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2002 Survey for Ocean Quahogs (*Arctica islandica*) at the mouth of St. Marys Bay, Nova Scotia

Relevé de 2002 du quahog nordique (*Arctica islandica*) à l'entrée de la baie St. Mary's (Nouvelle-Écosse)

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ABSTRACT

There has been sporadic interest in developing a fishery for ocean quahogs (*Arctica islandica*), in Nova Scotia since the 1920's. Aa small inshore fishery sells small ocean quahogs to the live market, but there is interest in establishing a processing plant to utilise the larger quahogs. One area of interest is St. Mary's Bay, Nova Scotia, where a large inshore bed of quahogs has been known to exist. A survey conducted in 1997 had difficulty determining the distance towed, and did not cover the full extent of the bed. This document reports on a 2002 industry funded survey which covered a larger area. The ocean quahog bed in St. Mary's Bay has an estimated biomass of 158,000 mt which can produce a sustainable yield of 2,344 t per year. The meat yield would be approximately 27% of this or 633 t. The fishery would have little bycatch of other species. This harvest rate would not be enough to supply a processing plant and so other quahog beds would have to be utilized.

RÉSUMÉ

La pêche du quahog nordique (Arctica islandica) a suscité un intérêt sporadique en Nouvelle-Écosse depuis les années 1920. Une petite pêche côtière sert à capturer des quahogs destinés à être vendus vivants, mais on s'intéresse à l'établissement d'une usine de transformation pour utiliser les quahogs de grande taille. À cet égard, la baie St. Mary's (Nouvelle-Écosse) est un endroit qui retient l'intérêt, car on sait qu'il y existe un grand gisement de quahogs. Un relevé réalisé en 1997 n'a pas permis de déterminer la distance parcourue et ne portait pas sur la totalité du gisement. Le présent document s'appuie sur un relevé financé par l'industrie en 2002, qui s'étendait sur une plus vaste zone. La biomasse estimative du gisement de quahog nordique de la baie St. Mary's serait de 158 000 tm, pouvant produire un rendement soutenu de 2 344 t par année. Le rendement de chair serait d'environ 27 % ou 633 t. Les prises accessoires d'autres espèces au cours de cette pêche seraient très limitées. Le taux de capture ne serait pas suffisamment élevé pour approvisionner une usine de transformation, de sorte qu'il faudrait avoir recours à d'autres gisements de quahogs.

INTRODUCTION:

The earliest cited attempt to fish for ocean quahogs in Nova Scotia was made during the 1920's by Capt. McKenzie Bower of Jordan Bay. After finding quahogs in his lobster traps and attached to his ground lines, he built a dry dredge to tow behind his gas-powered boat. He caught small quantities of quahogs which he used for baiting long-lines. (Chandler, 1983)

Ocean quahogs have drawn commercial interest, and there have been attempts to develop a fishery. In 1970-71 Triton Sea Products established a fishery and processing facility at Port Medway, Nova Scotia. They shipped live or frozen quahogs to the United States for the half-shell trade. Larger quahogs were shucked, minced and shipped frozen to the United States for use in the canned chowder and stuffed clam market. The company reported landings of 907 t and 1,361 t for 1970 and 1971 (Rowell and Chaisson, 1983). Although they ceased operations in 1971, the economics of fishing, processing, and marketing of the ocean quahogs was not a significant factor in the decision to cease operations (Bissell, 1972). Although there have been several surveys to assess the biomass and potential yield for an ocean quahog fishery (Medcof 1957; Chandler 1965, 1983; Medcof *et al.* 1971; Rowell and Chaisson 1983), the Triton Sea Products facility has been the only attempt at establishing a processing plant in Nova Scotia.

Currently there is a small inshore fishery that markets the smaller ocean quahogs live, and there is renewed interest in starting a plant to process ocean quahogs. This would allow for an expansion of the inshore fishery and use of larger quahogs not suitable for the live market. One proponent of a processing plant was interested in a large ocean quahog bed at the mouth of St. Mary's Bay. This bed was partially surveyed in 1997 with an estimated biomass of 59,500 tonnes (Duggan et al. 1998). It was concluded that the annual landings necessary to support a processing plant (6,000 t), was not sustainable from a bed of this size. It was recognized that the quahog bed probably extended beyond the 1997 survey area, and that an expanded survey should be conducted to estimate the biomass and potential yield in this area.

This document describes an industry-funded survey conducted in 2002, and discusses the potential yield from this bed.

Methods:

The area to be surveyed was first defined using past surveys, maps of bottom types, and information on quahog distribution from fishermen. Stations were randomly assigned with the provision that the stations would be at least 1.5 km apart. The random station assignment was plotted to confirm that the entire area would be covered by the station assignment.

A 44' Cape Island design vessel equipped with a cage type hydraulic dredge and stern ramp was used for the survey. The dredge was 2 m wide and 4 m long with a 1.4 m knife blade. The dredge had bar spacing of 31.75 mm, although for the survey it was lined with 1 inch square wire mesh. The vessel was equipped with both a Mac-Sea 7.5 navigation package and a Questar-Tangent bottom discrimination system.

At each assigned station the bottom was first checked with the vessel's echo sounder and the Questar-Tangent system to confirm that the bottom was dredgeable. A five-minute tow was conducted, with the navigation system recording the tow track so that the exact distance would be known. If there was no suitable bottom in the area of the assigned station, the location was marked as not dredgeable and the vessel moved to the next station.

For each station the volume of the catch was measured by shovelling the entire catch into $0.0413 m^3$ ($1.46 ft^3$) plastic totes. All ocean quahogs and other large clam species were separated out from five totes. From a second sub-sample of two totes, all material and animals were sorted and weighed. When the catch was less than 7 totes the entire catch was processed. The total catch weight of ocean quahogs for each tow was estimated from these two sub-samples as:

$$W_{tot} = (W_{QCl} + W_{QCo}) * V_{Tot}/(V_{QCl} + V_{QCo}) \qquad 1$$

where:

W_{tot} = Estimated total weight of quahog catch

W_{QCl} = Weight of quahogs in 5 tote clam subsample

W_{QCo} = Weight of quahogs in 2 tote catch composition subsample

V_c = Volume of catch

V_{QCl} = Volume of 5 tote clam subsample

V_{QCo} = Volume of 2 tote catch composition subsample

An estimate of the total number of quahogs caught in each tow was obtained by counting out two totes of quahogs of known weight and applying this to the estimated total weight of quahogs caught as:

$$N_{tot} = N_{ss} * W_{tot}/W_{ss} \qquad 2$$

where:

N_{tot} = Total number of quahogs caught in tow

N_{ss} = Number of quahogs in counted subsample

W_{tot} = Estimated total weight of quahogs in tow

W_{ss} = Weight of quahogs in counted subsample

These estimates were then standardized to a 300-meter tow by multiplying by the factor:

$$F = 300/\text{Tow distance} \qquad 3$$

For each station a random sample of 100 quahogs were measured to construct a length frequency, and a sample of 30 quahogs, selected to cover the full size range of quahogs from the tow, was labelled and frozen for morphometric analysis in the laboratory.

For the morphometric sample, the length, width and height of each shell were measured to the nearest mm. The weights, recorded to the nearest 0.01g, were total wet weight, total wet tissue weight (no shell), wet foot weight, gutted foot weight (gonad and digestive diverticulum removed), remaining tissue weight, and shell weight. For all except the first two, dry weights were recorded after drying to constant dry weight at 90°C. If there was sand evident within the shell, it was scraped out and weighed separately. Gonad condition was determined for each quahog according to the five stages described in Ropes (1968): fully spent; early active; late active; ripe; and spawning. The shells were numbered and a subsample was aged.

Biomass in the survey area was calculated as:

B = survey area/area of a standard tow * (average catch/standard tow) 4

Equation 4 assumes that the stations are independent of each other and thus there is no spatial correlation (stations close together being more similar than those further apart), so a second estimate which included spatial correlation was calculated using the Surfer software package. For this analysis the spatial correlation was first modeled with a variogram using a spherical model with a nugget. The variogram model was fit to the data with least squares, and then used to produce a kriged grid. The biomass was then calculated from this grid. For both these analysis the stations too rocky to dredge were assigned a catch of 0.0 kg. The variogram was cross-validated using the formulas outlined by Cressie (1993):

Cressie's (2.6.15) $$(1/n)\sum_{j=1}^{n}\left\{\left(Z(s_j)-\hat{Z}_{-j}(s_j)\right)/\sigma_{-j}(s_j)\right\} \qquad 5$$

Cressie's (2.6.16) $$\left[(1/n)\sum_{j=1}^{n}\left\{\left(Z(s_j)-\hat{Z}_{-j}(s_j)\right)/\sigma_{-j}(s_j)\right\}^2\right]^{1/2} \qquad 6$$

These formula cannot prove the variogram is correct, merely that it is not grossly incorrect. If successful the cross validation means "one can feel confident that the prediction based on the fitted variogram is approximately unbiased and that the mean-squared prediction error is about right." (Cressie 1993).

Plots were created of morphometric parameters that were necessary in understanding growth of *A. islandica* and potential meat yield from different sizes.

A subsample of quahogs from the morphometrics samples were aged using the acetate peel technique (Thompson, Jones and Dreibelbis. 1980; Thompson, Jones and Ropes 1980; Ropes, Murawski et al. 1984; Ropes, Jones et al. 1984). There was a lack of small clams in the survey samples, making it difficult to fit a growth curve. To overcome this, data from Rowell et al.'s 1990 ocean quahog maturity study in St. Mary's Bay were included. These data consisted of 104 quahogs 21 to 65 mm in length and 2 to 28 years old. The data from the two data sets were combined and a von Bertalanffy growth curve was fit to the combined data using the S-Plus statistical package. The growth curve formula is:

$$L_t = L_\infty [1-e^{-k(t-t_0)}] \qquad 7$$

where L_t is length at time t, L_∞ is the asymptotic length, t_0 is the theoretical age at length zero, and k is a growth coefficient for the rate at which the animal grows towards L_∞.

Since the aged sample was small, it was not suitable for constructing an age length key to convert the length frequency data to age frequencies. This would have allowed and estimate of total mortality (Z) using the catch curve method (Ricker 1975). An alternative was to use Beverton and Holt's (1956) method. This method takes the length frequency data and applies a time period for the animals to grow through a size range using the von Bertalanffy parameters. Total mortality is estimated with the formula:

$$Z = (K(L_\infty - L_m))/(L_m - L') \qquad 8$$

where L' is the smallest length fully represented in the length frequency data, L_m, is the mean length of all clams ≥ L', and K and L_∞ are von Bertalanffy growth curve parameters.

