ASSESSMENT OF THE INFLUENCE OF FINFISH AQUACULTURE ON HARD BOTTOM HABITATS IN A BOREAL/SUB-ARCTIC MARINE ENVIRONMENT

TERRENCE ROSS BUNGAY

Assessment of the Influence of Finfish Aquaculture on Hard Bottom Habitats in a Boreal/Sub-Arctic Marine Environment

by

©**Terrence Ross Bungay**

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Abstract

Determining the extent of influence of marine salmonid farms on surrounding habitats is mandatory as an environmental monitoring procedure. In Newfoundland, environmental monitoring of salmonid farms relies on measuring geochemical properties of underlying sediment to assess the environmental impact of fish feces, mortalities, uneaten food and/or detached fouling organisms that deposit on the seafloor. This approach is problematic in coastal Newfoundland because it is difficult or impossible to obtain the intact sediment samples required for these analyses, given that the region has mostly hard bottom substrate. In this thesis, a new approach to habitat assessment, relying on indicator benthic species and habitat determinations based on benthic video drop-transects, is used to determine the environmental impact of salmonid farms. All identifiable species were counted from a series of underwater video drop-transects from sample stations running through aquaculture lease boundaries, as well as control sites where depth did not exceed 100 meters. Abundances, proportions, and percent coverage of species were then used in a cluster analysis to determine spatial differences in sample stations. Sites characterized by high *Beggiatoa*, Opportunistic Polychaete Complexes, and deposit-feeding sea stars were identified as being influenced by aquaculture, the area of influence being larger under active cages with mid production. Non-production (control) sites and fallowed sites displayed no such assemblage but were dominated by suspension-feeding taxa (anemones and sponges). A decrease in the latter taxa along with

the increase in deposition-tolerant species could be used for assessing the environmental influence of aquaculture on hard substrates.

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There are many thanks that the Aquaculture section of DFO should receive. Many of the employees not only have helped in this project but have guided me through working with DFO and have furthered my career and helped me grow as a person.

Here is a special thanks to my family for everything they have given me over the years; the support, guidance, and upbringing needed to succeed. Mom and dad, thank you for everything, raising three successful children couldn't have been easy, I hope this makes you proud. Thank you Sam, you were the most encouraging and understanding

through this entire process. Even though I don't like to talk about work or school at home you always had time for anything that I had to say.

To anybody that I had forgot I'm sorry, but despite having my this thesis done, I'm still really busy. I may have accomplished another stepping stone in my life but I'm still the same person as before, no bigger or better than anyone else, and not changing who I am for anyone.

"Try not to become a man of success, but rather try to become man of value"

Albert Einstein

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List of Abbreviations and Symbols

ADCP	-	Acoustic Doppler Current Profiler
DFA	-	Department of Fisheries and Aquaculture
DFO	-	Department of Fisheries and Oceans
F	-	Fallowed Site
GPS	-	Global Positioning System
Mx	-	Maximum Production
Md	-	Medium Production
Mn	-	Minimum Production
NL	-	Newfoundland and Labrador
Np	-	No Production
OPC	-	Opportunistic Polychaete Complex
r	-	Correlation Coefficient

Chapter 1 - Introduction

Finfish aquaculture is a fast growing industry in Newfoundland and is considered to be one of the major economic drivers in the province. The industry has experienced a 12.4 % production increase from 2010 to 2011, reaching a value of 120 million dollars in 2011 (DFA 2011). Rural communities along the coast benefit from increased employment opportunities related to aquaculture. The fast growth in aquaculture production presents challenges in ensuring that effects on the environment are minimal. Assessing the impact of aquaculture on the environment is important for both ensuring sustainability and for making sound regulatory decisions in managing the industry. The impacts of finfish aquaculture on the environment can stem from deposition of uneaten feed, feces, mortalities, and/or detached fouling organisms on cage sites (AMEC 2004). This deposition could have both beneficial and negative effects, depending to a large extent on depth of sites, as well as environmental conditions, habitat, bottom type, and benthic fauna (Rensel and Forster 2007, Strain 2005). Deposition under cages could result in nutrient loading, eutrophication, habitat smothering/defaunation, and changes in benthic sediment and water biogeochemistry (Miller et al.. 2002).

The major sources of deposits around finfish aquaculture cage sites are uneaten feed and, to a lesser extent, feces (Ackefors and Enell 1990). The amount of each depends on site conditions and stocking density, along with the type and amount of feed being used, feed monitoring techniques, and the consumption rate of the species being cultured. The amount of food being supplied to cages is regulated based on the appetite of cultured fish, which is influenced by various factors having long and short-term effects such as temperature patterns, diseases, and stress events (Black 2008). Since feed is the most expensive input in intensive aquaculture operations, it is in the best interest of growers to minimize the amount lost as waste. As a result, the industry has developed automatic feeding systems that supply food pellets to cages according to fish-growth models, where the frequency and timing of pellet addition can be changed to optimize growth under different temperature and day length regimes (Black 2008). In conjunction with feed systems, growers commonly use underwater camera systems within cages to monitor feeding and adjust meal amounts and the time between feedings. Without systems such as these, the scope for financial loss and environmental change is high (Black 2008). With a typical supply of 0.7% biomass as feed per day in the summer, a farm with 1000 tonnes of biomass will require 7 tonnes of feed per day. With 5% overfeeding, this can potentially result in 350 kg of feed being lost per day (Black 2008).

The effects of deposition on the environment are dependent on the duration of farm life cycle, physical and oceanographic conditions, natural biota, and the assimilative capacity of the surrounding environment. Not all deposits will settle directly underneath the cage; deposits have been shown to settle up to 1.2 kilometers from a farm site (Homer 1991). Where current velocities are relatively high, flocculants tend not to accumulate directly under the cages (Hargrave et al.. 1997), whereas in areas of low flow, natural flocculants and deposits accumulate under the cages.

The hydrography at aquaculture sites can have large implications on the amount of deposition in coastal waters. Anderson et al.. (2005) have evaluated and described typical oceanographic conditions for a large portion of the south coast. Hydrography could strongly influence the seasonality and spatial variability of rates of waste sedimentation and resuspension. Steep fjords with water depths above 500 m are common; in some areas, these depths can be attained in less than 50 m from shore. As a result of such bathymetry, typical temperatures of 1 to 5°C are observed on the bottom. In most bays and coves on the southern shore, the shoreline is exposed to inclement weather resulting at times in fetch of greater than 700 km. With such exposure, storm events and surges can be quite common, resulting in deep water exchange, resuspension events and sediment focusing. Because it can affect depositional focusing, dispersion, and resuspension, the hydrography of aquaculture sites is important, and sites having similar husbandry practices can potentially experience different levels of deposition. Hydrographic patterns can have different effects: they can either cause all deposits to disperse, with very little influence on the benthos, or they could lead to increases in local deposition, with potentially greater impacts on the benthos.

Impacts of nutrient loading on the benthos

With increased nutrient loading under aquaculture sites, there can be an associated change in the structure of the benthic community. Changes in diversity (a measure of habitat complexity with respect to the number of species), evenness (a measure of how evenly represented species are within the community), richness (the total number of species), and abundance (a count of each species or group) can be expected. Organic wastes produced by aquaculture activities add to the suspended particle load and can either enrich benthic habitats or smother organisms (Strain and Hargrave 2005). Nutrient loading can lead to an increase in biomass that may alter the community by supporting higher rates of predation and a greater number of individuals (Karlson et al.. 2002). Alternately, nutrient loading may lead to a mass depletion of oceanic resources (oxygen, phosphorus, nitrogen, etc.) and result in a decrease in biodiversity. Drastic changes in communities have been observed: in soft substrate environments, the response to high levels of organic enrichment is a local extinction of the natural community followed by an establishment of opportunists (Wildish et al.. 2004). In areas close to intensive aquaculture operations, abundances of most polychaetes, bivalves, amphipods, and cumaceans were found to decrease dramatically, while the nut clam *Nucula* thrived (Pohle et al.. 2001) These changes are correlated with organic matter content in sediments (Pohle et al.. 2001).

The water column may also be enriched through the addition of organic wastes, sometimes causing blooms of phytoplankton and/or macroalgae (Strain and Hargrave 2005). The increased biomass of primary producers depositing on the benthos contributes to increased levels of organic and inorganic carbon, nitrogen, and phosphorus, and increases in microbial biomass and the enzymatic decomposition potential of substrates (Meyer-Reil and Koster 2000). This benthic-pelagic coupled effect can add to the direct effect of deposition on the benthos, for a greater total impact.

Impacts of oxygen depletion on the benthos

In areas where deposition is high, the demand for oxygen will be high as a result of the breakdown of organic matter brought into the system (Miller et al.. 2002). This is partly due to decomposition of organic matter by aerobic bacteria (Strain and Hargrave 2005). If oxygen consumption is not associated with a high influx of oxygen, aerobic metabolism can become limited (Miller et al.. 2002). In the absence of oxygen, other electron acceptors are sequentially utilized by benthic microbes: anaerobic respiration uses, in order, nitrate, manganese, iron oxides, and sulphates (Middelburg and Levin 2009). The order is determined by energy yield but is also influenced by the physiology of the involved organisms. Anaerobic respiration can result in the fermentation of organic matter and the production of methane or sulphides. In soft sediments, the deposition of high organic matter can lead to the redox potential discontinuity moving closer and closer to the sediment surface (Hargrave 2000). With enough deposition the redox potential discontinuity will even move into the water column with depletion of oxygen levels.

Changes in dissolved oxygen concentrations near the substrate can impact the local species composition (Miller et al.. 2002). Motile organisms may move if they can't tolerate changes in oxygen concentrations, but sessile organisms either have to adapt, or die. Changes in species composition are dependant on each species' degree of resistance to hypoxia (Wildish et al.. 2004). In areas normally exposed to low oxygen levels, the community structure will show an increased tolerance to low oxygen (Wildish et al.. 2004). In other areas, a shift to low oxygen conditions can contribute to the destruction of habitats; in some cases, dead zones (where all fauna are smothered or forced to relocate) can be produced (Miller et al.. 2002). For more tolerant species such as the marine bacterium *Beggiatoa* sp. and capitellid polychaetes (e.g., *Capitella* spp.), aquaculture sites can be viable habitats (Hargrave 2000).

Opportunistic species following organic enrichment events

More tolerant organisms like *Beggiatoa* sp. and species forming Opportunistic Polychaete Complexes (OPC) may colonize vacated areas and help break down/digest deposited organic matter (Holmer et al.. 2008, Jorgensen et al.. 2010). *Beggiatoa* sp. is a widespread marine bacterium that colonizes surface sediments and possesses the ability to produce sulfur from the oxidation of hydrogen sulfide (Jorgensen et al.. 2010). They are typically found in eutrophic coastal zones, highly productive upwelling regions, aquaculture sites, and areas experiencing low oxygen concentrations (Jorgensen et al.. 2010). *Beggiatoa* sp. can also be found in areas where sulfides are introduced geochemically: cold seeps and hydrothermal vents (Jorgensen and Boetius 2007). Within these areas, *Beggiatoa* sp. generally occur in the zone between the oxic layer, that can be only millimeters thick, and the diffusion front that can be located several centimeters below the surface (Jorgensen et al.. 2010). Thus, *Beggiatoa* sp. are preferentially located in zones characterized by optimal concentrations of both oxygen and sulfides (Priesler et al.. 2007). In contrast, OPC (epibenthic aggregates of polychaetes surrounded by mucus), have been observed underneath aquaculture cages in Newfoundland, but have not been fully characterized. OPCs from aquaculture sites in Newfoundland are dominated by a new species of polychaete, *Ophryotrocha n.* sp. of the family Dorvilleidae (Murray et al.. 2012). This family of polychaetes forms an opportunistic group commonly associated with nutrient rich and polluted habitats (Thornhill et al.. 2009). Most dorvilleids occur in low densities but some stress tolerant species can reach high densities (Thornhill et al.. 2009). Habitats supporting high dorvilleid densities include whale-falls and organically enriched environments such as those underneath marine aquaculture cages (Wiklund et al.. 2009).

Biological indicators of aquaculture impact

As a response to changing sediment geochemistry and water chemistry the benthic community under aquaculture cages may change. The species richness and total abundance of macrofauna at an aquaculture site can be used to indicate potential areas of impact (Henderson and Ross 1995), as disturbed or polluted conditions can be associated with the loss of sensitive species (Dean 2008, Henderson and Ross 1995) and an increase in tolerant species. Also, faunal densities can be indicative of impact: relatively high faunal densities were observed on moderately impacted salmon aquaculture sites (Henderson and Ross 1995). Densities in their reference stations varied dramatically, illustrating the natural spatial variability and patchiness of biological populations.

The shift in community structure from suspension feeding to surface and subsurface deposit feeding taxa in organically enriched sites may be a tool for observing the degree of organic enrichment impact on aquaculture sites. Such a shift is evident in organically enriched sites (Birkeland 1987, Weigelt 1991, Lapointe et al.. 1992, Henderson and Ross 1995).

Environmental monitoring of aquaculture sites in Newfoundland

In most regions, environmental monitoring is required to detect any potential impacts that aquaculture could have on the surrounding environment. Monitoring can also be used to assess the recovery of impacted sites. Typically, environmental monitoring on aquaculture sites is based on the measurement of habitat variables to assess the degree of influence on the benthos. Presence and absence of particular species along with measureable sulfide and redox values in sediments provide indications of the degree of influence of aquaculture, useful for subsequent evaluation during the farm life cycle.

Environmental monitoring of aquaculture sites is mandatory in Newfoundland, and begins when a license is sought for a proposed aquaculture site. At this stage, an application must be completed, requiring initial monitoring of the environment. Measured parameters undergo a review process to assess their compliance with the Canadian Environmental Assessment Act. Once sites have been approved through this process, the Department of Fisheries and Oceans assumes all responsibility in the evaluation of environmental influence and habitat alteration (DFO 2011). The initial documentation process requires that underwater video and bottom grabs (for sulphide and redox measurements) be collected through a 100 m grid and the cardinal corners of a cage with a drop camera and Ekman grab. Protocols presently in place for habitat monitoring in Newfoundland were developed in Nova Scotia and New Brunswick, where soft substrates and shallow sites are common (Bob Sweeney, pers. comm.). At shallow sites, sediment core samples can be collected along transects by divers while in deeper sites, bottom grabs can be used to collect sediment samples. The redox potential and sulphide levels are then determined from each sediment sample using handheld probes and few reagents. These procedures are also currently used at sites with hard substrates. In Newfoundland, sampling is done primarily by grabs because most sites are in deep water (DFO 2011). When grab samples from soft sediments are collected, processing of the samples can be completed as usual; however, due to great water depths and hard bottoms, grab sampling is rarely effective. In deep water, grabs often have scope (angled deployment line), leading to failure in sample retrieval because the angle can affect how the grab hits or rests on the bottom. This is especially problematic for grabs that employ a messenger for triggering closure of the instrument. Substrate type also affects the efficiency of grab sampling: even on soft substrates, patches of bedrock and boulders can prohibit sample collection using grabs (Sutherland et al.. 2006). As a result, it is often impossible to get sediment samples for sulphide and redox measurements from Newfoundland aquaculture sites. To effectively monitor the impacts of aquaculture on hard bottoms, a more appropriate tool is needed.

Older sampling procedures included taking video recordings as supplementary material. From these recordings (taken at an angle), species can be subjectively quantified. Because it is easier to obtain videos than grab samples in Newfoundland, protocols based on the monitoring of benthic epifaunal communities could be a better approach for this province. The benthic communities associated with hard substrates can be characterized using faunal counts and percent coverage determinations. Hard bottom environments are typically colonized by sessile invertebrates such as sponges, cnidarians, ascidians, and bryozoans, responsible for both relatively high diversity and biomass in hard bottom areas (Wenner et al.. 1983). It is suggested that this high diversity and biomass is associated with habitat complexity (hard bottom environments can be composed of various types of substrates such as sand, gravel, cobble, boulders, and bedrock in various formations ranging from flat expanses to rocky outcrops forming cliff like structures), and does not exhibit a pattern with depth (Wenner et al.. 1983). Other hard bottom communities of the Atlantic are dominated by Enchinodermata, followed by Mollusca, Annelida, Chordata (as fish), and Cnidaria (Schneider et al.. 1987). Grouped by locomotory categories, crawling organisms are most abundant, with discretely motile, sessile, and swimming animals sequentially decreasing in abundance (Schneider et al.. 1987). Whether the grouping is taxonomic or locomotory, there is an inherent patchiness that is evident on hard bottom communities.

The purpose of this study was to investigate the influence that finfish aquaculture has on the marine sub-arctic hard benthic substrate on the south coast of Newfoundland, Canada using video monitoring procedures. The study was designed to address multiple issues:

1) A lack of knowledge of the typical hard-bottom benthic habitat, environment, and community of the south coast of Newfoundland,

2) An understanding of the influences of finfish aquaculture on typical Newfoundland benthic habitats within 100 m of depth,

3) The identification of potential candidate properties to distinguish influence of aquaculture, and

4) An assessment of the usefulness of remote video monitoring for classifying typical environmental conditions.

The approach used here was to collect benthic habitat and community data from videos collected at aquaculture sites on the south coast of Newfoundland at different stages of salmonid production. Statistical approaches (discriminant analysis based on stage of production, and cluster analysis) were then used to evaluate whether specific assemblages could characterize stages of salmonid production. The ultimate goal is to develop a benthic index that could be used to effectively assess the environmental impact of aquaculture in Newfoundland.

Supplemental data on local bathymetry, currents, and depositional models could be useful in the assessment of the benthic impacts of aquaculture. In this thesis the bathymetry and predominant current speed and strength were obtained to help interpret the area of influence (i.e., the benthic surface where deposits arising from aquaculture activities will accumulate and influence benthic community structure).

Chapter 2 – Materials and Methods

Video Collection and Analysis

The design of this study purposefully incorporates aspects of existing environmental monitoring protocols (as of 2010) concerning video recordings in Newfoundland (similar protocols and regulations exist in other Atlantic provinces of Canada and, but it is important to note that they are not standardized despite similarities in conditions and cultured species)(DFO 2011). Guidance documents (site applications and accompanying documents) include constraints related to depth (recordings are done only in depths < 100 m), the type of camera used, and the approach used for quantifying/qualifying habitat and benthic communities (DFO 2011). In this study, we adhered to many of those guidelines (recording only in depths < 100 m, and using a video camera of similar quality), but made improvements relative to the imaging angle. Previous video recordings were taken at angles to give oblique views of the bottom and species were subjectively quantified based solely on novel identification. Species that could be measured by percent coverage could be over- or underestimated because of the angle used and were judged by eye. To better quantify abundance and coverage of species, the camera was oriented so that it was perpendicular to the bottom, and included a measureable size reference.

