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# Polyculture of sea scallops (*Placopecten magellanicus*) suspended from salmon cages

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**Abstract.** Commercial and developmental operations for the culture of the sea scallop, *Placopecten magellanicus*, are present in Atlantic Canada and New England. In an experiment designed to examine the commercial feasibility of polyculture of scallops with Atlantic salmon (*Salmo salar*), we measured growth and survival of sea scallops grown in suspension at two salmon aquaculture sites in northeastern Maine (Johnson Cove (JC) and Treats Island (TI)). Sea scallop spat were grown in pearl nets and deployed on drop lines containing ten nets in August 1994. One drop line of ten nets was sampled about every four months and scallops were counted, measured and weighed. Scallop tissues were also analysed for paralytic shellfish toxins (PSP). The maximum level of PSP recorded during the study was 1174 $\mu$g STX equiv.·100 g tissue$^{-1}$ (excluding adductor muscle weight). After one year, shell heights were 53.6 and 56.4 mm, growth rates were 0.11 and 0.12 mm per day and wet adductor muscle weights were 3.3 and 4.1 g (TI and JC, respectively). These growth rates were comparable to sea scallops grown in suspension culture to a nearby scallop aquaculture site and other areas in Atlantic Canada. Reduced rates of survival were found during the latter part of the experiment and were attributable, in part, to heavy fouling, predators and high stocking density. The potential for supplemental income, diversification of the salmon aquaculture industry, and feasibility of culturing scallops at adjacent sites to salmon operations does exist.

## Introduction

The Atlantic salmon (*Salmo salar*) aquaculture industry in northeastern US and eastern Canada is currently investigating ways of diversifying their reliance on salmon to ensure long term economic viability and financial stability. Marine finfish, shellfish and seaweed species are all being considered as new candidates for aquaculture. The biological feasibility and potential of culturing sea scallop (*Placopecten magellanicus*) has been demonstrated in a number of studies (Naidu and Cahill 1986; Dadswell and Parsons (1991, 1992); Parsons and Dadswell 1992; Grecian et al. 2000). This species offers potential as an additional cash crop, which could be grown in integrated culture with salmon. Salmon aquaculture operations already have the infrastructure, such as cages and mooring blocks, in place upon which long lines could be installed and scallops suspended in nets. In turn, the organic nutrients associated with salmon pens could potentially be used directly or indirectly to support growth of filter-feeding bivalves (Wallace 1980; Jones and Iwama 1991; Taylor et al. 1992; Stirling and Okumus 1995).

Recently, there has been much emphasis on developing sustainable approaches for aquaculture (Folke and Kautsky 1989; Wurts 2000). An integrated approach to improving the sustainability of marine fish aquaculture is to co-culture with macroalgae and or bivalve species such as oysters, mussels and scallops (Jones and Iwama 1991; Shpigel et al. 1993; Troell and Norberg 1998; Chopin et al. 1999). The reported benefit of this integrated approach is a reduction in nutrients generated by finfish culture; macroalgae can reduce dissolved organic nutrients and bivalves can reduce suspended particulate matter (Ahn et al. 1998; Troell and Norberg 1998; Chopin et al. 1999). Hence, in addition to diversification of the salmon industry and enhanced growth of scallops, polyculture of scallops and salmon may offer a more sustainable approach to culture of these two species.

The goal of this study was to determine the commercial feasibility and logistics of co-culture of sea scallops grown in suspension near Atlantic salmon net pens in Maine, USA. Our objectives were to grow scallops in intermediate culture to a size of about 70 mm, compare growth and survival rates of scallops grown in suspension to those grown at a reference site (benthic cages adjacent to salmon sites), and to test for the presence of marine biotoxins, especially those responsible for paralytic shellfish poisoning (PSP).

## Methods

The study was conducted at two salmon sites located at Treats Island, outer Passamaquoddy Bay, near Lubec, Maine, USA and in Johnson Cove, Passamaquoddy Bay near Eastport, Maine, USA. The two study sites are part of the Quoddy region, where the water column is well-mixed with a maximum tidal range of 8.3 m and annual water temperatures range from 1 °C to 12 °C with a mean annual temperature of 7 °C and annual salinity ranging from about 30 to 32.6 ‰ (Trites and Garrett 1983; Parsons and Dadswell 1992).

