Mechanized Clam Harvesting for Coastal British Columbia: Environmental Implications

by

David Stirling
B.Sc., Memorial University, 2002

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Supervisory Committee

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Dr. Stephen Cross, (Department of Geography)
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Dr. Mark Flaherty, (Department of Geography)
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Abstract

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For certain shellfish species, a mechanical harvester has the potential to greatly reduce harvesting costs. Traditionally, hand rakes are used in shellfish harvesting in British Columbia. In order to determine if it is environmentally feasible to use a mechanical harvester, an environmental assessment on mechanical harvesting and traditional harvesting needs to occur for comparison. In July 2008, a preliminary oceanographic assessment was conducted at three study sites in Baynes Sound. Each of the three study sites contained a mechanical and manual harvest plot and reference stations. Sampling stations were established at fixed positions within each plot and at four positions along a downstream transect (following the dominant current direction.) Surveys were conducted 24 hours pre-harvest, immediately post-harvest, and 24 hours post-harvest. Parameters included *in situ* sediment sulphides, eH (REDOX), sediment grain size (SGS), visual condition (digital imagery), sedimentation (silt flux) and sediment macro-fauna. Results show only localized environmental effects associated with each harvest approach; with no significant difference documented between the manual and mechanical harvesting methods on the study beaches. These results indicate the use of a mechanical shellfish harvester is as environmentally sound as the traditional method of hand harvesting, and poses no additional environmental risks. Introducing mechanization in shellfish harvesting will allow shellfish producers to reduce costs and increase profits, making the British Columbian shellfish industry more competitive with other suppliers.

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Acknowledgments

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Nathan Blasco, Courtenay Edwards, and Andrea Bartsch all played a huge part in working within the strict timeframes of the tide to allow for my data to be collected, even in the middle of the night. Additionally, they provided me with insight and sanity on those days when nothing seemed to work as it should.

I thank my parent’s for much more than I could list here.

I thank my wife Jessica for listening to me talk about the project and pretending that she was interested in what I was saying, while still providing support.

Dedication

This thesis is dedicated to my wife, Jessica. Her understanding and acceptance of the time and effort needed to complete this thesis is beyond my comprehension. Many hours have been spent away from home, and even more hours have been spent at home in a mess of papers and in front of a computer screen. She has accepted the ups and downs associated with this project without complaint. She is an amazing woman with patience well beyond what I could ever imagine and she is my inspiration.

Chapter 1 - Introduction

Aquaculture – it's Increasing Role in Aquatic Food Production

In the past, the oceans appeared to supply an endless bounty of seafood, encompassing all sorts of finfish and shellfish. In the past 30 years, seafood stocks have remained stable or have seen a decline, despite an increase in public demand for seafood (FAO, 2010; Naylor et al, 2000). The amount of seafood obtained through world capture fisheries has remained around 80 million tonnes since 1980 (FAO, 2010). Concerns of overfishing leading to stock depletion as well as environmental factors have created a surge in aquaculture development. With a limited supply of biological marine resources available in the oceans, aquaculture production has steadily increased its importance in supplying seafood.

In 1980, world aquaculture production accounted for 70 million tonnes, almost the same amount as capture fisheries, and half of total global seafood production (FAO, 2010). The Fisheries and Agriculture Organization of the United Nations (FAO) statistics show that in 2008, world aquaculture production accounted for 140 million tonnes of total seafood production, doubling in three decades from 1980. These numbers show the staggering growth experienced by aquaculture production in the past 30 years. The majority of aquaculture production is destined for human consumption (FAO, 2010). As can be seen in Figure 1, the explosive growth of aquaculture since 1950 has occurred worldwide.

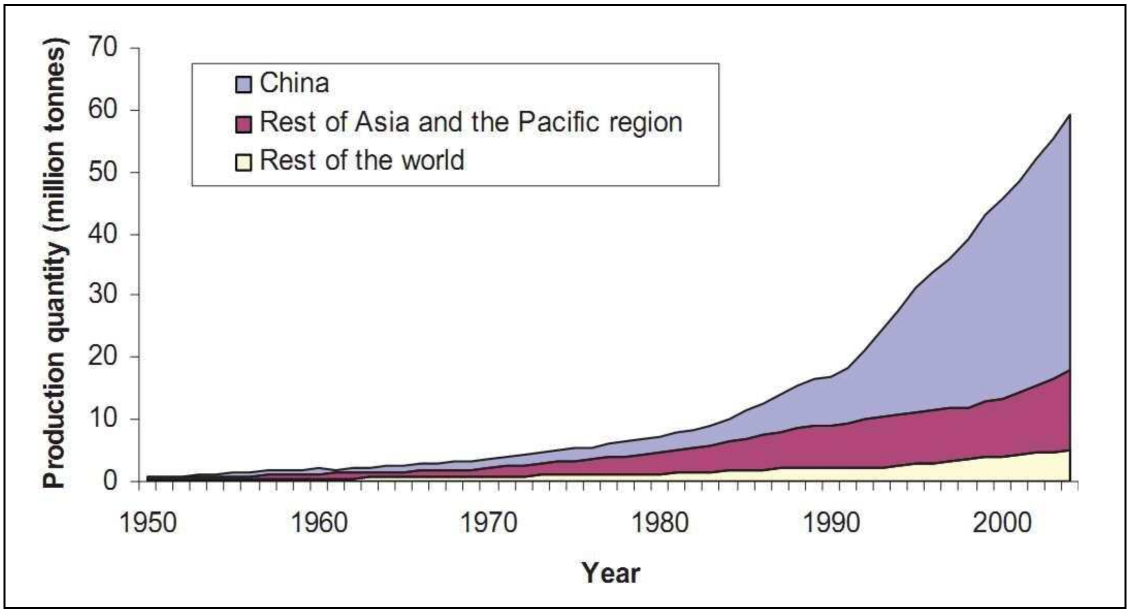

Figure 1. Global aquaculture production with China and rest of Asia and the Pacific Region disaggregated from the rest of the world between 1950 and 2004 Source: Food and Agriculture Organization of the United Nations 2006

The Food and Agriculture Organization of the United Nations provides yearly statistics of worldwide fisheries and aquaculture production, backlogging data to the 1970s. Africa alone has seen an increase from 10 271 tonnes in 1970 to 940 440 tonnes in 2008. Their production percentage of the world market has jumped from 0.40% to 1.80% in the same time period. China had a total production of 764 380 tonnes in 1970 to 32 735 944 tonnes in 2008. China currently accounts for 62.3% of the total production of aquaculture worldwide. North America has seen a general increase in its total production from 1970 to 2008, but its percentage of the world market production has decreased significantly over the same period to 1.2%. This discrepancy of production as a value of world percentage illustrates the competitive nature of the aquaculture industry.

Aquaculture is defined by the Food and Agriculture Organization of the United Nations as "the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture, while aquatic organisms which are exploitable by the public as a common property resource, with or without appropriate licences, are the harvest of fisheries" (IPEC, 1988). Simply put, aquaculture is the farming of aquatic organisms with some sense of ownership, implied or otherwise.

Aquaculture has been practiced for over 4000 years. There is evidence of fish ponds in China dating back to 2000 B.C. (Swann, 1992; Pillay, 1993; Munroe and McKinley, 2007). Ancient Egyptian paintings show ornamental fish ponds (Swann, 1922; Randall, Brummett and Williams, 2000).

European aquaculture began in the middle ages and the introduction of culture methods for trout during the 1800's gave rise to the science and techniques currently used today in modern aquaculture (Swann, 1992). Aquaculture production can take many forms. Each type of production involves techniques specific to that production, to help ensure efficient production. With specific techniques and production, there are also specific issues and obstacles to overcome. Added to production specific concerns, there are also general concerns that are present in all types of aquaculture production. These concerns mainly centre on water quality (Abeysinghe, Shanableh and Rigden, 1996; Neori et al, 2004; Hudson and Lester, 1992). Since, by definition, aquaculture is the growing of organisms in water, access to water supplies with proper concentrations and levels of dissolved oxygen, salinity, and acidity are paramount to a successful operation. Levels of each of these factors have to be within a specific range to ensure the health and survival of the organisms being grown, thereby maintaining viable aquaculture production.

Aquaculture in Canada

In Canada, aquaculture production can be found in every province but most of the aquaculture production in Canada is centred on the western and eastern coasts (Statistics Canada, 2010). Finfish production is the largest type of aquaculture production in Canada and the main species produced is Atlantic salmon (Salmo salaar) which is grown mainly in New Brunswick and British Columbia (Statistics Canada, 2010). British Columbia accounted for just under half of the total aquaculture production in Canada in 2009, with 76 420 tonnes of the 154 554 total tonnage produced within Canada.

Statistics Canada publishes the national aquaculture statistics on a yearly basis. The following data was reported in the Statistics Canada 2010 report on aquaculture statistics in Canada. The Salmon production accounted for 68 670 tonnes of that production in British Columbia. British Columbia is also the second largest producer of shellfish in Canada, behind Prince Edward Island. Prince Edward Island produced 20 365 tonnes of shellfish in 2009, compared to 7 300 tonnes produced in British Columbia. The total value of aquaculture in Canada was worth slightly over 800 million dollars (CDN) with British Columbia providing 413 million dollars (CDN) of that. It can be seen from these numbers that despite Canada's small percentage of worldwide aquaculture production, aquaculture provides a significant source of income to the Canadian economy.

Figure 2. Aquaculture production and value in Canada for 1990 to 2009
Source: Statistics Canada 2010

Providing over half of the total aquaculture production in Canada, British Columbia aquaculture producers are heavily involved with both finfish and shellfish. The finfish aquaculture sector in British Columbia is mostly controlled by a handful of large companies. Conversely, the shellfish sector is mainly comprised of a higher number of smaller companies.

Shellfish Aquaculture Sector in British Columbia

Along with Statistics Canada, the provincial government of British Columbia provides yearly reports on aquaculture statistics within the province. The following data has been taken from 2009-2010 reports on aquaculture statistics by Statistics Canada and the Ministry of Agriculture and Lands of the Province of British Columbia.

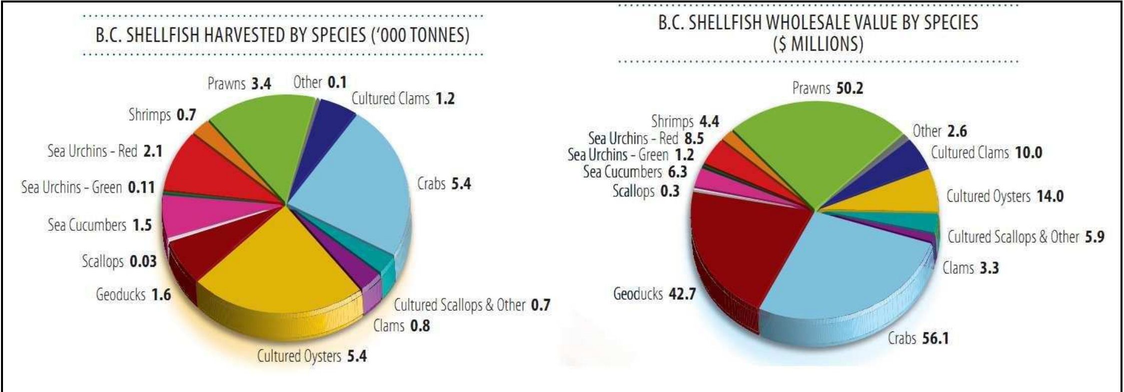

Figure 3. British Columbia shellfish statistics for 2009. Source: BC Seafood Year in Review 2011

Of the 76 420 tonnes of total shellfish harvested in British Columbia in 2009, 7 300 tonnes were cultured shellfish. The majority of the shellfish produced in British Columbia were oysters, at 5 400 tonnes, followed by clams at 1 200 tonnes. As scallops do not attach to substrates, they are grown using suspended culture methods. This involves placing them within a mesh cage and suspending multiple cages along a single line in the water. Geoducks are also cultured in British Columbia. They account for 1 600 tonnes of harvested shellfish in British Columbia.

Manila clams are currently the only cultured species of clam in British Columbia (British Columbia Ministry of Agriculture and Lands, 2011; BCSGA, 2010). Although the production level of oysters was much higher than clams, the dollar value of clam production was higher than the dollar value of oyster production. Clam production for 2009 was valued at $6.8 million dollars CDN and oysters were valued at $6.5 million CDN. Being able to grow less of a product for more value, compared to oysters, highly increases the potential for manila clam production in British Columbia.

The manila clam, Tapes philippinarum, is a subtropical to low boreal species of the western Pacific and is also distributed in temperate areas of Europe (FAO Fishery Statistics, 2006). It was accidentally introduced to British Columbia in the 1930's through contaminated imported Japanese oyster seed (Fisheries and Oceans, 1999). The first manila clams in British Columbia were found in Ladysmith on Vancouver Island in 1936 (BCSGA, 2010; Fisheries and Oceans Canada, 1999). Once introduced, they quickly spread along the Vancouver Island coastline as well as the southern mainland coast. In North America, their range includes the Strait of Georgia, north Barkley Sound on the west coast of Vancouver Island and from the central coast of British Columbia to California (Fisheries and Oceans, 1999). They are found intertidally, above the half-tide level, in mixed substrates of gravel, sand or mud (Goulletquer, Robert and Trut, 1999; Fisheries and Oceans Canada, 1999; FAO Fishery Statistics, 2006). The maximum recorded age of a manila clam in British Columbia is 14 years. Growth occurs quickly up to 5 years, and then slows. Maximum size reached by a manila clam is 75 mm and occurs in 8-10 years (Bourne, 1982). Legal size for manila clam harvesting in British Columbia is 38 mm in length, which takes approximately 3.5 years. This allows at least one spawning period to occur before the clam reaches legal size for harvest.

Until the 1950s, butter clams dominated the landings of commercial clams in British Columbia. The focus shifted to manila clams in the 1980s, as a preference for ‘steamers’ (Manila and littleneck clams) arose (Fisheries and Oceans, 1999). The manila clam is considered an attractive clam and separates easily from the shell after cooking, leading to an increase in market preference.

There is an active manila clam commercial fishery in British Columbia. Between the 1950s and the 1980s, landings increased from 189 tonnes to 1 668 tonnes (Fisheries and Oceans, 1999). Due to numerous difficulties including licensing issues and water quality issues, the landings decreased in the 1980s and have remained between 1 000 and 1 400 tonnes since (Fisheries and Oceans, 1999). Area closures resulting from questionable water quality and paralytic shell poisoning (PSP) can have adverse effects on human health. Partially because of these uncertain conditions in the manila clam commercial fishery, the culture of manila clams was adopted in British Columbia. By utilizing culture techniques, the shellfish grower could maintain control over some aspects of the operation, reducing the risk and dependency on the wild stock. Although the manila clam has been harvested in British Columbia since the 1950s, it was not until 1985 that they were farmed (BCSGA personal communication; Fisheries and Oceans, 1999).

Farming techniques for manila clams in British Columbia have been adapted from Washington State and have since expanded in both jurisdictions.

Shellfish culture in British Columbia is highly concentrated in the area of Baynes Sound. Baynes Sound produces 39% of total farmed oysters in British Columbia and 55% of total manila clam production (BCSGA personal communication; Fisheries and Oceans, 1999). Baynes sound is located between Denman Island and Vancouver Island. It separates Vancouver Island from the mainland of British Columbia. The average width of Baynes Sound is approximately 2 km with the widest point reaching 3.5 km. Baynes Sound is 40 km long.

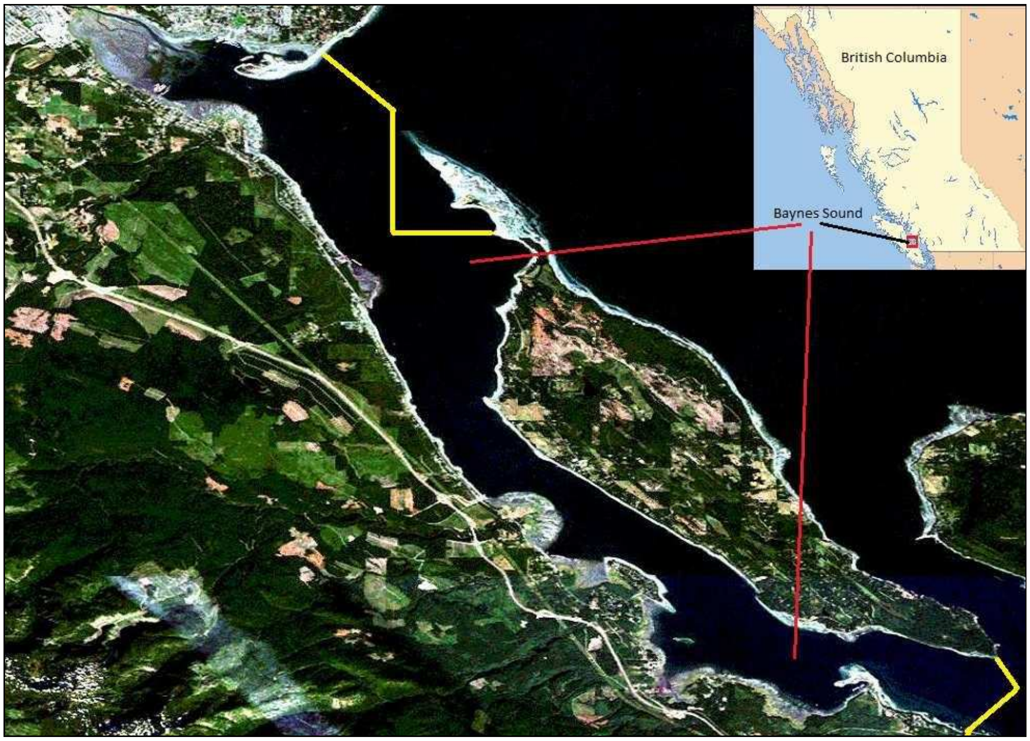

Figure 4. General location overview of Baynes Sound. Yellow line indicate Baynes Sound geographic boundary in regards to Vancouver Island and Denman Island Source: Google Maps

The following information on the processes involved in Manila clam culture in British Columbia was provided by the British Columbia Shellfish Growers

Association, personal communication with shellfish growers active in the industry in British Columbia, and personal observation.

