BENTHIC BIOLOGY OF TWO NEAR-SHORE ARCTIC LOCATIONS, AND POTENTIAL IMPACTS OF SEA LEVEL CHANGE, COASTAL EROSION, AND CLIMATE CHANGE

TANYA BROWN

BENTHIC BIOLOGY OF TWO NEAR-SHORE ARCTIC LOCATIONS, AND POTENTIAL IMPACTS OF SEA LEVEL CHANGE, COASTAL EROSION, AND CLIMATE CHANGE

by

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ABSTRACT

Near-shore benthic communities can undergo shifts in abundance and biodiversity in response to climate change especially changes in surface temperature, productivity, and geomorphology. One of the most dramatic effects is habitat modification: coastal erosion lead to increased deposition of sediment. Factors driving coastal erosion include isostatic sea-level rise and a variety of climatic change impacts, including reduced sea ice cover, increased summer rainfall, increased thawing of permafrost, and eustatic sea-level rise.

Benthic communities were studied in two near-shore Arctic locations (Sachs Harbour and Gjoa Haven) associated with different degrees of coastal erosion. Sachs Harbour has a submergent shoreline with locally rapid coastal erosion. By contrast Gjoa Haven has an emergent shoreline with very little to no coastal erosion. Grab and drop-video were used to conduct benthic surveys of the two locations and detailed habitat maps were produced. Species richness was significantly greater in Gjoa Haven than in Sachs Harbour. Species composition differed greatly among locations and varied significantly among substrate types for grab and depth classes for video. Shallow (<10 m) mobile sand sheets with low biodiversity were the dominant habitat sampled in Sachs Harbour. Gravelly-sand or mud substrates (10-20 m) with high cover of macroalgae had the greatest biodiversity in Gjoa Haven. Macroalgae beds were found throughout the Gjoa Haven study area providing abundant food and shelter to benthic fauna. This high diversity is due to the heterogeneity of the substrate. Lastly, Gjoa Haven's sediment

starved near-shore environment makes for a stable environment compared to Sachs Harbour near-shore environment, which receives a continuous supply of sediment as a result of coastal erosion and runoff.

This study establishes a detailed baseline for two near-shore Arctic locations. Given the rapidity with which the Arctic ecosystems are changing this study will be valuable in designing future studies of biodiversity, and will enable detection of future climate driven change in near-shore arctic environments.

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CHAPTER ONE

INTRODUCTION AND OVERVIEW

1.1 INTRODUCTION

A potential threat to benthic biodiversity is climate change (Snelgrove 1998). In the Arctic increased coastal erosion and resultant sedimentation in near-shore marine environments is one of many predicted effects of climate change (ACIA 2005a). Other predicted changes include eustatic sea level rise, decreased sea-ice extent, sea-ice thinning, and increased storm frequency and precipitation (IPCC 2001b; ACIA 2005a; Manson et al. 2005). Eustatic sea level change is a global change in sea level due to water mass added from the melting of ice sheets and thermal expansion (Masselink and Hughes 2003). For further explanation on geological/physical geographical terms please refer to the Glossary Terms (Appendix A). Observed warming and thawing trends of discontinuous permafrost, along with extensive areas of thermokarst are increasingly being reported (Osterkamp and Romanovsky 1999; Osterkamp et al. 2000). Areas in the Western Arctic undergoing glacio-isostatic submergence, such as Tuktoyaktuk and Sachs Harbour have experienced rapid coastal erosion and are characterized as being 'highly sensitive' to sea-level rise (Shaw et al. 1998b; Manson et al. 2005). Eustatic sea level rise from thermal expansion and melting glaciers combined with glacio-isostatic effects will likely lead to amplified relative sea-level rise in parts of the Western Arctic (Belliveau 2007). As well, areas undergoing the effects of climate change and that are currently on the cusp of emergence to submergence may begin to experience relatively rapid eustatic sea level rise, with the attendant coastal erosion and sedimentation. Areas that are on the cusp of emergence to submergence are areas that are rising (due to postglacial rebound) at a similar or slower rate to global sea level rise. To evaluate possible effects of climate change and coastal erosion on Arctic benthic biodiversity, the fauna of two near-shore Arctic locations associated with different degrees of coastal erosion have been studied. An inferential approach has been applied to evaluate the possible effects of climate change on Arctic benthic biodiversity. To do so a quantitative assessment of a changing climate is based on 'present day' predicted effects of climate change. It is however, much more desirable to use an experimental approach to evaluate the effects of climate change, though at the present time and within the scope of this project that approach is not a viable option.

Benthic grab sample and underwater videography, used in tandem are a data-rich method for surveying benthic communities and provide information on characteristics of the sea bottom and species composition of epibenthos and infauna (Matarrese et al. 2004). Benthic grab sampling is generally the primary tool used to sample benthos, as it provides a direct and accurate means of sampling physical and biological properties in an area, such as changes in grain size and species composition. Unlike grab sampling, however, underwater videography is non-destructive and allows the researcher to view the seabed and epibenthos characteristics (Stevens and Connolly 2005).

These two techniques in combination can be used to produce benthic habitat maps. Habitat mapping meets various scientific needs, providing useful information on the seabed conditions, and biological distribution as well as increasing the ease of interpretation and comparison on both a spatial and temporal scale (Matarrese et al. 2004). Habitat maps are useful to ascertain the impacts that pollution, climate change, over-fishing and other activities have on benthos. Across the Arctic basic information about the benthos is limited, therefore baseline information must be gathered if changes and impacts are to be monitored. Habitat mapping can be used to protect areas around vulnerable ecosystems (Stevens and Connolly 2005).

Evidence shows that the Arctic environment is sensitive to change and the impacts of future climate change are expected to be felt earliest at Arctic latitudes (Maxwell 1997; IPCC 2001b). The Arctic represents a relatively pristine area (Clarke and Harris 2003) in which to study the effects of climate change on benthic communities. The two near-shore locations chosen for this study were Sachs Harbour, N.W.T. and Gjoa Haven, Nunavut. Sachs Harbour is an area of high environmental disturbance mainly due to its submergent shoreline with locally rapid coastal erosion. Erosion rates along this shoreline are believed to be similar to the mainland Beaufort Sea, between 0.6 and 22.5 m annually (Solomon 2005). Due to unlithified ice-rich Quaternary sediments along the south-western coastline of Banks Island coastal erosion rates are likely at the lower end of this range, with higher short term rates seen during a single event (e.g. storm). By contrast, Gjoa Haven has an emergent shoreline with a relatively low energy coastline surrounding the community. Furthermore, the surficial geology of Gjoa Haven makes it apparently less susceptible to erosion than Sachs Harbour. Both study areas are subject to extensive ice scouring, especially during break up times and increased wind and storm activity.

The aims of the present study were: *(i)* to describe and map benthic community composition of two near-shore Arctic locations associated with different degrees of coastal erosion in emergent versus submergent settings; *(ii)* to assess whether the differences in environmental characteristics of the two study areas and their distinct habitats were accompanied by differences in diversity and species composition.

1.2 PURPOSE AND GOAL OF THE STUDY

1.2.1 Conceptual Framework

Increased coastal erosion and resultant sedimentation in near-shore marine environments is a predicted effect of climate change (ACIA 2005c). To evaluate possible effects of coastal erosion on Arctic benthic biodiversity, the fauna of two near-shore Arctic locations associated with different degrees of coastal erosion have been studied (Table 1.1).

The two near-shore Arctic areas chosen for this study are located on the southwest coast of Banks Island, NWT and the southeast coast of King William Island, Nunavut, near to the communities of Sachs Harbour and Gjoa Haven, respectively (Figure 1.1).

Sachs Harbour has a submergent shoreline with locally rapid coastal erosion. By contrast, Gjoa Haven has an emergent shoreline with very little to no coastal erosion (Table 1.1). The surficial geology of Sachs Harbour is composed of unconsolidated ground-ice laden erodible sediments, compared to Gjoa Haven's coarse-grained ice-contact sediments with low soil ice content (Table 1.1). The coastlines of both study areas are microtidal with a mean tidal range of less than or equal to 0.25 m (Department of Fisheries and Oceans Canada 2007; Table 1.1). As well, the beaches of both Sachs Harbour and Gjoa Haven appear to be mostly dissipative systems, such that most of the incoming wave energy is dissipated during the wave breaking process. Both study areas are subject to extensive ice scouring, especially during times of ice break up and increased wind and storm activity. Sachs Harbour is more exposed and likely experiences more ice scour disturbance.

Table 1.1 Physical characteristics of the Sachs Harbour and Gjoa Haven study areas.

	Sachs Harbour	**Gjoa Haven**
Isostatic sea level change	Submergent	Emergent
Coastal Erosion	Rapid coastal erosion	Not eroding
Surficial Geology	Fine-grained, organic-rich unconsolidated sediments and ground ice	Coarse-grained ice-contact sediments disseminated ground ice
Permafrost characteristics	Isolated ice lenses and disseminated ground ice, with high (>20%) soil ice content	Disseminated ground ice with low (<10%) soil ice content
Tidal Range	0.2-0.4 m	0.3-0.55 m
Degree of ice-free wave exposure	Moderate-low	Low

While the dominant patterns in relative sea level change in the Arctic are driven by isostatic crustal flexure, climate change also brings about a eustatic sea level rise, at increasingly rapid rates (IPCC 2001a; Shepherd and Wingham 2007). With future sea level rise there will be tendencies for eroding shorelines to erode further (Sachs Harbour) and stable shorelines to begin to erode (Gjoa Haven) (Bird 1993). If areas which are currently experiencing near zero rates of isostatic vertical movement begin to experience relatively rapid eustatic sea level rise, coastal erosion and sedimentation are possible consequences, however the nature and degree of these processes will depend on local conditions (e.g substrate type, exposure to wave action, frequency of storms). Increased sedimentation into nearshore environments may lead to changes in benthic habitats and community composition, with consequent effects on the marine organisms, which depend on these benthic communities.

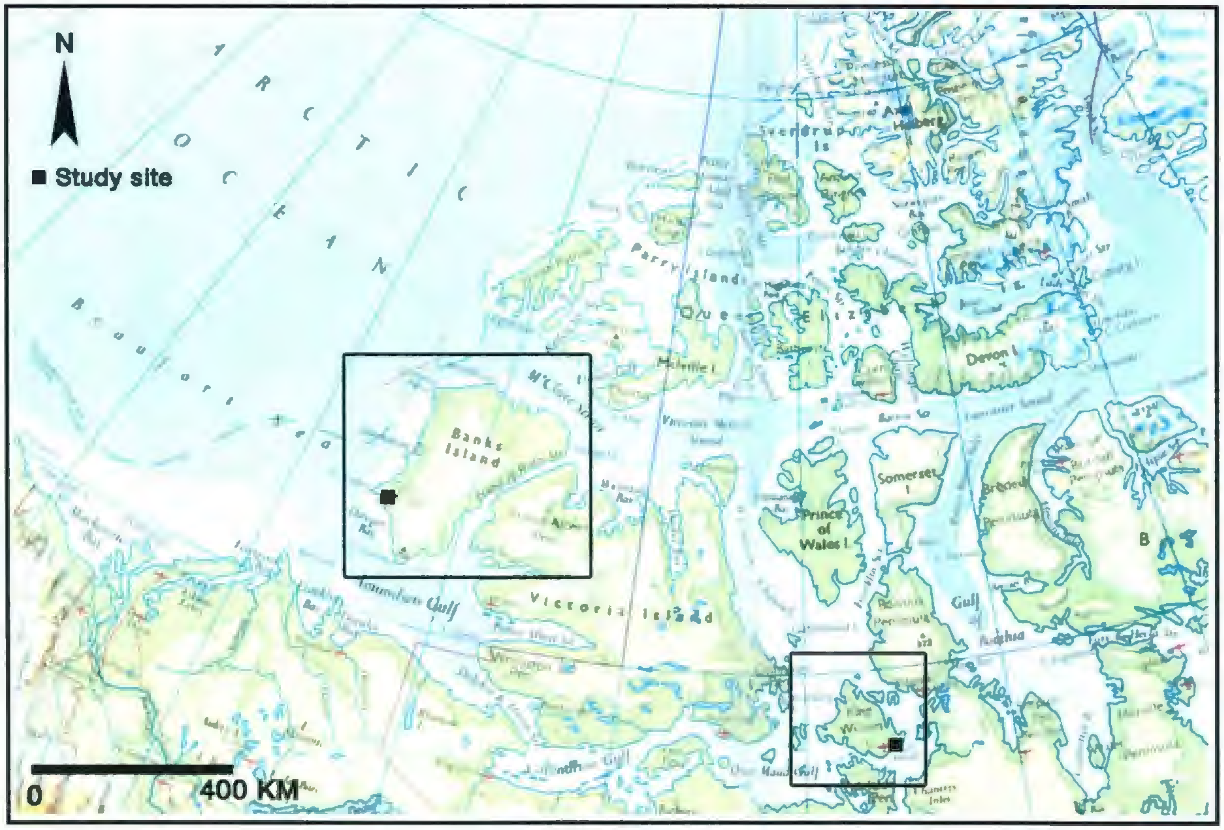

Figure 1.1 Map of the Canadian Arctic showing Banks Island, NWT and King William Island, Nunavut.

1.2.2 Rationale

The most immediate effects of climate change are being felt in the Arctic, with surface temperatures exceeding 1 to 2°C per decade for the region (ACIA 2005b). Over the past 40 years temperature increases in the Arctic, north of 60 degrees, exceed those of southern latitudes with mean increases of 0.04°C/a (ACIA 2005b). Increased coastal erosion and sedimentation, both predicted effects of climate change, are likely to alter near-shore benthic communities. Benthic fauna inhabiting near-shore areas have been described from various Arctic locations (Slaney and Company Ltd. 1975; Heath and Thomas 1984; Aitken and Risk 1988; Hopky et al. 1994; Leontowich and Dale 2002). However, there are no comparative studies that look at two sites with different degrees of coastal erosion with opposing rates of isostatic vertical movement.

To allow for future comparison of these sites and long term monitoring of climate change impacts on benthic habitats, baseline characterizations must be made. The present study presents a baseline characterization of the benthic community composition and habitat structure for two near-shore areas in the Arctic exposed to different degrees of coastal erosion and sedimentation and opposing trends of relative sea-level change.

1.3 STUDY AREAS

1.3.1 Geological Setting

The Sachs Harbour study area covers a 40 km length of the Beaufort Sea along the exposed coast of Banks Island, N.W.T. in Western High Arctic Canada.

Unconsolidated sediments of the Miocene to Pliocene Beaufort formation are overlain by the sandy Sachs Harbour till (Vincent 1983). Continuous permafrost extends to depths greater than 500 m (Harry et al 1983). The coastline is characterized as 'highly sensitive' to sea level rise due to tectonic submergence, low topographic gradient, and extensive permafrost and ground ice (Shaw et al. 1998a). At Sachs Harbour, high concentrations of ground ice are present along the coast (Manson et al. 2005). Ground ice in the region is revealed by ice wedges in the coastal cliffs and by the existence of pingos (French et al. 1982; Gurney and Worsley 1997). These ice wedges can spread out laterally and join with other wedges to form ice wedge polygons (French 1996). Rapid coastal erosion for Sachs Harbour has been tied to long-term sea level rise, fine-grained sediments, abundant ground ice, and high storm frequency during the open-water season (Solomon 2001; Manson et al. 2005). Gravel and mixed sandy beaches dominate the Sachs Harbour coastline (Manson et al. 2005). Sandy substrates of the Sachs Till and unconsolidated sand and gravel of the Beaufort Formation (Vincent 1982) are eroded from coastal cliffs, exposing ground ice along the southwestern shoreline of Banks Island (Figure 1.2). Most erosion and sediment supply in Sachs Harbour is due to sea level rise and melting of permafrost, rather than coastal erosion in the classic sense: driven by wind, waves, and longshore currents. The beaches are prograding and there is a net progradation in most areas of the community, except for Cape Kellett and Duck Hawk Bluffs (Belliveau 2007; Figure 1.4). Ultimately, warming temperatures throughout the region could lead to increased active layer thickness and melting of massive ice and ice lenses, increasing erosion throughout the Sachs Harbour coastline (Belliveau 2007).

Gjoa Haven is located on the southern coast of King William Island in the central Canadian Arctic region (Figure 1.1). Paleozoic dolomite is overlain by Pleistocene ice-contact sediments mainly composed of sands and gravels. The community is built on flights of raised beaches which are composed of wind-deflated sand, gravel, and cobbles, with some glacial erratic boulders, mixed with locally derived Silurian carbonates (Figure 1.3). The Gjoa Haven study area encompasses an 18 km length of Rae Strait along a low energy coast of King William Island, Nunavut in central Arctic Canada.

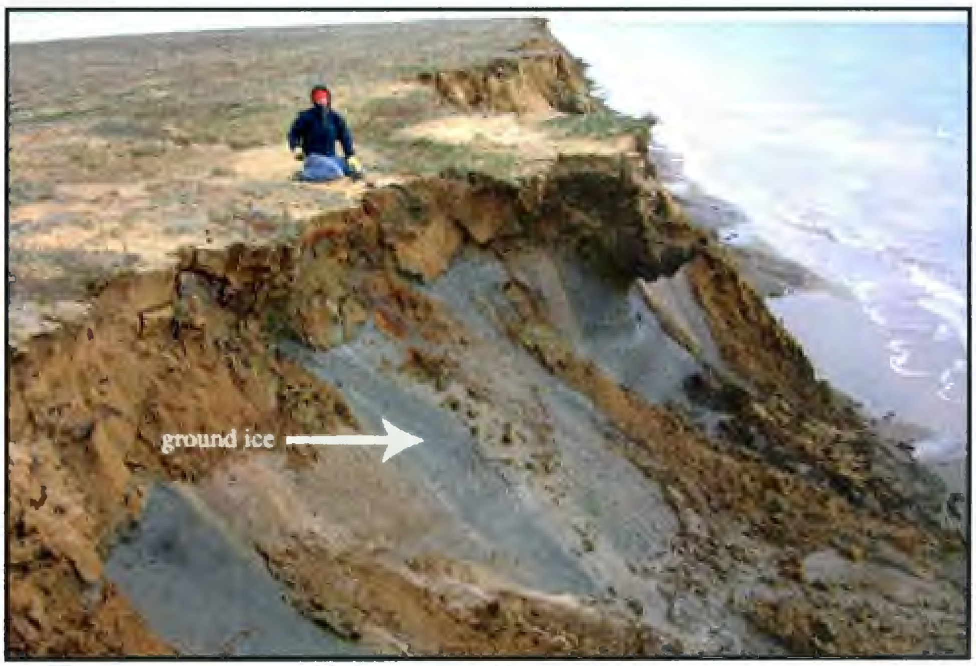

Figure 1.2 Erosion of coastal cliffs and ground ice along the southwestern shoreline near the community of Sachs Harbour (Person for scale: D. St. Hilaire, seated height = 122 cm).

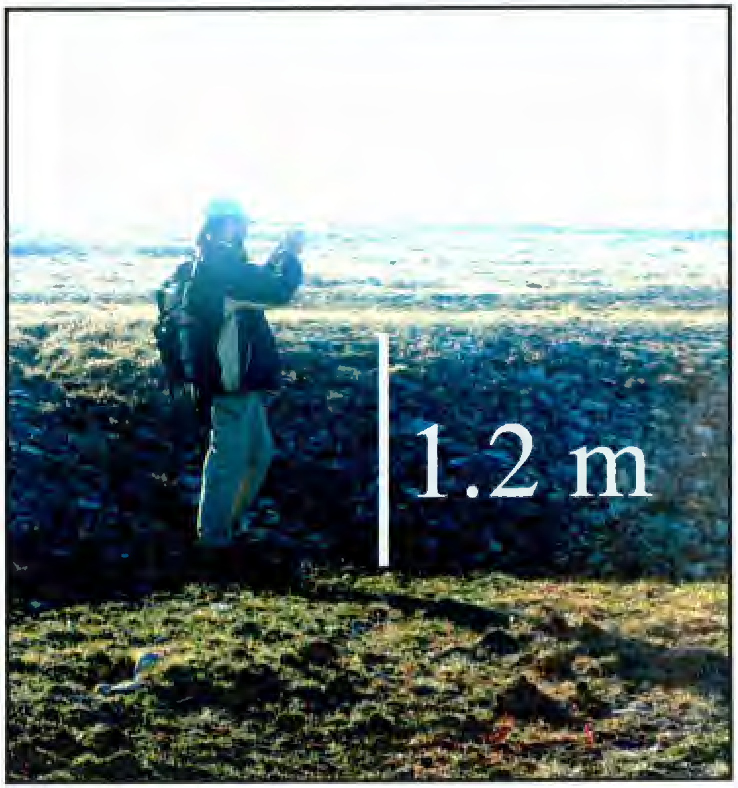

Figure 1.3 Emergent coastline of raised beaches near the community of Gjoa Haven composed of sand, gravel, and cobbles, with some glacial erratic boulders (top); raised beach approximate height 1.2 meters (bottom).

1.3.2 Southwestern Banks Island, Sachs Harbour

Sachs Harbour, N.W.T. (71°59' N 125°14' W), with a population of 114 lies on the southwest coast of Banks Island in the southwestern Canadian Arctic Archipelago (Statistics Canada 2002). Banks Island (67,340 km²) is the westernmost of the group and is separated from the mainland of the Northwest Territories by the Amundsen Gulf. To the North M'Clure Strait separates Banks Island from Melville and Prince Patrick Islands; to the east is Victoria Island separated from Banks by Prince of Whales Strait; and to the west Banks is bordered by the Beaufort Sea (Figure 1.1). Banks Island was first named Banksland in 1820, after Sir Joseph Banks during the British exploration of the North West Passage. The community of Sachs Harbour was named after the ship "Mary Sachs" which visited the southwestern part of the island during the Canadian Arctic Expedition in 1913 (Indian and Northern Affairs 2005). In 1929, Sachs Harbour was established as a permanent community and later gained Hamlet status in 1986 (Indian and Northern Affairs 2005). The Inuktitut name for this community is 'Ikaahuk', which means "where to go across to". The name refers to the annual migration of hunters and trappers to the community from Victoria Island. Banks Island is treeless and characterized by sparse vegetation that consists of mosses, lichens, grasses, and dwarf willows (Indian and Northern Affairs 2005). The study area on the southwestern coastline of Banks Island is approximately 40 km in length, from the second basin along the Sachs River (Mary Sachs Estuary), east of the community to the tip of Cape Kellett located on the southwestern edge of the island (Figure 1.4).

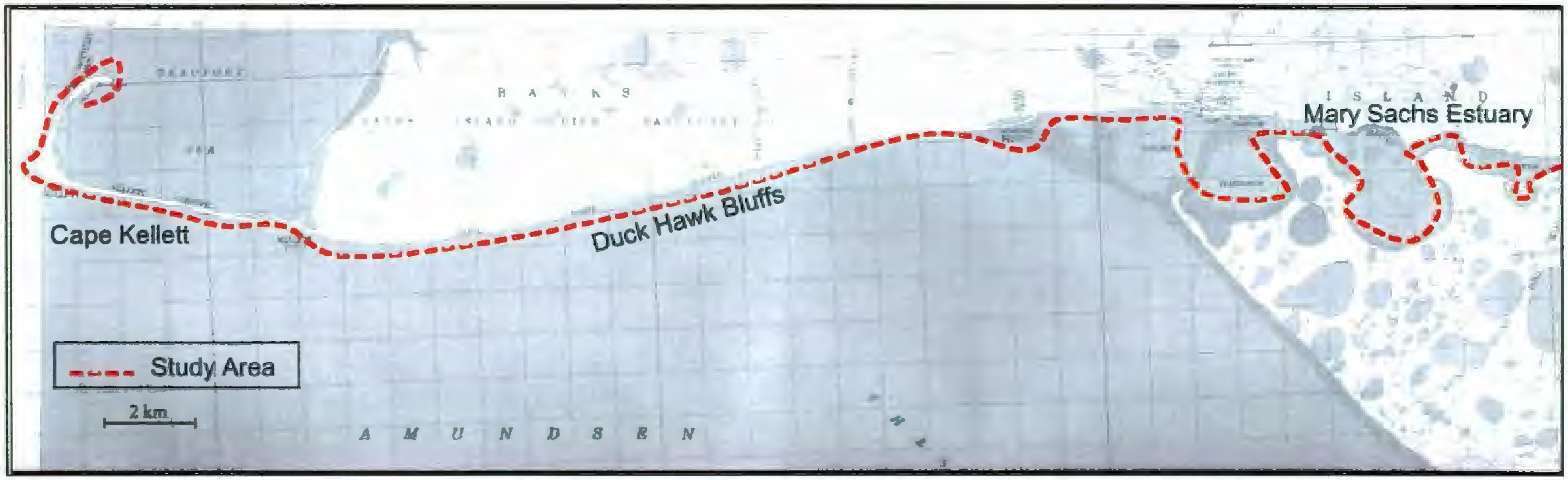

Figure 1.4 1:50,000 topographic map of the southwest coast of Banks Island showing the Sachs Harbour study area (Adapted from the 1/50,000 NTS# 097G15 provided by Natural Resources Canada 2005).

1.3.3 Southeastern King William Island, Gjoa Haven

The community of Gjoa Haven (68°38' N and 95°52' W) is located on the southeastern coast of King William Island, Nunavut in the Kitikmeot Region (Figure 1.1). To the east the James Ross Strait and the Rae Strait separate King William Island from the Boothia Peninsula; to the west Victoria Strait separates King William Island from Victoria Island, and to the south the Simpson Strait separates King William Island from the Adelaide Peninsula.

Gjoa Haven is the only community on King William Island and has a population of approximately 960 (Statistics Canada 2002). The community is continually growing due to people moving from other communities to be close to the educational and healthcare facilities available at Gjoa Haven (R. Kamookak 2006 personal communication). The community is named after Roald Amundsen's ship, the 'Gjoa'. Roald Amundsen, his crew of seven and his ship, the Gjoa were attempting the first traverse of the Northwest Passage in 1903 in search of the location of the Magnetic North Pole (Huntford 1999). During their travels, the waters began to ice up and Amundsen put the Gjoa in a protected harbour located on the southeast coastline of the King William Island, where the community of Gjoa Haven exists today. They over wintered in the harbour for two years, gathering information about the Magnetic North Pole and learning about the land from the local Inuit, Nattilik (Huntford 1999).

The Inuktitut name for Gjoa Haven is 'Uqsuqtuaaq', meaning 'lots of fat'. The name refers to the abundance of blubbery sea mammals in the nearby waters. King William Island is located above the tree line and has sparse vegetation with a combination of low and high arctic species. The study area on the Southeastern coast of King William Island is approximately 18 km in length, extending north of Betzold Point to the western coast of Peterson Bay (Figure 1.5).

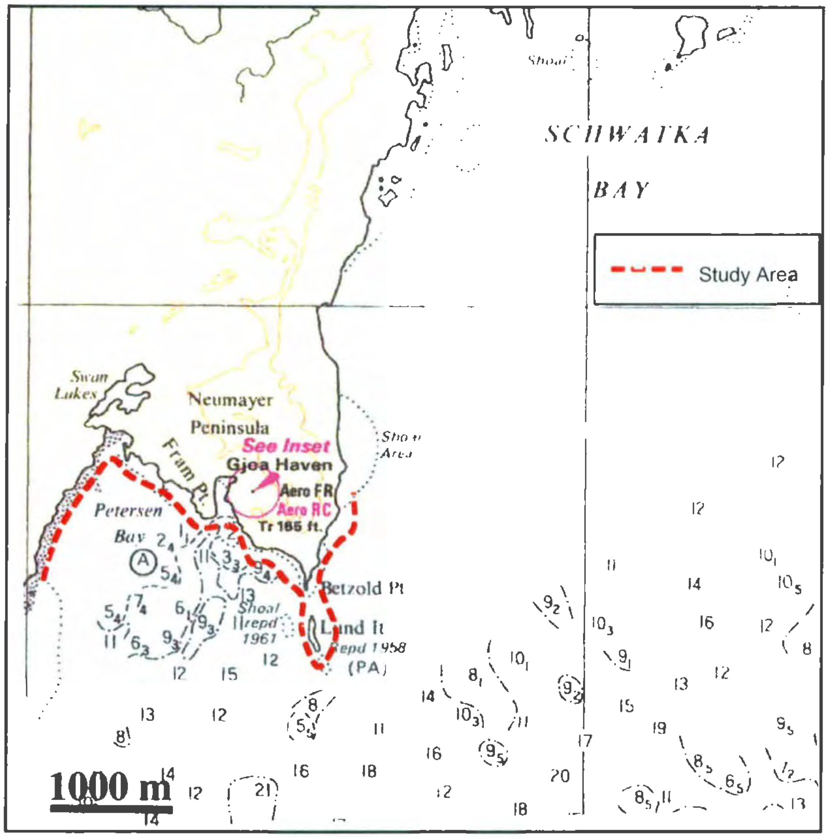

Figure 1.5 1/200,000 bathymetric map of the southeastern coast of King William Island showing the Gjoa Haven study area (Adapted from the 1/200,000 Hydrographic Chart# 7760 provided by the Canadian Hydrographic Service 1983).

