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PEI Benthic Survey

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Abstract
Sediment core and Ekman grab samples were collected from 20 estuaries throughout Prince Edward Island in August and September, 1997. Core samples were analysed for water content, organic matter content, redox potential (Eh) and total sulfide levels. From these values, a Benthic Enrichment Index (BEI) was calculated. Grab samples were analysed for abundance and biomass of each species and abundance and biomass of each feeding group. From these values, a Shannon-Wiener Diversity Index and an Euclidean Distance Similarity Index were calculated. Each sample was categorized as *lease* (under mussel lease), *reference* (area removed from mussel lease in the same estuary), or *culture-free* (estuary with no mussel culture). There was no significant difference found between the *lease* and *reference* values for water content, organic matter content, or total sulfides. Invertebrate abundance, biomass, diversity, and percentage of deposit feeders also showed no significant difference between *lease* and *reference* samples. Eh and BEI values were significantly higher in *reference* samples than in *lease* samples in the top sediment layer only. *Culture-free* samples were significantly lower than *lease* samples in water content, organic matter content, and total sulfides. *Culture-free* samples had significantly higher Eh, BEI, and invertebrate abundance values than *lease* samples. The differences in water content, organic matter and Eh were minor. Due to various factors contributing to sediment quality, which are unique in each estuary, the differences between *lease* samples and *culture-free* samples cannot be attributed to mussel culture alone. Decreased abundance in *lease* samples seems to be the only significant impact on the macrofaunal population due to the sediment chemistry differences between the *lease* and *culture-free* samples. The overall quality of the muddy sediment in the estuaries surveyed was anoxic with high organic matter levels.

Introduction

Many estuaries throughout Prince Edward Island support a vibrant mussel (*Mytilus edulis* L.) aquaculture industry, producing in excess of 8800 tonnes annually. P.E.I. estuaries are abundant in phytoplankton, have good water exchange and are well sheltered from prevailing winds which make them ideal for culturing mussels (Bernard 1994).

It is reported that mussel herbivory accounts for a substantial removal of phytoplankton (Meeuwig et al. 1997, Asmus and Asmus 1991) which serves to control eutrophication (Officer et al. 1982). Mussel beds are also a major component in the recycling of nutrients in estuaries (Dame and Dankers 1991).

Dahlback and Gunnarson (1981) have found that the sedimentation rate under a mussel culture site is nearly three times higher than at a reference station. Due to the production of faecal material the sediment underlying the mussel cultures tends to be richer in organic material than sediment unexposed to mussel cultures (Dahlback and Gunnarson 1981, Kaspar et al. 1985, Mattsson and Linden 1983). Baudinet et al. (1990) report however, that biodeposit input due to mussel culture does not affect the ecosystem in a mussel farming zone in France.

Sulfides are produced from the decomposition of organic matter (Greenberg et al. 1992) thus total sulfide levels are sensitive indicators of benthic organic enrichment (Hargrave et al. 1997). A measure of the redox potential (Eh) of sediment cores serves as a guide to the biological condition of the sediment and the degree of organic loading to which it is subjected (Pearson and Stanley 1979). Whitfield (1969) describes Eh as a semi-quantitative indicator of the degree of stagnation of a particular environment. Relative to reference stations, increased sulfide levels and reduced Eh levels have been reported in sediment collected under mussel cultures in Sweden (Dahlback and Gunnarson 1981) and under salmon aquaculture cages in the Bay of Fundy (Hargrave et al. 1995). In contrast, Grant et al (1995) conclude that the mussel lines cause minimal impact on the benthos of a small Nova Scotia cove.

A few species of annelids, such as *Capitella capitata*, have a capacity for very rapid production given the right conditions and have been termed “opportunistic” (Pearson and Stanley 1979). These are often small, short-lived, prolific, and capable of exploiting suboptimal environments. The hypoxic sediments typical of organic enrichment are a haven for such species (Grant et al 1995). Mattsson and Linden (1983) have reported that after 6-15 months of mussel culture on the Swedish west coast, the dominant species in the underlying benthic community disappeared and were replaced by opportunistic polychaetes. The benthic infauna of a mussel farm in New Zealand consisted only of polychaete worms while the reference sediment also contained bivalves, brittle stars and crustaceans (Kaspar et al 1985). Due to the dominance of these opportunists, it is generally assumed that a macrobenthic community subject to organic loading will exhibit reduced species richness, reduced total biomass, and shifts in the dominance of feeding groups (Weston 1990). It has been reported that, relative to reference sites, macrobenthic communities exposed to aquaculture outfall had reduced species richness (Grant et al 1995, Hargrave et al 1995, Weston 1990), reduced biomass (Hargrave et al 1995, Weston 1990), reduced abundance (Weston 1990), and an increase in *Capitella capitata* density (Weston 1990). Grant et al (1995) found that the mussel line sediments in Upper South Cove, Nova Scotia were not anoxic and did not display a reduced biomass in the macrofaunal community.

There was a general inverse correlation between species diversity and organic matter levels in sediment from four aquaculture sites in Atlantic Canada (Schafer et al 1995). Tsusumi et al (1990) suggest that *Capitella* sp. have a physiological requirement for sediment with high organic matter for normal growth. Pearson and Stanley (1979) found that as sediment redox potential decreases on the west coast of Scotland, the total number of species declines but the proportion of annelid species rises. Hargrave et al (1995) claim that *Capitella* sp. would not be expected to be present in sediment with high sulfide levels.

Trophic group diversity was reduced with proximity to a salmon farm in Puget Sound, Washington (Weston 1990) and Hargrave et al (1995) found that the biomass of deposit feeders was higher at salmon cage sites than at reference sites in the Bay of Fundy. Hargrave et al (1995) also suggest that biomass of deposit feeders as a percentage of total biomass would be a sensitive indicator for detecting organic enrichment.

The abundance biomass comparison (ABC) method has been suggested by Warwick (1986) as a technique for detecting pollution effects on marine macrobenthic communities. Using this technique, Ritz et al (1989) reported that the macrofaunal community structure beneath salmonid seacages indicated a moderately disturbed condition. Seven weeks after harvest, the community adopted an undisturbed condition. The ABC method did not indicate an impact of mussel biodeposition on the benthic community in Upper South Cove, Nova Scotia (Grant et al 1995). This was due to the dominance of relatively large molluscs as opposed to classical pioneering species.

To date, information concerning the benthic conditions of Island estuaries is limited. The objective of this study is to survey the condition of sediments across P.E.I. and to provide insight to the impact of mussel leases on the sediments and macrofaunal communities. The survey takes a province-wide approach in order to provide a general overview of Island conditions.

Materials and Methods

Site Selection

Mussel lease maps were obtained from the Dept. of Fisheries and Oceans for the following estuaries throughout P.E.I.: **Boughton, Murray River, Brudenell, Montague, Savage Harbour, St. Peter's, St. Mary's, Tracadie, Rustico, New London, and Malpeque (Marchwater).** Estuaries in which there is no mussel culture were also sampled for reference purposes. These include **Kildare, Mill, Foxley, Grand, Dunk, Southwest, West, Hillsborough, and Orwell**. Several of these estuaries do however support other shellfish aquaculture. Table 1 demonstrates the amount of years each estuary has been exposed to mussel production (Gallant, pers. comm.). Maps of sample locations are included in Appendix D. These maps were created using MapInfo and sampling locations are approximations.

Table 1. Years of exposure to mussel culture per estuary

Estuary	Years of mussel production

Boughton	15
Brudenell	15
Marchwater	8
Murray River	15
New London	12
Rustico	5
Savage	2
St. Mary's	15
St. Peter's	15
Tracadie	12

Sample Collection

Samples for chemical analysis were collected from the surface at four or five stations per estuary. In the estuaries with mussel culture each station consists of a lease sample (1 core) and a corresponding reference sample (1 core). *Reference* sample locations were chosen as areas equidistant from the source, and of similar water depth, as the corresponding *lease* sample. In the estuaries with no leases, only one sample was collected per station. A 50 cm Wildco Core Sampler was used for sampling and core liners were constructed from PVC tubing in both 50 cm and 30 cm lengths. These liners had holes drilled every 2 cm and they were wrapped in duct tape to prevent water and sediment loss. Upon sample retrieval, the cores were capped with plastic caps, kept upright on ice and transported to the lab.

Invertebrate sampling was done at one or two stations per estuary with a 0.05 m^2 Ekman Grab Sampler. A graduated bucket was used to determine the volume of the sample. The sample was then sieved through a 500 µm screen and flushed with tap water. Invertebrates were preserved in a 5% buffered formalin solution.

All samples were collected between August 11, 1997 and September 24, 1997.

Core Analysis

All core samples were analysed within 24 hours of collection and most were analysed immediately upon return to lab. If necessary, samples were refrigerated overnight. Each sample was analysed for the following four variables: water content (WC), organic matter content (OM), redox potential (Eh), and total sulfide concentration (S). Water content and organic matter content were only determined in the surficial sediment layer for each core.

Five ml of sediment were extracted from the surface layer of the core (i.e., the top hole that has underlying sediment) with a 5 ml cut-off syringe for determination of water content and organic matter content. The sediment was placed in a pre-weighed crucible and then weighed on a Sartorius MC1 to determine sediment wet weight. It was placed in an Isotemp Incubator Model 225D at 60°C for 48 hours and then re-weighed to determine water content expressed as a percentage of the original wet weight. Finally, it was placed in an Isotemp Muffle Furnace Model 186A at 600°C for one hour and weighed to determine organic matter content expressed as a percentage of sediment dry weight.

Five ml of sediment were extracted from the second hole with underlying sediment with a cut-off syringe for measurement of sulfide concentrations. This was repeated at every fourth hole (8 cm) and the sediment from each hole was inserted into a separate 30 ml plastic vial. Calibration of the Orion 9616BN Combination Silver/Sulfide Electrode and sulfide measurements were performed as described in Hargrave et al. (1995).

Eh was measured with an Orion 9678BN Combination Redox Electrode at each hole that had underlying sediment. Electrode calibration and Eh measurement were done as described in Hargrave et al. (1995).

Invertebrate Analysis

Invertebrates were analysed at the Acadia Centre for Estuarine Research. Results include abundance and biomass (wet weight) for species and abundance and biomass (wet weight) for feeding group as per Wildish and Peer (1983).

Statistical Analysis

All statistical analysis was done on Systat 7. There are essentially three data sets each of which is assigned a category name:

Name	**Description**
culture-free	**Samples taken from estuaries with no mussel culture**
lease	**Samples taken under leases**
reference	**Samples taken from area removed from leases in estuaries**
with mussel	**culture**

Data sets are comprised of sample site, sample station, values for WC, OM, Eh, S, and BEI, water depth, sediment depth, position in estuary, years in which estuary supported mussel culture, and flushing rate. WC, OM, Eh, and S values for core profiles are found in Appendix A. Six cores (4 *reference*, 2 *culture-free*) were very sandy in texture and were not included in the statistical analysis. These cores cannot be compared with the rest of the samples due to their failure to meet reference sample criteria. They were not collected from an area suitable for mussel culture. Core analysis results from these samples are shown in Appendix B.

A benthic enrichment index (BEI) was calculated using water content, Eh, and organic carbon content (OC) as per Hargrave (1994) [eq. 1]. Organic carbon levels were obtained by dividing organic matter levels by 1.7 as per Bartlett (1971a). This was used as a fifth variable.

$$BEI = [\{(100\text{-}WC/100\} \times 10^4 \times \{(OC/100)/12\}] \times Eh \qquad \text{[eq. 1]}$$

Sediment cores were divided into 4 sediment layers of 6 cm (3 holes) each. This applied only to sulfide level and Eh comparisons as the remaining variables were determined from the top sediment layer. Since sulfide readings were taken from every 8 cm, there is no sulfide data in sediment layer 3 (14-18 cm).

The data sets from stations at which invertebrate sampling was done include values for abundance, biomass, biomass of deposit feeders as a percentage of biomass, Shannon-Wiener diversity index (Shannon and Weaver 1949), and Euclidean distance similarity index (Krebs 1985). The Shannon-Wiener index was calculated for each sample using eq. 2

$$H' = - \ p_j \log p_j \qquad \text{[eq. 2]}$$

where p_j equals the proportion of the population that is of the j^{th} species. The Euclidean Distance was calculated as an index of similarity between *lease* samples and their corresponding *reference* samples [eq. 3].

$$_{jk} = [\ (x_{ij} - x_{ik})^2]½ \qquad \text{[eq. 3]}$$

where $_{jk}$ equals the distance between j (*lease*) and k (*reference*), x_{ij} equals the number of individuals of species i in sample j (*lease*) , and x_{ik} equals the number of individuals of species i in sample k (*reference*).

A Planix Tamaya Digital Planimeter was used to determine the volume of water in the estuaries at low tide and the volume of the average tidal prism. Using eq. 4 as per Lane (1985), the flushing rates for each estuary were calculated. These values were used as covariates in all ANOVA tests in order to account for variations in results due to differing flushing rates.

$$\text{Flushing Rate} = (\text{volume of estuary} + \text{tidal prism})/\text{tidal prism} \qquad \text{[eq. 4]}$$

Variable values from the 3 sample categories were compared using an one-way ANOVA. WC, OM and S data were log transformed and abundance was square root transformed for all ANOVA tests. A p-value < 0.05 was considered to indicate a significant statistical difference.

Each sample was categorized according to its position in the estuary creating three “Position” groups: *upper*, *mid*, and *lower*. Values from these groups were compared using an one-way ANOVA. Following this, the values from three sample categories were compared in the *upper* position only. The same was done for *mid* and *lower*.

Samples taken from estuaries with mussel culture were categorized according to the length of time, in years, in which the estuary supported mussel culture. Two groups were created, the first being 2-5 years and the second being 12-15 years. One estuary (Marchwater) falls in between these two groups and was therefore omitted. Values from the two groups were compared using a one-way ANOVA. Values from *reference* and *lease* categories were then compared in the 2-5 year group only and the same was done in the 12-15 year group.

Samples were categorized according to the water depth at which they were collected (2 m -10 m). Values from each water depth were compared using a one-way ANOVA. Values from the three sample categories were then compared at each water depth individually. A Bonferroni pairwise test was used to determine differences between individual depths and between categories at individual depths. There were no c*ulture-free* samples at 9 and 10 m and there were no *reference* or l*ease* samples taken at 2 m.

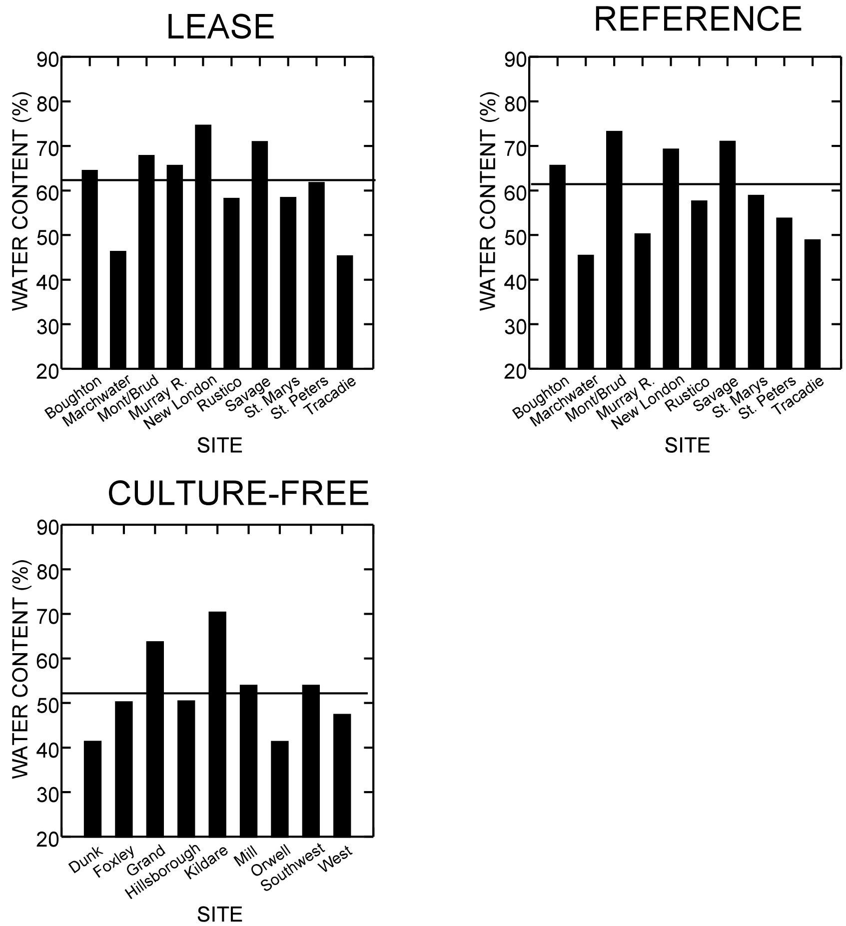
Core profiles of Eh and S were created by running a LOWESS smoother line through scatter plots and deleting plot symbols. Figures 19 through 23 (water depth) were created in the same manner. Abundance biomass comparison curves were created as per Warwick (1986).