The production cycle starts with the procurement and planting of seed and finishes with the harvesting of the manila clam (See Figure 5). When manila clam culture was first adapted in British Columbia in 1985; the seed was taken from wild stock. Since then, seed production has evolved with the use of hatcheries. Hatcheries maintain broodstock for the production of clam larvae (known as clam seed). By maintaining their own broodstock, the hatchery allows for multiple spawning events. Within a hatchery, control of many of the variables that affect spawning and growth of manila clams can be controlled. Water temperature, salinity, flow and overall quality is monitored and adjusted as necessary to meet the requirements of the larvae. Manila clam seed is usually available for shellfish growers in the spring. In order to produce spawning events in the spring, conditioning of broodstock begins in the winter. Feed and water temperature are manipulated to induce spawning. Once spawning occurs, the larvae are grown until they ‘set’ (attach to substrate). This process takes 12-20 days. Once the larvae are set, they are kept in the hatchery until they become large enough to be shipped to the farmers, also known as growers. When the grower purchases the post-set juvenile manila clams, they do not generally plant, or seed, them directly on the beach. At this point, the juveniles are still small enough to be damaged and washed away by strong tides and currents. They are also highly susceptible to environmental conditions at this time.

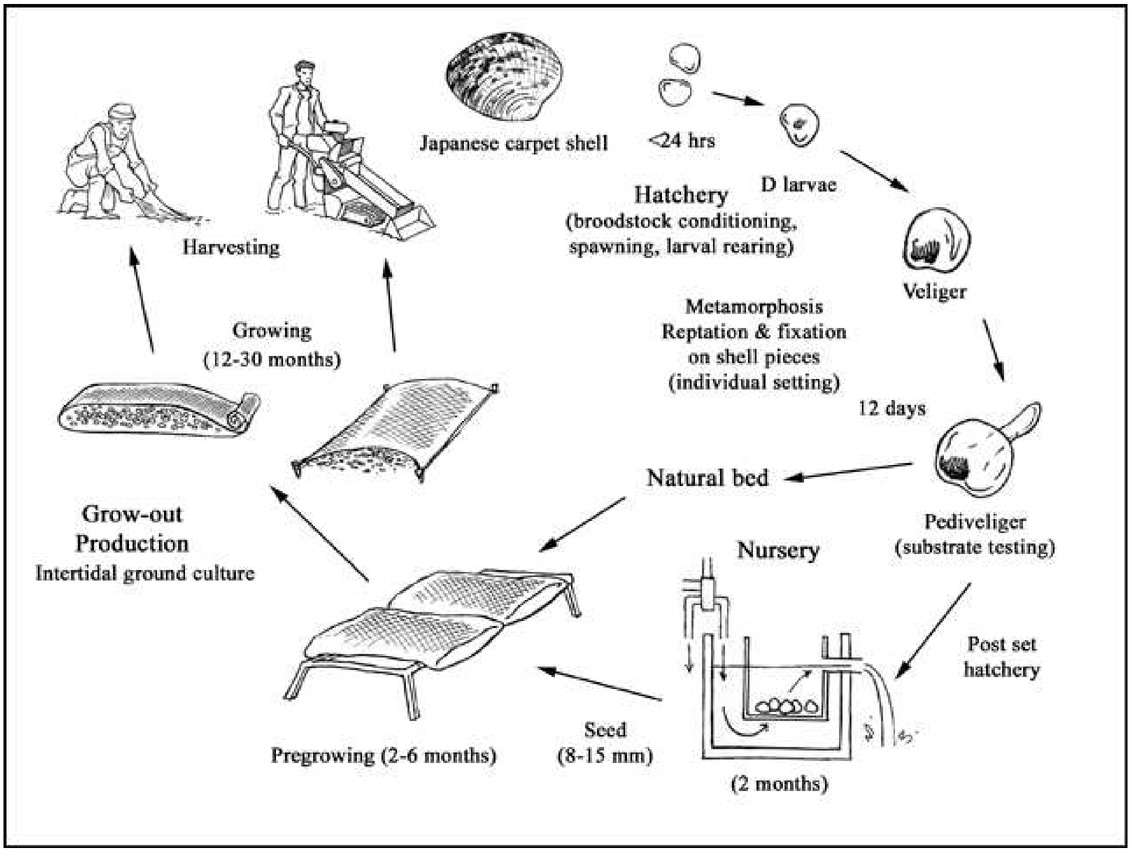

Figure 5. Production cycle of manila clam culture. Japanese carpet shell is common name in Japan. Source: FAO 2006

Instead, the juveniles are kept within the hatchery to allow them to increase in size under controlled conditions. This is referred to as nursery rearing. During nursery rearing, there are several stages. Initially, the set juveniles, which are approximately 0.2 mm in size, are reared in indoor upwellers until they reach the size required by the grower. This range can be from 2-3 mm to 6-9 mm, depending on the growers need. The upweller consists of a tank filled with water and feed. Manila clam feed consists of single-celled algae, either diatoms, a plant with a shell of silica, or naked flagellates, a plant without a cellulose cell wall that has a tail like structure enabling it to swim. The water and feed is provided to the manila clam juveniles in a highly controlled and gentle manner to prevent damage to the organism.

The longer seed remains in the hatchery, the more expensive it is for the grower to purchase. However, cost savings by buying smaller seed is usually offset by the higher rate of mortality of the smaller seed. Most growers buy larger seed that are more capable of handling environmental conditions and have lower subsequent mortality rates. Some growers buy slightly smaller seed and use their own upwellers, either on land or floating in the ocean, to grow the seed to the size required for planting on the beach. A floating upwelling system (FLUPSY) is used to create a vertical flow through system of water past the juvenile clams. As the water flows, it is replaced by water from deeper depths, which is the process of upwelling. The seed is placed in screened trays that sit within the water. As the upwelled water flows through the screened trays, bringing with it an abundance of clean water full of planktonic feed. The manila clam juveniles can be reared in these systems until they reach a size of 20 mm. Once this size is exceeded, shell erosion and mortality rates increase.

Once clam seed is the required size, it is ready to be planted. Areas used by shellfish growers have been assessed to meet specific biophysical criteria. This includes tidal action, current flows, substrate type and accessibility. Beaches are divided into subareas for seeding. These areas are seeded with manila clams to a density determined by the grower. The beach can be seeded in the fall, if the juveniles were grown in the spring. In some instances, the seed may be kept in a hatchery facility over the winter and planted in the following spring. As the clams are distributed over the beach, they burrow into the substrate. The ideal substrate is a combination of sand and pea gravel. Growers then cover the seeded areas with some sort of netting; plastic mesh or something similar. This netting protects the clams from predators such as birds and crabs. The netting is staked in the corners and weighed down along the edges to prevent access to predators.

After 2-4 years the clams are ready to harvest. The discrepancy in the timeframe is due to site specific characteristics (temperature, water pH, salinity, available food, and other environmental conditions). The predator netting is removed and clams are dug from the substrate and collected. This process currently, and historically, involves the use of hand rakes with long tines. As the substrate is turned over with the rake, clams are brought to the surface. The clams are collected and placed in mesh bags. This process is very labour intensive. Clam harvesting has the potential to become less labour intensive with the use of new technology. Cultured Manila clam yields can reach a density of 2 kg / m^2, compared to a yield of 0.05-0.1 kg / m^2 for wild harvested stock.

The harvested clams are stored in water, termed ‘wet storage’ for at least 24 hours to purge sand. This can be done at the grower’s site or at the processing facility. If necessary, the clams can be wet stored for a longer period of time.

With all aquaculture, there are inherent risks, as with any food cultivation. Shellfish are highly susceptible to natural forces and trauma as they are grown ‘passively’. A run of poor water quality, a cold winter causing lots of ice, disease, and natural predators are just a few of the inherent risks that shellfish growers encounter yearly. Just one of these risk factors can wipe out a seeded beach, leaving the grower with no stock, and in turn, a loss of revenue. In order to offset these risks, new technology is always being sought out.

Advances in technology can allow for a shellfish grower to more efficiently grow their product, thus mitigating the impact of these inherent risks. One example of an emerging technological advance is the development of a mechanical shellfish harvester. For certain species, such as the manila clam, the use of a mechanical harvester has the potential to greatly reduce harvesting costs, therefore leading to increased profitability. The traditional method of harvesting manila clams is by hand using rakes with tines ranging from 10-15 cm in length. Even though this is the accepted method in BC, an environmental assessment of this method has not been conducted.

Potential Impacts of Clam Harvest Mechanization

Mechanical shellfish harvesters are used throughout the world. In Canada, the technology is just now being adapted and used for aquaculture harvesting. Two main obstacles to this technology in Canada are capital and governmental regulations affecting operation. The mechanical harvester under development by the BCSGA is not cheap. The unit, modelled after a Washington state prototype, was eventually purchased by the BCSGA for $45 000 USD. For small companies involved in manila clam cultivation, this is a sizeable investment. Perhaps the deciding factor for purchase of a mechanical shellfish harvester in British

Columbia is the total reduction of labour and costs when compared to the initial cost of purchase.

Although the financial benefits of using a mechanical shellfish harvester appear to be significant, there has been no work done in Canada on the environmental impacts of using a mechanical harvester and hence authorization of their use within intertidal habitats has not been granted. Fisheries and Oceans Canada (DFO), maintain control over waterways and aquatic ecosystems in Canada. The mandate of DFO is to “develop and implement policies and programs in support of Canada’s scientific, ecological, social and economic interests in oceans and freshwaters” (Fisheries and Oceans Canada, 2011). In order to provide sustainable fisheries and aquaculture resources, Fisheries and Oceans Canada is “guided by the principles of sound scientific knowledge” (Fisheries and Oceans Canada, 2011). In order to approve the use of new technology, DFO requires an environmental impact assessment to be completed to determine if such technology will be detrimental to the aquatic environment in which it operates. Despite numerous environmental impact assessment studies being completed worldwide, prior to this study, none have been completed within Canada, and more specifically, within the unique intertidal ecosystems of British Columbia and with respect to the engineering design developed in this region. The ecological damage of shellfish farming has been well documented (Crawford, Mcleod and Mitchell, 2003; Diaset et al, 2008; Dahlback and Gunnarrsson, 1981). The impacts range from small to large and can largely be attributed to various local effects that include heterogeneity of the coastline, oceanographic and biological parameters and husbandry practices (Miron et al, 2005; Shaw, 1998). The locality of these effects underscores the need for proper site selection when planning a shellfish aquaculture operation.

Intertidal soft-bottom ecosystem are subject to a wide array of environmental conditions that create habitats for many species (Munroe and McKinley, 2007; Lenihan and Micheli, 2001). Some of the potential environmental impacts of shellfish aquaculture are phytoplankton depletion, increased biodeposition and ecosystem changes (Munroe and McKinley, 2007; Ogilvie et al, 2000; Zhou et al, 2006; Dahlback and Gunnarsson, 1981; Baudinet et al, 1990; Bartoli et al, 2001; Beadman et al, 2004).The main concern with using a mechanical shellfish harvester is whether environmental impacts that are normally associated with shellfish aquaculture increase with the use of a mechanical harvester and, if so, the spatial and/or temporal longevity of the impacts.

Spencer et al. (1998) examined consequences of physical disturbance of sediment and its associated fauna with a mechanical harvester. A long-term study was undertaken that encompassed a full production cycle of manila clam cultivation. The study started with beach seeding of clam stock and continued through the grow-out and harvest phase. Total production took 30 months. On plots that were covered with predator netting, increased sedimentation rates were seen. The areas with increased sedimentation also saw an increase in the proliferation of deposit feeding worm species (Spencer et al., 1998). The increased sedimentation and abundance of deposit feeding worm species remained until harvesting began. The mechanical harvester used was a suction dredger. Immediately after harvest, Spencer, Kaiser and Edwards saw a reduction of infaunal abundance by 80%. Sediment structure and invertebrate infaunal communities recovered to the composition of control plots within 12 months after harvest (Spencer et al., 1998). When their results were compared to other similar studies, the authors concluded that, in general, large, short term, habitat change was caused by suction harvesting. The rate that recolonization of infaunal species and sediment structure occurred varied according to local hydrography, exposure to natural physical disturbance and sediment stability (Spencer, Kaiser and Edwards, 1998). Studies completed since have shown similar results (Munroe and McKinley, 2007; Bartoli et al., 2001; Ogilvie et al., 2000).

In 2004, Pranovi et al. conducted a study of the immediate effects of mechanical clam harvesting. Research took place in the Venice Lagoon and the species harvested was the manila clam. The harvesting gear is locally called ‘rusca’ and consists of an iron cage, an outboard engine propeller, which directs the water flow onto the bottom, suspending sediment and fauna, and a net bag to catch clams (Pranovi et al., 2004). The engine and propeller are attached to the side of the boat and as the boat moves forward slowly, the propeller disturbs the sediment, which flows through the net bag. The mesh on the bag is large enough to let organisms below the target size fall through (Figure 6).

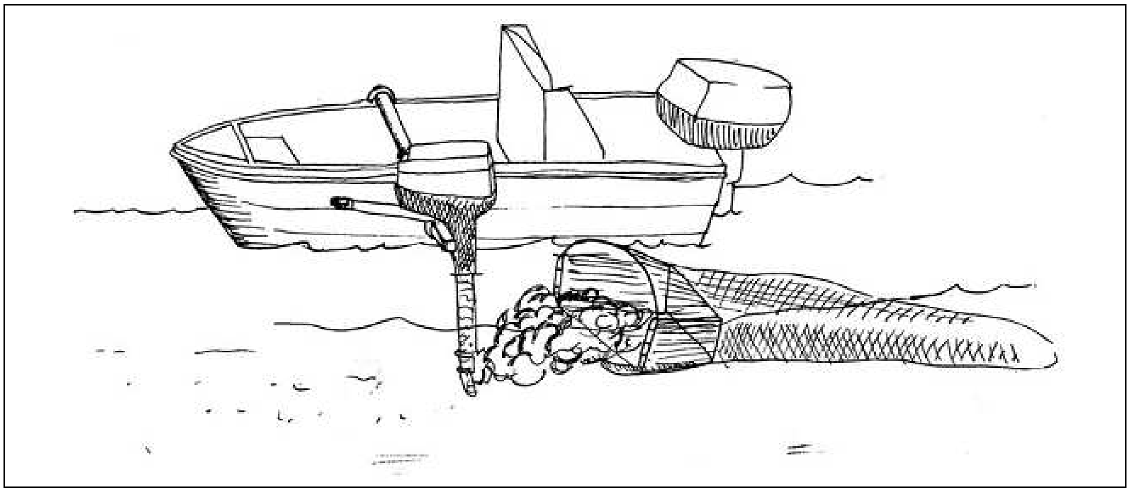

Figure 6. Rusca dredge technique. Source: Pranovi et al, 2004

Pranovi et al. found that one haul using the rusca was insufficient to produce detectable alteration in sediment flux. However, they did not rule out the possibility of multiple hauls causing a loss of fine sediment, leading to a permanent change in the sediment structure. A single haul was reported to be capable of affecting organism density, but not species richness and it was suggested that over time this could produce a loss in more fragile species (Pranovi et al., 2004). It was concluded that the disturbance induced by the rusca is comparable to natural disturbance (Pranovi et al., 2004).

Coen (1995) provided a review of potential impacts of mechanical shellfish harvesting on shellfish resources in the subtidal and intertidal, and summarized the concerns regarding the use of hydraulic shellfish harvesters in South Carolina. Coen organized the general environmental issues into 7 categories: (1) resuspension and turbidity effects; (2) direct burial/smothering; (3) release of contaminants; (4) release of nutrients; (5) decreased water quality; (6) direct disturbance or removal of infauna; (7) effects on economically important finfish and crustacean resources.

Resuspension and turbidity effects

Resuspension and turbidity effects are generally site specific (Coen, 1995; Hayes et al, 1994; LaSalle, 1990) due to a number of factors that include sediment grain size and type, hydrological conditions, faunal influences, currents and water mass size (Coen 1995; Barnes et al, 1991). Numerous studies have discussed the potential effects of turbidity and sediment resuspension on eggs, larval, juvenile and adult fishes and shellfish (Peddicord et al, 1975; Simenstad, 1990) but they have mainly taken place in the laboratory, under controlled situations.

These data are of limited value due to the system- and species-dependent nature being highly variable and often conflicting (Coen, 1995). Generally, shellfish dredging operations have been not considered harmful since its effects are negligible compared to natural variation (Coen, 1995; Godwin, 1973). Studies were cited (Simenstad, 1990; Auld and Schubel, 1978) that concluded marine organisms ranging from larva to finfish are adapted to elevated suspended solids and sublethal effects seen in the lab are ambiguous. It is unlikely that the limited turbidity plumes created by mechanical shellfish harvesting will have a major impact on biological resources in the habitat (Coen, 1995; Auld and Schubel, 1978).

Direct burial-smothering

Barnes et al (1991) noted that mortality from direct burial or smothering is limited to organisms with limited mobility, including attached eggs, juveniles, burrowing infauna and oysters. Most organisms have adapted to normal sediment movement. Mechanical harvesting affects the sediment at a depth of 10-30cm (Coen, 1995). This depth is not considered lethal to small infauna (Barnes et al, 1991). The issue of subtidal burial-smother is not of primary concern (Coen, 1995).