Equipment used for video collection consisted of a digital underwater video camera (Shark Marine, 520 TV lines), two 150 watt lamps (Shark Marine), a Datavideo digital video recorder, GEOstamp, glare resistant monitor, GPS (Garmin GPS map CSX), and a Shark Marine deck box with light control (Figure 1). This system was accompanied by 120 meters of Shark Marine analog camera cable, 1000 watt EU1000i Honda generator (1.8 HP), and a Raymarine A50D sounder. Camera system was raised and lowered by hand. Previous experience and consultation with both industry and Fisheries and Oceans Canada (DFO) technical staff confirmed that this equipment provides video that is on par or of greater quality than that currently obtained for environmental monitoring in Newfoundland and Labrador.

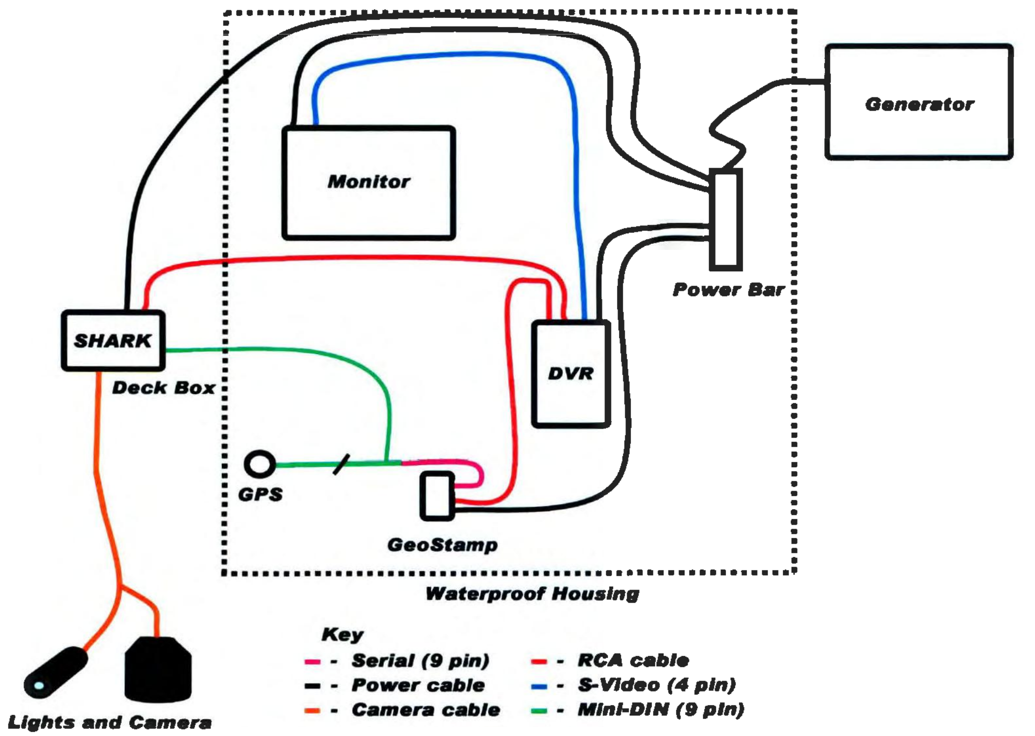


Figure 1. Underwater video collection equipment and setup.

The camera and lights were fixed to a stainless steel frame fabricated for underwater video collection using a direct drop-camera method. Dimensions and structure of the frame are shown in Figure 2. Both the lights and camera were attached in the pyramid-like upper portion of the frame, facing downward. The lights were positioned on either side of the camera to reduce the amount of shadows generated. For size referencing, a 25 cm square was suspended inside the larger frame.

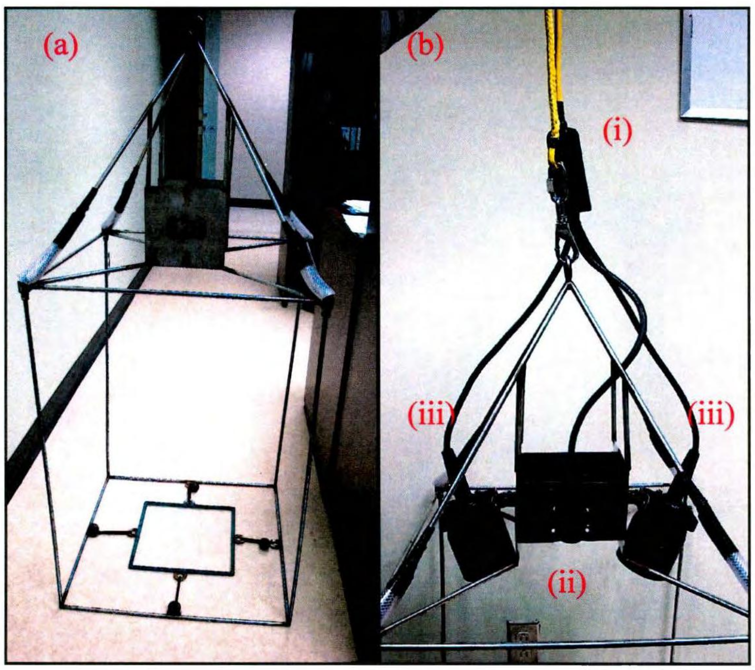


Figure 2. Underwater video camera frame. (a) shows the total camera frame, (b) shows the upper portion of the frame with; (i) umbilical cable attached, (ii) camera, and (iii) lights.

Collection of benthic video took place during July and August 2010, when water temperatures were warmer and thus larger amounts of feed were given to the salmon at each production site, which theoretically should lead to the largest degree of influences for each of the impact classes which are defined by the stage of production (none, minimum, mid, maximum, and fallow). Video collection protocols closely mimicked those in provincial and federal guidelines for industry (DFO 2011). However, the grid system, 100 m positional grid throughout a lease, that is conventionally used was replaced with higher density transects to increase spatial coverage. Video sampling was completed by transposing six transect lines through each of the aquaculture sites. Three transect lines ran parallel and three ran perpendicular to the coastline, creating a grid of measurements within the lease boundaries of a site, as shown in Figure 3. Each transect line ran the entire length or width of a given site, with sampling stations spaced 50 m apart. The distance between transect lines depended on the size of the lease, such that larger sites had transect lines spaced farther apart and smaller sites had transect lines closer together. The number of sampling stations at each site also varied, with smaller sites having fewer sampling stations than larger sites.

The eight study sites were located on the south coast of Newfoundland in the Fortune Bay, Bay D'Espoir, and Connaigre Bay areas, and coded as N1, N2, Mn1, Mn2, Md1, Md2, Mx1, and Mx2 (Figure 4).

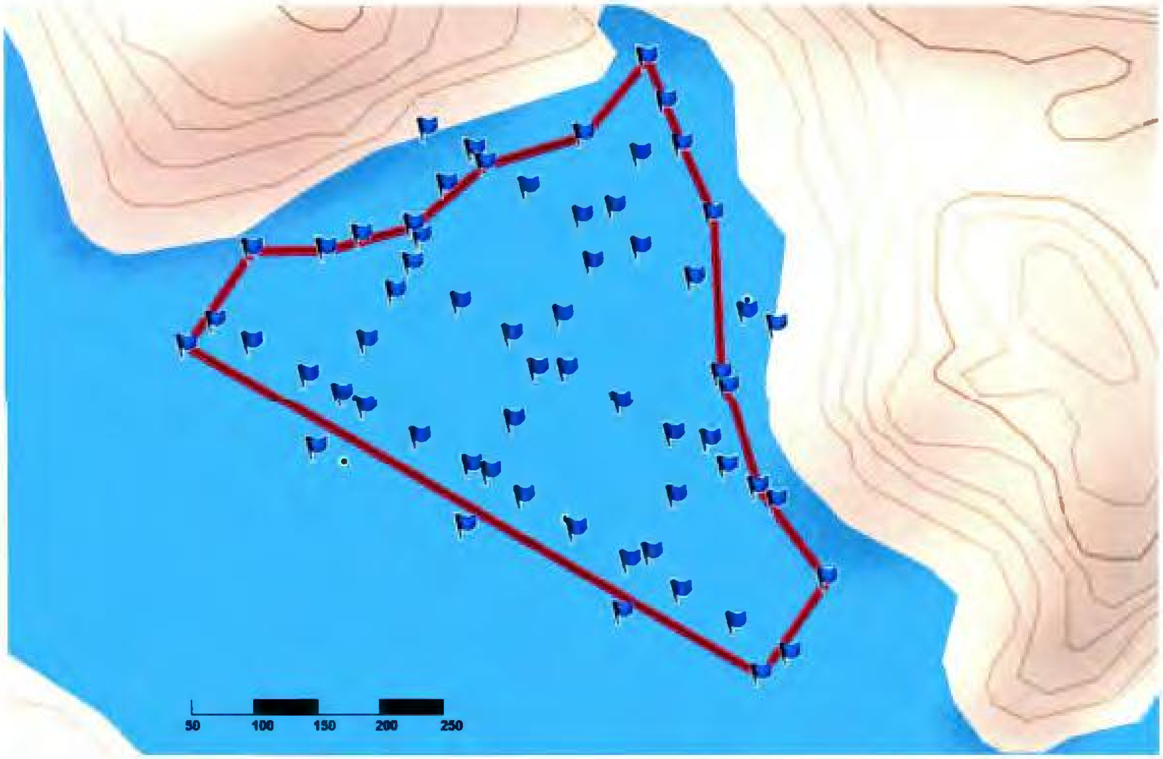


Figure 3. Example of sample sites within a lease. Red outline shows lease boundaries, blue flags are sample stations as shown by GPS plotting software.

These sites were chosen based on information (species being grown, bottom type, bathymetry and production stage) gathered from industry partners participating in this study. Because most sites varied in bathymetry and bottom type, sites were selected primarily based on production stage and species cultured (all were Atlantic salmon sites). Sites were grouped into 5 stages; No production (N), minimal production (Mn), medium production (Md), maximum production (Mx), and fallowed (F). N sites were identified by industry as potential sites for future use, but have had no previous production. Table 1 summarizes site information including depth range, production stage and the number of stations. Mn, Md, and Mx production sites were at different points in the production life cycle. Mn sites had fish that were introduced in the spring of 2010, while Md sites had summer or fall 2009 introduced fish. Mx production sites were at the pre-harvest stage, with large fish that were about to be harvested. Fallowed sites were at least one year post production, which is the mandatory fallowing period in Newfoundland for salmonid aquaculture sites (DFO 2011).

Table 1: Site Summary Information

Site	Bay	Production Stage	Cultured Species	Depth Range*	Num. of Stations	Num. of Altered Stations **
N_1	Fortune Bay	No Production	Atlantic Salmon	15-98 m	37	0
N_2	Hr. Breton Bay	No Production	Atlantic Salmon	13-100 m	43	0
Mn_1	Fortune Bay	Fish Introduced	Atlantic Salmon	15-88 m	32	3
Mn_2	Fortune Bay	Fish Introduced	Atlantic Salmon	17-54 m	32	6
Md_1	Bay D'Espoir	One year at sea	Atlantic Salmon	10-80 m	41	4
Md_2	Bay D'Espoir	One year at sea	Atlantic Salmon	7-67 m	47	3
Mx_1	Hr. Breton Bay	Fish Recently Harvested	Atlantic Salmon	6-93 m	26	0
F_1	Fortune Bay	Two years fallowed	Atlantic Salmon	6-100 m	51	0

*Values are for recorded video stations, stations without video recorded that were too deep still had a depth recorded sometimes exceeding 100m

**Altered stations were locations where physical obsticals obstructed collection of video and therefore station was moved

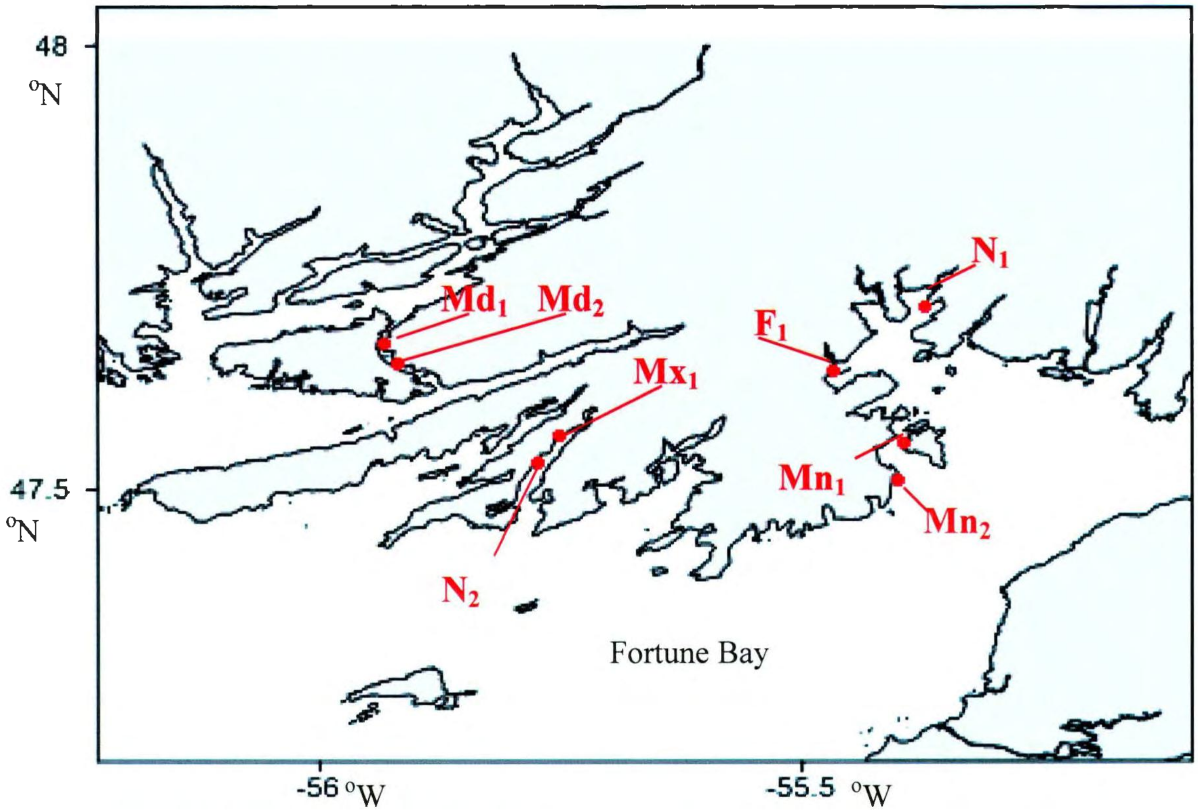


Figure 4. Aquaculture sites sampled during the summer of 2010. Coded to protect anonymity. N: no production, Mn: minimum production, Md: mid production, Mx: maximal production, F: fallowed.

Videos were collected in the following manner: for each video clip, recording started when the sea bottom comes into view; the camera is then slowly lowered until it is approximately 12 inches off the bottom (based on pulling cable in to lift the frame off the benthos) , providing a clear view of the benthos while allowing the camera to move. Recordings lasted at least 1 minute, and this footage was used to identify and perform counts of all species encountered. It should be noted that the benthic area covered during each video recording varied between stations due to movement of both the camera and boat but on average the area of coverage was 3.16 m^2 (+/- 0.31). Although boat operators tried to keep the vessel on station within the error of GPS units (± 10 m), the amount of drift of the camera above the bottom can vary. Therefore, the exact area covered by the camera is unknown and variable; however, drift was observed to be relatively slow. At the end of each video recording, a test was performed to determine substrate type: the camera frame was lifted off the seafloor and then dropped onto the substrate, resuspending loose material. Due to physical obstacles on site (barges, boats, cage, etc), some of the sample stations had to be moved to the nearest possible sampling location (this happened 12 times). In four cases, the sampling station was blocked by a large marine cage and was replaced by two sample stations on either side of the obstacle. Video collection was also limited by depth. In Newfoundland, video collection for aquaculture environmental monitoring is only performed to a depth of 100 m. Consequently, no video collection took place in depth in excess of 100 m, and these stations were removed from any statistical analysis. Due to scope of cable extended to the bottom this method would prove difficult in excess of 100 m.

Video analysis software supplied with the digital video recorder (DV Video Converter) and freeware (ImageJ and ImageGrab) were used to reduce the cost of visual analysis. The first minute of each video clip was viewed to determine the abundance of benthic species on the surface observed. All identifiable species (listed in Appendix 1) seen within or through the outer grid of the camera frame (50 x 50 cm) were quantified. Species were identified based on a key including a series of images and identifying visual characteristics for particular species, to the lowest taxonomic level attainable, usually the family level (Buzeta 2011). Figures 5 and 6 depict typical images obtained. For each station, substrate type and the percent cover of each mat forming species (coralline algae, seaweeds, kelps, bacterial mats, and OPC) were also recorded. Percent coverage of each mat forming species was determined from a representative image taken at each station when the camera frame was resting on the bottom before resuspension of sediments reduced image quality. The percent coverage of each mat forming species is obtained by defining regions of interest by hand using ImageJ.

Figure 5. Sample image extracted from benthic video showing a crinoid (*Heliometra sp.*) and coralline algae.

Figure 6. Sample image extracted from benthic video showing common anemones (*Stomphia sp.)*, coralline algae and sponges.

Data Analysis and Statistics

A general approach for the development of a benthic index was first formulated by Weisberg et al.. (1997). This process consisted of 3 steps: choosing a test data set, normalizing data, and running both stepwise discriminant analysis and canonical discriminant analysis as adopted by Engle et al.. (1994). This approach provides important measures of variability in the test dataset al.lowing the classification of test sites (and eventually future sites) within one of the five influence classes (N, Mn, Md, Mx, F).

The test dataset used here consisted of species-composition data from 315 stations within the 8 study sites, representing the 5 classes of influence or response. Table 1 lists the candidate measures used to develop the benthic index, chosen to represent ecological conditions of assemblages on the benthos. The second step in the creation of this index was to normalize candidate measures for the effects of aquaculture. Benthic abundance for particular species, evenness, and diversity were expected to be affected by changes in depth throughout a site. To test for this, correlations with depth were made, and r values < 0.25 were interpreted as not being influenced by depth (Engle et al.. 1994, Weisberg et al.. 1997). There are no variables with significant relationships with depth included in the analysis; any variables that were found to be correlated with depth were corrected using expected values, calculated from cubic functions fitted to depth versus abundance scatterplots (Weisberg et al.. 1997). These expected values were then substituted to measured values to remove the effect of depth (Engle et al.. 1994, Weisberg et al.. 1997).

All candidate metrics listed in Table 2 were included in a stepwise discriminant analysis using Systat 13©.

Table 2. List of candidate benthic measures.