Sea scallop spat were obtained from Passamaquoddy Bay, New Brunswick, Canada from a commercial spat supplier (Great Maritime Scallop Trading Co., Chester, Nova Scotia, Canada). The spat collection site was about 10 km and 20 km from the two study sites, respectively (Johnson Cove and Treats Island). At the start of the study on August 11, 1994, initial mean size of spat was 13.5 mm (SE = 0.3). Spat were held in 9-mm-mesh square-base pearl nets at a density of about 40 per net. Drop lines of 10 pearl nets were suspended from long lines at a depth of about 3 m, and were placed immediately adjacent to salmon cages (about 4 m away) off Treats Island and in Johnson Cove. A benthic cage, consisting of a modified lobster trap and stocked with 250 spat, was deployed about 100 m away from the cages at each of the study sites at a depth of 10 m at Treats Island and 15 m at Johnson Cove. The cages, which measured 80 cm × 60 cm × 60 cm (L × W × H), were made of wire mesh and contained three levels. Scallops were only held on the top and second level (i.e., about 20 cm and 40 cm off bottom). The benthic cages served as a reference site to compare scallop growth in suspension to growth off bottom. The 9-mm-mesh pearl nets were retrieved in May 1995 and scallops were placed in 15-mm-mesh pearl nets at a density of 30 per net.

An initial sample of thirty scallops and a sample of ten pearl nets (one drop line) from December 1994, April 1995, August 1995, January 1996 and June 1996 were obtained from each study site. A sample of about 60 scallops was obtained from the benthic cage at Johnson Cove on December 1994, April 1995, August 1995, March 1996 and June 1996 and about 60 animals from the benthic cage at Treats Island on August 1995, March 1996 and June 1996. The number of live and dead animals was determined and live animals were measured for shell height, total weight, and adductor and other viscera weight (wet and dry).

A sample of scallops held in suspension was obtained from each site in April 1995, August 1995, March 1996 and June 1996 in order to determine concentration of paralytic shellfish toxins (PSP). Scallop tissues were separated into adductor muscle samples and remaining soft tissues. Standard mouse bioassays were performed at the Maine Department of Marine Resources to determine PSP concentrations on the separate tissue samples.

## Results

Scallop spat held in intermediate suspension culture for one year grew to a mean shell height of 56.4 mm (SE = 0.52) and 53.6 mm (SE = 0.42) at Johnson Cove and Treats Island, respectively and to a mean shell height of 73.0 mm (SE = 0.62) and 69.0 mm (SE = 0.62), respectively after 1.5 years (Figure 1). Mean shell height of scallops grown in the benthic cages was 59.6 mm (SE = 1.06) and 46.2 mm (SE = 0.71) after one year and 68.5 mm (SE = 2.41) and 52.0 mm (SE = 2.52) after 1.5 years for the respective sites (Figure 1). This was equivalent to growth rates of 0.115, 0.107, 0.100, and 0.071 mm per day, respectively over the 1.5-year period (Table 1). Survival of scallops held for one year in the pearl nets was 89.4% and 87.0% and in benthic cages 23.2% and 66.0% for Johnson Cove and Treats Island, respectively (Figure 2). Survival of scallops held for eighteen months in the pearl nets was 72.7% and 63.9% and in benthic cages 28% and 32.0% for Johnson Cove and Treats Island, respectively (Figure 2). There was a substantial amount of fouling on the pearl nets prior to reducing stocking density and a number of sea stars (*Asterias* sp.) settled in the nets and cages.