1.4 BACKGROUND INFORMATION

This section provides a review of the relevant literature for this study. Topics include: Arctic nearshore biology, effects of sea ice, benthic-sediment/depth relationships, climate change conditions in the Arctic, impacts of climate change in the Beaufort and central Arctic region, sea-level history in the Beaufort and central Arctic region, present-day sea level change, sensitivity of coastlines of southwestern Banks Island and King William Island to sea level rise, and impacts of sedimentation on nearshore marine systems.

1.4.1 Arctic Marine Ecosystems

Arctic marine ecosystems are unique in that they experience strong seasonality in sunlight and low temperatures, as well as having a large volume of freshwater delivered by rivers and spring snow melt to the marine environment (ACIA 2005c). In general Arctic marine ecosystems have low productivity and biodiversity, as well as a short trophic structure to allow for enough energy to carry over the brief summer production period (ACIA 2005c). Biological production in the Arctic is strongly influenced by mixing, nutrients, sea ice, irradiance, and water column stratification.

Primary production in the Arctic is partitioned between microalgae and macroalgae living on the sea floor and ice algae and phytoplankton (Kühl et al. 2001; Glud et al. 2002; Clough et al. 2005). Ice algae are algal communities found in annual and multi-year sea ice (Clough et al. 2005). Both ice algae and phytoplankton fall to the bottom and provide food for benthic macrofauna, such as bivalves, polychaetes, and crustaceans. With present sea ice conditions, primary production is dominated by ice algae, which sink during spring melt (ACIA 2005c). If the reduction of sea ice continues, algae reaching the sea floor will shift from ice algae and phytoplankton, to phytoplankton only (Clough et al. 2005). Clough et al. (2005) suggest that if these two food sources have different digestibility and/or nutritional value to benthos, then such a transition will likely impact benthos. Zooplankton graze on phytoplankton, thereby resulting in a decrease of food supply to benthos, and an increase in zooplankton will provide more food for birds and fish, relative to benthic organisms (ACIA 2005c). Sunlight in the nearshore environment is not a limiting factor. Sunlight reaches the seabed in a gradient effect and can usually reach to 60 m (ACIA 2005c), which allows mico- and macroalgae to be a significant food source for benthic organisms in the nearshore environment. The hard bottom nearshore marine area in the Arctic supports beds of *Fucus distichus* and in depths down to approximately 40 m kelp forests of *Alaria esculenta*, *Saccharina longicruris*, *L. digitata*, and *L. solidungula* (Borum et al. 2002; Hop et al. 2002). Glud et al. (2002) studied primary production in a high Arctic fjord and found that for water depths <30 m, the average benthic net photosynthesis was quantitatively more important than the gross photosynthesis of the pelagic environment. Glud et al. (2002) conclude that the benthic primary production at these water depths is a primary food source for benthic communities.

Biogeographically, benthos of the Bering Sea and Canadian Archipelago between the New Siberian Islands and Bathurst Island is mainly Pacific (Dunton 1992), whereas benthos of the central Arctic are primarily Atlantic fauna (ACIA 2005c). Previous studies have mostly focused on sampling benthos along regions of the North American arctic shelf and fjord areas (Stewart et al.1985; Grebmeier et al. 1989; Aitken and Fournier 1993; Feder et al. 1994; Wlodarska et al. 1996; Wlodarska-Kowalczuk et al. 1998).

The Arctic's benthic diversity is poor relative to lower latitudes and the Southern Ocean (Piepenburg 2005). The low diversity of benthic macrofauna in the intertidal zone and shallow nearshore area is usually attributed to the extreme conditions, such as extensive ice scouring (Ellis 1955; ACIA 2005c).

1.4.2 Effects of Sea Ice

Ice cover is an important physical characteristic of marine ecosystems in the Arctic. It affects light penetration to organisms, and provides a biological habitat for many marine mammals, such as seals and polar bears (ACIA 2005c). Sea ice thickness and extent influence primary production of micro- and macroalgae, phytoplankton and ice algae in Arctic marine ecosystems. For example, during spring melt ice algae sinks to the bottom providing a direct food source to benthos (Clough et al. 2005). Ice also affects organisms in the intertidal and shallow nearshore area of the Arctic during winter months, such that ice cover along with extreme cold temperatures may kill or damage benthic organisms (Stephenson and Stephenson 1972). On the other hand, fast ice, which is sea sea ice that has frozen along coasts or to the sea floor over shallow depths is immobile and offers protection to benthos from cold air temperatures and scouring of the nearshore seabed (Stephenson and Stephenson 1972; Aitken and Gilbert 1986; Forbes and Taylor 1994).

Ice scouring of the seabed is a natural occurrence in nearshore areas of the Arctic. Scouring of the seabed by sea ice pressure-ridge keels is most predominant in shallow water depths (Heath and Thomas 1984). The Beafort Sea is 100% scoured by pressure ridges and multiyear ice keels from shore to the 40 m depth, with scouring reaching to depths of 72 m (Conlan et al. 1998). Sea ice pressure-ridge keels scour the seabed, displacing sediments laterally, resulting in a characteristic roughened or excavated seabed morphology that may affect resuspension rates and could change the degree of consolidation of the seabed surface. The movement of these ice keels through the sediment redistributes substrates and eliminates benthic communities living in and on the seabed (Conlan and Kvitek 2005). Disruption by the ice keel includes a zone or berm on both sides of the excavation, redistributing substrate types, and thereby modifying the benthic habitats. Consequences to benthos are loss of biomass, modification of abundance and diversity patterns, and change in community structure and function (Gutt et al. 1996; Conlan et al. 1998; Gutt 2001; Conlan and Kvitek 2005). Flora and fauna not adapted to periodic disruption will be at greatest risk and their absence will likely influence the overall community structure and function. The excavated areas of the seabed are leveled by redistribution of sediment, such as siltation from rivers, wave and bottom currents on mobile sediments, and slumping of scour edges (Heath and Thomas 1984). Frequent ice scouring occurs on the Beaufort Sea continental shelf as a result of onshore and longshore movements of pressure-ridge keels (Barnes et al. 1984).

1.4.3 Impact of Sedimentation on Nearshore Marine Systems

Terrigenous sediments may pose a threat to the biodiversity of coastal areas and estuaries (Gray 1997). Episodic events such as erosion, extreme rain events, landslides, and flooding can result in catastrophic deposition of sediments and elevated turbidity to the marine environment and may have a profound influence on the structure and function of macrobenthic communities (Ellis et al. 2000). Flora and fauna not adapted to periodic disruption will be most vulnerable to the impacts. Increased suspended sediment concentrations in the water column can decrease light levels at the seafloor affecting benthic primary producers, clog filter-feeding structures of benthos interfering with benthic food intake, decrease oxygen concentrations, and change sediment properties such as grain size, chlorophyll a and organic matter content at the seafloor (Nicholls et al. 2003). Nicholls et al. (2003) conducted an in-situ experiment to mimic storm induced sediment run off events. They studied the behavioral responses of four macrofauna species to a range of suspended sediment concentrations and found that with increased suspended sediment, burial times and death rates of infaunal heart urchins increased, feeding rates of a tube building worm decreased, death rates of the wedge shell *Macomona liliana* increased, and with extremely high rates of sedimentation the scallop *Pecten novaezelandiae* was not able to process the amount of particles present. These in-situ experiments help to identify benthic organisms that may be at a higher risk to increased sedimentation. These experiments also are useful in predicting and interpreting long-term impacts on benthos.

Ellis et al. (2000) presented a number of case studies documenting sedimentation-induced structural and functional changes to benthic communities. One of the case studies they presented were changes in benthic community composition that had been documented in Kane'Ohe Bay (Hawaii) in response to high rates of sedimentation (Smith and Kukert 1996). Arctic case studies documenting impacts of sedimentation on benthos are minimal therefore references from other regions have been documented in this study. In response to the high rates of sedimentation Smith and Kukert (1996) found high macrobenthic abundance, with very small deposit feeding polychaetes dominating the community. Smith and Kukert (1996) also recorded a macrobenthos of low diversity, small mean body size, low biomass, and relatively low productivity. They attributed these effects to gradual accumulative sedimentation on the bay. Peterson (1985) documented macrofaunal changes following a major rainstorm that caused catastrophic sedimentation. Peterson (1985) found that in the high current sandy channel, effects of sedimentation were negligible, whereas in the low energy muddy-sand environment, the storm deposited approximately 10 cm of silt and clays, which increased mortality of two suspension feeding bivalves.

Suspension feeders are the functional group most likely to be impacted by suspended sediment concentrations (Nicholls et al. 2003). Suspension feeders remove particles from the water column, which can improve water clarity and aid in the removal of pollutants (Snelgrove 1998). However, with increased suspended sediment concentrations their filter feeding structures may clog, which could be detrimental to the organism survival. Ellis et al. (2000) also note that one potential sublethal effect of increased sedimentation on benthic macrofauna is the change in feeding and digestion efficiency. Such that, an increase in the concentrations of mud in suspension may significantly increase pseudofaeces production and decrease the amount of algal food actually ingested. Significant changes in sediment regimes where coastal areas receive continuous inputs of sediment result in functional and structural changes in soft sediment benthic communities (Ellis et al. 2000).

Most of the studies assessing the impacts of sedimentation on benthic organisms have been conducted either in the laboratory or in tropical marine environments (Peterson 1985; Smith and Kukert 1996; Ellis et al. 2000; Nicholls et al. 2003). Generally impact studies on benthic organisms/communities in the Arctic are limited to ice scouring effects (Conlan et al. 1988; Conlan and Kvitek 2005). However one study compared benthic faunal composition in two Arctic glacial bays with differing degrees of sedimentation. The main differences between the two glacial bays were water temperature and type of glacier (i.e. actively retreating 'warm' glacier and a much less active 'cold' type) (Wlodarska-Kowalczuk and Weslawski 2001). The study found that the bay with a lower level of inorganic sedimentation was more diverse than the more active 'warm' glacial bay. Low macrofaunal diversity in many other Arctic localities have been attributed to high inorganic sedimentation induced by glacial or fluvial outflow (Feder and Jewett 1986; Kendall and Aschan 1993; Schmid and Piepenburg 1993; Holte et al. 1996). Wlodarska-Kowalczuk and Weslawski (2001) suggested that the large amounts of inorganic particles affect the light regimes and hence the primary production in areas with high inorganic sedimentation. As well, benthic organisms have to expend much of their energy on regulatory processes connected with the maintenance of their position in unstable substrate (i.e. muddy substrate continuously buried by inorganic particles) (Wlodarska-Kowalczuk and Weslawski 2001). The availability of food may also be a limiting factor in high sedimentation areas, such that the organic material in the water column is diluted by the large amounts of inorganic suspended sediment (Görlich et al. 1987).

1.4.4 Benthic-sediment/depth Relationships

Various sediment properties, such as particle size, permeability, porosity, organic content, and water content can influence the distribution of fauna (Longbottom 1970; Pollock 1971; Thomson 1982).

Sediment particle size can affect distribution of organisms. For example, encrusting organisms such as blue mussels (*Mytilus edulis*) and barnacles (*Balanus balanoides*) require larger rocks and pebbles to anchor to; soft-bodied polychaetes, on the other hand, are adapted to finer, muddier sediment through which they can burrow (Ruppert and Barnes 1994). Abundance of benthic fauna generally decreases in coarse sediments and increases in finer sediment (McIntyre 1969).

Feeding activity of marine benthos plays a critical role in processes that occur both within the water column and marine sediments. Generally, marine benthos are classified as either suspension feeders, deposit feeders, and carnivores. Suspension feeders remove particles from the water column, which can improve water clarity and aid in the removal of pollutants (Snelgrove 1998). Deposit feeders ingest sediment particles and the organic material associated with the sediment. They play a critical role in the functioning of marine benthos, in terms of bioturbating sediments, resulting in increased sediment oxidation and redistribution of organic material (Rhoads and Young 1970).

Typically, deposit feeders are more commonly found in finer sediments where organic content is greater. Suspension feeders feed on phytoplankton and suspended matter in the water column and are more common in coarse sediments where faster currents renew food supply (Peterson 1991; Aitken and Fournier 1993). Deposit and suspension feeders feed on organic matter. Terrestrial runoff delivers some organic matter to the marine environment, however much of this material is difficult to digest and if turbidity is too high, the environment is no longer advantageous to suspension feeders (Leontowich 2003).

Species and habitat distribution may not only be influenced by substrate, but also by depth. Changes in suspended sediment, light attenuation, salinity, dissolved oxygen, and water temperature are all depth-dependent variables (Dale et al. 1989).

1.4.5 Climate Change Conditions in the Arctic

Climate change is already occuring particularly in the Arctic, where permafrost is thawing, sea-ice extent is decreasing, and glaciers are receding (IPCC 2001b; ACIA 2005a). Predicted changes in the coastal zone include a continuation of these effects, as well as an increase in storm frequency and sea level rise (IPCC 2001b; ACIA 2005a; Manson et al. 2005). In most areas of the Arctic, average annual temperatures have risen by about 2 to 3°C since the 1950s and up to 4°C during the winter months (ACIA 2005a). Over the past century increases in average air surface temperatures in the Arctic have been 50% greater than increases observed over the entire Northern Hemisphere (IPCC 2001b; ACIA 2005a). General Circulation Models (GCMs) project increases in temperature between 1.4 and 5.8°C globally over the next century (IPCC 2007). The Arctic is particularly vulnerable to climate change and major physical and ecological impacts are expected to arise suddenly (IPCC 2007). Increases in temperature over the next century will result in the continuation of the reduction in sea-ice cover, increased precipitation, increased melting of permafrost, increased erosion of coastlines, a rise in sea-level, and subsequent effects on terrestrial, freshwater, and marine ecosystems (ACIA 2005a). The IPCC Fourth Assessment Report concludes that global average temperatures will rise between 1.1 and 6.4°C by 2100. As well, some models project a 5-10% precipitation increase and late summer ice-free conditions in the Arctic by the latter part of the 21st century (ACIA 2005a; IPCC 2007). Tide gauge measurements and satellite altimetry suggest that the global sea level rise for the 20th century was approximately 12 to 22 cm (IPCC 2007). Lastly, the present rate of eustatic sea level rise (3 mm a^{-1}) (Shepherd and Wingham 2007), suggests a global rise in sea level of nearly 30 cm by the end of the 21st century.

1.4.6 Impacts of Climate Change in the Beaufort and Central Arctic Region

In the Beaufort Sea, climate warming is causing the thawing of permafrost, which will ultimately lead to an acceleration of erosion along coastlines (Manson *et al.* 2005). The Beaufort Sea coast has been characterized by rapid rates of erosion forced by long-term sea level rise and periodic storms (Solomon 2005). Storm surges up to 2.4 m or higher have been recorded along the Beaufort Sea coast in an area with <0.5 m tides (Forbes 2000). Rising relative sea level along these coasts contributes to more frequent inundation at a particular reference level and predicted accelerated global sea level rise will enhance this impact (Forbes 2000). The high concentration of ground ice in unconsolidated sediments and 3-4 month open water season suggests that open-water periodic storms will likely accelerate erosion rates (Solomon 2005). If predicted increases in sea level rise, storm events and periods of open water due to climate warming take place (Shaw et al. 1998b; IPCC 2001b; ACIA 2005a), erosion of this coastline will accelerate even more. This will result in increased sedimentation into the nearshore marine environment (Brown et al. 2005; Belliveau 2007).

Research suggests that melting of the Greenland ice sheet is likely to occur more rapidly than what was previously believed and sea level is continually rising (ACIA 2005a). The most recent estimate for the rate of global sea level rise is 3.0 mm a^{-1} (Shepherd and Wingham 2007). Therefore a coastal location in the central Arctic, such as Gjoa Haven which is currently experiencing a present day vertical uplift rate of 1-2 mm a^{-1} (Tarasov and Peltier 2004), may begin to experience a relative sea-level rise. If rates of eustatic sea level rise continue to accelerate, coastal areas in the central Arctic which are currently experiencing near zero rates of isostatic vertical motion will likely begin to experience relative sea level rise. Because relative sea level rise is one of the factors that contributes to coastal erosion (Forbes 2000), this transition may contribute to possible coastal erosion and increased sedimentation into the nearshore environment. Ultimately, we may not only see changes in benthic habitats and community composition (Brown et al. 2006), but also marine mammal and fish species which depend on these benthic communities will be altered.

The current thickness of fast ice (1-2 m) in the Northwest Passage is projected to decrease substantially this century. Potential for increased marine access through the Northwest Passage, suggests likely impacts of pollution on the marine environment (Catto and Papadimitriou 2006). Increased transport not only increases the risk of oil spills, but also increases the risk of the introduction of invasive species, carried in the ballasts of ships. Invasive species may introduce new parasites and diseases and change the species composition of the environments they inhabit.

1.4.7 Sea level History in the Beaufort and Central Arctic Region

During the time of the last glacial maximum (LGM), approximately 20,000 years ago, almost all of Canada was covered by massive ice sheets, which extended roughly to the southern boundary of the Great Lakes (Fulton 1989). In the Beaufort region ice did not cover Banks Island, however; the ice was present to the south, near the mainland Beaufort Sea coastline and sea level was 70 m lower than at present in the region (Vincent 1990; Hill et al. 1993). In contrast to the Beaufort region, the area of the Canadian Shield west of Hudson Bay and the Gulf of Boothia, where King William Island lies, was covered by the Keewatin Ice Sheet during the LGM (Dyke and Dredge 1989).

Sea level rise for a region results mainly from glacio-isostatic effects and eustatic sea level rise. Glacio-isostatic effects refer to isostatic adjustments of the Earth and result from crustal depression due to the loading of an ice sheet, associated forebulge development, and land uplift and forebulge collapse following unloading of the ice sheet (Liverman 1994; Lambeck 1995; Masselink and Hughes 2003). The forebulge is an uplift at the edge of a glacier caused by tilting of the lithosphere (Masselink and Hughes 2003). Eustatic sea level rise will be discussed in more detail in the next section (1.4.8).

Sea level rise in the Beaufort region results from glacio-isostatic effects, eustatic sea level rise, and to a lesser extent, basin subsidence, sediment loading, and consolidation of sediments (Forbes 1980; Hill et al. 1985; Belliveau 2007). During LGM, many areas of the Beaufort Sea and Banks Island were at the margins of the ice covered land, referred to as the forebulge (Dyke 1987). Areas that were influenced by forebulge are currently going back to their former positions, such that the land is now subsiding. In conclusion studies identify the Beaufort region as an area that is undergoing submergence (Richards 1950; Mackay 1963; Forbes 1980). A sea level curve has not been completed for southwest Banks Island. However, the rate of subsidence has been suggested at 2.50 mm a^{-1} in Sachs Harbour and Tuktoyaktuk from modeling (Andrews and Peltier 1989; Peltier 1994).

The Keewatin region, where Gjoa Haven lies is now emerging to its former position prior to glaciations. The rates of sea level change for this region are uncertain, but have been estimated based on modeling (Tarasov and Peltier 2004). Areas in the Canadian Arctic displaying the greatest vertical uplift are over the Keewatin, Quebec, and Fox Basin regions. Gjoa Haven appears to have an estimated 1-2 mm a^{-1} present-day uplift rate; in contrast to Sachs Harbour which has a -2 mm a^{-1} present-day uplift rate (Figure 1.6).

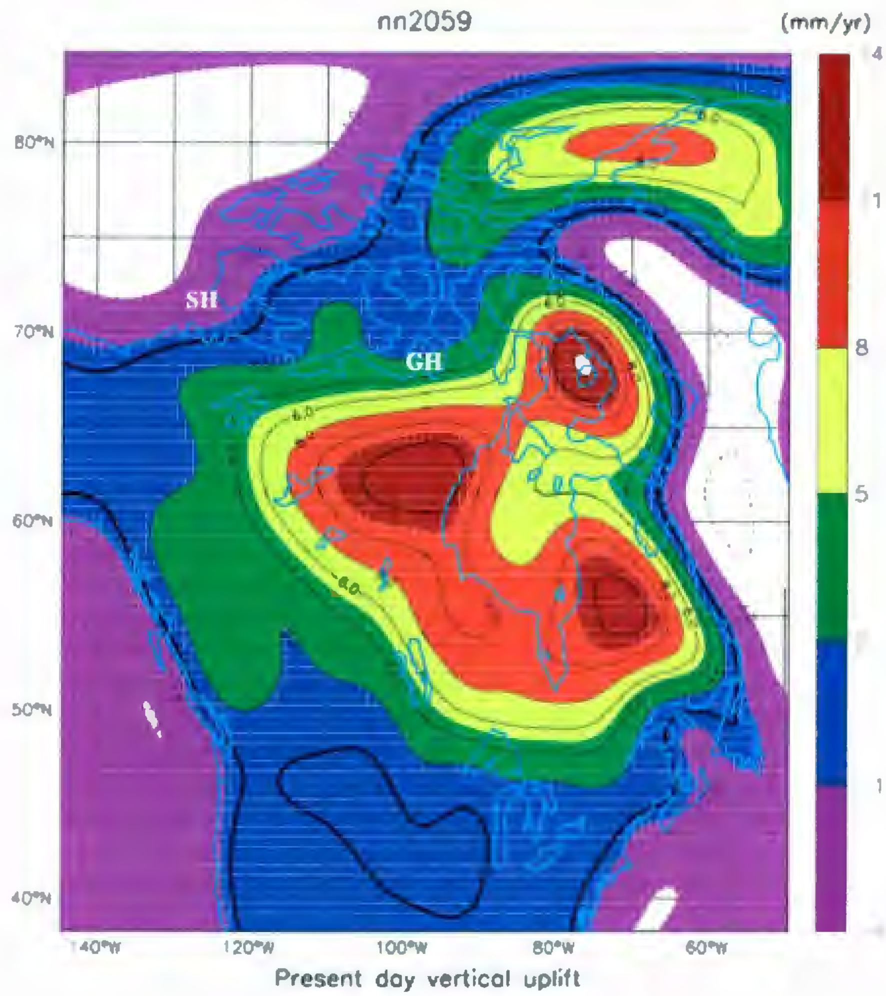

Figure 1.6 Present-day vertical uplift rates for the Canadian Arctic (Tarasov and Peltier 2004). Sachs Harbour is -4 to -1 mm a^{-1}; Gjoa Haven is 1-2 mm a^{-1}.

1.4.8 Present-Day Sea Level Change

Due to the melting of the ice sheets, the volume of water in the world's oceans has increased since the last glaciation (ACIA 2005a). Over the past 20,000 years, global average sea level has risen over 100 m (Church et al. 2004). Even though eustatic sea level has risen, areas that were once ice covered have risen far more from isostasy (Masselink and Hughes 2003). Evidence of this, such as flights of raised beaches can be seen throughout the Canadian Arctic, and are continually forming because the land continues to rise above the current volume of water in our oceans. By contrast, the margins of the Beaufort Sea are experiencing subsidence caused by glacioisostasy. In contrast to long-term sea level change driven by deglaciation and glaciosostatic change, present day sea level rise is a consequence of climate warming. Significant climate warming causes our oceans to warm, glaciers and ice caps to melt, thermal expansion of ocean waters and an increase of meltwater into our world oceans (IPCC 2001b). Predictions for the next century indicate a rise in the global sea level of 0.09-0.88 m (IPCC 2001b).

Estimated rates of global average sea level rise over the last 1000 yr, prior to the twentieth century are less than 0.2 mm a^{-1} (Church et al. 2004). Estimates for the twentieth century rate of eustatic sea level rise are 3 mm a^{-1} (Shepherd and Wingham 2007). These estimates are based mainly on historical tide gauge data (Woodworth and Player 2003). Tide gauges are used to measure the height of the sea surface relative to the coastal benchmarks (Church et al. 2004). Modeling and continuous GPS stations estimate 3.6 mm a^{-1} relative sea level rise for Tuktoyaktuk (Manson et al. 2005). This estimate is in agreement with tide gauge data, indicating 3.5 mm a^{-1} $\pm$ 0.1 relative sea level rise (Manson et al. 2005). Manson et al. (2005) suggest that similar rates of relative sea level rise (3.6 mm a^{-1}) are occurring in Sachs Harbour due to comparable rates of subsidence and eustatic sea level rise between the two areas. There is currently no estimate for the relative sea level rise for Gjoa Haven. Gjoa Haven's estimated vertical uplift rate is 2.0 mm a^{-1} (Tarasov and Peltier 2004). Therefore, for Gjoa Haven to go from an emergent setting to one that is submergent would require a large increase in eustatic sea level rise. Areas which are currently experiencing near zero rates of isostatic vertical movement may begin to experience relatively rapid eustatic sea level rise. Coastal erosion and sedimentation are likely consequences, however the nature and degree of these processes will depend on local conditions.

1.4.9 Sensitivity of Coastlines of Southwestern Banks Island and King William Island to Sea Level Rise

Sensitivity means the degree to which a coastline may experience physical changes such as flooding, erosion, beach migration, and coastal dune destabilization as a result of sea level rise. Significant climate warming is predicted to cause warming of the oceans and continual melting of glaciers and ice caps, resulting in a global rise in sea level (Shaw et al. 1998a). Shaw et al. (1998b) used seven criteria to assess the sensitivity of all coastal regions of Canada to sea level rise: relief, geology, coastal landforms, isostatic sea-level tendency, shoreline displacement, tidal range, and wave height. The Beaufort Sea coast is one of two regions in Canada identified as having high sensitivity coastlines, Atlantic Canada being the other. The remaining areas of the Canadian Arctic fall under low or moderate sensitivity to sea level rise. Gjoa Haven's coastline was rated as having moderate sensitivity to sea level rise (Shaw et al. 1998a).

The southwestern coastline of Banks Island is considered highly sensitive to sea level rise due to its sediments laden with ground ice, low lying unconsolidated coastal cliffs, an eroding coastline, and its current rate of relative sea-level rise of 3.6 mm a^{-1} (Shaw et al. 1998b; Manson et al. 2005, Belliveau 2007, Figure 1.7). Predicted impacts for the southwestern coastline of Banks Island are increased erosion rates, beach migration, increased rates of lake breaching, and destabilization of sediments in the coastal zone (Shaw et al. 1998b). Climate warming is predicted to cause an increase in the extent and duration of open water in the summer (IPCC 2001a). Shaw (1998a) suggests that if these predictions occur, beaches would be reworked by waves for longer periods of time, and the greater fetch over the more extensive open water would allow storms to impact coastlines even more severely than at present. This may lead to increased sedimentation into the nearshore area in some regions of the Arctic.

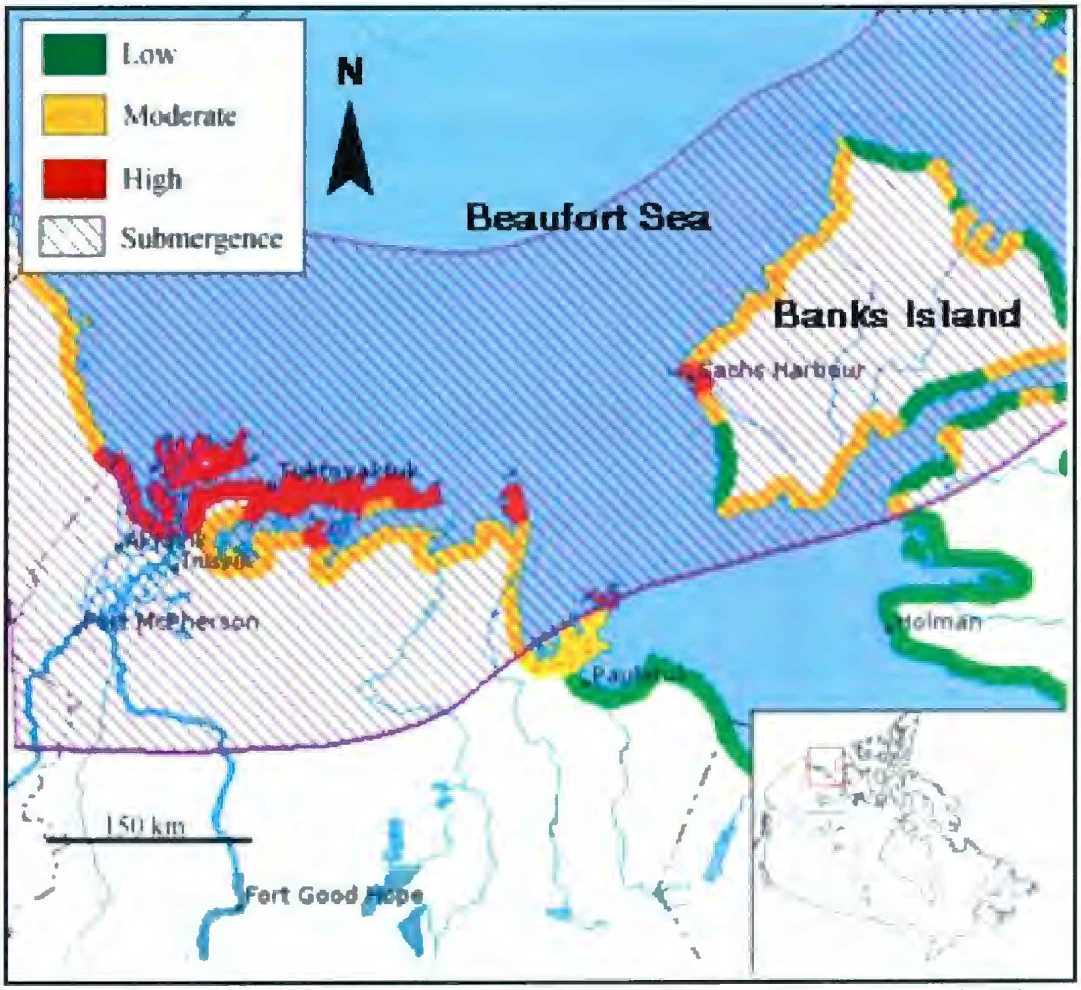

Figure 1.7 Coastal sensitivity to sea-level rise in the Canadian Western Arctic. The southwest coast of Banks Island is highly sensitive to sea-level rise and is submerging (Shaw et al. 1998b).

