The effect of sock spacing on the productivity of mussel on a longline system

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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 (sock spacing treatments [Tx]) 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 relations 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 (i.e. Tx 80) 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.

RÉSUMÉ

Dans le domaine de la culture des moules bleues (*Mytilus edulis*) suspendues, le lien entre l'espacement des boudins et le rendement de moules sur un système de filières jamais n'a été démontré expérimentalement. Par conséquent, l'objectif de cette étude fut de comparer la productivité des boudins de moules espacés de 10 centimètres, 20 centimètres, 40 centimètres, 60 centimètres et 80 centimètres sur une filière. Une expérience à grande échelle fut entreprise dans des secteurs distincts de la baie de Tracadie à l'ÎPÉ, pendant un cycle d'une année de production. La croissance des coquilles et la survie des moules avant leur vente furent démontrées comme étant significativement reliées à un espacement plus élevé des boudins, alors que l'index de condition ne démontra aucune relation temporelle ou spatiale avec les divers espacements des boudins. À deux des quatre emplacements d’expérimentation, à la fin du cycle de production, les résultats démontrèrent que des niveaux significativement plus élevés de croissance et de survie étaient atteints sur les boudins espacés de 80 centimètres. La croissance des coquilles augmenta de 8% (3.4 millimètres) et de 7% (3.4 millimètres), tandis que le taux de survie fut de 42% (233 moules/m) et 18% (87 moules/m) plus élevé, si l’on compare les densités faibles (Tx 80) aux densités élevées (Tx 10) de moules cultivées. Quand toutes les stratégies de gestion (c.-à-d. la densité des boudins et la taille des moules d’ensemencement) étaient maintenues constantes, la relation entre l’espacement des boudins et la productivité était non significative. Les différences significatives entre les espacements de boudins à deux des quatre emplacements peuvent être dues à une densité initiale élevée de boudins et à la taille inférieure des moules d’ensemencement. Les emplacements démontrant des relations significatives avec l’espacement des boudins produisirent 58% et 47% plus de moules par mètre, alors que les moules d’ensemencement étaient 46% et 23% plus petites. La concentration élevée des bivalves dans la ferme maricole et à l’intérieur des boudins peut mener à une concurrence intraspécifique entre les individus, alors que la demande de nourriture au niveau local peut dépasser l'offre et finalement limiter la croissance. Les niveaux de nourriture à l’échelle locale ne furent pas mesurés pendant cette étude, mais dans cette région maricole, ils sont confirmés comme étant très variables dans le temps et dans l'espace.

INTRODUCTION

Blue mussel (*Mytilus edulis*) culture in Prince Edward Island (PEI, Figure 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 mussel 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 strain 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 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., 2006). 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), 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 (Fréchette et al., 1996; Dowd, 1997; Heasman et al., 1998; Penney et al., 2001). The grazing potential of dense aggregations of bivalves has 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; 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; Fréchette 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 are 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 link between sock spacing and mussel productivity on four grow-out leases in Tracadie Bay, PEI by means of a controlled trial.

MATERIALS AND METHODS

STUDY AREA

Tracadie Bay is a semi-enclosed coastal inlet connected to the Gulf of St. Lawrence by a single narrow channel through a sand dune barrier beach. 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, rapidly renewed tidal currents from outside the embayment from the Gulf of St. Lawrence, and relatively quick mussel growth. However, the inner most part of the bay is characterized by slower growth, reduced water flow and increased food utilization from the cultured population (Waite et al., 2005).

EXPERIMENTAL SITES

Experimental sites (Figure 1) were selected based on a husbandry survey conducted in Tracadie Bay (2003) (Drapeau et al., 2006) 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 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 thus management practices were very similar.

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 from site to site. Mussel socks were spaced at intervals (sock spacing treatments [Tx]) of 10 cm, 20 cm, 40 cm, 60 cm and 80 cm to evaluate the effect 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., 2006): 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 effect on productivity. On each longline, sock spacing treatments were deployed in a randomized block design (Figure 2), in which 15 socks of each treatment were arrayed over the entire longline in triplicate.