The Maximum Constant Yield (MCY), the level of harvesting activity that can be maintained annually without depleting the stock, was calculated from the biomass estimate using Gulland's Model (Gulland 1971), with modifications (Zhang 1999). The equation for MCY that was used is as follows:

$$MCY = x\ M\ B_o \qquad 9$$

where x is a constant that is related to growth and mortality characteristics of a particular stock, M is the natural mortality rate of the population, and B_o is the virgin biomass of the target stock (Zhang 1999). A recent Expert Opinion on harvest levels for inshore ocean quahogs recommended the use of the MCY method with a constant of 0.33 in data poor situations (DFO, 2005).

Results:

The survey area is shown in Figure 1 with tow locations and stations that were determined to be too rocky to tow. A large portion of the proposed survey area consisted of rocky bottom and was not dredgable. In the areas of suitable bottom, 43 stations were sampled. In tow 20 the cage came up full of gravel and rather than trying to shovel it into totes for processing, a catch composition sample of two totes was taken, and then the rest of the catch was processed on the dumping table to pick out all quahogs caught. The set locations and tow information is provided in Table 1. The data on the total and quahog raw catch weights are given in Table 2. Up to 85% by weight of the dredge contents was quahogs. Catches were standardized to a 300 m long tow with the 1.44 m width of the cutting blade of the dredge. Figure 2 shows catch per standard tow as a contour map of the survey area. There appears to be a patch of high abundance in the northern tip of the survey area, and these animals have average lengths between 70 and 80 mm.

Table 5 shows the composition of the catch from the survey. Quahogs made up 44% of the catch by weight, and after taking quahogs and inert material (rock, shell, mud and driftwood) into account, other living species only made up 1.2% of the catch. There does not appear to be a by-catch problem with this gear in this area. The largest by-catch of a commercial species was 0.1% for rock crab, and no other species made up more that 0.33% of the catch.

The biomass estimated by applying equation 4 to the average catch per standard tow was 157,843 t of *A. islandica* within the survey area. The mean catch per standard tow for the stations that were dredged was 309.3 kg with a standard error of 43.5 kg. When the rocky stations are included with zero catch the mean catch per standard tow is 137.1 kg with a standard error of 24.8 kg. The 95% confidence interval for the biomass was 95,248 to 201,671 t.

To examine this further, the data was converted to UTM coordinates and analysed with the Surfer surface mapping system (Golden Software Inc.). A spherical variogram (Figure 7) fit with least squares showed anisotrophy, tows were more similar in one direction (30.1 degrees) than others. This analysis produced a range of 3.3 km at 30.1 degrees for the major axis, a nugget value of 303.6 and a sill at 75310. The anisotrophy ratio, the ratio of the range of the major axis to that of the minor axis, was 1.06. This is considered mild anisotrophy, as ratios less than 3 are usually not clearly visible on a map of the data.

The data was gridded using this variogram, and the volume within the survey area calculated. The resulting biomass estimate was lower than the formula above at 141,717 t in an estimated area of 464.90 km^2.

The bar spacing of the dredge (31.75 mm), can be used to obtain a rough estimate of the selectivity when it is fishing commercially, i.e. without the liner. Since quahogs do not struggle like a finfish, the gear selectivity is due to the mechanical sorting process. Quahogs with a shell width less than the bar spacing can pass through the dredge. Taking the data from the quahogs processed for morphometrics, a regression equation gives a shell length of 62.655 mm or 63 mm at a width of 31.75 mm (Figure 3). This should in theory be the approximate size at 50% retention. Using the length frequency data, approximately 89.8% by weight of the quahogs is made up of animals which are equal to or greater than 63 mm in length, and this would be 141,743 t of biomass. Smaller animals are being caught in the dredge, but not at 100% efficiency.

Figure 4 shows a non-linear regression of shucked meat weight versus shell length. The main product for a plant utilizing the larger quahogs would be shucked meats. With their thick shell the average meat yield for the quahogs from the survey was 26.7% of the total weight. This appears to be higher than the yield reported by Murawski and Serchuk (1979) for the Middle Atlantic Shelf, which is shown as a dashed line in Figure 4. Figure 5 shows a linear regression of the ratio of shucked meats to total weight. Although the regression is significant ($p = 0.000$), with larger quahogs having slightly better meat yields, it only explains 3% of the total variation in meat yield. This means that there would be no benefit for a fishery to target specific sizes for meat yield, and that for most applications the average meat yield would be an adequate representation of meat yield over the full size range.

Figure 6 shows a contour map for average shell length per tow. The overall average length was 72.1 mm. There seems to be larger animals along the edges of the survey area, closer to the shore, and smaller ones in the center of the area.

The ageing data and growth curve are shown in Figure 9. The aged quahogs from the survey samples ranges in size from 41 to 103 mm and 15 to 69 years old. The total length frequency of the survey catch is shown in Figure 10. Most of the catch consisted of quahogs 60 to 85 mm shell length. There were very few small or large quahogs observed in the survey, the small quahogs from Rowell et al. (1990) are shown with plus signs in Figure 9. The upper end of this data and the lower sizes in the survey data overlap, giving some confidence that the two data sets are exhibiting similar growth rates.

From an examination of the length frequency data a range of sizes from 70 to 85 for L' was used in equation 8. The resulting estimates of Z are given in Table 6.

Since the estimate of Z from the Beverton and Holt model is very dependent on the choice of L', published mortality rates for other populations were examined. Rowell and Chaisson (1983) used a range of natural mortality from 0.01 to 0.05, while Surchuk and Murawski (1980) used a range of 0.01 to 0.1. The authors of these papers felt that given the lifespan of the species, this covered the probable range of natural mortality. The U.S. quahog stock assessments (NEFSC, 2000) currently use an M of 0.02 for ocean quahogs, but note that it is imprecisely known. They also report much larger and older quahogs than observed in St. Mary’s Bay, which would indicate a lower mortality rate. A large portion of the U.S. offshore catch is

40 to 80 years old (Murawski and Serchuk, 1989), and the oldest recorded was 225 years old.

The length frequencies in Figure 10 suggest that L' should be in the range of 75 to 80 mm. Much smaller than this and the quahogs would not be fully selected by the gear. Much larger and there is not much data for the calculation. It also indicates that one of the main assumptions for this type of estimate, that recruitment has been constant over the time period, may not be valid. There is a mode in the 80 to 85 mm sizes that could indicate a pulse of recruitment. Using as large a size range as possible would help include periods of both good and poor recruitment, but if there is a trend in recruitment during this period it will bias the estimates. Choosing the value of L' is subjective, but the range of values in Table 6 for an L' of 75-80 indicates that Z is in the range of 0.04 to 0.05.

A biomass per recruit analysis with no fishing mortality was calculated using the estimated growth and mortality parameters for St. Mary's Bay. The resulting biomass per recruit curve is shown in figure 11, along with the size at 50% selectivity converted to age using the growth curve, and the range of ages of male and female quahogs in intermediate maturity stage given by Rowell et al. (1990).

Maximum Constant Yields (MCYs) were calculated from the biomass estimate using equation 9. Results for a range of mortalities and using an x of 0.33 are provided in Table 3. The MCY values obtained using the two biomass estimates as B_0 and setting x = 0.33 give estimates of sustainable fishing activity from 468 t to 2,604 t depending on the value of M. If an M of 0.04 to 0.05 is assumed to be the current best estimate, the sustainable harvest from this bed is in the range of 1,871-2,604 t per year.

Discussion:

The maximum catch rates from this survey are not as high as those reported in the 1997 survey (Duggan et al. 1998). Figure 8 shows a comparison of the catch rates for the two surveys. The 2002 survey catch rate was converted to kg/m^2 as that was how the 1997 survey catch rate was reported. The highest catch rate in the 1997 survey was 10.4 kg/m^2. For the 5 stations in the area that were towed in the 2002 survey, the highest catch rate was 1.5 kg/m^2, while the highest in the entire 2002 survey was 2.7 kg/m^2.

There were large problems in determining the tow distance in the 1997 survey (Duggan et al. 1998), and after tow 10 they had to estimate the weight of the catch from volume as the scale had broken. These problems may have resulted in overestimates of the densities of some tows. There were also large differences in the dredges used in the two surveys. The 1997 survey used a dredge with a 0.818 m blade and towed for 3 minutes. This resulted in a standard tow covering approximately 31.36 m^2 compared to 430.53 m^2 during this survey. If the quahog distribution was patchy on a scale smaller than the area of the larger tows, it would result in higher variances with the smaller tows, but with a large number of tows the means should be similar. With only 5 tows in the 2002 survey falling in the area covered by the 1997 survey there is not enough data to be conclusive with this comparison, but for the 1997 survey the mean catch rate was 3.78 kg/m^2 with a standard deviation of 0.7932, and for the 5 stations in the same area from the 2002 survey the mean was 0.95 kg/m^2 with a standard deviation of 0.375. The variance was larger for the 1997 survey, but so was the mean. For many population variables the variances are heteroscedastic, increasing with the mean, so with only 5 stations to compare it is difficult to say anything about the differences. One way to resolve this difference would be to do some comparison tows with the two sets of gear to determine if there were any differences in efficiency. Since there were problems with the 1997 survey it was felt best to use the 2002 survey results as they are. If the gear used in the 2002 survey is less efficient than other gear it will make for a more conservative estimate of the biomass and yields.

Developing fisheries do not have a time series of catch and fishing effort data, and most lack detailed information on population parameters such as growth and mortality rates. In the case of sedentary species, care must be taken with methods that make the assumption that the stock is one unit and all animals are available to the fishery and equally vulnerable to the fishing gear, the “dynamic pool” assumption. For species such as ocean quahogs this assumption is not valid. This also affects the use of a time series of catch rates to fit model parameters. With a sedentary species, the fishery can be depleting the resource in the area it is currently fishing, but maintain a high catch rate by constantly moving to new grounds. This is often referred to as serial depletion. Catch rates can stay relatively high until the available beds have been fished through, and then drop quickly as the fishery has to return to previously fished areas and starts to rely on production from growth and recruitment rather than on an accumulated biomass of mature quahogs.

A current operational component of a precautionary management approach is to set up a pair of Reference Points (RP’s). The Target Reference Point (TRP) is set as the target for exploitation, while the Limit Reference Point (LRP) is a level of exploitation that should not be approached and definitely not exceeded (Zang 1999). These reference points are usually determined from either empirical analysis of fisheries and biological data, or from modelling. Developing fisheries tend to be data limited, and thus rely on empirical equations to determine reference points. Parameter estimates are thus approximations, but are intended to be refined as the fishery evolves and a time series of data is collected and additional studies carried out.

