. This is followed by descriptions of the groundtruth samples collected and a classification of these results into substrate classes. Biotic assemblages were statistically derived for each substrate from the grab and video samples and are reported in detail. The maps created from these results are then discussed with reference to the spatial distribution of classified substrates and habitats.

3.2 Multibeam Sonar Survey

The sub-tidal portion of Newman Sound, not including Swale Tickle, out to the 250 m bathymetric contour in Bonavista Bay, is 82 km^2. The multibeam sonar survey covered 62 km^2 of this area, achieving 100% seafloor coverage of the deep water portions of the fjord (Fig. 3.1). Due to ship time limitations and the time intensive nature of shallow water mapping, multibeam coverage was not complete for the shallowest parts of the fjord near the coastline, around islands and in most coves.

3.2.1 Bathymetry

A bathymetric profile along the long axis of Newman Sound from the head of the fjord to the mouth reveals four areas of distinct bathymetry, each of which is described separately and form the basis for further data analysis (Figs. 3.2a and b).

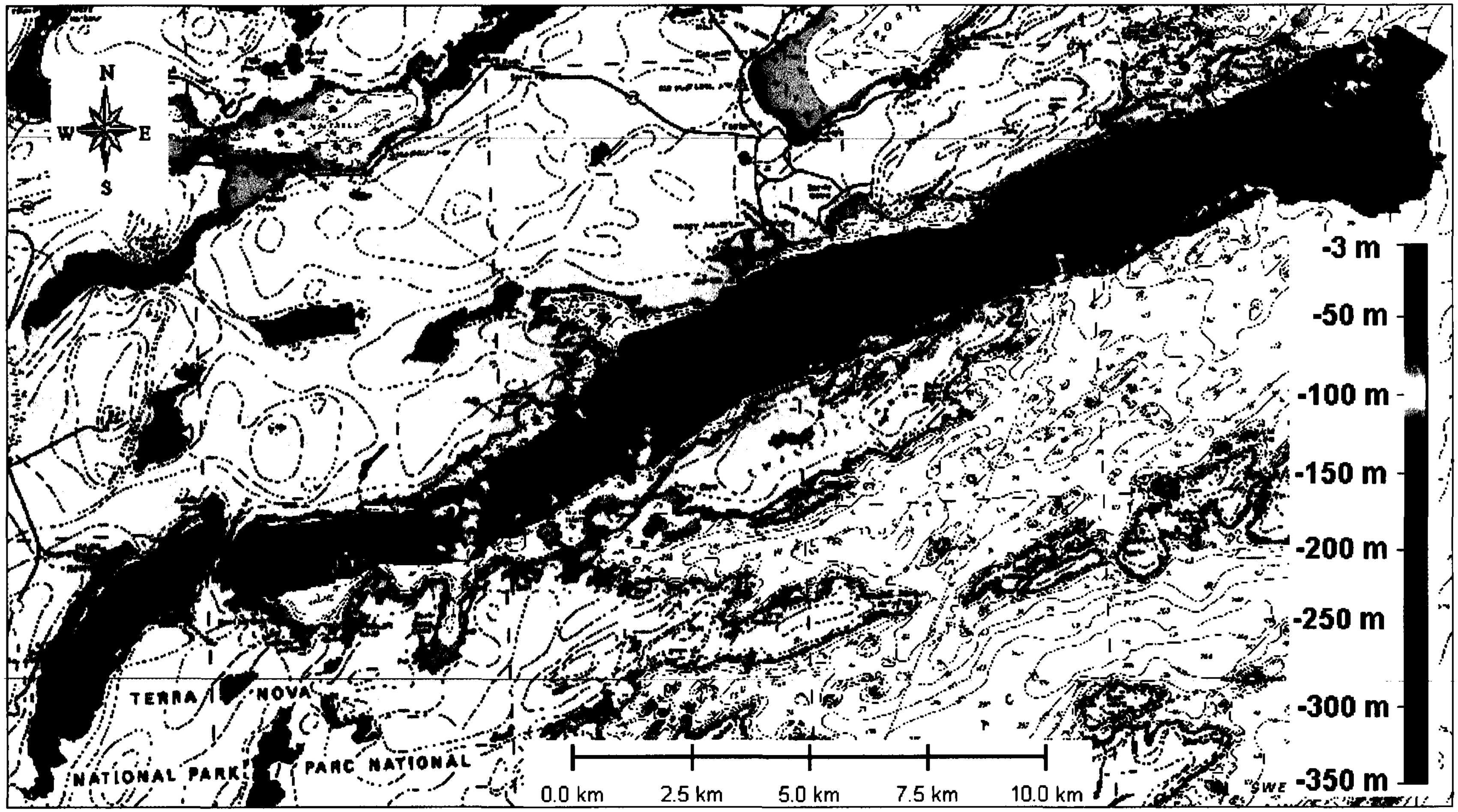


Figure 3.1 Multibeam bathymetry overlain on the nautical chart of Newman Sound and sun illuminated from the northeast.

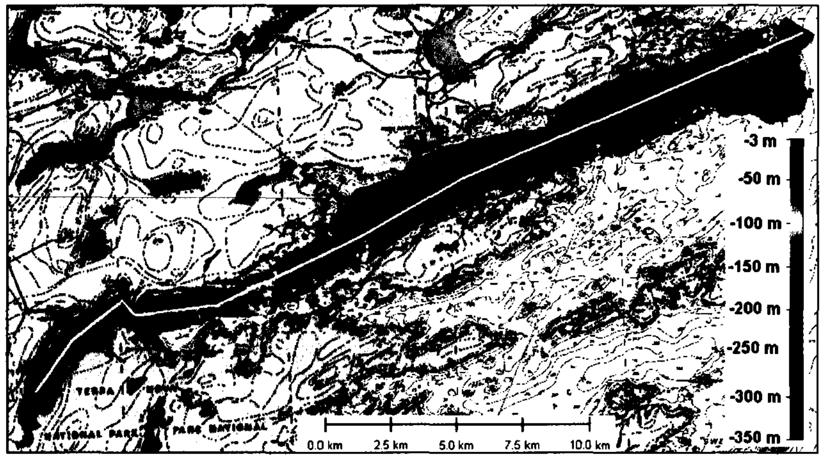


Figure 3.2a Multibeam bathymetry with the profile shown in 3.2b indicated.

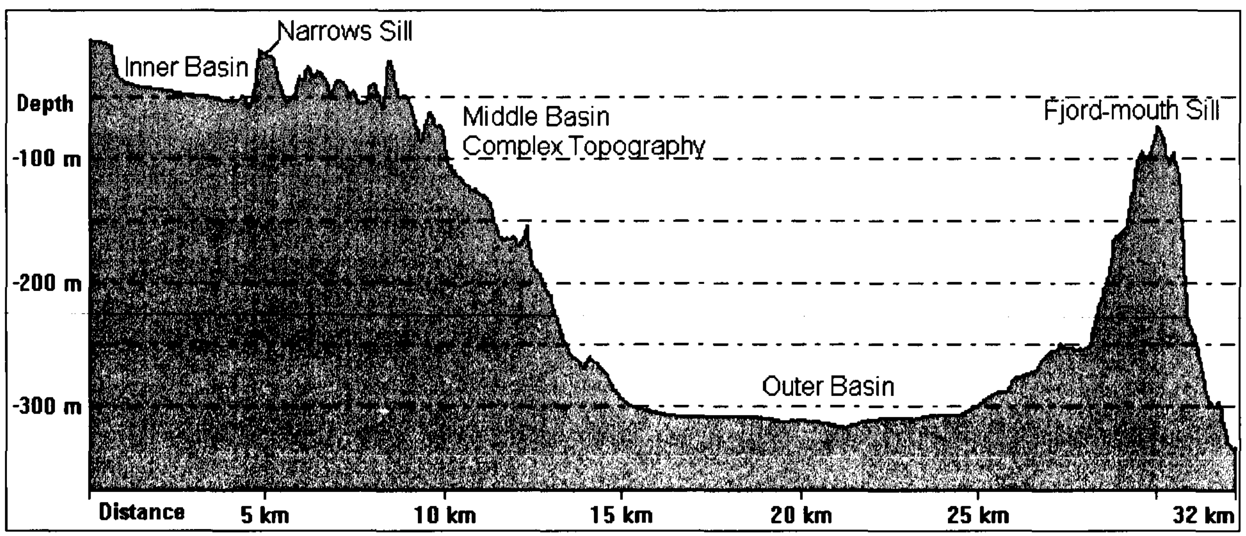


Figure 3.2b Profile along the long axis of Newman Sound from head to mouth, showing four bathymetrically defined zones. Vertical exaggeration is 35x.

3.2.1.1 Inner Basin

The inner basin is 7.3 km^2 and contains more shallow water than either of the other two basins. The bottom of the inner basin slopes gently away from the head of the sound towards the northeast (Fig. 3.2b). The deepest point (63 m) was recorded at the northeastern end, just inside the sill (Fig. 3.3). The inner basin has moderately steep (6 to 20°) side walls. The basin floor is flat, with over 90% having a slope angle of 1 to 2°.

A significant part (42%) of the inner basin is less than 20 m deep, but only half of this area was surveyed. The remainder comprises the basin floor, between 20 and 50 m deep (52%), and a small portion below 50m depth.

A submerged delta at the head of the inner basin has a characteristic flat top (<2°) in less than 10 m water depth and steep front (20 to 35°). The sill separating the inner and middle basins is located at the Narrows and has slope angles between 20 and 47°. A small cliff scarp running along the eastern side of the inner basin, just north of Cannings Cove, has a slope angle of 65°.

3.2.1.2 Middle Basin

The sill at the Narrows creates a shallow channel between 10 and 17 m deep and 350 m wide off Buckley Point (Fig. 3.4). It is steeper on the inner basin side (15°) than the seaward side (5°). The top of the sill and much of the surrounding area are flat (<5° slope angle) and shallow.

Seaward of the sill, there is a region of complex seafloor topography that stretches from the Narrows to the western end of Swale Island, a distance of 7.7 km. This part of the fjord is about 2.5 km wide, except for where it narrows to 1.5 km at Minchin Head. The basin deepens seaward, with about one half shallower than 50 m, and one quarter

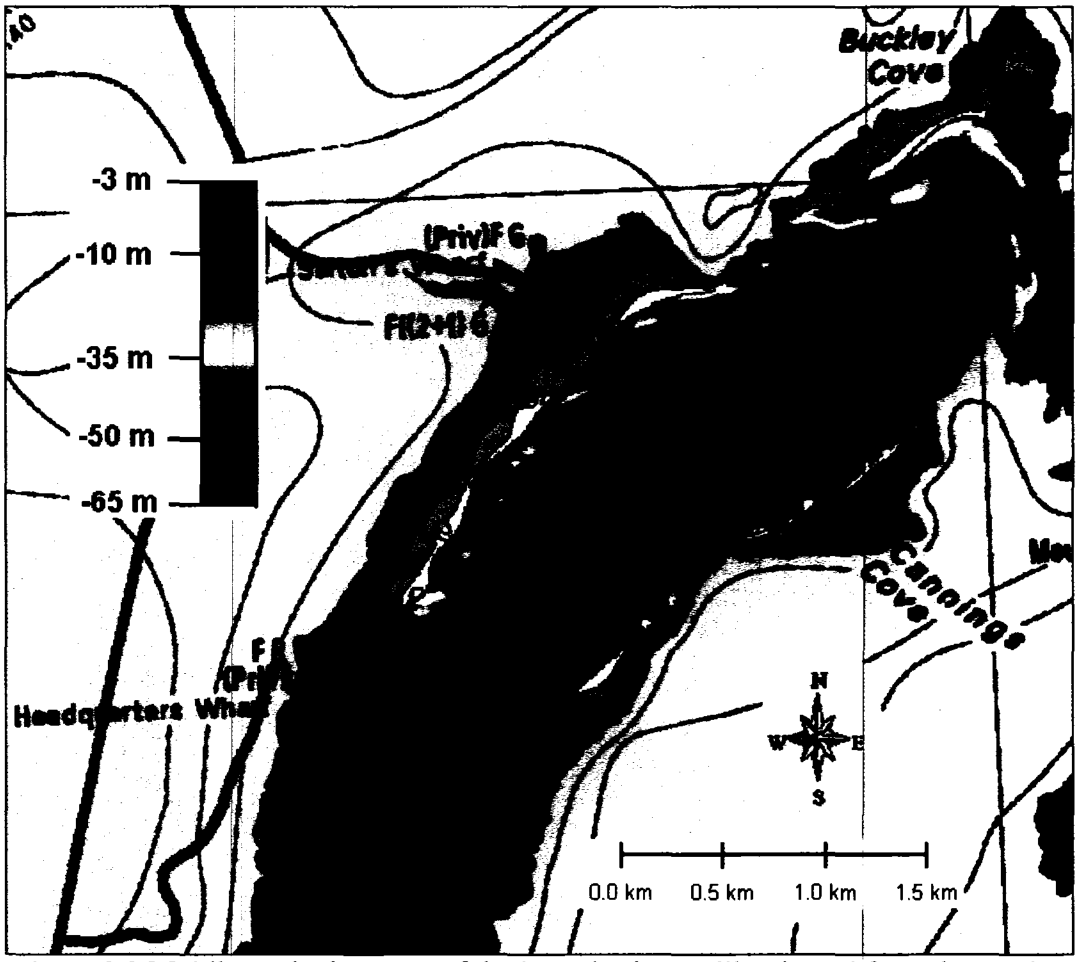


Figure 3.3 Multibeam bathymetry of the inner basin sun illuminated from the southwest and depth shaded to the maximum of this basin.

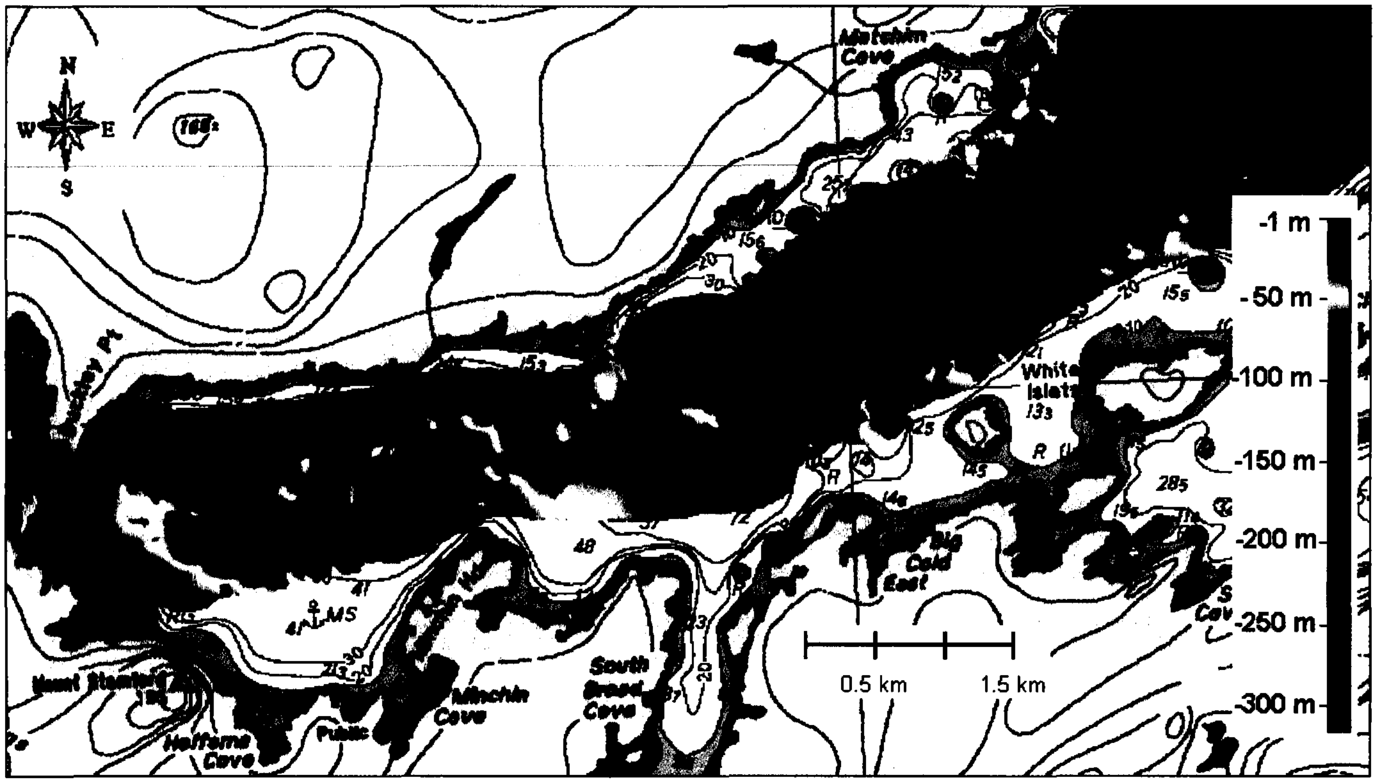


Figure 3.4 Multibeam bathymetry of the middle basin between the Narrows and western Swale Island sun illuminated from the northeast. The probable location of the Clode Sound fault appears north of the White Islets.

deeper than 100 m. About three quarters of this basin was surveyed with multibeam (Fig. 3.4).

Immediately outside the Narrows the north side of the fjord is shallow (<40 m deep) and relatively flat (<5° slope). The south side, off Heffern's Cove, although not surveyed appears to have similar bathymetry according to the nautical chart. In contrast, the centre of the fjord beyond the Narrows is deeper (>50 m) and has a hummocky seabed with moderate relief. Hummocks are separated by enclosed basins up to 90 m deep. The sides of the hummocks have slope angles between 15 and 25°. Similar undulating terrain is found in the middle of the fjord between Minchin Head and South Broad Cove, but here the hummocks are broader and rounder and spaced farther apart.

East of South Broad Cove the hummocky topography gives way to a gently sloping (<5°) bottom more than 100 m deep. The sidewalls become steeper too, between 20 and 60°. A 120 m-wide, 230 m-deep channel runs between the middle and outer basins, north of the White Islets. The strikingly straight appearance of the south side of this channel may indicate the submarine extension of the Clode Sound fault.

3.2.1.3 Outer Basin

The outer basin is the largest and deepest of the three basins in Newman Sound. It is 15 km long and on average less than 2.5 km wide. In cross-section, the basin has a typical "U" shaped profile with moderately to extremely steep sidewalls and a flat bottom (Fig.3.5). It is bounded to the north by the shoreline of the Eastport Peninsula and to the south by shallow seabed, shoals and islands.

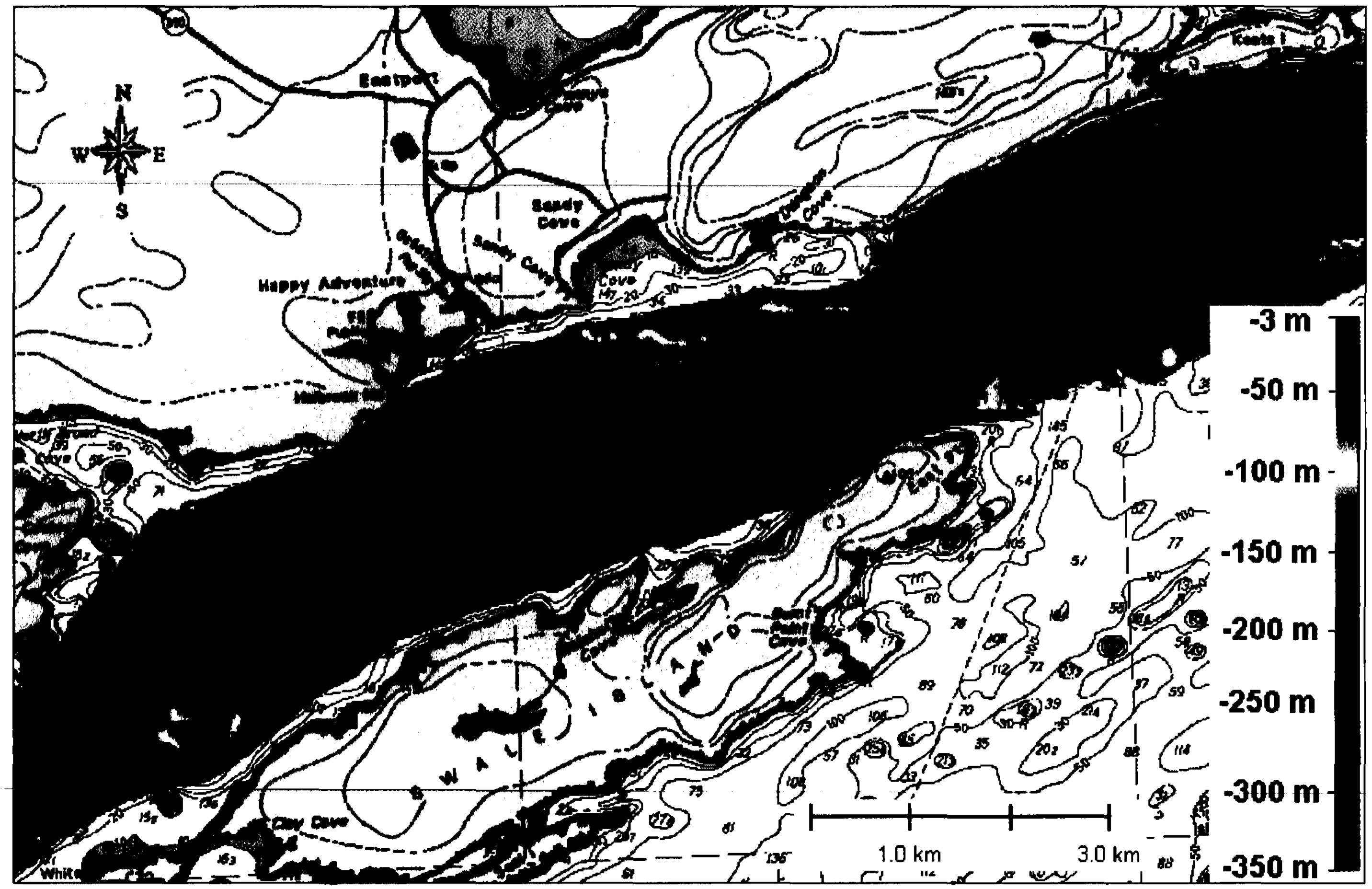


Figure 3.5 Multibeam bathymetry of the outer basin sun illuminated from the west, showing steep side walls and deep basin floor.

Although most of the outer basin has moderately sloping sidewalls between 20 and 35°, some parts are much steeper, between 45 and 65°, usually in water depths greater than 100 m. The steepest slopes are found off Swale Island between Ratchet Cove and East Point, off Dungeon Cove and below Holbrook Head (Fig. 3.5). Such steep walls are typical of a glacially carved valley, and provide habitats unique to fjords (Syvitski et al. 1987). The bathymetric data also show that the sidewalls of the outer basin are indented by numerous small channels.

The outer basin floor is 14 km^2, and mostly below 300 m water depth (Fig. 3.5). The deepest point of Newman Sound is at 332 m near Ratchet Cove, off Swale Island. The basin floor is mainly flat, with a slope angle of 5° or less. Like the inner basin, the outer basin is aligned northeast – southwest, parallel to the structural geologic trend in the region (Jenness 1963).

3.2.1.4 Fjord Mouth Sill

The deep outer basin of Newman Sound is connected to Bonavista Bay through a 1.2 km wide channel over 240m-deep. On either side of the channel the seabed rises abruptly to form a shallow sill at the fjord mouth (Fig. 3.6). Only the northern part of the sill was mapped by multibeam sonar. These data reveal an asymmetrical onshore-offshore profile with a steeper seaward flank. The surface of the sill is covered by small knobs and incised with northwest – southeast trending channels. The sides of some of these small knobs are steeper than 25°, but in general the top of the ridge has a slope angle of less than 10°.

3.2.2 Multibeam Backscatter

The acoustic backscatter intensity values recorded from Newman Sound ranged from −1 to −61 decibels (dB). Backscatter values were low on the floor of the inner and outer

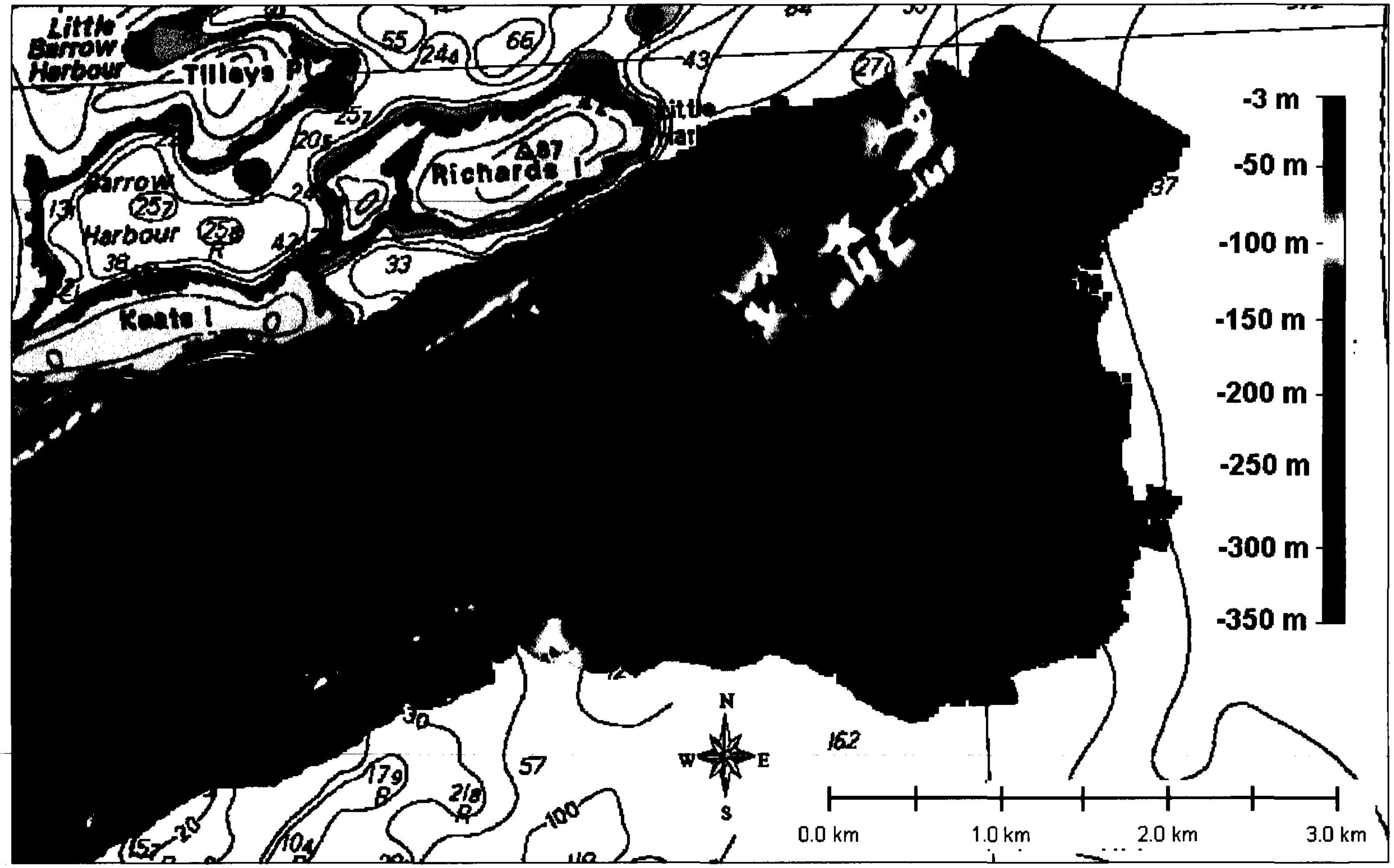


Figure 3.6 Multibeam bathymetry of the fjord mouth sill sun illuminated from the east.

basins and in bathymetric depressions. The lowest values were found in the inner basin, the Narrows and in depressions in the hummocky seabed near Hefferns Cove. Low backscatter (< −25 dB) was relatively rare east of the White Islets.

The outer sound walls and fjord mouth returned moderate to high backscatter values, with consistently high values along the bottom of the sidewalls, especially on the south side of the fjord. The most extensive area of very high backscatter (> −5 dB) occurred across the mouth of the fjord (Fig.3.7).

3.2.2.1 Inner Basin

The head of the fjord has a mottled pattern of high (−15 dB) and low (−37 dB) reflectance (Fig.3.8a). The flat floor of the inner basin (~2.5 km^2) produced low backscatter values between −25 and −35 dB. The northeastern and southwestern edges of the basin contained patches of lower backscatter between −35 and −46 dB. On the basin floor, between Cannings Cove and Salton's Wharf, several rings of slightly higher backscatter (between −16 to −20 dB) were observed. The diameters of the rings are about 250 m. The margins of the inner basin reflected backscatter values ranging from −10 to −15 dB. Small areas of very high backscatter (> −5dB) were recorded in Buckley Cove and between Cannings Cove and the Narrows, corresponding with slopes over 20°. The low backscatter basin floor and moderate backscatter margins are represented by the bimodal distribution of backscatter in the inner basin (Fig. 3.8b).

3.2.2.2 Middle Basin

The multibeam survey covered 13.5 km^2 of the 21.5 km^2 between the Narrows and western Swale Island. Within this area the full range of acoustic backscatter values recorded in the multibeam survey are found (Fig. 3.9b).

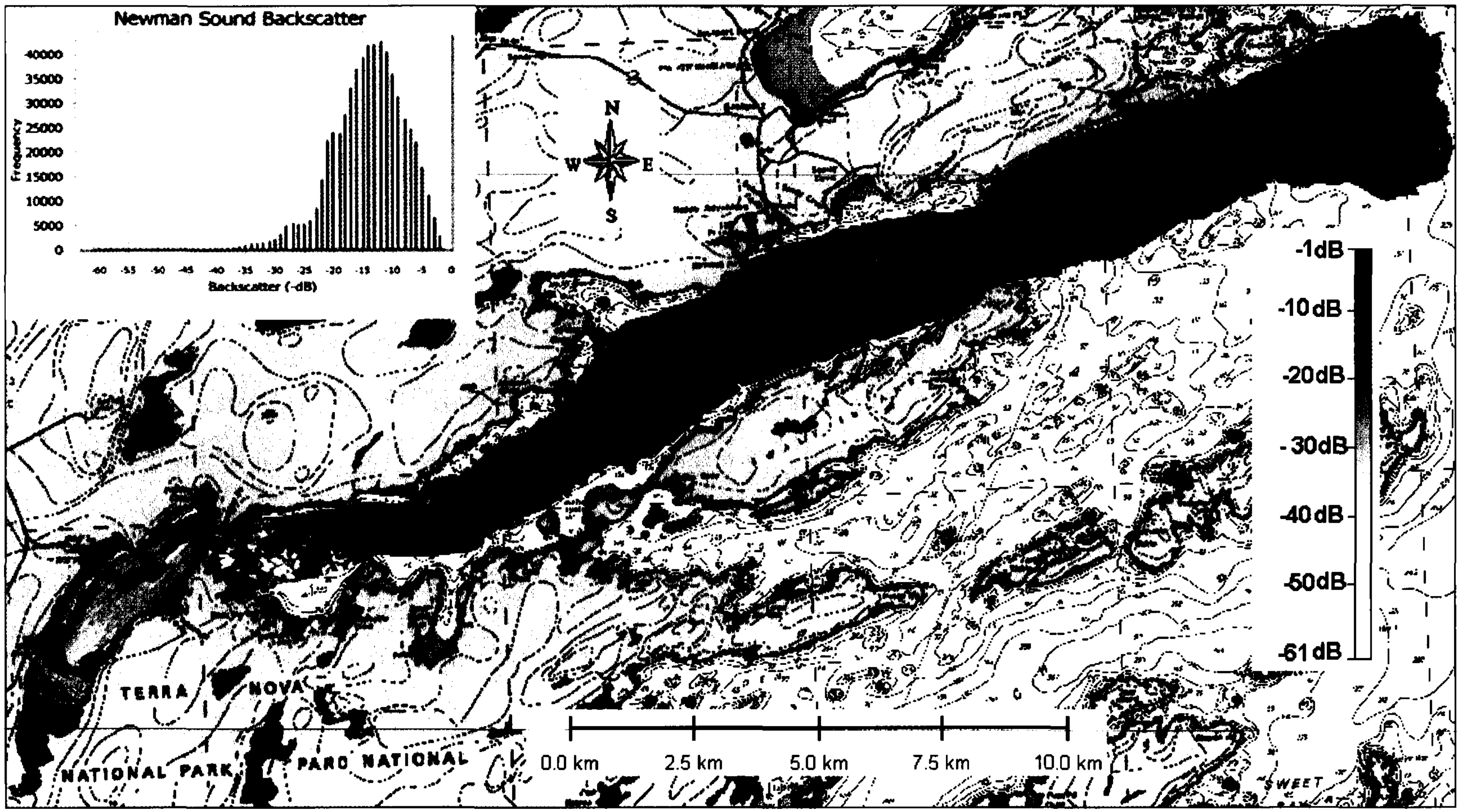


Figure 3.7 Multibeam backscatter map of Newman Sound and histogram of occurrence of each backscatter value

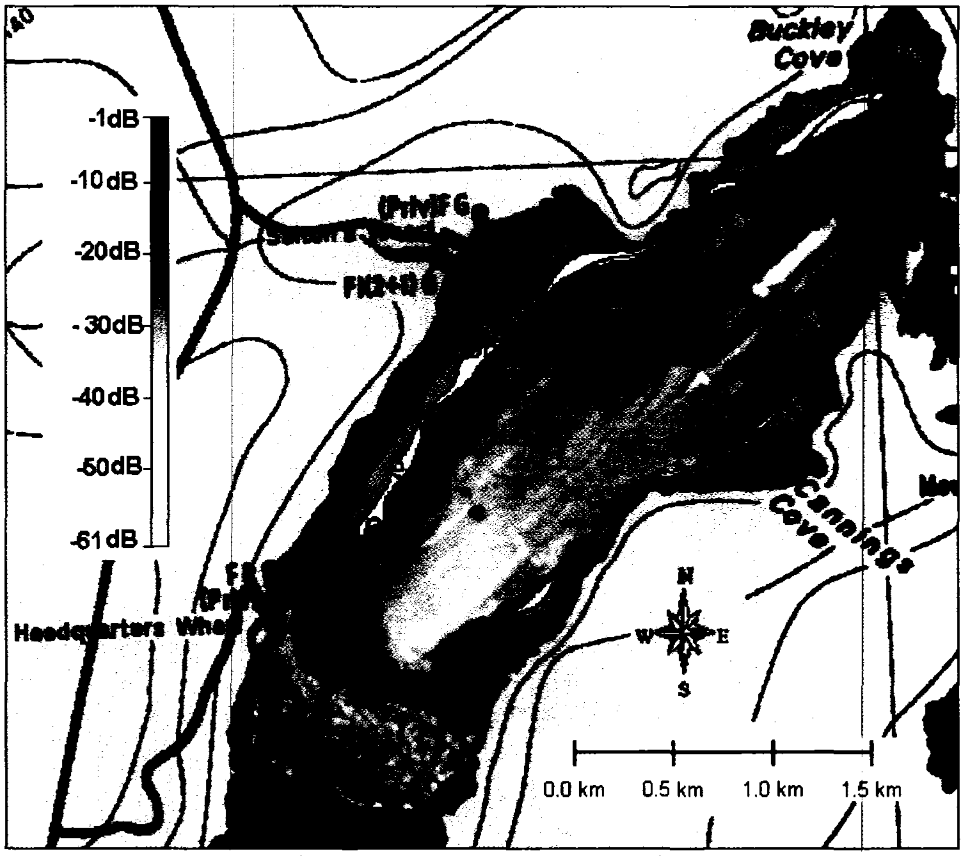


Figure 3.8a Multibeam backscatter map of the inner basin, showing low reflectance basin floor and moderate backscatter rings.

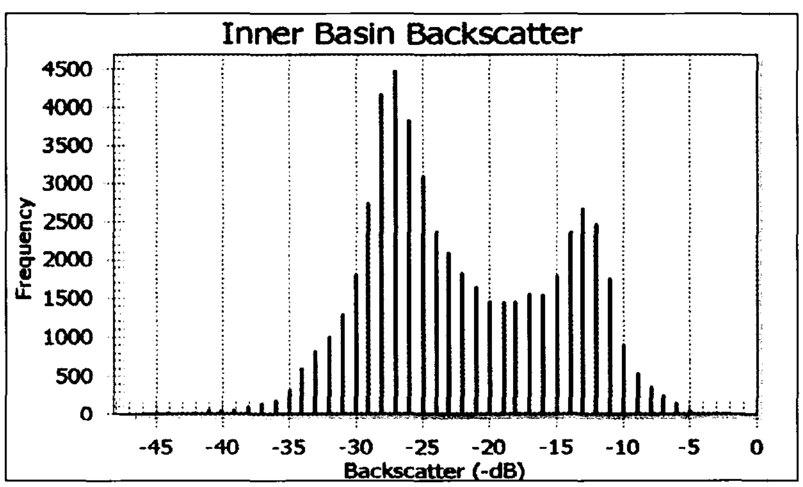


Figure 3.8b Histogram of backscatter value frequency of occurrence in the inner basin showing bimodal distribution.

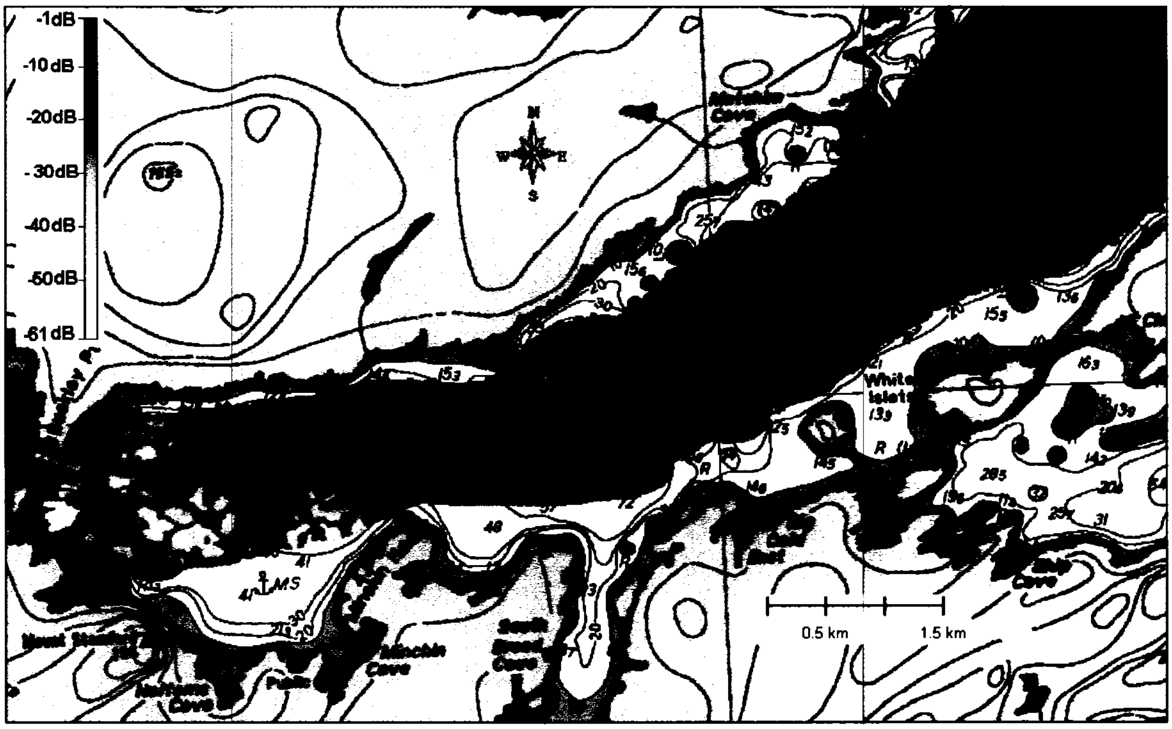


Figure 3.9a Multibeam backscatter of the sill at the Narrows and Middle Basin. The lowest backscatter values in Newman Sound are found here (circled).

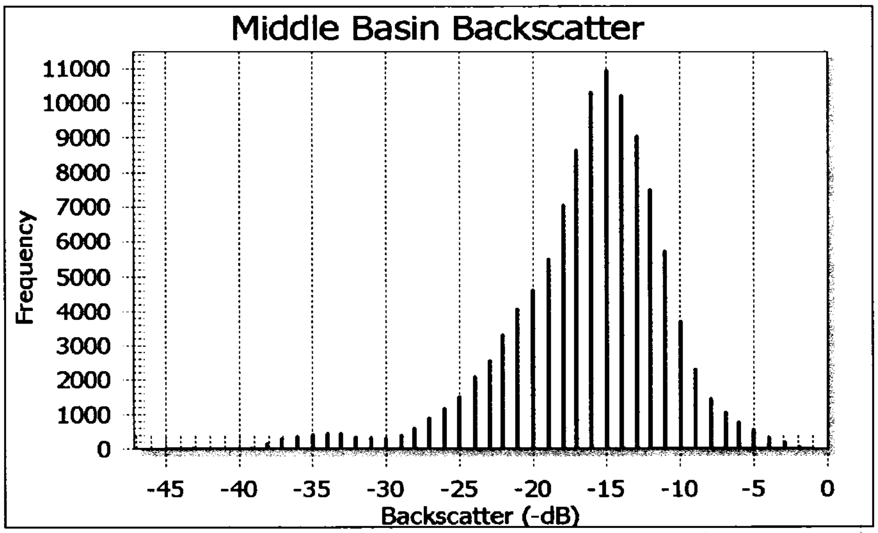


Figure 3.9b Histogram of backscatter value frequency of occurrence in the middle basin.

Immediately south of the Narrows is a 500 m^2 patch of seafloor reflecting backscatter values less than −40 dB (Fig. 3.9a). This location is the only extensive area of very low reflectance in the fjord and also contains the lowest backscatter value recorded in the multibeam survey, −61 dB. In contrast, the surrounding seafloor reflected moderate backscatter values around −15 dB. The flat north side of the Middle Basin generally had backscatter values greater than −15 dB. The hummocky centre of the fjord had a more complicated backscatter pattern; low backscatter (−25 to −35 dB) was confined to depressions whereas higher backscatter (−17 to −10 dB) coincided with hummocks. The channel linking the middle and outer basins has values as low as −23 dB on its floor and up to −2 dB along its walls.

3.2.2.3 Outer Basin

The distribution of backscatter values in the outer sound follows the orientation of the basin, like the inner sound. The centre of the outer basin reflected the lowest backscatter values (to −24 dB) whereas higher backscatter, around −15 dB, was observed along the edge of the basin (Fig. 3.10a).