Results

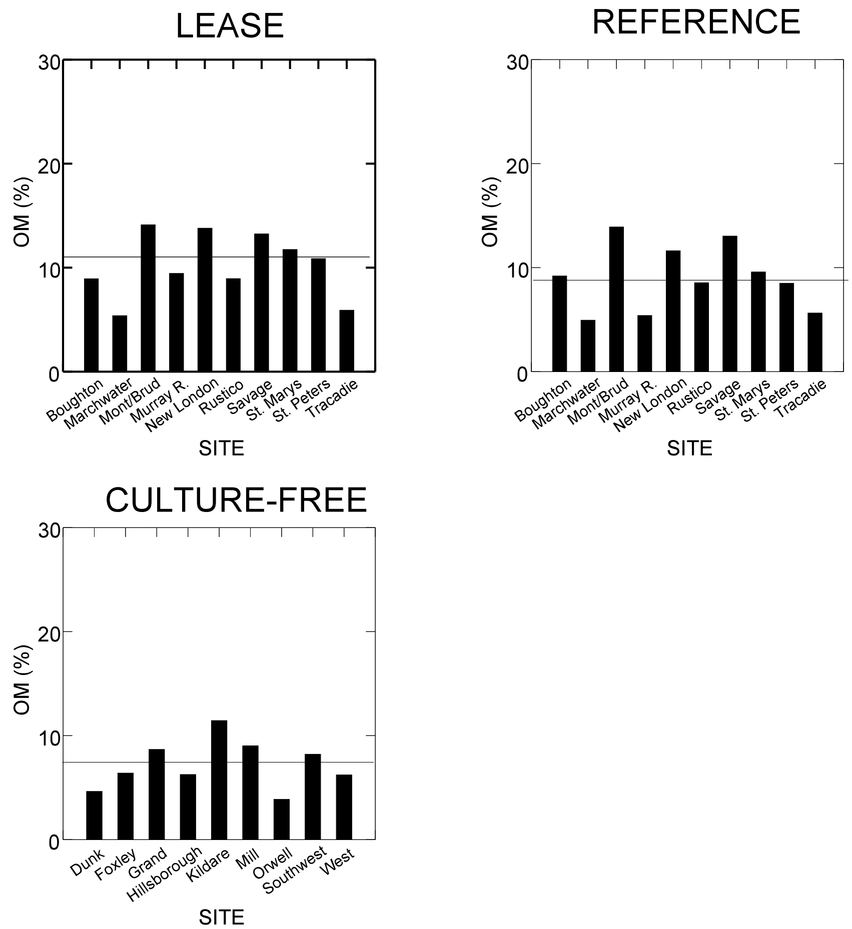
Surface sediment water content values ranged from 29.44% to 85.02% (Table 3). There was no significant difference between mean *lease* and *reference* values (Fig. 1). A significant difference was found between the mean *lease* value and the mean *culture-free* value (p value: 0.014). The mean *lease* value in Murray River was markedly higher than its mean *reference* value. Surface organic matter content values varied widely

(1.99% to 27.84%). There was no significant difference between mean *lease* and *reference* values (Fig. 2). The mean *lease* value for Murray River was again higher than its mean *reference* value. A significant difference was found between the mean *lease* value and the mean *culture-free* value (p value: 0.031). Ten sample locations from this survey were similar to samples taken by Bartlett (1971-72). Bartlett's organic matter values were calculated by multiplying organic carbon values by 1.7. Bartlett used an Organic Carbon Analyser to determine organic carbon values while weight loss on ignition was

used in this survey to determine OM values. Bartlett's OM values ranged from 1.33% to 6.15%



0 Mean water content values for Lease, Reference and Culture-Free samples. Horizontal lines indicate category mean values.



0 Mean organic matter content values for Lease, Reference, and Culture-Free samples. Horizontal lines indicate category mean values.

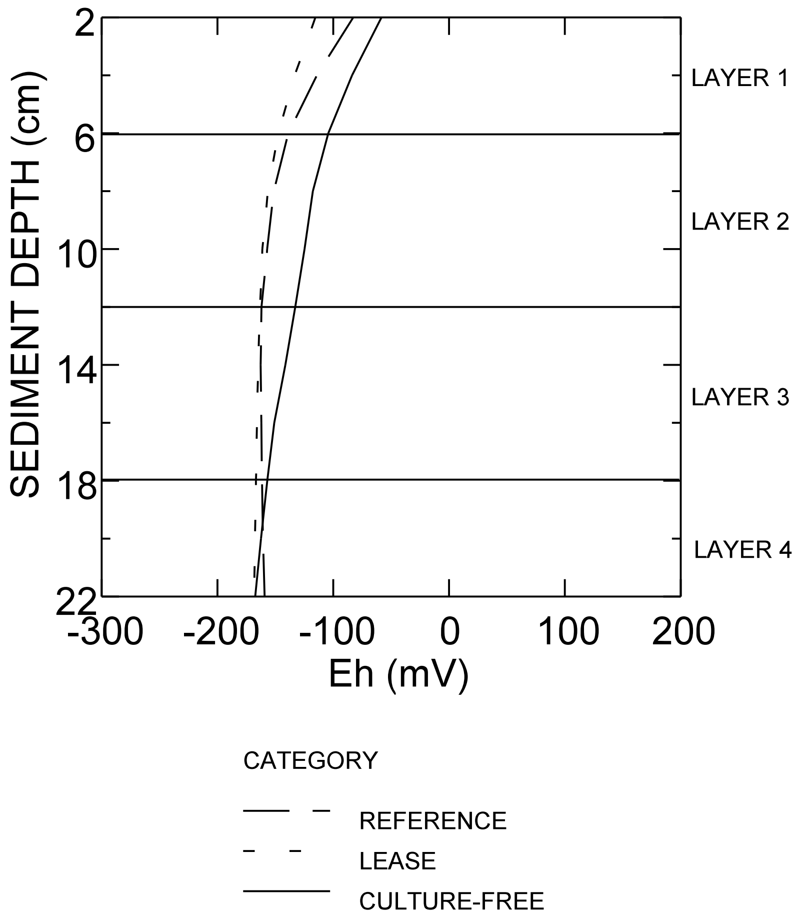
with a mean of 3.17%. The corresponding ten organic matter values from this survey ranged from 1.91% to 8.34% with a mean of 5.35 % (Table 2).

Table 2. Organic matter levels (%) from 10 stations with corresponding values from Bartlett (1971-72)

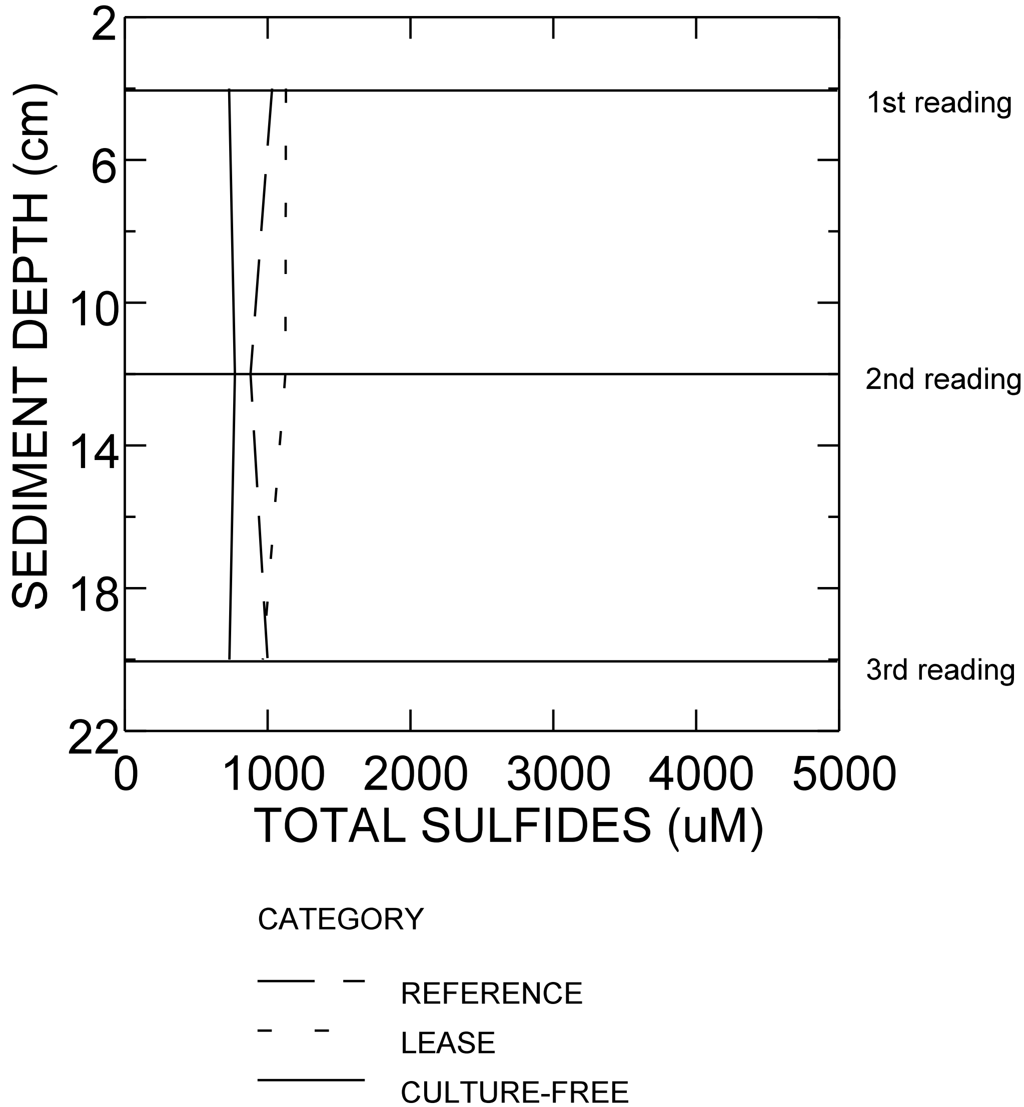
Site	Station	1997	1971-72
Mont/Brud	5	4.495	2.720
Hillsborough	5	8.336	3.184
West	1	7.318	4.206
West	2	8.340	3.587
West	3	5.048	2.967
West	4	4.170	3.050
Dunk	1	4.560	1.870
Dunk	2	3.775	2.584
Dunk	3	5.594	6.154
Dunk	4	1.909	1.326

The top sediment layer showed the greatest range of Eh values (-159 mV to 100 mV). In this layer, there is a significant difference between all three categories (p value: 0.000) with *culture-free* showing the highest Eh values (Fig. 3). Sediment layer 2 exhibits a significant difference between *culture-free* and *lease* samples (p value: 0.000). The bottom two sediment layers for all three categories are not significantly different.

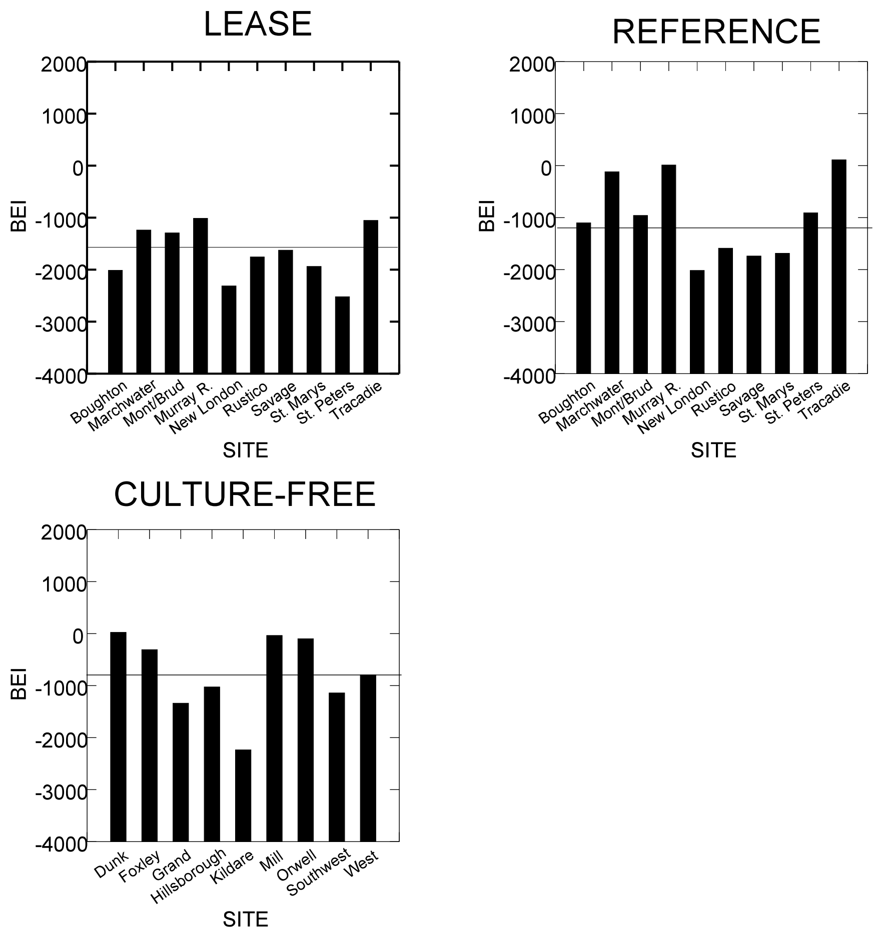
Total sulfide values varied widely in the top sediment layer, ranging from 1098 µM to 4188 µM. There was no significant difference between mean *lease* and *reference* values. In the top layer, *culture-free* samples have significantly lower S values than the *lease* samples (p value: 0.047) (Fig. 4). Layers 2 and 4 do not show a significant difference between all three categories. BEI values ranged from -3928 to 1594. The mean *culture-free* and *reference* BEI value was significantly higher than the mean *lease* BEI value (p value: 0.004) (Fig. 5).



0 Core profile for Eh values for Lease, Reference, and Culture-Free samples



0 Core profile of S values for Lease, Reference, and Culture-Free samples



0 Mean Benthic Enrichment Index values for Lease, Reference, and Culture-Free samples. Horizontal lines indicate category means

The mean *culture-free* abundance values were significantly higher than the mean abundance values for the *lease* and *reference* samples (p value: 0.000) (Fig. 6). Mean biomass and mean Shannon-Wiener diversity values were not significantly different between all three categories. The mean *reference* diversity value was however more than twice as high as the mean *culture-free* diversity value (Fig. 7). Figure 8 shows the mean percentage of each feeding group in each sample category. There was no significant difference between mean percentage of deposit feeders between the three categories. *Lease* samples were dominated by predators and *culture-free* samples were dominated by deposit feeders.

Table 3 presents a summary of category mean, maximum, minimum, and SD values for all variables. Complete chemical and invertebrate analysis results are on file with the P.E.I. Dept of Fisheries and Environment. Table 4 demonstrates which categories are significantly different for all variables. A bar joining the categories represents no significant difference.

