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# Polychaete response to different aquaculture activities

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## ABSTRACT

The benthic macrofauna was examined at four aquaculture sites in Eastern Canada over a period of one year to determine if the heavy organic loading had a detrimental effect on the benthic communities. Two sites, one in Prince Edward Island and one in Nova Scotia, were occupied by blue mussel lines, and two sites, one in Nova Scotia and one in New Brunswick, were occupied by Atlantic salmon culture operations. Polychaete communities beneath each site plus reference sites were analyzed for comparative diversity, dominance, and the presence of indicator species such as "opportunistic" or "pioneer" species. The polychaetes which dominated the fauna beneath the mussel lines were different than those from beneath the fish cages. In both geographical locations, the sediment beneath the shellfish lines was black, finely pelletized and had high organic material content and the dominant macrofaunal organism was *Nephtys neotena*. The sediments beneath the fish cages in the New Brunswick site were black, smelled strongly of $H_2S$, had high organic material content and at times were covered with a *Beggiatoa* sp. bacterial mat. The dominant and sometimes only species was *Capitella capitata*, a species known for its tolerance to anoxic conditions and high organic enrichments. The dominant polychaete found under the fish pens at the smaller Nova Scotia site was *Nereis diversicolor*. The difference in the two fish farm sites is explained by the scale and duration of the operation. Similarly, degree of dominance at the two shellfish sites corresponds with the density of mussels and duration of operation.

## RÉSUMÉ

**Réponse des polychètes à différentes activités aquacoles**

La macrofaune benthique de quatre sites d'aquaculture de l'Est du Canada a été étudiée durant une année pour déterminer si les rejets organiques avait un effet défavorable sur les communautés benthiques. Deux sites, l'un sur l'île du Prince Édouard et l'autre en Nouvelle Ecosse étaient occupés par des cordes à moules et deux autres sites, l'un en Nouvelle Écosse et l'autre dans le Nouveau Brunswick correspondaient à des fermes à saumons. Les communautés de Polychètes sous chaque site et dans des stations de référence furent analysées en terme de comparaison de la diversité, de la dominance de la présence d'espèces indicatrices telles que les "opportunistes" ou les "pionnières". Les polychètes qui dominaient la faune sous les cordes à moules étaient différentes de celles situées sous les cages à poissons. Dans les deux sites, les sédiments sous les cordes à coquillages étaient noirs, finement pélitisés et avaient une forte concentration en matière organique, l'organisme dominant était la *Nephtys*

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*neotena*. Les sédiments sous les cages à poissons dans le Nouveau Brunswick étaient noirs, avaient une forte odeur d'$H_2S$, une forte concentration en carbone organique et étaient, momentanement, recouverts d'une couche bactérienne à *Beggiaota* sp. L'espèce dominante, parfois unique, était *Capitella capitata*, connue pour sa tolérance aux conditions anoxiques et aux fortes concentrations organiques. Le polychète dominant trouvé sous les cages à poissons en Nouvelle Ecosse était *Nereis diversicolor*. La différence entre les deux fermes à poissons est expliquée par l'échelle et la durée de l'opération. De même, le degré de dominance dans les deux sites à coquillages correspond à la densité des moules et à la durée de l'exploitation.

## INTRODUCTION

One of the reported effects of sustained aquaculture activity on coastal environments is the deposition and accumulation of organic rich sediments under the aquaculture site (ANONYMOUS, 1987; GOWEN & BRADBURY, 1987; LARSSON, 1985; O'CONNOR *et al.*, 1989; PRAKASH, 1989; WESTON, 1990). A main source of organic material (OM) under shellfish lines is faeces and pseudofaeces deposited by the shellfish (KAUTSKY & EVANS, 1987). Conversely, the main source of organic material found under the fish cages at fin–fish culture sites is derived from the deposition of uneaten food in addition to the excretory products of the fish. At peak filtering time, an intensive culture of shellfish can completely filter the water contained in a bay having a volume of 548 x $10^6$ $m^3$ in seven days (DANKERS & KOELEMAIJ, 1989) and can deposit 10 kg. $m^{-2}$ of OM per annum to the sediments (TENORE *et al.*, 1982). Similarly, levels of 10 kg. $m^{-2}$ of "mixed" or multisource OM per annum (GOWEN & BRADBURY, 1987) can be deposited under a fish farm.