Measures of biodiversity/species richness/abundance
Shannon-Weiner diversity index Pielou's evenness index Mean number of species Total Abundance % coverage *Beggiatoa* % coverage OPC % coverage coralline algae
Measures of taxonomic composition
Mean abundance of sea stars Proportion of total abundance of sea stars Mean abundance of sponges Proportion of total abundance of sponges Mean abundance of anemones Proportion of total abundance of anemones Mean abundance of soft corals Proportion of total abundance of soft corals Mean abundance of tube worms Proportion of total abundance of tube worms Mean abundance of urchins Proportion of total abundance of urchins Mean abundance of chaetognaths Proportion of total abundance of chaetognaths Mean abundance of euphausiids* Proportion of total abundance of euphausiids*

*Identification not certain, resembles euphausiids but could potentially be mysid or decapodid shrimp

To validate *a priori* influence groupings, cluster analysis was used to generate five assemblages, so that the structure and similarity of groups with respect to candidate parameters could be determined. Using this approach, an assemblage could be assigned to each of the sample stations based on the similarity of measured values of each candidate metric (unlike the discriminant analysis procedures that require a pre-assigned group for classification). The cluster analysis was run with all candidate measures to determine overall groups. To assess the similarity between groups, the distances between centroids of groups was recorded. This measure of similarity is the Euclidean distance in 3D space between centroids; the lower the value, the more similar the groups.

The geostatistical software Surfer 9©, which plots, groups, and interpolates values of parameters over larger areas, was then used to plot the spatial distribution of assemblages, substrate type, and depth within each aquaculture lease. Using nearest neighbour techniques and the data available for each station, assemblages and dominant substrate type were plotted by grouping like points together and creating an outline between dissimilar groups, the latter being generated evenly between groups. Plotting depth within a lease required a different technique, kriging. A commonly used method for generating full coverage depth maps using point samples, kriging takes the depth values of sample stations and generates a grid of values by interpolating from the measured values. It is important to note that interpolated values, but not the measured values are represented in the generated image.

Current Data

Water column speed and direction have been collected and analyzed around aquaculture sites in most parts of the south coast of Newfoundland, as part of projects aimed at modeling deposition in these areas. These data were collected using moored ADCP (Acoustic Doppler Current Profilers) in model A2 SUBS system (Figure 7). With ADCPs mounted on the bottom in an upward facing direction, current speed and direction in the entire water column are measured in 1m bins. Bin depth, frequency and period of measurement are variable and were adjusted based on the type of ADCP, operating depth, and battery charge.

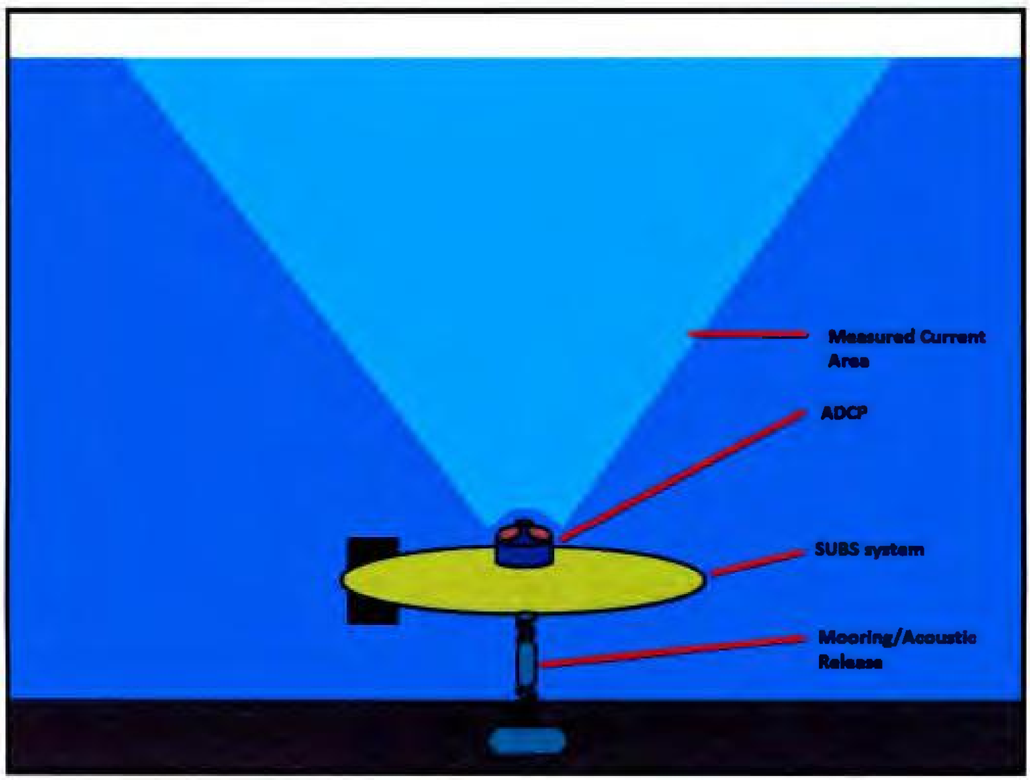


Figure 7. ADCP deployment setup. Approximately 1 meter above sea bed, beam area extending past surface to ensure total water column measurement.

Chapter 3 – Results

Statistics

Pearson Correlations

Pearson correlations between depth and all potential candidate metrics revealed some statistically significant correlations with depth (Table 3). These correlations were significant at $p < 0.01$ but none of these significant relationships exceed an r value of 0.25. The percent coverage of coralline algae, abundance of anemones, proportion of anemones, abundance of euphausiids, proportion of euphausiids, total abundance, diversity, and evenness had significant relationships with depth. Therefore, these values were then corrected for depth using the method of Weisberg (1997).

Stepwise Analysis

With all potential candidate metrics included (and depth corrections made), the stepwise discriminant analysis calculated f-scores for each candidate metric, with little change in results for f values of 0.100 and 0.200. These values were then chosen in a stepwise order to maximize the amount of explained variation in the data set. Forward stepwise analysis returned the percent coverage of OPC, abundance of corals, proportion of euphausiids, abundance of sea stars, proportion of sea stars, proportion of urchins, abundance of anemones, proportion of anemones, richness, and total abundance as being major discriminating variables. These variables were then carried over into canonical analysis.

Table 3. Pearson correlations between each candidate metric and depth.

	r
Coralline algae % Coverage	-.319**
Beggiatoa % Coverage	.024
OPC % Coverage	.113*
Sea Star Abundance	.192**
Sea Star Proportion	-.161*
Urchin Abundance	-.137*
Urchin Proportion	-.250**
Coral Abundance	.057
Coral Proportion	-.027
Anemone Abundance	.282**
Anemone Proportion	.385**
Euphausiids Abundance	.352**
Euphausiid Proportion	.371**
Chaetognath Abundance	.122*
Chaetognath Proportion	.070
Tube Worm Abundance	.166**
Tube Worm Proportion	.097
Sponge Abundance	.248**
Sponge Proportion	.110
Richness	.025
Total Abundance	.384**
H	.445**
E	.445**

*: significant at the 0.05 level (2-tailed)

**: significant at the 0.01 level (2-tailed)

Canonical Analysis

With the variables identified from the stepwise discriminant analysis, the canonical analysis developed a series of models to then classify each sample point. This new classification would then be compared to the pre-determined classification from the same point (based on stage of aquaculture production). Classification efficiency was calculated to compare the number of correctly classified sites based on the stage of production versus the model's prediction. This classification was relatively poor: using 4 models the total classification efficiency was only 56%. Classification efficiency was somewhat higher (77% and 92 %) for the Mn and F sites, respectively.

Cluster Analysis

The structure of each cluster is mainly characterized by primary variables with high f-ratio scores; the percent coverage of coralline algae, abundance of anemones, and the total abundance are three variables expressing extremely high f-ratios, with percent coverage of *Beggiatoa*, percent coverage of OPC, Shannon-Weiner diversity and evenness also expressing relatively high f-ratios. Each cluster is distinct in structure with multiple candidate metrics standing out as identifying characteristics; profile plots (Figures 8-12) depict the average of each measured parameter for all sample stations grouped within a cluster.

Cluster 1 has low average percent coverage of coralline algae, *Beggiatoa spp.* and OPC (under 0.05%), low total abundance and among groups a higher overall richness. Anemones, euphausiids, sea star abundances and subsequent proportions are very low with zero counts of other candidate metrics (Figure 8). Cluster 2 has a high abundance of anemones and sea stars and a very high total abundance and richness, resulting in high proportions of the candidate metric species and a high diversity with low evenness (Figure 9). Other groups that were represented include corals, euphausiids, and sponges in low numbers. Coral, chaetognath, and sponge abundances were elevated but are not substantially large. Cluster 3 has a very high percent coverage of coralline algae with very low amounts of other candidate metrics (Figure 10). Anemone, sea star, urchin, coral, and sponge abundances are very low. Sea stars make up a large proportion of the poor evenness group. On average this group has very low numbers despite a spike in total abundance, this spike only reaches 5 counts, which compared to other groups is very poor. Cluster 4 has low abundances of most species (near zero) with a slightly elevated count (and higher proportions) of anemones and euphausiids and a high percent coverage of *Beggiatoa* and OPC (Figure 11). Counts and related proportions for other species are zero. Evenness and diversity are essentially zero. Cluster 5 is represented by very large numbers and a high proportion of anemones, low richness, and a high total abundance (Figure 12). Lower amounts of euphausiids, sea stars and sponges also contribute to the community. These clusters are ordered in level of frequency, with cluster 1 being the most common and cluster 5 the least common (6 cases). Figures 13 through 17 show a typical still image of each cluster.

There is a similar Euclidean distance between most groups, suggesting that groups are equally distinct from one another (Table 4). However, groups 1 and 2 are more similar to each other than any other pair among the five groups.

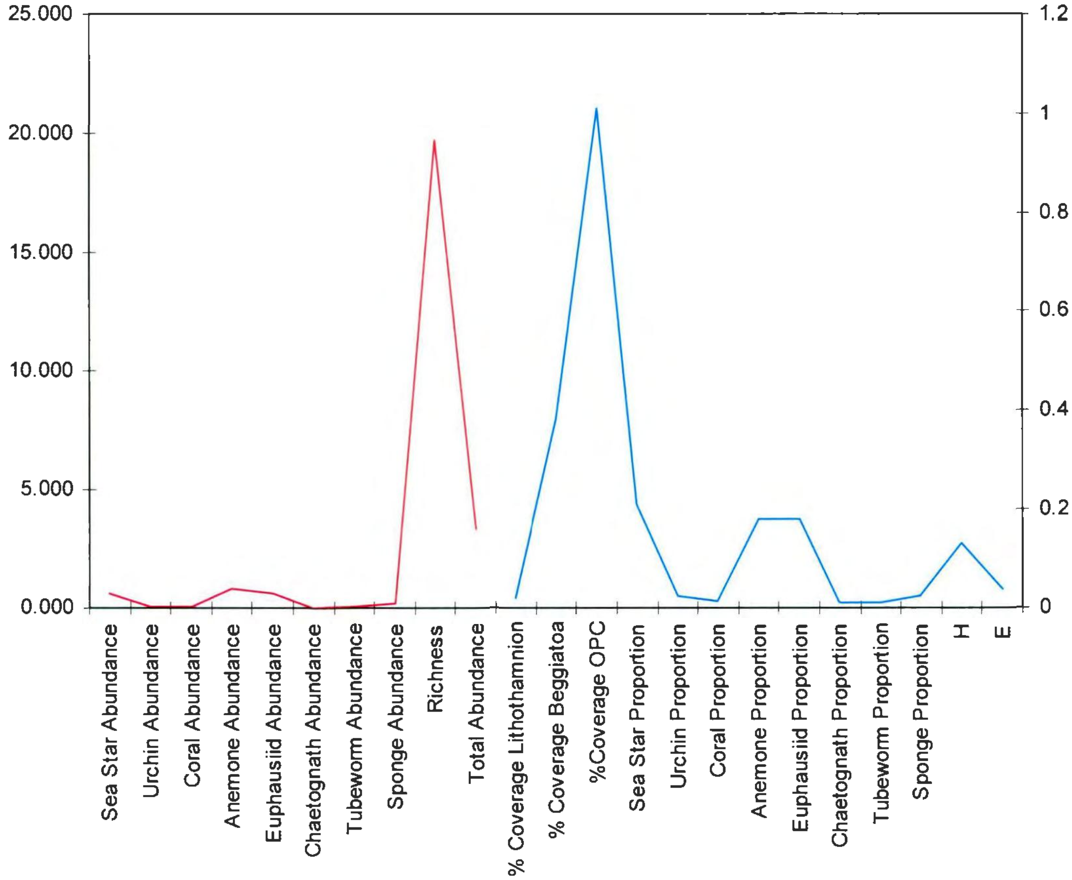


Figure 8. Cluster 1 Profile Structure. Lines connect averages of candidate metrics, with the red line corresponding to the left Y axis and the blue line corresponding to the right Y axis. Depending on the metric, values on the Y axis refer to abundance, % area of coverage, proportion of the observed community, diversity or evenness.

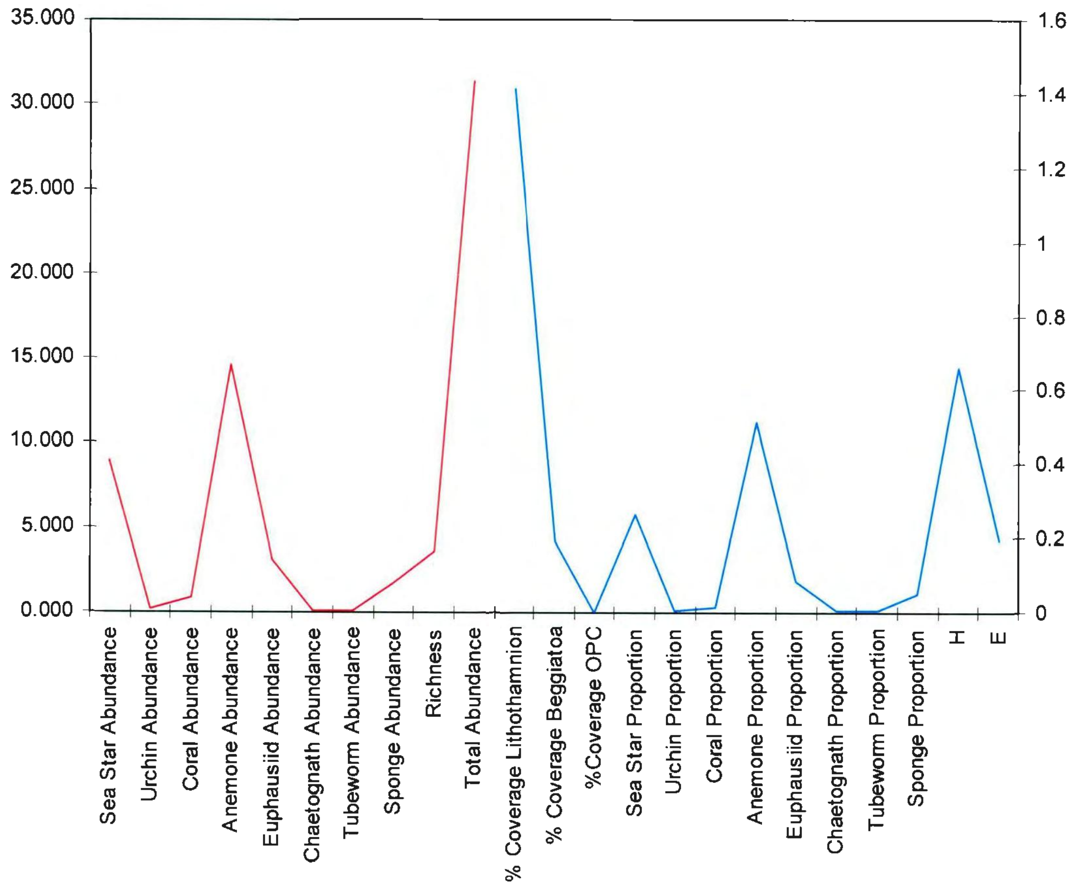


Figure 9. Cluster 2 Profile Structure. Lines connect averages of candidate metrics, with the red line corresponding to the left Y axis and the blue line corresponding to the right Y axis. Depending on the metric, values on the Y axis refer to abundance, % area of coverage, proportion of the observed community, diversity or evenness.

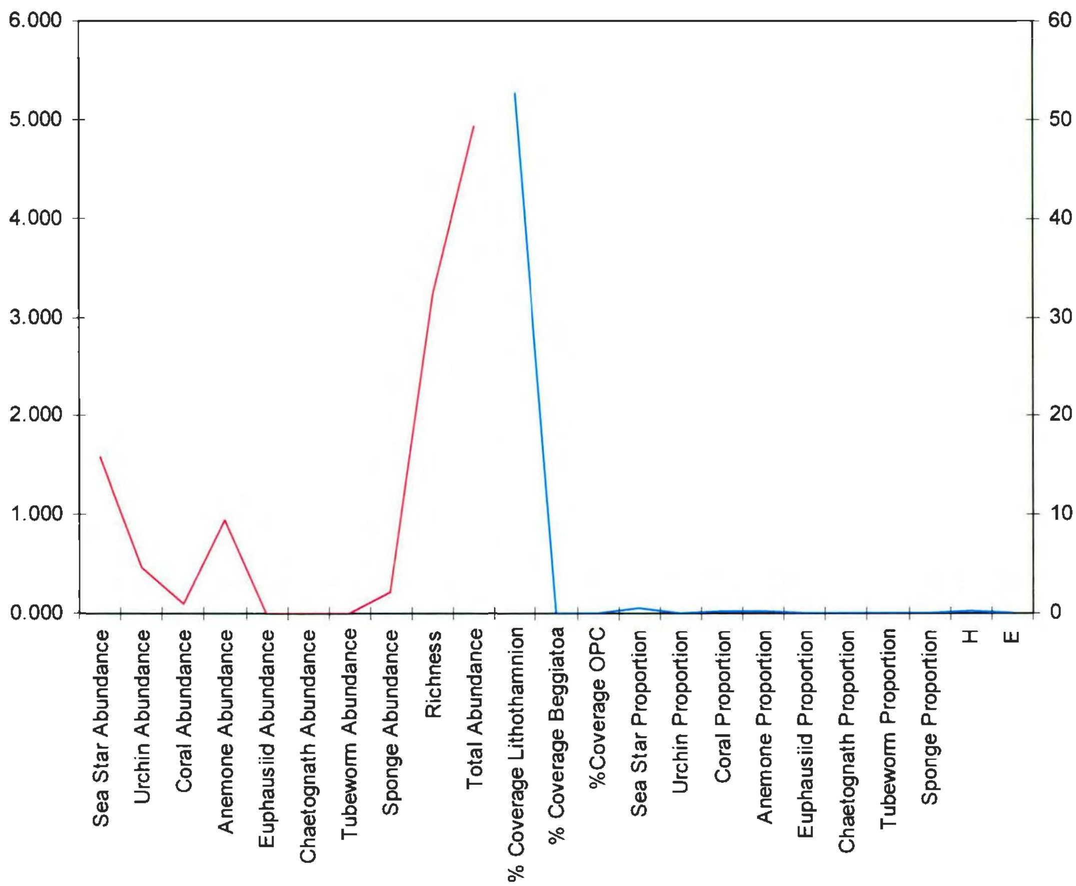


Figure 10. Cluster 3 Profile Structure. Lines connect averages of candidate metrics, with the red line corresponding to the left Y axis and the blue line corresponding to the right Y axis. Depending on the metric, values on the Y axis refer to abundance, % area of coverage, proportion of the observed community, diversity or evenness.