SAMPLING PROTOCOL

Samples were collected on four periods over a one-year production cycle. During the initial setup on May 11th 2004, baseline information was collected from 10 convenient mussel socks, 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 period, one replicate from each site was selected for sampling and only sampled once during the study. For each treatment, 10 socks were randomly (generated number) selected from the 13 inner socks, in order to minimize possible shadowing effects from neighboring socks of other treatment groups. Productivity analyses 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 interactions with the benthos, while the remaining 0.3 m was labeled and stored frozen at -20°C until processed.

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 meter). 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 recorded. 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 (i.e. increased power) 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):

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

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 to previous models. The statistical analyses were performed using Stata software (version 9; Stata Corporation, College Station, Texas); the linear mixed models analyses used the "xtreg" command.

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, 47, 49 and 42 socks 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 1 to 3 show sample 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 to 6 display the temporal evolution of mussel length and CI over the one-year production cycle, separately for each site.

SHELL LENGTH

At site 1, shell lengths were significantly different when compared among sampling dates (SD) ($P < 0.001$), treatments (Tx) ($P < 0.001$) and an SD*Tx interaction ($P < 0.001$) variable. 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 (**Tx 20**), 10 cm (**Tx 10**) and 40 cm apart (**Tx 40**). In November 2004, mussel lengths from **Tx 40** had grown significantly longer compared to those from **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, shell lengths were significantly different between SD ($P < 0.001$), while Tx and a SD*Tx interaction variables were not significantly different ($P = 0.08$ and $P = 0.18$ respectively).

At site 3, shell lengths were significantly different between SD ($P < 0.001$) and the SD*Tx interaction ($P = 0.04$) variable, while Tx were not significantly different ($P = 0.46$). Mussel shell lengths in May 2005 and November 2004 were similar under 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 with all other treatment groups.

At site 4, shell lengths were significantly different between SD ($P < 0.001$), Tx ($P < 0.001$) and an SD*Tx interaction ($P < 0.001$) variable. 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 by comparison to other treatment groups, while **Tx 20** and **80** were also significantly higher in comparison to **Tx 10**. 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's 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.

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, CI were significantly different between SD ($P < 0.001$), Tx ($P = 0.003$) and SD*Tx interaction ($P = 0.04$) variable. 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, CI were significantly different between SD ($P < 0.001$), Tx ($P < 0.001$) and SD*Tx interaction ($P = 0.002$) variable. 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, CI was significantly different between SD ($P < 0.001$), while Tx ($P = 0.37$) and SD*Tx interaction ($P = 0.27$) variable were not significantly different. 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, CI were significantly different between SD ($P < 0.001$), SD*Tx ($P < 0.001$), while Tx was marginally significant ($P = 0.06$). Final CI values in May 2005 and August 2004 were similar for all sock spacing treatments and displayed no significant association. In November 2004, CI from Tx 60 was significantly higher in comparison to Tx 10.

MUSSEL DENSITY

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

At site 1, mussel density was significantly different between SD ($P < 0.001$), Tx ($P < 0.001$) and SD*Tx ($P < 0.001$). 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, mussel density was significantly different between SD ($P < 0.001$, $P < 0.001$ respectively), while Tx ($P = 0.57$, $P = 0.59$ respectively) and a SD*Tx ($P = 0.59$, $P = 0.70$ respectively) were not significantly different. Associations between sock spacing treatment and mussel density showed similar temporal trends amongst all treatments, mussel density displayed no effect from the sock spacing treatments.

At site 4, mussel density was significantly different between SD ($P < 0.001$), Tx ($P < 0.001$) and SD*Tx ($P < 0.001$). 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 relation between treatments groups.

DISCUSSION

SHELL LENGTH

In this study, we present a detailed report of the effect of sock spacing on the 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, the 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 (1 and 4), shell growth increased by 8% (3.4 mm) and 7% (3.4 mm) respectively when comparing higher sock spacing (Tx 80) to smaller sock spacing (Tx 10) of cultured mussels. Since our shell growth results reflects those of half-grown mussels, it is from a biological perspective reasonable to assume a heightened correlation between sock spacing and the productivity of commercial size mussels due to the greater filtration and food retention capability in larger mussels (Winter, 1978; Heasman et al., 1998).