The consequences of the build–up of organic wastes in both types of aquaculture operations can include a change in the sedimentary regime (MATTSON & LINDEN, 1983; OTTMAN & SORNIN, 1985), an increase in oxygen consumption by the sediment (KASPAR *et al.*, 1985), formation of anoxic sediments (BROWN *et al.*, 1987) and the production and release of harmful gasses (e.g. methane, hydrogen sulphide and carbon dioxide) from the sediments to the water column (DAHLBACK and GUNNARSSON, 1981; BROWN *et al.*, 1987). These conditions can influence the structure of the benthic macrofaunal community inhabiting the affected sediments (BROWN, GOWEN, & MCCLUSKY, 1987); RITZ *et al.*, 1989; WESTON, 1990), and in severe conditions even affect the fish above (BROWN *et al.*, 1987).

It has been found that when the capacity of some sites to assimilate wastes is exceeded, it is necessary to abandon or move the installations (ROSENTHAL & RANGELEY, 1989; SORNIN, 1981; Sea Farm Canada Inc., personal comm.). A search for methods to detect the change in conditions in the environment before critical conditions develop is one of the objectives of this work. Polychaetes are widely used as indicator organisms for marine environmental quality studies (BELLAN, 1984, 1991; GLÉMAREC & HILY, 1981; see also review by POCKLINGTON & WELLS, 1992) and have been employed in this study to provide a measure of local benthic environmental impact for fin fish and shellfish aquaculture operations.

The amount of organic material in sediments under and around four aquaculture installations in eastern Canada was measured to establish that organic material was higher under the aquaculture installations than background levels. The macrobenthic community of these sediments was then examined seasonally over one year, with particular attention to the change in the polychaete fraction of the macrofauna. We wanted to determine if the effects of organic enrichment to the benthic environment from fin–fish aquaculture could be distinguished from that derived from shellfish culture activities based on the response of the polychaete community to the two types of OM loading. Quantitative approaches which have been shown to be useful in such studies such as change in diversity and degree of dominance were used. Also, we endeavoured to identify indicator species (i.e. "opportunistic" or "pioneer" species) to augment our quantitative community structure observations and to act as sentinels for monitoring environmental change between control and aquaculture sites.

## METHODS

Four aquaculture sites were monitored over one year. These include a salmon farm in the Bay of Fundy, a salmon farm with mussel lines in St. Margaret's Bay, N.S., and mussel leases in Cardigan River Estuary, P.E.I., and Lunenburg Bay, N.S. (Fig. 1). At each location, samples were taken directly under the aquaculture site, at a local reference site 25–50 m away from the aquaculture site and at reference sites 1.5–2 km away. The sites were sampled in spring, summer, fall and winter using a 225 $cm^2$ Ekman grab. Samples were sieved on a 0.5 mm mesh sieve and all benthic macrofauna was recovered and identified to the lowest taxon, counted and stored in 70 % alcohol. Sediment from all the samples was analyzed for organic carbon content based on weight loss on ignition at 500 °C for 2.5 hours.