CHAPTER TWO

METHODS

2.1 FIELD METHODS

2.1.1 Selection of Sampling Sites

In total, 147 sites were sampled off two nearshore Arctic locations: Sachs Harbour, N.W.T. (71°59' N 125°14' W) and Gjoa Haven, Nunavut (68°38' N, 95°52' W). Sampling sites were located 150 to 1200 m from the coastline along shore-perpendicular transects at depths of 2 to 40 m. Generally, three sampling sites were sampled along each transect at approximately 200 m, 700 m, and 1200 m from shore. Transect location and sample stations were selected to ensure a gradient in depth, and maximum substrate and habitat variability. Samples were collected from an 18 ft aluminum boat owned and operated by a local community member during July and August of 2005 (Sachs Harbour) and 2006 (Gjoa Haven). For the Sachs Harbour study area 27 nearshore transects and 90 stations were sampled from the second basin along the Sachs River Estuary, east of the community of Sachs Harbour to Cape Kellett (Figure 2.1). For the Gjoa Haven study area, a total of 19 nearshore transects and 57 stations were sampled from the southwest coast of Schwatka Bay, north of Betzold Point, to the western point of Peterson Bay (Figure 2.2).

Figure 2.1 Location of sampling sites in 2005 for the Sachs Harbour, N.W.T. study area. (modified from imagery © Digital Globe).

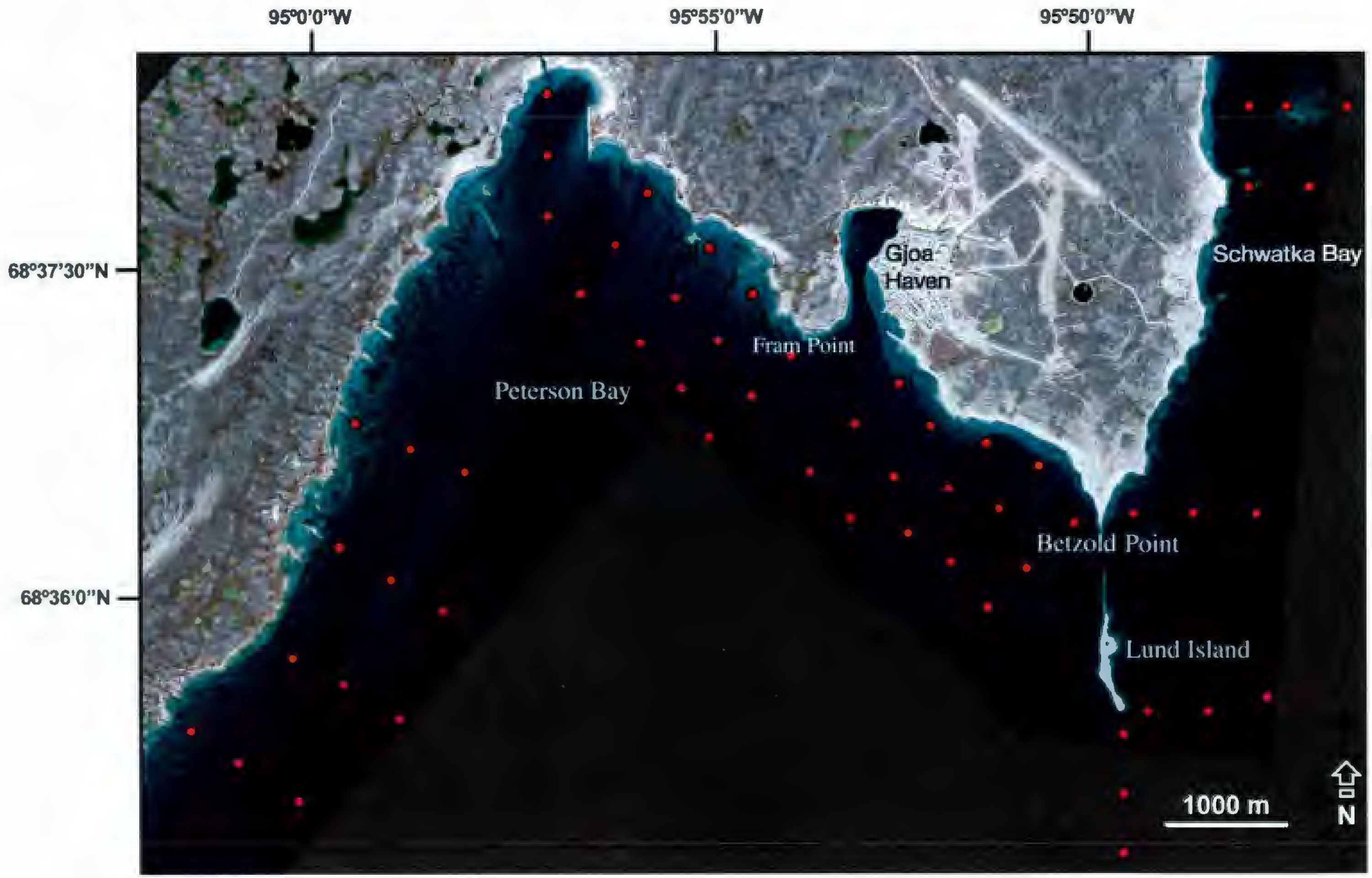

Figure 2.2 Location of sampling sites in 2006 for the Gjoa Haven study area
(modified from imagery © Digital Globe)

2.1.2 Grab Sampling

Biological sampling at each sample site included benthic grab samples and drop video camera transects. Benthic fauna were sampled at each station using a Petit-Ponar grab sampler with a 17 cm by 15 cm scoop area, and sieved on a 1.0 mm mesh screen. Residues were preserved with 4% buffered formaldehyde solution. The location of each grab was recorded using a Garmin ETrex GPS unit or Garmin 178C GPS-depth sounder (accuracy <15 m).

2.1.3 Video Recording of the Seabed

In the Sachs Harbour study area 47 transects were video recorded at 90 of the grab sample sites. Geographical positions and depth were registered at the start and end of each transect using a Garmin 178C GPS-depth sounder. The total time for the video data was 2 hours and 33 minutes, with an average time of 3 minutes, 20 seconds per station. Sachs Harbour stations covered depths between 1 m and 39 m and varied from 3 m to 138 m in length (average length 31 m) (Table 2.1, see Appendix B and C for more details).

Fifty-seven stations were video recorded from all 57 grab sampling sites for the Gjoa Haven study area. The total time for the video data was 1 hour and 56 minutes, with an average time of 2 minutes, 2 seconds. Transects of the Gjoa Haven study area covered depths between 2 and 31 m, and were between 2 and 75 m long (average length 37 m) (Table 2.1, see Appendix D, E and F for more details).

Table 2.1 Video transect features for the Sachs Harbour and Gjoa Haven study areas.

	Sachs Harbour	**Gjoa Haven**
Number of video sampled sites	90	57
Total time recorded	2 hours 33 minutes	1 hour 56 minutes
Average time recorded	3 minutes 20 seconds	2 minutes 2 seconds
Depth range	1 – 39 m	2 – 31 m
Average length (range)	31 m (3-38 m)	37 m (2-75 m)

The data was collected using SeaView Seamaster 600 underwater drop video camera (SeaView Video Technology, Florida) (Figure 2.3). The SeaView Seamaster 600 underwater drop video camera was bolted into an aluminum cage, lowered to the seafloor on a 45 m tether, and held approximately 1-2 m above the substrate. The SeaView was powered on a 12 volt DC battery, and the video signal was recorded on a SONY Digital TRV38 'handycam' (Sony Corporation, Tokyo), which doubled as a video monitor with its LCD screen. Digital video was captured at 29.97 frames per second. Video footage was also captured using the SONY 'handycam' secured inside an Amphibico underwater housing. This apparatus was used on 19 of 57 transects in Gjoa Haven, after the SeaView Seamaster 600 drop video camera failed. The Amphibico housing was attached to the aluminum cage and lowered to the seafloor. The frame series for each transect was stored as a iMovie HD file, and digital enhancement (e.g. colour correction) was carried out where required to enhance clarity and contrast. Geographical positions and depth were registered at the start and end of each transect. Laser beams provided a 15 cm scale for measuring approximate width of the video frame and size of the video images.

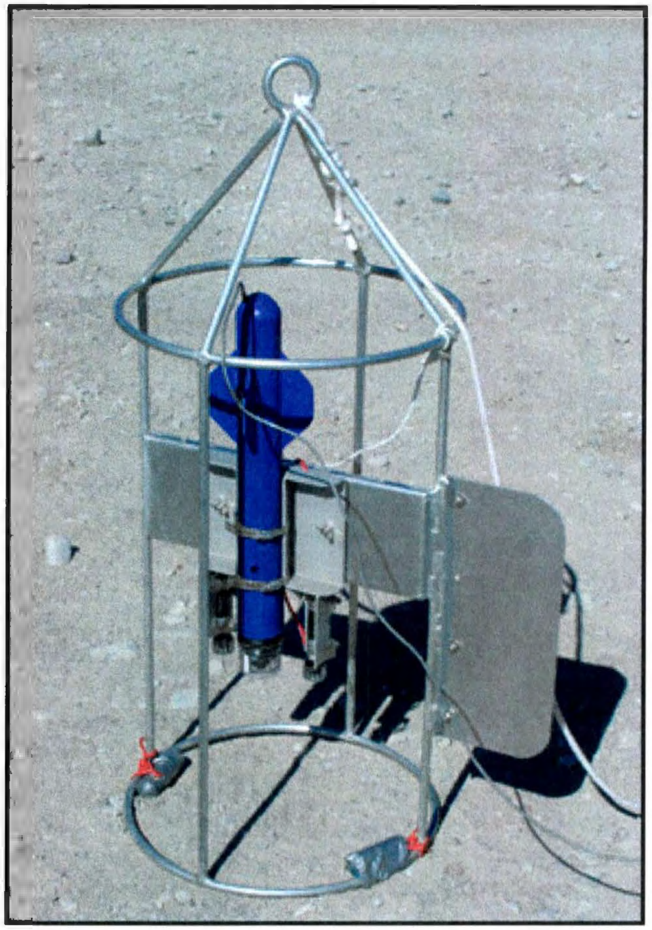

Figure 2.3 Underwater drop video camera (SeaView Seamaster 600) apparatus.

2.1.4 Bathymetry

Soundings were conducted using the Garmin GPSMAP 178C sounder with WAAS-dGPS compatible sounded at 1-5 sec. intervals. A bathymetric grid was developed for the Sachs Harbour and Gjoa Haven study area from soundings obtained during the two field seasons in 2005 and 2006. Using the sounding data in ArcGIS, bathymetric contours were estimated manually. Digital base maps, primarily a 1:50,000 digital topographic map, a Quickbird satellite image (if available) for the two study areas were then overlaid with five meter interval contour lines.

2.2 LABORATORY METHODS

2.2.1 Grab Analysis

In the laboratory, benthic fauna samples were preserved in 70% ethyl alcohol. All benthic fauna, with the exception of foraminiferans and nematodes, were identified to species level where possible, unless the organism was damaged and could not be identified. Identification guides were used to identify specimens (Bousfield 1960; Gosner 1971; Fauchald 1977; Bernard 1979; Gosner 1979; Appy et al. 1980; Quijón 2004). Taxonomic identification of each species was made using a compound microscope and/or a Fisher Scientific stereoscopic microscope.

Macroalgae were preserved in 4% formalin. All macroalgae were identified down species level where possible. Identification guides were used to identify specimens (Taylor 1957; Gosner 1971; Gosner 1979; Gotschall 1994; Mondragon and Mondragon 2003). Dr. Robert Hooper (Benthic Phycologist) assisted in the identification. Taxonomic identification of each species was made using a compound microscope and/or a Fisher Scientific stereoscopic microscope.

At each station a 120 ml sediment sample was removed from the top of the grab for grain-size analysis prior to sieving; larger clasts (greater than 4 mm) were noted but not included in sieving. Grain-size analysis was completed for nearshore sediment samples using dry-sieving, with sediments classified according to the modified Udden-Wentworth grade scale (Krumbein 1934) (Table 2.2). Dried sediment samples with grain sizes ranging from granules (between 2 – 4 mm) to coarse silt (0.031 -0.0625 mm) were analyzed, using masses of 100 or 50 grams, respectively. Dry sieving followed the procedure outlined in Catto et al. (1989). The samples were placed in a series of stacks, ranging in sieve mesh size of -5 to +4 phi, and mechanically shaken for 10 minutes. The mass of sediment retained in each sieve was weighed and recorded. The phi scale, devised by Krumbein (1934) is a grain size scale for siliciclastic sediments.

Dried coarse silt and clay sediment (< 0.031 mm) were analyzed by wet-sieving using masses of 5 grams. Wet sieving followed the procedure outlined in Catto et al. (1989). Clumps were broken up using a pestle and mortar. The samples were placed on a +4 phi sieve. Tap water was run over the samples to disaggregate any remaining clumps and allow the fine sand sediment fraction to separate from the silt and clay sediment fraction. The sand fraction remained on the surface of the sieve, while the silt and clay fraction passed through. No chemicals (e.g. calgon, sodium hexametaphosphate) were used to disaggregate the clays. Not using a chemical to disaggregate the sediments may lead to some error, for example clays can appear as silt in size since they flocculate together. For the purpose of this study the silts and clays did not need to be separated from one another because all muds were being lumped together. Once sieving was complete, sediment on the 4 phi sieve was dried in a drying oven at 70-100°C for 24 hours and weighed to obtain the proportion of fine sand within the whole sediment. The mass of the fine sand retained in the 4 phi sieve was then recorded and subtracted from the initial mass to obtain the silt and clay fraction.

Mean grain size (M) and sorting (D) were calculated using the cumulative probability of the sample and the grain size in phi scale (Folk and Ward 1957; Folk, 1966).

Table 2.2 Udden-Wentworth Grade Scale. (Taken from N.R. Catto and Quaternary Research Group, University of Alberta, 1989).

Wentworth – Udden Grain Size Classification

Clast Size	Phi	Size Classification
-- 256 mm --	**-8**	**Boulder**
--64 mm --	**-6**	**Cobble**
-- 32 mm --	**-5**	**Coarse Pebble**
-- 16 mm --	**-4**	**Medium Pebble**
-- 4 mm --	**-2**	**Fine Pebble**
-- 2 mm --	**-1**	**Granule**
-- 1 mm --	**0**	**Very Coarse Sand**
-- 0.50 mm --	**+1**	**Coarse Sand**
-- 0.25 mm --	**+2**	**Medium Sand**
-- 0.125 mm --	**+3**	**Fine Sand**
-- 0.0625 mm --	**+4**	**Very Fine Sand**
-- 0.031 mm --	**+5**	**Coarse Silt**
-- 0.0156 mm --	**+6**	**Medium Silt**
-- 0.0078 mm --	**+7**	**Fine Silt**
-- 0.0039 mm --	**+8**	**Very Fine Silt**
-- 0.0020 mm --	**+9**	**Coarse Clay**
		Clay

(After Udden 1898, Wentworth 1922, Krumbein 1934)

2.2.2 Video Analysis of the Seabed

The video records of each video transect were viewed and all macro algae and fauna were identified to the lowest possible taxonomic level. Relative abundance (RA) of macroalgae, macrofauna, and substrate type was estimated by dividing the time (seconds) of each macro benthos species or substrate type present within a video transect by the total time (sec) of the video transect:

(*equation: RA=time (sec) of species/substrate viewed/ total time (sec) of transect*). Appendices A-E show a description of the video transects (depth range, depth median, length, time, mean substrate, substrate class, macroalgae and macrofauna cover). Frame grabbed images were captured from the digital video data for species identification purposes. Video analysis was especially useful for the identification of epibenthos and for substrates with dispersed cobble/pebbles and boulders. These sampling sites often yielded no recovery with the grab sampler.

2.3 STATISTICAL ANALYSIS

Species richness was compared among stations classified by location, depth, and sediment type using 2-way ANOVA, followed by the Tukey post-hoc test (SPSS 1999).

A matrix of species presence-absence at each station was compiled, with data gathered by the video and grab sampler analyzed separately. Video transects were also compared using relative abundance data with a double square root transformation. Bray-Curtis similarities were calculated with the data using the PRIMER 5 Package (Clarke and Warwick 2001) according to Bray-Curtis similarity.

(1) $BC_{ij} = \sum \frac{|n_{ik} - n_{jk}|}{(n_{ik} + n_{jk})}$

where BC_{ij} is the similarity between the ith and jth sites, and n_{ik} represents the abundance for the ith species in the kth site.

Relationships between sediment, depth, location and species composition were analyzed by ordination using multidimensional scaling (MDS) and analysis of similarity (ANOSIM). MDS plots are used to represent the relatedness of samples and treatments in a two-dimensional and/or three-dimensional space. Stress values associated with each MDS plot reflect how well the distance among the samples in the plot represent the actual distance among samples (Clarke and Warwick 2001). The ANOSIM test compares groups of samples defined a priori in a similar way as an ANOVA test, weighting the variation within versus between groups (Quijón and Snelgrove 2006). ANOSIM generates a Global R-statistic that is between -1 and +1 and a significance test. High Global R-statistic values indicate that ANOSIM is able to discriminate between groups. Finally, similarity percentage analysis (SIMPER) was used to determine the contribution of individual species to total group similarity, or to dissimilarity between sample groups (substrate and depth class, or location). Most of the benthic fauna were identified to species level, however for species composition analysis, family level was used for polychaetes. Description of benthic faunal composition on a family level have been considered appropriate elsewhere (Warwick et al. 1990; Gray et al. 1992; Kostylev et al. 2001; Quijón 2004), where minimal loss of discriminate information is shown in multivariate analyses.

2.4 HABITAT MAPS

Based on the near-shore sampling, a marine habitat map was constructed for each study area, using the following data types: sediment composition, macroalgae and epifauna from the drop video, epifauna and infauna from the grab sampler, and bathymetric profiles. Relationships between sampling sites were visualized using multidimentional scaling (MDS) ordination, supplemented with cluster analysis. Sample sites that consistently grouped together represent groups of relative similarity based on species composition. Habitat types were derived from analysis of similarity (ANOSIM) based on substrate, depth, and statistically distinct species assemblages. Each representation of the derived habitat types within the two study areas was constructed with point data using ESRI ArcView® 9.2. Point data assume no spatial extrapolation of the habitats classified from a single point in space. Habitat maps are represented as points, rather than vectorized polygons, because multibeam backscatter data with which to extrapolate habitat classification (c.f Kostylev et al. 2001; Copeland et al. 2007) was not available for either study area.

CHAPTER THREE

RESULTS

3.1 BENTHIC SUMMARY OF SACHS HARBOUR AND GJOA HAVEN

Benthic samples for the Sachs Harbour and Gjoa Haven study area included red, brown, and green algae, polychaetes, mollusks, sipunculids, priapulids, foramnifera, and echinoderms (Figure 3.1). Most of the biota was identified to species level. Annelids made up 56%, mollusks 20%, and algae 10% of the 89 taxa found in the material examined for the Sachs Harbour study area (Appendix G). Annelids accounted for 38%, algae 35%, and mollusks 12% of the 125 taxa examined in the material for the Gjoa Haven study area (Appendix F). Some of the common and uncommon species found in this study of Sachs Harbour and Gjoa Haven are shown in Figure 3.1 (a-o).

The circumboreal bivalve, *Macoma balthica* was found in Gjoa Haven (Figure 3.1m), which indicates a possible range extension for this species. Previously *Macoma balthica* has extended along the entire Hudson Bay coast, along the Hudson Strait, north to Pangnirtung on the East coast of Baffin Island, on the southeastern tip of Greenland, along the entire coastline of Iceland, and south, continuing its range to the Bay of Fundy (Dyke et al. 1996; Väinölä 2003). As well, this species has an Atlantic extension ranging from the northwestern tip of Alaska, south to California (Dyke et al. 1996). The reported findings of this species in Gjoa Haven suggest that this species has spread into the central Arctic, possibly extending its range from Baffin Bay, west. This species was identified using morphometric indices (e.g. size, symmetry, pallial lines and sinus) presented in various identification keys.

The most common species found in Sachs Harbour study area were deposit-feeding bivalves and carnivorous (Family: Nephytidae) and deposit-feeding polychaetes (Family: Opheliidae, Phyllodocidae) (Appendix G). Algal mats were the most common form of algae found within the area.

Shallow low diversity sand sheets dominated the Sachs Harbour study area. These sand sheets were found along the nearshore area just west of the sill separating the Sachs estuary from Thesiger Bay, along Martha Point, Duck Hawk Bluffs to Cape Kellett (Figure 2.1, 3.8, 3.10). Polychaete species from the family Nephthydidae were the dominant taxa found within these sand sheets. A diverse gravelly-sand bottom with the red algae *Coccotylus truncatus* was present to the northeast of the Cape Kellett spit. Beds of the tube anemone, *Cerianthus borealis* were found in the deep (20-40 m) muddy-sands of the outer basin. Sandy substrates covered with beds of algal mats and the bivalve *Yoldia myalis*, as well as muddy substrates with red algae *Coccotylus truncatus*, algal mats, and bivalves *Thyasira sp* and *Macoma calcarea* were observed at various sampling stations in the inner basin and in the first basin of the Sachs River Estuary. The deepest (20-40 m) depth class in the two basins along the Sachs River Estuary was characterized by anoxic black mud.

Intermediate depth (10-20 m) gravelly-sand or mud substrates with high cover of macroalgae had the greatest biodiversity in the Gjoa Haven study area. Brown, red, and green algae were found throughout the study area. Beds of *Saccharina longicruris*, *Fucus sp., and Coccotylus truncatus* were observed around Lund Island. The bottom substrate within this area was gravelly-sands and pebble-cobble gravel. Beds of the tube anemone, *Cerianthus borealis* and filamentous green algae were found in offshore sampling sites within muddy-substrates at 20-40 m depths around the shoal area near Betzold Point west to Fram Point (Figure 2.2; 3.12). Shallow depths (0-20 m) within this region were characterized by sandy bottoms with diverse macroalgae beds (*Coccotylus truncatus*, *Fucus sp.*, *Sphacelaria sp.*, and filamentous green algae). The southwestern coastline of Peterson Bay was characterized by sand, gravelly-sand, and boulder-gravel with wide coverage of *Saccharina longicruris*, *Coccotylus truncatus*, and *Fucus sp* (Figure 2.2; 3.13). Furthermore, the sampling sites running perpendicular from the river mouth were characterized by sands with the tunicate, *Molgula sp.*, sands with diverse macroalgae beds, and gravelly-sands with *Fucus* beds. Overall, the most common species found in Gjoa Haven were carnivorous and suspension-feeding polychaetes (Family: Maldanidae, Nephtyidae), deposit-feeding bivalves (*Astarte montagui, Yoldia myalis*), and macroalgae (*Coccotylus truncatus, Fucus sp.*) (Appendix G). The red algal *Coccotylus truncatus* was the dominant macroalgal species found within the Gjoa Haven study area.

Figure 3.1a: *Eumida sanguinea* (c), SH,GH

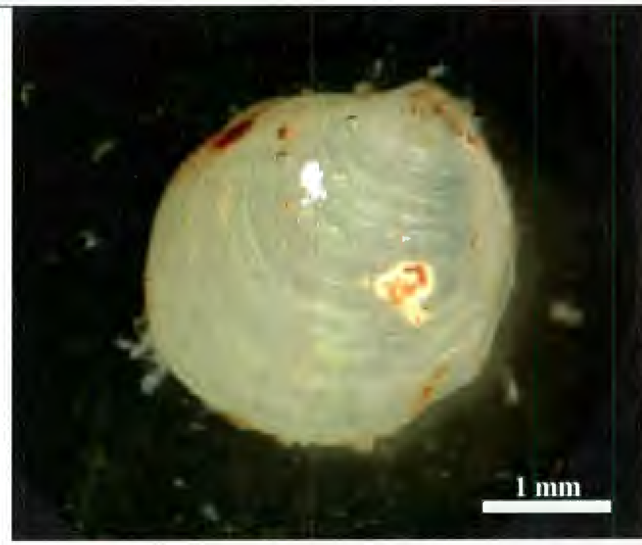

Figure 3.1b: *Thyasira sp* (c), SH

Figure 3.1c: *Hiatella arctica* (c), SH,GH

Figure 3.1d: *Hyas coarctatus alutaceus* (c), SH

Figure 3.1 Common (c) and uncommon (u) species of Sachs Harbour (SH) and Gjoa Haven (GH).

Figure 3.1e: *Melampus bidentatus* (u), SH

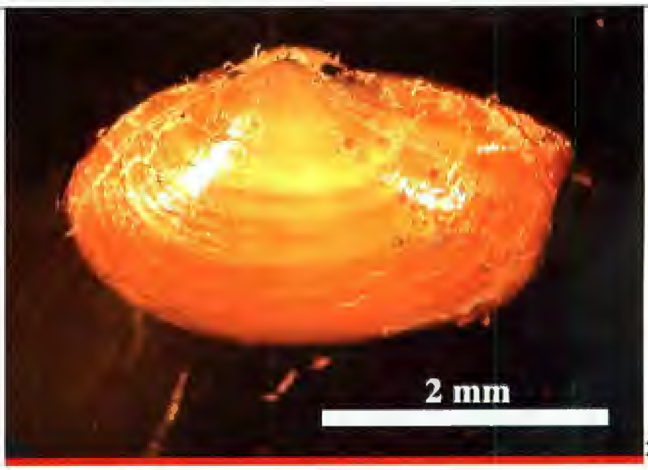

Figure 3.1f: *Nucula tenuisulcata* (c), GH

Figure 3.1g: *Terebellides sp.* (c), SH

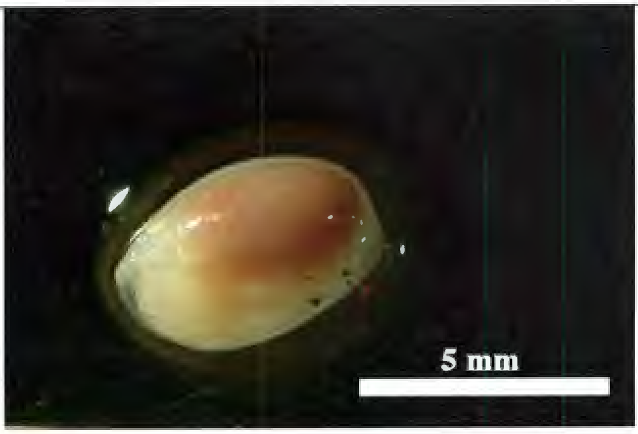

Figure 3.1h: *Retusa obtuse* (c), GH

Figure 3.1 Common (c) and uncommon (u) species of Sachs Harbour (SH) and Gjoa Haven (GH).

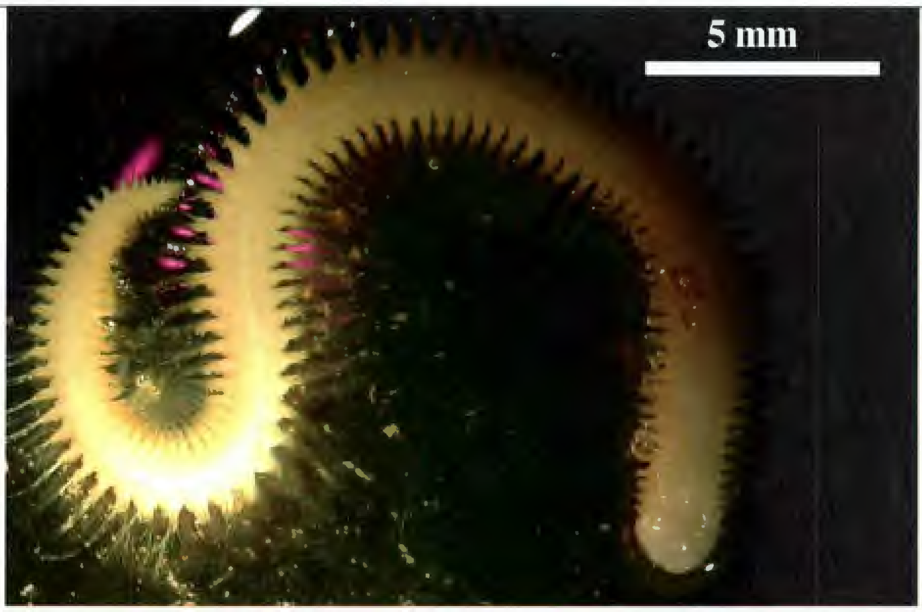

Figure 3.1i: *Nephtys bucera* (c), SH,GH

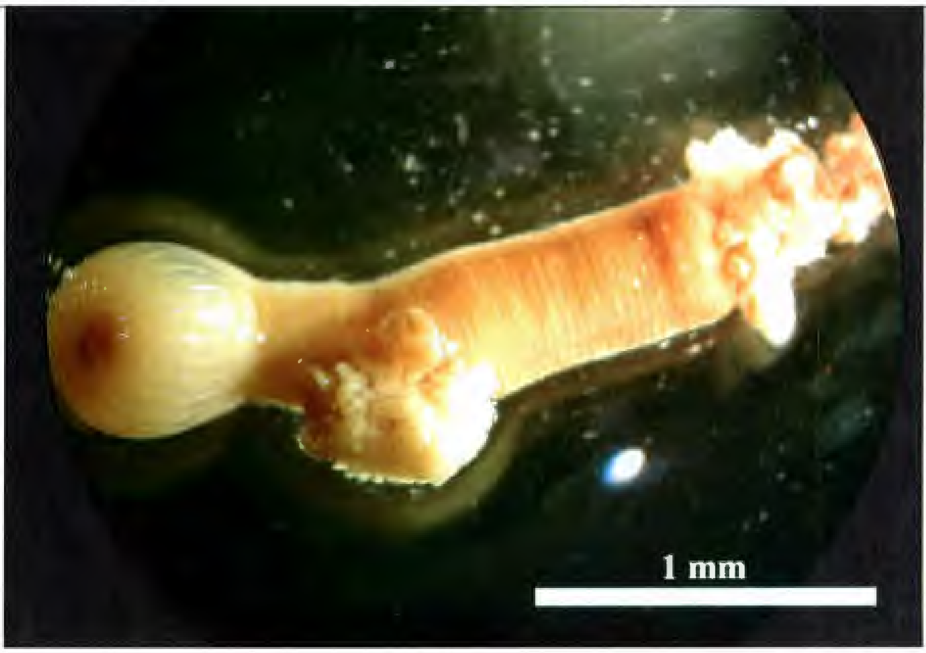

Figure 3.1j: *Priapulus sp.* (u), GH

Figure 3.1 Common (c) and uncommon (u) species of Sachs Harbour (SH) and Gjoa Haven (GH).

