THE SUITABILITY OF THE NORTHUMBERLAND COAST OF NOVA SCOTIA FOR THE CULTURE OF THE NORTHERN QUAHOG, *Mercenaria mercenaria*.

by

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The Suitability of the Northumberland Coast of Nova Scotia for the Culture of the Northern Quahog, *Mercenaria mercenaria*.

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Abstract

An investigation into the potential of *Mercenaria mercenaria* culture in the Northumberland Strait area of Nova Scotia was conducted, which included several important aspects which are relevant to the success of an aquaculture project. Areas considered were market potential, biology of the animal, environmental impacts, economic feasibility and potential obstacles specific to Nova Scotia including socio/political climate and human health considerations. Most of the factors proved to have negative implications regarding hard clam culture. Much of the suitable area in the Northumberland Strait is closed to shellfish harvest due to contamination, while a large proportion of rural Nova Scotians are strongly opposed to aquaculture development. Slow growth, high mortalities and low landed prices provide inadequate returns. Profitable operations are unlikely unless growth rates increase by 30% and landed prices are raised to over $15/kg. As the current price is less than $2.00/kg, such an increase seems highly unlikely. It was therefore concluded that *M. mercenaria* culture in Nova Scotia is not a viable industry.

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Introduction

The clam species *Mercenaria mercenaria*, commonly known as the northern quahog, bay quahog and northern hard clam has been cultured for several decades in the United States from the Gulf of Mexico to Maine. Cultured production of hard clams increased by 350 percent during the 1980s and was worth approximately $40 million (US) at the wholesale price in 1989 (Adams et al, 1993). The Nova Scotian quahog industry during this same time period was restricted to a commercial fishery and no significant development of aquaculture was undertaken. *Mercenaria* are not common in Canada as the colder waters of the Atlantic Provinces mark the northern limit of quahog distribution. Despite the limitations on distribution, there are localized populations throughout the Northumberland Strait which sustain a small commercial fishery. The reason that these populations are able to exist is because the Northumberland Strait which flows past the northern coast of Nova Scotia, as well as New Brunswick and Prince Edward Island carries water warmed in the St. Lawrence River which raises temperatures sufficiently for *Mercenaria* to reach commercial lengths (Dillon and Manzi, 1992) (see Appendix 1 for area map). Several reports in recent years (Carver and Mallet, 1991, Carver and Mallet, 1992 and Scarret, 1993) have provided evidence that the Northumberland coast of Nova Scotia has conditions which are suitable for quahog aquaculture based on the environmental and the biological potential of the animals. This project investigates the potential of quahog aquaculture along the Northumberland coast of Nova Scotia, but moves beyond the biological aspects and into environmental impacts, market and economic considerations as well as the socio/political climate of Nova Scotia.

Brief Overview of **Mercenaria** *Culture*

The first successful attempts at quahog rearing were in the 1920's with the work of William Firth Wells when he developed methods for concentrating clam larvae from sea water and growing them to commercial size. Despite his successes, there was very little interest in the culture of quahogs until the 1950's when Victor Loosanoff developed methods for the conditioning of broodstock for spawning, methods to prevent unwanted spawning, the use of thermal shock for spawn induction, the use of algae as a feed supplement and some disease control techniques. The successes of early operations were variable as hatcheries were plagued with technical problems and high costs which made them not economically viable. It was not until the 1980's when breakthroughs in nursery techniques for growing clams to the seedable sizes of 8-10 mm made quahog farming a truly viable proposition (Manzi and Castagna, 1989).

For the typical modern clam farmer, the operation really begins at the nursery stage. Most seed is supplied from hatcheries at a size of 3-4mm which means that they must be grown to 8-10mm before they can be seeded to the beach. They can be grown either in a land based system of flowing seawater in the form of a raceway, or upweller system or a field based nursery system. The land based raceway usually contains layers of trays with sand in the bottom of each tray. Raw seawater is pumped into one end of the raceway to create a horizontal flow of water past the seed clams. Upweller systems are similar in many respects to raceways, except that the flow is vertical through the seed clams. In an upweller system, cylindrical containers with mesh bottoms are placed into a larger reservoir and seed sized clams placed into the cylinder on top of the mesh. Field based systems may consist of trays or cages placed either subtidally or intertidally. Mesh coverings are necessary with these trays to allow for water to flow through while maintaining protection from predators. Other field based nurseries may include trays, or nets suspended from a raft or longline (Adams, et al.,1993)

The growout portion of an operation can take on many forms. Growout systems are necessary so that the clams can be as free from predators as possible while they grow to market size. Nets, pens and trays are the most common growout systems, although they may be highly variable in their form from one operation to the next. Pens are essentially a stationary rigid frame with a mesh covering, placed in the intertidal zone. The pen encases the clams, where they can burrow into the silt which accumulates within the structure. Harvesting is usually done by hand, rake or mechanical harvester. Trays are similar to cages as they are mostly rigid frames covered in mesh and placed in the intertidal or subtidal zone. The big difference is that trays are moveable and can be lifted up to allow for harvest. This may require a mechanical lifter. Net systems are the simplest of the three basic types. The nets are simply pulled over an area which has been seeded with clams and anchored to the bottom so that the clams can be protected from predators. Nets are the cheapest and least labor intensive although they may be more susceptible to predation and fouling than other growout systems (Adams, et al., 1993).

Each of these nursery and growout systems are evaluated in relation to their appropriateness to the Northumberland Strait of Nova Scotia in the Culture Techniques section of this report.

Aquaculture in Nova Scotia

In the economically depressed province of Nova Scotia, expansion of the industrial base is highly desirable so as to stimulate the economy and to increase long term employment. Aquaculture as a budding industry has been endorsed by the Nova Scotian government and is believed to be a potentially viable supplement to wild harvests of both finfish and shellfish. Production of aquaculture products in Canada has been steadily increasing over the last ten years and as of 1995 was responsible for 60,000 tonnes of production and $300 million in revenue. Aquaculture in Atlantic Canada makes up 38% of the industry as a whole but Atlantic shellfish culture contributes less than 3% of the revenue (Anonymous,1995). The small contribution of bivalves to the industry suggests that it may be underdeveloped and not keeping pace with salmonid culture. The potential of this field has only been superficially examined and much work needs to be done to develop species which may be able to contribute significantly to the Atlantic regions economy.

The only bivalve species in Atlantic Canada which is cultivated on a large scale is the mussel *Mytilus edulis*. Atlantic Canadian production of this species was worth $5.7 million in 1993 and is expected to be worth $20 million dollars in Atlantic Canada at the turn of the century. Clam aquaculture in Atlantic Canada has lagged far behind mussel culture with only a few pilot projects operating in 1996. It has been forecast, however, that 400 tonnes of clams will be farmed in Atlantic Canada by the year 2000, but there is little evidence to suggest that these projections will be met (Anonymous,1995). Due to the increases of Manila clam aquaculture on the Pacific Coast and the success of *Mercenaria* aquaculture in the United States, it seems that investigations into the viability of the clam aquaculture industry in Atlantic Canada should be pursued more vigorously.

The object of this report was to comprehensively investigate the potential of *Mercenaria* as an aquaculture species in Nova Scotia. Major aspects covered include market potential, the biology of the animal as it relates to Northumberland Strait waters, an assessment of the most appropriate culture techniques, environmental impacts and obstacles to aquaculture in Nova Scotia including sociopolitical considerations and human health concerns, the socio/political climate of Nova Scotia and the economic feasibility of a quahog operation.

Market Trends

Entrance to a new industry has inherent risks. The product in question must have a market which it can fill otherwise the venture is doomed before it starts. In the present study, the overall strength of the shellfish market is assessed through the export values of all shellfish products from Canada and how they compare to the values of finfish exports during the same time period. Following this, the Nova Scotia clam industry is examined and the ability of the existing market to absorb increased clam production is evaluated through a demand analysis.

Performance of Canadian Shellfish Industry

The value of Canada's shellfish exports have been steadily on the rise since 1968, yet the value of all finfish products combined has declined since the late 1980's (Figure 1). Although the total value for finfish has remained higher, total shellfish value is rapidly approaching that of finfish and may surpass it in the near future. Undoubtedly this enormous drop in total value of finfish has been the direct result of the collapse of the groundfish fisheries in Atlantic Canada. Shellfish exports in contrast, have continued to increase in total value, possibly the result of a shift from finfish to shellfish exploitation in the absence of a large groundfish fishery. This evidence suggests that the Canadian shellfish industry is strengthening while the finfish industry continues to decline.

Figure 1. Export values of shellfish and finfish products from Canada (1968-1994).

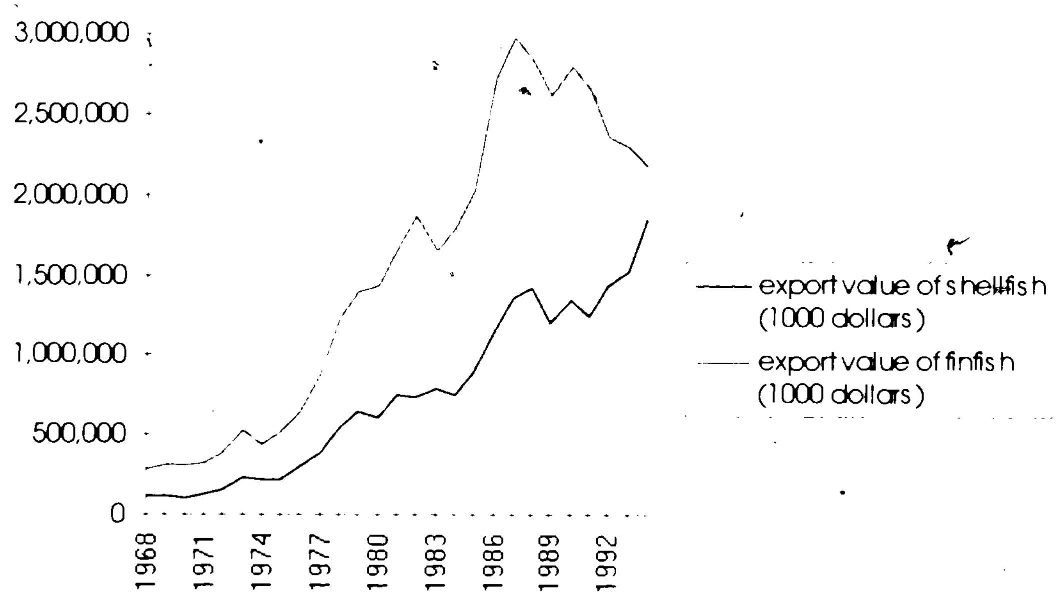

Table 1. Clam landings and landed value in Nova Scotia from 1985 to 1995 (value in 1994 Canadian dollars[1])

Year	Total MT	Total Landed Value	Value per Metric Ton
1985	1,498	2,112,419	1410
1986	1,968	3,400,614	1728
1987	2,614	2,607,724	998
1988	4,167	4,772,124	1145
1989	10,132	8,299,167	819
1990	10,627	10,574,813	995
1991	4,924	5,696,012	1157
1992	5,933	8,331,936	1404
1993	8,004	10,560,173	1319
1994	9,699	10,911,000	1125
1995	9,650	9,346,775	969

(data supplied by Nova Scotia Department of Fisheries, Marketing Division)

Nova Scotia clam industry

Clam landings in Nova Scotia more than doubled from 1988 (4,167 MT) to 1989 (10,132 MT) which coincided with the collapse of the groundfisheries of Atlantic Canada (Table 1) and in 1990 exports of clams started to increase as well. The increased value of Canadian shellfish exports as a whole is reflected in the total value of clams exported from Nova Scotia from 1988 to 1995. In 1988, these exports totaled just under $2.5 million compared to nearly $31 million in 1995 (Table 2). This represents an increase in value of over 1200%, while the exports have increased by only 800%. Despite this encouraging trend, clam landings appear to have peaked and the value per unit has been dropping since 1992 (Table 1). The rise in exports came in 1990 soon after the sudden increase in clam harvests. The higher production levels may have led to more of the product being shipped outside of Canada in search of new markets, or the increasing values per unit of clams may have encouraged processors to export more product (Table 2). The unit value of exported

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[1] All dollar values in this report are expressed in 1994 Canadian dollars.

clams is up to ten times higher that for the landed value. Although it is highly unusual for the difference in value to be so high, it may be accounted for if higher value and higher quality clams are exported, while the low value clams are kept within the local market. Peaked natural harvests and increasing values of exported clams are good indications that the market potential for a clam aquaculture operation is strong.

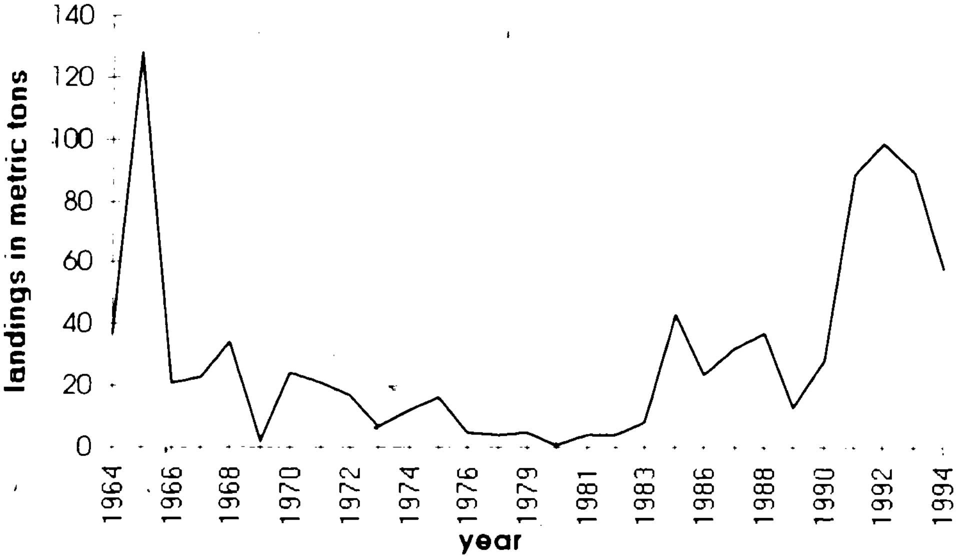
Table 2. Volume, value and percentage of clams exported from Nova Scotia.

year	weight (MT)	Value (1994 dollars)	Percent exported	value/MT
1988	231	2,486,874	5.5	10,754
1989	513	4,403,153	5.1	8,580
1990	1,354	13,336,020	12.7	9,843
1991	942	9,057,608	19.1	9,620
1992	1,188	11,392,189	20.0	9,586
1993	772	7,780,576	9.6	10,075
1994	2,116	24,010,893	21.8	11,349
1995	1,938	30,570,491	20.1	15,778

(data supplied by Nova Scotia Department of Fisheries, Marketing Division)

While clam exports from Nova Scotia have been increasing, *Mercenaria* harvests have decreased since the early 1990's (Figure 2). The decline in harvests is not likely due to a weak market for quahogs. In fact, the 1995 price for hard clams was $1622/MT (Table 3) compared to average value of all other clam species which was $969/MT (Table 1). Why harvests have been decreasing is unclear, but fewer available fishing grounds due to contamination closures and reduced stocks caused by overfishing are the most likely reasons for the declining harvest.

Figure 2. Quahog landings in Nova Scotia (1964-1994)



(data supplied by Nova Scotia Department of Fisheries)

Demand for Nova Scotia Clams

Although, hard clams make up only 1% of the clam harvests in Nova Scotia, one cannot assume that such a low market share ensures that there is room for expansion, as increases in production may depress prices (Copps, et al, 1989). In the late 1980's, as mussel production from Prince Edward Island increased, traditional markets (mainly consisting of local restaurants) became saturated, forcing some culturists to postpone harvests while waiting for a buyer. Although the problem in Prince Edward Island was corrected through aggressive marketing techniques (Koole, 1989), a clam farming facility in Nova Scotia may be subject to the same market limitations faced by the Prince Edward Island mussel growers.

Observing the trends in the market is not sufficient to determine whether or not the demand is sufficient to justify investing in a new operation. A demand curve for the landed price of clams was therefore constructed and included three factors, quantity, price of exported clams and price of imported clams. The quantity of clams harvested (Table 1) was included, to test if increases in output suppress price significantly, while the price of all exported clams (Table 2) was included to test for the impacts of changing foreign prices on landed price. Finally, the price of imported clams (Table 4) was included to see what effects a substitute has on the landed price of clams in Nova Scotia.

Demand was examined from the producers point of view. Therefore, the landed price was regressed on quantity, the price of exports and the price of imports, all of which may exhibit influence on the variability of the landed price of clams. Linear regression was applied to the data from 1989 to 1995. A regression of landed price on quantity was significant (t-value = 2.40, $p<0.1$) with an R^2 of 0.48. A multiple linear regression of landed price on quantity and the price of imports improved the R^2 to 0.64, but it was not significant (F_s=3.534, p>0.25). An additional multiple linear regression of landed price on quantity, price of imports and price of exports was also not significant (F_s=1.78, p>0.25). These results may have been insignificant due to the small sample size. As only quantity proved significant, a linear regression was applied to landed price and quantity from 1985 to 1995. This was significant (t-value=2.4, p<0.05) with an R^2 of 0.39. The regression equation for demand of Nova Scotia clams was;

$P = -0.0465\ x + 1480$

P = landed price (1994 \$Can/mt)
x = quantity (mt of clams)

Due to the low R^2 value and the insignificance of export and import prices, there are likely other factors which influence clam prices. In fact, hard clam landings in the U.S. were found not to impact exvessel price as much as disposable income of consumers and shellfish poisoning outbreaks (Copps, et al, 1989). Market impacts due to contamination are well documented in the shellfish industry, especially in the oyster industry where PSP outbreaks cause seasonal depressions in demand. Such outbreaks have caused market reductions as high as 100% as was the case in August, 1980 in California. Although most of the product available was safe for human consumption, public perception was that all of the product was unsafe (Conte, 1984). Public perceptions of safety risks may be influencing clam demand in Nova Scotia, just as markets in the United States have demonstrated.

The price elasticity of demand (PED) was calculated from the price/quantity regression at the sample mean and revealed a PED of 44.46. This PED indicates that a 1% change in price causes a 311.3% change in the quantity of clams demanded, meaning that Nova Scotia clam demand is highly elastic. In this case, however, the demand is probably quantity driven and not price driven, which means that large changes in the amount of clams harvested has little impact on the landed price. This matches the results found by

Copps, et al (1989). Due to the high elasticity of the demand it appears that increased production is likely to be absorbed by the processors without impacting the landed price.

Table 3. Landed Values of Quahogs From the Southern Gulf of St. Lawrence Area and value per metric ton of Nova Scotia quahogs (1994 Canadian Dollars).

year	NS	NB	PEI	Total	value/metric ton
1985	46	143	570	759	1,393
1986	22	602	453	1077	1,180
1987	41	764	847	1651	1,490
1988	43	527	686	1256	1,352
1989	12	277	1430	1719	1,060
1990	32	304	1284	1620	1,225
1991	99	668	950	1716	1,135
1992	120	378	820	1318	1,244
1993	86	375	813	1274	975
1994	102	234	1108	1443	1,766
1995*	82	138	945	1165	1,611

(data provided by Thomas Sephton, DFO Science Branch, Maritimes Region Aquaculture Division, Gulf Fisheries Centre)

Table 4. Quantity and value of clams imported into Nova Scotia from 1989 to 1995.

year	MT	Value (1994 $Can)	value/MT
1989	342	1,249,694	3,659
1990	310	1,076,024	3,466
1991	99	319,767	3,245
1992	701	2,361,782	3,370
1993	413	113,709	275
1994	271	950,770	3,508
1995	254	869,959	3,425

(data supplied by Nova Scotia Department of Fisheries, Marketing Division)

Conclusions

The value of Canadian exports of shellfish products have been growing strongly when compared to the export value of finfish products since the late 1980's. This indicates that Canadian shellfish are highly marketable as exports, which is reflected by the increasing exports of Nova Scotia clams. The decreasing landings which have been experienced this decade show that the supply is dropping, and therefore, a gap is developing. As demand appears to be elastic in relation to quantity, the potential to sell cultured clams should be high and without fear of price reduction, so long as outside factors such as contamination outbreaks remain low. The combination of weak and uncertain supply with elastic demand make for a favorable climate in which to begin a *Mercenaria* culturing facility.