Maximum Constant Yield (MCY) reference points based on empirical equations are frequently used for developing fisheries. Commonly used equations are based on Gullands (1971) model for Maximum Sustainable Yield (MSY) of: $MSY = 0.5\ M\ B_o$, this is equivalent to equation 9 with x set to 0.5. The parameter x is a constant that is related to the growth and mortality rates of the stock being examined. Setting x = 0.5 is equivalent to setting fishing mortality equal to M based on the logistic growth model. Current researchers consider 0.5 to be too high and too risky to use with developing fisheries. Beddington and Cooke (1983) suggested that x normally was approximately 0.3, while Garcia (1989) proposed a value of 0.2. Patterson (1992) suggested that x should be set between 0.2 and 0.3. He had examined a number of stocks of small pelagic fish with high natural mortality rates and noted that $x \geq 0.33$ consistently caused stocks to collapse while using $x \leq 0.25$ generally allowed stocks to increase in size. Calculating MCY with x = 0.5 is generally only used with an established fishery when average historic recruited biomass is used instead of B_o, while x = 0.25 is a more conservative estimate used for a developing fishery (Zhang 1999). Beddington and Cooke (1983) found that x would be expected to increase as M decreased, and Clark (1991) showed that if the size at maturity is less than the size of recruitment to the fishery, fishing mortality could exceed $F_{0.1}$ without affecting the spawning stock biomass. Although ocean quahogs have a low M (approximately 0.02 for offshore stocks and 0.04-0.05 from this study on an inshore stock), and it appears that recruitment to the fishery will be above the size at maturity, other aspects of the quahogs life history warrant a cautious approach to setting a TRP. With their long lifespan, slow growth rate and the high efficiency of hydraulic clam gear (Medcof and Caddy 1974, Meyer et al. 1981), once an area is fished down below economic catch rates it will be a long time before the biomass increases to levels that are once again economical to fish. In addition, the U.S. experience is that recruitment to quahog stocks is more sporadic than consistent, which means that periods of good recruitment must be fished at low enough levels to carry the fishery through the periods of poor recruitment. In looking at setting yield levels for inshore stocks of ocean quahogs in south western Nova Scotia, DFO produced an expert opinion recommending that MCY calculated as $0.33MB_0$ be used (DFO 2005). The higher constant was due to the fact that the MCY approach is usually applied to a fishery with no monitoring to calculate a yield that is sustainable at all historic biomass levels. In the case of a regulated Canadian fishery there will be a regulated level of monitoring. Both Rowell and Chaisson (1983) and Duggan *et al.* (1998) used a value of 0.5 for x, based on Gulland's original model. Duggan *et al*. did say the use of Gulland's model was questionable, and could produce overly optimistic results. This means that even with the increase in the biomass estimate for this survey over the 1997 survey, the sustainable yield estimates are not that much higher.

A LPR should be set independently of the TRP, and in fact it is recommended that it be set in advance of the TRP. In the U.S fishery, Applegate et al. (1998) recommended 0.25 B_0 as a biomass LRP for ocean quahogs. The estimates from this survey for the quahog stock in St. Mary's Bay is thus B_0 equal to the survey biomass estimate of 157,843 (±53,211) t, a Target Reference Point for catch based on MCY = .33 M B_0, with M = 0.045, of 2,344 and a biomass based Limit Reference Point of 0.25 B_0 or 39,461 t. When more precise growth and mortality estimates are available, these RP's could be restated in terms of the equivalent fishing mortalities.

Using the average meat yield from all sizes (26.7%) the meat yield from an allowable catch of 2,344 t would be 633 t of quahog meat.

One of the main aspects of size selectivity from a management perspective is that for long term sustainability, a fishery should not be harvesting animals before they have had a chance to reproduce. Several studies have been carried out to determine the approximate size at sexual maturity for ocean quahogs (Table 4). The results indicate that quahogs less than 50 mm should not be taken by the fishery. The study by Rowell et al (1990) used quahogs from Mary's Bay in their study of size at maturity. They found that males matured at smaller sizes and younger ages than females, and that the maturation at size was more "knife-edged" in females than in males. The smallest mature quahogs they found were a 27 mm male and a 30 mm female, while the largest quahogs still in intermediate maturation stage (Ropes et al. 1984) were 48 mm for males and 52 mm for females. Quahogs in the intermediate stage of maturation ranged from 3-20 years old for males and 3-24 years old for females. In general ocean quahogs mature over a protracted period of time, both as a population and as individuals. They also have a protracted and variable spawning period with ripe individuals being found year around and peak spawning time varying from year to year at the same location. In the samples taken from this survey, the full range of gonad development was observed.

The biomass per recruit analysis with no fishing mortality (Figure 11), indicates the age of 50% selectivity is close to the age of maximum biomass per recruit, which should help prevent growth overfishing, and most quahogs would have spawned several times before being recruited to the gear, which aids in preventing recruitment overfishing. This should help make a fishery for this species sustainable.

Duggan et al. (1998) stated that the minimum length for the larger clam market would be 62 mm. This is very close to the estimated size at 50% selectivity for the dredge used in this survey. The length frequencies show that 91.4% of the total weight of ocean quahogs came from animals equal to or greater than 62 mm in length. This is similar to what was found in the 1997 survey, although the dredges used in the two surveys were very different (Duggan et al 1998). If 62 mm or greater is the proposed market size, then 91.4% of the survey biomass, or 130,000-144,000 t, would be of marketable size. With the minimum market size still an estimate, and so close to the 50% retention size, it was not felt that the biomass and MCY estimates should be adjusted. It is probable that a small percentage of quahogs under 62 mm would be processed with the remainder of the catch if they arrived at a plant mixed in with the larger quahogs.

The distribution of mean lengths shown in Figure 6 implies either a different growth rate or mortality rate throughout the bed. The population has more large quahogs around the edges of the Bay and smaller ones in the centre. A plot of numbers per standard tow shows the same distribution as Figure 2, so this does not reflect density dependent growth variations. One possibility is better habitat suitability around the edges than in the middle. Habitat suitability in this sense is the sum of all environmental effects on the growth and survival of the species. This would have two effects that could result in the observed distribution of sizes. Habitat suitability could be reflected in higher growth rates, which would result in larger quahogs in the better areas even with the same age distribution throughout the bed. Alternatively, the less suitable habitat may be subject to periodic higher natural mortality whenever environmental conditions deteriorate, or a constantly higher natural mortality due to low suitability. Either of these would result in an age distribution with a greater accumulation of older clams in the better habitat, and a younger age distribution in the poorer areas. The fact that the size differences do not follow the density pattern goes against the theory of Density Dependent Habitat Suitability (MacCall, 1990). This theory says that with variations in habitat suitability the better habitats are occupied first, but as density effects reduce habitat suitability of the initially best areas, the initially marginal habitat becomes just as attractive. If this theory were true for quahogs in St. Mary's Bay, the expected result would be higher densities in the better habitats, and the density effects balancing out habitat suitability to result in an even distribution of growth and mortality rates. This does not appear to be what is observed here.

To determine the cause of these differences would take the ageing of samples from different areas to look at variations in growth rates and age structure across the population.

The semi-variogram shown in Figure 7 indicates that the catch rates of tows close to each other were more similar than those further apart, up to a distance of 3.3 km. Although the station allocation had been set up to keep stations at least 1.5 km apart, actual tow locations and towing directions resulted in some tows being closer than this, allowing a fit to smaller distances. If this spatial correlation holds up with future surveys, it would mean that assessment methods that take this relationship into account, such as kriging, should be used for the analysis.

Quahogs and inert material (shell, gravel and mud) account for 98.8% of the catch weight, of which 43.9% is quahogs. The most abundant by-catch organisms were the Astarte clams, which made up only 0.3% of the catch by weight. With only 1.8% of the catch weight consisting of non-target species there would appear to be minimal problems with by-catch species for a clam fishery in this area. In Duggan et al. (1998) the by-catch was stated to be a handful of Greenland cockles (*Serripes groenlandicus*), and a few razor clams (*Ensis directus*). There were no Greenland cockles caught in the 2002 survey, although the false quahog (*Pitar morrhuanus*) is somewhat similar in appearance and was one of the more abundant large bivalves caught. One of the more abundant organism caught in the 2002 survey was a small white sea cucumber. It is most likely *Pentamera calcigera*, but unfortunately no specimens were retained for positive identification, and so it is listed in Table 5 as Unidentified White cucumber.

The impacts on habitat would be of greater concern than by-catch for a hydraulic dredge fishery. Gilkinson et al. (2002) reported on the long term impacts of a hydraulic dredge fishery on Banquereau Bank, Nova Scotia. The macrofaunal community showed evidence of substantial recovery in terms of species composition based on abundance after three years. The reduction in biomass of large bivalve species was still apparent after three years, and with the slow growth rates of some of these species this effect would be long term. In the case of an ocean quahog fishery the time to recovery of the quahog biomass after fishing would be very long, and an ongoing fishery would be expected to permanently reduce the biomass from it's pre-fished state. With it's low productivity the sustainable yield would be low, so the rate of biomass reduction from a fishery would be slower than on a more productive organism.

Duggan et al. (1998) suggested that an annual quota of 6,000 t is needed to make a quahog processing plant viable. It is obvious that this bed does not have sufficient biomass on it's own to support a long-term fishery of this magnitude. A plant would have to rely on catches from a number of beds of this size. There are reports of similar beds along the coast, and Rowell and Chaisson (1983) report on beds in the harbours along south-east Nova Scotia. Further surveys of the inshore areas are needed to determine if there is a sufficient biomass of quahogs to support a processing facility.

The calculation of sustainable yield used here is a very simplistic one. If this fishery goes ahead it will provide data for more complex models. More precise growth and mortality estimates would allow for more precise estimates of the productivity of the quahog population in this area. The long lifespan of this species will complicate the use of most stock assessment models. With their low productivity, sustainable levels of harvest for a fishery must be kept low. This means that a fishery will not have a large measurable impact on the population, and thus there will be little change in time series of data for a model to try and fit parameters to. The U.S. experience is that the ocean quahog populations on the U.S. east coast have sporadic recruitment, so constant recruitment models may not fit.