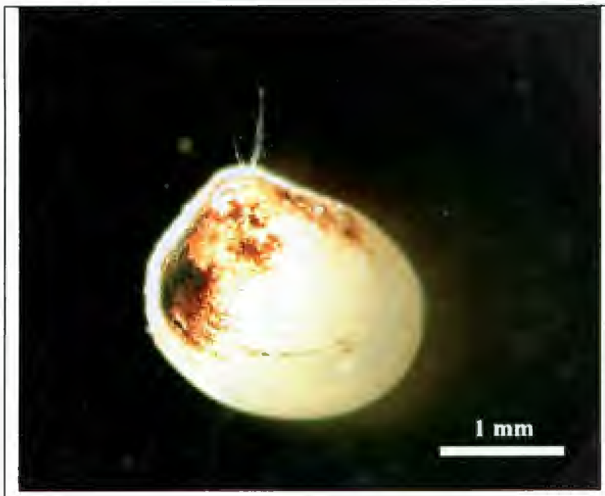

Figure 3.1k: *Mysella planulata* (u), SH

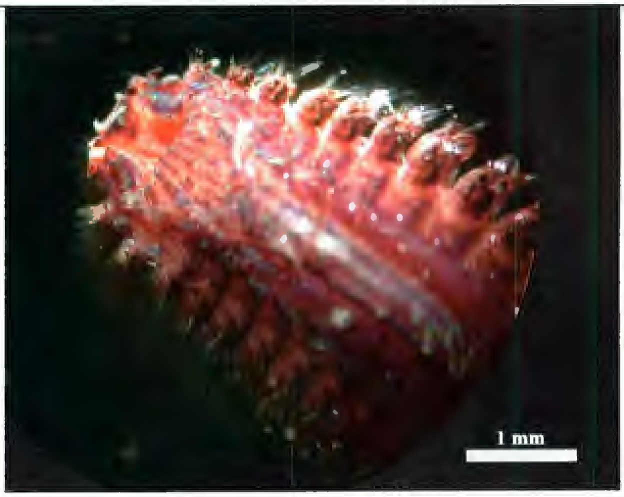

Figure 3.1l: *Nephtys caeca* (c), SH, GH

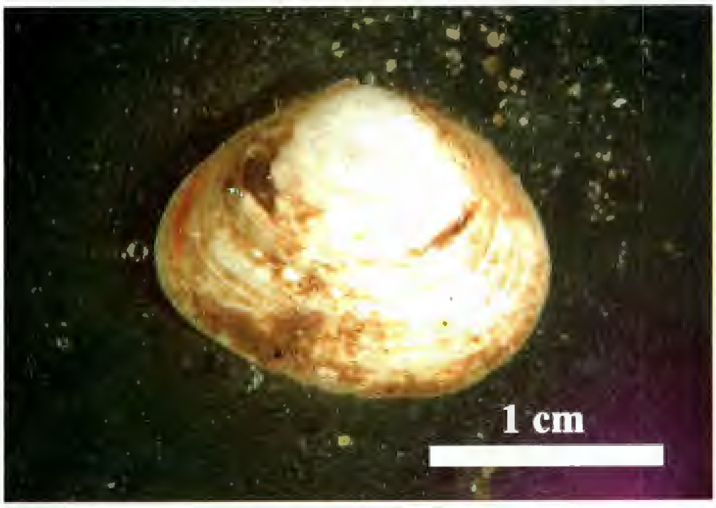

Figure 3.1m: *Macoma balthica* (u), GH

Figure 3.1 Common (c) and uncommon (u) species of Sachs Harbour (SH) and Gjoa Haven (GH).

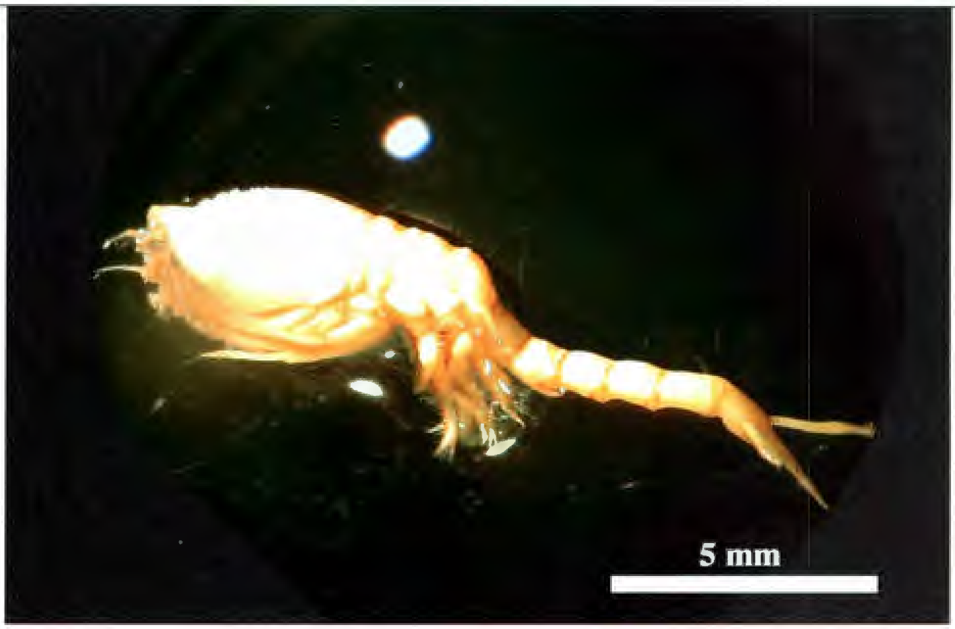

Figure 3.1n: *Diastylis rathkei* (u), GH

Figure 3.1o: *Mesidotea sp.* (u), GH

Figure 3.1 Common (c) and uncommon (u) species of Sachs Harbour (SH) and Gjoa Haven (GH).

3.2 SUMMARY OF SUBSTRATE AND DEPTH CLASSES

Total sampling for the two study areas included 246 samples classified into 6 substrate classes and 3 depth classes. Table 3.1 outlines the characteristics used for classifying each substrate class based on the Wentworth scale and grain-size and video analysis.

There were 90 benthic grab samples and 49 video transects analyzed for the Sachs Harbour study area. The samples were classified into six substrate classes: mud, sand, muddy-sand, gravelly-sand, pebble-gravel, and anoxic mud (Table 3.1). Sand was the dominant substrate and (0-10 m) depths was the dominant depth class, contributing to 62% and 50% of the grab and video sampled sites, respectively.

The Gjoa Haven study resulted in the collection of 52 grab samples and 57 video transects. The grabs were classified into four substrate classes: sand, mud, muddy-sand, and gravelly-sand (Table 3.1). Muddy-sand, gravelly-sand, and sand were the dominant substrate classes sampled, each contributing to more than 20% of the grab and video sampled sites. The pebble-cobble gravel and boulder-gravel classes were described visually using the Wentworth scale during video analysis. Video transects with pebble-cobble gravel and boulders present for greater than 10% of the total recorded time-period were classed as boulder-gravel. A relatively equal distribution among depth classes was sampled in the Gjoa Haven study area (Table 3.2).

Table 3.1. Substrate class description and representation by sampling sites
Number of sampling sites of each substrate class for the two study areas.

Substrate Class	Description	Sachs Harbour		Gjoa Haven	
		Grab	Video	Grab	Video
Mud	Fine sediments with > 50% mud	13	9	2	2
Anoxic-mud	Reduced-sediments with > 50% mud	1	3	0	0
Muddy-sand	Sand with > 20% mud	14	7	24	24
Sand	Fine, medium, and coarse grained sands	56	23	12	12
Gravelly-sand	Sand with dispersed > 20% pebbles/cobbles	4	7	14	13
Pebble-gravel	Pebbles	2	0	0	0
Pebble-cobble gravel	Pebbles and cobbles only	0	0	0	2
Boulder-gravel	Pebble and cobbles with > 10% boulders	0	0	0	4
Total		**90**	**49**	**52**	**57**

Table 3.2 Depth class representation by sampling sites
Number of sampling sites of each depth class for the two study areas.

Depth Class	Sachs Harbour		Gjoa Haven	
	Grab	Video	Grab	Video
0-10	67	24	18	23
10-20	17	13	18	18
20-40	6	12	16	16
Total	**90**	**49**	**52**	**57**

3.3 SPECIES RICHNESS

Species richness of macroflora and fauna was significantly greater in Gjoa Haven (n=97) than in Sachs Harbour (n=83) (ANOVA, F=4.26, df=2, P=0.04). Species richness increased with depth and was most diverse among the (20-40 m) depth class for video sampled material for the Sachs Harbour study area (Figure 3.2). Differences in species richness among depth classes for the video sampled material in Gjoa Haven were not significant (ANOVA, F=0.835, df=2, P=0.441; n=52). Overall, species richness among depth classes for the two locations was not significant among grabs (ANOVA, F=0.746, df=2, P=0.477; n=102) or video (ANOVA, F=0.228, df=2, P=0.797; n=88) (Figure 3.3).

For the video sampled material, species richness was greatest in the mud and gravelly-sand substrate for the Sachs Harbour study area, while muddy-sand and pebble-cobble-gravel was greatest for the Gjoa Haven study area (Figure 3.4). Gravelly-sand and mud substrates had the greatest diversity among the grab sampled material for both locations (Figure 3.5). Overall, differences in species richness among substrates were not significant among video (ANOVA, F=0.305, df=5, P=0.908; n=88; Figure 3.4) or grabs (ANOVA, F=0.653, df=3, P=0.585; n=102) (Figure 3.5).

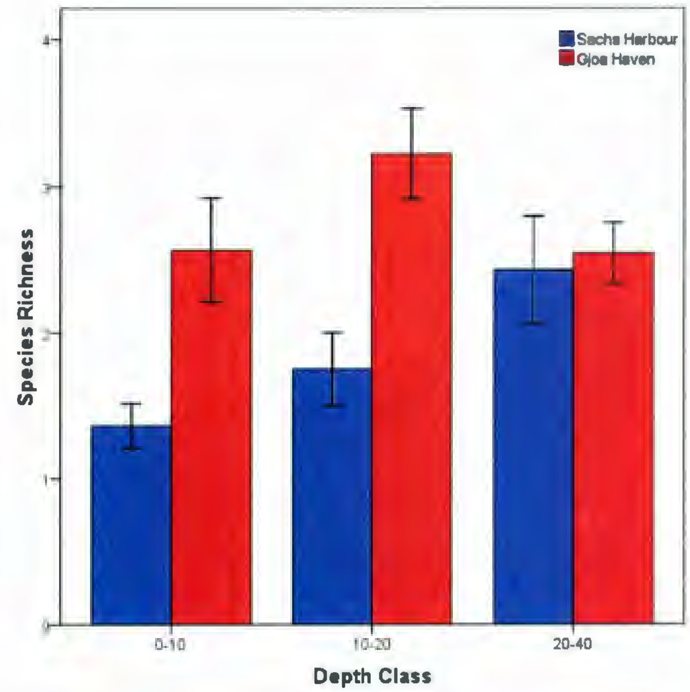

Figure 3.2 Average species richness among depth classes for video sampled material. Error bars represent ±1 SE.

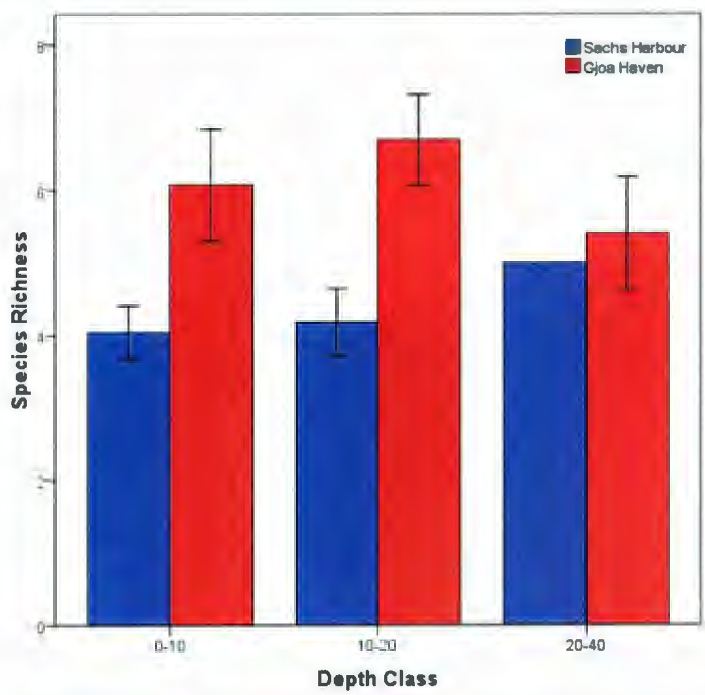

Figure 3.3 Average species richness among depth classes for grab sampled material. Error bars represent ±1 SE.

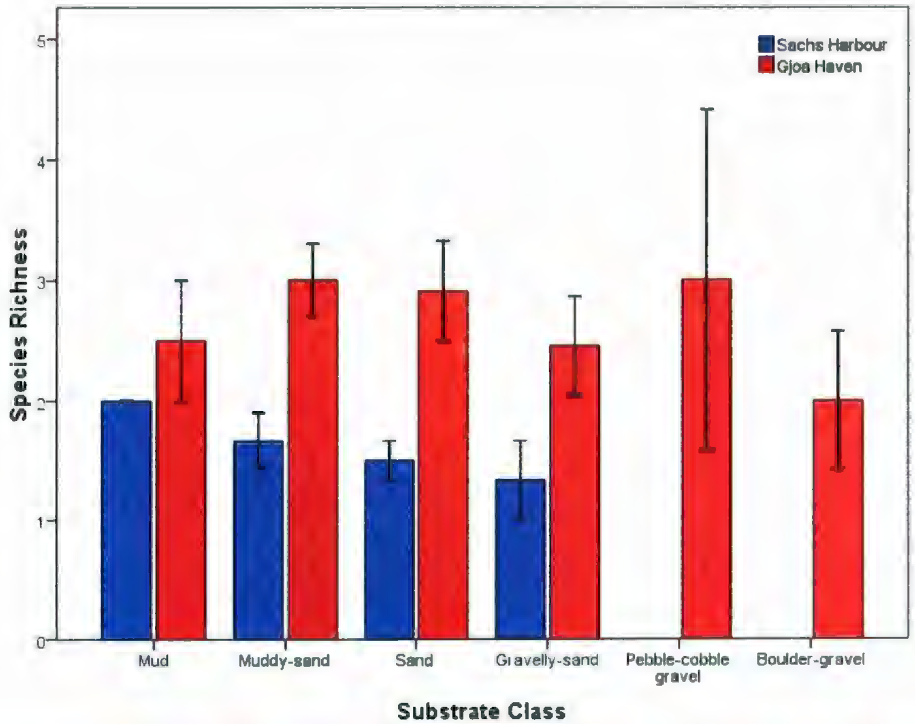

Figure 3.4 Average species richness among substrate classes for video sampled material. Error bars represent ±1 SE.

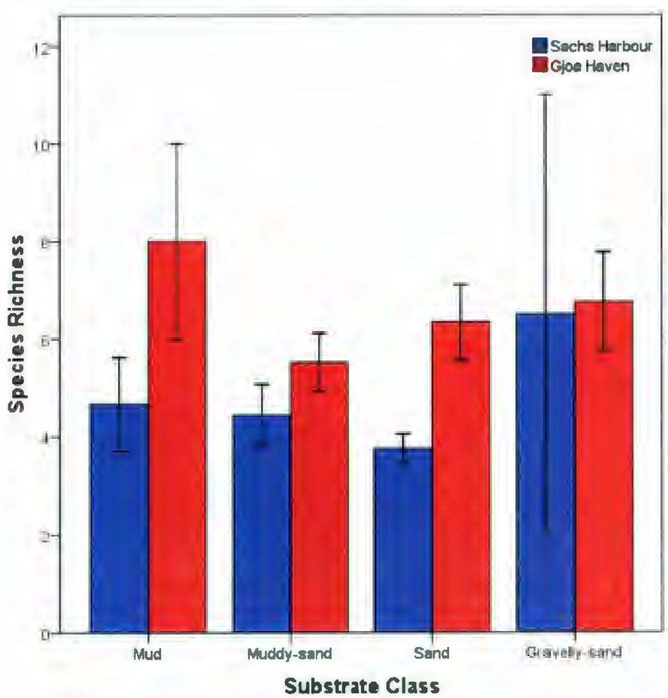

Figure 3.5 Average species richness among substrate classes for grab sampled material. Error bars represent ±1 SE.

3.4 SPECIES COMPOSITION

The species composition (flora and fauna) of Sachs Harbour samples differed greatly from that of Gjoa Haven samples for the video and grab (Figure 3.6; 3.7). Stress levels in three-dimensional MDS plots were much lower for video sampling (0.03), than for grab sampling (0.12). ANOSIM analysis confirmed that the two locations were significantly different for species composition collected by video (78 sites, $R=0.533$, $P<0.01$) and grab (102 sites, $R=0.262$, $P<0.01$).

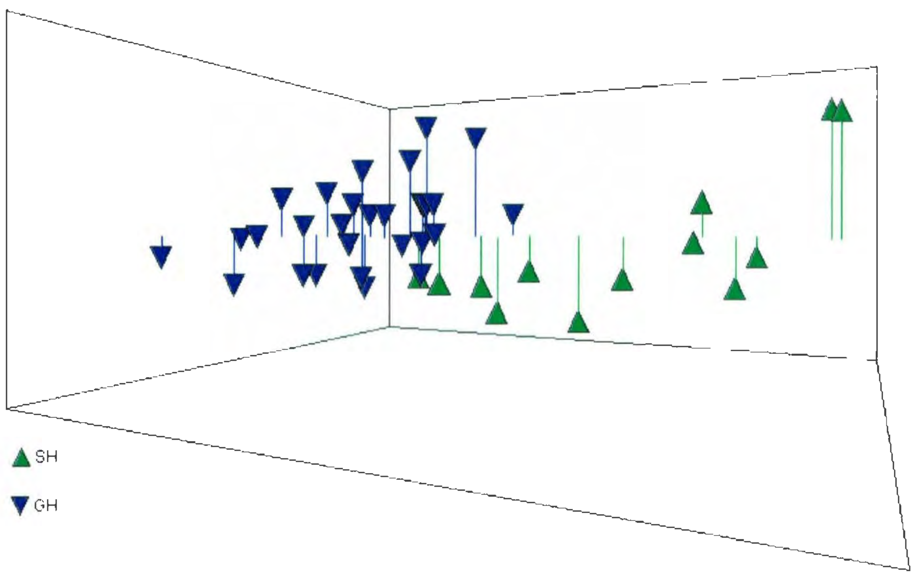

Figure 3.6 3D multidimentional (MDS) plot of taxa presence/absence data from video samples with points coloured to represent Sachs Harbour (SH) and Gjoa Haven (GH) (stress value= 0.03).

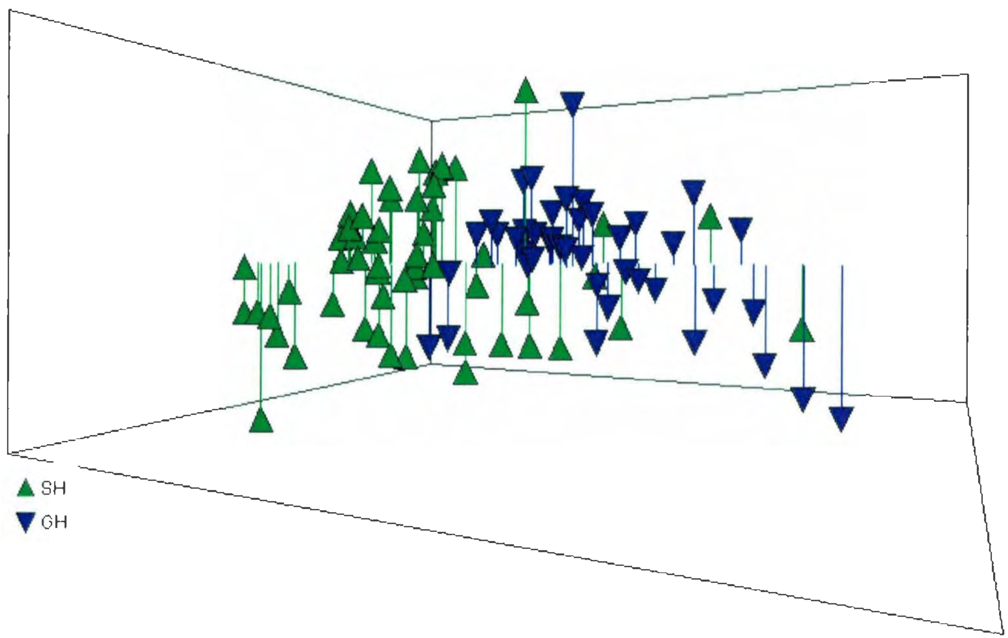

Figure 3.7 3D multidimentional (MDS) plot of taxa presence/absence data from grab samples with points coloured to represent Sachs Harbour (SH) and Gjoa Haven (GH) (stress value= 0.12).

Species composition for video varied significantly among depth classes (ANOSIM, 78 sites, $R=0.175$, $p<0.01$) but not among substrate types (Figure 3.8). Note that the MDS plot (3D) with the lowest stress value was presented in this paper because of its greater reliability. All depth classes were significantly different from one another. The shallow (0-10) and deep (20-40) depth classes differed the greatest from one another (ANOSIM, 78 sites, $R=0.282$, $p=0.001$). Species composition for grabs was significantly different among substrate types (ANOSIM, 102 sites, $R=0.076$, $p=0.015$) (Figure 3.9). ANOSIM analysis demonstrated that substrate classes: mud and muddy-sand ($R=0.032$, $P=0.13$), mud and gravelly-sand ($R=0.31$, $P=0.003$), and muddy-sand and gravelly-sand ($R=0.159$, $P=0.04$) were significantly different from one another (Table 3.3). Sand appeared to be highly variable, showing no significant differences among all other substrate classes (Table 3.3).

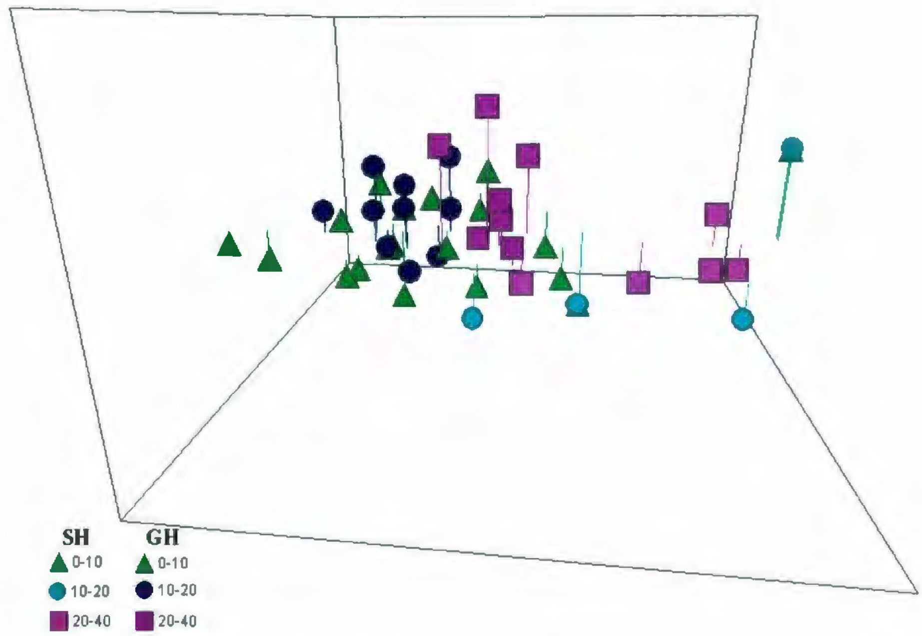

Figure 3.8 3D multidimentional (MDS) plot of taxa presence/absence data from video samples with points coloured to represent the three depth classes for Sachs Harbour (SH) and Gjoa Haven (GH) (stress value= 0.03).

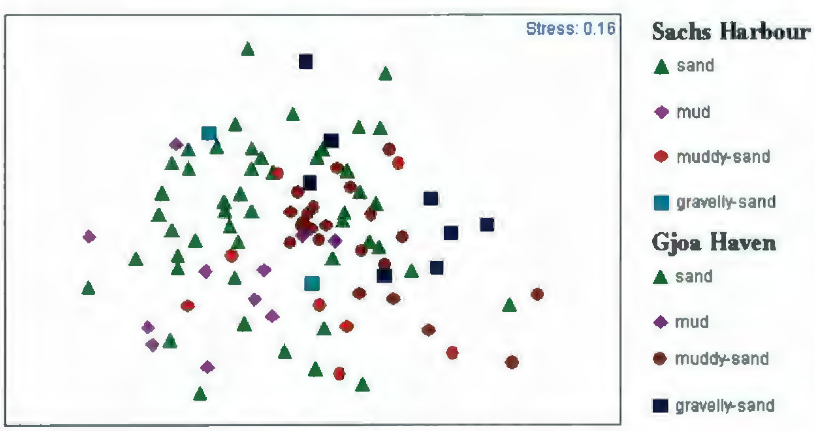

Figure 3.9 2D multidimentional (MDS) plot of taxa presence/absence data from grab samples with points coloured to represent the substrate classes for Sachs Harbour (SH) and Gjoa Haven (GH).

Table 3.3 ANOSIM results for Sachs Harbour and Gjoa Haven species composition among substrate classes for grab samples. (n=102 sites)

	Mud	Muddy-sand	Gravelly-sand
Sand	NS (*R=0.033, P=0.28*)	NS (*R=0.032, P=0.13*)	NS (*R=0.089, P=0.07*)
Mud		*R=0.268, P=0.003*	*R=0.31, P=0.003*
Muddy-sand			*R=0.159, P=0.04*

ANOSIM analysis verified that Sachs Harbour species composition was significantly different among depth classes for video (26 sites, *R=0.202, P=0.014*) and substrate classes for grab sampled material (57 sites, *R=0.076, P=0.015*). Species composition for the Gjoa Haven study area varied significantly among substrate and depth for video (ANOSIM, 52 sites, *R=0.221,0.461, P<0.01*) (Table 3.4). Faunal species composition for grab was significantly different among depth classes (ANOSIM, 45 sites, *R=0.182, P<0.01*) and demonstrated a weak difference among substrate classes (ANOSIM, 45 sites, *R=0.13, P=0.05)* (Table 3.5).

Table 3.4 ANOSIM results for species composition (flora and fauna) among depth and substrate factors for video (V) and grab (G) material.

Factor		**Sachs Harbour**		**Gjoa Haven**	
		Pres/absence	Relative Abundance	Pres/absence	Relative Abundance
Depth	**V**	n=26, *R=0.202, P=0.014*	n=26, *R=0.222, P=0.006*	n=52, *R=0.461, P=0.001*	n=52, *R=0.425, P=0.001*
	G	NS (n=58, *R=0.00, P=0.49*)	-	NS (n=45, *R=-0.034, P=0.90*)	-
Substrate	**V**	NS (n=26, *R=-0.049, P=0.77*)	NS (n=26, *R=-0.04, P=0.70*)	n=52, *R=0.221, P=0.001*	n=52, *R=0.303, P=0.001*
	G	n=58, *R=0.132, P=0.015*	-	NS (n=45, *R=-0.046, P=0.72*)	-

Table 3.5 ANOSIM results for fauna species composition among depth and substrate factors for video (V) and grab (G) material. NS=non significant.