Biology of *Mercenaria mercenaria*

Suitability of an organism for aquaculture depends on an number of biological factors. Species averse to high densities, and handling are prone to slow growth and low survival. The following sections discuss various aspects of quahog biology as they pertain to the culture of these animals. Areas of discussion are behavior, growth and Mortality.

Mercenaria Behavior

A number of behavioral features of quahogs are important and have significant relevance to the culture of this species. Quahogs generally burrow 2-10 cm into the sediment (Krauter and Castagna, 1989) but in the Northumberland area of Nova Scotia they are found at depths up to 15 cm (Witherspoon, 1984). Shallow burrowers such as quahogs are more desirable as a commercial clams species due to the decreased digging effort which is required for harvest. Some deep burrowers with high market value such as *Cyrtopleura costata* have been excluded from aquaculture development because of their deep burrowing behavior (Gustafson, et al., 1991)

Quahog shelf-life makes it a desirable product to the processor and wholesaler. When hard clams are removed from the substrate, they will seal tight for a number of weeks. Quahogs have been kept out of the water for as long as 59 days and shipments may be held for 15 days before any mortalities are experienced. The southern quahog, *M. campechiensis*, may suffer up to 80% mortality after 15 days if kept under identical conditions (Menzel, 1989).

Growth and Mortality

Attempts to grow quahogs on Prince Edward Island from 1977 to 1981 proved for the most part to be unsuccessful. The reason for this lack of success was the high variability of growth and mortality rates (Burleigh, 1988). These unpredictable growth and mortality rates which are experienced in the Northumberland Strait make it critical that the reasons for the high variability be investigated. Through such an investigation, more reasonable estimates of growth and mortality may be obtained, therefore allowing for more accurate forecasting of yields and revenue.

Growth of *Mercenaria* to market size is highly dependent on geographic location. The warmer waters of the southern United States allow for growth rates which are much higher than those observed in the Northumberland Strait. In Florida, hard clams can be marketable (50mm) in as little as 2 years compared to an average of 5-6 years in Canada (Menzel, 1989). Although the average time to market is estimated at 5-6 years in Canada, this rate is highly variable and dependent on location ., The time required to reach harvestable clam lengths of 50 mm in the Northumberland Strait area of Nova Scotia has been estimated to be an average of 6 years by Witherspoon (1984). Landry et al. (1993) reported that quahog growth in the Strait is highly variable and very slow, requiring 9 to 13 years depending on the site to reach 50mm.

Quahog survival rates can be as varied as growth rates and also dependent on location and as well as growout methods. In Virginia, survival of quahogs during the 2 to 3 year growout period can be expected to be 70% (Castagna, 1984). To expect such high survival rates in Canada is unrealistic due to the high levels of mortality generally experienced during the winter months (Bourne, 1989). Witherspoon (1984), experienced dismal survival rates of 0.56% and 4.93% for plantings of 1mm seed, while reciprocal transfers of adult quahogs (38mm-40mm shell length[2]) on Prince Edward Island had

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[2] Shell length refers to the length of the shell between the two points farthest apart.

mortality rates of 53.3% and 24% only 6 months after being transplanted (Landry et al., 1993). Although the reasons for the high mortality rates of these two situations are not known, handling procedures, harsh conditions (winter freezing) and high predation rates may have all contributed. The long growout period of 6 years in Canada compared to 2-3 years in the southern United States may compound the problem by exposing the clams to potentially lethal conditions for a much longer time before they are harvestable.

The following sections discuss various factors which contribute to the variability of growth and mortality rates which were noted above. The factors of greatest concern are water temperature, water chemistry (salinity and dissolved oxygen), sediment characteristics, and the biological factors of feed availability and competition. Each of these factors is discussed in the context of the Northumberland Coast of Nova Scotia. In addition, explanations for the determination of growth and mortality rates are provided.

Water Temperature

Mercenaria are capable of growing at temperatures ranging between 8-28 °C (Castagna and Krauter, 1981). Burying activity stops when temperatures dip below 10°C, (Malouf and Bricelj, 1989), while at temperatures below 8 °C there is a cessation of pumping, at which point growth cannot occur. Further cooling to 5-6 °C induces a state of hibernation (Menzel, 1989). Above 8 °C, when growth is possible, the rates of growth are highly dependent on the temperature. At low temperatures of 10 °C, 1 year old quahogs will grow at a rate of approximately 20 µm/day while at 18 °C quahogs will grow at a rate of 100 µm/day. Five year old quahogs show similar growth improvements with increased temperatures, growing at a rate of 1 µm/day at 10 °C and 50 µm/day at 18 °C (measurement referred to is shell length) (Hibbert, 1977). Optimal temperature for quahog growth is 23

°C, beyond which growth becomes increasingly inhibited (Malouf and Bricelj, 1989). Northumberland Strait temperatures typically don't rise beyond 25 °C (Witherspoon, 1984) and have an average maximum temperature of 17 °C (Figure 3)[3]. Temperatures in the Northumberland Strait are closest to the optimal growth temperature during July, August and September.

An important factor to think about when growing clams in the natural environment is growing season. The growing season is the period of each year during which temperatures are in a range that allows for growth of the animals. When average spring temperatures rise above the 8-10 °C range (when quahog growth is possible) the growing season can be said to have begun. Likewise, when the average temperatures are less than 8-10 °C in the late fall, the growing season may be said to be over. The Northumberland Strait growing season generally begins around May to June and ends in late October to November (Figure 3). Oceanographic data collected by Carver and Mallet (1991 and 1992) for studies on quahog culture strategies in the Northumberland Strait, indicated that the length of the growing season can vary from year to year at a given location. In 1990, the growing season at Chance Harbor, Nova Scotia extended into late October and early November, while in 1991, the growing season ended in early October. Due to these variations in the length of the growing season, unpredictable growth rates can be expected.

Quahog mortality rates, like growth rates are, highly affected by temperature. Although they are able to withstand low temperatures below freezing as well as high temperatures greater than 34 °C for brief periods, (Castagna and Kraeuter, 1981) the

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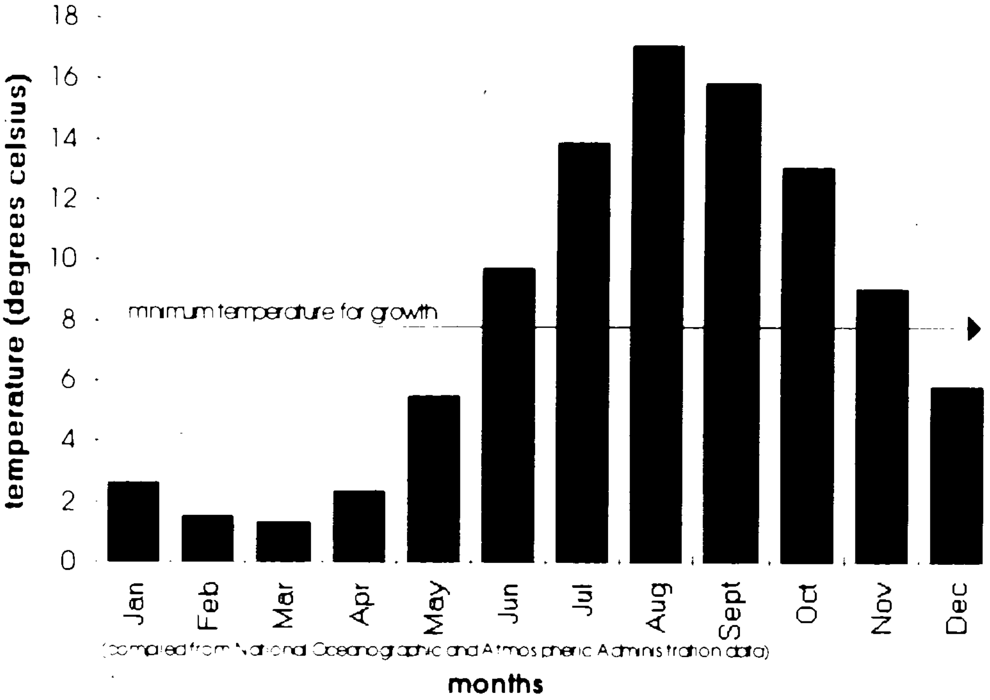
[3] Oceanographic data supplied by NOAA. Data is an average from 1982-1995.

prolonged and persistent cold temperatures in Canada which last for up to five months of the year take their toll on hard clams. Cold winter temperatures when compounded with ice mortalities from scouring have been known to kill up to 100% of planted clams during one winter season (Scarret, 1993, Carver and Mallet, 1992, Burleigh, 1988).

Figure 3. Average monthly water temperatures from the Northumberland Strait.



(compiled from National Oceanographic and Atmospheric Administration data)

Salinity

Preferred salinities of hard clams range between 20 and 30 parts per thousand (ppt) (Menzel, 1989). This matches with the ranges recorded in Northumberland Strait which are typically between 20 and 30 ppt (Landry et al, 1993 and Witherspoon, 1984). Quahogs will continue to filter water at salinities down to 15 ppt. This gives quahog farmers an advantage over oyster farmers as 15 ppt is lethal to most oysters. Salinity levels below this however, are stressful to *Mercenaria* and may be fatal if levels lower than 10 ppt are experienced for extended periods (Menzel, 1989). Low salinity areas or areas which are subject to freshets should be avoided when selecting potential sites for hard clam culture.

Dissolved Oxygen and Anoxic conditions

In areas subject to seasonal hypoxia, tolerance to low levels of dissolved oxygen (DO) is of concern. Low oxygen may asphyxiate the clams and along with reduced DO comes increased hydrogen sulfide production from sulfate reducing bacteria. Hydrogen sulfide is toxic and may compound the effects of the low DO. Hard clams are quite resistant to hypoxic conditions and are able to tolerate DO levels as low as 0.9 mg/l. Conditions of hypoxia are generally experienced in the warmer waters of the southern United States (Malouf and Bricelj, 1989).

Effect of Sediment Characteristics on Growth

Little work has been done to determine which sediments are best for hard clam growth although it is believed that clams grow better in sandy substrate than mud (Malouf and Bricelj, 1989). There is a lot of contradictory evidence pertaining to the effects of substrate type on growth. *Mercenaria* in Prince Edward Island were found to grow better in sediments with higher silt/clay component and higher total organic component (Landry et al , 1993). This may be explained by the fact that many bivalves show improved growth rates if silt is suspended in the water column. *Mercenaria* however, do not exhibit this growth improvement and show decreased growth if the silt content reaches 44 mg/l. This growth inhibition is likely due to increased sedimentation rate and pseudofeces production (Malouf and Bricelj, 1989). These contradictory findings make it difficult to determine exactly how sediments effect the growth of quahogs. Concerns have been raised as to how increasing silt runoff from agricultural operations in Nova Scotia will affect bivalves (Witherspoon, 1984) and should be investigated further.

Plankton Levels

Levels of plankton have direct impacts on the growth rates of bivalves. The concentration of cells which is necessary for maximal growth in juvenile *Mercenaria mercenaria* is 25 cells/µl of the algae *Pseudoisochrysis tricornutam*. Maximum growth of *M. campechiensis* adults was measured at similar concentrations (25-60 cells/µl) of *Isochrysis* (Malouf and Bricelj, 1989). Areas of higher chlorophyll *a* concentrations in P.E.I. have been correlated to higher growth rates as well (Landry et al,1993). Algal blooms however, are not necessarily site specific and often differ from year to year at any given site. In 1991, chlorophyll estimates at Melmerby, Nova Scotia, were less than 5 µg/l from June to early August, which were much lower than 1990 estimates of 14.6-25.9 µg/l for the same time period (Carver and Mallet, 1992).

Chlorophyll *a* measurements do not have a lot of meaning by themselves. To make them more useful, one may convert these estimates of chlorophyll into cell concentrations. To estimate what the cells concentrations at a typical site in the Northumberland Strait might be like an average estimate from Pownal Bay, P.E.I was used from Landry et al (1993). The estimate was 1.01ug of chl *a*/l which is a relatively low value for the area. Assuming that these chlorophyll estimates were taken from a bloom consisting of several species of phytoplankton, one may estimate the concentration of algal cells based on the method outlined in Strickland (1966). This conversion indicates that even the low estimate of 1.01µg/l has a concentration of 30 cells/µl which falls into the range which is acceptable for quahog growth.

Density and Competition

Density and competition are very similar considerations as they both relate to the effects of crowding and competition, be it interspecific or intraspecific. In order to achieve optimal growth and survival, one must investigate the problems of density and competition so that proper husbandry practices may implemented.

Density must be considered from the nursery phase through to the growout phase. Stocking density experiments in an upweller nursery showed that densities of up to 12,440 clams /upweller (4.4mm seed) showed little growth suppression when compared to 6,200 clams /upweller. 7.4 mm seed at densities of 6,500 clams /upweller and 9,790 clams/upweller did not show different growth rates (an upweller unit has approximately 0.2 m^2 of surface area for clams) (Summerson et al, 1995). Carver and Mallet (1991) stocked upwellers with 4,400 to 19,000 clams/unit (4.3mm size at beginning) and found that there was growth suppression only at densities above 13,500 clams/unit which supports the findings of Summerson et al (1995). Although growth suppression has been measured at densities above 13,000/upwelling unit, clams are still able to reach seedable size (8-10mm) within 3 months at densities higher than that (Carver and Mallet, 1991, Summerson et al, 1995). Carver and Mallet (1992) found that if larger seed of 13 mm shell length are kept in an upweller unit, growth suppression is observed at a density of 4,000/upweller unit.

In addition to the suppression effects caused by overcrowding of clams in the upweller units, fouling organisms which often invade via seawater systems may also suppress growth. Fouling organisms such as tunicates (*Molgula*), mussels, and marine worms may enter into a hatchery or nursery in larval form and become competitors for space and food, or predators on the clams (Castagna, 1984, Gibbons and Blogoslawski, 1989). If fouling becomes a problem, then treatment of the water may become a necessity to kill any potential invaders.

Beach planted clams show density dependent growth as well, although the densities at which growth is affected are much lower. Eversole, et al (1990) found that the highest growth rates of beach planted seed were achieved at 290 clams /m^2 when compared to 869/m^2 and 1,159/m^2 at a starting shell length of 13mm. As previously discussed, growth rate is highly site specific but optimal planting density of quahogs is generally in the range of 250 to 1000/m ^{2}, depending on the site (Castagna, 1984).

Growth suppression is for the most part the result of food limitation. As bivalves grow, their food requirements increase geometrically (Castagna, 1984). If food levels are sufficiently low, there is competition for this resource and growth rates decrease. Under conditions of high density where there is food competition, quahogs less than 5 mm in length migrate to a less crowded area. This was demonstrated by Ahn et al (1993). They found that juvenile quahogs when in the presence of a high density competitor (gem clams at a density of 5 to 6 gem clams/cm^2), migrated more readily with low algal cell concentrations than high algal cell concentrations. This indicates that the presence of competitors has stressful effects on quahogs, especially in food limited situations. If stocking densities are too high, then the clams may migrate out of the plot site and be lost from future harvests. In addition to growth suppression and emigration, mortalities may increase by as much as 15% with excessive competition (Ahn, et al. 1993).

Although food limitation caused by crowding and competition may be the main reason for suppressed growth, space competition may also be a problem. Deposit feeders for example can be competitors for space with clams. Turbation of the substrate potentially increases the mortality and reduces growth rates of clams by interrupting feeding and increasing exposure time to predators. Constant turbation of the sediment also forces clams to spend more time digging and reorienting than feeding (Malouf and Bricelj, 1989).

Possible competitors of quahogs commonly found on the Northumberland coast are surf clams (*Spisula solidissima*) in the subtidal zone, razor clams (*Ensis directis*) in the sandy mud in both the intertidal and subtidal zones, especially in sheltered bays, and soft-shelled clams (*Mya arenaria*) in the upper part of the intertidal zone in sand and gravel substrates (Witherspoon, 1984). Each of these are potential competitors, as hard clams have wide distributions throughout the subtidal and intertidal zones (Walker and Heffernan, 1994) which puts them in the proximity of all of these species.

Growth related to shore level

Shore level has a direct impact on the growth rate of quahogs in the intertidal zone. Wild populations tend to be smaller in the upper intertidal zones when compared to others of the same cohort in the lower intertidal zones (Walker and Heffernan, 1994). Similarly, seeded quahogs in Georgia with an initial mean shell length of 19.5 mm grew to a mean length of 58 mm after 15 months when planted at the spring low water level (SLW[4]), which was 10mm longer than those planted at the mean low water level (MLW[5]). The same experiment showed that clams planted at higher shore levels were approximately 44 mm, and significantly smaller than the clams at SLW and MLW (Walker and Heffernan, 1990). This indicates that the low intertidal zone produces the best growth rates within the intertidal, while the difference is less pronounced for clams grown at upper tide levels. Reasons for the differences in growth at the various tidal heights may be, increased stress due to more exposure time, less feeding time, and substrate differences (Walker and Heffernan, 1994).

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[4] Spring Low Water refers to the period during the lunar cycle when tides have their lowest point.

[5] Mean Low Water refers to the average level of all low tides.

Results concerning growth rates in the subtidal zone however, are inconsistent. In Nova Scotia, average sizes of clams of the same age in the subtidal were demonstrated to be 13% to 40% larger than intertidal clams in the same area (Witherspoon, 1984). Eversol et al (1990) on the other hand, found that subtidal plantings did not grow significantly faster, as did Walker and Heffernan (1990). Both speculated that excessive fouling of subtidal cages may offset the advantages of a subtidal location.

Seagrass beds (*Zostera*) which are located in the subtidal zone may be a factor which contributes to the growth and mortality rates which are shown by quahogs. Subtidal populations of quahogs associated with seagrass beds have increased growth rates, likely due to the baffling effect of the blades. The baffling effect decreases localized water flow by up to 50%. Decreased flow allows for more efficient filtration and increases the rate at which phytoplankton deposits to the sediment, thereby increasing the amount of food in the proximity of the clams, allowing for more feed to be ingested (Peterson et al, 1984). Witherspoon (1984) however, claimed that the proliferation of eel grass in Nova Scotia coincided with the reduction of suitable quahog habitat, although there was no statistical evidence to prove this assertion. Survival rates in the subtidal zone may be higher for hard clams that are located in seagrass beds as well. Sea grasses apparently make detection and extraction of quahogs more difficult for some predators, therefore providing a refuge for the clams (Irlandi, 1994).

Northumberland Strait tidal ranges are characteristically narrow, between 2-3m (Landry et al, 1993 and Witherspoon, 1984), and as low as 0.5-1m in enclosed inlets such as Chance Harbor Nova Scotia (Carver and Mallet, 1992). The narrow tide range combined with the steep slopes of the beaches (Pers obs.) in this area limit the amount of space available for the culture of quahogs in the intertidal zone. Unless an extensive mud flat can be acquired, subtidal culture of *Mercenaria* may be a necessity.

Although predation on quahogs in sea grass beds may be lower, there is very little evidence that the level of the shore at which quahogs are planted has any effect on mortality. Walker and Heffernan (1994) in a study in Georgia found that tidal height of the plantings did not effect mortality.

Diseases

A number of diseases are known to affect the growth and mortality of bivalves, although few epizootics of shellfish have occurred on the east coast. The possible reason for this is that the open system used for bivalve culture reduces the chance of infection (McGladdery and Stephenson, 1991). Despite low levels of disease outbreaks, one must be aware of the disease threats facing potential quahog facilities. Of particular concern are operations which have a land based component, as diseases are more likely to spread through an intensive system.