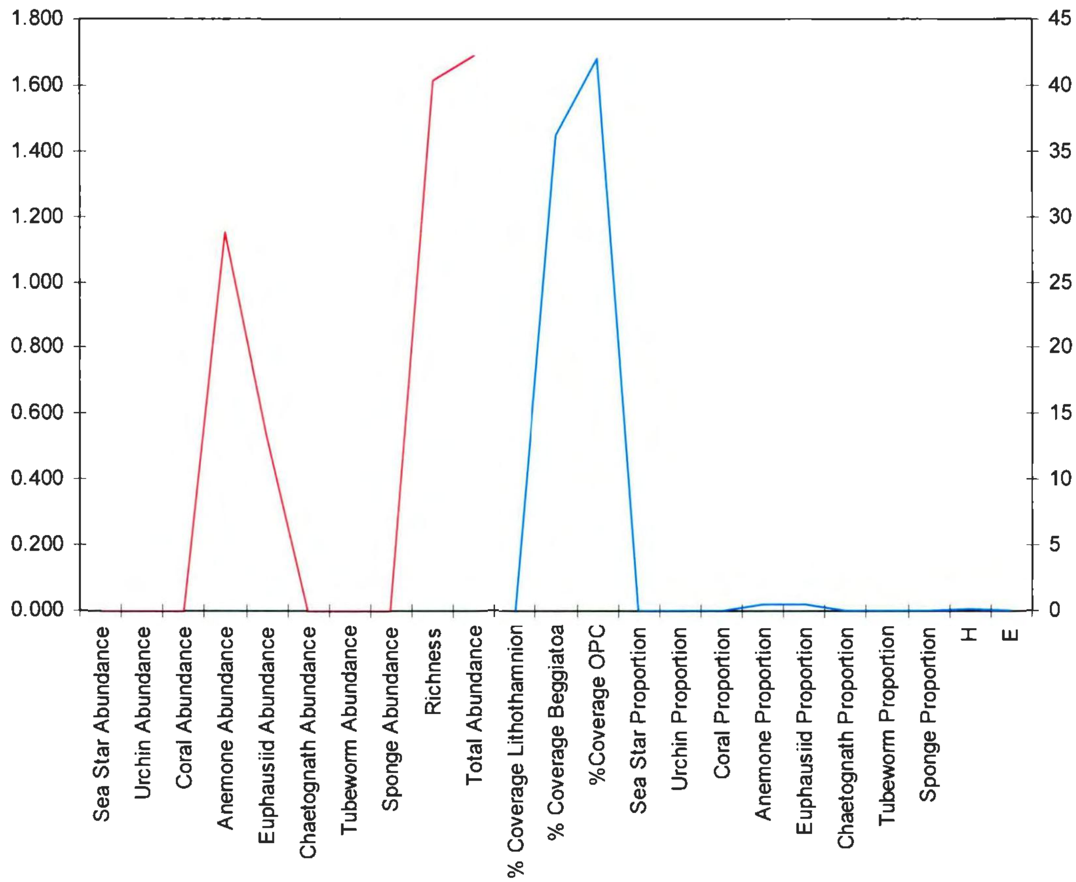


Figure 11. Cluster 4 Profile Structure. Lines connect averages of candidate metrics, with the red line corresponding to the left Y axis and the blue line corresponding to the right Y axis. Depending on the metric, values on the Y axis refer to abundance, % area of coverage, proportion of the observed community, diversity or evenness.

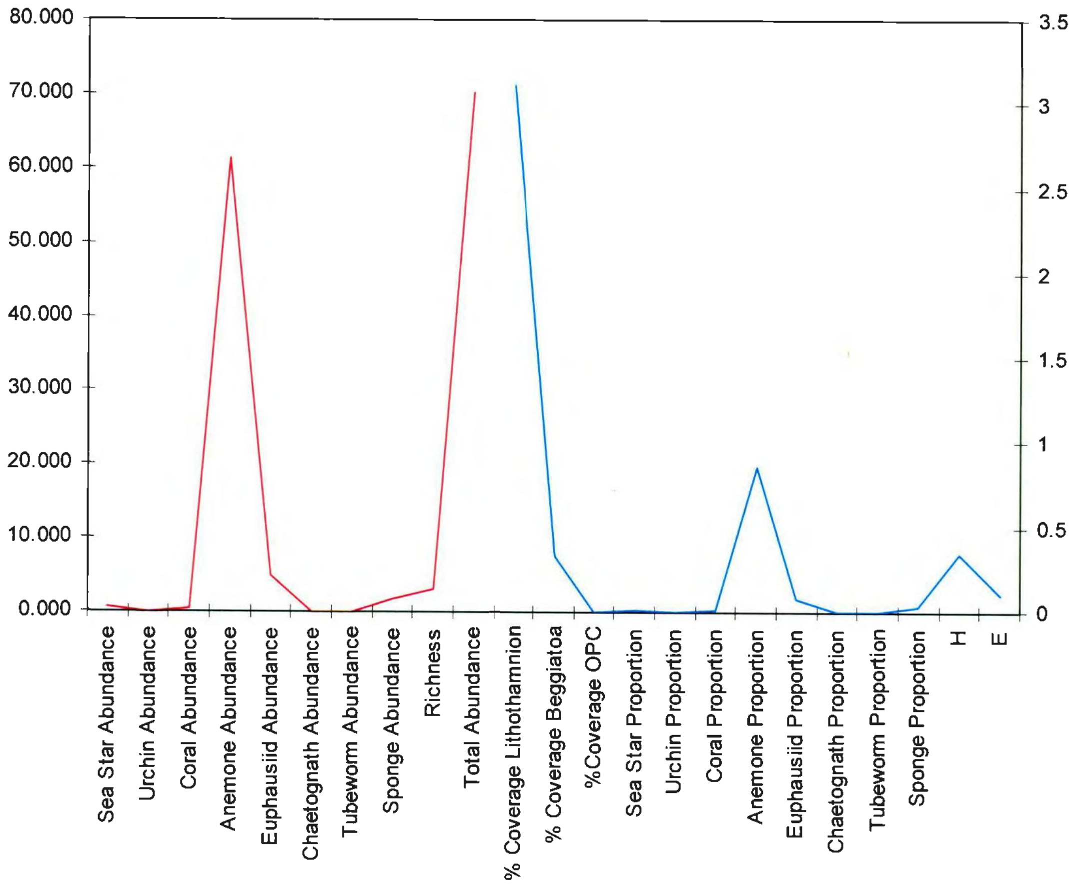


Figure 12. Cluster 5 Profile Structure. Lines connect averages of candidate metrics, with the red line corresponding to the left Y axis and the blue line corresponding to the right Y axis. Depending on the metric, values on the Y axis refer to abundance, % area of coverage, proportion of the observed community, diversity or evenness.

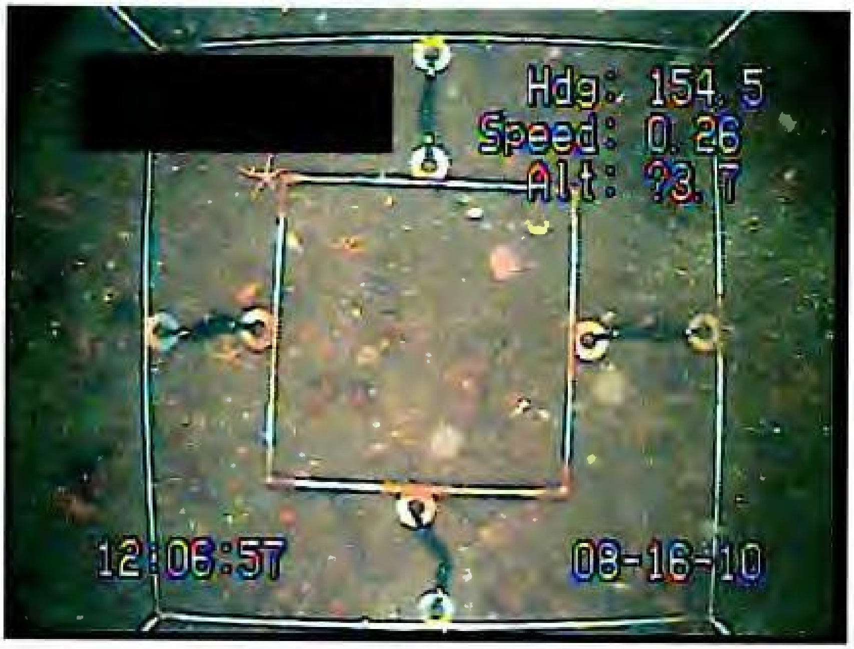


Figure 13. Typical cluster 1 still image. Individual sea stars and solitary anemone shown with a depth around 60 meters.

Figure 14. Typical cluster 2 still image. As shown anemones very abundant, other species less common. Depth at around 60 meters.

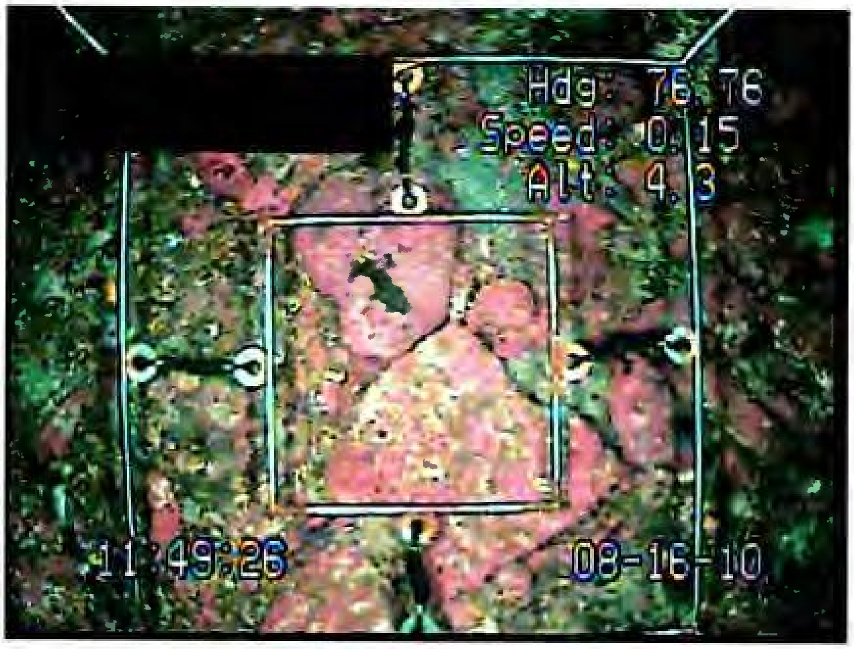


Figure 15. Typical cluster 3 still image. As shown coralline algae coverage very high, very low abundances of other groups. Depth is about 60 meters.

Figure 16. Typical cluster 4 still image. OPC coverage very high. When present *Beggiatoa* coverage is similar to this degree.

Figure 17. Typical cluster 5 still image. Very high abundance of anemones, crinoids and coralline algae also depicted. Depth is about 60 meters.

Table 4. Euclidean distances to centroids of each cluster

Cluster	1	2	3	4	5
1	0.0000	-	-	-	-
2	5.5501	0.0000	-	-	-
3	10.5692	11.8021	0.0000	-	-
4	14.7747	9.3912	17.7399	0.0000	-
5	17.4455	18.4637	20.7148	23.0124	0.0000

Sample Station Positioning

Within all aquaculture sites, obstacles were encountered when trying to obtain video data in pre-determined locations. With polar circle cages of variable size, and the presence of feed barges, pipelines, floating docks, buoys, and mooring lines, some sample stations had to be moved. Twelve sample stations were moved as close as possible to obstacles, but were not directly located on the predetermined point. On four occasions, single sample stations were replaced with two sample stations, one on each side of the obstructing object.

There were some errors in GPS positioning, which became evident when coordinates recorded on site were later plotted on a map (Figs. 18-25). Such errors can have a variety of sources, many of which are uncontrollable and depend greatly on the location of the positioning device. Ionosphere and troposphere delays, multipath signals, orbital errors, clock error, satellite geometry and the number of satellites detectable by the device are major sources of error (Garmin 2008). For some of the sites, error in the number of satellites detected, caused by surrounding islands and cliffs, led to some of the points being off. Such errors can easily be seen in sites Mn_1, Mn_2, Md_1, and Md_2, where some sample stations appeared on land. The exact distance of error varies depending on the source of error, but standard operating error of the GPS used is ± 10 m.

Bathymetry

Using depths that were recorded at each sample station, bathymetry charts could be generated to a finer scale than that available on conventional charts (Figs. 18-25). Conventional nautical charts for the area were Canadian Hydrographic Service CC4644, CC4830, and CC4831. These new charts provide a depiction of the highly variable environment that exists in coastal Newfoundland. Sites varied in depth from 15 to 150 m.

The sites Mn_1, Md_2, Md_2, N_1, N_2, and Mx_1 were similar in their bathymetry. These sites contained shallow in-shore areas with both steep and shallow declines into deeper water. Further from the shore (generally), there were deeper areas with very little slope, indicated by large spacing in the contour lines. Some deeper basins were observed, as in N_1, N_2, and F_1. It is important to note that these deeper features may not be representative of actual conditions, but could be due to interpolation using the krigging software. Mn_2 and F_1 were exceptional: these sites had low slopes with no coastline close to the lease.

N_1 and N_2 have features that are unique among the collection sites. These two sites contain a rock wall, typified by the sharp increase in depth that can be seen in video clips and photos along with bathymetry maps.

Habitat Mapping

The dominant type of bottom that was observed in the video analysis was used, along with corresponding geographical coordinates, in nearest neighbor plotting; generating areas of similar dominant substrate type (Figs. 18-25 (b)). Because there were multiple substrates observed at each station (in most cases, three or four out of eight possible bottom types were observed), only the dominant type of substrate was used in this analysis for simplification.

Each site varies greatly in bottom type as can be seen from the Figures 18-25 b. All sites are patchy, but one bottom type tends to be more common, filling the gap between patches of other substrates. Most sites are dominated by a combination of silt/sand, sand, and coarse gravel. Mx_1 and N_1 are less variable, being dominated throughout the lease boundaries by silt/sand and coarse gravel, respectively. Large scale patches of substrate appear to be the common trend in the studied region.

Spatial Distribution of Assemblages

No Production

N_2 has a very distinct benthic assemblage map with inshore and offshore stations dominated by two different assemblages. The inshore area is dominated by the type 1 assemblage (cluster 1) which spreads along the shore throughout the lease, while the larger offshore area is dominated by the type 2 assemblage (cluster 2), except for a relatively small patch of assemblage 1 offshore (Figure 19c). At boundaries between the type 1 and 2 assemblage there are small patches of the type 3 assemblage (cluster 3) that are relatively small compared to the expanse occupied by types 1 or 2. Towards the east end of the lease there is a small patch of the type 5 assemblage (cluster 5). The other no production site, N_1, has a much different spread of assemblages. There appears to be no inshore or offshore pattern but there is a similar patchiness as seen on other sites (Figure 18c). However, like N_2, N_1 has patches of assemblage type 5 located towards the western edge of the lease and just outside the lease in the same direction.

Min Production

Mn_1 is dominated by assemblage type 1 (Figure 20c) except for a number of small patches spread throughout the site. These patches contain both type 2 and 3 assemblages with no type 4 (cluster 4) or 5 assemblage. Mn_2 is similar to Mn_1 in dominance of type 1 assemblage and the patchiness of type 2 and 3 assemblages (Figure 21c); however patches of the type 3 assemblage are more common with fewer type 2 assemblages. There is also a small patch of the type 4 assemblage found in proximity to the cages contained within the lease boundaries. This patch is under cages and spreads northwest of the cages.

Mid Production

Both Md_1 and Md_2 have a similar distribution of assemblages throughout the area of the lease. There is a patchiness of assemblages 1 and 2 for the majority of the site with relatively few small patches of assemblage 3 closer to shore and in shallower areas of the lease (Figure 22c, Md_1, and Figure 23c, Md_2). Both sites also have areas in which assemblage 4 has been identified. In Md_2 assemblage 4 appears to be centered underneath the cages on site while in Md_1 this assemblage is pushed slightly southward and occupies a much greater area.

Max Production

The assemblage map of Mx_1, a maximum production site, is dominated by the type 1 assemblage spread throughout the site with some patchy type 2 and 3 assemblages (Figure 24 (c)). This somewhat patchy and semi-dominant distribution is similar to that of the difference in habitat. However there is a patch of the type 4 assemblage on the western side of the cages contained within the lease. This patch of high *Beggiatoa* and OPC is on the windward side of the cages with respect to currents, with predominant current coming from the southwest (Figure 27).

Fallowed

From Figure 15, F_1 can be seen as being dominated by the type 1 assemblage. The lease is almost entirely type 1 with four patches of type 3 and 1 patch of type 2 assemblages. The type 2 assemblage that is observed is to the southeast of the lease boundary.

Hydrographic Data

The hydrographic data, taken from moorings whose exact locations are shown on Figure 26, are presented in Figures 27 - 29. These figures show average speed and direction for approximately 90 day deployments of ADCP moorings on the south coast of

Newfoundland. Figure 27 shows the currents experienced in the greater Fortune Bay area. Throughout the summer, this area had surface currents that were relatively strong. However, the strength of currents rapidly decreases and switches to a predominant southeast direction with increasing depth. A similar pattern is seen in Gaultois Passage, where very strong currents are observed at the surface and current speed and direction change with depth (Fig. 28). Predominant currents within the first several meters are strong in the southwest direction, and change to a northwest direction, and approximately half the strength measured at the surface, for the majority of the water column. The deepest current measures increase in speed, but do not reach the speed of the surface. This pattern of high surface currents with slightly elevated bottom currents is repeated again in Harbour Breton Bay (Fig. 29). Currents in this bay are extremely strong, nearly 4 times the strength measured at other moorings. As the depth increases, currents drop to nearly zero for the majority of the water column. In the deepest measurements the current speed remains relatively high and is directed towards the northeast.