Factor		Sachs Harbour		Gjoa Haven	
		Pres/absence	Relative Abundance	Pres/absence	Relative Abundance
Depth	**V**	NS (n=17, *R=0.069, P=0.16*)	NS (n=17, *R=0.046, P=0.24*)	n=20, *R=0.772, P=0.001*	n=20, *R=0.697, P=0.001*
	G	NS (n=56, *R=0.026, P=0.34*)	-	n=44, *R=0.182, P=0.001*	-
Substrate	**V**	NS (n=17, *R=-0.061, P=0.64*)	NS (n=17, *R=-0.011, P=0.50*)	n=20, *R=0.229, P=0.032*	n=20, *R=0.251, P=0.04*
	G	NS (n=56, *R=0.086, P=0.09*)	-	n=44, *R=0.13, P=0.05*	-

Overall, six taxa for Sachs Harbour and seven taxa for Gjoa Haven (Table 3.6) were very common, each contributing more than 5% to total-group similarity for each study area. Four of the six taxa for Sachs Harbour were characteristic for the grab samples, contributing 65% and two of the six taxa were characteristic for the video contributed 99% to the total-group similarity (Table 3.6). In Gjoa Haven four of the seven taxa were characteristic for the grab samples and three of the seven taxa were characteristic for the video contributing 63 and 70%, respectively to the total-group similarity (Table 3.6). Characteristic taxa (Table 3.6) in the two locations were very different, with only one polychaete Family (Nephtyidae) characteristic of both locations.

Six algal taxa contributed the greatest dissimilarity between the two locations for video-sampled material (Table 3.7). Of these taxa, *Fucus sp.* and *Coccotylus truncatus* were widespread in Gjoa Haven but rarely found in Sachs Harbour. Four bivalves and five polychaete families contributed the greatest dissimilarity between the two locations for grab sampled material. Of these, the bivalve *Thyasira sp* and species from polychaete Family Opheliidae were found only in Sachs Harbour.

Table 3.6 Characteristic taxa in the two study areas. (A Algae, B Bivalvia, C Crustacea, P Polychaeta).

	Grab	Video
Sachs Harbour	Family Nephtyidae (34%) (P)	Algal mat (50%) (A)
	Gemma gemma (20%) (B)	*Hyas coarctatus* (49%) (C)
	Family Opheliidae (6%) (P)	
	Family Phyllodocidae (5%) (P)	
Gjoa Haven	*Astarte montagui* (28%) (B)	*Coccotylus truncatus* (27%) (A)
	Yoldia myalis (15%) (B)	*Fucus sp.* (25%) (A)
	Family Malanidae (15%) (P)	Filamentous green algae (18%) (A)
	Family Nephtyidae (5%) (P)	

CTGS=Contribution to total-group similarity, derived from SIMPER analysis. CTGS for each characteristic taxa is given in parentheses.

Table 3.7 Distinguishing taxa contributing to dissimilarity in the two study areas. (A Algea, B Bivalvia, C Crustacea, P Polychaeta, E Echinodermata).

	Grab	Video
Sachs Harbour	*Gemma gemma* (4%) (B)	Algal mats (14%) (A)
	Family Opheliidae (2%) (P)	*Hyas coarctatus* (13%) (C)
	Family Phyllodocidae (2%) (P)	*Echinarachinus parma* (3%) (E)
	Family Nephtyidae (6%) (P)	
	Macoma calcarea (1%) (B)	
Gjoa Haven	*Astarte montagui* (8%) (B)	Filamentous green algae *(10%) (A)*
	Yoldia myalis (6%) (B)	*Fucus sp. (13%) (A)*
	Family Malanidae (6%) (P)	*Sphacelaria sp.* (9%) (A)
	Family Orbiniidae (4%) (P)	*Coccotylus truncatus (13%) (A)*
	Sphacelaria sp. (3%) (A)	*Saccharina longicruris* (7%) (A)

CTDS=Contribustion to total-group dissimilarity, derived from SIMPER. CTDS for each characteristic taxa is given in parentheses.

3.5 HABITAT MAPPING

3.5.1 Derived Habitat Classification

Thirteen groups of sampling sites clustered across MDS analyses and were statistically different from one another for the two study areas. Each study area was analyzed separately to determine the dominant habitat groups for the area. Stress levels in two-dimensional MDS plots ranged from 0.01 to 0.16. Common species, substrate class, and depth class were used to describe the habitat groups (see Appendix H). ANOSIM analysis verified that the derived groups were significantly different from each other (Table 3.8).

Table 3.8 ANOSIM results for flora and fauna species composition among habitat groups. Habitats E and G are not included in the table, as no species were found in either

	B	C	D	F	H	I	J	K	L	M
A	p=0.001	p=0.002	p=0.0001	p=0.001	p=0.001	p=0.001	p=0.001	p=0.001	p=0.001	p=0.001
B		p=0.001	p=0.002	p=0.04	p=0.001	p=0.001	p=0.001	p=0.001	p=0.001	p=0.001
C			p=0.003	p=0.003	p=0.001	p=0.001	p=0.001	p=0.001	p=0.001	p=0.001
D				p=0.04	p=0.001	p=0.001	p=0.001	p=0.001	p=0.001	p=0.001
F					p=0.001	p=0.001	p=0.001	p=0.001	p=0.001	p=0.001
H						p=0.001	p=0.001	p=0.001	p=0.001	p=0.001
I							p=0.03	p=0.04	p=0.04	p=0.001
J								p=0.04	p=0.002	p=0.008
K									p=0.002	p=0.008
L										p=0.004

Habitat E and G are not included in this table; no species were found in either group.

the anoxic muds or the barren ice-scoured sands and gravels

3.5.2 Description of Habitat Groups for the Sachs Harbour Study Area

Shallow (<10 m) mobile sand sheets with low biodiversity were the dominant habitat sampled in the study area (Figure 3.10a). Group A represents this habitat and accounts for 45% of the total sampled sites (Figure 3.12; Table 3.12). This habitat group was found just west of the outer basin, and continued along the coastline of the Duck Hawk Bluffs. Polychaete species from the family Nephthydidae was the dominant taxa found within this habitat. Deposit-feeding and carnivorous polychaete families dominated this habitat. Sparse mats of algae were found within this area. Refer to Figure 3.11 for the habitat map boundaries for Figure 3.12, 3.13, 3.14.

Group B sites were algal mats with low diversity (average no. taxa=2) with sand and muddy-sand substrates (Figure 3.10b). This group was distributed in the inner and outer basin of the harbour and in the two basins east of the community, along the Sachs River Estuary (Figure 3.13). Deposit feeding bivalve, *Yoldia myalis* and carnivorous polychaete family Nephthydidae were the most dominant species in this habitat.

Group C stood out as having relatively high diversity (average no taxa=6). This group was mostly distributed in the inner and outer basin of the harbour. Macrobenthos of Group C were dominated by bivalves and algae (Figure 3.10c). Deposit-feeding bivalve, *Macoma calcarea* and suspension-feeding bivalve *Thyasira sp* accounted for two of the most dominant species of this habitat. Red algae, *Coccotylus truncatus* and algal mats were the dominant algal taxa. Species from 17 polychaete families were found in this habitat group.

Group D covered 2 sites in the outer basin that were muddy-sand at depths greater than 30 m. Sites within this Group were dominated by tube anemone *Cerianthus borealis* and toad crab *Hyas coarctatus alutaceaus*. Group F was an estuarine shallow muddy-sand environment dominated by red algae *Coccotylus truncatus* (Figure 3.10e). Occasional mats of algae were present in sampling sites of this habitat group.

Figure 3.10a: Habitat A, Shallow low diversity sands

Figure 3.10b: Habitat B, Algal Mats

Figure 3.10c: Habitat C, Diverse Muds

Figure 3.10d: Habitat D, Cerianthid Beds

Figure 3.10 Habitat Groups for Sachs Harbour.

Figure 3.10e: Habitat F, *Coccotylus truncatus* dominated

Figure 3.10f: Habitat G, Barrens sands and gravels (note evidence of ice scouring the seabed)

Figure 3.10 Habitat Groups for Sachs Harbour.

Figure 3.11 Sachs Harbour habitat map boundaries for Figures 3.12, 3.13, 3.14.

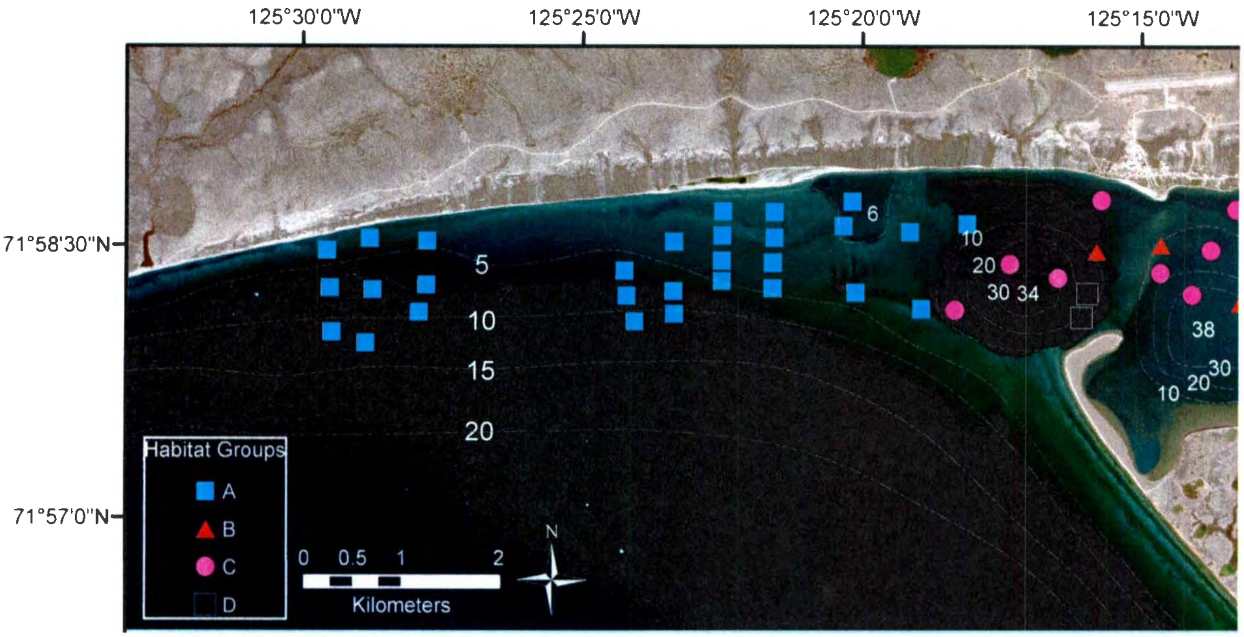

Figure 3.12 Sachs Harbour study area showing habitat groups near to the community. Letters refer to habitat groups as follows: A, shallow low diversity sands B, algal mats; C, diverse muds; D, Cerianthid beds. Numbers refer to depth contours. (modified from imagery © Digital Globe 2005)

Table 3.9 Species composition and characteristics of derived habitat groups for the Sachs Harbour study area.

Group	No. Sites	Av. No. Taxa	Dominant taxa (>10% CTGS)
A Shallow low diversity sands	29	4	F. Nephtyidae (54%) g
B Algal Mats	12	2	Algal mats (98%) v *Yoldia myalis* (35%) g F. Nephtyidae (31%) g
C Diverse muds	11	6	*Coccotylus truncatus* (56%) v *Thyasira sp* (49%) g Algal mats (44%) v *Macoma calcarea* (13%) g F. Opeliidae (12%) g
D Cerianthid Beds	2	2	*Cerianthus borealis* (80%) v *Hyas coarctatus* (20%) v
E Anoxic Muds	5	0	n/a
F *Coccotylus truncatus* dominated	3	2	*Coccotylus truncatus* (75%) v Algal mats (25%) v
G Barrens sands and gravels	6	0	n/a

CTGS = Contribution to total-group similarity, derived from SIMPER analysis. CTGS for each dominant taxon is given in parentheses.
v – collected by video; g – collected by grab

Group E and G highlight sites with no taxa found. Group E were deep anoxic muddy environments located in the two basins along the Mary Sachs estuary (Figure 3.13). Group G covered six sites in the most western part of the study area, off the Cape Kellett sandspit (Figure 3.14). Sites in Group G were barren sands and gravels between 0 and 20 m depth (Figure 3.10f). Pebble-cobble gravel substrates were observed in the inshore area, while sandy substrates were found at about 10 m depth and below.

Site CK3-3 did not group with any of the other habitat groups (Figure 3.14). This site was a shallow gravelly-sand environment with unusually high species richness (s=11) for one site. The surrounding sampling sites within this area fell within Group G (barren sands and gravels). The seabed of this site was dominated by red algae, *Coccotylus truncatus*. Three other algae species were present at this site, along with four bivalves, and taxa from three deposit-feeding polychaete families.

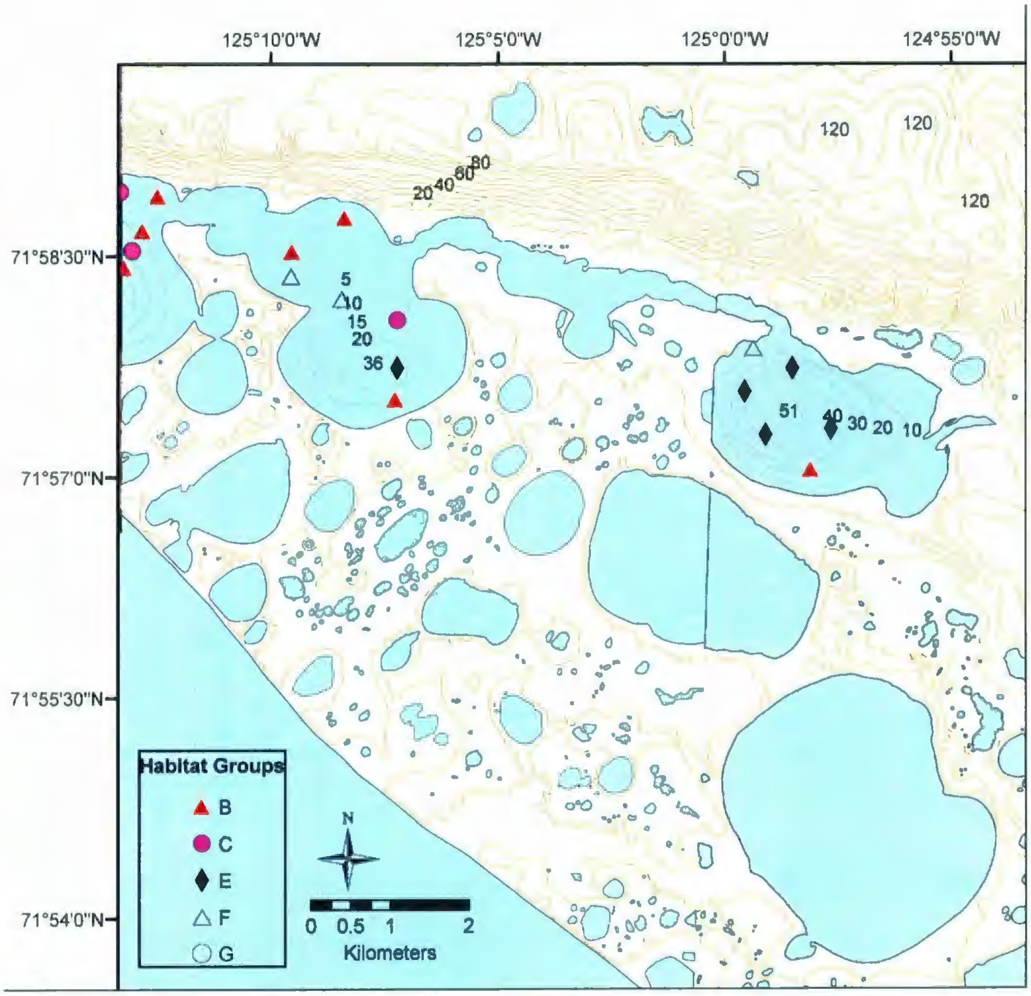

Figure 3.13 Sachs Harbour study area showing habitat groups along the Mary Sachs Estuary, located east of the community. Letters refer to habitat groups as follows: B, algal mats; C, diverse muds; E, anoxic mud; F, coccotylus dominated; G, barren sands and gravels. Numbers refer to depth and elevation contours.

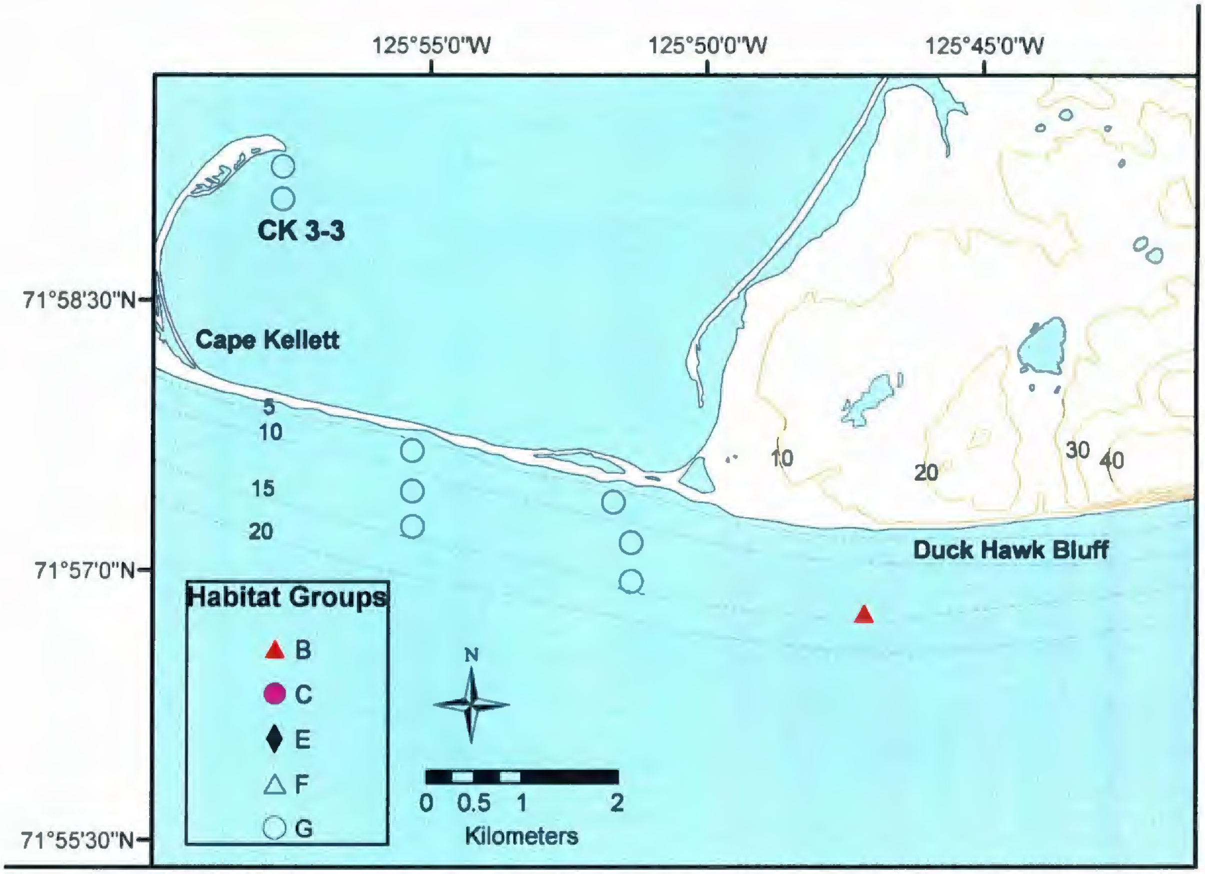

Figure 3.14 Sachs Harbour study area showing habitat groups along Cape Kellett, located west of the community. Letters refer to habitat groups as follows: B, algal mats; G, barren sands and gravels. Numbers refer to depth and elevation contours.

3.5.3 Description of Habitat groups for the Gjoa Haven study area

Groups H and I had the greatest number of taxa per grab (5 taxa) (Table 3.10). Group H was a deep (10-40 m) muddy environment dominated by filamentous green algae (Figure 3.15a; 3.18). The dominant fauna in this habitat were two deposit-feeding bivalves (*Yoldia myalis; Astarte montagui)*, suspension-feeding polychaetes from the family Malanidae, and carnivorous polychaetes from the family Nephtyidae. This habitat group was found mainly west of Betzold Pt., and in the deeper sites off Lund Island.

Table 3.10 Species composition and characteristics of derived habitat groups for the Gjoa Haven study area.

Group	No. Sites	Av. No. Taxa	Dominant taxa (>10% CTGS)
H Deep muddy substrates	12	5	filamentous green algae (88%) v
			Yoldia myalis (30%) g
			Astarte montagui (23%) g
			F. Malanidae (18%) g
			F. Nephtyidae (14%)g
I Sands with diverse macroalgae beds	18	5	*Sphacelaria* sp. (38%) v
			Coccotylus truncatus (22%) v
			Fucus sp. (20%) v
			fimlamentous green algae (15%) v
			Astarte montagui (33%) g
J Fucus sp. dominated gravelly-sand	8	4	*Fucus sp.* (97%) v
K Shallow gravels	5	3	*Fucus sp.* (97%) v
L Gravel with kelp beds	6	4	*Coccotylus truncatus* (42%) v
			Saccharina longicruris (39%) v
			Fucus sp. (18%) v
			Astarte montagui (43%) g
			Retusa obtusa (28%) g
			Hiatella arctica (15%) g
			Family Maldanidae (15%) g
M Shallow sands with *Molgula sp.*	4	4	*Molgula sp.* (60%) v
			filamentous green algae (37%) v
			F. Orbiniidae (30%) g
			F. Maldanidae (14%) g

CTGS = Contribution to total-group similarity, derived from SIMPER analysis. CTGS for each dominant taxon is given in parentheses

v = collected by video, g = collected by grab

Group I was a sand and muddy-sand environment, mostly within the 0-20 m depth range, with diverse macroalgae beds (Figure 3.15b). *Sphacelaria sp.*, *Coccotylus truncatus*, *Fucus sp.*, and filamentous green algae, together, were responsible for 95% of the overall similarity within Group I. *Astarte montagui* was a common species found within habitat Group I. Group I was found mainly along the eastern coastline of Peterson Bay and in the shallow sample sites east of the community, towards Betzold Point (Figure 3.17; 3.18).

Figure 3.15a: Habitat H, Deep muddy substrates

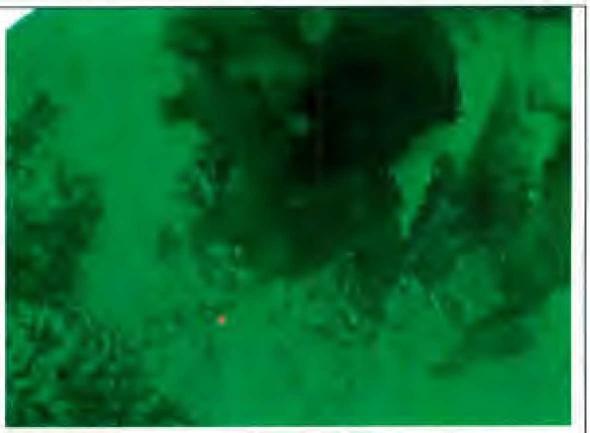

Figure 3.15b: Habitat I, Sands with diverse macroalgae beds

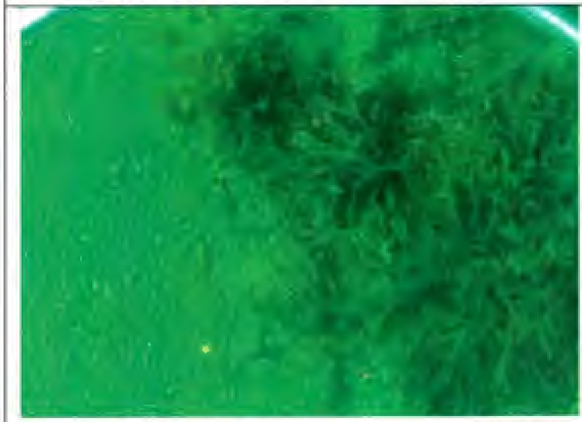

Figure 3.15c: Habitat J, *Fucus sp.* dominated gravelly-sand

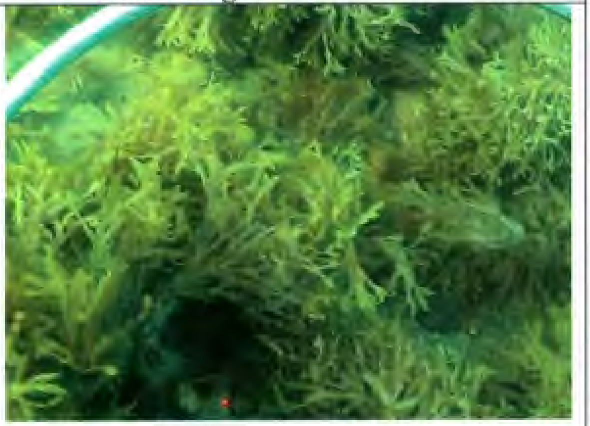

Figure 3.15d: Habitat K, Shallow gravels

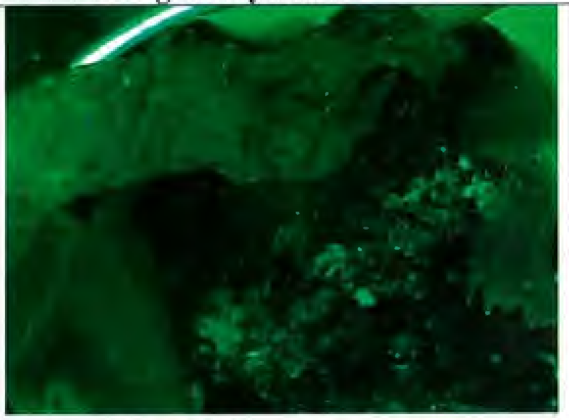

Figure 3.15e: Habitat L, Gravel with kelp beds

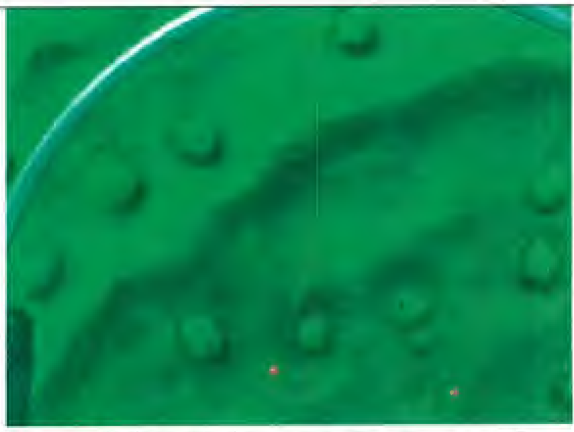

Figure 3.15f: Habitat M, Shallow sands with *Molgula sp.*

Figure 3.15 Habitat Groups for Gjoa Haven.

Groups J and K were shallow nearshore environments dominated by *Fucus* beds. These groups were mainly found along the eastern and western portion of Peterson Bay (Figure 3.18). Group J was a gravelly-sand environment with *Fucus sp.* and filamentous green algae coverage (Figure 3.15c), whereas K was pebble-cobble gravel and boulder-gravel substrates with greater coverage of *Fucus* beds (Figure 3.15d). Group K was only successfully sampled by video. Group J had 3 deposit-feeding bivalves (*Macoma calcarea, Astarte montagui, and Astarte sp.*), sparse pockets of tunicates (*Molgula sp.*), and polychaete species from 6 families.

Group L were gravelly-sands and pebble-cobble gravel substrates dominated by *Coccotylus truncatus*, *Saccharina longicruris*, and *Fucus sp* (Figure 3.15e). The gravelly-sand sites covered three sites in the western portion of Peterson Bay (Figure 3.18), while the pebble-cobble gravel sites covered four sites around Lund Island (Figure 3.17). The dominant fauna present within this habitat group were three bivalves (*Astarte montagui, Retusa obtusa, and Hiatella arctica*), and suspension-feeding polychaetes from the family Maldanidae.

Group M was a shallow sandy environment dominated by the tunicate *Molgula sp.* and filamentous green algae (Figure 3.15f). Group M accounted for four sites, which were dispersed throughout the study area. Two polychaete families, Orbiniidae and Malanidae were responsible for 44% of the overall similarity within the group sampled by grabs.