In the two other sites (2 and 3), 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 et 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 densely 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 with 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., 2006). It was hypothesized that the negative relation between longline setup (i.e. close sock spacing) and productivity was only apparent at times of scarce food resources (Drapeau et al., 2006). Growth performance reported by the Shellfish Monitoring Network (SMN) established by DFO suggests that phytoplankton quantity or quality fluctuates spatially and temporally in the southern Gulf of St. Lawrence.

CONDITION INDEX

Effect 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. This result might be related to the ineffectiveness of CI analysis to accurately determine differences among mussels within a growing area. In order to increase sensitivity of our regression models, dry meat weight should be used.

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 is closely linked to food quantity and quality in order to produce ripe gametes during gametogenesis (Seed and Suchanek, 1992; Cartier et al., 2004).

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 coincides in most bays and estuaries across PEI 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 increase in CI 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.

MUSSEL DENSITY

The mussel sock density provides information about the survival of mussels over a one year production cycle across Tracadie Bay. At two of the four sites, final mussel density (May 2005) results indicated positive effect with sock spacing treatments; highest mussel density was observed on socks spaced 80 cm apart. Comparing mussel density per meter of sock of those spaced 80 cm averaged 233 mussels / m, while those spaced 10 cm apart averaged 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 effect. Sites which displayed no significant effect in the response variables were owned and operated by the same lease holder. 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 intense cultured densities at the farm level resulting from closer sock spacing, in addition to high mussel sock density and small seed may have led to decreased shell growth and increased mortality due to a reduction in food resources due to intra-specific competition among individuals. Food demand at the farm level may exceed food supply which may limit growth (Fréchette et al., 2000). Throughout this study, food resources were not quantified; but indirect evidence from the SMN showed that food abundance within Tracadie Bay has varied spatially and temporally over the years.

Over the course of the production cycle, mussel sock density underwent a gradual and progressive reduction of mussels across all sites in Tracadie Bay. The largest (58%) reduction of mussel sock density over time was observed at one of the sites, which had the smallest initial seed size (16.3 mm) and highest initial mussel socking density (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 with 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 reduce 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 has 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.

RECOMMENDATION

This investigation provides the first detailed account of the effect 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) often 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 sock spacings and their associations to productivity. Additional work is needed to clarify the association between seed size and mussel density and their impact on productivity.

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Table 1 Mean shell length (mm) 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	16.3	0.08	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
			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
2	29.3	0.14	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
			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
3	31.1	0.16	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
			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
4	23.4	0.09	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
			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 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
1	25.1	0.26	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
			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
2	26.1	0.31	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
			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
3	27.2	0.25	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
			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
4	22.6	0.29	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
			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 Mean mussel sock density (# mussel/meter) 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

