Farm management practices and their associations to productivity in Prince Edward Island (PEI) mussel farms

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Abstract

The mussel industry of Prince Edward Island (PEI) has grown rapidly over the last 25 years by adapting the subsurface longline system. Presently there are limited coastal sites that can support new farming operations across PEI. It remains unclear whether variation in production is mainly related to environmental factors or longline setup. A multi-year (2002-2004) survey was conducted in Tracadie Bay; as well as across PEI in 2003 to (1) document longlines design variability and (2) quantify its potential association on productivity. In 2004, a controlled trial investigated the effect of sock spacings on productivity of mussel socks in Tracadie Bay. Results from the multi-year survey showed that longline setup varied temporally over the three years: sock spacing increased by 30% and was directly correlated to a 28% reduction in lease stocking density. This change coincided with the implementation of an adaptive bay management plan, which limited lease stocking density to 12 socks/100 m^2. Regression analyses from our multi-year survey showed that sock spacing was positively associated to sock weight (2002) and condition index (2004). Our models suggested that for every 10 cm increase in sock spacing, sock weight increased by 1.24 kg and condition index by 1.59 respectively. Across PEI, analyses showed a correlation between sock spacing and stocking density in association to the total farming area at the bay scale. The magnitude of the adjustment was important, with an increase in sock spacing of 2.6 cm and a decline of 5.6 socks/100 m^2 for each additional 100 hectares in farm coverage within a given bay. A third correlation indicated that the condition index was also negatively correlated within embayments characterized by extensive farm coverage compared to those with little farming development. Multiple regression analysis from this survey also revealed variability in sock weights across PEI leases, while longline setup was also highly variable. Results from our controlled trial showed that shell growth and survival were positively associated with higher sock spacing treatments (Tx 80) at two of the four sites. Shell growth increased by 8% and 7% respectively, while survival was 42% and 17% higher, when comparing higher sock spacing (Tx 80) to lower sock spacings (Tx 10) of cultured mussels. Sites where all management strategies (i.e. socking density and seed size) were kept constant displayed no association to sock spacing treatments. The significant differences between sock spacing treatments at two of the four sites may be due to high initial socking density and smaller seed size. These sites were characterized as having 58% and 47% more mussels per meter and initial shell lengths were on average 46% and 23% smaller in comparison to the sites that displayed no association. Our results have shown that simple management strategies such as increasing sock spacing at the lease level can have a substantial influence on productivity. These studies have also generated information for aquaculturists on the relative cost and benefits of longline design and their associations to productivity. Further development of the PEI mussel industry is dependent upon optimal usage of coastal inlets.

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List of Abbreviations

ACRDP	Aquaculture Collaborative Research and Development Program
ANOVA	Analysis of Variance
AVC	Atlantic Veterinary College
β	Beta Coefficient From Regression Models
°C	Degree Celsius
CI	Condition Index
CND	Canadian Dollars
CV	Coefficient of Variation
DFO	Department of Fisheries and Oceans
GEE	Generalized Estimating Equations
IWS	Island Wide Survey
max	Maximum Observed Value
min	Minimum Observed Value
MLH	Multilocus Heterozygosity
n	Sample Size
N	Nitrogen
P	P-value
P	Phosphorus
PEI	Prince Edward Island
SE	Standard Error
R^2	R-squared
SE	Standard Error
Si	Silica
SMN	Shellfish Monitoring Network
STD	Standard Deviation
Tx	Treatment
t	Tonnes

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Chapter 1 GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1. Introduction

The ability of the blue mussel (Mytilus edulis) to grow and reproduce under a wide range of environmental conditions can explain its distribution across the world. This filter-feeding bivalve is commercially exploited in Japan, China, Spain, Italy, Scotland, Canada, United States, Denmark, South Africa, Portugal and France. World-wide, most cultivated mussels are grown in the water column utilizing various production methods including: (1) rafts (Boyd and Heasman, 1998; Okumus and Stirling, 1998; Fuentes et al., 2000), (2) "bouchots" (i.e. poles) (Garen et al., 2004), (3) individuals socks (McDonald, 2002) as well as (4) continuous socks (Spencer, 2002). In some parts of the United States and in the Netherlands bottom culture is practiced (Mallet and Myrand, 1995). In North America, the blue mussel can be found from North Carolina to the Arctic Ocean. In Canada, mussel aquaculture became established in the 1970s and has since grown steadily in terms of production, as of 2004, Canadian mussel production was evaluated at 22,875 t annually (~ 3% of world-wide production). Nearly 80% (17,575 t) of the Canadian production originates from the eastern coast, specifically from the province of Prince-Edward Island (Figure 1-1). The industry provides employment for over 2,500 persons and contributes 106 million CND to the local economy (Department of Fisheries and Oceans Canada [DFO], Policy and Economics Branch).

Approximately 4,500 hectares of estuarine waters in PEI are leased out to individuals and companies for the specific purpose of cultivating mussels (DFO

Licensing, Charlottetown). This area is divided amongst 320 farms (leases) located in 28 embayments on the northern and the eastern sides of the Island. Within individual embayments, the total farming area ranges from 5 to 620 hectares. With the tremendous production increase over the past four decades, space for mussel culture now appears to be limited and would seem to signal the end of the mussel industry developmental phase. Slower growth rates and decreased yields at harvest across many bays and leases in PEI may seem to indicate problems of over-stocking (Scarratt, 2000). However, it remains unclear whether these productivity fluctuations are mainly related to environmental factors or longline setup (Landry 2003). Certainly, there is a scarcity of documented information relating to longline setup at the farm level in PEI, and the coupling between the PEI longline technique and mussel performance is still poorly understood in quantitative and predictive terms.

Through observational surveys and a controlled trial, this study documents temporal and spatial variability of mussel longline setup and quantifies their associations to productivity in Tracadie Bay (2002-2004) and across PEI (2003) as well we investigated the effects of sock spacing on productivity in Tracadie Bay (2004). Relevant information on PEI mussel farming practices (i.e. mussel biology, seed collection and socking, longline setup), factors impacting productivity, ecological interactions and longline setup are provided.

1.2. PEI mussel industry

1.2.1. Longline description and setup

The PEI mussel industry developed innovative husbandry practices by adapting the subsurface longline system of individually suspended polyethylene sleeves, commonly referred to as "socks", to handle the environmental conditions of Atlantic Canada (Figure 1-2). Elevating mussels from the seabed into the pelagic zone has lead to the (1) production of quality mussels, reduction in grit and pearl production and increased condition index , (2) year-round availability (i.e. winter harvest) for marketing purposes and (3) the co-existence with ice coverage over the winter months (McDonald et al., 2002). Mussels are grown using a longline system that is similar throughout the province. Cultivation sites (leases) within sheltered bays or estuaries are based on the availability of suitable conditions for successful cultivation such as a mean water depth of 5-10 m and protection from excessive waves. A mussel farm production unit is a longline of approximately 100-200 m with mussel socks hanging from it in suspension. The longlines are anchored at each end by 350 kg concrete blocks or screw-in anchors and are kept buoyant by a series of buoys. Longlines are typically buoyed a meter below the surface during the open water season, but before freeze-up, weights are added to keep longlines and buoys below the depth of the ice (30-100 cm).

1.2.2. Mussel biology and seed collection

Mussels are dioecious species. Spawning in eastern Canada usually occurs when water temperature rises through 10-12°C, generally from mid-May to late June (Mallet and Myrand, 1995). Following external fertilization, embryos quickly differentiate into free-swimming larvae. After two to four weeks in the water column at the mercy of tides and currents, motile larvae metamorphose into settlement stage larvae. Although there may be a secondary spawn (or continuous spawning) later in the year, this primary spawn is responsible for seed collection by the mussel industry.

Seed collectors are deployed in the water column after the major spawning event has been detected by a reduction in mussel condition index (CI) and the presence of larvae in the water column by the PEI Mussel Monitoring Program (Smith, 2005). With the help of their byssal thread, larvae are capable of adhering to various substrates (i.e. natural and artificial substrate). Seed mussels are harvested in the fall either from the natural beds or seed collectors deployed during early June. Seed collectors are made primarily from polypropylene rope (12-18 mm) that are attached to the backline 30-50 cm apart and weighted to keep them suspended vertically in the water column. Larvae settle on these collectors and grow rapidly, reaching sizes of 10-25 mm by fall.

1.2.3. Mussel socking

In early October and late November seed is manually stripped from the collectors, then declumped and graded by size to ensure uniform growth as mussels reach maturity. Seed mussels are loaded into mesh socks at a density of 300-800 per meter. Individual socks are about 40 mm in diameter and average 2-3 m in length depending on local water depths. After socking, seed mussels attach themselves to the socking material and other mussels with their byssal threads and then migrate outwards through the mesh to the outside of the sock. Depending on the location, mussels of marketable size (55-60 mm) can be grown in 12-24 months.

1.3. Mussel productivity and factors which can induce variability

Farm productivity around PEI has been shown to vary spatially as well as temporally (Landry, 2003). Productivity at the bay level can be measured through annual mussel production, while lease level production can be analyzed through shell length, CI or European steamed meat yield (industry standard). While the industry has grown rapidly over the past decades, there are presently very few coastal sites in PEI where the water is sufficiently deep to support new farming operations. This situation is evidenced by a moratorium on the granting of new leases, and also by the leveling of the Island-wide production in recent years (Smith, 2005). After many years of continual increase, annual mussel production on PEI has plateaued at approximately 17,000 t/year since 2002. This stable production over the past few years would seem to indicate the end of developmental phase and signal the start of a new management phase. In the short to medium term, it appears that any further development of the PEI mussel industry is dependent upon optimal usage of the coastal inlets. The factors presented below have been shown in the literature to impact productivity.

1.3.1. Genetic variability

Differential growth performance between stocks of mussel populations within a common site has been observed. This difference in shell growth was a reflection of different physiological ability and suggests a genetic influence (Mallet et al., 1987). Fitness in bivalves has been shown to be correlated with multilocus heterozygosity (MLH) (Koehn and Shumway, 1982; Tremblay et al., 2001; Myrand et al., 2002). Heterozygosity is the main form of genetic variability related to physiological performance in bivalves. Nevertheless, the genetic variation mechanism regulating physiological performance is poorly understood. In terms of a growth perspective, a more heterozygous stock may result in increased productivity through faster growth. This relationship is a reflection of greater efficiency in the conversion of consumed energy into soft tissue growth (Koehn and Shumway, 1982; Widdows et al., 1984).

Estimated survival in suspension cultured mussels has also been correlated with MLH and fitness (Tremblay et al., 2001). The correlation between MLH-fitness becomes apparent under stressful conditions (i.e. high water temperature or extended air exposure). Under such circumstances, important modifications of the metabolism are needed in order to maintain a constant internal environment (Myrand et al., 2002). Mussels with the highest MLH demonstrated a higher level of fitness, which increased the scope for growth due to lower maintenance metabolic rates (Tremblay et al., 2001; Leblanc, 2006). Any factor that reduces the overall genetic variability may compromise the capacity of a species to adapt to environmental change. Loss of variation within the population may result in a convergence towards one type and a narrower range of options.

Previous research conducted in the Magdalen Islands, Canada found that the degree of heterozygosity could be an indicator for the performance of a stock. The degree of heterozygosity tended to decrease after wild mussel spat was transferred to a suspension-cultured environment. It was hypothesized that after socking, the faster growing and more active heterozygote population passed through the mesh sleeve more rapidly and were thus prone to loss due to fall-off (Tremblay et al., 2001).

1.3.2. Food

Mussel growth is dependent on the supply of organic matter from the environment which gets consumed as water being filtered actively or passively. Bivalves are equipped with gills which are responsible for gas exchanges and are the main food collecting organ. Cilia presents on the gills can create a current of water which collects and transports particulate material for ingestion (Winter, 1978). The growth of filter feeders appears to be dependent on food availability more than any other environmental factors (Penney et al., 2001; Cartier et al., 2004). In a productivity context, assessing food availability which may limit growth is of utmost importance. The spatial and temporal variability in phytoplankton abundance is a major factor in determining the productivity of a growing area (Ogilvie et al., 2000). Bays and estuaries in higher latitudes show sharp seasonal peaks in primary production (spring bloom), especially following ice break-up (Grant, 1996). A second seasonal peak in primary production occurs in the fall when water temperature decreases and water turnover and nutrient availability increase.

Mussels are selective filter-feeders and are influenced by the quality and quantity of seston (Riisgard and Randlov, 1981). Seston is composed of phytoplankton and other sources of organic and inorganic matter. This organic/inorganic ratio can be used as a measure of food quality (Penney et al., 2001). Most bivalves can retain particles 3-7 μm in diameter with an efficiency of 100%, while retention efficiency declines below this size range, with 50% of particles 1 μm in diameter retained by mussels. Mussels can also remove bacteria (0.3-1.0 μm) with low efficiency (Gosling, 2003).

Food is therefore chosen on the basis of its high nutrient content which will maximize soft tissue growth (Leblanc et al., 2003). Suspension feeders have the capacity to filter the water column and reduce its seston content. Mussels may compensate for limited flow and low food availability by altering feeding behavior. Assuming food quality is high, filtration rates would increase, no pseudofeces would be produced, gut passage time would be increased and assimilation and absorption would improve (Heasman et al., 1998).

Primary production can be roughly estimated with two variables, chlorophyll *a* and light availability (Therriault and Levasseur, 1985). The availability of light in the mixed layer can be correlated with phytoplankton growth (Levasseur et al., 1984). No substantial phytoplankton growth occurs between the months of October and March (Therriault and Levasseur, 1985). However, phytoplankton growth over the winter months has been reported under the ice when the snow cover was absent (Waite 2004). Between June and September, the mean light conditions in the mixed layers are well above the limitation level. This translates into phytoplankton growth (Therriault and Levasseur, 1985). The depth of light penetration, turbidity and stratification are important factors in determining primary production of a growing area. Other important factors that contribute to phytoplankton biomass yield are set partly by the inorganic nutrient (Nitrogen [N], Phosphorus [P] or Silica [Si]) availability (Alpine and Cloern, 1992). These nutrients are easily assimilated by chlorophyll *a* and can therefore stimulate primary production within a growing area.

1.3.3. Temperature

Mussels are an intertidal species that have evolved, adapted and are thus capable of tolerating temperature fluctuations frequently experienced in our Canadian climate. This parameter has also been widely acknowledged as an important factor controlling growth rates and activity levels in bivalves (Incze et al., 1980; Grant, 1996). Bays and estuaries in Atlantic Canada are often exposed to temperatures ranging from sub-zero to 25°C (Mallet and Myrand, 1995). Filtration rates in bivalves have been shown to be positively correlated with increasing temperatures up to an optimum (18-20°C). Further increases in temperature above this optimum lead to a decrease in the filtration rate (Winter, 1978). Bivalve growth and mortality have been directly associated with environmental temperatures. Reduced growth rates in mussels have been observed at low temperatures (0°C) regardless of food availability and high temperatures (above 20°C) because of such physiological factors as decreased filtration rates and increased metabolic costs (Mallet and Myrand, 1995). Optimal growth is generally observed at 10-20°C, while temperatures around 27-29°C have lethal consequences (Incze et al., 1980). Incze et al. (1980) reported a 35-90% mortality of mussels held in suspended raft culture in Damariscotta River, Maine, while 80% mortality was reported in the Magdalen Island, Quebec (Tremblay et al., 1998). In both these studies, high water temperature (>20 °C) contributed significantly to the physiological stress and mortality of the mussels when associated with other "sub-optimal" environmental conditions.

1.3.4. Currents

Spatial distribution of food supply depends on water circulation, local sources and sinks (Dowd, 2003). Semidiurnal tides, current velocity and wind are all important factors in the water flux process which play a pivotal role in particle renewal and food availability within a bay or estuary (Newell, 1990; Grant and Bacher, 2001; Pilditch et al., 2001). Tides offer a regular and consistent pattern of particle exchange and renewal within a growing area can be used as a useful measurement of food supply (Raillard and Menesguen, 1994). Spatial growth rate variation is provided by differences in the magnitude in tidal currents which renews particles (Wilson, 1987). Diminished tidal effects towards the inner part of the embayment in association to increase food utilization can often result in decreased growth rates and a spatial growth gradient throughout the bay (Waite et al., 2005). Current velocity and wind effects can be highly variable over several days, but can increase food availability through the re-suspension of organic/inorganic material (Bacher et al., 2003). In areas of greater current speed, food renewal is able to alleviate reduction in food concentration (Bacher et al., 2003). The rate of phytoplankton delivery is controlled by horizontal advection and vertical mixing. Therefore, enhanced horizontal diffuse transport through higher current speed results in an increased rate of replenishment of phytoplankton in food impoverished areas (Frechette et al., 1989). Water residence time is a mathematical method of calculating the time needed for a volume of water within an embayment to be replaced with water from an outside system (Dame and Prins, 1998). A growing area with a short residence time (i.e. rapid food renewal) should have increased food availability and growth.

1.4. Ecological interactions

Questions of sustainability have inevitably been raised since the development and expansion of the mussel industry in most embayments around PEI. A growing area's productivity can often be assessed and explained by its carrying capacity. The interaction between a growing area's environmental factors (i.e. bivalve feeding behavior, phytoplankton dynamics, current regime and cultured biomass) contributes to the determination of its carrying capacity. Each embayment is characterized by its own set of biological, physical, and chemical parameters. These dynamic and unique values can vary from one bay to the next as well as from year to year. Carrying capacity can be defined in terms of exploitation which is the standing stock at which the annual production of a marketable cohort is maximized (Smaal et al., 1998) or ecologically:

stock density at which production levels are maximized without negatively affecting growth rates (Carver and Mallet, 1990). Carrying capacity models can also be defined as the balance between particle renewal and depletion (Grant and Bacher, 2001) or water mass residence time, primary production time and bivalve clearance time (Dame and Prins, 1998). This situation can become problematic when a growing area carrying capacity is assessed using computer modeling. The precision of the parameters used to measure and estimate (i.e. food quantity/quality, biomass density, flushing time, water currents, and filtration rates) a growing area carrying capacity can lead to its overestimation.

One of the reasons PEI can support a thriving mussel industry may be related to its close relationship with land-use practices. Agricultural activities on PEI largely influence nutrient levels transported into estuaries (Meeuwig, 1999; Chapelle, 2000). During the 1990s, PEI increased the area allocated to potato farming, which may be a potential source of nutrients transported to coastal waters (Meeuwig, 1999; Landry, 2002). Phosphorus and nitrogen are recognized as key nutrients in coastal systems. Both nutrients are found in the heavily applied synthetic fertilizers used on PEI and are easily assimilated by phytoplankton biomass. These nutrients can therefore stimulate primary production, increase phytoplankton standing stocks, increase an embayment carrying capacity, and possibly eliminate or curtail the correlations between longline setup and mussel productivity.

In each growing area, the environmental parameters will be influenced by the cultured population; however, the cultured population will also be influenced by the growing area environmental parameters. It is suspected that overstocking a growing area (i.e. decreased longline and sock spacing) will alter food webs and its availability through increased intra-specific competition between mussels. This impact should be correlated with slower growth rates and decreased yield, impacting the overall time to harvest for the production of marketable size mussels which may threaten the economic viability of mariculture ventures (Dowd, 2003; Nunes et al., 2003). Therefore, in order to optimize the production potential of a growing area we need to have knowledge of the interactions between longline setup of the culture population and its association with the environmental parameters.

1.5. Longline setup

To this date, longline setup on PEI, which includes stocking density, longline spacing, sock spacing and sock length have never been quantified, but is believed to be highly variable. It remains unclear whether variable annual production levels across PEI are related to environmental parameters or longline setup (Landry, 2003). Management strategies which may increase productivity can either be implemented at the bay level or at the lease level. Management strategies such as the variation in longline spacing, sock spacing, sock length and seeding density can easily be applied and controlled by aquaculturists.