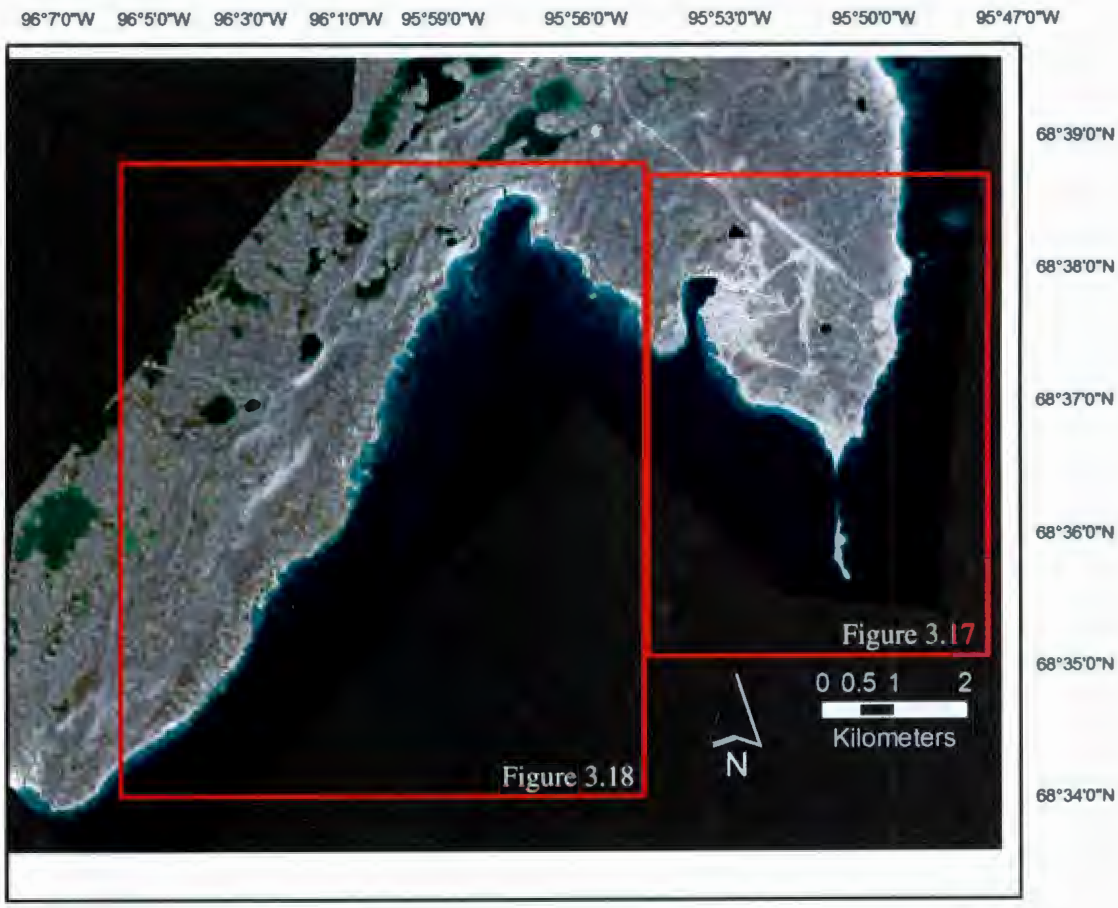

Figure 3.16 Gjoa Haven habitat map boundaries for Figures 3.17 and 3.18.

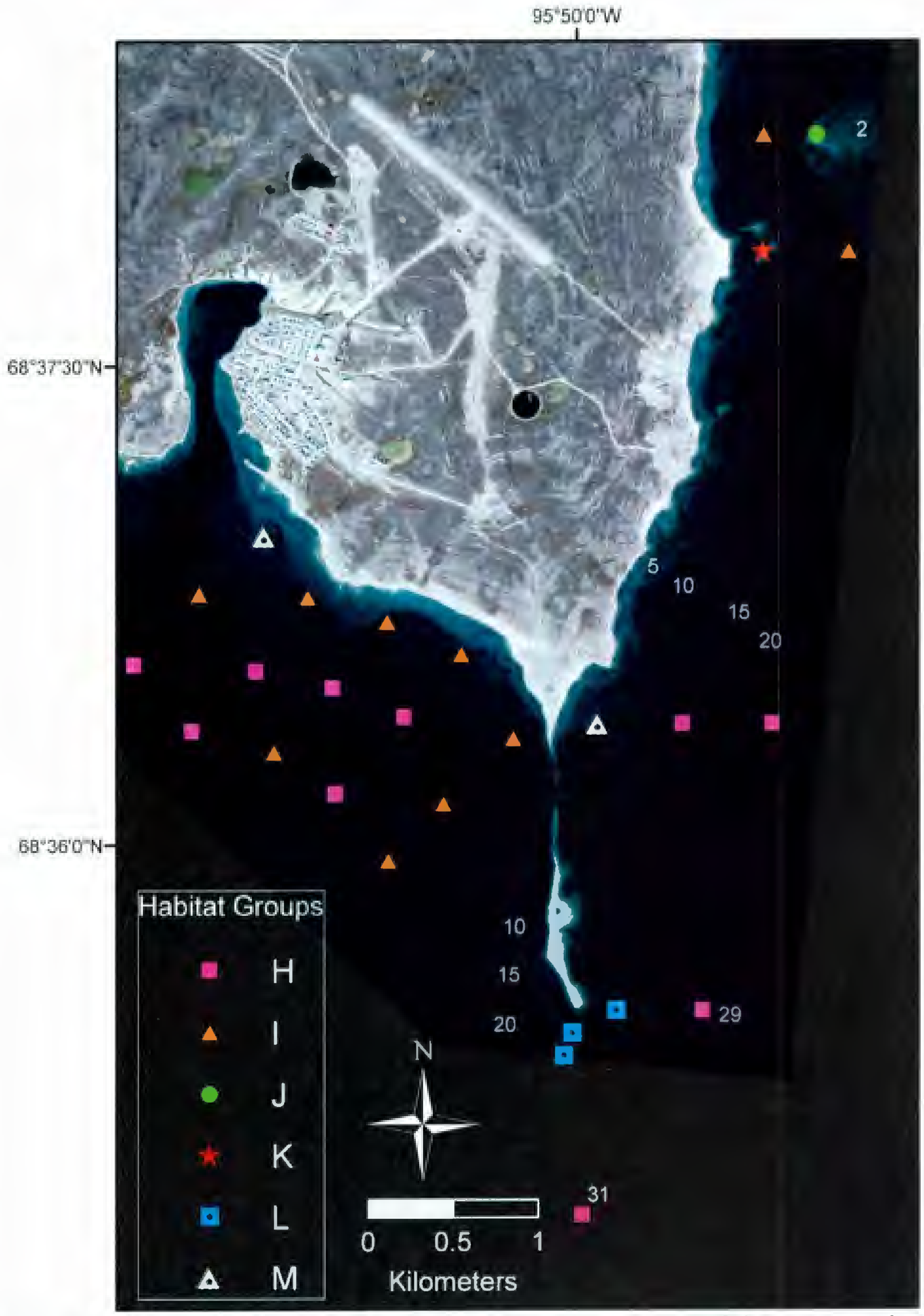

Figure 3.17 Gjoa Haven study area showing habitat located east of the community. Letters refer to habitat groups as follows: H, deep muddy substrates; I, sands with diverse macroalgae beds; J, *Fucus sp.* dominated gravelly-sands; K, shallow pebble-cobble and boulder gravels; L, gravels with kelp beds; M, shallow sands with *Molgula sp.* Numbers refer to depth contours. (modified from imagery © Digital Globe 2006)

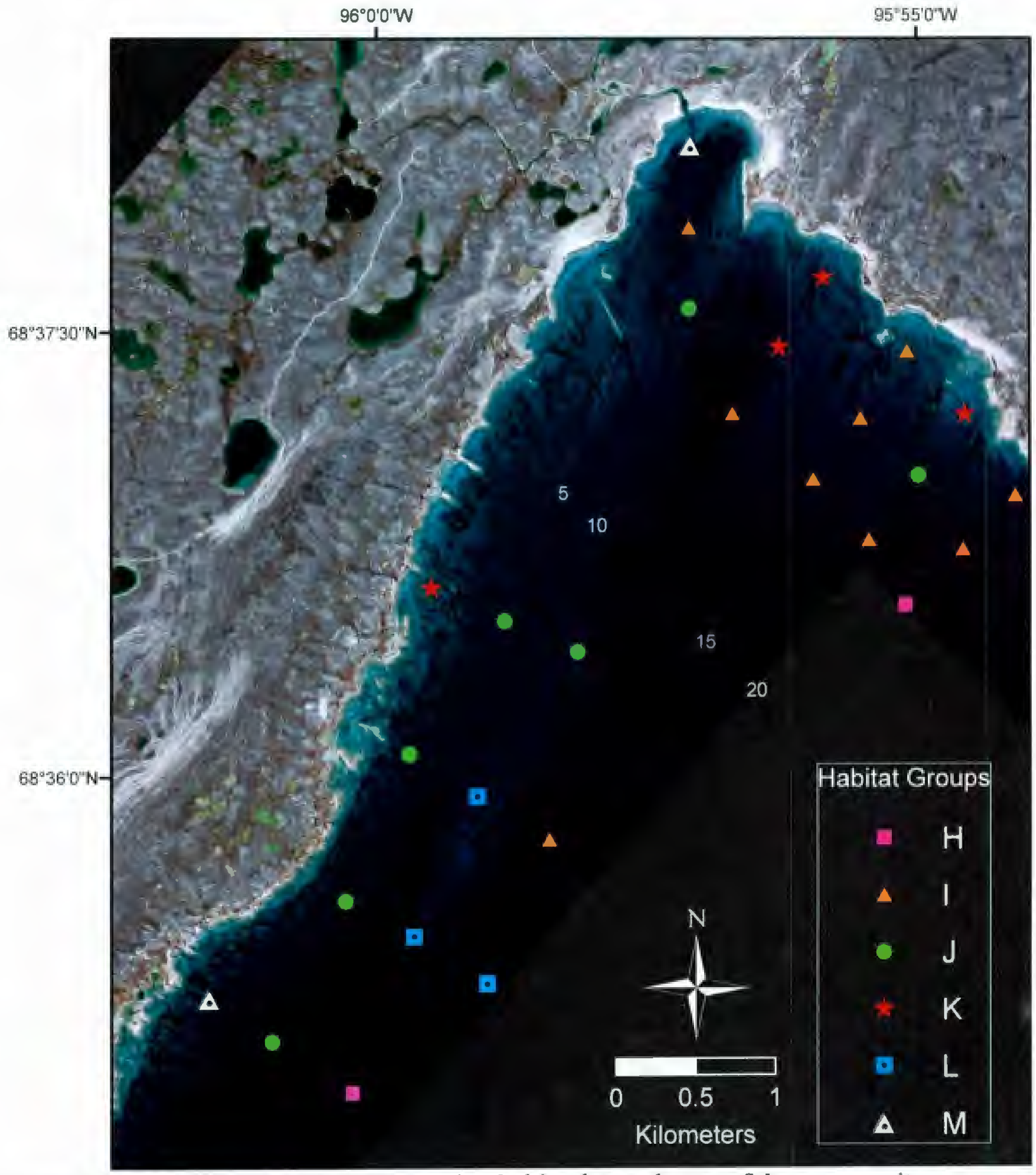

Figure 3.18 Gjoa Haven study area showing habitat located west of the community. Letters refer to habitat groups as follows: H, deep muddy substrates; I, sands with diverse macroalgae beds; J, *Fucus sp.* dominated gravelly-sands; K, shallow pebble-cobble and boulder gravels; L, gravels with kelp beds; M, shallow sands with *Molgula sp.* Numbers refer to depth contours. (modified from imagery © Digital Globe 2006)

CHAPTER FOUR DISCUSSION

4.1 INTRODUCTION

This study described and classified benthic habitats of two near-shore Arctic locations associated with different degrees of coastal erosion on the basis of sediment characteristics, water depth, and dominant benthic species assemblages. This information was interpreted from grab samples and drop-video transects. Previous Arctic subtidal studies have generally used a descriptive approach to classify macrobenthos composition within their study area (Heath et al. 1981; Thomas et al. 1982; Thomas and Heath 1982; Aitken and Fournier 1993; Siferd 2001; Leontonwich 2003). Studies of benthos in such reports typically use either grabs or video transects and rarely have used both sampling techniques together. Grabs and drop-video transects used adjacent to one another, provide information on the characteristics of the sea bottom and species composition of epifauna and infauna living within a surveyed area (Heath and Thomas 1984).

The use of drop-video transects instead of SCUBA allows for greater sampling coverage of a study area and collection of data at reduced expense. The major drawback of this approach is the loss of detail that would be retained with SCUBA; the presence of some epifaunal species may be missed using a drop-video camera as a result of speed of the camera over the seafloor and distance and pitch of the camera from the seafloor.

4.2 SPECIES COMPOSITION & RICHNESS

Overall, species composition differed significantly between the two study areas (See Appendix G; Table 4.1). Only one polychaete Family (Nephtyidae) was characteristic of both locations. This family was found in all substrate types and was the dominant taxon in deeper muddy-sand environments in Gjoa Haven and shallow sand environments in Sachs Harbour. Nephtyidae are carnivorous and typically inhabit sandy to muddy substrates (Rouse and Pleijel 2001). Polychaetes had the greatest species diversity for the two study areas. Mollusks and macroalgae accounted for the majority of the remaining taxa found within the two study areas. Mollusks accounted for 15-20% of the total number of species found within the two study areas. Macroalgae species accounted for only 11% of the total number of species found in Sachs Harbour, whereas algae species accounted for 21% in Gjoa Haven (Table 4.1). Deposit feeders dominated both polychaetes and mollusks in species richness for both Sachs Harbour and Gjoa Haven (See Appendix G; Table 4.1). Lalli et al. (1973) suggested that most Arctic benthic species appear to be deposit feeders.

One principle difference in the benthos at Gjoa Haven compared to Sachs Harbour was the presence of macroalgae attached to gravel substrates to depths of 25 m and beyond. Gjoa Haven demonstrated high macroalgae diversity and cover compared to Sachs Harbour, which was dominated by sparse algal mats in the shallow areas of the inner basin and Mary Sachs Estuary. Both Gjoa Haven and Sachs Harbour had close to 100 benthic fauna species, however 26 macroalgae species were found in Gjoa Haven in contrast to only 10 macroalgae species found in Sachs Harbour (See Appendix G; Table 4.1).

Table 4.1 Total number of macrofauna and macroalgae species found in Gjoa Haven and Sachs Harbour.

	Gjoa Haven	**Sachs Harbour**
Macrofauna species	98	80
Polychaetes species	62	52
Deposit feeding	35	27
Carnivorous feeding	20	17
Suspension feeding	7	8
Mullusca species	25	18
Deposit feeding	12	6
Suspension feeding	5	5
Macroalgae species	26	10
Total species	**124**	**90**

Coccotylus truncatus and *Fucus sp.* were ubiquitous in the Gjoa Haven study area. Large kelp species, such as *Saccharina longicruris* were found along the western coastline of Peterson Bay and surrounding Lund Island, located just south of Betzold Pt. This exceptional contrast of macroalgae diversity and cover between the two locations is likely a result of differences in the nature of the substrate and degree of long-term sediment deposition into the nearshore area. The nature of Gjoa Haven's substrate, such that pebbles and cobbles are dispersed throughout the study area provides a suitable attachment surface for many algal species. These macroalgae species are an important habitat and food source for many epifauna species, such as sea urchins and gastropods (Harvey-Clark 1997), which may contribute to the greater benthic faunal species diversity found in the Gjoa Haven study area. The presence of macroalgae and gravel substrates also increases the structural heterogeneity of an area, and typically the number of species found within this area increases (Bruno and Bertness 2000). For example, the gravel substrates support attached epibenthos such as sea urchins, starfish, and brittle stars.

High species richness found in Gjoa Haven may be attributed to its sediment-starved low-energy environment. Very little sand from the land is being deposited into the nearshore marine environment, leaving gravel substrates exposed for epifauna and flora attachment. Alternatively Sachs Harbour is a moderate energy erosional environment at the shoreline most likely due to thermal erosion, demonstrated by the prograding beaches along the southwestern shoreline of Banks Island. The nearshore area is a depositional environment; demonstrated by the broad rippled sand sheets dominating the nearshore of this study area. The lower average faunal diversity in Sachs Harbour is possibly caused by the scarcity of habitat-structuring macroalgae and high rates of sedimentation and resuspension in the nearshore environment. Rapid coastal erosion of this coastline has resulted in continuing deposition of sand onto the nearshore marine environment. The low primary production by macroalgae is likely a result of the absence of pebble/cobbles present in the broad sand sheets dominating the study area. If once present, the exposed pebble/cobbles and attached macroalgae would have been buried by sand with time. Low primary production by macroalgae results in a reduced food supply and habitat for macrobenthos species.

4.3 UNREPORTED SPECIES AND SPECIES RANGE EXTENSION (*M. balthica*)

This study has brought to light previously unreported species and aspects of the macrobenthic communities of Sachs Harbour and Gjoa Haven. This is the most detailed comprehensive study carried out around the communities of Sachs Harbour and Gjoa Haven. This study identified ninety species in Sachs Harbour. Only one other study in 2001 completed a benthic survey (Siferd 2001) characterizing benthic communities in the Sachs Harbour inner and outer basin, the Sachs River Estuary, and Thesiger Bay, on the basis of epifauna from photographs collected along transects. Twenty-six species were reported in Siferd (2001) report (Table 4.2; Appendix 1), most of which were found in very low numbers. Differences in the epifauna species found in the Siferd (2001) survey and this study are likely due to sampling method. Siferd (2001) conducted the sampling transects using a drop video camera and SCUBA, using these two methods he was able to quantify abundance per unit area more effectively.

Table 4.2 Counts of species found at Sachs Harbour reported in Siferd (2001) and this study.

Higher Taxa	Siferd (2001)	This study
Chlorophyta	0	2
Phaeophyceae	2	6
Rhodophyta	0	2
Polychaeta	1	53
Bivalvia	7	11
Gastropoda	2	6
Crustacea	6	3
Cnidaria	3	1
Echinodermata	5	3
Sipunculid	0	2
Ascidiacea	0	1
Total	**26**	**90**

The circumboreal bivalve, *Macoma balthica* found in Gjoa Haven, indicates a possible range extension into the central Arctic. As previously mentioned in section 3.1, circumboreal *Macoma balthica* has a range gap that extends from the northwestern tip of Hudson Bay west, to the northwestern tip of Alaska (Dyke et al. 1996). In the North Atlantic *Macoma balthica* has been thought to have gain access to the Arctic basin from the North Pacific following the Pliocene opening of the Bering Strait (Väinölä 2003). A genetic subdivision distinguishes the *Macoma balthica* of the NE Pacific from those of the NE Atlantic. (Väinölä 2003; Hummel et al. 1997). Väinölä (2003) suggests that NE Atlantic and NE Pacific taxa be distinguished as sub-species. The reported findings of this species in Gjoa Haven suggest that this species has spread into the central Arctic, possibly extending its range from Baffin Bay, west. The expansion west of this circumboreal species may coincide with the recent rapid climate change of today. An inevitable consequence of climate change will be species range extension and resultant changes in community dynamics within marine ecosystems (ACIA 2005a; Mieszkowska et al. 2006).

4.4 DETERMINING FACTORS

Depth and substrate type are two important factors which influence species composition, diversity, and habitat structure (Etter and Grassle 1992; Kostylev et al. 2001). The current study found that variation in species composition appeared to be driven mainly by depth for video, and mainly by substrate for grabs for the two study areas. This implies a methological bias, such that video mainly analyses algae, which are likely to be zoned by light availability, while grab sampling analyzes infauna (e.g bivalves, polychaetes), which are likely zoned by substrate type. The variation in species richness appeared to be driven mainly by depth for both the Sachs Harbour and Gjoa Haven study areas.

Species richness was greatest among the (10-20 m) and (20-40 m) depth zone for the two study areas. Low species richness in the shallower areas (less than ten metres) is likely due to its rigorous environment for benthic organisms. For example three important physical factors acting in this environment are fast ice, which forms and remains attached to the shore, anchor ice, which is submerged ice attached or anchored to the bottom, and scouring of the seabed by sea ice. Fast ice can often cause decreased dissolved oxygen concentration in sediments (Lagoe 1979, Reimnitz et al. 1987). Anchor ice can rip off ice-trapped benthos from the seafloor when the ice aggregates and becomes too buoyant to stay attached (Barnes and Conlan 2007). Low diversity of benthic macrofauna in the intertidal zone and shallow nearshore areas is usually attributed to ice scouring (Ellis 1955; Gutt 2001; ACIA 2005c). Scouring of the seabed by pressure ridge keels is most predominant in shallow water depths (Heath and Thomas 1984). As noted above the movement of these ice keels through the sediment redistributes substrates and can eliminate benthos from scoured areas of the seabed (Conlan and Kvitek 2005). Consequences to benthos are loss of biomass, modification of abundance and diversity patterns, and change in community structure and function (Conlan et al. 1998; Gutt 2001; Conlan and Kvitek 2005). Although this study found no physical evidence for ice scour in either area during the drop video stations, the substrates of these two areas are inevitably affected seasonally by ice scouring and ice keel gouging, especially during times of ice break up and increased wind and storm activity. Sachs Harbour is more exposed and likely experiences more ice scour disturbance. The degree of disturbance within the two study areas is unknown, however, ice scour disturbances will likely play an important role in the abundance and diversity of species found in the shallower depth zones. Recolonization rates for Arctic benthos at 0 to 70 m depth after ice scouring have been estimated at 53 years (Gutt et al. 1996), however rates of recolonization after ice scouring are dependent on many factors and recovery time estimates may be variable. For example, Conlan and Kvitek (2005) found that after 9-years two of their studied ice scours were at 65% to 84% complete recovery. Factors affecting recolonization of ice scour disturbances are timing, size, type, location, and frequency of disturbance, physical-chemical characteristics and natural stability of the system, supply of colonizers, characteristics of colonizers, and biological interactions among the colonists (Conlan and Kvitek 2005).

Surprisingly, there was not a strong relationship between substrate and species richness. Generally benthic species composition is significantly correlated with sediment type (McIntyre 1969, Etter and Grassle 1992). Although there was not a strong relationship found between substrate and species richness, there were, however, some differences among species richness and substrate classes, which may be attributed to a few different factors. Muddy-sand and pebble-cobble gravel substrates for the video sampled material had the greatest diversity in Gjoa Haven. The high diversity in the pebble-cobble gravel is likely due to the heterogeneity of this substrate, which provides habitat and shelter for many benthos not available in an otherwise homogeneous environment, such as the broad sand sheets found in Sachs Harbour. As well, a heterogeneous substrate with pebbles and cobbles provides an attachment surface for many epibenthos species, such as sea urchins, starfish, brittle stars, and several species of macroalgae.

Physical factors such as deposition of sediment and resuspension of particulate matter can also influence benthic ecosystems. After rain/storm events the nearshore marine environment receives runoff from the land. Sediment runoff can be a source of disturbance to benthos in the nearshore environment. Based on field observations, it appears that the Sachs Harbour nearshore marine environment receives greater amounts of sediment runoff than Gjoa Haven. Sachs Harbour's coastline experiences rapid coastal erosion and is composed of unconsolidated sediments ranging from silt/clays with vegetative debris to medium to coarse sands. During the Sachs Harbour 2005 field season, a sister-study Belliveau (2007) assessed the impacts of climate change on the coastal geomorphology of southwestern Banks Island. Belliveau (2007) measured suspended particulate matter (SPM) at distances 100 m to 1000 m from shore before and after a wind/rain event along the southwest coast of Banks Island and found that areas sampled west of the community in locations of coastal retreat showed the largest increase in SPM after the event. The finer materials (e.g. silts/clays) and vegetative debris stay suspended longer in the water column and can travel further distances, in contrast to sediment produced from areas of medium to coarse sands which would rapidly settle from suspension. Field and laboratory experiments and surveys of macrofauna and sedimentation of silt/clay substrates have found that increased sediment deposition onto the seafloor can adversely affect macrofauna by reducing oxygen concentrations, altering grain size, and changing organic matter content (Norkko et al. 2000; Nicholls et al. 2003). Overall, the modification of these habitats due to elevated sedimentation has been shown to reduce overall habitat heterogeneity, resulting in lower diversity and reduced ecological functioning of ecosystems (Gibbs and Hewitt 2004).

Gjoa Haven, on the other hand is not eroding and has a coastline composed of sand with mixed cobbles and pebbles along with some glacial erratics. The main source of sediment into the marine system in Gjoa Haven is from a river mouth located at the head of Peterson Bay. Local observers in 2006 commented that mud plumes from the river occur typically during spring thaw, but are not commonly seen following rain events (B. Porter, personal communication, 2006).

4.5 MARINE HABITAT MAPPING

This study has used a comprehensive approach to describing the habitats present within these two study areas using analyses from drop video and grabs. The nearshore environments within these two study areas were classified into habitat type and defined on the basis of macroalgae and macrobenthos distributions. From this, descriptions were made of 7 habitat types in the Sachs Harbour study area and 6 habitat types in the Gjoa Haven study area. Each habitat type has a unique species assemblage and physical characteristic based on depth and substrate type. This approach of describing and mapping habitats demonstrates clearly that the differences in the environmental characteristics of the two study areas are accompanied by vast differences in diversity and species composition. Of particular interest are the shallow low diversity sands (Habitat group: A) dominating the Sachs Harbour study area extending from the outer basin to Cape Kellett. The rapidly eroding coastline of south-western Banks Island has impacted this nearshore marine environment with continual deposition of sand, resulting in a homogeneous mobile sand sheet environment. The nature of this environment yields limited habitat-structuring macroalgae and therefore low diversity of macro-flora and fauna. The diverse muds (Habitat group: C) were the most diverse habitat of Sachs Harbour and are found within the inner and outer basin. The inner and outer basins have depths ranging from 10 to 40 m and are more protected from ice scouring. Beds of macroalgae, *Coccotylus truncatus* serve as the dominant primary producer of this habitat. Cerianthid beds (Habitat group: D) were found in the deepest part of the outer basin. Cerianthid anemones are often found in environments with high to moderate current flows, where they can feed on plankton (Holohan et al. 1998). Anoxic muds (Habitat group: E) located in the deep basins of the river estuary are affected by winter infill of brine (Smith et al. 2007), which causes the seabed to turn anoxic, killing resident benthos and making it an unlikely habitat for benthic species.

Gjoa Haven's dominant habitat was sands with diverse macroalgae beds (Habitat group: I). This habitat was found on the southeastern coastline of Peterson Bay and along the southern coast between Fram Point and Betzold Point. Fifteen different species of algae were found in this habitat. All habitats in Gjoa Haven had hard substrates with algae species attached. Pebbles and cobbles were dispersed throughout and some boulders were found in the shallower areas. The hard substrates provided an optimal environment for numerous epibenthos. Even the deep muddy substrates (Habitat group H) which were dominated by filamentous green algae had dispersed pebbles with some macroalgae attached. Habitats H and I had dispersed beds of tube anemone, *Ceriantlus borealis*. The gravels with kelp beds (Habitat group: L) dominated the seabed around Lund Island and also were found along the western coastline of Peterson Bay. Kelp beds of *Saccharina longicruris*, red algae *Coccotylus truncatus*, and *Fucus sp.* were ubiquitous within this habitat.

On the Georges Bank, Thouzeau et al. (1991) described sand-shell bottoms as being 10-times more diverse than sand dunes, and gravel bottoms being even more diverse than sand-shell environments. Kostylev et al. (2001) showed a similar pattern on the Scotian Shelf. Sediment type controls species distribution and similar groups of species commonly occur on similar substrata. Overall the findings in this study show a similar pattern in regard to macrobenthos and sediment type. Between the two study areas epifauna and flora density and richness increased on sand-pebble/cobble bottom and gravel bottom habitats compared to sandy bottoms. Also, species such as cerianthid anemones were commonly found in muddy-sand environments while *Molgula sp.* acidians were more commonly found in sandier environments.

The habitat groups not only demonstrate the habitat variation found within these two study areas with respect to distinct environmental characteristics, but are derived from a constant survey methodology and provide a robust baseline against which to assess future changes in habitat distribution, species composition, and diversity as a result of climate and sea-level changes.

4.6 IMPACT OF CLIMATE AND SEA-LEVEL CHANGE

Current climate change conditions are reducing the amount of sea ice (ACIA 2005a), causing permafrost to melt, increasing rates of erosion and likelihood of slope failure (Solomon 2001, Solomon 2005, Manson et al. 2005), and leaving coastal communities more open to damage from storm surges and waves (Papadimitriou et al. 2006). In addition, while the dominant patterns in relative sea-level change in the Arctic are driven by isostatic crustal flexure (Tarasov and Peltier 2004), climate change also brings about a eustatic sea level rise, at increasingly rapid rates (Shaw et al. 1998b; Shepherd and Wingham 2007). Areas which are currently experiencing near zero rates of isostatic vertical movement may begin to experience relatively rapid relative sea-level rise, with the possibility of attendant coastal erosion and sedimentation and decrease in biodiversity, depending on surfical geology. In the current study, the submergent region of southwestern Banks Island with rapid coastal erosion was characterized by a high-sedimentation, low diversity sand plain environment. By contrast, the emergent region (Gjoa Haven) was sediment-starved, and commonly had gravel and boulders in sand or mud substrates, high cover of macroalgae, and relatively high biodiversity. These two locations are currently subject to differing impacts of climate and sea-level change.