Table 3. Mean, maximum, minimum, and SD values for variables for 3 sample categories

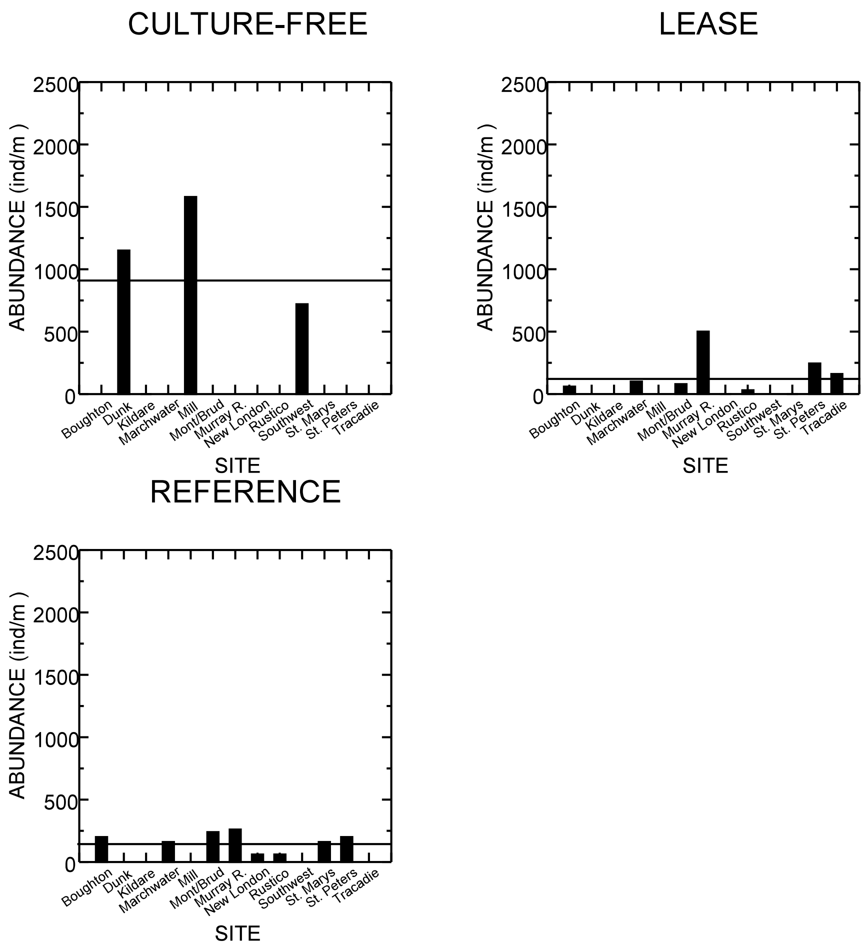
Variable	Mean	Maximum	Minimum	SD
Water Content (%)				
Lease	62.111	85.019	30.954	14.853
Reference	60.960	82.238	35.884	13.540
Culture-Free	53.120	80.738	29.453	13.286
Organic Matter (%)				
Lease	10.427	27.839	3.057	5.141
Reference	9.492	21.951	2.667	4.543
Culture-Free	7.374	14.918	1.987	3.350
Benthic Enrichment Index (mol C_{org} m^{-2} x Eh [mV])				
Lease	-1662	92	-3741	877
Reference	-1060	1154	-2707	1062
Culture-Free	-827	1594	-3928	1225

Table 3 (Cont./...)

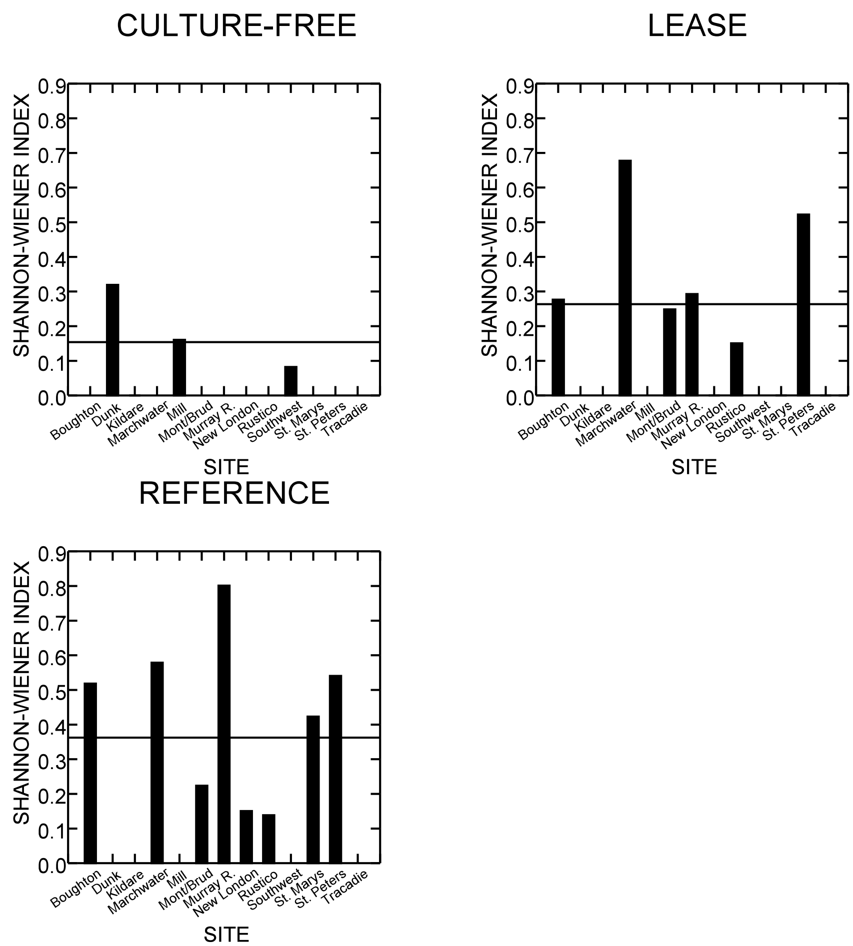
Variable	Mean	Maximum	Minimum	SD
Redox Potential (mV)				
Layer 1				
Lease	-127	5	-231	45
Reference	-100	120	-240	67
Culture-Free	-71	159	-209	85
Layer 2				
Lease	-158	-48	-205	33
Reference	-150	33	-206	45
Culture-Free	-121	34	-219	60
Layer 3				
Lease	-164	-84	-214	29
Reference	-165	-107	-222	31
Culture-Free	-150	-27	-210	44
Layer 4				
Lease	-164	-114	-197	26
Reference	-157	-120	-181	20
Culture-Free	-143	35	-211	67
Total Sulfides (µM)				
Layer 1				
Lease	1320	4188	287	879
Reference	1121	3343	297	682
Culture-Free	851	2857	115	533
Layer 2				
Lease	1262	3592	360	816
Reference	1056	2983	218	790
Culture-Free	893	2476	227	510
Layer 4				
Lease	1274	3914	286	1050
Reference	993	1678	218	585
Culture-Free	734	1302	170	317

Table 3 (Cont./...)

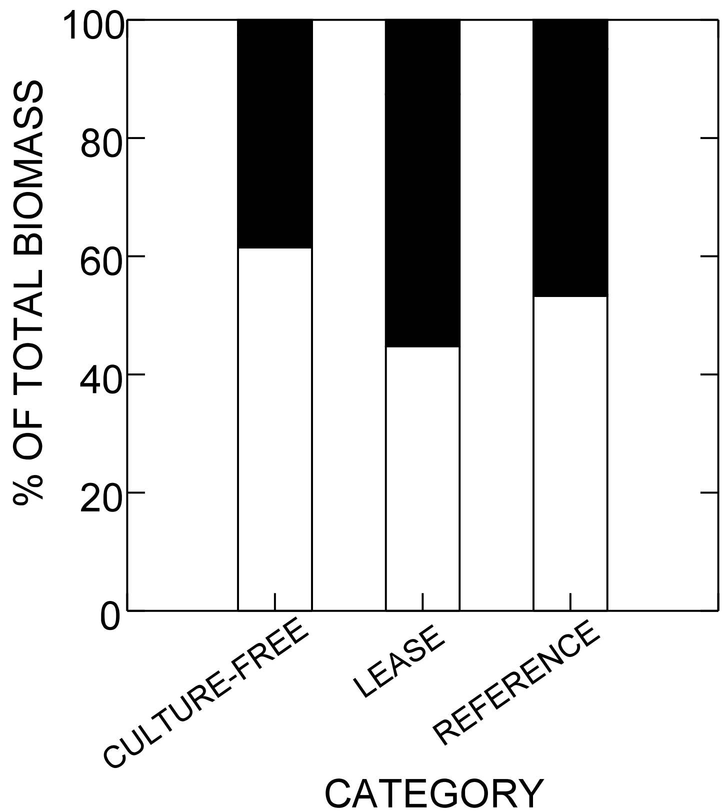
Variable	Mean	Maximum	Minimum	SD
Abundance (organisms/m^2)				
Lease	135	500	0	152
Reference	158	300	40	87
Culture-Free	887	2220	0	866
Biomass (g/m^2)				
Lease	32.74	203.98	0.00	65.82
Reference	15.38	42.70	0.04	12.45
Culture-Free	18.99	56.08	0.00	23.66
Deposit Feeders (%)				
Lease	36.7	100	0.0	35.4
Reference	45.7	100	0.0	36.6
Culture-Free	61.7	95.4	0.0	38.5
Shannon-Wiener Index				
Lease	0.275	0.677	0.000	0.242
Reference	0.369	0.801	0.000	0.245
Culture-Free	0.161	0.452	0.000	0.165



0 Mean abundance values for Lease, Reference, and Culture-Free samples. Horizontal lines indicate category means.



0 Mean Shannon-Wiener Diversity Index values for Lease, Reference, and Culture-free samples. Horizontal lines indicate category mean values.



0

Percentage of total biomass represented by each feeding group.

Table 4. Significant similarities between *lease, reference,* and *culture-free* samples

Variable	**Layer**	**Lease**	**Reference**	**Culture-Free**
Water Content	1	XXXXXXXXXXX		
			XXXXXXXXXXX	

Organic Matter	1		XXXXXXXXXX	
				XXXXXXXXXX
Total Sulfides	1	XXXXXXXXXX		
				XXXXXXXXXX
	2		XXXXXXXXXXXXXXXXXXX	
	4		XXXXXXXXXXXXXXXXXXX	
Eh	1			
	2		XXXXXXXXXX	
	3		XXXXXXXXXXXXXXXXXXX	
	4		XXXXXXXXXXXXXXXXXXX	
BEI	1			XXXXXXXXXX
Diversity	1		XXXXXXXXXXXXXXXXXXX	
Abundance	1		XXXXXXXXXX	
Biomass	1		XXXXXXXXXXXXXXXXXXX	
% Deposit Feeders	1		XXXXXXXXXXXXXXXXXXX	

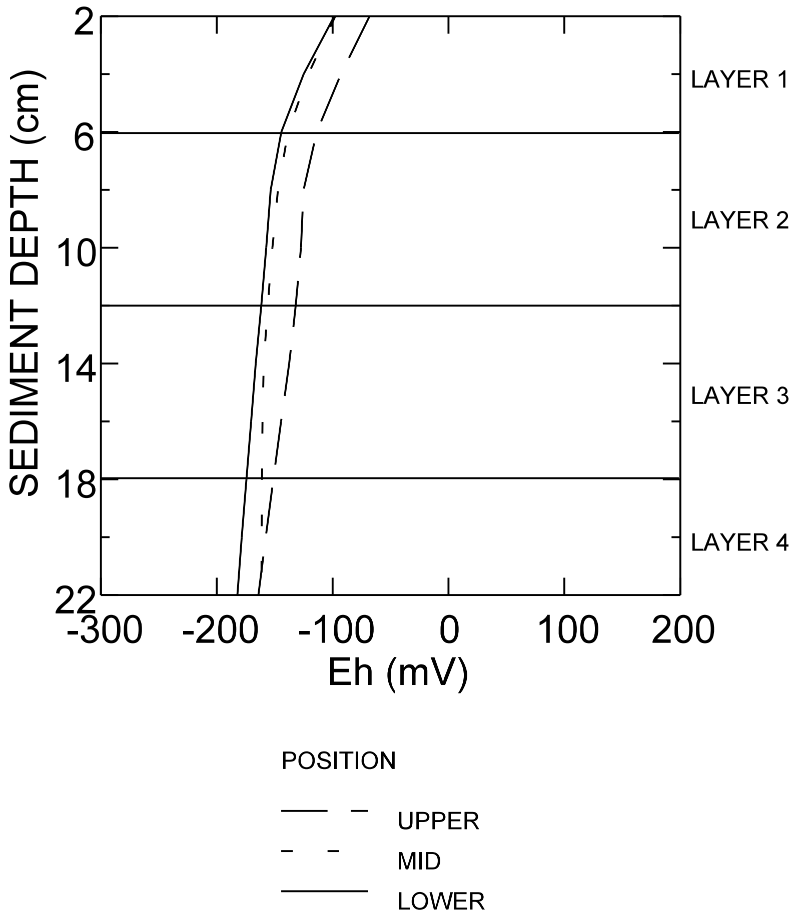
Position in Estuary

Figure 9 shows the relationship of Eh values between samples taken from *upper*, *mid*, and *lower* estuary positions. In layer 2, *upper* samples had significantly higher Eh values than the *mid* and *lower* samples. In layer 3, *upper* samples had significantly higher Eh values than the *mid* samples. There were no differences in Eh values in layers 1 and 4 and no significant differences were found between the three positions in WC, OM, S, BEI, abundance, diversity, biomass, and percentage of deposit feeders. Table 5 demonstrates which positions are significantly different for all variables. A bar joining the positions represents no significant difference.

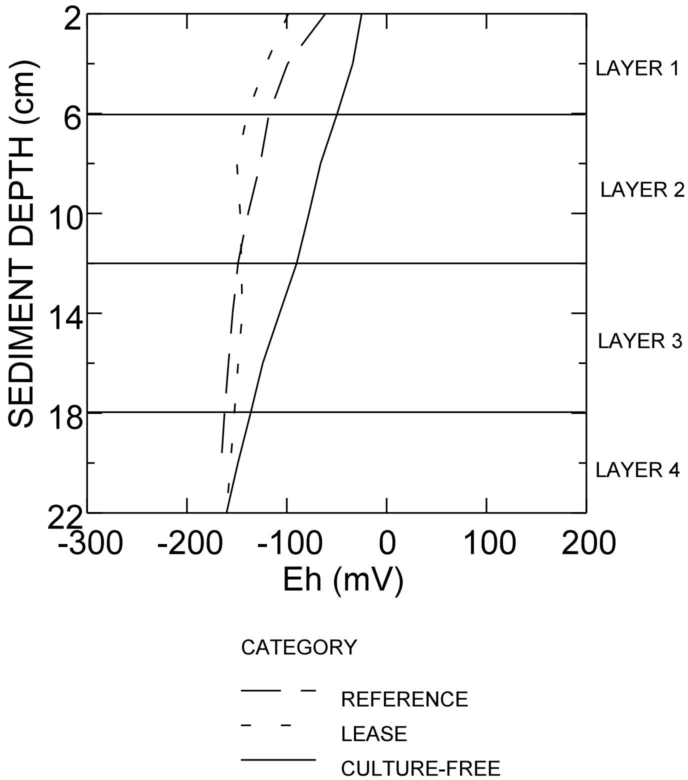
In the *upper* positions, *culture-free* samples had significantly higher Eh and abundance values than both the *lease* and *reference* samples in layers 1 and 2 (Figs. 10 and 11). No significant differences were found in sediment layers 3 and 4. No significant differences were found between the three categories in WC, OM, S, BEI, diversity, biomass, and percentage of deposit feeders.

Of the samples taken from the *middle* estuary position, the *culture-free* samples had a significantly higher mean Eh value and mean abundance value than the *lease* samples in layers 1 and 2 (Fig. 12). The *culture-free* Eh values were also significantly higher than the *reference* values in layer 2. It should be noted that there was only one *culture-free* invertebrate sample taken from the *middle* estuary position. The three categories were not significantly different in layers 3 and 4 and the three categories were not significantly different in WC, OM, S, BEI, diversity, biomass, and percentage of deposit feeders.

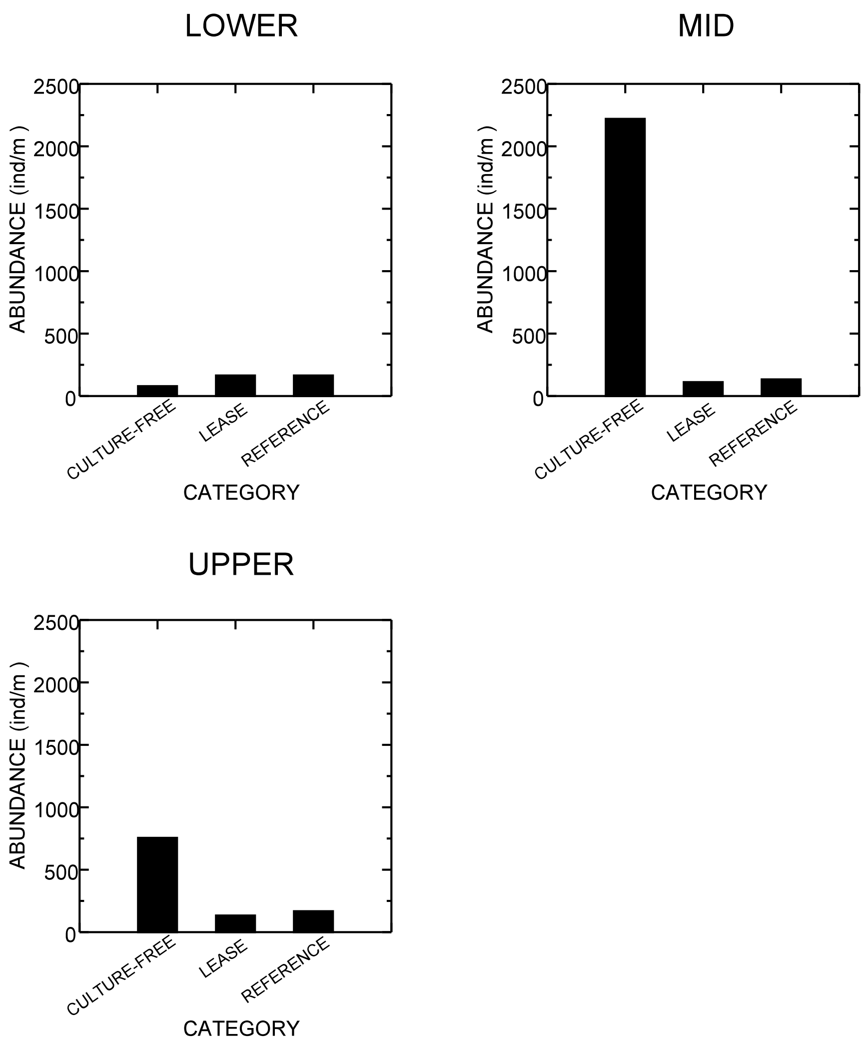
The *culture-free* and *reference* samples taken from the *lower* position had a significantly higher mean Eh values than the *lease* samples from the *lower* position in layer 1 (Fig. 13). In layer 2 , the mean Eh value from the *culture-free* samples was significantly higher than the mean *reference* and *lease* values. The three categories were not significantly different in layers 3 and 4 and the three categories were not significantly different in WC, OM, S, BEI, abundance, diversity, biomass, and percentage of deposit feeders. There was only one *culture-free* invertebrate sample taken from the *lower* estuary position.