The extensive fjord walls of the outer basin had higher backscatter values than those of the inner basin. The bottom of the side walls reflected particularly high backscatter values, especially on the south side of the fjord. For example, the bottom of the fjord wall near Swale Island had backscatter values of −5 dB or higher. Values higher than −5 dB were commonly reflected by sloping surfaces with angles greater than 60°. The remainder of the fjord wall (~90%) reflected values between −6 and −15 dB (Fig.3.10b).

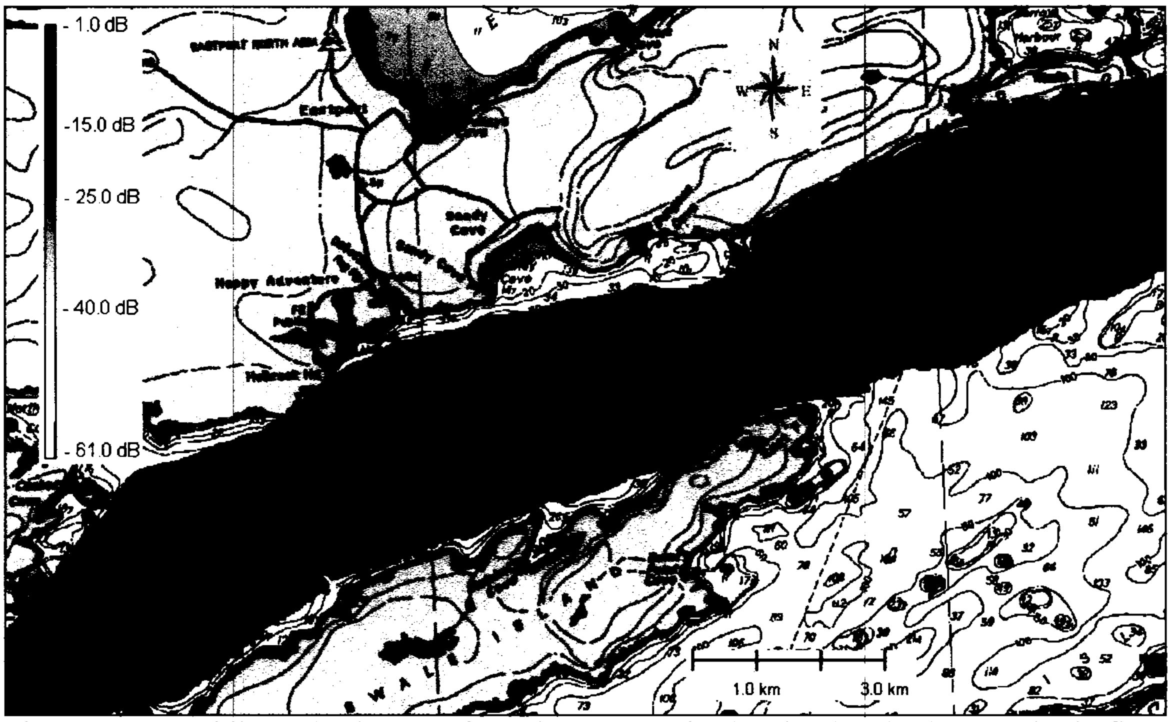


Figure 3.10a Multibeam backscatter from the outer basin showing low backscatter basin floor with high backscatter fjord walls and dredge spoil at Happy Adventure (circled).

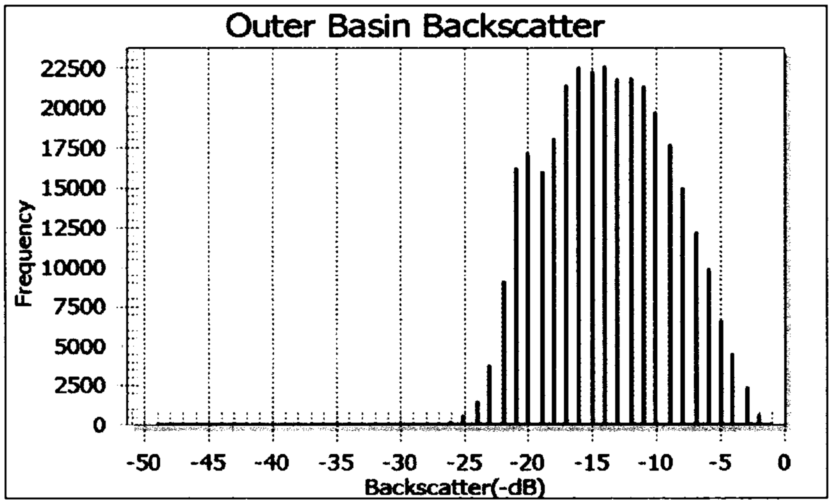


Figure 3.10b Histogram of backscatter value frequency of occurrence in the outer basin

Circular patterns of high backscatter (−3 to −7 dB) with diameters of about 50 m were observed on the floor of the outer basin near Happy Adventure (Fig. 3.10). This pattern resembled the sand and gravel dredge spoil on a mud bottom identified in St. George's Bay by Shaw et al. (1997).

3.2.2.4 Fjord Mouth Sill

The largest expanse of very reflective seabed in Newman Sound is at the mouth of the fjord (Fig. 3.11b). Here, 51% of the 12 km^2 area produced backscatter intensity values higher than −10 dB, of which 8% were over −5 dB. Most of these high values came from the channel floor southeast of the fjord mouth sill. Small pockets of moderately reflective (between −10 and −15 dB) seabed occurred on the surface of the sill, especially in the shallow water near Richards Island. At the edge of the multibeam coverage in Bonavista Bay, two areas of backscatter with lower values between −15 and −21 dB occurred in deep water.

3.3 Shallow Seismic Survey

Three acoustic units were identified from the seismic survey of Newman Sound. Unit A, the lowermost unit, has an acoustically reflective surface and minimal acoustic penetration. It occurs in all parts of the fjord, forming positive and negative relief features, with both smooth and rough surfaces. Unit B is acoustically stratified with horizontal internal reflectors, which indicate the presence of layers with different acoustic properties within the unit. Unit C, the uppermost unit, is acoustically transparent, indicating low reflectance sediments. This unit appears homogeneous, containing few changes in reflectance. Units B and C commonly occurred together as thick deposits

Figure 3.11a Multibeam backscatter map of the fjord mouth.

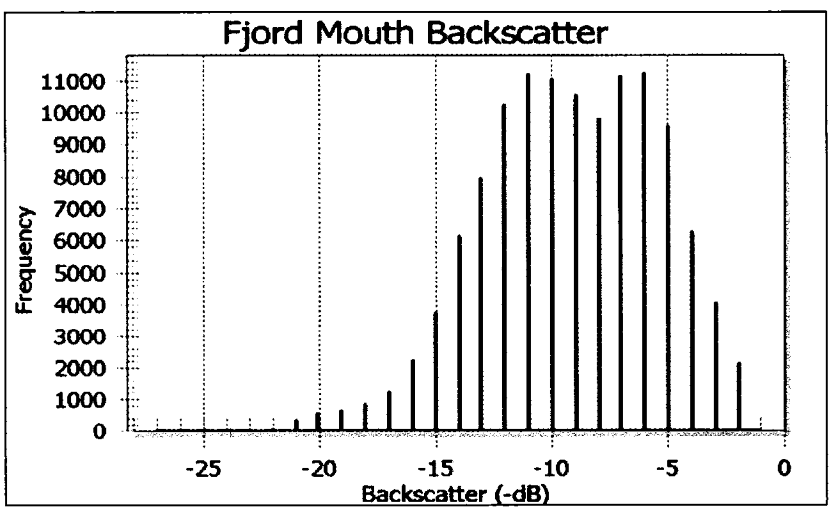


Figure 3.11 b Histogram of backscatter value frequency of occurrence at the fjord mouth

infilling the bottom of both basins. Units A, B and C are shown in their typical configuration in Fig. 3.16.

The stratigraphic relationship between these three units and their distribution in the fjord are discussed below. Seismic points are referred to in this section for location purposes; they are times recorded by the Seistec boomer during the survey and were used to geo-reference the results.

3.3.1 Inner Basin

Unit A

The sides of the inner basin appeared as reflective surfaces with no internal stratification or structure; these were interpreted as bedrock. The surface of the bedrock walls appear smooth and reflected multibeam backscatter intensities between −10 and −15 dB. Bedrock was most common in the northeastern part of the inner basin, near the sill and the mouth of Buckley Cove. At Buckley Cove the seismic survey passed over the very high (> −5 dB) backscatter area mapped by the multibeam. Here point reflectors were recorded on the surface of the bedrock unit, and interpreted as boulders.

Unit B

The horizontal reflectors in this deposit are arranged parallel to the sediment surface. Undulations in the surface of this unit are mirrored by strata below and infilled by Unit C above. Unit B is 6.5 to 14 m deep. The acoustic basement was not detected by the boomer, so the exact depth of this deposit remains unknown.

The acoustically transparent upper layer (Unit C) pinches out abruptly near seismic point 21:40 off Salton's Wharf, exposing the underlying stratified material at the surface (Fig. 3.12). Groundtruthing at this location revealed mixed lithology gravel and

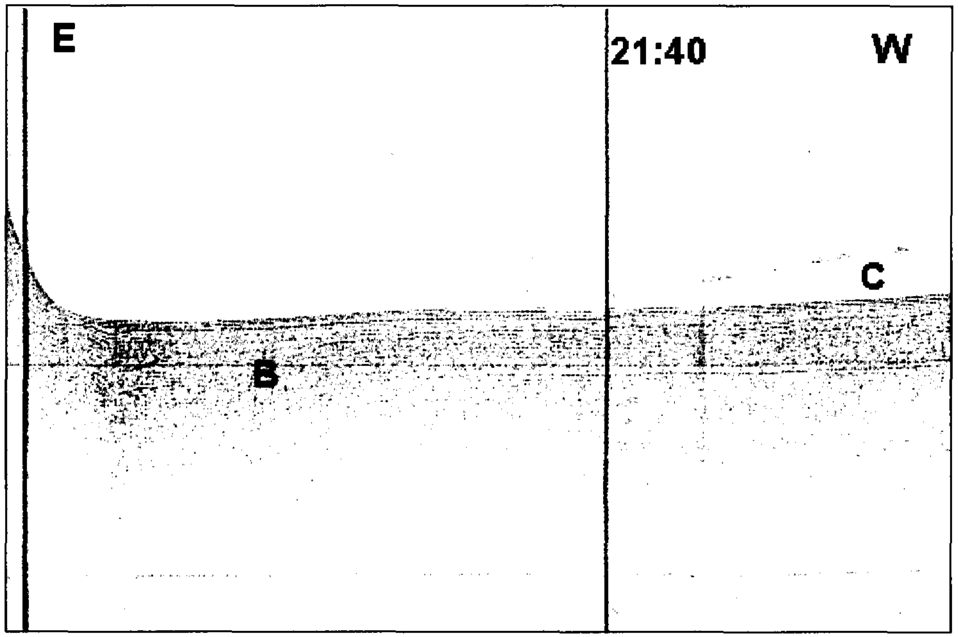


Figure 3.12 Sub-bottom profile from point 21:40 showing acoustically transparent material (C) giving way to stratified material (B) in the inner basin.

Location of Fig. 3.12 on backscatter image

sand, which was interpreted as being of glaciomarine origin. The reason for the abrupt discontinuation of Unit C is possibly erosion by currents moving over the sill into the inner basin.

Unit C

Unit C ranges from 3.5 m thick near the centre of the inner basin to 0.8 m thick near the sill. It thickens gradually away from the delta at the head of the fjord, reaching maximum thickness in the centre of the basin, and then thins rapidly towards the sill at the northeastern end of the basin. This deposit also thins towards the sides of the basin. Samples collected at the surface of Unit C contained silty mud.

Unit D

Seismic sub-bottom profiles of the submerged delta at the head of the inner basin revealed a steeply sloping unit of acoustically stratified material. The internal reflectors on top of the delta are horizontally arranged, while those on the delta front slope downward. This arrangement was interpreted as topset and foreset beds (Fig. 3.13).

The surface of the delta is rough, with numerous point reflectors apparent on the surface, interspersed with patches of acoustically transparent material. This is consistent with the multibeam backscatter which shows small patches of high and low values here. The point reflectors recorded on the sediment surface were interpreted as boulders, as the nearby shoreline is strewn with boulders.

3.3.2 The Narrows Sill

Unit A

The sill across the Narrows is composed of homogenous material with no internal reflectors, which produced a strongly reflected multiple of the seabed surface (Fig.3.14)

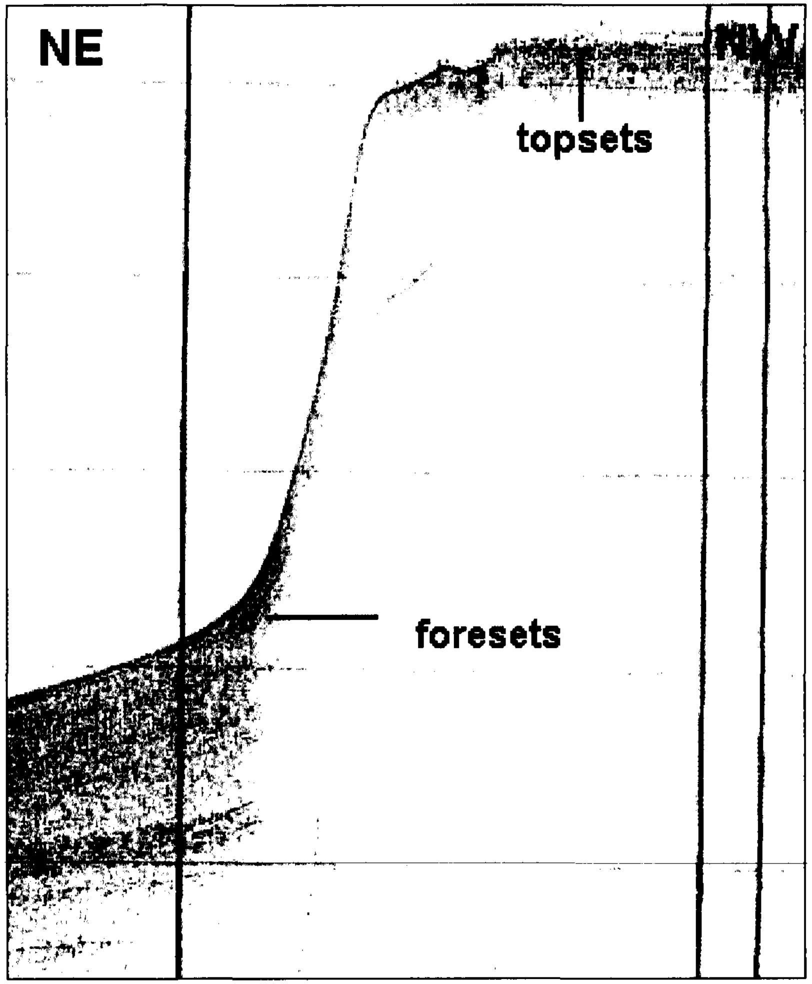
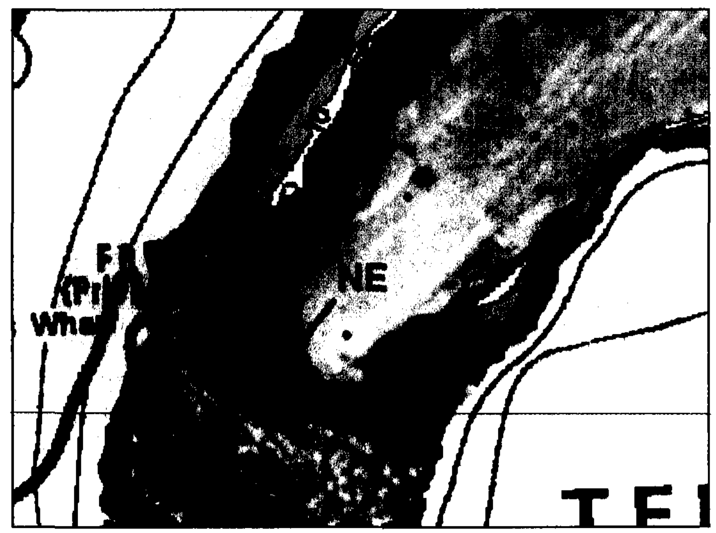


Figure 3.13 Sub-bottom profile showing topsets and foresets of the fjord-head delta



Location of Fig. 3.13 on backscatter image

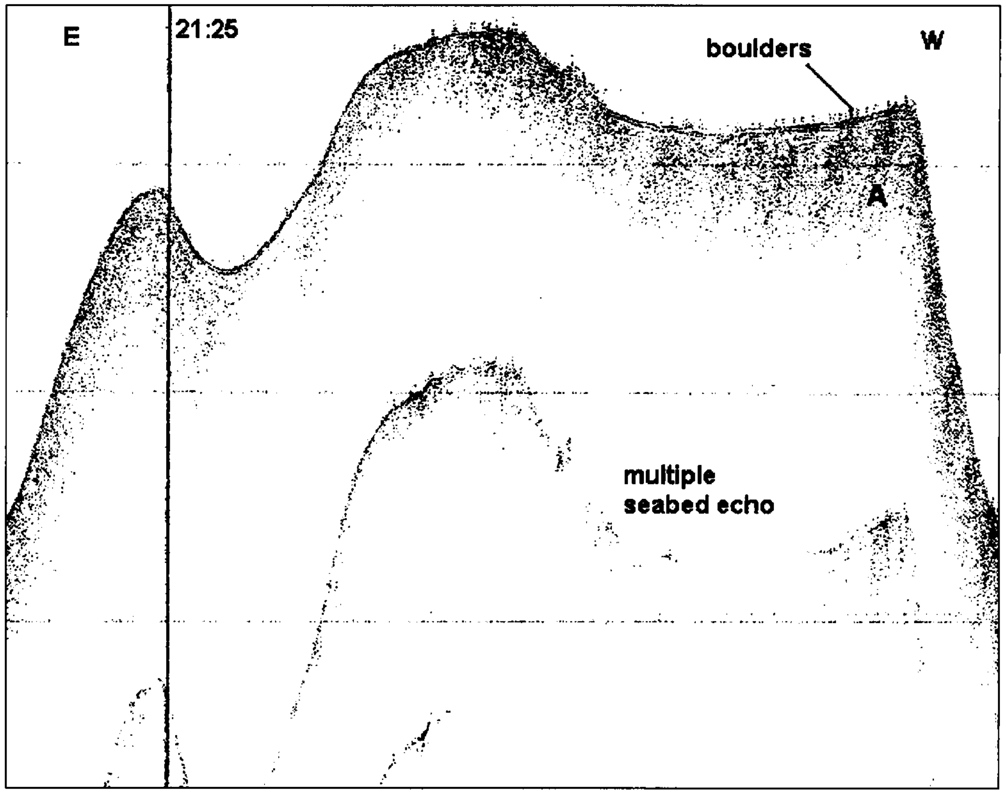
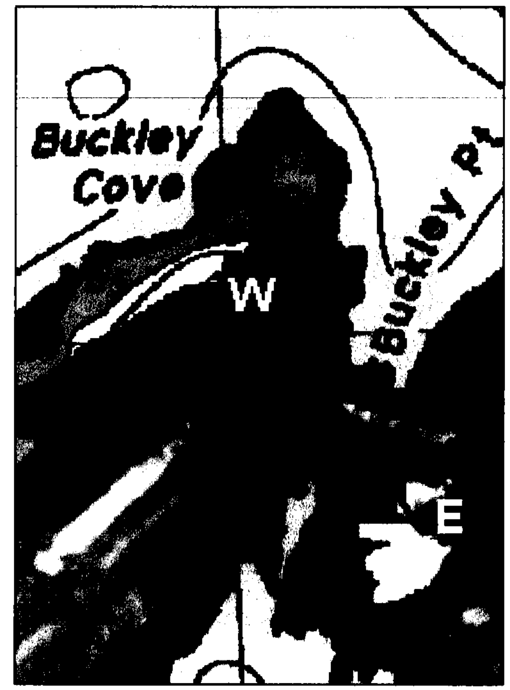


Figure 3.14 Sub-bottom profile across the sill at the Narrows, showing reflective bedrock (A) and boulders.



Location of Fig. 3.14 on backscatter

indicating a hard substrate. This material was interpreted as bedrock since its appearance was similar to confirmed bedrock from elsewhere in the fjord. The surface of the sill was very rough, producing many point reflectors. Fewer of these hard returns were recorded at the eastern end of the Narrows than in the west (Fig. 3.14). Video sampling confirmed that boulders are present in the Narrows, and they are more numerous towards the west. The multibeam backscatter intensity map shows low backscatter for parts of the Narrows, which is unexpected given the presence of these boulders.

The multiple reflection of the seabed at the Narrows implies reverberation of the signal from the seismic boomer, which is also inconsistent with low multibeam backscatter (Stoker et al. 1997). Groundtruthing in the Narrows later indicated that the discrepancy was related to biota (see 3.4).

3.3.3 Middle Basin

Unit A

In the middle basin Unit A forms numerous positive relief features, such as the hummocks noted in the bathymetric survey. Unit A also forms bathymetric depressions in the hummocky terrain which are infilled by other units (Fig. 3.15). Several grab samples were attempted off Minchin Head on this substrate and all were unsuccessful, further supporting the interpretation of Unit A as bedrock.

Unit C

Small pockets of Unit C were observed in the middle basin infilling depressions in Unit A. An example is shown in Fig. 3.15. Here the smaller deposit is 1.2 m thick and corresponds to a multibeam backscatter of −34 to −37 dB. The deeper deposit (2.79 m thick) corresponds to low multibeam backscatter (−35 to −37 dB). A grab sample

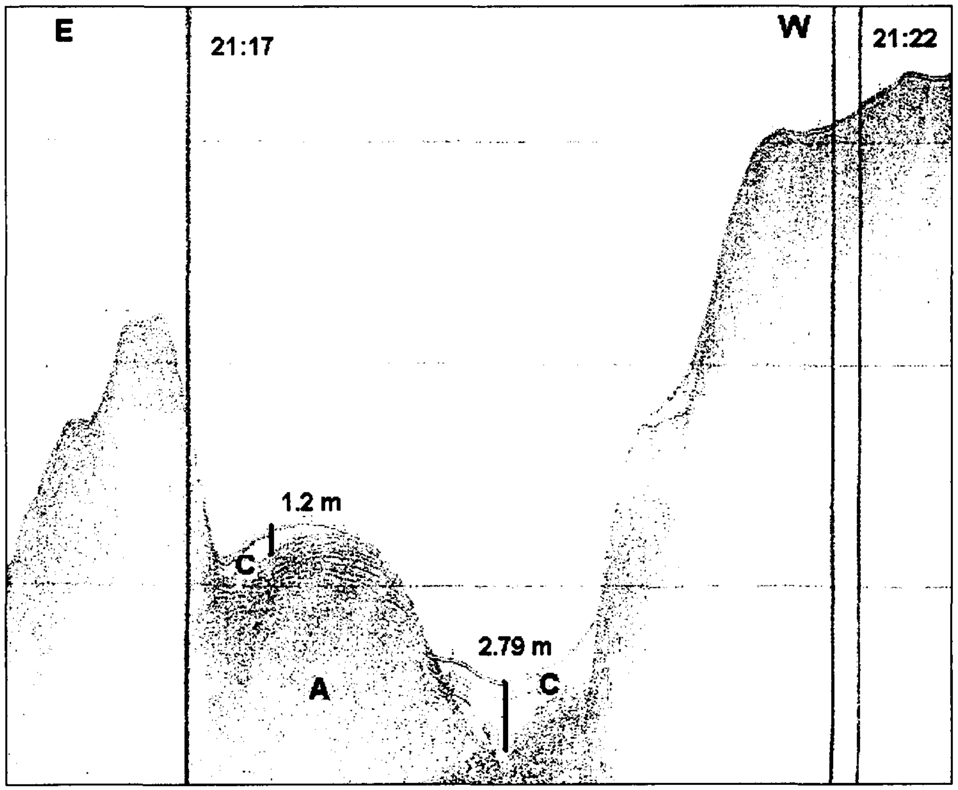


Figure 3.15 Sub-bottom profile between points 21:17 and 21:22 acoustically transparent sediment (C) and bedrock (A).

Location of Fig. 3.15 on backscatter

collected from the deeper deposit confirmed Unit C was mud. Elsewhere in the middle basin depressions in the bedrock do not show obvious drapes of sediment; however a grab sample retrieved from one contained compacted sand.

3.3.4 Outer Sound Basin

Unit A

Unit A was observed along the margins of the outer basin, coinciding with bedrock sampled on the fjord wall. It is likely that bedrock underlies the sediments through out the entire outer basin, but at a depth below the penetration ability of the seismic boomer. On the basin floor the underlying bedrock was only observed where Units B and C thinned towards the basin margin (Fig.3.16).

The outbound leg of the seismic survey extensively covered the very high backscatter (> −5 dB) region along the seaward margin of the outer basin. The seabed surface was smooth and reflected a hard return with no internal reflectors, which was interpreted as bedrock.

Unit B

The seismic survey did not cross any locations in the outer basin where Unit B was exposed at the surface, therefore it was not sampled. However its acoustic characteristics are similar to the gravel sampled from Unit B in the inner basin, so it is believed to be glaciomarine gravel.

Unit C

The flat floor of the outer basin contained an acoustically transparent unit similar to that seen in the inner basin. As in the inner basin, sampling confirmed it was silty mud. In the outer basin Unit C is thicker (max. 22 m) than the inner basin (max. 3.5 m).

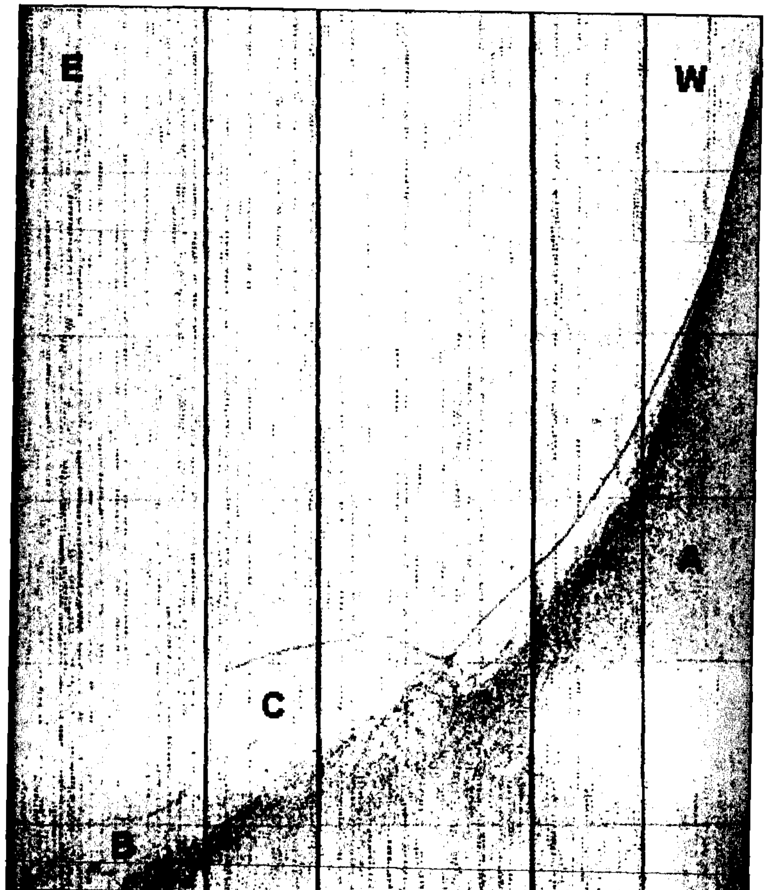
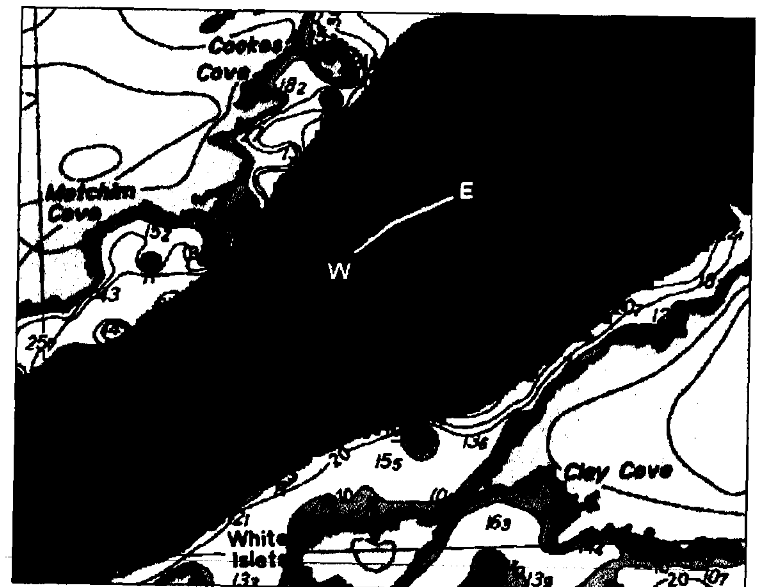


Figure 3.16 Sub-bottom profile of the western margin of the outer basin showing acoustically transparent material (C) over a stratified deposit (B), draped on the fjord wall (A).



Location of Fig. 3.16 on backscatter image

The multibeam backscatter values for the surface of Unit C in the outer basin are higher and more variable than in the inner basin. The seismic data indicate that there is no direct relationship between the thickness of Unit C and the multibeam backscatter. However this mud unit was deepest in the middle of the outer basin and the lowest backscatter occurred there.

Scours

On the north side of the outer basin near seismic point 01:55 the survey track passed over one of the deep depressions identified from the multibeam bathymetry. This feature is formed by the surface Unit C sloping very suddenly downwards to a point where it contacts the bedrock fjord wall, forming a V shaped depression (Fig. 3.17). The stratified deposit (B) below remains unchanged. This was interpreted as a scour where the upper unit had been eroded, probably by currents moving along the bottom of the fjord wall. The scour is found in a place where the fjord wall is more reflective than the surrounding substrate (~ −5 dB) and juts out slightly into the basin which would affect local current flow. A similar shaped depression was observed on the multibeam bathymetry map on the south side of the fjord near Ratchet Cove on Swale Island. The deepest water depth in Newman Sound, 332 m, was recorded at the bottom of the Ratchet Cove depression.

3.3.5 Fjord Mouth Sill

Unit A

The outbound leg of the seismic survey passed over the rise on the south side of the fjord mouth. Here the seabed returned a strong, homogenous reflection similar to those seen elsewhere in the fjord. This is consistent with the multibeam backscatter map which shows values of – 5.5 to −13 dB at this location.

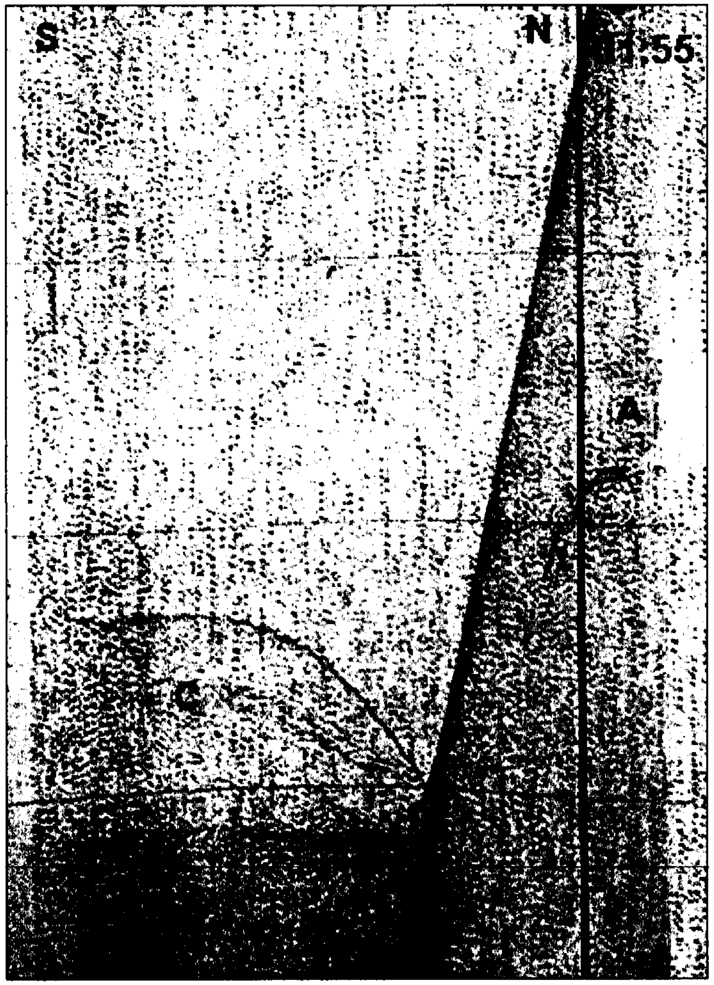
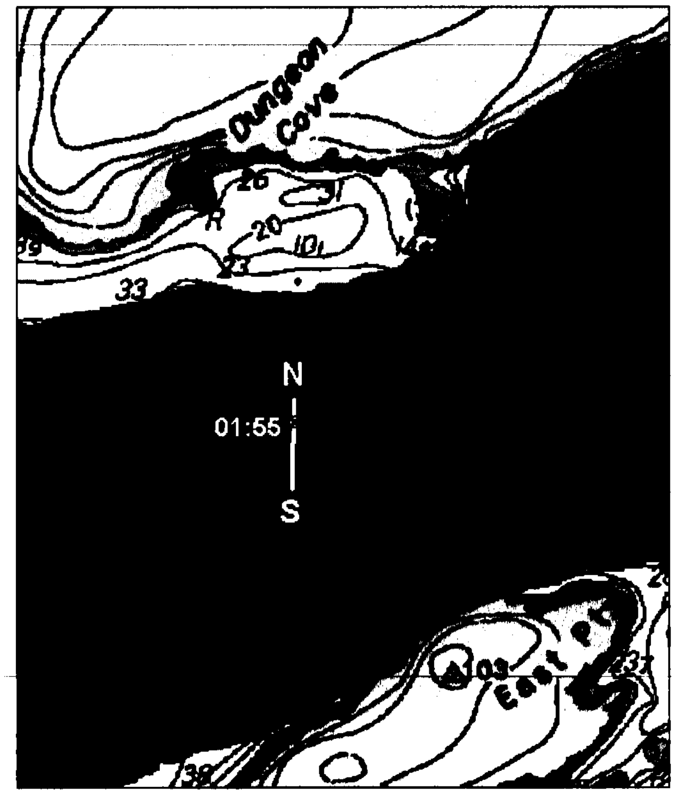


Figure 3.17 Sub-bottom profile showing acoustically transparent sediment (C) overlying stratified deposit (B) eroding away from bedrock (A) at Dungeon Cove.



Location of 3.17 on backscatter image

On the north side the survey track passed over the fjord mouth sill. The surface of the sill was very rough, unlike other areas surveyed in the fjord (Fig. 3.18). Video imagery collected near seismic point 03:36 revealed that the substrate was bedrock and the surface of the bedrock formed hills with an amplitude of about 1 m.

The deep water at the mouth of the fjord, seaward of the sill was also surveyed, to the edge of the multibeam coverage. Highly reflective material with a rough upper surface was recorded here. It is also possible that at the fjord mouth Unit A is winnowed till, as the surface is not smooth like bedrock sampled elsewhere in the fjord. Gravel was collected in two grabs from the fjord mouth sill which would support this interpretation.

Unit C

The multibeam backscatter map for the fjord mouth sill shows some small patches of low (< −25 dB) to moderate (−15 to −25 dB) backscatter which are likely pockets of sediment. One thin pocket of acoustically transparent material was observed during the seismic survey infilling a depression in Unit A. Seaward of the sill the seismic survey crossed a 4 m thick unit of acoustically transparent material with a rough upper surface. A grab sample here confirmed the unit was mud.

3.4 Groundtruthing

The collection of groundtruth samples confirmed a number of the substrate interpretations made from the multibeam bathymetry and backscatter, as well as the shallow seismic survey. In addition details emerged that were not apparent from the acoustics, such as a spectrum of gravelly substrates. All of the main regions of the fjord - the inner basin, sills, middle and outer basins - were groundtruthed. Eight substrate classes were resolved by

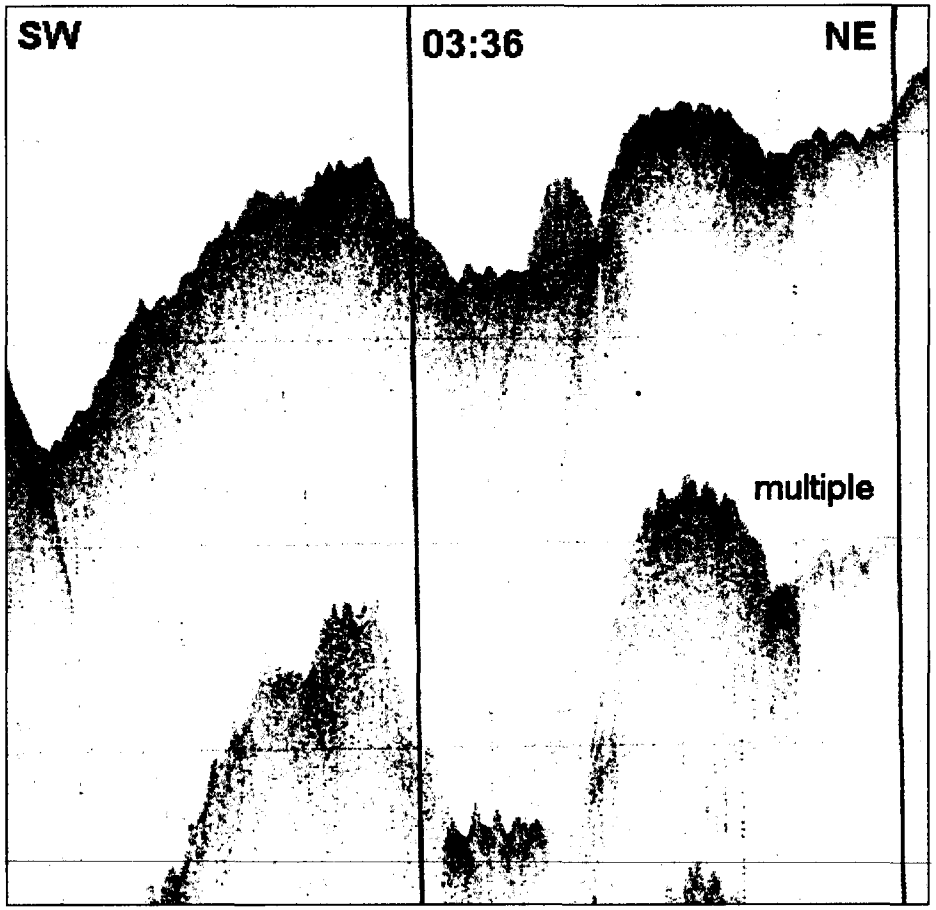
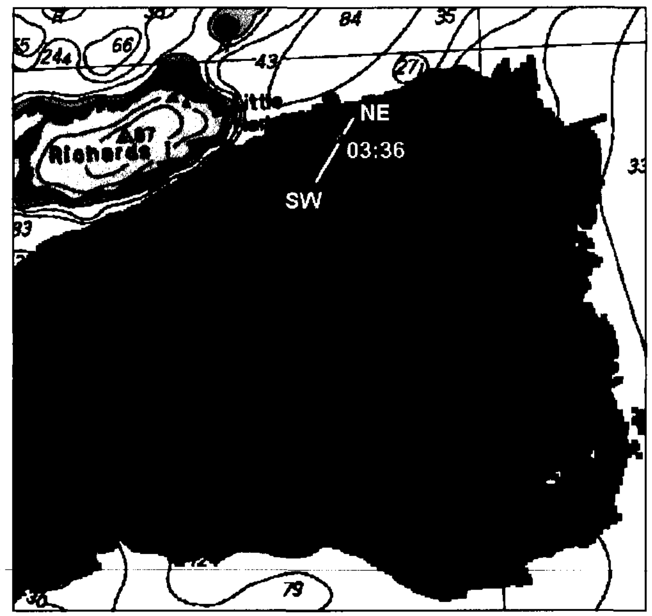


Figure 3.18 Sub-bottom profile from point 03:36 on the fjord mouth sill showing hard, rough seabed.



Location of Fig. 3.18 on backscatter image

groundtruthing; six from directly sampling with the benthic grab and two more from video imagery. The physical characteristics of these substrate classes, their distribution within Newman Sound and their appearance in the acoustic surveys are discussed below.

Biological information collected during groundtruthing confirmed that the benthos of Newman Sound supports a variety of invertebrates and algae, with diverse life forms and feeding habits. These biota act as structural components, as well as occupiers of, the habitats discussed below.

3.4.1. Benthic Grab Results

Substrate samples collected with the benthic grab were processed to define the grain size distribution and form a classification system for Newman Sound substrates. As grain size has a demonstrated effect on multibeam backscatter intensity (Lurton 2002), a backscatter range for classified each substrate was also found. The organic content of sampled sediments was also examined, as this will influence the attractiveness of a substrate to invertebrates, and possibly affect the backscatter values reflected by the substrate. Descriptions of all grab samples and the sediment class to which they were assigned can be found in Appendix A.

3.4.1.1 Grain Size Analysis

Grain size analysis of collected sediments was undertaken by sieving and sedigraph. The results of the grain size analysis for each sample were plotted as cumulative mass curves (Fig. 3.19). These curves show the percentage of the sieved sample coarser than a given grain size diameter, measured in phi units. A spectrum of grain size distributions can be seen from these curves, and some groups of samples can be detected.