Several bacterial species have been problematic in land based nurseries and hatcheries. The species of greatest concern are *Vibrio alginolyticus, V. anguillarum* (Elston, 1984), *Pseudomonas* spp., and *Aeromonas* spp. (Gibbons and Blogoslawski, 1989). especially in systems which lack substrate for the clams to burrow into (Krauter and Castagna, 1989). Bacterial diseases can be recognized by gaping shells, empty shells, black spots on the shells and slimy mud among the clams (Castagna, 1984). Bacteria which proliferate in hatchery and nursery systems need to be monitored closely, as the transfer of broodstock and seed to other facilities may also transfer pathogens. This may cause disease outbreaks at other hatcheries, nurseries or growout sites, thereby impacting cultured and possibly wild stocks (Gibbons and Blogoslawski, 1989).

Parasitic organisms have been known to cause severe losses of clams in several instances. Parasitic copepods which have been identified in hard clams are *Mytilicola porrecta*, *Myocheres major* and *Ostrincola* spp. Copepods do not often kill clams directly but have deleterious effects on the physiology of clams which makes them susceptible to secondary infections. Mass mortalities of the Chinese hard clam *Meretrix meretrix* have been observed due to this effect (Ho and Zheng, 1994). *Tylocephalum* spp. cestodes which cause stress and decrease meat quality in clams have also been identified. Fungi are often responsible for mass mortalities of larvae but are not as harmful to juveniles and adults (Gibbons and Blogoslawski, 1989).

Tumors or neoplasms are often found in quahogs, although the causes are not quite clear. Neoplasms have been found in 2% of Chesapeake Bay clams in the gonads, red gland, heart and in the genital pore of females (Gibbons and Blogoslawski, 1989). Gonadal neoplasia, appears to have a biphasal cycle with peaks in May to July and September to October. Gonadal neoplasms are not necessarily fatal or even growth limiting, yet there is potential that these tumors may invade other tissues within the clam and cause death (Eversole and Heffernan, 1995). Hybrids of *M. mercenaria* and *M. campechiensis* are more susceptible to these neoplasms than non-hybrid quahogs. Natural populations of hybrids have been shown to have up to 22% infection rates while pure lines under the same conditions exhibit 6-12 % infection rates (Bert et al., 1993). The cause of increased presence of neoplasms in hybrids is uncertain. One theory is that tumor suppresser genes produce unrecognizable signals in hybrids which allows the tumors to grow, uninhibited (Bert et al., 1993).

Another disease which may arise in a land based nursery or hatchery is 'air bubble disease'. This disease is caused by the supersaturation of water which is often caused by improperly set up seawater systems. Poorly sealed pipes suck air in to the pipes through the cracks which supersaturates the water. In systems where heated water is used, supersaturation is a danger because cool water with dissolved gas content can easily become supersaturated during the heating process. 'Air bubble disease' arises when supersaturated water is ingested by the clams. The excess gases come out of solution and cause blistering of the flesh, which may be followed by death (Castagna and Kraeuter, 1981).

Currently, an unknown disease is causing severe *Mercenaria* mortalities in Massachusetts (Anonymous, 1996c). Similar die offs were experienced in Nova Scotia and New Brunswick in 1915 and 1954 (Witherspoon, 1984). It is not known what causes these periodic mass mortalities or if there are even caused by the same disease. This current outbreak will have to be monitored and researched more closely to determine if it will continue to be a threat.

Harvesting Mortalities

During the process of harvesting, shell breakage and subsequent stresses cause mortalities of clams. In a study by Creaser and Packard (1993), *Mya arenaria* harvested for depuration[6] had an average of 4.75% breakage before and after depuration, yet the ranges in breakage ranged from 18.75% to 1.59% throughout a harvesting season. Such high breakage rates are not to be expected with quahogs as their shells are much thicker than *Mya*, but if traditional methods of harvest which include rakes and shovels are used, quahogs will also show harvest mortalities. Mortalities caused by harvest tools can likely be more easily avoided if a tray system is utilized. The use of trays allows for easier access to the clams without the need for digging tools which can break shells.

Predation

Predation is potentially the greatest threat to survival in clam culture and if not dealt with effectively can result in severe losses of stock and revenue. Marine bivalves, especially those located in the intertidal zone are exposed to predators of many types throughout the tidal cycle. The most common predators are crustaceans, birds, fish,

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[6] Depuration is the process where bivalves which are mildly contaminated by bacteria are placed in land based tanks with treated sea water. This allows for the animals to eliminate bacteria from their gut, thereby reducing bacteria to levels which are safe for human consumption.

mollusks and echinoderms. Most of these predators are size selective in their strategy of feeding, with effort being concentrated on juvenile clams (less than 25mm) and larger clams of 40 mm or more. Clams within the 25mm to 40mm size range are less subject to predation (Hibbert, 1977). Some predators can exert enough selective feeding pressure on a bivalve population to cause a shift in the size distribution (Martin and Corkum, 1994, Seed and Hughes, 1995). Some species of crabs will concentrate foraging effort in areas with the highest densities of prey as described in Seed and Hughes (1995), which makes a clam growout operation a prime feeding ground and likely to attract predators.

Crustaceans, especially crabs pose a great threat to juvenile clams shortly after seeding as their preference is for 2-10 mm clams (Stelik, 1993). Some crabs are able to eat as many as 300 small clams per day, and will dig up to 19 cm into the substrate to reach their prey (Gibbons and Blogoslawski, 1989). Due to the costs associated with digging for infaunal prey species, it is likely that *Mercenaria* are less susceptible to size selection although there is evidence that digging crabs have size preferences. The blue crab (*Callinectes sapidus*), for example, when tested for size preferences of *M. mercenaria* in various substrates, selected clams of a size relative to their own body size. The maximum size of quahogs taken overall was 40mm in shell length. This suggests that as clams reach a length of 40 mm there is a size refuge from predation by blue crabs (Arnold, 1984). Clams are safe from most other crustaceans however, when they reach a length of 18-20 mm (Krauter and Castagna, 1989).

In Nova Scotia, the species of crabs which are known to eat quahogs are *Carinus maenus* and *Cancer irroratus*. Large *C. irroratus* crabs of 45 mm carapace width have been found at densities of up to two individuals per m^2 in kelp beds in Nova Scotia. (Drummond et al, 1982). These crabs are able to feed on up to 100 seed sized clams per day (Gibbons and Blogoslawski, 1989). In Nova Scotia they have been observed to consume 2.7 mussels/crab/day at a winter temperature of 5^0C (Drummond et al, 1982).

Undoubtedly feeding rates increase during the summer months. Such densities and feeding rates could prove devastating to a clam farming operation.

Several species of birds are known to eat bivalves and have been pests for mussel farming operations for years. A single eider duck, for example can consume up to 600 pounds of cultured mussels per year (ICES. CM., 1986, k:28). Ducks and gulls are less size specific than crabs but do show preferences for smaller and larger mollusks. Larger bivalves are preferred if the birds exhibit shell dropping behavior. Shell droppers will switch to alternative prey species before selecting smaller prey, because small shelled mollusks do not break open as readily as larger mollusks when dropped (Zach, 1978). The selection of larger prey increases the energy intake per unit of effort (Schneider, 1981 and Zach, 1978). Herring gulls have been estimated to remove adult quahogs (>40 mm shell length) at a rate of 5-10 clams/m^2/yr from a single clam bed (Hibbert, 1977).

Of the mollusk predators, moon snails and whelks are the greatest threat to clams. Whelks of the genus *Busycon* are capable of consuming one quahog per week per whelk, although they tend to prefer soft shell calms (Gibbons and Blogoslawski, 1989). *Busycon* whelks shows a preference for larger clams, greater than 4.4 cm, and are capable of feeding on clams greater than 13 cm (Peterson, 1982). Moon snails (*Lunatia* spp.) tend to drill holes in clams of 55mm or less and predate at a rate of less than one clam per snail per day. They are also capable of burrowing in search of prey (Gibbons and Blogoslawski, 1989)

Predation is usually considered to result in mortality, yet sublethal predation on clams is very common and in some cases has been known to inhibit growth. Browsing fish and shrimp nip at the exposed siphons of adult clams which produces variable effects on shell growth. Coen and Heck (1991) and Kamermans and Huitema (1994) found that clams when subjected to siphon nipping grew at a slower rate, yet Irlandi and Mehlich (1996) indicated that nipping by pin fish (*Logodon rhomboides*) had little effect on *M. mercenaria* growth. Mortalities may be indirectly increased by siphon nipping, as nipped individuals have shortened siphons and therefore must bury at shallower depths (Kamermans and Huitema, 1994) which may make them more susceptible to other predators.

Potential for the improvement of growth and prevention of disease

Several strategies have been experimented with in an attempt to increase the growth rates and lower the mortality rates of bivalves. Genetic manipulation has been the most heavily researched and some improvements have been made through the use of hybridization, selective breeding and triploid induction.

Treatment of diseases in a growout situation is virtually impossible as the clams are placed into the natural environment. In an open culture system, the animals are subjected to any pathogens which may be present in the water column. Only through prevention can disease be avoided as the cultured animals cannot be kept out of contact from pathogens at the growout site. Selective breeding may be the best preventative measure.. For the oyster *Crassostrea virginica*, breeding experiments have produced offspring which are 2 to 9 times more likely to survive exposure to *Halosporidium nelsoni* (MSX) than individuals not selected for resistance (Haskin and Ford, 1987).

Effective husbandry is the best way to prevent diseases in a nursery situation. Stress reduction through proper handling and densities is important, as high stress often causes the expression of latent diseases. Frequent washing and drying of equipment is critical. UV sterilization of water which is pumped into a system kills bacteria and other pathogens which may enter via the seawater system. Regular examination of upwellers, runways or trays for bacterial and fungal growth is also important. Most diseases can be treated with sodium hypochlorite, antibiotics, air drying of the clams, and temperature alterations (Castagna and Kraeuter, 1981).

Mercenaria growth rates have been demonstrably improved through a number of methods. Marked improvements have been achieved through hybridization of *M. campechiensis* and *M. mercenaria* (Hadley , 1988). Hybrids when planted in New York, reached market size within 505 days while pure strains required 670 days. As mentioned earlier, *M. campechiensis* have a poor shelf life, but the hybrid shelf life proved to be similar to that of *M. mercenaria* (Menzel, 1989). However, asserting that the use of hybrids may be beneficial to potential clam growers in Nova Scotia is premature, as no studies have been done to test the tolerance of hybrids to the cold weather of the Northumberland Strait. As *M. campechiensis* is a southern species, its hybrids may succumb to northern environmental conditions to which the parent stocks have not been adapted.

Selective breeding to improve growth rates is certainly not a new development and has been applied to virtually all species cultured by humans, quahogs being no exception. Mass selection for the largest individuals (top 10%) from wild South Carolina stock indicated that growth had heritability of 0.42 to 0.43. With this level of heritability, it was suggested that growth can be increased by up to 25% within two generations of selective breeding (Hadley et al, 1991). Breeding programs are however too costly for individual hatcheries to undertake and Burleigh (1988) suggested that breeding programs should be done as an integrated project in association with a number of hatcheries and subsidized by the government.

Triploid induction has improved the growth of some oyster species and has been tested on other bivalves as well. Triploidy increases growth in some animals as it often renders them reproductively sterile and retards gonad production. The energy which is normally channeled to gonad production becomes available for growth and the animals become larger faster. Results for clams are not so promising however. Triploid induction in *Tapes philippinarum* with the use of cytochalasin B is only 50% to 80% effective in causing triploidy , and is only 50% effective in preventing gonad development in those which are triploids (Ekaratne and Davenport, 1993). This means that in a treatment, only 25% to 40% of the animals fail to produce gonads. With such inconsistent results, and the prospect of reproductively viable triploids, this field needs much more study before it should be considered as an option.

The use of better stock/site combinations has potential for the improvement of production for bivalves as well. *Mytilus edulis* production in the Magdalen Islands was improved through reciprocal transfers. Certain mussels stocks when introduced to a new site had significantly improved production over the naturally occurring stocks. These heartier stocks grew and survived better in their new environments and performed better than the mussels native to the site. (Myrand,1990). Production increases may be achieved with quahogs using similar stock/site combination techniques, although little work has been done in this area. Reciprocal transfer experiments in Prince Edward Island from three sites, using hard clams of the same size revealed that growth rates were site specific, regardless of the source of clams (Landry et al, 1993). Given this knowledge, it may be more effective to attempt production improvement through careful site selection rather than stock/site selection.

Some producers have attempted to reduce the time it takes for clams to reach market size by feeding the seed in the nursery stage. Feeding unicellular algae to small clams at this stage helps them to reach a larger size before being transferred to a growout area. Growers in Maine, often grow algae in ponds and feed the clams in their land based nursery (Burleigh, 1988). The nutritional value of feeds may be improved through mechanical processing of the algae. If diatoms are used as feed, breaking the diatom chains and theca improves the nutritional value of the plankton by releasing organic contents of the theca and reducing diatom chains to lengths which are more manageable to small clams. Less feed is wasted with the processing of diatoms as well, as the shorter chains tend not to settle as readily as the longer chains. In addition, short chains of diatoms are more readily accepted as feed than long chains which are often rejected and excreted as pseudofeces (Sauriau and Baud, 1994). Such advances may be critical to the success of clam culture in regions with slow growth rates such as the Northumberland Strait, although the potential of such advances in that region have not been explored.

Growth Curve Derivations

To make predictions of harvests for an aquaculture operation, one needs to construct a growth curve in order to determine when the animals will reach a marketable size. For quahogs, the market size is generally 50mm shell length, but in Nova Scotia, the legal limit is 38mm (Anonymous, 1996d). The first step to determining growth in this project was to create a generalized shell length growth curve for the Northumberland Strait, based on the available literature. As there is often a wide distribution of sizes within a particular cohort[7] of quahogs, (Thomas Landry, pers. com.) the use of a generalized growth curve is however not enough to predict when cultured clams will reach market size. Size distribution within a cohort was therefore incorporated into the growth rate determination. Quahogs in Nova Scotia are harvested by length but sold by weight, therefore, after determining growth rates based on shell length, growth rates based on the weight of individual clams was determined.

Shell length derivation

The growth curve used for this analysis was based on observations from a number of sites in the Northumberland Strait area. Growth rates are somewhat site specific with differences often being reported between sites. This project, however, is meant to look at

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[7] Cohort for the purposes of this project refers to the seed which is planted in a particular year.

the overall potential of the area and therefore a mean growth curve was constructed from data collected at West River, Pownal Bay and Hillsborough River on the Prince Edward Island side of the Northumberland Strait (Landry et al., 1993) as well as Tatamagouche Bay, Wallace Harbor and Fox Harbor on the northern coast of Nova Scotia (Witherspoon, 1984) (Figure 4). The details of the determination of the generalized growth curve are outlined in Appendix 2. The use of this curve should give a generalized growth pattern which could be applied to most areas. Because it does not take site specific growth patterns into account, it was subjected to a sensitivity analysis with respect to growth rate in the economic analysis.

Distribution of growth within a cohort of clams is a matter rarely considered in the economic analysis of quahogs. Burleigh (1988) for example estimated that a cohort of quahogs would be harvestable (50mm) 4 years after planting. This assumption however seems unrealistic as Summerson et al. (1995) found that depending on stocking density and substrate, the percentage of marketable clams can range between 8% and 46% after 3 years of growout in the warmer waters of the southern United States. Although it is reasonable to assume that some clams will be of harvestable length within 4 years, to assume that all will be harvestable is clearly erroneous. In operations where the cultured species are short lived or have tight distributions of growth, it may be reasonable to plan to harvest all of the animals at one time. Quahogs do not however fit into this category. Selective breeding and inbreeding programs are able to maximize growth rates and reduce variability in growth (Dillon, 1989) but at this time little has been done to achieve this end with Atlantic Canadian hard clams (Burleigh[8], pers. com.).

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[8] Paul Burleigh is the manager of the shellfish hatchery for Holland College in Prince Edward Island.

The principal advantage of incorporating size distributions into the growth analysis is that it provides a much clearer picture of when the clams will be harvestable. If one looks at the generalized growth curve in Figure 4 for example, it may be assumed that all of the clams will be harvestable around year seven. In reality, however, some of the individuals within a cohort may be harvestable after 3 years of growth while others will not be harvestable for up to ten years or more (Thomas Landry, pers. com.). It is therefore easy to see that predicting harvests based on a mean curve may lead to errors. In addition, by incorporating the size distributions into the growth predictions, one can investigate the potential of harvesting subgroups within a cohort when certain proportions of that cohort are of market size. In a bottom seeding growout system, this sort of a harvest would be impractical, but it is possible with a tray system for growout. Partial harvests of a cohort based on size allows for revenue to be generated earlier than if the producer waits for all of the clams to reach market size. Plus, this selective harvest allows for the taking of larger individuals, while smaller individuals can be replaced in the tray to be grown out for the full length of time required for them to reach market size.

In order to superimpose the distribution of size groups onto the generalized growth curve in Figure 4, two assumptions were made. The first assumption was that the distribution of sizes is normal and the second was that the standard deviation (SD) is representable as a constant percentage of the mean throughout the entire growth period. With a normal distribution, we can break the stock into five growth subgroups as described in Askew (1978): fast growers (F) (10% of stock), moderate fast growers (MF) (20% of stock), average growers (40% of stock), moderate slow growers (MS) (20% of stock) and slow growers (S) (10% of stock). In this case, the average growers were further divided into high average growers (HA) (20%) and low average growers (LA) (20%). These growth groups are shown in Figure 5.

Information concerning the distribution of size within a cohort of quahogs is poorly represented in the literature. Therefore, the size distribution had to be constructed

Figure 4. Average quahog growth curve for six locations in the Northumberland Strait.