1.5.1. Stocking density

An important consideration in bivalve aquaculture is how many individuals can be grown within a lease or growing area before negatively impacting growth. Optimal stocking density can be defined as the population density which would lead to maximum net production of a bivalve group (Frechette and Bacher, 1998). Often, like carrying capacity, this value appears to be species and site specific (Parsons and

Dadswell, 1992). However, high stocking density has been shown by many authors to play a detrimental role on productivity of mussels (Newell, 1990; Frechette et al., 1996; Dowd, 1997; Heasman et al., 1998; Penney et al., 2001), oysters (Taylor et al., 1997; Honkoop and Bayne, 2002; Mallet et al., 2003), scallops (Parsons and Dadswell, 1992; Roman et al., 1999; Frechette et al., 2000) and quahogs (Crenshaw et al., 1996). High stocking density may lead to intra-specific competition between individuals as growth proceeds (Frechette et al., 2000). As more biomass is added to a growing area, food demands can often exceed food supply; which may limit growth. Therefore, the cultured population may begin to experience signs of self-thinning or density dependent growth (Dowd, 2003).

1.5.2. Seeding density and seed size

Recent studies conducted on seeding density and seed size and their association to productivity in PEI has shown the importance of simple management strategies applied at the lease level (Lauzon-Guay et al., 2005). The seeding density and size of seed mussels placed in socks for suspended culture have been shown as important factors affecting productivity. In field trials conducted in PEI, survival results after 10 months indicated an interaction between initial density and seed size. Survival of smaller seed was lower and dependent on density levels (Lauzon-Guay et al., 2005). Likely factors contributing to the differential survival may be associated with initial fall-off, predation or greater packing of seed at higher densities. Higher seed density possibly increased packing pressure inside the sock. Mussels packed as such densities have been shown to have reduce filtration rates, which is directly linked to the difficulty of valve opening (Riisgard, 1991). This could explain the density-dependent loss. However, mussel growth was independent of density levels and mussel sizes, smaller mussel seed reached commercial size in the same time period as larger seed (Lauzon-Guay et al., 2005).

1.5.3. Longline spacing and sock spacing

As for longline and sock spacing, few studies have assessed the impact of these two variables and their associations on mussel productivity across PEI. In South Africa, Heasman et al. (1998) investigated the relationship between food removal by mussels, growth condition and production of cultured mussels at two rope spacings (60 cm vs 90 cm) in raft culture. Results showed that lower sock spacing was responsible for local food supply limitation and this relationship was a function of increased feeding and greater retardation of current and water exchange. This correlation suggests that the close spacing of mussels on a longline can significantly reduce the concentration of food particles in the water column. Sock spacing and sock maturity also determine the amount of "free water" between ropes within a growing area. In culture areas of high mussel stocking density, mussel socks tend to be spaced closer to each other, thus hindering flow and particle renewal, and thus depleting local primary production (Boyd and Heasman, 1998). Suspended structures (i.e. mussel socks) in the water column have impacts on particle renewal by retarding ambient flow via enhanced drag (Boyd and Heasman, 1998; Heasman et al., 1998; Kaiser et al., 1998; Grant and Bacher, 2001 and Newell, 2001). Grant and Bacher (2001) reported current speed reduction in the midst of a culture area which minimized water exchange and particle renewal. Culture structure caused a 40% decrease in particle exchange rate compared to a control area and a 54% reduction in current speed in the midst of an aquaculture area.

1.5.4. Sock length

Published research concerning the effects of sock length on mussel performance is scarce. A study conducted by Fuentes et al. (2000) reported such an association and results showed that longer socks which had a greater proportion out of the upper boundary layer (i.e. photic zone) are less productive per meter. However, this study was conducted with mussel socks of nine meters in length. The average sock length used for mussel culture around PEI varies from farm to farm, but is limited by the depth of the water at low tide (Scarratt, 2000). However, judging by the water depths (5-10 m) within the bays around PEI, we should not expect sock length to impact productivity.

1.6. Objectives

Gaining an understanding of the relationship between productivity and current longline setup is of utmost importance to optimize lease productivity. With growing evidence that bivalve farms regulate phytoplankton production (Frechette and Bourget, 1985a, 1985b; Newell, 1990; Asmus and Asmus, 1991; Alpine and Cloern, 1992; Pilditch et al., 2001) in association to the lack of information about the spatial and temporal growth variability of cultured bivalves in relation to longline setup; this has prompted us to investigate the possible links between PEI longline setup and farm production.

The objectives of this two part study were first to document longline setup and quantify its potential association with mussel productivity on leases across PEI by means of an observational study. The second objective of this study was to investigate the effect of sock spacing on mussel productivity on four grow-out leases in Tracadie Bay, PEI by means of a controlled trial. Greater knowledge of the factors which regulates lease productivity needs to be assessed in order to improve mussel culture across PEI.

1.7. References

Alpine, A.E., Cloern, J.E., 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. Limnol Oceanogr 37, 946-955.

Asmus, R.M., Asmus, H., 1991. Mussel beds-limiting or promoting phytoplankton. J Exp Mar Biol Ecol 148, 215-232.

Bacher, C., Grant, J., Hawkins, A.J.S., Fang, J.G., Zhu, M.Y., Besnard, M., 2003. Modelling the effect of food depletion on scallop growth in Sungo Bay (China). Aquat Living Resour 16, 10-24.

Boyd, A.J., Heasman, K.G., 1998. Shellfish mariculture in the Benguela system: Water flow patterns within a mussel farm in Saldanha Bay, South Africa. J Shellfish Res 17, 25-32.

Cartier, S., Pellerin, J., Fournier, M., Tamigneaux, E., Girault, L., Lemaire, N., 2004. Use of an index based on the blue mussel (Mytilus edulis and Mytilus trossulus) digestive gland weight to assess the nutritional quality of mussel farm sites. Aquaculture 241, 633-654.

Carver, C.E.A., Mallet, A.L., 1990. Estimating the carrying-capacity of a coastal inlet for mussel culture. Aquaculture 88, 39-53.

Chapelle, A., 2000. Modeling nitrogen, primary production and oxygen in a Mediterranean lagoon. Impact of oysters farming and inputs from the watershed. Ecol Model 127, 161-181.

Crenshaw, J.W., Heffernan, P.B., Walker, R.L., 1996. Effect of growout density on heritability of growth rate in the northern quahog, Mercenaria mercenaria (Linnaeus, 1758). J Shellfish Res 15, 341-344.

Dame, R., Prins, T.C., 1998. Bivalve carrying capacity in coastal ecosystems. Aquat Ecol 31, 409-421.

Dowd, M., 1997. On predicting the growth of cultured bivalves. Ecol Model 104, 113-131.

Dowd, M., 2003. Oceanography and shellfish production: A bio-physical synthesis using a simple model. Bull Aquacult Assoc Can 100(2), 3-9.

Frechette, M., Bacher, C., 1998. A modelling study of optimal stocking density of mussel populations kept in experimental tanks. J Exp Mar Biol Ecol 219, 241-255.

Frechette, M., Bergeron, P., Gagnon,P., 1996. On the use of self-thinning relationships in stocking experiments. Aquaculture 145, 91-112.

Frechette, M., Bourget, E., 1985a. Energy flow between the pelagic and benthic zones: factors controlling particulate organic matter available to an intertidal mussel bed. Can J Fish Aquat Sci 42, 1158-1165.

Frechette, M., Bourget, E., 1985b. Food-limited growth of Mytilus edulis-L in relation to the benthic boundary-layer. Can J Fish Aquat Sci 42, 1166-1170.

Frechette, M., Butman, C.A., Geyer, W.R., 1989. The importance of boundary-layer flows in supplying phytoplankton to the benthic suspension feeder, Mytilus edulis-L. Limnol Oceanogr 34, 19-36.

Frechette, M., Gaudet, M., Vigneau, S., 2000. Estimating optimal population density for intermediate culture of scallops in spat collector bags. Aquaculture 183, 105-124.

Fuentes, J., Gregorio, V., Giraldez, R., Molares, J., 2000. Within-raft variability of the growth rate of mussels, Mytilus galloprovincialis, cultivated in the Ria de Arousa (NW Spain). Aquaculture 189, 39-52.

Garen, P., Robert, S., Bougrier, S., 2004. Comparison of growth of mussel, Mytilus edulis, on longline, pole and bottom culture sites in the Pertuis Breton, France. Aquaculture 232, 511-524.

Gosling, E., 2003. Bivalve Molluscs: Biology, Ecology and Culture. Fishing New Books, Oxford, UK, 443 pp.

Grant, J., 1996. The relationship of bioenergetics and the environment to the field growth of cultured bivalves. J Exp Mar Biol Ecol 200, 239-256.

Grant, J., Bacher, C., 2001. A numerical model of flow modification induced by suspended aquaculture in a Chinese bay. Can J Fish Aquat Sci 58, 1003-1011.

Heasman, K.G., Pitcher, G.C., McQuaid, C.D., Hecht, T., 1998. Shellfish mariculture in the Benguela system: Raft culture of Mytilus galloprovincialis and the effect of rope spacing on food extraction, growth rate, production, and condition of mussels. J Shellfish Res 17, 33-39.

Honkoop, P.J.C., Bayne, B.L., 2002. Stocking density and growth of the Pacific oyster (Crassostrea gigas) and the Sydney rock oyster (Saccostrea glomerata) in Port Stephens, Australia. Aquaculture 213, 171-186.

Incze, L.S., Lutz, R.A., Watling, L., 1980. Relationships between effects of environmental-temperature and seston on growth and mortality of Mytilus edulis in a temperate northern estuary. Mar Biol 57, 147-156.

Kaiser, M.J., Laing, I., Utting, S.D., Burnell, G.M., 1998. Environmental impacts of bivalve mariculture. J Shellfish Res 17, 59-66.

Koehn, R.K., Shumway, S.E., 1982. A genetic physiological explanation for differential growth-rate among individuals of the American oyster, Crassostrea virginica (Gmelin). Mar Biol Lett 3, 35-42.

Landry, T., 2002. The potential role of bivalve shellfish in mitigating negative impacts of land use on estuaries. Can Tech Rep Fish Aquat Sci 2408 155-157.

Landry, T., 2003. Development and evaluation of standardized monitoring and data acquisition systems for the management of mollusc culture in Atlantic Canada. Bull Aquacult Assoc Can 102(3), 102.

Lauzon-Guay, J.S., Dionne, M., Barbeau, M.A., Hamilton, D.J., 2005. Effects of seed size and density on growth, tissue-to-shell ratio and survival of cultivated mussels (Mytilus edulis) in Prince Edward Island, Canada. Aquaculture 250, 652-665.

Leblanc, A.R., Landry, T., Miron, G., 2003. Fouling organisms of the blue mussel Mytilus edulis: Their effect on nutrient uptake and release. J Shellfish Res 22, 633-638.

Leblanc, N.G. Mussel Genetics in relation to selection methods for high quality seed and treatment for tunicates. PhD. diss. Univ. of Prince Edward Island, Charlottetwon, PE, Canada, 2006.

Levasseur, M., Therriault, J.C., Legendre, L., 1984. Hierarchical control of phytoplankton succession by physical factors. Mar Ecol-Prog Ser 19, 211-222.

Mallet, A.L., Carver, C.E.A., Coffen, S.S., Freeman, K.R., 1987. Winter growth of the blue mussel Mytilus edulis L.: Importance of stock and site. J Exp Mar Biol Ecol 108, 217-228.

Mallet, A.L., Myrand, B., 1995. The culture of the blue mussel in Atlantic Canada. Cold-Water Aquaculture in Atlantic Canada. The Canadian Institute for Research on Regional Development, Moncton, pp. 255-296.

Mallet, M., Boghen, A.D., Landry, T., 2003. Effects of environmental conditions and stocking density on the eastern oyster, Crassostrea virginica (Gmelin), reared in floating bags. Bull Aquacult Assoc Can 6, 46-48.

McDonald, C., Gallant, R., Couturier, C., 2002. Canadian mussel aquaculture: an industry with room to grow. Proceedings of the First International Mussel Forum Aquaculture Canada super (OM) 2002 102, 87-92.

Meeuwig, J.J., 1999. Predicting coastal eutrophication from land-use: an empirical approach to small non-stratified estuaries. Mar Ecol-Prog Ser 176, 231-241.

Myrand, B., Tremblay, R., Sevigny, J.-M., 2002. Selection against blue mussel (Mytilus edulis L.) homozygotes under various stressful conditions. J Hered 93, 238-248.

Newell, C.R., 1990. The effect of mussel (Mytilus edulis, Linnaeus, 1758) position in seeded bottom patches on growth at subtidal lease sites in Maine. J Shellfish Res 9, 113-118.

Newell, C.R., 2001. Sustainable mussel culture: A millennial perspective. Bull Aquacult Assoc Can 101(2), 15-21.

Nunes, J.P., Ferreira, J.G., Gazeau, F., Lencart-Silva, J., Zhang, X.L., Zhu, M.Y., Fang, J.G., 2003. A model for sustainable management of shellfish polyculture in coastal bays. Aquaculture 219, 257-277.

Ogilvie, S.C., Ross, A.H., Schiel, D.R., 2000. Phytoplankton biomass associated with mussel farms in Beatrix Bay, New Zealand. Aquaculture 181, 71-80.

Okumus, I., Stirling, H.P., 1998. Seasonal variations in the meat weight, condition index and biochemical composition of mussels (Mytilus edulis L.) in suspended culture in two Scottish sea lochs. Aquaculture 159, 249-261.

Parsons, J.G., Dadswell, M.J., 1992. Effect of stocking density on growth, production, and survival of the giant scallop, Placopecten magellanicus, held in intermediate suspension culture in Passmaquoddy Bay, New Brunswick. Aquaculture 103, 291-309.

Penney, R.W., McKenzie, C.H., Mills, T.J., 2001. Assessment of the particulate food supply available for mussel (Mytilus spp.) farming in a semi-enclosed, northern inlet. Estuar Coast Shelf S 53, 107-121.

Pilditch, C.A., Grant, J., Bryan, K.R., 2001. Seston supply to sea scallops (Placopecten magellanicus) in suspended culture. Can J Fish Aquat Sci 58, 241-253.

Raillard, O., Menesguen, A., 1994. An ecosystem box model for estimating the carrying-capacity of a macrotidal shellfish system. Mar Ecol-Prog Ser 115, 117-130.

Riisgard, H.U., 1991. Filtration rate and growth in the blue mussel, Mytilus edulis Linnaeus, 1758: Dependence on algal concentration. J Shellfish Res 10, 29-35.

Riisgard, H.U., Randlov, A., 1981. Energy budgets, growth and filtration-rates in Mytilus edulis at different algal concentrations. Mar Biol 61, 227-234.

Roman, G., Campos, M.J., Acosta, C.P., Cano, J., 1999. Growth of the queen scallop (Aequipecten opercularis) in suspended culture: influence of density and depth. Aquaculture 178, 43-62.

Scarratt, D.J., 2000. Development of the mussel industry in eastern Canada. Bull Aquacult Assoc Can 100(2), 37-40.

Smaal, A., Prins, T.C., Dankers, N., Ball, B., 1998. Minimum requirements for modelling bivalve carrying capacity. Aquat Ecol 31, 423-428.

Smith, G., 2005. PEI Mussel Monitoring Program 2004 Report. P. E. I. Tech. Report. 235: 94pp.

Spencer, B.E., 2002. Mussel cultivation. Molluscan Shellfish Farming, Blackwell Publishing, LTD, Oxford, pp. 147-165.

Taylor, J.J., Rose, R.A., Southgate, P.C., 1997. Effects of stocking density on the growth and survival of juvenile silver-lip pearl oysters (Pinctada maxima, Jameson) in suspended and bottom culture. J Shellfish Res 16, 569-572.

Therriault, J.-C., Levasseur, M., 1985. Control of phytoplankton production in the lower St. Lawrence estuary: Light and freshwater runoff. Nat Can 112, 77-96.

Tremblay, R., Myrand, B., Sevigny, J.M., Blier, P., Guderley, H., 1998. Bioenergetic and genetic parameters in relation to susceptibility of blue mussels, Mytilus edulis (L.) to summer mortality. J Exp Mar Biol Ecol 221, 27-58.

Tremblay, R., Myrand, B., Sevigny, J.-M., 2001. Impacts of aquaculture practices on genetic variability of blue mussel (Mytilus edulis). Bull Aquacult Assoc Can 101, 11-14.

Waite, L. Growth of cultured mussel and food availability. MSc. diss. Univ. of Prince Edward Island, Charlottetwon, PE, Canada, 2004.

Waite, L.E., Grant, J., Davidson, J., 2005. Bay-scale spatial growth variation of mussels (Mytilus edulis) in suspended culture, Prince Edward Island, Canada. Mar Ecol-Prog Ser 297, 157-167.

Widdows, J., Donkin, P., Salkeld, P.N., Cleary, J.J., Lowe, D.M., Evans, S.V., Thomson, P.E., 1984. Relative importance of environmental-factors in determining physiological differences between 2 populations of mussels (Mytilus edulis). Mar Ecol-Prog Ser 17, 33-47.

Wilson, J.H., 1987. Environmental parameters controlling growth of Ostrea edulis l and Pecten maximus l in suspended culture. Aquaculture 64, 119-131.

Winter, J.E., 1978. A review on the knowledge of suspension-feeding in Lamellibranchiate bivalves, with special reference to artificial aquaculture systems. Aquaculture 13, 1-33.

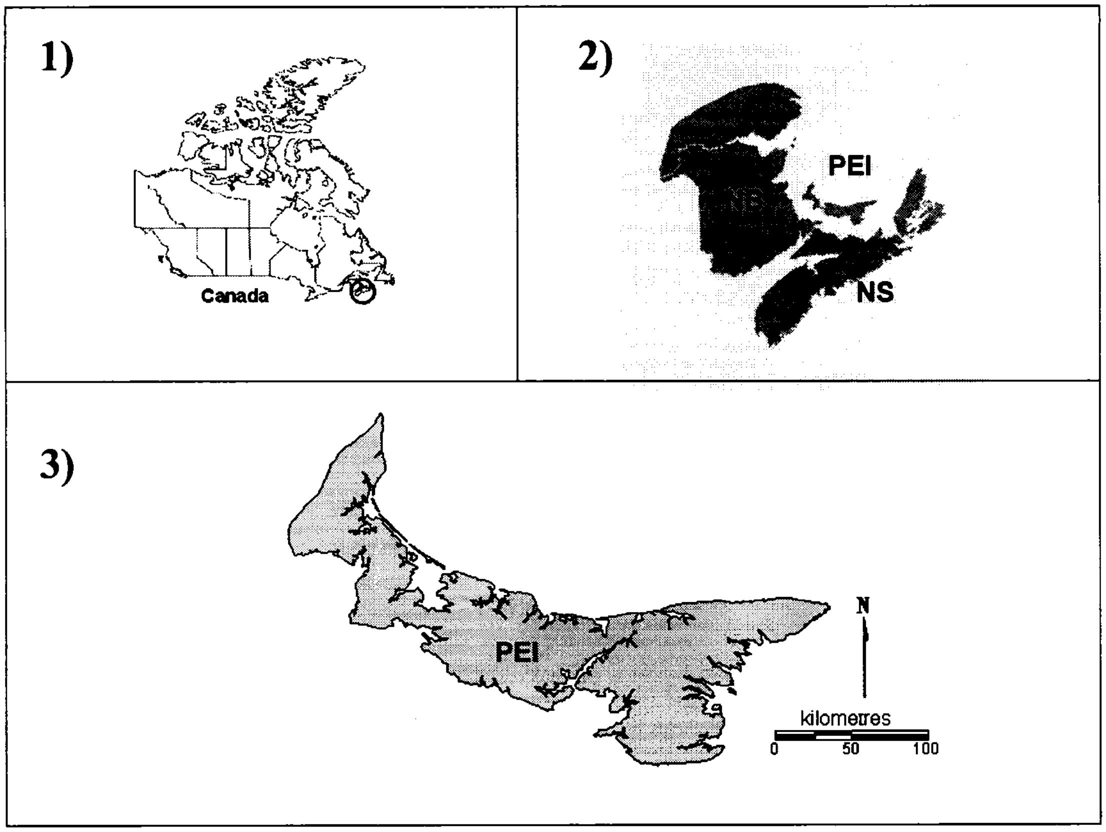

Figure 1-1 Map of Canada (1), with inserts of map of Atlantic Canada (2) and Prince Edward Island (3).

