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Mussel Aquaculture Regulatory Effectiveness Monitoring: Validation of the St. Ann's Harbour Environmental Assessment and Monitoring Program

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ABSTRACT

Potential pelagic and benthic effects of mussel (*Mytilus edulis*) aquaculture were studied in St. Ann's Harbour, Nova Scotia, Canada. Water column and sediment sampling were conducted in October, 2008 to test Environmental Impact Assessment (EIA) predictions for a 4.9 km^2 suspended mussel aquaculture operation that was initiated in 2003 and which, at the time of sampling, was at ~70% of the planned development capacity. Surficial sediment sampling was conducted at 59 lease and 29 reference sites to assess the effectiveness of the annual benthic survey design employed by industry for monitoring benthic organic enrichment effects. Annual site monitoring data collected by industry and pre-development data collected by DFO Science were also utilized in a retrospective analysis of mussel aquaculture/ecosystem interactions. The EIA prediction that the leased area in St. Ann's Harbour is not out of proportion to the size of the harbour was assessed using indicators of mussel grazing effects on the phytoplankton. The presence of local bivalve-induced food limitation in one mussel lease was indicated by a reduction in annual mussel production during a period when stocking biomass was relatively high. The possibility of a bay-scale change in phytoplankton size-structure was indicated by a relatively high picophytoplankton biomass relative the total phytoplankton biomass (indicated by size-fractioned chlorophyll *a* concentrations).

Average (±SE) total 'free' sulphide (S^{2-}) concentrations in surficial sediments within mussel leases (n=58) (698 ± 75 µM) and at reference sites (n=29) (238 ± 30 µM) were significantly different ($p < 0.001$) and this organic enrichment effect was most evident within one mussel lease (Lease 1188) (n=26, 1025 ± 129 µM). These lease-scale effects are known to indicate reductions in benthic community diversity. The relatively small numbers of locations sampled during the industry monitoring program (3 locations within each lease and a total of 3 reference sites) resulted in an underestimation of the actual degree of benthic organic enrichment within the mussel leases relative to the normal background variability ($p > 0.11$). S measurements conducted between 2000 and 2008 within Lease 1188 showed that benthic organic enrichment increased in 2005 to levels that are statistically comparable with those presently observed. Data from the extensive 2008 benthic sampling program were used to provide advice on how shellfish aquaculture monitoring programs may be made more spatially and statistically meaningful using the same sampling effort (number of seabed samples collected). The recommendations contained in this report are provided to increase the scientific certainty of monitoring results while permitting the mussel aquaculture industry to remain economically viable.

RÉSUMÉ

On a étudié les effets potentiels de l'élevage des moules (*Mytilus edulis*) sur les zones pélagique et benthique dans le havre St. Anns, en Nouvelle-Écosse, au Canada. On a échantillonné la colonne d'eau et les sédiments en octobre 2008 pour vérifier les

prévisions de l'évaluation des incidences environnementales (EIE) d'une installation de culture en suspension d'une superficie de 4,9 km^2, dont les activités ont commencé en 2003 et qui, au moment de l'échantillonnage, avait atteint ~ 70 % de sa capacité de développement prévue. On a réalisé un échantillonnage des sédiments de surface dans 59 concessions et dans 29 sites de référence afin d'évaluer l'efficacité des méthodes de relevés benthiques annuels utilisées par l'industrie pour surveiller les effets de l'enrichissement organique de la zone benthique. Les données annuelles de surveillance des sites recueillies par l'industrie ainsi que les données préliminaires recueillies par la Direction des sciences du ministère des Pêches et des Océans (MPO) ont également servi dans le cadre d'une analyse rétrospective des interactions entre les installations mytilicoles et l'écosystème. La prédiction de l'EIE voulant que la concession située dans le havre St. Anns n'est pas hors de proportion par rapport à la superficie du havre a été vérifiée à l'aide d'indicateurs des effets du broutage par les moules sur le phytoplancton. Dans une des concessions, la réduction de la production annuelle de moules durant une période où la biomasse d'ensemencement était relativement élevée a permis de déceler des limites alimentaires attribuables à la présence de bivalves indigènes. La biomasse relativement élevée de picophytoplancton par rapport à la biomasse totale de phytoplancton (mesurée à l'aide des concentrations en chlorophylle *a* par classe de taille) indique que l'on pourrait observer des changements à l'échelle de la baie sur le plan de la taille et de la structure du phytoplancton.

Les concentrations totales moyennes (± erreur type) de sulfures libres (S^{2-}) dans les sédiments de surface des concessions mytilicoles (n = 58) (698 ± 75 µM) et des sites de référence (n = 29) (238 ± 30 µM) présentaient des différences significatives ($p < 0,001$), et cet effet de l'enrichissement organique était plus évident dans une des concessions (concession n° 1188) (n = 26; 1 025 ± 129 µM). On sait que ces effets à l'échelle des concessions indiquent une réduction de la diversité des communautés benthiques. Le nombre relativement faible d'endroits échantillonnés dans le cadre du programme de surveillance de l'industrie (3 endroits dans chaque concession, et 3 sites de référence au total) a donné lieu à une sous-estimation du degré réel d'enrichissement organique de la zone benthique dans les concessions mytilicoles par rapport à la fourchette normale de variabilité ($p > 0,11$). Les mesures des concentrations de sulfures réalisées de 2000 à 2008 à la concession n° 1188 montrent que l'enrichissement organique de la zone benthique a augmenté en 2005 à des concentrations statistiquement comparables à celles que l'on observe actuellement. Des données tirées du programme intensif d'échantillonnage benthique de 2008 ont été utilisées pour formuler des recommandations sur la façon dont les programmes de surveillance des installations mytilicoles pourraient être modifiés de manière à les rendre plus significatifs spatialement et statistiquement, en prélevant le même nombre d'échantillons. Les recommandations formulées dans le présent rapport visent à accroître la certitude scientifique des résultats des travaux de surveillance, tout en permettant à l'industrie de la mytiliculture de demeurer viable sur le plan économique.

1. Introduction

Mussel aquaculture operations in St. Ann's Harbour (Fig. 1) were initiated in 2003 and approximately 70% of the 4.9 km^2 leased area is currently developed. The project Environmental Impact Assessment (St. Ann's EIA, 2001) concluded "*no significant adverse residual effects on marine habitat are likely with proper implementation of the identified mitigative measures*", which included the annual monitoring program identified in the site Environmental Management Plan (St. Ann's EMP, 2003). A key component of the EIA was predictions from models that concluded "*the level of culture proposed for St. Ann's Harbour does not appear to be out of proportion to the size of the harbour and its ability to tidally exchange particles.*" However, some concern was expressed by Fisheries and Oceans Canada (DFO) Science regarding the potential for excessive seston depletion and benthic organic enrichment effects due to enhanced biodeposition, particularly in the inner region of the Harbour. Now that these mussel leases are operational, the objective of this study was to test both the EIA model predictions and the effectiveness of the ongoing EMP benthic survey design for detecting benthic habitat effects. The EMP was designed by DFO Science and the DFO Habitat Protection and Sustainable Development Division with industry input. An extensive sampling program was conducted in St. Ann's Harbour in October, 2008 that coincided with the annual site monitoring activities conducted by industry. Existing site monitoring data and pre-development data were also utilized in a retrospective analysis of aquaculture/ecosystem interactions. The information was collected to advance regulatory science and to improve regulatory certainty.

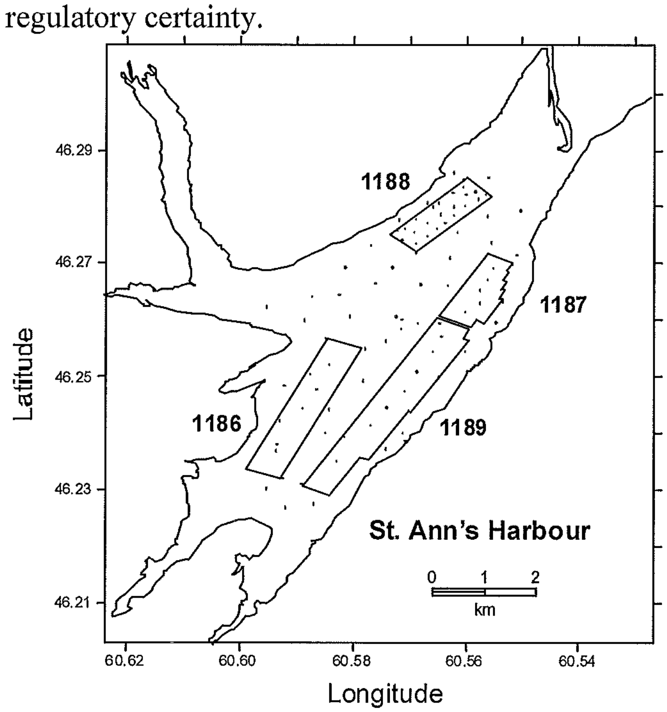

Figure 1. Map of St. Ann's Harbour showing the locations of the Bounty Bay Shellfish Inc. suspended mussel aquaculture leases and the October, 2008 grab sample sites. Two pre-existing mussel leases located to the south-west of lease 1188 are not shown.