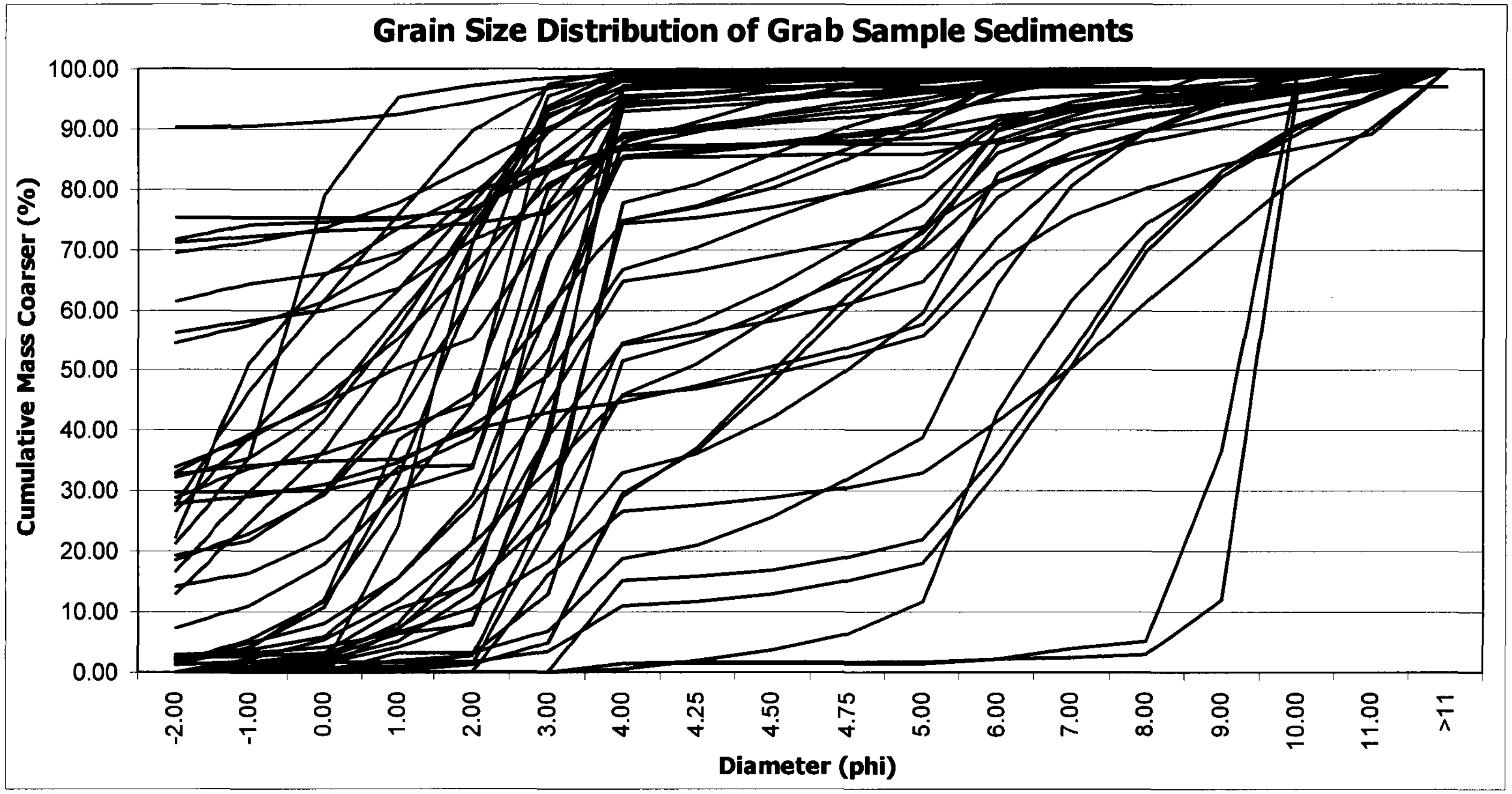


Figure 3.19 The cumulative mass curves for grab sampled sediments determined from sieving and sedigraph analysis.

3.4.1.2 Cluster Analysis

Cluster analysis was performed on the grain size distribution percentages to better define groups of samples and build a sediment classification. The cumulative mass curves were then coloured to represent the cluster to which each grab sample belonged, and used to interpret clusters. The resulting 9 clusters of grab samples were named based on the grain sizes from the Wentworth scale that defined the cluster (Table 2.1 in Chapter 2).

The five samples in Cluster 1 (Figs. 3.20 and 3.21), are composed primarily of fine (3ø) and very fine (4ø) sand, with at least some silt but no gravel. Therefore these samples were named silty fine sand. Cluster 7 was closely related to Cluster 1. The seven samples in this cluster were composed primarily of fine sand with substantial amounts of coarse sand. For example sample 126 contained 17% coarse sand (1ø) and 6% very coarse sand (0ø). This cluster was labelled fine sand with coarse sand.

Cluster 8 contained two samples composed mostly of coarse (1ø) to fine (3ø) sand. Neither sample had significant amounts of gravel or material finer than 3ø. This cluster is very similar to Cluster 7, but made of slightly coarser sand (Fig. 3.21). Grabs in this group were labelled coarse sand with fine sand. The branch of the dendrogram containing these three clusters was labelled sand, as the majority of the weight in these clusters came from grains between 0 and 4ø.

The second branch on the dendrogram (Fig.3.20) was labelled mud as most of the weight of these grabs was sediment smaller than 4ø (63μm). Cluster 3 contained seven grab samples, all but one of which was devoid of gravel. These samples were composed primarily of silt (4.25 to 8ø). Sample 112 was the finest sample, with about one quarter of its weight composed of clay. Grab 131 would be more typical of the cluster, having 52%

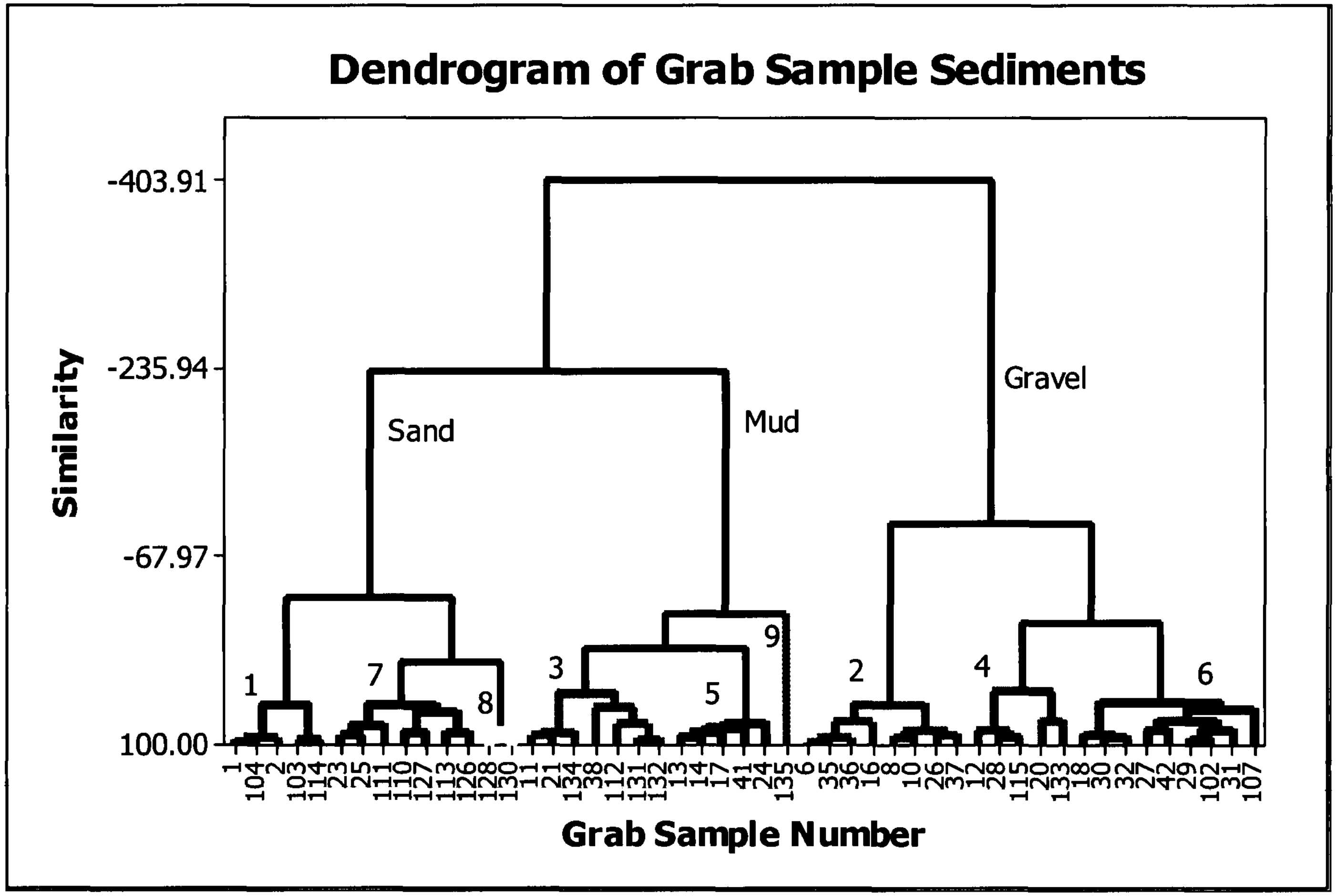


Figure 3.20 Dendrogram showing the similarity between grab sampled sediments based on cluster analysis of their grain size distribution.

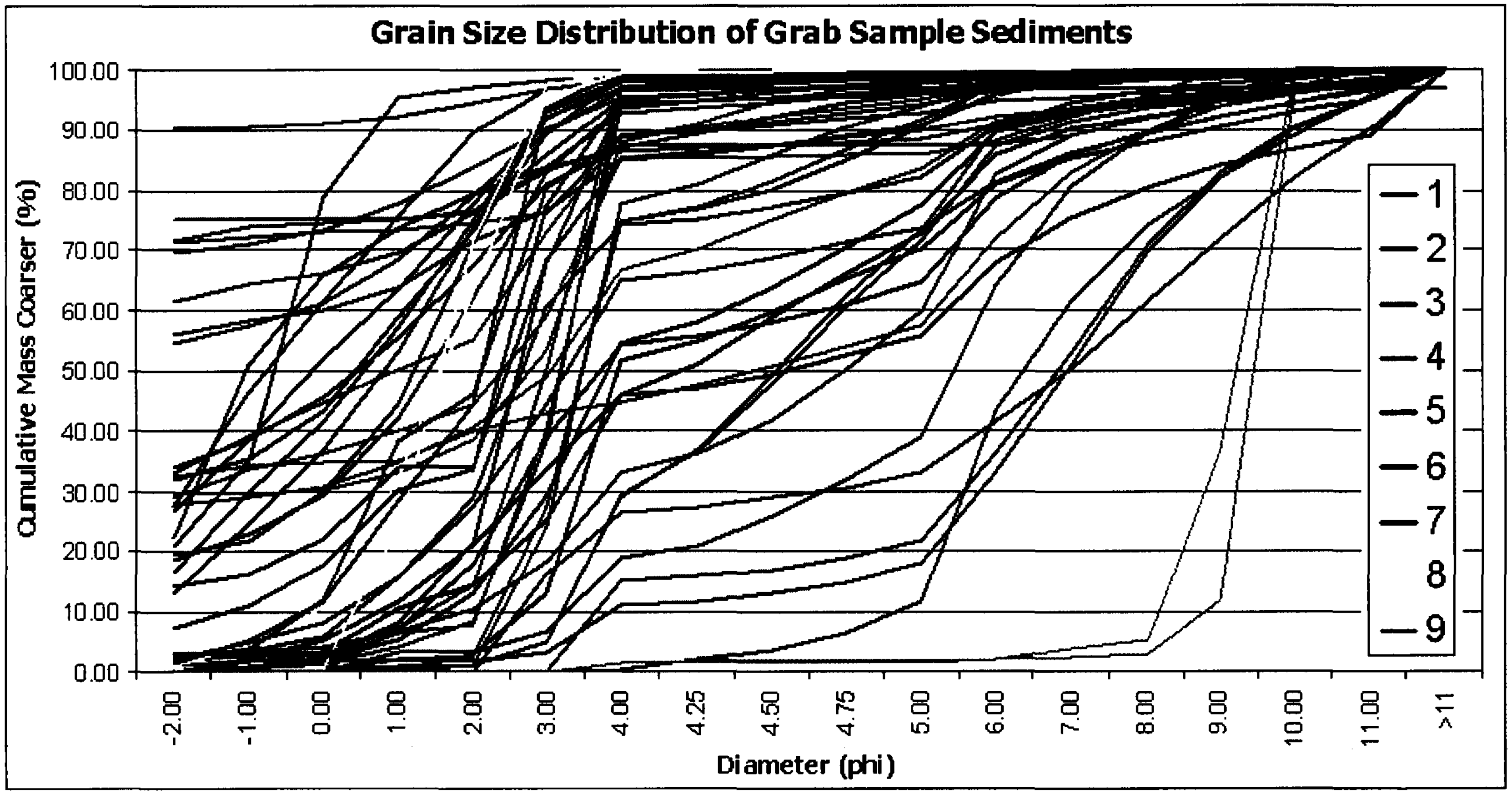


Figure 3.21 Cumulative mass curves showing the percent of total sample weight in each phi size class. The curves are coloured according to which cluster the grab sample belongs. Cluster numbers are shown in the legend.

of its weight between medium (6ø) and very fine (8ø) silt. Thus cluster 3 was labelled silty mud. The two samples that differed the most from the others - 112 and 38 - were the only members of this cluster not collected in the inner basin. Cluster 9 contained only one grab sample, which was collected from the inner basin, and contained 94% clay (9 to10ø). There was no coarse fraction; therefore this cluster was labelled clay. Cluster 5 contained five grab samples composed of fine sand and silt with some coarse sand and clay. For example, sample 24 was composed of 54% grains finer than very fine sand (4ø). The grabs in this cluster were labelled sandy mud.

The third branch of the dendrogram was labelled gravel. This branch contained more samples (n = 22) than the sand and mud branches, which had 14 and 13 samples respectively. The first cluster on the gravel branch, Cluster 2, contained eight samples, all containing over 50% gravel by weight. The gravel content (> –2ø) of this cluster ranged from 55 to 90 %.This cluster was defined by high gravel content alone, as the matrix material varied. Three of the samples had a muddy sand matrix, whereas the other 4 had a sandy matrix. The two grab samples collected at Happy Adventure contained organic poor gravel and some pieces of plastic and paint chips, which confirmed the earlier interpretation of dredge spoil. Cluster 2 was labelled sandy gravel.

Cluster 4 contained five samples composed of gravel and fine sand with silt. These sediments ranged from 29 to 33% gravel. Cluster 4 was formed based on the gravel and clay percentages and was labelled gravelly muddy sand.

Cluster 6 contained nine samples composed of coarse sand and gravel. These samples ranged from 13 to 34% gravel. Sample 107 is very sandy (95% coarser than 1ø), while sample 27 is muddy with 13% silt and clay. The other seven samples in this cluster all have grain size distributions with almost even percentages of weight in the gravel and coarse sand phi classes. Grabs in this Cluster 6 were labelled gravelly sand. A summary of all named clusters from Fig. 3.20 can be found in Table 3.1.

Table 3.1 Results of cluster analysis of grain size distribution of grab samples

Cluster Number	**Cluster Name**	**No. of Grabs**
1	silty fine sand	5
2	sandy gravel	8
3	silty mud	7
4	gravelly muddy sand	5
5	sandy mud	5
6	gravelly sand	9
7	fine sand with coarse sand	7
8	coarse sand with fine sand	2
9	clay	1

3.4.1.3 Definition of Substrate Classes

In order to create a complete substrate map using all groundtruth samples, the substrate classification developed for Newman Sound had to be equally applicable to both video and grab samples. Therefore named clusters from grain size analysis could not be used directly as the substrate classification. Clusters which were determined to be indistinguishable from each other on a video were grouped together producing five sediment types that are recognisable in all groundtruth samples.

Cluster 2 (sandy gravel) was retained because statistically it was the most dissimilar from any other cluster, and the defining characteristic of sediments in this cluster was that they contained over 50% gravel of pebble size or larger, which could be estimated from a video image. Therefore pebble/cobble gravel was the first substrate class created. The dredge spoil samples were removed from the class, which increased the range of pebble content in the group to 61 to 90%.

Cluster 4, gravelly muddy sand, was retained as a sediment class even though it is characterised by its mud fraction which would be hard to see on a video. This sediment class is also characterised by a high amount of fine and very fine sand, so the presence of a large amount of fine sediment with pebbly gravel was used in applying this class to video imagery.

Similarly, Cluster 6 (gravelly sand) was used as a sediment class. Samples were placed in this class if they i) had less than 50% gravel and therefore were not classed as pebble/cobble gravel and ii) did not have a large amount of fine material and therefore were not classed as gravelly muddy sand.

Clusters 3, 5 and 9 were simplified into a single class of mud as the different combinations of fine sand, silt and clay that define them cannot be seen from video data.

Cluster 7 (fine sand with coarse sand) and Cluster 8 (coarse sand with fine sand) are closest to each other statistically. When cluster analysis was performed at 25% similarity, these two clusters became one. Also Cluster 8 contained only 2 samples. Therefore Clusters 7 and 8 were joined into a class of sediment and labelled sand. The third cluster on the sand branch - Cluster 1 (silty sand) - was initially recorded as sand in the field notes. Therefore it is possible to recognise this type of sediment as fine sand without sieving it, and the silt content is low enough that it is not visually apparent. Hence this type of sediment was included in the 'sand' substrate class with Clusters 7 and 8. In summary, the five sediment classes defined by grain size analysis that can be visually determined are: mud, sand, pebble/cobble gravel, gravelly sand, and gravelly muddy sand.

Coarse gravel samples with no matrix were not sieved and therefore were described visually using the Wentworth scale (Table 2.1). The largest clasts were measured and if they were less than 256 mm the sample was placed in the pebble/cobble gravel class. Material larger than 256 mm is a boulder on the Wentworth scale, so any samples containing these large clasts were placed in a separate class (see below). None of the grab samples contained boulders so all were classified as pebble/cobble gravel.

The 6th substrate class identified was rhodolith. Rhodolith substrate could be reliably identified from video observation and was successfully collected by grab sampling. Rhodoliths are formed when coralline red algae encrust loose gravel, shells or the calcium carbonate skeletons of other coralline algae. The algae grow on top of the core material, usually in areas of moderate current which helps keep them from being smothered by sediment (Bosence 1983). The current also rolls the rhodoliths over periodically, enabling algae to grow on all surfaces of the core material. Rhodoliths are therefore commonly spherical, but may be ellipsoidal or discoidal in shape (Bosence 1983). Rhodoliths collected in Newman Sound displayed all three shapes.

Rhodoliths were the only biogenic substrate sampled in Newman Sound. Although the formation of rhodoliths relies on the presence of core material for algal growth, the surface of the substrate that is actively used as habitat is the live coralline algae or its calcium carbonate skeleton. In most cases it was possible to speculate on the identity of the core material based on the weight of a rhodolith, but most could not be positively identified so all cobble and pebble gravel with greater than 50% of its surface covered by dense branches of coralline algae were classified as rhodolith. The branching of the coralline algae is the key characteristic that distinguished rhodoliths from encrusted gravel. The grain sizes found were similar to pebble/cobble gravel, with the largest rhodolith reaching 11cm in diameter, but most were around 5 cm. Rhodolith was used as a separate substrate class from pebble/cobble gravel because the dynamics of a habitat on this substrate would be unique, as the rhodoliths are frequently moved. Also the structural complexity of this substrate is much higher than gravel due to the dense branching of the rhodolith-forming algae.

3.4.1.4 Organic Content

Samples processed for organic content came from five sediment classes; mud (n = 13), sand (n = 14), gravelly muddy sand (n = 5), gravelly sand (n = 10), and pebble/cobble gravel (n = 6). The two samples of dredge spoil from Happy Adventure were also tested. Grabs containing rhodoliths or 100% pebble/cobble gravel had no matrix material to analyze. The organic content of Newman Sound sediments ranged from 0.5 to 35.6%, with a mean of 8.2% and most samples, (38 of 62) having less than 5%. These results are high compared to those of Ramey (2001) who reported organic carbon values between 1 and 8% ($C.mg^{-1}$) for muddy sediments in Placentia Bay.

In general the sediments from the inner basin had higher organic content than samples from elsewhere in the fjord, with five of the seven stations having values between 24 and 35% (Fig. 3.22). Four of these samples were collected from the inner basin floor, and one from the delta top. The other two samples, both of which were collected near the delta front, had organic content values of 9%.

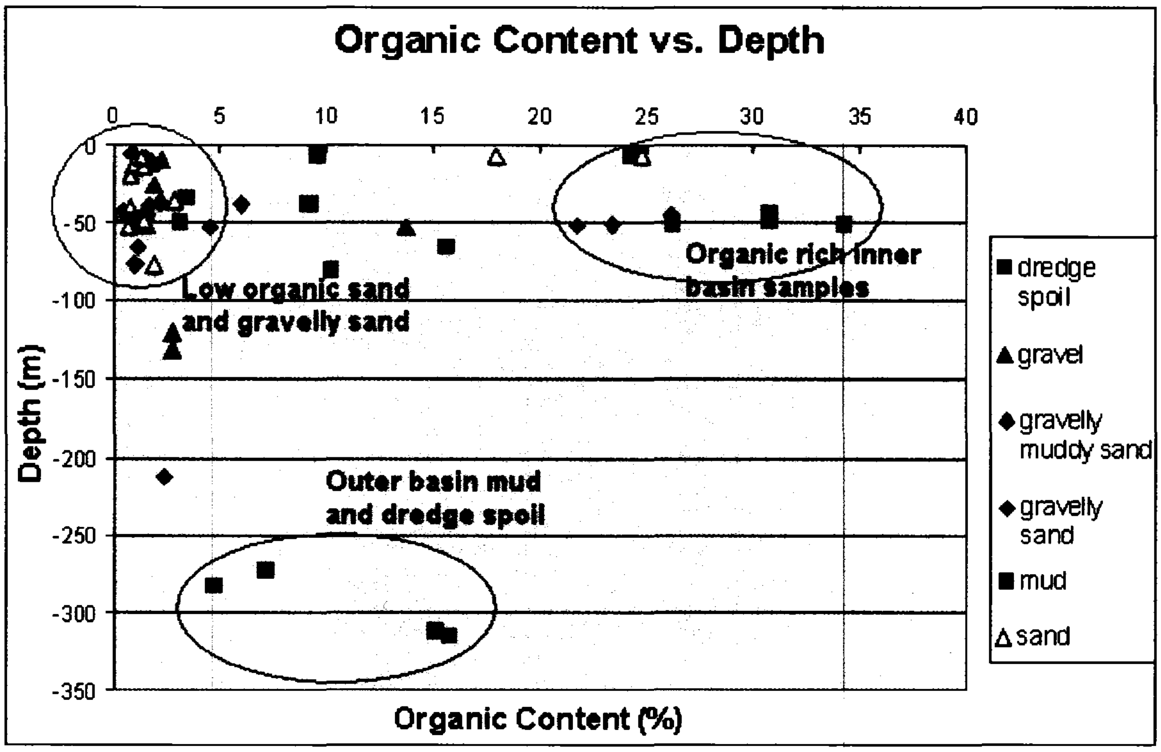


Figure 3.22 Scatterplot of organic content of grab sampled sediments vs. water depth.

Mud samples from other parts of Newman Sound also had relatively high organic content. The only sample from the floor of the outer basin contained 16% organic material. This suggests that like the inner basin, the muddy floor of the outer basin is organic rich, but more samples would be needed to confirm this. Mud sampled in locations other than the basin floors had an average organic content of 9.3%.

The lowest organic content values were found in shallow-water sand and gravelly sand collected at the White Islets, Minchin Head and Buckley Cove. These samples (n = 7) had organic content values ranging from 0.40 to 0.98% and occurred in a range of water depths from 5 to 42 m.

Sediments rich in organic material tended to have a larger mud fraction, whereas coarse sand generally contained less organic material. Mud is typically found in bathymetric settings that promote accumulation of both fine sediments and of organic material. For example, organic-rich samples of mud from the deepest part of the inner basin contained dead eelgrass and other material from surrounding shallow water environments.

The depth of the samples also influenced the organic content. Terrestrial plant debris was found in shallow-water samples from the inner basin, including aspen leaves and spruce cones. Inner basin sediments would also have been enriched with terrestrial plant debris from logging and associated human activities that occurred historically on the shores of inner Newman Sound. The impact of this logging on the benthic habitats of the sound are unknown, but the presence of a significant amount of woody debris was noted in inner basin grab samples. Woodchips were also encountered by Anderson et al. (2002) who made this a separate class in their benthic classification.

3.4.2 Video Results

Video methods were used to groundtruth additional sites, as well as several where grab sampling had failed. Video sample locations were assigned to established substrate classes (modified from cluster analysis of grab samples) based on the percentage of visible seabed that each class occupied in screen shots. Two new substrate classes were created to incorporate substrates found in videos that had not been found by grab sampling; boulder gravel and bedrock.

3.4.2.1 SCUBA Transects

The two substrates most commonly encountered during the SCUBA video transects were pebbly sand with macroalgae and rounded boulders in pebbly sand. The dives revealed that cobble and boulder slopes, and pebble to boulder gravel on sand are the most common substrates near Buckley Point, the Narrows and Mt. Stamford Cove. In some cases, these coarse substrates represent the submarine extension of talus slopes on the fjord walls, whereas in others, they may represent submerged gravel beaches formed during Holocene low stands of sea level (T.Bell, personal communication 2006).

The most important result from the SCUBA transects was the documentation of broadleaf kelp (genus *Laminaria*). Dive sites 3 and 4 were chosen to investigate the patch of extremely low backscatter located 200 m east of the island in the Narrows. The dives were aligned so that the transects crossed the transition from very low to moderate backscatter (Fig. 2.12, Chapter 2). The very low backscatter values at the start of both dives, −55 and −59 dB, coincide with seabed that was very densely covered by *Laminaria* kelp. It was thus concluded that the acoustic signal was being scattered by the kelp, creating this anomalous patch of low backscatter (white area on Fig. 2.12).

Dives 5 and 6 just to the west of dives 3 and 4 had moderate backscatter between −11 and −13 dB. Here the flat seabed was covered by sand with angular pebbles and bivalve shells. Notably, algae cover was sparse, with 10 to 25% of the seabed covered by fine green algae, and only sparse patches of *Laminaria* kelp (<5% cover). Similarly, gravelly sand with 25% *Laminaria* cover was observed in Buckley Cove, where backscatter values were −11 to −14 dB. It was therefore concluded that although *Laminaria* kelp occurs elsewhere in shallow water, 75% or more of the surface must be covered to affect the multibeam backscatter signal in the way seen near the Narrows.

3.4.2.2 Tethered Drop Video Camera

The drop camera was deployed at 7 stations around the Narrows to determine the extent of the rhodolith bed sampled there and to investigate the low multibeam backscatter pattern. Video images revealed pebble-cobble sized rhodoliths with dense branches and leafy red algae (*Ptilota serrata*) which covering about 75% of the bottom. In contrast, where backscatter was higher, coralline encrusted pebbles with a few rhodoliths and sparse kelp cover were observed along with scattered boulders.

The drop camera also successfully characterised locations where grab sampling had failed. For example at grab station 109, the sampler had been recovered open with the cable wrapped under the arm of the grab, suggesting it had tipped over on the bottom. The camera indicated that the sandy seafloor at this location was ~50% covered by large boulders, which likely tipped the grab.

3.4.2.3 Remotely Operated Vehicle Video (ROV)

Station A was selected to include low and high backscatter areas on the shallow sill at the Narrows. The ROV images confirmed both contained rhodoliths. Station B represented the high backscatter seabed which had been unsuccessfully grab sampled about 1 km north-west of Minchin Head in 55 to 60 m water depth. The ROV video revealed that cobbles thinly covered by mud occurred adjacent to a field of biogenic mounds in fine sand. The mounds where cone shaped with circular holes in the apex and there was evidence of bioturbation on the sides of the mounds and surrounding seabed.

The most important aspect of the ROV survey was the opportunity to investigate bedrock substrate and the biological communities associated with exposed bedrock. Also, the ROV surveyed the outer basin which had not been accessible with other video methods.

The fjord wall on the southern side of the outer basin was sampled at East Point, on the eastern end of Swale Island (station D). Here a bedrock cliff drops abruptly from the intertidal zone to the basin floor over 300 m below. Bedrock habitat was also surveyed at station E, located 1 km from Little Harbour Head on Richards Island. Here the bedrock formed round-topped parallel ridges 1 to 2 m high on a moderate slope, which contrasted with the relatively smooth cliff face at station D. The origins of these mounds are unknown.

3.4.2.4 Classification of Video Samples

All video samples collected by SCUBA divers, tethered drop camera and the ROV were assigned a substrate class. The six classes described from grain size analysis of the grabs were used, and two new classes were added. In some cases video samples were collected at the same site as grab samples, and consequently the video was assigned to the same class as the grab sample. In all other cases, the six substrate classes derived from the grab samples were applied to video images based on the estimated percentage of gravel and fine sediments observed.

Videos with less than 50% of the surface covered by pebbles and cobbles were assigned to one of two classes based on the composition of the sediment matrix. If a large proportion of fine-grained sediment was present the sample was classified as gravelly muddy sand. If the matrix appeared coarser the sample was classified as gravelly sand. When 50% or more of the seabed was covered by pebble or cobble size clasts, the video sample was placed in the pebble/cobble gravel class. Videos where 100% of the seabed was covered by fine sediment were classified as mud or sand.

One substrate class generated solely from the video data is boulder gravel with or without sand. The term 'boulder gravel' is used because the dominant feature of the seabed was boulders, although cobbles and pebbles were also present. Large boulders approximately 2 m in diameter were observed in some videos. Boulders were often well rounded and exposed on the sediment surface. It is possible that grab samples containing pebble/cobble gravel, gravelly sand or sand may have been sampled from between the boulders on this type of substrate, but it is impossible to tell if boulders are present using a grab sampler.

The other substrate class identified by video sampling was bedrock. This class was easily identified from video imagery, but could only be sampled with the ROV as it occurred primarily in the outer sound, which could not be reached by the vessels used to conduct other video sampling.

3.4.3 Summary of Substrate Classes

The total groundtruthing effort using videos and the benthic grab resulted in 146 samples classified into eight substrate classes. They are: mud, sand, gravelly muddy sand, gravelly sand, pebble/cobble gravel, rhodolith, boulder gravel and bedrock. The distribution of sampling effort among the eight substrate classes is shown in Table 3.2. The attributes of each classified point can be found in Appendix A.

Table 3.2 Number of grab and video samples containing biota and total number of samples in each substrate class

Substrate Class	**# of Grabs**	**# of grabs with biota**	**# of videos**	**# of videos with biota**	**Total samples in class**
Mud	13	10	7	6	20
Sand	13	7	11	1	24
Gravelly muddy sand	5	3	0	0	5
Gravelly sand	11	10	9	9	20
Pebble/cobble gravel	17	16	1	1	18
Rhodolith	5	5	9	9	14
Boulder gravel (with or without sand)	*	0	18	18	18
Bedrock	n/a	0	5	5	5
No recovery	22	0	n/a	0	22
Total	**86**	**51**	**60**	**59**	**146**

* No grab samples in this class, however grab samples classified as pebble/cobble gravel or gravelly sand may have come from boulder gravel substrates.

3.5 Groundtruthing: Biological Data

Biological samples were collected to gain an understanding of substrate-specific habitat use by benthic macroinvertebrates and algae in Newman Sound. Biological samples were collected from 53 of the 67 grab samples. Biota were also observed in all but one of the videos (Table 3.2). In total 93 taxa were recorded from 12 phyla. This includes 84 invertebrate and 9 algal taxa. Tables of species identified can be found in Appendices B and C.

Newman Sound has a primarily boreal faunal assemblage, with some arctic species also present. Overall the shallow-water parts of the fjord contained the most biota, both in terms of number of individuals and species richness. Samples collected in deep water, particularly in the outer basin, contained sparse biota. Biological data from video and the benthic grabs showed some significant differences in both the number and type of organisms captured; the reasons for these differences and the importance to the overall biological data set are discussed below.

3.5.1 Grab-Sampled Invertebrates

The segmented worms (Phylum Annelida: Class Polychaeta) were the most frequently observed and most species rich invertebrate group in the grabs, with 24 taxa identified. Tube-dwelling polychaetes were the most numerous group, and were found attached to hard substrates and in sediment. Free living, non-tube building (errant) polychaetes were less common and more difficult to identify as these specimens were easily damaged. Polychaete worms spanned all possible feeding guilds including filter feeders, scavengers, predators, detritivores and deposit feeders.

Molluscs from the class Bivalvia were the second most common invertebrate group, with individuals identified from 14 taxa. Again, a range of forms were represented with burrowing infaunal species, boring clams, surface-dwelling bivalves and attached species observed. Most of the identified bivalves were filter feeders, but some notable taxa of detritivores were also found (see below). A number of juvenile bivalves were found attached to algae and rhodoliths.

Echinoderms from four classes were sampled with the benthic grab. The most diverse class was Ophiuroidea; the brittle stars. Larger echinoderms, such as sandollars (*Echinarachnius parma)* and sea urchins (*Strongylocentrotus droebachiensis)* were only collected in a few grabs, usually as juveniles. Other Phyla represented include Porifera, Arthropoda, Bryozoa, Rhizopoda and Cnidaria.

The most commonly occurring flora was encrusting coralline red algae from the genus *Lithothamnion.* It was tentatively identified as *L. glaciale* based on descriptions by Morgan (1998) from Bonne Bay and Portugal Cove, Newfoundland.

3.5.2 Biota from Videos

Much of the biota recorded by video methods was the same as those identified from grab samples. Additional taxa identified from video only are: two species of crab (Arthropoda: Crustacea); and organisms typical of hard substrates including an attached anemone species, a sea squirt (Chordata: Ascidiacea), an encrusting sponge and hydroids (Cnidaria: Hydrozoa).

Along with the invertebrate species, six species of fish were recorded from the videos. The fish did appear to be substrate specific, with cod associated with vegetated boulder gravel and sand, and flounder with sand or gravelly sand. The fish species are listed with the invertebrates in Appendix C but they were not included in any of the analyses or the resulting maps.

Broadleaf kelp from the genus *Laminaria* was recorded at 10 video sites. This was the only algal taxon sampled by video which was not collected in the grab samples. This type of kelp is large and secured to hard substrates by a holdfast, so it is unlikely to be collected by the benthic grab.

3.6 Biotic Assemblage and Substrate Associations

Habitat characterisation and mapping require that the biological data from groundtruth samples are examined in the context of the substrates from which they were collected. The associations between groups of organisms must also be considered. Statistical analysis was performed on the two biological datasets to explore the relationship between classified substrates and their biotic assemblages.

3.6.1 Species Richness

In general species richness appears to be well correlated with surface complexity; with complex, harder substrates showing high species richness whereas the muddy substrates exhibited low species richness. It is likely that the sampling methods used played a role in this distribution. As bedrock was only sampled by video, a larger surface area was viewed per sample compared with unconsolidated substrates, such as gravelly muddy sand, which was only sampled by grabs. There are, however, real ecological gradients evident in the relationship between species richness and substrate class (Fig. 3.23).

The rhodolith bed demonstrated the highest species richness with an average of 7.4 identified species per video sample and 21.6 per grab. Most species were small fauna hidden in rhodolith branches, which explains the discrepancy between sampling methods.

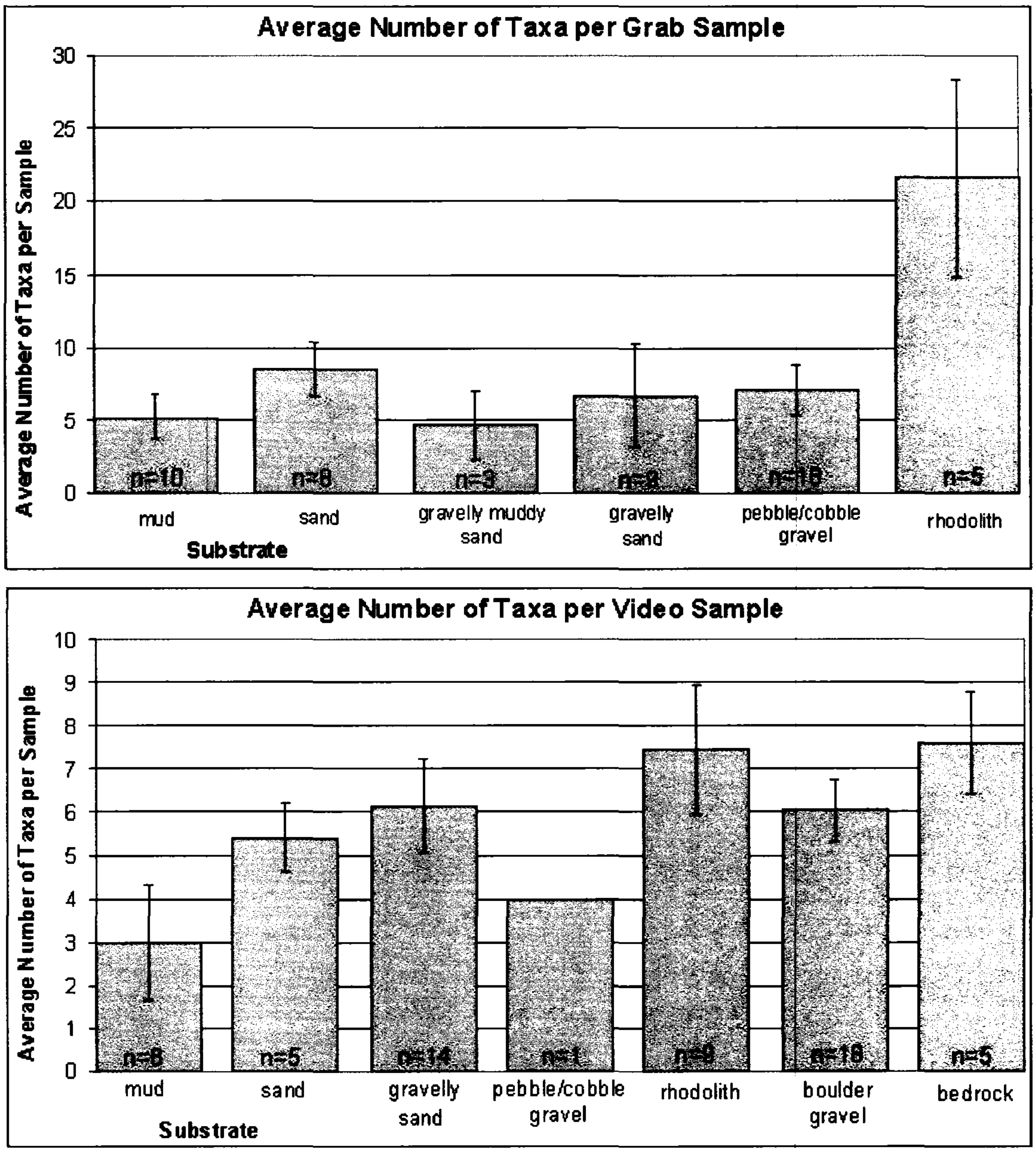


Figure 3.23 Chart of the average number of taxa per sample in each of the substrate classes. Error bars represent 95% confidence limits.

This habitat also had the highest diversity with 31 species identified from 9 phyla. Overall, the rhodolith bed was the most bio-diverse habitat sampled and one of the most structurally complex.

The two substrates with the lowest structural complexity - mud and gravelly muddy sand - had the lowest species richness. Muddy substrates primarily supported infaunal species which would be undetectable on video and may be missed by a shallow penetrating grab. However grab samples, particularly from mud in the inner basin, contained a high number of individuals, but species diversity was low. Therefore the low structural complexity of this substrate, and thus few available microhabitats, is the likely cause of its low richness.

3.6.2 Non-metric Multi-dimensional Scaling

The fact that benthic organisms display substrate preference, and are not arranged randomly on the seabed, is key to habitat mapping. Non-metric multi-dimensional scaling (NMDS) was used to visualise patterns in the biological data as an initial step towards determining if the sampled biota were indeed showing preference for particular substrates.

3.6.2.1 Non-metric Multi-dimensional Scaling of Grab Samples

Ordination of the grab sampled biota showed a general separation of hard and soft bottom taxa. Samples from hard-bottom substrate classes (rhodolith and pebble/cobble gravel) appear towards the left of the plot, sand and gravelly sand generally occur near the middle and soft-bottom mud and gravelly muddy sand are on the right (Fig. 3.24).

Samples that are geographically close together, such as mud samples 135, 134 and 131, had eigenvalues which placed them close together on the ordination diagram.

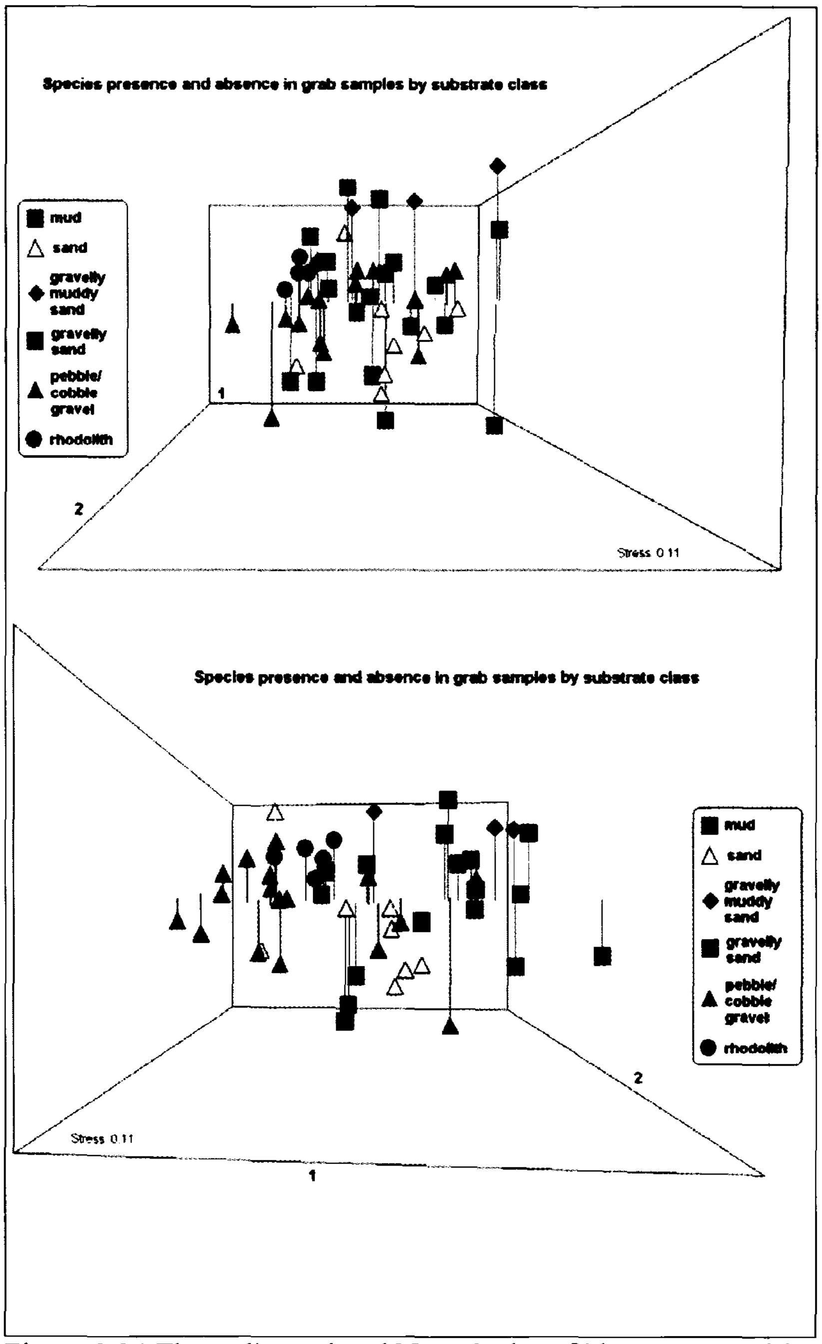


Figure 3.24 Three-dimensional NMDS plot of biota presence/absence data from grab samples with points coloured to represent substrate classes.