Some factors may indicate that the harvest level recommended here is too conservative. In the U.S. fishery the recommended harvest level is in the range of 2-3% of the biomass, while the levels suggested here amount to 1-2% of the biomass. The U.S. fishery does not land the allowed harvest level, so it is not known if that level would be sustainable in the long term. The other factor is the higher catch rates observed in the 1997 survey.

Conclusions:

The ocean quahog bed in St. Mary's Bay has a biomass of approximately 158,000 t which can produce an estimated sustainable yield of 2,344 t of quahogs per year. The meat yield would be approximately 27% of this or 633 t of quahog meat. The fishery would have little bycatch of other species. This harvest would be well short of the estimated 6,000 t needed to make a processing plant viable, so other quahog beds in South West Nova Scotia would need to be exploited if a processing plant were to be viable.

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Table 1. Position, depth (m) and bearings for 2002 St. Mary's Bay ocean quahog survey.

Date	Tow	Bearing	Depth	Start Latitude	Start Longitude	Time	End Latitude	End Longitude
10/24/02	1	155	38.5	4413.338	6617.524	15:08	4413.200	6617.472
10/24/02	2	345	39.0	4412.255	6617.907	16:23	4412.213	6618.124
10/24/02	3	213	48.5	4412.261	6619.103	16:46	4412.001	6619.124
10/24/02	4	178	36.0	4411.274	6616.209	17:32	4411.097	6616.158
10/24/02	5	178	38.0	4410.453	6616.011	17:50	4410.275	6615.957
10/24/02	6	180	34.0	4409.537	6616.396	20:04	4409.401	6616.290
10/24/02	7	208	29.5	4411.102	6614.028	20:55	4410.993	6614.069
10/25/02	8	166	32.0	4412.369	6614.407	07:47	4412.258	6614.331
10/25/02	9	210	34.0	4412.454	6616.073	08:14	4412.000	6616.000
10/25/02	10	212	35.0	4413.729	6616.153	08:45	4413.610	6616.165
10/25/02	11	210	33.5	4414.378	6614.553	09:13	4414.274	6614.568
10/25/02	12	220	38.0	4414.574	6615.869	09:36	4414.438	6615.965
10/25/02	13	214	41.0	4415.164	6616.237	09:57	4414.960	6616.334
10/25/02	14	210	42.5	4415.975	6616.021	10:36	4415.764	6616.052
10/25/02	15	214	47.0	4417.208	6616.540	11:04	4417.093	6616.490
10/25/02	16	225	36.5	4418.254	6615.671	11:32	4418.114	6615.732
10/25/02	17	204	43.0	4417.252	6614.926	11:56	4417.117	6614.882
10/25/02	18	186	47.5	4416.951	6613.710	12:15	4416.802	6613.618
10/25/02	19	214	38.0	4416.491	6613.523	13:16	4416.383	6613.489
10/25/02	20	305	36.0	4415.071	6614.062	14:28	4415.174	6614.195
10/25/02	21	34	28.0	4419.911	6611.099	18:51	4419.091	6611.117
10/25/02	22	33	39.5	4418.460	6613.891	19:45	4418.581	6614.051
10/25/02	23	196	41.5	4418.390	6612.762	20:15	4418.423	6612.782
10/25/02	24	198	42.0	4417.436	6613.098	21:02	4417.332	6613.041
10/25/02	25	224	27.5	4417.309	6611.790	21:34	4417.264	6611.898
10/25/02	26	219	53.0	4414.987	6617.767	12:07	4414.873	6617.907
10/26/02	27	210	67.0	4414.482	6619.346	12:32	4414.322	6619.452
10/26/02	28	188	54.0	4413.865	6619.656	12:53	4413.701	6619.594
10/26/02	29	186	60.5	4413.540	6621.601	13:20	4413.398	6621.695
10/26/02	30	42	68.0	4412.075	6622.073	13:51	4412.232	6622.068
10/26/02	31	338	59.5	4411.279	6620.432	14:24	4411.376	6620.573
10/26/02	32	336	54.5	4410.169	6619.734	14:54	4410.386	6620.024
10/26/02	33	272	47.0	4409.633	6618.126	15:25	4409.697	6618.349
10/26/02	34	222	46.0	4410.922	6617.605	16:05	4410.773	6617.724
10/26/02	35	176	43.0	4410.817	6617.265	16:23	4410.654	6617.245
10/26/02	36	255	39.0	4409.888	6616.865	16:44	4409.739	6617.026
10/26/02	37	254	40.5	4409.293	6617.312	17:02	4409.141	6617.543
10/31/02	38	347	53.5	4408.792	6618.960	11:08	4408.886	6619.000
10/31/02	39	337	47.0	4408.870	6617.978	11:34	4408.171	6618.090
11/01/02	40	348	43.5	4407.597	6617.987	12:17	4407.634	6618.135
11/01/02	41	168	50.0	4404.602	6618.874	13:44	4404.501	6618.687
11/04/02	42	320	60.0	4407.914	6620.416	13:20	4407.837	6620.473
11/04/02	43	172	59.0	4409.265	6620.525	14:04	4409.248	6620.408

Table 2. Tow distance and catch information for 2002 St. Mary's Bay ocean quahog survey.

Tow	Distance (m)	Total Catch Volume (m^3)	Total Catch Weight (kg)	Quahog Catch Weight (kg)	Quahog Catch Numbers	Bottom Type
1	478	0.88	854.7	504.5	5,117	mud
2	420	0.65	444.8	257.9	2,909	shell and quahog
3	404	1.71	1,092.3	474.9	5,108	shell and quahog
4	383	1.18	927.4	686.0	5,610	quahog
5	278	0.66	495.0	368.2	2,697	quahog
6	226	0.68	531.6	396.2	2,617	quahog
7	248	0.33	223.8	106.0	802	shell and razors
8	219	0.33	228.2	149.1	1,045	quahog and razor
9	302	1.04	814.6	635.5	4,855	quahog
10	248	0.66	508.5	394.0	3,749	quahog
11	267	1.08	808.0	621.7	2,930	quahog
12	335	0.22	146.7	108.5	701	quahog
13	361	0.35	259.8	194.2	1,405	mud
14	348	0.77	677.6	365.6	2,632	mud
15	220	1.36	1,106.8	581.3	3,690	mud and shell
16	322	0.21	126.8	42.5	270	shell and quahog
17	232	1.40	1,072.4	728.9	5,864	shell and quahog
18	320	0.27	162.2	83.2	488	shell and quahog
19	209	0.72	491.4	304.8	1,905	shell and quahog
20	330	0.27	204.6	45.7	296	gravel
21	226	1.45	1,373.0	369.2	2,433	shell
22	280	1.36	971.5	427.1	3,134	shell and quahog
23	296	1.25	948.0	329.4	2,790	shell and quahog
24	289	0.80	596.8	446.2	2,677	shell and quahog
25	254	0.89	664.4	15.5	54	shell
26	228	0.05	47.1	3.5	10	mud
27	224	0.05	38.4	2.5	12	mud
28	259	0.08	45.9	6.4	39	mud
29	256	0.58	435.4	127.5	716	mud
30	389	0.76	513.9	316.9	2,313	shell and quahog
31	346	1.65	1,279.2	24.2	83	shell
32	306	1.10	811.1	0.0	0	shell
33	372	1.34	1,112.2	162.4	970	shell
34	335	0.90	561.2	374.1	2,728	quahog and shell
35	261	1.01	715.4	463.7	3,855	quahog
36	370	0.47	341.6	270.8	1,926	quahog
37	344	0.35	268.9	198.1	1,481	quahog
38	187	1.55	1,377.0	40.0	242	shell
39	215	0.95	719.9	548.3	3,509	quahog
40	224	1.07	1,024.9	14.6	47	shell and rock
41	433	0.69	484.4	0.0	0	shell and rock
42	194	0.52	359.3	0.0	0	shell
43	202	0.80	524.0	0.0	0	shell
Total	12642	34.46	26,390.5	11,188.7	83,706	

Table 3. Biomass and MSY estimates from 2002 St. Mary's Bay ocean quahog survey using a value of x of 0.33 and a range of M for the MSY estimates.

Model	Area (km^2)	Biomass (t)	Values of M						
			0.010	0.015	0.020	0.025	0.030	0.040	0.050
Formula	464.85	157,843	521	781	1042	1302	1563	2084	2604
Surfer	464.85	141,717	468	701	935	1169	1403	1871	2338

Table 4. Size and Age at sexual maturity for *Arctica islandica*.

Location			Mean Size at maturity	Range	Mean Age at maturity	Range
1.	Iceland	Males	44	24-60		7-32
		Females	46			
2.	Long Island	Males	47.1	36-58	9.8	5-18
		Females	55.0	41-60	13.2	6-16
3.	Nova Scotia	Males	47.1	27-64	13.1	7-20
		Females	49.2	30-65	12.5	7-28

1. Thorarinsdóttir, G.G., and S.A. Steingrímsson. 2000 Northwest Iceland.
2. Ropes, J.W., S.A. Murawski, and F.M. Serchuk. 1984.
3. Rowell, T.W., D.R. Chaisson, and J.T. McLane. 1990.

Table 5. Catch composition of 2002 St. Mary's Bay ocean quahog Survey.