The mean wet meat weight (adductor muscle) of the scallops held for one year in suspension was 4.1 g (SE = 0.11) and 3.3 g (SE = 0.09) for Johnson Cove and Treats Island, respectively (Figure 3). The corresponding meat weights for the

*Table 1.* Mean seasonal and overall daily growth rates for cultured sea scallops from two sites in north-eastern Maine.

| Growth Period | Johnson Cove | | | Treats Island | | |
|---|---|---|---|---|---|---|
| | Growth (mm) | # days | Growth rate (mm/d) | Growth (mm) | # days | Growth rate (mm/d) |
| Pearl nets | | | | | | |
| Aug'94-Dec'94 | 26.06 | 112 | 0.233 | 21.92 | 112 | 0.196 |
| Dec'94-Apr'95 | 7.07 | 142 | 0.050 | 6.78 | 142 | 0.048 |
| Apr'95-Aug'95 | 9.77 | 111 | 0.088 | 11.44 | 111 | 0.103 |
| Aug'95-Jan'96 | 16.67 | 155 | 0.108 | 15.33 | 152 | 0.101 |
| Aug'94-Jan'96 | 59.57 | 520 | 0.115 | 55.47 | 517 | 0.107 |
| Off-bottom cages | | | | | | |
| Aug'94-Jan'96 | 52.00 | 520 | 0.100 | 36.50 | 517 | 0.071 |

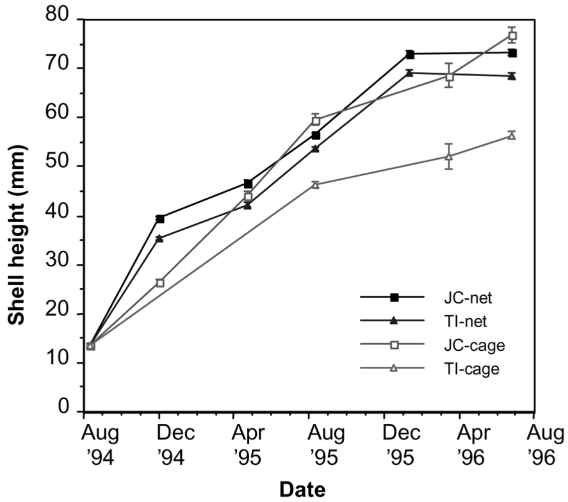


*Figure 1.* Growth of sea scallops grown in pearl nets and off-bottom cages at two sites in Maine (JC=Johnson Cove, TI=Treats Island). Error bars represent ± SE.

benthic cages were 3.8 g (SE = 0.24) and 2.6 g (SE = 0.14). The mean wet meat weight (adductor muscle) of the scallops held in suspension after eighteen months was 7.8 g (SE = 0.19) and 6.5 g (SE = 0.18) for Johnson Cove and Treats Island, respectively (Figure 3). The overall meat weight to shell height and total weight to shell height regressions were all significant for Johnson Cove and Treats Island, respectively (Table 2).

The percentage coverage of floor by scallops increased throughout the study period from an initial value of about 5% to 62% at the end of the study (Figure 4).

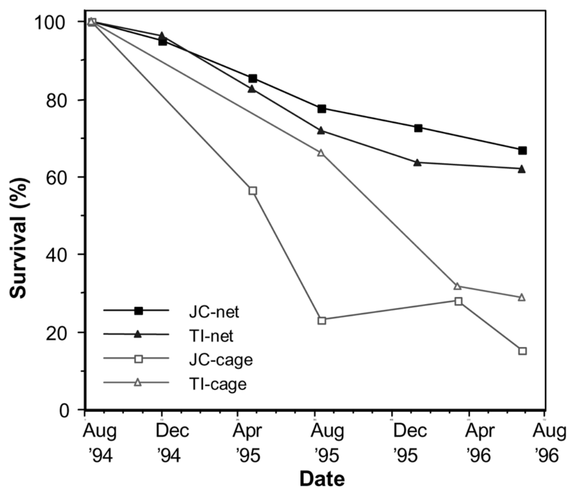


*Figure 2.* Survival of sea scallops grown in pearl nets and off-bottom cages at two sites in Maine (JC=Johnson Cove, TI=Treats Island). Error bars represent ± SE.