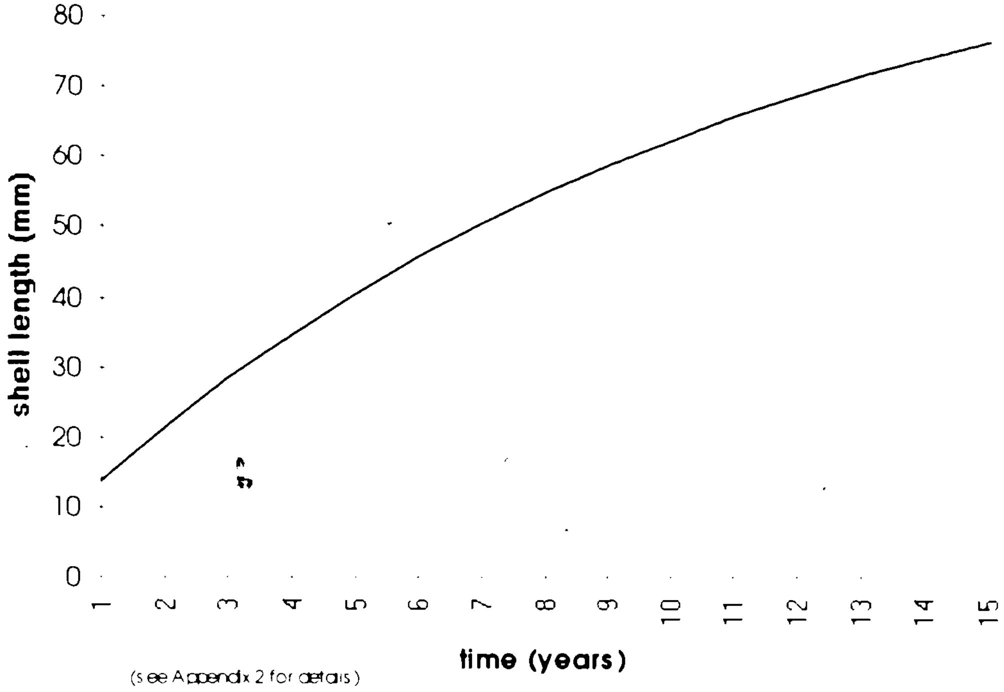
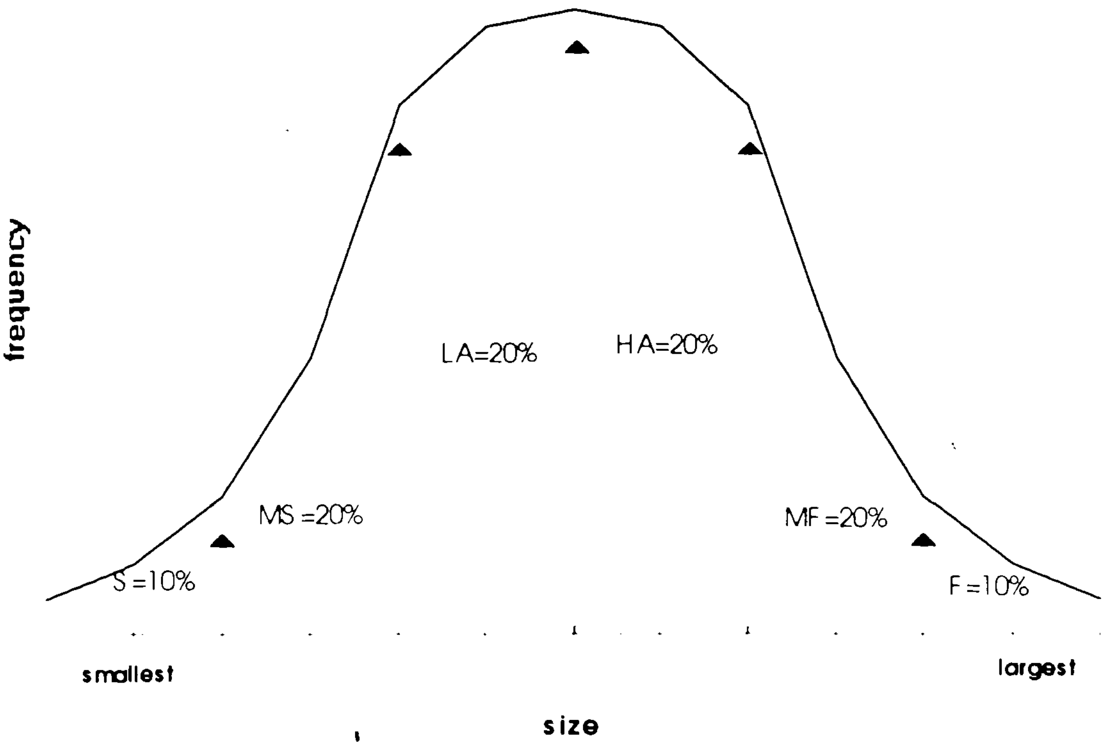


Figure 5. Normal distribution of the growth groups of quahogs (S =slow growers, MS =moderately slow growers, LA=low average growers, HA=high average growers, MF =moderately fast growers, F =fast growers).



indirectly and applied to the generalized growth curve which has been proposed. First year growth data for seed clams (*Mercenaria*) was used to estimate the distribution through the growout of a cohort (data was supplied by Thomas Landry of DFO, Moncton). The seed was purchased on June 29, 1990 at a mean length of 3.57 mm with a standard deviation of 0.69 (Appendix 3). Groups of these clams were planted in several locations in New Brunswick which were, Caraquet, Lameque, Bouctouche and Cocaqne. These were sampled through the summer of 1990, until October. From this data the standard deviation at each time of sampling was estimated.

The SD then in turn was used to calculate the minimum length which defines each size group in the distribution. This was done by finding the standard unit, the z value, which was appropriate for each division point (Table 5).

Table 5. Z-values which define the various size groups of *Mercenaria* in relation to a normal distribution.

Size group	z value
fast growers	1.30
moderate fast growers	0.55
high average growers	0.0
low average growers	-0.55
moderate slow growers	-1.30
slow growers	-3.30

Through the use of the equation, $z = \frac{(x - \bar{x})}{SD}$, the value of x (length), which delimits each growth category was calculated. Each of these was then converted to a percentage of the mean (Table 6). Once the length for each of the growth groups is represented by a percentage of the mean, it may be applied to the mean growth curve at various points in time to estimate the distribution in size throughout the growout period (see Figure 6).

Figure 6. Minimum shell lengths of each quahog growth group over 15 years (two potential harvest lengths of 38mm and 50mm are shown)

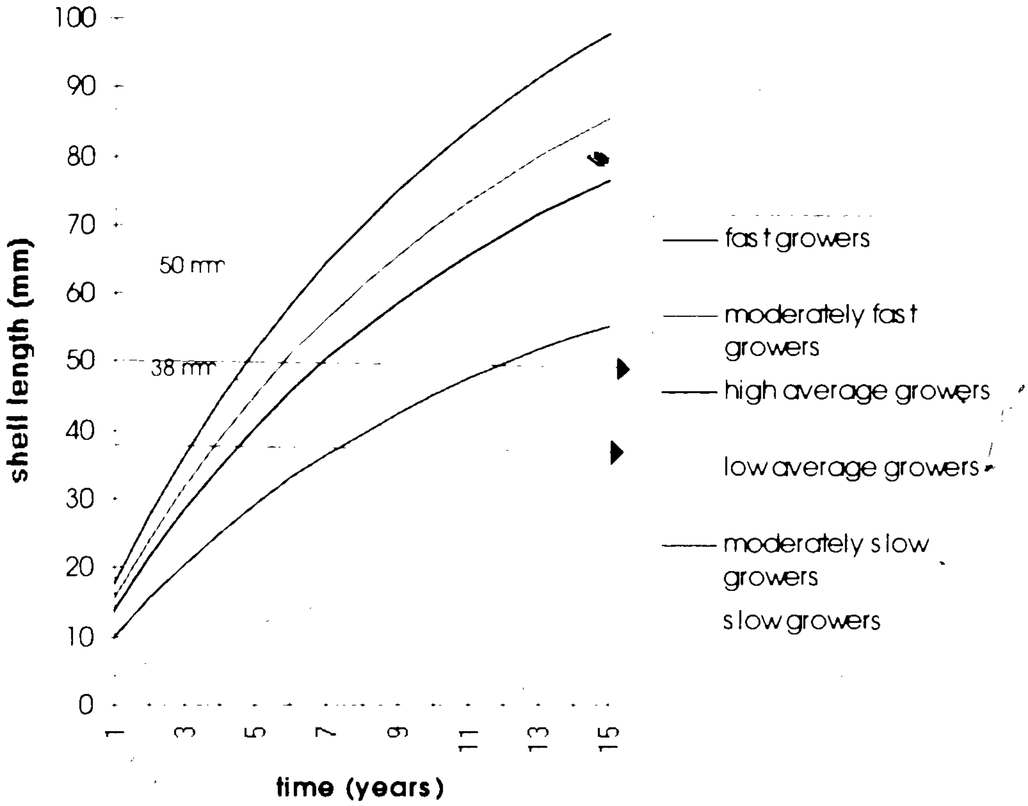


Table 6. Size groups within the normal shell length distribution of a quahog cohort and the percentage of the mean giving the value for the smallest length in each size group.

size group	percentage of the mean
fast	128
moderate fast	111.8
high average	100
low average	89.2
moderate slow	73.2
slow	29.3

As the z values used above delimit each group based on the smallest length in each of the groups, it is suggested that the curves generated be used to set a harvesting schedule. A size group is ready for harvest when the smallest individuals within that group are ready for harvest. For example, when the smallest individuals of the fast growth group are 50mm, then all individuals within that group are 50mm or greater.

Although the use of this curve may be useful for determining the harvest time, it is not useful for estimating the wet weight of the clams harvested. The minimum length which defines each group is not a representative of the mean length of the group, therefore, if it is used to determine the average weight of the group an underestimate in the average weight will arise. Therefore, new curves for the average length of each size group were constructed. The procedure employed was identical to that used for determining the minimum sizes which define each size group, with the exception that the z values were selected to represent the average length of the groups instead of the minimum length of each size group (Table 7).

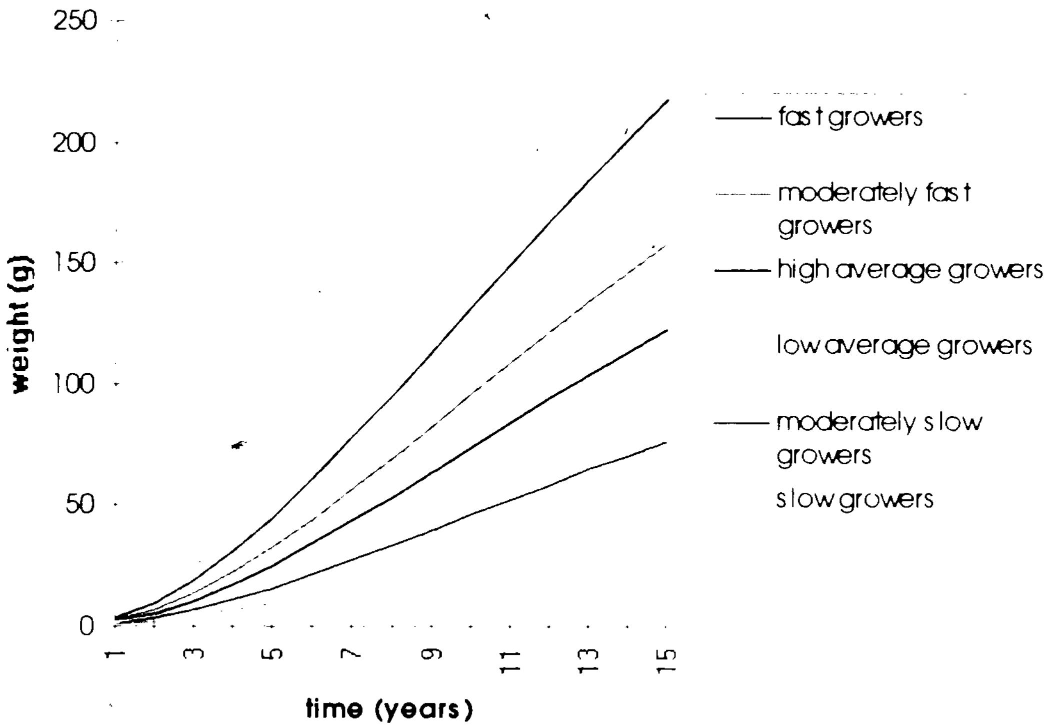
Table 7. Z-values which represent the average length for each of a quahog cohorts growth groups.

Size group	z value
fast growers	1.65
moderate fast growers	0.85
high average growers	0.25
low average growers	-0.25
moderate slow growers	-0.85
slow growers	-1.65

Wet Weight Curve Derivation

The average length per clam curves calculated above were transformed to average wet weight per clam using the equation; whole wet weight (g) = $0.0023102 * (\text{length})^{2.49063}$ from Carver and Mallet (1991). See Figure 7. With these weight curves, we can estimate the average weight of individual clams in each growth group and when combined with the estimate of survivorship, harvest weight and revenue may be calculated. Estimates of survivorship, harvest weight and revenue are in the economics section of this report.

Figure 7. Average weight per individual in each quahog growth group over 15 years.



Culture Techniques

To create a successful quahog farming operation, the various culture techniques must be evaluated to determine which are the most appropriate for the region in question. This section evaluates all aspects of an operation including site selection, nursery strategies, overwintering strategies and final growout options. For each of these it is recommended which are the most appropriate systems for the Northumberland Strait.

Site Selection

A successful clam farm site has a number of basic requirements: good substrate, adequate food and high quality water. The key indicator normally used to pin point a site is the presence of a natural clam population. Certain areas which are particularly good have high quahog populations. Oyster bars for example, tend to be good culture sites and have natural quahog populations up to 17 times higher than adjacent areas (Micheli, 1995). Using the strength of natural hard clam populations in Nova Scotia may not be an effective strategy for site selection however. Certain areas may be devoid of quahogs as a result of over harvesting or low water temperatures, not poor site characteristics. The reason why low water temperatures exclude quahogs is spawn induction. Spawn induction will happen only if water temperatures reach 25 °C. A given area may have temperatures adequate for quahog growth and survival, yet too low to induce spawning, thereby excluding a natural population. Aside from this, the site may be acceptable (Malouf and Bricelj, 1989). Areas with soft mud, shell or gravel substrates with moderate flow rates (50 cm/second) are favorable to hard clam culturing (Castagna and Krauter, 1981), but high mortalities may result in areas with excessively soft mud or high flow rates as sediment deposition may smother clams (Carver and Mallet, 1992) (Appendix 1 shows area with culture potential).

Prior to selecting a site, monitoring of plankton levels, DO, temperature and silt content in the substrate and water should be done. This will ensure that the site is adequate in relation to the environmental factors which were discussed in the growth and mortality section of this report.

Seed and Nursery

Other forms of bivalve culture such as mussel culture are able to take advantage of natural settlement to sustain the operation (Mallet and Myrand, 1995). The natural set of quahogs in Nova Scotia sustains a standing crop of only about 4-6 clams/m^2 (Witherspoon, 1984). This rate of settlement is far too low as 200-1000 clams/m^2 are needed in a commercial clam farming operation (Castagna, 1984). Because of this low natural settlement, a reliable supply of seed from a hatchery is a necessity to maintain stocks at the required densities.

The small seed, generally 3-4 mm, supplied from a hatchery is, however, very vulnerable to predation (Stehlik, 1993, Gibbons and Blogoslawski, 1989) and subject to mass mortalities if not properly cared for. In addition to predation, small seed clams are vulnerable to strong currents (Krauter and Castagna, 1981) and harsh environmental conditions such as storms and cold weather (Burleigh, 1988). Many producers opt for nursery systems which offer a more hospitable environment to the young clams. Nurseries either partially or fully isolate the seed clams from the elements (Adams, et al, 1993). Nursery systems take on a variety of forms, some of which are land based, such as upwellers and raceways, or field based such as trays, cages, rafts and longline systems.

Upweller systems are basically cylinders which share a common tank of ambient sea water. These cylinders have a mesh bottom on which the seed clams rest while sea water is forced upward. The upward flow provides for equal nourishment of all the clams and constantly removes waste material. Stocking densities of small seed can be as high as $80,000/m^2$ with no harmful effects (Carver and Mallet, 1991). Although the capital costs associated with a land based upweller are high, the maintenance requirements are low (Adams, et al, 1993) and the seed may be carefully watched and graded regularly. These systems have reported very high survival rates at around 90% or better during nursery periods of up to 100 days (Summerson et al., 1995) and display superior growth rates to field based nurseries (Carver and Mallet, 1991). First year clams can reach 10-12mm after the first growing season, while naturally set clams generally reach only 6 mm during the same period (Carver and Mallet, 1992).

Field nurseries such as tray systems and cage systems are typically wooden structures covered with protective mesh to isolate the clams from predators. These may be located subtidally or intertidally (Adams, et al, 1993). Tray nurseries have however yielded variable mortalities. Carver and Mallet (1991) experienced up to 75% mortality, mostly due to predation while the commercial quahog producers ARC claim that 85% of the clams survive during the cage nursery portion of their cycle (Burleigh, 1988). Rafts and long-line systems using hanging trays, bags, lantern nets and oyster nets have been experimented with as well but are highly vulnerable to storm damage and may experience up to 100% mortality in the Northumberland Strait (Burleigh, 1988). Raft systems are expensive to build and require elaborate anchoring systems. In addition, maintenance is labor intensive which often makes them too costly to employ (Krauter and Castagna, 1989).

Given the high maintenance, high mortality and the poorer growth rates associated with the field based nursery systems, it is suggested that in the harsh climate of Nova Scotia, a land based upweller be used. One of the biggest advantages is the ability to sort and grade clams effectively. Due to the high variability in growth as previously discussed, it may be critical to separate size groups as much as possible to avoid suppression of growth of the smaller clams by the larger fast growing individuals.

Over Winter Strategies

High mortalities during the first winter have plagued attempts to grow quahogs in Atlantic Canada (Bourne, 1989, Burleigh, 1988, Witherspoon, 1984, Carver and Mallet, 1992). To make the culture of these clams feasible, a strategy for wintering them must be employed. As overwinter growth rates in Nova Scotia are nil due to the cold water temperatures, survival should be the main priority when choosing a strategy. Carver and Mallet (1992) found that highly variable survival rates occur in upweller systems during the first winter (39-86 % survival). Results from field plantings in protected plots were even more variable, ranging from 0% to over 90% survival. The expected winter survival for each of these methods is 63% and 45% respectively, but their high variability makes them inherently risky. More consistent survival rates (approximately 65%) during the first winter were found, however, with subtidal tray systems. To avoid unpredictable winter mortalities, it is recommended that a subtidal tray system be adopted. This is especially important to first year clams which are the most vulnerable and exhibit the most variation in winter mortality rates.

Growout

Several options for growout exist, and most involve planting in the subtidal or intertidal zones. Bottom seeding without protection has inherent problems such as, shifting sediments that may smother your animals and susceptibility to predators (Castagna and Krauter, 1981). Most of the types of growout therefore, involve trays, nets or pens. In Nova Scotia due to the short growing seasons, the growout of clams may take between four and ten years. With such long growout time and harsh winters, one must choose the specific type of growout method carefully. The annual ice scour and the winter storms place limitations on which approaches can be used. An inappropriate method could result in high mortalities or even a total loss of crop. As trays, nets and pens are the most common form of growout, the following discussion will be based on them.

Tray systems are typically rigid box structures made of wood or plastic with protective plastic mesh and sediment added to the bottom. Rigid trays may be set directly on the bottom or have legs attached which raise them off of the sediment (Appendix 4).An alternate tray form is the soft tray which is made of flexible plastic mesh. Both designs may be placed intertidally or subtidally. The soft trays have a number of advantages as they are light weight, inexpensive and easy to harvest. Soft trays, as they are made of flexible material, can have a float attached to the middle of the tray which causes a tenting effect (Adams, et al, 1993). Tenting has several advantages. It may increase growth rates for the tent acts as a baffle which increases deposition rates of plankton (Peterson et al., 1984). Tenting also prevents the mesh from interfering with clam siphons, allowing for more effective filtration (Krauter and Castagna, 1981). Tents also provide better predator protection as crabs have difficulty manipulating the raised mesh and are unable to reach the clams (Spencer, et al, 1992).

Trays which are raised off of the bottom and located subtidally show better growth and survival characteristics than bottom trays in the subtidal or intertidal. In addition to more predictable winter survival (65%) as previously mentioned, summer survival rates in the subtidal trays are very good at 85% to 94% (Carver and Mallet, 1992). Walker (1983) also noted that recovery of clams is higher from trays. Raised trays show improved growth over bottom trays. At the end of two growing seasons, Carver and Mallet (1992) found that quahogs raised in subtidally located: off bottom trays had an average length of 22.44 mm which was 18% greater than quahogs grown in subtidally located bottom set trays. Subtidal trays have an added advantage in Nova Scotia as they are not exposed to winter ice scouring.

Nets and pens are simple and inexpensive, but they lack most of the advantages of a tray system. For net growout, seed clams are placed directly on the bottom and covered over with a net which is then staked down and weighted along the edges. Adding floats for tenting provides many of the advantages previously discussed for soft trays. Pens consist of a rigid frame which is enclosed with mesh on the top and sides. Water flows freely through the mesh while providing predator protection (Adams et al, 1993). These two systems however may not be the best suited for Nova Scotia as Carver and Mallet (1992) found that bottom seeded clams had inferior growth when compared to trays. The icy winters with scouring puts any sort of apparatus which is located in the intertidal at risk and as it is desirable to have nets and pens located intertidally, they may be destroyed during the winter. Witherspoon (1984) found that intertidal baffles for pens were destroyed by ice in their first winter and Carver and Mallet (1992) dismantled intertidal apparatus to avoid having it get destroyed during the winter. Harvesting bottom seeded clams is also much more difficult than with a tray system. The clams must be harvested by hand and the recovery by this method is only about 60% efficient and chances of breakage is greatly increased (Anonymous.1988).