Interestingly, samples from the same part of the inner basin but from other substrate classes, such as grabs 16 and 133, also plotted close to this group. These two samples are muddy gravel and gravelly muddy sand, but they share polychaete and bivalve species with the mud samples, indicating that the muddy matrix is the cause for similarity. The mud samples from other parts of the fjord are dispersed around the plot and do not form an associated group.

The scattered distribution of the gravelly sand and gravelly muddy sand samples on the NMDS ordination diagram indicates that these substrate classes do not share as many species as the other classes for which samples appear close together (Fig. 3.24). This is understandable given the range in water depths and geographic locations of the gravelly sand and gravelly muddy sand samples. Gravelly sand samples which contained more gravel, such as grab 102, appeared near the rhodolith and pebble/cobble gravel group due to their high diversity of encrusting and epilithic fauna. Pebble/cobble gravel samples from grabs 3, 5, 105, 40, 39 and 35 formed a group at the right side of Fig. 3.24. These contain very high percentages of pebble and cobble, and share epilithic taxa such as limpets, bryozoans and forams.

The rhodolith grab samples appear close to the pebble/cobble gravel group, as these substrates share a number of infaunal and small epifaunal species. Notably, grabs 119 and 33 are plotted very close to the rhodolith group. These grabs were taken very close to the Narrows and contained large cobbles, which were heavily encrusted with coralline algae and share many other species with the rhodolith class.

3.6.2.2 Non-metric Multi-dimensional Scaling of Videos

Non-metric multi-dimensional scaling of biota sampled by video demonstrated that there is some distinction between the biota sampled on hard substrates, such as bedrock, boulder or rhodolith, and those found in mud. In general the harder substrates appear near the top of the ordination diagram, whereas the muddy substrates are on one side and the gravelly sand samples are near the bottom of the plot (Fig. 3.25).

Some of the boulder samples, such as the dives in Mt. Stamford Cove and Buckley Point 1 and 2, were on sand and contained more sand-associated biota. These plotted lower than the other boulder samples, close to the gravelly sand from dives 5, 6 and Buckley Point 3, as well as sand from drop camera stations 126 and 7 and dive 3. Most of these samples are close to each other geographically.

As in the grab samples, videos in the rhodolith class formed a fairly cohesive group, which was closely associated with other hard substrates such as bedrock and boulders. Only one video was classified as pebble/cobble gravel, and this sample did not appear near rhodolith or boulder gravel samples. Instead it appeared close to the mud samples as this video, ROV station B, contained cobbles coated in mud and largely lacked epifauna.

3.6.3 Analysis of Similarity

Analysis of similarity (ANOSIM) was used to test if each substrate class had a different species assemblage. In the grab sample dataset ANOSIM revealed that within class similarity was lower than similarity between the pebble/cobble gravel and rhodolith classes. The R value for this test pair was −0.123 (Table 3.3). A number of test pairs had low R values and high significance, indicating they had very similar biotic assemblages.

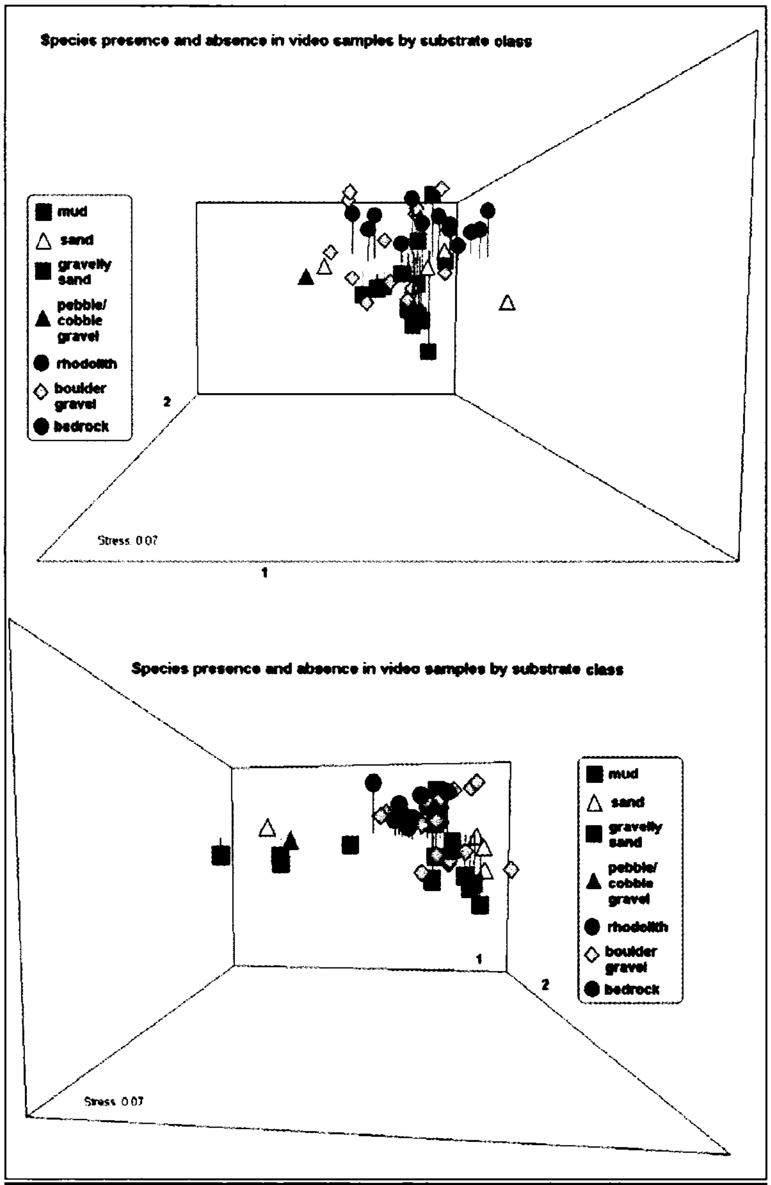


Figure 3.25 Three-dimensional NMDS plot of biota presence/absence data from video samples with points coloured to represent substrate classes.

Table 3.3 Analysis of Similarities (ANOSIM) pair-wise tests of classified substrates based on biota from grab samples

Test Pairs		**R Statistic**	**Significance Level %**
sand	pebble to cobble gravel	0.104	8.6
sand	mud	0.345	0.2
sand	gravely muddy sand	0.594	1.2
sand	rhodolith	0.534	0.4
sand	gravely sand	0.094	12.9
pebble to cobble gravel	mud	0.325	0.1
pebble to cobble gravel	gravely muddy sand	0.441	1.0
pebble to cobble gravel	rhodolith	**−0.123**	83.1
pebble to cobble gravel	gravely sand	0.143	5.2
mud	gravely muddy sand	0.305	8.2
mud	rhodolith	0.81	0.1
mud	gravely sand	0.204	0.6
gravely muddy sand	rhodolith	0.851	1.8
gravely muddy sand	gravely sand	0.03	35
rhodolith	gravely sand	0.209	5.8

In general, soft sediments such as mud and gravelly muddy sand appear to share similar taxa. The coarser substrate classes- namely sand, gravelly sand, rhodolith and pebble/cobble gravel- also shared a similar species assemblage.

Analysis of similarity for the videos produced only positive R values, indicating that for all test pairs, within class biotic similarity is greater than similarity between samples in different substrate classes (Table 3.4). Again, hard-bottom substrate classes, such as pebble/cobble gravel, boulder gravel, rhodolith and bedrock appear to have a similar biotic assemblage, as shown by the low R values and high significance. The sand, gravelly sand and pebble/cobble gravel classes also appear to have similar species.

Table 3.4 Analysis of Similarities (ANOSIM) pair-wise tests of biota from videos

Test Pairs		**R Statistic**	**Significance Level %**
gravelly sand	boulder gravel	0.151	1.4
gravelly sand	sand	0.231	7.2
gravelly sand	rhodolith	0.51	0.1
gravelly sand	mud	0.927	0.1
gravelly sand	bedrock	0.613	0.1
gravelly sand	pebble/cobble gravel	0.903	7.1
boulder gravel	sand	0.348	2.6
boulder gravel	rhodolith	0.059	19.8
boulder gravel	mud	0.972	0.1
boulder gravel	bedrock	0.137	13.5
boulder gravel	pebble/cobble gravel	0.95	5.0
sand	rhodolith	0.722	0.2
sand	mud	0.781	0.2
sand	bedrock	0.616	0.8
sand	pebble/cobble gravel	0.36	33.3
rhodolith	mud	1.0	0.1
rhodolith	bedrock	0.767	0.2
rhodolith	pebble/cobble gravel	1.0	10.0
mud	bedrock	1.0	0.2
mud	pebble/cobble gravel	0.911	14.3
bedrock	pebble/cobble gravel	1.0	16.7

3.6.4 SIMPER – Similarity Percentages

As ANOSIM had indicated some similarity between the assemblage of species present in hard and soft substrates, SIMPER was used to explore which taxa contributed to similarity of samples within each substrate class. Thus a better understanding was gained of which individual species were characteristic of hard and soft substrates, and which substrate classes, if any, hosted unique biota. Similarity analysis also demonstrated which substrate classes, as determined by grain size analysis, represented the most biologically similar groups of samples (Table 3.5).

Table 3.5 SIMPER average similarity of biota sampled within substrate groups

Substrate	**Average Similarity in Videos**	**Average Similarity in Grab Samples**
mud	**76.44**	18.82
sand	36.33	19.24
gravelly muddy sand	*	11.76
gravelly sand	51.99	14.11
pebble to cobble gravel	**	11.99
boulder gravel	47.66	*
bedrock	66.55	*
rhodolith	69.86	**27.61**

* no samples were collected in these substrate classes
** as there is only one video classified as pebble/cobble gravel no SIMPER was conducted.

3.6.4.1 Bedrock Biotic Assemblage

High similarity between biological samples was found in the bedrock substrate class (Table 3.5). As this class contained the smallest number of samples (n = 5 from 3 locations) it is logical that there would be significant agreement. SIMPER showed that the frilled anemone (*Metridium senile)*, the green sea urchin (*Strongylocentrotus droebachiensis)*, and an encrusting coralline red alga (*Lithothamnion glaciale)* each contributed 20% of the similarity in the bedrock biotic assemblage (Table 3.6). The rest of the assemblage was composed of attached anemones and echinoderms, including the northern red anemone (*Teallafelina)* and purple sunstar *(Solaster endeca)*. The bedrock assemblage had the highest number of taxa unique to this substrate class, including Cnidaria, which were abundant. Other unique species include the breadcrumb sponge (*Halichondria panacea*), the sea peach tunicate (*Halocynthia pyriformis*), and hydroids. These three taxa together with the anemones *Teallafelina* and *Metridium senile* are characteristic of bedrock substrate.

Table 3.6 Contributors to 90% similarity in the bedrock assemblage

Taxon	Video (%)
Lithothamnion glaciale	19.96
Metridium senile	19.96
Strongylocentrotus droebachiensis	19.96
Teallafelina	11.33
Asterias vulgaris	6.77
Ophiuroidea sp.	5.68
purple urchin	5.43
Solaster endeca	5.43

3.6.4.2 Boulder Gravel Biotic Assemblage

SIMPER results revealed that there was high similarity (48%) between biota sampled from boulder substrate (Table 3.5). As there were no grab samples in this group the biotic assemblage was dominated by large fauna and algae. The coralline red alga *Lithothamnion glaciale,* green algae and *Agarum cribrosum* kelp were significant contributors to similarity in this class (Table 3.7). Echinoderms were the most significant faunal group, with the northern sea star *(Asterias vulgaris)* contributing the most to similarity within the assemblage, followed by the green sea urchin (*Strongylocentrotus droebachiensis)* and the purple sunstar (*Solaster endeca)*. The frilled anemone (*Metridium senile)* was the third highest contributor to similarity.

Pair-wise SIMPER tests determined that the boulder and bedrock species assemblages had the lowest dissimilarity. Algal species found on boulders but absent from bedrock contributed to this dissimilarity, especially green algae and *Agarum cribrosum*. Therefore the characteristic assemblage for the boulder class is green algae, colander kelp (*Agarum cribrosum*), anemones (*Metridium senile*), sea stars (*Asterias vulgaris*) and green sea urchins (*Strongylocentrotus droebachiensis*).

Table 3.7 Contributors to 90% similarity in the boulder assemblage

Taxon	Video (%)
Asterias vulgaris	29.33
Strongylocentrotus droebachiensis	25.42
Metridium senile	16.62
Lithothamnion glaciale	6.79
green algae	6.72
Solaster endeca	4.63
Agarum cribrosum	4.01

3.6.4.3 Rhodolith Bed Biotic Assemblage

The rhodolith samples had the second highest percentage of similarity in video samples and the highest similarity in grab samples (Table 3.5). The encrusting coralline red alga (*Lithothamnion glaciale*) constituted the primary component of the rhodoliths, and was therefore not surprisingly a high contributor to similarity in the rhodolith biotic assemblage.

SIMPER analysis of grab sampled biota showed seven species contributing 8.98% to group similarity (Table 3.8). Five of these were small fauna that were collected from among the branches of the rhodoliths and therefore had not been recognised by video analysis. Of these, the ophiuroids *Ophiura robusta* and *Ophiopholis aculeata* were particularly abundant in rhodolith grabs.

SIMPER analysis of the videos showed the high contributions to similarity from large echinoderms, such as sea stars (*Asterias vulgaris*) and green sea urchins (*Strongylocentrotus droebachiensis)*. Colander kelp (*Agarum cribrosum*) contributed 15.18% of the similarity of videos in this assemblage, the highest result for this species in any substrate.

Biota sampled in rhodoliths had a high diversity of feeding methods. Suspension-feeding sessile benthos like bryozoans, sponges, bivalves and polychaetes were important members of the assemblage. Grazers were also significant, particularly chitons, limpets, grazing snails and sea urchins. The rhodolith bed was one of the few habitats where predatory or scavenging polychaetes, such as *Lepidonotus squamatus*, were significant members of the assemblage. The abundance of predatory species in this assemblage is indicative of the abundance and diversity of biota in other trophic groups.

Characteristic taxa of the rhodolith assemblage are branching *Lithothamnion glaciale* algae, the arctic rock borer (*Hiatella arctica*), the red chiton (*Tonicella rubra*), ophiuroids, the 12 scaled worm (*Lepidonotus squamatus*) and colander kelp (*Agarum cribrosum*).

Table 3.8 Contributors to 90% similarity in the rhodolith assemblage

Taxon	Video (%)	Grab Only (%)
Lithothamnion glaciale	19.97	8.98
Asterias vulgaris	19.97	
Strongylocentrotus droebachiensis	19.97	8.98
Agarum cribrosum	15.18	1.23
Metridium senile	7.89	
Spirorbis borealis	7.17	
Hiatella arctica		8.98
Tonicella rubra		8.98
Ophiopholis aculeata		8.98
Ophiura robusta		8.98
Lepidonotus squamatus		8.98
Puncturella noachina		5.45
encrusting bryozoans		5.45
Asteroidea juvenile		4.68
Tonicella marmorea		2.99
Anomia simplex		2.34
Porifera		2.28
lichen bryozoan		2.18
white crust bryozoan		0.90

3.6.4.4 Mud Biotic Assemblage

SIMPER analysis showed that video samples in the mud class had the highest biotic similarity of all substrate classes, while muddy grab samples had the third highest similarity (Table 3.5). Both video and grab samples collected from muddy bottoms were dominated by deposit feeding taxa, especially tube-dwelling polychaetes.

The most important contributor to similarity in the mud assemblage was the deposit feeding bamboo worm, *Maldane sarsi* (Table 3.9). This species, which was particularly numerous in grabs from the inner basin, constructs a tube of fine-grained sediment particles. A number of unidentified tubes where recorded in video protruding from muddy sediments, and contributed significantly to group similarity. These are thought to also be *M. sarsi* but it was impossible to confirm this. The deposit feeding, chalky macoma (*Macoma calcarea*) was also abundant in mud grab samples. As it is an infaunal bivalve, *M. calcarea* was likely under represented in the videos. A number of siphon pits were observed in videos which are likely this species. A second tube-dwelling polychaete, *Pectinaria granulata*, was also a significant contributor to similarity in the mud class. This species builds tubes of slightly coarser material than *M. sarsi*, and feeds by filtering particles from water pumped through its tube. Echinoderms were sparse in the mud-bottom fauna, with the only significant species being the orange-footed sea cucumber (*Cucumaria frondosa*).

Table 3.9 Contributors to 90% similarity in the mud assemblage

Taxon	Video (%)	Grab (%)
polychaete tubes	48.26	9.24
Maldane sarsi	48.26	7.60
Pectinaria granulata		42.10
Macoma calcarea		14.63
amphipod		13.76
Cucumaria frondosa		2.95

3.6.4.5 Sand Biotic Assemblage

The most significant members of the sand assemblage were the purple sandollar (*Echinarachnius parma)* and tube-dwelling polychaete *Pectinaria granulata* (Table 3.10). Algae contributed significantly towards similarity within the sand class, notably green algae which were prolific in shallow water. Kelp from the genus *Laminaria* were also observed in a number of videos. A strong association was seen between sourweed (*Desmarestia aculeata),* amphipods, lichen bryozoans (*Lichenopora spp.)* and the smooth top snail (*Margarites helicinus).* These three taxa were found attached to sourweed in grab samples from sand. Therefore the presence of macroalgae as a host for epifauna is an important biotic component of the sand habitat. This would obviously only apply to sand found within the photic zone.

Analysis of grab samples showed that suspension feeders are important within the sand assemblage, particularly suspension feeding polychaetes and Bryozoa. Infaunal suspension feeding bivalves were also important components of this assemblage, such as members of the genus *Astarte*. The characteristic species of the sand assemblage are the purple sandollar (*Echinarachnius parma*), the trumpet worm (*Pectinaria granulata),* green algae, sourweed (*Desmarestia aculeata),* and amphipods, especially the genus *Gammarus.*

Table 3.10 Contributors to 90% similarity in the sand assemblage

Taxon	Video (%)	Grab (%)
Echinarachnius parma	30.28	17.7
Pectinaria granulata		28.64
green algae	4.59	9.87
Gammarus sp.		9.62
unknown polychaete tubes		7.37
unknown polychaete		3.63
Desmerestia aculeata	14.68	2.82
Margarites helicinus		2.82
Caprella sp.		2.82
lichen bryozoan		2.82
Astarte sp.		2.54
Asterias vulgaris	30.28	
Spirorbis borealis	5.50	
Laminaria sp.	5.50	

3.6.4.6 Pebble/Cobble Gravel Biotic Assemblage

There was only one video in the pebble/cobble gravel class, therefore SIMPER was only possible for grabs in this class. Thus the resulting assemblage was dominated by small epifauna. Encrusting epifauna, such as foraminiferans, bryozoans and calcareous tube worms (*Spirorbis borealis*) were the most significant contributors to similarity of pebble/cobble gravel samples (Table 3.11). All are filter feeders and were commonly found as epifauna on pebble to cobble sized gravel when it was exposed at the sediment surface. Small grazers, such as the red chiton (*Tonicella rubra*) and the limpet (*Puncturella noachina*) were also found in gravel grabs in shallow water. The only algal taxon that appeared in the SIMPER results was the encrusting coralline red alga *Lithothamnion glaciale*. Perhaps for this reason the pebble/cobble gravel biota was most similar to rhodolith biota in grab sample analysis (79.2% dissimilarity). The characteristic taxa of pebble/cobble gravel substrate were foraminiferans, chitons, limpets, filter feeding tube-dwelling polychaetes and encrusting bryozoans.

Table 3.11 Contributors to 90% similarity in the pebble/cobble gravel assemblage

Taxon	Grab Only (%)
calcareous forams	14.57
encrusting bryozoans	14.09
polychaete tubes	14.06
Lithothamnion glaciale	13.01
Tonicella rubra	13.01
Puncturella noachina	5.02
Spirorbis borealis	4.11
Pectinaria granulata	3.18
unknown polychaete	2.96
white crust bryozoan	2.8
Porifera	1.8
other foraminiferan	1.31
Maldanid polychaete	1.11

3.6.4.7 Gravelly Muddy Sand Biotic Assemblage

Gravelly muddy sand biota was only sampled by three grab samples and no videos. In general the biota from this substrate class was characterised by deposit feeding infaunal bivalves and ophiuroids. The only species which contributed to similarity in the SIMPER results was the ophiuroid *Ophiura robusta*, which occurred in all samples (Table 3.12). Bivalves, such as *Macoma calcarea, Mya arenaria* and *Clinocardium ciliatum* were also found in this substrate and contributed to dissimilarity between gravelly muddy sand grab samples and related substrates such as gravelly sand.

Table 3.12 Contributors to 90% similarity in the gravelly muddy sand assemblage

Taxon	Grab (%)
Ophiura robusta	100

3.6.4.8 Gravelly Sand Biotic Assemblage

The biotic assemblage sampled from gravelly sand substrate contained a variety of large echinoderms such as sea stars (*Asterias vulgaris*), green sea urchins (*Strongylocentrotus droebachiensis*) and purple sandollars (*Echinarachnius parma*). These species are large surface dwellers and occurred frequently in video samples, with *E. parma* also being an important contributor to similarity in grab sampled gravelly sand (Table 3.13).

Infaunal bivalves where important contributors to similarity within this assemblage, notably *Macoma calcarea* and *Astarte sp.* Tube-dwelling polychaetes were also common in gravelly sand grab samples, with *Onuphis conchylega* and *Pectinaria granulata* contributing to similarity in this assemblage. *Onuphis conchylega* and *Astarte sp.* are of particular note, as they were also high contributors to dissimilarity between gravelly sand and grabs from sand, which had the most similar biota.

Filamentous green algae were very abundant in videos of shallow-water gravelly sand and were the highest contributors to video similarity (Table 3.13). Broadleaf kelp from the genus *Laminaria* also contributed to similarity in this assemblage. These algae, along with *Macoma calcarea*, sandollars (*Echinarachnius parma*), sea stars (*Asterias vulgaris*), *Onuphis conchylega* and *Astarte sp.* are the characteristic biota of gravelly sand in Newman Sound.

Table 3.13 Contributors to 90% similarity in the gravelly sand assemblage

Taxon	Video (%)	Grab (%)
Echinarachnius parma	19.92	17.39
Macoma calcarea		25.72
Astarte sp.		11.07
polychaete tubes		10.05
Onuphis conchylega		6.89
calcareous forams		5.81
unidentified polychaete		3.95
Pectinaria granulata		3.95
Acmaea testudinalis		2.92
red algae		2.91
green algae	23.84	
Asterias vulgaris	21.10	
Laminaria sp.	15.72	
Strongylocentrotus droebachiensis	9.73	

3.7 Mapping

3.7.1 Mapping Substrate Classes from Groundtruthed Acoustic Data

The primary objective of this thesis is to create classified substrate and habitat maps of Newman Sound from groundtruthed multibeam acoustic data. In order to create the substrate map, the ranges of backscatter intensity, water depth and slope angle for each substrate class were determined from the samples collected (Table 3.14).

The ranges of backscatter found in Table 3.14 are comparable to those in the published literature. For example Shaw et al. (1997) reported that in St. George's Bay on the west coast of Newfoundland fine-grained sand reflected backscatter values between −40 and −60 dB. Similarly, Kostylev et al. (2001) recorded fine-grained sand with low backscatter between −30 dB and −60 dB on Brown's Bank on the Scotian Shelf. Gravelly substrates at both St. Georges Bay and Brown's Bank reflected backscatter between −10 and − 30 dB (Shaw et al. 1997; Kostylev et al. 2001).

Table 3.14 Ranges of 3 acoustically recorded physical attributes for the 8 substrate classes and *Laminaria* kelp-covered seabed from grab and video samples.

Substrate Class	Depth Range (m)	Backscatter Range (dB)	Slope Range (°)
Mud	5.8 - 315	−15.5 - −43.5	9.7 - <1
Sand	4 - 81	−9.5 - −41.5	16.6 – 1
Gravelly Muddy Sand	37 - 51	−17 - −30.5	9 – 1
Gravelly Sand	5 - 212.5	−2 - −23.7	22.5 – 1
Gravel	8.5 - 132	−7.4 - −14.8	33.6 – 1
Rhodolith	10.6 - 32.8	−10 - −31.8	8.2 – 2
Boulder Gravel	6.8 - 42.5	−7.43 - −17	20.6 – 2
Bedrock	14.5 - 47.4	−10.4 - −14.8	64.4 – 20
Laminaria Kelp-covered Seabed	9.9 - 15.2	−54.98 - −58.71	6.9 – 2

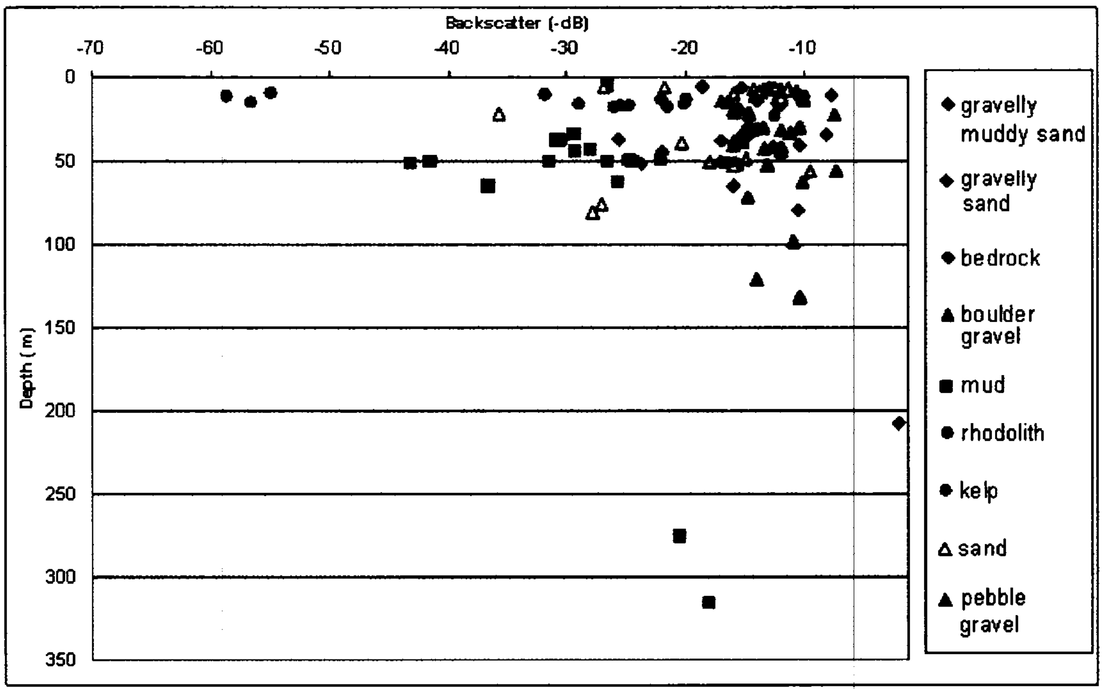


Figure 3.26 Scatterplot of water depth against multibeam backscatter intensity for all samples classified by substrate

These three physical attributes were, however, not equally important in defining each substrate. The attribute that best defined each class was found by plotting the depth of each sample against its backscatter intensity (Fig. 3.26). The mud, rhodolith and sand classes, all have a horizontal distribution indicating they had a larger backscatter range than depth range, and therefore are depth controlled classes that can not be easily interpreted from backscatter. Classes such as pebble/cobble gravel, and to some extent gravelly sand, had a vertical distribution on the scatterplot, indicating they are better defined by backscatter. Substrate classes such as bedrock and boulder were clustered, indicating small backscatter and depth distributions.

Sampling in deep water was limited by the equipment and methodologies used, so depth is not considered as a physical constraint on substrate types, except in a few cases discussed below. The absence of data below 100 m depth can be seen on Fig. 3.26. Also, a small gap in the data set can be seen in the high backscatter range, as samples generally could not be collected above −5 dB. Part of the reason for this is that the grab sampler could not sample high backscatter substrate. In addition, very high backscatter was more common near the mouth of the fjord where there were few sampling opportunities.

3.7.2 Failed Grab Sampling Attempts

The average depth of failed recovery was shallow, 38.7 m, therefore depth is probably not the main contributor to failed sampling attempts. The hardness of the seabed was a more likely cause, as many of the failed attempts were on sites with backscatter values of less than −10 dB; these sites are expected to have hard or bouldery substrate.

3.7.3 Definition of *Laminaria* Kelp Covered Seabed

A group of five samples with very low backscatter values emerged when depth was plotted against backscatter (Fig. 3.26). These points were in water less than 20 m deep with a backscatter range from −55 to −59 dB. An explanation for this anomalous group was discovered by examining the biological data from these sites. Three of the samples had significant kelp cover, with two having greater than 75 % coverage of *Laminaria sp.* The two other grab samples were found to have backscatter values less than −50 dB, but no kelp was recorded at these sites. *Laminaria* is suspected at these sites however, as the samples are located very close to the sampled kelp, although none was retrieved with the grab sampler. Also, no video was recorded at these locations. Therefore these samples, 125.2 and 126, were removed as outliers in their respective substrate classes, whereas drop camera station 126, the start of dive 3 and the start of dive 4 were classified as *Laminaria* kelp-covered seabed. Due to its unique acoustic backscatter signature the patch of *Laminaria* covered seabed was included on the final habitat map, however this unit does not represent a true habitat as it is ephemeral (see section 4.5).

3.7.4 Expressions for Mapping Substrates

Mathematical expressions for each substrate class were constructed using ranges of bathymetry, slope and backscatter. These were used for mapping substrates following the method described in section 2.2.5. By adjusting the mathematical expressions used to select pixels, the distribution pattern of substrates can be changed. In this way, a substrate map can be iteratively produced that best reflects the interpreted acoustic and groundtruth sample data.

The first map of substrate distribution was created using depth, backscatter and slope ranges derived from the classified groundtruth samples (Table 3.14). As a result of generating mapping expressions from the sample data alone, most of the outer basin remained unclassified as it was not groundtruthed.

In order to expand the amount of the fjord that could be classified, points from the shallow seismic survey were added to the mapping process. Only seismic points which had been interpreted as bedrock (Unit A) or mud (Unit C) were used, as these two substrates are the only ones which could be interpreted with confidence from the seismic record as it had not been extensively groundtruthed (see Appendix E). The addition of the seismic points increased the depth and backscatter ranges of both the bedrock and mud classes (Fig. 3.27). Therefore the second map successfully classified more of the deep outer basin and fjord mouth.

A third map was made by relaxing the selection criteria to account for gaps in the groundtruthing. Depth limits were removed from all substrates except rhodolith, which is limited to the photic zone. The literature indicated that rhodoliths moved to below their normal depth range became buried by sediment, while those place in shallower water were rapidly dispersed by water movement (Steller and Foster 1995). Therefore both the upper and lower depth limits for this substrate, as determined by groundtruthing, were retained.

For all other substrate classes the depth variable was removed in creating the final substrate distribution to remove any influence of sampling methodology on the results. For example, observations from other Newfoundland fjords indicate that bouldery rubble occurs at the base of fjord walls (Haedrich and Gagnon 1991). In Newman Sound,

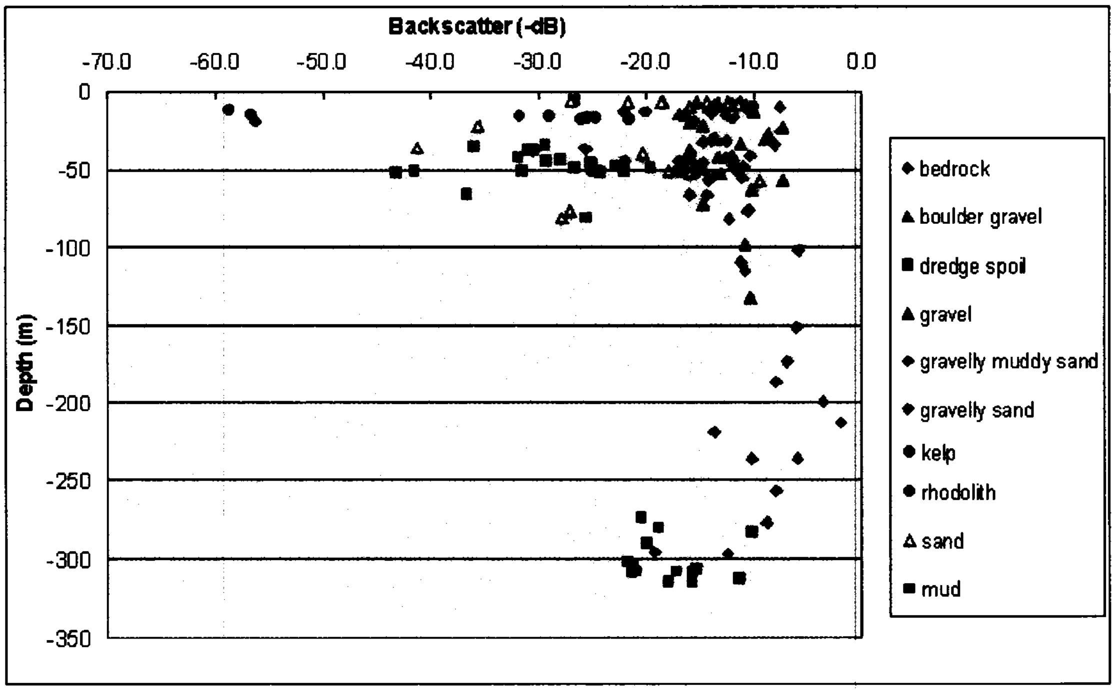


Figure 3.27 Scatterplot of water depth against multibeam backscatter intensity for classified substrate samples and points from shallow seismic profiling.

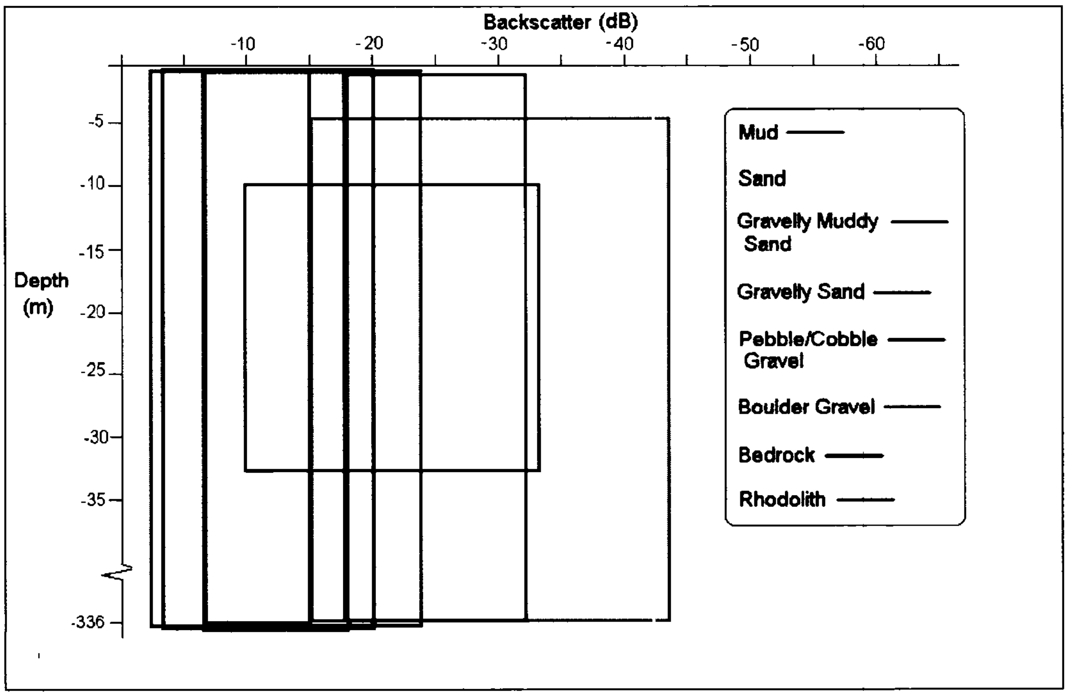


Figure 3.28 The depth and backscatter ranges used to create the final substrate map, showing the overlaps between classes.

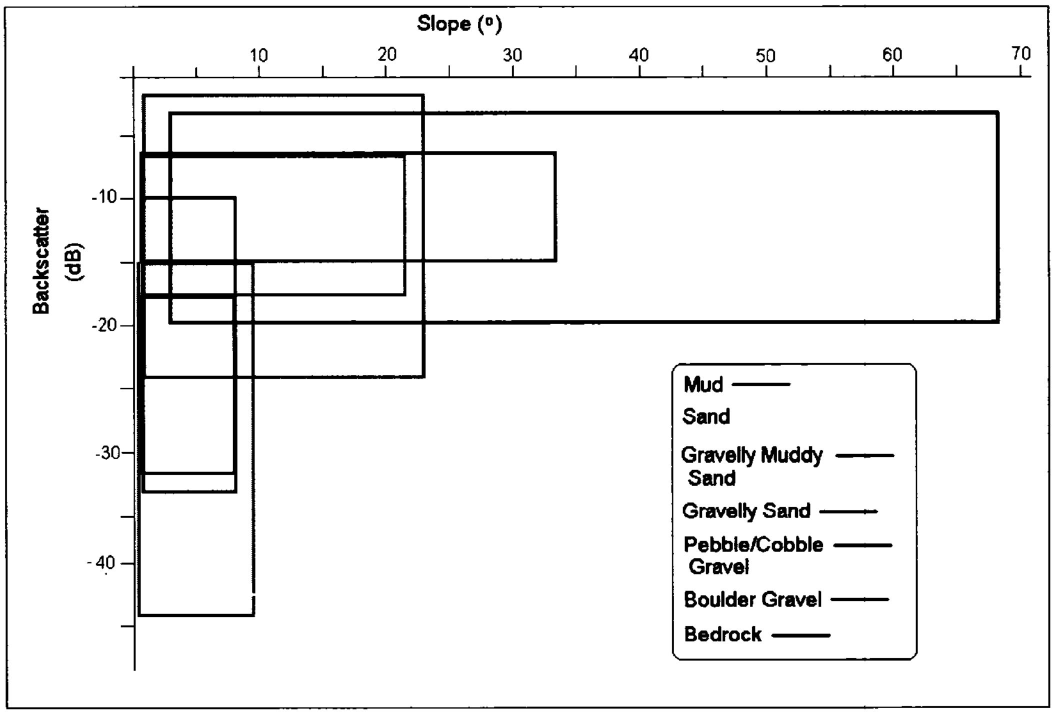


Figure 3.29 The slope and backscatter ranges used to create the final substrate map, showing the overlaps between classes.

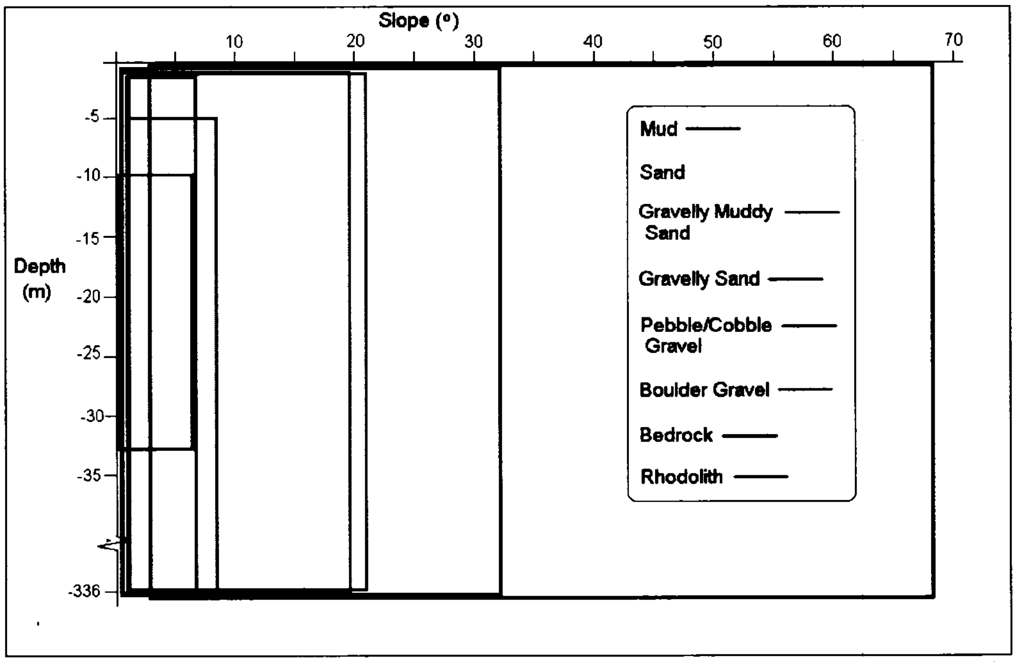


Figure 3.30 The depth and slope ranges used to create the final substrate map, showing the overlaps between classes.

boulder gravel substrate was sampled by SCUBA diving and tethered drop camera, both of which are depth limited sampling methods, so it seems appropriate to assume that this substrate occurs outside the recorded depth range. Relaxing the classification criteria achieved the objective of classifying more of the fjord, but also meant that there was more overlap between the substrate classes (Figs. 3.28 - 3.30). Due to the greater overlap, more pixels were assigned to multiple substrate classes, therefore increasing the relative uncertainty associated with each pixel classification (see section 4.4).The backscatter, depth and slope values used to map each substrate class are shown in Table 3.15.

Table 3.15 Criteria Used to Map Substrate Classes and *Laminaria* Kelp Covered Seabed

Class	**depth range (m)**	**backscatter range (dB)**	**slope range (°)**	**extents in UTM**
Mud	any value	< = −15 > = −44	< = 10	unlimited
Sand	any value	< = −9 > = −42	< =17	unlimited
Gravelly Muddy Sand	any value	< = −17 > = −31	< = 9	unlimited
Gravelly Sand	any value	< = −2 > = −24	< = 23	unlimited
Gravel	any value	< = −7 > = −15	< = 34	unlimited
Rhodolith	< = −10 > = −33	< = −10 > = −32	< = 9	min. x = 727604.4329 max. x = 728630.0016 min. y = 5384130.8057 max. y = 5386198.5249
Boulder Gravel	any value	< = −7 > = −17	< = 21	unlimited
Bedrock	any value	< = −3 > = −20	< = 67 > = 3	unlimited
Laminaria Kelp Covered Seabed	> = − 30	< = −37	< = 7	unlimited

The final substrate map (Fig. 3.31) was created by overlaying classified pixel grids for each substrate class in each of the fjord basins (Figs. 3.32 – 3.36). The grids were overlain to reflect the most likely distribution of substrates based on interpretation of the acoustic surveys and the classified groundtruthing samples. For example, longitude and latitude were used to constrain rhodolith to the Narrows sill top.

The groundtruthed samples and seismic points were plotted on the substrate map, and the order of the layers was adjusted to reflect the distribution of substrates shown by the classified samples. Maps were created for each basin separately, as the arrangement of overlain substrate grids was not the same throughout the fjord. The order in which the layers were arranged for each basin can be found in Appendix F.