Common Name	Scientific Name	Total (kg)	% of catch	Cumulative %
Shell		12,280.50	48.3522	48.3522
Ocean Quahog	*Arctica islandica*	11,146.61	43.8877	92.2399
Rock		1,526.70	6.0111	98.2510
Mixed shell & mud		120.06	0.4727	98.7238
Astarte sp.	*Astartidae*	85.60	0.3370	99.0608
Unid. White Cucumber	*Holothuroidea*	79.38	0.3125	99.3733
Rock Crab	*Cancer irroratus*	32.19	0.1267	99.5001
Truncate Soft Shell Clam	*Mya Subtruncata*	23.39	0.0921	99.5922
Driftwood		15.79	0.0622	99.6544
False Quahog	*Pitar morrhuanus*	14.91	0.0587	99.7131
Sea Scallop	*Placopecten magellanicus*	12.89	0.0508	99.7638
Northern Cardita	*Cyclocardia borealis*	8.99	0.0354	99.7992
Atlantic Razor or Jackknife Clam	*Ensis directus*	8.98	0.0353	99.8345
Atlantic Surfclam	*Spisula solidissima*	7.68	0.0302	99.8648
Undulate Thracia	*Thracia conradi*	7.51	0.0296	99.8943
Whelk	*Colus sp.*	5.12	0.0202	99.9145
Moon Snail	*Euspira sp.*	3.16	0.0125	99.9270
Jonah Crab	*Cancer borealis*	2.92	0.0115	99.9385
Kelp	*Laminaria longicurus*	2.39	0.0094	99.9479
Waved Whelk	*Neptuna lyrata decimocosta*	2.26	0.0089	99.9568
Hermit crab	*Pagurus sp.*	1.70	0.0067	99.9634
Sea Anemone	*Coelenterata*	1.65	0.0065	99.9699
Polychaete Worms	*Polychaeta*	1.56	0.0061	99.9761
Bloodworm	*Glycera dibranchiata*	1.02	0.0040	99.9801
Iceland Cockle	*Clinocardium ciliatum*	0.86	0.0034	99.9834
Dulse	*Palmaria palmata*	0.81	0.0032	99.9866
Burrowing Seacucumber	*Molpadia oolitica*	0.77	0.0030	99.9897
Propellor Clam	*Cyrtodaria siliqua*	0.65	0.0026	99.9922
Sculpin	*Myoxocephalus sp.*	0.48	0.0019	99.9941
Rock Weed	*Ascophyllum nodosum*	0.40	0.0016	99.9957
Sponge	*Porifera*	0.33	0.0013	99.9970
Northeast Lucine	*Lucinoma filosus*	0.26	0.0010	99.9980
Rat Tailed Cucumber	*Caudina arenata*	0.23	0.0009	99.9989
Lemonweed	*Flustra foliacea*	0.20	0.0008	99.9997
Atlantic Awning Clam	*Solemya velum*	0.08	0.0003	100.0000
Grand Total		25,398.00	100.0000	100.0000

Table 6. Mortality estimates from Beverton and Hold (1956) method for selected L' sizes. L' is the minimum fully recruited size.

Size (L')	Mortality
70	0.055854
71	0.053941
72	0.054368
73	0.051937
74	0.050466
75	0.047956
76	0.046776
77	0.043779
78	0.040703
79	0.040551
80	0.039203
81	0.028215
82	0.020367
83	0.012233
84	0.001608
85	-0.011209

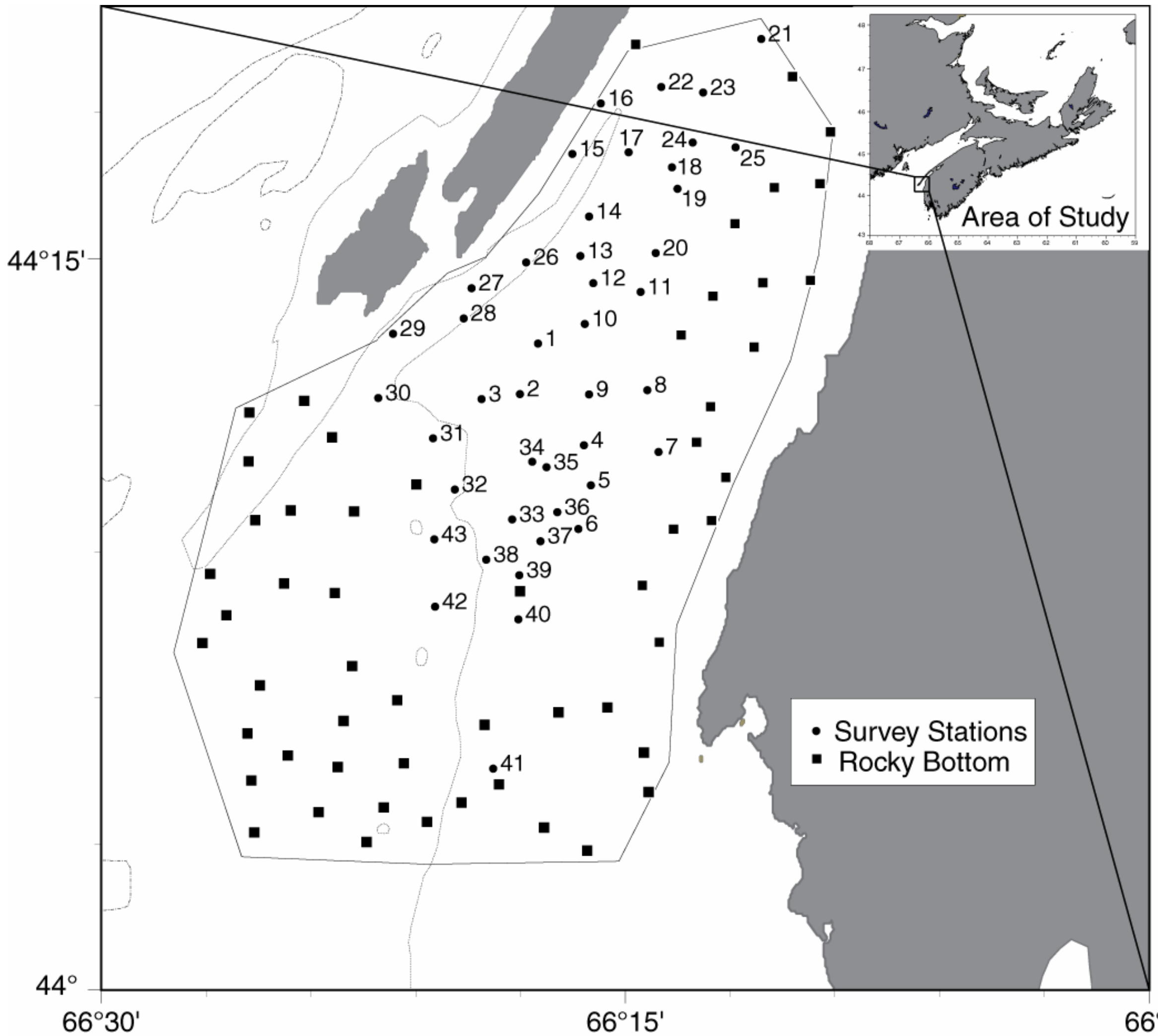

Figure 1. Study area with locations of survey tows and rocky areas.

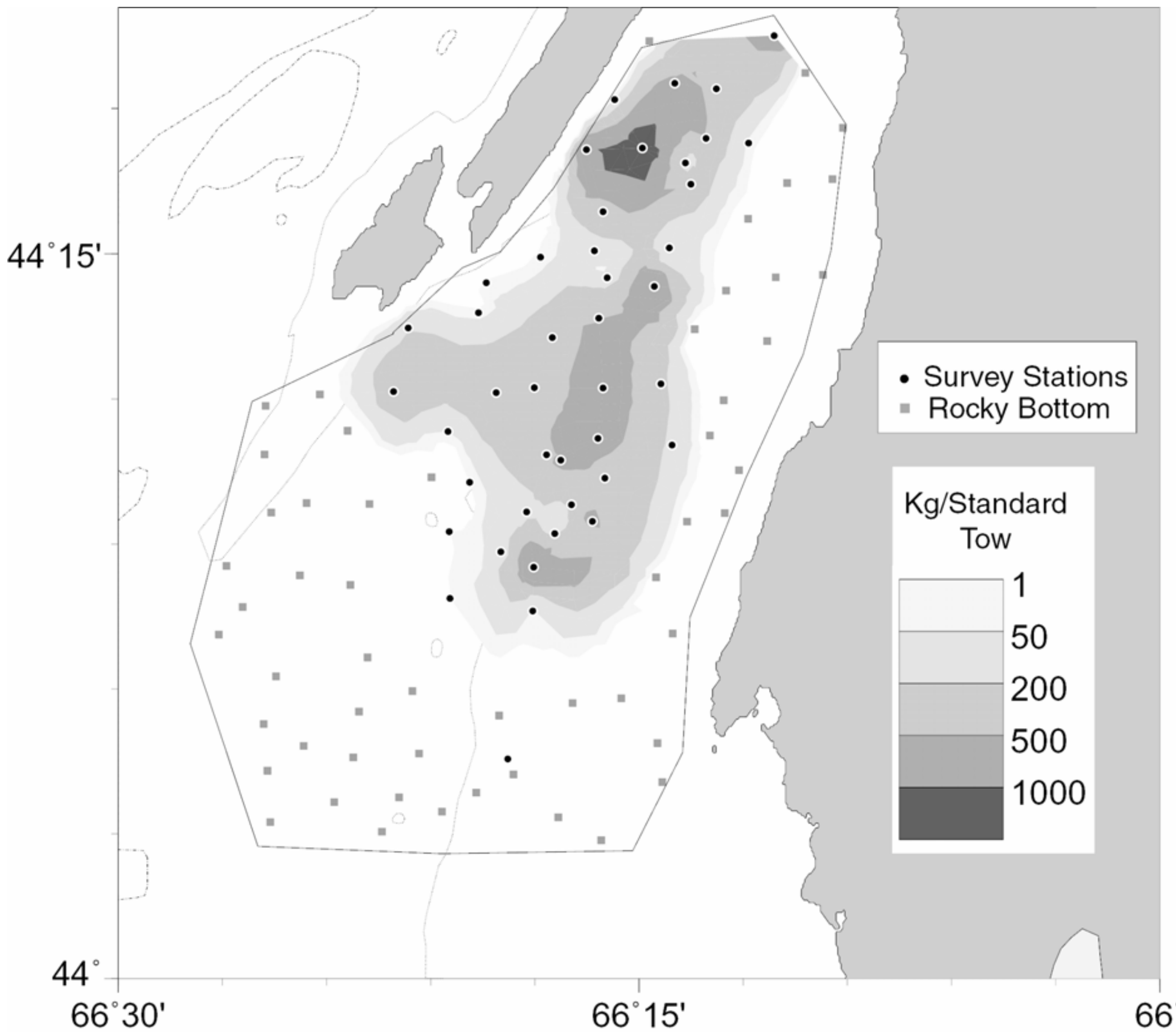

Figure 2. Contour map of the catch per standard tow for the 2002 St. Mary's Bay quahog survey.