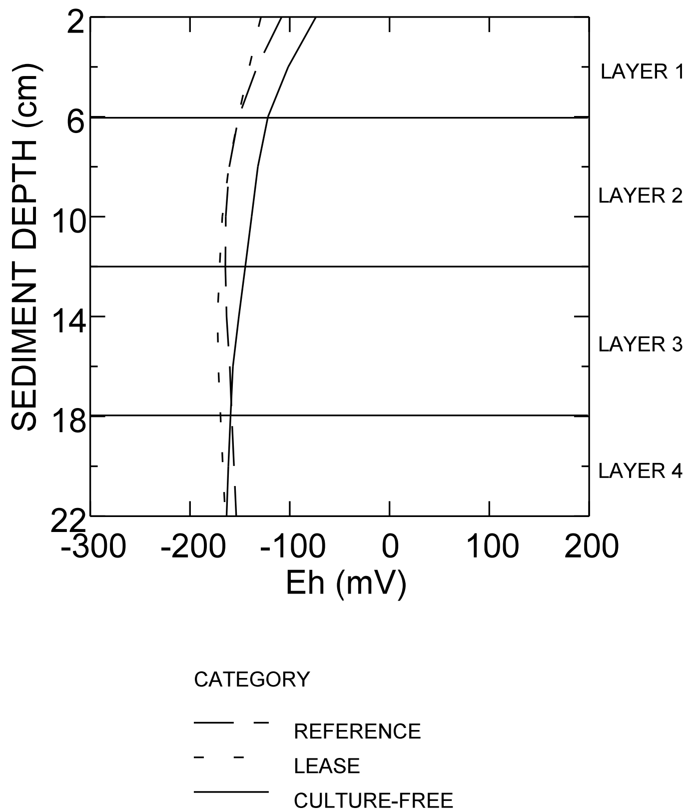
0 Core profile of Eh values for Upper, Mid, and Lower estuary samples.



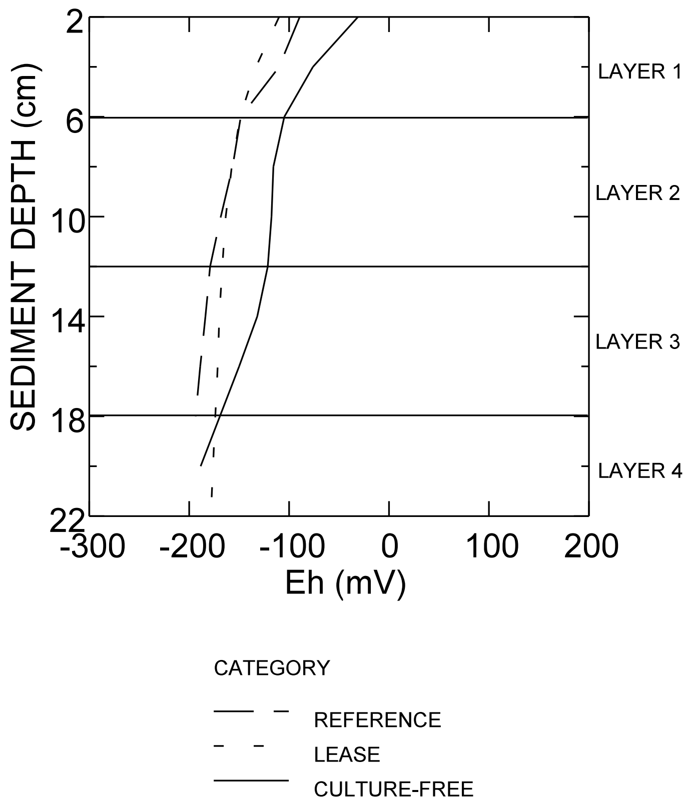
0 Core profile of Eh values for Lease, Reference, and Culture-Free samples from the Upper estuary position.



0 Mean abundance values for Lower, Mid, and Upper samples



0 Core profile of Eh values for Lease, Reference, and Culture-Free samples from the Middle estuary position.



0 Core profile of Eh values for Lease, Reference, and Culture-Free samples from the Lower estuary position.

Table 5. Significant similarities between *upper, middle,* and *lower* samples

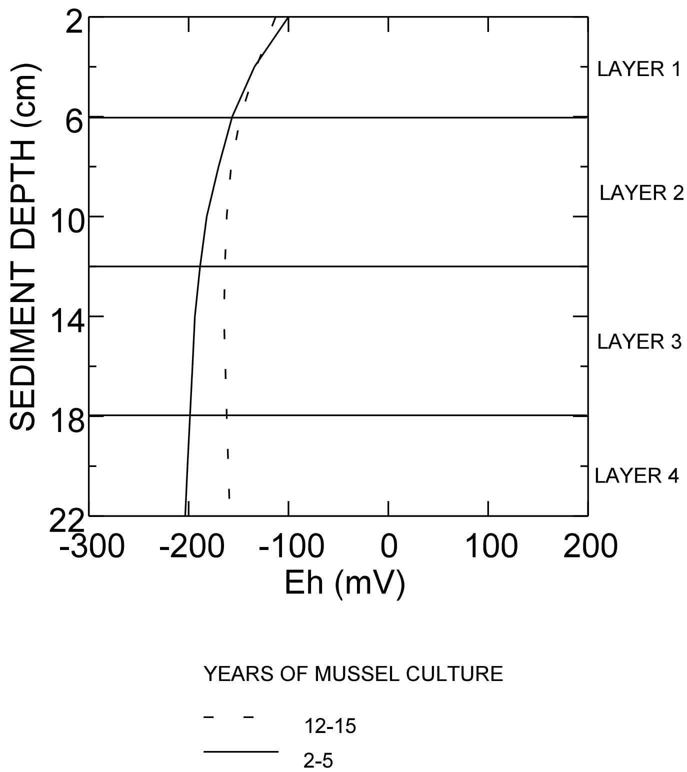
Variable	Layer	Upper Middle	Lower
Water Content	1	XXXXXXXXXXXXXXXXXXX	
Organic Matter	1	XXXXXXXXXXXXXXXXXXX	
Total Sulfides	1	XXXXXXXXXXXXXXXXXXX	
	2	XXXXXXXXXXXXXXXXXXX	
	4	XXXXXXXXXXXXXXXXXXX	
Eh	1		XXXXXXXXXX
	2		XXXXXXXXXX
	3	XXXXXXXXXXXXXXXXXXX	
	4	XXXXXXXXXXXXXXXXXXX	
BEI	1	XXXXXXXXXXXXXXXXXXX	
Diversity	1	XXXXXXXXXXXXXXXXXXX	
Abundance	1	XXXXXXXXXXXXXXXXXXX	
Biomass	1	XXXXXXXXXXXXXXXXXXX	
% Deposit Feeders	1	XXXXXXXXXXXXXXXXXXX	

Years of Mussel Culture

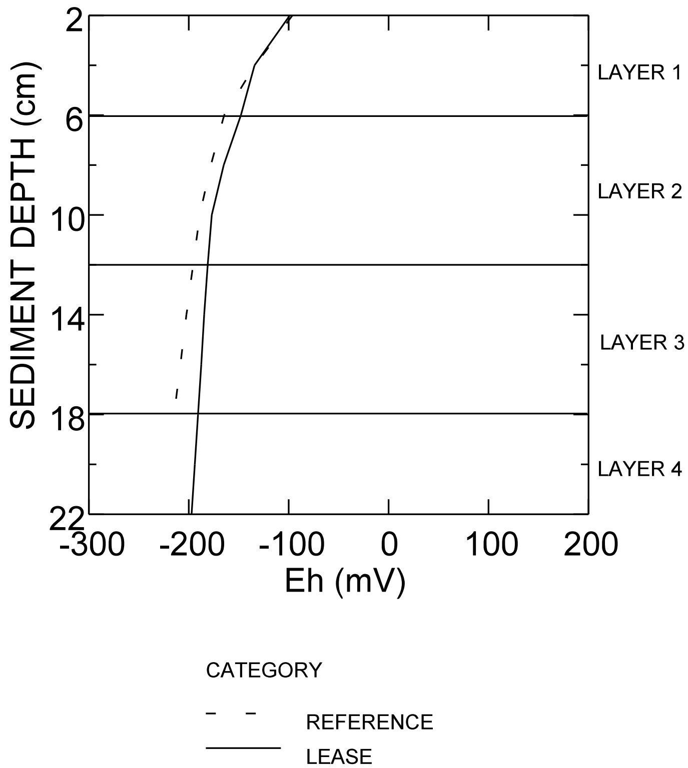
Mean organic matter content values were significantly higher in the estuaries exposed to 2- 5 years of mussel culture. The relationship between the Eh values of estuaries subject to 2-5 years of mussel culture and those subject to 12-15 years of mussel culture is shown in Figure 14. The estuaries with 12-15 years mussel culture had significantly higher Eh values than those more recently exposed to mussel culture in layers 3 and 4. No significant differences were found between the two groups in the top two layers or in WC, S, BEI, abundance, diversity, biomass, and percentage of deposit feeders. Table 6 demonstrates if estuaries exposed to 2-5 years of culture are significantly different from those exposed to 12-15 years for all variables. A bar joining the two groups of estuaries represents no significant difference.

In the estuaries exposed to 2-5 years of mussel culture, *lease* samples had significantly higher Eh values than *reference* samples in layer 3 (Fig. 15). *Reference* samples had significantly higher abundance values than *lease* samples (Fig. 16). There was no significant difference in Eh values in the top two layers and there is insufficient data to make a comparison in layer 4. No significant differences were found between the two categories in WC, OM, S, BEI, diversity, biomass, and percentage of deposit feeders.

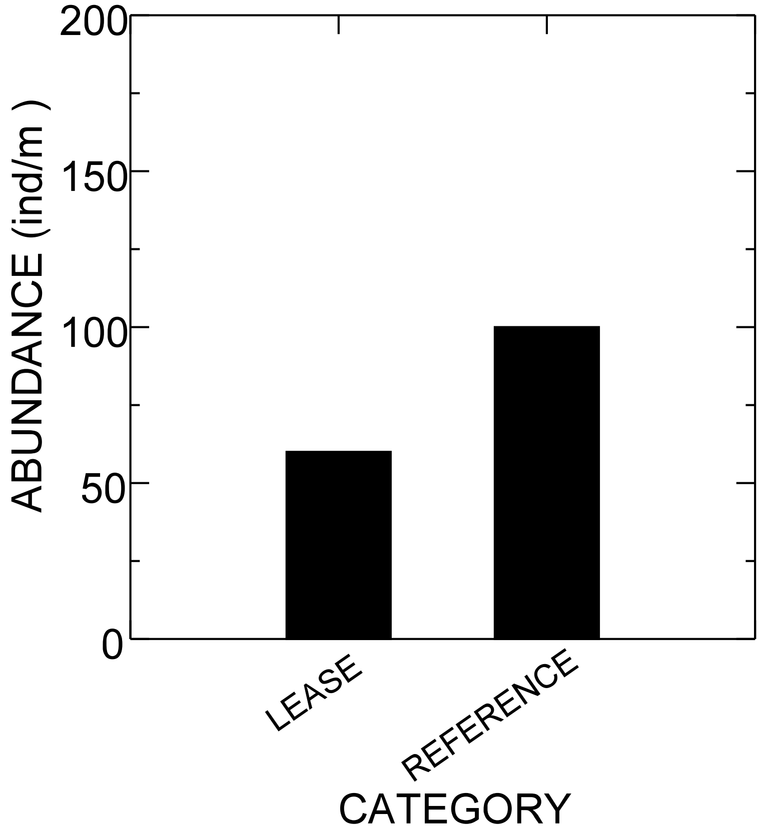
In the estuaries exposed to 12-15 years of mussel culture, *reference* samples had significantly higher Eh values than *lease* samples in layers 1 and 2 (Fig. 17). There was no significant difference in Eh values in the bottom two layers. BEI values were also significantly higher in the *reference* samples than those in the *lease* samples (Fig. 18). WC, OM, S, abundance, diversity, biomass, and percentage of deposit feeders were not significantly different.



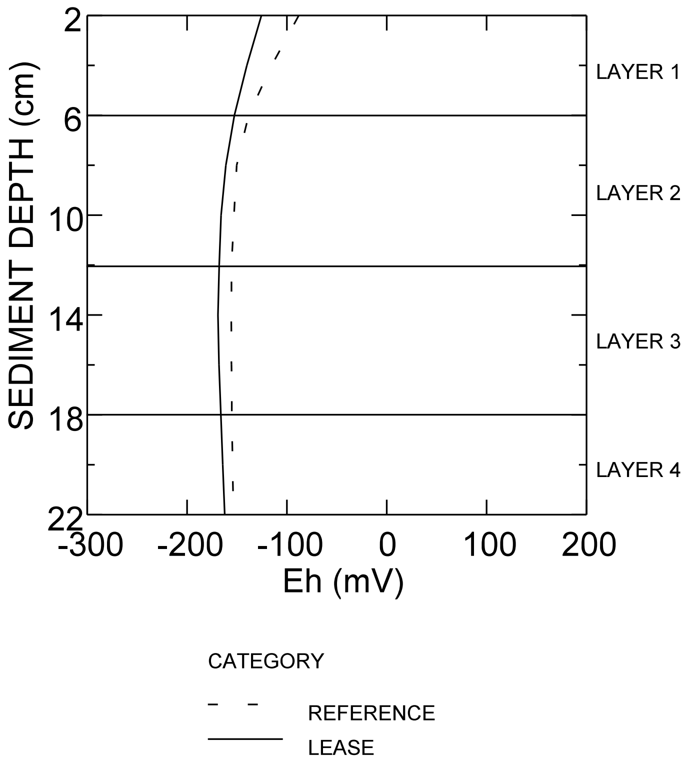
0 Core profile of Eh values for estuaries exposed to 2-5 and 12-15 years of mussel culture.



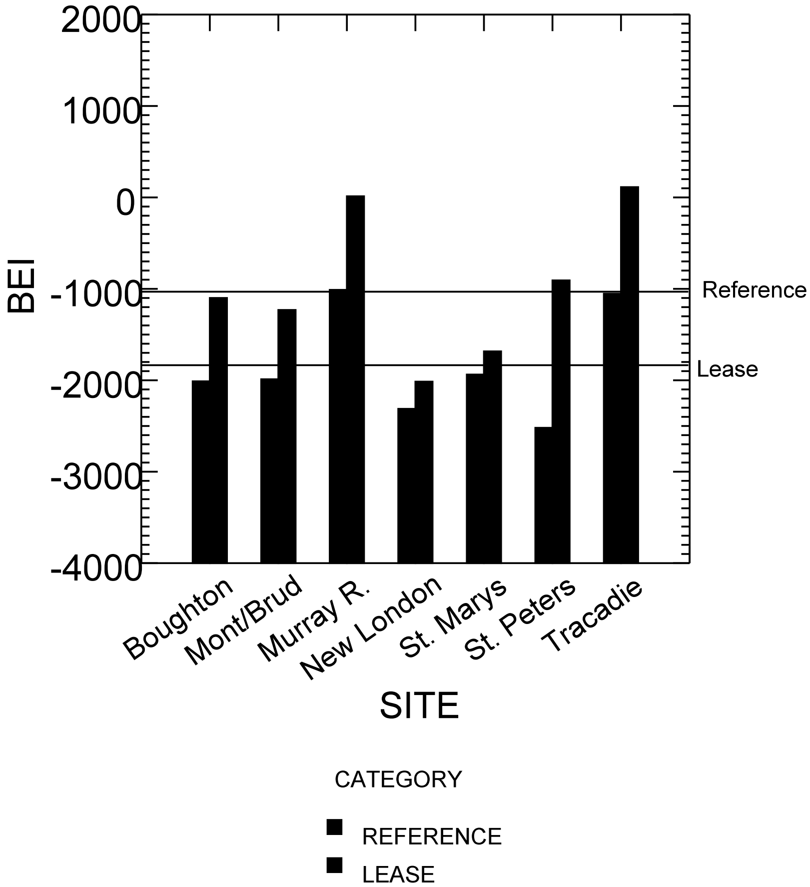
0 Core profile of Eh values for Lease and Reference samples taken from estuaries exposed to 2-5 years of mussel culture.