*Table 2.* Weight-shell height relationships for sea scallops grown in pearl nets and off-bottom cages at two sites in northeastern Maine (Tww = total wet weight, Mww = meat (adductor muscle) wet weight, Sh = shell height, N = sample size, P = probability level). Scallops of different sizes from over the study period were pooled for each treatment.

| Regression equation | Correlation (r) | N | P | Range (mm) |
|---|---|---|---|---|
| Johnson's Cove pearl nets | | | | |
| Ln Tww = 3.015 • Ln Sh − 9.359 | 0.984 | 1063 | < 0.001 | 18–95 |
| Ln Mww = 3.281 • Ln Sh − 12.130 | 0.970 | 1063 | < 0.001 | 18–95 |
| Johnson's Cove off-bottom cage | | | | |
| Ln Tww = 2.920 • Ln Sh − 9.082 | 0.993 | 92 | < 0.001 | 16–83 |
| Ln Mww = 2.944 • Ln Sh − 10.838 | 0.987 | 92 | < 0.001 | 16–83 |
| Treats Island pearl nets | | | | |
| Ln Tww = 2.988 • Ln Sh − 9.278 | 0.990 | 1022 | < 0.001 | 18–85 |
| Ln Mww = 3.474 • Ln Sh − 12.890 | 0.980 | 1022 | < 0.001 | 18–85 |
| Treats Island off-bottom cage | | | | |
| Ln Tww = 2.516 • Ln Sh − 7.230 | 0.957 | 67 | < 0.001 | 39–64 |
| Ln Mww = 2.286 • Ln Sh − 7.879 | 0.895 | 67 | < 0.001 | 39–64 |

Scallop growth ceased after 60% of the floor coverage was exceeded (cf. Figures 1 and 4).

Scallops were held in pearl nets, in a string of ten nets, and each net was spaced about 40 cm apart. Mean shell height and mean survival of scallops from each site on each sampling date were significantly different among pearl nets (or relative depth) (ANOVA, $p < 0.05$, all cases). There was, however, no consistent pattern in shell height with depth (or net position) at either the Johnson Cove site (Figure 5)

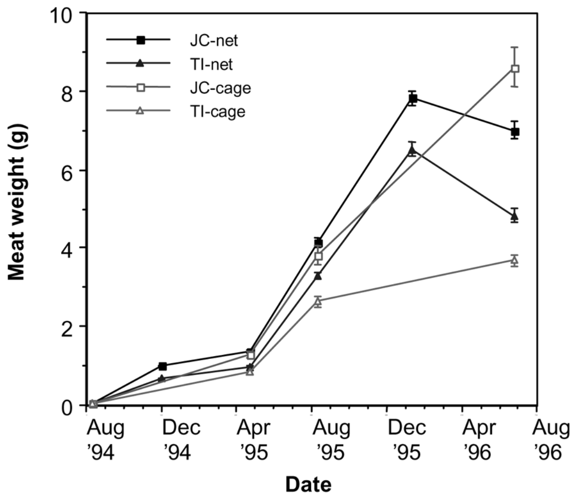


*Figure 3.* Meat weight of sea scallops grown in pearl nets and off-bottom cages at two sites in Maine (JC=Johnson Cove, TI=Treats Island). Error bars represent ± SE.

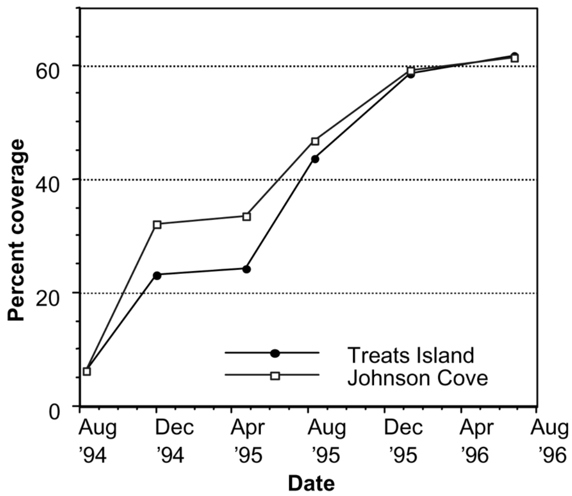


*Figure 4.* Percent coverage of floor space of sea scallops grown in pearl nets from two sites in Maine.

or the Treats Island site (Figure 6) and there was no consistent pattern in the survival at either site (Figures 7 and 8).