Grading, density reduction and harvesting are much more practical with tray systems than with nets and pens. Although the maintenance of intertidally located nets and pens is relatively simple, it is very difficult if they are located subtidally. Harvesting of clams which are bottom seeded under nets or in pens subtidally requires special mechanical harvesters. All that needs to be done to harvest a tray is to raise it and recovery is 100%. Raising a tray may require a mechanical lifter however (Adams, et al., 1993). As previously discussed, the distribution of shell lengths within a single cohort of quahogs is quite high. A tray system allows for an annual harvest which is not practical with bottom seeding. The trays can be raised and the harvestable clams retrieved while the rest may be placed back into the tray for further growth.

Conditions in Nova Scotia are such that the tray system is the most viable option. To avoid losses due to ice scouring, a subtidal growout should be used and the best system for subtidal plantings is the tray system. The use of trays also allows for the use of locations which may not have suitable substrate for bottom seeding, or steep sloped beaches which have limited area for intertidal bottom plots. Growth and survival are improved with trays, while annual harvests are possible, thereby allowing for a collection of the larger sized clams. It is therefore recommended that this type of culture be adopted in the Northumberland Strait.

Environmental Impacts

A single species aquaculture facility can place high stress on the ecosystem in which it is situated, either as a polluter or competitor for space and resources. These stresses caused by aquaculture come in many forms. With finfish aquaculture, threats to the environment typically come from the use of prepared feeds which cause organic deposition either directly as feed or as feces, disease treatments such as antibiotics and chemicals which can contaminate the area surrounding the site, harvest impacts and escapement. All of these factors when combined can potentially have deleterious impacts on the wild species which make up the natural community surrounding an aquaculture operation (DeFur and Radar, 1995). Although clam farms do not use artificial feeds or therapeutic agents for disease treatment, they do have the potential to negatively impact the environment. The simple idea of introducing a selectively bred or genetically altered animal in to the environment should raise concerns. If these animals are allowed to breed freely with wild populations, the consequences may be harmful. The filtration process itself by which bivalves feed removes plankton and suspended particles from the water column which affects not only the quality of the water, but sedimentary rates and the chemistry of the sediment. The combined effects of high densities of clams, high filtration and culture techniques may also impact the community structure which has serious implications if the food web becomes altered. Each of these concerns will be discussed in further detail.

Introduced domesticated stock and the risk of genetic pollution

Bivalve aquaculture has a history of introducing non-native species into new regions for culture (Conrad, 1992, Carlton, 1992). For the most part, adherence to proper shipment and handling protocols have reduced the problems of introductions (DeFur and Rader, 1995) but clams which are spread on the bottom in many instances have a much better chance to outbreed with wild stocks than do other cultured species. Harvests can never recover 100% of bottom seeded clams and spillages of seed have very little chance of being recovered. These two factors may lead to long term establishment of these animals.

Mercenaria, as a native species to the Atlantic region is a good candidate for expansion into the aquaculture industry. As hatchery produced seed from Nova Scotian quahog stocks may not be readily available for a commercial scale farm (Burleigh, pers. com.) there is a possibility that American seed may need to be imported. It has been demonstrated that American *M. mercenaria* are genetically distinct from their Canadian counterparts (Dillon and Manzi, 1992) and may have different characteristics, possibly to the detriment of Nova Scotia populations if the two interbreed. These concerns are much the same as those of the salmon hatchery projects in Alaska. Fears of genetic alteration of native populations have lead to the stock concept of artificial propagation[9]. Much of this concern relates to the genetic dilution of natural stocks which may lead to reduced genetic diversity which can have an overall negative impact on the natural populations through decreased fitness (Helle, 1981).

In addition to the fact that seed clams may be coming from a different stock, genetic ateration of *M. mercenaria* broodstock is common. Genetic drift through bottleneck

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[9] Stock concept of artificial propagation refers to the idea that each population of a species has unique characteristics which have been selected to suit their particular environment. The concept is that any artificially propagated animals should be from the native broodstock, as the introduction of genes from other stocks may be detrimental to the native population in the long term.

effects[10] (Dillon and Manzi, 1987), the artificial selection of broodstock for faster growth (Hadley et al, 1991) and the hybridization of *Mercenaria* species (Manzi et al, 1991) have demonstrably altered the genetics and characteristics of seed clams. There are three possible outcomes which will follow the introduction of a genetically altered stock. The introduced genomes diffuse into the natural population and are diluted beyond detection, the introduced genomes are disadvantageous to the population and selected out rapidly, or the introduced genomes are selectively advantageous and spreads throughout the population, possibly to the detriment of the community (Metzner-Roop, 1994). The genes of hatchery produced *M. mercenaria* appear to be persistent within the wild population after introduction. Metzner-Roop (1994) found that genetic markers from the stock of a clam farm were evident in the wild population ten years after the operation had shut down. This planting was only a one year trial but made a lasting contribution to the wild population. One can never be certain how the propagation of genetically altered clams will affect the population as a whole, but disease susceptibility is a serious concern. The hybrids of *M. mercenaria* and *M. campechiensis* as mentioned previously are more susceptible to neoplasia than their pure line counterparts, and are fully capable of breeding with pure lines (Bert et al., 1993). Continued seeding of hybrids or other genetically altered quahogs may lead to outbreeding with natural stocks, therefore increasing disease susceptibility or other unknown effects which may reduce overall fitness.

Sedimentation and Sediment alterations

The process of filtration and deposition of feces and pseudofeces by bivalves can alter the sediments in which they reside (Mojica and Nelson, 1993). Mussel farms are known to increase sedimentation rates by up to three times when compared to reference

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[10] Bottleneck effects are the effects of a limited breeding population which may lead to reduced heterozygosity of genotypes.

sites, and have more compact sediment with less water content underneath the lines (Dahlbäck and Gunnarsson, 1981). The impacts of mussels has been demonstrated to be highly localized, with sedimentation rates being unaffected 30 m from the culture site (Grant et al, 1995).

Clearly, the sedimentation rate is affected by bivalve culture, but the sediments which are deposited are of roughly the same carbon content as the phytoplankton from which they are derived, therefore they have similar carbon content by percentage as areas that are removed from the culture site (Grant et al, 1995). The sediment at a Florida clam farm site, however, had decreased grain size, increased organic content, higher volatile solids (in winter)within one meter of grow out bags and a higher silt/clay percentage (all months except December) (Mojica and Nelson, 1993). Despite the fact that there is no net increase in the organic matter in the water, bivalves through their filtration process, cause an aggregation of waste materials (, Mojica and Nelson, 1993, Grant et al, 1995). These waste materials appear to affect the chemistry of sediments under mussel lines as there is a difference in the amount of anaerobic mineralization in the areas beneath mussel lines. This results in anoxic conditions in the upper layers of the sediment (Grant et al, 1995). A much shallower redox layer was recorded at a *M. mercenaria* farm (0.5mm deep) compared to control areas where the redox layers were 24.5mm and 16.5mm (Mojica and Nelson, 1993). Typically, these anaerobic conditions will quickly revert back to the original state within a few years after the removal of the aquaculture facility (Folke and Kautsky, 1989).

As bivalve fecal material is easily resuspended, (Dame et al., 1991) its effects are not expected to be long term. In fact, wave action caused by wind over a prolonged period has been correlated to the reduction of volatile solids in the sediment of a clam farm in Florida (Mojica and Nelson, 1993). Transport of waste from an aquaculture site through water currents, however, may not be a solution to the waste accumulation problem, as materials may be deposited downcurrent in a nearby sediment sink. In this way the problem is not solved, but moved to another location where it may be more difficult to deal with (Frid and Mercer, 1989).

Faunal responses

Under conditions of organic loading, communities tend to respond through a reduction in diversity and an increase in opportunistic species which are tolerant of such adverse environmental conditions. Often, opportunistic organisms are prolific and short lived varieties of polychaete worms, which are rapid to colonize and exploit a disturbed area. Capitellid and phylodocid polychaetes were found to be more abundant at a quahog farm site than at reference sites (Mojica and Nelson, 1993), which indicates that there may be the potential for reduction of biodiversity due to hard clam farming. Larger mobile macrofauna numbers however, show no evidence of being impacted by clam farm sites (Mojica and Nelson, 1993) or mussel farm sites (Grant, et al.,1995).

Predator control strategies are also responsible for the alteration of faunal composition. The addition of gravel as a form of predator control has been shown to effect epibenthic crustaceans, either by enhancing or decreasing their numbers depending on the conditions. Likewise, exclusion nets increase sedimentation rate and reduce sediment size, which also impacts on epibenthic crustaceans. As these copepods and amphipods are important links in the food web, alterations in their abundance may have significant impacts affecting all trophic levels. Shifts in the trophic structure can have economic as well as ecological implications as the larval stages of other commercially important species may feed on these epibenthic crustaceans which are affected by a clam farm (Simenstad and Fresh, 1995).

Impacts on Nutrients and Primary Production

Artificially high densities of suspension feeding bivalves have the potential to cause a shift in the community structure through competition for phytoplankton with other suspension feeders and zooplankton, and direct removal of zooplankton from the water (Folke and Kautsky, 1989). High density assemblages of bivalves have been found to have decreased growth rates, likely due to the depletion of resources (Peterson and Black, 1987, Folke and Kautsky, 1989). It is difficult to determine if the reduction in growth is the result of only localized resource depletion or if the effects are wide spread. Mojica and Nelson (1993) found that there was no correlation between the presence of a clam farm and the levels of chlorophyll or nutrients (ammonia, nitrate, nitrite, and phosphate) in the water. This suggests that, at least on the larger scale, resource levels are more likely the result of oceanographic events than the effects of the clam farm.

Bivalve filtration may have direct negative effects on phytoplankton and community structure, but by increasing nutrient turn over time, the filter feeding process may promote new phytoplankton production (Dame, et al., 1991). Introductions of *Mercenaria* have been shown to increase phytoplankton production (Doering, et al., 1986). Increases in the P:N ratio to greater than 1:16 combined with the accumulation of nutrients from the deposition of feces may lead to increases in primary production (Asmus and Asmus, 1991). One of the dangers associated with this potential to promote plankton blooms is that local red tides may be caused (Folke and Kautsky, 1989). If plankton blooms caused by nutrient accumulation become a problem at a shellfish farm site, it has been suggested that blooms can be avoided through the deliberate introduction of macroalgae which can utilize the excess nutrients (Simenstad and Fresh, 1995).

Overall primary production impacts of a shellfish farm are far less than for a finfish farm. When looked at in terms of primary production, a single salmon farm on average uses 5.3 tons of feed for every ton of harvest which equals 1 km^2 of primary production (in the Baltic Sea) or 50,000 times the surface area of the cages. Shellfish on the other hand are direct consumers of primary production. This means that in order to produce a ton of bivalves, primary production equal to only 20-40 times the surface area of the site is required (Folke and Kautsky, 1989).

Conclusions

Although the impacts of individual aquaculture sites are inconsequential, the cumulative impacts can be devastating (DeFur and Radar,1995). To determine if the risks to the environment are acceptable, one must consider the true value of the operation which includes not only economic costs and benefits, but also environmental impacts and social costs. (Simenstad and Fresh, 1995). Costs to consider include subsidies, cleanup costs and downstream impacts. The incremental impact of the operation in relation to all of the other industries within the vicinity should also be addressed, to determine if the impacts of a new operation may be compounded by the effects of other nearby industries (DeFur and Rader, 1995).

The evidence is quite clear that clam farming does have an impact on the environment. Genetic pollution can and does occur as found by Metzner-Roop (1994) and direct impacts can be seen through sediment alteration and disturbances in the fauna (Monjica and Nelson, 1993). The real question is whether these are acceptable levels of disturbance. Based on the evidence given, the answer is probably yes. The clam farm in Florida monitored by Monjica and Nelson (1993) experienced seasonal cleansing with the impacts of the clams being less during the stormier months in winter. The conditions in Nova Scotia are such that the growing season is short, so the opportunity for organic accumulation is less and the long stormy winters will remove whatever accumulation does arise. Therefore, the potential to alter fauna and cause plankton blooms is diminished. So far as genetic pollution is concerned, it seems unavoidable as clams are broadcast spawners. Although interbreeding of wild and hatchery stocks is inevitable, heterozygosity of hatchery reared clams is high (Dillon and Manzi, 1987), which means that the threat of reduced genetic diversity may not be as great as with the introduction of other domesticated stocks. Intertidal areas are known to be resilient, with disturbances not leading to long term impacts (Simenstad and Fresh, 1995). As the impacts of clam culture appear to be limited enough that long term impacts are improbable, the environmental risks associated with clam farming are likely acceptable.

Potential Obstacles to Culture in Nova Scotia

Although Nova Scotia has a long coast line with a multitude of areas with aquaculture potential ,obtaining a culture site has traditionally been difficult. This difficulty has arisen mostly due to opposition from the general public. The government has attempted to gain public support of aquaculture by founding organizations such as the Regional Aquaculture Development Advisory Committees (RADAC). These advisory committees are community based and located in areas where aquaculture development is of interest, to allow for direct input from the communities which will be most affected by aquaculture development. Human health considerations are also a problem as toxic phytoplankton and bacterial contamination have plagued Maritime shellfish producers for years.

Public Opposition to Aquaculture

Opposition to aquaculture in Nova Scotia comes from all segments of society including fishers, boaters, landowners and environmentalists. Fishers and boaters share concerns about aquacculture equipment acting as navigational hazards or the loss of rights of passage to an aquaculture facility. Landowners typically fear that aesthetics will be disrupted by floats cages and constant human activity at an aquaculture site, while environmentalists concerns usually center around impacts to the environment. Past conflicts have been heated and in some cases have resulted in acts of vandalism such as the destruction of salmon pens along the south shore of Nova Scotia and cutting of mussel lines in Tatamagouche (Muzzerall,1987, Scarret, 1993).

Conflicts between traditional fisheries and aquaculture are one of the biggest obstacles faced when attempting to open an aquaculture operation in Canada. Fishers fear aquaculture for three main reasons; enclosure, scale and loss of income. The enclosure issue has to do with the granting of exclusive rights of a particular stretch of coastline. The fishers believe that this infringes on their traditional rights to fish those areas. Scale is the fear that an operation may become too large or that large companies will move in and build large facilities. What is likely feared most of all is the prospect of competition from aquaculture which may subsequently bring a loss of income to the fisherman (Sharp and Larson, 1988). Many fisherman complain of gear conflicts, especially with salmon farms (Muzzerall, 1987). The concern for conflicts is so strong, that the Aquaculture Act states that an application may be refused if there is a potential use conflict for a site (Aquaculture Act, R.S.,c.18,s.1.)

It has been suggested that fisherman should be given first choice for beginning new aquaculture operations to help relieve tensions between fishers and aquaculturalists: Although the skills of the fisherman would be limited, it is suggested that the initial operations be small so that they will be able to develop the skills over time (Ives, 1989). This seems to be a solution that is destined to fail, for a small operation is not usually economically viable. Government subsidization of these operations would be heavy and the returns low. Any new facilities should be managed by skilled and experienced aquaculturalists so that the operation will be run properly from the beginning, thereby minimizing the initial losses due to inefficiencies that the above proposal is willing to accept. The danger of Ives' suggestion is that aquaculture development will become another form of unemployment insurance rather than a legitimate industry which will help to boost the economy of the province.

The government has taken steps to reduce the amount of mistrust toward aquaculture in Nova Scotia. First of all the Aquaculture Act states that each new license must be put through a public hearing so that the opinions and objections of community members can be heard (Aquaculture Act, R.S.,c.18,s.1.). Also, Regional Aquaculture Development Advisory Committees (RADAC) were started for the purpose of developing a trust between the government and the general public. This helps to bring the decision making process to the community level and allows for committee members who represent the interests of fishers, boaters, land owners and business owners to review applications. Thus far this has been deemed successful by the government (RADAC, 1995). Links between government and the public in the decision making processes are critical. Past attempts to grant aquaculture rights without public consultation in New Brunswick led to bitter conflicts between landowners and government which had the potential to damage aquaculture development in that province (Muzzerall, 1987).

Government Regulations

The Aquaculture Act of Nova Scotia sets out guidelines for aquaculture development and operations. The Governor in Council has the authority to regulate where, and how operations will take place and strict guidelines concerning water quality at the culture site and its surrounding areas must be adhered to, while any violations of the Act may result in loss of license. The government reserves the right to change the provisions of a license and impose these changes at any time. No deleterious substances may be added to the water above the preexisting levels. The objective of the Act was to provide an environment which would help aquaculture to flourish in Nova Scotia (Aquaculture Act, R.S.,c.18,s.1.).

Although the objective of the Act was to encourage aquaculture, the concerns about public opinion were very evident in the approval process. The first step of obtaining an aquaculture site is to get the area approved for aquaculture development. This application must get approval from the Department of Agriculture and Marketing, the Department of the Environment, the Department of Lands and Forests, the Department of Mines and Energy, the Department of Municipal Affairs and any other boards, boards and commissions which are prescribed. After passing through these departments, the application is put to public consultation through RADAC and public hearings. In the event that a site is designated for aquaculture development, a similar approval process must be done before a license may be granted. The process is identical to the above. (Aquaculture Act, R.S.,c.18,s.1.). An application may be rejected at any point of the approval process (Nova Scotia Dept. Fisheries, 1996). With each application running the gauntlet in this fashion, the odds are stacked against an individual obtaining a site and a license.

Human Health Considerations

In 1989, there was a 5-year $250 million program started by the Canadian Council of Ministers of the Environment known as the National Contaminated Sites Remediation Program (NCSRP). The program was to continue until the end of fiscal 1996. The purpose of this project was to recognize areas which presented human health risks and to remediate the problems with funding supplied by both polluters and the government. Only two sites were cleaned up under this program in Nova Scotia, one at Five Islands Lake and another at Amherst Aerospace (Anonymous, 1996e).

Potential shellfish growing areas are classified under the Canadian Shellfish Sanitation Program (CSSP) through the Department of the Environment. The waters are screened for pathogenic microorganisms, radionuclides and toxic wastes. The sources and range of impacts of any pollutants were determined as well as the effects on the receiving environment (Anonymous, 1996b) (shellfish closure areas shown in Appendix 1).

Sites which have been evaluated for shellfish aquaculture fall into 3 classifications, approved, conditionally approved and closed. Approved areas have mean fecal coliform levels of 14 mpn/100ml or less, with no more than 10% of samples having greater than 43 mpn/100ml. Conditionally approved sites have the same water quality as those which are approved, except that their water quality varies with rainfall, river flow, the effectiveness of nearby sewage treatment and seasonal influences such as increased cottage tourism during the summer months. Approved sites have no variation in water quality under any circumstances. Closed areas have high bacterial contamination and/or chemical contamination (Machell and Menon, 1992). They may be used only under permit with approved depuration or relaying techniques (Anonymous, 1996a).

Areas which are approved for shellfish aquaculture are subject to annual reappraisal for contamination levels, while all sites are reevaluated every three years (Anonymous, 1996b) to ensure that these areas have not had significant changes in contamination levels (Machell and Menon, 1992). Any site selected should be carefully considered, for current pollution levels may rise within a few years depending on human activities.

Clean up of potential sites is on the agenda for the CPPS under the direction of the DOE. However, cleanup and prevention programs have been ineffective and most actions taken against polluters have not been directed toward sewage treatment plants which are the largest contributors to bacterial contamination of shellfish closures, but to industrial operations (Anonymous, 1996b).

As of 1992, 36% of all evaluated shellfish sites in Nova Scotia were closed to harvesting. Much of the Northumberland shore has been hit hard by closures. St. George's Bay and Pictou Northumberland Shore areas had 84% and 63% of the evaluated areas closed. The Cumberland Northumberland Shore had 25% of evaluated areas closed while Colchester Northumberland Shore had the lowest percentage of closures with 12%. Despite the high number of closures however, there was still over 200 km^2 of approved sites available. Although this total of approved areas is high, the highly productive areas are mostly small and close to human activities (Machell and Menon, 1992). There are no suitable estuaries along the north shore of Nova Scotia which are not partially closed, and closures of these areas is increasing (Scarret, 1993).

High levels of closures place limits on the number of areas which may be suitable for clam culture. Scarret (1993) suggested that strategically located depuration facilities be established so that the full potential of the shellfish areas could be realized. He also suggested that depuration be made mandatory as a final quality control. There is however only one depuration facility in the province which is generally running at full capacity.