0 Mean abundance values for Lease and Reference samples from estuaries exposed to 2-5 years of mussel culture



0 Core profile of Eh values for Lease and Reference samples taken from estuaries exposed to 12-15 years of mussel culture.



0 Mean

BEI values for Lease and Reference samples taken from estuaries exposed to 12-15 years of mussel culture. Horizontal lines indicate category means.

Table 6. Significant similarities between estuaries exposed to 2-5 years and 12-15 years of mussel culture

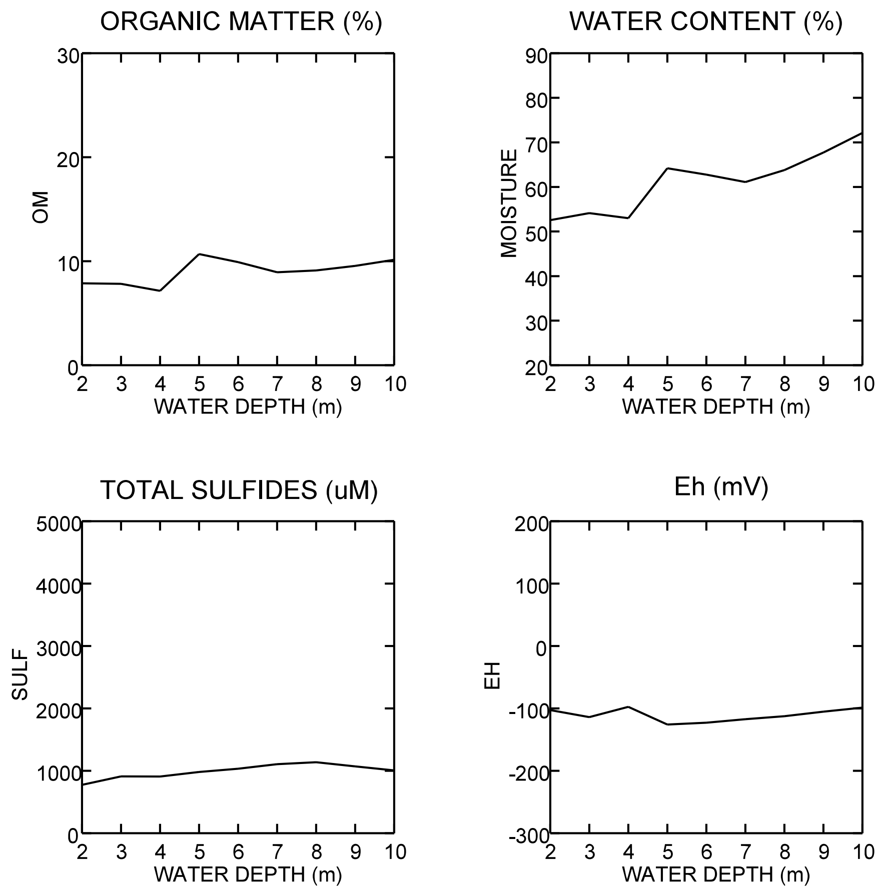
Variable	Layer	2-5 years	12-15 years
Water Content	1	XXXXXXXXXXXXXXX	
Organic Matter	1		
Total Sulfides	1	XXXXXXXXXXXXXXX	
	2	XXXXXXXXXXXXXXX	
	4	XXXXXXXXXXXXXXX	
Eh	1	XXXXXXXXXXXXXXX	
	2	XXXXXXXXXXXXXXX	
	3		
	4		
BEI	1	XXXXXXXXXXXXXXX	
Diversity	1	XXXXXXXXXXXXXXX	
Abundance	1	XXXXXXXXXXXXXXX	
Biomass	1	XXXXXXXXXXXXXXX	
% Deposit Feeders	1	XXXXXXXXXXXXXXX	

Water Depth

Figure 19 demonstrates the relationship between OM, WC, S, and Eh and water depth for the top sediment layer. Samples taken from 2 m and 4 m water depth had a lower OM, WC, S and a higher Eh than those taken at other depths. The only significant differences however were that 2 m had a higher Eh than 3 m and 5 m and samples from 4 m had a higher Eh than those from 3 m. The elevated Eh at 2 m and 4 m was consistent throughout the length of the cores (Fig. 20).

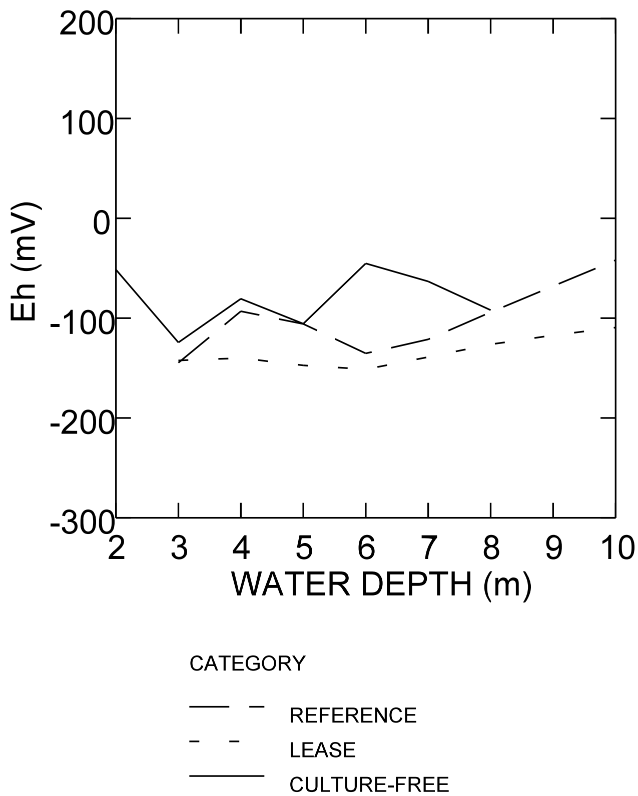
In sediment layer 1, *culture-free* samples had significantly higher Eh values at 4, 5, 6, and 7 m than *lease* samples (Fig. 21). Significant differences are found at these same water depths in sediment layer 2 (Fig. 22). In sediment layer 1, S values were significantly higher in *lease* samples than in culture-free samples at 3 m and 6 m of water (Fig. 23). No significant differences were found in S values in layer 2. There is insufficient data to make meaningful comparisons of sample categories at different water depths in sediment layers 3 and 4. There is also insufficient data to test the effects of water depth on invertebrate results.

Using the abundance-biomass comparison method, the relative positions of the abundance and biomass curves indicate the severity of benthic community disturbance. In undisturbed environments, the biomass curve overlies the abundance curve due to a biomass dominance by a few large species. When a few small opportunistic species become numerically dominant, the abundance curve should overlie the biomass curve, indicating grossly disturbed conditions. Moderate disturbance is indicated when the two curves are superimposed and cross each other (Weston 1990). The ABC curves for the three categories are shown in Figures 24-26. According to this method, the *lease* communities are classified as undisturbed and the *reference* and the *culture-free* communities are classified as mildly disturbed.

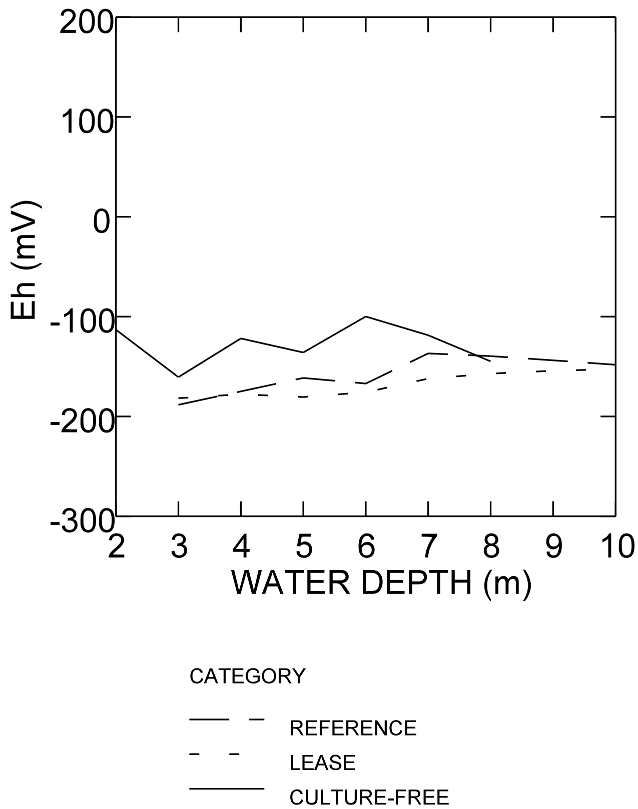


0 Layer 1 organic matter (OM), water content (WC), total sulfides (S), and Eh values relative to water depth

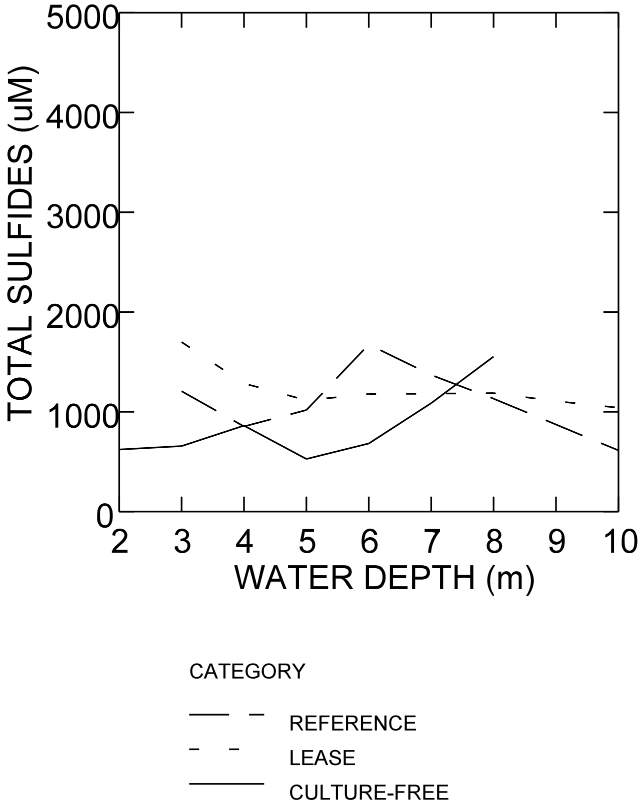
0 Core profile of Eh values relative to water depth



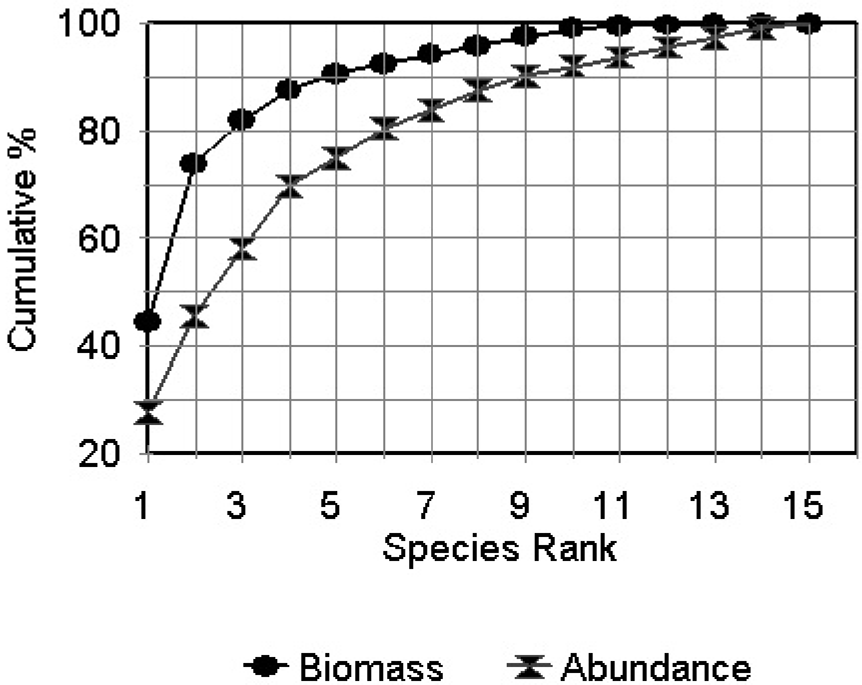
0 Layer 1 Eh values relative to water depth for Lease, Reference, and Culture-Free samples.



0 Layer 2 Eh values relative to water depth for Lease, Reference, and Culture-Free samples.

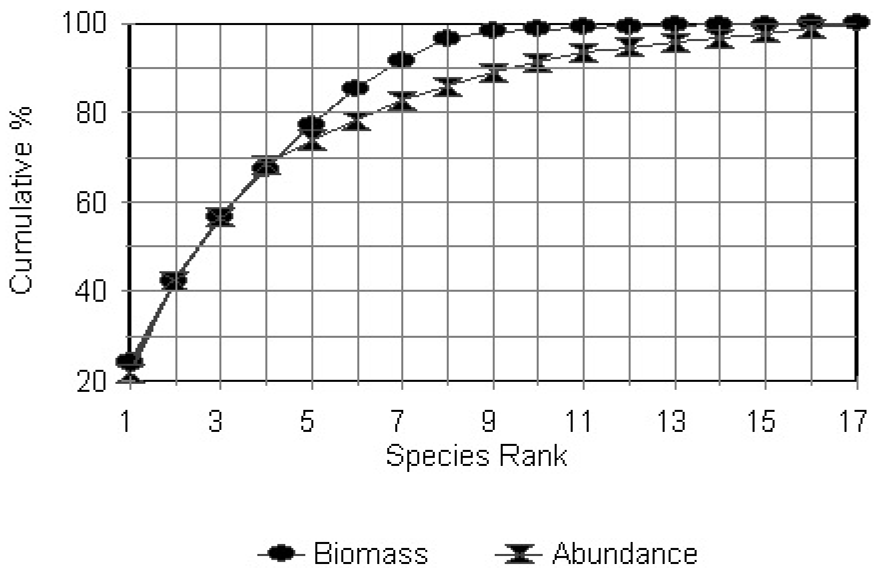


0 Layer 1 total sulfide (S) values relative to water depth for Lease, Reference, and Culture-Free samples



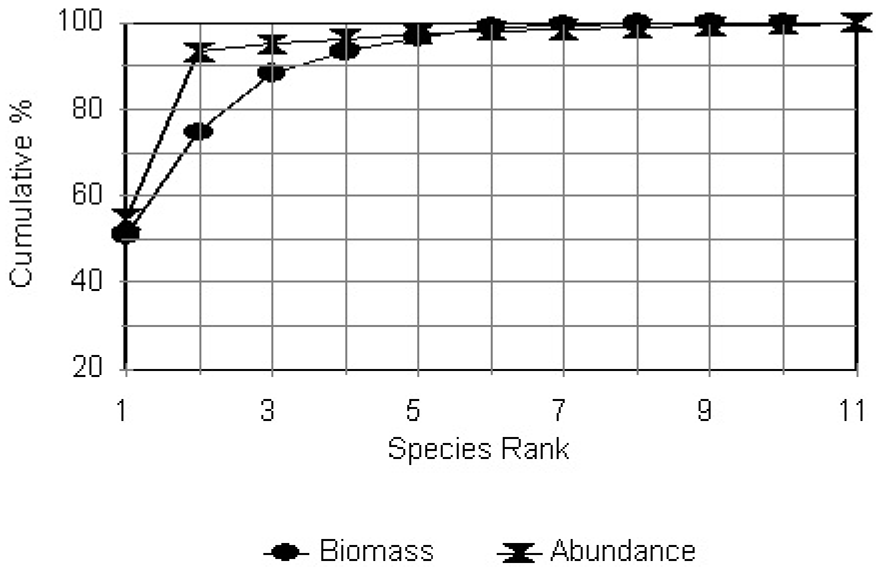
0 ABC

Curve for lease estuaries.



0 ABC

Curve for reference estuaries.