Release of contaminants

A major concern of sediment resuspension is the release of contaminants (Coen 1995; Barnes et al, 1991). Research has shown that sediment disruption can release contaminants, if present, but the magnitude and spatial extent of the release is dependent on the type of disruption, sediment density, sediment grain size and local hydrological conditions (Coen 1995; LaSalle, 1991). Barnes et al (1991) indicated that natural physical processes such as waves, currents and bioturbation were as likely to release contaminants as mechanical harvesters were. All of these physical processes maintain a dynamic equilibrium with respect to surface sediments (Coen, 1995). There is little evidence to support any claims of mechanical shellfish harvesters releasing contaminants. Coen (1995) points out that this is probably due to the fact that areas where shellfish are grown for human consumption require high standards of water quality. If a mechanical shellfish harvester is being used on a manila clam cultured beach, that has been selected with proper water and sediment criteria taken into account, the release of contaminants is a non-issue.

Nutrient release and associated elevated BOD

Similar to the release of contaminants, the release of nutrients is a concern of using a mechanical shellfish harvester. As with contaminants, sediment disturbance due to a number of factors (see Release of contaminants section) can lead to a release of nutrients. The concern with nutrient release is the potential for increased algal growth and increased BOD leading to eutrophy (Coen, 1995; Barnes et al, 1991; Kyte and Chew, 1975). Most of the changes are short-term and indistinguishable from ambient natural variations (Coen, 1995). These changes can occur in pH, dissolved oxygen (DO), sulphides, chlorophyll a, phosphate and salinity (Kyte and Chew, 1975; Godwin, 1973; Coen, 1975). Increased BODs due to elevated nutrient release was determined to be of short duration by Godwin (1973).

The potential impacts of nutrient release by mechanical shellfish harvesters are considered to be limited temporally and spatially due to the minor magnitude of the nutrient release when compared to the natural estuarine ecosystem nutrient budget (Barnes et al, 1991l Coen, 1995; Tarr, 1977; Kyte et al, 1975).

Direct disturbance or removal of infauna

It is generally accepted the disruption of sediment associated with mechanical shellfish harvesting leads to some mortality of infaunal and epifaunal organisms due to soft-tissue cutting, shell breaking and low bivalve reburial rates (Coen, 1995; Barnes et al, 1991; Kyte and Chew, 1975; Kyte et al, 1975). However, it needs to be noted that these organisms tend to have rapid generation times, high fecundities and high recolonization capacities (Coen, 1995; Bennet et al, 1990;

Hall et al 1990), pointing to the effects being short-term. As with direct burying, these effects are apparent only in organisms that are primarily immobile (Hall et al, 1990). Kaplan et al (1975) indicated that with extensive sediment disruption, changes in sediment characteristics could occur. For example, a shift from fine sediment to coarse sediment could occur, causing changes in the benthic community. Kaplan et al (1975) produced a case study in which muddy sediment dominated by polychates shifted to an environment dominated by bivalve fauna, which are indicative of sandy sediments (Coen, 1995). The evidence indicates disturbance or removal of infauna does not pose a significant concern. However, the literature is sparse in this area and the potential for effect should be further examined (Coen, 1995).

Habitat Effects and Interactions

Literature indicates that predators and opportunistic species tend to be attracted to the areas in which sediment was disrupted due to use of a mechanical shellfish harvester (Hasking and Wagnerm 1986; Caddy, 1973; Meyer et al, 1981). Caddy (1973) found a 33 fold increase in crab abundance one hour after harvesting, in harvested plots compared to non harvest plots. The limited evidence indicates that mechanical shellfish harvesting may attract larger numbers of fish, crustaceans and birds to the area (Coen, 1995).

Tarnowski (2001) also performed an extensive literature review for mechanical shellfish harvesters in order to assess the environmental impact of a hydraulic escalator dredge in Maryland, USA. He found that impacts are highly dependent on the hydrological processes of the beach, indicating that high erosion sites have low temporal rates and low erosion sites have more long lasting effects, with sediment deposition limited to a distance of 75 feet.

Many of the harvesters used in the reviewed literature have a different design, and are used in subtidal rather than intertidal areas, than the harvester used for this project. While the results of these studies are important as context, due to harvester design differences and unique hydrological conditions in Baynes Sounds, an independent environmental assessment was needed to provide detailed information on specific hydrological and physical characteristics of beaches in British Columbia.

Purpose

The purpose of this project was to determine the potential near field effects of mechanical and hand harvesting, particularly with respect to the risks to valued habitat productivity. This provides the scientific information necessary for the development of appropriate regulatory approval criteria for such activities.

The primary goal of this project was to complete an evaluation of the operational performance, with respect to environmental ‘risk’, of using a mechanical clam harvester that has been designed to extract cultured clam stock from beach substrate in a way that is projected to be more efficient, and hence more cost-effective, than that of currently employed manual harvesting methods.

The specific objectives in achieving this goal included:

- Completion of an initial, short-term assessment to determine if significant environmental impacts are expected from mechanical manila clam harvesting;

- Provision of detailed background information on critical habitat values and physical-chemical characteristics within the projected zone of influence of the mechanical clam harvester for comparative work;
- Completion of a detailed valuation of mechanical clam harvester operational impacts in terms of habitat disruption – specifically spatial and temporal aspects of impacts.
- Examine and document economic effects of using the mechanical shellfish harvester and quantify the environmental risks associated. Mitigation measures of negative impacts associated with the mechanical shellfish harvester will be provided.

Chapter 2 – Methods

Mechanical Harvester Design

In 2002, Chuckanut Shellfish, Inc. modified a mechanical tulip bulb harvester to successfully harvest Manila clams in Samish Bay, Washington. The design of the mechanical harvester was supplied by Taylor Shellfish Ltd. The BCSGA was allowed use of this harvester for research purposes and it was the device used to compare the environmental effects with that of traditional, manual harvesting methods in this project.

The prototype mechanized clam harvester, powered by a diesel hydraulic motor, is approximately 2 metres in length and just above one metre high. This Washington state harvester was used as a baseline from which to design a mechanical shellfish harvester better suited to the beaches in British Columbia. A secondary machine was built with these upgrades in mind and local growers are keen to use it. After the initial trials, the mechanical harvester used in the trials was purchased by the BCSGA.

Figure 7. Side view of prototype mechanical shellfish harvester

The width of the mechanical harvester does not exceed one metre at any point. The harvester has a grated shovel, approximately 80cm in width, that penetrates the substrate. The depth of penetration of the shovel into the sediment is adjustable. The shovel vibrates constantly, sieving the sediment, and allowing the collected organisms to move onto the connected conveyor belt. The clams pass along the conveyor belt, which is equipped with grading tines. The grading tines allow for the retention of the target size clams. Non-targeted organisms and clams that do not meet the target size fall through the grading tines back into the

Figure 8. Operator view of prototype mechanical shellfish harvester

substrate. The conveyor moves the clams to a collection basket attached to the harvester. Once the basket is full, the clams are bagged and the process continues. The operator of the harvester is able to sort through the collected clams, releasing any non-target organisms and discarding damaged clams, all the while maintaining control of the harvester.

Study Area

Five sites were selected in consultation with members of the BC Shellfish Growers Association. The study sites (beaches) were selected to represent the varying physical conditions present in manila clam culture that might be expected to be encountered in the deployment of a mechanized clam harvester in British Columbia. All 5 sites are located within Baynes Sound, in beach areas comprised of a mix of gravel and sand, which is considered ideal for clam culture (Munroe & McKinley 2007). Three study beaches included Comox, Royston, and Ship's Point, as well as an ancillary sampling program at two additional commercial tenures. Both commercial tenures are located at Base Flats. Figure 9 illustrates the location of the sampling sites within Baynes Sound.

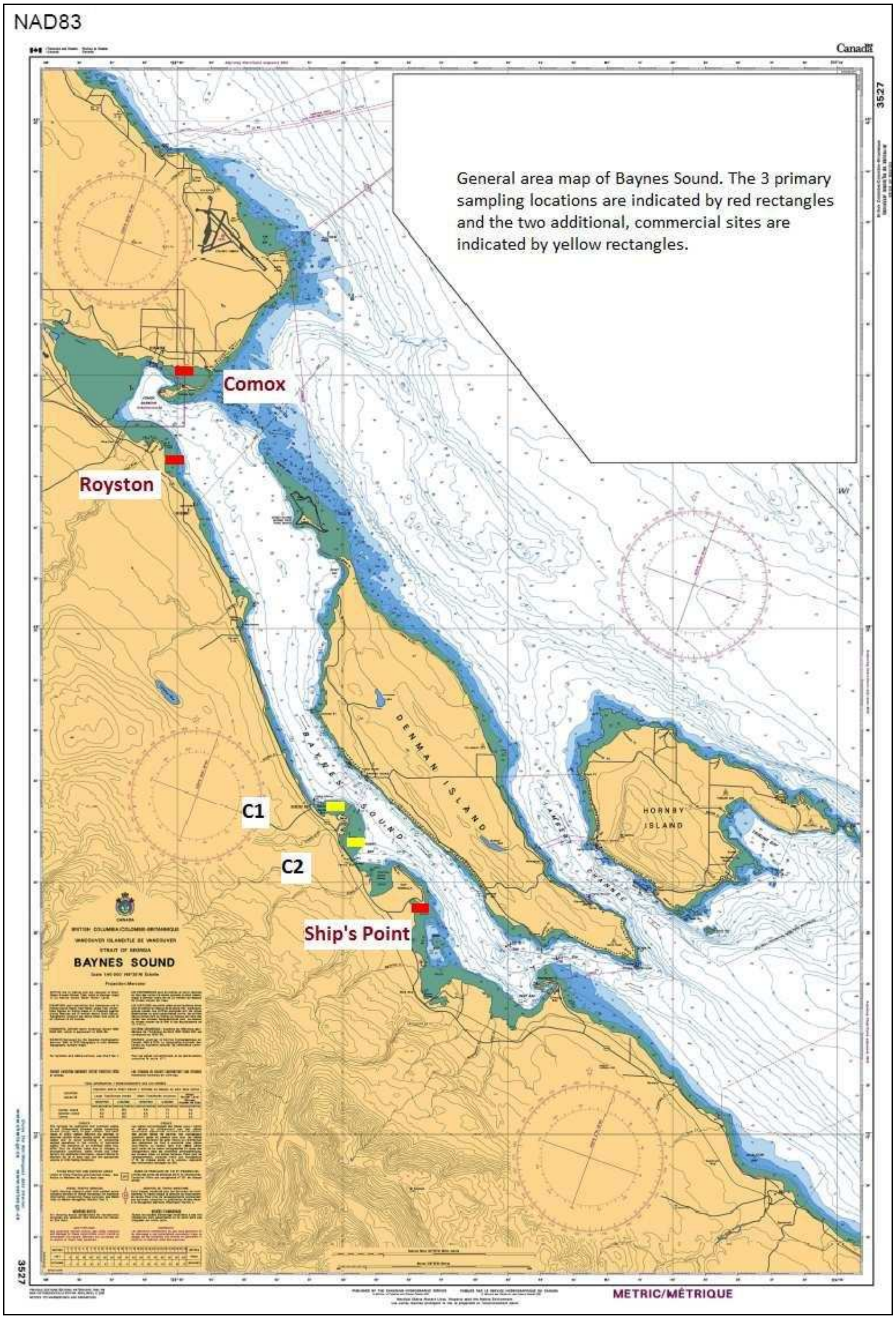

Figure 9. General area map of Baynes Sound. The 3 primary sampling stations are indicated by red rectangles and the two commercial site by yellow rectangles

Oceanographic Assessment

A short-term oceanographic survey was conducted at each of the proposed study sites in late July 2008 and May 2009 (spring tide period). In July 2008, the survey was conducted for Comox, Royston, and Ship's Point. In May 2009, the survey was conducted for the two commercial tenures, C1 and C2. The purpose of the oceanographic survey was to ascertain residual tidal flow directions over each beach and hence allow for the proper design the subsequent pre- and post-harvest sampling program. Knowing the residual tidal flow directions ensured that all sampling would occur in the net 'downstream' direction of water flow across each of the study areas.

A 1200 khz ADCP was mounted within the substrate in the mid-study area and left for a 24-hour period to examine vertical and horizontal flow dynamics as the water came in during the flood tide and subsided during the ebb. Water velocity and direction, determined using the Doppler shift of the acoustic signal, was acquired every 15 minutes. Post data analysis included development of speed-direction frequency tables as well as progressive vector diagrams (PVDs) for each 5-10 cm depth bin. These latter data were used to predict the best transect location for the subsequent per- and post-harvest sampling/survey program.

Sampling Program

Sampling Design

A comprehensive sampling program was completed at each of the 3 study sites in the initial harvest trials. Each site comprised of a mechanical harvest plot and a manual harvest plot. Each plot measured 15 m by 30 m. These plot sizes were comparable to areas that would be harvested during commercial operation. The manual harvest plots were harvested in the traditional method of using hand rakes and manual labour. There were 8 diggers working in this manner for every manual harvest plot at all sample sites. The plot was divided into sections that were determined by individual diggers. Each digger had their specific area and commenced digging. As the sections were dug, the clams were graded by the diggers and collected and bagged.

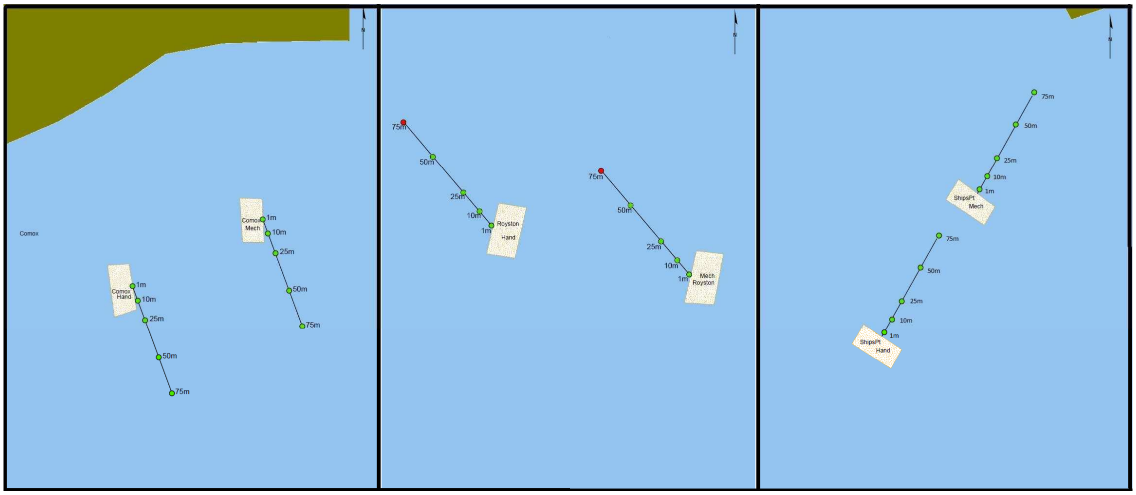

Figure 10. Diagram illustrating the location of plots and transect for the three initial sample beaches (Comox, Royston & Ships Point)

Sampling stations were established downstream of each of these plots and included various positions within the plots as well as at 1m, 10m, 25m, 50m and 75m stations. Three replicates, for each parameter, were acquired at each station plus the two established reference stations during each survey. Surveys were conducted 24 hours pre-harvest, immediately post-harvest, and 24 hours post-harvest. The harvesting of the manila clam is done in an intertidal zone, therefore, the use of the harvester and all sampling took place during low tide. Parameters that were sampled included in situ sediment grain size (SGS), visual condition (digital imagery), sedimentation accumulation (silt flux), and sediment macro-fauna.

Sampling Parameters

Sediment Chemistry

At each sampling station, in situ physical-chemical conditions were documented by appearance using a digital image record, total free sulphides, eH (REDOX) and sediment grain size (SGS). The digital image record was recorded using a Canon Powershot camera. The free sulphides and eH were determined using a Thermo Orion 5 Star Portable meter. Redox and sulfide levels were assessed according to procedures outlined in Hargrave et al. (1995).

SGS samples were extracted and submitted to an external laboratory for analysis. The sediment grain size composition was determined as a percentage of total sample weight. Classification categories included %Mud, %Sand, and %Gravel. The samples were analyzed using methods outlined by Walton (1978) and according to the methods described in Protocols for Marine Environmental Monitoring (2002).

Sedimentation

A key variable used to assess the physical disturbance results from harvesting was sedimentation, or localized siltation effects. Past studies have shown that sedimentation has a major effect on local flora and fauna (Breuer, 1962; Copeland and Dickens, 1969). The largest single cause of mortality in invertebrates associated with sediments is attributable to the effects of sediment deposition, and not from suspended solids per se (Appleby and Scarratt, 1989). The most obvious effect of deposited sediments is the smothering of non-motile species (Appleby and Scarratt, 1989). Another major effect is that of delaying or prevention of larvae settlement through substrate alteration (Appleby and Scarratt, 1989).

Triplicate sediment canisters made of PVC pipe, each measuring 21cm in height and 8cm circumference, were buried at each of the sampling stations established on each of the study beaches. The canisters were buried with approximately 1-2cm of the canister top showing. For the pre- and post-harvest sampling, the sediment canisters were deployed for a 24 hour period before and after harvest. After 24 hours, the canisters were retrieved at low tide and the sediment within retained. The sediment collected was used to determine volume acquired over the deployment period.