Environmental concerns regarding mussel culture are related primarily to how the culture interacts with, and potentially controls, fundamental ecosystem processes. Mussels have an exceptional capacity to filter large volumes of water to extract food (phytoplankton and other suspended particulate matter) and also excrete large quantities of ammonia and biodeposit undigested organic matter on the seabed. Filter-feeding by mussels naturally results in some local reduction (depletion) of their food. However, if the mussel culture is consuming seston faster than suspended material can be replaced by tidal flushing and phytoplankton growth, then the mussels will become food limited and production will be less than maximal for that site. If the spatial scale of phytoplankton depletion expands outward from the farm(s) to include a significant fraction of the coastal inlet, then this effect on the base of the marine food web generates ecological costs to other components of the ecosystem.

Detection of the zone of phytoplankton depletion in and around aquaculture sites is not trivial due to the large degree of natural variation in coastal waters. A new approach has been developed by DFO Science for observing large-scale phytoplankton depletion by focusing on changes in phytoplankton size-structure that may accompany mussel-mediated changes in phytoplankton concentration. Since the mussel biofilter can only effectively retain food particles larger than approximately 3 μm diameter, picophytoplankton (0.2 to 2.0 μm size range) are not effectively ingested and can dominate in areas where filter-feeding bivalves are known to deplete their food supply (Olsson et al. 1992, Vaquer et al. 1996, Prins et al. 1998, Cranford et al. 2006 and 2008). Phytoplankton size-structure (e.g. size-fractioned chlorophyll *a*) is an ecologically relevant and inexpensive indicator of bay-scale changes in marine ecosystems (Cranford et al. 2008). The approach was employed in this project along with more conventional theoretical and mussel performance measurements to assess the EIA predictions of no significant seston depletion by the mussel aquaculture activities in St. Ann's Harbour.

Impacts of shellfish aquaculture on benthic habitat and communities are related to the deposition of shellfish faeces and pseudofaeces and other fall-off from the holding structures (shellfish and fouling organisms and their biodeposits). The accumulation and mineralization of this excess organic matter in sediments causes stress on benthic organisms through oxygen deficiency and the toxic effects of H_2S. The impacts on benthic communities of increased organic matter sedimentation are well known (Pearson and Rosenberg 1978, Hargrave et al., 2008a and b). Total 'free' sulphide (S^{2-}) is a cost-effective indicator of organic enrichment effects on benthic communities and threshold values have been identified based on organic enrichment classifications (Hargrave et al., 2008b) that enable managers to distinguish normal ranges of "background" concentrations from those indicative of benthic habitat degradation. It is important to determine the sampling design criteria that must be used to determine if a threshold has been exceeded. A change may occur due to a disturbance, but its detection depends on the sampling effort. No change will be detected if the sampling effort is too low to provide the statistical power needed to detect the effect.

The sampling program conducted in St. Ann's Harbour in October, 2008 was designed to:

(1) determine if changes in seston and phytoplankton concentration and size have occurred due to the grazing activity of cultured mussels;

(2) determine if the St. Ann's Harbour benthic monitoring program using geochemical measures was sufficient to make scientifically defensible determinations of organic enrichment degradation within the mussel leases relative to the normal background variability; and

(3) provide advice on how shellfish aquaculture monitoring programs may be made more spatially and statistically meaningful, so as to increase the scientific certainty of monitoring results while permitting this industry to remain economically viable.

National and regional end users of the outputs from this regulatory research project were invited to a workshop on 23 March 2009 where project results were summarized. A facilitated discussion was held on how the new knowledge can lead to improvements, if needed, to the current regulatory framework for shellfish aquaculture. Participants in the workshop were invited to present their views on project results and potential applications. Summaries from stakeholders that accepted this invitation are presented in the Appendices.

2. Methods

Water samples were collected with a 4.2 l Kemmerer water sampler at 12 locations along the length of St. Ann's Harbour on 20 October, 2008 during flood tide conditions between 1150 h and 1330 h GMT. Water was taken from 8 m depth at all sites, which is at the mean depth of the mussel socks. In addition, water was collected at 2 m depth at 7 of these locations. Rough weather conditions prevented sampling outside the Harbour. Water was processed for phytoplankton analysis on the same day. Subsamples of a known volume were filtered through 0.2 and 3.0 µm pore size polycarbonate filters (AMD Manufacturing Inc., Mississauga, Ontario) and chlorophyll *a* concentration was determined from the *in vitro* fluorescence (Turner Designs fluorometer calibrated against pigment from spinach) of 90% acetone extracts of the filtered material. The picophytoplankton contribution (P_i = % of total phytoplankton biomass) was calculated from the size-fractioned chlorophyll *a* concentrations ($P_i = 100 * [Chl_{0.2\ \mu m} - Chl_{3.0\ \mu m}]/Chl_{0.2\ \mu m}$). In addition, 2 ml subsamples were preserved for later analysis by flow cytometry for determination of the abundance of different phytoplankton classes.

A survey of seabed geochemical conditions was conducted in St. Anns Harbour on 21 to 23 October, 2008 immediately after industry site monitoring activities on 20 October, 2008. The industry Environmental Management Plan (St. Ann´s EMP, 2003) included sampling at 15 locations with three replicate samples taken at each site. The EMP sampling design requires sampling at three permanent sites located along the central axis of each of the four mussel leases, and at three reference sites outside of lease boundaries along the central axis of the harbour. A network of 76 additional sampling sites were sampled (one grab per site) during this study, including locations previously sampled during baseline surveys in 2001 and 2002. Locations of these additional sites were selected to provide extensive and even spatial coverage at the bay-scale, as well as including relatively high spatial resolution within and around lease 1188 (Fig. 1). This lease was the first of the new leases to be populated with mussels and has the longest history of continuous mussel production.

The same approach and equipment was utilized for collecting and analyzing surficial sediment samples at both the permanent EMP sites and at the additional sites. Surficial sediment was collected from two vessels using Ekman grabs (15 x 15 cm) for measurements of redox potentials (Eh_{NHE}), total 'free' sulfides (S)(H_2S, HS^- and $S^=$), water content (WC), organic matter (OM) and grain size in the 0-2 cm surface layer. Immediately after collection, surface water was allowed to drain off each grab aboard the vessel without disturbing the sediment surface. Two replicate 5 mL sub-samples (one replicate for both Eh_{NHE} and S analysis and one for both WC and OM determinations) were immediately collected from the grab sample using cut-off 5-mL plastic disposable syringes filled by withdrawing the barrel as the syringe was inserted into the upper 2 cm surface layer. Syringes were tightly closed using a plastic cap to avoid exposure to air and stored on ice until analysis (12-24 h). An additional sample was collected in a similar manner from each grab, stored in a scintillation vial, and returned to the lab for grain size analysis. All sampling positions were recorded as provided by GPS systems on each boat.

Eh_{NHE} potentials were determined in 3.0 mL of sediment extruded from one of the syringe sub-samples from the Ekman grabs into a glass scintillation vial using an Orion Epoxy Redox/ORP electrode 9678BNWP containing an internal Ag/AgCl reference electrode filled with 4M KCL (Orion 900011). An Accumet AP63 portable pH/Ion meter was used to measure potentials (mV) that stabilized within 2 minutes. Eh_{NHE} was calculated by addition of the normal hydrogen electrode (NHE) potential of the reference electrode at the sample temperature as described in Wildish et al. (1999).