PSP toxins analysis showed that all samples of adductor muscles were < 40 $\mu$g STX equiv.·100 g tissue$^{-1}$ (Table 3). Samples of the remaining soft tissues obtained in April 1995 had a level of 51 $\mu$g STX equiv.·100 g tissue$^{-1}$ and 47 $\mu$g STX equiv.·100 g tissue$^{-1}$ for Johnson Cove and Treats Island, respectively (Table 3). The remaining soft tissues obtained in August 1995 had toxin concentrations of 1174 $\mu$g STX equiv.·100 g tissue$^{-1}$ and 824 $\mu$g STX equiv.·100 g tissue$^{-1}$, respectively. By the following year, the levels had dropped to < 40–82 $\mu$g STX equiv.·100

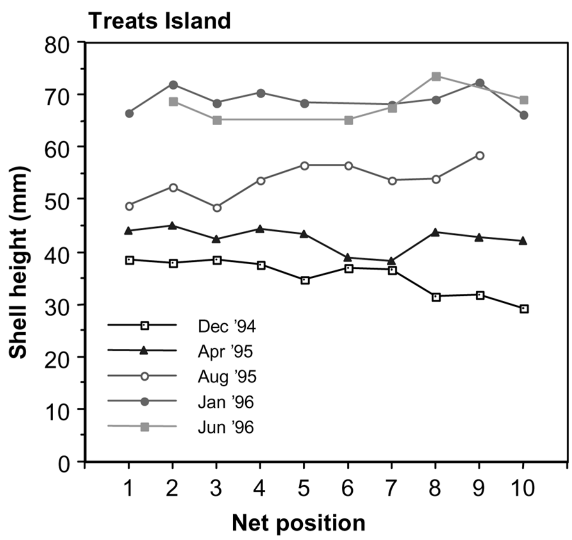


*Figure 5.* Shell height of sea scallops in pearl nets suspended at different depths at Treats Island site. Position 1 was at the top of the drop line.

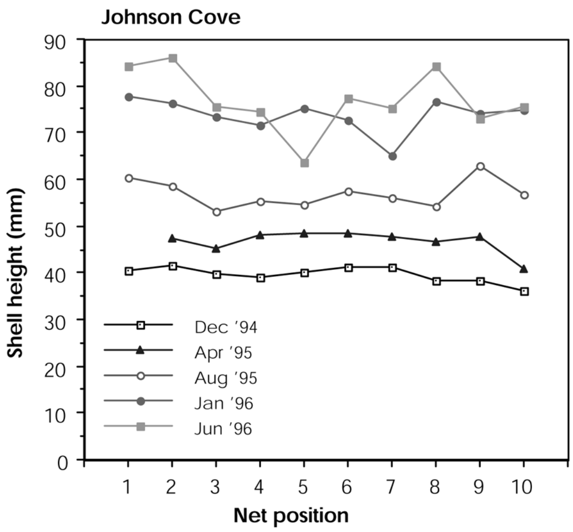


*Figure 6.* Shell height of sea scallops in pearl nets suspended at different depths at Johnson Cove site. Position 1 was at the top of the drop line.

g tissue$^{-1}$ for Treats Island and 295 $\mu$g STX equiv.·100 g tissue$^{-1}$ for Johnson Cove in March 1996 and to < 70 $\mu$g STX equiv.·100 g tissue$^{-1}$ by June 1996 at both sites. Domoic acid was suspected to be present in the March and June 1996 samples (Hurst, pers. comm.; based on mouse reactions to toxins).

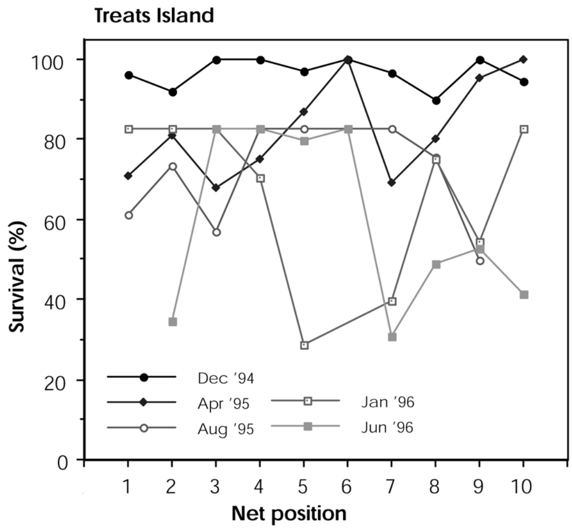


*Figure 7.* Survival of sea scallops in pearl nets suspended at different depths at Treats Island site. Position 1 was at the top of the drop line.