Patches of unclassified pixels remained at the fjord mouth (Table 3.16). The backscatter values of these pixels are higher than −3 dB but the slope in this location is very low and falls outside the characteristic range for bedrock. Although bedrock is suspected, the area was left unclassified. On the final map only 1.08% of the study area remained unclassified (see section 4.4).

Table 3.16 The percentage of each map area classified into the 8 substrate classes.

	Inner Basin	**Middle Basin**	**Narrows**	**Outer Basin**	**Fjord Mouth**	**Total Fjord**
Mud	64.07	26.91	1.10	25.45	2.14	24.06
Sand	93.12	81.68	85.88	58.53	44.06	62.94
Gravelly Muddy Sand	62.66	26.77	17.89	25.49	2.15	24.10
Gravelly Sand	50.35	83.62	82.31	75.73	85.43	76.97
Pebble/Cobble Gravel	22.75	44.22	60.82	44.37	54.11	44.61
Boulder Gravel	24.82	48.95	65.65	36.64	51.14	41.04
Bedrock	23.32	65.05	42.40	66.06	71.88	63.13
Rhodolith	0.37	0	28.31	0	0	0.60

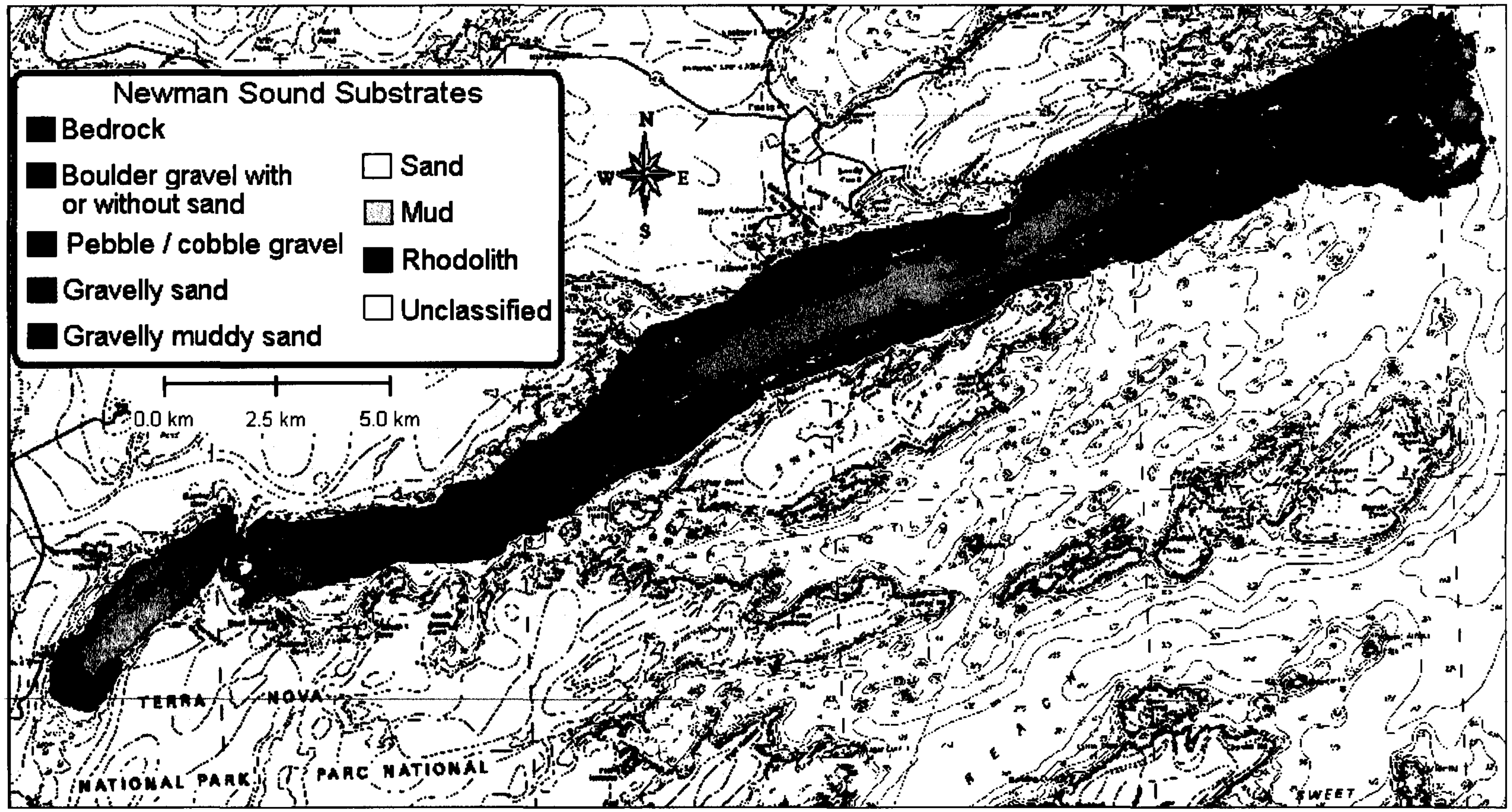


Figure 3.31 Benthic substrate map of Newman Sound showing the 8 classified substrates

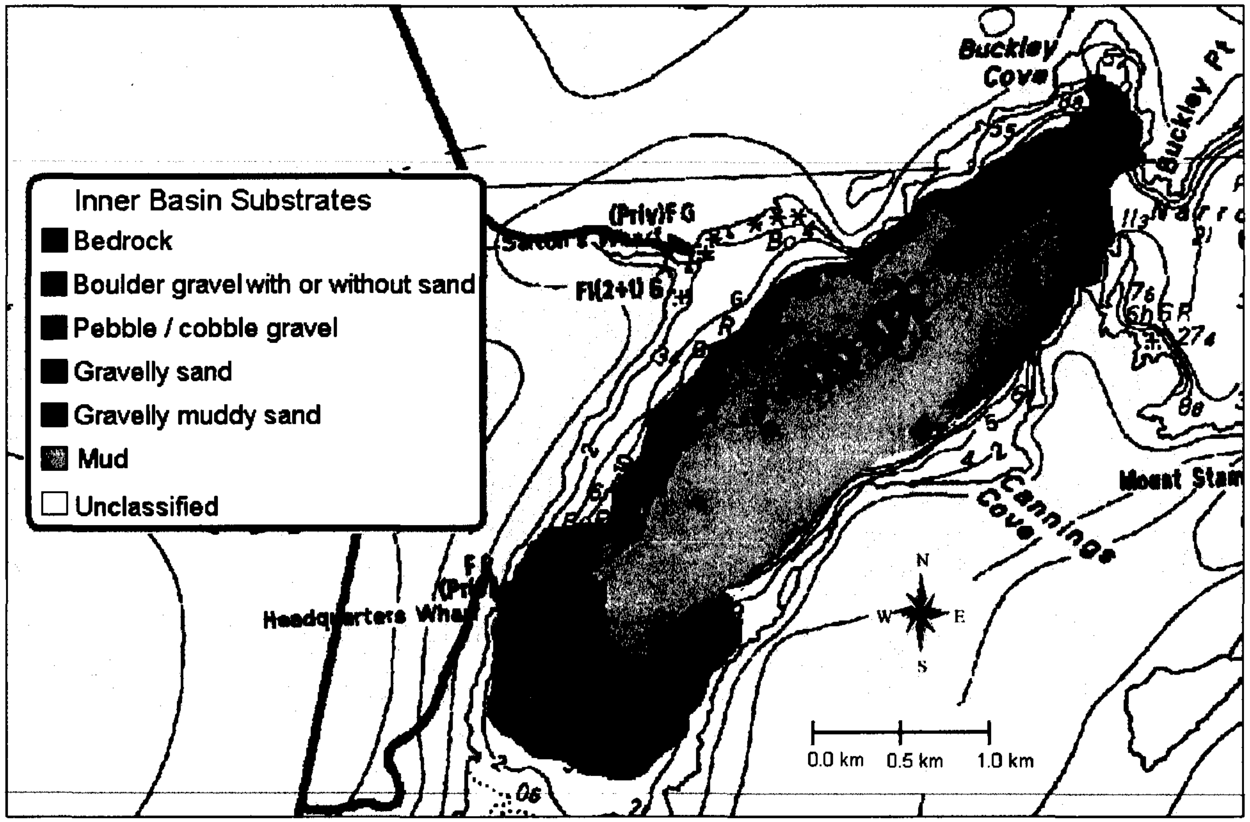


Figure 3.32 Substrate map of the inner basin of Newman Sound

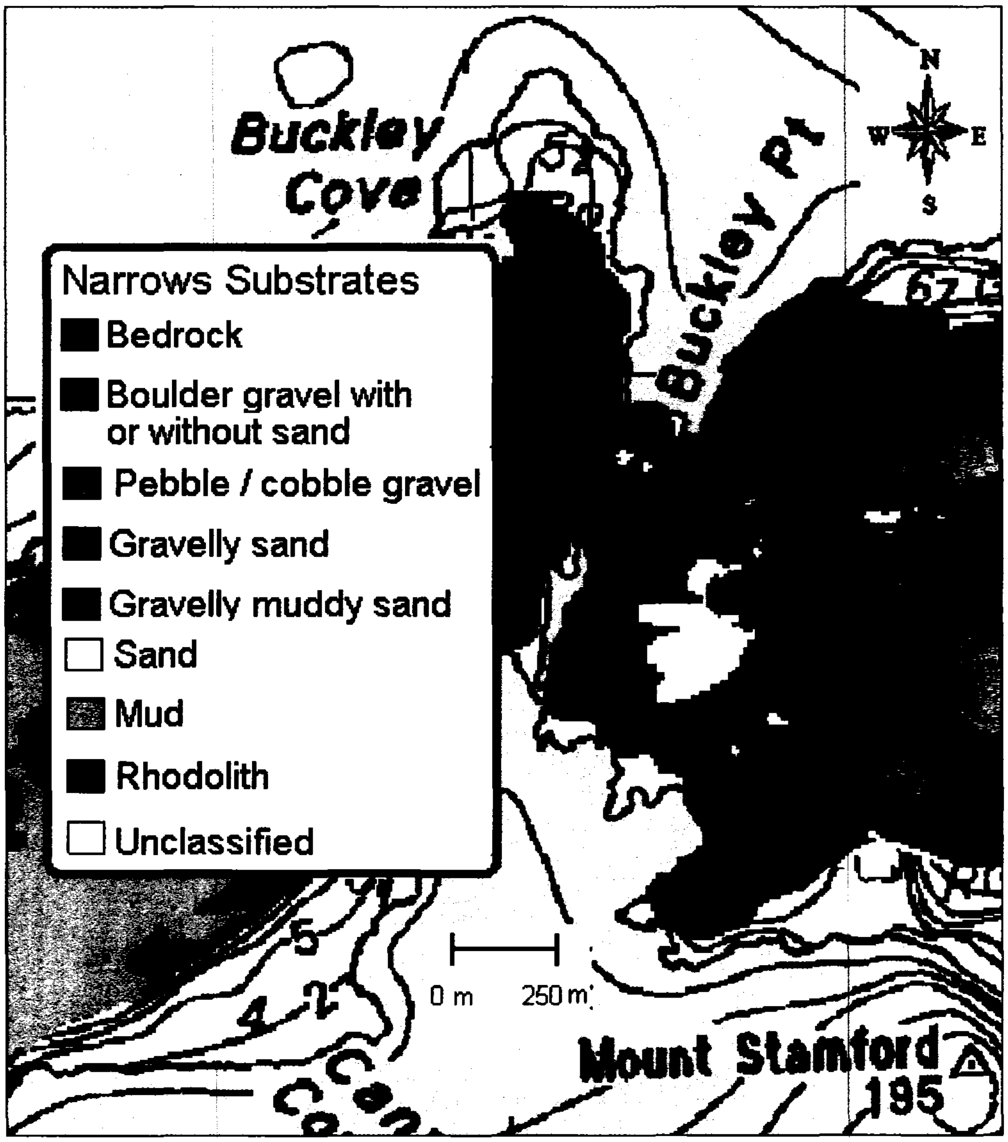


Figure 3.33 Substrate map of the sill at the Narrows

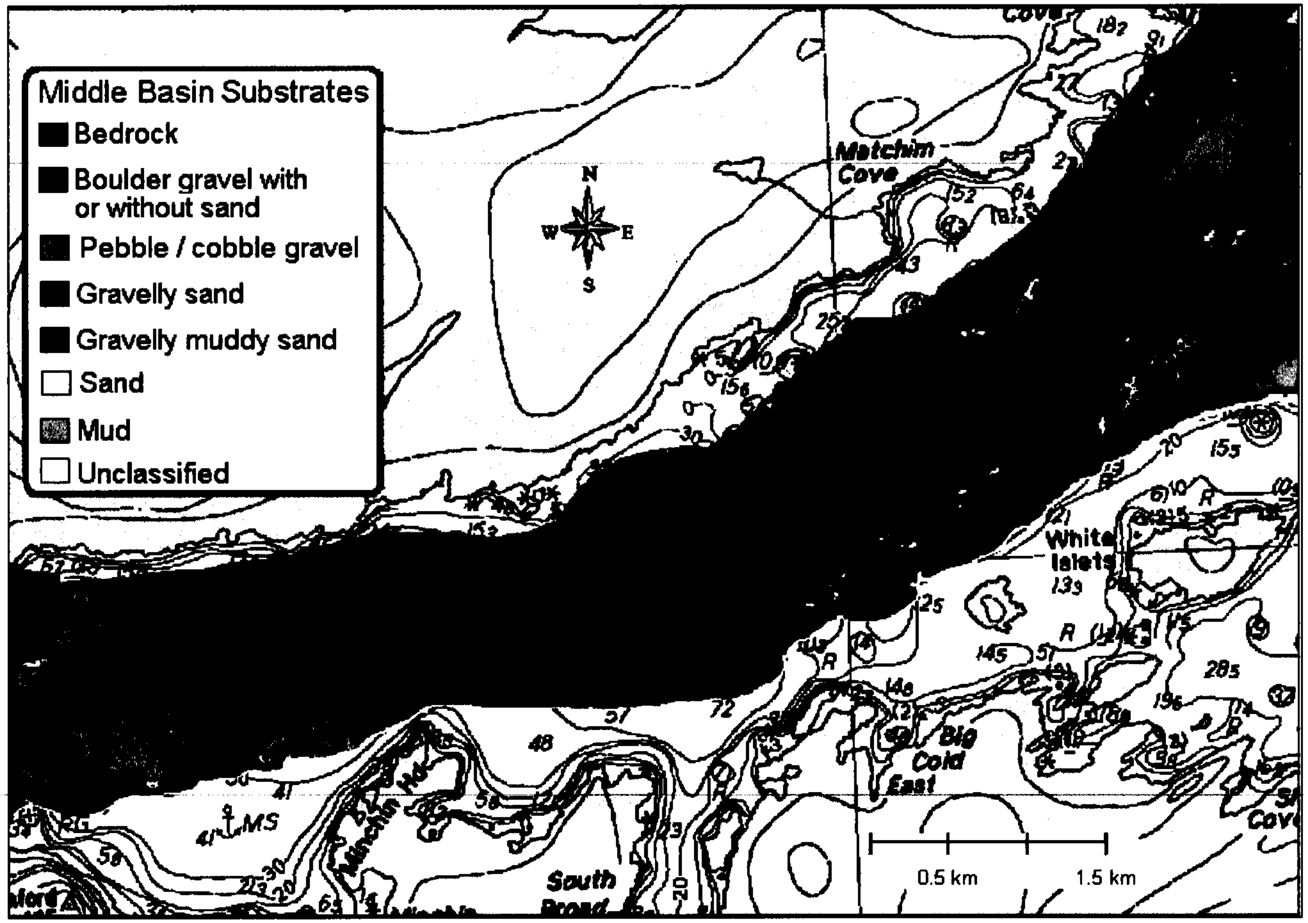


Figure 3.34 Substrate map of the middle basin from outside the Narrows to the White Islets

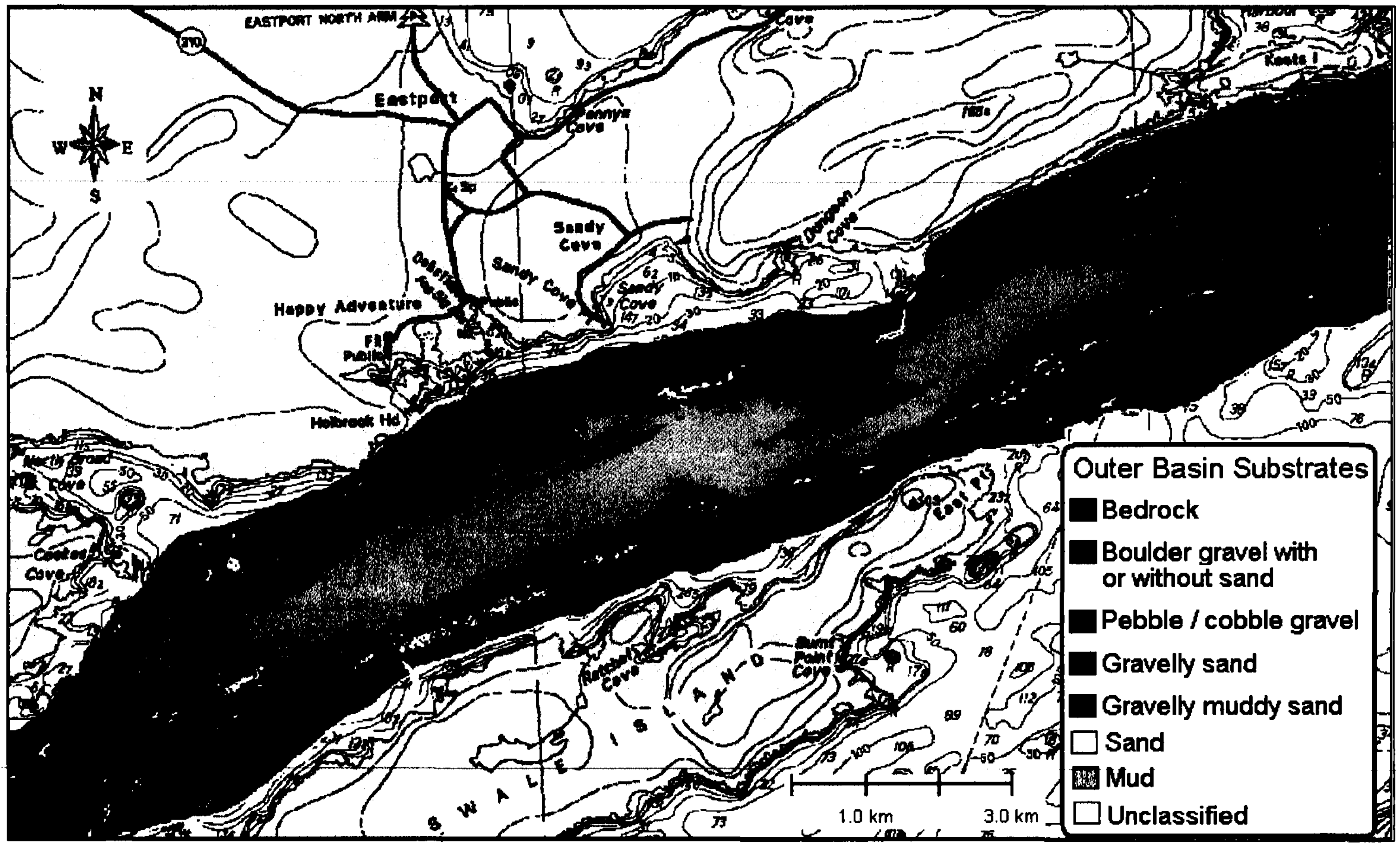


Figure 3.35 Substrate map of the outer basin of Newman Sound showing extensive bedrock fjord wall and basin floor mud

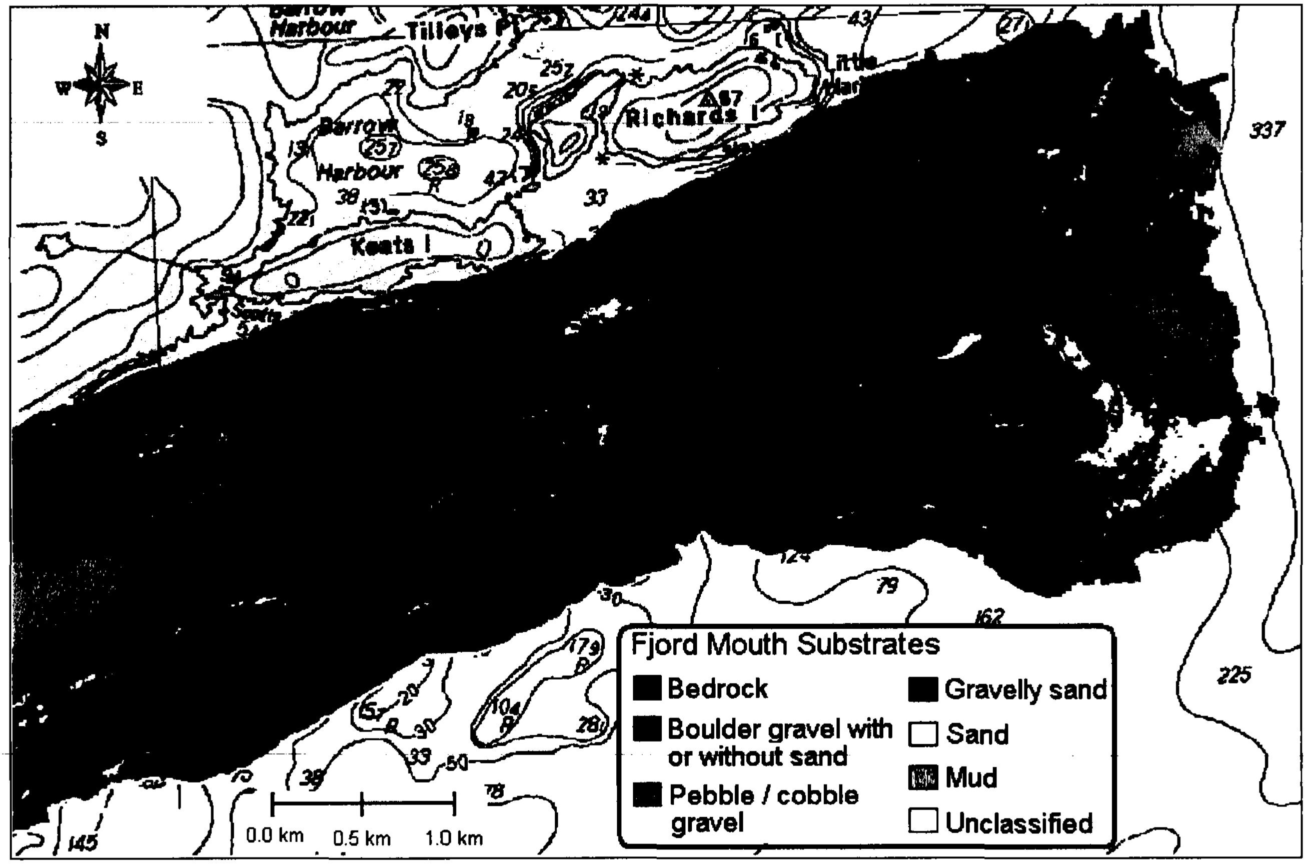


Figure 3.36 Substrate map of the fjord mouth

3.7.5 Mapping Habitats from Substrate Maps

For habitat mapping, substrates in deep water or on steep slopes were separated from shallow ones based on their potential to host vegetation. Of the floral taxa collected during groundtruthing, *Agarum cribrosum* kelp and *Ptilota serrata* had the deepest occurrences at 34 m and 51 m respectively. Sears (2002) reports that *Agarum cribrosum* has adapted to lower light than other macroalgae, allowing it to grow to depths around 50 m. Also, Anderson (2001) only reported macroalgae below 50 m depth once during benthic observations in Newman Sound. Therefore all substrates shallower than 50 m could potentially host vegetation and herbivores, while those deeper than 50 m likely would not. Thus the 50 m depth contour was included on the habitat map as an indication of whether algae could be expected or not. The 30 m depth contour was also added to indicate areas shallow enough for *Laminaria* kelp to occur (see section 3.7.5.2). Habitat names were constructed using the substrate underlying each habitat combined with commonly identified members of the biotic assemblage. In total 10 habitats were identified (Fig. 3.37).

3.7.5.1 Inner Basin Habitat Map

Both pebble/cobble gravel and boulder gravel in sand were mapped around the margins of the inner basin (Fig. 3.38). The distributions of these substrates were very similar and overlapped each other. The biota expected in gravel and boulders include attached anemones on boulders and small epifauna such as limpets, chitons, foraminiferans and bryozoans on both boulders and smaller gravel. The distribution of this habitat is similar to the distribution of boulders shown in the previously drawn map of the inner basin (Cote et al. 2004). Boulder and pebble/cobble gravel habitat mapped along the delta-front

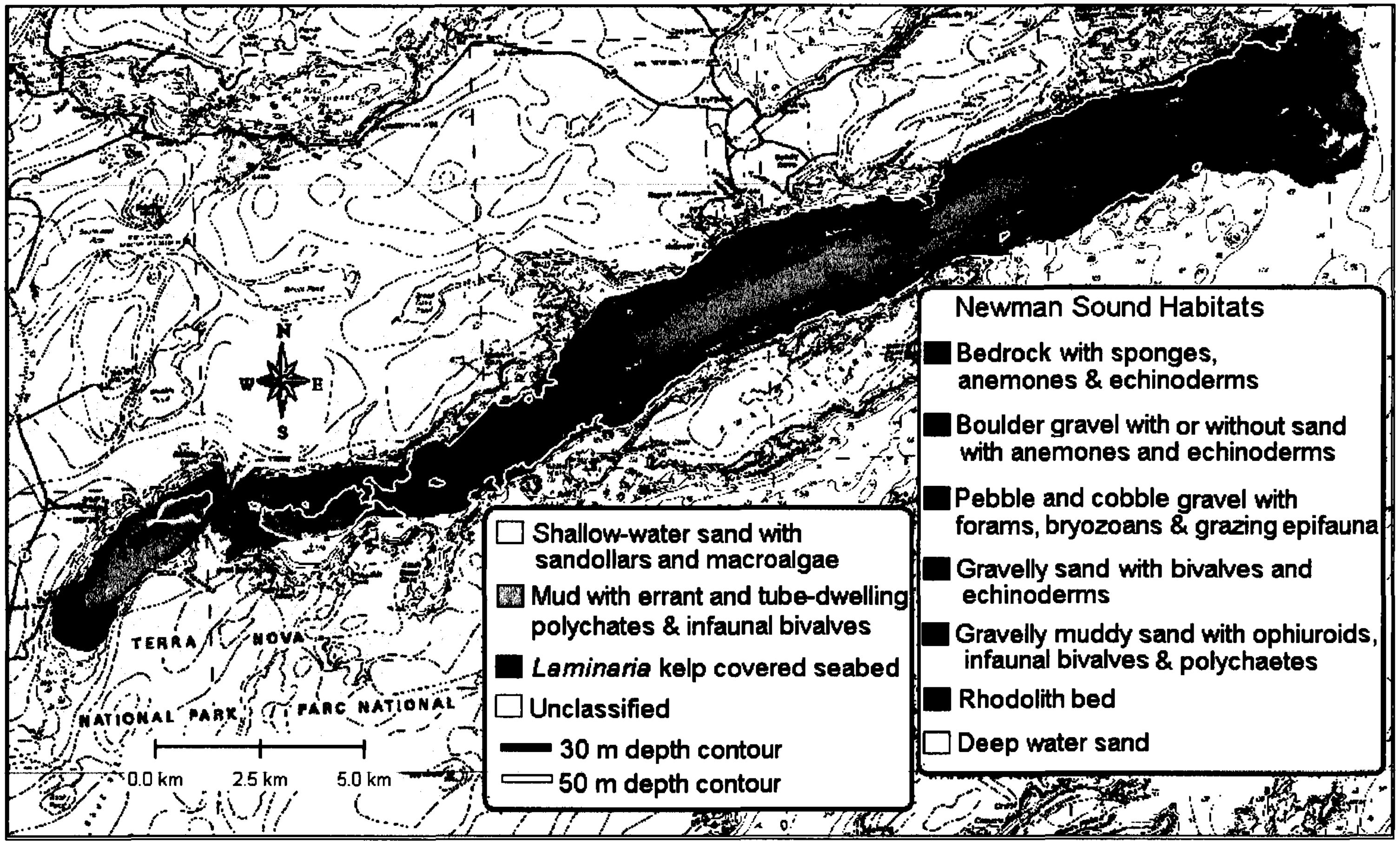


Figure 3.37 Benthic habitat map of Newman Sound showing the 10 classified substrates

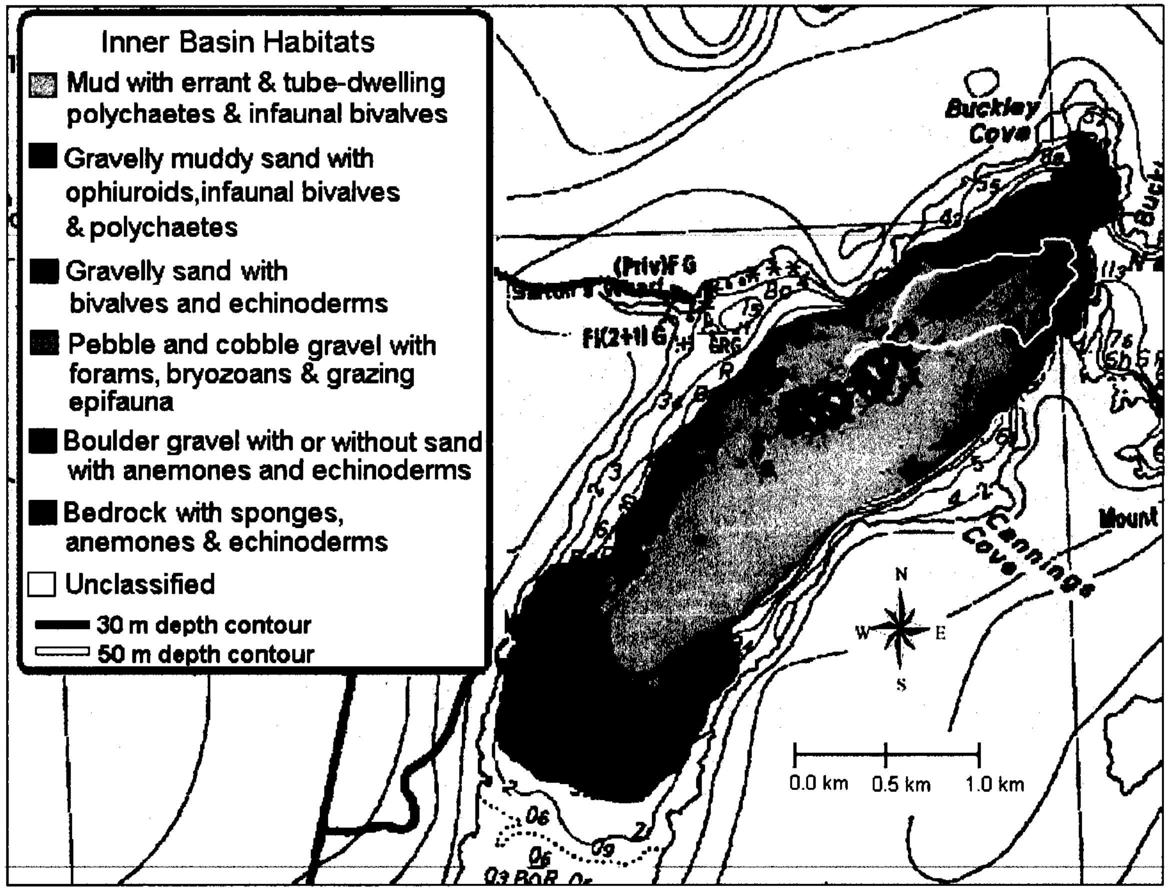


Figure 3.38 Habitat map of the inner basin of Newman Sound

coincide with a kelp unit on the previously drawn map (Cote et al. 2004). Groundtruthing showed that both *Laminaria sp.* and *Agarum cribrosum* kelps occur on bouldery sand and pebble/cobble gravel, so it is likely that kelp on a gravel substrate is found here.

Overlapping boulder and pebble/cobble gravel substrates were found in water deeper than 50 m at the northeastern end of the inner basin. This patch of gravel near the sill was the only location that was classified as gravel by Cote et al. (2004). Gravelly sand was also mapped on the floor of the inner basin as well as on the delta top interspersed with mud and gravelly muddy sand. Gravelly sand in shallow water in the inner basin contained sandollars, sea urchins and macroalgae, while in deeper water it contained more polychaetes and bivalves.

The most unique habitat in the inner basin is organic-rich mud and gravelly muddy fine sand found on the basin floor. This deposit feeder habitat is dominated by the polychaete *Maldane sarsi* and bivalve *Macoma calcarea.* It overlaps with the sand unit on the previously drawn map (Cote et al. 2004).

3.7.5.2 Narrows Habitat Map

The rhodolith bed was dominated by *Lithothamnion glaciale* which was the most abundant species and also the primary substrate. A second red algae, the red sea fern (*Ptilota serrata)*, was also a key inhabitant of this habitat. Sessile species such as small sponges, bryozoans and spirorbid polychaetes were attached to *Ptilota serrata* and *Lithothamnion glaciale*, as well as gravel present in this habitat. Errant polychaetes, numerous ophiuroids, juvenile sea stars, limpets, chitons, boring clams and juvenile Iceland scallops (*Chlamys islandicus*) were also found attached to red algae and in the branches of the rhodoliths.

The criteria used to map *Laminaria* kelp covered seabed were very specific and only a small area east of the island in the Narrows met the criteria (Fig. 3.39). The primary criterion was the extremely low backscatter produced by dense *Laminaria* kelp, which set it apart from all other habitats. The backscatter range included all sample points where this kelp was sampled. The deepest reported occurrence of a *Laminaria* species that would likely occur in Newman Sound was 30 m (Sears 2002). This was used as the lower depth limit for this habitat. The resulting distribution covered most of the area south of the Narrows where *Laminaria* was found and a few pixels on the delta-top where shallow-water eelgrass (*Zostera marina)* had been previously mapped (Forsyth and Borstad 1999).

Laminaria was present both as an inhabitant of benthic substrate and as a structural part of the habitat upon which other species lived. Fauna found associated with *Laminaria* kelp include sea stars (*Asterias vulgaris*) and sea urchins (*Strongylocentrotus droebachiensis)*. The expressions used to map the observed distribution of *Laminaria* kelp-covered seabed are found in Table 3.15.

Around the Narrows most of the water less than 30 m deep contained boulder gravel with sand habitat (Fig. 3.39). At Buckley Point large boulders on sand covered by green algae, anemones (*Metridium senile)*, and *Laminaria* kelp were recorded. On the south side of the Narrows, toward Mt. Stamford Cove, smaller boulders and pebble gravel in sand are found. This habitat supports *Lithothamnion glaciale*, sandollars, sea stars and macroalgae. In the Narrows boulder gravel occurs with less sand, and a cover of *Agarum cribrosum* kelp and *Metridium senile* anemones. The remainder of the Narrows map area

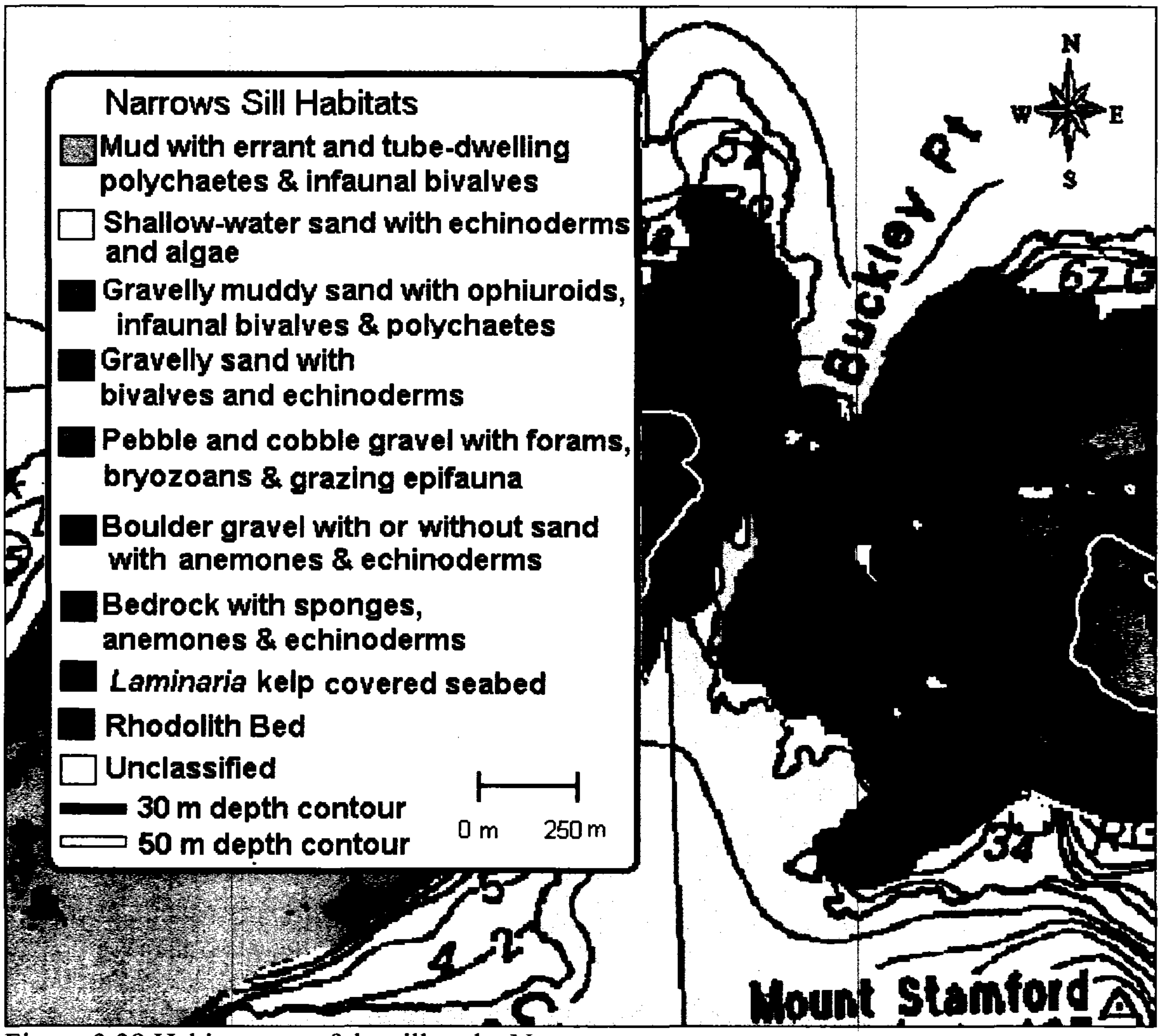


Figure 3.39 Habitat map of the sill at the Narrows

is composed of sparsely vegetated gravelly muddy sand with abundant polychaetes and gravelly coarse sand with echinoderm tests and bivalve fragments.

3.7.5.3 Middle Basin

Most of the shallow parts of the middle basin are covered by boulder gravel with sand, or gravelly sand (Fig. 3.40). Both of these habitats can support macroalgae, such as kelp and leafy red and green algae. In shallow water gravelly sand is inhabited by sandollars, as well as many species of bivalves. The boulder habitat contains both infaunal and surface dwelling bivalves and echinoderms, as well as large anemones attached to boulders.

The majority of the middle basin that is deeper than 50 m contains bedrock and muddy habitats. Vegetation is unlikely here; however coralline algae may occur on bedrock at this depth. Gravelly muddy sand and mud, found in the deeper parts of the middle basin, support a community of infaunal bivalves, ophiuroids and polychaetes, particularly tube-dwelling species. Patches of mud with no gravel were surveyed just west of Minchin Head (Fig. 3.40). Samples from this mud habitat contained no live fauna and the mud was dark and smelled anoxic.