Total 'free' sulphide was measured on the same 3.0 mL of sediment immediately after Eh_{NHE} measurements by adding 3.0 mL of sulfide antioxidant buffer solution (SAOB; 20.0 g NAOH, 17.9 g EDTA and 8.75 g L-ascorbic acid in 250 mL distilled water) to the sample. S concentration was read immediately (<2 min) using an Accumet AP63 portable pH/Ion meter with an Orion 9616BNWP Sure-Flow™ combination silver/sulfide electrode filled with Orion Optimum "A" filling solution. A three-point electrode calibration was conducted with $Na_2S{\cdot}9H_2O$ (Wildish et al. 1999, Thermo Fisher Scientific 2007). S concentrations were expressed as µM based on the 3.0 mL total sediment volume.

WC and OM were determined using 1.0 mL of wet sediment sample extruded from the second 5 mL syringe into a pre-weighed scintillation vial. Vials were tightly capped to prevent dehydration until weighed using a Denver Instrument Summit Series SI 234
analytical balance. After drying to a constant weight (60°C, 24 h) and re-weighing, WC was determined as percent weight loss. The sample was then pulverized using a mortar 5

and pestle, placed on pre-ashed and pre-weighed aluminum foil (~2 cm^2), combusted in a muffle furnace (550°C, 4 h) and OM calculated from weight loss as a percent of sample dry weight.

Sediment for grain size analysis was treated with excess 50% hydrogen peroxide to remove all organic material. The disaggregated inorganic grain size (DIGS) distributions of samples were determined using a Coulter Laser in the Sediment lab of the Geological Survey of Canada, Atlantic. Particle sizes were binned in 1/5 phi intervals ($\phi = -\log_2 d$)(d = diameter in mm) and grain size distributions were measured between 0.4 and 3600 μm.

Contour maps were created with Surfer 8 (Golden Software) to illustrate inlet-wide patterns in the distribution of surficial sediment grain size and geochemical variables. The kriging algorithm was used to create grid files that were then blanked with a digitized outline of the surveyed area. Grid files were mapped for specified contour intervals as grey scale values.

3. Results and Discussion

3.1 Indices of Phytoplankton Depletion

Picophytoplankton contribution index: Chlorophyll *a* concentration data from 12 locations in St. Ann's Harbour are presented in Table 1. Total chlorophyll *a* ($Chl_{0.2\ \mu m}$) at 2 and 8 m depth averaged (±SD) 3.88±1.15 and 2.14±0.49 μg l^{-1}, respectively. The picophytoplankton fraction (P_i) dominated total phytoplankton and averaged 66±4% and 61±14%, respectively, at 2 and 8 m depth. These picoplankton contributions fall between average percentages reported for other coastal embayments where the main trophic feature is the large-scale of shellfish farming (mean P_i = 30% in Thau Lagoon; Vaquer et al., 1996, and 72% in Tracadie Bay; Cranford et al. 2008). There was no discernable spatial gradient in P_i along the axis of the harbour. However, phytoplankton counts provided by flow cytometry analysis show a spatial gradient, with highest counts of picophytoplankton and nanophytoplankton towards the head of the bay (Fig. 2). Since water sampling was conducted on the flood tide the spatial gradient may reflect lower phytoplankton concentrations in water entering from outside the bay. The theoretical (predicted) contribution of picophytoplankton in St. Ann's Harbour is between 16 to 24% based on application of an empirical relationship with Chl *a* concentration (2.1 to 3.9 μg Chl *a* l^{-1}) in marine systems (Bell and Kalff, 2001). The observed relatively high P_i values (picophytoplankton dominate) may have resulted from grazing of larger phytoplankton by mussels. However, the picophytoplankton contribution can vary naturally over a large range (see Fig. 4 in Bell and Kalff 2001) and further sampling is underway to quantify the degree of natural variability in Atlantic Canadian coastal systems.

Dame depletion index: A common theoretical approach for assessing the potential for shellfish aquaculture to cause bay-scale phytoplankton depletion is to apply the Dame depletion index (I_D; Dame and Prins, 1998). This index quantifies the major physical (tidal flushing time) and biological (clearance time due to mussels) processes at work within a volume of water containing dense suspension feeder populations. The 2001 St. Ann's Harbour EIA utilized this approach to predict that the removal of phytoplankton by mussels would be almost equal to the tidal renewal ($I_D = 0.9$; St. Ann's EIA, 2001): indicating some potential for significant food depletion. This prediction was updated utilizing data collected by industry on the actual standing stock of cultured mussels and average feeding rates of mussels reported in 61 primary publications (Cranford et al. in preparation). Given the 2007 mussel stocking densities, the depletion index indicates a relatively low potential for bay-scale phytoplankton depletion (Table 2; $I_D = 2.5$). However, more limited flushing of water at the head of the harbour, and/or in deeper areas where the mussel socks are located would result in a greater degree of food depletion than would be predicted using this theoretical approach, which is based on an average flushing time for the total bay.

Mussel performance index: The monitoring of shellfish farming activities worldwide has led to the recognition of noticeable reductions in commercial yield at high stocking densities (i.e. production limits for a given area). This reduction is largely the consequence of a negative feedback on bivalve growth stemming from depletion of the available food supply and food limitation. Consequently, detailed farm inventory and production data have been recommended as effective indicators of the effect of shellfish farming on pelagic food supplies (Cranford et al., 2006). Changing husbandry practices in St. Ann's Harbour, such as increasing the number of months from spat introduction to harvest and changing spat socking densities also affect the commercial yield and need to be accounted for prior to assessing potential effects of food limitation on mussel production. One approach is to calculate mussel yield per unit effort (YPUE) for each lease from data provided in St. Ann's Harbour annual lease reports as follows:

$$\text{YPUE} = S_Y / t, \quad (1)$$

where S_Y is the average lease sock yield (kg dry meat) and t is the number of months from introduction to sock harvest. YPUE accounts for the changes in grow-out times on St. Ann's Harbour leases that have varied between 24 and 36 months from 2004 to 2008. Variable socking densities (number of spat added to each sock), as well as yearly changes in total lease stocking are accounted for within industry measurements of the total biomass of mussels on each lease. The relationship between annual YPUE and total mussel biomass for Leases 1188 (76.5 ha) and 1189 (72 ha) is shown in Fig. 3. Although the data are somewhat sparse, a polynomial relationship was fit to this production/biomass relationship using the regression function in Microsoft Excel ($r^2 = 0.478$). These data indicate that production (YPUE) initially increased with increasing lease biomass, but that a lease stocking limit exists somewhere between 40 and 50 tonnes dry meat. The biomass on Lease 1188 was generally lower than on 1189 and the 7 production maximum does not appear to have been exceeded. Although the data are limited and the relationship between production and stocking biomass remains theoretical, the available data conform to production carrying capacity concepts, which maintain that increasing shellfish stocking in a given area will eventually reach a point (production carrying capacity) where the food supplies become limiting. Further increases in stocking biomass overly deplete the food supply and cause a reduction in farm production.

Table 1. Size-fractioned chlorophyll *a* concentrations in St. Ann's Harbour on 20 October, 2008 and the picophytoplankton contribution index (P_i).

Latitude (N)	Longitude (W)	Depth (m)	Chl $a_{0.2\ \mu m}$ ($\mu g\ l^{-1}$)	Chl $a_{3.0\ \mu m}$ ($\mu g\ l^{-1}$)	P_i (%)
46° 16.606'	60° 33.222'	8	2.05	0.69	66.2
46° 16.236'	60° 33.499'	8	1.55	0.64	58.9
46° 15.774'	60° 33.910'	8	1.72	0.69	59. 7
46° 15.318'	60° 34.218'	8	1.94	0.69	64.3
46° 14.739'	60° 34.694'	8	2.22	0.72	67.5
46° 14.302'	60° 34.998'	8	1.50	1.19	20.4
46° 13.750'	60° 35.183'	8	2.29	0.89	61.3
46° 13.777'	60° 35.926'	8	2.16	0.69	68.0
46° 14.403'	60° 35.179'	8	3.29	1.11	66.3
46° 15.403'	60° 34.989'	8	1.99	0.64	68.1
46° 15.876'	60° 35.340'	8	2.43	1.00	59.0
46° 16.166'	60° 34.452'	8	2.57	0.64	75.3
46° 13.750'	60° 35.183'	2	3.86	1.36	64.8
46° 13.777'	60° 35.926'	2	3.43	1.19	65.3
46° 14.403'	60° 35.179'	2	3.29	1.22	63.0
46° 15.403'	60° 34.989'	2	3.86	1.43	63.0
46° 15.876'	60° 35.340'	2	3.86	1.36	64.8
46° 16.166'	60° 34.452'	2	2.57	0.91	64.5
46° 16.508'	60° 33.320'	2	6.26	1.57	74.9

Table 2. Predictions of bay-scale phytoplankton depletion in St. Ann's Harbour based on the Dame depletion index (I_D) as provided in the site Environmental Impact Assessment (St. Ann's EIA, 2001) and recalculated based on 2007 mussel stocking data. DW = dry tissue weight. Note that $I_D < 1.0$ indicates depletion.