There was a small amount of in-field sample processing. This included decanting of water from each of the canisters, with the remaining sediment residue retained. The remaining residue was secured in labelled Ziploc bags. The water was decanted to allow for easier transportation of the samples to a laboratory. Once all samples were collected for a sampling event, they were brought to the laboratory. Sediment volume measurements were taken by discharging the contents of the bags into a plastic tote, removing organic material and detritus, and emptying the sediment into graduated conical measurement flask. The graduated measurement of the flasks was millilitres. The plastic tote was rinsed with water and the excess water was deposited into the flasks. This allowed for any remaining sediment to be captured. Once all contents were entered into the flasks, they were left to settle for a period of 15 minutes. After the 15 minute time period, the amount of sediment was measured and recorded. The flasks were then emptied and samples of the sediment were retained. The flasks were rinsed and the process continued until all sediment samples were processed.

Sediment Macro/Meio-fauna

Core samples were taken at each of the sampling and reference stations during both pre- harvest and post-harvest surveys. These samples were brought back to the laboratory and fixed with 7% buffered formalin solution. They have subsequently been transferred to 70% isopropynol for preservation.
Samples were sent to a local taxonomist, Columbia Science, and sorted infauna were identified to the species level when able and to the family level otherwise.

Ancillary Sampling Program – Commercial Beaches

At each of the commercial sites, the harvest areas evaluated were 15 m by 30 m, the same size as the sample plots from the beaches sampled previously. The 30m side of the plot being the main axis. At the C1 harvest site, the direction of the main axis of the plot was 71℉, with the sampling start location being located in the middle of the northernmost 15m side. The main direction of the axis of the plot at the C2 harvest site was 26℉. The sampling start location was located in the middle of the northernmost 15m side. Sampling for the commercial beaches consisted of sediment collection utilizing the sediment collection canisters deployed during initial sampling program. Analysis of the sediment followed the protocols used during the initial sampling of the Comox, Royston and Ships Point beaches. In addition to sediment volume, sediment grain size was also analyzed. As before, the samples were sent to an external laboratory that followed the sediment grain size analysis outlined by Walton (1978).

In January 2009 and January 2010, canisters were redeployed at test beaches during storm events. In 2009 the storm event occurred on January 8. In 2010, the storm event occurred on January 14. In each case, canisters were deployed in triplicate at sampling stations used in the initial sampling program. The purpose of this sampling was to gauge how much sedimentation flux occurs during a natural disturbance event.

Statistical Analysis

All individual sampling stations were subjected to statistical analysis (pre-harvest vs. post-harvest; manual harvest vs. mechanical harvest). As well, sampling transect were statistically analyzed (pre-harvest vs. post-harvest; manual harvest vs. mechanical harvest). Initial statistical analysis consisted of 2-tailed t-tests, ANOVA (1-way and 2-way) and Kruskal-Wallis.

The null and alternative hypotheses are:

H_0 = There will be no statistically significant difference in measured amounts of sediment flux, between mechanically harvested plots and hand harvested plots, on the three sample beaches.

H_1= There will be a statistically significant difference in measured amounts of sediment flux, between mechanically harvested plots and hand harvested plots, on the three sample beaches.

Chapter 3 - Results

The following results are provided as a detailed analysis of the environmental assessment of the mechanical clam harvester.

Oceanographic Influences

The pre-study assessment for each of the study sites was completed in July 2008 and May 2009. The data have been summarized in representative progressive vector plots (PVP's) for each study site, and are shown in Figures 11-15. The residual flow information from these data were used to establish the orientation of the sampling transects for the other components of this study, ensuring that sampling locations were established downstream of the anticipated dispersion of materials.

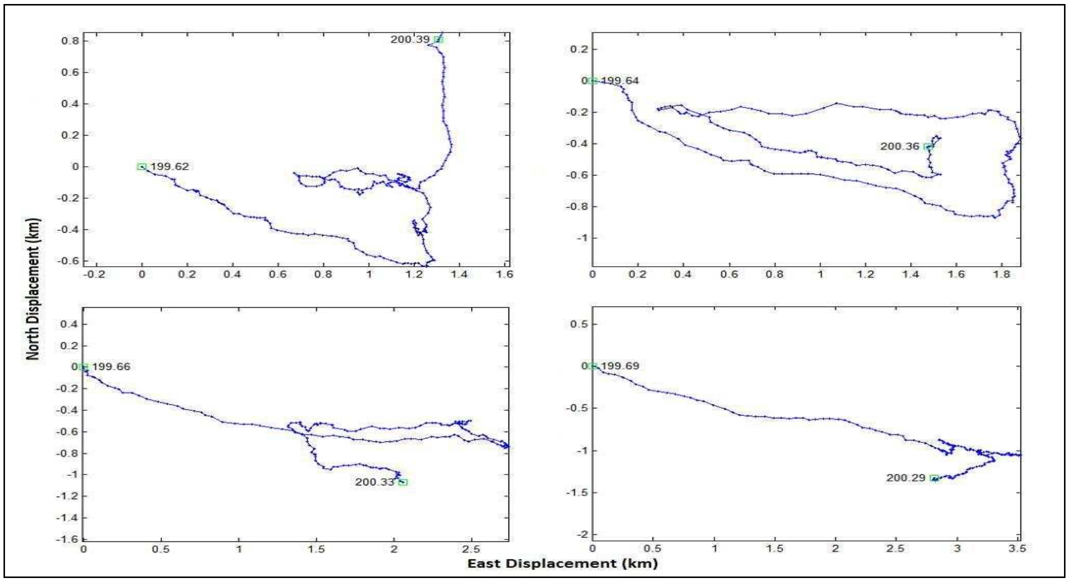

Figure 11. 24-hour tidal flow data collected using a 1200 khz ADCP. Progressive Vector Diagrams (PVDs) for Comox sample beach. Subsequent survey design (transect orientation and location) is based on these

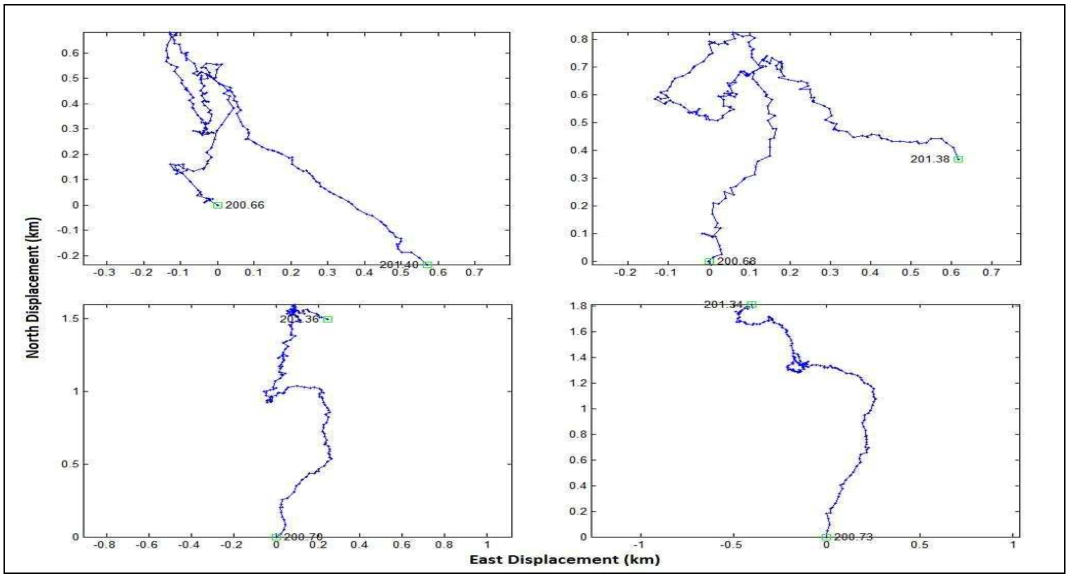

Figure 12. 24-hour tidal flow data collected using a 1200 khz ADCP. Progressive Vector Diagrams (PVDs) for Royston sample beach. Subsequent survey design (transect orientation and location) is based on these data

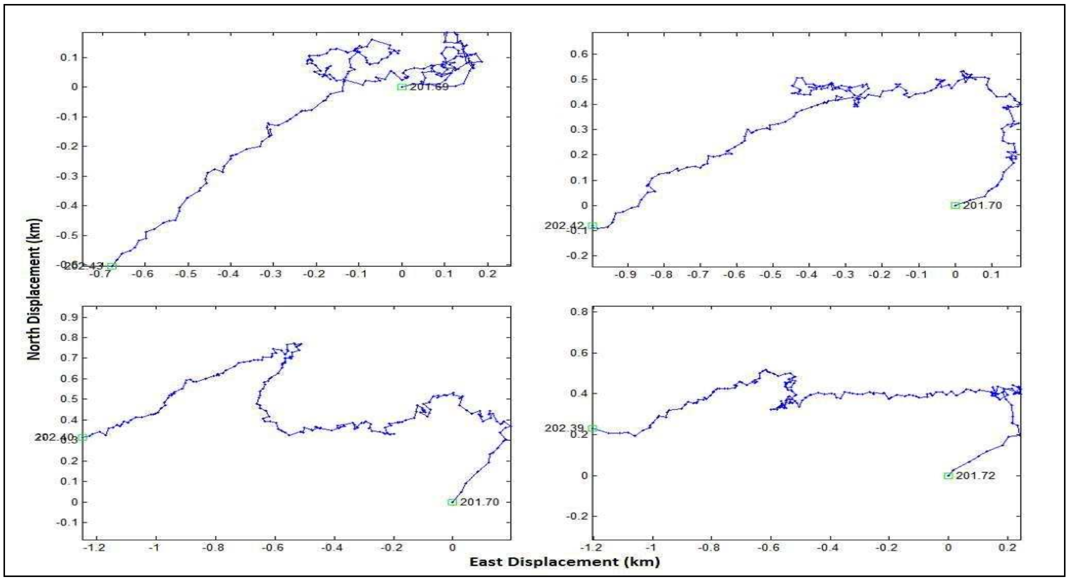

Figure 13. 24-hour tidal flow data collected using a 1200 khz ADCP. Progressive Vector Diagrams (PVDs) for Ships Point sample beach. Subsequent survey design (transect orientation and location) is based on these data

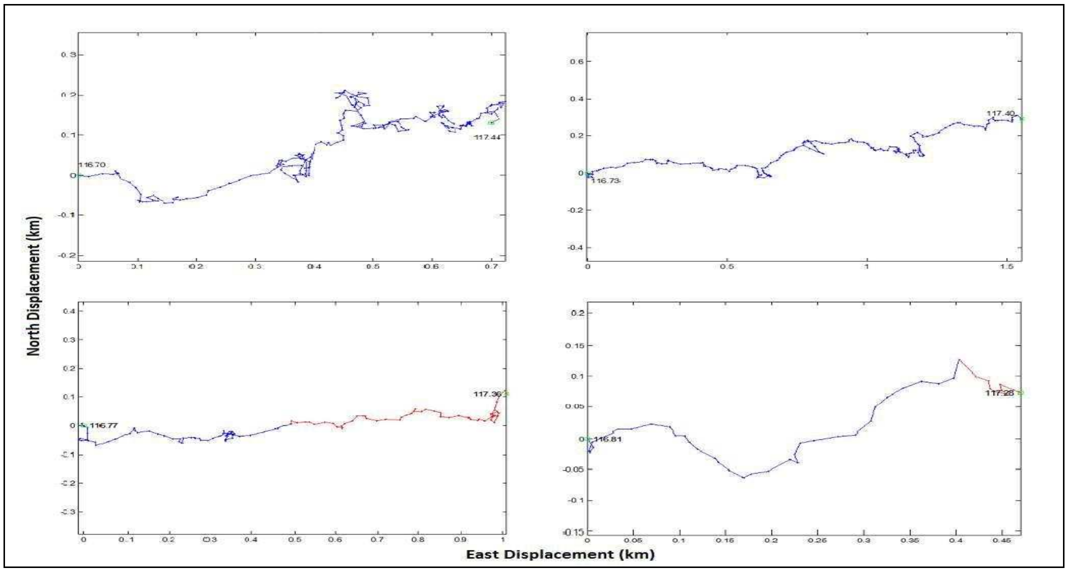

Figure 14. 24-hour tidal flow data collected using a 1200 khz ADCP. Progressive Vector Diagrams (PVDs) for C1 sample beach. Subsequent survey design (transect orientation and location) is based on these data

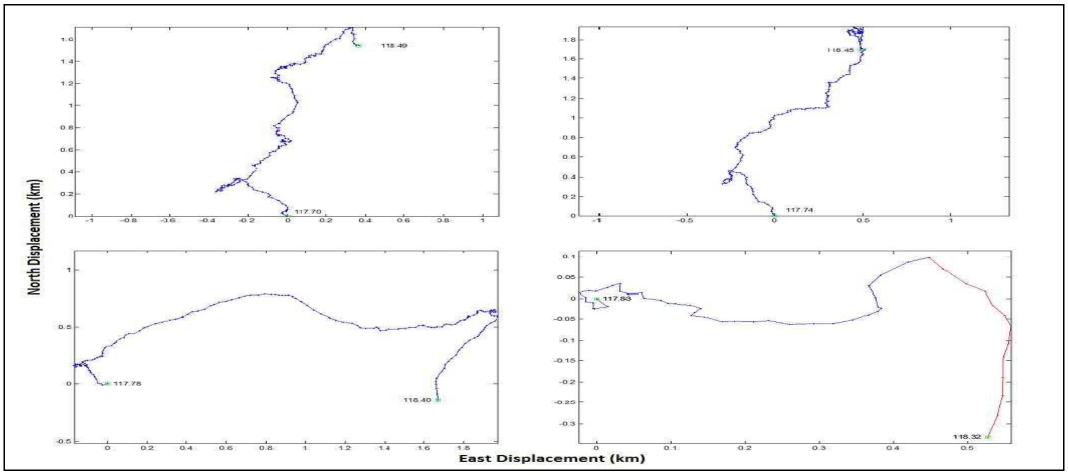

Figure 15. 24-hour tidal flow data collected using a 1200 khz ADCP. Progressive Vector Diagrams (PVDs) for C2 sample beach. Subsequent survey design (transect orientation and location) is based on these data

The data collected indicates the dominant and subdominant current flows. The data was collected during a 24 hour period and then downloaded for analysis. The ADCP was calibrated and initialized using Aquadopp proprietary software, AquaPro v1.35. The sampling interval was set at 5 minutes. Once data was downloaded, it was sent to ASL Environmental Sciences (ASL), located in Victoria, British Columbia. ASL converted the retrieved data to a usable format that allowed for the residual current flow to be determined. The dominant and subdominant current flows can be seen in Appendix 1.

Sediment Dynamics

All sediment canister samples were processed, providing volume of silt accumulated pre- and post-harvest during the field surveys, and have been compiled and subjected to statistical analysis. Sediment grain size data is included in Appendix 1.

The sample means of sediment canister stations (for each study site), have been plotted for the manual- harvested and the mechanically-harvested plots and stations (Figures 16-19). These figures illustrate the mean sediment volumes for downstream transects, at each study site, for both pre and post-harvest surveys. Pre-harvest data were used as control data.

Samples collected during storm events in January 2009 and 2010 were not subjected to statistical analysis. In these instances, the canisters were uniformly, completely filled with sediment (~1000ml). This large amount of sediment greatly exceeded any sample taken during other sampling events

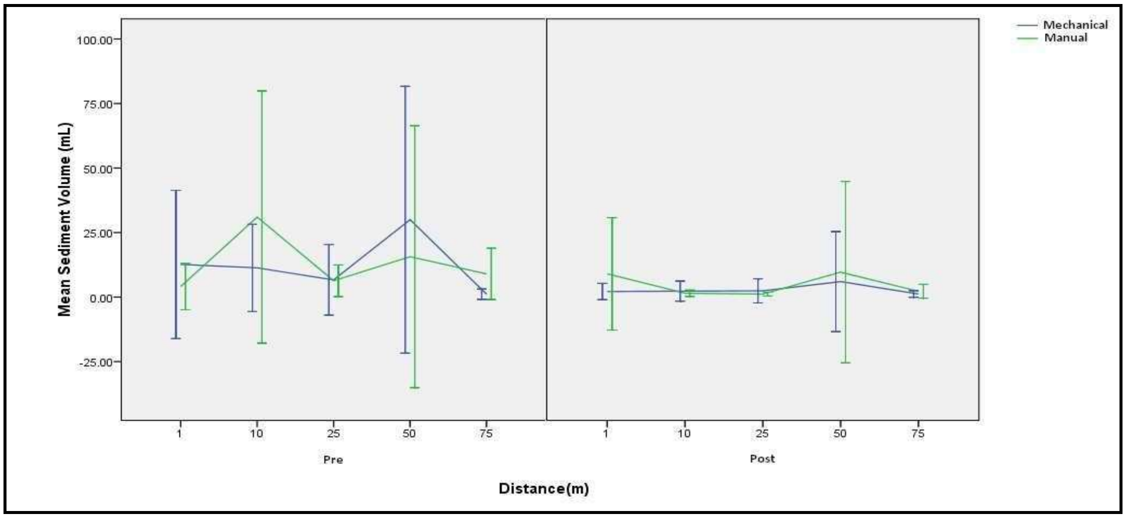

Figure 16. Mean values of sediment collected in sediment collection traps for Comox beach. Mechanical and manual harvest data is shown for pre- and post-harvest. 95% confidence interval