3.7.5.4 Outer Basin

Most of the floor of the outer basin is deep-water mud and gravelly muddy fine sand below 200 m water depth (Fig. 3.41). The sample from the mud habitat had 16% organic content, indicating that there is organic material available in the sediment. However the deep water mud generally had scarce invertebrate fauna compared to shallower mud habitat. The remainder of the outer basin floor contained either boulders or pebble/cobble gravel. The distribution of gravel on the margins of the basin floor may indicate either erosion of the postglacial mud or rock falling from the fjord wall. Shallow water bedrock

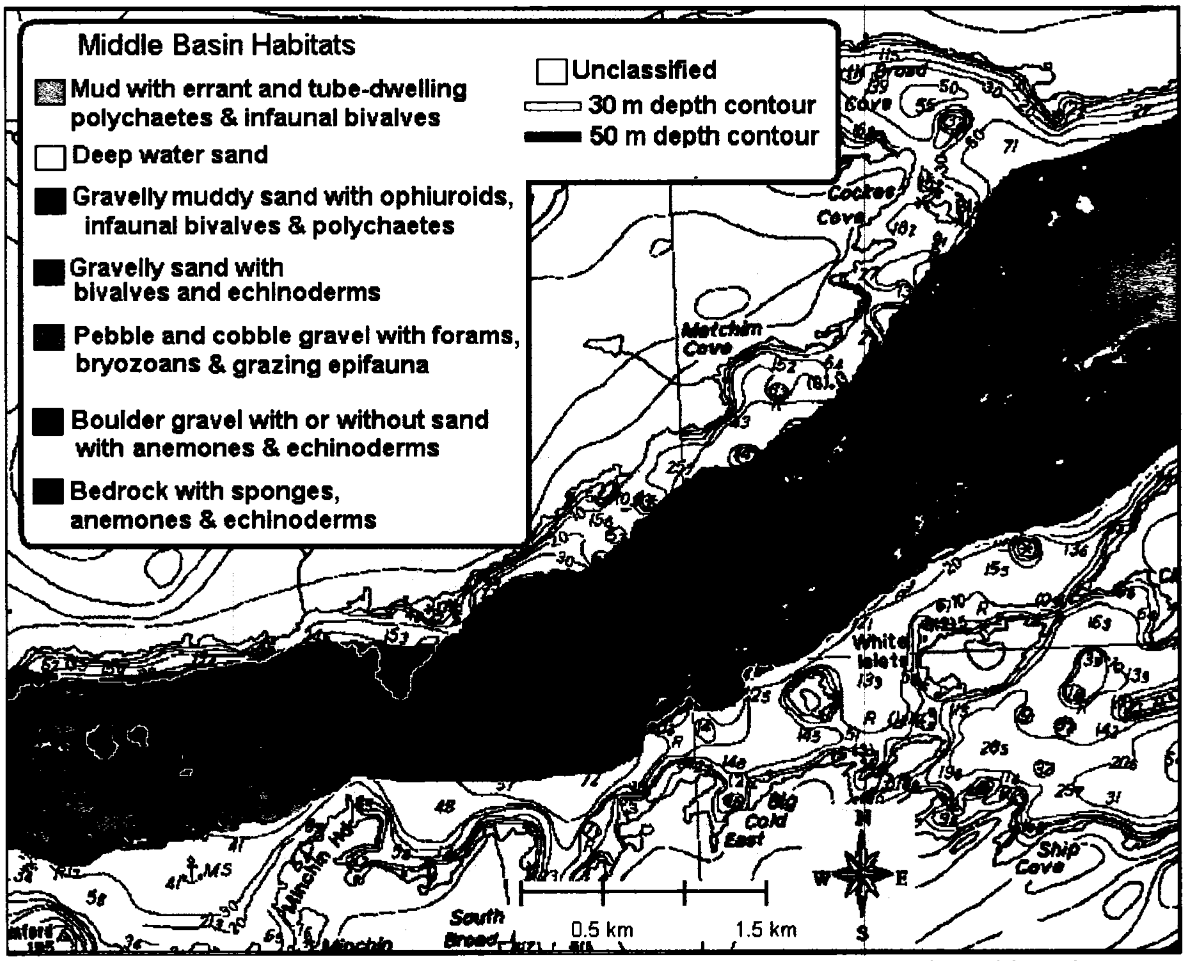


Figure 3.40 Habitat map of the middle basin from outside the Narrows to the White Islets

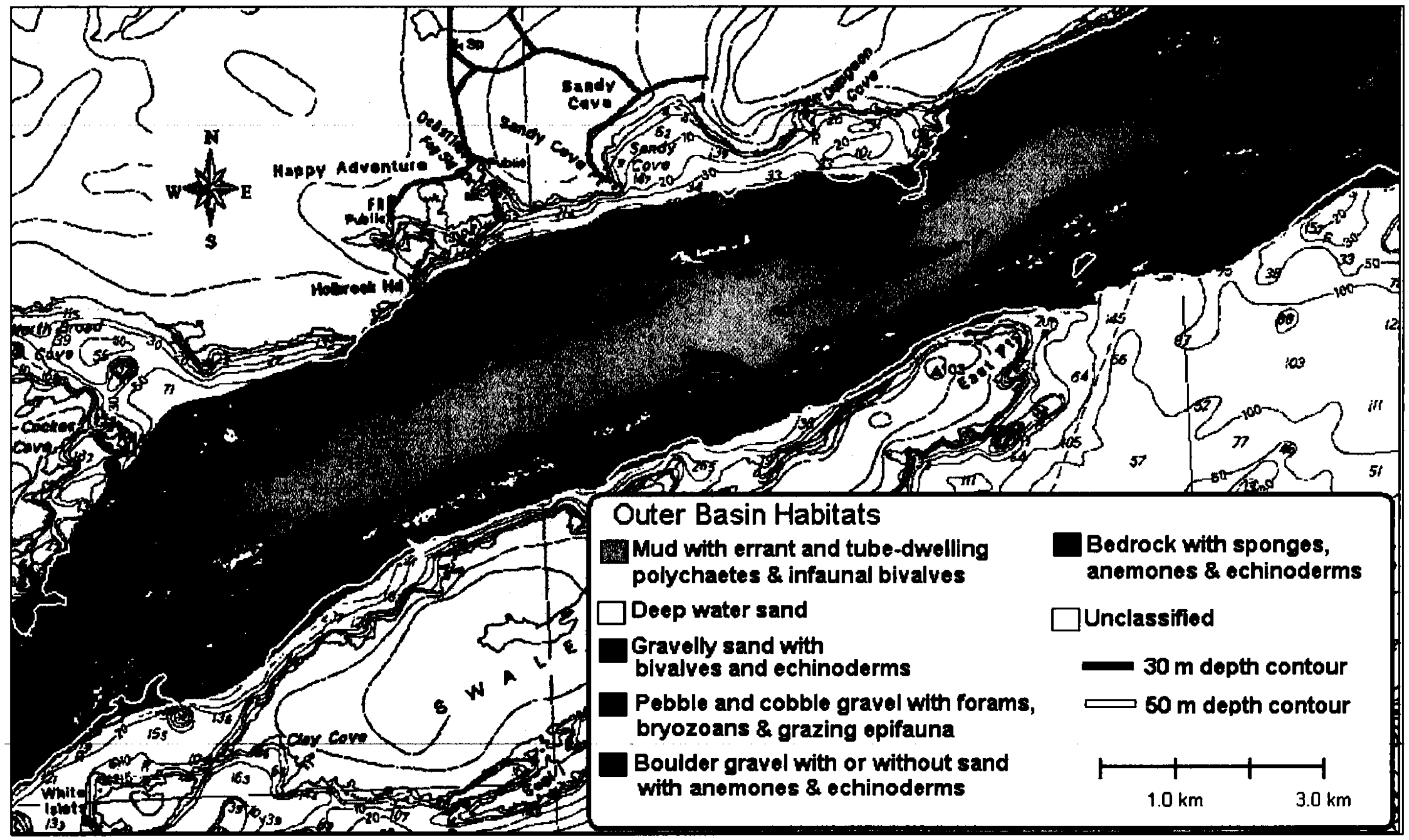


Figure 3.41 Habitat map of the outer basin of Newman Sound

sampled on the margins of the outer basin was heavily encrusted with biota, including attached anemones, sponges, sea urchins, sea stars and hydroids. The biota of deep-water bedrock is unknown.

3.7.5.5 Fjord Mouth Sill

Shallow water bedrock habitat, videotaped on the fjord mouth sill, was heavily encrusted with un-branched coralline red algae, along with sea stars and sea urchins.
Also the anemone *Metridium senile* was noticeably more abundant here than in other sampled habitats.

Mixed lithology pebble/cobble gravel and gravelly sand, possibly winnowed till, were sampled on the fjord mouth sill and in deep water to the southeast of the sill (Fig. 3.42). This gravel is inhabited by a surprisingly rich biotic assemblage, including polychaetes, foraminiferans, ophiuroids, bryozoans, infaunal bivalves and limpets. The deep water mud sampled from the fjord mouth had 7% organic content. Mud stars (*Ctenodiscus crispatus*) and *Macoma calcarea* were sampled here, demonstrating that deposit feeders are utilising this habitat.

In total ten benthic habitats were mapped in Newman Sound. Shallow water (<50 m) habitats displayed the most habitat heterogeneity as well as the most biological diversity.

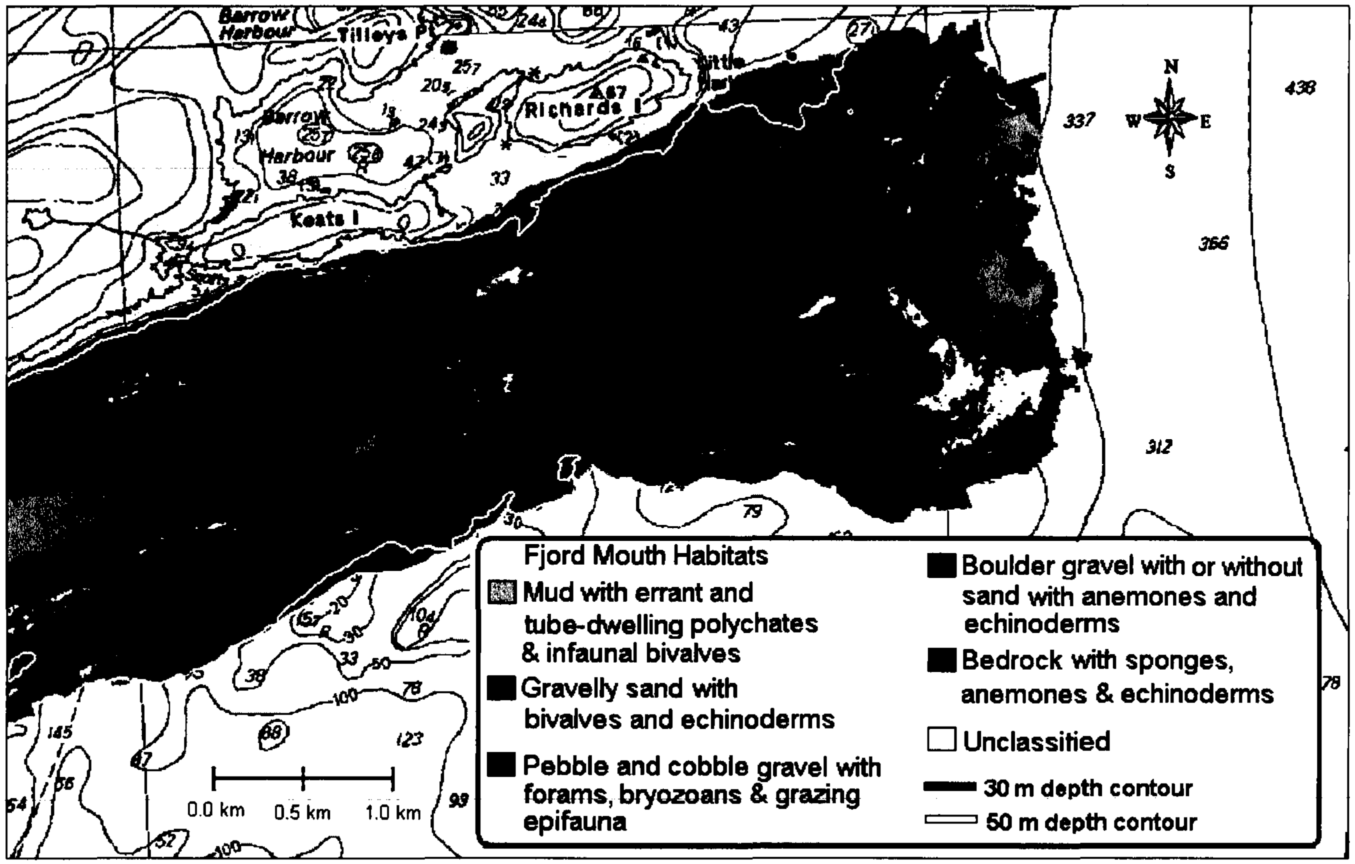


Figure 3.42 Habitat map of the fjord mouth

Chapter 4: Discussion

4.1 Introduction

The main objectives of this thesis were 1) to demonstrate the usefulness of multibeam sonar, groundtruthed with shallow seismic surveys, grab samples and videos, for benthic habitat mapping in a fjord, 2) to identify bio-diverse areas in the fjord and 3) to create complete benthic substrate and habitat maps for Newman Sound. These objectives were developed to fill existing gaps in the literature, as multibeam habitat mapping had not previously been attempted in a Newfoundland fjord environment and no complete benthic habitat map existed for the Newman Sound.

Groundtruthed multibeam data were used successfully in the fjord, and an assessment of this methodology appears below. The thesis results also show that it is possible to gather enough biological information using this methodology to successfully identify biologically diverse habitats with conservation value. Lastly, preliminary benthic substrate and habitat maps were created for Newman Sound.

4.2 Assessment of Methodology

The multibeam sonar component of this methodology was highly effective in the fjord, and was crucial in delimiting substrate and habitat units within the study area. As expected, the bathymetry and backscatter patterns described from Newman Sound were more heterogeneous over a small spatial scale than previously studied continental shelves.

The use of multibeam data, particularly backscatter, was helpful in planning locations for benthic sampling and can be used in future for choosing appropriate sampling methods. For example, coring and grab sampling can be concentrated on moderate to low backscatter substrates were the likelihood of sampling success is higher.

The multibeam bathymetry was also useful in identifying features such as sills and the fjord-head delta where sampling and seismic surveys were targeted. Using multibeam data to direct sampling is especially relevant where previous documentation of the benthos is limited, which is the case in much of coastal Newfoundland and Labrador.

The presence of biological structures, especially vegetation, is known to disrupt the pattern of geological substrates revealed by backscatter (Lurton 2002). An example was seen in the Narrows of Newman Sound where low backscatter (about −30 dB) was produced by the rough surface and low density of the carbonate rhodoliths. Thus ranges of depth-backscatter-slope values for each substrate and habitat are not directly transferable from one location to another; however they may be used for reference when interpreting multibeam data from new locations. Extensive groundtruthing of new areas is still required and samples of the local biota must be taken to produce a habitat map.

The biotic assemblage of a habitat is often more informative about the environmental conditions of the seabed than substrate. Kostylev et al. (2001) noted that interpreted multibeam sonar cannot be used to identify habitats covered by a very thin layer of silt. Instead, on the Scotian Shelf, these habitats were identified through the dominance of deposit-feeding species in their biotic assemblages. Such is the case with the gravelly muddy sand class in Newman Sound. The backscatter range, and distribution of coarse-grained sediments are similar to the gravelly sand class, and these samples were clustered on the same dendrogram branch as gravelly sand samples. The key difference in the two groups of samples was the larger mud fraction, and statistically more frequent occurrence of mud-associated biota in the gravelly muddy sand samples.

4.3 Considerations for Future Work

Several recommendations for future acoustic mapping in fjords resulted from the assessment of the strengths and weaknesses of the methodology employed in this thesis. Deploying a tethered camera at grab sampling sites before each grab is made would be helpful, as this approach would allow notes on topography and large, mobile fauna to be made before they were disturbed by the grab sampler. Deploying the camera first would also allow assessment of the ability of the grab sampler to effectively sample the substrate, thus saving time and effort. Collecting both grabs and video together would also eliminate some of the error from the resulting classification, for example boulder gravel on sand would not be classified as gravelly sand. Some generalisation was done on the substrates identified by cluster analysis that could not be identified on a video. Simultaneous grab and video collection would eliminate the need to generalise substrates.

The placement of SCUBA video transects across the boundary between very low and moderate backscatter values allowed the identification of dense *Laminaria* kelp as the cause of the acoustic signal loss. Therefore this approach to transect placement is recommended.

In this thesis it was only possible to sample depth, organic content and slope as physical variables contributing to habitat definition. Some existing temperature and salinity data were available opportunistically, but were not used in final habitat determination. Further information that would contribute to refining habitat classes include current speed and direction, year round bottom temperature and salinity, light penetration and a more detailed study of the seabed geology.

Water currents were noted by Kostylev et al. (2001) as playing a major role in sediment grain size distribution and benthic biota. Currents have not been studied in Newman Sound, although some evidence of scouring was seen in the seismic survey. The effect of currents and resulting seabed disturbance on benthic biota was seen in the rhodolith bed on the sill in the Narrows. Investigation of the current regime within the fjord and the effects on substrate stability and particle mobility would be beneficial.

More intense sampling is needed to improve the habitat divisions in the outer basin of Newman Sound. Most of the fjord lies below 100 m which was the limit of our sampling capability on all but one trip. In future benthic mapping initiatives in fjord environments, particular attention should be paid to sampling these water depths.

4.4 Accuracy Assessment

The substrate and habitat maps produced from this thesis were created based on supervised classification of groundtruthed acoustic data; the final map units have not been tested. Consequently, the occurrence of mis-classification could not be assessed. Accuracy assessment should be undertaken as part of any future mapping endeavour. This assessment should test both the positional accuracy of the map units produced (the user's accuracy) and the ability of the habitat classes to accurately reflect all habitat types likely to be encountered in the study area (the producer's accuracy).

The producer's accuracy of the methodology used in Newman Sound can be improved by i) pairing grabs and videos at each station, ii) repetitive grabbing at each station, and iii) making sure that all parts of the study area are sampled in a representative manner.

The user's accuracy of a created habitat or substrate map can be tested by randomly excluding a number of groundtruth samples from consideration when generating classification criteria. The excluded points can then be used to test the resulting substrate and habitat polygons. This type of assessment was not possible in Newman Sound due to the small number of data points collected and limited time of the project. A preferable method is to collect an independent set of samples for accuracy assessment. Ideally, a first field season would be spent groundtruthing the acoustic data set, creating substrate classes, identifying habitats and creating preliminary maps. Further sampling would then be carried out using the mapped habitat units as a guide to test their accuracy and make adjustments. Examples of this type of user accuracy assessment for maps created from acoustic data exist in the literature (White et al. 2003; Cochran-Marquez 2005). The additional points can be used to create an error matrix with the total number of pixels correctly classified in each benthic class versus the total number of pixels (Cochran-Marquez 2005).

It was possible to generate an idea of the uncertainty associated with supervised classification of pixels into substrates based on the backscatter-depth-slope ranges presented in table 3.15 (Fig. 4.1; Table 4.1). The results show that other approaches to accuracy assessment are need, as pixels which fell into only one substrate class may still have been wrongly classified. There was agreement between the existing benthic substrate map of the inner basin (Cote et al. 2004) and the map shown in Fig. 3.32, which gives some confidence in the results. The collection of additional samples to refine the criteria for supervised classification, particularly in the outer basin and fjord mouth, are needed as well as independent sample points for accuracy assessment.

Table 4.1 Percentage of each basin with pixels meeting classification criteria for multiple substrates

	Inner Basin	Narrows	Middle Basin	Outer Basin	Fjord Mouth	Total Fjord
1 substrate class	0.82	3.60	5.09	12.03	10.48	8.81
2 substrate classes	9.01	2.96	9.94	17.73	26.47	16.10
3 substrate classes	42.77	13.37	68.39	10.21	3.79	20.63
4 substrate classes	24.70	29.31	30.18	36.19	20.08	28.74
5 substrate classes	19.04	28.84	38.20	21.49	31.06	24.54
6 substrate classes	0	10.36	0	0	0	0.09
unclassified	0.02	7.68*	0.43	0.85	2.75	1.08

* This percentage includes the area later determined to be kelp-covered seabed

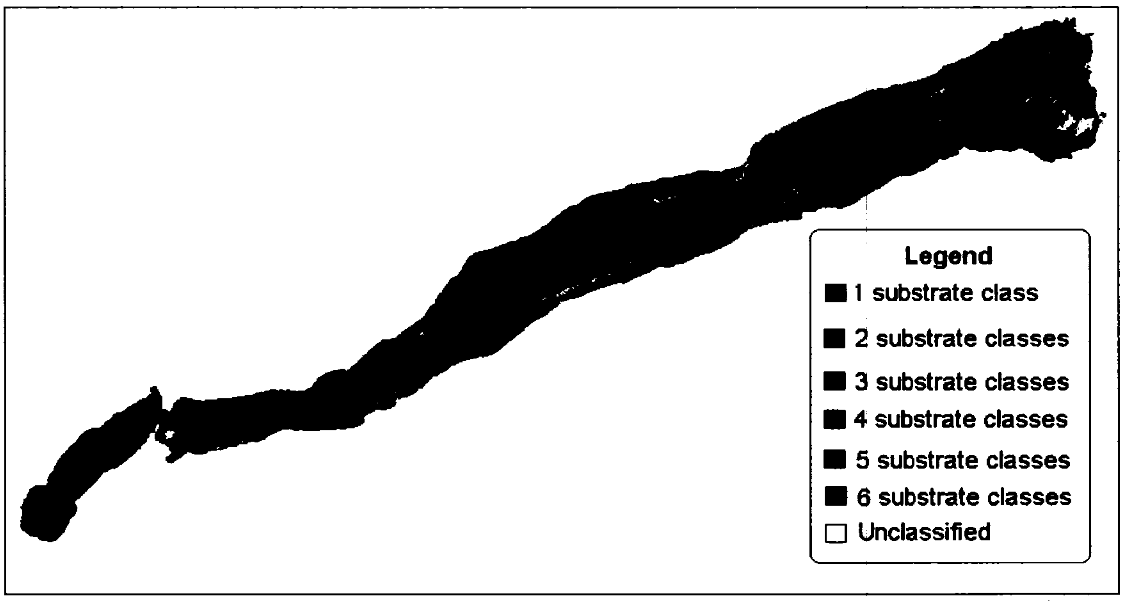


Figure 4.1 Map of Newman Sound showing the number of substrate classes into which each pixel was classified.

4.5 The Effect of Kelp on Signal Return

The effect of *Laminaria* kelp on the multibeam signal was demonstrated in this study. If kelp or other significant vegetation are known to occur in the survey area, it would be helpful to plan multibeam surveys and other acoustic work in the spring when vegetation cover should be at its lowest. Of equal importance, groundtruthing should be carried out as soon as possible after the acoustic survey is carried out.

The multibeam survey of Newman Sound on which the kelp signal was identified was carried out in July of 2003. Dives were conducted on the site in July of 2004 and significant kelp cover was recorded. Subsequent groundtruthing with the drop video camera was done in December 2004 at which time sparse kelp was recorded. Grab samples were collected in the area of the multibeam survey thought to represent the kelp habitat in May of 2005, at which time no kelp was collected.

It is likely that the *Laminaria* was free floating, as it was observed over pebbly sand substrate and it was impossible to establish from the videos if the kelp were attached to the seabed. Unattached masses of *Laminaria longicruris* have been reported over soft bottoms in sheltered Newfoundland estuaries (South 1983). The reduction of kelp in the winter and spring samples could be due to the kelp shedding fronds as some dead kelp was observed in one of the videos. Also an intense storm that occurred in the fall of 2004 may have disturbed the seabed and destroyed the kelp bed. The identification of kelp-covered seabed from the multibeam backscatter data is still an important result of this work, and therefore *Laminaria* kelp- covered seabed was included in the final habitat map even though it is an ephemeral feature.

4.6 Conservation Applications of Maps Generated from Multibeam Data

The ability to achieve 100% seabed mapping coverage with multibeam sonar in the coastal zone is an important advance for marine conservation and coastal zone management in Canada. Three of the most recent five marine protected areas designated by Fisheries and Oceans Canada have been in the coastal zone. Two of these new protected areas are in this province; Gilbert Bay in Labrador and Eastport in Bonavista Bay. Of the five areas of interest currently under consideration for MPA status, three are in shallow coastal waters, and one is in coastal Newfoundland. Therefore the ability to generate complete coverage benthic habitat maps for coastal waters, and coastal Newfoundland in particular, is critical. Multibeam sonar technology allows this critical need to be met in a timely and cost effective manner.

Marine conservation strategies, such as marine protected areas, often aim to protect areas that are representative of local habitats. By creating a habitat map the location of benthic habitats, their extents and relationships to other habitats are recorded. Consequently representative examples of local habitats can be identified, together with locally unique habitats or those that are sensitive to disturbance.

Rhodolith beds have been reported from the sills of fjords in Scotland and Norway (Hall-Spencer 1998) and are likely present on the sills of other Newfoundland fjords, so the investigation of fjord sills as biodiversity hotspots would be beneficial. The literature on rhodolith beds shows that they contain high biodiversity (Hall-Spencer 1998; Morgan 1998; Kamenos et al. 2004), and also provide greater substrate heterogeneity than surrounding sand and gravel habitats (Steller and Foster 1995; Kamenos et al. 2004). This is certainly the case in Newman Sound. Rhodolith-forming coralline algae do not produce toxins to prevent grazing like other algae, which probably contributes to high invertebrate biodiversity (Hinojosa-Arango and Riosmena-Rodriguez 2004). The preference of juvenile gadoid fish for this habitat type is attributed to this high invertebrate biomass and diversity (Kamenos et al. 2004). Juvenile Atlantic cod and juvenile and adult Icelandic scallops were observed in the rhodolith bed of Newman Sound. Therefore the value of this habitat as a nursery for two commercially important species should be investigated. Due to its high biodiversity and vulnerability to anthropogenic damage (Hall-Spencer 1998) rhodolith bed habitat should be a conservation priority.

Juvenile Atlantic cod (*Gadus morhua*) in Newman Sound associate with seagrass habitat in shallow water, and cobble substrate in deeper water (Anderson 2001). Protection from predators and the availability of food are the main habitat requirements of age 0 cod (Cote et al. 2001). Juvenile cod were observed in video samples associating with coarse gravel substrate and dense algae cover. Dense *Agarum cribrosum* kelp on boulders and rhodoliths in the Narrows, and dense *Laminaria* kelp on gravely sand appeared especially attractive to young cod. Delineation of substrate areas with which young cod and other juvenile fish are known to associate would allow for better monitoring of the juveniles as indicators of stock growth potential, as well as locating areas for protection if necessary.

The sill at the Narrows and adjacent areas of the inner and middle basins are highly heterogeneous, allowing a small marine protected area here to represent all described shallow water habitats. A circle with a diameter of 1.5 km, drawn from the centre of the Narrows, encloses patches of 9 habitats (Fig. 4.2). The entire rhodolith bed is contained within the circle, as are the area of kelp-covered seabed and substantial amounts of shallow water boulder and gravelly sand habitat. Small amounts of gravelly muddy sand and organic-rich mud also occur here. Shallow water pebble/cobble gravel, sand and bedrock are represented, but only occur in small patches in this part of the fjord. In this way benthic habitat maps, drawn from groundtruthed multibeam sonar data, can be used to select the best placement of a protected area so that it encompasses as many habitats as possible or targets bio-diverse habitats.

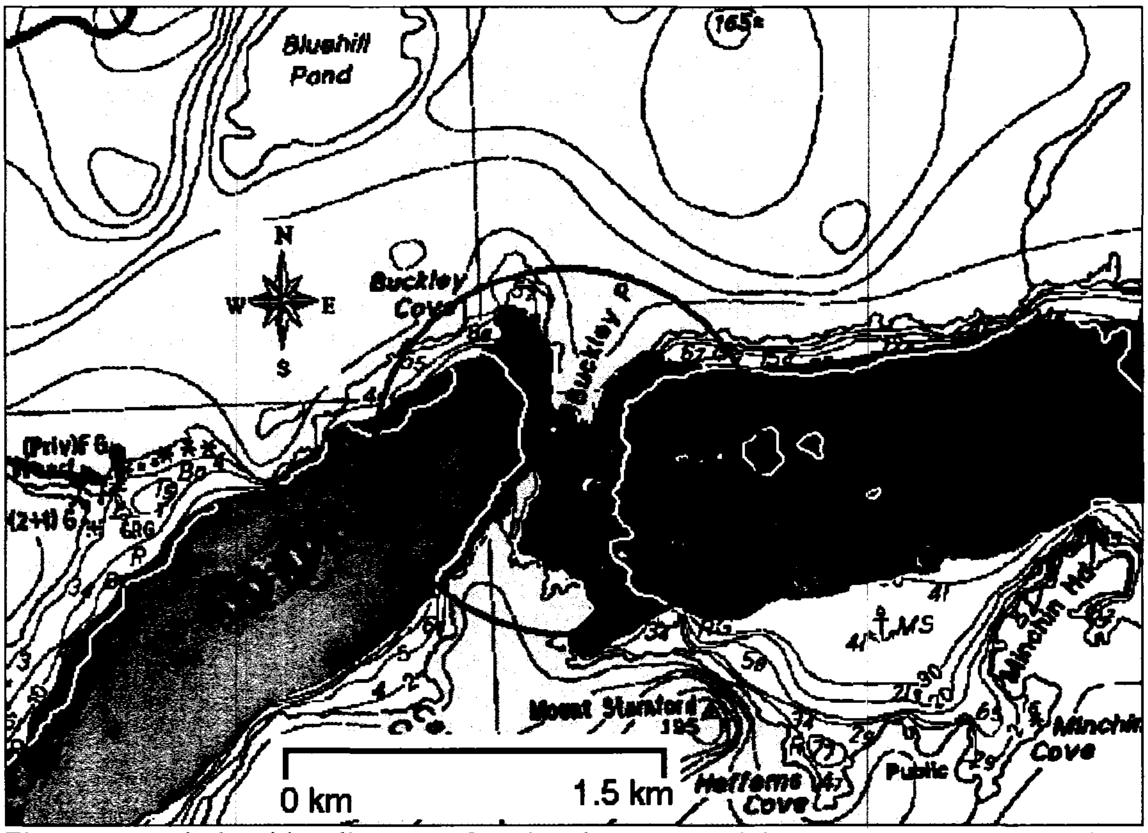


Figure 4.2 A circle with a diameter of 1.5 km drawn around the Narrows encompasses 9 described habitats, making it a good candidate location for a protected area. The bio-diverse and locally unique rhodolith bed falls completely within this circle.

4.7 Conclusions

1. The results of this thesis have demonstrated that substrates and biota present in a Newfoundland fjord can be characterised by grab sampling and video methods.
2. It was possible to map the likely distribution of characterised benthic substrates and habitats by supervised classification of multibeam bathymetry and backscatter data in a Geographic Information System (GIS). The resulting benthic habitat maps generated for Newman Sound provide continuous coverage of the seafloor at a scale that had not been possible before.
3. It was possible to identify biologically diverse and locally unique habitats in Newman Sound by mapping groundtruthed multibeam data. This mapping approach, therefore, has potential as a tool for marine conservation.

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Appendix A: Physical Attributes of Classified Samples

Sample Name	Latitude (NAD 83)	Longitude (NAD 83)	Depth (m)	Back scatter (-dB)	Slope (o)	Organic content (%)	Substrate Class	Habitat
grab 1	48.585453	53.812028	18.0	n/a	n/a	0.78	sand	sandy <30m potentially vegetated
grab 2	48.586215	53.812913	20.0	n/a	n/a	0.83	sand	sandy <30m potentially vegetated
grab 3	48.587162	53.814942	30.0	-10.5	33.6	~	gravel	gravel with small epifauna
grab 4	48.587447	53.814157	44.0	-7.8	33.0	~	no recovery	~
grab 5	48.58683	53.815295	32.0	-12.0	28.0	~	gravel	gravel with small epifauna
grab 6	48.587972	53.816355	121.0	-14.0	26.9	2.76	gravel	gravel with small epifauna
grab 7	48.567545	53.88961	22.0	n/a	n/a	~	gravel	gravel with small epifauna
grab 8	48.567248	53.889015	26.0	n/a	n/a	1.87	gravel	gravel with small epifauna
grab 9	48.566278	53.890505	4.0	n/a	n/a	~	sand	sandy <30m potentially vegetated
grab 10	48.5667417	53.88938	11.0	n/a	n/a	1.73	gravel	gravel with small epifauna
grab 11	48.569385	53.888718	50.0	n/a	n/a	3.16	mud	mud with sparse fauna
grab 12	48.5725	53.888	45.0	-22.0	9.0	1.58	gravelly muddy sand	gravelly muddy sand with brittle stars and bivalves
grab 13	48.575055	53.889074	80.7	-25.6	9.7	10.26	mud	mud with polychaetes and infaunal bivalves
grab 14	48.574872	53.906117	34.4	-29.4	4.0	3.45	mud	mud with polychaetes and infaunal bivalves
grab 15	48.580987	53.911483	16.2	-31.8	2.0		rhodolith	rhodolith bed
grab 16	48.579525	53.923847	53.0	-13.1	1.0	13.73	gravel	gravel with small epifauna

grab 17	48.562145	53.95273	38.0	-30.5	1.0	9.31	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
core 18	48.579597	53.923008	52.4	-16.0	1.0	4.55	gravelly sand	gravelly sand with
core 20	48.561428	53.95346	37.5	-30.5	2.0	5.98	gravelly muddy sand	gravelly muddy sand with brittle stars and bivalves
grab 21	48.5617139	53.953338	38.0	-31.0	2.0	9.17	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
core 23	48.5574566	53.9564725	6.5	-21.8	1.0	17.97	sand	sandy <30m potentially vegetated
core 24	48.556925	53.9580767	5.8	-26.6	1.0	24.26	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
core 24cc	48.556925	53.9580767	5.8	-26.6	1.0	9.60	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
grab 25	48.557119	53.958087	6.3	-27.0	1.0	24.80	sand	sandy <30m potentially vegetated
grab 26	48.558764	53.956088	8.5	-10.7	2.0	2.27	gravel	gravel with small epifauna
grab 27	48.576815	53.928672	51.5	-23.7	2.0	21.76	gravelly sand	gravelly sand, shell hash and echinoderms
grab 28	48.570858	53.92624	44.6	-17.0	3.0	26.20	gravelly muddy sand	gravelly muddy sand with brittle stars and bivalves
grab 29	48.5705833	53.92529	39.3	-15.2	4.0	1.69	gravelly sand	gravelly sand, shell hash and echinoderms

grab 30	48.569345	53.925506	8.0	n/a	n/a	1.50	gravelly sand	gravelly sand, shell hash and echinoderms
grab 31	48.5828917	53.9249167	5.0	n/a	n/a	0.90	gravelly sand	gravelly sand, shell hash and echinoderms
grab 32	48.581753	53.920675	46.0	-14.7	9.5	1.34	gravelly sand	gravelly sand, shell hash and echinoderms
grab 33	48.575323	53.905995	30.0	-13.6	8.0		gravel	gravel with small epifauna
grab 35	48.5890417	53.829108	132.0	-10.4	4.0	2.77	gravel	gravel with small epifauna
grab 36	48.621967	53.748267	312.0	-11.4	1.0	15.16	dredge spoil	~
grab 37	48.624804	53.747328	283.0	-10.2	17.0	4.75	dredge spoil	~
grab 38	48.629452	53.700868	315.0	-18.0	5.0	15.77	mud	mud with polychaetes and infaunal bivalves
grab 39	48.6528717	53.602145	98.0	-10.9	6.6		gravel	gravel with small epifauna
grab 40	48.655306	53.608542	72.0	-14.8	8.0		gravel	gravel with small epifauna
grab 41	48.647958	53.576424	273.0	-20.5	6.6	7.18	mud	mud with polychaetes and infaunal bivalves
grab 42	48.64336	53.583457	212.5	-2.0	22.0	2.32	gravelly sand	gravelly sand, shell hash and echinoderms
grab 100.1	48.58429	53.82707	95.0	-4.1	47.0	~	no recovery	~
grab 100.2	48.584	53.82747	65.0	-4.7	40.9	~	no recovery	~
grab 101.1	48.58107	53.82874	58.0	-25.0	10.6	~	no recovery	~
grab 101.2	48.58058	53.82945	52.0	-25.5	6.2	~	no recovery	~
grab 102	48.58237	53.85122	66.0	-16.0	11.0	1.17	gravelly sand	gravelly sand, shell hash and echinoderms
grab 103	48.58563	53.85315	77.0	-27.1	11.7	1.94	sand	sandollars in sand, possibly

								vegetated
grab 104	48.57747	53.85967	53.0	-16.0	2.0	0.76	sand	sandollars in sand, possibly vegetated
grab 105.1	48.57983	53.86669	64.0	-14.3	6.3	~	no recovery	~
grab 105.2	48.57957	53.86695	63.0	-10.2	5.8		gravel	gravel with small epifauna
grab 106.1	48.58329	53.86582	19.0	-16.0	10.0	~	no recovery	~
grab 106.2	48.5832	53.86583	19.0	-16.0	14.2	~	no recovery	~
grab 107.1	48.57792	53.87216	76.0	-10.4	19.3	~	no recovery	~
grab 107.2	48.57792	53.87213	76.6	-10.6	19.4	1.04	gravelly sand	gravelly sand, shell hash and echinoderms
grab 108	48.57969	53.87958	53.0	-8.8	13.2	~	no recovery	~
grab 109	48.58108	53.88086	38.0	-15.2	3.0	~	no recovery	~
grab 110	48.58171	53.86998	39.5	-20.4	3.7	0.83	sand	sandollars in sand, possibly vegetated
grab 111	48.57654	53.88836	51.2	-18.0	15.3	1.55	sand	sandollars in sand, possibly vegetated
grab 112	48.57568	53.89869	66.0	-36.6	3.9	15.65	mud	mud with polychaetes and infaunal bivalves
grab 113	48.57801	53.89083	49.3	-14.9	13.1	1.48	sand	sandollars in sand, possibly vegetated
grab 114	48.5810845	53.8987464	36.0	-41.3	2.0	2.83	sand	sandollars in sand, possibly vegetated
grab 115.1	48.58281	53.90222	36.0	-25.9	2.0	~	no recovery	~
grab 115.2	48.58285	53.90217	37.0	-25.6	2.3	2.18	gravelly muddy sand	gravelly muddy sand with brittle stars and bivalves
grab 116.1	48.58414	53.9011	23.0	-8.0	11.1	~	no recovery	~

grab 116.2	48.58405	53.90127	24.0	-9.0	10.0	~	no recovery	~
grab 117.1	48.58443	53.90377	7.0	-12.5	2.3	~	no recovery	~
grab 117.2	48.5845	53.90367	7.3	-13.0	2.0	~	no recovery	~
grab 118	48.57986	53.90502	32.8	-12.5	8.2		rhodolith	rhodolith bed
grab 119	48.57929	53.90731	22.0	-14.7	4.0		gravel	gravel with small epifauna
grab 120	48.58048	53.90975	17.0	-24.7	2.0		rhodolith	rhodolith bed
grab 121.1	48.57995	53.90964	16.0	-13.1	3.4	~	no recovery	~
grab 121.2	48.57995	53.90971	18.0	-13.1	3.0	~	no recovery	~
grab 122	48.57938	53.91001	14.0	-20.1	2.0	~	rhodolith	rhodolith bed
grab 123	48.57912	53.91148	10.5	-10.0	2.6	~	rhodolith	rhodolith bed
grab 124.1	48.57829	53.9085	17.8	-35.6	15.0	~	no recovery	~
grab 124.2	48.5782	53.9084	23.3	-32.9	15.3	~	no recovery	~
grab 125.1	48.57638	53.90871	18.1	-57.3	8.0	~	no recovery	~
grab 125.2	48.5763	53.90851	19.4	-56.3	8.0	~	gravel	gravel with small epifauna
grab 126	48.57632	53.90977	12.3	-58.5	5.6	0.98	sand	sandy <30m potentially vegetated
grab 127	48.57406	53.90922	13.0	-12.0	8.8	1.40	sand	sandy <30m potentially vegetated
grab 128	48.570814	53.909278	7.6	-12.5	3.9	1.34	sand	sandy <30m potentially vegetated
grab 129.1	48.58349	53.91396	31.0	-9.0	14.0	~	gravel	gravel with small epifauna
grab 129.2	48.5835	53.91371	28.0	-8.8	13.2	~	gravel	gravel with small epifauna
grab 130	48.58367	53.91607	42.0	-12.6	5.0	0.48	gravelly sand	gravelly sand, shell hash and echinoderms
grab 131	48.57751	53.92476	51.0	-31.5	2.0	34.28	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves

grab 132	48.57622	53.92396	49.3	-26.6	1.9	30.81	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
grab 133	48.57741	53.92875	51.0	-17.1	1.0	23.42	gravelly muddy sand	gravelly muddy sand with brittle stars and bivalves
grab 134	48.57712	53.92968	51.0	-24.5	1.0	26.28	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
grab 135	48.56819	53.93727	43.7	-28.0	2.0	30.82	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
D15 start	48.58201	53.90545	30.8	-14.0	4.9	~	gravelly sand	gravelly sand, shell hash and echinoderms
D20	48.58218	53.89248	34.0	-11.2	2.0	~	boulder gravel	boulder gravel with or without sand, with attached anemones
D21	48.57992	53.88595	45.0	-29.3	5.0	~	mud	mud with polychaetes and infaunal bivalves
D22 start	48.58139	53.88072	38.3	-16.0	3.0	~	boulder gravel	boulder gravel with or without sand, with attached anemones
D22 end	48.58071	53.88056	41.0	-16.0	4.9	~	boulder gravel	boulder gravel with or without sand, with attached anemones
D25 start	48.58351	53.87318	42.5	-13.4	5.8	~	boulder gravel	boulder gravel with or without sand, with attached anemones
D25 end	48.58361	53.87265	41.7	-12.0	5.0	~	boulder gravel	boulder gravel with or without sand,

								with attached anemones
D26 start	48.58323	53.86527	14.5	-17.0	2.2	~	boulder gravel	boulder gravel with or without sand, with attached anemones
D26 end	48.58311	53.86462	15.5	-16.5	2.5	~	boulder gravel	boulder gravel with or without sand, with attached anemones
D30	48.58563	53.85290	81.0	-27.8	9.5	~	sand	deep water sand
D126 start	48.57628	53.90926	15.2	-56.6	6.9	~	sand	*Laminaria* kelp bed
D126 end	48.57541	53.90871	22.0	-35.7	9.3	~	sand	sandy <30m potentially vegetated
D13 start	48.57801	53.90968	11.2	-10.7	3.9	~	gravelly sand	gravelly sand, shell hash and echinoderms
D13 end	48.57776	53.90933	12.5	-10.1	6.4	~	boulder gravel	boulder gravel with or without sand, with attached anemones
D12 start	48.58010	53.91198	13.5	-20.0	3.1	~	rhodolith	rhodolith bed
D12 end	48.57936	53.91036	13.5	-22.0	6.1	~	rhodolith	rhodolith bed
D11 start	48.58096	53.91156	16.2	-29.0	2.0	~	rhodolith	rhodolith bed
change to red	48.58028	53.90901	18.0	-21.6	2.2	~	rhodolith	rhodolith bed
D11 end	48.57978	53.90744	20.0	-15.5	5.3	~	rhodolith	rhodolith bed
D10 start	48.58150	53.91080	14.0	-10.0	5.0	~	boulder gravel	boulder gravel with or without sand, with attached anemones
D10 end	48.58030	53.90958	17.5	-25.5	2.0	~	rhodolith	rhodolith bed
D9 start	48.58186	53.91345	21.0	-16.0	20.6	~	boulder gravel	boulder gravel with or without sand, with attached anemones
D9 end	48.58118	53.91291	16.3	-12.2	2.0	~	rhodolith	rhodolith bed
D8 start	48.58349	53.91410	34.5	-8.1	14.0	~	gravelly sand	gravelly sand, shell hash and echinoderms
D8 end	48.58280	53.91304	23.0	-7.4	15.8	~	boulder gravel	boulder gravel with or without sand, with attached

								anemones
D7 start	48.58581	53.91320	8.0	-11.5	3.6	~	sand	sandy <30m potentially vegetated
D7 end	48.58458	53.91215	7.5	-13.4	1.1	~	sand	sandy <30m potentially vegetated
D6 start	48.57932	53.92322	52.5	-15.6	2.0	~	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
D6 end	48.57928	53.92336	52.4	-16.3	1.3	~	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
D5 start	48.57817	53.92274	51.5	-43.2	2.0	~	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
D5 end	48.57814	53.92230	51.0	-41.5	2.0	~	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
D4 start	48.57746	53.92918	50.5	-22.0	1.0	~	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
D4 end	48.57772	53.92943	50.5	-24.8	1.0	~	inner basin mud	organic rich inner basin mud with deposit feeding polychaetes and bivalves
cliff	48.57725	53.91677	14.5	-14.0	38.2	~	bedrock	bedrock with encrusting sponges, attached anemones & echinoderms