Parameter	**EIA**	**2007**
Harbour volume (V_T; m^3)	2.87×10^8	2.87×10^8
Tidal exchange (m^3)	23.7×10^6	23.7×10^6
Flushing time (τ_f; days)	5.7	5.7
No. of mussels (1 g DW)	9.7×10^8	-
No. of year 1 mussels (0.4 g DW)	-	50×10^6
No. of year 2 mussels (0.85 g DW)	-	320×10^6
Clearance rate (l mussel^{-1} h)	2.4	1.5 (year 1); 2.4 (year 2)
Clearance volume ($m^3\ d^{-1}$)	56×10^6	20×10^6
Clearance time (CT; days)	5.1	14
Depletion index ($I_D = CT/\tau_f$)	0.9 (depletion)	2.5 (no depletion)

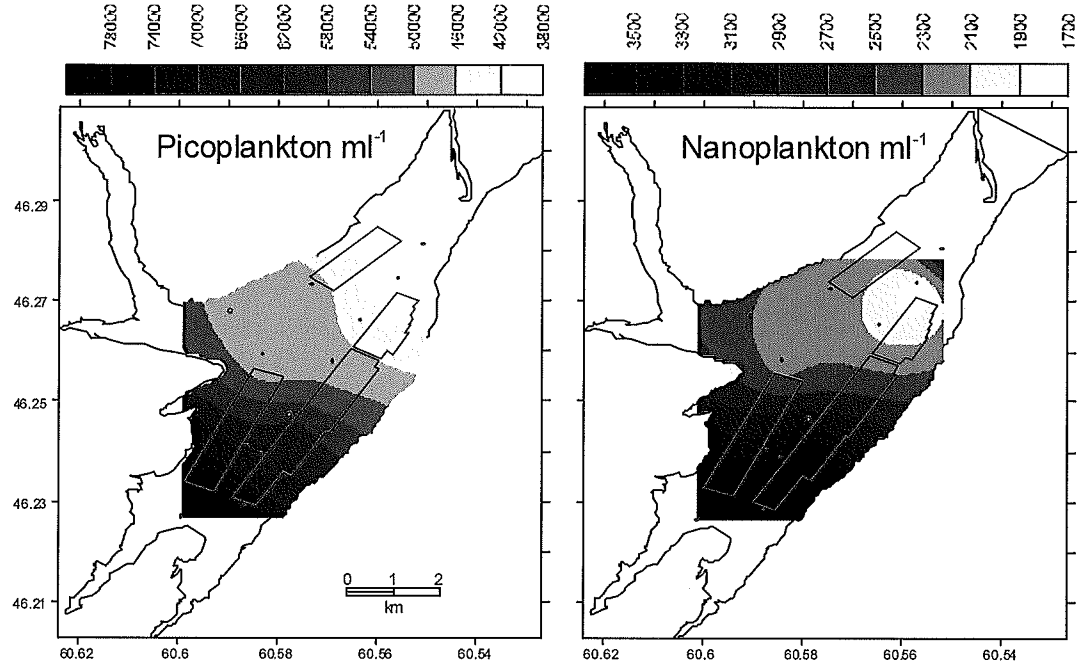

Figure 2. Abundance of picophytoplankton (left) and nanophytoplankton cells (right) as cell numbers mL^{-1} at 8 m depth (mid-depth of mussel socks) in St. Ann's Harbour on October 20, 2008. Water sample sites are shown as red circles.

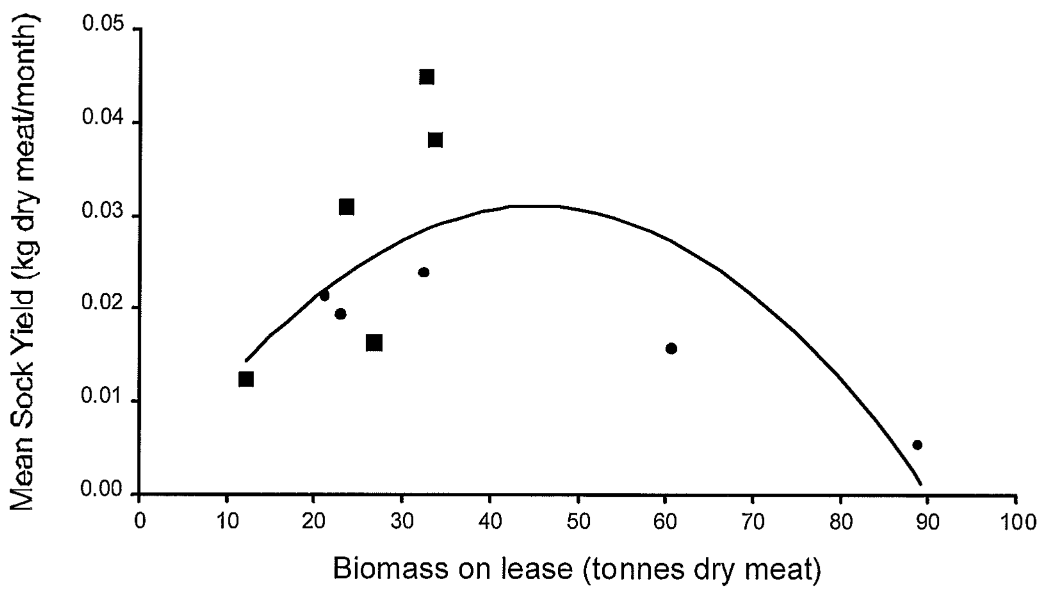

Figure 3. Relationship between annual mussel yield per unit effort (average mussel sock dry meat weight/months to harvest) and annual total standing stock of mussels on St. Ann's leases 1188 (■) and 1189 (●)(Fig. 1). The polynomial was fit to data for the period 2004 to 2008.

3.2. Indices of Benthic Organic Enrichment

3.2.1. Surficial Sediment grain size

Inherent in the grain size distributions of bottom sediments is a record of the particle sources and physical transport processes responsible for their formation (Kranck, 1980). In general, sandy sediments represent areas in which current shear stress is high while muddy sediments are representative of areas where shear stress is low. St. Ann's Harbour can be generally classified as a depositional environment with the majority of bottom sediments consisting of mud or inorganic grain sizes <63 μm (Fig. 4a). The settling of aggregates is responsible for the majority of deposition of these fine cohesive sediments (Kranck, 1980, McCave et al., 1995). Aggregation is the process whereby particles adhere either by electrochemical attraction or organic bonding, forming large porous structures called "aggregates" or "flocs". Aggregates sink much faster than the component particles within them. The outer portions of the harbour near the entrance, where current velocities are high, consist of bottom sediments that contain a sand fraction of up to 50-60% and a low percentage of clay (i.e. <7%) (Fig. 4a).

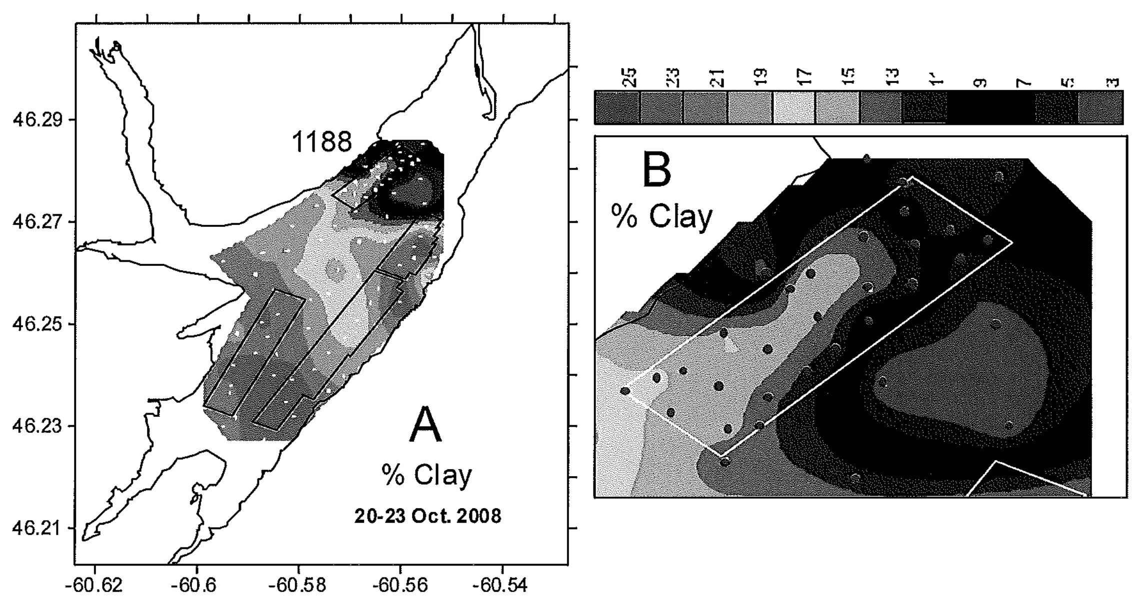

Figure 4. Percentage of clay in surficial sediments (0-2 cm depth) in (A) St. Ann's Harbour and (B) in the vicinity of mussel Lease 1188.