0 ABC Curve for culture-free estuaries.

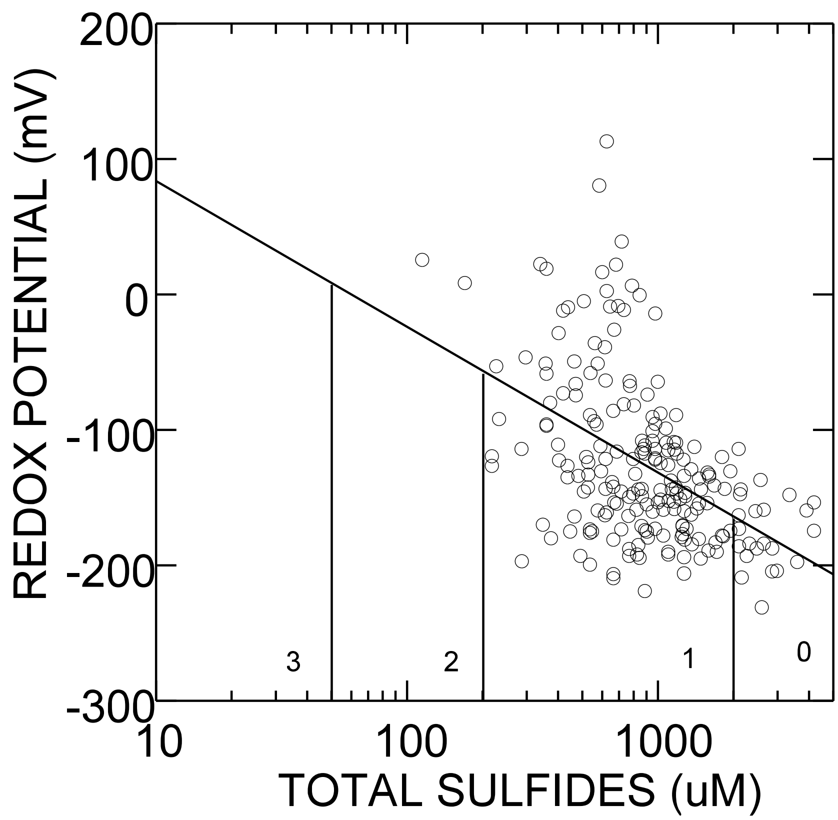
The Euclidean distance similarity indices, based on abundance, are given in Table 7.

Table 7. Euclidean distance similarity indices between corresponding *lease* and *reference* samples

Site	Station	Similarity Index
New London	1	40
Rustico	2	40
Rustico	1	53
New London	4	57
St. Peter's	3	98
St. Mary's	1	102
Boughton	3	118
Mont/Brud	2	169
Mont/Brud	3	265
Murray River	2	299

Discussion

According to the results from this survey, the benthic condition of muddy bottoms in P.E.I. estuaries is highly anoxic with high organic matter levels, regardless of mussel aquaculture. High organic matter content causes a rapid depletion of oxygen and permits the development of anoxic environments (Bartlett 1973). The OM mean for all of the samples was 9.10% and some samples were over 25%. These values are similar to those found on the Swedish west coast (Mattson and Linden 1983, Dahlback and Gunnarsson 1981) and in coastal Maritime Canada (Schafer et al 1995). Kaspar et al. (1985) reported water content values (mussel farm: 65.8%, reference: 60.9%) in New Zealand comparable to those from this survey. Hargrave et al (1997) found sub-surface Eh values in the Bay of Fundy to be mostly positive while Eh values in this study were rarely positive. Sediment grain size may be an important factor in this difference in Eh values as sandy sediment tends to be more aerobic than muddy sediment and therefore has higher Eh values. Grain size was not measured in this study. The relationship between S and Eh (Fig. 27) can be used to quantify benthic enrichment zones (Hargrave et al. 1997). Zones 0 to 3 represent anoxic (grossly polluted), hypoxic (polluted), oxic (transitory), and normal, respectively. The majority of the samples from this study fall into the hypoxic zone with some in the anoxic zone.



0 Relationship between Total Sulfides and Redox Potential.

In respect to the parameters used in this survey, the benthic condition under the mussel leases on P.E.I. is similar to that in reference areas. This suggests the occurrence of one of the following two situations: mussel culture is not increasing the anoxic levels of the underlying sediment, or mussel culture is increasing the anoxic levels of the benthos of the entire estuary. The anoxic levels in the estuaries with no mussel culture are significantly lower in the top sediment layer than those under the leases. However, these differences are minor and it is questionable whether these estuaries can be compared to those supporting mussel culture. Other contributing factors (water depth, flushing rates, surrounding land use, other shellfish culture) prevent a significant difference in sediment quality from being attributed to mussel culture alone. Regardless of the source of these differences in sediment chemistry, Weston (1990) predicts that they should result in lower diversity and biomass and higher abundance levels in the *lease* samples. There was no significant difference found however, between the *lease* and *culture-free* samples in diversity or biomass and abundance was actually lower in the *lease* samples. Ritz et al (1989) suggest that organic enrichment can result in a disturbed benthic condition as indicated by the ABC comparison method. This is not seen in this study as the ABC curves indicate an undisturbed condition in the *lease* samples and a mildly disturbed condition in the *culture-free* samples which are slightly less organically enriched than *lease* samples. The *culture-free* samples did however exhibit the benthic community characteristics of an organically impacted condition: low diversity and high abundance of a few species.

The position in the estuary has no effect on WC, OM, S or BEI. The elevated Eh in the samples from the *upper* position could be due to higher current velocities (which were not measured) which stir the sediments, causing them to be more oxygenated. This increased Eh has no impact on the macrofauna population variables. Each of the three positions showed higher Eh values in the *culture-free* samples than the *lease* samples. This indicates that this trend occurs evenly throughout the estuary, regardless of sample position. *Upper* and *middle* samples also showed higher invertebrate abundance values.

The length of time that the estuary was subject to mussel culture does not seem to affect WC, OM, S, BEI, abundance, diversity, biomass, and percentage of deposit feeders. In the estuaries exposed to mussel culture for only 2-5 years, *lease* and *reference* samples had similar Eh values in Layers 1 and 2. *Lease* samples from estuaries exposed to mussel culture for 12-15 years however, had lower Eh and BEI values than *reference* samples in layers 1 and 2. This could suggest an accumulation of anoxic conditions under the leases over time of mussel culture. It is notable that Murray River, Tracadie, and St. Peter's, which have supported mussel culture for 15 years, exhibit a large difference between the *lease* and *reference* benthic conditions (Fig. 18). The *reference* and *lease* samples are similar at New London and St. Mary's thus it might be concluded that the accumulation of anoxic conditions over time is site-specific. A sediment quality monitoring program would indicate if this condition worsens as time progresses.

The elevated Eh of the samples taken from 2 m water depth is to be expected. These sediments are often sandier, frequently stirred, and therefore well oxygenated. These samples were taken from *culture-free* estuaries only and a majority of them were taken from Dunk and Foxley River which showed relatively high Eh readings in general. The trend of higher Eh values in *culture-free* samples is seen at 4 to 7 m water depth. It should be noted that there were no *culture-free* samples taken at 9 or 10 m and there was only one taken at 8 m. Also, there were no *reference* or *lease* samples taken at 2 m. The failure to determine significant differences at each water depth is due to lack of data.

Conclusion

All estuaries surveyed in this study contain highly organic, anoxic sediments. Sediment samples taken from under mussel leases were no more anoxic, or organic, than sediment from reference samples. However sediment samples taken from estuaries with no mussel culture were marginally healthier overall than *lease* samples. Whether or not this is due to mussel culture cannot be determined with the available data. Other factors such as mean water depth, flushing rates, other shellfish culture, and surrounding land use may play a role in sediment quality. These factors must be accounted for before this minor difference in sediment quality can be attributed to mussel culture. These differences do not appear to be substantial enough to have any serious impacts on benthic macrofaunal populations.

Any differences in sediment quality due to position in the estuary, years of exposure to mussel culture, and water depth were mostly determined by Eh values. Redox potential is a sensitive parameter and serves only as a guide to the condition of the sediment. The magnitude of these differences do not seem to be large enough to seriously impact biological activity.

The increase of organic matter levels from 1971 and the overall poor sediment quality across the province raise a concern. The difference in methodology between Bartlett and this study may be a factor in the increase in values. A sediment quality monitoring program for P.E.I. estuaries should be implemented to determine if organic matter levels are increasing and the biological condition of the sediments is deteriorating over time. Significantly higher BEI values in the *reference* samples than those in the *lease* samples in the estuaries exposed to 12-15 years of mussel culture may reflect a long-term effect of the lease sites. A monitoring program would determine if anoxic levels under the mussel leases are accumulating at a greater rate than at reference locations.

Acknowledgements

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Literature Cited

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

Baudinet, D., E. Alliot., B. Bernard., C. Grenz, M. Plante-Cuny, R. Plante, and C. Salen-Picard. 1990. Incidence of mussel culture on biogeochemical fluxes at the sediment-water interface. *Hydrobiologica* 207:187-196.

Bartlett, G.A. and J.L. Usher. 1971a. Environmental analysis, ecology and nutrient study of Charlottetown harbour and environs, Queen's University.

Bartlett, G.A. and J.L. Usher. 1971b. Environmental analysis, ecology and nutrient study of Summerside harbour and environs, Queen's University.

Bartlett, G.A. 1973. Environmental analysis and sediment investigation of Georgetown harbour. Department of Regional Economic Expansion.

Bernard, T. 1994. P.E.I. Mussel Monitoring Program, 1994 Report. P.E.I. Department of Agriculture, Fisheries and Forestry, Fisheries and Aquaculture Division.

Dahlback, B. and L.A.H. Gunnarsson. 1981. Sedimentation and sulfate reduction under a mussel culture. *Mar. Biol.* 63:269-275.

Dame, R. F., N. Dankers, T. Prins, H. Jongsma, and A. Smaal. 1991. The influence of mussel beds on nutrients in the Western Wadden Sea and Eastern Scheldt estuaries. *Estuaries* 14:130-138.

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Grant, J., A. Hatcher, D.B. Scott, P. Pocklington, C.T. Schafer, and G.V. Winters. 1995. A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities. *Estuaries.* 18:124-144.

Greenberg, A.E., L.S. Clesceri, and A.D. Eaton [ed.] 1992. Standard Methods for the Examination of Water and Wastewater, 18th ed. American Public Health Association, Washington, DC.

Hargrave, B.T. 1994. A benthic enrichment index. *Can. Tech. Rep. Fish. Aquat. Sci.* 1949:79-91.

Hargrave, B.T., G.A. Phillips, L.I. Doucette, M.J. White, T.G. Milligan, D.J. Wildish, and R.E. Cranston. 1995. Biogeochemical observations to assess benthic impacts of organic enrichment from marine aquaculture in the Western Isles region of the Bay of Fundy, 1994. *Can. Tech. Rep. Fish. Aquat. Sci.* 2062.

Hargrave, B.T., G.A. Phillips, L.I. Doucette, M.J. White, T.G. Milligan, D.J. Wildish, and R.E. Cranston. 1997. Assessing benthic impacts of organic enrichment from marine aquaculture. *Wat., Air, and Soil Poll.* 99:641-650.

Kaspar, H.F., P.A. Gillespie, I.C. Boyer, and A.L. MacKenzie. 1985. Effects of mussel aquaculture on the nitrogen cycle and benthic communities in Kenepuru Sound, Marlborough Sounds, New Zealand. *Mar. Biol.* 85:127-136.

Krebs, C.J. 1989. Ecological Methodolgy. Harper & Row Publishers, Inc., NY.

Lane, P. 1985. A study of water quality issues at selected Prince Edward Island causeways. P. Lane and Associates Limited. Halifax NS.

Mattson, J. and O. Linden. 1983. Benthic macrofauna succession under mussels, *Mytilus edulis* L. (Bivalvia) cultured on hanging long lines. *Sarsia.* 68:97-102.

Meeuwig, J.J., J.R. Rasmussen, and R.H. Peters. 1997. Turbid waters and clarifying mussels: their moderation of empirical Chl:nutrient relations in P.E.I. estuaries. McGill University.

Officer, C.B., T.J. Smayda, and R. Mann. 1982. Benthic filter feeding: a natural eutrophication control. *Mar. Ecol. Prog. Ser.* 9:203-210.

Pearson, T. and S.O. Stanley. 1979. Comparative measurement of the redox potential of marine sediments as a rapid means of assessing the effect of organic pollution. *Mar. Biol.* 53:371-379.

Ritz, D.A., M.E. Lewis, and Ma Shen. 1989. Response to organic enrichment of infaunal macrobenthic communities under salmonid seacages. *Mar. Biol.* 103:211-214.

Schafer, C.T., G.V. Winters, D.B. Scott, P. Pocklington, F.E. Cole, and C. Honig. 1995. Survey of living foraminifera and polychaete populations at some canadian aquaculture sites: potential for impact mapping and monitoring. *J. Foram. Res.* 25:236-259.

Shannon and Weaver 1949. The Mathematical Theory of Communication. University Illinois Press, Urbana, Il.

Tsusumi, H., S. Fukunaga, N. Fujita, M. Sumida. 1990. Relationship between growth of *Capitella* sp. and organic enrichment of the sediment. *Mar Ecol. Prog. Ser.* 63:157-

Warwick, R.M. 1986. A new method for detecting pollution effects on marine macrobenthic communities. *Mar. Biol.* 95:557-562.

Whitfield, M. 1969. Eh as an operational parameter in estuarine studies. *Limnol. Oceanogr.* 14:547-558.

Wildish, D.J. and D. Peer. 1983. Tidal current speed and production of benthic macrofauna in the lower Bay of Fundy. *Can. J. Fish. Aquat. Sci.* 40 (Suppl.):309-321.

APPENDIX A. SEDIMENT PROFILES FOR CORE SAMPLES

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)	
Rustico 1 reference	2			-240		
Rustico 1 reference	4			-189	1592	
Rustico 1 reference	6			-207		
Rustico 1 reference	8			-196		
Rustico 1 e	10			-206		referenc
Rustico 1 e	12			-204	2983	referenc
Rustico 1 e	14			-195		referenc
Rustico 1 e	16			-216		referenc
Rustico 1 e	18			-212		referenc
Rustico 2 reference	2			-164		
Rustico 2 reference	4			-180	911	
Rustico 2 reference	6			-175		
Rustico 2 reference	8			-176		
Rustico 2 e	10			-186		referenc
Rustico 2 e	12			-198		referenc
Rustico 2 e	14			-193		referenc
Rustico 3 reference	2	56.055	8.042	-70		
Rustico 3 reference	4			-89	1183	
Rustico 3 reference	6			-123		
Rustico 3 reference	8			-86		
Rustico 3 e	10			-100		referenc
Rustico 4 reference	2	59.045	9.062	-108		
Rustico 4 reference	4			-134	1271	
Rustico 4 reference	6			-173		

Rustico 4 reference	8			-179		
Rustico 4 e	10			-184		referenc
Rustico 4 e	12			-193	768	referenc
Rustico 4 e	14			-209		referenc
New London1 reference	2	57.684	6.695	-128		
New London1 reference	4			-151	1227	
New London1 reference	6			-143		
New London2 reference	2	80.216	15.128	-121		
New London2 reference	4			-148	3343	
New London2 reference	6			-174		
New London2 reference	8			-177		
New London2 reference	10			-182		
New London2 reference	12			-177	1254	
New London2 reference	14			-176		
New London3 reference	2	76.931	14.056	-129		
New London3 reference	4			-148	2126	
New London3 reference	6			-152		
New London3 reference	8			-167		
New London3 reference	10			-169		
New London3 reference	12			-171	1254	
New London3 reference	14			-165		
New London4 reference	2	69.282	10.890	-108		
New London4 reference	4			-136	1458	
New London4 reference	6			-147		
New London4 reference	8			-158		
New London4 reference	10			-185		
New London5 reference	2	61.831	11.348	-128		

New London5 reference	4			-159	1163
New London5 reference	6			-170	
New London5 reference	8			-181	

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
Savage 1 reference	2	74.866	13.999	-69	
Savage 1 reference	4			-118	1189
Savage 1 reference	6			-149	
Savage 1 reference	8			-167	
Savage 2 reference	2	77.702	17.206	-109	
Savage 2 reference	4			-133	1600
Savage 2 reference	6			-165	
Savage 3 reference	2	59.662	9.381	-103	
Savage 3 reference	4			-153	1104
Savage 3 reference	6			-168	
Savage 4 reference	2	71.491	11.564	-113	
Savage 4 reference	4			-143	526
Mont/Brud1 reference	2	74.908	15.724	-6	
Mont/Brud1 reference	4			-47	297
Mont/Brud1 reference	6			-104	
Mont/Brud2 reference	2	63.695	12.942	-55	
Mont/Brud2 reference	4			-50	464
Mont/Brud2 reference	6			37	
Mont/Brud3 reference	2	76.702	10.538	-7	
Mont/Brud3 reference	4			-36	561