$^{a\text{-}c}$ 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

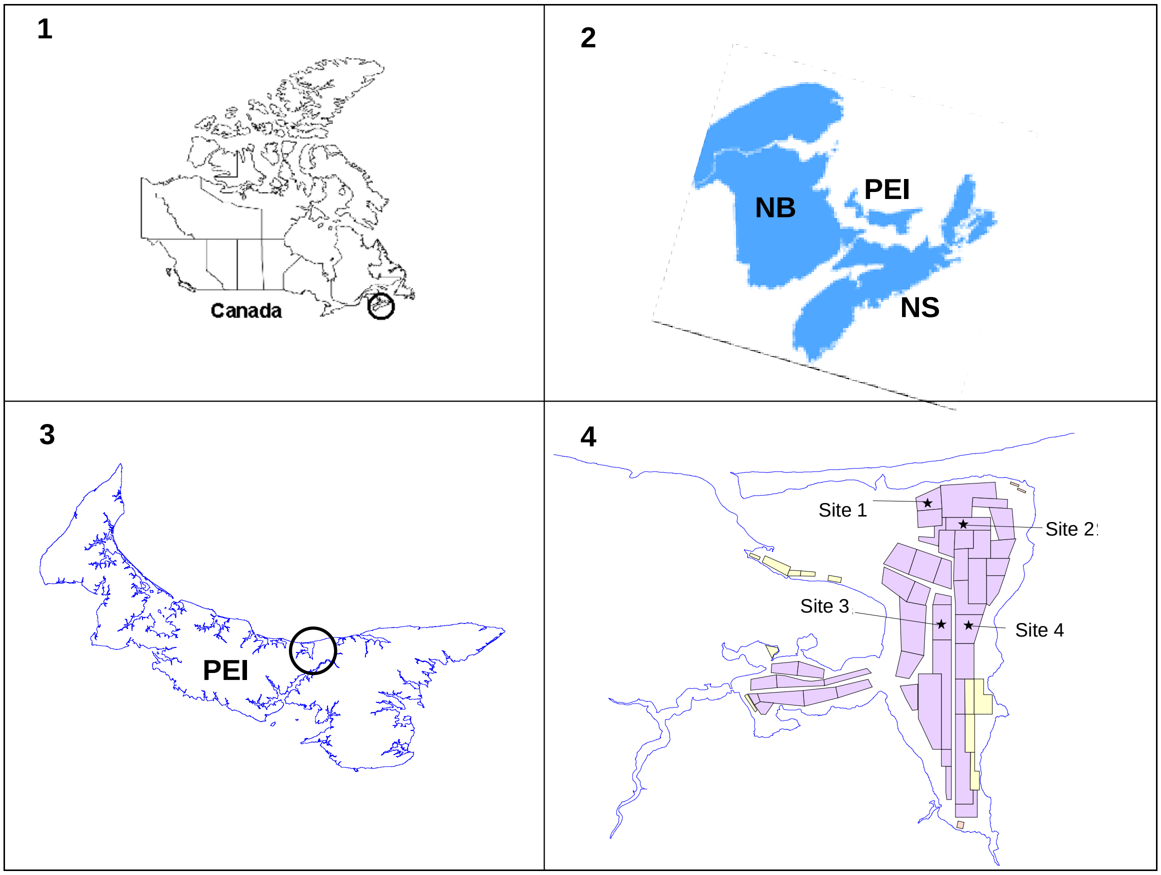


Figure 1 Map of Canada (1), with inserts of map of Atlantic Canada (2), Prince Edward Island (3) and Tracadie Bay (4). Gray areas indicate location of mussel aquaculture leases (Department of Fisheries and Oceans, Canada). The black stars indicate the location of our experimental sites.