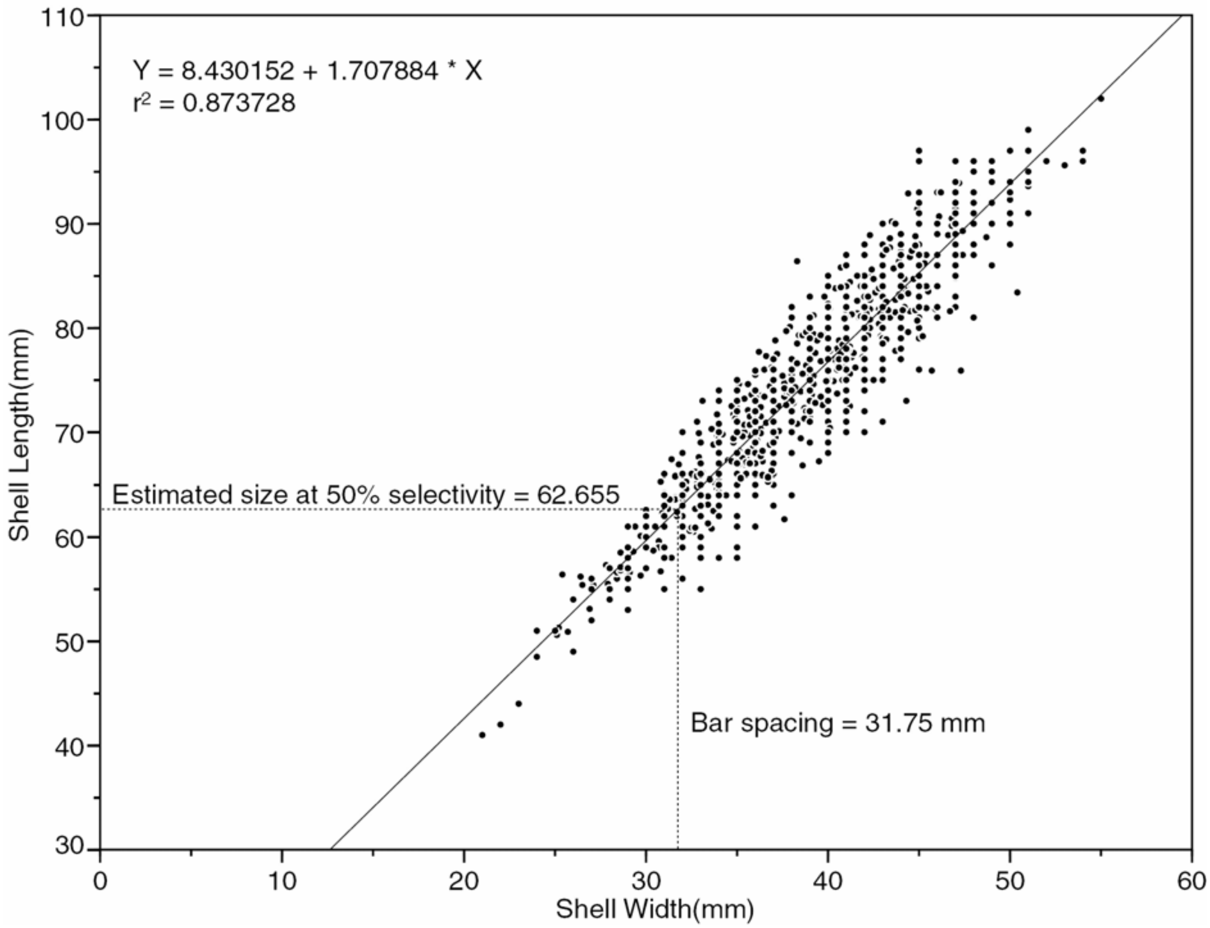

Figure 3. Regression of shell length on shell width and estimated size at 50% selectivity for a dredge with a bar spacing of 31.75 mm.

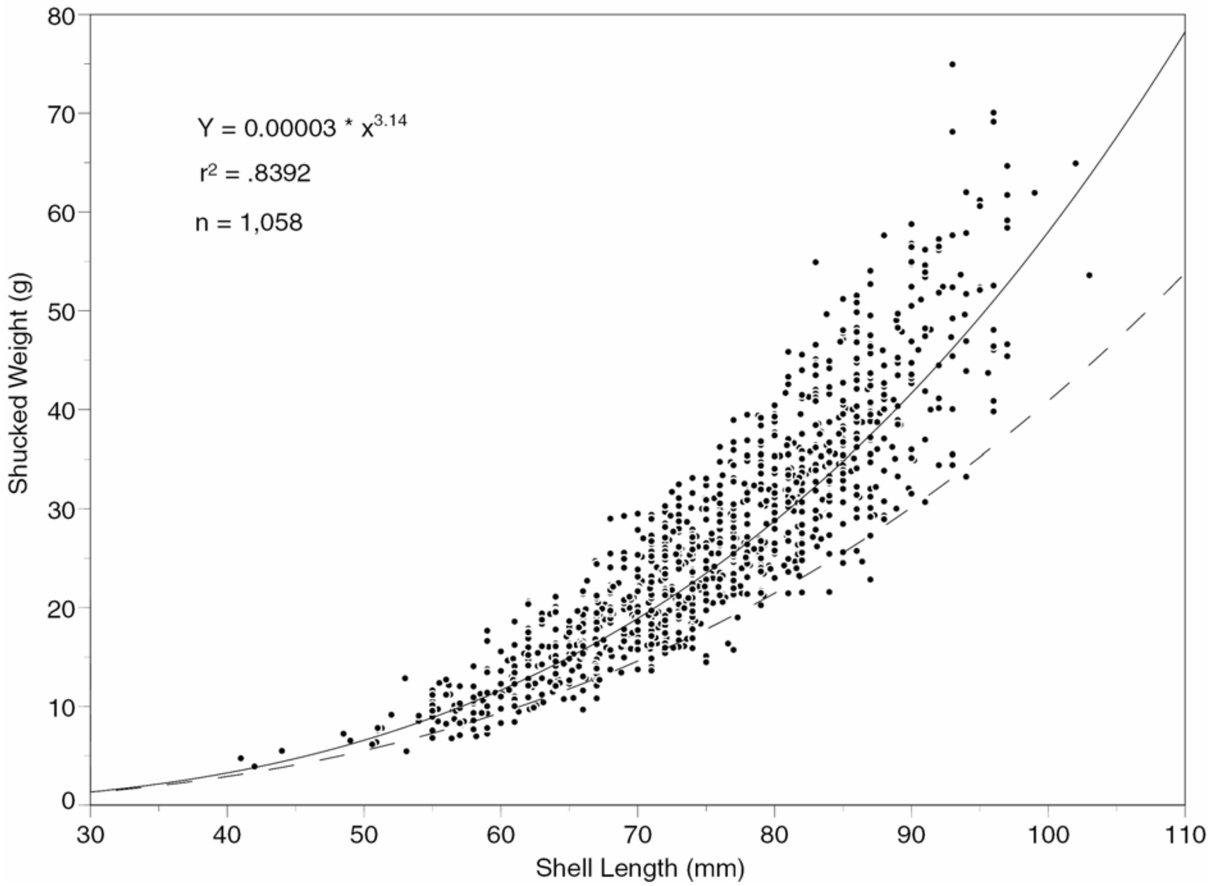

Figure 4. Non Linear regression (solid line) of shucked meat weight on shell height for quahogs from the survey. Dashed line is regression for Mid-Atlantic Shelf population from Murawski and Serchuk (1979).

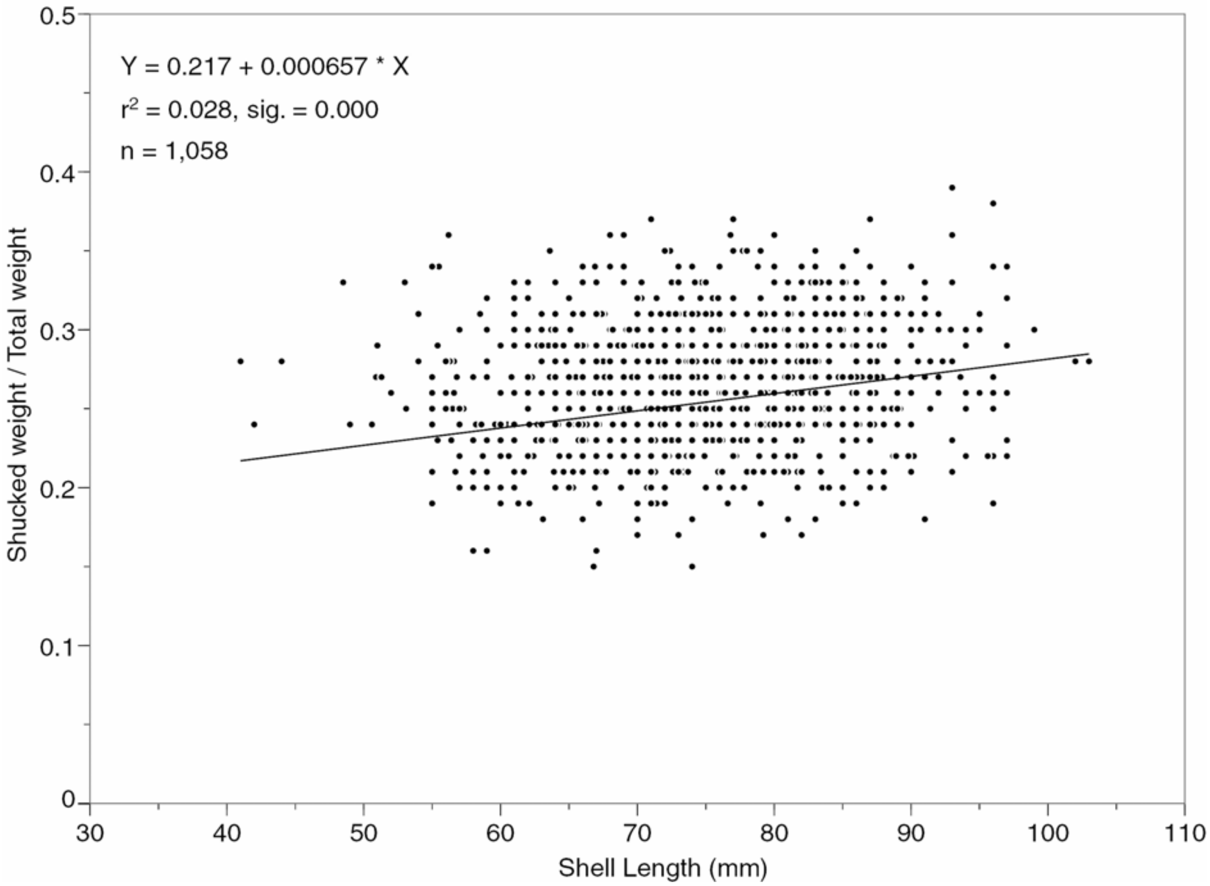

Figure 5. Regression of meat yield (Shucked meat weight / Total wet weight) for clams collected from the 2002 St. Mary's Bay quahog survey.