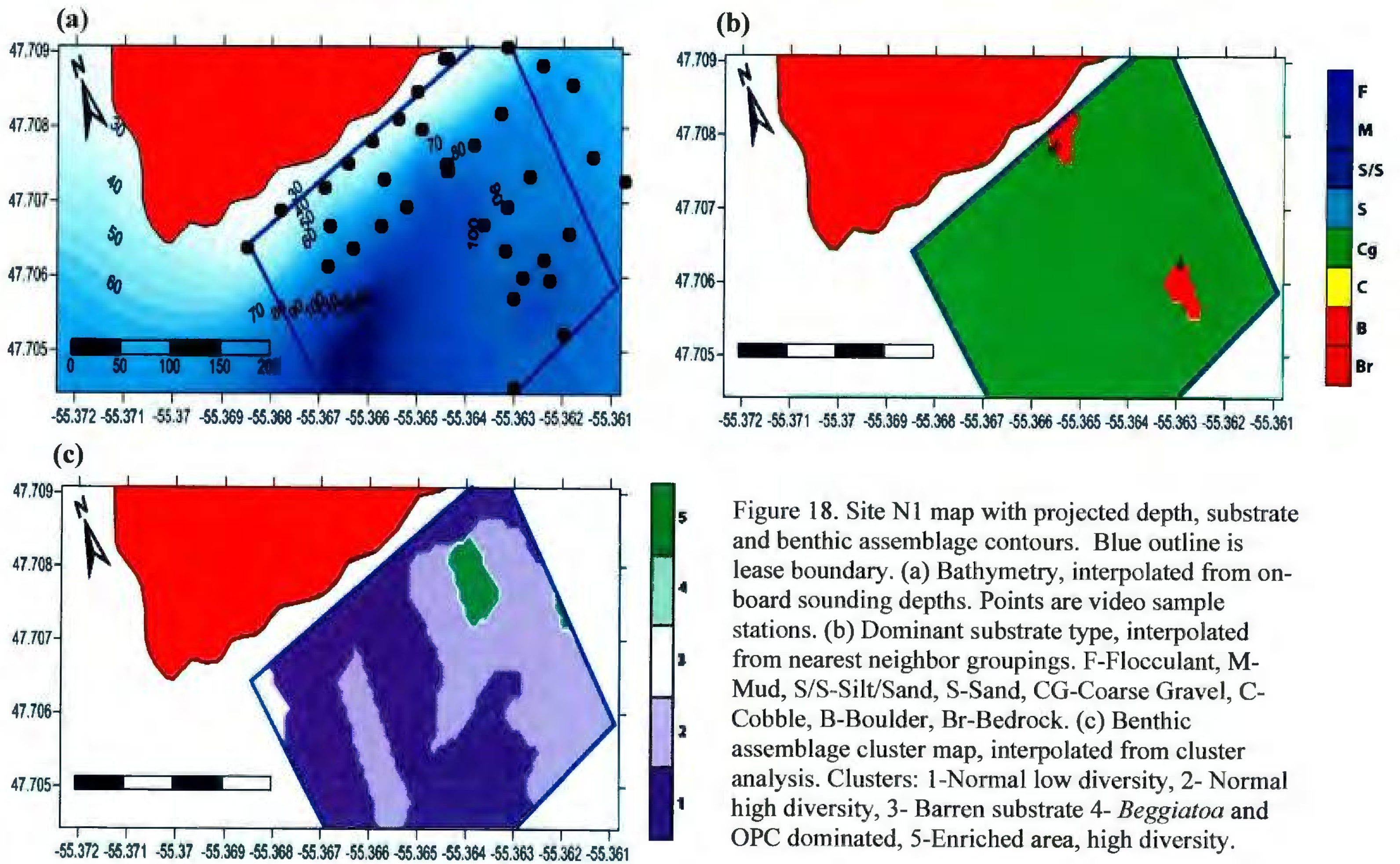
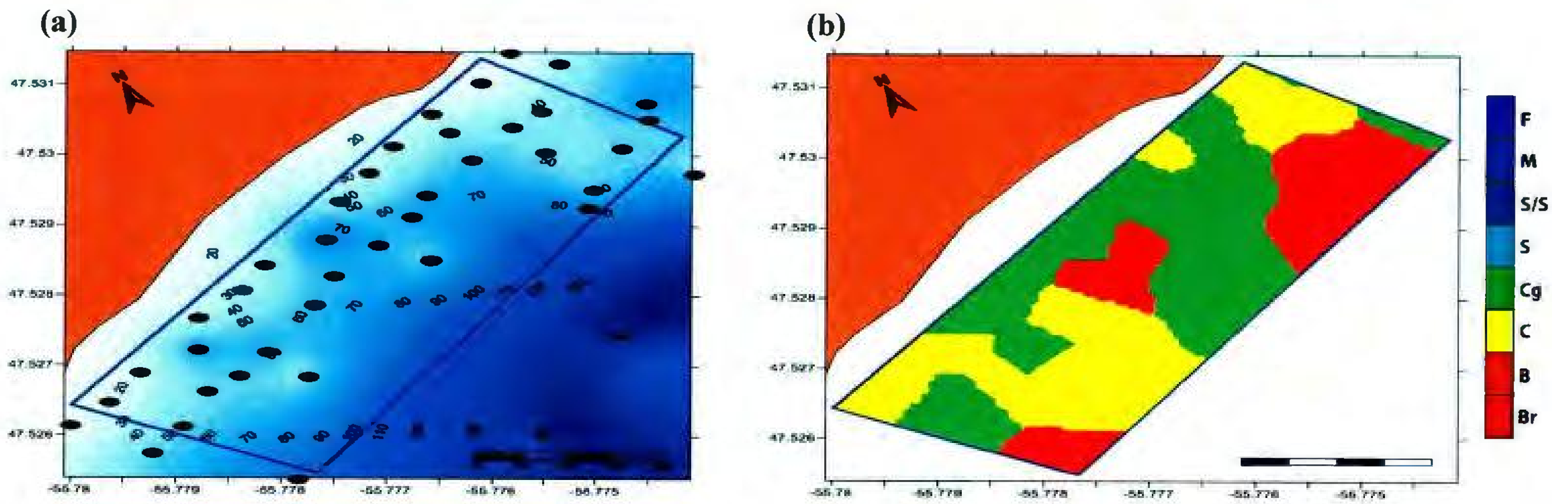


Figure 18. Site N1 map with projected depth, substrate and benthic assemblage contours. Blue outline is lease boundary. (a) Bathymetry, interpolated from on-board sounding depths. Points are video sample stations. (b) Dominant substrate type, interpolated from nearest neighbor groupings. F-Flocculant, M-Mud, S/S-Silt/Sand, S-Sand, CG-Coarse Gravel, C-Cobble, B-Boulder, Br-Bedrock. (c) Benthic assemblage cluster map, interpolated from cluster analysis. Clusters: 1-Normal low diversity, 2- Normal high diversity, 3- Barren substrate 4- *Beggiatoa* and OPC dominated, 5-Enriched area, high diversity.



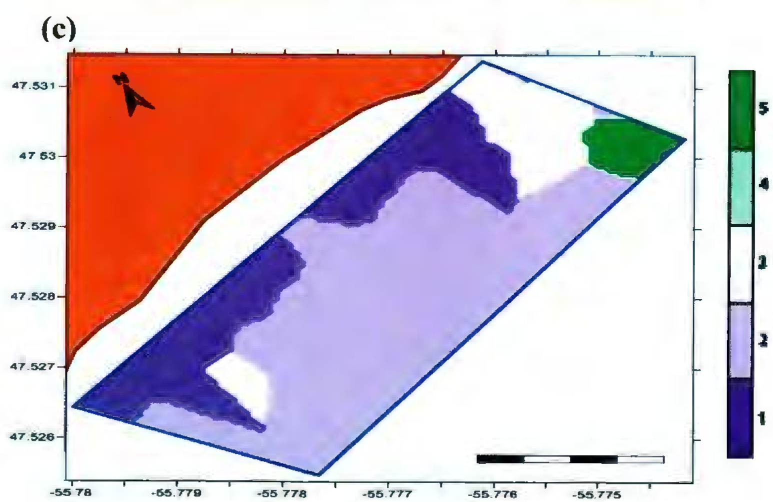


Figure 19. Site N2 map with projected depth, substrate and benthic assemblage contours. Blue outline is lease boundary. (a) Bathymetry, interpolated from on-board sounding depths. Points are video sample stations. (b) Dominant substrate type, interpolated from nearest neighbor groupings. F-Flocculant, M-Mud, S/S-Silt/Sand, S-Sand, CG-Coarse Gravel, C-Cobble, B-Boulder, Br-Bedrock. (c) Benthic assemblage cluster map, interpolated from cluster analysis. Clusters: 1-Normal low diversity, 2- Normal high diversity, 3-Barren substrate 4- *Beggiatoa* and OPC dominated, 5-Enriched area, high diversity.

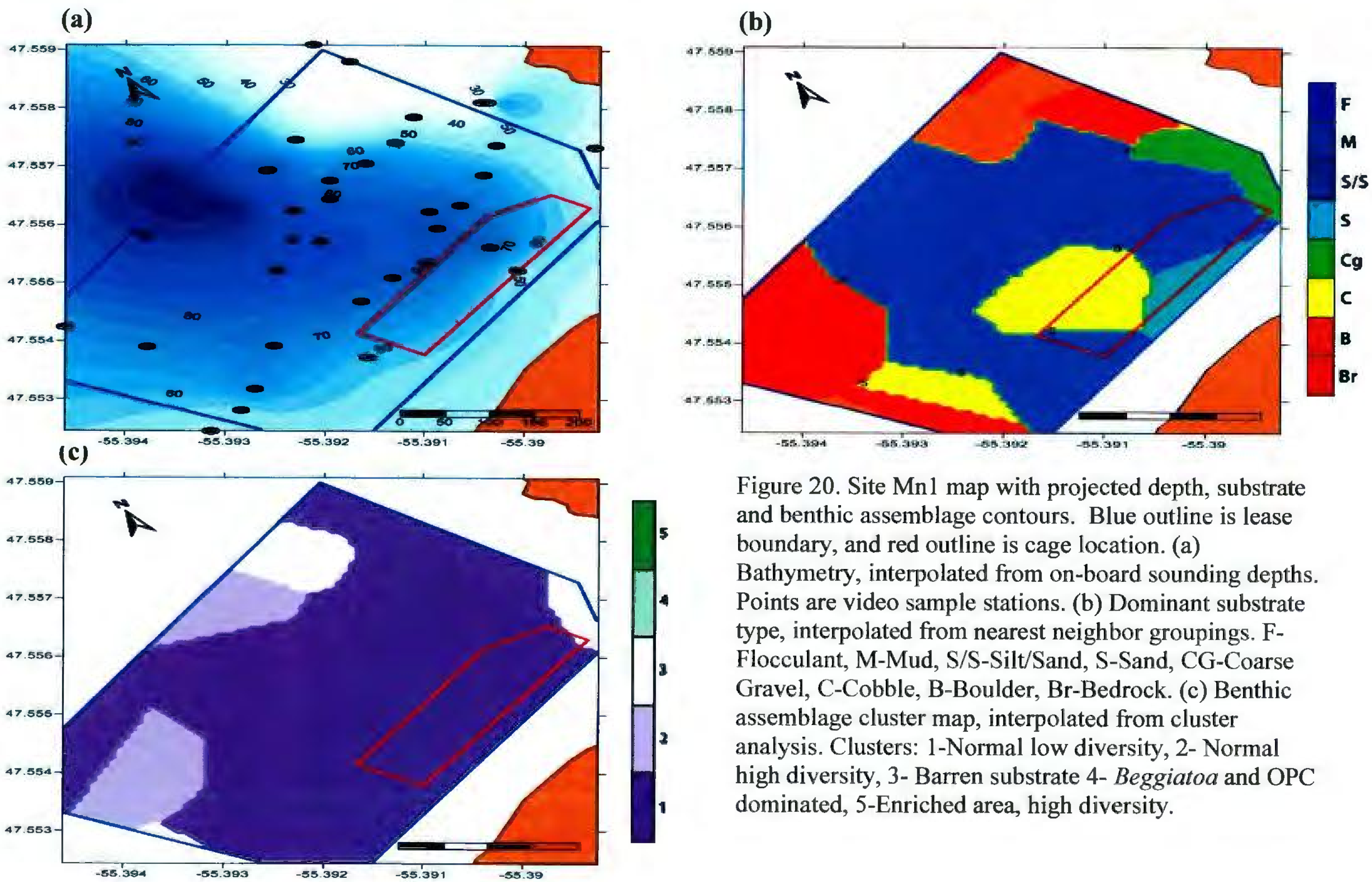
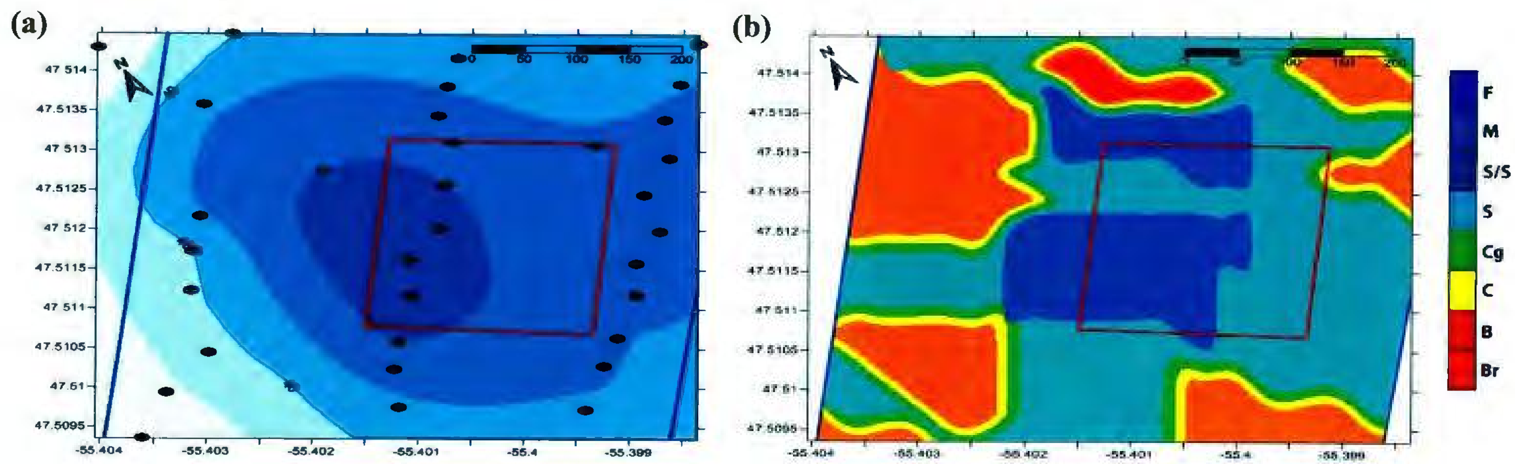


Figure 20. Site Mn1 map with projected depth, substrate and benthic assemblage contours. Blue outline is lease boundary, and red outline is cage location. (a) Bathymetry, interpolated from on-board sounding depths. Points are video sample stations. (b) Dominant substrate type, interpolated from nearest neighbor groupings. F-Flocculant, M-Mud, S/S-Silt/Sand, S-Sand, CG-Coarse Gravel, C-Cobble, B-Boulder, Br-Bedrock. (c) Benthic assemblage cluster map, interpolated from cluster analysis. Clusters: 1-Normal low diversity, 2- Normal high diversity, 3- Barren substrate 4- *Beggiatoa* and OPC dominated, 5-Enriched area, high diversity.



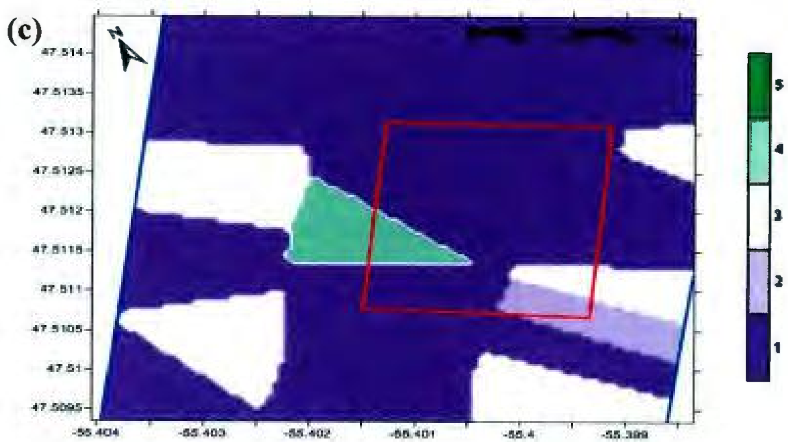


Figure 21. Site Mn2 map with projected depth, substrate and benthic assemblage contours. Blue outline is lease boundary, and red outline is cage location. (a) Bathymetry, interpolated from on-board sounding depths. Points are video sample stations. (b) Dominant substrate type, interpolated from nearest neighbor groupings. F-Flocculant, M-Mud, S/S-Silt/Sand, S-Sand, CG-Coarse Gravel, C-Cobble, B-Boulder, Br-Bedrock. (c) Benthic assemblage cluster map, interpolated from cluster analysis. Clusters: 1-Normal low diversity, 2- Normal high diversity, 3- Barren substrate 4- *Beggiatoa* and OPC dominated, 5-Enriched area, high diversity.