Coastal erosion, driven by relative sea level rise and climate warming appears to be the dominant factor responsible for the low diversity sand sheet environment in Sachs

Harbour. The relative rate of sea level rise for the region around Sachs Harbour has an estimate of 3.6 mm/a (Manson et al. 2005) and the sensitivity of this coastline to sea level rise has been ranked as high (Shaw et al. 1998a). The emergent region (Gjoa Haven) of this study has an isostatic vertical uplift rate of 1 to 2 mm/a (Figure 4.1). This vertical uplift rate combined with the current rate of global sea-level rise (3.0 mm/a), may shift Gjoa Haven from an emergent setting to one that is submerging at an estimated rate of -1 to -2 mm/a. If these estimates hold true, and sea level continues to rise at these rates Gjoa Haven, along with other areas in the Arctic that are on the cusp of emergence to submergence (indicated on the map in green; Figure 4.1) may begin to experience relatively rapid relative sea level rise, accompanied by coastal erosion. The degree to which these areas would be impacted would depend on many factors: surficial geology, the nature of permafrost, slope angle of the coastline, sea ice conditions, and wind and storm activity. For example, a coastline composed of unconsolidated, finer silty sediments exposed to high winds and storm activity will be more vulnerable to rapid coastal erosion rates compared to a protected coastline composed of sandier coarser grained sediments. Increased coastal erosion of these finer sediments will lead to sedimentation into the near-shore environment, impacting and modifying the marine benthic near-shore habitats.

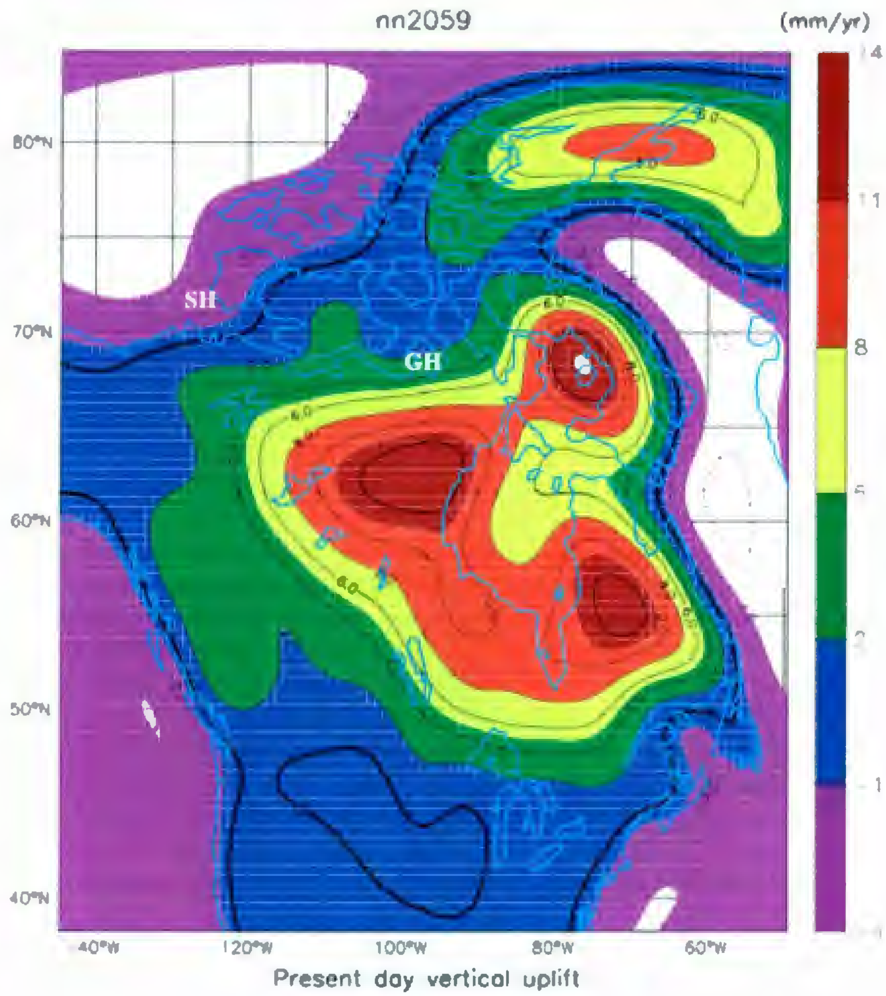

Figure 4.1 Present-day vertical uplift rates for the Canadian Arctic (Tarasov and Peltier 2004). Sachs Harbour is -4 to -1 mm a^{-1}; Gjoa Haven is 1-2 mm a^{-1}. Heavy black line indicates zero isostatic crustal motion.

Sachs Harbour is an area that has received continuous deposition of sediment into the marine environment due to its submergent shoreline with locally rapid coastal erosion. Extensive coastal erosion in the region results in increased sedimentation into the nearshore environment. As well, the Sachs Harbour nearshore area acts as a repository for sediments following intense wind and rainstorm events. The benthic communities observed in the nearshore area of Sachs Harbour are affected by natural events, such as extreme storms and wind/rain events which contribute to coastal erosion, increased runoff, and increased sedimentation into the marine environment. By contrast, Gjoa Haven appears to be an area that has minimal deposition of sediment into the marine environment. The main source of sediment into the marine system is from a river that empties into Peterson Bay, which typically causes mud plumes during spring thaw periods. Muddy sedimentation following rain event are not commonly seen in the area (B. Porter, personal communication, 2006). Gjoa Haven has an emergent shoreline with a relatively low energy coastline surrounding the community. Furthermore, the bedrock and surficial geology of Gjoa Haven make it less susceptible to erosion than Sachs Harbour. The beaches in Gjoa Haven are composed of sand and gravel, and are mostly low energy (Catto and Papadimitriou 2006). In areas of the Arctic where the sediments are sand and gravel (Gjoa Haven), the sediment is not easily transported; on the other hand where the sediments are fine sands and silt (Sachs Harbour), waves and currents remove the sediment in suspension, transporting it to the marine environment. No eroding cliffs were observed in the summer 2006 in any areas surrounding Gjoa Haven. Possible negative effects on marine benthos in this study area due to natural events appear to be negligible. The dominant environmental difference between these two study areas is the degree of sand released from eroding Quaternary sediments. Muddy runoff released into the nearshore in both Sachs Harbour and Gjoa Haven, appears to be less of an environmental driving factor compared to eroding sediments and resultant sedimentation.

The Beaufort Sea has experienced a significant reduction in sea ice cover over the last 5 years and climate models suggest an extraordinary decline in the next century (IARC 2007). The greatest magnitude and frequency of onshore winds is during summer months of open water and extensive ice-free fetch across the Amundsen Gulf and Beaufort Sea (Harry et al. 1983; Belliveau 2007). If the Amundsen Gulf remains ice-free for extended periods, the southwest coastline of Banks Island will likely experience increased erosion rates with larger amounts of sediment deposition into the marine environment. Long-term change and sediment transport directions reported by Belliveau (2007) suggest that, as sediment is transported towards the east, the deep outer basin located to the west of Sachs spit will begin to infill. Through time this will likely affect two habitats (diverse muds and cerianthid beds) located in the Sachs Harbour study area. These deep thermokarst basins located in the inner and outer harbour receive mobile sediments carried by bottom currents which result in high levels of sediment accumulation and may contribute to local smothering of benthos and habitat. The diverse muds dominated by red algae, *Coccotylus truncatus* will likely be smothered over time, whereas the cerianthid beds are likely more tolerant to sedimentation and may be able to survive.

In contrast to the potential threat climate change poses to benthic habitats, sea ice thinning due to climate change, will likely result in decreased draft of sea-ice keels, thereby reducing depth of ice scour, but if the mobility of sea ice increases then greater ice scour in shallow water will likely occur.

4.7 OTHER ANTHROPOGENIC IMPACTS

Anthropogenic effects appear to be minimal in the Sachs Harbour study area. No dredging of the harbour has ever taken place (K. Parewick, personal communication, 2006) and minimal boating activity occurs within the community. Benthic habitat modification or destruction as a result of anthropogenic disturbances are not likely to be causing changes in benthic habitats around Sachs Harbour. Benthic communities observed in the Gjoa Haven study area are likely affected by anthropogenic affects. Boating activity, visiting cruise ships, and garbage pollution, which is often blown from the land into the marine environment are some of the anthropogenic affects that persist along the Gjoa Haven coastline. The study area for Gjoa Haven focused on the nearshore area located east and west of the community and not within the harbour. This was to avoid altered benthic habitats due to anthropogenic activities of the town, including dredging of the harbour and high volumes of boat activity.

As global temperatures continue to rise, the ice-free season may lengthen, making the Northwest Passage a widely accessible shipping route (Catto and Papadimitriou 2006). This will ultimately lead to increased traffic, suggesting that the impact of pollution, such as petroleum contamination may be a significant threat to Gjoa Haven's marine biodiversity. Pollution and disturbance of sediments as a result of increased anthropogenic activity could be detrimental to benthic habitats of these two areas in the future. As well, traffic through the Northwest Passage increases the chance of invasive species being introduced into areas of the Arctic (Rice 2003). Invasive species can change the species composition of the environment they inhabit or impact the normal functioning of the ecosystem (Levine 2000).

4.8 POSSIBLE IMPLICATIONS FOR HIGHER LEVELS OF THE FOOD CHAIN

Marine benthos fulfill many important functional roles in marine ecosystems. Polychaetes are typically the dominant component of macrobenthos both in terms of species richness and the number of individuals (Hutchings 1998). Marine benthos not only act as direct food sources for humans (e.g. mussels, clams) but are also considered a primary food source for various bottom feeding fish and marine mammals (Snelgrove 1998). Arctic cisco, arctic flounder, blackline prickleback, eelpout, and slender eelbleeny in Tuktoyaktuk Harbour fed predominately on polychaetes (Lacho 1991). Other fish species, such as whitefish, arctic cod, fourhorn sculpin, and staghorn sculpin feed mostly on copepods (Bradstreet et al. 1986; Chiperzak et al. 1990; Lacho 1991). Bearded seals mainly feed on crabs, shrimp, clams, and bottom fish (Burns 1978). The main concentration of bearded seals in the Banks Island region are located in offshore areas, north of Cape Kellett and to the east of Cape Lambton (Heath and Thomas 1984). Previous reports on the southwest of Banks Island concluded that there was a low density of clams of appreciable size in the region (Heath and Thomas 1984; Siferd 2001). As well, community residents of Sachs Harbour indicated that there had been a decline in Arctic char over the last decade (Sachs Harbour residents, personal communication, 2005). Potential causes of a reduction of Arctic char may be changes in water temperature, changes in benthic community composition and density, and over-harvesting. If the decline in Arctic char is due to over harvesting, closure to fishing for Arctic char around Sachs Harbour for a set number of years or setting a quota of fish per individual or family may be required to regain subsistence fishing for the community.

Settlements located throughout the Canadian Arctic archipelago rely heavily on the resources from the marine environment. Residents of these communities eat large amounts of traditional foods, such as Arctic char, ring seal, beluga whale, and mussels. Community residents of Sanikiluaq, located in the Belcher Islands harvest mussels, sea cucumbers, and sea urchins for personal use (Topoluiski et al. 1987). Fishing for char and other anadromous fish during the summer months is a tradition in most Arctic communities and helps sustain local food supplies during the winter. Community residents of Gjoa Haven put out gill-nets, running perpendicular to shore and fish from boats or off the shoreline during fish migration months (R. Kamookak, personal communication, 2006). Given that high concentrations of both fish and marine benthos typically co-exist, a decrease in the density of benthic biota as a result of environmental and anthropogenic disturbance will likely impact fish stocks, reducing food resources for Arctic communities. For example, petroleum pollution into the nearshore environment, a potential consequence of increased traffic in marine waters, could result in severe loss of the diverse and abundant macroalgae habitats found in Gjoa Haven, thereby reducing food sources for benthos, fish, and humans.

CHAPTER FIVE CONCLUSIONS

5.1 SUMMARY OF THE BENTHIC BIOLOGY OF SACHS HARBOUR AND GJOA HAVEN

The Gjoa Haven study area exhibited high diversity among all taxonomic groups and had greater diversity per sample site than the Sachs Harbour study area. Species composition of Gjoa Haven differed significantly from that of Sachs Harbour. Macroalgae beds were found throughout the study area providing abundant food and shelter to benthic fauna. This high diversity is mostly due to the heterogeneity of the substrate (cobbles and pebbles dispersed throughout the mud and sand substrates). These substrate types provide an attachment surface for epibenthos, and habitat and shelter for many benthos not available in an otherwise homogeneous environment, such as the broad sand sheets sampled in Sachs Harbour. As well, the continuous supply of sediment into the nearshore environment of Sachs Harbour makes for an unstable environment compared to Gjoa Haven's sediment starved nearshore environment.

5.2 PHYSICAL COMPARISON OF SACHS HARBOUR AND GJOA HAVEN

The physical differences (e.g. isostatic sea-level change, surficial geology, sea-bed morphology) and opposing degrees of erosion (eroding versus not eroding) among these two study areas play an important role in characterizing the benthic habitats found in the two nearshore environments. The Sachs Harbour coastline is composed of unconsolidated Tertiary sedimentary rocks overlain by sandy till. Rapid coastal erosion has been tied to climate change and isostatic submergence for the region. The Sachs Harbour coastline supplies a continuous supply of sediment into the nearshore environment due to its submergent shoreline with locally rapid coastal erosion. As well, the Sachs Harbour nearshore area acts as a repository for muddy sediments following intense wind and rainstorm events. By contrast, Gjoa Haven's nearshore environment appears to be sediment starved, due to the lack of erosion found along this coastline. Gjoa Haven has an emergent shoreline with a relatively low energy coastline surrounding the community. Gjoa Haven's coastline consists of flights of raised beaches composed of wind-deflated sand, gravel, and cobbles, with some glacial erratic boulders.

The physical environment of the seafloor of Sachs Harbour is vastly different to that of Gjoa Haven. The nearshore environment of Sachs Harbour has largely been determined by the continuous deposition of sediment into the marine environment and isostatic submergence of the land. Shallow mobile sand sheets dominate the Sachs Harbour study area. Submerged thermokarst basins composed of muddy-sand, mud, and anoxic mud that reach to depths of 40 m are located in the inner and outer harbour and along the Sachs River estuary. In contrast to Sachs Harbour, muddy-sand and gravelly-sand substrates dominate the seafloor of Gjoa Haven. Pebbles and cobbles, along with some boulders are dispersed throughout the area and provide an attachment surface to many macroalgal species found within the area.

Both study areas are subject to extensive ice scouring, especially during ice break up and increased wind and storm activity. However, Sachs Harbour most likely experiences greater ice scour due its more exposed coastline.

5.3 EFFECTS OF CLIMATE AND SEA-LEVEL CHANGE

Increased coastal erosion and resultant sedimentation in nearshore marine environments is a predicted impact of climate change. Significant climate warming is causing the oceans to warm, glaciers and ice caps to melt, and an increase of melt water into the world's oceans (IPCC 2001b). Currently, the present rate of sea-level rise is 3.0 mm a^{-1} (Shepherd and Wingham 2007). If this rate continues over the next century, global sea-level will have risen 30 cm. If current trends continue, global temperatures will continue to rise, along with rates of snowfall, ice melting, glacial flow, and ultimately rates of global sea-level rise. Predictions for the next century indicate a rise in global sea level between 0.24-0.48 m (IPCC 2007). With continuous sea-level rise the ocean will continue to encroach on coastlines around the world. Based on the projected increases in sea level, IPCC (2001b) notes that current and future climate change has a number of impacts, particularly along coastlines. Such impacts include accelerated coastal erosion, increased storm surge, and more extensive coastal inundation. Coastlines currently undergoing isostatic submergence are particularly vulnerable to sea level rise (e.g. Tuktoyaktuk, Sachs Harbour) (Figure 5.1). Sachs Harbour has a subsidence rate estimated at 2.0 mm a^{-1} to 2.50 mm a^{-1}, in contrast to Gjoa Haven which has an emergence rate estimated at 2.0 mm a^{-1}. The estimated rate of global sea-level rise (3.0 mm a^{-1}) may shift Gjoa Haven from a positive to a negative trend of relative sea-level change and Sachs Harbour at an even greater negative rate of relative sea-level change. Climate warming is predicted to cause an increase in the extent and duration of open water in the summer. If predictions are correct, coastlines will be reworked by waves for longer periods of time, and the greater fetch over the more extensive open water would allow storms to impact coastlines even more than at present.

Overall, if climate warming predictions hold true coastal erosion and resultant sedimentation into the nearshore environment would be expected to continue in Sachs Harbour. While, climate warming and eustatic sea level rise could push Gjoa Haven from emergent to submergent conditions, leading to limited coastal erosion and increased runoff during spring melt. Climate warming may result in the Northwest Passage becoming a viable shipping route. If this occurs, anthropogenic impacts, such as petroleum pollution, tourism pollution, and the introduction of invasive species will likely increase along Arctic coasts. Biotic consequences of these various impacts could result in change or loss of benthic species and habitat at these two study areas.

Arctic coastlines, in addition to the Beaufort Sea shore (e.g. Tuktoyaktuk and Sachs Harbour), which are most likely to suffer climate related changes is the shoreline around the Hudson Bay Basin and the shore around the west side of Baffin Island, along the eastern shore of Foxe Basin (Figure 5.1). These two areas are emergent and have a coastline composed of fine-grained sediments. Studies carried out along the eastern Hudson Bay coast suggested that permafrost bodies had retreated along this rapidly emerging coastline (Beaulieu and Allard 2003). Marine clayey silts are the most widespread Quaternary sediments along the eastern portion of the Hudson Bay and the shoreline is dominated by discontinuous permafrost on a low-lying terrain, making the coastline particularly vulnerable to erosion by storm and wave activity (Beaulieu and Allard 2003).

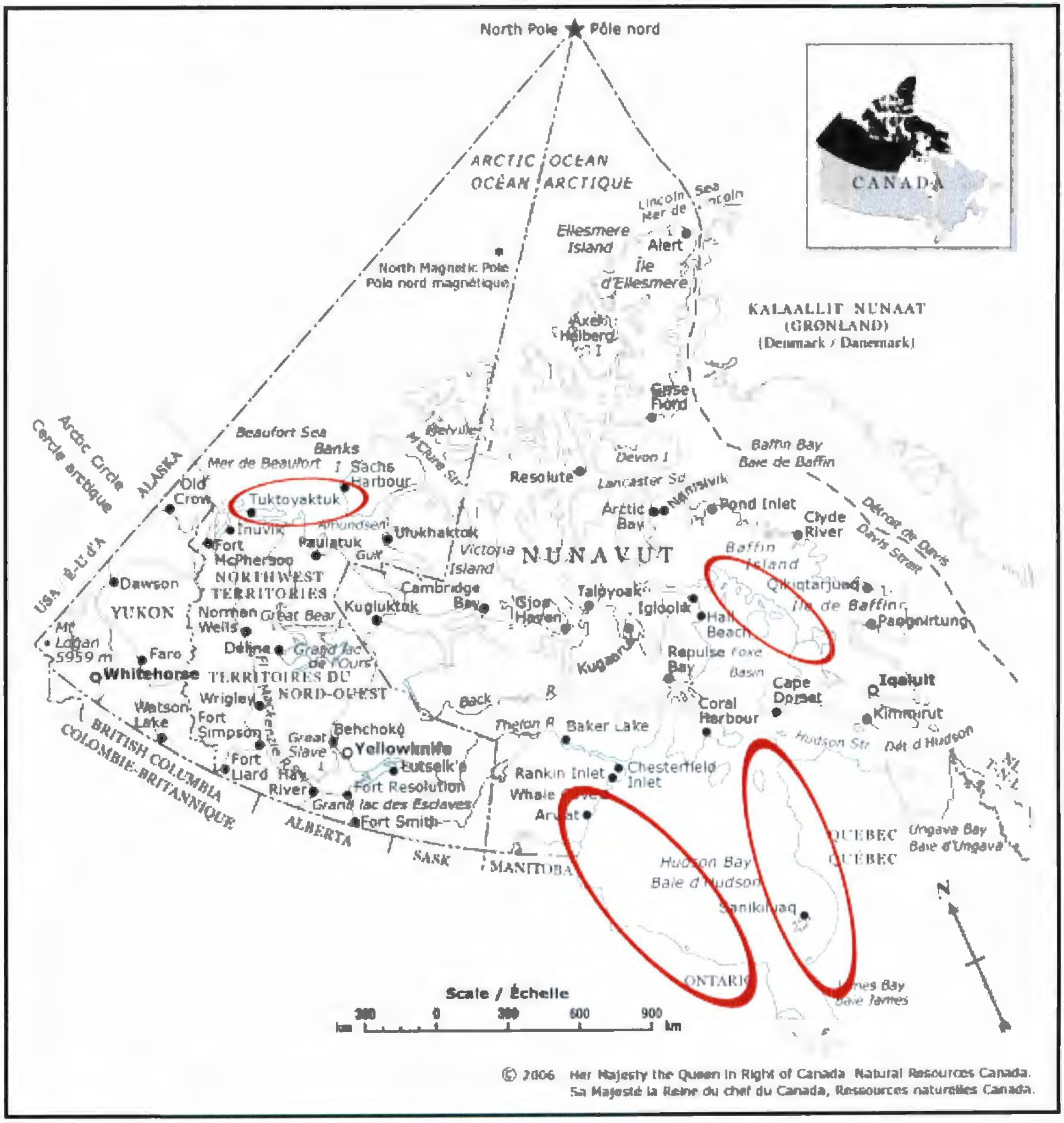

Figure 5.1 Map of the Canadian Arctic; red circles indicating coastlines, which are most likely to suffer from climate related changes and are best suited for a comparison study with Sachs Harbour.

The results of this study suggest that a decline in macrobenthos diversity may follow the increase in sea-level rise and resultant coastal erosion and sedimentation in nearshore waters, which is one of the predicted consequences of climate change in the

Arctic. The magnitude of these processes will significantly depend on the surficial geology and vertical uplift rates for the area and the rate of global sea-level rise. Other physical processes that will be of importance will be the degree of exposure of the coast in study, as well as the amount of rain/snow and storm activity for the area. The effects may not be negligible. Sachs Harbour, for example, lies along an Arctic coastline that has already experienced rapid coastal erosion and demonstrates low macrobenthos diversity and low macroalgae distribution and cover.

5.4 RECOMMENDATIONS FOR FUTURE WORK

5.4.1 Methods

A few factors should be considered for future comparative studies of Arctic nearshore locations. One factor, which should be considered, is the use of grab and drop video camera, adjacent to one another at each sampling site. This provides an assessment of both the epifauna and infauna species living among the two study areas. As well, using a comprehensive approach (e.g habitat mapping) to describe the habitats present within a study area provides a clear baseline against which to assess future changes in habitat distribution as a result of climate and sea-level changes.

Sampling method likely played a role in the identified species among the various habitats for the video sampled material. Most species are hidden among rocks and beneath macroalgae cover, making it difficult to identify all present species found within each surveyed area. As well, the speed of the camera moving over the seafloor affected the video being recorded. For example, there were segments of the video where the seafloor was blurred and organisms, if present, could not be identified. One possible way to overcome this would be to conduct video transects by SCUBA. However, to survey a large area by SCUBA poses many logistical constraints such as depth, and endurance for SCUBA divers (Stevens and Connolly 2005).

5.4.2 Additional Variables

In this study it was only possible to sample depth, substrate, epifauna, and infauna. Further information that would contribute to the study would be water current speed and direction, salinity, oxygen, and light penetration. Water currents play a major role in sediment grain size distribution and the delivery and replenishment of nutrients and suspended particles to benthos. Measuring phytoplankton and zooplankton production and biomass and primary production by algal mats and macroalgae in the nearshore area of these two locations would be beneficial.

Continued monitoring of the benthic biology of these two Arctic locations and other nearshore Arctic locations is necessary. With changing climate and sea-level conditions in the Arctic it is important to understand past and present marine biological systems associated with these changes, as Arctic communities rely heavily on the marine environment for food sources. Areas which are currently experiencing near zero rates of isostatic relative sea-level change may begin to experience relatively rapid sea-level rise, with possible attendent coastal erosion and sedimentation and decrease in biodiversity, as a result of eustatic sea-level rise driven by climate change. Areas most likely to experience biological changes resulting from relative sea level driven coastal erosion and sedimentation are areas with relative sea level rise, fine-grained sediments, and high winds and frequent storms during the open-water season. Future coastal biological studies should focus on Arctic nearshore locations that are most likely to undergo the shift from emergence to submergence and have a surficial geology similar to that of Sachs Harbour. For a comparison study a better fine-grained emergent setting with Sachs Harbour would be either the west side of Baffin Island, along the eastern shore of Foxe Basin or around the Hudson Bay Basin (Figure 5.1). Also, to increase replication for statistical reasons choose a fine-grained submergent setting similar to Sachs Harbour (e.g. Tuktoyaktuk).

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APPENDICES

Appendix A: Glossary of Terms

Discontinuous permafrost – permafrost is ground that remains at or below the freezing point of water for two or more years. Discontinuous permafrost is permafrost that does not form a continuous underground layer throughout the whole of the tundra-covered region and/or permafrost that covers less than 90% of the ground (Pielou 1994).

Continuous Permafrost – permafrost forms a continuous underground layer throughout the whole of the tundra-covered region (Pielou 1994).

Eustatic sea-level change – a world-wide or global change in sea level and is unrelated to local/regional effects e.g. change in the ocean water volume (Masselink and Hughes 2003).

Fast ice – sea ice that has frozen along coasts or to the sea floor over shallow depths.

Forebulge – an uplift at the edge of a glacier caused by tilting of the lithosphere.

Glacial-isostasy – isostatic adjustments of the Earth;s crust due to loading and unloading of ice sheets (Masselink and Hughes 2003).

Glacial-isostatic emergence/submergence – When the ice sheet melts, the land surface will resort back to its former position, thus the area formerly covered by ice will *emerge* (come up) and the land surface located in areas at the forebulge of the icesheet will *submerge* (go down) (Masselink and Hughes 2003).

Ice algae – algal communities found in annual and multi-year sea ice. Sea ice algal communities can be found between ice crystals or attached to them, in the interstitial water or brine channels between ice crystals, or associated with the undersurface of the ice (Clough et al. 2005).

Ice wedge – with temperatures of -15°C or lower the ground cracks as it contracts from the cold. In the spring, meltwater seeps into the cracks and freezes, forming vertical seams of ice (ice wedges) (Pielou 1994).

Pingo – a conical hill with a core of clear ice (Pielou 1994); a mound of earth covered ice.

Relative sea-level change – changes in sea level relative to that of the land and operates on a regional/local level. This can occur by a change in the sea level and/or change in the level of the land (Masselink and Hughes 2003).

Thermal expansion – an increase in sea water temperature induces a sea level rise; if a volume of water is heated it will occupy a larger volume (Masselink and Hughes 2003).

Thermokarst – a land surface that forms as ice-rich permafrost melts (Bucksch 1997).

Thermokarst lake – a body of freshwater, usually shallow, that is formed in a depression by meltwater from thawing permafrost (Bucksch 1997).

Appendix B: Description of video transects for the Sachs Harbour study area. Percentages of time present for each substrate type is given for each video transect.

Transect ID	Depth range (m)	Depth median (m)	Length (m)	Time (sec)	Mean Substrate Cover (% of total time)					Substrate Class
					Sa	Pe/Co	MSa	Mud	Amud	
FL 2-3	5	5	92	295	0	0	100	0	0	muddy-sand
FL 1-3	8	8	17	78	0	0	100	0	0	muddy-sand
FL 1-2	2	2	65	468	100	0	0	0	0	sand
FL 1-1	1	1	35	152	100	0	0	0	0	sand
FL 3-3	15	15	-	235	0	0	100	0	0	muddy-sand
FL 3-2	37	37	-	107	0	0	0	0	100	anoxic mud
FL 3-1	5	5	-	113	0	0	0	100	0	mud
FL 2-1	5	5	-	60	0	0	100	0	0	muddy-sand
FL 2-2	1	1	3	127	100	0	0	0	0	sand
BL 2-5	16	16	18	210	0	0	100	0	0	muddy-sand
BL 3-1	7	7	-	119	100	0	0	0	0	sand
IB 3-5	29	29	-	50	0	0	0	100	0	mud
IB 3-1	7	7	-	272	100	0	0	0	0	sand
IB 2-1	6	6	-	150	0	0	0	100	0	mud
IB 1-1	3	3	-	95	100	0	0	0	0	sand
IB 1-3	18	18	8	275	100	0	0	0	0	sand
IB 1-5	2	2	16	169	100	0	0	0	0	sand
IB 2-5	23	23	-	60	0	0	0	100	0	mud
IB 2-3	39	39	-	240	0	0	0	100	0	mud
IB 3-3	5	5	44	293	100	0	0	0	0	sand
IB 3-5	25	25	-	225	100	0	0	0	0	mud
SS 4-1	26	26	-	294	0	0	100	0	0	muddy-sand
SS 4-2	29	29	93	263	0	0	100	0	0	muddy-sand
SS 4-3	10	10	70	173	100	0	0	0	0	sand
IB 5-1	6	6	83	170	0	0	0	100	0	mud
IB 4-1	5	5	42	90	0	0	0	100	0	mud
IB 2-5	23	23	-	265	0	0	0	100	0	mud
TB 3-2	-	-	95	333	100	54	0	0	0	gravelly-sand
TB 2-3	-	-	80	300	100	0	0	0	0	sand
TB 1-3	-	-	138	352	100	64	0	0	0	gravelly-sand
DHB 2-3	16	16	36	257	100	88	0	0	0	gravelly-sand
DHB 2-2	10	10	-	125	100	9	0	0	0	sand
DHB 2-1	6	6	-	180	100	6	0	0	0	sand
DHB 1-3	14	14	37	347	100	0	0	0	0	sand
DHB 1-2	9	9	9	233	100	0	0	0	0	sand
DHB 1-1	6	6	13	165	100	0	0	0	0	sand
TH 13-8	26	26	11	280	100	0	0	0	0	sand
TH 13-7	21	21	68	293	100	0	0	0	0	sand
TH 13-6	16	16	66	240	100	53	0	0	0	gravelly-sand
TH 13-4	-	-	10	141	100	0	0	0	0	sand
TH 13-1	-	-	-	141	100	0	0	0	0	sand
CK 1-3	14	14	-	170	100	0	0	0	0	sand
CK 1-2	11	11	-	220	100	0	0	0	0	sand
CK 1-1	8	8	-	215	100	36	0	0	0	gravelly-sand
CK 2-1	8	8	-	153	100	39	0	0	0	gravelly-sand
CK 2-2	12	12	-	144	100	86	0	0	0	gravelly-sand
CK 2-3	14	14	-	163	100	0	0	0	0	sand

Appendix C: Description of video transects for the Sachs Harbour study area. Percentages of time present for each macroalgae and macrofauna species is given for each video transect.