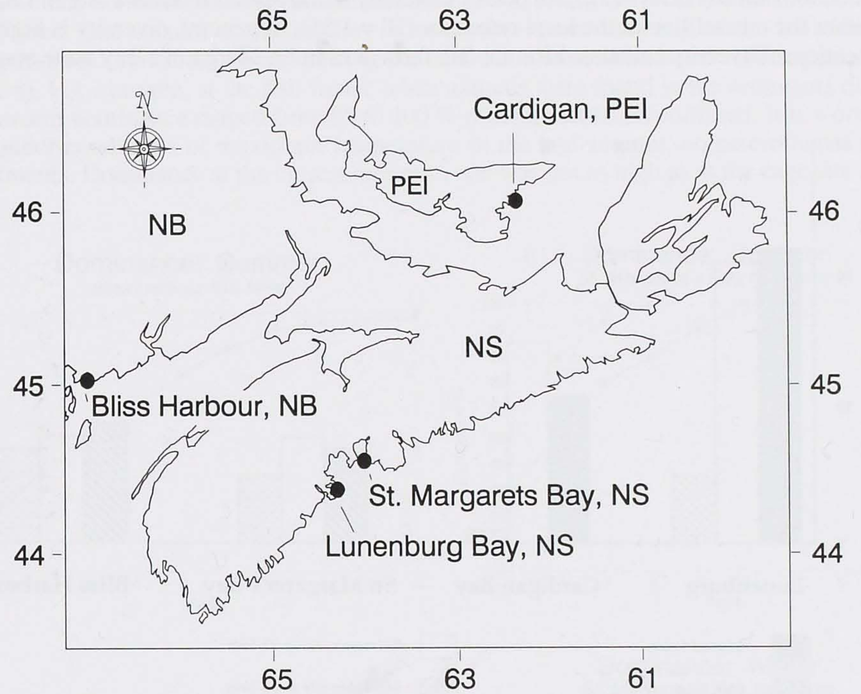


FIG. 1. — Map of eastern Canada showing location of aquaculture sites studied. PEI = Prince Edward Island; NS = Nova Scotia; NB = New Brunswick.

Polychaete macrofauna data were analyzed for diversity using the Shannon Weiner information statistic H' (SHANNON &WEAVER, 1964), dominance curves were generated by calculating cumulative per cent dominance of species (LAMBSHEAD *et al.*, 1983); in addition, the faunal lists were examined for indicator species *sensu* PEARSON &ROSENBERG (1978). All stations were subjected to cluster analysis on seasonal basis to determine natural groupings based on macrobenthic species composition. We examined these data to see if sites subjected to similar aquaculture activities were more similar than sites subjected to different aquaculture activities, or to no aquaculture activity.

## RESULTS

ORGANIC MATERIAL. — Organic material (OM) content was higher at all aquaculture sites and their closest reference sites than at their more distant reference stations (Fig. 2).

DIVERSITY. — In general, the diversity (H') of the macrofaunal community in the sediments directly beneath the aquaculture installations was lower than at the respective reference sites (Fig. 3). For example, directly beneath the fish cages in Bliss Harbour, diversity was found to be 0 in both winter and summer compared to the more distant reference site where the value of H' reached 2.2 in the winter and 2.7 in the summer. In contrast, diversities calculated for the fish farm sites in St. Margaret's Bay were relatively high in both winter and summer (H' = 1.3 and 1.1) respectively. At the 25–50 m reference sites in St. Margaret's Bay, H' ranged between 1.6 in winter and 0.56 in summer. Diversity of fauna under the shellfish lines at the Cardigan Bay location was calculated to be 0.08 in the winter and 0 in the summer with similar values at the local reference site (i.e. 0.05 and 0 respectively). Though our Cardigan Bay winter reference sample was invalid, H' for the most distant reference station in the summer was 1.07 suggesting higher diversity in summer than winter. Diversity under the mussel lines in Lunenburg Bay was slightly higher than at the near reference site in both seasons (H' = 0.9 vs 0.09 in winter and H' = 1.1 vs H' = 0.38 in summer). This is thought to be due to the increased surface area provided by the mussel lines as well as the mussels themselves which provide additional substrate for attachment by other taxa which enhanced colonization (GRANT *et al.*, in press). Diversity at the distant reference site in Lunenburg Bay was higher than at either the mussel line or the local reference (H' = 1.55). In general, diversity is higher in winter than summer at all locations. Diversity calculated for the fish farm sites in St. Margaret's Bay were consistently higher