Mont/Brud3 reference	6			-137		
Mont/Brud3 reference	8			-141		
Mont/Brud3 e	10			-152		referenc
Mont/Brud3 e	12			-175	447	referenc
Mont/Brud4 reference	2	77.306	16.437	-130		
Mont/Brud4 reference	4			-149	1286	
Mont/Brud4 reference	6			-159		
Mont/Brud4 reference	8			-167		
Murray R.1 reference	2	44.119	6.406	54		
Murray R.1 reference	4			17	600	
Murray R.1 reference	6			-41		
Murray R.2 reference	2	55.422	6.513	-69		
Murray R.2 reference	4			-82	803	
Murray R.2 reference	6			-126		
Murray R.2 reference	8			-134		
Murray R.3 reference	2	42.863	2.667	-28		
Murray R.3 reference	4			-59	360	
Murray R.4 reference	2	58.255	6.027	25		
Murray R.4 reference	4			-9	694	
Murray R.4 reference	6			-46		
Murray R.4 reference	8			33		
Murray R.4 reference	10			-54		
Murray R.4 reference	12			-94	557	

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)	
Tracadie2 reference	2	72.247	10.155	-93		
Tracadie2 reference	4			-133	528	
Tracadie2 reference	6			-146		
Tracadie2 reference	8			-162		
Tracadie2 reference	10			-34		
Tracadie2 e	12			-124	528	referenc
Tracadie2 e	14			-147		referenc
Tracadie2 e	16			-170		referenc
Tracadie2 e	18			-162		referenc
Tracadie2 e	20			-164		referenc
Tracadie3 reference	2	38.341	3.704	42		
Tracadie3 reference	4			19	360	
Tracadie4 reference	2	35.884	3.060	120		
Tracadie4 reference	4			-12	419	
St. Peters1 reference	2	49.347	8.375	-30		
St. Peters1 reference	4			-120	1801	
St. Peters1 reference	6			-123		
St. Peters1 reference	8			-97		
St. Peters1 reference	10			-155		
St. Peters1	12			-159	1052	

reference					
St. Peters1 reference	14			-158	
St. Peters1 reference	16			-165	
St. Peters1 reference	18			-155	
St. Peters1 reference	20			-173	975
St. Peters1 reference	22			-178	
St. Peters2 reference	2	57.804	9.094	-80	
St. Peters2 reference	4			-114	2099
St. Peters2 reference	6			-135	
St. Peters2 reference	8			-147	
St. Peters2 reference	10			-149	
St. Peters2 reference	12			-160	2448
St. Peters2 reference	14			-161	
St. Peters2 reference	16			-162	
St. Peters2 reference	18			-160	
St. Peters2 reference	20			-158	1431
St. Peters3 reference	2	53.941	8.065	-33	
St. Marys1 reference	2	82.238	21.951	-109	
St. Marys1 reference	4			-115	1099
St. Marys1 reference	6			-151	
St. Marys1 reference	8			-160	
St. Marys1 reference	10			-164	
St. Marys1 reference	12			-174	889
St. Marys1 reference	14			-178	
St. Marys1 reference	16			-186	
St. Marys1 reference	18			-183	
St. Marys2 reference	2	41.454	4.018	-83	
St. Marys2	4			-122	1265

reference

St. Marys3 reference	2	44.704	3.002		1024

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
St. Marys4 reference	2	66.755	9.414	-131	
St. Marys4 reference	4			-137	2563
St. Marys4 reference	6			-139	
St. Marys4 reference	8			-137	
St. Marys4 reference	10			-115	
St. Marys4 reference	12			-129	1358
St. Marys4 reference	14			-133	
St. Marys4 reference	16			-122	
St. Marys4 reference	18			-118	
St. Marys4 reference	20			-141	1678
Boughton1 reference	2	70.805	11.612	-146	
Boughton1 reference	4			-161	952
Boughton1 reference	6			-171	
Boughton2 reference	2	49.085	5.581	79	
Boughton2 reference	4			23	340
Boughton2 reference	6			-114	
Boughton2 reference	8			-142	
Boughton2	10			-115	referenc

e

Boughton2	12			-127	218	reference
Boughton2	14			-116		reference
Boughton2	16			-125		reference
Boughton2	18			-107		reference
Boughton2	20			-120	218	reference
Boughton2	22			-144		reference
Boughton2	24			-151		reference
Boughton3	2	68.996	8.962	-108		reference
Boughton3	4			-147	1187	reference
Boughton3	6			-157		reference
Boughton3	8			-186		reference
Boughton3	10			-190		reference
Boughton3	12			-193	491	reference
Boughton3	14			-200		reference
Boughton3	16			-222		reference
Boughton4	2	73.289	10.685	-115		reference
Boughton4	4			-144	1847	reference
Boughton4	6			-160		reference
Boughton4	8			-182		reference
Marchwater1	2	42.973	6.309	6		reference
Marchwater1	4			-89	536	reference
Marchwater1	6			-105		reference
Marchwater1	8			-114		reference
Marchwater1	10			-116		reference
Marchwater1	12			-176	536	reference
Marchwater1	14			-160		reference
Marchwater1	16			-150		reference
Marchwater1	18			-148		reference

Marchwater1 e	20			-181	665	referenc
Marchwater3 reference	2	47.696	3.596	-37		
Marchwater3 reference	4			-51	576	
Rustico 1	2		9.250	-167		lease
Rustico 1	4			-173	2104	lease
Rustico 1	6			-186		lease
Rustico 1	8			-201		lease
Rustico 1	10			-204		lease

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)	
Rustico 2	2		10.318	-131		lease
Rustico 2	4			-231	2594	lease
Rustico 2	6			-171		lease
Rustico 2	8			-186		lease
Rustico 2	10			-179		lease
Rustico 2	12			-186	2104	lease
Rustico 2	14			-180		lease
Rustico 3	2	58.139	7.312	-117		lease
Rustico 3	4			-160	1271	lease
Rustico 3	6			-183		lease
Rustico 3	8			-195		lease
Rustico 3	10			-196		lease
Rustico 3	12			-192	1101	lease
Rustico 3	14			-182		lease
Rustico 3	16			-196		lease
Rustico 3	18			-187		lease
Rustico 3	20			-194	1271	lease

Rustico 3	22			-197		lease
Rustico 4	2			-51		lease
Rustico 4	4			-132	1576	lease
Rustico 4	6			-145		lease
Rustico 4	8			-161		lease
Rustico 4	10			-174		lease
Rustico 4	12			-179	1820	lease
New London1	2	80.813	14.823	-155		lease
New London1	4			-163	2099	lease
New London1	6			-176		lease
New London1	8			-184		lease
New London1	10			-173		lease
New London1	12			-163	615	lease
New London1	14			-165		lease
New London1	16			-163		lease
New London1	18			-169		lease
New London1	20			-185	836	lease
New London2	2	81.689	15.015	-147		lease
New London2	4			-175	4188	lease
New London2	6			-181		lease
New London2	8			-191		lease
New London2	10			-194		lease
New London2	12			-198	3592	lease
New London2	14			-198		lease
New London3	2	69.992	11.277	-148		lease
New London3	4			-178	1052	lease
New London3	6			-186		lease

New London3	8			-194		lease
New London4	2	66.022	10.294	-112		lease
New London4	4			-171	1254	lease
New London4	6			-150		lease
New London4	8			-164		lease
New London4	10			-177		lease
New London4	12			-183	1696	lease
New London4	14			-178		lease

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)	
New London5	2	74.104	17.559	-137		lease
New London5	4			-154	1572	lease
New London5	6			-168		lease
New London5	8			-177		lease
Savage 1	2	69.515	12.570	-94		lease
Savage 1	4			-135	1600	lease
Savage 1	6			-145		lease
Savage 2	2	68.413	11.111	-28		lease
Savage 2	4			-91	952	lease
Savage 2	6			-98		lease
Savage 3	2	69.698	12.142	-131		lease
Savage 3	4			-144	1485	lease
Savage 3	6			-164		lease
Savage 3	8			-151		lease

Savage 3	10			-187		lease
Savage 4	2	67.303	11.717	-113		lease
Savage 4	4			-139	657	lease
Mont/Brud1	2	79.417	18.673	-75		lease
Mont/Brud1	4			-111	400	lease
Mont/Brud1	6			-124		lease
Mont/Brud1	8			-153		lease
Mont/Brud2	2	77.810	15.939	3		lease
Mont/Brud2	4			-58	539	lease
Mont/Brud2	6			-103		lease
Mont/Brud2	8			-115		lease
Mont/Brud2	10			-136		lease
Mont/Brud2	12			-80	372	lease
Mont/Brud3	2	81.984	20.392	-85		lease
Mont/Brud3	4			-108	951	lease
Mont/Brud3	6			-131		lease
Mont/Brud3	8			-198		lease
Mont/Brud4	2	76.004	15.692	-133		lease
Mont/Brud4	4			-147	1286	lease
Mont/Brud4	6			-152		lease
Mont/Brud4	8			-143		lease
Mont/Brud5	2	35.240	4.495	-87		lease
Mont/Brud5	4			-88	1025	lease
Mont/Brud5	6			-109		lease
Mont/Brud5	8			-140		lease

Mont/Brud5	10			-126		lease
Mont/Brud5	12			-101	951	lease
Murray R.1	2	59.229	9.206	5		lease
Murray R.1	4			-9	645	lease
Murray R.1	6			-31		lease
Murray R.1	8			-48		lease
Murray R.2	2	69.203	9.983	-96		lease
Murray R.2	4			-109	1157	lease
Murray R.2	6			-122		lease
Murray R.2	8			-134		lease
Murray R.2	10			-141		lease
Murray R.2	12			-149	864	lease
Murray R.2	14			-153		lease

SITE/STN	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)	CATEGORY
Murray R.3	2	71.299	9.919	-105		lease
Murray R.3	4			-108	864	lease
Murray R.3	6			-123		lease
Murray R.3	8			-139		lease
Murray R.3	10			-146		lease
Murray R.3	12			-134	482	lease
Murray R.3	14			-130		lease
Murray R.3	16			-138		lease
Murray R.3	18			-102		lease
Murray R.3	20			-120	518	lease
Murray R.3	22			-131		lease
Murray R.4	2	62.430	8.734	-76		lease
Murray R.4	4			-99	1076	lease

Murray R.4	6			-136		lease
Murray R.4	8			-150		lease
Murray R.4	10			-154		lease
Murray R.4	12			-153	1157	lease
Murray R.4	14			-161		lease
Murray R.4	16			-175		lease
Murray R.4	18			-176		lease
Murray R.4	20			-179	1245	lease
Murray R.4	22			-168		lease
Murray R.4	24			-146		lease
Tracadie1	2	43.514	5.175	-81		lease
Tracadie1	4			-96	360	lease
Tracadie1	6			-94		lease
Tracadie1	8			-105		lease
Tracadie1	10			-121		lease
Tracadie1	12			-97	360	lease
Tracadie1	14			-107		lease
Tracadie1	16			-115		lease
Tracadie1	18			-120		lease
Tracadie1	20			-114	286	lease
Tracadie1	22			-116		lease
Tracadie1	24			-147		lease
Tracadie2	2	40.643	4.130	-17		lease
Tracadie2	4			-68	774	lease
Tracadie2	6			-139		lease
Tracadie2	8			-161		lease
Tracadie2	10			-142		lease
Tracadie2	12			-160		lease
Tracadie2	14			-175		lease

Tracadie3	2	65.883	10.601	-147		lease
Tracadie3	4			-144	1136	lease
Tracadie3	6			-150		lease
Tracadie3	8			-174		lease
Tracadie3	10			-180		lease
Tracadie3	12			-178	1801	lease
Tracadie3	14			-181		lease
Tracadie3	16			-189		lease
Tracadie3	18			-193		lease
Tracadie3	20			-184	2643	lease
Tracadie3	22			-184		lease

SITE/STN	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)	CATEGORY
Tracadie4	2	30.954	3.730	-20		lease
Tracadie4	4			-115	1163	lease
Tracadie4	6			-120		lease
Tracadie4	8			-121		lease
Tracadie4	10			-147		lease
Tracadie4	12			-146	507	lease
Tracadie4	14			-160		lease
Tracadie4	16			-150		lease
Tracadie4	18			-130		lease
Tracadie4	20			-155	686	lease
St. Peters1	2	66.191	12.049	-106		lease
St. Peters1	4			-131	1944	lease

St. Peters1	6			-153		lease
St. Peters1	8			-164		lease
St. Peters1	10			-169		lease
St. Peters1	12			-175	1944	lease
St. Peters1	14			-175		lease
St. Peters1	16			-184		lease
St. Peters1	18			-183		lease
St. Peters2	2	65.693	13.187	-133		lease
St. Peters2	4			-154	4188	lease
St. Peters2	6			-166		lease
St. Peters2	8			-180		lease
St. Peters2	10			-198		lease
St. Peters2	12			-205	2854	lease
St. Peters2	14			-201		lease
St. Peters2	16			-214		lease
St. Peters2	18			-193		lease
St. Peters3	2	53.180	7.406	-148		lease
St. Peters3	4			-159	2643	lease
St. Peters3	6			-165		lease
St. Marys1	2	85.019	27.839	-183		lease
St. Marys1	4			-197	287	lease
St. Marys1	6			-196		lease
		St. Marys1 lease	8			-194
St. Marys1	10			-197		lease
St. Marys1	12			-190	1099	lease
St. Marys1	14			-192		lease
St. Marys2	2	43.815	5.980	-43		lease

St. Marys3	2	38.868	3.057	-121		lease
St. Marys3	4			-126	1099	lease
St. Marys3	6			-142		lease
St. Marys3	8			-155		lease
St. Marys3	10			-157		lease
St. Marys3	12			-161	625	lease
St. Marys3	14			-163		lease

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)	
St. Marys4	2	65.642	10.150	-129		lease
St. Marys4	4			-143	1179	lease
St. Marys4	6			-154		lease
St. Marys4	8			-159		lease
St. Marys4	10			-174		lease
St. Marys4	12			-181	1457	lease
St. Marys4	14			-174		lease
St. Marys4	16			-174		lease
St. Marys4	18			-185		lease
St. Marys4	20			-160	3914	lease
St. Marys4	22			-183		lease

Boughton1	2	67.419	9.640	-150		lease
Boughton1	4			-181	1278	lease
Boughton1	6			-183		lease
Boughton2	2	43.927	4.517	-146		lease
Boughton2	4			-159	822	lease
Boughton2	6			-110		lease
Boughton3	2	70.019	10.206	-144		lease
Boughton3	4			-164	763	lease
Boughton3	6			-202		lease
Boughton4	2	76.244	11.425	-133		lease
Boughton4	4			-144	2140	lease
Boughton4	6			-163		lease
Boughton4	8			-182		lease
Boughton4	10			-187		lease
Boughton4	12			-190	1716	lease
Boughton4	14			-181		lease
Boughton4	16			-196		lease
Boughton4	18			-201		lease
Boughton4	20			-195	1481	lease
Marchwater1	2	41.204	4.193	-29		lease
Marchwater1	4			-64	619	lease
Marchwater1	6			-98		lease
Marchwater1	8			-128		lease
Marchwater1	10			-120		lease
Marchwater1	12			-110	1183	lease
Marchwater1	14			-130		lease
Marchwater1	16			-84		lease

Marchwater1	18			-117		lease
Marchwater2	2	44.291	4.339	-122		lease
Marchwater2	4			-150	768	lease
Marchwater2	6			-109		lease
Marchwater2	8			-95		lease
Marchwater2	10			-91		lease
Marchwater2	12			-118	887	lease
Marchwater2	14			-137		lease
Marchwater2	16			-161		lease
Marchwater2	18			-144		lease
Marchwater2	20			-185	1365	lease
Marchwater2	22			-177		lease

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)	
Marchwater3	2	52.694	7.111	-102		lease
Marchwater3	4			-144	619	lease
Marchwater3	6			-152		lease
Marchwater3	8			-149		lease
Marchwater3	10			-120		lease
Marchwater3	12			-146	715	lease
Marchwater3	14			-142		lease
Marchwater3	16			-149		lease
Marchwater3	18			-174		lease
Marchwater3	20			-160	576	lease

Marchwater4	2	46.715	5.927	-96		lease
Marchwater4	4			-142	665	lease
Marchwater4	6			-169		lease
Marchwater4	8			-130		lease
Marchwater4	10			-174		lease
Marchwater4	12			-180	375	lease
Marchwater4	14			-165		lease
Marchwater4	16			-175		lease
Marchwater4	18			-183		lease
Marchwater4	20			-164	465	lease
Marchwater4	22			-169		lease
Orwell 1 culture-free	2	42.102	4.600	-26		
Orwell 1 culture-free	4			-81	732	
Orwell 2 culture-free	2	44.877	2.780	-148		
Orwell 2 culture-free	4			-209	2154	
Orwell 2 culture-free	6			-184		
Orwell 2 culture-free	8			-195		
Orwell 2 culture-free	10			-189		
Orwell 2 culture-free	12			-184	2315	
Orwell 2 culture-free	14			-199		
Orwell 2 culture-free	16			-202		
Orwell 2 culture-free	18			-195		
Orwell 2 culture-free	20			-173	1302	
Orwell 3 culture-free	2	32.034	3.152	-51	357	
Orwell 5 culture-free	2	46.063	4.983	121		
Orwell 5 culture-free	4			-14	976	
Orwell 5 culture-free	6			-37		