Practice dive start	48.577	53.9163	10.6	-7.7	10.0	~	gravelly sand	gravelly sand, shell hash and echinoderms
Practice dive end	48.5774	53.91565	10.5	-14.2	17.0	~	boulder gravel	boulder gravel with or without sand, with attached anemones
Buckley Pt dive 1 start	48.58398	53.90428	12.8	-10.1	16.0	~	boulder gravel	boulder gravel with or without sand, with attached anemones
Buckley Pt dive 1 end	48.58441	53.90362	7.4	-12.6	3.2	~	boulder gravel	boulder gravel with or without sand, with attached anemones
Buckley Pt dive 2 start	48.58447	53.90319	7.4	-12.0	2.9	~	boulder gravel	boulder gravel with or without sand, with attached anemones
Buckley Pt dive 2 end	48.58452	53.90241	8.5	-12.0	7.6	~	boulder gravel	boulder gravel with or without sand, with attached anemones
Buckley Pt dive 3 start	48.58491	53.90355	6.8	-18.6	2.0	~	sand	sandy <30m potentially vegetated
Buckley Pt dive 3 end	48.58496	53.90277	7.2	-14.3	1.0	~	sand	sandy <30m potentially vegetated
Mt. Stamford Cove dive 1 start	48.570394	53.909591	6.8	-18.5	2.0	~	boulder gravel	boulder gravel with or without sand, with attached anemones
Mt. Stamford Cove dive 1 end	48.57113	53.90922	6.8	-15.4	3.1	~	boulder gravel	boulder gravel with or without sand, with attached anemones
dive 6 start	48.57591	53.91343	7.3	-12.5	2.0	~	gravelly sand	gravelly sand, shell hash and echinoderms
dive 6 end	48.57629	53.91371	6.7	-13.0	4.0	~	gravelly sand	gravelly sand, shell hash and echinoderms
dive 5 start	48.57638	53.91371	6.6	-13.0	3.9	~	gravelly sand	gravelly sand, shell hash and

								echinoderms
dive 5 end	48.57676	53.91343	7.1	-11.3	2.3	~	boulder gravel	boulder gravel with or without sand, with attached anemones
dive 4 start	48.57648	53.90975	11.7	-58.7	4.7	~	sand	*Laminaria* kelp bed
dive 4 end	48.5769	53.90995	10.3	-16.0	2.0	~	sand	sandy <30m potentially vegetated
dive 3 start	48.57669	53.91032	9.9	-55.0	2.0	~	sand	*Laminaria* kelp bed
dive 3 end	48.57704	53.91073	9.3	-13.8	2.0	~	sand	sandy <30m potentially vegetated
ROV A start	48.579806	53.908438	17.5	-12.0	4.5	~	rhodolith	rhodolith bed
ROV A end	48.580548	53.908451	18.4	-26.0	2.1	~	rhodolith	rhodolith bed
ROV B start	48.579457	53.879461	56.8	-9.5	16.6	~	sand	deep water sand
ROV B end	48.579537	53.8793	56.6	-7.4	11.1	~	gravel	gravel with small epifauna
ROV D start	48.6202517	53.6974917	41.2	-10.4	64.4	~	bedrock	bedrock with encrusting sponges, attached anemones & echinoderms
ROV D end	48.6205133	53.69663	47.4	-12.0	60.9	~	bedrock	bedrock with encrusting sponges, attached anemones & echinoderms
ROV E start	48.662719	53.594093	32.9	-14.8	20.0	~	bedrock	bedrock with encrusting sponges, attached anemones & echinoderms
ROV E end	48.662617	53.593925	31.8	-14.0	21.0	~	bedrock	bedrock with encrusting sponges, attached anemones & echinoderms

Appendix B: Biota Sample by Benthic Grab

ID #	Phylum	Class	Genus	Species	Quantity	Feeding Mode	Comments	Refs.
1	Annelida	Polychaeta	Spirorbis	borealis	many	suspension	on sourweed	Gosner 1979, p.195; Bousfield p.44
1	Arthropoda	Malacostraca	Caprella	spp.	3	predator on inverts	skeleton shrimp	Harvey-Clark, p.45; Gosner 1971, p.507
1	Bryozoa	Gymnolaemata	Lichenopora	spp.	1	suspension	on algae stipe	Gosner 1979, p.115
1	Bryozoa	Gymnolaemata	~	~	few	suspension	branching	~
1	Echinodermata	Ophiuroidea	Ophiura	robusta	1	carnivore		Smith, p.189; Gosner 1979, p.264
1	Mollusca	Bivalvia	Cerastoderma	pinnulatum	1	filter	Northern dwarf cockle	Bousfield28,53. Gosner 1979, p.151
1	Mollusca	Bivalvia	Hiatella	arctica	2	suspension	Arctic rock borer	Bousfield35,57; Gosner 1979,p.158
1	Mollusca	Gastropoda	Margarites	helicinus	many	grazer/ detritivore		Gosner 1979, p.136; Bousfield p.15
1	Chlorophyta		Enteromorpha	intestinalis	frag	~	green year round	Gosner 1979, p.27
1	Phaeophyta		Desmarestia	aculeata		~	sourweed	Harvey-Clark,p.14; Sears,p.75

2	Bryozoa	Gymnolaemata	~	~	few	suspension	branching	~
2	Bryozoa	Gymnolaemata	Lichenopora	spp.	1	suspension	on algae stipe	Gosner 1979, p.115

2	Echinodermata	Echinoidea	Echinarachnius	parma	1	deposit	purple sandollar	Gosner 1979, p.258; Harvey-Clark, p.40
2	Mollusca	Gastropoda	Margarites	helicinus	many	grazer/ detritivore		Gosner 1979, p.136; Bousfield p.15
2	Chlorophyta		Enteromorpha	intestinalis	frag	~	green year round	Gosner 1979, p.27
2	Phaeophyta		Desmarestia	aculeata		~	sourweed	Harvey-Clark,p.14; Sears,p.75

3	Annelida	Polychaeta	Spirorbis	borealis	several	suspension		Gosner 1979, p.195; Bousfield p.44
3	Rhizopoda	Granuloreticulosea	~	~	several	suspension	white chambered foram	~
3	Rhizopoda	Granuloreticulosea			1	suspension	high spiral shell	~
3	Rhizopoda	Granuloreticulosea			2	suspension	shell with perforations	~

5	Bryozoa	Gymnolaemata	~	~	1	suspension	brownish, branching	~
5	Bryozoa	Gymnolaemata	~	~	patch	suspension	pink, lacy crust	Gosner 1979, p115
5	Mollusca	Bivalvia	Chlamys	islandicus	1	filter	spat	Smith147; Bousfield,p.29
5	Mollusca	Polyplacophora	Tonicella	rubra	1	omnivorous grazer	also Ischnochiton ruber	Bousfield,p.38; Gosner 1979, p.123
5	Rhizopoda	~	~	~	1		like snail with perforations	~
5	Rhizopoda	Granuloreticulosea			few			~
5	Rhodophyta		Lithothamnion	spp.	patch	~		Harvey-Clark, p.13; Sears,

								p.105
6	Annelida	Polychaeta	Lepidonotus	squamatus	1	scavenger/ predator		Gosner 1979, p.169; Smith,p.75
6	Annelida	Polychaeta	~	~	several	~	sandy tubes	~
6	Annelida	Polychaeta	Pectinaria	granulata	1	filter with setae		Gosner 1979 p.191, Harvey-Clark p28
6	Annelida	Polychaeta	~	~	several	~	muddy tubes	~
6	Annelida	Polychaeta	Maldanid		1	deposit	dark jaw, rounded posterior - Maldanid	
6	Arthropoda	Crustacea	~	~	1	scavenger	amphipod	Gosner 1979, plate 51
6	Bryozoa		Tricellaria	ternata	2	suspension	erect bryozoan, "antler like"	Gosner 1979, p.117,plate15
8	Annelida	Polychaeta	Paranaitis	speciosa	3	carnivore?	very small fragile	Gosner 1979, p.167
8	Annelida	Polychaeta	Pherusa	plumosa	2	deposit	fragments, tentative identififcation	Gosner 1979, p.194
8	Annelida	Polychaeta	~	~	1	~	fragment	~
8	Annelida	Polychaeta	Harmothoe	extenuata	1	carnivore		Gosner 1979, p.170
8	Annelida	Polychaeta	Pectinaria	granulata	1	filter with setae	empty tube	Gosner 1979 p.191, Harvey-Clark p28
8	Annelida	Polychaeta	~	~	5	~	fine sand tubes, all with worms	~
8	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	1	omnivorous grazer	1cm diameter	Smith, p.188, Harvey-Clark,p.40

8	Echinodermata	Holothuroidea	Cucumaria	frondosa	1	filter with tentacles	1.5-2cm long	Smithpp189; Gosner 1979 p.254
8	Mollusca	Bivalvia	~	~	1	filter	3mm bowl shape, was live	~
8	Mollusca	Bivalvia	Astarte	spp.	7	suspension	5 live, 2 dead. Largest 0.9cm, smallest 0.3cm.	Bousfield, p. 30; Gosner 1979, p.150
8	Mollusca	Bivalvia	Cerastoderma	pinnulatum	2	suspension	dwarf cockles	Bousfield28,53. Gosner 1979, p.151
8	Mollusca	Gastropoda	~	~	1	~	live, id?	~
8	Mollusca	Polyplacophora	Ischnochiton	albus	1	omnivorous grazer	0.8cm	Gosner 1979, p.123
8	Rhodophyta		Phyllophora?	membranifolia	1	~	attached to pebble	Gosner 1979, p.42

9	Cnidaria	Anthozoa	Tealla	felina	4	predator		Gosner 1979, p.96; Harvey-Clark, p.20

11	Annelida	Polychaeta	~	~	1	~	mud covered soft tube, not mucous?	~
11	Annelida	Polychaeta	Pectinaria	granulata	1	filter with setae	empty tube	Gosner 1979 p.191, Harvey-Clark p28
11	Annelida	Polychaeta	Capitella	spp.	3	detritivore		Gosner 1979, p.184
11	Echinodermata	Echinoidea	Echinarachnius	parma	1	deposit	small	Gosner 1979, p.258; Harvey-Clark, p.40

11	Mollusca	Bivalvia	Macoma	calcarea	2	suspensivore/ detritivore	cracked clams, dead, both shells still has two valves	Bousfield,p.37; Gosner 1979, p.158
11	Mollusca	Bivalvia	Gemma	gemma	1	suspension		Bousfield, p.56
12	Annelida	Polychaeta	~	~	1	~	pink worm in sandy tube on rock	~
12	Echinodermata	Ophiuroidea	Ophiuria	robusta		carnivore		Smith, p.189; Gosner 1979, p.264
12	Echinodermata	Ophiuroidea	Ophiopholis	aculeata		filter with arms	daisy brittle star	Gosner 1979,p.263; Harvey-Clark p.42
12	Mollusca	Bivalvia	Clinocardium	ciliatum	1	suspension	large shell, was live	Bousfield,p.53; Harvey-Clark,p.32
12	Mollusca	Bivalvia	Astarte	spp.	1	suspension		Bousfield, p. 30; Gosner 1979, p.150
12	Mollusca	Bivalvia	Cuspidaria	spp.	1	predator / scavenger	live	Gosner 1979, p.160
12	Mollusca	Gastropoda	Margarites	costalis	1	grazer		Gosner 1979, p.136; Bousfield p.15
13	Annelida	Polychaeta	Pectinaria	granulata	1	filter with setae	large empty tube	Gosner 1979 p.191, Harvey-Clark p28
13	Annelida	Polychaeta	~	~	1	~	fragment small white	~
14	Annelida	Polychaeta	Spirorbis	spirillum	many	filter	attached to algae	Gosner 1979, p.195

14	Annelida	Polychaeta	Spirorbis	borealis	lots	filter		Gosner 1979, p.195; Bousfield p.44
14	Annelida	Polychaeta	Pectinaria	granulata	3	filter with setae	all empty tubes	Gosner 1979 p.191, Harvey-Clark p28
14	Arthropoda	Crustacea	~	~		scavenger?	amphipod	~
14	Mollusca	Bivalvia	Mytilus	edulis	3	suspension	mussels. 2 open, 1 closed prob live.	Bousfield26,53.
14	Rhodophyta	~	~	~	1	~	branching red alage, looks black	

15	Annelida	Polychaeta	~	~	1	~	4 eyes, tentacles, heartshaped head???	~
15	Annelida	Polychaeta	Pectinaria	granulata	2	filter with setae	empty tubes	Gosner 1979 p.191, Harvey-Clark p28
15	Annelida	Polychaeta	Lepidonotus	squamatus	9	scavenger/ carnivore		Gosner 1979, p.169; Smith,p.75
15	Annelida	Polychaeta	Paranaitis	speciosa	1	carnivore?		Gosner 1979, p.167
15	Annelida	Polychaeta	Euchone	rubrocincta	2	suspensivore		Gosner 1979, p.194
15	Annelida	Polychaeta	~	~	1	~	v. small	~
15	Annelida	Polychaeta	Harmothoe	imbricata	4	predator	1 with everted proboscis (imbricata?h-cp26)	Harvey-Clark,p.26; Gosner 1979, p.170
15	Bryozoa	Gymnolaemata	Tubulipora	spp.		suspension	pan pipe	Rogickpp175, Gosner 1979, p114
15	Bryozoa	Gymnolaemata	Lichenopora	spp.	few	suspension	on algae	Gosner 1979

								p115
15	Bryozoa	Gymnolaemata			many	suspension	white encrusting	~
15	Echinodermata	Asteroidea	Asterias	vulgaris	2	predator	small, red eye spot	Smith, p.189; Harvey-Clark, p.40
15	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	2	omnivorous grazer	green, 1 very small	Smith, p.188, Harvey-Clark,p.40
15	Echinodermata	Ophiuroidea	Ophiothrix	angulata	3		tiny	Gosner 1979, p.263
15	Echinodermata	Ophiuroidea	~	~	3	suspension/ predator	too small to tell species	~
15	Echinodermata	Ophiuroidea	Ophiopholis	aculeata	53	filter with arms	some large	Gosner 1979,p.263; Harvey-Clark p.42
15	Echinodermata	Ophiuroidea	Ophiura	sp	15	carnivore?		Smith, p.189; Gosner 1979, p.264
15	Echinodermata	Ophiuroidea	Ophiura	robusta	51	carnivore	boreal species	Smith, p.189; Gosner 1979, p.264
15	Mollusca	Bivalvia	Chlamys	islandicus	1	filter	iceland scallop	Smithpp147
15	Mollusca	Bivalvia	Anomia	simplex	2	filter	jingle shell	Gosner 1979, p.149
15	Mollusca	Bivalvia	Hiatella	arctica	9	suspension	live	Bousfield35,57; Gosner 1979,p.158
15	Mollusca	Gastropoda	Acmaea	testudinalis	3	grazer	tortoise shell limpet	Harvey-Clark, p.33; Gosner 1979, p.125
15	Mollusca	Gastropoda	Puncturella	noachina	5	grazer	limpets.all live, largest 6mm across	Bousfield, p.12

15	Mollusca	Polyplacophora	Tonicella	rubra	12	omnivorous grazer	aka Ischnochiton ruber	Bousfield, p.58; Gosner 1979, p.123
15	Polyplacophora	Polyplacophora	Tonicella	marmorea	5	omnivorous grazer		Gosner 1971, p.255; Gosner 1979, p.123
15	Porifera	Calcarea	Scypha	ciliata	6	filter		Harvey-Clark 18, Smith 6
15	Rhodophyta	Rhodophyceae	Lithothamnion	spp.		~	rhodoliths	Harvey-Clark, p.13; Sears, p.105
15	Rhodophyta		Ptilota	serrata	pieces	~	some large pieces in rhodoliths, attached and not attached	Gosner 1979, p.45; Sears 2002, p.114
15	Rhodophyta		Phyllophora?	membranifolia		~		Gosner 1979, p.160
16	Annelida	Polychaeta	Sabaco	elongatus	1	deposit	bamboo worm	Ramey, 2001
16	Annelida	Polychaeta	Maldane	sarsi	1	deposit	"deep subsurface head down feeding" p73	Smith,p.69; Gosner 1971,p.356
16	Annelida	Polychaeta	~	~	2	~	fragments, same worm?	~
16	Arthropoda	Crustacea	Gammarus	sp.1	4	scavenger	very small, damaged	Gosner 1979, plate 51
16	Echinodermata	Ophiuroidea	Ophuira	robusta	3	carnivore	small	Smith, p.189; Gosner 1979, p.264
16	Mollusca	Bivalvia	Mya	arenaria	1	suspension	only one valve	Bousfield,p.37; Gosner 1979, p.158
16	Mollusca	Bivalvia	Macoma	calcarea	1	suspensivore/ detritivore	1 valve	Bousfield,p.37; Gosner 1979, p.158

17	Annelida	Polychaeta	Pectinaria	granulata	1	filter with setae	large tube and worm	Gosner 1979 p.191, Harvey-Clark p28
17	Annelida	Polychaeta	Maldane	sarsi	2	deposit	bamboo worms in muddy tubes	Smith,p.69; Gosner 1971,p.356
17	Annelida	Polychaeta	Harmothoe	imbricata	1	carnivore	orange scale`worm	Harvey-Clark,p.26; Gosner 1979, p.170
17	Arthropoda	Crustacea	~	~	1	scavenger	amphipod	Gosner 1979, plate 51
17	Echinodermata	Holothuroidea	Cucumaria	frondosa	2	filter with tentacles	"in areas of current on rock and sand/mud bottoms"hc39	Smithpp189; Gosner 1979 p.254
17	Mollusca	Bivalvia	Macoma	calcarea	2	suspensivore/ detritivore	live, open	Bousfield,p.37; Gosner 1979, p.158
18	Annelida	Polychaeta	Polyphysia	crassa	1			Gosner 1979, p.185
26	Annelida	Polychaeta	Pectinaria	granulata	2	filter with setae	one empty tube, one with worm	Gosner 1979 p.191, Harvey-Clark p28
26	Annelida	Polychaeta	~	~	1	~		~
27	Echinodermata	Holothuroidea	Cucumaria	frondosa		filter with tentacles	"in areas of current on rock and sand/mud bottoms"hc39	Smithpp189; Gosner 1979 p.254
27	Echinodermata	Ophiuroidea	Ophiopholis	aculeata	1	filter with arms		Gosner 1979,p.263;

								Harvey-Clark p.42
27	Mollusca	Bivalvia	Macoma	calcarea	1	suspensivore/ detritivore	large, white, dead	Bousfield,p.37; Gosner 1979, p.158
27	Mollusca	Bivalvia	Musculus	discors	1	filter		Bousfield, p. 27;
27	Mollusca	Bivalvia	Hiatella	arctica	2	suspension		Bousfield35,57; Gosner 1979,p.158
28	Mollusca	Bivalvia	Musculus	discors	1	filter	large, live with bysuss	Bousfield, p. 27;
28	Mollusca	Bivalvia	Mya	arenaria	1	suspension	live, deep burrower (Harvey-Clark31)	Bousfield,p.37; Gosner 1979, p.158
28	Mollusca	Bivalvia	Macoma	calcarea	3	suspensivore/ detritivore	live	Bousfield,p.37; Gosner 1979, p.158
29	Mollusca	Bivalvia	Macoma	calcarea	3	suspensivore/ detritivore	2 live, 1 old	Bousfield,p.37; Gosner 1979, p.158
29	Mollusca	Bivalvia	Astarte	borealis	1	suspensivore		Bousfield30,54.
29	Mollusca	Gastropoda	~	~	1	~	old shell, snail sp?	~
30	Arthropoda	Crustacea	Gammarus	sp. 2	1	scavenger		Gosner 1979, plate 51
30	Echinodermata	Echinoidea	Echinarachnius	parma	1	deposit	Harvey-Clark,p.40"sand dweller"	Gosner 1979, p.258; Harvey-Clark, p.40
31	Echinodermata	Echinoidea	Echinarachnius	parma	3	deposit		Gosner 1979, p.258; Harvey-

								Clark, p.40
32	Annelida	Polychaeta	Pherusa	plumosa	3	deposit		Gosner 1979, p.194
32	Annelida	Polychaeta	~	~	1	~	fragment of cemented sand grain tube, round.	
32	Annelida	Polychaeta	Goniada	maculata	1	predator	10/11 chevrons, Photo at 4	Smith, p.68; Gosner 1979, p.172
32	Annelida	Polychaeta	Pectinaria	granulata	4	filter	1 live, 2 small empty, 1 large`empty	Gosner 1979 p.191, Harvey-Clark p28
32	Annelida	Polychaeta	Onuphis	conchylega	5	predator	1 live, empty tubes, one turned black - dead a long time?	Smith, p.71; Gosner 1979,p.179
32	Annelida	Polychaeta	~	~		~	pebble with sandy tube, spiral, empty round opening 2.5mm across.	~
32	Annelida	Polychaeta	~	~	4	~	damaged	~
32	Echinodermata	Echinoidea	Echinarachnius	parma	1	deposit	sandollar was live	Gosner 1979, p.258; Harvey-Clark, p.40
32	Mollusca	Bivalvia	Astarte	borealis	3	suspensivore		Bousfield, p. 30; Gosner 1979, p.150
32	Mollusca	Bivalvia	Astarte	undata	5	suspensivore	fragments	Bousfield, p. 30; Gosner 1979, p.150
32	Mollusca	Bivalvia	Macoma	calcarea	1	suspensivore/ detritivore	fragment	Bousfield,p.37; Gosner 1979, p.158

33	Annelida	Polychaeta	~	~	several	~	sandy, orange worm tubes	~
33	Arthropoda		Gammarus	spp.	1	scavenger	Amphipod, red eyes.	Gosner 1979, plate 51
33	Echinodermata	Asteroidea	~	~	1	predator	small, white with red eye spots	~
33	Echinodermata	Ophiuroidea	Ophiopholis	aculeata	6	filter with arms		Gosner 1979,p.263; Harvey-Clark p.42
33	Mollusca	Bivalvia	Hiatella	arctica	5	suspension		Bousfield35,57; Gosner 1979,p.158
33	Mollusca	Gastropoda	Puncturella	noachina	1	grazer		Bousfield, p.12
33	Mollusca	Gastropoda	Margarites	helicinus	1	grazer/ detritivore		Gosner 1979, p.136; Bousfield p.15
33	Mollusca	Polyplacophora	Tonicella	rubra	46	omnivorous grazer		Bousfield,p.38; Gosner 1979, p.123
33	Mollusca	Polyplacophora	Tonicella	maromea	7	grazer		Gosner 1971, p.255; Gosner 1979, p.123
33	Porifera	~	~	~	several	filter		~
33	Rhodophyta	Rhodophyceae	Lithothamnion	spp.		~	rhodoliths	Harvey-Clark, p.13; Sears, p.105

35	Annelida	Polychaeta	~	~	1	~	round, fat, sand tube empty	~
35	Annelida	Polychaeta	Onuphis	conchylega	1	predator	tube frag	Smith, p.71; Gosner 1979,p.179

35	Annelida	Polychaeta	~	~	few	~	thin, orange, sand tubes	~
35	Mollusca	Bivalvia	Macoma	calcarea	1	suspensivore/ detritivore	dead valves	Bousfield,p.37; Gosner 1979, p.158
35	Mollusca	Gastropoda	Acmaea	testudinalis	3	grazer	2 large, 1old	Harvey-Clark, p.33; Gosner 1979, p.125
35	Mollusca	Gastropoda	Aporrhais	occidentalis	1	detritivore	old shell	Bousfield18, 50.
35	Rhizopoda	Granuloreticulosea	~	~	few	~		~

36	Mollusca	Bivalvia	Cuspidaria	sp.	1	predator / scavenger	dipper shell	Gosner 1979, 160
37	Annelida	Polychaeta	Pectinaria	granulata	1	filter with setae	still in fine grained tube.	Gosner 1979 p.191, Harvey-Clark p28
37	Annelida	Polychaeta	Goniada	maculata	1	predator		Smith, p.68; Gosner 1979, p.172
37	Annelida	Polychaeta	Ammotrypane	aulogaster	1			Smith, p. 77
37	Mollusca	Bivalvia	Pandora	gouldiana	1			Harvey-Clark, p.32

38	Mollusca	Bivalvia	Pandora	gouldiana	1			Harvey-Clark, p.32

39	Annelida	Polychaeta	~	~	1	~	orange sandy worm tube	~
39	Bryozoa	Gymnolaemata	Scrupocellaria	scabra	patch	filter	branching shield bryozoan	Gosner 1979, p.117
39	Mollusca	Gastropoda	Puncturella	noachina	1	grazer		Bousfield, p.12

39	Rhizopoda	Granuloreticulosea			few		aglutinating foram	
39	Rhizopoda	Granuloreticulosea			few		calcareous forams	
40	Annelida	Polychaeta	~	~	several	~	orange worm tubes	~
40	Annelida	Polychaeta	Spirorbis	borealis	several	filter		Gosner 1979, p.195; Bousfield p.44
40	Bryozoa	Gymnolaemata	~	~	several	suspensivore	white, lacy	Gosner 1979, p.115
40	Bryozoa	Gymnolaemata			1	suspensivore	beaked	Gosner 1979, p.115
40	Mollusca	Bivalvia	Clinocardium	ciliatum	2	suspensivore?	1 valve old, 1 small live	Harvey-Clark, p.32; Bousfield, p.53
40	Mollusca	Gastropoda	Puncturella	noachina	3	grazer		Bousfield, p.12
40	Rhizopoda	Granuloreticulosea			several		chambered, purplish	
41	Annelida	Polychaeta	~	~	3	~	errant	
41	Annelida	Polychaeta	~	~	2	~	errant	
41	Echinodermata	Asteroidea	Ctenodiscus	crispatus	2	deposit	1 with 4 arms, 1 with 5	Gosner 1979, p. 260
41	Mollusca	Bivalvia	Macoma	calcarea	1	suspensivore/ detritivore	live	Bousfield,p.37; Gosner 1979, p.158
41	Mollusca	Gastropoda	~	~	1	grazer	old shell with bore hole	~
42	~	~	~	~	few	~	holes in granite, one with shadow 4mm across	
42	Annelida	Polychaeta	~	~	2	~	fragment	~

42	Annelida	Polychaeta	~	~	1	~	fury worm with rounded posteriro and orange anterior fringe	~
42	Annelida	Polychaeta	~	~	2	~	conical heads	~
42	Annelida	Polychaeta	Spirorbis	borealis	several	filter	in pebble bag	Gosner 1979, p. 195
42	Annelida	Polychaeta	~	~	3	~	branching chitonous tube, empty	~
42	Annelida	Polychaeta	~	~	2	~	in sandy tubes	~
42	Arthropoda				1	scavenger	2.5cm long	Gosner 1979, plate 51
42	Bryozoa	Gymnolaemata	~	~	patches	suspensivore	on pebbles, lacy white crust	Gonser 1979, p.115
42	Bryozoa	Gymnolaemata	Lichenopora	spp.	patches	suspensivore	lichen bryzoan	Gosner 1979, p.115
42	Bryozoa	Gymnolaemata			patches	suspensivore	oval branching along surface	Gosner 1979, p.119
42	Bryozoa	Gymnolaemata			several	suspensivore	round hole with horns	Gosner 1979, p.115
42	Echinodermata	Ophiuroidea	Ophiura	robusta	2	predator	ophuria with weakly dev't combs	Smith, p.189; Gosner 1979, p.264
42	Mollusca	Bivalvia	Astarte	spp.	4	suspensivore	several old shells, one live	Bousfield, p. 30; Gosner 1979, p.150
42	Mollusca	Bivalvia	Macoma	calcarea	4	suspensivore/ detritivore	dead, one with bore hole	Bousfield,p.37; Gosner 1979, p.158
42	Mollusca	Gastropoda	Margarites	costalis	1	grazer	old, dead	Gosner 1979, p.136; Bousfield p.15
42	Mollusca	Monoplacophora	Acmaea	testudinalis	3	grazer	one dead, hole in apex; other live	Harvey-Clark, p.33; Gosner

								1979, p.125
42	Rhizopoda	Granuloreticulosea			many		calc forams on pebbles	
42	Rhizopoda	Granuloreticulosea			several		aglutinating forams	
42	Rhizopoda	Granuloreticulosea			4		high releif snail foram?	

102	Annelida	Polychaeta	Onuphis	conchylega	7	carnivorous	aka Nothria conchylega	Smith, p.71; Gosner 1979,p.179
102	Annelida	Polychaeta	~	~	1	~	round mud and sand tube frag.	~
102	Annelida	Polychaeta	Pectinaria	granulata	3	filter with setae	1with worm, 2 empty	Gosner 1979 p.191, Harvey-Clark p28
102	Annelida	Polychaeta	~	~	3	~	leathery sand covered tube	
102	Annelida	Polychaeta	~	~	1	~	small leathery sand tube with neck-chordate?	
102	Bryozoa	Gymnolaemata			several	suspensivore	white lacy crust	Gosner 1979, p.115
102	Bryozoa	Gymnolaemata	Lichenopora	spp.	several	suspensivore	lichen bryozan	Gosner 1979, p.115
102	Echinodermata	Ophiuroidea	Ophiothrix	angulata	2	predator/particles		Gosner 1979, p.263
102	Mollusca	Bivalvia	Astarte	borealis	6	suspensivore	dead valves, all sizes, eroded	Bousfield, p. 30; Gosner 1979, p.150
102	Mollusca	Bivalvia	Astarte	undata	3	suspensivore	live	Bousfield, p. 30; Gosner 1979, p.150

102	Mollusca	Bivalvia	Hiatella	arctica	2	suspensivore	large frag with bore holes	Bousfield,p.35; Gosner 1979, p.158
102	Mollusca	Gastropoda	Puncturella	noachina	1	grazer	no inside features, worn apex	Bousfield, p.12
102	Rhizopoda	Granuloreticulosea			several	suspensivore	calcareous forams	

105	Annelida	Polychaeta	Spirorbis	spirillum	few	filter		Gosner 1979, p.195
105	Bryozoa	Gymnolaemata	~	~		suspensivore	white, ovals in line	Gosner 1979, p.119
105	Bryozoa	Gymnolaemata	Lichenopora	spp.		suspensivore	lichen bryzoa	Gosner 1979, p.115
105	Bryozoa	Gymnolaemata	Electra	crustulenta	large patch	suspensivore		Gosner 1979, p.115
105	Bryozoa	Gymnolaemata	~	~	small patches	suspensivore	other white lacy crust	Gosner 1979, p.119
105	Bryozoa	Gymnolaemata	~	~	patch	suspensivore	tuby, not pan pipe	Gosner 1979, p.115
105	Bryozoa	Gymnolaemata	~	~	patches	suspensivore	beaked crust	Gosner 1979, p.115
105	Bryozoa	Gymnolaemata	~	~	patches	suspensivore	encrusting sp?	Gosner 1979, p.115
105	Mollusca	Gastropoda	Acmaea	testudinalis	2	grazer		Harvey-Clark, p.33; Gosner 1979, p.125
105	Mollusca	Gastropoda	Crepidula	fornicata	1	filtering suspension feeder	v small with shelf	Gosner 1979, p.128
105	Mollusca	Polyplacophora	Tonicella	rubra	1	omnivorous grazer		Bousfield,p.38; Gosner 1979, p.123
105	Porifera	~	~	~		filter	not vase	~

105	Rhizopoda	Granuloreticulosea			few		calcareous forams	
105	Rhizopoda	Granuloreticulosea			several			
105	Rhodophyta	Rhodophyceae	Lithothamnion	spp.	small patches	~		Harvey-Clark, p.13; Sears, p.105
106	Arthropoda	Isopoda	Idotea	baltica	2	scavenges plant and animal	in algae	Harvey-Clark, p.45
106	Mollusca	Polyplacophora	Ischnochiton	albus	1	grazer		Gosner 1979, p.123
106	Mollusca	Polyplacophora	Tonicella	marmorea	2	grazer		Bousfield,p.38; Gosner 1979, p.123
106	Rhodophyta	Rhodophyceae	Lithothamnion	spp.	crust	~	on encrusted large shell frag in lumps	Harvey-Clark, p.13; Sears, p.105
106	Rhodophyta		Ptilota	serrata	mat	~		Gosner 1979, p.45; Sears 2002, p.114
110	Annelida	Polychaeta	Capitella	sp.	1	detritivore		Gosner 1979, p.184
110	Annelida	Polychaeta	Sabella	microphthalina	2	filter		Smith, p.60
110	Annelida	Polychaeta	Flabelligera	affinis	2	deposit		Gosner 1979, p.194
110	Annelida	Polychaeta	Sabellaria	vulgaris	3	filter	small empty sand tubes	Smith, p.60
110	Annelida	Polychaeta	Pectinaria	granulata	3	filter with setae		Gosner 1979 p.191, Harvey-Clark p28
110	Echinodermata	Echinoidea	Echinarachnius	parma	1	deposit	juvenile, diameter 2cm	Gosner 1979, p.258; Harvey-Clark, p.40

110	Echinodermata	Ophiuroidea	Ophiura	robusta		carnivore		Smith, p.189; Gosner 1979, p.264
110	Mollusca	Bivalvia	Mya	arenaria	1	suspensivore	old valve	Bousfield,p.37; Gosner 1979, p.158
110	Mollusca	Bivalvia	Gemma	gemma	1	filter		Bousfield31
110	Mollusca	Gastropoda	Margarites	costalis	1	grazer	ridged or rosy top, formerly cinereus	Gosner 1979, p.136; Bousfield p.15
110	Rhizopoda	Granuloreticulosea			1		aglutinating foram	

111	Annelida	Polychaeta	Onuphis	conchylega	4	predator	mobile, carries tube	Smith, p.71; Gosner 1979,p.179
111	Annelida	Polychaeta	~	~	2	~	mud tubes	~
111	Annelida	Polychaeta	Pectinaria	granulata	1	filter with setae		Gosner 1979 p.191, Harvey-Clark p28
111	Arthropoda	Amphipoda	Gammarus	sp.	1	scavenger	white scud	Gosner 1979 p227
111	Arthropoda	Amphipoda	~	~	2	scavenger		Gosner 1979, plate 52
111	Echinodermata	Echinoidea	Echinarachnius	parma	1	deposit	not kept, juvenile	Gosner 1979, p.258; Harvey-Clark, p.40
111	Echinodermata	Ophiuroidea	Ophiura	sp.	1	carnivore?		Smith, p.189; Gosner 1979, p.264
111	Mollusca	Bivalvia	Astarte	undata	1	suspensivore		Bousfield, p. 30; Gosner 1979, p.150
111	Mollusca	Bivalvia	Mya	arenaria	1	suspensivore	juvenile, v. small	Bousfield,p.37; Gosner 1979, p.158

111	Mollusca	Gastropoda	~	~	1			~
112	Mollusca	Gastropoda	Margarites	costalis	1	grazer	old, shell crushed	Gosner 1979, p.136; Bousfield p.15
113	Annelida	Polychaeta	Pectinaria	granulata	2	filter with setae		Gosner 1979 p.191, Harvey-Clark p28
113	Annelida	Polychaeta	Clymenella	torquata	1	deep head down deposit	high energy sandy, may make orange sandy tubes?	Gosner 1979, p186
113	Annelida	Polychaeta	Maldane	sarsi	3	deep head down deposit		Smith,p.69; Gosner 1971,p.356
113	Annelida	Polychaeta	~	~	several	~	orange sandy tubes on cobble, thin white worm	
113	Bryozoa	Gymnolaemata	~	~	patch	suspensivore	white crust, lacy	Gosner 1979, p. 115
113	Mollusca	Bivalvia	Gemma	gemma	1	filter	live	Bousfield31
113	Mollusca	Bivalvia	Astarte	undata	1	suspensivore	small live	Bousfield, p. 30; Gosner 1979, p.150
113	Mollusca	Gastropoda	Acmaea	testudinalis	1	grazer	live on cobble	Harvey-Clark, p.33; Gosner 1979, p.125
113	Rhizopoda	Granuloreticulosea			several		snail forams on cobble	
113	Rhodophyta	Rhodophyceae	Lithothamnion	spp.	patch	~		Harvey-Clark, p.13; Sears, p.105

118	Annelida	Polychaeta	Harmothoe	imbricata	1	carnivore	large scale worm,	Harvey-Clark,p.26; Gosner 1979, p.170
118	Annelida	Polychaeta	Lepidonotus	squamatus	4	predator / scavenger	12 scaled worm	Gosner 1979, p.169; Smith,p.75
118	Annelida	Polychaeta	Sabella	spp.	several	filter		Gosner 1979, p.194
118	Annelida	Polychaeta	Spirorbis	spirillum	few	filter	in P.serrata	Gosner 1979, p.195
118	Arthropoda	Crustacea	~	~	several	scavenger	amphipod	Gosner 1979, plate 51
118	Bryozoa	Gymnolaemata			several	suspensivore	encrusting sp?	Gosner 1979, p. 115
118	Bryozoa	Gymnolaemata			few	suspensivore	encrusting with spikes	Gosner 1979, p. 115
118	Bryozoa	Gymnolaemata	Lichenopora	spp.	several	suspensivore	lichen bryzoan	Gosner 1979, p.115
118	Bryozoa	Gymnolaemata			lots	suspensivore	brown pipes	~
118	Echinodermata	Asteroidea	Henricia	sanguinolenta	1	predator, particles		Smith, p.189, Gosner 1979, p.271
118	Echinodermata	Asteroidea	Asterias	vulgaris	1	Predator	adult	Smith, p.189; Harvey-Clark, p.40
118	Echinodermata	Asteroidea	~	~	4	predator	small white, red eyes	~
118	Echinodermata	Echinoidea	Strongylocentrotus	droebachiensis	1	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
118	Echinodermata	Ophiuroidea	Ophiopholis	aculeata	54	filters with arms		Gosner 1979,p.263; Harvey-Clark p.42

118	Echinodermata	Ophiuroidea	Ophiura	robusta	72	predator		Smith, p.189; Gosner 1979, p.264
118	Mollusca	Bivalvia	Hiatella	arctica	13	suspension	old valve, and other old clam, sp?	Bousfield35,57; Gosner 1979,p.158
118	Mollusca	Bivalvia	Modiolus	modiolus	~	filter	horse mussel, 3 shell valves encrusted by coralline	Harvey-Clark, p.29
118	Mollusca	Bivalvia	Chlamys	islandicus	2	filter	iceland scallop spat in P.serrata	Smith, p.147
118	Mollusca	Bivalvia	Astarte	undata	1	suspensivore	old	Bousfield, p. 30; Gosner 1979, p.150
118	Mollusca	Bivalvia	Anomia	simplex	3	filter		Gosner 1979, p.149
118	Mollusca	Gastropoda	Acmaea	testudinalis	1	grazer	tortoise shell limpet	Harvey-Clark, p.33; Gosner 1979, p.125
118	Mollusca	Gastropoda	Margarites	costalis	1	grazer	in shallow water on cold coasts	Gosner 1979, p.136; Bousfield p.15
118	Mollusca	Gastropoda	Margarites	helenicus	2	grazer/detritivore		Gosner 1979, p.136; Bousfield p.15
118	Mollusca	Gastropoda	Puncturella	noachina	6	grazer	no inside features, worn apex	Bousfield, p.12
118	Mollusca	Polyplacophora	Ischnochiton	albus	1	grazer		Gosner 1979, p.123
118	Mollusca	Polyplacophora	Tonicella	rubra	2	omnivorous grazer		Bousfield,p.38; Gosner 1979, p.123

118	Porifera	~	~	spp.	lots	filter	in rhodoliths, encrusting greyish white	~
118	Porifera	Calcarea	Scypha	ciliata	15-20	filter	often attached to P.serrata	Harvey-Clark, p.18; Smith,p.6
118	Rhizopoda	Granuloreticulosea			many		calc forams	
118	Rhizopoda	Granuloreticulosea			few		coiled snail	
118	Phaeophyta	Phaeophyceae	Chorda	filum	1 strand	~	annual, matures late summer	Gosner 1979 p33,
118	Rhodophyta	Rhodophyceae	Lithothamnion	spp.	rhodoliths	~		Harvey-Clark, p.13; Sears, p.105
118	Rhodophyta		Ptilota	serrata	lots	~	attached to rhodoliths, some 15cm long	Gosner 1979, p.45; Sears 2002, p.114
119	Annelida	Polychaeta	Lepidonotus	squamatus	2	predator / scavenger		Gosner 1979, p.169; Smith,p.75
119	Bryozoa	Gymnolaemata	~	~	3	suspension	pink crust	Gosner 1979, p. 115
119	Echinodermata	Asteroidea	~	~	1	predator	juvenile, white	~
119	Echinodermata	Asteroidea	Asterias	vulgaris	1	Predator	yellow madrop.	Smith, p.189; Harvey-Clark, p.40
119	Echinodermata	Ophiuroidea	Ophiopholis	aculeata	6	filters with arms		Gosner 1979,p.263; Harvey-Clark p.42
119	Echinodermata	Ophiuroidea	Ophiura	robusta	4	predator		Smith, p.189; Gosner 1979, p.264
119	Mollusca	Bivalvia	Hiatella	arctica	6	suspension		Bousfield35,57; Gosner

								1979,p.158
119	Mollusca	Gastropoda	Puncturella	noachina	4	grazer		Bousfield, p.12
119	Mollusca	Monoplacophora	Ischnochiton	albus	1	grazer		Gosner 1979, p.123
119	Mollusca	Monoplacophora?	Tonicella	rubra	2	omnivorous grazer		Bousfield,p.38; Gosner 1979, p.123
119	Porifera	~	~	~	1	filter	grey	~
119	Rhizopoda	Granuloreticulosea			few		calcareous forams	
119	Rhodophyta	Rhodophyceae	Lithothamnion	spp.	encrust	~		Harvey-Clark, p.13; Sears, p.105

120	Annelida	Polychaeta	Nereis	spp.	2	predator		Gosner 1979, p.176
120	Annelida	Polychaeta	Pectinaria	granulata	1	filter with setae		Gosner 1979 p.191, Harvey-Clark p28
120	Annelida	Polychaeta	Lepidonotus	squamatus	5	predator / scavenger		Gosner 1979, p.169; Smith,p.75
120	Annelida	Polychaeta	Harmothoe	imbricata	2	predator	other scale worms	Harvey-Clark,p.26; Gosner 1979, p.170
120	Annelida	Polychaeta	~	~	3	~		~
120	Annelida	Polychaeta	Spirorbis	borealis	lots	filter	in red fern mat	Gosner 1979, p.195; Bousfield p.44
120	Bryozoa	Gymnolaemata	~	~	patches	suspension	beaked crust	Gosner 1979, p.115
120	Bryozoa	Gymnolaemata	Lichenopora	spp.	3	suspension	lichen bryozoans	Gosner 1979, p.115

120	Echinodermata	Asteroidea	Asterias	vulgaris	3	predator	v small white, 2 in fern	Smith, p.189; Harvey-Clark, p.40
120	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	3	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
120	Echinodermata	Ophiuroidea	Ophiopholis	aculeata	77	filter with arms		Gosner 1979,p.263; Harvey-Clark p.42
120	Echinodermata	Ophiuroidea	Ophiura	robusta	11	predator		Smith, p.189; Gosner 1979, p.264
120	Echinodermata	Ophiuroidea	~	~	several		juveniles	~
120	Mollusca	Bivalvia	Hiatella	arctica	7	suspension	3 live, 3 dead from underside of cobble	Bousfield35,57; Gosner 1979,p.158
120	Mollusca	Bivalvia	~	~	several		juveniles	~
120	Mollusca	Gastropoda	~	~	1	~	white snail	~
120	Mollusca	Gastropoda	~	~	1	~	white limpet in hole	~
120	Mollusca	Gastropoda	Puncturella	noachina	5	grazer		Bousfield, p.12
120	Mollusca	Gastropoda	Acmaea	testudinalis	3	grazer	red and white limpet	Harvey-Clark, p.33; Gosner 1979, p.125
120	Mollusca	Gastropoda	Margarites	costalis	4	grazer	live	Gosner 1979, p.136; Bousfield p.15
120	Mollusca	Gastropoda	Margarites	helicinus	1	grazer/detritivore	live	Gosner 1979, p.136; Bousfield p.15
120	Mollusca	Polyplacophora	Tonicella	rubra	4	omnivorous grazer		Bousfield,p.38; Gosner 1979, p.123