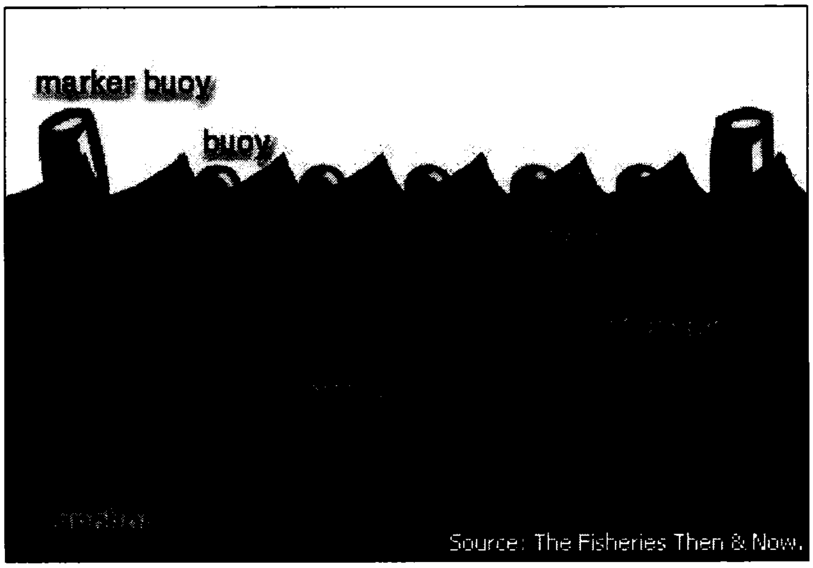

Figure 1-2 Schematic representation of a typical longline used for mussel culture across Prince Edward Island.

Chapter 2 ASSOCIATION BETWEEN LONGLINE DESIGN AND MUSSEL PRODUCTIVITY IN PRINCE EDWARD ISLAND, CANADA

2.1. Abstract

The first objective of this study was to document the setup of subsurface longlines used for the farming of blue mussels (Mytilus edulis) in Prince Edward Island (PEI), Canada; the second objective was to identify possible associations between longline setup and mussel growth. In 2003, SCUBA divers visited 54 farms distributed in 16 culture embayments; they measured the spacing between longlines and the spacing between individual socks (sleeves) attached to longlines; they also sampled 1-yr old mussels for the determination of the shell length, condition index, and sock weight. Here we report a remarkable degree of variation in longline configuration, with the following range of values: 1.2 to 3.0 m for sock length, 1.5 to 29.5 m for longline spacing, 26.4 to 62.4 cm for sock spacing, and 6.2 to 179.9 socks/100 m^2 for stocking density at the farm level. A negative correlation was found between the stocking density at the farm level and the total farming area at the bay scale, suggesting that growers adjusted husbandry in relation to the surrounding level of farming activity. In one major culture bay, Tracadie Bay, measurements were repeated over a three-year period (2002-2004). This monitoring led to the discovery of a coordinated effort by growers in raising the average sock spacing by 30% (+11 cm). Multiple regression analyses identified sock spacing as the only explanatory variable correlated with mussel weight in Tracadie Bay. The model suggests that an 11-cm increase in sock spacing can lead to an 18% weight gain for pre-market mussels (~ 34 mm), the size group investigated in the study. However, this correlation between sock spacing and

sock weight was tenuous over the three year study period, showing up only in 2002. A similar correlation was found between sock spacing and the condition index, although only in 2004. We conclude by suggesting that close spacing of mussel socks can negatively affect mussel yield, but only becomes apparent at times when particulate food resources are scarce.

2.2. Keywords

Mytilus edulis; mussel; husbandry; sock; longline; stocking density

2.3. Introduction

Blue mussel (Mytilus edulis) culture is a relatively new industry in Canada. It became established in the 1970s and has since grown steadily in terms of production, as of 2004, Canadian mussel production was evaluated at 22,875 t annually (~ 3% of world-wide production). Nearly 80% of the Canadian production originates from the Atlantic coast, specifically from the province of Prince-Edward Island (PEI, Figure 2-1). The industry employs over 2,500 persons and contributes nearly 70 million CND to the local economy (Department of Fisheries and Oceans Canada [DFO], Policy and Economics Branch).

Approximately 4,500 hectares of estuarine waters in PEI are leased out to individuals and companies for the specific purpose of cultivating mussels (DFO Licensing, Charlottetown). This area is divided amongst 320 farms (leases) located in 28 embayments on the northern and the eastern sides of the Island. Within individual embayments, the total farming area ranges from 5 to 620 hectares. Mussels are grown in suspension using a subsurface longline system of individual suspended polyethylene sleeves, commonly referred to as “socks” (Figure 2-1). Longlines measure between approximately 100 and 200 m in length. In late autumn, longline buoyancy is reduced in order to lower the culture gear at a safe depth below the winter ice cover. Winter harvesting is regularly practiced by cutting holes through the thick (1 m) ice using mechanical saws. Divers locate the longlines, which are then winched up onto the ice cover (Scarratt, 2000). This specialized approach ensures a year-round production of mussels.

While the industry has grown rapidly over the past decades, there are presently very few coastal sites in PEI where the water is sufficiently deep to support new farming operations. This situation is evidenced by a moratorium on the granting of new leases, and also by the Island-wide production leveling in recent years (Smith, 2005). The possibility of expanding the industry into the open waters of the Gulf of St. Lawrence is being discussed, but the level of interest so far has been quite low considering the elevated setup and operation costs associated with offshore farming. In the short to medium term, it appears that any further development of the PEI mussel industry is dependent upon an optimal usage of the coastal inlets.

In this context, the issue of shellfish overstocking and food particle depletion represents a growing concern. It is well documented that dense bivalve beds can remove food particles from the water column faster than primary production and advection currents can replace them, consequently limiting growth of down current individuals (e.g. Wildish and Kristmanson, 1979; Fréchette and Bourget, 1985 a, b; Fréchette et al., 1989; Newell, 1990; Dolmer, 2000; Petersen, 2004; Jonsson et al., 2005). When such grazing potential is considered in the context of shellfish farming, it is useful to distinguish between the different spatial scales at which particle depletion may occur. “Bay-scale” particle depletion implies a growth reduction of all molluscs in the system attributed to a widespread overstocking of suspension feeders. It can be investigated using computer models that incorporate the total number of molluscs introduced in the system, their capacity to clear the entire bay volume of food particles, and the rate of particle renewal by primary production and tidal flushing. It is noteworthy that, in recent years, PEI has been a focal point with respect to bay-scale modeling research (Meeuwig et al., 1998; Dowd, 2003, 2005; Cranford et al., 2003; Grant et al., 2005). By contrast, “local-scale” particle depletion relates to within-farm phytoplankton reductions due to gear configurations and localized (directly under the culture structure) overstocking. To our knowledge, published research concerning the effects of gear setup on mussel performance has focused mainly on the raft culture technique (Heasman et al., 1998; Fuentes et al., 2000). Certainly, there is a scarcity of documented information relating to longline setup at the farm level in PEI, and the coupling between the PEI longline technique and mussel performance is still poorly understood in quantitative and predictive terms.

The principal objective of this study was to document the setup of the PEI longline system, and to investigate to which extent the setup varies from one farm to the next. The secondary objective was to determine whether or not some of the setup configurations are associated with improved mussel performance. Our approach was based on an extensive field sampling effort carried out between 2002 and 2004, followed by a series of correlative analyses.

2.4. Materials and Methods

2.4.1. Study area

Tracadie Bay (62° 59.5' N, 46° 23.6' W) is a semi-enclosed embayment (total area 1,900 hectares, farming area 605 hectares) situated on the north shore of PEI. It was selected for the study because some of its growers expressed a concern regarding particle depletion. In August 2002, all active farms (21) in Tracadie Bay were surveyed, whereas 15 and 11 farms were visited in August of 2003 and 2004, respectively, due to time and resource constraints. In 2002, divers collected data at three random sites within each farm (results expressed as averages), whereas in 2003 and 2004 data was collected at one random location per farm. All measurements relate to one-year-old crop, since most of the commercial-size (two-year-old) mussels were already harvested by the time the surveys began. The one-year-old crop represents half-grown mussels that were socked during the previous autumn of each survey year; consequently, they were exposed to approximately eight months of lease husbandry conditions prior to sampling.

In 2003, 16 mussel-producing bays (see Figure 2-1) across PEI were purposively selected based on a farming activity criterion, the total farming area within the bay. The intent was to cover a broad spectrum of bays. Within each of these bays, individual farms were selected through a random stratified sampling process. More specifically, each bay was divided into three sections: 1) outer part of the bay (i.e. area closest to Gulf of St. Lawrence), 2) middle part of the bay and 3) inner part of the bay. Within each farm, divers collected information at three randomly chosen locations, resulting in a total of 111 sampling sites in 54 farms across PEI. The sites were surveyed by divers between the months of July and September 2003.

2.4.2. Husbandry and Productivity Measurements

In areas where one-year-old crop was found, divers measured the distance between longlines and the spacing between mussel socks attached to longlines. Also, three socks per farm were collected to determine the length, weight and condition index of the cultivated mussels. All sock weight measurements reported in this paper were standardized to a 2.14 m sock (the sock length most commonly used by PEI growers). A standardized stocking density index was calculated using the formula below. This stocking density index does not take into account empty areas within farms; it reflects the density in the immediate area where one-year-old crop were found by divers.

$$Stocking\ Density = \frac{1}{Longline\ Spacing\ (m) \times Sock\ Spacing\ (m)} \times \frac{Sock\ Length\ (m)}{2.14\ m} \times 100 \quad (1)$$

To evaluate the physiological condition of the mussels, a sample of 20 randomly selected mussels were taken from the bottom 0.3 m of each sock collected by the divers. A dry meat weight for each mussel was obtained by placing the tissues into a drying oven at 60°C for a minimum of 12 h. The condition index was then calculated according to the formula given in Abbe and Albright (2003):

$$Condition\ Index = \frac{Dry\ meat\ weight\ (g)}{Dry\ shell\ weight\ (g)} \times 100 \quad (2)$$

2.4.3. Statistical analysis

Inter-annual differences of sock weight, condition index, longline and sock spacing, stocking density and sock length in Tracadie Bay were investigated using analysis of variance (ANOVA). Variables with a non-normal distribution within years or with clearly different variation between years were analyzed using a non-parametric Kruskal-Wallis test.

Possible links between longline setup and mussel productivity were investigated by applying multiple linear regression analysis to the Island Wide Survey (IWS) dataset (2003) and the Tracadie datasets (2002-2004, individual years analyzed separately). The productivity or "outcome" variables were sock weight and condition index. The "predictor" variables were longline spacing, sock spacing, sock length, stocking density and, for the IWS dataset, the bay was included as a categorical predictor. The functional relationship between stocking density and the other predictor variables resulted in high collinearity, and precluded use of stocking density in combination with the other variables. However, when stocking density had the highest significant correlation level with the outcome variable, it was retained as a sole predictor. Univariate associations between outcomes and predictors were assessed with Pearson correlation coefficients, and only predictors having some degree of association with the outcome ($P \leq 0.2$) were retained for further model-building by backward stepwise elimination. Predictors with $P \leq 0.1$ in the final model were further assessed for confounding and interaction; unless any of these were noted, predictors were kept in the model only at $P \leq 0.05$. The models' fit and adequacy were checked by analysis of residuals and influence diagnostics. The potential correlation between multiple measurements within the same lease in the IWS dataset was accounted for by using a generalized estimating equation (GEE) procedure clustered on leases (Dohoo et al., 2003).

Additional GEE regression analyses were performed on the IWS dataset (2003) to determine whether total farming area in the bay or the location of the farm within the bay (inner versus outer) influenced husbandry or mussel productivity. The former analysis was clustered on bays, and the latter was clustered on leases and included fixed effects of bays. All statistical analyses were performed using Stata (version 9; Stata Corporation, College Station, Texas).

2.5. Results

2.5.1. Tracadie Bay - Longline setup

Descriptive statistics for the longline setup are given in Table 2-1. For Tracadie Bay, results show that the distance separating the longlines from one another (longline spacing) varied little between 2002 and 2004, with the yearly averages ranging from 12.0 to 13.1 m. In contrast, the distance separating individual socks along the longlines (sock spacing) was significantly ($P < 0.001$ by ANOVA) different between the investigated years, increasing by 30% (38.4 to 49.8 cm) from 2002 to 2004. Stocking density showed concomitant temporal differences ($P = 0.03$ by ANOVA), falling by 22% (22.8 to 17.8 socks/100 m^2) over the study period. By modeling the data in equation (1), we found that the decline in stocking density was mostly driven by the observed changes in sock spacing. In more details, the inter-annual differences in stocking density persisted after assigning a constant term to either longline spacing or sock length in equation (1), indicating that these two variables had a minor influence on the observed reduction in stocking density. However, the inter-annual differences in stocking density were no longer statistically significant after assigning a constant value to the sock spacing denominator in equation (1).

With respect to the sock spacing variability within Tracadie, it is noteworthy that sock spacing displayed low variability from one farm to the next. The coefficient of variation (CV) values for sock spacing ranged from 16 to 20% within individual survey years. Similarly, the CV values for sock length were between 16 and 18%. For longline spacing, however, the CV values were higher (33-43%), which in turn increased the variability in stocking density. In 2002, for instance, the CV value for stocking density was 65% in Tracadie Bay; but when a constant term was assigned to the longline spacing denominator in equation (1), the stocking density CV value fell from 65 to 34%. Similar declines in CV values were obtained by modeling the data for years 2003 and 2004. Thus, in Tracadie Bay, approximately one-half of the variability in stocking density can be ascribed to the distance separating the longlines from one another.

2.5.2. Island Wide - longline setup

Results similar to the ones presented for Tracadie were obtained using the IWS dataset (2003). Sock spacing and sock length displayed low variability (CV 15-18%) across PEI, but longline spacing and stocking density were both highly variable, with CV values of 44 and 79%, respectively. After substituting the longline spacing denominator in equation (1) by a constant term, the stocking density CV value fell from 79 to 23%. Thus, as in the case for Tracadie Bay, the longline spacing measured by divers was a major factor in raising the variability in stocking density across PEI. The magnitude of this variability is made evident by a 29 fold-difference between the minimum (6.2 socks/100 m^2) and maximum (179.9 socks/100 m^2) stocking density values; the density values between the 25^{th} and 75^{th} percentiles ranged from 14.5 to 27.3 socks/100 m^2.

2.5.3. Correlative analyses

We continued by examining whether the location of farms within the bays could explain some of the observed variability in the configuration of longlines. By applying simple GEE regression analysis to the IWS dataset, we found that the only significant ($P = 0.05$) outcome was sock length: socks were on average 7% longer in the inner bays compared to the outer bays. We next investigated whether the level of farming activity at the bay scale had an influence on the configuration of longlines. We found no significant correlation between the total farming area in a bay and longline spacing ($P = 0.13$). On the other hand, the total farming area was correlated with both sock spacing ($P = 0.02$) and stocking density ($P = 0.01$): for each additional 100 farming hectares inside a bay, sock spacing increased by 2.6 cm (± 0.012 SE), while stocking density decreased by 5.6 socks/100 m^2 (± 0.021 SE). Despite this apparent reduction in mussel density, the condition index decreased by 1.6 (± 0.004 SE) units for each additional 100 farming hectares inside a bay ($P < 0.001$).

We then asked if some of the husbandry decisions taken by the growers were associated with enhanced mussel productivity. The reduction in stocking density from 2002 to 2004 in Tracadie Bay was not accompanied by corresponding increases in mussel productivity (Table 2-2). The sock weight yearly averages ranged from 7.8 to

9.1 kg with no significant ($P = 0.32$ by Kruskal-Wallis) differences between years. Both the condition index and shell length presented inter-annual differences ($P < 0.001$ by ANOVA), although none were consistent with the reduction in stocking density. Final models from multiple regression analyses are presented in Table 2-3 for Tracadie Bay. Both sock spacing and stocking density were retained as predictor variables; the strongest correlations are shown graphically in Figures. 2-3 and 2-4. In more details, sock spacing was positively correlated with sock weight in 2002 ($R^2 = 0.41$, $P < 0.001$) and also with the condition index in 2004 ($R^2 = 0.37$, $P = 0.047$). The slopes suggest that an 11-cm increase in sock spacing (number selected to reflect husbandry change observed between 2002 and 2004 in Tracadie Bay) can enhance the sock weight by 1.24 kg and the condition index by 1.59. Although stocking density was also retained as a predictor variable for the condition index in 2002, this correlation was particularly weak ($R^2 = 0.12$, $P < 0.03$), driven by a single outlier, and unexpectedly positive.

A multiple regression analysis was also performed on the IWS 2003 dataset (Table 2-4). Although sock spacing was identified as the best predictor variable for sock weight, the model was not statistically significant ($P = 0.11$) and failed to explain the variability observed between the bays. However, sock weight varied among the different bays surveyed ($P < 0.001$).

2.6. Discussion

2.6.1. Longline setup

World-wide, most cultivated mussels are produced in the water column using rafts, poles and longlines holding continuous socks. Here we present the first detailed report of the individual sock longline system used in Atlantic Canada for the culture of

M. edulis. Our approach was based on an extensive field sampling survey off the coastline of PEI, where the majority of mussel farms are located. The survey showed that the average length of mussel socks was 2.0 m with relatively little variation (CV = 15%) between the 111 sites (54 farms) visited by divers. This result indicates that mussel socks in PEI are relatively short in comparison to those deployed elsewhere in the world, which typically range from 4 to 9 m (Hurlburt and Hurlburt, 1980; Boyd and Heasman, 1998; Fuentes et al., 2000). This attributable to the shallow (~ 4 m) estuarine waters where mussel farms operate in PEI. While such reporting of sock length may appear tedious, it is necessary for any future investigation requiring a robust estimate of stock inventory. In the existing literature on shellfish farming, there is an apparent lack of detailed information regarding the setup of culture gear. In most papers, gear setup information is usually provided in the introduction or methodology sections and is un-cited, thereby suggesting anecdotal sources. This situation is problematic for the growing field of computer modeling, where input gear variables can weigh heavily in shaping output variables such as seston depletion and biodeposition rates.

In continuing with our description of the PEI longline setup, we found that single socks suspended from the main backlines were separated by an average distance of 44.3 cm, again without much variability between sites. This finding is consistent with the distance separating culture poles (~ 40 cm apart) in the Normandy area (Gosling, 2003), and also dropper ropes (~ 50 cm apart) attached to continuous-sock longlines in New Zealand (Spencer, 2002). In general, however, the sock spacing values reported in the literature are larger than to those measured in PEI. Individual socks suspended from submerged longlines are reportedly distanced 120 cm apart in

France's Pertuis Breton region (Garen et al., 2004) and 60 cm apart in Scottish sea lochs (Okumus and Stirling, 1998). Similarly, socks hung from culture rafts are spaced at either 60 or 90 cm apart in South Africa (Heasman et al., 1998) and 100 cm apart in the Galician province of Spain (Fuentes et al., 2000). Thus it could be said that the PEI mussel socks are relatively short and hung at a close distance from one another.