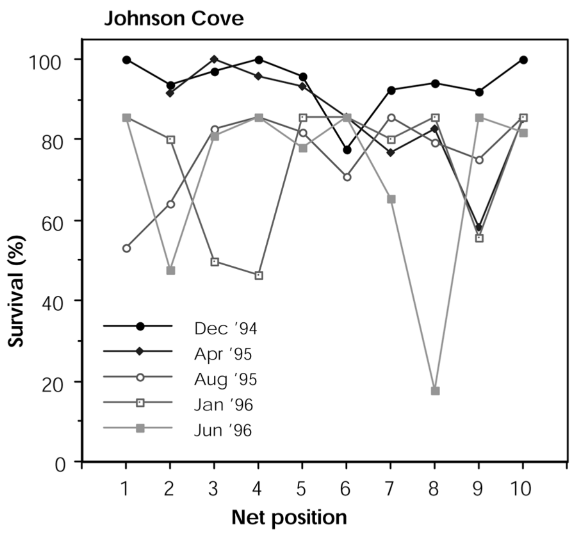


*Figure 8.* Survival of sea scallops in pearl nets suspended at different depths at Johnson Cove site. Position 1 was at the top of the drop line.

## Discussion

Growth, in shell height, of scallops held in suspension (pearl nets) was better than the benthic cages at Treats Island but comparable to growth of scallops in benthic cages at Johnson Cove. However, mean meat weight, meat weight in relation to

*Table 3.* PSP toxins levels in $\mu$g STX equiv.·100 g tissue$^{-1}$ (adductor muscle and remaining soft tissue) for sea scallops grown in suspension culture at two sites in northeastern Maine.

| Date | Treats Island | | Johnson Cove | |
|---|---|---|---|---|
| | Adductor muscle | Remaining soft tissue | Adductor muscle | Remaining soft tissue |
| April 1995 | < 40 | 47 | < 40 | 51 |
| August 1995 | < 40 | 824 | < 40 | 1174 |
| March 1996 | < 40 | 82, < 40 | < 40 | 295 |
| June 1996 | < 40 | 68 | < 40 | 69, 68 |

shell height and survival were lower in the benthic cages compared to the pearl nets. The one exception was the final meat weight sample from the bottom cage for Johnson Cove, where because of lower survival due to the presence of predators, the stocking density of the remaining scallops was low, hence growth was higher. Reduced growth and lower meat weight in relation to shell height in bottom grown sea scallops or ones grown lower in the water column compared to ones held in suspension has been previously reported (MacDonald 1986; Dadswell and Parsons 1991; Emerson et al. 1994; Grecian et al. 2000) but not in all cases (Kleinman et al. 1996). Reduced rates of growth and or survival at lower depths have been reported for other species of scallops (Duggan 1973; Wallace and Reinsnes 1984; Thorarinsdóttir 1994; Lodeiros et al. 1998). Differences in growth between scallops grown in suspension and those on the bottom (or lower in the water column) have been attributed to differences in temperature and food quantity and quality (MacDonald 1986; Emerson et al. 1994; Kleinman et al. 1996; Lodeiros et al. 1998). The lack of any consistent difference in scallop growth among the individual pearl nets with depth in this study was probably due to the restricted depth range of all the nets; all scallops were held in nets within 3 to 4 m of each other. Hence, there was probably no consistent difference in temperatures and food quantity and quality within these depths. However, even within this depth range, there was a high degree of variability in growth (Figure 5). The differences in growth rates between the two sites can be attributed to differences in the environmental conditions between the two sites, including fouling, especially given that the same source of seed was used at both sites.