Sediments containing low percentages of clay represent a small percentage of the total area of St. Ann's Harbour (Fig. 4a). Natural particle aggregation and sinking processes, combined with the redistribution of the silt/clay fraction by currents and storms are responsible for the majority of the large-scale surficial sediment grain-size features in the harbour. However, the influence of mussel aquaculture can be detected at the lease scale. Lease 1188, which was sampled extensively, is largely depositional with the exception of the northern section where a channel extends in an east to west direction (Fig. 4b). This channel is represented by coarser grained material with a low percentage of clay (<7-8%) which probably reflects higher current velocities that resuspend and transport fine-grained particulate material out of the channel. The mean clay fraction (% ± SE) immediately outside lease 1188 was 6.44% ± 1.91 (n = 4), compared with 13.6% ± 0.71 (n = 23) inside the lease. The ingestion of fine suspended particles by mussels results in the settling of large quantities of faeces and pseudofaeces and this significant flux of fine sediment to the seabed appears to have resulted in the localized fining of bottom sediments.

3.2.2. Benthic Geochemistry

Summaries of the October 2008 spatial distributions of S and Eh_{NHE} measurements in surficial sediments are shown in Figure 5 and Table 3. Overall bay-wide averages (± SE) from all sampling stations were 544 ± 56 μM S (n = 87) and -76 ± 15 mV Eh_{NHE} (n = 88). The highest S concentrations and lowest Eh_{NHE} potentials occurred within farmed areas (Fig. 5; Table 3) and S was high (mean of 1025 ± 129 μM) under Lease 1188 relative to measurements at the reference stations for this lease (130 ± 40 μM) (Fig. 6, Table 3). Sediment water and organic content were poorly correlated with S ($r^2 \leq 0.11$), but the higher average water content and organic matter content of sediments under Lease 1188, relative to the adjacent reference sites, are consistent with a conclusion of relatively high organic enrichment within this farm (Table 3).

Both positive and negative Eh_{NHE} potentials occurred throughout much of the harbour (both inside and outside mussel leases) except in the area around the harbour mouth where values were all positive (Table 3, Fig. 5),. Hargrave et al. (2008b) identified ranges of Eh_{NHE} and 'free' S characteristic of oxic-hypoxic sediment categories. The ranges of Eh_{NHE} potentials and S values throughout much of the bay are representative of Oxic A (Eh_{NHE} >100 mV and <100 to ~750 μM S) conditions with Oxic B type sediments (Eh_{NHE} <100 mV and 750 to ~1500 μM S) present primarily inside Lease 1188 Oxidation-reduction potentials can be used as an indicator of the presence of dissolved oxidizing and reducing agents that can be related to important sediment geochemical properties and processes, including the energy-yielding reactions of bacterial cells. These bacterial reactions generally lead to a close relationship between Eh potentials and total S concentrations in marine sediments (Hargrave et al. 2008b). Eh potentials are also related to, and affected by, the biogeochemical cycling of numerous trace metals. It is possible that the low Eh values measured (relative to S) are related to previous observations of elevated levels of some metal ions in St. Ann's Harbour sediments (Philip Yeats, personal communication). Further discussion of these geochemical data focuses on the total 'free' sulphide data, which is the primary measure used for managing organic enrichment effects on benthic habitat within the aquaculture management framework for St. Ann's Harbour (St. Ann's EMP, 2003) and in the DFO Maritimes Region.

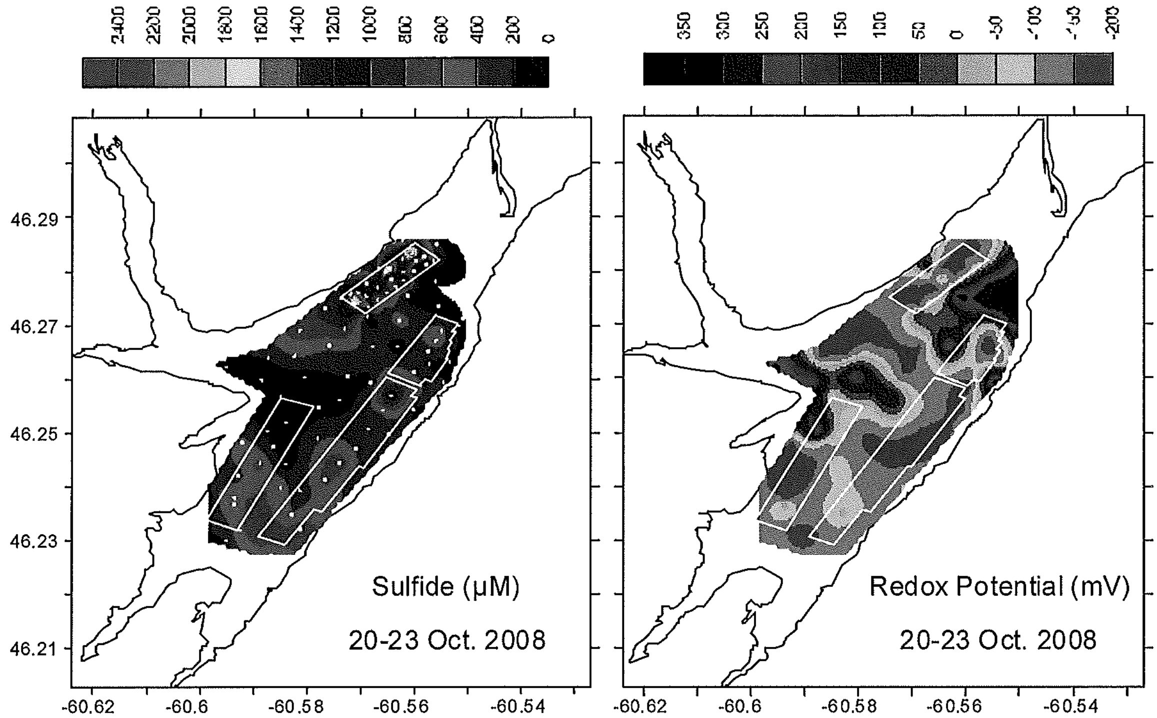

Figure 5. Total 'free' sulphide concentrations (left) and redox potentials (Eh_{NHE}; right) of surficial sediments in St. Ann's Harbour in October, 2008. Sampling locations are shown.