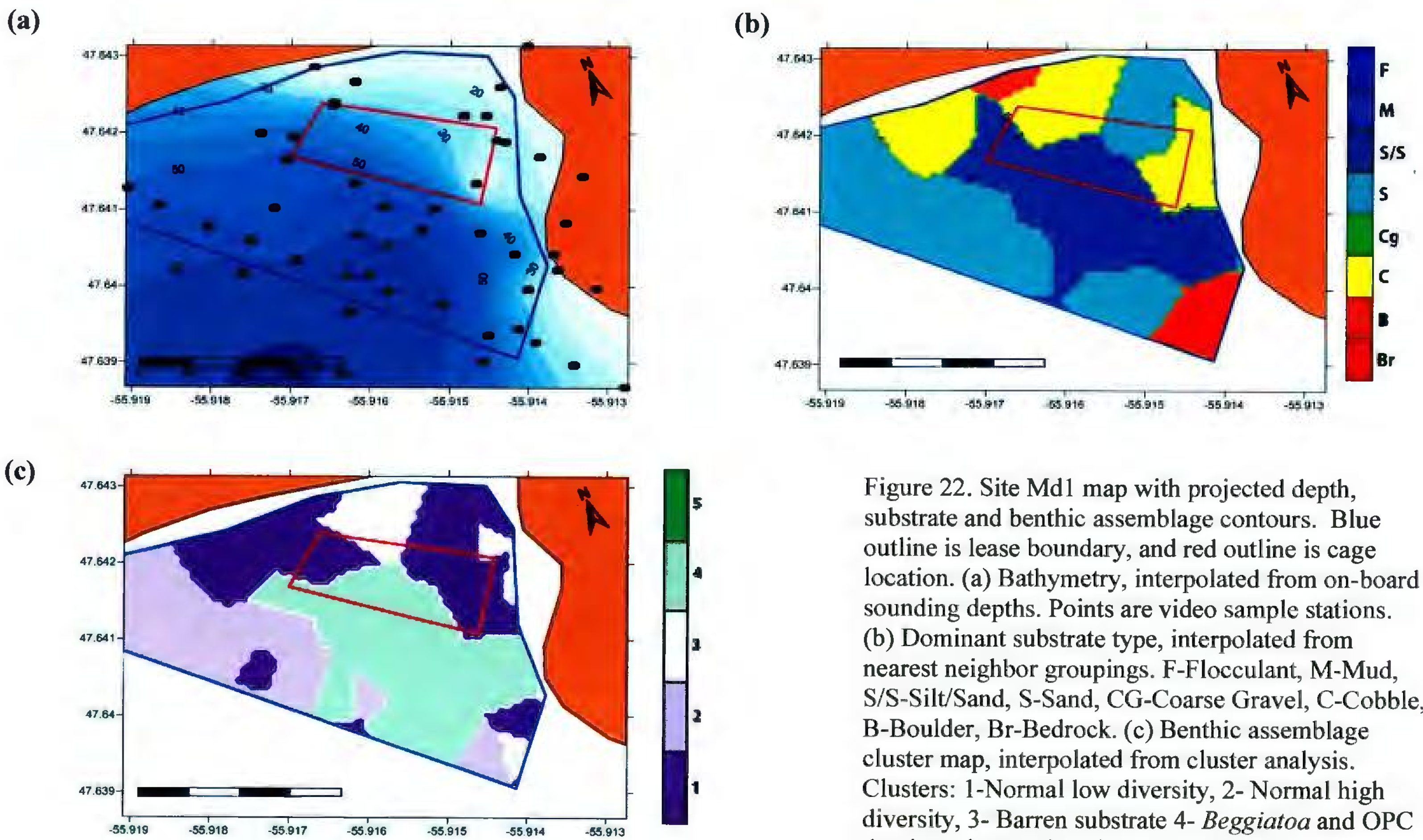
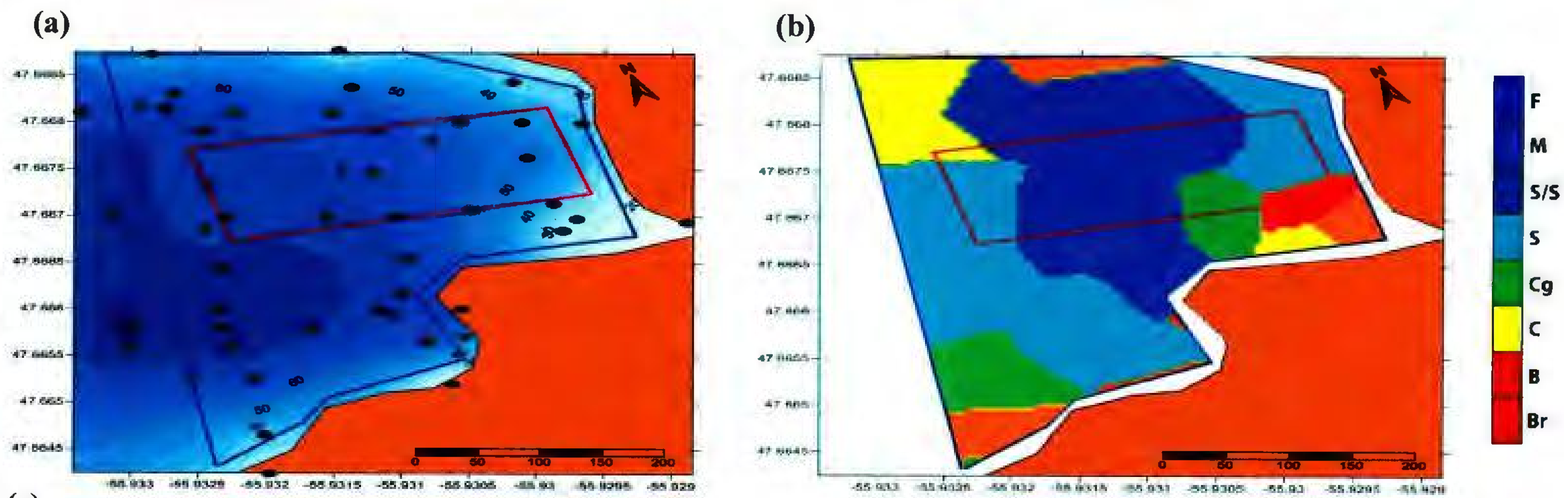


Figure 22. Site Md1 map with projected depth, substrate and benthic assemblage contours. Blue outline is lease boundary, and red outline is cage location. (a) Bathymetry, interpolated from on-board sounding depths. Points are video sample stations. (b) Dominant substrate type, interpolated from nearest neighbor groupings. F-Flocculant, M-Mud, S/S-Silt/Sand, S-Sand, CG-Coarse Gravel, C-Cobble, B-Boulder, Br-Bedrock. (c) Benthic assemblage cluster map, interpolated from cluster analysis. Clusters: 1-Normal low diversity, 2- Normal high diversity, 3- Barren substrate 4- *Beggiatoa* and OPC dominated, 5-Enriched area, high diversity.



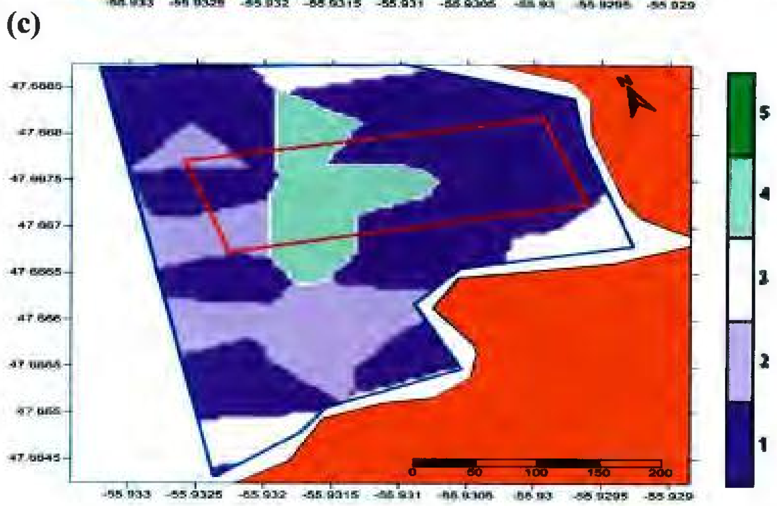
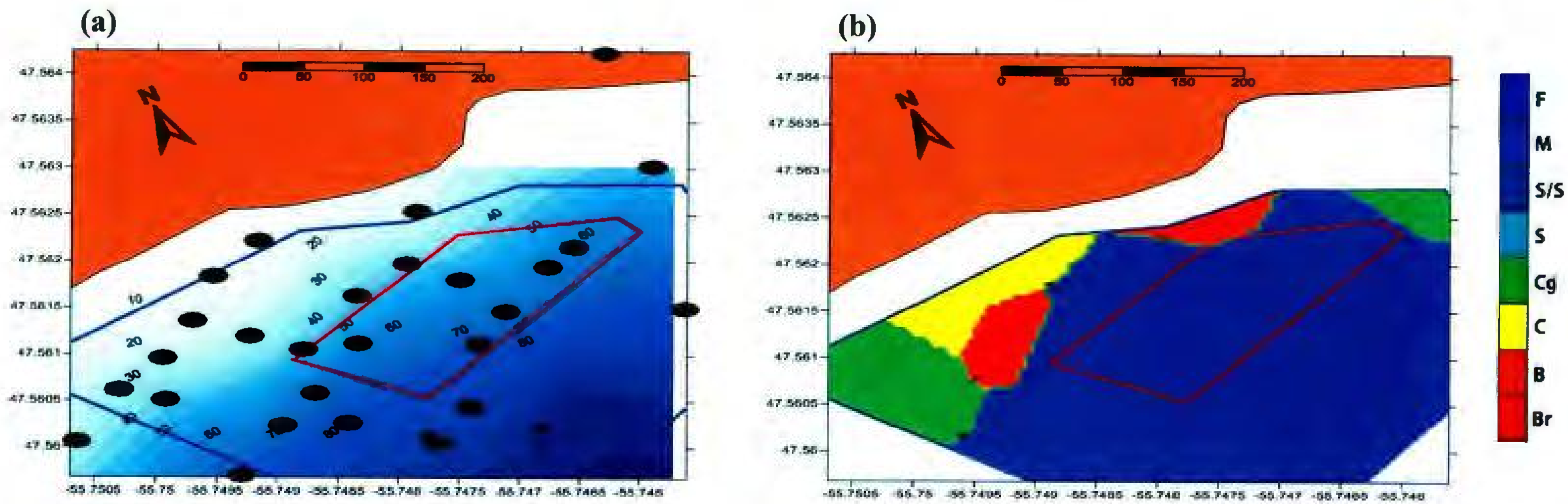


Figure 23. Site Md2 map with projected depth, substrate and benthic assemblage contours. Blue outline is lease boundary, and red outline is cage location. (a) Bathymetry, interpolated from on-board sounding depths. Points are video sample stations. (b) Dominant substrate type, interpolated from nearest neighbor groupings. F-Flocculant, M-Mud, S/S-Silt/Sand, S-Sand, CG-Coarse Gravel, C-Cobble, B-Boulder, Br-Bedrock. (c) Benthic assemblage cluster map, interpolated from cluster analysis. Clusters: 1-Normal low diversity, 2- Normal high diversity, 3-Barren substrate 4- *Beggiatoa* and OPC dominated, 5-Enriched area, high diversity.



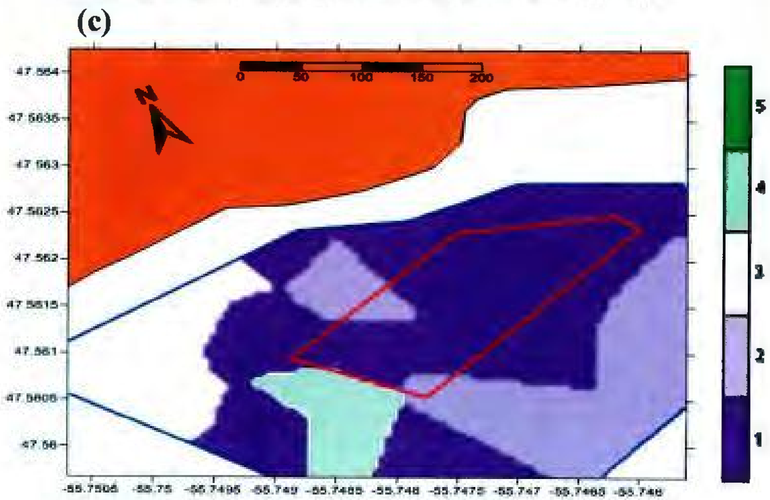
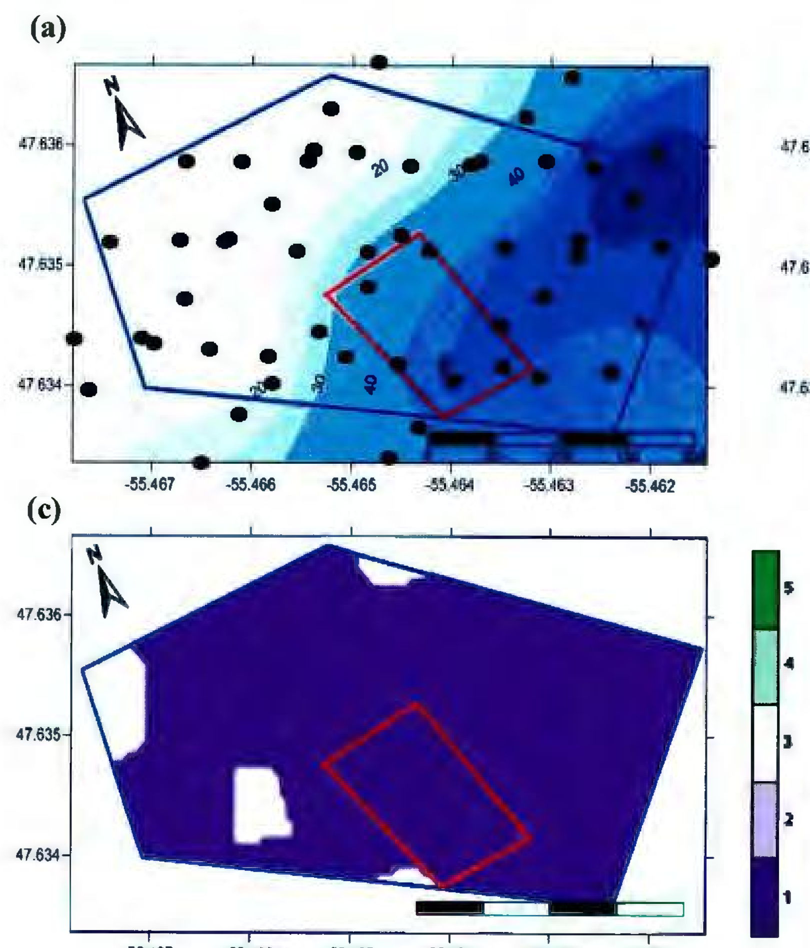


Figure 24. Site Mx1 map with projected depth, substrate and benthic assemblage contours. Blue outline is lease boundary, and red outline is cage location. (a) Bathymetry, interpolated from on-board sounding depths. Points are video sample stations. (b) Dominant substrate type, interpolated from nearest neighbor groupings. F-Flocculant, M-Mud, S/S-Silt/Sand, S-Sand, CG-Coarse Gravel, C-Cobble, B-Boulder, Br-Bedrock. (c) Benthic assemblage cluster map, interpolated from cluster analysis. Clusters: 1-Normal low diversity, 2- Normal high diversity, 3-Barren substrate 4- *Beggiatoa* and OPC dominated, 5-Enriched area, high diversity.



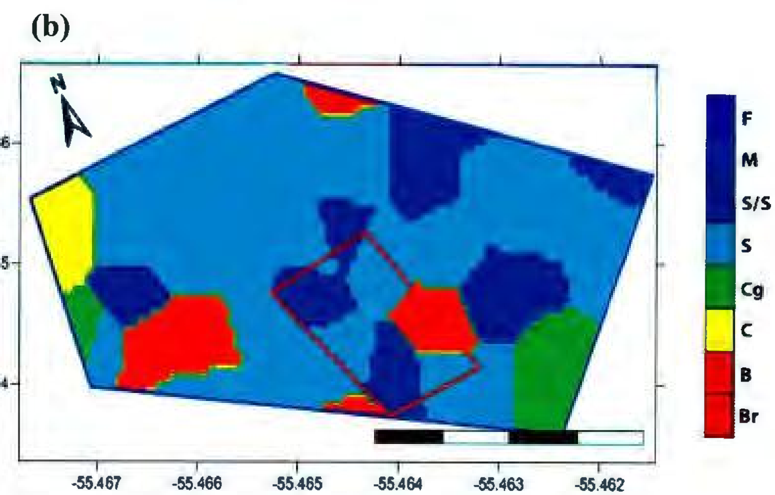


Figure 25. Site F1 map with projected depth, substrate and benthic assemblage contours. Blue outline is lease boundary, and red outline is cage location. (a) Bathymetry, interpolated from on-board sounding depths. Points are video sample stations. (b) Dominant substrate type, interpolated from nearest neighbor groupings. F-Flocculant, M-Mud, S/S-Silt/Sand, S-Sand, CG-Coarse Gravel, C-Cobble, B-Boulder, Br-Bedrock. (c) Benthic assemblage cluster map, interpolated from cluster analysis. Clusters: 1-Normal low diversity, 2- Normal high diversity, 3-Barren substrate 4- *Beggiatoa* and OPC dominated, 5-Enriched area, high diversity.

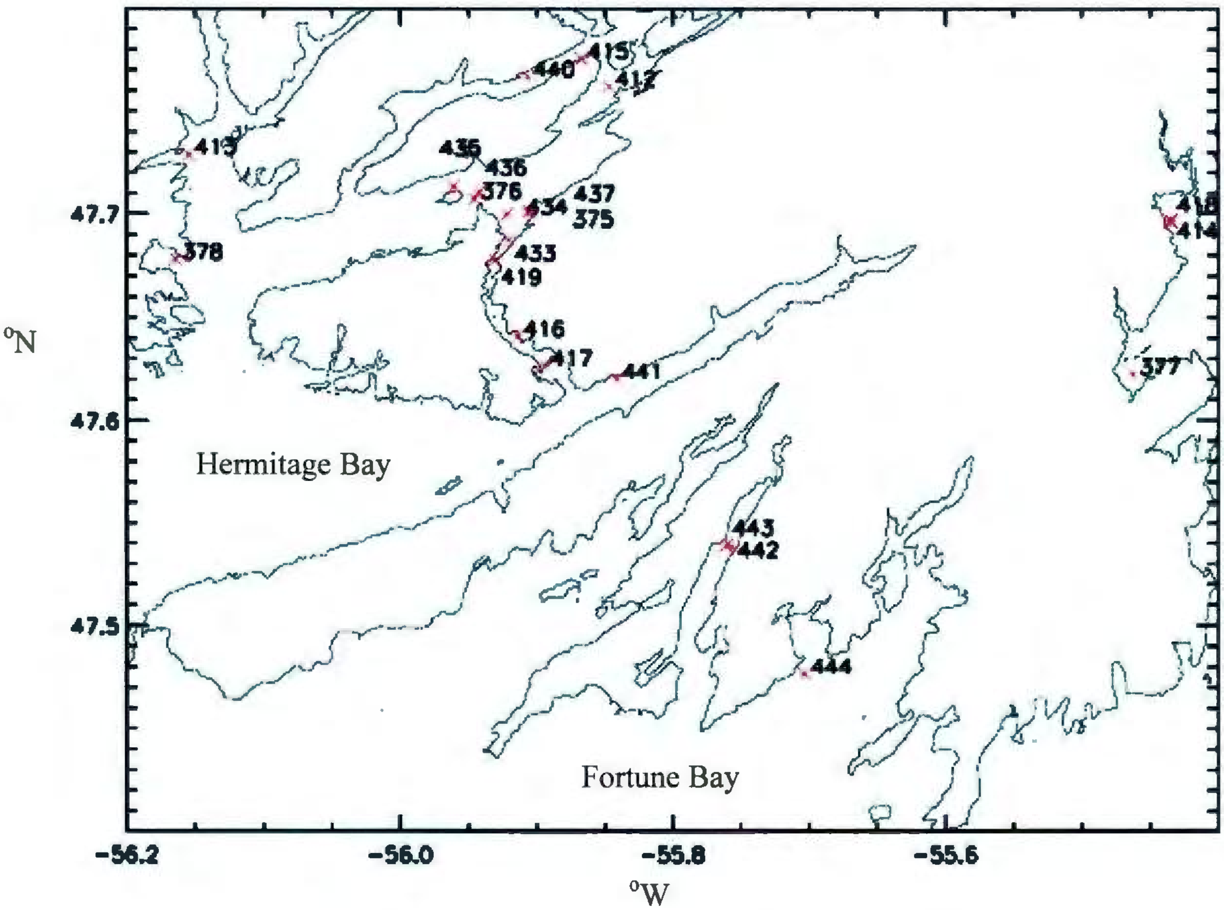


Figure 26. ADCP mooring locations. Numbers denote database classification number.