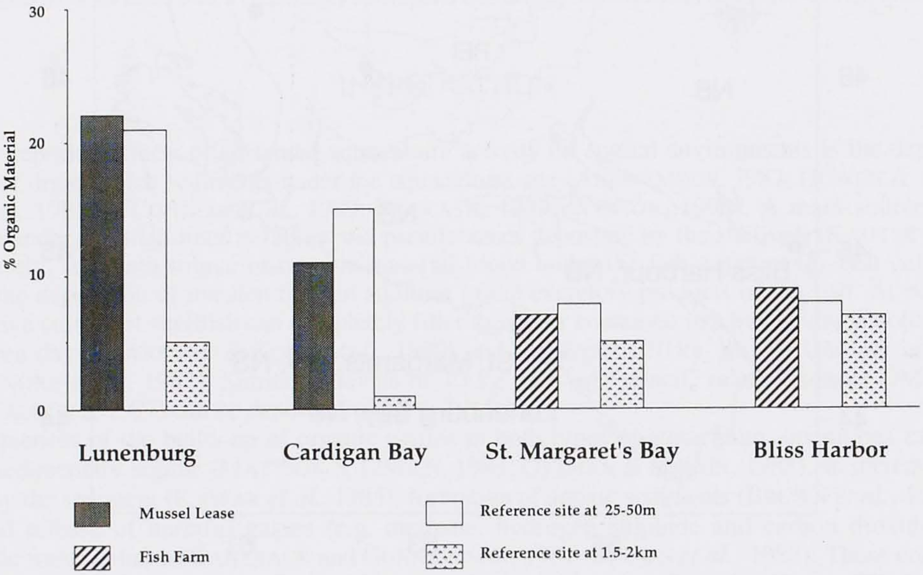


FIG. 2. — Percent organic material in sediment of site, near reference and distant reference of each aquaculture operation in summer.

than at the Bliss Harbour fin fish operation suggesting that the local impact from this installation was not as severe as at other fish farm site. As well, diversity at the mussel lease of Lunenburg Bay was higher than diversity in Cardigan Bay suggesting that the former is less impacted.

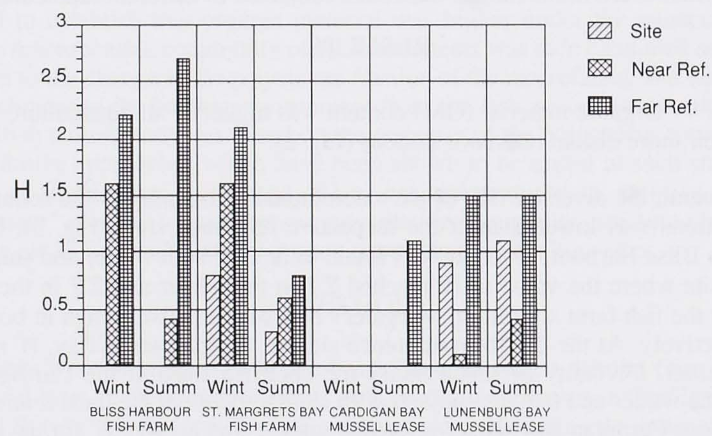


FIG. 3. — Diversity in winter and summer at the site, near reference and distant reference of each aquaculture operation. Wint = Winter; Summ = Summer.

DOMINANCE. — The dominance of the benthic community was relatively pronounced at both the fish farm and the shellfish line sites. One species accounted for, in most cases, more than half of the individuals collected at these sites. Comparative dominance curves showing per cent cumulative abundance versus species rank are given in Fig. 4 (a, b, c, d). For example, at the fish farms, when animals were found in the sediments directly under the fish cages, the percent dominance ranged from 85 to 100 % of all macrofauna collected. It is worth noting that, in Bliss Harbour, under conditions of maximum temperature in the late autumn, no macrofaunal specimens were found in the sediments. Dominance at the closest reference site was not as high as at the cage site in winter. At the