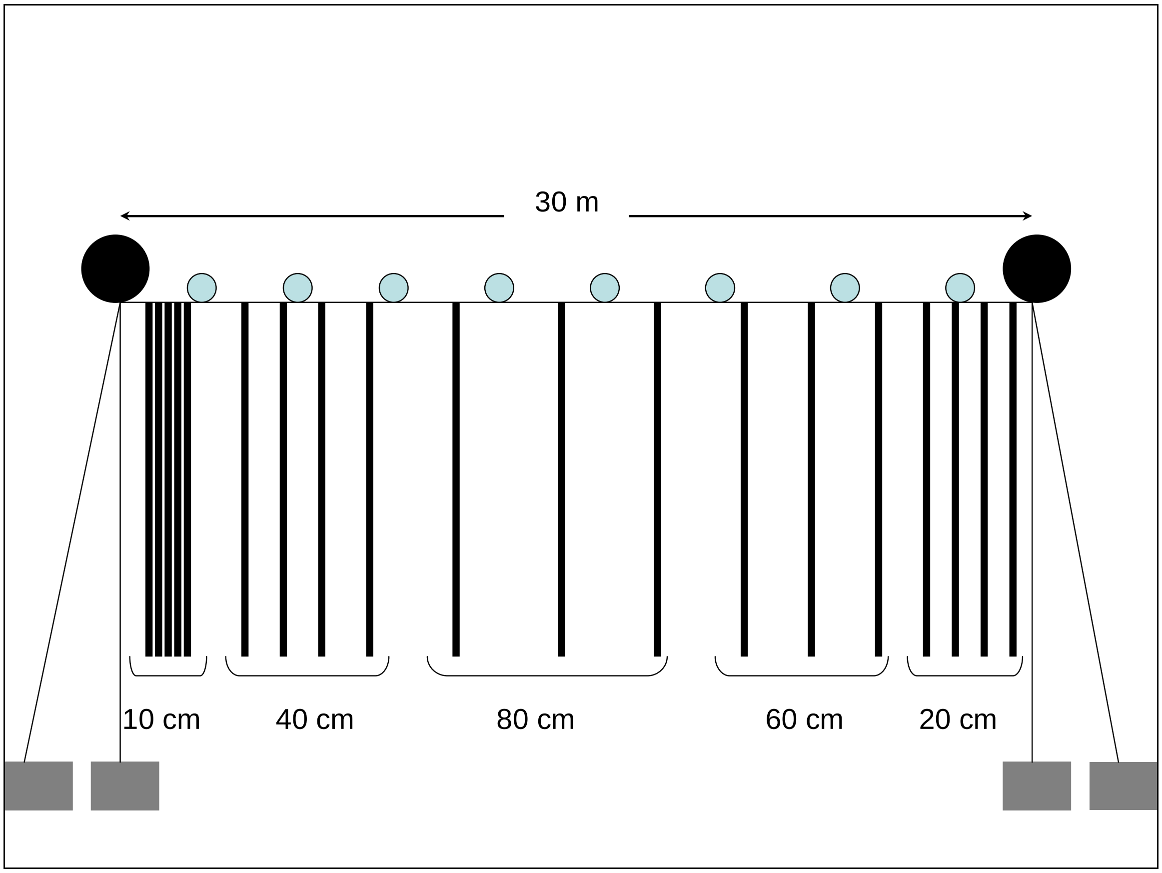


Figure 2 Schematic representation of a longline containing blocks of socks; an actual longline contained three blocks. Each block contained 15 replicates of each sock spacing treatment: 10, 20, 40, 60, and 80 cm. There was one longline per site.