Growth rates observed for scallops in intermediate culture over the study period were similar to results from other sea scallop growth studies conducted in the same area as this study (Passamaquoddy Bay and Quoddy region) (Dadswell and Parsons 1992; Parsons and Dadswell 1992; Parsons et al. 1993) and in other regions of Atlantic Canada (Côté et al. 1993; Kleinman et al. 1996; Grecian et al. 2000). Survival rates were lower than previously reported but were due probably to a combination of high stocking density, handling, predators and fouling, especially near the end of the study. As growth rates of scallops held on salmon aquaculture sites were comparable to sea scallops grown in suspension elsewhere in Atlantic Canada, this suggests that scallop growth was not hindered as a result of being near salmon cages. Likewise, scallop growth did not appear to be enhanced as a result of being placed adjacent to the salmon cages. This agrees with the findings of some studies on growth of bivalves in relation to fish farms, but not others (cf. Wallace (1980) and Jones and Iwama (1991), Taylor et al. (1992), Stirling and Okumus (1995)). The lack of an influence of nutrients from the salmon farms on enhancing scallop growth may be explained by the large tidal range, high currents, and well-mixed waters in the Quoddy region (Trites and Garrett 1983).

The logistics of hanging several strings of pearl nets (containing about 10,000 scallops) around the salmon cages was also successful. However, the availability of space and the logistics of growing larger numbers of scallops (e.g., >100,000–1,000,000 scallops) around a salmon cage site would be restricted and would require a larger space (lease) adjacent to a salmon cage than suspended directly from or around the cages. Concerns about growing bivalves in the vicinity of finfish have also been raised, especially in relation to incorporation of antibiotics and other chemicals related to salmon culture and the potential risk of disease transmission (Olafsen et al. 1993; Bjoershol et al. 1999; Nordtug et al. 1999). In Canada, the Canadian Shellfish Sanitation Program (CSSP) regulations require that shellfish must be raised at least 125 m away from finfish operations. Hence, an integrated scallop-fish farm operation would have to be on an expanded site or on separate but adjacent sites. These issues will have to be further studied in order to assess the actual risk to human, salmon and scallop health in relation the physical oceanography of aquaculture sites.

The first samples tested for PSP toxin levels in April 1995 were below the maximum allowable level of 80 $\mu$g STX equiv.·100 g tissue$^{-1}$ at both sites. Levels increased to >800 and >1100 $\mu$g STX equiv.·100 g tissue$^{-1}$ during the summer of 1995 and declined again to below 80 $\mu$g STX equiv.·100 g tissue$^{-1}$ by the following June 1996. The Passamaquoddy Bay and outer Quoddy region is an area where the toxic dinoflagellate *Alexandrium* sp. is known to occur seasonally, especially during the summer (Martin and White 1988; Wildish et al. 1990). PSP is generally not a health risk associated with sea scallop consumption as the adductor muscle (meat), a tissue which remains relatively free of toxins, is normally the only part of the scallop that is marketed and consumed in North America (Shumway and Cembella 1993). There is growing interest in culture and marketing of whole or 'roe-on' sea scallops in New England and Atlantic Canada. Since scallops store most of the toxins which cause PSP in their digestive gland, mantle and gonads (Jamieson and Chandler 1983; Shumway and Cembella 1993), the selling of whole or roe-on scallops would increase the risk of PSP to consumers and clearly a strict testing program for the presence of phycotoxins will have to be in place (Shumway et al. 1988). The rapid rise and subsequent detoxification of the PSP toxins in these cultured scallops suggests that there may be a window of opportunity for selling tested whole or roe-on scallops from areas known to experience *Alexandrium* blooms. Even lower levels of PSP were found in cultured scallops about 10 km away in northern Passamaquoddy Bay but levels were higher in scallops cultured in the outer Quoddy region (Robinson et al. 1999). The rate of detoxification of scallops from our study, which were grown in suspended culture, appears to be faster than rates reported for older wild scallops (Jamieson and Chandler 1983; Shumway and

Cembella 1993). Scallop culturists contemplating marketing whole or roe-on scallops from an area with a known occurrence of phycotoxins should base at least part of their production on meats-only, in order to sell product during periods when scallop viscera are too toxic to market.

The potential for supplemental income, diversification of the salmon aquaculture industry, and feasibility of culturing scallops at adjacent or expanded salmon operations does exist. While scallop growth was not hindered or enhanced in this study, the potential for integrating the culture of scallops and salmon in the same general area can be significant in the overall sustainability of the region. Scallops feeding on the particulate organic matter in the water column can potentially balance the outputs generated by fish farms.

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