The data presented in Fuentes et al. (2000) and those collected as part of this study were sufficiently detailed to allow a standardized comparison of the stocking biomass under a Galician raft and a PEI longline. Our standardized estimate is as follows: the mussel weight—adjusted to a shell length of 48 cm—contained in one cubic meter of water positioned *directly* under each of the two gear types, a longline and a wooden crossbeam. The calculations gave the following numbers: 15.11 kg / m^3 for the Galician raft and 13.57 kg / m^3 for the PEI longline. Thus the biomass per unit volume found directly under a PEI longline is similar to the one under a raft's wooden beam, which is an interesting observation considering major differences in husbandry between the two cultivation techniques. On the other hand, these two estimates do not take into account empty areas between individual longlines or wooden beams, which do matter when extrapolating the stocking biomass to the farm level. Due to highly variable spacing of longlines in PEI, it is difficult to provide a generalized statement regarding the stocking biomass at the farm level. Perhaps one reasonable way to generalize it is as follows: stocking density between the 25^{th}-75^{th} percentiles ranged from 14.5 to 27.3 socks/100 m^2 or, if expressed as mass per unit volume, from 73 to 165 kg/100 m^3. As expected, these farm-scale estimates are low in comparison to the ones associated with the Galician raft (~1500 kg/100 m^3, derived from Fuentes et al., 2000), which represents an intensive but localized cultivation technique. The PEI numbers are also low when compared to the French pole culture (125 to 300 kg/100 m^3, derived from Spencer, 2002 and Gosling, 2003). Unfortunately, we could not find sufficiently detailed longline data in the literature for further comparisons.

2.6.2. Mussel Productivity

In PEI, commercial-size (> 55 mm) mussels are typically produced in 18 to 24 months. In comparison, similar-size mussels are produced in less than 12 months in Spain (Camacho et al. 1991). There is no doubt that low temperatures in winter represent a major factor in lengthening the PEI production cycle. However, as indicated earlier, there is also the possibility that an overstocking of mussels has occurred in some areas, resulting in curtailed mussel growth. In keeping within this framework, we report a negative correlation between total farming area (i.e. increase number of leases within a bay) and the number of socks deployed per unit area (farm level). The relationship shows that growers longline design is correlated with the surrounding level of farming activity (as expressed by the total farming area), and more precisely supports a causal hypothesis that growers reduce their lease stocking density (through increased sock spacing) in response to intense farming development. The magnitude of the adjustment was important: sock spacing increased by 6% (2.6 cm), while stocking density declined by 24% (5.6 socks/100 m^2) for each additional 100 hectares in farm coverage within a given bay. This observation raises the question of whether such adjustments in stocking density alleviated any competition for the available food resources and prevented any curtailment in mussel condition. The answer to that question would seem to be no. Indeed, a second correlation indicates that the condition index was negatively correlated within embayments characterized by extensive farm coverage compared to those with little farming development. This latter correlation may indicate that there was an increased competition for natural seston in areas of intensive farming, in spite of the industry's inclination to reduce the farm stocking density within those areas. Thus it appears that mussel growers tended to reduce stock density at the farm level in response to increased aquaculture development at the bay level, but that this husbandry correction had little or no beneficial effect on mussel quality. This interpretation is in broad agreement with recent modeling work suggesting food particle depletion in major production bays (Grant et al., 2005).

The lack of influence of stocking density on mussel performance is also supported by observations made within Tracadie Bay. Here stocking density never convincingly emerged as an explanatory variable to mussel performance. A positive correlation between stocking density and the condition index was found in 2002, but the relationship was weak ($R^2 = 0.12$) and doubtful considering its dependence on a single observation. As regards the temporal dimension in Tracadie Bay, stocking density fell by 28% over the course of the three-year survey. However, this reduction in stocking density was not accompanied by corresponding changes in mussel performance. To sum up, in the present study stocking density at the farm level had no detectable effect on mussel productivity, neither within Tracadie Bay nor in other PEI embayments.

The modeling of equation (1) indicated that Tracadie Bay growers reduced farm stocking density by positioning individual socks at a greater distance from one another. According to the measurements taken by divers, sock spacing increased by 11 cm (from 38.4 to 49.8 cm) between 2002 and 2004. At the same time, sock spacing CV values were relatively low (16-20%) between farms within each year. Therefore it appears that Tracadie Bay growers increased sock spacing in a synchronized manner. This coordinated husbandry change coincided with the implementation of a bay management plan during the autumn of 2002 (Lea, 2002). This plan is specific to Tracadie and essentially limits the stocking density to 12.4 socks/100 m^2 (this limit is lower than our density estimates because it takes into account empty areas in the farm).

The Tracadie management plan was instigated as an attempt to re-establish growing conditions which according to anecdotal evidence had weakened since the late 1990s. Since Tracadie growers decided to implement the management plan by modifying sock spacing instead of longline spacing, as our results show, one may assume that the former variable has a greater influence on localized growing conditions and mussel productivity. This reasoning is consistent with the outcome of this study. Longline spacing was never retained as a significant predictor of mussel performance: there was no evidence that mussels on a given longline affected the growth of mussels on an adjacent longline, even when the two were moored at close distance (< 8 m) from one another. Sock spacing, on the other hand, explained 41% of the variability in sock weight in 2002. The correlation suggests that the close spacing (< 60 cm, see Fig. 3) of mussels on a longline can significantly reduce the concentration of food particles in the water column. Heasman et al. (1998) reported similar observations for mussels suspended from culture rafts in South Africa. They found that the removal of particulate matter in the immediate vicinity of mussel socks was significantly greater where socks were separated by 60 cm compared to 90 cm. Two factors likely operate in reducing the food levels near closely-spaced mussel socks: (1) an elevated rate of particle removal by densely aggregated grazers and (2) a low rate of particle renewal caused by the tightly packed culture gear disturbing water exchanges (e.g. Grant and Bacher, 2001).

Given the above finding on the effect of sock spacing, we proceeded by calculating the potential impact of an 11-cm change in sock spacing—which represents the husbandry change detected in Tracadie Bay—on bay-scale mussel production. According to the 2002 relationship, an 11-cm increase in sock spacing augments the sock weight by approximately 18%. Scaling these numbers to the entire bay implies the following: (1) that the number socks harvested annually in Tracadie would decline from approximately 300,000 socks (Davidson, unpublished data) to 234,000 socks due to a reduction in the number of socks per longline; (2) that the post-processing weight of each sock would increase from approximately 7.10 kg (Davidson, unpublished data) to 8.38 kg due to improved growing conditions, and (3) that the net harvest biomass would decline from approximately 2,130 to 1,961 tons. Thus, when scaling the 2002 relationship on sock spacing to bay production levels, we find that an 11-cm increase in sock spacing would reduce the sock deployment and any related husbandry effort by 22%, but curtail production by only 8%. Moreover, it could be argued that the 8% production deficit is over-estimated. Indeed, we calculated the magnitude of the deficit based on the regression slope shown in Fig. 3. Since that particular slope reflects half-grown mussels, it is reasonable to assume that it would be heighten for larger mussels, considering that they have a greater filtration capacity (Winter, 1978) and food depletion capability (Heasman et al., 1998). It could also be argued that any production deficit resulting from a greater spacing of mussel socks would ultimately be compensated by a gain in product quality. This quality argument is supported by a positive correlation detected between sock spacing and the condition index in 2004.

One caveat with the above argument favoring a greater spacing of individual socks is that it was built on correlations which were not consistent from year to year. Evidently this lack of consistency makes a convincing link between sock spacing and bay-scale production more difficult to establish. The underlying factors responsible for the non-repeatability between years are unclear. However, one plausible interpretation is linked to a fluctuating availability of the phytoplankton. There is indirect evidence that phytoplankton biomass varies substantially from year to year in the southern Gulf of St. Lawrence. A standardized shellfish monitoring network (https://www.glf.dfo-mpo.gc.ca/sci-sci/smn-rmm/index-e.jsp) reports that mussel and oyster growth rates at 56 sites in the southern Gulf of St. Lawrence, including 41 sites located in PEI embayments, were far superior in 2003 compared to 2002 and 2004. The better growing conditions in 2003 were therefore driven by large-scale events, presumably enhanced primary production throughout the southern Gulf of St. Lawrence. Abundant food resources provide a reasonable explanation for the lack of relationship between sock spacing and mussel productivity in 2003, both within Tracadie Bay and across PEI (IWS). Sock spacing may be insignificant to mussel performance in years of outstanding phytoplankton blooms, but may regain its relevance in years of low primary production. The latter condition may have been present in 2002 and 2004 as suggested by significant relationships between sock spacing and mussel productivity. In keeping with this interpretation, an intriguing question is how frequently, on a long term basis, is primary production sufficiently low in PEI embayments to justify a greater spacing of mussel socks along longlines.

2.7. Conclusion

This investigation provides the first detailed account of the submerged longline in PEI mussel farms, along with a description of the existing variability between individual farms. Our extensive field survey showed that the distance separating longlines from one another was extremely variable between farms, but that the spacing between socks along longlines was fairly stable from one site to the next. A yearly monitoring effort in Tracadie Bay led to the detection of a significant and coordinated increase in sock spacing between 2002 and 2004. Correlative analyses suggested a positive link between sock spacing and mussel productivity. However, that putative link was surprisingly unpredictable over the study period, presumably showing up only when food particles were in short supply.

2.8. References

Abbe, G.R., Albright, B.W., 2003. An improvement to the determination of meat condition index for the eastern oyster Crassostrea virginica (Gmelin 1971). J Shellfish Res 22, 747-752.

Boyd, A.J., Heasman, K.G., 1998. Shellfish mariculture in the Benguela system: Water flow patterns within a mussel farm in Saldanha Bay, South Africa. J Shellfish Res 17, 25-32.

Cranford, P., M. Dowd, J. Grant, B. Hargrave and S. McGladdery., 2003. Ecosystem level effects of marine bivalve aquaculture, p. 51-95. In Fisheries and Oceans Canada. A scientific review of the potential environmental effects of aquaculture in aquatic systems. Volume 1. Far-field environmental effects of marine finfish aquaculture (B.T. Hargrave); Ecosystem levels effects of marine bivalve aquaculture (P. Cranford, M. Dowd, J. Grant, B. Hargrave and S. McGladdery); Chemical use in marine finfish aquaculture in Canada: a review of current practices and possible environmental effects (L. E. Burridge). Can Tech Rep Fish Aquat Sci 2450: ix + 131 pp.

Dohoo, I., Martin, W., Stryhn, H., 2003. Alternative approaches to dealing with clustered data. In: Veterinary Epidemiologic Research, AVC Inc, Charlottetown, PE, Canada. pp. 521-542.

Dolmer, P., 2000. Algal concentration profiles above mussel beds. J Sea Res 43, 19-36.

Dowd, M., 2003. Seston dynamics in a tidal inlet with shellfish aquaculture: a model study using tracer equations. Est Coast Shelf Sci 57, 523-537.

Dowd, M., 2005. A bio-physical coastal ecosystem model for assessing environmental effects of marine bivalve aquaculture. Ecol Model 183, 323-346.

Frechette, M., Bourget, E., 1985a. Energy flow between the pelagic and benthic zones: factors controlling particulate organic matter available to an intertidal mussel bed. Can J Fish Aquat Sci 42, 1158-1165.

Frechette, M., Bourget, E., 1985b. Food-limited growth of Mytilus edulis L. in relation to the benthic boundary-layer. Can J Fish Aquat Sci 42, 1166-1170.

Frechette, M., Butman, C.H., Geyer, W.R., 1989. The importance of boundary-layer flows in supplying phytoplankton to the benthic suspension feeder, Mytilus edulis L. Limnol Oceanogr 34, 19-36.

Fuentes, J., Gregorio, V., Giraldez, R., Molares, J., 2000. Within-raft variability of the growth rate of mussels, Mytilus galloprovincialis, cultivated in the Ria de Arousa (NW Spain). Aquaculture 189, 39-52.

Garen, P., Robert, S., Bougrier, S., 2004. Comparison of growth of mussel, Mytilus edulis, on longline, pole and bottom culture sites in the Pertuis Breton, France. Aquaculture 232, 511-524.

Gosling, E., 2003. Bivalve Molluscs: Biology, Ecology and Culture. Fishing New Books, Oxford, UK, 443 pp.

Grant, J., Bacher, C., 2001. A numerical model of flow modification induced by suspended aquaculture in a Chinese bay. Can J Fish Aquat Sci 58, 1003-1011.

Grant, J., Cranford, P., Hargrave, B., Carreau, M., Schofield, B., Armsworthy, S., Burdett-Coutts, V., Ibarra, D., 2005. A model of aquaculture biodeposition for multiple estuaries and field validation at blue mussel (Mytilus edulis) culture sites in eastern Canada. Can J Fish Aquat Sci 62, 1271–1285.

Heasman, K.G., Pitcher, G.C., McQuaid, C.D., Hecht, T., 1998. Shellfish mariculture in the Benguela system: Raft culture of Mytilus galloprovincialis and the effect of rope spacing on food extraction, growth rate, production, and condition of mussels. J Shellfish Res 17, 33-39.

Hurlburt, C.G., and Hurlburt, S.W., 1980. European mussel culture technology and its adaptability to the North American waters. In: Mussel Culture and Harvest: a North American Perspective (ed. R.A. Lutz), pp.69-98. Elsevier Science Publishing Co. Inc., New York.

Jonsson, P.R., Petersen, J. K., Karlsson, Ö, Loo, L.-O., Nilsson, S., 2005. Particle depletion above experimental bivalve beds: In situ measurements and numerical modeling of bivalve filtration in the boundary layer. Limnol Oceanogr 50, 1989-1998.

Lea, L., 2002. Mussel Aquaculture Management Plan for Tracadie Bay, Prince-Edward Island. February 2002. 6 p.

Meeuwig, J.J., Rasmussen, J.B., Peters, R.H., 1998. Turbid waters and clarifying mussels: their moderation of empirical chl: nutrient relations in estuaries in Prince Edward Island, Canada. Mar Ecol-Prog Ser 171, 139-150.

Newell, C.R., 1990. The effect of mussel (Mytilus edulis, Linnaeus, 1758) position in seeded bottom patches on growth at subtidal lease sites in Maine. J Shellfish Res 9, 113-118.

Okumus, I., Stirling, H.P., 1998. Seasonal variations in the meat weight, condition index and biochemical composition of mussels (Mytilus edulis L.) in suspended culture in two Scottish sea lochs. Aquaculture 159, 249-261.

Petersen, J. K., 2004. Grazing on pelagic primary producers—the role of benthic suspension feeders in estuaries, p. 129-152. *In* S. L. Nielsen, G. T. Banta, and M. F. Pedersen [eds.], The influence of primary producers on estuarine nutrient cycling. Kluwer.

Scarratt, D.J., 2000. Development of the mussel industry in eastern Canada. Bull Aquacult Assoc Can 100(2), 37-40.

Smith, G., 2005. PEI Mussel Monitoring Program 2004 Report. P. E. I. Tech. Report. 235: 94pp.

Spencer, B.E., 2002. Mussel cultivation. In: Molluscan Shellfish Farming, Blackwell Publishing, LTD, Oxford, pp. 147-165.

Wildish, D.J., Kristmanson, D.D., 1979. Tidal energy and sublittoral macrobenthic animals in estuaries. J Fish Res Board Can 36, 1197-1206.

Winter, J.E., 1978. A review on the knowledge of suspension-feeding in Lamellibranchiate bivalves, with special reference to artificial aquaculture systems. Aquaculture 13, 1-33.

Table 2-1 Descriptive husbandry statistics grouped by survey year in Tracadie Bay (2002-2004) and across Prince Edward Island (2003).

Year	Husbandry Variable	n	Mean	STD	Min	Max	CV
Tracadie Bay 2002	Sock length (m)	46	1.8 [a]	0.3	1.1	2.7	17
	Line spacing (m)	46	12.4 [a]	4.9	2.7	27.5	40
	Sock spacing (cm)	46	38.4 [a]	7.8	13.0	56.1	20
	Stocking density (socks/100 m^2)	46	22.8 [a]	14.8	8.2	86.5	65
Tracadie Bay 2003	Sock length (m)	11	1.7 [a]	0.3	1.3	2.3	18
	Line spacing (m)	11	13.1 [a]	4.3	7.5	19.7	33
	Sock spacing (cm)	11	43.3 [b]	8.1	31.7	59.6	19
	Stocking density (socks/100 m^2)	11	16.9 [b]	7.3	6.2	29.2	43
Tracadie Bay 2004	Sock length (m)	11	1.9 [a]	0.3	1.5	2.4	16
	Line spacing (m)	11	12.0 [a]	5.1	7.5	24.9	43
	Sock spacing (cm)	11	49.8 [c]	7.8	40.4	63.0	16
	Stocking density (socks/100 m^2)	11	17.8 [c]	7.5	9.0	32.9	42
IWS 2003	Sock length (m)	111	2.0	0.3	1.2	3.0	15
	Line spacing (m)	111	11.6	5.1	1.5	29.5	44
	Sock spacing (cm)	111	44.3	7.8	26.4	62.4	18
	Stocking density (socks/100 m^2)	111	23.3	18.3	6.2	179.9	79

[a-c] Within the each husbandry variable, means without a common superscript were significantly different ($P < 0.05$)

IWS: Island Wide Survey
n: sample size
STD: standard deviation of the mean
Min: minimum observed value
Max: maximum observed value
CV: Coefficient of variation

Table 2-2 Descriptive productivity statistics grouped by survey year in Tracadie Bay (2002-2004) and across Prince Edward Island (2003).

Year	Productivity Variable	n	Mean	STD	Min	Max	CV
Tracadie Bay 2002	Sock weight (kg)	46	7.8 [a]	1.5	5.7	11.5	19
	Condition index	40	11.6 [a]	2.0	7.7	16.6	17
	Mussel length (mm)	240	33.8 [a]	5.4	18.0	45.0	16
Tracadie Bay 2003	Sock weight (kg)	15	8.2 [a]	3.1	2.9	15.5	38
	Condition index	15	11.8 [a]	2.2	8.5	16.3	19
	Mussel length (mm)	240	46.1 [b]	5.7	34.4	66.4	12
Tracadie Bay 2004	Sock weight (kg)	11	9.1 [a]	2.7	5.7	14.9	30
	Condition index	11	8.9 [b]	2.1	6.9	13.2	24
	Mussel length (mm)	240	42.0 [c]	6.1	25.5	66.4	15
IWS 2003	Sock weight (kg)	111	7.6	3.1	1.5	16.9	41
	Condition index	94	14.4	4.5	6.7	29.3	31
	Mussel length (mm)	877	41.4	5.2	24.3	62.7	13

[a-c] Within the each productivity outcome, means without a common superscript were significantly different ($P < 0.05$)

IWS: Island Wide Survey
n: sample size
STD: standard deviation of the mean
Min: minimum observed value
Max: maximum observed value
CV: Coefficient of variation

Table 2-3 Final multiple linear regression models for Tracadie Bay multi-year survey (2002-2004).

Year	Production Outcome	Independent variables entering the final model	n	β	SE	*P*
2002	Sock weight	Sock spacing	46	0.124	0.02	<0.001
	Condition Index	Stocking density	40	0.045	0.02	0.03
2004	Condition Index	Sock spacing	11	0.159	0.07	0.047

n: sample size
β: coefficient value from our regression models
SE: standard error
P: p-value

Table 2-4 Final multiple linear regression model of predictors correlated to sock weight in the IWS (2003). Sock weight values for every embayment are centered for an average sock spacing of 44 cm. Also included is the non-significant sock spacing predictor.