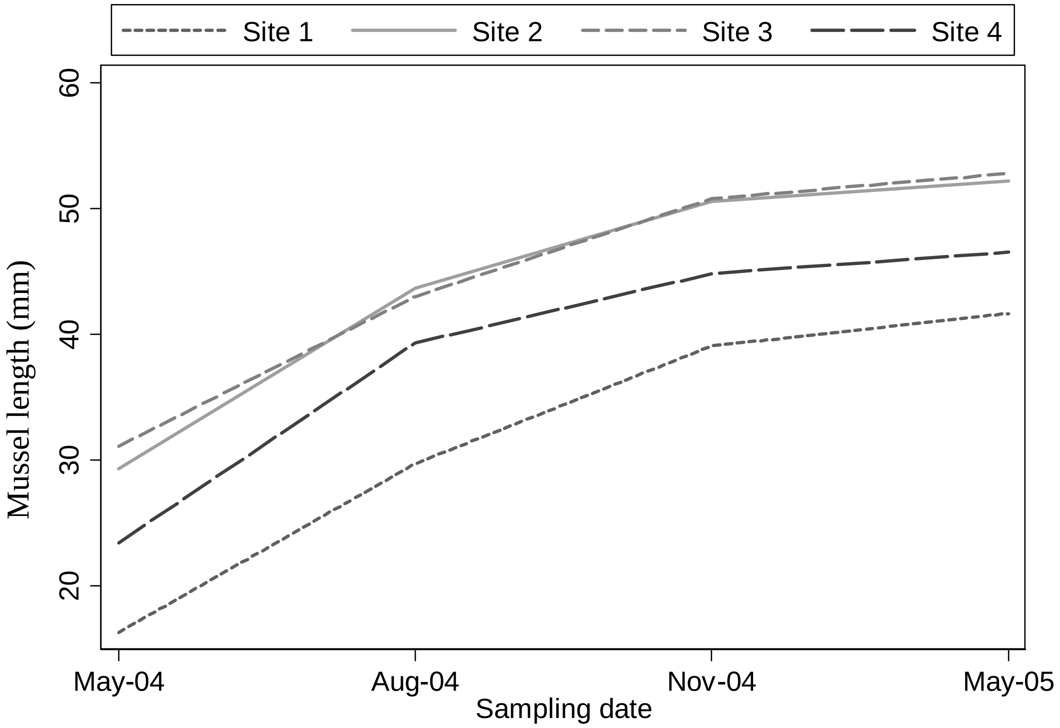
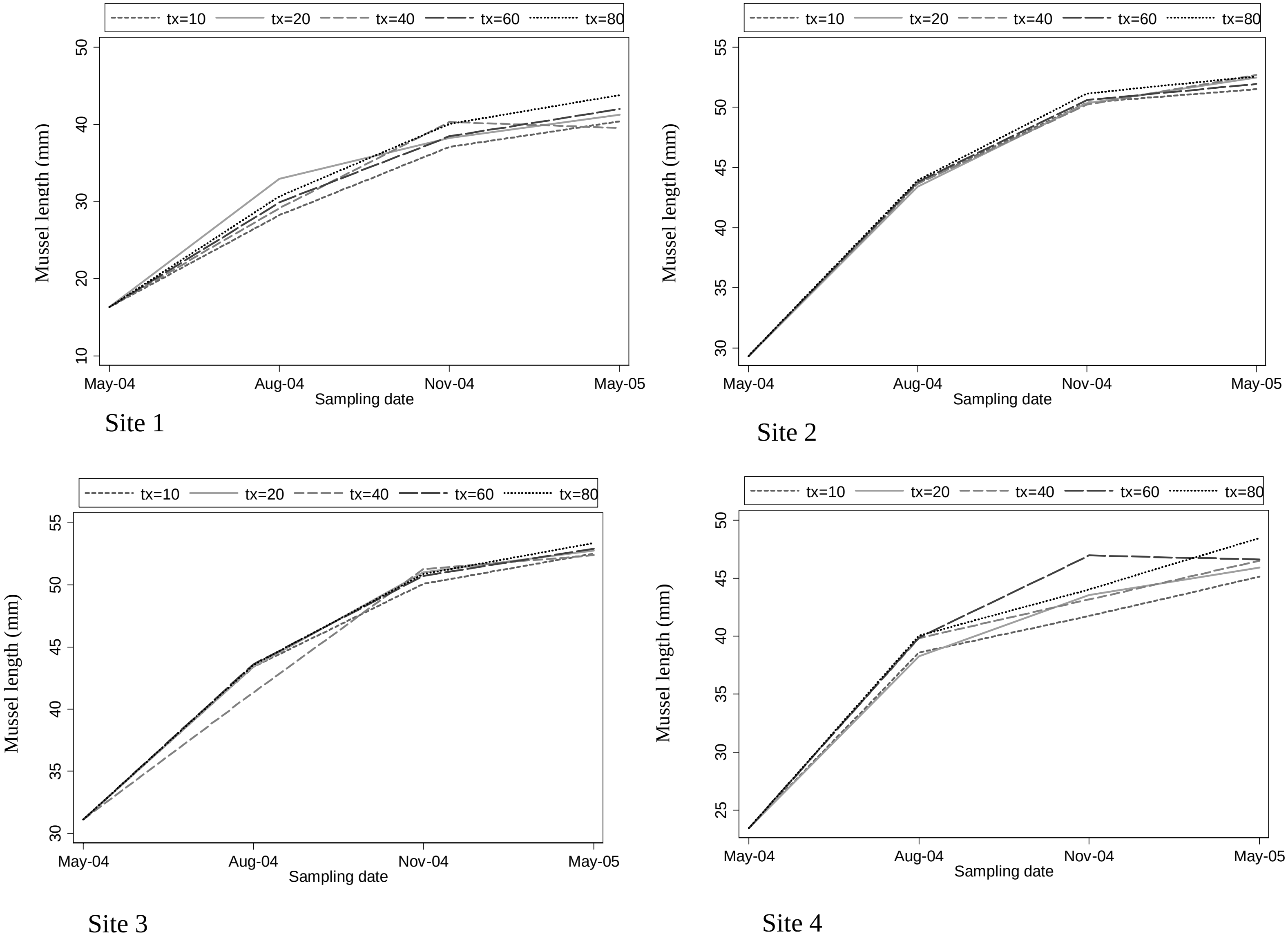


Figure 3 Mean shell length at each sampling date and sites in Tracadie Bay, PEI, Canada.