Orwell 5 culture-free	8			-59	
Orwell 5 culture-free	10			-65	
Orwell 5 culture-free	12			-74	909
Orwell 5 culture-free	14			-65	
Kildare 1 culture-free	2	74.436	11.952	-115	
Kildare 1 culture-free	4			-122	619
Kildare 1 culture-free	6			-137	
Kildare 1 culture-free	8			-148	
Kildare 1 culture-free	10			-164	
Kildare 1 culture-free	12			-174	715
Kildare 1 culture-free	14			-183	
Kildare 1 culture-free	16			-210	
Kildare 1 culture-free	18			-209	
Kildare 1 culture-free	20			-210	665
Kildare 1 culture-free	22			-211	

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
Kildare 2 culture-free	2	73.619	12.131	-153	
Kildare 2 culture-free	4			-174	536
Kildare 2 culture-free	6			-172	
Kildare 2 culture-free	8			-193	
Kildare 2 culture-free	10			-207	
Kildare 2 culture-free	12			-200	536
Kildare 2 culture-free	14			-196	
Kildare 2 culture-free	16			-197	
Kildare 2 culture-free	18			-191	
Kildare 2 culture-free	20			-207	665
Kildare 2 culture-free	22			-209	
Kildare 3 culture-free	2	71.950	11.268	-179	
Kildare 3 culture-free	4			-188	768

Kildare culture-free	3	6			-193	
Kildare culture-free	3	8			-209	
Kildare culture-free	3	10			-206	
Kildare culture-free	3	12			-219	887
Kildare culture-free	3	14			-205	
Kildare culture-free	3	16			-192	
Kildare culture-free	3	18			-191	
Kildare culture-free	3	20			-192	826
Kildare culture-free	3	22			-188	
Kildare culture-free	4	2	80.378	13.815	-185	
Kildare culture-free	4	4			-193	2258
Kildare culture-free	4	6			-206	
Kildare culture-free	4	8			-213	
Kildare culture-free	4	10			-209	
Kildare culture-free	4	12			-206	1271
Kildare culture-free	4	14			-206	
Kildare culture-free	5	2	51.018	8.116	-95	
Kildare culture-free	5	4			-145	1024
Kildare culture-free	5	6			-104	
Kildare culture-free	5	8			-160	
Kildare culture-free	5	10			-137	
Kildare culture-free	5	12			-112	887
Kildare culture-free	5	14			-143	
Kildare culture-free	5	16			-186	
Mill culture-free	1	2	53.292	8.546	-3	
Mill culture-free	1	4			3	625
Mill culture-free	1	6			-17	
Mill culture-free	1	8			-89	
Mill culture-free	1	10			-87	
Mill	1	12			-75	471

		culture-free					
Mill	1	culture-free	14			-39	
Mill	1	culture-free	16			-111	
Mill	1	culture-free	18			-136	

SITE/STN		CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
Mill	2	culture-free	2	64.578	11.183	-23	
Mill	2	culture-free	4			-10	439
Mill	2	culture-free	6			-63	
Mill	2	culture-free	8			-102	
Mill	2	culture-free	10			-118	
Mill	2	culture-free	12			-154	670
Mill	2	culture-free	14			-181	
Mill	2	culture-free	16			-182	
Mill	2	culture-free	18			-185	
Mill	3	culture-free	2	42.290	6.715	59	
Mill	3	culture-free	4			113	625
Mill	3	culture-free	6			59	
Mill	3	culture-free	8			6	
Mill	3	culture-free	10			-74	
Mill	3	culture-free	12			-26	670
Mill	3	culture-free	14			-87	
Mill	4	culture-free	2	67.985	14.918	-93	
Mill	4	culture-free	4			-155	1457
Mill	4	culture-free	6			-154	
Mill	4	culture-free	8			-174	
Mill	4		10			-174	

culture-free						
Mill	4	12			-163	1358
culture-free						
Mill	4	14			-183	
culture-free						
Mill	4	16			-192	
culture-free						
Mill	4	18			-189	
culture-free						
Mill	5	2	41.251	3.781	125	
culture-free						
Mill	5	4			179	505
culture-free						
Mill	5	6			159	
culture-free						
Mill	5	8			-32	
culture-free						
Mill	5	10			-80	
culture-free						
Mill	5	12			-64	772
culture-free						
Mill	5	14			-153	
culture-free						
Mill	5	16			-40	
culture-free						
Hillsborough1		2	44.815	4.063	-4	
culture-free						
Hillsborough1		4			-66	470
culture-free						
Hillsborough1		6			-38	
culture-free						
Hillsborough1		8			18	
culture-free						
Hillsborough2		2	44.405	4.754	-30	
culture-free						
Hillsborough2		4			-5	507
culture-free						
Hillsborough2		6			-42	
culture-free						
Hillsborough3		2	48.501	4.783	-48	
culture-free						
Hillsborough3		4			-65	1000
culture-free						
Hillsborough4		2	55.093	9.394	-94	
culture-free						
Hillsborough4		4			-116	686
culture-free						
Hillsborough4		6			-125	
culture-free						
Hillsborough4		8			-117	
culture-free						
Hillsborough4		10			-94	
culture-free						
Hillsborough4		12			-112	590
culture-free						
Hillsborough4		14			-118	
culture-free						

Hillsborough4 culture-free	16			-136	

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
Hillsborough5 culture-free	2	58.986	8.336	-130	
Hillsborough5 culture-free	4			-171	860
Hillsborough5 culture-free	6			-180	
Hillsborough5 culture-free	8			-186	
Hillsborough5 culture-free	10			-155	
Hillsborough5 culture-free	12			-147	797
Hillsborough5 culture-free	14			-146	
Hillsborough5 culture-free	16			-210	
West 1 culture-free	2	47.800	7.318	5	
West 1 culture-free	4			26	115
West 1 culture-free	6			40	
West 1 culture-free	8			6	
West 1 culture-free	10			34	
West 1 culture-free	12			-29	402
West 1 culture-free	14			-27	
West 1 culture-free	16			-88	
West 1 culture-free	18			-76	
West 1 culture-free	20			9	170
West 1 culture-free	22			-126	
West 1 culture-free	24			35	
West 2 culture-free	2	57.627	8.340	-30	
West 2 culture-free	4			-114	878
West 2 culture-free	6			-124	
West 2 culture-free	8			-122	
West 2 culture-free	10			-144	
West 3 culture-free	2	49.965	5.048	-102	
West 3	4			-152	1026

							culture-free
West	3	6			-165		culture-free
West	3	8			-175		culture-free
West	3	10			-143		culture-free
West	3	12			-133	812	culture-free
West	4	2	33.970	4.170	-110		culture-free
West	4	4			-131	594	culture-free
West	4	6			-152		culture-free
West	4	8			-179		culture-free
West	4	10			-169		culture-free
West	4	12			-125	1026	culture-free
West	4	14			-134		culture-free
West	4	16			-114		culture-free
West	4	18			-157		culture-free
Dunk	1	2	38.663	4.560	185		culture-free
Dunk	1	4			22	681	culture-free
Dunk	1	6			33		culture-free
Dunk	2	2	35.239	3.775	53		culture-free
Dunk	2	4			81	584	culture-free
Dunk	2	6			-59		culture-free
Dunk	2	8			-83		culture-free
Dunk	2	10			-77		culture-free

SITE/STN		DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)	CATEGORY
Dunk	3	2	49.974	5.594	-42		culture-free
Dunk	3	4			-92	233	culture-free
Dunk	3	6			-132		culture-free
Dunk	3	8			-129		culture-free

Dunk culture-free	5	2			7	
Dunk culture-free	5	4			130	
Grand culture-free	1	2	77.504	11.150	-82	
Grand culture-free	1	4			-110	1078
Grand culture-free	1	6			-119	
Grand culture-free	1	8			-122	
Grand culture-free	1	10			-136	
Grand culture-free	1	12			-123	404
Grand culture-free	1	14			-138	
Grand culture-free	1	16			-127	
Grand culture-free	1	18			-139	
Grand culture-free	1	20			-127	436
Grand culture-free	1	22			-120	
Grand culture-free	1	24			-101	
Grand culture-free	2	2	56.876	7.394	-117	
Grand culture-free	2	4			-135	436
Grand culture-free	2	6			-148	
Grand culture-free	2	8			-165	
Grand culture-free	2	10			-177	
Grand culture-free	2	12			-170	348
Grand culture-free	2	14			-161	
Grand culture-free	2	16			-178	
Grand culture-free	2	18			-186	
Grand culture-free	2	20			-175	547
Grand culture-free	3	2	78.641	11.938	-86	
Grand culture-free	3	4			-122	797
Grand culture-free	3	6			-130	
Grand culture-free	3	8			-145	
Grand culture-free	3	10			-148	
Grand	3	12			-117	860

culture-free					
Grand 3 culture-free	14			-123	
Grand 3 culture-free	16			-144	
Grand 3 culture-free	18			-139	
Grand 4 culture-free	2	41.477	4.186	-121	
Grand 4 culture-free	4			-144	860
Grand 4 culture-free	6			-150	
Grand 4 culture-free	8			-177	
Grand 4 culture-free	10			-150	
Grand 4 culture-free	12			-154	1000
Grand 4 culture-free	14			-152	
Grand 4 culture-free	16			-154	
Grand 4 culture-free	18			-148	

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
Foxley 1 culture-free	2	57.195	7.217	-64	
Foxley 1 culture-free	4			-121	975
Foxley 1 culture-free	6			-140	
Foxley 1 culture-free	8			-152	
Foxley 1 culture-free	10			-127	
Foxley 1 culture-free	12			-122	975
Foxley 1 culture-free	14			-130	
Foxley 1 culture-free	16			-114	
Foxley 1 culture-free	18			-110	
Foxley 1 culture-free	20			-155	903
Foxley 2 culture-free	2	44.845	4.229	64	
Foxley 2 culture-free	4			39	717
Foxley 2	6			40	

culture-free						
Foxley culture-free	2	8			-77	
Foxley culture-free	2	10			-93	
Foxley culture-free	2	12			-86	664
Foxley culture-free	2	14			-119	
Foxley culture-free	2	16			-139	
Foxley culture-free	2	18			-112	
Foxley culture-free	2	20			-73	419
Foxley culture-free	2	22			-129	
Foxley culture-free	3	2	29.435	1.987	81	
Foxley culture-free	3	4			-114	975
Foxley culture-free	3	6			-85	
Foxley culture-free	3	8			-113	
Foxley culture-free	3	10			-44	
Foxley culture-free	3	12			-53	227
Foxley culture-free	3	14			-114	
Foxley culture-free	3	16			-103	
Foxley culture-free	4	2	57.617	7.651	-60	
Foxley culture-free	4	4			-96	570
Foxley culture-free	4	6			-73	
Foxley culture-free	4	8			-110	
Foxley culture-free	4	10			-136	
Foxley culture-free	4	12			-144	836
Foxley culture-free	4	14			-151	
Foxley culture-free	4	16			-147	
Foxley culture-free	4	18			-144	
Foxley culture-free	4	20			-175	903
Foxley culture-free	4	22			-151	
Foxley culture-free	5	2	61.648	10.913	-44	
Foxley culture-free	5	4			-39	615

Foxley 5 culture-free	6			-20	
Foxley 5 culture-free	8			-32	
Foxley 5 culture-free	10			-100	

SITE/STN CATEGORY	DEPTH (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
Southwest1 culture-free	2	55.209	8.340	-91	
Southwest1 culture-free	4			-96	976
Southwest1 culture-free	6			-99	
Southwest1 culture-free	8			-117	
Southwest1 culture-free	10			-123	
Southwest1 culture-free	12			-113	1397
Southwest1 culture-free	14			-140	
Southwest1 culture-free	16			-151	
Southwest1 culture-free	18			-158	
Southwest1 culture-free	20			-138	1127
Southwest2 culture-free	2	60.988	11.134	-185	
Southwest2 culture-free	4			-188	2857
Southwest2 culture-free	6			-194	
Southwest2 culture-free	8			-185	
Southwest2 culture-free	10			-189	
Southwest2 culture-free	12			-188	2476
Southwest2 culture-free	14			-196	
Southwest2 culture-free	16			-196	
Southwest2 culture-free	18			-197	
Southwest2 culture-free	20			-195	846
Southwest3 culture-free	2	44.998	5.247	44	

Southwest3 culture-free	4			7	788
Southwest3 culture-free	6			-7	
Southwest3 culture-free	8			-15	
Southwest3 culture-free	10			-9	
Southwest3 culture-free	12			-12	733
Southwest4 culture-free	2	54.345	8.124	23	
Southwest4 culture-free	4			-1	846
Southwest4 culture-free	6			-77	
Southwest4 culture-free	8			-42	
Southwest4 culture-free	10			-80	
Southwest4 culture-free	12			-55	

APPENDIX B. SEDIMENT PROFILES FOR OMITTED CORE SAMPLES

SITE: Montague/Brudenell STATION: 5 Reference

Depth (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
0-2	29.941	2.993	270	
2-4			321	244

SITE: Tracadie STATION: 1 Reference

Depth (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
0-2	19.019	2.194	271	
2-4			277	299
4-6			314	

SITE: St. Peter’s STATION: 4 Reference

Depth (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
0-2	17.630	1.683	337	
2-4			220	2267
4-6			265	
6-8			320	

SITE: Marchwater STATION: 2 Reference

Depth (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
0-2	26.234	3.491	129	
2-4			9	261
4-6			78	
6-8			25	
8-10			11	

SITE: Orwell STATION: 2 Culture-Free

Depth (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
0-2	22.568	2.191	270	
2-4			266	443
4-6			248	
6-8			251	
8-10			212	
10-12			203	443
12-14			272	
14-16			223	

SITE: Dunk STATION: 4 Culture-Free

Depth (cm)	WC (%)	OM (%)	Eh (mV)	S (uM)
0-2	28.842	1.909	265	
2-4			161	-

APPENDIX C. INVERTEBRATE SAMPLE RESULTS

SITE/STN	DIVERSITY	BIOMASS	DEPOSIT FEEDERS	ABUNDANCE	CATEGORY
		(g/m)	(%)	(ind/m)	
Boughton 3	0.28	1.06	0.00	60	LEASE
Boughton 3	0.52	13.20	78.38	200	REFERENCE
Dunk 1	0.19	16.02	95.38	2220	CULTURE-FREE
Dunk 4	0.45	0.84	85.71	80	CULTURE-FREE
Kildare 1	0.00	0.00		0	CULTURE-FREE
Marchwater 2	0.68	181.04	18.37	100	LEASE
Marchwater 2	0.58	9.56	89.54	160	REFERENCE
Mill 1	0.16	39.48	77.71	1580	CULTURE-FREE
Mont/Brud 2	0.20	9.14	27.13	120	LEASE
Mont/Brud 2	0.28	0.90	82.22	180	REFERENCE
Mont/Brud 3	0.30	0.36	55.56	40	LEASE
Mont/Brud 3	0.17	25.04	0.00	300	REFERENCE
Murray R. 2	0.29	6.66	18.02	500	LEASE
Murray R. 2	0.80	25.32	31.00	260	REFERENCE
New London 1	0.00	0.00		0	LEASE
New London 1	0.00	18.12	0.00	40	REFERENCE
New London 4	0.00	0.00		0	LEASE
New London 4	0.30	15.00	8.43	80	REFERENCE
Rustico 1	0.30	26.36	0.00	40	LEASE
Rustico 1	0.28	1.14	100.00	60	REFERENCE
Rustico 2	0.00	0.94	100.00	20	LEASE
Rustico 2	0.00	0.70	100.00	60	REFERENCE
Southwest 3	0.16	56.08	48.72	720	CULTURE-FREE
Southwest 4	0.00	1.54	0.00	720	CULTURE-FREE
St. Marys 1	0.00	0.00		0	LEASE
St. Marys 1	0.42	9.84	69.72	160	REFERENCE
St. Peters 1	0.48	3.96	81.31	60	LEASE
St. Peters 1	0.47	42.70	38.92	140	REFERENCE
St. Peters 3	0.62	203.98	88.55	340	LEASE
St. Peters 3	0.61	23.16	41.36	260	REFERENCE
St. Peters 5	0.58	23.50	27.83	320	LEASE
St. Peters 6	0.41	30.70	20.85	260	LEASE
Tracadie 3	0.00	3.34	100.00	160	LEASE

APPENDIX D. MAPS OF SAMPLE SITES