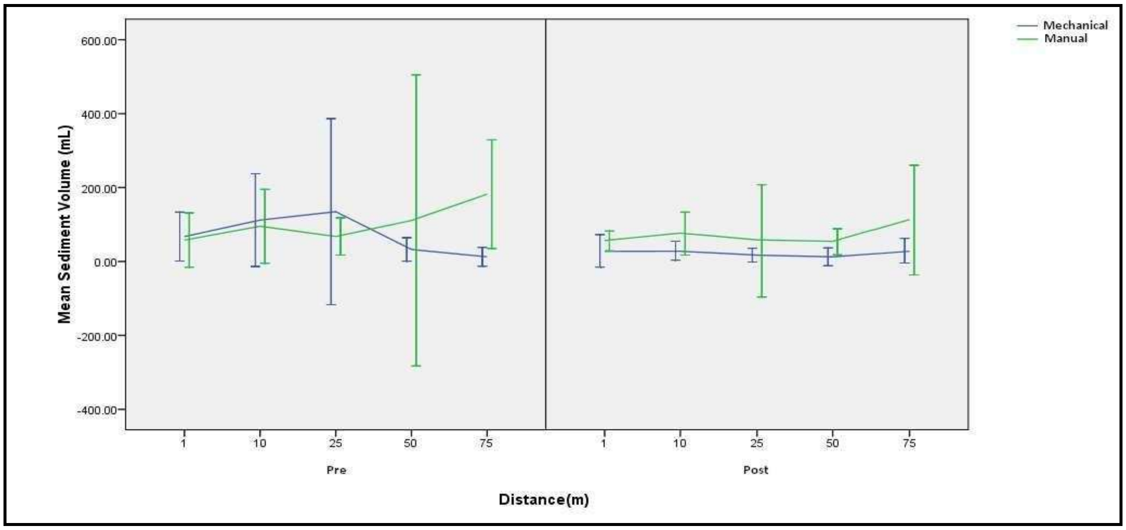

Figure 17. Mean values of sediment collected in sediment collection traps for Royston beach. Mechanical and manual harvest data is shown for pre- and post-harvest. 95% confidence interval

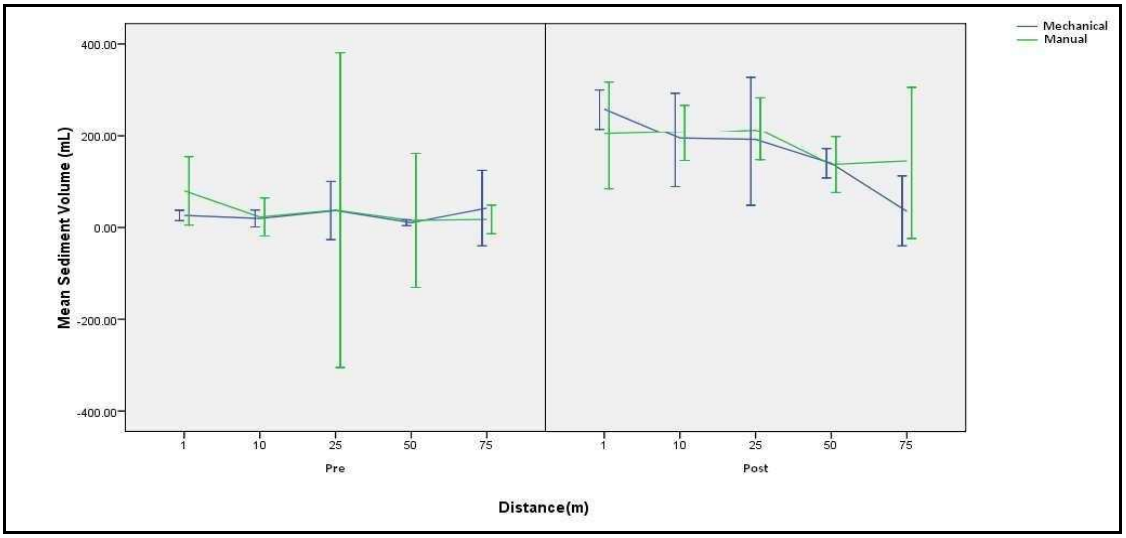

Figure 18. Mean values of sediment collected in sediment collection traps for Ships Point beach. Mechanical and manual harvest data is shown for pre- and post-harvest. 95% confidence interval

The bulk of useful results were gleamed from the sedimentation data. These data were subjected to thorough statistical analysis. Student t-tests, 2-tailed, were used to compare individual sampling stations along the transect originating from the mechanical harvested plot to the stations at the same distances on the manually harvested plot. In electing to perform t-tests, there was an assumption of independence. Data was analyzed between mechanical and manual harvested plots, and not pre- and post-harvest for the same plot. This coupled with the time and distance between sampling stations and events, indicated that the assumption of independence was met. Analysis of variance (ANOVA) was used to compare the complete transect of the mechanically harvested plot to the manually harvested plot transect for each sampling beach. These were 2-way ANOVA tests.

Although some individual stations show significance in their sedimentation difference between mechanical and manual harvest after conducting a t-test, this occurred in both the pre- and post-harvest sampling events (Table 1). Pre-harvest sampling constituted background data, so the significance in post-harvest differences per station is called into question. However, the post-harvest stations that had a significant difference between mechanical and manual harvest sedimentation were the 75m pre-harvest, 10m post-harvest, 25m post-harvest, & 50m post-harvest from Royston beach (respectively $\rho=0.035$, $\rho=0.032$, $\rho=0.026$, $\rho=0.015$).

Transects from the mechanical and manual plots were also compared and subjected to 2-way ANOVA, or where the assumptions necessary for ANOVA were not met, Kruskal-Wallis. In this case, only post-harvest sampling at Royston beach showed any significant difference of sediment volume collected between mechanical and manual harvesting ($\rho=0.000$). All other transects (pre- & post-harvest; mechanical & manual; all beaches) showed no statistically significant difference in sedimentation. This coincides with the individual station analysis and suggests that there is no general difference between the impacts of the mechanical harvest when compared to the manual harvest for these transects.

Royston sampling beach is the anomaly in the data set analysis, As Royston post-harvest did show significant difference between mechanical and manual harvesting, and the data was subjected to more analysis.

As seen in Figures 16-19, the amount of variance within sampling stations was very high. This variance was higher in the manual harvest stations then the mechanical harvest stations. The variance was also higher in the pre-harvest samples when compared to post-harvest samples.

Table 1. Statistical analysis (t-test, 2-tailed) for individual sample station sedimentation results; significant at the 0.05 level

Comox Pre-Harvest		Royston Pre-Harvest		Ships Point Pre-Harvest	
1m	$\rho_{\text{Mech-Hand}} = 0.288$	1m	$\rho_{\text{Mech-Hand}} = 0.706$	1m	$\rho_{\text{Mech-Hand}} = 0.038$
10m	$\rho_{\text{Mech-Hand}} = 0.177$	10m	$\rho_{\text{Mech-Hand}} = 0.678$	10m	$\rho_{\text{Mech-Hand}} = 0.767$
25m	$\rho_{\text{Mech-Hand}} = 0.928$	25m	$\rho_{\text{Mech-Hand}} = 0.371$	25m	$\rho_{\text{Mech-Hand}} = 0.984$
50m	$\rho_{\text{Mech-Hand}} = 0.443$	50m	$\rho_{\text{Mech-Hand}} = 0.230$	50m	$\rho_{\text{Mech-Hand}} = 0.706$
75m	$\rho_{\text{Mech-Hand}} = 0.029$	75m	$\rho_{\text{Mech-Hand}} = 0.035$	75m	$\rho_{\text{Mech-Hand}} = 0.294$
Comox Post-Harvest		Royston Post-Harvest		Ships Point Post-Harvest	
1m	$\rho_{\text{Mech-Hand}} = 0.252$	1m	$\rho_{\text{Mech-Hand}} = 0.081$	1m	$\rho_{\text{Mech-Hand}} = 0.118$
10m	$\rho_{\text{Mech-Hand}} = 0.448$	10m	$\rho_{\text{Mech-Hand}} = 0.032$	10m	$\rho_{\text{Mech-Hand}} = 0.644$
25m	$\rho_{\text{Mech-Hand}} = 0.315$	25m	$\rho_{\text{Mech-Hand}} = 0.026$	25m	$\rho_{\text{Mech-Hand}} = 0.520$
50m	$\rho_{\text{Mech-Hand}} = 0.714$	50m	$\rho_{\text{Mech-Hand}} = 0.015$	50m	$\rho_{\text{Mech-Hand}} = 0.873$
75m	$\rho_{\text{Mech-Hand}} = 0.198$	75m	$\rho_{\text{Mech-Hand}} = 0.077$	75m	$\rho_{\text{Mech-Hand}} = 0.063$

Table 2. Statistical analysis (2-way ANOVA & Kruskal-Wallis) for sampling transect sedimentation results; significant at the 0.05 level

Comox Pre-Harvest	Royston Pre-Harvest	Ships Point Pre-Harvest
$\rho_{\text{Mech-Hand}} = 0.852$	$\rho_{\text{Mech-Hand}} = 0.106$	$\rho_{\text{Mech-Hand}} = 1.00$
Comox Post-Harvest	Royston Post-Harvest	Ships Point Post-Harvest
$\rho_{\text{Mech-Hand}} = 0.999$	$\rho_{\text{Mech-Hand}} = 0.000$	$\rho_{\text{Mech-Hand}} = 0.588$
Significant @ the 0.05 level; 2-tailed	Significant @ the 0.05 level; 2-tailed	Significant @ the 0.05 level; 2-tailed

Sediment density and %Mud of sediment grain size were tested as variables, individually and combined, on sedimentation rates. Pearson's r, the correlation coefficient, was used to determine correlation. Sediment density was shown to have an effect on Comox pre-harvest ($\rho=0.021$), Ships Point post-harvest ($\rho=0.003$) and Royston post-harvest sediment flux ($\rho=0.004$). Both %Mud and sediment density were shown to have a significant effect on sediment flux for Royston Post harvest ($\rho<0.001$, $\rho=0003$ respectively).

When the factors (%Mud*Density) were subjected to analysis as a combination, only Royston post-harvest was shown to be affected by the combination of the %Mud*Density factor in a significant manner ($\rho<0.001$)

Table 3. Correlation analysis for Density as a variable on sedimentation rates on Comox and Ships Point beaches; significant at the 0.05 level

Comox Pre-Harvest		Ships Point Post-Harvest	
Density	R Squared 0.714	Density	
	$\rho_{Transect-Density}$ = 0.002		$\rho_{Transect-Density}$ = 0.740

Table 4. Correlation analysis for %Mud and Density as separate independent variables on sedimentation for Comox, Royston and Ships Point beaches; significant at the 0.05 level

Comox Pre-Harvest		Royston Pre-Harvest		Ships Point Pre-Harvest	
% Mud	Pearson Correlation 0.031	% Mud	Pearson Correlation -0.250	% Mud	Pearson Correlation 0.146
	$\rho_{Transect-\%Mud}$ = 0.871		$\rho_{Transect-\%Mud}$ = 0.190		$\rho_{Transect-\%Mud}$ = 0.467
Density	Pearson Correlation -0.421	Density	Pearson Correlation -0.119	Density	Pearson Correlation 0.353
	$\rho_{Transect-Density}$ = 0.021		$\rho_{Transect-Density}$ = 0.540		$\rho_{Transect-Density}$ = 0.071
Comox Post-Harvest		Royston Post-Harvest		Ships Point Post-Harvest	
% Mud	Pearson Correlation -0.166	% Mud	Pearson Correlation -0.695	% Mud	Pearson Correlation -0.130
	$\rho_{Transect-\%Mud}$ = 0.379		$\rho_{Transect-\%Mud}$ = 0.000		$\rho_{Transect-\%Mud}$ = 0.493
Density	Pearson Correlation 0.104	Density	Pearson Correlation -0.538	Density	Pearson Correlation 0.513
	$\rho_{Transect-Density}$ = 0.585		$\rho_{Transect-Density}$ = 0.003		$\rho_{Transect-Density}$ = 0.004

Table 5. Correlation analysis for %Mud*Density as a variable on sedimentation rates for Comox, Royston and Ships Point beaches; significant at the 0.05 level

Comox Pre-Harvest		Royston Pre-Harvest		Ships Point Pre-Harvest	
% Mud*Density	$\rho_{Transect-\%Mud*Density}$ = 0.852	% Mud*Density	$\rho_{Transect-\%Mud*Density}$ = 0.106	% Mud*Density	$\rho_{Transect-\%Mud*Density}$ = 0.896
Comox Post-Harvest		**Royston Post-Harvest**		**Ships Point Post-Harvest**	
% Mud*Density	$\rho_{Transect-\%Mud*Density}$ = 0.967	% Mud*Density	$\rho_{Transect-\%Mud*Density}$ = 0.000	% Mud*Density	$\rho_{Transect-\%Mud*Density}$ = 0.740

The positive correlation shown between percent mud (%Mud) of the sediment grain size (SGS) analysis and sediment density, on sediment deposition flux for all beaches, indicate that a higher percent mud of the SGS and a lower sediment density increases sediment deposition.

Both Royston beach post-harvest sampling and Ships Point beach post-harvest sampling showed a positive correlation between sediment density and sedimentation flux (ρ=0.003, ρ=0.004) (Table 5). Royston beach post-harvest showed a positive correlation between %Mud and sediment density on sediment deposition (ρ<0.001).

As mentioned, there was a high variability within results. Bassoullet (2000) found that large amounts of mobile sediment were consistently present within his study site in France. This mobile sediment was attributed to spring and neap tides, as well as wave action. The environmental characteristics (waves and tides) of the beaches used in this study appear to contribute more to the sediment flux than does the use of a mechanical shellfish harvester.

Substrate Characteristics

Physical-Chemical Data

Sulfide and eH data showed high variability within plots and transects, within beaches, and between beaches (Tables 1-3). Sulfide values ranged between

944µmol at the Ships Point mechanical 10m station to 11.2µmol at the Royston mechanical plot. Redox potential had positive values as well as negative. The probes used on the Thermo Orion meter are designed to function more efficiently in mud than in the sand/gravel habitat that made up most of the sample areas.

The variance seen in the redox measurements was typical for the operational limitations of the probes and meter. The temperature range of the samples fell between 14.6˚C and 25.7˚C, depending on how quickly the sample was collected and analyzed. Visually, none of the sulfide/redox samples indicated any difference with that of the surrounding areas.

Table 6. Mean sulphide, redox and temperature values for Comox sample beach

Pre/Post	Mech./Hand	Station (m)	Mean Sulfide (µmol)	Mean Redox (mv)	Standard Deviation (S^{2-})	Standard Deviation (REDOX)	Coefficient of Variance (S^{2-})	Coefficient of Variance (REDOX)
Pre	Hand	1	122.0	-106.1	104.956	99.835	0.860	-0.941
Pre	Hand	10	192.5	-147.4			0.545	-0.677
Pre	Hand	25	38.6	-91.0			2.721	-1.097
Pre	Hand	50	64.0	-133.2			1.639	-0.750
Pre	Hand	75	186.0	-187.8			0.564	-0.532
Pre	Mechanical	1	368.3	2.3	98.652	63.732	0.268	28.117
Pre	Mechanical	10	299.7	-130.5			0.329	-0.488
Pre	Mechanical	25	299.7	-159.4			0.329	-0.400
Pre	Mechanical	50	341.0	-140.4			0.289	-0.454
Pre	Mechanical	75	158.0	-128.8			0.624	-0.495
Post	Hand	1	46.3	-135.1	81.614	47.412	1.763	-0.351
Post	Hand	10	68.0	-119.6			1.200	-0.396
Post	Hand	25	89.3	-130.8			0.914	-0.362
Post	Hand	50	198.8	-148.4			0.411	-0.319
Post	Hand	75	126.7	-122.6			0.644	-0.387
Post	Mechanical	1	49.0	-57.8	35.812	64.652	0.731	-1.119
Post	Mechanical	10	89.0	-171.0			0.403	-0.378
Post	Mechanical	25	72.7	-95.4			0.493	-0.678
Post	Mechanical	50	96.2	-95.4			0.372	-0.678
Post	Mechanical	75	55.9	-93.1			0.640	-0.695

Table 7. Mean sulphide, redox and temperature values for Royston Sample beach

Pre/Post	Mech./Hand	Station (m)	Mean Sulfide (µmol)	Mean Redox (mv)	Standard Deviation (S^{2-})	Standard Deviation (REDOX)	Coefficient of Variance (S^{2-})	Coefficient of Variance (REDOX)
Pre	Hand	1	63.0	-74.2	12.476	44.248	0.198	-0.596
Pre	Hand	10	45.3	-9.9			0.276	-4.485
Pre	Hand	25	45.7	-28.3			0.273	-1.564
Pre	Hand	50	51.0	-49.5			0.245	-0.894
Pre	Hand	75	56.1	-53.8			0.222	-0.822
Pre	Mechanical	1	18.6	-43.9	16.528	29.911	0.890	-0.682
Pre	Mechanical	10	42.6	-83.7			0.388	-0.358
Pre	Mechanical	25	40.1	-69.9			0.412	-0.428
Pre	Mechanical	50	39.3	-63.8			0.420	-0.469
Pre	Mechanical	75	43.3	-58.5			0.381	-0.512
Post	Hand	1	164.7	-89.0	38.826	46.315	0.236	-0.520
Post	Hand	10	180.7	-88.9			0.215	-0.521
Post	Hand	25	154.3	-72.6			0.252	-0.638
Post	Hand	50	149.7	-62.4			0.259	-0.743
Post	Hand	75	112.8	-87.1			0.344	-0.532
Post	Mechanical	1	76.5	61.4	40.789	21.152	0.533	0.344
Post	Mechanical	10	127.3	52.4			0.320	0.404
Post	Mechanical	25	136.0	66.2			0.300	0.320
Post	Mechanical	50	167.0	40.7			0.244	0.520
Post	Mechanical	75	153.3	36.1			0.266	0.585

Table 8. Mean sulphide, redox and temperature values for Ships Point sample beach

Pre/Post	Mech./Hand	Station (m)	Mean Sulfide (µmol)	Mean Redox (mv)	Standard Deviation (S^{2-})	Standard Deviation (REDOX)	Coefficient of Variance (S^{2-})	Coefficient of Variance (REDOX)
Pre	Hand	1	46.7	-64.9	29.271	30.201	0.627	-0.466
Pre	Hand	10	73.2	-53.6			0.400	-0.563
Pre	Hand	25	61.0	-46.2			0.480	-0.654
Pre	Hand	50	83.8	-56.6			0.349	-0.534
Pre	Hand	75	63.1	-101.8			0.464	-0.297
Pre	Mechanical	1	210.5	-101.3	228.449	32.749	1.085	-0.323
Pre	Mechanical	10	579.7	-24.0			0.394	-1.365
Pre	Mechanical	25	533.0	-36.8			0.429	-0.889
Pre	Mechanical	50	351.7	-28.6			0.650	-1.146
Pre	Mechanical	75	236.0	-68.3			0.968	-0.479
Post	Hand	1	132.0	-68.9	38.184	38.550	0.289	-0.560
Post	Hand	10	103.9	-89.7			0.367	-0.430
Post	Hand	25	114.0	-127.5			0.335	-0.302
Post	Hand	50	119.4	-100.1			0.320	-0.385
Post	Hand	75	54.4	-30.3			0.701	-1.272
Post	Mechanical	1	108.6	-89.3	71.222	32.920	0.656	-0.369
Post	Mechanical	10	139.8	-121.0			0.509	-0.272
Post	Mechanical	25	249.3	-136.4			0.286	-0.241
Post	Mechanical	50	144.7	-137.3			0.492	-0.240
Post	Mechanical	75	194.7	-129.7			0.366	-0.254

Biological Attributes

Subsamples of representative samples from this study component were examined for species composition and relative abundance. These samples were highly variable and did not provide information considered to be a useful addition to those data generated through the sedimentation and physical-chemical components of the sampling program. In the event of a significant siltation effect these samples were intended to provide a measure of the effects of such processes downstream of the harvesting activities. As no such spatial effects were delimited, no further biological analyses were completed for these archived samples. Species composition and abundance can be found in Appendix 3.