Toxic Phytoplankton

Toxic phytoplankton monitoring has been ongoing in Nova Scotia since the 1940's, but with the fatalities in P.E.I in 1987, testing was increased. In the early 1990's the monitoring project expanded and aquaculturalists were encouraged to periodically send water samples and whole animals for toxicity level testing. This coordinated effort allows for industry wide monitoring which reduces the probability of contaminated shellfish reaching the market place. Ways to avoid shellfish poisoning include proper site selection and inspection for the cysts of toxic algae in the sediment near the growout site (Schinghamer et al., 1994). No preventative measures are foolproof however and early detection of toxic blooms would be a great advantage for the industry as it would allow shellfish farmers to avoid harvesting during high risk times and shipping unsalable product (Shumway, 1990). However, there are no early warning systems to detect toxic blooms before they occur (Watson-Wright, et al, 1993).

Several genera of toxic phytoplankton are known to exist in Atlantic Canada and these can be fit into three general categories; paralytic shellfish poisoning (PSP), amnestic shellfish poisoning (ASP) and diarrhetic shellfish poisoning (DSP). Each of these will be discussed individually and related to their effects on *Mercenaria*.

Diarrhetic Shellfish Poisoning

Of the three types of shellfish poisoning, the one which is least harmful is diarrhetic shellfish poisoning or DSP. *Dinophysis* spp. (dinoflagellates) are responsible for DSP and the first reported case in Canada was from Mahone Bay, Nova Scotia in 1990 (Watson-Wright, et al,1993). The DSP toxins, which are okadiac acid and similar compounds, increase the permeability of the large intestine, thereby causing diarrhea (Couturier,1988). In addition, it is believed that these toxins may promote tumor growth (Watson-Wright, et al,1993). DSP in all likelihood is common in Canada, however its symptoms are similar to other sorts of intestinal ailments including food poisoning from bacterial contamination. The similarities of symptoms may often lead to misdiagnosis (Shumway,1990).

Although toxic levels are achieved at low concentrations (~100 cells/l), (Shumway,1990) the effects of DSP are sublethal and therefore have been largely ignored. Monitoring however, should be vigilant as this poisoning has severe effects on product quality and marketability. Closure levels for DSP are between 20 and 60 µg/100g of soft bivalve tissue in most countries, and the toxins can be very persistent as monitoring of Mahone Bay, N.S. in 1992 showed that mussels retained high levels of the toxin for most of the summer months (Watson-Wright, et al,1993).

Paralytic Shellfish Poisoning

The most well known form of shellfish poisoning is PSP or red tide. PSP is caused by a number of different dinoflagellate species of the genera *Alexandrium* and *Gonyaulax* . The toxins which cause PSP are saxitoxins and neosaxitoxins (White 1988). There are 12 PSP toxins which exist in dinoflagellates and their toxicity is dependent on the specific types and levels of toxins within the algal cells. The toxicity of PSP may actually increase after ingestion by bivalves as metabolic processing of saxitoxins within the mollusk can produce six more toxins which are not present in the algae (Shumway,1990). The deadliest of the toxins are the carbomate toxins which tend to be more prevalent in the northern latitudes, their highest levels being found in the Gulf of St Lawrence area. Blooms in the southern latitudes tent to have the less toxic N-sulfocarbomoyl compounds (Bricelj et al., 1991). Its mode of attack is progressive paralysis to respiratory failure and death, usually occurring within 3 to 6 hours (White,1988). Closure levels are 80 µg/100g soft tissue (Watson-Wright, et al et al,1993).

Bivalves may encounter PSP from two different sources. The most obvious source is from a bloom of toxic planktonic algae which are ingested by the bivalves. Very often however, PSP reports are made in winter when algal blooms are rare or in places where no phytoplankton bloom has been recorded (Schinghamer, et al., 1994). These outbreaks may result when encysted forms of toxic plankton, which normally rest on the bottom, become resuspended and subsequently ingested by bivalves (Couturier, 1988). A positive correlation between the number of cysts in the substrate and PSP levels in mussels was found in Newfoundland. The same study revealed a similar correlation between the number of cysts in the stomach of mussels and PSP toxin levels (Schinghamer, et al., 1994). Relaying areas may become infected by cysts as contaminated clams purge their systems and cause undigested cysts to accumulate in the sediments where they may lead to subsequent blooms or be reinjested by other clams (Shumway, 1990).

M. mercenaria tend not to accumulate PSP toxins as readily as other species of bivalves (White,1988). In 1972 large stocks of quahogs on the eastern seaboard of the United States growing along side stocks of *Mytilus* and *Mya* did not accumulate toxic levels while the other bivalves became extremely toxic. Tests conducted in Maine from 1979-1986, all from the same location, revealed a similar result with no quahogs being reported as toxic, while mussels and soft clams reached toxicity levels of 2,604 μg of toxin/100g of tissue (Shumway, 1990).

Reasons for this non accumulation of toxins are found in the behavioral response of *M. mercenaria* to high toxin and phytoplankton levels (Bricelj, 1991). They tend to retract their siphons and close their shells in reaction to high levels of plankton, even when non toxic, possibly to avoid gill fouling and suffocation. This state of isolation which these clams assume may not be reversed until water of acceptable quality is circulated. During this state growth reduction may occur. There have been reported cases of reduced feeding and slowed growth due to *Prorocentrum* sp. and *Aureococcus anophagefferens* (Shumway, 1990) The level of response to toxic blooms appears to be dependent on the toxicity of the algal cells. Less toxic plankton are ingested readily while more toxic cells elicit a reduction in the filtration rate. Under laboratory conditions, *Mercenaria* can be induced to ingest carbomate and reach toxic levels if fed a mixture of toxic and nontoxic cells. This food selective behavior of quahogs may explain why they are less toxic than other bivalves during natural blooms, as many phytotoxin containing blooms are highly toxic and monospecific. Since these two conditions are necessary for the cessation of feeding in hard clams, they may avoid the ingestion of toxic cells while other bivalve species continue to filter feed and accumulate high levels of toxins (Bricelj, 1991).

In the Bay of Fundy area of Nova Scotia, PSP levels in shellfish are highly variable, with the highest risks coming during the period from April to October with peak occurrences in August. Although the oceanographic conditions are very different in the Bay of Fundy than those in the Northumberland Strait, it is believed that the main factor dictating when a bloom will occur is the amount of sunlight (Smith and Gaul, 1988). Therefore, plankton blooms can be expected at roughly the same times in the Northumberland Strait, although precise predictions of high risk times are impossible.

Amnestic Shellfish Poisoning

ASP is caused by the diatom species *Nitzschia pungens* or *Pseudonitzschia pungens* and is the type of poisoning which struck Prince Edward Island mussels in the 1980s, killing 3 and making 150 ill (Watson-Wright, et al,1993). Symptoms include nausea, vomiting, diarrhea, cramps, short term memory loss, vertigo, ataxia, confusion and disorientation. In extreme cases there may be permanent neurological damage or death (Altwein, et al., 1995). Its toxin is domoic acid which is a secondary amino acid and has weak neurotoxin effects on a few individuals (Couturier, 1988). Domoic acid is an analog of the neurotransmitter L-glutamate, therefore making it capable of causing neural excitation and degeneration of brain cells until their eventual rupture (Couturier, 1988).

Toxicity levels which cause closure are 2000 µg/100g soft tissue (Watson-Wright, et al,1993).

Monitoring of domoic acid in the United States (1991-1993) found that high levels of contamination (>20 ppm) were rare, even in areas which had recently had *Pseudonitzchia australis* blooms. This may have been due to the fact that domoic acid is rapidly depurated from some shellfish. Crabs and anchovies are also known to accumulate toxic levels of domoic acid. Razor clams however, appeared to be the greatest threat to human health in this study as they had for more incidence of toxic levels of domoic acid than mussels or oysters (Altwein, et al, 1995)

Bacterial and Viral Contamination

Growing populations and expanding settlements are dumping more waste into the environment each year. As filter feeders, bivalves have the ability to process large quantities of water and accumulate particulate matter in their guts. Contaminants and pathogens are no exception. Some studies have shown concentrations of particles in the guts of bivalves to be as high as 1000 times greater than the surrounding waters (Canzonier, 1988). Harmful particles in addition to the phytotoxins previously discussed are bacteria, heavy metals and enteroviruses. The bacteria of greatest concern are *Vibrio* spp. which cause vibriosis. Vibriosis causes chills, fevers and death in severe cases. Botulism (*Clostridium botulinum*) is a highly virulent bacteria which kills 25% of those infected and is present in mud as well as in the water column. The viruses of most concern are hepatitis, viral gastroenteritis and polio (GAO, 1988, Talley, 1989). Each of these contaminants affects the clams in a different way and depurate at different rates.

Depuration

The best way to avoid contamination is through proper site selection, thereby ensuring a clean product. Unfortunately, the best culture sites are often located near rural communities with poor or non existent sewage treatment facilities (Cook and Ruple, 1988). If suitable sites are not available, then an alternative is to depurate the product of contaminants. Over thirty percent of potential sites in Nova Scotia are closed due to bacterial or industrial contamination (DOE Nova Scotia,1995) which may make depuration necessary in order to take advantage of the best growout sites. The process of depuration may be done either by relaying in the intertidal, or in a land based depuration system. Both are similar in that the bivalves are transported into clean water, with relaying being done in the natural environment, and depuration being done in large tanks with treated water. Relaying is a less effective strategy than depuration for it is limited by the amount of available space with clean water. In several cases, Nova Scotia bivalves have been shipped to P.E.I. and even to Massachusetts for relaying which is very labor intensive and may place the animals under unnecessary stress. The clearance time for bacteria may be up to 30 days for relaying and testing is much less convenient. Depuration of bacteria in a land based system is much faster (usually within a few days), and the tests can be done easily on site (Canzonier, 1988).

Depuration as a process is much more effective for the removal of bacterial infestation than others, such as phytotoxins and viruses. Depending on the level of contamination, bacteria will usually be depurated within 24-48 hours (Canzonier, 1988). The reason for this rapid cleansing is that bacteria often line the visceral mass (gut lumen and hepatopancreas) of most bivalves as well as inside of the siphons of *Mercenaria*, which allows the bacteria to be removed readily by the filtration of clean water (Perkins et al, 1980). There are indications however, that some bacteria are more resistant to depuration depending on where they reside within the mollusk (Rodick and Scheider, 1990). Viruses may take weeks to depurate as they become engulfed in fixed cells in the digestive gland or held inside of hemocytes (Canzonier, 1988). Studies done using depurated oysters on human volunteers showed that of approximately 4500 tests, 52 people became ill from Norwalk virus, indicating that depuration for viral contaminants is not as effective as for bacterial contaminants (Grohmann, et al, 1981).

Attempts have been made to increase the effectiveness of depuration for viruses and bacteria through the use of ozone treated water. The ozone is believed to inactivate microbes inside of the animals while they filter. Ozone treated water has been shown to depurate 99% of vegetative bacteria within 42 hrs (Burkhardt et al, 1992). In *Mercenaria* however, male specific bacteriophages take 11-12 days to depurate and the bacteria *Clostridium perfingens* is much more resistant to ozone than *E. coli*, which is a common indicator species. Depuration is therefore a highly risky operation due to the differences in depuration rates among species, even with treated water (Burkhad et al., 1992).

Phytotoxins are reported to be not depuratable. Detoxification rates of saxitoxins in *Mercenaria* are very slow, with severely contaminated specimens retaining toxic levels after 3 weeks of depuration (Bricelj et al, 1991). Although saxitoxin depuration may not be viable due to the residence time, domoic acid is a hydrophilic chemical which accumulates in the digestive gland. This means that it is not readily bound to intracellular spaces and therefore is depuratable. It was found that mussels containing 22.6 ± 12.9 μg/g of domoic acid could reduce their toxin levels by 90% in 48-72 hrs. (Novaczek et al., 1992).

E. coli as mentioned before is the most common indicator of contamination used although it is not necessarily a good indicator of other bacteria such as *Clostridium perfingens*, *Vibrio* and *Aeromonas*. It is not effective for indicating hydrocarbons, heavy metals or biotoxins (Cook and Ruple, 1988). Given the limitations of the process itself and the limitations of the testing methods, depuration may not be a viable option to culturing clams in mildly contaminated areas unless the contaminants which are common to the area are known and they are depuratable. Moreover, there is only one depuration facility in Nova Scotia which limits the amount of product that can be dealt with during the harvesting season.

Economic considerations for a hypothetical quahog aquaculture operation

Bivalve farming has a number of considerations which effect the economic feasibility of an operation, the most important of which are usually biological and ecological factors which impact growth and mortality (Adams et al, 1993). Other factors to consider are the technology used (Croften and Charles, 1991), the frequency of harvest and the price in relation to size (Askew, 1978). The combination of these factors affect the revenue generated and the returns of the project.

This operation is assumed to be based on the best methods found in the culture techniques section. For the nursery phase, a land based upweller was selected so that the maximum growth and survival can be achieved during this critical stage of the cycle. A facility consisting of 40 tanks is proposed which at a density of 13,500 clams per upweller has a 540,000 clam capacity. The growout system is assumed to be off bottom trays as they demonstrated the best growth and have the most predictable winter survival (Carver and Mallet, 1992). They also are the least susceptible to winter damage if planted subtidally and are easily harvested from. A break down of costs for a system of upwellers and trays are shown in Appendix 5.

Production Schedules

The first step to determining the production schedule was to look at the mortalities which are expected during a the growth cycle. Mortalities as discussed in the growth and mortality section of this project indicated that the best survival can be expected during the upweller nursery portion of the operation, and the lowest may be expected winter months. It is assumed that the survivorship will be lower in the first two winters at roughly 65% and increasing as the clams become heartier with age. Higher survival is expected during the summers at roughly 85% after moving out of the nursery phase. This schedule is shown on Table 8.

Table 8. Expected survival for a cohort of quahogs in the Northumberland Strait of Nova Scotia over a ten year period.

year	summer	winter	annual survival	cumulative survival
1	95%	65%	61.75%	61.75%
2	85%	65%	55.25%	34.12%
3	85%	85%	72.25%	24.65%
4	85%	85%	72.25%	17.81%
5	85%	85%	72.25%	12.87%
6	85%	85%	72.25%	9.30%
7	85%	85%	72.25%	6.72%
8	85%	85%	72.25%	4.85%
9	85%	85%	72.25%	3.51%
10	85%	85%	72.25%	2.53%

From the predicted mortality rates, the number of surviving clams can be calculated for a single cohort as shown in Table 9. Although for each year mortality rates are not terribly high, the cumulative mortality is very high and less than 20% of clams can be expected to survive until year four. Due to this high mortality, it is probably critical that the harvest be taken as early as possible to reduce risk and optimize returns.

Table 9. Number of quahogs expected to survive from a single cohort over ten years.

year	beginning of summer	end of summer/beginning of winter	end of winter
1	540,000	513,000	333,450
2	333,450	283,433	184,231
3	184,231	156,596	133,107
4	133,107	113,141	96,170
5	96,170	81,744	69,483
6	69,483	59,060	50,201
7	50,201	42,671	36,270
8	36,270	30,830	26,205
9	26,205	22,275	18,933
10	18,933	16,093	13,679

Harvest Schedule

The inclusion of the distribution of growth makes the harvesting schedule much more difficult to determine than if only the mean size of the clams was determined. As previously discussed, the distribution of growth can be divided into six groups; fast growers (F), moderately fast growers (MF), high average growers (HA), low average growers (LA), moderately slow growers (MS) and slow growers (S). These make up 10%, 20%, 20%, 20%, 20% and 10% of a cohort respectively. By dividing them into groups we can better predict when the clams will be ready to harvest and how many will be harvestable. The process of how a harvesting schedule was determined is outlined below.

Harvesting is carried out when the lower limit of each group has reached a harvestable size. This ensures that all individuals within the size group will be ready for harvest. The minimum sizes for each size group are shown in Table 10. In Table 10 and each of the following tables, year will be assumed to mean the end of each growing season. As the legal limit in Nova Scotia for quahog harvest is 38mm, but the general market size for littlenecks is 50mm, both of these harvest sizes were considered in the cash flow analysis. As can be seen in Table 10, the S group never reaches harvestable size, while the MS group does not reach harvestable size at a 50 mm harvest limit.

Table 10. Distribution of minimum shell lengths (mm) which define each growth group of a cohort. Shown over a ten year period. (* indicates harvest year for 38 mm harvest. ** indicates harvest year for 50 mm harvest)

year	fast	moderate fast	high average	low average	moderate slow	slow
1	18	16	14	12	10	4
2	27	24	21	19	16	6
3	36	32	28	25	20	8
4	44*	39*	35	31	25	10
5	52**	45	40*	36	29	12
6	58	51**	46	40*	33	13
7	64	56	50**	44	36	15
8	70	61	55	48	39*	16
9	75	66	59	52**	42	17
10	80	70	62	55	45	18

Table 10 shows the size distributions and harvest years for only one cohort, but in an ongoing aquaculture operation, there is an annual planting of clams to account for. Four years is the minimum time required for the first harvest of 38mm clams, and five years is the minimum time for when 50mm clams are taken, therefore new cohorts are only started up to year 5 as too few of the clams will be harvestable if it is a 10 year operation. The complete harvesting schedule over the ten year period showing all cohorts is in Table 11.

Table 11. Expected harvests by size group over a ten year period for a 38mm harvest and 50mm harvest. (f=fast, mf=moderate fast, ha=high average, la=low average, ms=moderate slow, s=slow. numbers represent the cohort)

year	38mm harvest	50mm harvest
1		
2		
3		
4	f1,mf1	
5	ha1,f2,mf2,	f1,
6	la1, ha2,f3,mf3	mf1, f2,
7	la2, ha3, f4,mf4	ha1, mf2, f3,
8	ms1, la3, ha4, f5,mf5	ha2, mf3, f4
9	ms2, la4,ha5	la1, ha3, mf4,f5
10	ms3,la5	la2, ha4,mf5

Calculation of Revenue

In the United States, quahogs are sold to the processor by the bushel, or on a per clam basis. A bushel of littlenecks will fetch up to $104 (US) (Adams, et al, 1993). This works out to about $0.12(US) per clam at a length of 25mm (Adams and van Blokland, 1995). Burleigh (1988) estimated a price of $0.20 per clam at a length of 50mm. Processors in Nova Scotia however, tend not to purchase on a per clam basis, but on a per pound basis. When the two prices above are converted to a per kilogram price, they are $24/kg (Can) and $5/kg (Can) respectively. These prices are unrealistically high as the landed price of quahogs averaged $1.33/kg (1994 Can$) from 1985 to 1995. A base price of $1.33/kg is therefore assumed.

Calculating revenue requires several steps. Revenue in this case is total weight of the harvest multiplied by the price per kilogram, so we must first figure out how to determine the total weight of the harvest. The use of minimum shell length, as outlined above, allows one to determine when the groups are harvestable, but is not useful for determining the weight of the group. An underestimate of the weight harvested will arise if the minimum shell length is used to calculate the weight of the harvest. Average length of the group must be used to determine the average weight. Table 12 shows the average length of the groups.

Table 12. Distribution of mean shell lengths (mm) within each growth group. Shown over a ten year period. (* indicates harvest year for 38 mm harvest. ** indicates harvest year for 50 mm harvest)

year	fast	moderate fast	high average	low average	moderate slow	slow
1	18	16	14	13	12	10
2	28	25	22	21	18	15
3	37	33	29	27	24	20
4	45*	40*	36	34	30	24
5	53**	46	42*	39	34	28
6	59	52**	47	44*	39	32
7	66	58	52**	49	43	35
8	71	63	56	53**	47*	38
9	76	67	61	57	50	41
10	81	71	64	60	53	43

Using the average lengths from Table 12 the average weight per clam can be calculated using the equation from the wet weight curve derivation section. These weights are shown in Table 13. The whole wet weight for a clam refers to the mass of a living clam, including the shell. From the whole wet weight, total weight of the harvest can be estimated if the number of clams per size group is determined. The number of clams from each size group is shown in Table 14.