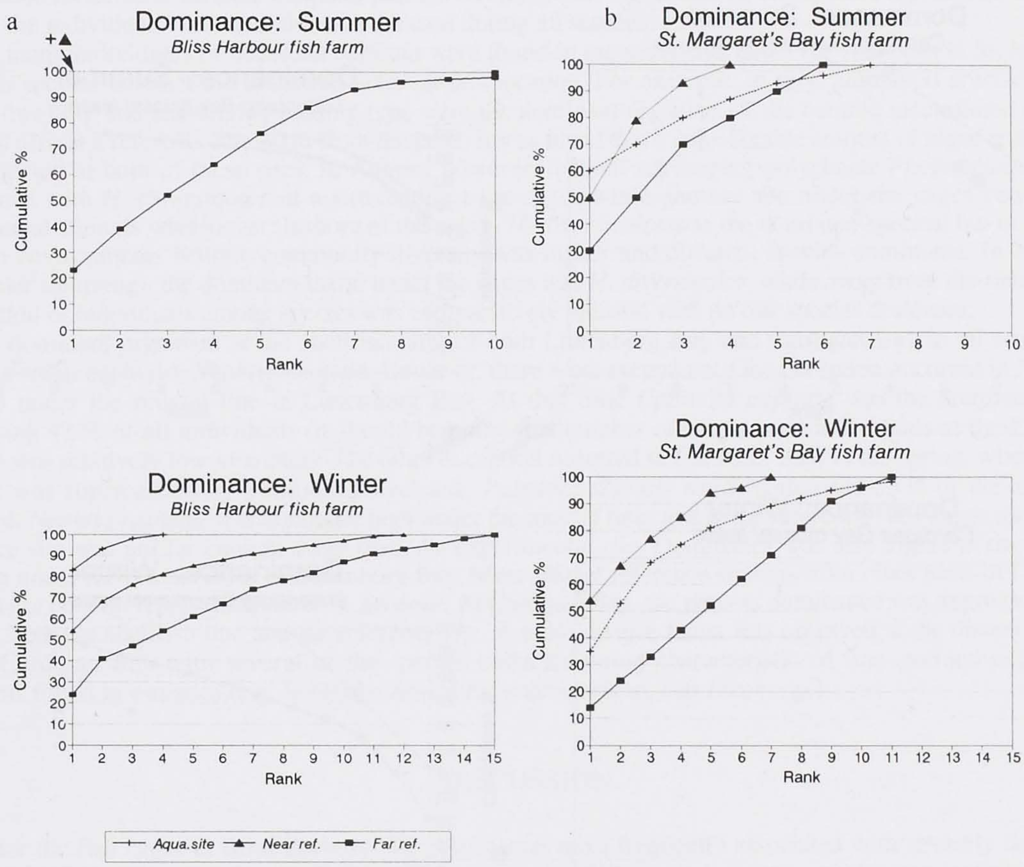


FIG. 4 a. — Dominance curve at Bliss Harbour in summer. There were no macrofaunal animals present under the fish cages in summer (August). Hence no line; only one species – *Capitella capitata* – group was collected at near reference site (30 m from fish cage), hence the * at 100 %; the cumulative abundance of species collected at the reference site 1.5–2 km away is shown. Dominance curves at Bliss Harbour in winter show greatest dodminanceoccurs at the site under fish cage (82 % of animals collected were 1 species – *Capitella capitata*) individuals collected at reference site nearest the cages are distributed over a greater number of species. At the reference site 1.5–2 km from fish cages distribution of individuals among species shows little variation from summer.

FIG. 4 b. — Dominance curves at fish cage and near reference location in St. Margaret's Bay in summer show little difference, whereas the distant reference site shows a more even distribution of individuals among species with no species accounting for more than 32 % of individuals. Dominance curve in winter similar to that in summer, animals are distributed over a greater number of species.

fish farm in St. Margaret's Bay, dominance seemed to be shared between two species (*Pholoe minuta* and *Hediste (Nereis) diversicolor*), each of which accounted for about 30 % of total number of individuals. Here, the closest reference site was dominated by *Nereis diversicolor* but not to the same extent as under the fish cages. At the shellfish lease site in Cardigan Bay, 55–100 % of the individuals collected at both the shellfish lines and the near reference site were *Nephtys neotena*. This same species represented 31 to 63 % of the individuals collected at the mussel lease in Lunenburg Bay and 76 to 87 % of the individuals collected at the local reference site. At the more distant reference sites for most of the locations studied, no one species accounted for more than 30 % of the individuals collected.