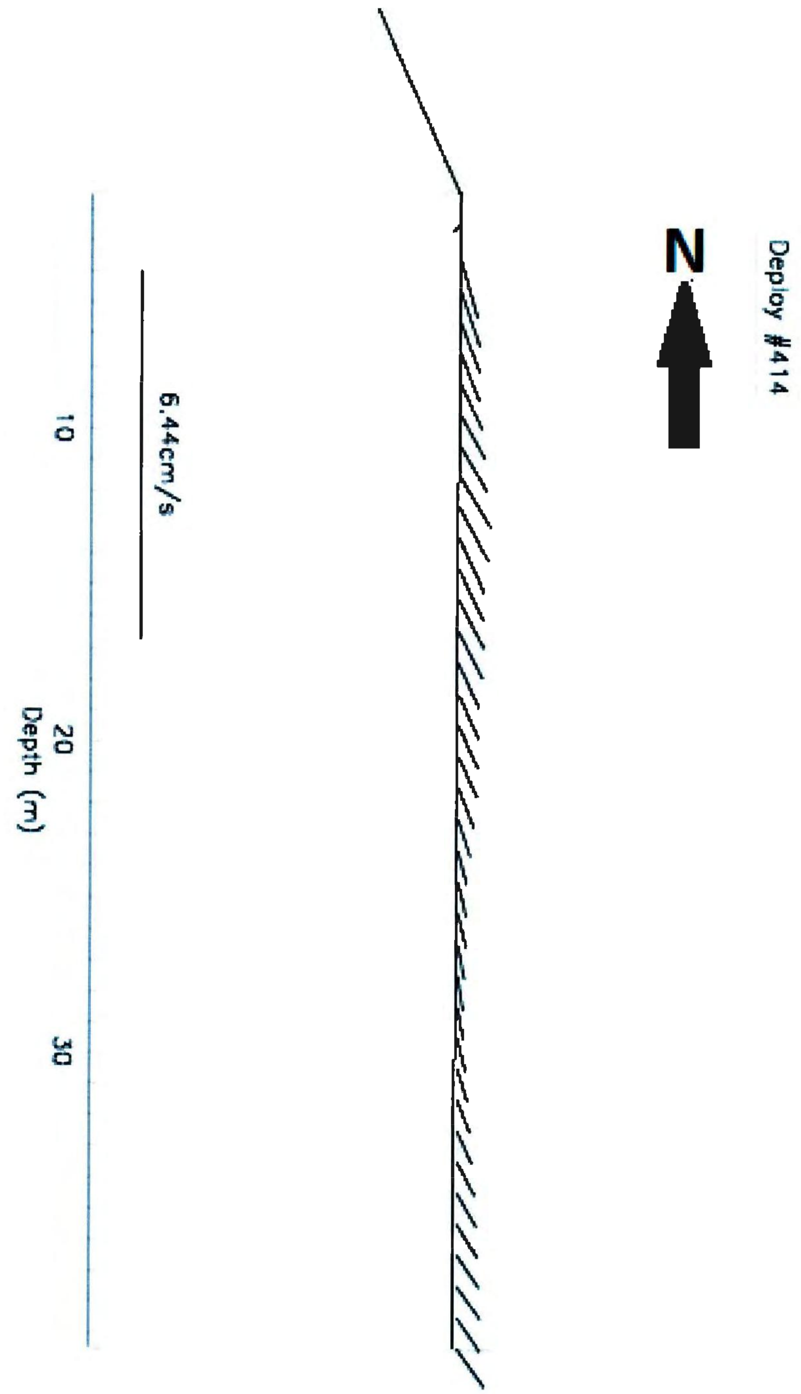


Figure 27. ADCP mooring #414, Fortune Bay, south coast of Newfoundland. Length of line denotes strength of current with direction indicated by the direction of line as leading away from the central axis.

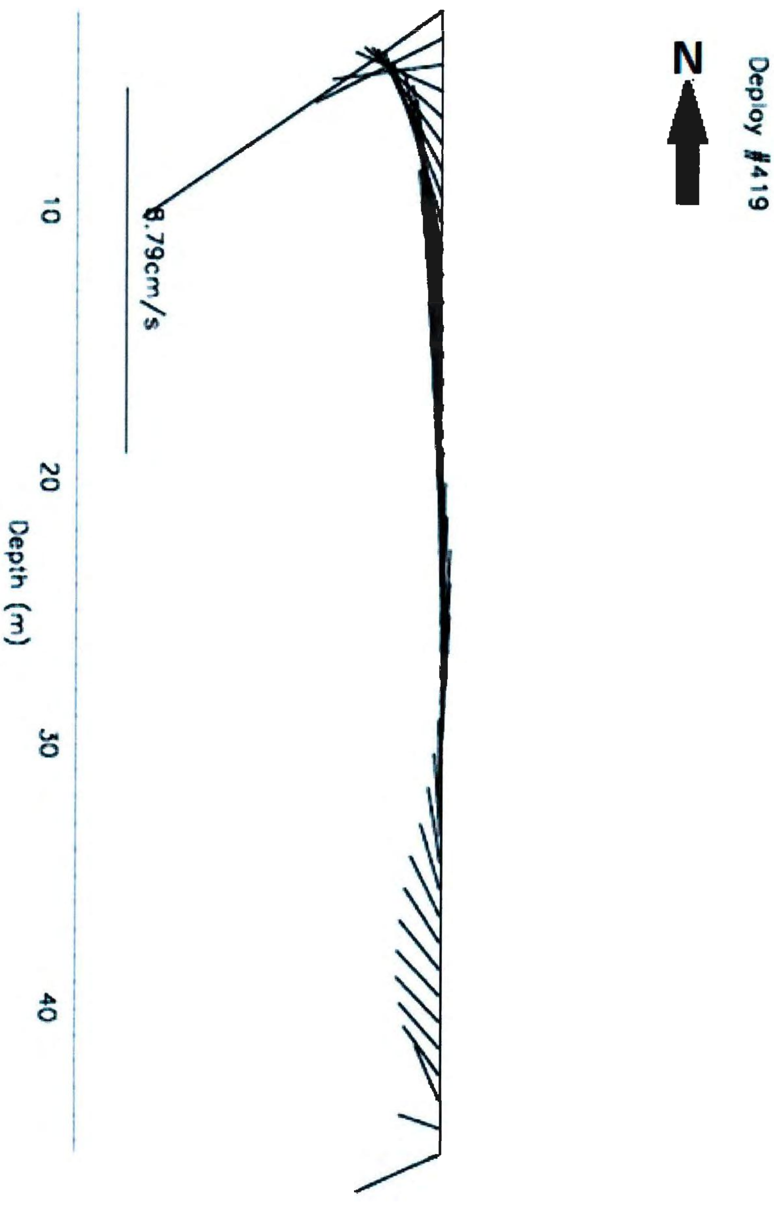


Figure 28. ADCP mooring #419, Gaultois Passage, south coast of Newfoundland. Length of line denotes strength of current with direction indicated by the direction of line as leading away from the central axis.

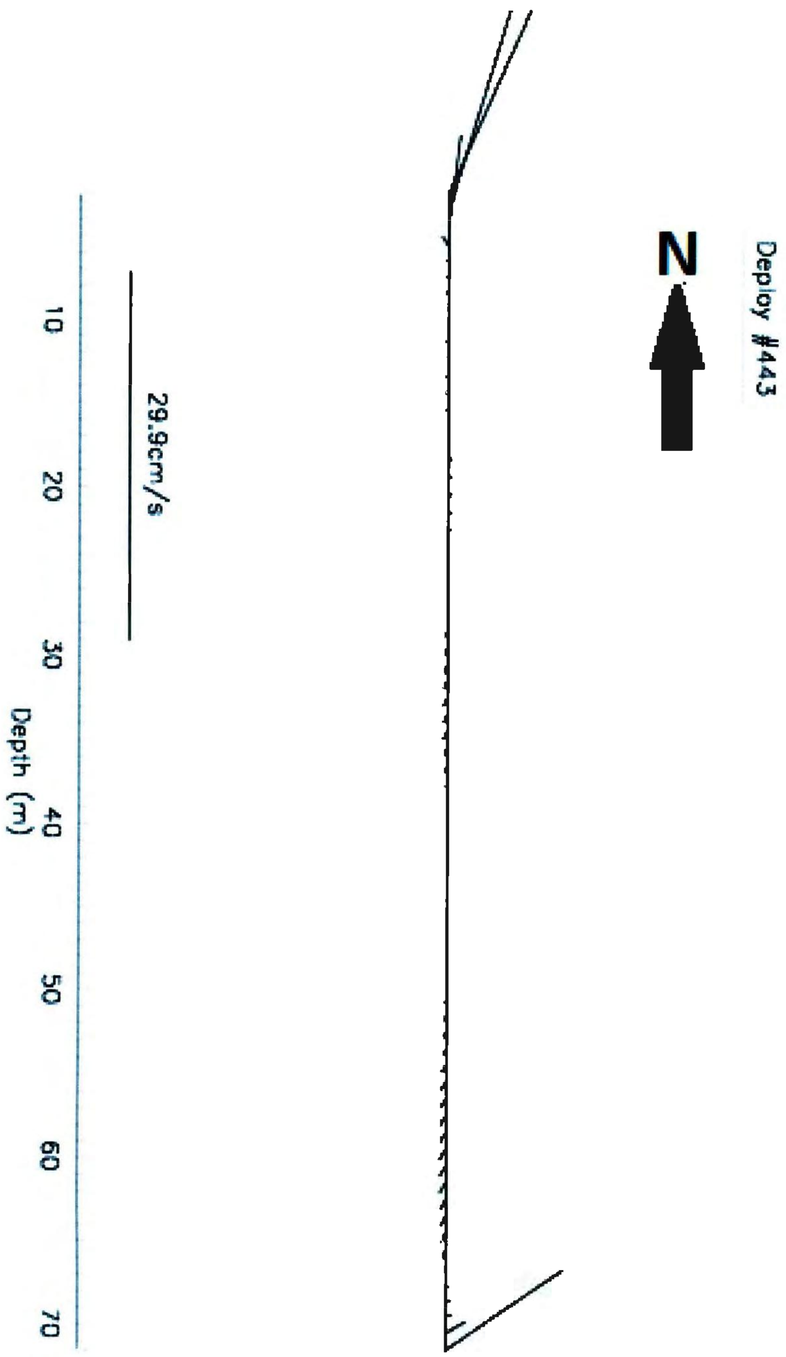


Figure 29. ADCP mooring #443, Hr. Breton Bay, south coast of Newfoundland. Length of line denotes strength of current with direction indicated by the direction of line as leading away from the central axis.

Chapter 4 – Discussion

Discriminant Analysis

The model generated from the data collected at all sample stations and sites identified the percent coverage of OPC, the abundance of corals, sea stars and anemones, the proportion of euphausiids, sea stars, urchins and anemones, richness and the total abundance as variables allowing the discrimination between production stage. Dramatic changes in these metrics were observed between control sites and sites under the influence of salmon aquaculture that are primarily differentiated by the time of production cycle and the approximate size and feed consumption of the fish. In particular, OPC were identified as being indicators of environmental impact for aquaculture sites, as was previously observed on soft sediment (Hargrave et al.. 1997, Hargrave 2005); the present study further validates their potential use as indicators of organic enrichment on hard bottom.

The classification efficiency of the models was very low (56 %) with only two groups, fallowed and non-production sites, having an acceptable classification efficiency of greater than 70 %. Multiple factors might have led to the difficulty in classifying sites according to degree of aquaculture influence. First, there may have been too few sample stations to correctly develop groups in the stepwise analysis. Second, the correct metrics may not have been measured: environmental parameters such as oxygen, sulphide levels, and redox potential might have improved classification efficiency of these sites. These measures could be estimated by a proxy, like sediment colour, or distance from cages. However, it is often difficult to obtain such measurements in the deeper waters and hard bottoms typical of Newfoundland aquaculture sites. Third, the spatial scale of this study is likely to have played a role in confounding classification. This study was designed to assess the influence of aquaculture throughout the entire lease, and therefore all sample stations at a given site were classified based on the production level at that site. It is unlikely that all stations within a lease are influenced by the same level of organic matter deposition: DEPOMOD (a predictive model of deposition at salmonid aquaculture sites based upon inputs of production data, typical depositional rates, and local current data) results on most aquaculture sites indicate that there is a predicted footprint of deposition that doesn't extend throughout the entire lease area, and for the most part barely exceeds the footprint of the cages (Ratsimandresy, pers. comm.). Therefore, the classification of all sample stations within aquaculture lease sites by the stepwise analysis (to compile a typical profile of that particular classification) generates error in the predictive model and leads to a biased classification efficiency in the canonical discriminant analysis. Correction for this type of error would be difficult given that personal judgment would have to be used to refine the classification of sample stations within a site, and adding subjectivity to the analysis is not desirable.

Newfoundland Habitat

When trying to evaluate the influence of aquaculture on hard bottom substrates with video monitoring, problems arise because of the depth of aquaculture sites in Newfoundland. To properly assess changes in the abundance and distribution of benthic species resulting from aquaculture, control sites are required; potential aquaculture sites with no previous production can serve as control sites. However, control sites (and aquaculture sites on the south coast of Newfoundland) exhibit a wide range of environmental conditions with respect to both depth and substrate type, and this variability complicates comparisons between such disparate sites.

With a wide range of depths, differences in community structure or habitat can be expected. The sites used in this study had a wide range of depths, some ranging from 15 m to 150 m within the lease. Not only does this have a great influence on the type of community that will be observed, but it also affects the settling of depositional material, the type of dominant substrate, and the accessibility of the video collection equipment. Basins, steep rock walls, and large expanses of low sloped areas have been observed within the eight sites of this study, revealing a mosaic of bathymetric conditions.

Substrate type also follows this mosaic. In preparation for this study, baseline monitoring reports provided by aquaculture companies, listing the dominant substrate found at each site, were examined. In analyzing the underwater video collected, it became clear that there is no clear dominant substrate type, but that multiple substrates are present in various locations, with no clear pattern. The habitat maps generated for each site illustrate the very patchy nature of the benthic habitat in coastal Newfoundland waters, with different types of substrates dominating at each study site. For the purpose of this study, sites were chosen to cover the entire active salmonid culture area in an attempt to typify the environment. From the habitat maps, the sites chosen appear to typify the natural habitat around Newfoundland (Anderson 2001, Gregory, R.S., pers. comm.).

Aquaculture Impact

It is likely that there is some form of influence of aquaculture on the cold deep waters of coastal Newfoundland. However, what exactly defines this influence on hard substrates is unclear. Accumulation of organic matter and the colonization of *Beggiatoa* and OPCs have been characterized as indicators of environmental change on soft substrates (Beveridge 1996, Hargrave 1997, 2005, Jorgensen et al.. 2010). Increases/decreases in numbers of suspension feeding anemones and deposit feeding sea stars can also indicate an impact of aquaculture activities (Birkeland 1987, Weigelt 1991, Lapointe et al.. 1992, Henderson and Ross 1995). The total abundance and richness of species can also be indicators (Henderson and Ross 1995). The area of influence can first be defined based on those metrics. The discriminant analysis results suggested that similar factors could distinguish between impacted and non-impacted sites. However, since the classification efficiency based on the discriminant analysis was low, we focused on the distinguishing characteristics of the cluster analysis in an attempt to better define areas under the influence of increased deposition. The metrics selected were the percent coverage of coralline algae, *Beggiatoa*, and OPC, the abundance of anemones and sea stars, and the total abundance, diversity, and evenness, all of which have previously been defined as indicators of community change in depositional, polluted, and eutrophic environments (Birkeland 1987, Weigelt 1991, Lapointe et al.. 1992, Henderson and Ross 1995, Beveridge 1996, Hargrave 1997, 2000, Kennedy and Jacoby 1997, Karakassis et al.. 1999, Jorgensen et al. 2010).

Min Production

Minimum production sites such as Mn_2 and Mn_1 are expected to have the lowest degree of influence from salmonid aquaculture. The fish harvested at these sites are small, likely producing lesser amounts of waste over a shorter period of time. Compared to control sites (N_1, N_2) there appears to be some benthic influence of aquaculture at the minimum production sites studied. Of the two minimum production sites, only Mn_2 deviated from the control sites, as evidenced by a small area of influence (assemblage type 4) under the western edge of the cages, extending outward. The benthic assemblage map of Mn_1 shows no type 4 assemblage. The bathymetry map of Mn_2 reveals a 50 m deep basin under the cages. This bathymetric structure may collect deposits that are carried by higher velocity currents at the surface. As in most areas of the south coast, current speed tends to be greatest at the surface; in the bay containing sites Mn_2 and Mn_1 current speeds are highest at the surface (approximately 4.0 cm/s directly at the surface) but quickly decline to 1.0 cm/s within 2 m from the surface. Even after it reaches such slow speeds the currents in the deeper portions of the water column become nearly zero. Within the rest of the water column the net water movement is south and southeast with very low velocity. With such low water speeds there is little dispersion of waste materials, and because of the basin, material has a high possibility of collecting in the center of the site as it settles in the basin. However, in the minimum production sites studied here, the influence did not seem to be excessive for the production level, as the type 4 assemblage appeared limited to a fairly small area, about 0.01 km^2.

Mid Production

Sites that had contained fish for 1 year were classified as mid-level production sites and were expected to show a degree of benthic impact between that of minimum and maximum production sites. The fish are growing, eating more, and therefore defecating more than that at min production sites, but there are fewer fish that are about to be harvested than at max production sites. Md_2 and Md_1 were located in same bay, Bay D'Espoir, had very similar bathymetric profiles, varied substrates and predominant surface currents coming from the north-northwest. Unlike most other sites, these mid-production sites had large patches of type 4 assemblages (Figs. 17c, 18c). These areas were highly dominated by the polychaete and *Beggiatoa* mats that are typically found on anoxic soft substrates (Hargrave et al.. 2005). The area occupied by these mats was larger in comparison to min production sites, likely because of greater amounts of deposits settling down or a reduced ability of the benthic community to assimilate deposits. Without a detailed model of the flow of water through the lease it is difficult to predict the movement of particles settling on the benthos. Based on the currents that were observed there is a typical surface current that is higher than that observed in the rest of the water column. It is these surface currents that have potential to push particulate matter, feces, and uneaten feed away from a site. With little to no speed at greater depths the particles then sink directly downward with no lateral movement and no more dispersion. The areas showing the greatest benthic impact (i.e. the area of influence), are at the southwest edge of the lease and cages. Mid production sites in this study seem to have a localized impact, possibly contained within the lease but somewhat outside the cage area. Deposition may not be limited to this area but without measurements or complex modeling we can only speculate that this is the only area where amounts of deposition are high enough to cause environmental change.