Effect		β	SE	*P*
Bay				< 0.001#
	Alberton	10.81	1.08	
	Bentick Cove	6.57	0.31	
	Bideford River	10.10	0.92	
	Boughton Bay	6.30	1.10	
	Covehead Bay	7.15	0.41	
	Darnley Bassin	7.09	0.73	
	Hunter River	12.73	1.46	
	Malpeque Bay	7.60	0.53	
	Montague River	6.88	0.31	
	Murray River	4.45	0.51	
	Rustico Bay	8.80	0.41	
	Savage Harbor	5.28	0.08	
	Southwest River	11.55	0.65	
	St. Mary's Bay	2.46	1.35	
	St. Peter's Bay	6.65	0.13	
	Tracadie Bay	8.25	0.80	
Sock spacing		0.066	0.042	0.11

β: coefficient value from our regression models
SE: standard error
P: p-value
#: Test for no difference between bays

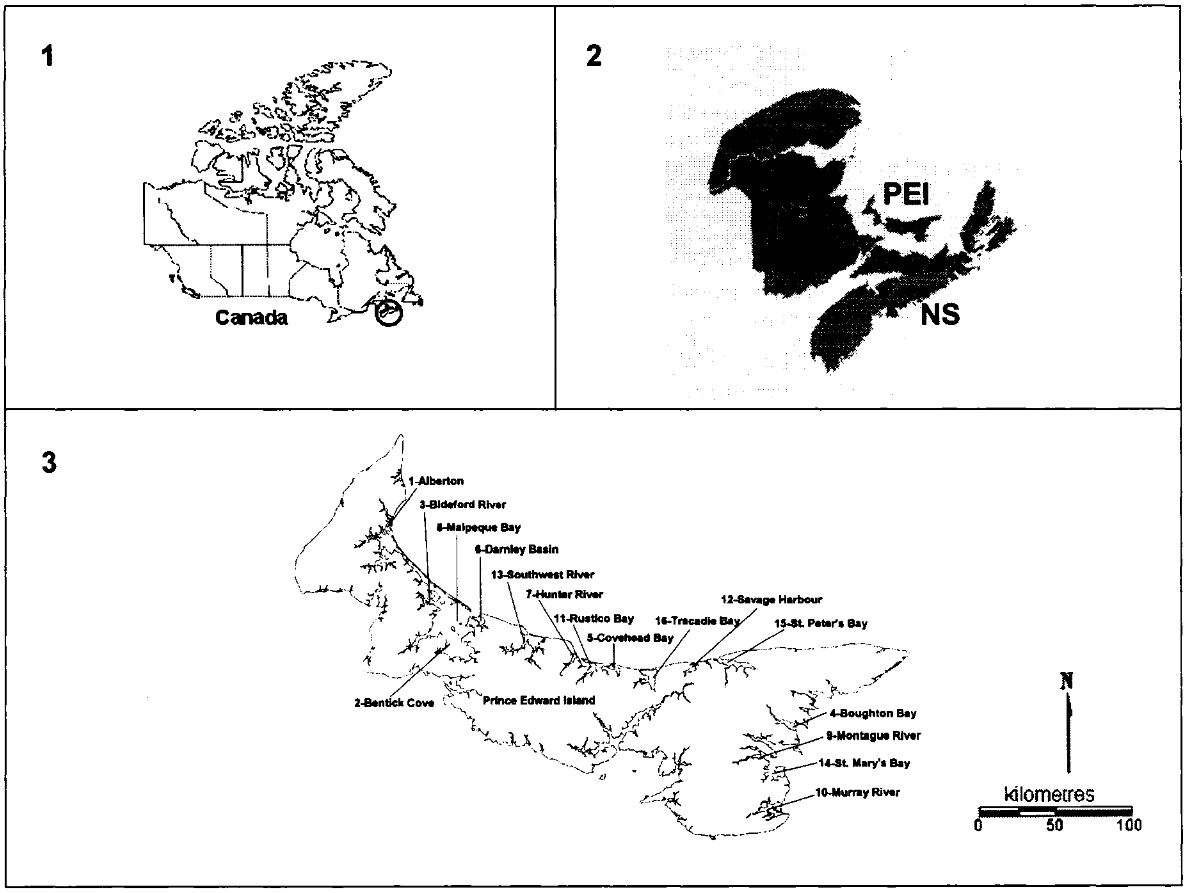

Figure 2-1 Map of Canada (1), with inserts of map of Atlantic Canada (2) and Prince Edward Island (3) with the location of sites survey as part of the Island Wide Survey in (IWS) 2003.

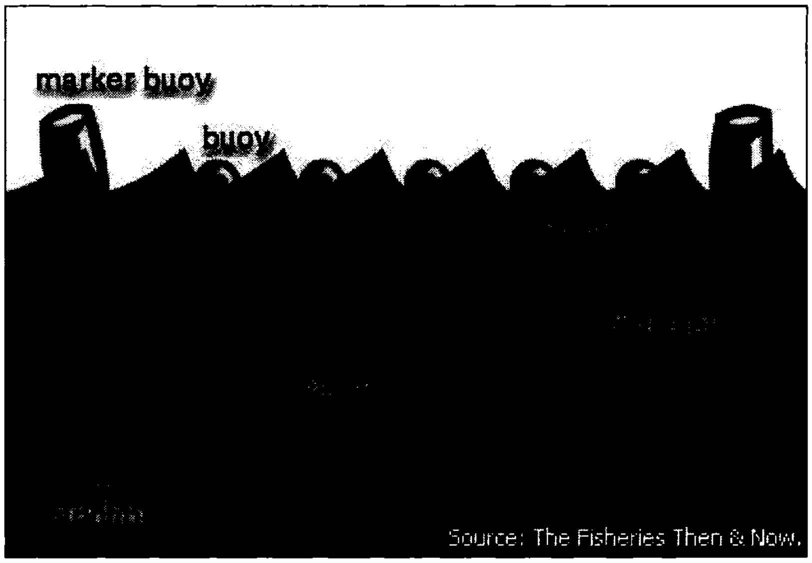

Figure 2-2 Schematic representation of a typical longline used for mussel culture across Prince Edward Island.

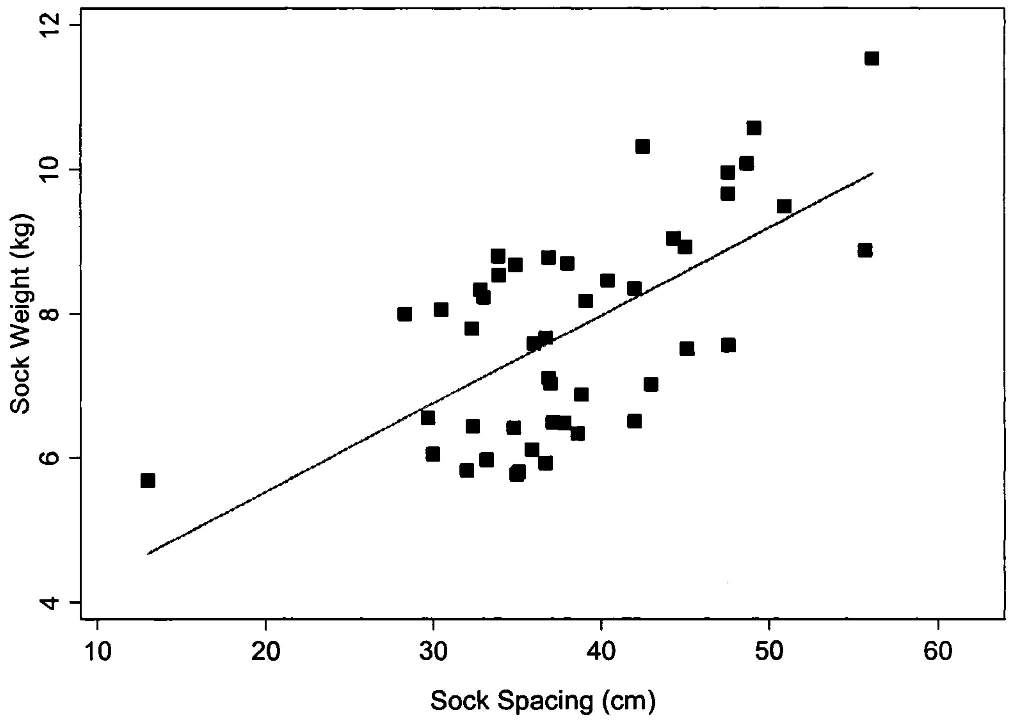

Figure 2-3 Regression plot of a significant correlation between sock weight and sock spacing (sock weight = 3.04 + 0.124 sock spacing, $R^2 = 0.41$, $P < 0.001$) in Tracadie Bay leases (2002).

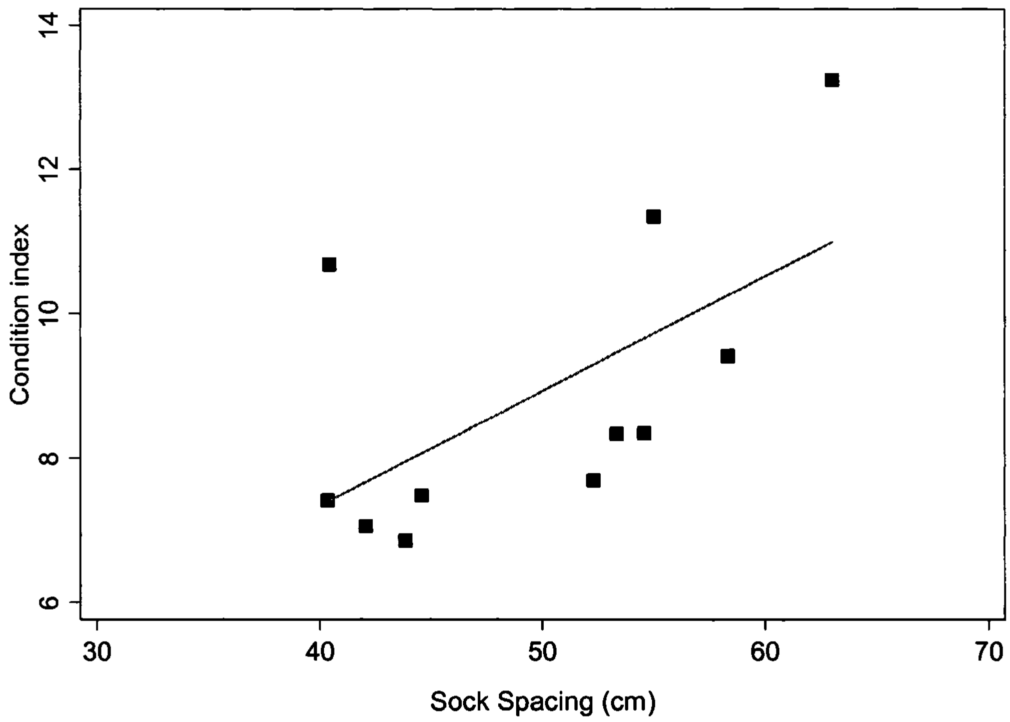

Figure 2-4 Regression plot of a significant correlation between condition index and sock spacing (condition index = 0.98 + 0.159 sock spacing, $R^2 = 0.37$, $P = 0.047$) in Tracadie Bay leases (2004).

Chapter 3 THE EFFCT OF SOCK SPACING ON THE PRODUCTIVITY OF MUSSELS ON A LONGLINE SYSTEM

3.1. Abstract

In suspended blue mussel (Mytilus edulis) culture, the link between sock spacing and mussel performance on a longline system has never been experimentally demonstrated. Therefore, the objective of this trial was to compare productivity of mussel socks spaced 10 cm, 20 cm, 40 cm, 60 cm and 80 cm apart on a longline. A large-scale experiment was conducted in distinct leases of Tracadie Bay, PEI over a one-year production cycle. Shell growth and survival of pre-market mussels were positively associated with higher sock spacing treatments, while condition index displayed no temporal and spatial associations to sock spacing treatments. In two of the four experimental sites, results showed significantly greater growth and survival levels on mussel socks spaced 80 cm apart at the end of the production cycle. Shell growth increased by 8% (3.4 mm) and 7% (3.4 mm), while survival was 42% (233 mussels/m) and 18% (87 mussels/m) higher when comparing low density levels (Tx 80) to high density levels (Tx 10) of cultured mussels. When all management strategies (i.e. socking density and seed size) were kept constant, the association between sock spacing treatments and productivity were non-significant. The significant differences between sock spacing treatments at two of the four sites may be due to high initial socking density and smaller seed size. Sites displaying significant associations were respectively characterized by having 58% and 47% more mussels per meter, while seed mussels were 46% and 23% smaller. Dense aggregation of bivalves at the farm level and inside mussel socks may lead to intra-specific competition

between individuals as food demand at the local scale may exceed food supply and ultimately limit growth. Food levels at the local scale were not measured during this study, but are documented to be highly variable temporally and spatially within this growing area.

3.2. Keywords

Mytilus edulis; management strategies; shell growth; condition index; sock spacing, stocking density

3.3. Introduction

Blue mussel (Mytilus edulis) culture in Prince Edward Island (PEI, Figure 3-1) began in the 1970s by adapting the subsurface longline system of suspended socks to co-exist with specific environmental conditions (i.e. ice coverage). Production has steadily increased over the years and PEI is now responsible for 80% of Canadian production (Department of Fisheries and Oceans [DFO], Policy and Economics Branch). Presently, there remain few bays and estuaries on PEI that can support new farming operations as evidenced by a moratorium on the granting of new leases. The PEI mussel industry has been challenged by the leveling of mussel production and with the recent arrival and colonization of invasive tunicates species (Leblanc et al., 2003; Smith 2005). These undesirable filter-feeders add additional strains on a growing area by competing with mussels for food resources, which may impact its carrying capacity. Carver and Mallet (1990) defined carrying capacity with respect to mussel culture as the maximum standing stock of bivalves in a growing area where production levels are maximized without negatively affecting growth rates.

On PEI, the issues of shellfish overstocking and optimum carrying capacity levels represent growing concerns. Tracadie Bay is situated on the north shore of PEI (Figure 3-1) and is an important mussel producing bay, contributing 20% of the Island's production. However, mussel farms occupy most of the areas available for farming. Such exploitation can create a spatial growth gradient throughout the bay when comparing the outer and inner reaches (Waite et al., 2005). This pattern may be associated to an increased utilization of food resources and decreased tidal exchange from the inlet mouth to the inner estuary. Between 1990 and 2000, annual sock deployment increased by 28 %, while harvest yield per sock showed the reversed trend: a 25 % decrease between 1995 and 2000 (Landry et al., in press). During the late 1990s, concerns over decreased sock weight, increased time to market and decreased condition index in harvested mussels led to the implementation of an adaptive bay management plan by the Tracadie Bay leaseholders in 2002. In an attempt to improve productivity, this bay level management strategy limited lease stocking density to approximately 12 socks/100 m^2 of leased surface (Lea, 2002). A multi-year survey (2002-2004) conducted across Tracadie Bay leases documented longline setup and quantified its association to productivity (Drapeau et al., in press). Over the three years, sock spacing increased by 30% (+11 cm), which was directly correlated with a 28% reduction (-5 socks/100 m^2) in lease stocking density. Results also showed that a farm level management strategy such as increasing sock spacing on a longline was correlated to a sock weight increase.

Optimizing lease productivity through the development of farm management strategies such as appropriate longline configuration (longline and sock spacing) and site specific mussel density and seed size selection can all be easily applied and controlled by aquaculturists. However, some management strategies can lead to increased mussel biomass at the farm level. It is well documented that increasing density levels may play a detrimental role on the productivity of mussels (Frechette et al., 1996; Dowd, 1997; Heasman et al., 1998; Penney et al., 2001). The grazing potential of dense aggregation of bivalves have the capacity to remove food particles from the water column faster than primary production and advection currents can replace them (Wildish and Kristmanson, 1979; Fréchette et Bourget, 1985 a, b; Fréchette et al., 1989; Newell, 1990; Dolmer, 2000; Petersen, 2004). Consequently, this impact would be cumulative over the entire bay as subsequent leases within a bay would receive substantially less food at reduced ambient flow (Heasman et al., 1998). This would limit growth of down current individuals.

The proximity of mussel socks to one another in the water column can also impact particle renewal by reducing ambient flow via enhanced drag (Boyd and Heasman, 1998; Heasman et al., 1998; Grant and Bacher, 2001; Newell, 2001). Water exchange through tidal currents has been shown to be closely coupled with spatial growth variability of cultured bivalves (Camacho et al., 1995; Dame and Prins, 1998). Heasman et al. (1998) investigated the effect of gear setup on mussel performance on raft culture. Results showed that smaller sock spacing (60 cm vs 90 cm) significantly reduced local food supply. This relationship was a function of increased feeding and greater reduction of current and water exchange. Depleting local food resources may lead to intra-specific competition between mussels and reduced growth rates (Dame and Prins, 1998; Frechette et al., 2000; Nunes et al., 2003). Therefore, the density dependent population may experience slower growth, decreased yield and impact the overall time to harvest for the production of marketable size mussels, which may threaten the economic viability of mariculture ventures (Dowd, 2003).

Production levels across PEI have been shown to vary spatially as well as temporally. However, it remains unclear as to whether the variability in productivity is mainly related to environmental factors or longline setup (Landry, 2003). Due to the limited availability of new coastal sites that could support mussel culture, further development of the PEI mussel industry will depend on optimizing the use of existing sites. Management strategies such as determining the optimal distance between mussel socks on a longline within a growing area is critical for optimizing farm level productivity. The relationship between sock spacing and mussel performance is still poorly understood in quantitative and predictive terms. The objective of this study was to investigate the direct association between sock spacing and mussel productivity on four grow-out leases in Tracadie Bay, PEI by means of a controlled trial.

3.4. Materials and Methods

3.4.1. Study area

Tracadie Bay is a semi-enclosed coastal inlet connected to the Gulf of St. Lawrence by a single narrow channel through a beach barrier sand dune development. Channel currents within the bay are generally strong (up to 70 cm/s) and are influenced by tides (Dowd et al., 2001). Extensive eelgrass (Zostrea marina) beds are established throughout the estuary. The bottom sediment composition of Tracadie Bay is mainly sand and silt-size particles. Surrounding land mass (farmland, coniferous forest, and sand dunes) is mainly composed of sandstone, and the estuary is normally ice covered from late December to mid April. The outer-most part of Tracadie Bay is characterized by high salinity, fast renewed tidal currents from outside the embayment from the Gulf of St. Lawrence, and higher mussel growth. However, the inner most part of the bay is characterized by slower growth, reduce flow and increased food utilization from the cultured population (Waite et al., 2005).

3.4.2. Experimental sites

Experimental sites (Figure 3-1) were selected based on a husbandry survey conducted in Tracadie Bay (2003) (Drapeau et al., in press) and productivity records from the Shellfish Monitoring Network (SMN) established by the DFO in 2002. The SMN's objective was to better understand the naturally-occurring variability (both spatial and temporal) in shellfish growing conditions (https://www.glf.dfo-mpo.gc.ca/sci-sci/smn-rmm/index-e.jsp). Four sites were chosen on the basis of their variation in productivity and lease stocking density. Two sites were selected in the higher productive northern end of the bay, while two other sites were selected in the less productive, central part of the bay.