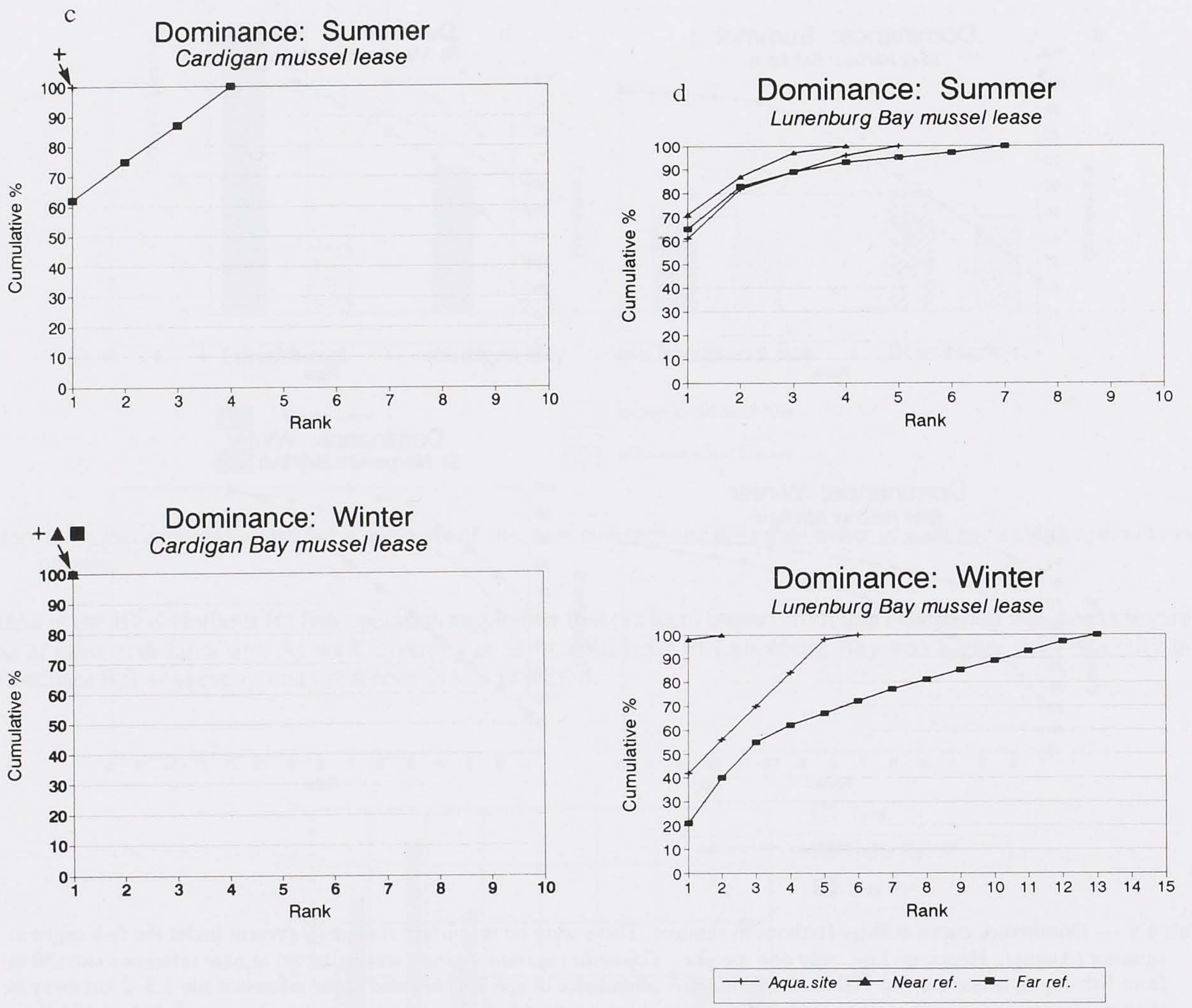


FIG. 4 c. — At Cardigan Bay in summer, the macrofauna at both mussel line and its near reference here shows 100 % comprised dominance of only one species *Nephtys neotena*. Far greater numbers at near reference site than mussel lease site. The distant reference was dominated by *Scoloplos armiger*. At Cardigan Bay in the winter, musseul lease and its near reference site only one species, *Nephtys neotena*, was collected. The distant reference site had to be discarded.

FIG. 4 d. — At Lunenburg Bay in summer, there is little difference in dominance curves between the mussel line, its near reference and its distant reference, the number of species at distance reference is greater. In winter the dominance was greatest and diversity greatest at the distant reference site.