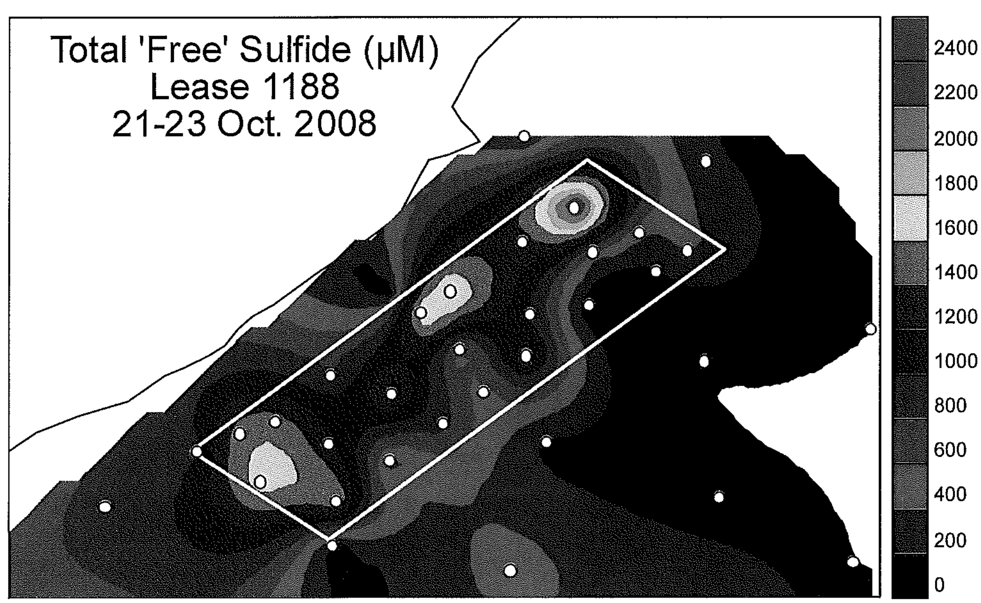

Figure 6. Total 'free' sulphide concentration in surficial sediments around mussel Lease number 1185 (Fig. 1) in St. Ann's Harbour in October, 2008. Sampling locations are shown.

Table 3. Summary statistics for water content (WC; %), organic matter (OM; %), redox potentials (Eh_{NHE}; mV), and total 'free' sulfides (S; μM) for surface (0-2 cm) sediment samples from St. Ann's Harbour collected October 20-23, 2008 grouped by station categories. n=sample number, SE=standard error.

Variable	n	Mean	SE	Min	Max
All Lease:					
S	58	698	75	8	2649
Eh_{NHE}	59	-115	13	-192	249
OM	56	12.3	0.5	4.1	19.6
WC	55	69.0	2.5	22.9	97.0
All Reference:					
S	29	238	30	4	581
Eh_{NHE}	29	1	34	-169	307
OM	29	11.6	0.9	2.7	18.6
WC	27	74.8	3.7	21.8	98.7
Lease 1188:					
S	26	1025	129	8	2649
Eh_{NHE}	26	-135	11	-188	74
OM	25	9.4	0.6	4.1	17.8
WC	26	53.9	2.5	22.9	73.1
Lease 1188 Reference:					
S	5	130	40	4	251
Eh_{NHE}	5	81	87	-136	296
OM	4	5.6	1.2	3.0	8.7
WC	4	40.2	7.5	21.8	56.4

The primary objective of this study was to "determine if the St. Ann's Harbour benthic monitoring program was sufficient to make scientifically defensible determinations of significant organic enrichment degradation within the mussel leases relative to the normal background variability". To respond to this question, statistical tests were employed to address the hypothesis that median S levels inside (mussel) and outside (reference) leased areas were equal, based on a significance level of $\alpha = 0.05$, for the different data groups shown in Table 4. The data groups were chosen to represent the following four sampling designs:

I. This group includes a subset of data from the 2008 industry EMP sampling program. Data were included from all 3 locations within each of the 4 leases plus the 3 reference locations, with 1 grab randomly selected from each sampling location (n = 12).

II. Same sampling design as for group I, except that S values at each location were the mean of all three grabs (n = 12);

III. Same sampling design as for I, except that all three grabs collected at each site were included and treated as separate locations (n = 36). This design utilized all data from the 2008 EMP sampling program; and

Table 4. Total 'free' sulfides (µM) data sets based on four different sampling designs. Data are from surface (0-2 cm) sediment from St. Ann's Harbour measured in 2008. See text for description of data sets.

	Sampling Design I		II		III		IV	
	Lease	**Reference**	**Lease**	**Reference**	**Lease**	**Reference**	**Lease**	**Reference**
	570	799	520	581	100	108	94	137
	740	72	680	105	145	156	136	73
	50	159	72	520	598	640	559	231
	338		341		326	349	305	219
	164		285		176	188	164	374
	259		494		653	699	611	403
	1709		1259		177	189	165	239
	295		456		521	557	487	112
	489		508		147	157	137	92
	606		397		177		166	455
	500		762		606		566	207
	338		446		124		116	64
					133		124	101
					71		67	167
					1002		936	106
					479		447	3
					1193		1115	143
					808		756	153
					1563		1460	251
					1067		998	98
					2834		2649	162
					1421		1328	469
					1999		1868	363
					2031		1898	187
					882		824	455
					1613		1507	431
					1626		1519	
					1760		1645	
					948		886	
					557		520	
					1478		1381	
					9		8	
					194		181	
					335		313	
					1846		1725	
					435		407	
							756	
							300	
							230	
							357	
							650	
							756	
							1317	
							258	
							766	
							780	
Mean	504	343	518	402	834	338	744	219
Median	414	159	475	520	602	189	589	177
Max	1709	799	1259	581	2834	699	2649	469
Min	50	72	72	105	9	108	8	3
SE	128	229	85	150	119	77	90	27
n	12	3	12	3	36	9	46	26

IV. Enhanced spatial sampling design including all 46 locations within each of the 4 leases, plus 26 reference locations with 1 grab per location (n = 72). This design included all non-EMP data from the 2008 benthic survey.

Pair-wise comparisons of lease-reference data groups were made using the non-parametric U test in Systat 10.0 and the rank sum test in SigmaStat 2.03 (Table 5). The small numbers of sites sampled by the industry EMP was insufficient to detect a significant difference between lease and reference sites. The increased number of stations sampled during the DFO spatial study permitted a more thorough and statistically powerful analysis and both tests indicated significant differences between lease and reference locations (Table 5, $p<0.001$). Consequently, the null hypothesis was rejected in favour of the alternate hypothesis: the St. Ann's Harbour benthic monitoring program is not sufficient to make scientifically defensible determinations of significant organic enrichment degradation within the mussel leases relative to the normal background variability.

Variability in S concentrations in surficial sediments is a characteristic of coastal areas with depositional environments that are spatially heterogeneous. Monitoring programs in such areas must have a sampling design that reflects this variation to avoid implementation of unnecessary mitigation measures (effect detected when none exists; Type I error) or the lack of detection of significant changes in fish habitat (no effect was detected when one exists; Type II error). Previous studies of mussel aquaculture effects on benthic organic enrichment and community impacts in Tracadie Bay, PEI reached a similar conclusion about the need for an appropriate sampling design to detect variance at lease and inlet-wide scales (Hargrave et al. 2008a). The spatial study of sediment geochemical variables in Tracadie Bay showed significant organic enrichment inside mussel leases (n = 24) relative to reference sites (n = 15), while the 21 stations in the same inlet (Miron et al. 2005), which included only two reference sites, was insufficient to detect lease-scale differences.

An objective of this study was to "provide advice on how shellfish aquaculture monitoring programs may be made more spatially and statistically meaningful, so as to increase the scientific certainty of monitoring results while permitting this industry to remain economically viable." We examined the possibility of utilizing the existing industry sampling effort (i.e. total of 45 grabs), but with increased spatial coverage by eliminating the collection of three replicate grabs at each site. It is not possible to test for differences between all sampling locations using this revised design, but this is not the intent of the monitoring program. To test the effectiveness of this revised sampling scheme, a new data set was created by randomly selecting sites from the full 2008 benthic survey. The new data set included a maximum of nine sites from each lease (only eight sites were sampled in Lease 1187), and nine reference sites that were evenly distributed throughout the Harbour. This gave a total of 35 lease (mean = 639±97 µM S) and nine reference site (252±66 µM) samples. The Kruskal-Wallis U test gave a *p*-value of 0.021, showing that this enhanced spatial sampling approach differentiated median S differences between mussel leases and the reference conditions. Although enhanced spatial sampling

Table 5. *P*-values for Kruskal-Wallis U tests (Systat 10.0) and Mann-Whitney Rank Sum tests (SigmaStat 2.03) for similarity of median values of total 'free' sulfides (μM) between reference and mussel lease locations in St. Ann's Harbour. Tests were repeated using the four different data groups (sampling designs) listed in Table 4 and described in the text.

Sampling Design	Kruskal-Wallis U test	Mann-Whitney Rank Sum test
EMP I	0.470	0.564
EMP II	0.942	1.000
EMP III	0.109	0.112
DFO IV	<0.001	<0.001

may require additional time for sample collection, the additional cost should be minimal given that the same number of grab samples are collected.