Ancillary Sampling Results

Commercial site sampling was initiated at Base Flats and contained sample sites from commercial tenures, C1 and C2. Analysis of these data using ANOVA, 1-way) suggested that there was no significant difference between the sediment volume pre- and post-harvest (C1 ρ=4.18, C2 ρ=0.294) and that %Mud did have not an effect on sedimentation.

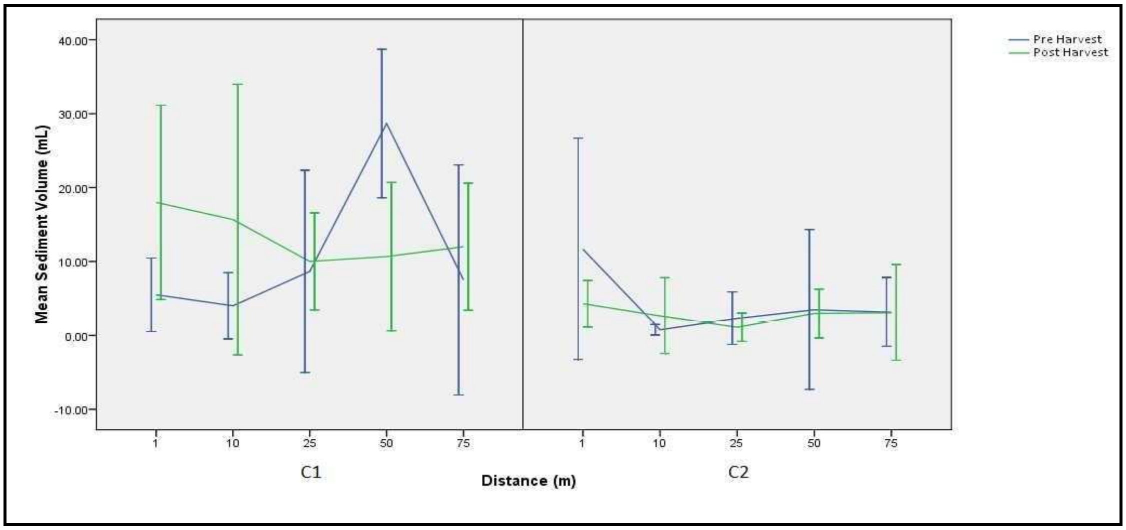

Figure 19. Mean values of sediment collected in sediment collection traps for C1 and C2 beaches. Mechanical data is shown for pre- and post-harvest. 95% confidence interval

Table 9. Correlation analysis for %Mud as an independent variable on sedimentation rates for C1 and C2 beaches; significant at the 0.05 level

C1 Pre-Harvest			C2 Point Pre-Harvest	
% Mud	Pearson Correlation -0.783		% Mud	Pearson Correlation 0.349
	$\rho_{Transect\text{-}\%Mud} = 0.118$			$\rho_{Transect\text{-}\%Mud} = 0.565$
C1 Post-Harvest			C2 Point Post-Harvest	
% Mud	Pearson Correlation 0.715		% Mud	Pearson Correlation -0.376
	$\rho_{Transect\text{-}\%Mud} = 0.175$			$\rho_{Transect\text{-}\%Mud} = 0.533$

Chapter 4 – Discussion

Environmental Assessment

Long term environmental impact from intertidal oyster raft culture has been shown by Martin et al. (1991) to be minimal. Oyster rafts present a habitat disturbance beyond that of seeded clam beaches, and on a continuous basis. Clam harvesting occurs in small scale temporal ranges. Suspended Eastern oyster culture research completed by Mallet (2006) indicated no significant difference in sulfide and redox values between culture and reference sites and attributed sedimentation to the highly dynamic conditions that showed frequent re-suspension of sediment. Crawford et al. (2003) determined that extensive monitoring of shellfish farms was not necessary as there were no clear signs of organic enrichment; and univariate and multivariate measures of benthic infauna were not significantly different, between sites inside and outside shellfish farms.

The levels of variance seen in the samples indicate that post-harvest mechanical sample plots offer a more uniform distribution of sediment than that of pre- & post-harvest manual sample plots. 4.9% of the tenures in Baynes Sound are covered in clam netting (Ministry of Sustainable Resource Management, 2002). Netting has been shown to cause sediment stability which can interfere with local hydrodynamic processes and increase silt and organic matter deposition (Munroe & McKinley, 2007). The presence of netting on a site would account for a higher sedimentation rate over the use of a mechanical harvester.

Royston beach post-harvest shows an effect of SGS and sediment density on sedimentation ($\rho<0.001$). Royston had the highest percentage of mud in the SGS analysis, 14.7% for the 75m station, post-harvest. When these data are factored, they indicate that the sedimentation flux differences seen between mechanical and manual harvesting at Royston beach post- harvest can be, at least, partially attributed to the difference in the percentages of mud present at sampling locations. This coincides with the fact that mud is the smallest and lightest of the sediment grain size categories.

Small and light particles are more susceptible to movement by external forces, such as waves and tides, than larger particles, such as sand and gravel, are (Coen, 1995; LaSalle, 1990; Hayes et al, 1994).

Royston was the only study beach that showed any difference in sediment flux between mechanical and manual harvesting. This can likely be attributed to differences in percent mud in the sediment grain size analysis (Coen, 1995). Had the percent mud been equal for both plots, the likelihood is that a significant difference would not have been indicated.

Sediment samples that were collected during winter storm events for each sampling beach showed high amounts of sedimentation flux; far higher than any seen during the sampling events pre- and post-harvest for both mechanical and manual harvest. The naturally occurring, massive sediment flux shows sedimentation amounts resulting from both mechanical and manual harvesting to be negligible in comparison. The amount of sediment collected during a storm event was 4 times greater than that collected during sampling around harvest.

Other studies have shown that sedimentation rates are highly dynamic and site specific, with natural effects being more pronounced than those produced by a mechanical shellfish harvester (Pranovi et al, 2004; Godwin, 1973; Coen, 1975). Most mortality under normal harvesting is a direct result of sub-lethal or lethal damage to adult and juvenile bivalves during harvester operation; however, actual rates are almost always much lower than hand methods (Kyte and Chew, 1975).

The data collected and analyzed in this report, coupled with results from numerous other studies conducted over the past forty years, indicate that the use of a mechanical shellfish harvester shows no environmental impact, beyond that created by natural occurring disturbances and manual harvesting, on the study beaches during sampling events.

Improvements and mitigation measures

There are numerous improvements that are slated to be part of newer model mechanical shellfish harvester. These improvements include: increased horse power to more effectively penetrate substrate; increased shovel and screening efficiency; increased use of ‘green’ technology such as biofuels; adjustments to reduce noise levels; adjustments to reduce juvenile and non-target organism mortality. Combined, these improvements will increase the efficiency of the mechanical harvester and illustrate to the public that environmental concerns, including noise pollution, are being addressed.

Socio-economic considerations

The socio-economic implications of using a mechanical shellfish harvester also need to be addressed. Socio-economic concerns can range from increased profitability to public perception.

High levels of uncertainty that surround socioeconomic aspects in aquaculture have resulted in the failure of many operations. Ekasingh and Letcher (2008) found that including agricultural and natural resource economists has led to greater success. They also found that various social science disciplines were hard to incorporate into socioeconomic consideration. This was attributed to factors such as administrative boundaries and differences in agendas. Divisive factors such as these can lead to a breakdown in communication and result in socioeconomic issues being diminished. Overcoming these factors will allow open and productive discussions around socioeconomic issues.

The main purpose of utilizing the technology of a mechanical shellfish harvester is to increase profitability. Estimates from the BCSGA put the current cost to harvest manila clams by hand at $0.28/lb. China currently has a cost of $0.07/lb for hand harvesting manila clams, a quarter of the cost of harvesting in British Columbia. This cost difference makes it difficult to for local producers to compete in the global market. The cost estimate of harvesting manila clams with the mechanical shellfish harvester in British Columbia is $0.06/lb. This is based on costs from trials in Samish Bay, Washington. The cost savings would put British Columbia producers on par with global competitors.

As seen with the mechanical shellfish harvester used in this study, increased profitability comes with a decrease in labour costs and reduced mortality. The mechanical shellfish harvester performed the same work as 8 manual diggers, with a comparable environmental impact and shorter time frame. The reduction in labour can greatly increase the profitability for manila clam growers. However, the mechanical shellfish harvester reduces labour, leading to a decrease in jobs. While this may initially seem like a major concern, when the issue is examined, it is shown to be relatively minor. Currently, shellfish growers have a hard time retaining labour (Pentlatch Seafoods, personal communication). Shellfish harvesting is very labour intensive and is dependent on tides, leading to necessary harvests in the middle of the night at times. These two factors are unappealing for many workers. The mechanical shellfish harvester may reduce the overall number of jobs available, but these jobs are becoming increasingly harder to fill. New positions that involve using the mechanical harvester will require specialization. These specialized jobs will provide higher wages.

As previously mentioned, the prototype harvester used in this project was bought for $45 000 CAD, and a newer model costs $90 000 to build. Fuel prices are an additional cost. Fuel prices are steadily increasing, creating an increasing expense. As the mechanical shellfish harvester is being used in intertidal areas, salt water and sediment become an issue. Hydraulic repairs and rust will need to be addressed on a continuous basis. Larger growers can afford to incur this cost, but many smaller growers may not be able to invest in this technology. This could give larger growers an edge on the smaller growers for the mass market. Smaller growers could look to niche markets for their product. This would allow them to sell their product at a premium price

Noise from the mechanical harvester is a concern for recreational users and home owner on beaches. Recording of the noise level of the mechanical harvester show a range of 90 dB directly alongside the harvester, to 52 dB at 100m away. In comparison, a food blender is rated at 90 dB and standard conversation is rated at 60 dB (Truaz, 1999). This comparison puts the noise level of the mechanical harvester into perspective.

The opportunities for employment, income and foreign exchange from coastal aquaculture have been overshadowed by negative environmental and social effects (Primavera, 2006). The general public may be weary of new industrial technology, often due to poor or misinformation. This can be counteracted with an educational program that provides data to concerned citizens that illustrates the benefits of introducing this technology, while addressing environmental and social concerns. Whitmarsh and Palmieri (2009) found that a survey-based approach provided useful information of the general public's perception towards aquaculture. This information can then be used in an education campaign.

Conclusions

Based on the field data collected in this study, we can conclude that that the use of the mechanical clam harvester represents a minimal and localized environmental risk and one that is generally comparable to that of traditional hand harvesting methods on sampled beaches during sampling events. In particular, the level of sediment disruption (and resulting siltation) that results from clam harvesting is extremely small in comparison with the natural disruptive processes that occur in any wind-induced event (e.g., seasonal storms). Given the low level environmental risk, and the potential socio-economic benefits of utilizing such mechanization, it is further concluded that this approach be considered a safe and viable means of shellfish harvesting.

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Appendix 1
Sedimentation and Physical-Chemical Data

Table 10. Plot location GPS coordinates and transect (dominant tidal flow) direction in degrees True for all sample beaches

Comox Mechanical			
	Transect & Dominant Tidal Flow Direction (°T)	Latitude	Longitude
Plot	110	49 40.078	124 54.562
		49 40.062	124 54.560
		49 40.077	124 54.550
		49 40.062	124 54.549

Comox Manual			
	Transect & Dominant Tidal Flow Direction (°T)	Latitude	Longitude
Plot	110	49 40.055	124 54.634
		49 40.036	124 54.631
		49 40.055	124 54.623
		49 40.039	124 54.619

Royston Mechanical			
	Transect & Dominant Tidal Flow Direction (°T)	Latitude	Longitude
Plot	130	49 38.971	124 56.320
		49 38.970	124 56.308
		49 38.956	124 56.326
		49 38.955	124 56.313

Royston Manual			
	Transect & Dominant Tidal Flow Direction (°T)	Latitude	Longitude
Plot	130	49 38.986	124 56.411
		49 38.985	124 56.398
		49 38.971	124 56.417
		49 38.970	124 56.404

Ships Point Mechanical			
	Transect & Dominant Tidal Flow Direction (°T)	Latitude	Longitude
Plot	240	49 29.402	124 47.554
		49 29.409	124 47.546
		49 29.392	124 47.533
		49 29.399	124 47.527

Ships Point Manual			
	Transect & Dominant Tidal Flow Direction (°T)	Latitude	Longitude
Plot	240	49 29.350	124 47.607
		49 29.357	124 47.601
		49 29.341	124 47.586
		49 29.348	124 47.580

C1			
	Transect & Dominant Tidal Flow Direction (°T)	Latitude	Longitude
Plot	71	49 31.510	124 50.368
		49 31.513	124 50.376
		49 31.505	124 50.391
		49 31.507	124 50.399

C2			
	Transect & Dominant Tidal Flow Direction (°T)	Latitude	Longitude
Plot	26	49 30.726	124 49.617
		49 30.730	124 49.627
		49 30.712	124 49.628
		49 30.716	124 49.639

Table 11. Sediment grain size percentages of Comox, Royston, andShips Point sample sites

Beach	Mech/Hand	Station	% Mud	% Sand	% Gravel
Comox	N/A	Reference	4.5	76.3	19.2
Comox	QA/QC[1]		4.7	73.0	22.3
Comox	Manual	75 m	9.8	90.1	0.1
Comox	Manual	Plot	11.3	88.6	0.1
Comox	Mechanical	75 m	12.4	87.4	0.2
Comox	Mechanical	Plot	3.7	69.1	27.1
Royston	N/A	Reference	10.8	66.4	22.8
Royston	Mechanical	75 m	11.6	47.3	41.1
Royston	Mechanical	Plot	13.5	62.8	23.8
Royston	Manual	75 m	9.9	90.1	0.0
Royston	Manual	Plot	11.9	82.2	5.9
Ships Point	N/A	Reference	3.1	96.9	0.0
Ships Point	QA/QC[2]		3.4	96.6	0.0
Ships Point	Manual	75 m	4.4	95.2	0.4
Ships Point	Manual	Plot	2.0	98.0	0.0
Ships Point	Mechanical	75 m	2.0	98.0	0.0
Ships Point	Mechanical	Plot	1.5	98.5	0.0

Table 12. Sediment grain size percentages of C1 and C2 sample sites

Beach	Pre/Post Harvest	Station	% Mud	% Sand	% Gravel
C1	Pre	1 m	3.4	88.1	8.5
C1	Post	1 m	20.0	65.1	14.9
C1	Pre	10 m	2.6	85.9	11.5
C1	Post	10 m	11.7	60.0	28.2
C1	QA/QC[1]		10.3	60.6	29.2
C1	Pre	25 m	2.8	71.9	25.3
C1	Post	25 m	4.6	45.3	50.2
C1	Pre	50 m	1.7	33.8	64.4
C1	Post	50 m	6.6	67.7	25.7
C1	Pre	75 m	1.9	44.4	53.7
C1	Post	75 m	5.1	46.4	48.5
C2	Pre	1 m	12.9	68.9	18.2
C2	Post	1 m	3.7	85.1	11.3
C2	Pre	10 m	15.8	72.3	11.9
C2	Post	10 m	3.3	82.9	13.8
C2	Pre	25 m	3.6	39.2	57.2
C2	Post	25 m	3.6	65.3	31.1
C2	Pre	50 m	6.2	57.5	36.4
C2	Post	50 m	2.8	54.7	42.5
C2	Pre	75 m	5.8	45.0	49.2
C2	Post	75 m	2.2	39.8	58.1