Shell growth at two northern sites of Tracadie Bay from the SMN (2002-2004) averaged 2.97 and 3.08 mm/month compared to 2.31 mm/month from the central part of the bay. Site 1 (62°59,703' N, 46° 24,652' W) and site 2 (62°59,385' N, 46° 24,373' W) are situated in the northern part of the bay nearest to the mouth of the Gulf; based on a preliminary survey, site 1 had the lowest lease stocking density (6 socks/100 m^2), while site 2 had the higher lease stocking density (30 socks/100 m^2). Site 3 (62°59,431' N, 46° 23,664' W) and site 4 (62°59,247' N, 46° 23,658' W) are neighboring leases situated in the narrower middle part of Tracadie Bay, separated by a navigational channel. Stocking density level from site 4 was not assessed, and site 3 was unused for production in 2004 except for the experimental longlines. From our survey conducted in 2003, stocking density levels from this site was 11 socks/100 m^2. Sites 2 and 3 were owned and operated by the same lease holder so management practices were very similar.

3.4.3. Experimental design and setup

Mussels from this project were socked in the fall 2003 with seed collected in the spring 2003. The experimental setup was conducted in May 2004. Prior to our experimental setup, socking operations were conducted by the respective leaseholder and therefore initial seed size, seed source and socking density varied across our sites. Mussel socks were spaced at intervals of 10 cm, 20 cm, 40 cm, 60 cm and 80 cm to evaluate the association of sock spacing on productivity. The range of treatments was selected based upon a husbandry survey conducted in 2003 across PEI leases (Drapeau et al., in press): sock spacing averaged 44 cm and ranged from 26 to 62 cm. Extreme sock spacing values (10 cm and 80 cm) were included to evaluate the extent of the association on productivity. On each longline, sock spacing treatments were deployed in a randomized block design (Figure 3-2), where 15 socks of each treatment were triplicated over the entire longline.

3.4.4. Sampling protocol

Samples were collected on four occasions over a one-year production cycle. During the initial setup on May 11th, 2004, baseline information was collected from 10 mussel socks (conveniently chosen), which were removed from the longline. Sampling was also conducted on August 19th, 2004, November 2nd, 2004 and on May 4th, 2005.

At each sampling occasion, one replicate from each site was selected for sampling and only sampled once during the study. For each treatment, 10 socks were randomly (i.e. generated number) selected from the 13 inner socks, in order to minimize possible shadowing effects from neighboring socks of other treatment groups. Productivity analysis used the bottom third (0.6 m) of each sock of which the bottom 0.3 m portion of the sock was discarded to eliminate possible interaction with the benthos, while the remaining 0.3 m was labeled and stored frozen at -20°C until processed.

3.4.5. Productivity analysis

Mussel productivity assessment was based on growth, physiological condition and survival. Growth was assessed by measuring shell length, physiological condition was assessed by determining shell and somatic tissue weight ratio (condition index; CI), and survival was assessed by evaluating mussel density (mussel count per sample). Shell length was determined by measuring the maximum posterior-anterior axis of the shell with a Mitutoyo Digimatic^{tm} electronic caliper (± 0.02 mm). All mussels from the 0.3 m sample were measured for the May 2004 and August 2004 samples. Measurements for the November 2004 and May 2005 samples were conducted on 100 randomly selected mussels, while the count of the remaining was noted. CI of mussels from the initial samples was evaluated on 30 randomly selected mussels per sock. CI from the August and November 2004 samples was evaluated on 60 randomly selected mussels per treatment, while sample size was increased to 100 mussels per treatment in May 2005. A dry meat weight for each mussel was obtained by placing the tissues into a drying oven at 60°C for a minimum of 12 h. The CI was then calculated according to the formula given in Abbe and Albright (2003):

$$Condition\ Index = \frac{Dry\ meat\ weight\ (g)}{Dry\ shell\ weight\ (g)} \times 100 \quad (1)$$

3.4.6. Statistical analysis

Shell length and CI were analyzed separately for each site, with individual mussels as measurement units and mussel socks as experimental units for the sock spacing treatments. Due to the absence of site replication in the trial, productivity comparison between sites was considered of little interest. The analyses used linear mixed models with fixed effects of sampling periods, sock spacing treatments and their interaction, as well as random effects of socks (within treatments) to account for potential clustering within socks (Dohoo et al., 2003). Parameters were estimated by the maximum-likelihood method, and statistical hypotheses were assessed by Wald test. Multiple comparisons between treatments within a given and sampling period were adjusted by the Bonferroni procedure, in effect leading to a significance level of $P < 0.005$ for individual treatment comparisons. The level of clustering within socks was expressed in terms of inter-class correlation coefficients (ICC). Model evaluation was based on the mussel and sock level residuals. Mussel density (measured per sock) was also analyzed separately for each site, by a linear model but otherwise in a similar fashion. The statistical analyses were performed using Stata software (version 9; Stata Corporation, College Station, Texas); the linear mixed models analyses used the xtreg command.

3.5. Results

Shell length and CI were determined for a total of 62,902 and 5,251 mussels respectively, while mussel density was determined for a total of 582 socks. The average number of socks sampled at sites 1, 2, 3 and 4 were 42 socks, 47, 49 and 42 respectively. The average number of socks sampled per treatment was 28, 27, 27, 29 and 26 for Tx 10, 20, 40, 60 and 80 respectively. The average number of socks sampled at each period was 47 in August 2004, 43 in November 2004 and 46 in May 2005 and the number of socks sampled per treatment ranged between 1 and 10, with two exceptions. In August 2004, Tx 20 from site 1 was not included in statistical analysis because only one sock could be sampled. In November 2004, Tx 40 from site 4, mussels from the bottom portion of the sock were absent due to high mortality or fall off.

Tables 3-1 to 3-3 show simple means and standard errors of means for shell length, CI and mussel density, respectively, with letter coding indicating statistical significance between treatments within each site and sampling period. Figures 3-3 to 3-6 display the temporal development of mussel length and CI over the one-year production cycle, separately for each site.

3.5.1. Shell length

At site 1, sampling dates, treatments and a date*Tx interaction variable were all significantly different ($P < 0.001$, $P < 0.001$ and $P < 0.001$ respectively). Final mussel shell length in May 2005 was significantly higher in socks spaced 80 cm apart (Tx 80), in comparison to socks spaced 20 cm apart (Tx 20), 10 cm apart (Tx 10) and 40 cm apart (Tx 40). In November 2004, mussel lengths from Tx 40 had grown significantly longer compared to Tx 10 and 20, while mussel lengths from Tx 80 were also significantly longer in comparison to Tx 10. During the first sampling frame in August 2004, shell lengths were significantly higher at Tx 80 in comparison to Tx10 and 40.

At site 2, sampling dates was significantly different ($P < 0.001$), while treatments and a date*Tx interaction variable were not different ($P = 0.08$ and $P = 0.18$ respectively).

At site 3 sampling dates and the date*Tx interaction variable were significantly different ($P < 0.001$, $P = 0.04$), while treatments were non significant, $P = 0.46$). Mussel shell lengths in May 2005 and November 2004 were similar at every treatment and displayed no significant association. However, in August 2004, shell lengths from all treatments were similar, with the exception of mussels from Tx 40, which were significantly smaller in comparison to other treatment groups.

At site 4, sampling dates, treatments and a date*Tx interaction variable were all significant different ($P < 0.001$, $P < 0.001$ and $P < 0.001$ respectively). Final mussel shell length in May 2005 showed orderly association among treatment groups. Shell length observed at Tx 80 was significantly higher in comparison to other treatment groups, while shell lengths from Tx 60 were also significantly higher than those observed at Tx 10. In November 2004, Tx 60 was significantly higher in comparison to other treatment groups, while Tx 20 and 80 were also significantly higher in comparison to Tx10. Results from August 2004 showed that Tx 80, 60 and 40 displayed superior shell lengths and were significantly larger than mussels from Tx 10 and 20.

At all four sites, Inter-Class Coefficients (ICC) were low (i.e. very little clustering within socks) for all sampling dates. ICC from sites 1, 2, 3, and 4 ranged from 0.015 to 0.077; 0.002 to 0.041; 0.0 to 0.013 and 0.008 to 0.035 respectively.

3.5.2. Condition index

The pattern observed at all sites was similar with an initial high condition index in May 2004, decreasing dramatically in August 2004 and steadily increasing for the rest of the sampling period. At site 1, 2, 3 and 4, CI decreased by 72%, 57%, 67% and 67% respectively. Again, ICC were low at all sites and ranged from 0.06 to 0.12; 0.03 to 0.12; 0.01 to 0.16 and 0.03 to 0.24 respectively

At site 1, sampling dates, treatments and a date*Tx interaction variable were all significant different ($P < 0.001$, $P = 0.003$ and $P = 0.04$ respectively). Final CI values in May 2005 were similar for all treatments and displayed no significant association. In November 2004, CI values from Tx 60 were significantly higher in comparison to other treatment groups, while in August 2004, CI values from Tx 80 was significantly higher in comparison to Tx 10.

At site 2, while sampling dates, treatments and a date*Tx interaction variable were all significant different ($P < 0.001$, $P < 0.001$ and $P = 0.002$ respectively). Final CI values in May 2005 and August 2004 were similar for all treatments and displayed no significant association. However, in November 2004, CI values from Tx 60 and 40 were significantly higher in comparison to Tx 10.

At site 3, sampling dates was significantly different ($P < 0.001$), while treatments and a date*Tx interaction variable were not different ($P = 0.37$ and $P = 0.27$ respectively). Associations between sock spacing treatment and CI showed similar temporal trends amongst all treatments, CI values displayed no associations to the sock spacing treatments.

At site 4, sampling dates and a date*Tx interaction variable were significantly different ($P < 0.001$, $P < 0.001$ respectively), while treatments was marginally significant ($P = 0.06$). Final CI values in May 2005 and August 2004 were similar for all treatments and displayed no significant association. In November 2004, CI from Tx 60 was significantly higher in comparison to Tx 10.

3.5.3. Mussel density

The pattern of reduction in mussel density over a one-year production cycle was higher in sites with high initial density levels and smaller size seed. Site 1 and 4 displayed a temporal reduction of 58% and 45% respectively, while site 2 and 3 temporal reduction equaled 39% and 30% respectively. Site 1 and 4 were on average respectively initially socked with 58% (540 mussels/m) and 47% (337 mussels/m) more mussels than site 2 and 3, while initial shell lengths from site1 and 4 were on average 46% (13.9 mm) and 23% (6.8 mm) smaller.

At site 1, sampling dates, treatments and a date*Tx interaction variable were all significant different ($P < 0.001$, $P < 0.001$ and $P < 0.001$ respectively). Final mussel density in May 2005 was significantly higher in Tx 80 in comparison to Tx 60, 10 and 40. In November 2004, mussel density from Tx 80 and 40 was significantly higher in comparison to Tx 10. In August 2004, mussel density from Tx 80 was significantly higher in comparison to Tx 40 and 10.

At site 2 and 3, sampling dates was significantly different ($P < 0.001$, $P < 0.001$ respectively), while treatments and a date*Tx interaction variable were not different at site 2 ($P = 0.57$ and $P = 0.59$ respectively) and site 3 ($P = 0.59$ and $P = 0.70$ respectively). Associations between sock spacing treatment and mussel density showed similar temporal trends amongst all treatments, mussel density displayed no associations to the sock spacing treatments.

At site 4, sampling dates, treatments and a date*Tx interaction variable were all significant different ($P < 0.001$, $P < 0.001$ and $P < 0.001$ respectively). Final mussel density in May 2005 was significantly higher in Tx 80 in comparison to Tx 20. In November 2004, mussel density from Tx 60 and 80 was significantly higher in comparison to Tx 10. In August 2004, mussel density results displayed no association between treatments groups.

3.6. Discussion

3.6.1. Shell length

In this study, we present a detailed report of the association between sock spacing and productivity of cultured pre-market mussels (M. edulis). Our approach was based on an extensive field trial conducted in Tracadie Bay, PEI, over a one-year production cycle. At two of the four sites, highest shell growth in May 2005 was observed on socks spaced 80 cm apart and was significantly higher than for most other sock spacing. In addition, socks spaced 10 cm apart were often located on the bottom tier and displayed poorest growth. At both of these sites, shell growth increased by 8% (3.4 mm) and 7% (3.4 mm) respectively when comparing low density levels (Tx 80) to high density levels (Tx 10) of cultured mussels. Since our shell growth results reflects those of half-grown mussels, it is biologically reasonable to assume a heighten correlation between sock spacing and the productivity of commercial size mussels due to greater filtration and food retention capability in larger mussels (Winter, 1978; Heasman et al., 1998). As for the two other sites, all sock spacing treatments displayed similar shell growth, and the non-significant shell growth differences between socks spaced 80 cm apart compared to socks spaced 10 cm apart averaged 2% (1.1 mm and 0.9 mm respectively). Both of these sites are owned and operated by the same leaseholder. Therefore, we can assume similar management strategies were applied over the course of the production cycle.

Results from this study provide additional information on the impact of increasing bivalve culture density on shell growth. Heasman and al. (1998) reported similar observations for mussels suspended from cultured rafts in South Africa. They found that spacing mussel socks 60 cm apart in comparison to 90 cm significantly reduced local food supply. Two likely factors contributing to this relationship were: (1) increased utilization of food particles in the vicinity of the mussel socks by densely aggregated grazers, and (2) decreased particle renewal due to reduction of water exchange associated with highly packed culture gear (e.g. Grant and Bacher, 2001). A multi-year survey (2002-2004) conducted in Tracadie Bay documented longline setup and quantified its association to mussel productivity. In 2002, farm level results showed that positioning mussel socks at a shorter distance on a longline was correlated with a reduction in sock weight (Drapeau et al., in press). It was hypothesized that the negative association between longline setup (i.e. close sock spacing) and productivity was only apparent at times of scarce food resources (Drapeau et al., in press). Results on growth performance from the Shellfish Monitoring Network (SMN) established by DFO suggest that phytoplankton quantity or quality fluctuates spatially and temporally in the southern Gulf of St. Lawrence.

3.6.2. Condition index

Dependence of the temporal variation of condition index (CI) on sock spacing in suspended culture mussels over a one year production cycle has not been well documented in the literature. Our results showed that final (May 2005) CI values were not significantly different among most sock spacing treatments in any of the Tracadie Bay leases. Throughout most of the production cycle, CI values in association to sock spacing treatments displayed no significant differences between treatments at various sampling dates. This relationship was consistently observed across Tracadie Bay leases. These results seem to indicate a lack of interaction between CI and sock spacing treatments, mussel density or seed size.

In autumn (November 2004), CI results showed an average increase of 14% (1.1 ± 0.5) from socks spaced 80 cm apart compared to socks spaced 10 cm apart across Tracadie Bay leases. This time of year in most bays and estuaries across PEI coincides with a sharp seasonal peak in primary production (fall bloom). Absorbed food by mussels is invested for the production of gamete (i.e. gametogenesis) and energy reserve for the upcoming winter (Cartier et al., 2004). This relationship was however not significant, but seems to suggest that decreasing cultured densities at the farm level could be a beneficial management strategy for increasing tissue-to-shell ratio and the overall quality of mussels.

CI drastically declined from the initial values in May 2004 to the values observed in August 2004. On average, CI decreased by 66% across Tracadie Bay leases but was followed by a gradual increase in tissue-to-shell ratio over time. This sudden reduction in CI over a four month period can be attributed to a rapid shell growth during the spring period (phytoplankton bloom). Young bivalves (one-year old) are reported to grow fast, converting all available energy into somatic growth and more specifically on gonadal growth on a seasonal basis (Gosling 2003). To a lesser extent, the reduction in CI could be related to spawning events. It is well documented that mussels in PEI can become sexually mature during their first year without being size (shell) specific (Brake et al., 2004). Spawning activity, on the other hand, is closely linked to food quantity and quality in order to produce ripe gametes during gametogenesis (Seed and Suchanek, 1992; Cartier et al., 2004).

3.6.3. Mussel density

The mussel density provides information about the survival of mussels over a year production cycle across Tracadie Bay. At two of the four sites, final mussel density (May 2005) results indicated positive associations with sock spacing treatments; highest mussel density was observed on socks spaced 80 cm apart. Mussel density differences between socks spaced 80 cm apart compared to socks spaced 10 cm apart averaged 42% (233 mussels/m) and 18% (87 mussels/m) respectively. These sites were also characterized has having high initial socking density and smaller seed size in May 2004. On average, initial socking density was 58% (540 mussels/m) and 47% (337 mussels/m) greater, while seed size was 46% (13.9 mm) and 23% (6.8 mm) smaller in comparison to sites which displayed no associations. Sites which displayed no significant associations in the response variables were owned and operated by the same lease holder. Again, we hypothesize that similar management strategies (seed size and mussel density) were applied over the course of the production cycle. Such management strategies in suspended culture have been shown as important factors affecting mussel productivity (Lauzon-Guay et al., 2005). Therefore, our results seem to suggest that dense cultured densities at the farm level from lower sock spacing, in addition to high mussel density inside the socks and small seed may have lead to decreased shell growth and increased mortality due to the a reduction in food resources due to intra-specific competition between individuals. Food demand at the farm level may exceed food supply which may limit growth (Frechette et al., 2000). Throughout this study, food resources were not quantified; but indirect evidence from the SMN showed that food abundance within Tracadie Bay varied spatially and temporally over the years.

Over the course of the production cycle, mussel density displayed a gradual and progressive temporal reduction of mussels across all sites in Tracadie Bay. The largest (58%) temporal reduction was observed at one of the sites, which had the smallest initial seed size (16.3 mm) and highest mussel socking (923 mussels/m). This result is consistent with those of Lauzon-Guay et al. (2005) who demonstrated a similar relationship in field trials conducted in PEI. Survival results after 10 months indicated an interaction between seed size and initial density. Survival of smaller seed was lower and dependent on density levels. Likely factors contributing to the differential survival may be associated to initial fall-off, predation or greater packing of seed at higher densities. Higher seed density possibly increases packing pressure inside the sock, which has been shown to reduced filtration rates in mussels directly linked to the difficulty of valve opening (Riisgard, 1991). This could explain the density-dependent loss.

Many aquaculturists view small seed as less valuable than larger seed. Since seed is sold by volume, the cost for larger number of small seed is the same as a lower number of large seed. Smaller seed as also been shown to reach commercial size in the same time period as larger seed, but often display lower survival rates (Lauzon-Guay et al., 2005). Developing good management strategies to reduce mortality such as increasing sock spacing and decreasing initial socking density of smaller seed could be a cost effective way of producing commercial size mussels.

3.7. Conclusion

This investigation provides the first detailed account of the association between shell growth, condition index and survival over a one-year production cycle in Tracadie Bay. Our extensive field survey showed that mussel socks spaced at lower density levels (Tx 80) consistently displayed superior shell growth and mussel density in comparison to other treatment groups at two of the four sites. Sites displaying significant associations were characterized as having higher initial socking density per meter (58% and 47% respectively) and smaller seed mussels (46% and 23% respectively) in comparison to sites which displayed no differences between sock spacing treatment. Our results have generated information for growers on the relative cost and benefits of various socks spacing and their associations to productivity. Additional work is needed to clarify the association between seed size and mussel density and their impact on productivity.

3.8. References

Abbe, G.R., Albright, B.W., 2003. An improvement to the determination of meat condition index for the eastern oyster Crassostrea virginica (Gmelin 1971). J. Shellfish Res.22, 747-752.

Boyd, A.J., Heasman, K.G., 1998. Shellfish mariculture in the Benguela system: Water flow patterns within a mussel farm in Saldanha Bay, South Africa. J. Shellfish Res.17, 25-32.

Brake, J., Davidson, J., Davis, J., 2004. Field observations on growth, gametogenesis, and sex ratio of triploid and diploid Mytilus edulis. Aquaculture 236, 179-191.