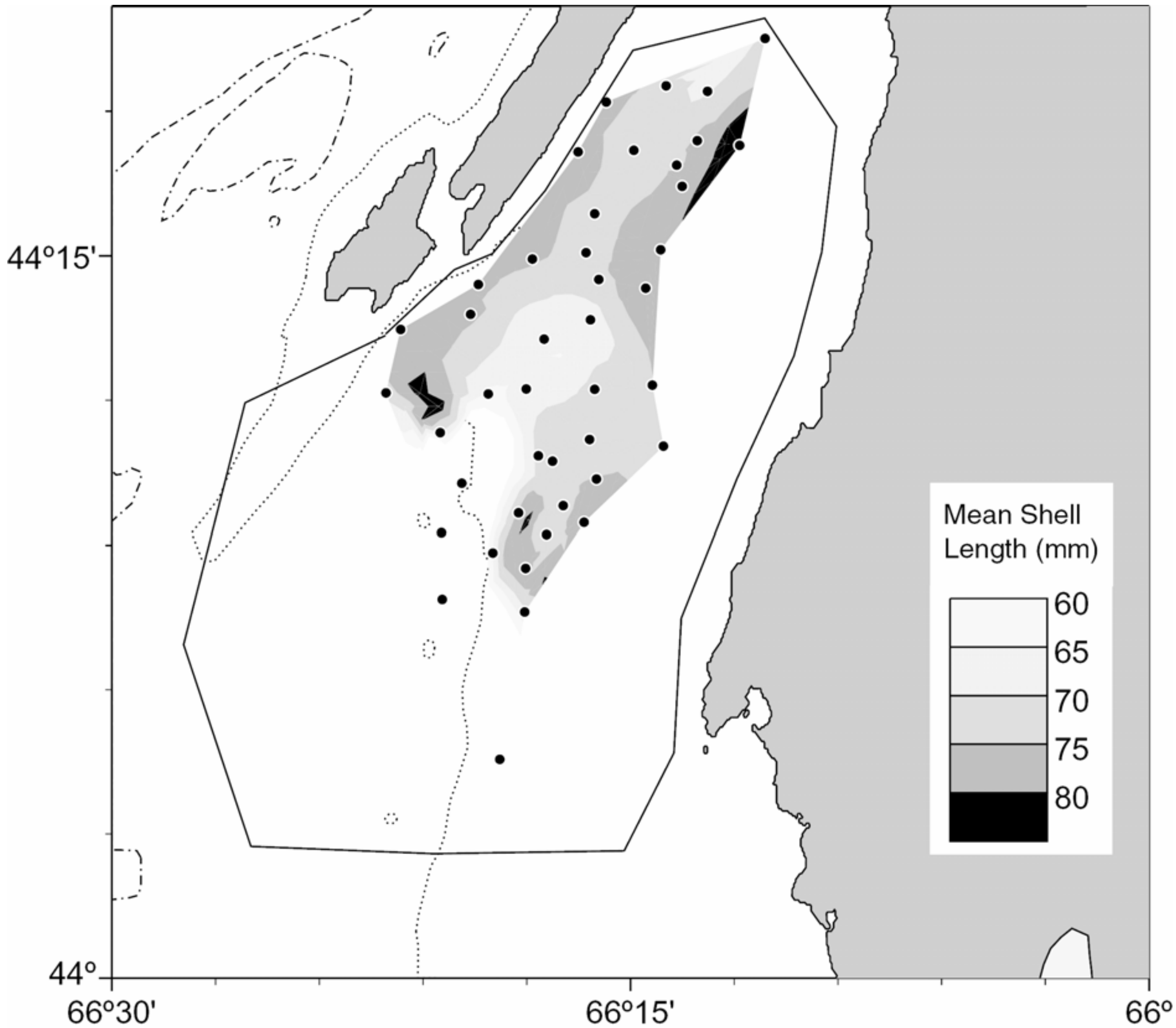

Figure 6. Countour map of the average shell length at each survey station.

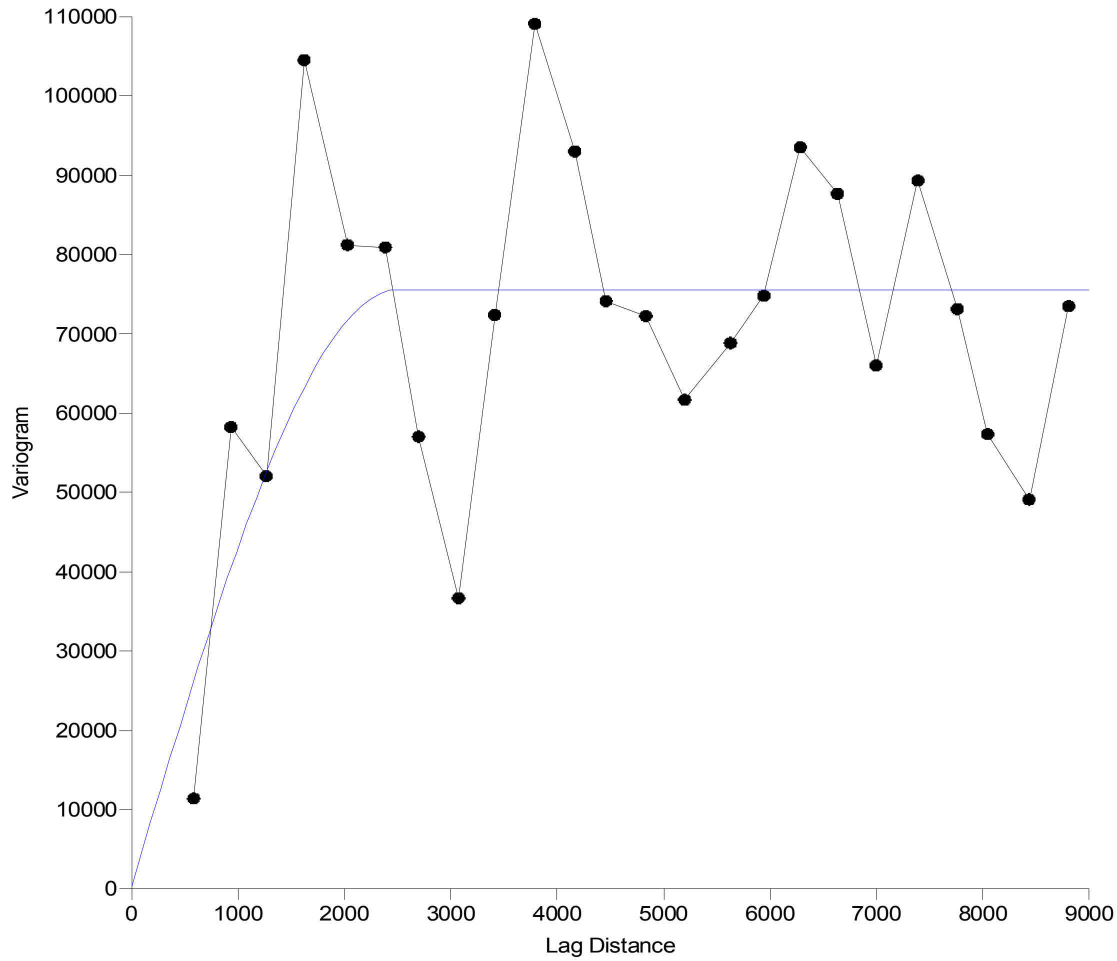

Figure 7. Variogram of 2002 quahog survey data showing relationship of variance between stations and the distance separating them.

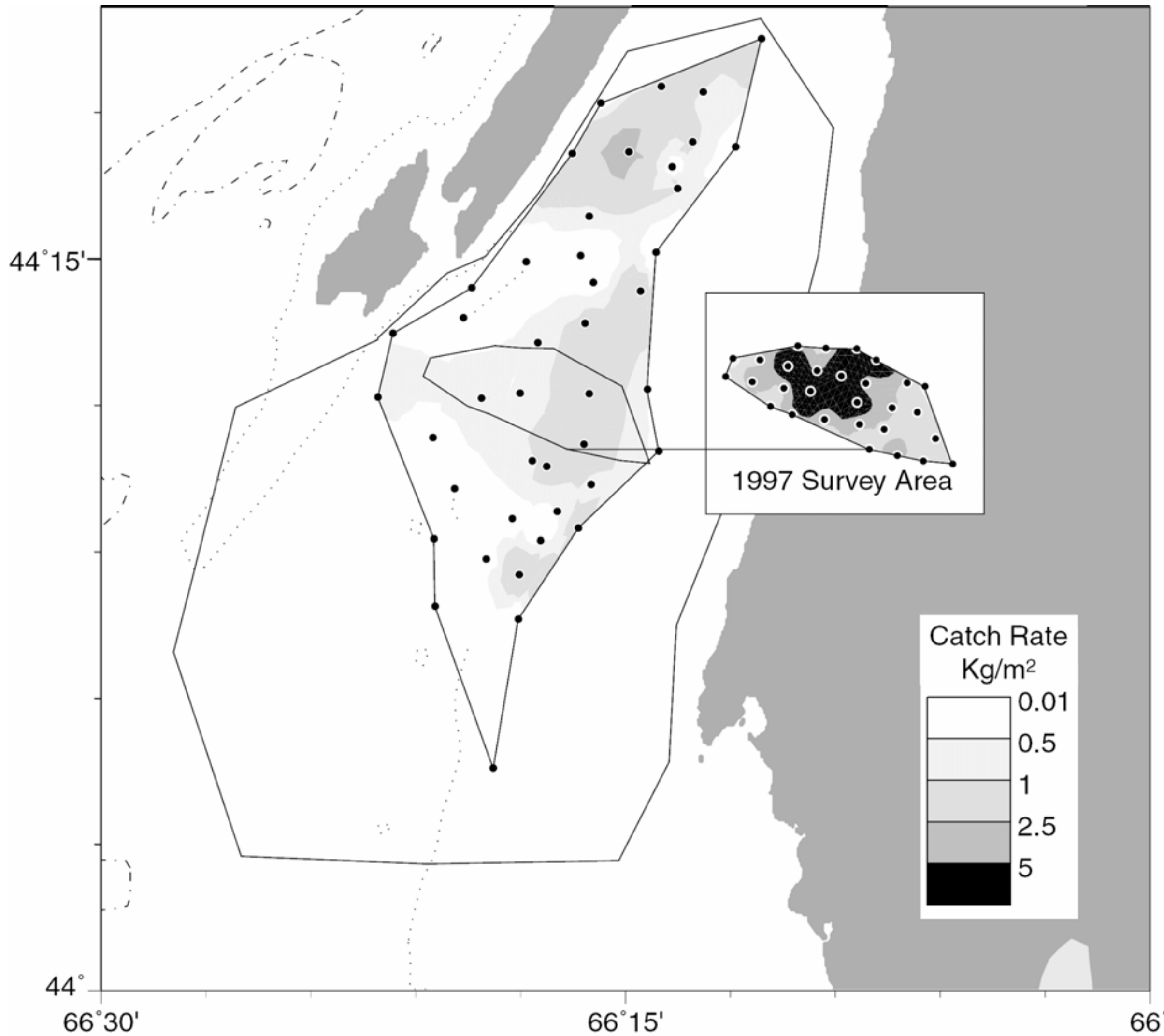

Figure 8. Catch rate for the 2002 survey compared to the1997 survey catch rate.