INDICATOR ORGANISMS. — Dominant organisms under the fish cages varied with geographic location. At the late February sampling under and amongst the fish cages in Bliss Harbour, *Capitella capitata* occurred in very large numbers in all grabs (average of 11,581 ind. $m^{-2}$) and dominated the fauna, averaging 92 % of all individuals collected (range 85–98 %) under the fish cages (Fig. 5). The sediment from which they were taken was black, oozy material that smelled strongly of $H_2S$ and that was covered by a thin bacterial mat of *Beggiatoa* sp. In August, *Capitella capitata* was the only species found under the fish cages but numbers at that time were very low (44 ind. $m^{-2}$). Similarly in November, it was the dominant species found associated with sediment under the fish pens but its numbers were still relatively low (440 ind.$m^{-2}$). Away from the cages, at the local reference site faunal composition reflected a different temporal pattern. Diversity was higher and no one species represented more than 25 % of the individuals collected; this was the case during all seasons.

Though many individuals of *Capitella capitata* were found in the sediments under the fish pens at St. Margaret's Bay, this species was not the dominant taxon at this location. For example, in July, amphipod crustaceans of a surface dwelling and scavenging feeding type were the dominant organism of the benthic macrofauna under the pens and also at a reference site 20 m from the pens. It was noted that a considerable amount of algae and eel grass was collected at both of these sites. In August, however, a small scavenging polychaete *Pholoe minuta* shared dominance with *H. diversicolor* at a site amongst the cages while another site under the cages contained no macrofaunal animals whatsoever. Inshore of the cages, *H. diversicolor* was the dominant species, but in subjacent offshore environments benthic community diversity was higher and different species dominated. In November (the winter sampling), the dominant taxon under the cages was *H. diversicolor*, while away from the fish pens, the distribution of individuals among species was comparatively uniform with no one species dominant.

The dominant organism at the shellfish sites of both Lunenburg Bay and Cardigan Bay in all seasons was usually a small nephtyid, *Nephtys neotena*. However, there were exceptions. One exception occurred in November (winter) under the mussel line in Lunenburg Bay. At that time *Capitella capitata* was the dominant species comprising 42 % of all individuals (it should be noted that number of species and individuals at the Lunenburg Bay site was relatively low in winter). The other exception occurred in Cardigan Bay, in the spring, when *Nephtys neotena* was superceeded by a spionid polychaete, *Polydora socialis* which comprised 55 % of the individuals collected. *Nephtys neotena* was dominant both under the mussel lines and at the reference sites suggesting that the reference site was not far enough away from the experimental site. Dominance was also higher at the reference site than under the mussel lines in Lunenburg Bay. More distant reference stations from other parts of Lunenburg Bay did not contain representatives of *N. neotena*. At Cardigan Bay, the percent dominance was approximately the same at both the shellfish line and the reference site. A more diverse fauna was observed at the distant reference site in Cardigan Bay with several of the species collected being characteristic of fine–grained organic–rich sediments found in estuaries (e.g. *Scoloplos armiger*, *Lumbrineris* sp. and *Eteone* sp.).

## DISCUSSION

Under the fish cages in Bliss Harbour, the polychaetes most frequently associated with severely deteriorated conditions, *Capitella capitata*, prevailed. Large numbers of small specimens of this species were collected. Larvae of this species are known to use sulphur dioxide as a settlement cue (CUOMO, 1985). One reason this species may withstand the conditions that have developed in the aquaculture site sediments is thought to be the ability of females to build a membranous tube in which to incubate eggs which we interpret as a means of keeping the developing eggs from direct contact with the sediments. *Capitella capitata*, on the other hand, was only occasionally found associated with the shellfish leases. A different species, *Nephtys neotena*, appears to be an indicator of organic enrichment from biodeposition at shellfish line sites. Like *Capitella capitata*, it is a small burrowing, deposit–feeding species which can occur in very large numbers to the exclusion of other species in sites of organic enrichment. Though many species of the genus *Nephtys* are aggressive carnivores, the stomach contents of *Nephtys neotena* was examined whenever it was encountered and found to contain only fluidized detrital particles, suggesting a deposit–feeding mode of nutrition. Furthermore, the presence of external branchiae on this species (and not on *Capitella capitata*) suggests that it requires the presence of some oxygen in the sediment for respiratory purposes. The environmental interpretation based on this evidence is that though the levels of organic material in the sediments under the shellfish leases are very high, they do not become as anoxic as quickly as at the fish sites.