Table 13. Mean wet weight per clam (g) for each of the growth groups over a ten year period.

year	fast	moderate fast	high average	low average	moderate slow	slow
1	3.12	2.27	1.75	1.49	1.09	0.66
2	9.26	6.73	5.19	4.42	3.24	1.96
3	18.54	13.48	10.40	8.86	6.49	3.92
4	30.51	22.19	17.11	14.58	10.67	6.46
5	44.64	32.46	25.03	21.33	15.61	9.45
6	60.39	43.92	33.86	28.86	21.12	12.78
7	77.29	56.21	43.34	36.94	27.04	16.36
8	94.95	69.05	53.23	45.38	33.21	20.10
9	113.00	82.17	63.36	54.00	39.53	23.92
10	131.16	95.39	73.54	62.69	45.88	27.76

Table 14. Number of clams per size group for a single cohort over a ten year period(* indicates harvest year for 38 mm harvest. ** indicates harvest year for 50 mm harvest)

year	total	fast	moderate fast	high average	low average	moderate slow	slow
1	513,000	51,300	102,600	102,600	102,600	102,600	51,300
2	283,433	28,343	56,687	56,687	56,687	56,687	28,343
3	156,596	15,660	31,319	31,319	31,319	31,319	15,660
4	113,141	11,314 *	22,628*	22,628	22,628	22,628	11,314
5	81,744	8,174**	16,349	16,349*	16,349	16,349	8,174
6	59,060	5,906	11,812**	11,812	11,812*	11,812	5,906
7	42,671	4,267	8,534	8,534**	8,534	8,534	4,267
8	30,830	3,083	6,166	6,166	6,166	6,166*	3,083
9	22,275	2,227	4,455	4,455	4,455**	4,455	2,227
10	16,093	1,609	3,219	3,219	3,219	3,219	1,609

Finally revenue for a single cohort may be calculated from the information in tables 13 and 14. This is accomplished by multiplying the harvest number for each size group by the average weight for that size group in the year of harvest and the expected price. This is representable by the equation:

$$r_{cn} = \sum_{a=1}^{6} (W_{acn} * N_{acn} * P)$$

r_{cn} = revenue for cohort c in year n
W= weight (kg) per clam in group 1...6 in cohort c in year n
N = number of clams harvested per growth group
P = price in dollars per kg
a = index for growth group
  1 = fast growers
  2 = moderate fast growers
  3 = high average growers
  4 = low average growers
  5 = moderate slow growers
  6 = slow growers

c = index for cohort
n = year

This equation will give total annual revenue per cohort for any given year. The harvest schedule in Table 11 must be used to determine when a harvest of a particular size group will occur. An example for a harvest at 38mm in year 4 is tabulated below (Table 15). This represents cohort (c) number one which was planted in the first year.

Table 15. The total revenue collected from the first cohort of clams in year 4. Table shows number of clams harvested, weight per clam and unit price for each of the growth groups.

	F	MF	HA	LA	MS	S	total
$N_{1,4}$ number of clams harvested	11,314	22,628	0	0	0	0	33,942
$W_{1,4}$ weight per clam (kg)	0.03	0.02	0.02	0.01	0.01	0.01	
price	1.33	1.33	1.33	1.33	1.33	1.33	
revenue	459	667	0	0	0	0	1,127

Total revenue per year must be a sum of revenue collected from all cohorts in a particular year. This calculation is represented by the equation:

$$R_n = \sum_{c=1}^{c=5} r_{cn}$$

R_n = total revenue for all cohorts in year n
c = index for cohort (equation shows sum of c=1 to c=5, but cohort number depends on flows of the operation)
n = year

Cash Flow

All relevant costs for the cash flow analysis are tabulated in Appendix 5. Most costs are straight forward except the cost of trays. Number of trays needed is calculated by using the total number of clams present and the preferred stocking density at any particular point in the growout cycle. The preferred stocking density used for the seed sized clams diring the first summer was equivalent to 13,500 per upweller unit as taken from Carver and Mallet (1991), which makes for a 40 unit upweller system. It was decided that the clams should move to a tray system at the end of the first summer to avoid some of the risks such as equipment failure during the first winter. A tray is equal to $1.62m^2$, so the first winters stocking density was 3700/tray. Castagna (1984) stated that optimal densities for seeded clams ranges between 250 to $1000/m^2$ depending on the site, which means that the selected stocking density is fairly high. But as no growth is expected during the winter it is assumed that this high stocking density is adequate so long as the density is reduced in the following year. By stocking the clams at high densities during the first year, the expense of purchasing the number of trays necessary for lower stocking densities is delayed until the following spring. As it is uncertain which densities are appropriate for the various sites in the Northumberland Strait, an intermediate density of 435/m^2 was chosen, which is equal to 704/tray. This is the density which is proposed for the rest of the growout period. Natural mortalities and harvests make old trays available each year, but each tray is assumed to have a four year life span at which point it must be replaced. The number of trays needed and the total cost of trays per year for a harvest at 38mm is shown in Table 16. Different harvest schedules, growth rates and mortality rates all effect the number of trays required for the operation. The cost per tray is assumed to be $35.

Table 16. Total number of trays needed annually, the number of new trays purchased each year and the total cost of the trays for a 38mm harvest.

year	total trays needed	number of trays purchased	cost of trays
1	139	139	4,865
2	805	667	23,345
3	1,028	222	7,770
4	1,140	112	3,920
5	1,198	197	6,895
6	1,223	692	24,220
7	1,223	222	7,770

The complete cashflows for a 38mm harvest and a 50mm harvest are shown in Appendixes 6 and 7. Both revealed that the net present values (NPV) for a *Mercenaria* farm with the expected growth and mortalities used above are extremely negative (discount rate used for the cashflows was 8%). The 38mm harvest size has an NPV of -$512,889, while the 50mm harvest size has an NPV after 10 years[11] of -$522,275. Using 38mm as

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[11] A ten year period was chosen for the length of the operation as an aquaculture lease in Nova Scotia is for 10 years.

the harvest size slightly improves the NPV and suggests that harvest should indeed take place when the size groups reach 38mm. It is also wise to harvest at the 38mm size because the 50mm harvest means that all size groups will be harvested at least one winter later. As winter mortalities are the most unpredictable, avoiding an extra winter is desirable. Harvesting at 38mm also reduces the time to first return which is also desirable.

Overall, however, quahog farming has little potential under the predicted conditions. The high mortalities combined with the long growout and low price produce revenues which are far too low to have a viable operation. The maximum revenue generated in a single year for the two scenarios is in year 8 for a 38mm harvest and it is only $2397. Revenues this low will not cover the cost of the trays or the cost of the seed, let alone the costs of the entire operation. For quahog culturing to become an option in Nova Scotia, many improvements need to be made.

One option to reduce costs is to discard a large portion of the clams at a small size so that the high cost of trays can be reduced. It was therefore proposed that smaller clams which are presumed to be the slowest growers be discarded at the end of the first growing season after the upweller phase of the operation. The groups that were kept were the F, MF and HA clams. These may be selected by sorting out all clams that are approximately 14mm and larger after the end of the first summer. By keeping only the largest clams, the operation can focus on the fast growers which reduces the number of trays needed. The NPV after 10 years for a 38mm harvest, with only the F, MF and HA size groups being kept, improved to -$486,476, which is considerably better than for when all size groups are kept (Appendix 8). Although the improvement is large, the NPV is still very unfavorable and the operation is highly unlikely to be profitable.

Sensitivity analysis

As we already know, quahog farming with a tray system is a massive money loser. In order for it to become successful, there must be drastic improvements in either growth, mortality, price or all three. A sensitivity analysis was done to determine the effects of improving these factors. These improvements were applied to an operation which uses a 38 mm harvest minimum for a scenario in which all size groups are kept and for a scenario where only the fastest growers are kept.

Growth was the first factor adjusted at 10%, 20% and 30% growth increase. These were chosen as reasonably achievable increases in growth due to selective breeding. The increases were applied to the average shell length estimates which in turn were used to calculate the per clam wet weight and revenue. The increases in growth rates meant that an adjustment needed to be done to the tray densities and the timing of tray requirements. In the previous analysis a stocking density of 3700 clams per tray was suggested for the first winters growout. With increased growth rates however, the optimal density at which the clams should be planted at will change due to the increased probability of competition between the clams. For simplicity, it was proposed that the clams be planted at a density of 704 clams/tray from the first overwinter phase to the end of growout. Also, a shorter growout time allows for more cohorts to be planted over the 10 year period. These growth improvements allow for plantings to year 7 when all size groups are kept, and up to year 8 when only the largest size groups are kept.

The winter mortalities are a severe problem in the Northumberland Strait and are predicted to kill 35% of the stock in each of the first two years. If these mortalities can be improved, then the returns will improve. The first two winters survival rates were improved to up to 95% in 5% increments. These survival improvements were applied to each of the growth improvements to determine what the effects of increased survival and growth are.

Price estimates for quahogs range from $1.33/kg to $24/kg. Therefore, prices within this range were applied to the expected growth and mortality rates as well as the growth improvements. Improvements in survival were not accounted for in this part of the analysis, as survival is the least controllable factor. Expected mortality rates were maintained throughout the sensitivity analysis for prices.

Results

All size groups kept

The results in some ways were surprising, as a 10% increase in growth actually reduced the net present value to -$535,023 (Table 17). This is explained, however, by the fact that with the increased growth, the bulk of the trays need to be purchased in the first year due to the lower stocking density, while at the predicted growth rate the biggest purchase of trays is delayed. It is not a good sign that the value of the operation decreases with increased growth. The cost of the trays far exceeds the revenue which is expected as well as the price of seed. A 20% increase in growth does improve the NPV but only slightly, to -$511,695 (Table 17). At around this level of growth increase, the increased cost of trays begins to be offset by the improved revenue, which has a maximum of $6593 in years 7 to 8. A 30% growth increase has a maximum revenue of nearly $12,000 from years 5 to 9, and a much improved NPV of -$485,485. This NPV is still very low and revenues are well below an acceptable level.

The resulting NPV's for increased winter survival combined with growth improvements are shown in Table 17. With the predicted growth the NPV's drop as mortality increases. This is because the increased survivorship produces a need for more trays which in turn drives up the costs of the operation which any improvements in revenue are not able to cover. All others show improvement in NPV's as survival increases, but the best NPV of -$447,923 for 95% winter survival and a 30% growth improvement is much too poor to indicate a viable operation.

Table 17. Net present values of a quahog farm with increased winter survival rates and growth rates when all size groups are kept (price=$1.33)

winter survival rates (percent)	predicted growth	10 percent growth increase	20 percent growth increase	30 percent growth increase
65	-512,889	-535,023	-511,695	-485,485
70	-515,898	-534,166	-511,190	-480,543
75	-519,011	-531,161	-510,522	-475,109
80	-522,228	-529,018	-509,690	-469,183
85	-525,547	-526,738	-508,695	-462,764
90	-528,971	-524,318	-507,536	-455,853
95	-532,498	-521,760	-506,213	-447,923

Although the effects of improved growth and reduced mortality are significant in improving returns, the biggest factor appears to be price, as drastic increases in survival and growth fail to produce a positive NPV. Price for quahogs is difficult to determine, however, due to the differences in reported values. As already mentioned, prices may be as low as $1.33/kg or as high as $24/kg. Therefore a test was conducted to determine if prices within this range would yield positive returns. With an assumed winter mortality of 65% for the first two years, neither the predicted growth rate nor growth increases up to 20% yielded positive returns (Table 18). In order to generate a non-negative NPV, growth has to be increased by 30% and the price has to be greater than $13/kg. At 30% higher growth and $24/kg the NPV was $402,652. With the apparently low price for quahogs in Nova Scotia however, it is unlikely to increase so drastically.

Table 18. Net present values of a quahog operation with variable price and growth rates when all size groups are kept. (winter survival is 65%)

price ($Can)	predicted growth	10% growth increase	20% growth increase	30% growth increase
2	-529,915	-517,691	-487,040	-448,087
3	-518,976	-508,907	-467,408	-409,417
4	-508,038	-500,124	-447,769	-370,747
5	-497,099	-491,340	-428,129	-332,077
6	-486,161	-482,557	-408,489	-293,407
7	-475,222	-473,773	-388,850	-254,737
8	-464,284	-464,989	-369,210	-116,067
9	-453,345	-456,206	-349,571	-177,397
10	-422,407	-447,422	-329,932	-138,727
11	-431,468	-438,638	-310,292	-100,057
12	-420,530	-429,855	-290,653	-61,387
13	-409,591	-421,071	-271,013	-22,717
14	-398,653	-412,288	-251,374	*15,953
15	-387,714	-403,504	-231,734	54,623
16	-376,776	-394,720	-212,095	93,293
17	-365,837	-385,937	-192,455	131,963
18	-354,899	-377,153	-172,816	170,633
19	-343,960	-368,369	-153,177	209,303
20	-333,022	-359,586	-133,537	247,973
21	-322,083	-350,802	-113,898	286,642
22	-311,645	-342,018	-110,564	325,312
23	-300,206	-333,235	-74,619	363,982
24	-289,268	-324,451	-54,979	402,652

* point where positive net present values are achieved

Fast, moderately fast and high average growth groups kept

The analysis shows that improvements in survival and growth make very little difference in the NPV's when only the three largest growth groups are kept (Table 19). The expected growth and survival rates give a better NPV, but when growth and survival rates are improved, there is very little improvement in the NPV's (Table 19). The reason for this is likely that the removal of the smallest groups decreases the cost of trays, but limits the revenue considerably. In the improved growth scenarios, they should be able to collect more clams faster than with the predicted growth and when the smaller groups are discarded, it eliminates the advantages gained from the improved growth. The results listed in Table 20 also indicate that focusing on the faster growing groups will not improve returns if the prices are increased. Even with a price increase up to $24/kg, the NPV is -$264,274 (Table 20).

In the above analysis, a standard number of clams was discarded regardless of the level of growth increase. More clams should in fact be kept with increased growth rates as a larger proportion of the first year clams will meet the minimum size requirement for retention. Optimum discard levels of undersized clams in relation to growth increases is a topic which may be considered for future investigation.

Table 19. Net present values (in dollars) of a quahog farm with increased winter survival and growth rates when F, MF and HA growth groups kept.

winter survival rates (percent)	predicted growth rates	10 percent growth rate increase	20 percent growth increase	30 percent growth increase
65	-486,476	-487,179	-500,657	-498,164
70	-488,783	-489,100	-500,381	-497,493
75	-489,424	-489,723	-500,293	-496,981
80	-490,061	-490,337	-500,432	-496,378
85	-490,684	-490,940	-499,950	-495,688
90	-491,301	-491,533	-499,671	-494,910
95	-491,907	-492,144	-499,367	-496,916

Table 20. Net present values (in dollars) for a quahog farm with variable prices and growth rates when only F, MF and HA growth groups are kept.

Price (Canadian dollars)	predicted growth	10% growth increase	20% growth increase	30% growth increase
1.33	-486,476	-487,180	-500,654	-498,164
2	-483,198	-482,999	-495,292	-491,546
3	-478,306	-476,759	-487,288	-481,671
4	-473,413	-470,519	-479,284	-471,793
5	-468,521	-464,279	-471,280	-461,917
6	-463,628	-458,039	-463,276	-452,040
7	-458,736	-451,799	-455,272	-442,164
8	-453,843	-445,558	-447,268	-432,287
9	-448,951	-439,318	-439,265	-422,411
10	-444,059	-433,078	-431,261	-412,534
11	-439,166	-426,838	-423,257	-402,658
12	-434,274	-420,598	-415,253	-392,781
13	-429,381	-414,358	-407,249	-382,905
14	-424,489	-408,118	-399,245	-373,028
15	-419,597	-401,878	-391,241	-363,152
16	-414,704	-395,638	-383,237	-353,276
17	-409,812	-389,398	-375,234	-343,399
18	-404,919	-383,158	-367,230	-333,523
19	-400,027	-376,918	-359,226	-323,646
20	-395,135	-370,678	-351,222	-313,770
21	-390,242	-364,438	-343,218	-303,893
22	-385,350	-358,197	-335,214	-294,017
23	-380,457	-351,957	-327,210	-284,140
24	-375,565	-345,717	-319,206	-274,264

Discussion of economic factors

The technology for improving the growth rates of quahogs is well understood and proven, but these improvements have yet to make their way into Atlantic Canadian shellfish hatcheries. Growth improvement takes several generations with a breeding program which is still distant with respect to Nova Scotia brood stock. Hybrids and clams selected for faster growth are likely available from US suppliers, but their performance in the cooler waters of Nova Scotia is unknown and the importation of foreign seed is tightly regulated. Without these improvements available, the potential for the farming of quahogs is very low and not likely to succeed.

Improving the growth rates of quahogs is however not enough to make *M. mercenaria* farming a profitable industry in Nova Scotia. Growth rate improvements of up to 30% alone do not appear to give the hypothetical quahog farm described any chance of having positive returns. The combination of improved growth rates and winter survival rates still has an NPV of about -$448,000. Clearly the costs of tray farming of clams in Nova Scotia are too high to allow for profit under the expected conditions, as revenues generated are never enough to cover the cost of trays or seed. If one looks at the cumulative NPV's of the scenarios in appendices 6,7 and 8, they will see that in all of these cases, the NPV's decrease in every year of the operation. This means that money is lost in every year of a ten year operation in those scenarios. There is no real chance for a profitable business with this kind of negative cash flow.

Apparently, the only way that a Nova Scotia quahog farming can become profitable is to increase growth rates by approximately 30% and drastically increase the landed price to over $13/kg. However, the price of approximately 1.33/kg which presently exists is very unlikely to change even with declining wild stocks. This is because the PED for Nova Scotia quahogs is 0.16 (as discussed under market considerations) which indicates that the demand is far too elastic to increase to the necessarily high levels. Unless market conditions change drastically and there is much effort put into the improvement of quahog growth rates, the only reasonable conclusion to make is that clam farming on the Northumberland coast is not economically viable and will remain so.

Conclusions

As a potential location for quahog aquaculture, the Northumberland Strait has a number of negative factors working against it. Although the Northumberland coast itself has numerous estuaries with suitable conditions which, on a biological basis are adequate for survival, they are not the best conditions for aquaculture. The long winters make for a short growing season and high winter mortalities. The growing season lasts only about 5 months with temperatures only approaching optimal levels during July, August and September. When compared to the southern United States where quahog culture is already well established, this is a very short season. Winter storms in the Northumberland Strait have been known to destroy equipment or damage it to the point which allows for greater susceptibility to the numerous predators which inhabit the area. Primary production is high enough for good growth, but the low temperatures overall do not allow for much growth and the clams are unable to take advantage of the high productivity.

Human health concerns are another problem. Much of the coastline is closed to shellfish harvest due to contamination and the Department of the Environment has been ineffective in cleaning up areas and dealing with polluters. Depuration is an option although there is only one facility in the province. This coastline is also notorious for shellfish poisoning which has direct effects on sales as well as negative growth effects on the clams themselves.

The socio/political climate in Nova Scotia does not lend itself to aquaculture either. Much of the population have a strong fishing and coastal use heritage which they feel will be threatened by aquaculture. It is not seen , in most cases, as an opportunity to broaden the economic base of their community but as a threat to the traditional way of life, through resource conflicts and destruction to the environment. The government has implemented organizations such as the Regional Development Advisory Committees to try to win support for new development projects by getting the communities involved in the decision making process. Despite these efforts obtaining a lease is a very long and complex process which makes the commencement of new projects very difficult.

Economically speaking, quahog culture has very little potential for success. The low landed price which ranges between $1 and $1.60 per kilogram is simply too low to permit adequate returns. Although the market in Nova Scotia seems as if it should be able to absorb any production, this low price guarantees failure to any producer. Also, the elastic demand of Nova Scotia quahogs indicates that it is unlikely that the price will increase to a level which could potentially make the culture of these clams viable. Revenues generated simply cannot cover costs and any operation is very unlikely to be profitable.