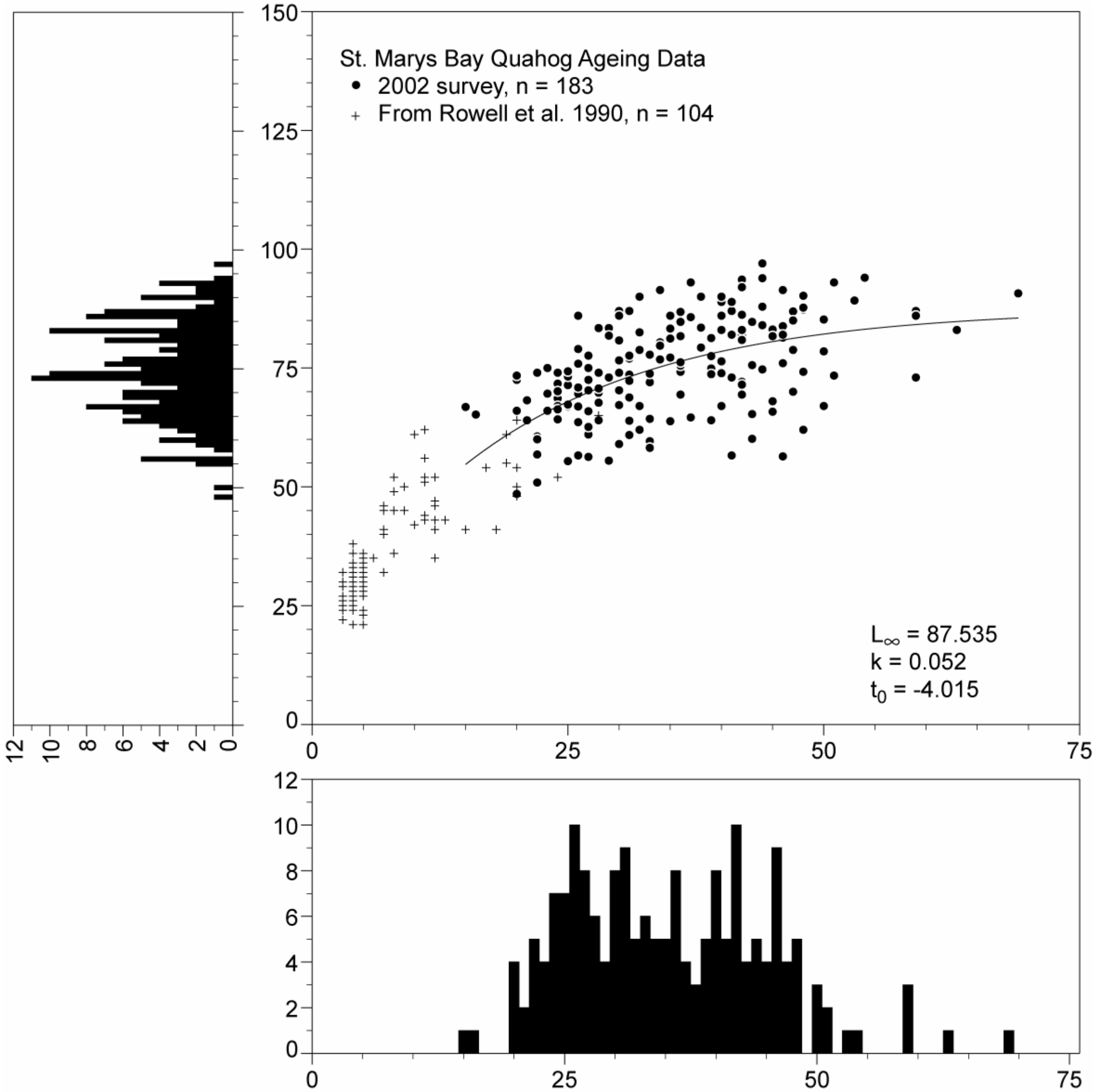

Figure 9. Aged sample of quahogs from St. Mary's Bay ocean quahog (*Arctica islandica*) survey. Histogram on the left is the size frequency of the sample. The age date is shown in the scattergram in the center. The plus signs are additional small quahogs from Rowell et al 1990, and the von Bertalanffy growth parameters are shown. The histogram on the bottom is the resulting age frequency

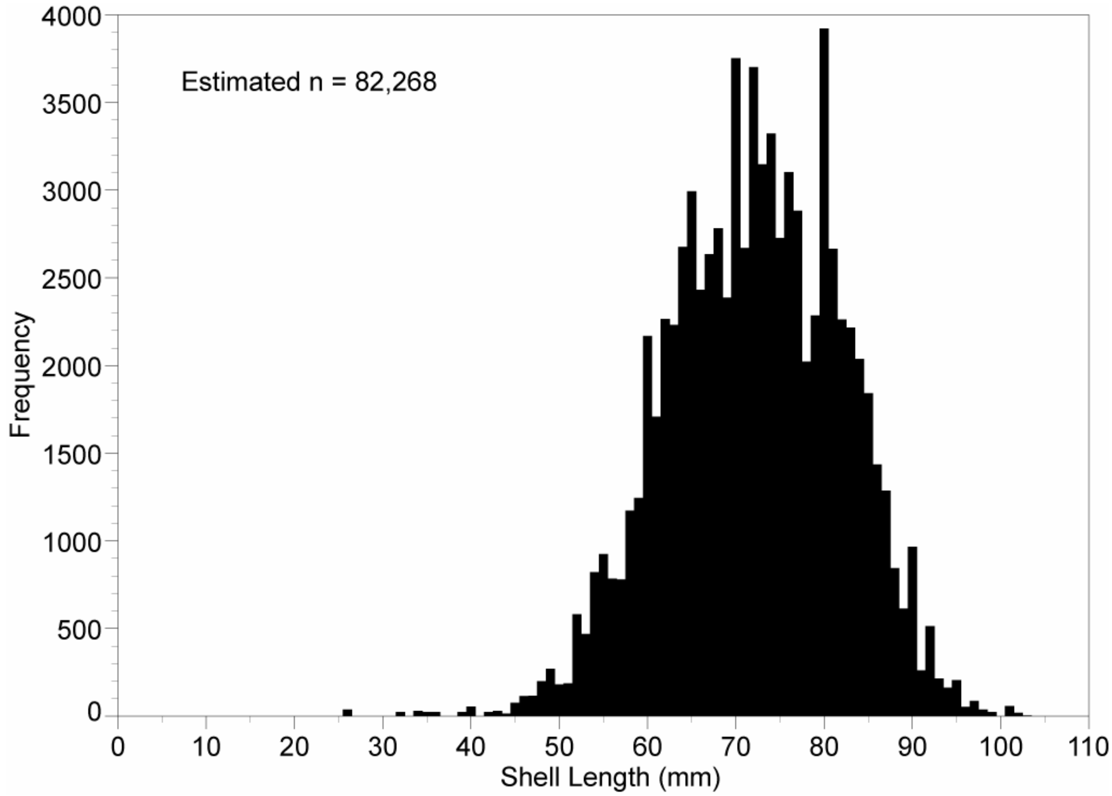

Figure 10. Total length frequency for the St Mary's Bay ocean quahog survey catch. Length frequency sample from each tow were scaled up to the total tow quahog catch and then summed for the entire survey.

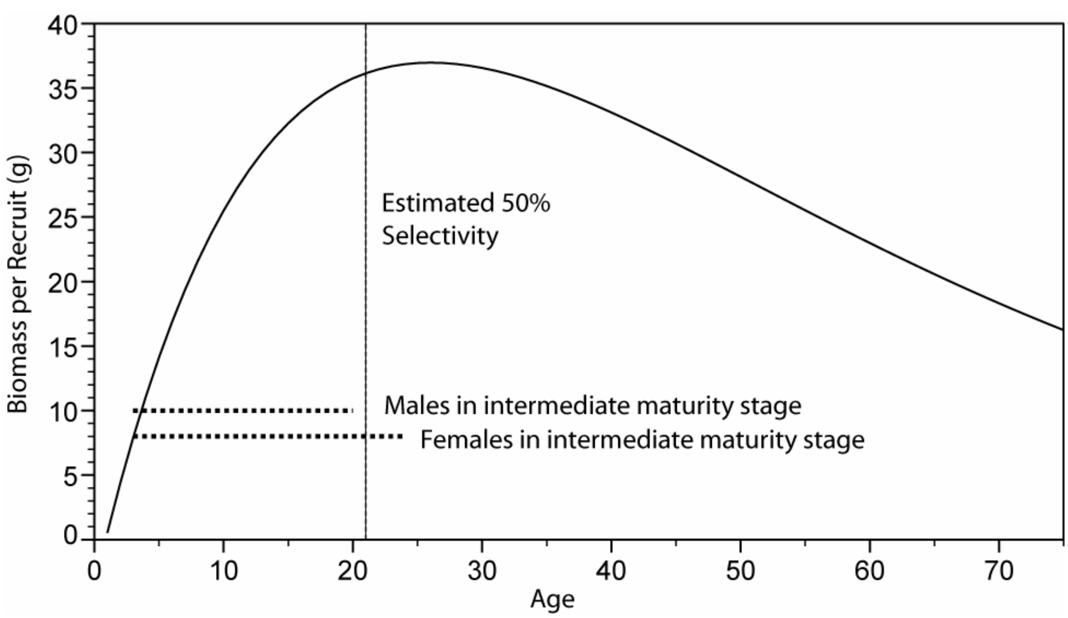

Figure 11. Biomass per recruit for St. Mary's Bay ocean quahogs. Also shown is the estimated 50% gear selectivity at age, and the range of ages of both male and female ocean quahogs in the intermediate maturity stage reported in Rowell et al. 1990.