In general, the impact of aquaculture activities in Nova Scotia (both fish farms and mussel leases) appears to be less than similar activities in New Brunswick and Prince Edward Island. It seems that a mix of natural and anthropogenic factors are involved in determining the degree of impact of an aquaculture operation on the local marine environment. One must consider the physical setting. The two Nova Scotian sites are located in bays having relatively unrestricted exchange with the Atlantic. Studies have shown that complete flushing of both St. Margaret's Bay and Lunenburg Bay can occur in a matter of 2 to 2–1/2 days (SHARAF *et al,* 1970; M. DOWD, pers. comm.). However, the Lunenburg Bay site had a causeway emplacement 20 years ago which has affected circulation in the location of the shellfish lines. Cardigan Bay, on the other hand, is a low energy way environment most of the summer, there is a greater exchange of water in the system during storms in the autumn (DRINKWATER & PETRIE, 1988; T. SEPHTON, pers. comm.). In winter, the ice cover in Cardigan Bay prevents wave–generated flushing. In Bliss Harbour, on the L'Etang Inlet of the Bay of Fundy, though the tidal range generally is relatively vigorous, there is only partial flushing of bays and inlets in this system (R. TRITES, pers. comm.), a condition which could contribute to the uninterrupted flux of organic material. Temperature range at the Nova Scotia sites are different from the other two sites. For example, maximum temperature in Lunenburg Bay is 22 °C and minimum temperature is –1.5 °C (A. HATCHER, pers. comm.). St. Margaret's Bay is similar except the lower end temperature never reaches below –0.5 °C (SHARAF *et al,* 1970). Maximum temperature in Bliss Harbour is about 14 °C while minimum to date is +2 °C (R. TRITES, pers. comm.). No precise data were available for Cardigan Bay but temperatures can get as high as +26 °C and below 0 °C in the winter (T. SEPHTON, pers. comm.) and it is an environment in which species with southern affinities are found (FOURNIER & POCKLINGTON, 1984; POCKLINGTON & TREMBLAY, 1987). Cardigan Bay also has had a causeway emplacement in the last 30 years that affects circulation in the area of aquaculture.

Along with contrasts in the rate and extent of flushing of the sites, there are other differences. One of these is density of organisms cultured and the length of time the installations have been in place. The Nova Scotian sites are much smaller and much more recent operations than the Bay of Fundy and Cardigan Bay sites. For example, there are an estimated 40,000 fish in the St. Margaret's bay operation whereas the fish farm in Bliss Harbour is about 10 times larger. Similarly, there is one mussel lease operating in the Lunenburg Bay site whereas, at last report, 10 leases were in operation in Cardigan Bay each with an estimated 35 x $10^6$ mussels per lease (T. SEPHTON & S. BATES, pers. comm.). All of these factors can contribute to the observed differences in impact on the local fauna that we have observed, together with causeway emplacements.

## CONCLUSION

Analysis of the benthic macrofauna suggests that fish farms in Bliss Harbour have a greater impact on the environment than the fish farm in St. Margaret's Bay. Low diversity and dominance by large numbers of *Capitella capitata* and the occurrence of a *Beggiatoa* sp. bacterial mat indicate that the Bliss Harbour sediments are severely impacted locally as a result of high organic loadings from the fish pens compounded by increased bacterial activity due to the lack of aeration of the sediments by flushing. The shellfish lines at the Cardigan Bay and Lunenburg Bay locations have less negative impact than the fish pens at Bliss Harbour. Sediments under and adjacent to the mussel lines continue to support populations of the small, relatively oxygen dependent, deposit feeding species (*Nephtys neotena*) which is commonly associated with the fine sediments having a high organic content. *N. neotena* is typical of estuarine environments and is common in the organic enriched and relatively fine sediments found in these nearshore settings. The occurrence suggests that, under worst case scenarios, given their location and natural setting, the impact of shellfish lines is not as deleterious as that of the fish farms.

Benthic macrofauna are useful organisms for monitoring the impact of aquaculture operations on the marine environment, and they also appear to be helpful in defining the stage of degradation. It appears that more severely impacted environments have a characteristic fauna which shows anomalous dominance and low diversity.

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