Max Production

Based on the observed site, the impact of maximum production is similar to that of mid production. Whereas most studied sites were dominated by type 1 and type 2 assemblages with some patches of the type 3 assemblage, Mx_1 also has a patch of the type 4 assemblage, as did the mid production sites, Md_1 and Md_2. The position of this patch would not have been predicted. The current in this area comes from the southwest suggesting that deposition would be centered towards the north-east edge of the cages (Figure 19). The dominating currents are only present in the upper four meters of the water column with relatively little or no current in deeper water. With only surface currents in the area no spread of deposition was to be expected. Salmon in marine cages around Newfoundland tend to reside at varying depths dependant on various biological and behavioral factors but have a tendency to be at the surface only during feeding. With the salmon under the depth of major surface currents the major source of deposition as feces would be sinking directly to the bottom, uninfluenced by currents.

Fallow

The fallowing of aquaculture sites is meant to return the habitat to natural conditions before another production cycle begins, to help mitigate environmental changes on the benthos. These fallow periods are mandatory and are experienced on sites between production cycles, duration being dependant on whether or not a site returns to previous natural conditions. All fallow periods are supposed to be at least one year in length (DFO 2011). Observations at site F_1 suggest that a fallowing period of two years is effective. F_1 was likely to have previously had a patch of the type 4 assemblage, similar to that observed at Md_1, Md_2, or Mx_1, because it went through a full production cycle. One would expect an increased coverage of both the OPC and *Beggiatoa* mats during production. However, F_1 shows no evidence of long lasting influence on the benthos in terms of short lived species, following a two year fallow period, at least in the form of a type 4 assemblage. It can be noted, however, that the benthic diversity at site F_1 may have been lower than at N_1 and N_2 sites but this may be due to the natural patchiness of the substrates and to previous, unknown conditions. In terms of long lived species a two year fallow period may not be adequate. It may take decades or centuries for longer lived species to recolonize an area with recruitment of some other species being dependant on their recovery, coralline algae is one such case (Martin et al.. 2009).

Community Response

Changes in community structure have been observed at sample stations around the cages of active aquaculture sites, as reflected by the benthic assemblage maps. However, it is important to note assemblages that are associated with aquaculture impact are underrepresented in the cluster analysis. Measuring species abundances, proportions, percent coverage, richness, diversity, and evenness can reveal how a normal habitat may transition into an influenced habitat, with some patches of increased diversity and abundance in what may be high productivity areas. In areas around cages, the community can become unable to cope with the amount of deposition resulting from salmonid culture. Increases in the percent coverage of the OPC and *Beggiatoa* mats indicate an area of hypoxia/anoxia under cages (Hargrave 2005). Other species appear to be responding as well. Based on the structure of assemblage 4, the abundance and proportion of the brittle star *Ophiura* increases in the patches of high OPC and *Beggiatoa* mats. These brittle stars may be attracted to the layer of deposits that is settling on the bottom (Reese 1966, Buzeta 2011). They are thought to respond in aggregations to favorable environmental conditions: sufficient oxygen levels and food sources (Reese 1966). As generalists, brittle stars utilize varying feeding strategies ranging from macrophagous predation to non-selective or selective deposit feeding as observed in most arctic brittle star species, with smaller species tending to exploit sediment bound nutrients and detritus (Warner 1982, Gibson and Barnes 2000). Other, non-motile species that are generally abundant or dominant in Newfoundland coastal waters can be smothered by the deposits if the deposits are long lived. *Lithothamnion* spp., laminarians, soft corals, and *Halichondria* spp. are all intolerant to smothering, deoxygenation, and high depositional rates (Miller et al.. 2002, Buzeta 2011). Smothering is a result of high organic or inorganic deposition. The depositional rate is so high that it blankets the entire benthos, decreasing oxygen and exposure to light (Pearson 1975, Miller et al.. 2002). Resulting in a lower diversity and abundance in the community (Miller et al.. 2002, Trannum et al.. 2010). These sensitive species could act as indicator species; in particular, coralline algaes and anemones were both identified in discriminant and cluster analysis as determining metrics. However, more work would be needed to develop thresholds and recovery timeframes. Nearshore, predominantly sessile benthic macroinvertebrate communities can act as good indicators for organic enrichment (Kennedy et al.. 1997, Karakassis et al. 1999, Buzeta 2011), and could also possibly be indicators of recovery. Very few populations are able to recover quickly after degradation occurs, with recovery rates varying greatly depending on individual species in community structure, recruitment, and secondary stress factors such as additional deposition (Karakassis et al. 1999). Time frames for recovery in some areas of Scotland were in excess of 10 years (Karakassis et al. 1999). Reoccurrence of these sensitive species may indicate the return of the habitat to pre-influence conditions (Pickett and White 1985, Valiela 1995, Barnes et al. 1999).

Localization of Impact

All aquaculture sites that have sample stations with type 4 assemblages show similarities in the positioning of those patches. In all of these sites, the type 4 assemblage patch is localized and constrained within the lease boundary, with the possible exception of site Md_1 in which such patches may extend past the lease boundary but since no sampling outside the lease was done the full extent of the patch cannot be seen. In most cases, these influenced patches are located close to the cages holding fish. With presumably little deposition spreading outside the lease boundaries, the benthic impact of aquaculture in observed sites was relatively limited. Previous reports stated that benthic disturbance due to aquaculture deposition was limited to 50 - 60 meters away from cages

(Carroll et al. 2003, Nash et al. 2005). In other historical cases, a clearly defined area of influence is only observed within 15 meters from cages, although there is some evidence for influence up to 120 m away (Brown et al. 1987). The results here reveal impact on the benthos at a greater distance from the cages. In the Md_1 site, the influenced area of type 4 assemblages is observed up to approximately 200 meters from cages, and may extend farther but again there was no sampling outside the lease and therefore no patches could be accurately represented outside data points plotted. In the other sites that exhibit areas of type 4 assemblages the distance of influence is consistent with previous work (Mente et al. 2010).

Video Sampling Problems

This study uncovers certain problems inherent to video sampling on the south coast of Newfoundland. Image and video quality is one of the largest and most difficult problems to deal with. Quality issues are not related with image resolution or hi/low-def images, but rather to suspended material, densities of species, individual overlap, washing out due to lights, motion, and the slope of the bottom. These issues interfere with species and substrate identification, particularly for smaller species; as a result, counts at some of the stations could be underestimated and therefore misrepresented in later analyses. This misrepresentation could have had a small effect on the benthic assemblage maps in this study. Rock faces could also impact image analysis, leading to underestimations of the abundance and the number of species at particular sampling stations where clear views of the substrate could not be obtained.

Defining substrate types and percent coverage can also be difficult when using video analysis. In the absence of samples to determine grain size, porosity, and other geophysical characteristics, it is difficult to define substrates. Due to the nature of the hard bottom environments, these samples would be hard to collect. The natural patchiness of the benthos also brings forth problems in the ways of the substrate being heterogeneous. Trying to typify assemblages of species and then associating these assemblages with a type of substrate has proven difficult.

Suggestions for Future Work

To address the problems identified by this study, some additional work could be done both in the field and at the analytical stage. With more habitat or environmental parameters measured (such as oxygen levels at the seafloor and deposition rates), links could be made between these parameters and the structure of the benthic community which could lead to establishing a list of indicator species. For example, anemones could be linked to levels of deposition or anoxia, or coralline algae to smothering. These indicator species could then act as a measure of such parameters in the future. This type of study would need extensive collection of water samples or real time measurements of the environmental parameters along with a high density collection around the cages of aquaculture sites to determine both the effects on species in greater detail and the spatial extent of the impact on hard substrates.

With this type of exploratory analysis the results should be treated as preliminary and not confirmatory. A in depth look at the intensity of sampling throughout a lease would greatly help in understanding the influence of aquaculture on hard substrates. This would include looking at the spacing of transects and stations, the number of transects, surveying depth, and drift speed.

Chapter 5 – Conclusion

The goal in assessing the environmental influence of aquaculture in sub-arctic hard bottom communities is to help develop proper environmental monitoring criteria, and to help understand how aquaculture wastes influence the benthic community. In southern Newfoundland, this goal can be reached through the identification of indicator species, and a better understanding of the spatial distribution of bottom types and of aquaculture footprints in the area.

With little previous research done on influences of aquaculture on hard bottom substrates, evaluating the impact that salmonid farms have in sub-arctic rocky bottom habitats is very important. To assess the influences of aquaculture in this habitat, it is important to recognize what is abnormal in a boreal-subarctic marine environment. Through this study this has proven to be a conundrum. Newfoundland has such a variable benthic habitat that there are no apparent patterns in substrate structure. As a result, a "normal" benthic habitat in this environment is extremely spatially patchy according to substrate and depth. The community structure follows a similar pattern. In areas away from the influence of aquaculture, three different assemblages can be observed as defined by the first three identified clusters. In shallow depths, typical Newfoundland benthic communities are dominated by encrusting species, with a high abundance and low diversity of macrobenthic species (assemblage 3). At greater depths suspension feeding taxa become more dominant and community structure shifts to a high abundance and relatively high diversity of these taxa (assemblage 2), or another assemblage (assemblage 1) where the abundance and diversity are low. These three assemblages are consistent with other hard bottom communities in similar locations in the Atlantic Ocean (Barrie 1979, South 1983, Martinez et al. 1994). A low diversity is shared by all apparently normal assemblages, some lower than others. Other communities (less common) include those influenced by aquaculture, which are dominated by deposit feeding brittle stars (making up a large portion of the sea star category), the OPC, and *Beggiatoa* mats (assemblage type 4), and a community associated with a high natural productivity in areas of rock ledges (assemblage type 5). These assemblages appear relatively tolerant of eutrophication. They may only tolerate these conditions for short periods of time.

On Newfoundland hard bottom communities, the influence of aquaculture is very localized, affected by bathymetry, currents, benthic community, and stage of production based on results presented. The areal extent of this influence is important in the assessment of the impact of aquaculture on hard bottoms. Deposition on farm sites is generally limited to the area within lease boundaries, providing a defined area of study. As farm production progresses, the area of influence grows in association with the amount of feed being used and of feces being produced. The south coast of Newfoundland, in particular the Bay D'Espoir, and Fortune Bay areas appear to support very little natural *Beggiatoa* and OPC growth, but those organisms can become dominant in patches on production leases. Other species, primarily suspension feeding taxa, are probably smothered by excess deposition and either relocate or die off. Deposit feeding brittle stars appear to respond to the new layers of deposition accumulating on farm sites in a positive manner, increasing in abundance. *Beggiatoa*, OPC, and brittle stars (characteristic of the type 4 assemblage described here) are identified as possible indicator species on hard bottoms underneath aquaculture cages in Newfoundland. These indicator species were not observed in the later fallowing stage of an aquaculture farm; this site was instead dominated by a type 1 assemblage.

Aside from allowing an influenced site to return to within a certain percentage of baseline conditions, specific measures of recovery are lacking for aquaculture sites in many areas. This can lead to confusion in the interpretation of farm-fallow monitoring reports. With subjective monitoring techniques where exact measures of species (abundances, presence/absence, community structure) are not used, returning to a desired conditions is logically impossible. However based on present protocols it will have to suffice. With current dependence on sediment sampling this would then make assessing the recovery of sites in turn impossible. However, if one were to look at some of factors that influence the recovery of benthic environments possible procedures could be developed to assist in evaluation of the influence of aquaculture. Factors like the surrogate measure of sediment condition (sulphide and redox), as well as infaunal or epifaunal counts could replace current (inadequate) monitoring techniques.

The observation of typical substrate conditions, community structure, and indicator species throughout the south coast of Newfoundland can help improve the efficiency of environmental monitoring protocols for salmonid production farms in the southern Newfoundland region. Further, understanding community structure and the recovery of sites is very important for the environmental sustainability of aquaculture.

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Appendix A - List of Identified Species

Species list and classification

Phylum[P]	Class[C]	SubClass[SC]	Order[O]	Family[F]	Genus	Species	Common name/ description
Bacteria	Proteobacteria	G-Proteobacteria	Thiotrichales	Thiotrichaceae	*Beggiatoa*		White bacterial mat
Annelida	Polychaeta		OPC	Dorvilleidae	*OPC*[1]		Literature suggests mostly: *Ophryotrocha*
Annelida	Polychaeta		Sabellida	Serpulidae	*Serpula*[L]		Calcareous tube worm, attached to rocks
Annelida	Polychaeta		Eunicida	Onuphidae			Mud tube worm, horizontal
Anthropoda	Crustacea		Decapoda	Xanthidae	*Cancer*		Rock crab. *C.irroratus or C.productus*
Chaetognatha	Sagittoidea		Aphragmophora	Sagittidae	*Sagitta*		Arrow worm
Cnidaria	Anthozoa	Octocorallia	Alcyonacea	Nephtheidae	*Gersemia*[L]		Soft coral, >12cm profusely branched. *G. antartica* or *Drifa spp.*
Cnidaria	Anthozoa	Octocorallia	Alcyonacea	Nephtheidae	*Gersemia*[P]		Lateral branching, <12cm, pink
Cnidaria	Anthozoa	Octocorallia	Alcyonacea	Nephtheidae	*Gersemia*[W]		Lateral branching, <12cm, white
Cnidaria	Anthozoa	Zoantharia	Actiniaria	Actinostolidae	*Stomphia*[L]		Swimming anemone, small, smooth column, wide pedal disc
Cnidaria	Anthozoa	Zoantharia	Actiniaria	Boloceridae	*Urticina*[L]		Northern red anemone (formerly *Telia*)
Cnidaria	Anthozoa	Zoantharia	Actiniaria	Sagartiadae	*Metridium*	*senile*	Frilled anemone
Cnidaria	Anthozoa	Zoantharia	Ceriantharia	Cerianthidae	*Cerianthus*	*borealis*	Burrowing anemone
Cnidaria	Staurozoa		Stauromedusae	Lucernariidae	*Lucernaria*	*quadricornis*	Stalked jelly
Ctenophora	Tentaculata		Cydippida	Pleurobrachiidae	*Pleurobrachia*	*pileus*	Sea gooseberry
Echinodermata	Asteroidea		Forcipulata	Asteriidae	*Asterias*	*vulgaris*	Common star
Echinodermata	Asteroidea		Forcipulata	Asteriidae	*Leptasterias*	*polaris*	6-arm star
Echinodermata	Asteroidea		Spinulosa	Echinasteridae	*Henricia*[L]	*sanguinolenta*	Blood star
Echinodermata	Asteroidea		Spinulosa	Solasteriidae	*Solaster*	*papposus*	Spiny sunstar
Echinodermata	Crinoidea		Comatulida	Comasteridae	*Heliometra*	*glacialis*	Crinoid, feather star
Echinodermata	Echinoidea		Diadematoidea	Strongylocentrotidae	*Strongylocentrotus*	*droebachiensis*	Sea urchin
Echinodermata	Holothuroidea		Dendrochirota	Cucumariidae	*Cucumaria*	*frondosa*	Orange-footed sea cucumber
Echinodermata	Ophiuroidea		Ophiurae	Ophiolepidae	*Ophiura*	*sarsi*[L]	Serpent star
Mollusca	Bivalvia		Pteroconchida	Pectinidae	*Placopecten*	*magellanicus*	Giant sea scallop
Mollusca	Bivalvia	Pteromorphia	Mytiloidea	Mytilidae	*Mytilus*	*edulis*	Blue mussel, or *M. trossulus*
Mollusca	Gastropoda	Prosobranchia	Neotaenioglossa	Epitoniidae	*Epitonium*[L]	*groenlandicum*	Shell tapered, whorled
Porifera	Demospongiae	(Leuconoid type)	Poecilosclerida	Myxillidae	*Melonanchora*[L]		Warty sponge
Porifera	Demospongiae	(Leuconoid type)	Halichondrida	Halichondriidae	*Halichondria*[W]		Crumb of bread, white encrusting sponge
Porifera	Demospongiae	(Leuconoid type)	Halichondrida	Halichondriidae	*Halichondria*[Y]		Yellow (Gosner) Encrusting sponge
Porifera	Demospongiae	(Leuconoid type)	Hadromerida	Polymastiidae	*Polymastia*[L]		Globe shape w numerous protrusions
Chordata	Osteichthyes		Perciformes	Labridae	*Tautogolabrus*	*adspersus*	Cunner
Chordata	Osteichthyes		Scorpaeniformes	Sebastidae	*Sebastes*		Redfish *S.fasciatus* or *S.mentella*
Chordata	Osteichthyes		Perciformes	Cottidae	*Myoxocephalus*	*octodecemspinosus*	Sculpin
Chordata	Osteichthyes		Gadiformes	Gadidae	*Gadus*	*morhua*	Atlantic cod
Chordata	Osteichthyes		Pleuronectiformes	Pleuronectidae	*Pseudopleuronectes*	*americanus*	Winter flounder

Phylum [F]	Class [C]	SubClass [sC]	Order [O]	Family [F]	Genus	Species	Common name/ description
Rhodophyta	Florideophyceae		Hildenbrandiales	Hildenbrandiaceae	*Hildenbrandia*	*rubra*	Smooth dark red encrusting algae
Rhodophyta	Florideophyceae		Corallinales	Corallinaceae	*Lithothamnium*		Encrusting coralline algae
Rhodophyta	Florideophyceae		Rhodymeniales	Rhodymeniaceae	*Rhodymenia*		Dulse
Rhodophyta	Florideophyceae		Gigartinales	Gigartinaceae	*Chondrus* [L]		Irish moss, may also be a mix of several red species
Phaetophyta	Florideophyceae		Ceramiales	Delesseriaceae	*Agarum*	*cribosum*	Sea colander
Phaetophyta	Phaeophyceae		Fucales	Fucaceae	*Fucus*		Rockweed
Phaetophyta	Phaeophyceae		Laminariales	Laminariaceae	*Laminaria*		Kelp
Unidentified					*Unidentified stalk*		Hydroid or sabellid
Unidentified					*Mix sponge and anemone*		Large numbers, small white
Unidentified					*UnID 01*		*Duva florida* or leaf?
Unidentified					*UnID 02*		Crinoid, basket star?
Unidentified					*UnID 03*		Colonial tunicate, sponge?
Unidentified					*UnID 04*		Tunicate,sponge,eggs?

*Table was obtained through:

Buzeta, M-I. 2011. Methodology for analyzing remote video imagery of hard-bottom habitats, from reference and aquaculture sites, for assessment of benthic substrate type and species in southwest Newfoundland. Department of Fisheries and Oceans Contract #F6090-10002. Can be retrieved through DFO St. John's, NL.