Camacho, A.P., Labarta, U., Beiras, R., 1995. Growth of mussel (Mytilus edulis galloprovincialis) on cultivation rafts: Influence of seed source, cultivation site and phytoplankton availability. Aquaculture 138, 349-362.

Cartier, S., Pellerin, J., Fournier, M., Tamigneaux, E., Girault, L., Lemaire, N., 2004. Use of an index based on the blue mussel (Mytilus edulis and Mytilus trossulus) digestive gland weight to assess the nutritional quality of mussel farm sites. Aquaculture 241, 633-654.

Carver, C.E.A., Mallet, A.L., 1990. Estimating the carrying-capacity of a coastal inlet for mussel culture. Aquaculture 88, 39-53.

Dame, R., Prins, T.C., 1998. Bivalve carrying capacity in coastal ecosystems. Aquat. Ecol. 31, 409-421.

Dohoo, I., Martin, W., Stryhn, H., 2003. Mixed models for continuous data. In: Veterinary Epidemiologic Research, AVC Inc, Charlottetown, PE, Canada. pp. 473-498.

Dolmer, P., 2000. Algal concentration profiles above mussel beds. J. Sea Res. 43, 19-36.

Dowd, M., 1997. On predicting the growth of cultured bivalves. Ecol. Model. 104, 113-131.

Dowd, M., 2003. Oceanography and shellfish production: A bio-physical synthesis using a simple model. Bull. Aquacult. Assoc. Can.100 (2), 3-9.

Dowd, M., Page, F.H., Losier, R., McCurdy, P., Bugden, G., 2001. Physical oceanography of Tracadie Bay, PEI: Analysis of sea level, current, wind and drifter data. Can. Tech. Rep. Fish. Aquat. Sci. 2347: iii+ 77p.

Drapeau, A., Comeau, L.A, Landry, T., Stryhn, H., Davidson, J., in press. Association between longline setup and mussel productivity in Prince Edward Island, Canada. Aquaculture.

Frechette, M., Bourget, E., 1985a. Energy flow between the pelagic and benthic zones: factors controlling particulate organic matter available to an intertidal mussel bed. Can. J. Fish. Aquat. Sci. 42, 1158-1165.

Frechette, M., Bourget, E., 1985b. Food-limited growth of Mytilus edulis L. in relation to the benthic boundary-layer. Can. J. Fish. Aquat. Sci. 42, 1166-1170.

Frechette, M., Bergeron, P., Gagnon, P., 1996. On the use of self-thinning relationships in stocking experiments. Aquaculture 145, 91-112.

Frechette, M., Gaudet, M., Vigneau, S., 2000. Estimating optimal population density for intermediate culture of scallops in spat collector bags. Aquaculture 183, 105-124.

Grant, J., Bacher, C., 2001. A numerical model of flow modification induced by suspended aquaculture in a Chinese bay. Can. J. Fish. Aquat. Sci. 58, 1003-1011.

Gosling, E., 2003. Bivalve Molluscs: Biology, Ecology and Culture. Fishing New Books, Oxford, UK, 443 pp.

Heasman, K.G., Pitcher, G.C., McQuaid, C.D., Hecht, T., 1998. Shellfish mariculture in the Benguela system: Raft culture of Mytilus galloprovincialis and the effect of rope spacing on food extraction, growth rate, production, and condition of mussels. J. Shellfish Res.17, 33-39.

Landry, T., 2003. Development and evaluation of standardized monitoring and data acquisition systems for the management of mollusc culture in Atlantic Canada. Bull. Aquacult. Assoc. Can.102 (3), 102.

Landry, T., Davidson, J., and Arsenault, G. in press. The development of a data acquisition tool for the blue mussel (Mytilus edulis) culture industry on Prince Edward Island. Can. Tech. Rep. Fish. Aquat. Sci.

Lauzon-Guay, J.S., Dionne, M., Barbeau, M.A., Hamilton, D.J., 2005. Effects of seed size and density on growth, tissue-to-shell ratio and survival of cultivated mussels (Mytilus edulis) in Prince Edward Island, Canada. Aquaculture 250, 652-665.

Lea, L., 2002. Mussel Aquaculture Management Plan for Tracadie Bay, Prince-Edward Island. February 2002. 6 p.

Leblanc, A.R., Landry, T., Miron, G., 2003. Fouling organisms of the blue mussel Mytilus edulis: Their effect on nutrient uptake and release. J. Shellfish Res.22, 633-638.

Newell, C.R., 1990. The effect of mussel (Mytilus edulis, Linnaeus, 1758) position in seeded bottom patches on growth at subtidal lease sites in Maine. J. Shellfish Res. 9, 113-118.

Newell, C.R., 2001. Sustainable mussel culture: A millennial perspective. Bull. Aquacult. Assoc. Can. 101 (2), 15-21.

Nunes, J.P., Ferreira, J.G., Gazeau, F., Lencart-Silva, J., Zhang, X.L., Zhu, M.Y., Fang, J.G., 2003. A model for sustainable management of shellfish polyculture in coastal bays. Aquaculture 219, 257-277.

Penney, R.W., McKenzie, C.H., Mills, T.J., 2001. Assessment of the particulate food supply available for mussel (Mytilus spp.) farming in a semi-enclosed, northern inlet. Estuar. Coast. Shelf S. 53, 107-121.

Petersen, J.K., 2004. Grazing on pelagic primary producers—the role of benthic suspension feeders in estuaries, p. 129-152. *In* S. L. Nielsen, G. T. Banta, and M. F. Pedersen [eds.], The influence of primary producers on estuarine nutrient cycling. Kluwer.

Riisgard, H.U., 1991. Filtration rate and growth in the blue mussel, Mytilus edulis Linnaeus, 1758: Dependence on algal concentration. J. Shellfish Res.10, 29-35.

Seed, R., Suchanek, T.H., 1992. Population and community ecology of Mytilus. In: Gosling, E. (Ed.), The Mussel Mytilus: Ecology, Physiology, Genetics and Culture. Elsevier, New York, NY, pp. 87-169.

Smith, G., 2005. PEI Mussel Monitoring Program 2004 Report. P. E. I. Tech. Report. 235: 94pp.

Waite, L.E., Grant, J., Davidson, J., 2005. Bay-scale spatial growth variation of mussels (Mytilus edulis) in suspended culture, Prince Edward Island, Canada. Mar. Ecol.-Prog. Ser. 297, 157-167.

Wildish, D.J., Kristmanson, D.D., 1979. Tidal energy and sublittoral macrobenthic animals in estuaries. J. Fish. Res. Board Can. 36, 1197-1206.

Winter, J.E., 1978. A review on the knowledge of suspension-feeding in Lamellibranchiate bivalves, with special reference to artificial aquaculture systems. Aquaculture 13, 1-33.

Table 3-1 Mean shell length with standard error of the mean (SE) per 0.3 m of mussel sock at four sites and four sampling periods.

Site	May 2004		Tx (cm)	Sampling periods: August 2004		November 2004		May 2005	
	Mean	SE		Mean	SE	Mean	SE	Mean	SE
			10	28.2^{a}	0.16	37.1^{a}	0.22	40.4^{a}	0.17
			20	33.0*	0.70	38.2^{ab}	0.15	41.2^{a}	0.20
1	16.3	0.08	40	29.1^{a}	0.13	40.3^{c}	0.15	39.5^{a}	0.23
			60	29.9^{ab}	0.11	38.4^{abc}	0.19	42.0^{ab}	0.20
			80	30.1^{b}	0.11	40.1^{bc}	0.16	43.8^{b}	0.16
			10	43.7^{a}	0.17	50.4^{a}	0.16	51.5^{a}	0.19
			20	43.4^{a}	0.17	50.4^{a}	0.16	52.5^{a}	0.17
2	29.3	0.14	40	43.6^{a}	0.17	50.2^{a}	0.16	52.7^{a}	0.18
			60	43.8^{a}	0.16	50.6^{a}	0.16	52.0^{a}	0.20
			80	43.9^{a}	0.17	51.2^{a}	0.16	52.6^{a}	0.20
			10	43.4^{b}	0.20	50.1^{a}	0.17	52.5^{a}	0.18
			20	43.4^{b}	0.21	51.0^{a}	0.16	52.8^{a}	0.18
3	31.1	0.16	40	41.3^{a}	0.27	51.3^{a}	0.16	52.4^{a}	0.18
			60	43.6^{b}	0.19	50.7^{a}	0.17	52.9^{a}	0.19
			80	43.6^{b}	0.17	50.9^{a}	0.19	53.4^{a}	0.17
			10	38.6^{a}	0.12	41.7^{a}	0.35	45.1^{a}	0.13
			20	38.3^{a}	0.12	43.5^{b}	0.15	46.0^{ab}	0.14
4	23.4	0.09	40	39.8^{b}	0.10	N/A	N/A	46.5^{b}	0.14
			60	39.9^{b}	0.10	47.0^{c}	0.16	46.6^{b}	0.14
			80	40.1^{b}	0.12	44.3^{b}	0.20	48.5^{c}	0.15

$^{a\text{-}c}$ Within each site and period, treatment means without a common superscript were significantly different ($P < 0.005$)

Tx: sock spacing treatments
cm: centimeter
*not included in statistical analysis due to small sample size

Table 3-2 Mean condition index with standard error of the mean (SE) per 0.3 m of mussel sock at four sites and four sampling periods.

Site	May 2004		Tx (cm)	Sampling periods					
				August 2004		November 2004		May 2005	
	Mean	SE		Mean	SE	Mean	SE	Mean	SE
			10	5.7 [a]	0.33	6.1 [a]	0.21	10.2 [a]	0.17
			20	7.3*	0.69	7.8 [a]	0.28	9.6 [a]	0.20
1	25.1	0.26	40	6.7 [ab]	0.26	7.3 [a]	0.31	10.7 [a]	0.25
			60	7.3 [ab]	0.30	8.9 [b]	0.42	11.2 [a]	0.25
			80	7.9 [b]	0.33	7.6 [a]	0.24	10.1 [a]	0.18
			10	10.7 [a]	0.24	10.6 [a]	0.27	13.2 [a]	0.25
			20	11.8 [a]	0.27	11.8 [ab]	0.45	13.0 [a]	0.30
2	26.1	0.31	40	10.3 [a]	0.27	12.7 [b]	0.43	12.0 [a]	0.23
			60	11.1 [a]	0.29	12.5 [b]	0.34	14.3 [a]	0.28
			80	11.7 [a]	0.23	11.7 [ab]	0.32	11.9 [a]	0.28
			10	9.4 [a]	0.31	11.5 [a]	0.35	12.5 [a]	0.28
			20	9.5 [a]	0.22	11.0 [a]	0.27	13.1 [a]	0.22
3	27.2	0.25	40	9.6 [a]	0.31	11.2 [a]	0.31	13.2 [a]	0.27
			60	8.7 [a]	0.28	11.6 [a]	0.30	12.9 [a]	0.29
			80	8.5 [a]	0.25	11.8 [a]	0.34	13.3 [a]	0.30
			10	7.6 [a]	0.24	7.3 [a]	0.30	9.3 [a]	0.17
			20	8.3 [a]	0.21	8.4 [ab]	0.27	9.6 [a]	0.16
4	22.6	0.29	40	6.9 [a]	0.23	N/A	N/A	9.6 [a]	0.16
			60	7.3 [a]	0.24	10.1 [b]	0.29	9.9 [a]	0.21
			80	6.8 [a]	0.20	8.7 [ab]	0.41	10.7 [a]	0.20

[a-c] Within each site and period, treatment means without a common superscript were significantly different ($P < 0.005$)

Tx: sock spacing treatments
cm: centimeter
* not included in statistical analysis due to small sample size

Table 3-3 Mean mussel density with standard error of the mean (SE) per 0.3 m of mussel sock at four sites and four sampling periods.

Site	May 2004		Tx (cm)	Sampling periods					
				August 2004		November 2004		May 2005	
	Mean	SE		Mean	SE	Mean	SE	Mean	SE
1	277	10	10	163 [a]	25	75 [a]	15	98 [a]	15
			20	59*	0	121 [ab]	14	114 [ab]	16
			40	231 [b]	28	154 [bc]	11	90 [a]	15
			60	274 [bc]	26	104 [ab]	23	99 [a]	17
			80	304 [c]	14	186 [c]	19	168 [b]	13
2	130	13	10	90 [a]	8	80 [a]	7	89 [a]	11
			20	93 [a]	7	95 [a]	8	87 [a]	6
			40	91 [a]	8	84 [a]	8	67 [a]	10
			60	90 [a]	9	93 [a]	9	72 [a]	4
			80	93 [a]	7	85 [a]	8	67 [a]	3
3	100	3	10	92 [a]	5	78 [a]	5	67 [a]	5
			20	88 [a]	5	77 [a]	6	69 [a]	4
			40	105 [a]	11	84 [a]	6	75 [a]	3
			60	85 [a]	4	72 [a]	5	69 [a]	4
			80	83 [a]	9	66 [a]	5	72 [a]	5
4	217	7	10	151 [a]	7	21 [a]	3	120 [ab]	7
			20	162 [a]	6	98 [b]	15	103 [a]	8
			40	161 [a]	8	N/A	N/A	115 [ab]	11
			60	160 [a]	5	149 [c]	14	115 [ab]	7
			80	159 [a]	8	106 [bc]	27	146 [b]	13

[a-c] Within each site and period, treatment means without a common superscript were significantly different ($P < 0.005$)

Tx: sock spacing treatments
cm: centimeter
* not included in statistical analysis due to small sample size

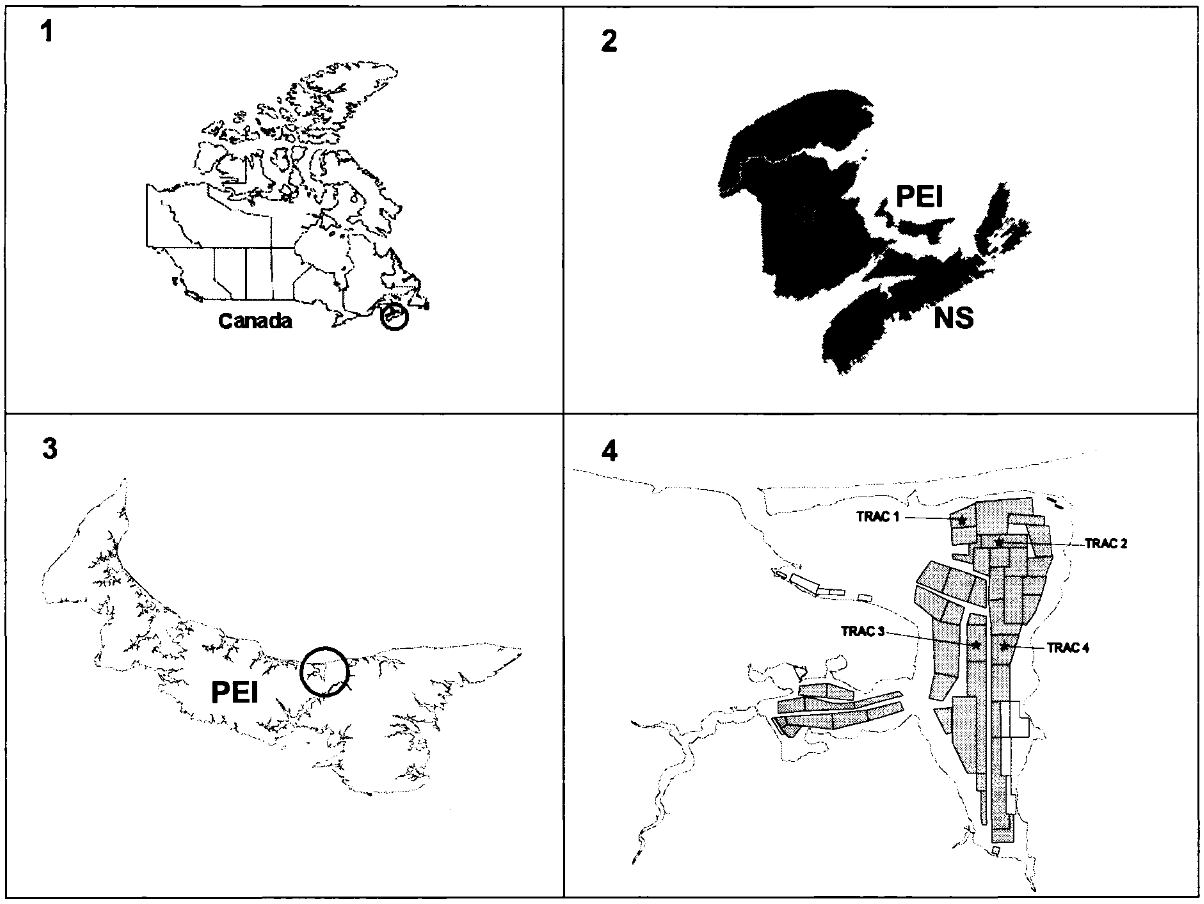

Figure 3-1 Map of Canada (1), with inserts of map of Atlantic Canada (2), Prince Edward Island (3) and Tracadie Bay (4). Gray areas indicate location of mussel aquaculture leases (Department of Fisheries and Oceans, Canada). The black stars indicate the location of our experimental sites.

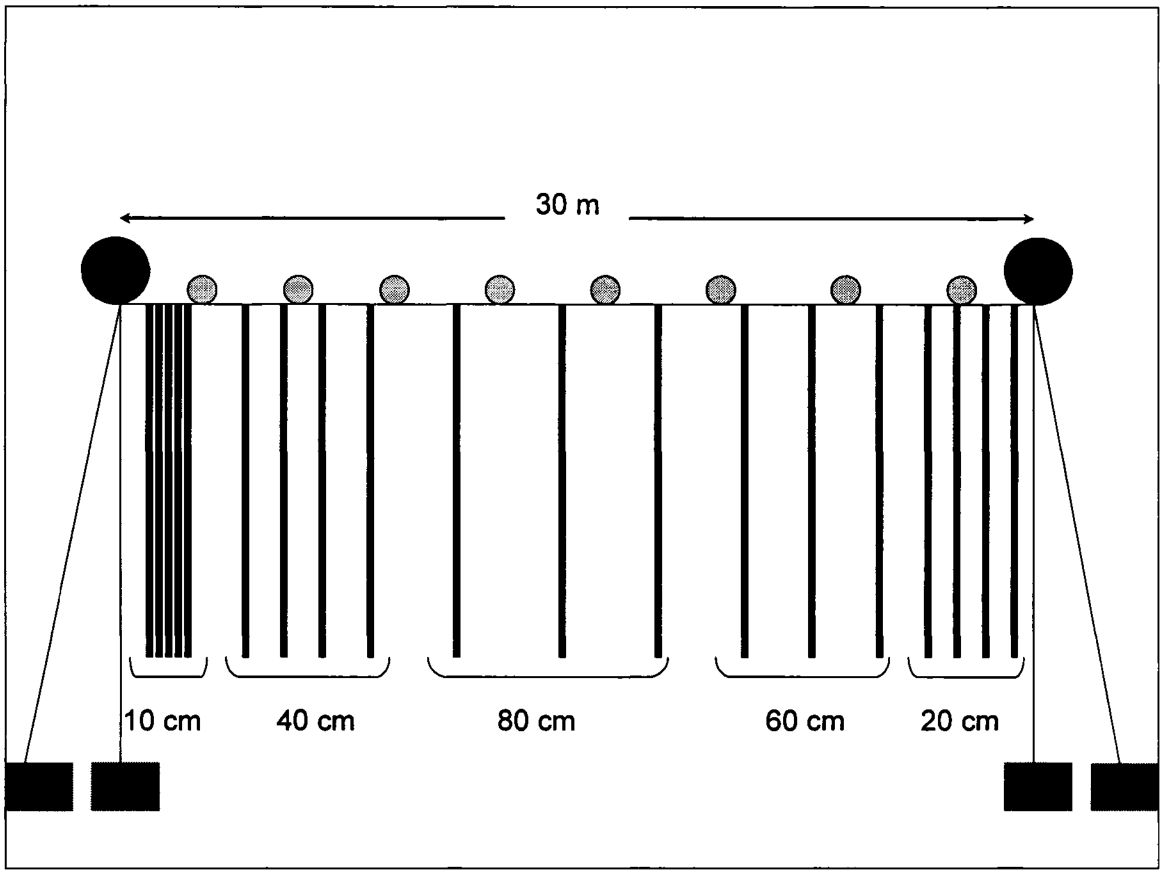

Figure 3-2 Schematic representation of a longline containing blocks of socks; an actual longline contained three blocks. Each block contained 15 replicates of each sock spacing treatment: 10, 20, 40, 60, and 80 cm. There was one longline per site.