120	Mollusca	Polyplacophora	Tonicella	marmorea	10	grazer		Gosner 1971, p.255; Gosner 1979, p.123
120	Porifera	~	~	~	1	suspension	yellow sponge	~
120	Rhodophyta	Rhodophyceae	Lithothamnion	spp.	rhod			
120	Rhodophyta		Ptilota	serrata	mat	~		Gosner 1979, p.45; Sears 2002, p.114

121	Bryozoa	Gymnolaemata	~	~	1	suspension	white crust	Gosner 1979, p.115
121	Echinodermata	Ophiuroidea	~	~	1		juvenile	~
121	Mollusca	Bivalvia	Hiatella	arctica	1	suspension		Bousfield35,57; Gosner 1979,p.158
121	Mollusca	Bivalvia	Anomia	simplex	1	filter		Gosner 1979, p.149
121	Mollusca	Polyplacophora	Tonicella	rubra	1	omnivorous grazer		Bousfield,p.38; Gosner 1979, p.123
121	Rhodophyta	Rhodophyceae	Lithothamnion	spp.	frag			

122	Annelida	Polychaeta	Lepidonotus	squamatus	4	predator / scavenger		Gosner 1979, p.169; Smith,p.75
122	Bryozoan	Gymnolaemata	~	~	patches	suspension	encrusting	Gosner 1979, p. 115
122	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	1	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
122	Echinodermata	Ophiuroidea	Ophiura	robusta	lots	predator		Smith, p.189; Gosner 1979, p.264

122	Echinodermata	Ophiuroidea	Ophiopholis	aculeata	lots	filters with arms		Gosner 1979,p.263; Harvey-Clark p.42
122	Mollusca	Bivalvia	Hiatella	arctica	5	suspension		Bousfield,p.35; Gosner 1979, p.158
122	Mollusca	Gastropoda	Puncturella	noachina	2	grazer		Bousfield, p.12
122	Mollusca	Polyplacophora	Tonicella	rubra	6	omnivorous grazer		Bousfield,p.38; Gosner 1979, p.123
122	Mollusca	Polyplacophora	Tonicella	marmorea	2	grazer		Gosner 1971, p.255; Gosner 1979, p.123
122	Phaeophyta		Agarum	cribrosum	1	~	perennial	Gosner 1979, p.34
122	Rhodophyta	Rhodophyceae	Lithothamnion	spp.		~		Harvey-Clark, p.13; Sears, p.105

123	Annelida	Polychaeta	Lepidonotus	squamatus	3	predator / scavenger		Gosner 1979, p.169; Smith,p.75
123	Annelida	Polychaeta	Spirorbis	borealis	few	filter		Gosner 1979, p.195; Bousfield p.44
123	Arthropoda	amphipoda	~	~	1	scavenger		Gosner 1979, plate 52
123	Bryozoa	Gymnolaemata	~	~	patches	suspension	white encrusting	Gosner 1979, p. 115
123	Bryozoa	Gymnolaemata	~	~	patches	suspension	encrusting	~
123	Echinodermata	Asteroidea	Asterias	vulgaris	1	predator		Smith, p.189; Harvey-Clark, p.40

123	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	1	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
123	Echinodermata	Ophiuroidea	Ophiopholis	aculeata	21	filters with arms		Gosner 1979,p.263; Harvey-Clark p.42
123	Mollusca	Bivalvia	Hiatella	arctica	17	suspension		Bousfield,p.35; Gosner 1979, p.158
123	Mollusca	Bivalvia	Anomia	simplex	2	filter		Gosner 1979, p.149
123	Mollusca	Gastropoda	Puncturella	noachina	2	grazer		Bousfield, p.12
123	Mollusca	Gastropoda	~	~	1			~
123	Mollusca	Polyplacophora	Tonicella	rubra	11	omnivorous grazer		Bousfield,p.38; Gosner 1979, p.123
123	Porifera	~	~	~	2	filter	grey	~
123	Rhizopoda	Granuloreticulosea						~
123	Rhodophyta	Rhodophyceae	Lithothamnion	spp.	rhod	~		
123	Phaeophyta		Agarum	cribrosum	1	~		Gosner 1979, p.34

124	Echinodermata	Asteroidea	Asterias	vulgaris	1	predator	juvenile	Smith, p.189; Harvey-Clark, p.40
124	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	1	omnivorous grazer	large, not kept	Smith, p.188, Harvey-Clark,p.40
124	Mollusca	Polyplacophora	Tonicella	rubra	2	omnivorous grazer		Bousfield,p.38; Gosner 1979, p.123
124	Phaeophyta		Agarum	cribrosum	2	~		Gosner 1979, p.34

124	Rhodophyta	Rhodophyceae	Lithothamnion	spp.		~		Harvey-Clark, p.13; Sears, p.105

125	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	1	omnivorous grazer	large, not kept	Smith, p.188, Harvey-Clark,p.40
125	Mollusca	Polyplacophora	Tonicella	marmorea	2	grazer		Gosner 1971, p.255; Gosner 1979, p.123
125	Rhodophyta	~	~	~	frag	~	leafy red	~

126	Annelida	Polychaeta	Pectinaria	granulata	1	filter with setae		Gosner 1979 p.191, Harvey-Clark p28
126	Annelida	Polychaeta	~	~	1	~	unidentified white polychaete	~
126	Annelida	Polychaeta	~	~	1	~	large unidentified worm, no head	~
126	Arthropoda	Crustacea	~	~	1	scavenger	white amphipod	Gosner 1979, plate 51, 52
126	Arthropoda	Crustacea	Diastylis	quadrispinosa	2	detritivore	Cumacean, found in sandy areas	Gosner 1979, p.219
126	Arthropoda	Crustacea	Gammarus	sp.3	1	scavenger		Gosner 1979, plate 51
126	Echinodermata	Echinoidea	Echinarachnius	parma	4	deposit	not kept	Gosner 1979, p.258; Harvey-Clark, p.40
126	Mollusca	Bivalvia	Clinocardium	ciliatum	1	suspension	v. small valve	Harvey-Clark, p.32; Bousfield, p.53
126	Rhodophyta	~	~	~	few	~	stringy red and green algae	~

127	Annelida	Polychaeta	Pectinaria	granulata	3	filter with setae	v. small	Gosner 1979 p.191, Harvey-Clark p28
127	Arthropoda	Crustacea	Ampelisca?	sp.	2	scavenger	amphipod	Gosner 1979, plate 51
127	Echinodermata	Echinoidea	Echinarachnius	parma	3	deposit	not kept	Gosner 1979, p.258; Harvey-Clark, p.40
127	Mollusca	Bivalvia	Ensis	directus	frag			Harvey-Clark, p.31
127	Phaeophyta	Phaeophyceae	Fucus	sp.	frag	~		~
127	Rhodophyta	~	~	~	frag	~	algae fragments, stringy red	~

128	Annelida	Polychaeta	Pectinaria	granulata	4	filter with setae		Gosner 1979 p.191, Harvey-Clark p28
128	Annelida	Polychaeta	~	~	2	~	v thin	~
128	Annelida	Polychaeta	Phyllodoce	sp.	1	~		
128	Arthrpoda	Crustacea	Gammarus	sp.	2	scavenger	white, small amphipod	Gosner 1979, plate 51
128	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	1	omnivorous grazer	very tiny, just post larval?	Smith, p.188, Harvey-Clark,p.40
128	Chlorophyta	~	~	~	blades	~	fil green algae	~
128	Phaeophyta	~	~	~	blades	~	fil brown algae	~

130	Annelida	Polychaeta	Onuphis	conchylega	10	carnivorous	live	Smith, p.71; Gosner 1979,p.179
130	Annelida	Polychaeta	Lepidonotus	squamatus	1	predator / scavenger	scale worm with jawa like in 118	Gosner 1979, p.169; Smith,p.75

130	Annelida	Polychaeta	~	~	2	~	coarse sand tube with crushed worm and other empty	~
130	Annelida	Polychaeta	~	~	3	~	sand tube, round, leathery	~
130	Annelida	Polychaeta	~	~	1	~	v. thin fine grain tube	~
130	Echinodermata	Ophiuroidea	Ophiopholis	aculeata	1	filter with arms	small	Gosner 1979,p.263; Harvey-Clark p.42
130	Mollusca	Bivalvia	Astarte	undata	2	suspensivore	small closed, 5mm at widest	Bousfield, p. 30; Gosner 1979, p.150
130	Mollusca	Gastropoda	Margarites	costalis	1	grazer		Gosner 1979, p.136; Bousfield p.15
130	Mollusca	Gastropoda	Acmaea	testudinalis	1	grazer	tortoise shell limpet	Harvey-Clark, p.33; Gosner 1979, p.125
130	Rhizopoda	Granuloreticulosea	~	~	few		calcareous forams	
130	Rhodopyta		Ptilota	serrata	frag	~	with holdfast	Gosner 1979, p.45; Sears 2002, p.114
130	Rhodophyta	Rhodophyceae	Lithothamnion	spp.	patch	~	small patch on peb.	
130	Spermatophyta		Zostrea	marina	1	~	recently dead fragment	Gosner 1979, p.52
131	Annelida	Polychaeta	Flabelligera	affinis	1	deposit	noted as mud dwellers	Gosner 1979, p.194
131	Annelida	Polychaeta	Maldane	sarsi	7	deposit	large bamboo worms in mud tubes, lots not kept	Smith,p.69; Gosner 1971,p.356
131	Annelida	Polychaeta	~	~	1	~	Family Phyllodocidae	~

131	Arthropoda	Crustacea	~	~	1	scavenger	pink amphipod	Gosner 1979, plate 52
131	Echinodermata	Ophiuroidea	Ophiura	robusta	13	carnivore		Smith, p.189; Gosner 1979, p.264
131	Echinodermata	Ophiuroidea	Ophiopholis	aculeata	11	filters with arms		Gosner 1979,p.263; Harvey-Clark p.42
131	Mollusca	Bivalvia	Macoma	calcarea	8	suspensivore/ detritivore		Bousfield,p.37; Gosner 1979, p.158
131	Rhodophyta	Florideophyceae	Ptilota	serrata	mat	~		Gosner 1979, p.45; Sears 2002, p.114

132	Mollusca	Bivalvia	Macoma	calcarea	4	suspensivore/ detritivore		Bousfield,p.37; Gosner 1979, p.158
132	Annelida	Polychaeta	Maldane	sarsi	5	deposit	large bamboo worms in mud tubes, lots not kept	Smith,p.69; Gosner 1971,p.356
132	Echinodermata	Holothuroidea	Cucumaria	frondosa	1	filter with tentacles	"in areas of current on rock and sand/mud bottoms"hc39	Smithpp189; Gosner 1979 p.254

133	Mollusca	Bivalvia	Macoma	calcarea	5	suspensivore/ detritivore	not all kept	Bousfield,p.37; Gosner 1979, p.158
133	Annelida	Polychaeta	Maldane	sarsi	5	deposit	not all kept	Smith,p.69; Gosner 1971,p.356

133	Echinodermata	Ophiuroidea	Ophiura	robusta	3	carnivore		Smith, p.189; Gosner 1979, p.264
134	Annelida	Polychaeta	Maldane	sarsi	5	deposit	11-25.5cms, not all in grab kept	Smith,p.69; Gosner 1971,p.356
134	Annelida	Polychaeta	Pectinaria	granulata	1	filter with setae	v.large, 5cm tube, curved, in good shape	Gosner 1979 p.191, Harvey-Clark p28
134	Annelida	Polychaeta	Chaetozone	setosa	1	surface feeding detritivore		Smith, p.70
134	Echinodermata	Ophiuroidea	Ophiura	spp.	1	carnivore?	arm combs	Smith, p.189; Gosner 1979, p.264
134	Mollusca	Bivalvia	Hiatella	arctica	3	suspension	live	Bousfield,p.35; Gosner 1979, p.158
134	Mollusca	Bivalvia	~	~	1		1 frag. Radially ribbed clam, white	~
134	Mollusca	Bivalvia	Macoma	calcarea	5	suspensivore/ detritivore		Bousfield,p.37; Gosner 1979, p.158
135	Annelida	Polychaeta	Maldane	sarsi	many	deposit	not all collected	Smith,p.69; Gosner 1971,p.356
135	Annelida	Polychaeta	Pectinaria	granulata	2	filter with setae		Gosner 1979 p.191, Harvey-Clark p28
135	Annelida	Polychaeta	~	~	2	~	white polychaetes	~

135	Echinodermata	Holothuroidea	Cucumaria	frondosa	5	filter with tentacles	"in areas of current on rock and sand/mud bottoms"hc39	Smithpp189; Gosner 1979 p.254
135	Mollusca	Bivalvia	Macoma	calcarea	3	suspensivore/ detritivore	very big	Bousfield,p.37; Gosner 1979, p.158
135	Mollusca	Bivalvia	Hiatella	arctica	1	suspension		Bousfield,p.35; Gosner 1979, p.158
135	Mollusca	Bivalvia	~	~	1	~	large thin shelled clam	~

Appendix C: Biota Sampled by Video

Sample #	**Phylum**	**Class**	**Genus**	**Species**	**Feeding Mode**	**Comments**	**ID Refs.**
ROV A	Annelida	Polychaeta	Spirorbis	borealis	filter	few on algae	Gosner 1979, p.195; Bousfield p.44
ROV A	Arthropoda	Crustacea	Hyas	coarctatus	predator /scavenger	1 on colander kelp	Gosner, 1979; p.245; Harvey-Clark,p.47
ROV A	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore		Harvey-Clark, p.56
ROV A	Chordata	Actinopterygii	Myoxocephalus	scorpius	predator /scavenger	eats worms, crabs, fish	Harvey-Clark,p.55
ROV A	Cnidaria	Anthozoa	Metridium	senile	Predator	frilled anemone	Harvey-Clark,p.19
ROV A	Echinodermata	Asteroidea	Asterias	vulgaris	Predator		Smith, p.189; Harvey-Clark, p.40

ROV A	Echinodermata	Asteroidea	Henricia	sanguinolenta	Predator/ particles	blood star	Gosner 1979, p.261
ROV A	Echinodermata	Asteroidea	Solaster	endeca	predator	noted as an active predator in rocky habitats	Harvey-Clark, p.41; Gosner 1979, p.260
ROV A	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
ROV A	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
ROV A	Echinodermata	Ophiuroidea	~	~	~		~
ROV A	Mollusca	Bivalvia	Hiatella	arctica	suspension	live	Bousfield,p.35; Gosner 1979, p.158
ROV A	Mollusca	Bivalvia	Chlamys	islandicus	filter		Smith, p.147
ROV A	Phaeophyta	Phaeophyceae	Agarum	cribrosum	~	sea colander, perennial	Gosner 1979, p.34
ROV A	Rhodophyta	Florideophyceae	Lithothamnion	sp.	~	rhodoliths	Harvey-Clark, p.13; Sears, p.105
ROV A	Rhodophyta	Florideophyceae	Ptilota	serrata	~	perennial	Gosner 1979, p.45; Sears 2002, p.114
ROV A	Rhodophyta	Florideophyceae	~	~	~	red algae	~

ROV B	Annelida	Polychaeta	Pectinaria	granulata	filter with setae	tube on vidoe on mud	Gosner 1979 p.191, Harvey-Clark p28
ROV B	Bryozoa	Gymnolaemata	Idmonea	atlantica	suspensivore	1, "antler like" on a cobble	Gosner 1979, p.114
ROV B	Chordata	Actinopterygii	Myoxocephalus	octodecemspinosus	predator / scavenger	longhorn sculpin, has bars	Harvey-Clark, p.56
ROV B	Cnidaria	Anthozoa?	Cerianthus	borealis	Predator		Harvey-Clark, p.20; Gosner 1979, p.98
ROV B	Echinodermata	Echinoidea	~	~	~	purple urchin, short spins	~

ROV B	Echinodermata	Ophiuroidea	~	~	~		~
ROV B	Mollusca	Bivalvia	~	~	~	shell fragments	~
ROV D	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore	14	Harvey-Clark, p.56
ROV D	Chordata	Actinopterygii	Sebastes	fasciatus	predator	1 under ledge. eats amphipods, fish, small inverts.	Harvey-Clark, p.58
ROV D	Cnidaria	Anthozoa	Metridium	senile	Predator		Harvey-Clark,p.19
ROV D	Cnidaria	Anthozoa	Tealla	felia	predator	eats small fish and invertebrates	Harvey-Clark, p.20; Gosner 1979, p.96
ROV D	Cnidaria	Hydrozoa	~	~	~	hydroids	~
ROV D	Echinodermata	Asteroidea	Solaster	endeca	predator		Harvey-Clark, p.41; Gosner 1979, p.260
ROV D	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
ROV D	Echinodermata	Echinoidea	Purple urchin		grazer		~
ROV D	Echinodermata	Ophiuroidea	~	~	~		~
ROV D	Porifera		Halichondria	panicea	filter	encrusting rock	Harvey-clark, p.16; Gosner 1979, p.67
ROV D	Rhodophyta	Florideophyceae	Lithothamnion	sp.	~		Harvey-Clark, p.13; Sears, p.105
ROV E	Chordata	Ascidiacea	Halocynthia	pyriformis	filter	ascidian sea squirt, "sea peach"	Harvey-Clark, p.49; Gosner 1979, p.271
ROV E	Cnidaria	Anthozoa	Tealla	felia	predator	may live 20 years	Harvey-Clark, p.20; Gosner 1979, p.96
ROV E	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
ROV E	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
ROV E	Echinodermata	Asteroidea	Solaster	endeca	predator		Harvey-Clark, p.41; Gosner 1979, p.260

ROV E	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
ROV E	Rhodophyta	Rhodophyceae	Lithothamnion	sp.	~		Harvey-Clark, p.13; Sears, p.105

Practice	Arthropoda	Crustacea	Hyas	coarctatus	Predator / scavenger		Gosner, 1979; p.245; Harvey-Clark,p.47
Practice	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Practice	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Practice	Echinodermata	Asteroidea	Solaster	endeca	predator		Harvey-Clark, p.41; Gosner 1979, p.260
Practice	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Practice	Chlorophyta	~	~	~	~	green algae	~
Practice	Phaeophyta	Phaeophyceae	Agarum	cribrosum	~		Gosner 1979, p.34
Practice	Rhodophyta	Rhodophyceae	Lithothamnion	sp.	~		Harvey-Clark, p.13; Sears, p.105

Mt.Stamford 1	Chordata		Pseudopleuronectes	americanus	predator	winter flounder - eats worms, molluscs and crustaceans	Harvey-Clark, p.54
Mt.Stamford 1	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Mt.Stamford 1	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Mt.Stamford 1	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
Mt.Stamford 1	Mollusca	Bivalvia	Ensis	directus	~	fragments	Harvey-Clark,p.31

Mt.Stamford 1	Chlorophyta	~	~	~	~	green algae	~
Mt.Stamford 1	Phaeophyta	Phaeophyceae	Desmerestia	spp.	~		Harvey-Clark, p.14; Gosner 1979, p.31
Dive 4	Chordata		Pseudopleuronectes	americanus	predator		Harvey-Clark, p.54
Dive 4	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Dive 4	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
Dive 4	Mollusca	Bivalvia	Ensis	directus	~	fragments	Harvey-Clark,p.31
Dive 4	Chlorophyta	~	~	~	~	Green algae	
Dive 4	Phaeophyta	Phaeophyceae	Laminaria spp.		~		Harvey-Clark, p.12; Gosner 1979, p.34
Dive 3	Chordata		Pseudopleuronectes	americanus	predator		Harvey-Clark, p.54
Dive 3	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
Dive 3	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer	just tests and fragments	Smith, p.188, Harvey-Clark,p.40
Dive 3	Mollusca	Bivalvia	~	~	~	clam fragments	~
Dive 3	Chlorophyta	~	~		~	green algae	~
Dive 3	Phaeophyta	Phaeophyceae	Laminaria	sp.	~	perennial	Harvey-Clark, p.12; Gosner 1979, p.34
Dive 6	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Dive 6	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Dive 6	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40

Dive 6	Mollusca	Bivalvia	Ensis	directus	~	fragments	Harvey-Clark,p.31
Dive 6	Chlorophyta	~	~		~	green algae	~
Dive 6	Phaeophyta	Phaeophyceae	Laminaria	spp.	~		Harvey-Clark, p.12; Gosner 1979, p.34
Dive 6	Phaeophyta	Phaeophyceae	Chorda	filum	~	summer annual	Harvey-Clark, p.13; Gosner 1979, p.33

Dive 5	Chordata	Actinopterygii	Tautoglabrus	adspersus			Harvey-Clark, p.55
Dive 5	Chordata		Pseudopleuronectes	americanus	predator		Harvey-Clark, p.54
Dive 5	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Dive 5	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Dive 5	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
Dive 5	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Dive 5	Mollusca	Bivalvia	Ensis	directus		fragments	Harvey-Clark,p.31
Dive 5	Chlorophyta	~	~	~	~	green algae	~
Dive 5	Phaeophyta	Phaeophyceae	Laminaria	sp.	~		Harvey-Clark, p.12; Gosner 1979, p.34
Dive 5	Phaeophyta	Phaeophyceae	Chorda	filum	~		Harvey-Clark, p.13; Gosner 1979, p.33

Buckley Point 1	Chordata	Actinopterygii	Tautoglabrus	adspersus			
Buckley Point 1	Chordata		Pseudopleuronectes	americanus	predator		Harvey-Clark, p.54
Buckley Point 1	Chordata		Myoxocephalus	scorpius	predator /scavenger		Harvey-Clark,p.55
Buckley Point 1	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19

Buckley Point 1	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Buckley Point 1	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
Buckley Point 1	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Buckley Point 1	Chlorophyta	~	~		~	green algae	~
Buckley Point 1	Phaeophyta	Phaeophyceae	Laminaria	sp.	~		Harvey-Clark, p.12; Gosner 1979, p.34
Buckley Point 1	Rhodophyta	Rhodophyceae	Lithothamnion	glaciale			Harvey-Clark, p.13; Sears, p.105

Buckley Point 2	Chordata	Actinopterygii	Tautoglabrus	adspersus			
Buckley Point 2	Chordata	Actinopterygii	Myoxocephalus	scorpius	predator /scavenger		Harvey-Clark,p.55
Buckley Point 2	Chordata		Pseudopleuronectes	americanus	predator		Harvey-Clark, p.54
Buckley Point 2	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Buckley Point 2	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Buckley Point 2	Mollusca						
Buckley Point 2	Chlorophyta	~	~		~	green algae	~
Buckley Point 2	Phaeophyta	Phaeophyceae	Laminaria	sp.	~		Harvey-Clark, p.12; Gosner 1979, p.34
Buckley Point 2	Spermatophyta		Zostera	marina		4 shoots of live eelgrass	

Buckley Point 3	Chordata		Pseudopleuronectes	americanus	predator		Harvey-Clark, p.54
Buckley Point 3	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Buckley Point 3	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Buckley Point 3	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
Buckley Point 3	Chlorophyta	~	~		~	green algae	~
Buckley Point 3	Phaeophyta	Phaeophyceae	Laminaria	sp.	~		Harvey-Clark, p.12; Gosner 1979, p.34
Buckley Point 3	Phaeophyta		Chorda	filum	~	smooth cord weed	Harvey-Clark, p.13; Gosner 1979, p.33
Drop 15	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 15	Echinodermata	Asteroidea	Solaster	endeca	predator		Harvey-Clark, p.41; Gosner 1979, p.260
Drop 15	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer	live and dead tests	Smith, p.188, Harvey-Clark,p.40
Drop 15	Mollusca	Bivalvia	~	~	~	Shell fragments – clam, scallop	~
Drop 15	Mollusca		Chlamys	islandicus	filter		Smith, p.147
Drop 15	Phaeophyta	Phaeophyceae	Agarum	cribrosum	~		Gosner 1979, p.34
Drop 15	Rhodophyta	Florideophyceae	Lithothamnion	glaciale	~		Harvey-Clark, p.13; Sears, p.105
Drop 20	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40

Drop 20	Echinodermata	Asteroidea	Solaster	endeca	predator		Harvey-Clark, p.41; Gosner 1979, p.260
Drop 20	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Drop 20	Mollusca	Bivalvia	Chlamys	islandicus	filter		Smith, p.147
Drop 20	Phaeophyta	Phaeophyceae	Desmerestia	spp.	~		Harvey-Clark, p.14; Gosner 1979, p.31
Drop 20	Phaeophyta	Phaeophyceae	Agarum	cribrosum			Gosner 1979, p.34
Drop 20	Rhodophyta	Florideophyceae	Lithothamnion	glaciale			Harvey-Clark, p.13; Sears, p.105
Drop 22	Arthropoda	Crustacea	Cancer	irroratus			
Drop 22	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore		Harvey-Clark, p.56
Drop 22	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Drop 22	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 22	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Drop 22	Echinodermata	Ophiuroidea	~	~	~		~
Drop 22	Mollusca	Bivalvia	Chlamys	islandicus	filter		Smith, p.147
Drop 22	Mollusca	Bivalvia	~	~	~	Shell fragmensts – clam	~
Drop 22	Mollusca	Gastropoda	Aporrhais	occidentalis	surface detritivore	Pelican's foot - sandy burrower	Harvey-Clark, p.35
Drop 22	Rhodophyta	Florideophyceae	Lithothamnion	sp.	~		Harvey-Clark, p.13; Sears, p.105
Drop 25	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore		Harvey-Clark, p.56
Drop 25	Chordata		Pseudopleuronectes	americanus	predator		Harvey-Clark, p.54

Drop 25	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 25	Echinodermata	Asteroidea	Solaster	endeca	predator		Harvey-Clark, p.41; Gosner 1979, p.260
Drop 25	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Drop 25	Mollusca	Bivalvia	Clinocardium	ciliatum	suspensivore?		Harvey-Clark, p.32; Bousfield, p.53
Drop 25	Mollusca	Bivalvia	~	~	~	fragments - possibly quahog?	~
Drop 25	Mollusca	Gastropoda	Colus	stimpsoni	omnivore / scavenger		Harvey-Clark, p.35
Drop 26	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore		Harvey-Clark, p.56
Drop 26	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Drop 26	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 26	Echinodermata	Asteroidea	Solaster	endeca	predator		Harvey-Clark, p.41; Gosner 1979, p.260
Drop 26	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Drop 26	Mollusca	Bivalvia	Mytilus	edulis	filter		
Drop 26	Phaeophyta	Phaeophyceae	Agarum	cribrosum	~		Gosner 1979, p.34
Drop 26	Rhodophyta	Florideophyceae	Lithothamnion	sp.	~		Harvey-Clark, p.13; Sears, p.105
Drop 126	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore		Harvey-Clark, p.56
Drop 126	Chordata	Actinopterygii	Myoxocephalus	scorpius	predator /scavenger		Harvey-Clark,p.55
Drop 126	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19

Drop 126	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 126	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
Drop 126	Mollusca	Bivalvia	Ensis	directus	~	shell fragments on sand	Harvey-Clark,p.31
Drop 126	Phaeophyta	Phaeophyceae	Desmerestia	spp.	~		Harvey-Clark, p.14; Gosner 1979, p.31
Drop 126	Phaeophyta	Phaeophyceae	Agarum	cribrosum	~		Gosner 1979, p.34
Drop 126	Phaeophyta	Phaeophyceae	Laminaria	sp.	~		Harvey-Clark, p.12; Gosner 1979, p.34
Drop 126	Spermatophyta		Zostera	marina	~	dead blades and fragments	Gosner 1979, p.52

Drop 13	Annelida	Polychaeta	Spirorbis	borealis	filter	few	Gosner 1979, p.195; Bousfield p.44
Drop 13	Chordata	Actinopterygii	Gadus	morhua?	piscivore/ invertevore		Harvey-Clark, p.56
Drop 13	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Drop 13	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 13	Echinodermata	Asteroidea	Solaster	endeca	predator		Harvey-Clark, p.41; Gosner 1979, p.260
Drop 13	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
Drop 13	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Drop 13	Mollusca	Bivalvia	~	~	~	Large shell fragments – razor clam, clams, tests	

Drop 13	Phaeophyta	Phaeophyceae	Desmerestia	spp.	~		Harvey-Clark, p.14; Gosner 1979, p.31
Drop 13	Phaeophyta	Phaeophyceae	Agarum	cribrosum	~		Gosner 1979, p.34
Drop 13	Phaeophyta	Phaeophyceae	Laminaria	sp.	~		Harvey-Clark, p.12; Gosner 1979, p.34
Drop 12	Annelida	Polychaeta	Spirorbis	borealis	filter	few	Gosner 1979, p.195; Bousfield p.44
Drop 12	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore		Harvey-Clark, p.56
Drop 12	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Drop 12	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 12	Echinodermata	Asteroidea	Henricia	sanguinolenta	Predator/ particles		Gosner 1979, p.261
Drop 12	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Drop 12	Phaeophyta	Phaeophyceae	Agarum	cribrosum	~		Gosner 1979, p.34
Drop 12	Rhodophyta	Florideophyceae	Lithothamnion	sp.	~		Harvey-Clark, p.13; Sears, p.105
Drop 11	Annelida	Polychaeta	Spirorbis	borealis	filter	few	Gosner 1979, p.195; Bousfield p.44
Drop 11	Arthropoda	Crustacea	Hyas	coarctatus	Predator / scavenger		Gosner, 1979; p.245; Harvey-Clark,p.47
Drop 11	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore		Harvey-Clark, p.56
Drop 11	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19

Drop 11	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 11	Echinodermata	Asteroidea	Henricia	sanguinolenta	Predator/ particles		Gosner 1979, p.261
Drop 11	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
Drop 11	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Drop 11	Mollusca	Bivavlia	Mytilus	edulis	filter		Harvey-Clark,p.29
Drop 11	Mollusca	Bivavlia	Chlamys	islandicus	filter		Smith, p.147
Drop 11	Phaeophyta	Phaeophyceae	Agarum	cribrosum	~		Gosner 1979, p.34
Drop 11	Rhodophyta	Florideophyceae	Lithothamnion	sp.	~		Harvey-Clark, p.13; Sears, p.105
Drop 11	Rhodophyta	Florideophyceae	Ptilota	serrata	~		Gosner 1979, p.45; Sears 2002, p.114

Drop 10	Chordata	Actinopterygii	Myoxocephalus	scorpius	predator /scavenger		Harvey-Clark, p.55
Drop 10	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Drop 10	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 10	Echinodermata	Asteroidea	Henricia	sanguinolenta	Predator/ particles		Gosner 1979, p.261
Drop 10	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Drop 10	Mollusca	Bivalvia	Mytilus	edulis	filter		Harvey-Clark,p.29
Drop 10	Mollusca	Bivalvia	~	~	~	fragments	~
Drop 10	Phaeophyta	Phaeophyceae	Agarum	cribrosum	~		Gosner 1979, p.34
Drop 10	Rhodophyta	Florideophyceae	Lithothamnion	sp.	~		Harvey-Clark, p.13; Sears, p.105

Drop 9	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore		Harvey-Clark, p.56
Drop 9	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Drop 9	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 9	Echinodermata	Asteroidea	Solaster	endeca	predator		Harvey-Clark, p.41; Gosner 1979, p.260
Drop 9	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Drop 9	Mollusca	Bivalvia	~	~	~	fragments	~
Drop 9	Phaeophyta	Phaeophyceae	Agarum	cribrosum	~		Gosner 1979, p.34
Drop 9	Rhodophyta	Florideophyceae	Lithothamnion	sp.	~		Harvey-Clark, p.13; Sears, p.105
Drop 9	Rhodophyta	Florideophyceae	Ptilota	serrata	~		Gosner 1979, p.45; Sears 2002, p.114

Drop 8	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore		Harvey-Clark, p.56
Drop 8	Cnidaria	Anthozoa	Cerianthus	borealis	predator		Harvey-Clark, p.20; Gosner 1979, p.98
Drop 8	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Drop 8	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Drop 8	Echinodermata	Ophiuroidea	~	~	~		~
Drop 8	Rhodophyta	Florideophyceae	Ptilota	serrata	~		Gosner 1979, p.45; Sears 2002, p.114

Drop 7	Annelida	Polychaeta	Spirorbis	borealis	filter		Gosner 1979, p.195; Bousfield p.44

Drop 7	Chordata	Actinopterygii	Gadus	sp.	piscivore/ invertevore		Harvey-Clark, p.56
Drop 7	Echinodermata	Asteroidea	Asterias	vulgaris	Predator		Smith, p.189; Harvey-Clark, p.40
Drop 7	Echinodermata	Asteroidea	Henricia	sanguinolenta	Predator/ particles		Gosner 1979, p.261
Drop 7	Echinodermata	Echinoidea	Echinarachnius	parma	deposit		Gosner 1979, p.258; Harvey-Clark, p.40
Drop 7	Phaeophyta	Phaeophyceae	Desmerestia	spp.	~		Harvey-Clark, p.14; Gosner 1979, p.31
Drop 7	Phaeophyta	Phaeophyceae	Laminaria	sp.	~		Harvey-Clark, p.12; Gosner 1979, p.34
Drop 6	Annelida	Polychaeta?	~	~	~	branched tubes	~
Drop 6	Annelida	Polychaeta	Maldane	sarsi	deposit		Smith,p.69; Gosner 1971,p.356
Drop 5	Annelida	Polychaeta?	~	~	~	branched tubes	~
Drop 5	Annelida	Polychaeta	Maldane	sarsi	deposit		Smith,p.69; Gosner 1971,p.356
Drop 4	Annelida	Polychaeta	Pectinaria	granulata	filter with setae	2	Gosner 1979 p.191, Harvey-Clark p28
Drop 4	Annelida	Polychaeta	Maldane	sarsi	deposit	several	Smith,p.69; Gosner 1971,p.356
Drop 4	Annelida?	Polychaeta?	~	~	~	Round opening burrow / tube	~
Drop 4	Echinodermata	Ophiuroidea	~	~	~		~
Drop 4	Mollusca	Bivalvia	~	~	~	Bivalve shell fragments	~
Drop 4	Mollusca	Gastropoda	~	~	~	Whorled snail shell	~

Cliff	Arthropoda	Crustacea	Hyas	coarctatus	Predator / scavenger	1	Gosner, 1979; p.245; Harvey-Clark,p.47
Cliff	Cnidaria	Anthozoa	Metridium	senile	predator		Harvey-Clark,p.19
Cliff	Echinodermata	Asteroidea	Asterias	vulgaris	predator		Smith, p.189; Harvey-Clark, p.40
Cliff	Echinodermata	Echinoidea	Strongylocentroyus	droebachiensis	omnivorous grazer		Smith, p.188, Harvey-Clark,p.40
Cliff	Echinodermata	Ophiuroidea	~	~	~	few	~
Cliff	Rhodophyta	Rhodophyceae	Lithothamnion	sp.	~		Harvey-Clark, p.13; Sears, p.105

Appendix D: Conductivity, Temperature and Depth Ranges for Newman Sound					
Station Number	**Original station Number**	**Date (d/m/y)**	**Depth Range (m)**	**Temperature Range (°C)**	**Salinity Range (‰)**
1	03266002	19/6/97	0 - 26	-0.498 - 6.137	31.265 - 32.418
2	93012001	21/7/96	0 - 49	1.490 - 8.349	31.523 - 32.269
3	15003003	17/8/92	0 - 32	-0.257 - 10.19	30.996 - 32.442
4	15003006	17/8/92	0 - 42	-1.189 - 10.155	31.017 - 32.624
5	15003008	17/8/92	0 - 41	-1.123 - 10.39	30.991 - 32.605
6	15003011	17/8/92	0 - 47	-1.276 - 10.476	30.984 - 32.61
7	15003014	17/8/92	0 - 37	-1.224 - 10.747	30.985 - 32.664
8	15003017	17/8/92	0 - 67	-0.561 - 10.134	31.018 - 32.456
9	15003019	17/8/92	0 - 72	-0.607 - 9.981	30.998 - 32.441
10	15003021	17/8/92	0 - 74	-0.555 - 10.365	30.950 - 32.402
11	93012021	20/9/96	0 - 38	11.608 - 13.959	30.572 - 30.724
12	03248002	26/9/95	0 - 56	-0.924 - 7.169	30.371 - 32.295
14	03272002	10/10/97	0 - 30	10.531 - 10.733	30.691 - 30.836
15	03260002	11/10/96	0 - 81	2.030 - 10.181	30.143 - 32.213
16	03260001	11/10/96	0 - 48	3.482 - 10.121	30.271 - 32.055
17	03248003	26/10/95	0 -41	-0.866 - 7.108	30.504 - 32.327
18	03248001	26/10/95	0 - 44	1.087 - 7.101	30.490 - 32.04
19	03284003	11/11/98	0 - 45	4.584 - 6.429	30.823 - 31.696
20	03284004	9/11/98	0 - 14	5.880 - 6.396	30.796 - 31.152
21	03284005	10/11/98	0 - 17	6.131 - 6.396	30.946 - 31.174
22	03261008	23/11/96	0 - 43	3.323 - 4.767	*
23	03389007	28/11/01	0 - 49	4.212 - 4.46	31.250 - 31.575
24	03389006	28/11/01	0 - 32	3.958 - 4.571	31.177 - 31.522
25	03506027	1/12/03	0 - 71	0.782 - 4.355	31.195 - 32.372
26	03446027	2/12/02	0 - 35	2.479 - 3.063	31.272 - 32.095
27	03296029	5/12/99	0 - 48	0.577 - 3.235	30.480 - 32.228
28	10164087	15/1/95	0 - 77	-0.755 - 0.643	31.580 - 32.187

Appendix E: Seismic Points Used for Mapping Substrates					
Time	Longitude	Latitude	Depth (m)	Backscatter (-dB)	Substrate interpretation
21:40	-53.92719	48.57789	51.4	-24.3	inner basin mud
21:45	-53.93456	48.57405	48.2	-22.7	inner basin mud
21:50	-53.94184	48.57019	45.6	-25.1	inner basin mud
21:55	-53.94773	48.56549	42	-31.9	inner basin mud
22:30	-53.95155	48.56035	35.3	-36	inner basin mud
22:52	-53.94254	48.5705	46.2	-25	inner basin mud
23:01	-53.93041	48.5753	48.8	-19.6	inner basin mud
23:05	-53.92215	48.57584	49	-25	inner basin mud
01:10:30	-53.758	48.61362	308.2	-21.4	mud
01:15	-53.75656	48.61888	307.9	-17.19	mud
19:05	-53.6536	48.63892	308	-15.8	mud
19:10:15	-53.67143	48.63696	306.2	-15.4	mud
19:15:30	-53.70456	48.62491	303.7	-21.3	mud
19:30:20	-53.70456	48.62491	314.3	-15.8	mud
20:00	-53.76089	48.61479	307.8	-21	mud
20:10	-53.77893	48.60985	301.3	-21.7	mud
20:17	-53.79141	48.60611	289.5	-20	mud
20:20	-53.79683	48.60464	280	-18.9	mud
00:56	-53.77448	48.60681	295.5	-19.2	bedrock
01:00	-53.76708	48.60594	199	-3.6	bedrock
01:05	-53.76007	48.60714	151	-6.1	bedrock
01:44	-53.71109	48.61595	66	-14.4	bedrock
01:55	-53.70833	48.62787	296.3	-12.5	bedrock
02:06	-53.70053	48.63379	49.8	-11.7	bedrock
02:29:00	-53.6625	48.62584	114.8	-10.9	bedrock
02:35:15	-53.65902	48.63291	219.2	-13.7	bedrock
02:50	-53.65144	48.65055	82.2	-12.4	bedrock
02:55	-53.64601	48.64804	256.5	-8	bedrock
03:06	-53.62822	48.63973	173	-7	bedrock
03:10	-53.62146	48.63695	49.7	-15.2	bedrock
03:15	-53.6165	48.64108	186.5	-8	bedrock
03:22	-53.61017	48.64796	236	-10.2	bedrock
03:28	-53.60461	48.65346	109.5	-11.2	bedrock
03:36	-53.59705	48.66131	48	-11	bedrock
03:44	-53.58941	48.65766	102	-5.9	bedrock
19:00	-53.6536	48.64092	277	-8.9	bedrock
20:23	-53.80191	48.60287	236	-6	bedrock
21:05	-53.87151	48.57914	55.1	-11.1	bedrock
23:40	-53.87367	48.57938	57.3	-14.2	bedrock

Appendix F: Order for overlaying substrate grids to create the substrate map – from top layer (drawn last) to bottom layer (drawn first).

Fjord mouth map
1. mud
2. bedrock
3. pebble/cobble gravel
4. boulder gravel
5. gravelly muddy sand
6. gravelly sand
7. sand

Outer basin map
1. bedrock
2. mud
3. gravelly muddy sand
4. pebble/cobble gravel
5. boulder gravel
6. gravelly sand
7. sand

Middle basin map
1. boulder gravel
2. pebble/cobble gravel
3. gravelly sand
4. gravelly muddy sand
5. mud
6. bedrock
7. sand

Narrows map
1. rhodolith
2. boulder gravel
3. pebble/cobble gravel
4. gravelly sand
5. gravelly muddy sand
6. sand
7. mud
8. bedrock

Inner basin map
1. boulder gravel
2. pebble/cobble gravel
3. gravelly sand
4. gravelly muddy sand
5. mud
6. sand
7. bedrock

Appendix G: Order for overlaying grids to create the habitat map – from top layer (drawn last) to bottom layer (drawn first).

Fjord mouth map
1. mud
2. bedrock
3. pebble/cobble gravel
4. boulder gravel
5. gravelly muddy sand
6. gravelly sand
7. deep water sand

Outer basin map
1. bedrock
2. mud
3. gravelly muddy sand
4. pebble/cobble gravel
5. boulder gravel
6. gravelly sand
7. deep water sand

Middle basin map
1. boulder gravel
2. pebble/cobble gravel
3. gravelly sand
4. gravelly muddy sand
5. mud
6. bedrock
7. deep water sand

Narrows map
1. rhodolith
2. *Laminaria* kelp covered seabed
3. boulder gravel
4. pebble/cobble gravel
5. gravelly sand
6. gravelly muddy sand
7. shallow water sand
8. mud
9. bedrock

Inner basin map
1. boulder gravel
2. pebble/cobble gravel
3. gravelly sand
4. gravelly muddy sand
5. mud
6. shallow water sand
7. bedrock