Table 13. Comox Beach sedimentation and physical-chemical raw data

Station	Pre/Post	Beach	Mech./Hand	Distance (m)	Replicate	Volume (ml)	Mean Volume (mL)	Sulfide (µmol)	Redox (mv)	Temp (°C)
Cd-1m-r1	Pre	Comox	Hand	1	1	4.5	4.1	240.0	-142.6	14.6
Cd-1m-r2	Pre	Comox	Hand	1	2	0.3		97.2	-102.5	20.2
Cd-1m-r3	Pre	Comox	Hand	1	3	7.5		28.9	-73.1	20.3
Cd-10m-r1	Pre	Comox	Hand	10	1	13.0	31.0	344.0	-173.9	20.5
Cd-10m-r2	Pre	Comox	Hand	10	2	52.0		163.0	-160.3	20.3
Cd-10m-r3	Pre	Comox	Hand	10	3	28.0		70.6	-108.0	20.3
Cd-25m-r1	Pre	Comox	Hand	25	1	7.5	6.3	81.9	-118.0	20.9
Cd-25m-r2	Pre	Comox	Hand	25	2	8.0		15.0	-91.7	20.9
Cd-25m-r3	Pre	Comox	Hand	25	3	3.5		18.8	-63.3	20.8
Cd-50m-r3	Pre	Comox	Hand	50	3	1.0	15.7	74.9	-202.0	21.2
Cd-50m-r1	Pre	Comox	Hand	50	1	7.0		54.9	-106.0	20.9
Cd-50m-r2	Pre	Comox	Hand	50	2	39.0		62.3	-91.6	21.1
Cd-75m-r1	Pre	Comox	Hand	75	1	9.0	9.0	109.0	-107.0	21.1
Cd-75m-r2	Pre	Comox	Hand	75	2	13.0		330.0	-318.8	21.4
Cd-75m-r3	Pre	Comox	Hand	75	3	5.0		119.0	-137.6	21.4
Cm-1m-r1	Pre	Comox	Mechanical	1	1	5.5	12.7	283.0	113.6	19.9
Cm-1m-r2	Pre	Comox	Mechanical	1	2	6.5		505.0	124.4	19.8
Cm-1m-r3	Pre	Comox	Mechanical	1	3	26.0		317.0	-231.2	19.7
Cm-10m-r1	Pre	Comox	Mechanical	10	1	6.0	11.3	334.0	-130.1	20.1
Cm-10m-r2	Pre	Comox	Mechanical	10	2	9.0		252.0	-125.5	20.1
Cm-10m-r3	Pre	Comox	Mechanical	10	3	19.0		313.0	-135.8	20.3
Cm-25m-r1	Pre	Comox	Mechanical	25	1	3.0	6.7	304.0	-148.6	20.3
Cm-25m-r2	Pre	Comox	Mechanical	25	2	4.0		212.0	-170.9	19.9
Cm-25m-r3	Pre	Comox	Mechanical	25	3	13.0		383.0	-158.6	19.8
Cm-50m-r1	Pre	Comox	Mechanical	50	1	19.0	30.0	409.0	-166.8	19.9
Cm-50m-r2	Pre	Comox	Mechanical	50	2	17.0		293.0	-103.2	20.1
Cm-50m-r3	Pre	Comox	Mechanical	50	3	54.0		321.0	-151.2	19.8
Cm-75m-r1	Pre	Comox	Mechanical	75	1	1.0	1.1	204.0	-184.9	20.2
Cm-75m-r2	Pre	Comox	Mechanical	75	2	2.0		135.0	-88.2	20.2
Cm-75m-r3	Pre	Comox	Mechanical	75	3	0.4		135.0	-113.2	20.2
Cd-1m-r1	Post	Comox	Hand	1	1	0.5	9.0	62.2	-270.0	23.9
Cd-1m-r2	Post	Comox	Hand	1	2	18.0		59.1	-99.9	23.9
Cd-1m-r3	Post	Comox	Hand	1	3	8.5		17.6	-35.5	22.8
Cd-10m-r1	Post	Comox	Hand	10	1	1.0	1.5	54.0	-94.0	23.6
Cd-10m-r2	Post	Comox	Hand	10	2	1.5		58.6	-50.2	23.5
Cd-10m-r3	Post	Comox	Hand	10	3	2.0		91.4	-214.7	22.3
Cd-25m-r1	Post	Comox	Hand	25	1	1.5	1.2	31.5	-130.1	23.0
Cd-25m-r2	Post	Comox	Hand	25	2	1.0		72.4	-125.1	23.9
Cd-25m-r3	Post	Comox	Hand	25	3	1.0		164.0	-137.3	21.4
Cd-50m-r1	Post	Comox	Hand	50	1	1.5	9.7	258.0	-190.1	20.3
Cd-50m-r2	Post	Comox	Hand	50	2	1.5		60.4	-91.8	19.7
Cd-50m-r3	Post	Comox	Hand	50	3	26.0		278.0	-163.3	20.2
Cd-75m-r1	Post	Comox	Hand	75	1	3.5	2.3	183.0	-190.0	20.1
Cd-75m-r2	Post	Comox	Hand	75	2	1.5		47.0	-66.2	20.2
Cd-75m-r3	Post	Comox	Hand	75	3	1.8		150.0	-111.5	20.1
Cm-1m-r1	Post	Comox	Mechanical	1	1	1.0	2.2	44.0	-51.4	21.9
Cm-1m-r2	Post	Comox	Mechanical	1	2	2.0		44.4	-60.3	23.2
Cm-1m-r3	Post	Comox	Mechanical	1	3	3.5		58.6	-61.6	23.3
Cm-10m-r1	Post	Comox	Mechanical	10	1	2.0	2.3	90.7	-143.3	24.2
Cm-10m-r2	Post	Comox	Mechanical	10	2	0.9		113.0	-212.7	22.3
Cm-10m-r3	Post	Comox	Mechanical	10	3	4.0		63.2	-157.0	23.0
Cm-25m-r1	Post	Comox	Mechanical	25	1	0.8	2.4	64.1	-85.6	25.0
Cm-25m-r2	Post	Comox	Mechanical	25	2	4.5		72.4	-87.9	23.8
Cm-25m-r3	Post	Comox	Mechanical	25	3	2.0		81.6	-112.6	24.9
Cm-50m-r1	Post	Comox	Mechanical	50	1	15.0	6.0	45.0	-130.6	22.3
Cm-50m-r2	Post	Comox	Mechanical	50	2	1.0		66.6	-25.4	22.9
Cm-50m-r3	Post	Comox	Mechanical	50	3	2.0		177.0	-130.1	25.7
Cm-75m-r1	Post	Comox	Mechanical	75	1	1.5	1.2	28.5	-96.3	19.9
Cm-75m-r2	Post	Comox	Mechanical	75	2	1.5		81.6	-80.3	23.5
Cm-75m-r3	Post	Comox	Mechanical	75	3	0.6		57.7	-102.6	24.6

Table 14. Royston Beach sedimentation and physical-chemical raw data

Station	Pre/Post	Beach	Mech./Hand	Distance (m)	Replicate	Volume (ml)	Mean	Sulfide (µmol)	Redox (mv)	Temp (°C)
Rd-1m-r1	Pre	Royston	Hand	1	1	24.0	58.0	93.6	-100.4	18.0
Rd-1m-r2	Pre	Royston	Hand	1	2	78.0		45.8	-55.6	17.7
Rd-1m-r3	Pre	Royston	Hand	1	3	72.0		49.7	-66.7	18.0
Rd-10m-r1	Pre	Royston	Hand	10	1	138.0	95.3	44.6	-50.5	18.3
Rd-10m-r2	Pre	Royston	Hand	10	2	58.0		47.7	31.2	18.3
Rd-10m-r3	Pre	Royston	Hand	10	3	90.0		43.5	-10.3	18.4
Rd-25m-r1	Pre	Royston	Hand	25	1	84.0	67.7	41.3	-5.8	18.3
Rd-25m-r2	Pre	Royston	Hand	25	2	45.0		44.0	21.1	18.5
Rd-25m-r3	Pre	Royston	Hand	25	3	74.0		51.8	-100.2	18.9
Rd-50m-r1	Pre	Royston	Hand	50	1	Missing	111.0	51.2	-89.1	18.8
Rd-50m-r2	Pre	Royston	Hand	50	2	142.0		50.2	-42.1	18.6
Rd-50m-r3	Pre	Royston	Hand	50	3	80.0		51.5	-17.3	18.7
Rd-75m-r1	Pre	Royston	Hand	75	1	250.0	182.0	52.8	-18.8	18.7
Rd-75m-r2	Pre	Royston	Hand	75	2	154.0		55.6	-32.4	18.7
Rd-75m-r3	Pre	Royston	Hand	75	3	142.0		60.0	-110.2	18.6
Rm-1m-r1	Pre	Royston	Mechanical	1	1	98.0	67.3	17.0	-42.1	16.6
Rm-1m-r2	Pre	Royston	Mechanical	1	2	54.0		19.1	-30.2	16.2
Rm-1m-r3	Pre	Royston	Mechanical	1	3	50.0		19.6	-59.3	16.1
Rm-10m-r1	Pre	Royston	Mechanical	10	1	170.0	112.0	23.0	-62.1	16.3
Rm-10m-r2	Pre	Royston	Mechanical	10	2	88.0		26.9	-91.2	16.8
Rm-10m-r3	Pre	Royston	Mechanical	10	3	78.0		77.8	-97.7	16.7
Rm-25m-r1	Pre	Royston	Mechanical	25	1	60.0	134.7	25.2	-25.8	16.9
Rm-25m-r2	Pre	Royston	Mechanical	25	2	250.0		56.2	-87.9	16.8
Rm-25m-r3	Pre	Royston	Mechanical	25	3	94.0		38.9	-95.9	17.0
Rm-50m-r1	Pre	Royston	Mechanical	50	1	30.0	30.0	37.9	-111.3	17.1
Rm-50m-r2	Pre	Royston	Mechanical	50	2	35.0		37.7	-39.5	17.0
Rm-50m-r3	Pre	Royston	Mechanical	50	3	25.0		42.4	-40.6	17.0
Rm-75m-r1	Pre	Royston	Mechanical	75	1	18.0	12.6	38.1	-76.6	16.1
Rm-75m-r2	Pre	Royston	Mechanical	75	2	19.0		54.2	-80.9	17.0
Rm-75m-r3	Pre	Royston	Mechanical	75	3	0.7		37.7	-17.9	17.8
Rd-1m-r1	Post	Royston	Hand	1	1	65.0	54.3	151.0	-176.3	17.3
Rd-1m-r2	Post	Royston	Hand	1	2	44.0		199.0	-50.0	17.3
Rd-1m-r3	Post	Royston	Hand	1	3	54.0		144.0	-40.7	17.3
Rd-10m-r1	Post	Royston	Hand	10	1	54.0	74.7	148.0	-106.3	17.3
Rd-10m-r2	Post	Royston	Hand	10	2	70.0		215.0	-100.2	17.3
Rd-10m-r3	Post	Royston	Hand	10	3	100.0		179.0	-60.2	17.1
Rd-25m-r1	Post	Royston	Hand	25	1	68.0	56.0	218.0	-37.2	17.1
Rd-25m-r2	Post	Royston	Hand	25	2	44.0		96.9	-25.3	17.0
Rd-25m-r3	Post	Royston	Hand	25	3	Missing		148.0	-155.2	17.0
Rd-50m-r1	Post	Royston	Hand	50	1	58.0	52.0	157.0	-64.6	17.0
Rd-50m-r2	Post	Royston	Hand	50	2	36.0		154.0	-102.3	17.1
Rd-50m-r3	Post	Royston	Hand	50	3	62.0		138.0	-20.2	16.9
Rd-75m-r1	Post	Royston	Hand	75	1	92.0	112.0	141.0	-80.7	16.9
Rd-75m-r2	Post	Royston	Hand	75	2	180.0		117.0	-60.2	16.8
Rd-75m-r3	Post	Royston	Hand	75	3	64.0		80.3	-120.5	16.8
Rm-1m-r1	Post	Royston	Mechanical	1	1	26.0	27.0	76.1	57.3	16.8
Rm-1m-r2	Post	Royston	Mechanical	1	2	45.0		72.2	62.2	16.8
Rm-1m-r3	Post	Royston	Mechanical	1	3	10.0		81.3	64.8	16.8
Rm-10m-r1	Post	Royston	Mechanical	10	1	35.0	27.3	173.0	44.2	16.8
Rm-10m-r2	Post	Royston	Mechanical	10	2	16.0		108.0	64.3	16.8
Rm-10m-r3	Post	Royston	Mechanical	10	3	31.0		101.0	48.7	16.8
Rm-25m-r1	Post	Royston	Mechanical	25	1	18.0	12.0	128.0	77.6	16.8
Rm-25m-r2	Post	Royston	Mechanical	25	2	15.0		114.0	57.7	16.8
Rm-25m-r3	Post	Royston	Mechanical	25	3	3.0		166.0	63.2	16.8
Rm-50m-r1	Post	Royston	Mechanical	50	1	17.0	11.8	208.0	44.9	16.8
Rm-50m-r2	Post	Royston	Mechanical	50	2	0.3		146.0	10.8	16.8
Rm-50m-r3	Post	Royston	Mechanical	50	3	18.0		147.0	66.3	16.8
Rm-75m-r1	Post	Royston	Mechanical	75	1	39.0	27.3	123.0	74.5	16.8
Rm-75m-r2	Post	Royston	Mechanical	75	2	30.0		155.0	13.6	16.8
Rm-75m-r3	Post	Royston	Mechanical	75	3	13.0		182.0	20.3	16.8

Table 15. Ships Point Beach sedimentation and physical-chemical raw data

Station	Pre/Post	Beach	Mech./Hand	Distance (m)	Replicate	Volume (ml)	Mean	Sulfide (µmol)	Redox (mv)	Temp (℃)
Sd-1m-r1	Pre	Ship's Point	Hand	1	1	110.0	80.0	17.1	-102.3	22.2
Sd-1m-r2	Pre	Ship's Point	Hand	1	2	80.0		52.0	-40.1	22.2
Sd-1m-r3	Pre	Ship's Point	Hand	1	3	50.0		70.9	-52.2	22.7
Sd-10m-r1	Pre	Ship's Point	Hand	10	1	16.0	23.0	42.5	-43.1	22.1
Sd-10m-r2	Pre	Ship's Point	Hand	10	2	11.0		55.0	-68.4	21.3
Sd-10m-r3	Pre	Ship's Point	Hand	10	3	42.0		122.0	-49.4	22.1
Sd-25m-r1	Pre	Ship's Point	Hand	25	1	11.0	38.0	67.7	-9.3	21.8
Sd-25m-r2	Pre	Ship's Point	Hand	25	2	65.0		73.8	-74.4	21.6
Sd-25m-r3	Pre	Ship's Point	Hand	25	3	Missing		41.5	-54.9	21.8
Sd-50m-r1	Pre	Ship's Point	Hand	50	1	4.0	15.5	57.3	-21.9	22.0
Sd50m-r2	Pre	Ship's Point	Hand	50	2	Missing		85.1	-58.4	21.3
Sd-50m-r3	Pre	Ship's Point	Hand	50	3	27.0		109.0	-89.5	22.3
Sd-75m-r1	Pre	Ship's Point	Hand	75	1	6.0	17.7	21.5	-103.5	21.5
Sd-75m-r2	Pre	Ship's Point	Hand	75	2	31.0		82.7	-98.9	21.3
Sd-75m-r3	Pre	Ship's Point	Hand	75	3	16.0		85.1	-102.9	21.1
Sm-1m-r1	Pre	Ship's Point	Mechanical	1	1	22.0	26.3	49.5	-127.3	20.2
Sm-1m-r2	Pre	Ship's Point	Mechanical	1	2	26.0		284.0	-81.3	20.1
Sm-1m-r3	Pre	Ship's Point	Mechanical	1	3	31.0		298.0	-95.2	20.5
Sm-10m-r1	Pre	Ship's Point	Mechanical	10	1	17.0	19.7	350.0	-42.5	19.9
Sm-10m-r2	Pre	Ship's Point	Mechanical	10	2	28.0		944.0	-23.7	20.2
Sm-10m-r3	Pre	Ship's Point	Mechanical	10	3	14.0		445.0	-5.8	21.1
Sm-25m-r1	Pre	Ship's Point	Mechanical	25	1	32.0	38.7	418.0	-44.3	21.0
Sm-25m-r2	Pre	Ship's Point	Mechanical	25	2	42.0		746.0	-27.8	22.1
Sm-25m-r3	Pre	Ship's Point	Mechanical	25	3	42.0		435.0	-38.4	23.9
Sm-50m-r1	Pre	Ship's Point	Mechanical	50	1	10.0	13.0	576.0	-30.7	21.5
Sm-50m-r2	Pre	Ship's Point	Mechanical	50	2	11.0		249.0	-37.1	21.3
Sm-50m-r3	Pre	Ship's Point	Mechanical	50	3	Missing		230.0	-17.9	21.8
Sm-75m-r1	Pre	Ship's Point	Mechanical	75	1	18.0	54.5	197.0	-66.9	21.5
Sm-75m-r2	Pre	Ship's Point	Mechanical	75	2	80.0		281.0	-61.2	20.8
Sm-75m-r3	Pre	Ship's Point	Mechanical	75	3	29.0		230.0	-76.9	21.3
Sd-1m-r1	Post	Ship's Point	Hand	1	1	250.0	260.0	123.0	-28.6	16.6
Sd-1m-r2	Post	Ship's Point	Hand	1	2	280.0		129.0	-94.4	16.5
Sd-1m-r3	Post	Ship's Point	Hand	1	3	250.0		144.0	-83.7	16.5
Sd-10m-r1	Post	Ship's Point	Hand	10	1	175.0	192.3	68.5	-73.7	16.6
Sd-10m-r2	Post	Ship's Point	Hand	10	2	162.0		73.3	-92.3	15.8
Sd-10m-r3	Post	Ship's Point	Hand	10	3	240.0		170.0	-103.2	16.2
Sd-25m-r1	Post	Ship's Point	Hand	25	1	180.0	189.3	121.0	-97.2	16.4
Sd-25m-r2	Post	Ship's Point	Hand	25	2	250.0		101.0	-141.5	16.4
Sd-25m-r3	Post	Ship's Point	Hand	25	3	138.0		120.0	-143.9	16.3
Sd-50m-r1	Post	Ship's Point	Hand	50	1	125.0	138.3	83.3	-81.9	16.4
Sd-50m-r2	Post	Ship's Point	Hand	50	2	150.0		152.0	-106.8	16.2
Sd-50m-r3	Post	Ship's Point	Hand	50	3	140.0		123.0	-111.5	16.0
Sd-75m-r1	Post	Ship's Point	Hand	75	1	48.0	35.7	41.3	-28.5	16.2
Sd-75m-r2	Post	Ship's Point	Hand	75	2	58.0		61.0	-24.6	16.3
Sd-75m-r3	Post	Ship's Point	Hand	75	3	1.0		61.0	-37.8	15.9
Sm-1m-r1	Post	Ship's Point	Mechanical	1	1	151.0	202.0	112.0	-113.3	18.4
Sm-1m-r2	Post	Ship's Point	Mechanical	1	2	210.0		138.0	-77.8	17.9
Sm-1m-r3	Post	Ship's Point	Mechanical	1	3	245.0		75.7	-76.9	17.6
Sm-10m-r1	Post	Ship's Point	Mechanical	10	1	194.0	206.3	156.0	-162.5	17.5
Sm-10m-r2	Post	Ship's Point	Mechanical	10	2	235.0		167.0	-95.5	18.0
Sm-10m-r3	Post	Ship's Point	Mechanical	10	3	190.0		96.4	-105.0	17.6
Sm-25m-r1	Post	Ship's Point	Mechanical	25	1	185.0	215.0	242.0	-142.3	17.1
Sm-25m-r2	Post	Ship's Point	Mechanical	25	2	220.0		162.0	-92.2	17.0
Sm-25m-r3	Post	Ship's Point	Mechanical	25	3	240.0		344.0	-174.8	17.1
Sm-50m-r1	Post	Ship's Point	Mechanical	50	1	152.0	135.7	113.0	-158.6	16.5
Sm-50m-r2	Post	Ship's Point	Mechanical	50	2	108.0		119.0	-114.1	16.8
Sm-50m-r3	Post	Ship's Point	Mechanical	50	3	147.0		202.0	-139.2	16.9
Sm-75m-r1	Post	Ship's Point	Mechanical	75	1	220.0	143.3	122.0	-95.4	17.0
Sm-75m-r2	Post	Ship's Point	Mechanical	75	2	100.0		237.0	-166.3	16.6
Sm-75m-r3	Post	Ship's Point	Mechanical	75	3	110.0		225.0	-127.5	16.5