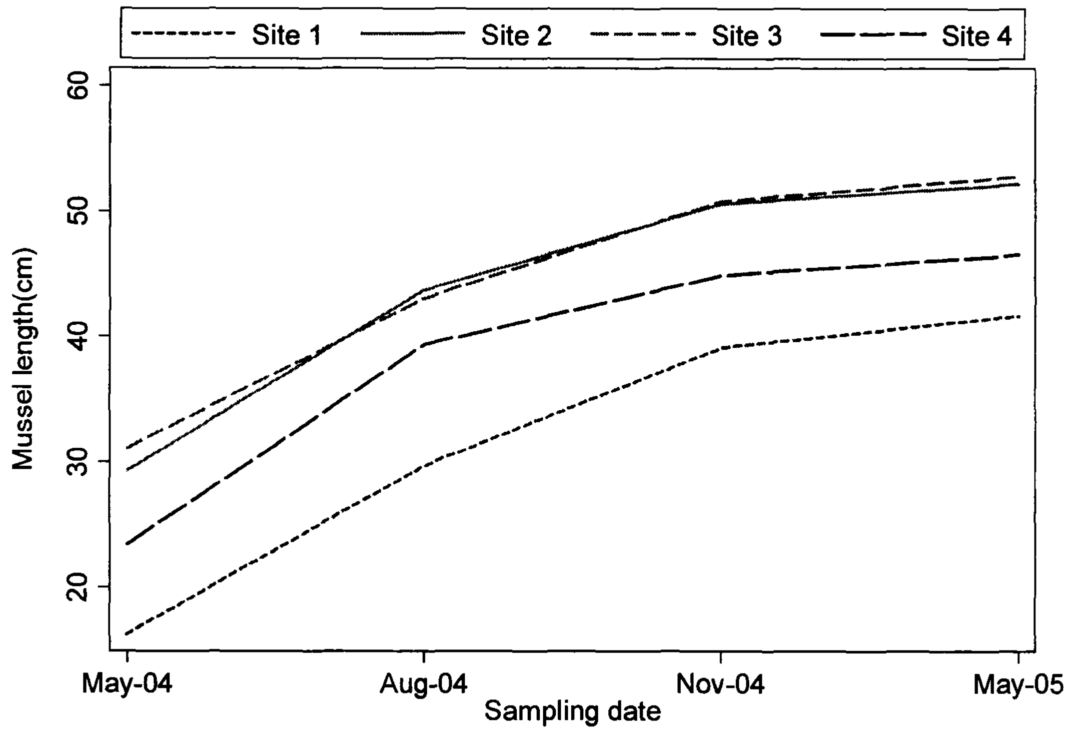

Figure 3-3 Mean shell length at each sampling date and sites in Tracadie Bay, PEI, Canada.

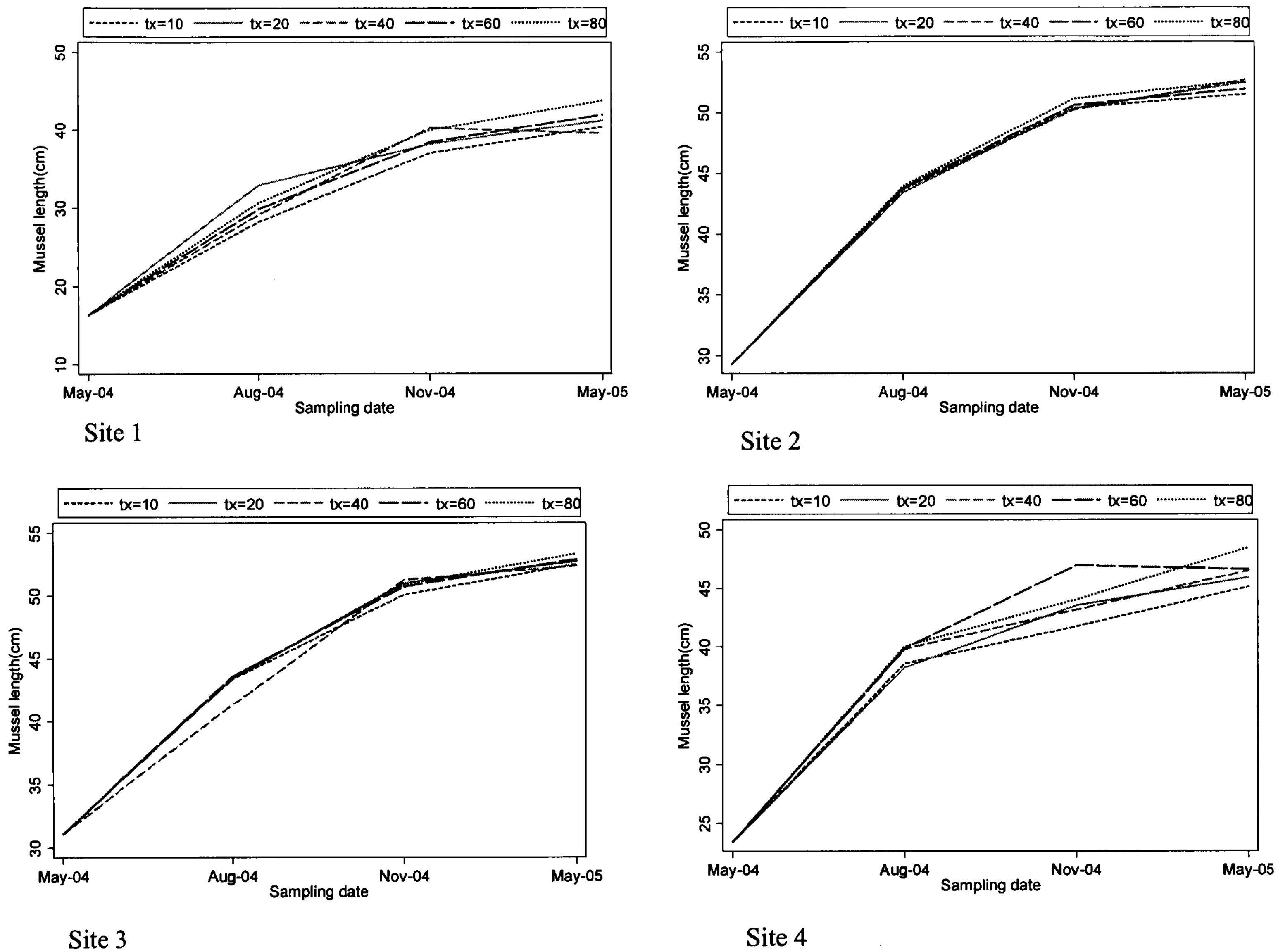

Figure 3-4 Mean shell length at each sampling date and site for five sock spacing treatments in Tracadie Bay, PEI, Canada.

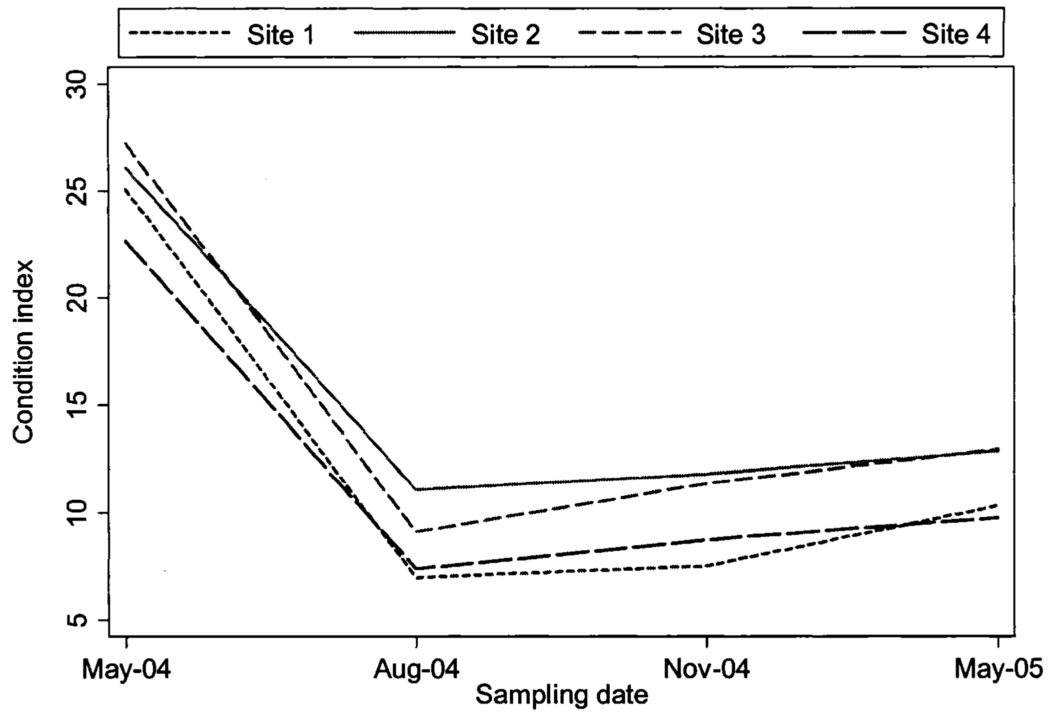

Figure 3-5 Mean mussel condition index at each sampling date and sites in Tracadie Bay, PEI, Canada.

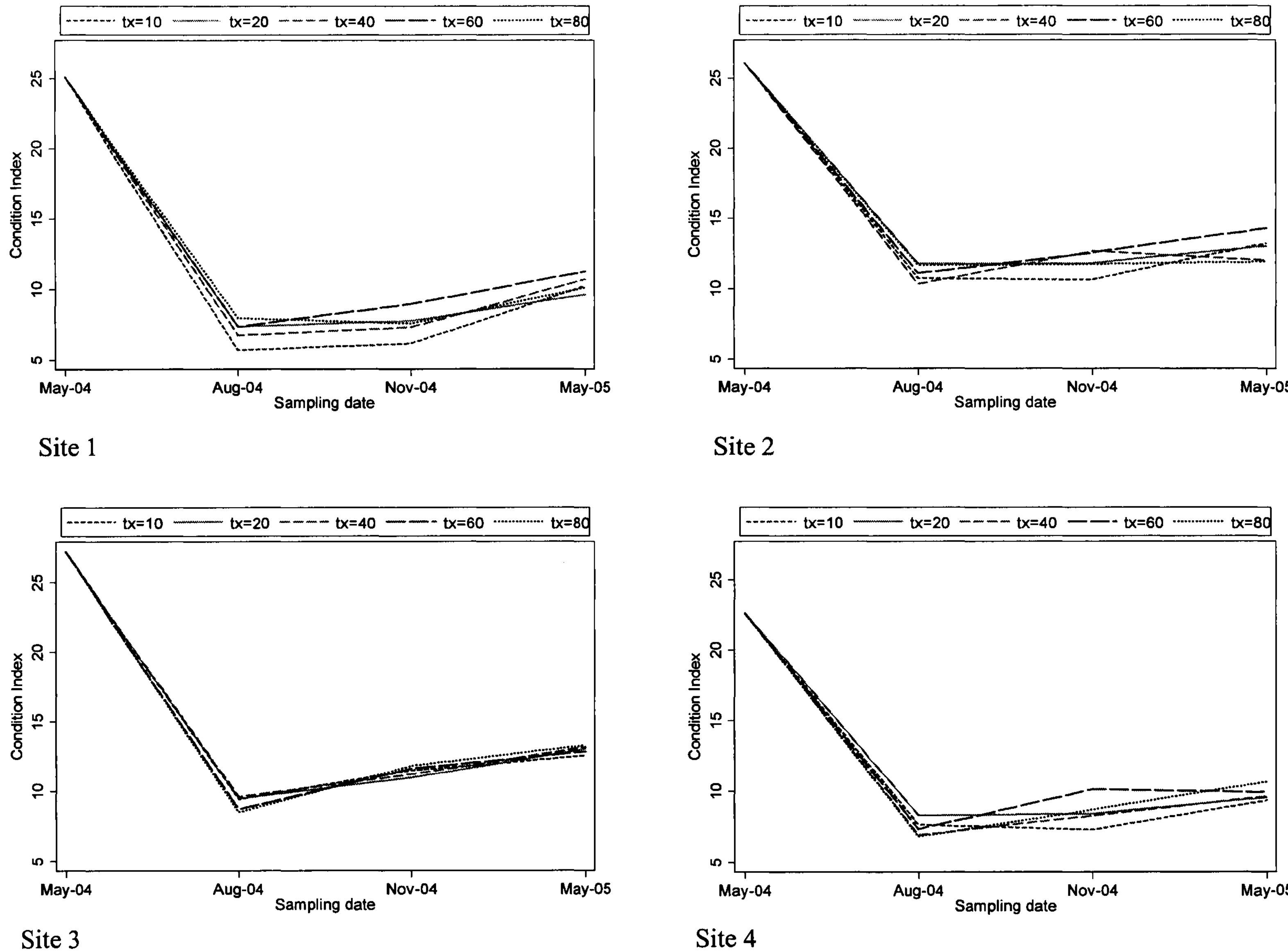

Figure 3-6 Mean shell length at each sampling date and site for five sock spacing treatments in Tracadie Bay, PEI, Canada.

Chapter 4 GENERAL CONCLUSION

The mussel (Mytilus edulis) aquaculture industry of PEI has grown exponentially over the past 25 years by adapting the subsurface longline system and by doing so; it has become the largest member of the aquaculture sector. However, in recent years this industry has been challenged by the leveling in production levels, due to limited expansion for new farming operations and with the arrival and colonization of invasive species in many embayments around PEI. These filter-feeding tunicates species may impact the production capacity of most embayments around PEI. However, to this date, it remains unclear whether the variability in productivity across PEI is due mainly to environmental factors or longline setup. Also, the coupling between longline setup and mussel performance is still poorly understood in quantitative and predictive terms. Therefore, the purpose of our research was to examine the design of longlines around PEI and quantify its association to productivity.

The first part of the study was designed to identify risk factors which could potentially impact productivity. Longline design was documented across PEI leases and more particularly in Tracadie Bay to determine its associations to productivity. The results showed that longline design varied temporally in Tracadie Bay over the three year survey: sock spacing increased by 30% (+11 cm) and was directly correlated to a 28% (5.6 socks/100 m^2) reduction of lease stocking density. Regression analysis showed that sock spacing was positively correlated with sock weight and condition index; for every 10 cm increase in sock spacing, sock weight increase by 1.24 kg and condition index by 1.59. Regression analysis conducted across PEI showed that longline design was correlated to the level of farming with a growing area; for every 100 hectare increase of farming, sock spacing increase 6% (2.6 cm), while stocking density decreased by 24% (5.6 socks/100 m^2) respectively. A third correlation indicated that the condition index was significantly lower within embayments characterized by extensive farm coverage compared to those with little farming development. It was hypothesized that the negative association between longline design and productivity was only apparent at times of scarce food resources, however one is left wondering how often food resources becomes limiting to merit reductions of cultured mussels through longline modification.

The second experiment conducted was designed to investigate the effect of sock spacing treatments on productivity of mussels across four leases in Tracadie Bay over a one-year production cycle. Mussel socks were spaced at intervals of 10 cm, 20 cm, 40 cm, 60 cm and 80 cm. Results from this large scale experiment showed that in two of the four leases in Tracadie Bay shell growth and survival displayed a positive association to higher socks spacing treatments. Comparing shell growth on socks spaced 80 cm versus those spaced 10 cm lead to average increase of 8% (3.4 mm) and 7% (3.4 mm) respectively, while mussel density increased by 42% (233 mussels/m) and 18% (87 mussels/m) respectively. When all management strategies (i.e. socking density and seed size) were kept constant, the association between sock spacing treatments and productivity were non-significant. It is noteworthy to add that both of these sites were owned and operated by the same leaseholder. It was hypothesized that significant associations between sock spacing treatments and shell growth at two of the four sites may be due to higher initial density and smaller seed mussels. On average, initial socking density was 58% (540 mussels/m) and 47% (337 mussels/m) greater, while seed size was 46% (13.9 mm) and 23% (6.8 mm) smaller in comparison to sites which displayed no associations to sock spacing treatments. Dense bivalve levels at the farm scale and inside mussel socks may lead to intra-specific competition between individual as food demand may exceed food supply and ultimately limit growth.

Results from these studies have demonstrated that isolating one predictor variable (i.e. sock spacing) did not give us a clear picture of the environmental effects on productivity, but rather illustrates the complexity of the ecosystem for the production of marketable mussels. Our results identified two possible risk factors which were not taken into consideration during the controlled trial set-up. We hypothesized that initial seed size and seeding density played a pivotal role in impacting productivity over the one-year production cycle in Tracadie Bay. Further investigations are needed to determine the extent of the association on mussel productivity.

These are the first studies which presents a detailed documentation of farm management practices and its association to longline mussel culture across PEI. Results from this study has generated information for growers on the relative cost and benefits of various socks spacing and there associations to productivity. If one could recommend specific longline set-up of pre-market mussels for growers of PEI, these would have to be base upon our Island Wide Survey averages: 2 m sock length, 12 m longline spacing, 44 cm sock spacing, which would represent a lease stocking density of 23 socks/100 m^2.

These studies also revealed that, in mussels, the effect of longline setup on productivity fluctuations is still not well understood and more works needs to be done to quantify the spatial and temporal variability in food concentrations across PEI embayments. However, results from our studies have shown that simple longline modifications can have a positive effect on productivity. When scaling the 2002-2004 relationship on sock spacing to bay production levels in Tracadie Bay, we find that an 11-cm increase in sock spacing would reduce the sock deployment and any related husbandry effort by 22%. Landing values obtained from DFO-Statistics (G, Nowlan, DFO, Moncton, NB) showed that over the three years reducing cultured densities across Tracadie Bay actually lead to a 3% (55,271 kg) increase in production levels.

Future directions:

1. Investigate temporal and spatial phytoplankton species composition and concentration in relation to longline setup and their possible correlation to bivalve growth.
2. Based on the results of the above studies, develop models for assessing the carrying capacity for the commercial production of mussels in Tracadie Bay.
3. Initiate an ongoing longline setup and environmental monitoring program which would be essential for the mussel industry planning and development. It is recommended the DFO should re-instate SMN; a standardized system for the monitoring of natural growth rates and physiological conditions of mussels across PEI leases. Husbandry data could be correlated with shellfish productivity and serve as a tool for assessing yearly growth trends.

4. Investigate the temporal and spatial association of stocking density in relation to farm level longline setup.
5. Investigate the relationship of longline setup and adult mussels and their correlation to longline setup in PEI mussel farms.
6. Encourage growers to collect accurate records on mussel growth at their farms on a regular basis. This valuable information regarding lease stocking density levels could be used in determining optimum production levels at the lease and bay level.