It is important to note that our recommendation to modify the sampling approach from three to nine locations within each mussel lease reflects a balance between statistical and practical considerations related to sampling costs to industry. While the increased spatial sampling will provide a better indication of S spatial variability within mussel leases, this sampling program is not intended to delineate the size of the organic enrichment zone (i.e. area of seabed where S concentrations exceeding a given threshold concentration). This would require a much greater sampling effort that may be warranted if there was indication that organic enrichment conditions were increasing over time within a mussel lease.

3.2.3. Temporal Variations in Surficial Sediment Geochemistry

Sediment S and Eh_{NHE} data collected in St. Ann's Harbour between 2000 and 2008, obtained through a combination of DFO, provincial and industry-lead sampling programs, are summarized in Figure 7. Average S concentrations remained relatively constant at less than ~400 μM at reference sites throughout this period while concentrations within the boundaries of Lease 1188 increased, starting in 2005, to the present average concentration of 1025 μM S. Eh_{NHE} at reference sites declined from average levels of approximately 150 to 0 mV over the eight-year observation period, but declined to an even greater extent within Lease 1188. The initial decrease in mean Eh_{NHE} in this mussel lease, relative to the reference sites, also occurred in 2005 and present levels average approximately -150 mV. The first mussel crop was harvested in 2004 from Lease 1188 and the increase in S and reduction in Eh_{NHE} relative to conditions at the reference sites is consistent with a gradual accumulation and degradation of organic biodeposits from mussels over the ensuing years. These indicators of benthic organic enrichment appear to have stabilized at the present condition, however, the variability in these data makes it difficult to establish a temporal trend.

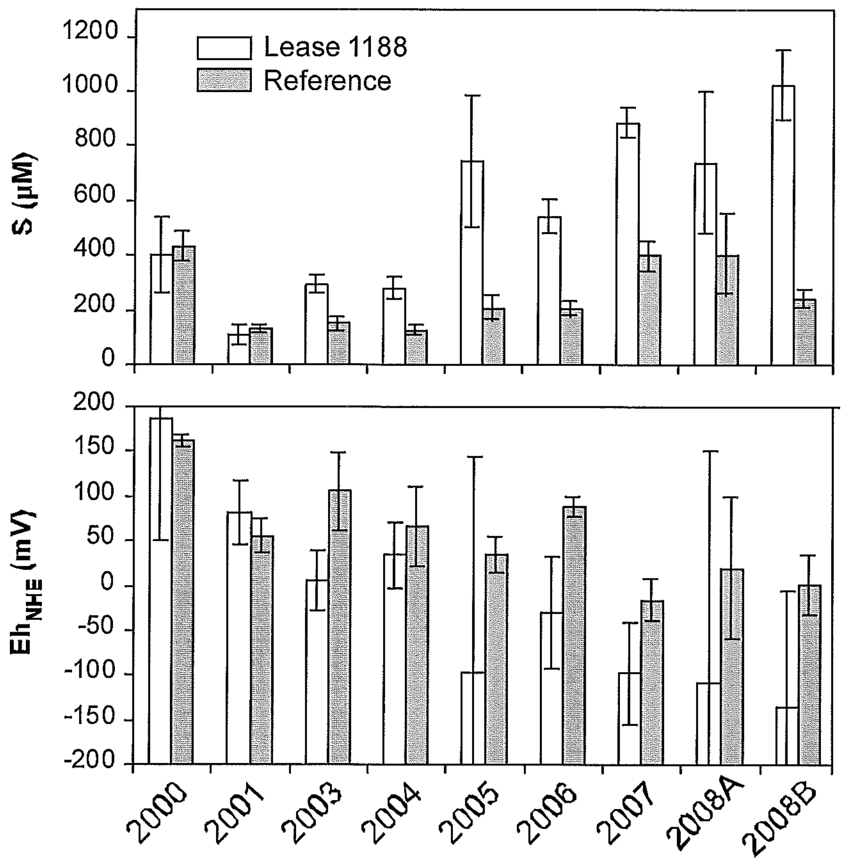

Figure 7. Changes in the average (±SE) total 'free' sulfides (S; μM) and redox potentials (Eh_{NHE}; mV) in surface (0-2 cm) sediment samples from St. Ann's Harbour collected within the region of mussel Lease 1188 and at reference sites over the indicated period. 2008 leases data are presented based on the industry EMP program (2008A) and the enhanced spatial sampling conducted by DFO (2008B).

4. Synopsis

EIA predictions of phytoplankton depletion in St. Ann's Harbour: Analysis of the magnitude of the major physical and biological processes controlling phytoplankton depletion by mussels suggested that there is a low potential for bay-scale phytoplankton depletion at the current level of mussel production. However, more limited flushing of water at the head of the harbour and in the deep areas where the mussel socks are located may result in a greater degree of food depletion than would be predicted by this method.

Size-fractioned chlorophyll *a* measurements showed that the picophytoplankton fraction dominated the phytoplankton, indicating a possible bay-scale depletion of phytoplankton by mussels. Industry data on mussel production (sock yield per number of months on site) suggest that production initially increased with increased stocking biomass, but that a lease production limit (production carrying capacity) was exceeded on Lease 1189 when the mussel biomass was at highest levels. This suggests a negative feedback on mussel growth from periodic mussel-induced local food depletion.

Benthic organic enrichment in St. Ann's Harbour: Surficial sediment grain size data indicate a largely depositional environment with the exception of the northern section near the mouth. The ingestion of fine suspended particles by mussels results in the settling of faeces and pseudofaeces and this appears to have resulted in the localized fining of bottom sediments. Mussel biodeposits typically contain >20% organic content and organic enrichment effects are the focus of mussel aquaculture environmental monitoring programs. Total 'free' sulphide is the primary measure used for managing organic enrichment effects on benthic habitat within the aquaculture management framework for St. Ann's Harbour and in the DFO Maritimes Region. Extensive sampling of S concentrations in surficial sediments from 58 mussel lease and 29 reference sites showed a significant difference between lease and reference locations, with concentrations in Lease 1188 averaging 1025 μM. The initial rapid increase in average S (and decrease in Eh_{NHE}) in surficial sediments under Lease 1188 occurred in 2005, one year after the first mussel harvest. Organic enrichment effects after 2005 appear to have stabilized, although the high variability in these data makes it difficult to establish a temporal trend.

Benthic monitoring sampling designs: A statistically effective benthic sampling design is required to avoid implementation of unnecessary mitigation measures (mussel aquaculture effect detected when none exists; Type I error) or the lack of detection of changes in fish habitat (no effect was detected when one exists; Type II error). The benthic sampling design employed by industry in their annual monitoring program (3 locations in each lease and 3 reference sites with 3 replicate grabs per location) was not sufficient to make scientifically defensible determinations of statistically significant organic enrichment within the mussel leases relative to the normal background variability. An enhanced spatial sampling approach with no site replication (9 locations in each lease and 9 reference sites with no replicate sampling) is able to differentiate median S differences between mussel leases and the reference conditions at no additional cost to industry. This suggested revised monitoring approach would not delineate the actual size of impact zones, but based on the results of the annual survey it could be used to trigger enhanced monitoring or management actions if deemed necessary.

5. Acknowledgements

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Development Division, the Nova Scotia Department of Fisheries and Aquaculture, the Department of Oceanography at Dalhousie University, and representatives of the St. Ann's mussel aquaculture industry.

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Appendices: Stakeholder Perspectives on Mussel Aquaculture Management in St. Ann's Harbour

Appendix 1: Habitat Management Program Perspectives (J. Crocker)

The Department of Fisheries and Oceans Canada, Habitat Management Program, Maritimes Region (HMP), is responsible to fulfill its mandate for regulating impacts to fish habitat in a manner that promotes healthy and productive aquatic ecosystems. In managing fish habitat, HMP applies current science understanding to assess risk based on the sensitivity of fish habitat relative to the scale of the potential effect. Low-medium risk effects are managed through avoidance and/or mitigation and regulatory efforts are focused on the residual, high risk effects and areas of uncertainty. Predicting and managing environmental effects is inherently difficult due to uncertainties and gaps in knowledge, the natural variability of ecosystems and the influences of unforeseen factors. Alone, the absence of full scientific certainty should not be used to postpone decisions. In cases of potential serious or irreversible harm to wild fisheries resources, the precautionary principle is applied by HMP to avoid impacts. However, uncertainty can also be mitigated through the implementation of monitoring programs designed to verify that actual effects do not exceed the predictions and are within predetermined limits.