Table 16. C1 Beach sedimentation and physical raw data

Tenure	Pre/Post	Sampling Location (m)	Replicate	Sediment Volume (ml)	Avg. Sediment Volume (ml)	Sediment Grain Size		
						%Mud	%Sand	%Gravel
Pentlach	Pre	1	1	7.5	5.5	3.4	88.1	8.5
			2	5.5				
			3	3.5				
	Pre	10	1	4.5	4.0	2.6	85.9	11.5
			2	2.0				
			3	5.5				
	Pre	25	1	5.0	8.7	2.8	71.9	25.3
			2	15.0				
			3	6.0				
	Pre	50	1	25.0	28.7	1.7	33.8	64.4
			2	33.0				
			3	28.0				
	Pre	75	1	14.0	7.5	1.9	44.4	53.7
			2	7.0				
			3	1.5				
	Post	1	1	20.0	18.0	20	65.1	14.9
			2	22.0				
			3	12.0				
	Post	10	1	24.0	15.7	11.7	60	28.2
			2	13.0				
			3	10.0				
	Post	25	1	11.0	10.0	4.6	45.3	50.2
			2	12.0				
			3	7.0				
	Post	50	1	15.0	10.7	6.6	67.7	25.7
			2	7.0				
			3	10.0				
	Post	75	1	14.0	12.0	5.1	46.4	48.5
			2	14.0				
			3	8.0				

Table 17. C2 Beach sedimentation and physical raw data

Tenure	Pre/Post	Sampling Location (m)	Replicate	Sediment Volume (ml)	Avg. Sediment Volume (ml)	Sediment Grain Size		
						%Mud	%Sand	%Gravel
Mac's	Pre	1	1	18.0	11.7	12.9	68.9	18.2
			2	6.0				
			3	11.0				
	Pre	10	1	1.0	0.8	15.8	72.3	11.9
			2	1.0				
			3	0.5				
	Pre	25	1	4.0	2.3	3.6	39.2	57.2
			2	1.5				
			3	1.5				
	Pre	50	1	0.5	3.5	6.2	57.5	36.4
			2	1.5				
			3	8.5				
	Pre	75	1	1.0	3.2	5.8	45	49.2
			2	4.5				
			3	4.0				
	Post	1	1	5.5	4.3	3.7	85.1	11.3
			2	3.0				
			3	4.5				
	Post	10	1	5.0	2.7	3.3	82.9	13.8
			2	2.0				
			3	1.0				
	Post	25	1	1.0	1.2	3.6	65.3	31.1
			2	2.0				
			3	0.5				
	Post	50	1	4.0	3.0	2.8	54.7	42.5
			2	3.5				
			3	1.5				
	Post	75	1	5.5	3.1	2.2	39.8	58.1
			2	0.3				
			3	3.5				

LAB	***Mud%***
Dup 1	11.7
Dup 2	10.3
% Diff.:	12.73

Appendix 2
Biological Data

Table 18. Taxonomic data of species composition and abundance

	Sieve Size						
Taxa	Phylum	Class	Order	Family	Genus	Species	Species NODC Code
	Annelida	Polychaeta					
	Annelida	Polychaeta				Indet.	
	Annelida	Polychaeta	Capitellida	Capitellidae			500160
	Annelida	Polychaeta	Capitellida	Capitellidae	Decamastus	gracilis	
	Annelida	Polychaeta	Capitellida	Capitellidae	Heteromastus	filiformis	
	Annelida	Polychaeta	Capitellida	Capitellidae	Mediomastus	spp.	50016004
	Annelida	Polychaeta	Capitellida	Capitellidae		Indet.	
	Annelida	Polychaeta	Phyllodocida	Glyceridae			500127
	Annelida	Polychaeta	Phyllodocida	Glyceridae	Glycera	americana	5001270104
	Annelida	Polychaeta	Phyllodocida	Goniadidae			500128
	Annelida	Polychaeta	Phyllodocida	Goniadidae	Glycinde	armigera	5001280103
	Annelida	Polychaeta	Phyllodocida	Nephtyidae			500125
	Annelida	Polychaeta	Phyllodocida	Nephtyidae	Nephtys	ferruginea	500120111
	Annelida	Polychaeta	Phyllodocida	Nereidae			500124
	Annelida	Polychaeta	Phyllodocida	Nereidae	Platynereis	bicanaliculata	
	Annelida	Polychaeta	Phyllodocida	Nereidae		Indet.	
	Annelida	Polychaeta	Opheliida	Opheliidae			500158
	Annelida	Polychaeta	Opheliida	Opheliidae	Armandia	brevis	
	Annelida	Polychaeta	Phyllodocida	Phyllodocidae			500113
	Annelida	Polychaeta	Phyllodocida	Phyllodocidae	Eteone	longa	5001130205
	Annelida	Polychaeta	Phyllodocida	Phyllodocidae	Eteone	sp.	
	Annelida	Polychaeta	Spionida	Spionidae			500143
	Annelida	Polychaeta	Spionida	Spionidae	Dipolydora	sp.	
	Annelida	Polychaeta	Spionida	Spionidae	Pseudopolydora	kempi	
	Annelida	Polychaeta	Spionida	Spionidae		Indet.	500143
	Annelida	Polychaeta	Phyllodocida	Syllidae			500123
	Annelida	Polychaeta	Phyllodocida	Syllidae	Exogone	spp	50012307
	Annelida	Polychaeta	Phyllodocida	Syllidae		Indet.	
	Annelida	Oligochaeta					
	Annelida	Oligochaeta				Indet.	
	Mollusca	Bivalvia					55
	Mollusca	Bivalvia				Indet.	55
	Mollusca	Bivalvia	Veneroida	Lasaeidae			
	Mollusca	Bivalvia	Veneroida	Lasaeidae	Rochefortia	tumida	
	Mollusca	Bivalvia	Pholadmyoida	Lyonsiidae			552005
	Mollusca	Bivalvia	Pholadmyoida	Lyonsiidae	Lyonsia	californica	5520050202
	Mollusca	Bivalvia	Mytiloida	Mytilidae			
	Mollusca	Bivalvia	Mytiloida	Mytilidae	Mytilus	sp.	
	Mollusca	Bivalvia	Veneroida	Tellinidae			551531
	Mollusca	Bivalvia	Veneroida	Tellinidae	Macoma	spp.	55153101
	Mollusca	Bivalvia	Veneroida	Veneridae			551547
	Mollusca	Bivalvia	Veneroida	Veneridae	Venerupis	philippinarum	
	Arthropoda	Malacostraca	Copepoda	Harpacticoida			
	Arthropoda	Malacostraca	Copepoda	Harpacticoida		Indet.	
	Arthropoda	Ostracoda					
	Arthropoda	Ostracoda				Indet.	
	Arthropoda	Malacostraca	Amphipoda	Ampithoidae			
	Arthropoda	Malacostraca	Amphipoda	Ampithoidae		Indet.	
	Arthropoda	Malacostraca	Amphipoda	Aoridae			
	Arthropoda	Malacostraca	Amphipoda	Aoridae	Grandidierella	japonica	
	Arthropoda	Malacostraca	Amphipoda	Aoridae		Indet.	
	Arthropoda	Malacostraca	Amphipoda	Corophiidae			
	Arthropoda	Malacostraca	Amphipoda	Corophiidae	Monocorophium	acherusicum	
	Arthropoda	Malacostraca	Amphipoda	Corophiidae	Monocorophium	sp.	
	Arthropoda	Malacostraca	Amphipoda	Gammaridae			
	Arthropoda	Malacostraca	Amphipoda	Gammaridae		Indet.	
	Arthropoda	Malacostraca	Amphipoda	Isaeidae			616926
	Arthropoda	Malacostraca	Amphipoda	Isaeidae	Protomedeia	sp.	
	Arthropoda	Malacostraca	Amphipoda	Ischyroceridae			
	Arthropoda	Malacostraca	Amphipoda	Ischyroceridae		Indet.	
	Arthropoda	Malacostraca	Cumacea	Nannastacidae			
	Arthropoda	Malacostraca	Cumacea	Nannastacidae	Cumella	vulgaris	
	Arthropoda	Malacostraca	Decapoda	Grapsidae			
	Arthropoda	Malacostraca	Decapoda	Grapsidae	Hemigrapsus	sp.	
	Nemertea						
	Nemertea					Indet.	
	Nemertea	Enopla	Hoplonemertea				4305
	Nemertea	Enopla	Hoplonemertea			Indet.	4305
	Nematoda						
	Nematoda					Indet.	
	Platyhelminthes	Turbellaria					
	Platyhelminthes	Turbellaria				Indet.	

RM Plot 1 PRE 250	RM Plot 1 PRE 250	RM Plot 1 PRE 425	RM Plot 1 PRE 425	RM Plot 1 PRE 500	RM Plot 1 PRE 500	RM Plot 1 PRE 850	RM Plot 1 PRE 850	RM Plot 1 PRE 1000	RM Plot 1 PRE 1000	RM 75m PRE 250	RM 75m PRE 250	RM 75m PRE 425	RM 75m PRE 425	RM 75m PRE 500
Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult
				3										
								7						
								1						4
								3						
								1						
								1						
					1				1					
	3				1						2		1	
														1
	3													
												4		
	1										2		1	
					1									
63				3						144		24		4
3				2						2		1		1
							3	3						
						4		11						18
	11		7		20						4		19	
				2										
							2							
	2		2		7			1					2	
									3					
26										108		21		9

RM 75m PRE 500	RM 75m PRE 850	RM 75m PRE 850	RM 75m PRE 1000	RM 75m PRE 1000	Sd Plot 1 PRE 250	Sd Plot 1 PRE 250	Sd Plot 1 PRE 425	Sd Plot 1 PRE 425	Sd Plot 1 PRE 500	Sd Plot 1 PRE 500	Sd Plot 1 PRE 850	Sd Plot 1 PRE 850	Sd Plot 1 PRE 1000	Sd Plot 1 PRE 1000
Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.	Adult & Subadult	Juv.
			3											
	1		2											
				9										
													1	
			1	1										
													1	
3		2	5	2										
1		2						1		1			1	
			1											
													3	
		2		1				4		3				
	1		3											
						1		3		2				
4		1	1											
1			1										2	
								1						
				1										
			1											
			1		358		12		5					
					57		96		92				1	
			14											
	1													
28	11		43	8							3		19	
						4		9		6				
									1					
14						1		4						
						2								
														1
			3		152		24		5					
1														

Appendix 3
Statistical Analysis

Table 19. Comox t-test for mechanical to hand harvest for individual stations

		Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
ComoxPre1	Equal variances assumed	6.544	.063	1.225	4	.288
	Equal variances not assumed			1.225	2.388	.328
ComoxPre10	Equal variances assumed	2.367	.199	-1.636	4	.177
	Equal variances not assumed			-1.636	2.472	.219
ComoxPre25	Equal variances assumed	3.777	.124	.096	4	.928
	Equal variances not assumed			.096	2.771	.930
ComoxPre50	Equal variances assumed	.006	.943	.851	4	.443
	Equal variances not assumed			.851	3.999	.443
ComoxPre75	Equal variances assumed	2.386	.197	-3.339	4	.029
	Equal variances not assumed			-3.339	2.163	.071
ComoxPost1	Equal variances assumed	3.386	.140	-1.337	4	.252
	Equal variances not assumed			-1.337	2.082	.308
ComoxPost10	Equal variances assumed	3.064	.155	.840	4	.448
	Equal variances not assumed			.840	2.401	.476
ComoxPost25	Equal variances assumed	5.524	.078	1.149	4	.315
	Equal variances not assumed			1.149	2.093	.365
ComoxPost50	Equal variances assumed	2.453	.192	-.393	4	.714
	Equal variances not assumed			-.393	3.116	.720
ComoxPost75	Equal variances assumed	2.983	.159	-1.543	4	.198
	Equal variances not assumed			-1.543	2.881	.224

Table 20. Royston t-test for mechanical to hand harvest for individual stations

		Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
RoystonPre1	Equal variances assumed	.079	.793	.406	4	.706
	Equal variances not assumed			.406	3.956	.706
RoystonPre10	Equal variances assumed	.440	.544	.447	4	.678
	Equal variances not assumed			.447	3.812	.679
RoystonPre25	Equal variances assumed	7.814	.049	1.123	4	.324
	Equal variances not assumed			1.123	2.160	.371
RoystonPre50	Equal variances assumed	165.336	.001	-3.461	3	.041
	Equal variances not assumed			-2.602	1.017	.230
RoystonPre75	Equal variances assumed	9.696	.036	-4.884	4	.008
	Equal variances not assumed			-4.884	2.121	.035
RoystonPost1	Equal variances assumed	.571	.492	-2.317	4	.081
	Equal variances not assumed			-2.317	3.273	.096
RoystonPost10	Equal variances assumed	1.977	.232	-3.226	4	.032
	Equal variances not assumed			-3.226	2.712	.056
RoystonPost25	Equal variances assumed	7.200	.075	-4.103	3	.026
	Equal variances not assumed			-3.425	1.299	.134
RoystonPost50	Equal variances assumed	.750	.435	-4.058	4	.015
	Equal variances not assumed			-4.058	3.608	.019
RoystonPosy75	Equal variances assumed	6.207	.067	-2.367	4	.077
	Equal variances not assumed			-2.367	2.190	.131

Table 21. Ships Point t-test for mechanical to hand harvest for individual stations

		Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
ShipsPointPre1	Equal variances assumed	2.798	.170	-3.064	4	.038
	Equal variances not assumed			-3.064	2.090	.087
ShipsPointPre10	Equal variances assumed	3.419	.138	-.317	4	.767
	Equal variances not assumed			-.317	2.756	.774
ShipsPointPre25	Equal variances assumed	247.254	.001	.032	3	.976
	Equal variances not assumed			.025	1.031	.984
ShipsPointPre50	Equal variances assumed	.	.	-.434	2	.706
	Equal variances not assumed			-.434	1.004	.739
ShipsPointPre75	Equal variances assumed	4.193	.110	1.207	4	.294
	Equal variances not assumed			1.207	2.567	.327
ShipsPointPost1	Equal variances assumed	2.303	.204	-1.987	4	.118
	Equal variances not assumed			-1.987	2.522	.158
ShipsPointPost10	Equal variances assumed	1.583	.277	.498	4	.644
	Equal variances not assumed			.498	3.262	.650
ShipsPointPost25	Equal variances assumed	1.359	.308	.705	4	.520
	Equal variances not assumed			.705	2.915	.533
ShipsPointPost50	Equal variances assumed	2.494	.189	-.170	4	.873
	Equal variances not assumed			-.170	3.016	.876
ShipsPointPost75	Equal variances assumed	3.675	.128	2.547	4	.063
	Equal variances not assumed			2.547	2.801	.090