On the brighter side, there may be a future for quahog culture provided that market changes and technological advances are taken advantage of. Growth rates are a heritable trait and selection of fast growing broodstock may help to eliminate much of the winter mortalities which are such a problem at this time, as well as shorten the time to return on investment. Advances in nursery technology through the use of upwellers and feeds may make growout times much shorter as well. These sorts of advances are meaningless however, unless the price of clams in Nova Scotia increases considerably, which seems unlikely with the current demand structure for clams. One can only conclude that at this point in time, that clam aquaculture in the Northumberland Strait is not a commercially viable industry.

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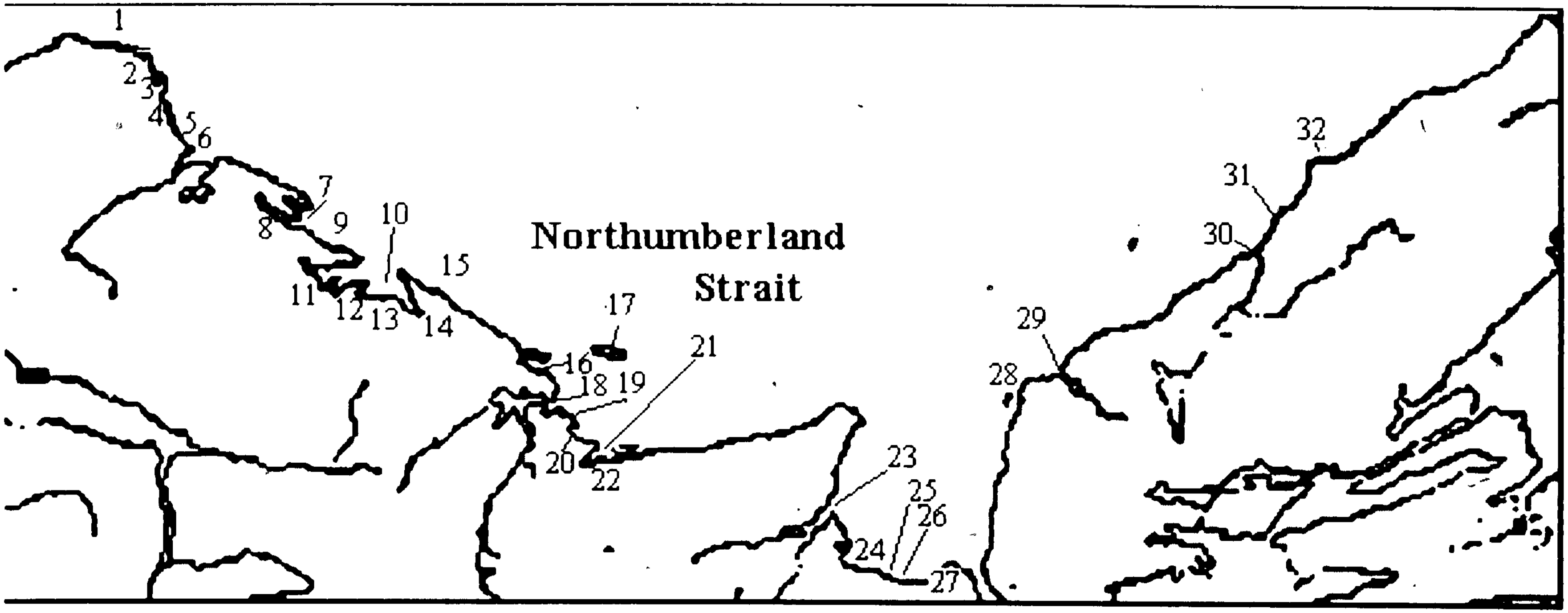
Appendixes

Appendix 1. The Norhtumberland Strait of Nova Scotia including areas with quahog culture potential (*=closed due to bacterial contamination, **=partially closed due to bacterial contamination, ***=open with high coliform counts or closed with depuration potential) (compiled from Scarret, 1993).



1 Tidnish (*) 2 Lorneville (*) 3 Northport (*) 4 Linden (*) 5 Port Howe, River Philip (*)6 Pugwash (**) 7 Fox Harbour (**) 8 Wallace (*) 9 Malagash North Shore 10 Amat Sound 11 McNabs Bay (Malagash) 12 Tatamagouche Bay (**) 13 Brule Harbour (**) 14 John Bay (*) 15 Toney River (**) 16 Caribou (**) 17 Pictou Island 18 Pictou Harbour (**) 19 Chance Harbour, 20 Little Harbour (***) 21 Merigomish Harbour 22 Roy's Gut (***) 23 Antigonish Harbour (**) 24 Pomquet (***) 25 Tracadie Harbour (**, ***) 26 Linwood 27 Havre Boucher (**) 28 Port Hood (**,***) 29 Mabou Harbour (***) 30 Margaree Harbour (*) 31 Grand Etang (*) 32 Cheticamp (*, ***)

Appendix 2 Derivation of the average shell length growth curve for Mercenaria mercenaria *in the Northumberland Strait.*

Derivation of the average shell length growth curve for *M. mercenaria* in the Northumberland involved several steps. The first step was to plot each of the von Bertallanffy equations listed in Table 1A. These growth equations are representative of quahog growth from six locations in the Northumberland Strait. Calculations of average shells length over 15 years at each location is shown in Table 2A. An average was taken of all of these growth weights and each area was given equal weight (Table 2A).

Table 1A. Von Bertalanffy growth equations for quahogs from six locations in the Northumberland Strait.

location	von Bertalanffy equation	source
West River P.E.I.	Lt=100.5(1-e$^{[illegible]}$)	Landry et al (1993)
Pownal Bay P.E.I.	Lt=125.4(1-e$^{[illegible]}$)	Landry et al (1993)
Hillsborough P.E.I.	Lt=96.8(1-e$^{[illegible]}$)	Landry et al (1993)
Fox Harbor N.S.	Lt=90.648(1-e$^{[illegible]}$)	Witherspoon (1984)
Tatamagouche N.S.	Lt=117.215(1-e$^{[illegible]}$)	Witherspoon (1984)
Wallace Harbor N.S.	Lt=121.361(1-e$^{[illegible]}$)	Witherspoon (1984)

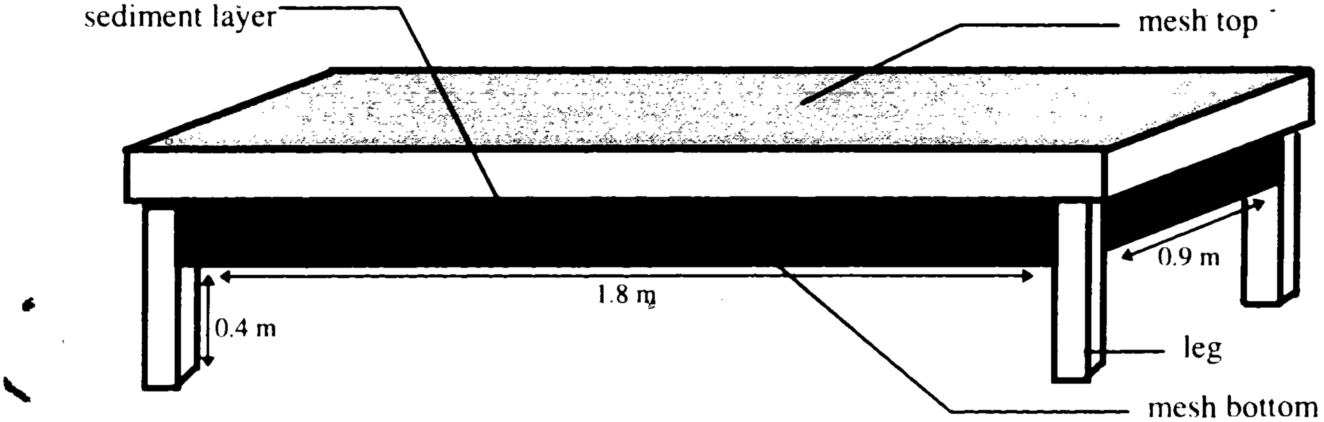
Table 2A. Average quahog shell lengths in mm for six locations in the Northumberland Strait over 15 years.

year	west river	pownal bay	hillsborough river	fox harbor	tatamagouche	wallace harbor	average length
1	24.79	16.77	9.45	12.33	10.19	9.70	13.87
2	28.84	20.29	18.31	21.88	19.60	19.92	21.47
3	32.67	23.70	26.28	30.26	28.18	29.21	28.38
4	36.30	27.01	33.43	37.62	36.00	37.64	34.67
5	39.74	30.20	39.86	44.09	43.14	45.30	40.39
6	42.99	33.29	45.64	49.76	49.65	52.26	45.60
7	46.07	36.28	50.83	54.74	55.59	58.59	50.35
8	48.98	39.17	55.49	59.12	61.00	64.33	54.68
9	51.74	41.97	59.68	62.96	65.94	69.55	58.64
10	54.35	44.68	63.45	66.34	70.45	74.30	62.26
11	56.82	47.30	66.83	69.30	74.56	78.60	65.57
12	59.15	49.83	69.87	71.90	78.31	82.52	68.60
13	61.37	52.29	72.61	74.19	81.73	86.07	71.37
14	63.46	54.66	75.06	76.19	84.85	89.30	73.92
15	65.44	56.96	77.27	77.96	87.69	92.24	76.26

Appendix 3. Shell lengths and standard deviations of first year quahogs planted in three different areas of New Brunswick during the summer of 1991.

		Caraquet	Caraquet	Caraquet	Lameque	Lameque	Bouctouc	Bouctouc	Bouctouch
	29-Jun	aug 20	10-Oct	10-Oct	24-Aug	18-Oct	27-Jul	24-Aug	12-Oct
	2.2	4.8	3.9	7	3.1	3.2	2.9	5.1	5.2
	3	4.9	4.1	7.1	3.2	3.2	3	5.7	6.4
	3	4.9	5.2	7.1	3.5	3.4	3.3	6	6.7
	3	5.1	5.3	7.1	3.7	3.9	3.3	6.1	6.7
	3	5.2	5.3	7.2	3.7	4	4	6.1	7.5
	3	5.2	5.5	7.2	3.7	4.1	4	6.4	8
	3	5.4	5.7	7.2	3.8	4.3	4.1	6.8	8.2
	3	5.4	5.7	7.2	3.9	4.3	4.2	7	8.3
	3	5.5	5.7	7.2	4	4.5	4.2	7.2	8.4
	3	5.5	5.7	7.3	4	4.6	4.2	7.3	8.4
	3.1	5.5	5.8	7.3	4	4.7	4.2	7.4	8.4
	3.1	5.5	5.8	7.3	4.1	4.8	4.2	7.5	8.6
	3.2	6	5.9	7.3	4.1	4.9	4.4	7.6	8.6
	3.2	6	5.9	7.4	4.2	5	4.5	7.6	8.7
	3.2	6.1	5.9	7.4	4.2	5	4.5	7.8	8.7
	3.2	6.1	6	7.5	4.3	5	4.8	7.9	8.9
	3.2	6.2	6	7.5	4.4	5	4.8	8	8.9
	3.2	6.3	6	7.5	4.4	5	4.8	8.1	8.9
	3.2	6.3	6	7.5	4.5	5	4.8	8.2	9.2
	3.2	6.4	6	7.6	4.6	5	5	8.2	9.2
	3.2	6.4	6.1	7.6	4.7	5.1	5	8.2	9.3
	3.2	6.5	6.1	7.6	4.7	5.1	5	8.3	9.6
	3.5	6.5	6.2	7.6	4.8	5.2	5	8.4	9.8
	3.5	6.6	6.2	7.7	4.8	5.2	5.1	8.6	10.1
	3.5	6.6	6.3	7.7	4.9	5.2	5.3	8.7	10.2
	3.5	6.6	6.3	7.8	5	5.6	5.4	8.8	10.5
	3.5	6.7	6.4	7.9	5.1	5.6	5.5	9	10.6
	3.8	6.8	6.4	8	5.1	5.7	5.5	9	10.7
	4	6.9	6.4	8	5.2	5.8	5.5	9	10.8
	4	7	6.5	8.2	5.2	5.8	5.6	9.1	10.9
	4	7.1	6.5	8.2	5.2	5.8	5.7	9.2	10.9
	4	7.1	6.6	8.2	5.2	5.8	5.7	9.5	11
	4	7.4	6.6	8.4	5.2	6	5.7	9.6	11
	4	7.6	6.6	8.5	5.3	6.4	5.8	9.6	11.1
	4	7.7	6.6	8.5	5.4	6.4	5.8	9.6	11.4
	4.2	7.9	6.6	8.6	5.4	6.5	6	9.7	11.4
	4.2	7.9	6.6	8.7	5.6	6.5	6.1	9.7	11.6
	4.8	8	6.6	8.9	5.6	6.5	6.2	9.7	11.6
	4.8	8.2	6.6	9	5.8	6.6	6.2	9.8	11.6
	5	8.2	6.7	9	5.8	6.6	6.2	9.8	11.6
	5.2	8.3	6.7	9	6	6.9	6.3	10.2	11.6
	5.3	8.4	6.7	9	6.2	7	6.3	10.4	11.7
			7	9		7.1	6.3	10.6	11.8
		8.4	6.7	9	6.2	7.2	6.6	11	12
		8.5	6.7	9	6.3	7.3	6.8	11.1	12.1
		8.6	6.8	9.1	6.8	7.3	6.9	11.3	12.2
		8.8	6.8	9.2	6.9	7.3	6.9	11.3	12.3
		8.9	6.8	9.7	8.1	7.7	7.9	11.6	12.6
		9.9	6.8	9.7	8.7	8.2	9.3	11.8	14.3
		10	6.8	9.8	8.8	8.3	11.2	12.3	15.3
		10.2	7	9.9					
				9.9					
				10.1					
				10.3					
				10.8					
				10.9					
				11.1					
				12.8					
mean	3.58	6.92		6.18	5.05	5.61	5.40	8.74	10.07
SD	0.69	1.40		0.64	1.27	1.25	1.48	1.70	1.99

Appendix 4. Diagram of an off bottom tray for quahog growout.



Appendix 5. Costs associated with nursery and growout of quahogs.

Capital costs

		price per unit (Canadian dollars)	
Fiberglass tanks		6,560	
electrical pumps		1180	
intake line		580	
upweller units (inc pipe, glue,mesh)		600	
temperature recorder		200	
salinity recorder		200	
electrical cord		40	
building supplies and tools		2,000	
building		20,000	
trays		35/tray	numbers depend on growth, mortality and stocking density
truck		10,000	
boat		20,000	

Other variable costs

-fuel		2,200/yr	
-seed clams		4,860/yr	$9/1000 clams
-electricity		700/yr	
-material and supply		2,000/yr	
-wages	4480/yr		based on part time help paid $7/hour

Other fixed costs

application and administration costs		317	
-Salary		30,000/yr	
-loan payment	3.375/yr		based on 10% interest rate on $30,000 loan
-insurance	6,135/yr		based on 10% of capital and seed clams

Appendix 6. Cash flow for a quahog operation with a harvest at 38 mm shell length, with expected growth and mortality rates and a price of $1.33/kg.

Year	0	1	2	3	4	5	6	7	8	9	10
Harvest Revenues	0	0	0	0	2,407	3,570	4,538	4,538	5,120	2,713	1,550
Capital expenses											
annual tray costs		-4,853	-23,331	-7,785	-5,625	-8,510	-25,387	-7,785			
Fiberglass tanks	-6,560										
electrical pump	-1,180										
intake line	-580										
upweller units	-600										
temperature recorder	-200		-200		-200						
salinity recorder	-200		-200		-200						
electrical cord	-40										
building supplies and tools	-2,000			-1,500							
building	-20,000										
truck	-10,000					-10,000					
boat	-20,000										
Operating cash flows											
application and administration c	-317	-117	-117	-117	-117	-117	-117	-117	-117	-117	-117
seed clams		-4,860	-4,860	-4,860	-4,860	-4,860					
electricity	-700	-700	-700	-700	-700	-700	-200	-200	-200	-200	-700
salary	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000
wages	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480
material and supply	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000
fuel	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200
loan payment	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375
insurance	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132
Net Cash Flows	-110,564	-58,717	-77,595	-63,149	-57,481	-68,804	-69,352	-51,751	-43,384	-45,791	-47,453
Present Value	-110,564	-54,367	-66,525	-50,130	-42,251	-46,827	-43,704	-30,196	-23,439	-22,907	-21,980
Cumulative Net Present Value	-110,564	-164,931	-231,456	-281,586	-323,836	-370,664	-414,367	-444,563	-468,002	-490,909	-512,889

Appendix 7. Cash flow for a quahog operation with expected growth and mortality rates, harvests at 50 mm shell length and a price of $1.33/kg.

Year	0	1	2	3	4	5	6	7	8	9	10
Harvest Revenues	0	0	0	0	0	485	1,175	1,667	2,039	2,039	1,652
Capital expenses											
annual tray costs		-4,853	-23,331	-7,785	-5,625	-8,510	-25,387	-7,785			
Fiberglass tanks	-6,560										
electrical pump	-1,180										
intake line	-580										
upweller units	-600										
temperature recorder	-200		-200		-200						
salinity recorder	-200		-200		-200						
electrical cord	-40										
building supplies and tools	-2,000			-1,500							
building	-20,000										
truck	-10,000					-10,000					
boat	-20,000										
Operating cash flows											
application and administration c	-317	-117	-117	-117	-117	-117	-117	-117	-117	-117	-117
seed clams		-4,860	-4,860	-4,860	-4,860	-4,860					
electricity	-700	-700	-700	-700	-700	-700	-200	-200	-200	-200	-200
salary	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000
wages	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480
material and supply	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000
fuel	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200
loan payment	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375
insurance	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132
Net Cash Flows	-110,564	-58,717	-77,595	-63,149	-59,889	-71,889	-72,715	-54,622	-46,465	-46,465	-46,852
Present Value	-110,564	-54,367	-66,525	-50,130	-44,020	-48,926	-45,823	-31,871	-25,103	-23,244	-21,701
Cumulative Net Present Value	-110,564	-164,931	-231,456	-281,586	-325,606	-374,532	-420,355	-452,226	-477,330	-500,574	-522,275

Appendix 8. Cash flow for a quahog operation focusing only on fast, moderately fast and high average growth groups. Expected growth and mortality rates, harvests at 38mm shell length and a price of $1.33 are assumed.

Year	0	1	2	3	4	5	6	7	8	9	10
Harvest Revenues	0	0	0	0	1,127	1,671	1,671	1,671	1,671	1,671	1,671
Capital expenses										0	0
annual tray costs		-2,415	-7,046	-3,893	-2,812	-813	-2,415	-7,046	-1,470		
Fiberglass tanks	-6,560										
electrical pump	-1,180										
intake line	-580										
upweller units	-600										
temperature recorder	-200		-200		-200						
salinity recorder	-200		-200		-200						
electrical cord	-40										
building supplies and tools	-2,000			-1,500							
building	-20,000										
truck	-10,000					-10,000					
boat	-20,000										
Operating cash flows											
application and administration c	-317	-117	-117	-117	-117	-117	-117	-117	-117	-117	-117
seed clams		-4,860	-4,860	-4,860	-4,860	-4,860	-4,860	-4,860	0	0	0
electricity	-700	-700	-700	-700	-700	-700	-700	-700	-200	-200	-200
salary	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000	-30,000
wages	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480	-4,480
material and supply	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000
fuel	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200	-2,200
loan payment	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375	-3,375
insurance	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132	-6,132
Net Cash Flows	-110,564	-56,279	-61,310	-59,257	-55,949	-63,006	-54,608	-59,239	-48,303	-46,833	-46,833
Present Value	-110,564	-52,110	-52,563	-47,040	-41,124	-42,881	-34,412	-34,565	-26,096	-23,428	-21,693
Cumulative Net Present Value	-110,564	-162,674	-215,237	-262,277	-303,401	-346,282	-380,694	-415,259	-441,356	-464,784	-486,476