Transect ID	Mean Macroalgae & Macrofauna Cover (% of total time)							
	algal mats	*Coccotylus truncatus*	*Hyas coarctatus alutaceus*	*Molgula sp.*	*Ponaster tenuispinus*	*Cerianthus borealis*	Strongylocentrotus droebachiensis	*Echinarachnius parma*
FL 2-3	40	60	1	0	0	0	0	0
FL 1-3	77	23	0	0	0	0	0	0
FL 1-2	13	0	0	72	0	0	0	0
FL 1-1	0	0	0	0	0	0	0	0
FL 3-3	0	6	0	0	1	0	0	0
FL 3-2	0	0	0	0	0	0	0	0
FL 3-1	100	0	4	0	0	0	0	0
FL 2-1	100	0	0	0	0	0	0	0
FL 2-2	0	0	0	0	0	0	0	0
BL 2-5	100	0	0	0	0	0	0	0
BL 3-1	0	100	0	0	0	0	0	0
IB 3-5	0	0	0	0	0	0	0	0
IB 3-1	78	0	0	0	0	0	0	0
IB 2-1	67	7	0	0	0	0	0	0
IB 1-1	0	0	0	0	0	0	0	0
IB 1-3	7	0	1	0	0	0	0	0
IB 1-5	0	0	0	0	0	0	0	0
IB 2-5	0	0	0	0	0	0	0	0
IB 2-3	0	0	2	0	0	0	0	0
IB 3-3	49	0	0	0	0	0	0	0
IB 3-5	100	0	2	0	0	0	0	0
SS 4-1	0	0	3	0	0	100	0	0
SS 4-2	0	0	6	0	0	100	0	0
SS 4-3	100	0	1	0	0	0	0	0
IB 5-1	0	0	0	0	0	0	0	0
IB 4-1	0	0	0	0	0	0	0	0
IB 2-5	76	24	0	0	0	0	0	0
TB 3-2	0	0	0	0	0	0	0	100
TB 2-3	0	0	1	0	0	10	0	0
TB 1-3	0	0	1	0	0	0	17	0
DHB 2-3	14	0	0	0	0	0	0	0
DHB 2-2	0	0	0	0	0	0	0	0
DHB 2-1	0	0	0	0	0	0	0	0
DHB 1-3	0	0	0	0	0	0	0	76
DHB 1-2	0	0	0	0	0	0	0	0
DHB 1-1	0	0	0	0	0	0	0	0
TH 13-8	0	0	1	0	0	0	0	0
TH 13-7	0	0	1	0	0	0	0	100
TH 13-6	0	0	1	0	0	0	0	0
TH 13-4	0	0	0	0	0	0	0	0
TH 13-1	0	0	0	0	0	0	0	0
CK 1-3	0	0	0	0	0	0	0	0
CK 1-2	0	0	0	0	0	0	0	0
CK 1-1	0	0	0	0	0	0	0	0
CK 2-1	0	0	0	0	0	0	0	0
CK 2-2	0	0	0	0	0	0	0	0
CK 2-3	0	0	0	0	0	0	0	0

Appendix D: Description of video transects for the Gjoa Haven study area. Percentages of time present for each substrate type is given for each video transect.

Transect ID	Depth range (m)	Median Depth (m)	Length (m)	Time (sec)	Mean Substrate Cover (% of total time)						Substrate Class
					Sa	Bo	Pe/Co	Pe	MSa	Mud	
SH 2-3	6	6	24	120	100	0	100	0	0	0	gravelly-sand
SH 2-2	2-3	2.5	32	180	100	0	56	0	0	0	gravelly-sand
SH 2-1	24	24	20	120	0	0	0	0	100	0	muddy-sand
SH 1-3	22-24	23	21	120	0	0	0	0	100	0	muddy-sand
SH 1-2	15-16	15.5	16	130	100	0	0	0	0	0	sand
SH 1-1	2	2	55	130	0	31	100	0	0	0	boulder-gravel
SH 0-3	24-26	25	8	140	0	0	0	0	100	0	muddy-sand
SH 0-2	24-27	25.5	13	150	0	0	0	0	100	0	muddy-sand
SH 0-1	6	6	-	123	100	0	0	0	0	0	sand
LIE-2	26-31	28.5	23	110	0	0	0	0	100	0	muddy-sand
LIE-1	14-16	15	40	130	100	0	0	0	0	0	sand
LIS-3	31-32	31.5	6	130	0	0	0	0	100	0	muddy-sand
LIS extra-2	8-11	9.5	21	120	40	0	100	0	0	0	pebble-cobble gravel
LIS extra-1	5-6	5.5	21	125	10	0	100	0	0	0	pebble-cobble gravel
BP 4-3	18-22	20	20	141	0	0	0	0	0	100	mud
BP 4-2	10-11	10.5	17	160	0	0	0	0	100	0	muddy-sand
BP 4-1	10-12	11	41	120	100	0	0	0	0	0	sand
BP 3-3	19	19	28	121	0	0	0	0	100	0	muddy-sand
BP 3-2	24	24	25	130	0	0	0	0	100	0	muddy-sand
BP 3-1	14	14	36	130	100	0	0	0	0	0	sand
BP 2-3	23	23	-	120	0	0	0	0	100	0	muddy-sand
BP 2-2	21	21	42	145	0	0	0	0	100	0	muddy-sand
BP 2-1	8-9	8.5	33	120	100	0	0	0	0	0	sand
BP 1-1	18-22	20	93	170	100	0	0	0	0	0	sand
BP 1-2	14-20	16	36	140	0	0	0	0	100	0	muddy-sand
H 1-3	20	20	2	130	0	0	0	0	0	100	mud
H 1-2	15-16	15.5	11	140	0	0	0	0	100	0	muddy-sand
H 1-1	5-6	5.5	30	155	0	0	0	0	100	0	muddy-sand
FP 1-3	14	14	37	150	0	0	0	0	100	0	muddy-sand
FP 1-2	13	13	42	110	100	0	0	0	0	0	sand
FP 1-1	11-12	11.5	46	130	0	0	0	0	100	0	muddy-sand
PB 1-3	9-11	10	12	140	100	0	0	0	0	0	sand
PB 1-1	3-4	3.5	75	140	7	11	90	0	0	0	boulder-gravel
PB 2-3	9-10	9.5	18	130	100	0	0	0	0	0	sand
PB 2-1	4	4	65	120	100	0	2	0	0	0	sand
PB 3-3	10-11	10.5	35	105	0	0	0	0	100	0	muddy-sand
PB 3-2	7	7	36	105	10	0	90	0	0	0	pebble-cobble gravel
PB 3-1	4	4	34	89	0	0	100	0	0	0	pebble-cobble gravel
RM 1-3	5	5	52	150	100	0	70	0	0	0	gravelly-sand
RM 1-2	6	6	38	145	0	0	0	0	100	0	muddy-sand
RM 1-1	3-5	4	59	130	0	0	0	0	100	0	muddy-sand
PBW 4-3	22	22	4	167	0	0	0	0	100	0	muddy-sand
PBW 4-2	10-11	10.5	16	105	100	0	0	100	0	0	gravelly-sand
PBW 4-1	4-5	4.5	17	180	100	0	0	100	0	0	gravelly-sand
PBW 3-3	15-16	15.5	27	195	100	0	0	100	0	0	gravelly-sand
PBW 3-2	10-11	10.5	19	125	100	0	0	10	0	0	gravelly-sand
PBW 3-1	7	7	23	160	100	0	0	100	0	0	gravelly-sand
PBW 2-3	17	17	31	142	0	0	0	0	100	0	muddy-sand
PBW 2-2	6	6	51	145	100	0	0	100	0	0	gravelly-sand
PBW 2-1	5	5	58	130	100	0	0	100	0	0	gravelly-sand
PBW 1-3	8	8	25	115	0	0	0	100	100	0	gravelly-muddy-sand
PBW 1-1	2	2	68	111	0	20	100	0	0	0	boulder-gravel

Appendix E: Description of video transects for the Gjoa Haven study area. Percentages of time present for each macroalgae species is given for each video transect.

Transect ID	Mean Macroalgae Cover (% of total time)							
	Fucus sp	*Coccotylus truncatus*	*Stictyosiphon sp.*	*Rhodomela sp*	*filamentous green algae*	*Saccharina longicruris*	*Sphacelaria sp.*	*Scytosiphon sp*
SH 2-3	88	75	75	75	0	0	0	0
SH 2-2	16	0	0	0	0	0	0	0
SH 2-1	0	50	0	0	100	0	0	0
SH 1-3	0	0	0	0	100	0	0	0
SH 1-2	23	0	0	0	0	35	8	0
SH 1-1	50	0	0	0	0	0	54	0
SH 0-3	0	0	0	0	100	0	0	0
SH 0-2	0	0	0	0	100	0	0	0
SH 0-1	0	0	0	0	0	0	0	0
LIE-2	0	0	0	0	80	36	0	0
LIE-1	0	54	0	0	0	54	0	0
LIS-3	0	0	0	0	100	0	0	0
LIS extra-2	25	79	0	0	0	79	0	0
LIS extra-1	80	8	0	4	0	16	0	0
BP 4-3	0	0	0	0	100	0	0	0
BP 4-2	0	63	0	0	80	28	53	9
BP 4-1	32	48	0	0	80	48	79	32
BP 3-3	0	33	0	0	0	21	0	0
BP 3-2	0	4	0	0	100	0	0	0
BP 3-1	0	23	23	0	0	0	23	0
BP 2-3	0	46	0	0	100	0	0	0
BP 2-2	0	66	0	0	31	0	0	0
BP 2-1	0	8	0	0	0	0	38	0
BP 1-1	0	17	0	0	0	0	0	0
BP 1-2	43	7	0	0	0	0	46	0
H 1-3	0	0	0	0	100	0	77	0
H 1-2	0	0	0	0	50	25	29	0
H 1-1	15	0	0	0	80	3	80	0
FP 1-3	0	37	0	0	50	0	50	0
FP 1-2	0	14	0	0	70	4	70	0
FP 1-1	0	23	0	0	75	4	75	0
PB 1-3	0	23	0	0	100	18	100	0
PB 1-1	90	4	0	0	0	0	18	0
PB 2-3	77	23	0	0	0	0	16	0
PB 2-1	30	0	0	0	0	0	8	0
PB 3-3	57	0	0	0	0	0	38	0
PB 3-2	100	0	0	0	0	0	0	0
PB 3-1	100	0	0	0	0	0	0	0
RM 1-3	67	0	0	0	0	0	0	0
RM 1-2	90	0	0	0	0	0	0	0
RM 1-1	0	0	0	0	65	0	0	0
PBW 4-3	0	9	0	0	100	0	0	0
PBW 4-2	27	27	0	0	100	0	10	0
PBW 4-1	0	0	0	0	0	0	4	0
PBW 3-3	0	85	0	0	0	64	0	0
PBW 3-2	0	12	0	0	0	8	0	0
PBW 3-1	22	9	0	0	0	0	13	0
PBW 2-3	0	42	0	0	70	0	0	0
PBW 2-2	76	10	0	0	0	7	0	0
PBW 2-1	65	0	0	0	0	0	0	0
PBW 1-3	70	0	0	0	0	0	0	0
PBW 1-1	9	0	0	0	0	0	0	0

Appendix F: Description of video transects for the Gjoa Haven study area. Percentages of time present for each macrofauna species is given for each video transect.

Transect ID	Macrofauna species (% of total time)					
	Mesidotea sp.	*Molgula sp.*	Pachycerianthus fimbriatus	Asterias sp.	Ponaster sp.	Brittle star
SH 2-3	0	65	0	0	0	0
SH 2-2	2	0	0	0	0	0
SH 2-1	0	0	3	0	0	0
SH 1-3	0	0	10	0	0	0
SH 1-2	0	0	0	0	0	0
SH 1-1	0	0	0	0	0	0
SH 0-3	0	0	36	0	0	0
SH 0-2	0	0	13	0	0	0
SH 0-1	0	100	0	0	0	0
LIE-2	0	0	5	0	3	0
LIF-1	0	0	0	0	0	0
LIS-3	0	0	7	5	5	12
LIS extra-2	0	0	0	0	0	0
LIS extra-1	0	0	0	0	0	0
BP 4-3	0	0	11	0	0	0
BP 4-2	1	0	13	0	0	0
BP 4-1	0	0	0	0	0	0
BP 3-3	0	0	0	0	0	0
BP 3-2	0	0	2	0	0	0
BP 3-1	0	0	0	0	0	0
BP 2-3	0	0	6	0	0	0
BP 2-2	0	0	2	0	0	0
BP 2-1	0	0	0	0	0	0
BP 1-1	0	0	2	0	0	0
BP 1-2	0	0	0	0	0	0
H 1-3	0	0	9	0	0	0
H 1-2	0	0	0	0	0	0
H 1-1	0	2	0	0	0	0
FP 1-3	0	0	0	0	0	0
FP 1-2	0	0	0	0	0	0
FP 1-1	0	0	0	0	0	0
PB 1-3	0	0	0	0	0	0
PB 1-1	0	0	0	0	0	0
PB 2-3	0	0	0	0	0	0
PB 2-1	0	0	0	0	0	0
PB 3-3	0	0	0	0	0	0
PB 3-2	0	0	0	0	0	0
PB 3-1	0	0	0	0	0	0
RM 1-3	0	0	0	0	0	0
RM 1-2	0	0	0	0	0	0
RM 1-1	0	23	0	0	0	0
PBW 4-3	0	0	0	0	0	0
PBW 4-2	0	0	0	0	0	0
PBW 4-1	0	14	0	0	0	0
PBW 3-3	0	0	0	0	0	0
PBW 3-2	0	0	0	0	0	0
PBW 3-1	0	4	0	0	0	0
PBW 2-3	0	0	0	0	0	0
PBW 2-2	0	0	0	0	0	0
PBW 2-1	0	0	0	0	0	0
PBW 1-3	0	0	0	0	0	0
PBW 1-1	0	0	0	0	0	0

Appendix G: List of species for Gjoa Haven and Sachs Harbour study areas.

	Gjoa Haven	Sachs Harbour
PLANTAE		
Phaeophyceae (brown algae)		
Desmarestia aculeata	X	X
Dictyosiphon sp.	X	
Fucus sp.	X	X
Petalonia sp.	X	
Pilayella littoralis	X	
Saccharina longicruris	X	X
Saccharina sp.	X	
Saccorhiza sp.	X	
Scytosiphon sp.		X
Sphacelaria sp.	X	X
Stictyosiphon sp.	X	X
Rhodoghyta (red algae)		
Audouinella sp.	X	
Ceratocolax hartzi		X
Coccotylus truncatus	X	X
Hildenbrandia ruber	X	
Odonthalia dentata	X	
Pantoneura sp.	X	
Polysiphonia sp	X	
Rhodomela sp.	X	
Scagelia sp.	X	
Chlorophyta (green algae)		
Chaetomorpha sp.	X	X
Cladophora sp.	X	
filamentous green algae	X	
Percursaria sp.	X	
Rhizoclonium sp.	X	
Spongomorpha sp.	X	
Ulothrix sp.	X	
Urospora sp.	X	
algal mats		X
POLYCHAETA		
Aglaophamus neotenus (c)	X	X
Aglaophamus sp. (c)	X	
Ampharete acutifrons (d)	X	
Ancistrosyllis groenlandica (c)	X	X
Apistobranchus tullbergi (d)	X	X
Apistobranchus sp. (d)	X	
Bylgides sarsi (c)	X	
Capitella capitata (d)	X	X
Cirratutus cirratus (d)	X	X

Cossura longocirra (d)	X	X
Enipo gracilis (c)	X	X
Enipo sp. (c)	X	X
Eteone sp. (d) (c)	X	X
Euchone rubrocincta (s)		X
Euclymene zonalis (s)	X	
Eumida sanguinea (d)	X	X
Eumida kefersteini (d)		X
Eunice sp. (c)	X	X
Euthalanessa sp. (c)	X	X
Fabricia sabella (s)	X	X
Fabricia sp. (s)	X	X
Goniadidae (c)		X
Harmothoe extenuata (c)	X	X
Harmothoe sp. (c)	X	
Laonice cirrata (d)	X	
Magelona sp. (d)	X	X
Malanidae (s)		X
Marenzelleria viridis (d)	X	
Naineris quadricuspida (d)	X	X
Naineris sp. (d)	X	X
Nephtys bucera (c)	X	X
Nephtys caeca (c)	X	X
Nephtys ciliata (c)	X	X
Nephtys discors (c)	X	X
Nephtys incisa (c)	X	X
Nephtys sp. (c)	X	X
Nereis sp. (c)	X	X
Nereis zonata (c)	X	
Ophelia sp. (d)	X	
Ophelia bicornis (d)	X	X
Ophelia limacine (d)	X	X
Ophelia sp. (d)		X
Opheliidae (d)		X
Ophelina acuminata (d)	X	X
Ophioglycera gigantean (c)	X	X
Orbinia ornate (d)	X	X
Paralacydonia sp. (d)	X	X
Paralacydonia paradoxa (d)	X	X
Pectinaria gouldi (d)	X	
Pholoe minuta (c)	X	X
Polycirrus sp. (d)	X	X
Potamilla reniformis (s)	X	X
Potamilla sp. (s)	X	
Praxiella gracilis (d)	X	
Praxillella praetermissa (d)	X	
Protodorvillea kefersteini (d)	X	X

Rhodine loveni (s)	X	X
Sabella penicillus (s)		X
Scalibregma inflatum (d)	X	X
Scolopus acutus (d)	X	X
Scolopus armiger (d)	X	X
Scolopus robustus (d)	X	
Scolopus sp. (d)	X	
Spirobis sp. (s)	X	X
Sternaspis scutata (d)		X
Streblospio benedicti (d)	X	
Terebellides stroemi (d)	X	X
Terebellides sp. (d)	X	
Tharyx acutus (d)	X	X
Travisia carnea (d)	X	X
SIPUNCULID		
Phascolosoma margaritaceum	X	X
Phascolosoma sp.	X	X
PRIAPULID		
Priapulus sp.	X	
ASCIDIAN		
Molgula sp.	X	X
CNIDARIAN		
Cerianthus borealis	X	X
Pachycerianthus fimbriatus	X	
BIVALVIA		
Astarte montagui (d)	X	
Astarte sp. (d)	X	
Astarte undata (d)	X	
Clinocardium ciliatum (s)	X	X
Cumingia tellinoides (d)	X	X
Thyasira sp (s)	X	X
Hiatella Arctica (d)	X	X
Macoma calcarea (d)	X	X
Macoma balthica (d)	X	
Mysella planulata (d)	X	X
Nucula sp. (d)	X	
Nucula tenuisulcata (d)	X	
Tellina agilis (s)	X	X
Thracia septentrionlic (s)	X	X
Turtonia minuta (s)	X	X
Yoldia limatula (d)	X	X
Yoldia myalis (d)	X	X

GASTROPODA		
Lacuna vincta (h)	X	X
Lora bicarinata	X	X
Melampus bidentatus (h)	X	X
Odostomia sp. (h)	X	X
Retusa obtusa (c)	X	X
Thais sp. (c)	X	X
ECHINODERMATA		
Asterias sp.	X	
Echinarachinus parma	X	X
Ponaster sp.	X	X
Family Ophiuridae		X
unknown brittle star	X	
CRUSTACEA		
Acanthostepheia malmgreni	X	X
Diastylis rathkei	X	
Gammarus mucronatus	X	X
Hyas coarctatus alutaceus (c)		X
Mesidotea sp. (c)	X	

Appendix H: List of species for habitat groups (A-M; CK 3-3) for Sachs Harbour 2005 and Gjoa Haven 2006.

HABITAT GROUP	**A**	**B**	**C**	**D**	**F**	**CK 3-3**	**H**	**I**	**J**	**K**	**L**	**M**
Dominant Substrate	sand	sand & muddy-sand	mud & muddy-sand	muddy-sand	muddy-sand	gravelly-sand	mud & muddy-sand	sand & muddy-sand	gravels	pe-co/ boulder gravel	pe-co gravel/ gravelly-sand	sand
DEPTH	0-20	0-40	0-40	20-40	0-10	0-10	10-40	0-40	0-20	0-10	0-20	0-10
PLANTAE												
Phaeophyceae (brown algae)												
Desmarestia aculeate			X									
Dictyosiphon sp.								X				
Fucus sp.								X	X	X	X	X
Petalonia sp.								X				
Pilayella littoralis								X				
Saccharina longicruris	X						X	X	X		X	X
Saccharina sp.								X	X			
Saccorhiza sp.					X							
Scytosiphon sp.	X					X	X	X				
Sphacelaria sp.			X				X	X	X	X	X	X
Stictyosiphon sp,								X	X		X	X
Rhodoghyta (red algae)												
Audouinella sp.					X							
Ceratocolax hartzi						X						
Coccotylus truncatus		X	X		X		X	X	X	X	X	
Hildenbrandia rubber									X			
Odonthalia dentate											X	X
Pantoneura sp.									X			
Polysiphonia sp							X	X	X			
Rhodomela sp.								X	X		X	
Scagelia sp.							X	X				
Chlorophyta (green algae)												
Chaetomorpha sp.								X			X	
Cladophora sp.												X
filamentous green algae							X	X	X			X
Percursaria sp.					X							
HABITAT GROUP	**A**	**B**	**C**	**D**	**F**	**CK 3-3**	**H**	**I**	**J**	**K**	**L**	**M**

Rhizoclonium sp.				X						
Spongomorpha sp.										X
Ulothrix sp.				X						X
Urospora sp.				X						
algal mats	X	X		X						
POLYCHAETA (Family)										
Apistobranchidae (d)	X		X							
Amphicorinidae			X			X				
Aricidae (d)			X		X					
Capitellidea (d)	X									
Cirratulidae (d)	X		X			X	X			
Cossuridae (d)										
Dorvilleidae (d)							X		X	
Euchaetidae	X		X							
Eunicidae (c)	X		X							
Goniadidae (c)	X		X							
Hesionidae	X									
Magelonidae (d)	X									
Malanidae (s)			X			X	X	X	X	X
Nephtyidae (c)		X	X			X	X	X	X	
Nereidae (c)	X						X	X		X
Opheliidae (d)	X		X							
Orbiniidae (d)			X			X	X	X		X
Paralacydoniidae (d)	X	X	X							
Paraonidae (d)									X	
Pectinaridae (d)							X		X	
Pholoidae (c)	X									
Phyllodocidae (d)	X		X				X			
Pilargidae (c)			X							
Pisonidae						X				
Polynoidae (c)	X						X	X	X	X
Sabelliidae (s)										

HABITAT GROUP	A	B	C	D	F	CK 3-3	H	I	J	K	L	M
Scalibregmidae (d)	X											
Serpulidae (s)												
Sigalionidae (c)			X									
Spionidae (d)								X	X		X	X
Sternaspidae (d)						X						
Terebellidae (d)	X		X			X						
Trichobranchidae (d)			X				X				X	X
OTHER												
Nemertean							X					
Naididae (d)							X					
Phascolosomatidae (d)	X											
PRIAPULID												
Priapulus sp.							X					X
ASCIDIAN												
Molgula sp.		X							X			X
CNIDARIAN												
Cerianthus borealis (s)				X			X	X				
BIVALVIA												
Astarte montagui (d)						X	X	X	X		X	
Astarte sp. (d)									X			
Astarte undata (d)							X					
Clinocardium ciliatum (s)	X											
Cumingia tellinoides (d)			X									
Thyasira sp (s)	X	X	X			X						
Hiatella Arctica (d)		X						X			X	

HABITAT GROUP	A	B	C	D	F	CK 3-3	H	I	J	K	L	M
Macoma calcarea (d)	X		X									
Macoma balthica (d)							X	X	X			
Mysella planulata (d)		X	X									
Nucula sp. (d)		X	X			X						
Nucula tenuisulcata (d)							X	X				
Tellina agilis (s)	X		X									
Thracia septentrionlic (s)												
Turtonia minuta (s)		X	X									
Yoldia limatula (d)												
Yoldia myalis (d)		X	X			X	X	X			X	X
GASTROPODA												
Lacuna vincta (h)	X											
Lora bicarinata	X	X	X									
Melampus bidentatus (h)	X											
Odostomia sp. (h)	X											
Retusa obtusa (c)								X	X		X	X
Thais sp. (c)			X									
ECHINODERMATA												
Asterias sp.							X					
Echinarachinus parma	X											
Ponaster sp.							X					
Family Ophiuridae			X									
unknown brittle star							X					
CRUSTACEA												
Acanthostepheia malmgreni	X											
Diastylis rathkei							X	X			X	
Gammarus mucronatus			X									
Hyas coarctatus alutaceus (c)		X		X	X							
Mesidotea sp. (c)							X	X				

Feeding guild for species is given in parentheses. d= deposit-feeding; s= suspension-feeding; c= carnivorous; h= herbivorous

Appendix I: List of species identified from grabs and video sampling for Sachs Harbour in 2005 and species identified from photographs collected by Siferd (2001). * indicate species only found in Siferd 2001 study.

SACHS HARBOUR

this study	Siferd (2001)
PLANTAE	
Phaeophyceae	**Phaeophyceae**
Desmarestia aculeate	*Fucus sp.*
Fucus sp.	*Laminaria solidungula* *
Saccharina longicruris	
Scytosiphon sp.	
Sphacelaria sp.	
Stictyosiphon sp.	
Rhodophyta	
Ceratocolax hartzi	
Coccotylus truncatus	
Chlorophyta	
Chaetomorpha sp.	
Algal mats	
ANNELIDA	
Aglaophamus neotenus	*Lumbrineris sp.* *
Ancistrosyllis groenlandica	
Apistobranchus tullbergi	
Capitella capitata	
Cirratutus cirratus	
Cossura longocirra	
Enipo gracilis	
Enipo sp.	
Eteone sp.	
Euchone rubrocincta	
Eumida sanguinea	
Eumida kefersteini	
Eunice sp.	
Euthalanessa sp.	
Frabicia sabella	
Frabicia sp.	
Goniadidae	
Harmothoe extenuata	
Magelona sp.	
Malanidae	
Naineris quadricuspida	
Naineris sp.	
Nephtys bucera	
Nephtys caeca	

Nephtys ciliata	
Nephtys discors	
Nephtys incisa	
Nephtys sp.	
Nereis sp.	
Nereis zonata	
Ophelia limacine	
Ophelia sp.	
Ophelina acuminata	
Opheliidae	
Ophelia bicornis	
Ophioglycera gigantea	
Orbinia ornate	
Paralacydonia paradoxa	
Paralacydonia sp.	
Pholoe minuta	
Polycirrus sp.	
Potamilla reniformis	
Protodorvillea kefersteini	
Rhodine loveni	
Sabella penicillus	
Scalibregma inflatum	
Scolopus acutus	
Scolopus armiger	
Spirobis sp.	
Sternaspis scutata	
Terebellides stroemi	
Tharyx acutus	
Travisia carnea	
SIPUNCULID	
Phascolosoma margaritaceum	
Phascolosoma sp.	
ASCIDIAN	
Molgula sp.	
CNIDARIAN	
Cerianthus borealis	*Cerianthus borealis*
	Pachycerianthus fimbriatus *
	Halcampa sp. *
BIVALVIA	
Clinocardium ciliatum	*Mya sp.* *
Cumingia tellinoides	*Serripes groelandicus* *
Thyasira sp (s)	*Clinocardium ciliatum* *
Hiatella Arctica (d)	*Hiatella arctica*
Macoma calcarea (d)	*Musculus sp.* *
Mysella planulata	*Delectopecten greenlandicus* *
Tellina agilis	*Macoma calcarea*
Thracia septentrionlic	

Turtonia minuta	
Yoldia limatula	
Yoldia myalis	
GASTROPODA	
Lacuna vincta	*Buccinum sp.* *
Lora bicarinata	*Natica clausa* *
Melampus bidentatus	
Odostomia sp.	
Retusa obtuse	
Thais sp.	
ECHINODERMATA	
Echinarachinus parma	*Ophiacantha bidentata* *
Ponaster sp.	*Ophiopleura borealis* *
Family Ophiuridae	*Gorgoncephalus sp.* *
	Heliometra glacialis *
	Ponaster tenuispinus
CRUSTACEA	
Acanthostepheia malmgreni	*Rhachotropis sp.* *
Gammarus mucronatus	*Stegocephalus inflatus* *
Hyas coarctatus alutaceus (c)	*Onismus sp.* *
	Mesidotea sp. *
	Hyas coarctatus alutaceus (c)
	Mysis sp. *