Site 1

Site 2

Site 3

Site 4

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

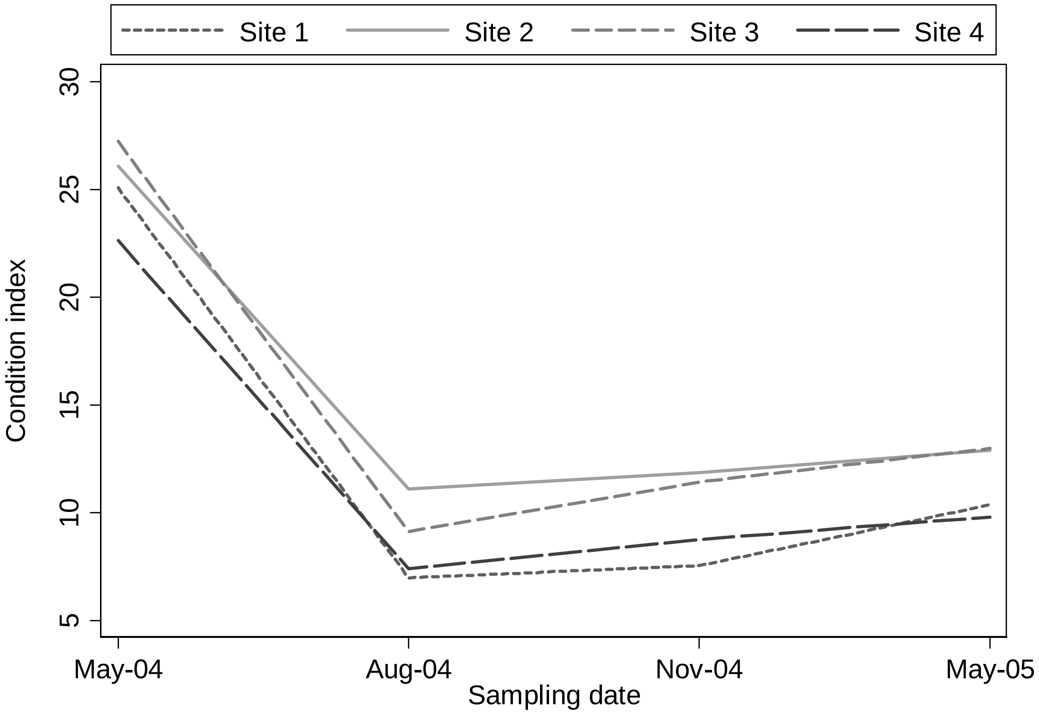
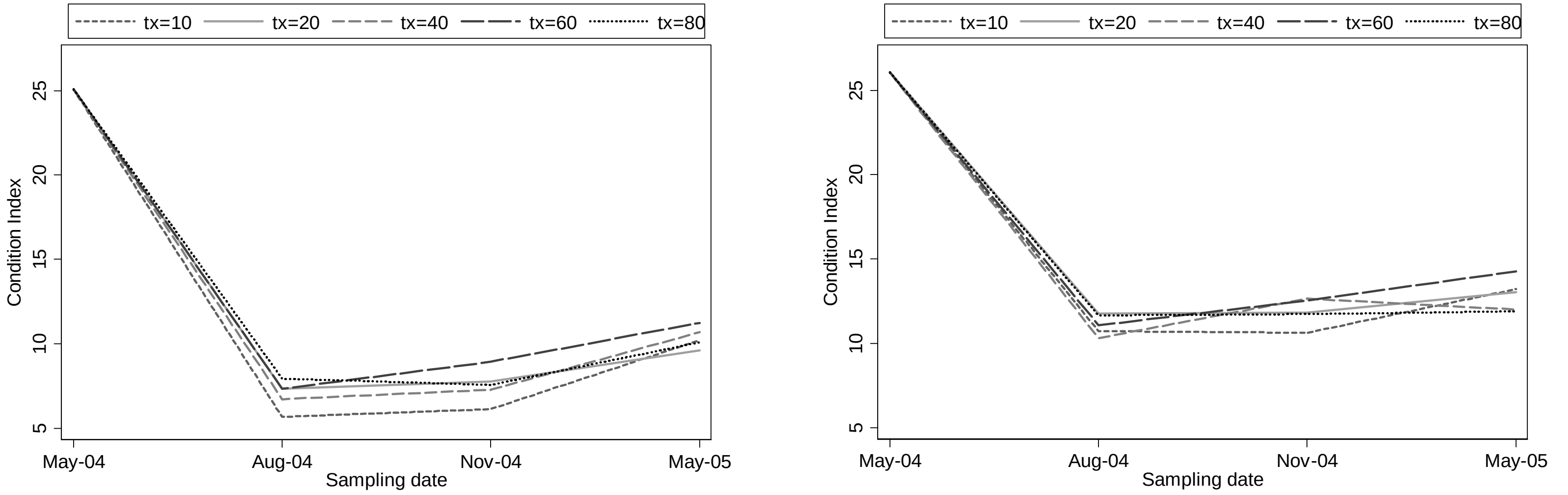
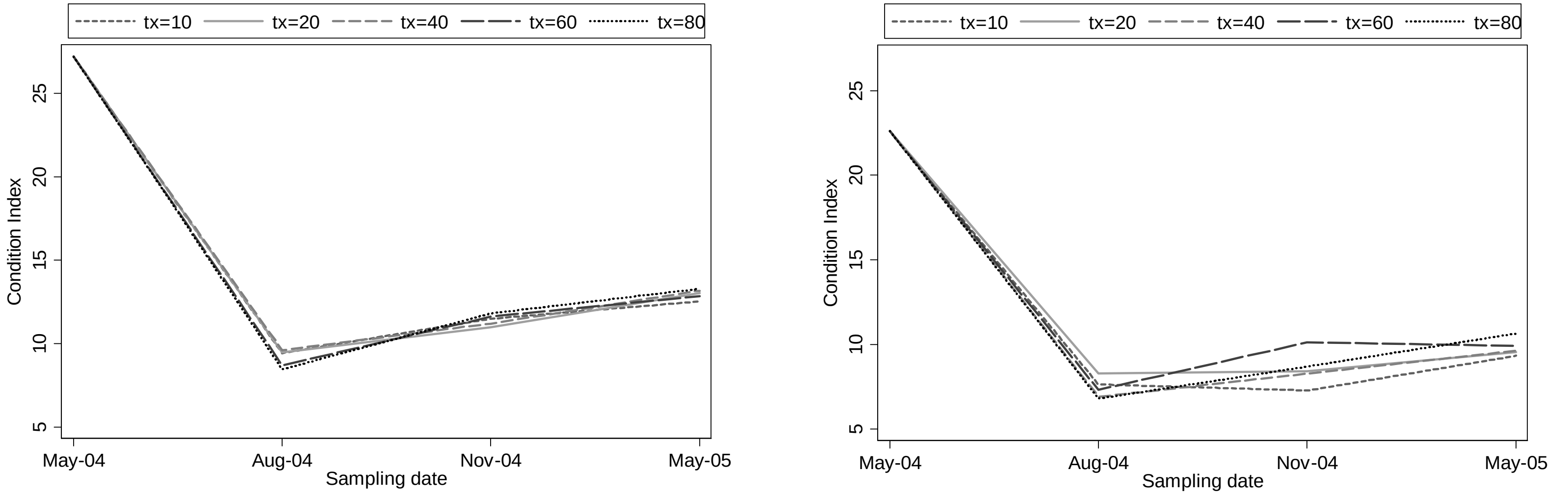


Figure 5 Mean mussel condition index at each sampling date and sites in Tracadie Bay, PEI, Canada.



Site 1

Site 2



Site 3

Site 4

Figure 6 Mean condition index at each sampling date and site for five sock spacing treatments in Tracadie Bay, PEI, Canada