The establishment of performance standards can allow an adaptive site management approach where operations are modified in response to the risk to fish habitat. In some cases, specific studies may also be required to assess and monitor impacts over time and determine if modifications are necessary. This was the case in 2001, when HMP received an application for one of the single largest shellfish sites in Canada. Following the federal environmental assessment of the proposal, HMP required the Proponent to establish an EMP prior to proceeding with the project. Through collaborative efforts with government regulators and the academic community, the Proponent provided the "Environmental Management Plan for the Bounty Bay Shellfish Inc. and 5M Aqua Farms Mussel Aquaculture Operation in St. Ann's Harbour, Cape Breton, NS (2003)" (St. Ann's EMP, 2003). Like any EMP, an Environmental Effects Monitoring (EEM) program was central to the program and in the case of St. Ann's this was developed to monitor mussel growth rates, organic loading to the benthos, and effects on seston concentration. Additionally, an adaptive management approach to site development occurred based on the results of the EEM. The approach was intended to rapidly inform decisions related to the implementation of mitigation measures and served as a milestone in the approach to the management of the aquaculture industry for HMP.

The cornerstone of the St. Ann's EMP is the use of biogeochemical measures in sediments to assess the health of fish habitat. Specifically, it considers the benthic organic enrichment impacts of aquaculture resulting from production waste and biofouling material. The relationships between redox potentials (Eh), S and the biodiversity of benthic organisms are well known (Brooks and Mahnken, 2003; Wildish and Pohle, 2005; Hargrave et al. 2008b) and are commonly used as indicators to assess local effects of aquaculture production on sediments in the vicinity of aquaculture sites. As organic enrichment increases in intensity and duration, the risk of impact to the biodiversity of benthic organisms increases (Pearson and Rosenberg, 1978). S in surficial (0-2 cm) sediments is one of the key indicators recommended by Wildish et al. (1999), Wildish et al. (2001) and Cranford et al. (2006) for measuring negative effects on the biodiversity of macrofauna as a result of changes in sediment biochemistry due to organic enrichment. Various studies (Hargrave et al., 1997; Wildish et al., 1999; Brooks, 2001; Brooks and |Mahnken 2003; Wildish et al., 2005; Cranford et al. 2006 and 2009; Hargrave, et al. 2008a and b; Holmer et al. 2005) have provide the scientific background to establish formalized ranges (sediment organic enrichment classification) of S concentrations that describe OXIC-HYPOXIC-ANOXIC sediment conditions. Relationships between organic enrichment and changes in the benthic macrofauna community structure and sediment chemistry have been represented in a nomogram (Hargrave et al. 2008b). These and other studies demonstrate that impacts to benthic fauna biodiversity, and consequently the productive capacity of fish habitat, resulting from increased S concentrations and reduced Eh potentials can be significant and occur at low S levels (>1500 μM).

The DFO Science Response (2006/14): Sulphide Monitoring Design for Aquaculture discusses a risk based and cost effective monitoring program for S. This publication indicates that in order to provide a high level of spatial resolution and increase the precision of statistical analysis, the distance between sampling sites should be minimized and have a uniform distribution along transects running radially away from the area of interest. Building upon the experiences of the St. Ann's EMP and DFO Science advice, HMP Maritimes Region has developed an EMP for aquaculture regarding the organic enrichment of fish habitat. The HMP EMP utilizes a tiered EEM in response to the site classification and a series of pre-determined site management responses are triggered in response to degrading sediment condition. These Targets, Thresholds and Limits are based primarily on S measurements as a proxy for fish habitat and are defined as follows:

- *TARGET*: OXIC sediment conditions (<1500 μM S) represent the Marine Environmental Quality Objective (MEQO) or baseline
- *THRESHOLD*: HYPOXIC B (3000 μM S), a sediment condition which poses high risk to fish habitat.
- *LIMIT*: ANOXIC (6000 μM S) is a grossly polluted state with reductions in benthic macrofaunal biodiversity on the order of 70-90%.

In the HMP EMP, the EEM program and mitigation measures are established in a tiered manner that recognizes increased risk to fish habitat requires an increase in management effort, proportionate with the severity of the measured impact. Together, the EEM and mitigation measures are applied at each threshold and act together to rapidly identify, evaluate and address measured impacts on fish habitat. They also ensure that operational effects do not exceed predictions made during the site assessment phase. This performance based approach ensures that mitigation and/or regulatory measures are undertaken in an adaptive manner which protects fish habitat. Thus the importance of EEM can not be overstated and is designed to not only assess the spatial extent and magnitude of site-specific habitat effects but also to ensure that the program itself is assessed. By adhering to basic scientific and habitat management principles, a wide range of statistical methodologies, including geospatial analyses can be applied to the data to ensure that the results are as informative as possible. The HMP EMP will evolve through constant evaluation and dialogue with Science.

Typically, shellfish aquaculture has been considered to be Low Risk and has relied solely on S as the benthic indicator for impacts to fish habitat. The publication by Cranford et al. (2006), discusses indicators and thresholds for use in assessing shellfish aquaculture impacts on fish habitat. This publication assessed EEM approaches for shellfish aquaculture production in the Maritimes Region of DFO and identified, evaluated and made recommendations regarding a range of quantitative indicators (measures of habitat and ecosystem status) that could be used to monitor for potential shellfish aquaculture effects. The report emphasized that multi-tiered impact assessment and management approaches utilized by DFO-HMP for finfish aquaculture are also suitable to address benthic impacts in the vicinity of shellfish farms. Cranford et al. (2009) and Hargrave et al. (2008a) provide further insight regarding the influence of mussel aquaculture on benthic organic enrichment in nutrient-rich coastal embayments showing that effects of shellfish aquaculture on benthic organic enrichment can occur over large scales. The results emphasize the need for additional indicators to assess risk to fish habitat, particularly at the bay scale and in the water column.

Given the uncertainty surrounding the impacts of aquaculture production on aquatic ecosystems, in order to afford the highest level of protection to fish habitat, the EEM must be subject to constant evaluation and updating. It is important that the most recent science related to the topic of aquaculture be used in DFO efforts aimed at developing, or updating existing management and monitoring programs for aquaculture production such as the HMP EMP. It is also important that existing programs related to benthic monitoring and organic enrichment be reviewed regularly to ensure they reflect the current state of knowledge. Effective management frameworks include evaluations (audits) of the performance measures or specific elements of them, to assess effectiveness. In light of this, the DFO-Program for Aquaculture Regulatory Research funded study "Mussel Aquaculture Regulatory Effectiveness Monitoring: Validation of the Environmental Assessment and Monitoring Program in St. Ann's Harbour" is timely in that its overarching goal is to improve regulatory certainty. To accomplish this task, the study aimed to:

- Assess the EIA model predictions: H_0= not likely to result in significant adverse environmental effects or HADD to fish habitat.
- Assess effectiveness of EMP to detect changes to avoid and respond to impacts to fish habitat.
- Undertake extensive sampling program to understand:
  - Scale and magnitude of water column particle depletion

- Scale and magnitude of benthic habitat effects

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Appendix 2. An Industry Perspective on Changes to the St. Ann's Harbour EMP (R. Stuart)

The proponents conducting mussel culture operations in St. Ann's Harbour believe that the EMP as presently designed is too costly per annum and this will increase significantly in 2010 as the work will be performed more by consultants. The following changes are recommended:

- Additional research is needed to demonstrate the positive components of change directly attributable to the farm's presence such as increased lobster and rock crab catches.
- Eliminate several required monitoring components from the EMP that do not provide direct indicators of impact. These include sediment redox potential, porosity and organic content and water column chlorophyll *a* and CTD measurements. If these are to be collected then industry would like to see the collection cost be covered by some party other than the farmers.
- In the report itself the data should only include a summary of the total live weight, dry meat weight, year class, numbers of mussels per sock, and invasive presence. A projection of the number of socks per line, and per lease by year class could be provided in this summary. The number of fallow lines would also be included. The individual data sheets should not be included in the document. A one page chart called "Annex Annual Lease Report Comparison Mussel Inventory: Data" should be all the information required. Suggest removal of reporting requirements for number of mussels/sock at socking and at harvest, mortality and mortalities to harvest. Data could be added on number of fallow lines, dry meat weight per sock and wet meat yield.
- Remove detailed bio-fouling information limiting any information to new comers or exceptional changes.
- Lift lines from 6 meter to 2 meter depth to improve growth and increase byssal strength. This move would prevent mussel falloff, increase the dispersion of biodeposits and both would decrease benthic impact.
- Keep colour coded individual maps indicating location of lines by year class.