Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S **S C C S**

Canadian Science Advisory Secretariat / **Secrétariat canadien de consultation scientifique**

Research Document 2007/036 / **Document de recherche 2007/036**

Not to be cited without permission of the authors *

Ne pas citer sans autorisation des auteurs *

Ocean Quahog (*Arctica islandica*) Survey and Yield Estimates for Sable Bank

Relevé des stocks de quahog nordique (*Arctica islandica*) et estimation du rendement pour le banc de l'île de Sable

Roddick, D., R. Kilada, and K. Mombourquette

Population Ecology Division
Science Branch, Maritimes Region
Fisheries and Oceans Canada
Bedford Institute of Oceanography
PO Box 1006
Dartmouth, NS B2Y 4A2

ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

A survey for ocean quahogs (*Arctica islandica*) was conducted on Sable Bank, Nova Scotia in 2003. 293 stations were sampled with a hydraulic clam dredge. A selectivity study of the survey dredge was conducted, and samples for morphometrics, ageing, and age and size at sexual maturity were collected. Survey biomass estimate was 1,262,628 t, and a preliminary dredge efficiency estimate (91.8% efficiency) produced an efficiency corrected biomass estimate of 1,373,913 t. Natural mortality was estimated as 0.03. Size of sexual maturity (30.96 mm) was below the size at 50% selectivity (69.6 mm). Sustainable yield estimates were produced for a range of models from MCY to $F_{0.1}$. Constant mortality models such as $F_{0.1}$ produced much higher yield estimates (54,957 t) than constant yield models such as MCY (13,602) as the biomass is presently in a virgin state. With such a long lived species (oldest aged from survey was 210 years old) and little knowledge of the temporal dynamics of the life history parameters or effects of the fishery on the benthos, it is advised to stay at a conservative end of the choices of yield models.

RÉSUMÉ

Un relevé des stocks de quahog nordique (*Arctica islandica*) a été effectué sur le banc de l'île de Sable (Nouvelle-Écosse) en 2003. Au total,293 stations ont été échantillonnées à l'aide d'une drague à palourde hydraulique. Une étude de sélectivité de la drague a été effectuée et des échantillons ont été prélevés afin de déterminer les caractéristioques morphométriques et celles qui sont liées au vieillissement, ainsi qu'à l'âge et à la taille à la maturité. L'estimation de la biomasse, selon le relevé, était de 1 262 628 t; une évaluation préliminaire de l'efficacité de la drague (91,8 % d'efficacité) a produit une estimation corrigée selon l'efficacité de 1 373 913 t. La mortalité naturelle a été estimée à 0,03. La taille à la maturité sexuelle (30,96 mm) était inférieure à la taille au stade de sélectivité de 50 % (69,6 mm). Une estimation du rendement durable a été réalisée pour une gamme de modèles, de la PMC à F0,1. Les modèles de mortalité constante comme F0,1 ont produit des estimations beaucoup plus élevées du rendement (54 957 t) que les modèles de production constante tels que celui de la PMC (13 602 t), puisque la biomasse est présentement dans un état vierge. Dans le cas d'une espèce qui vit aussi longtemps (l'individu le plus âgé selon le relevé avait 210 ans) et compte tenu du peu de connaissances de la dynamique temporelle des paramètres bioloigiques ou des effets de la pêche sur le benthos, il est conseillé de continuer à choisir des modèles de rendement se situant à l'extrémité prudente de la gamme.

INTRODUCTION

1 – Introduction:

The ocean quahog, *Arctica islandica,* is widely distributed in the North Atlantic, ranging in the northeast from the Bay of Cadiz in Spain, north to Iceland, and in the northwest from Cape Hatteras in North Carolina, USA to the Canadian Arctic (Nicol 1951, Merril and Ropes 1969, Abbott 1974, Brey *et al.* 1990, Witbaard *et al*. 1999). Ocean quahogs are very long lived, slow growing bivalves, the oldest aged to date estimated as 225 years old (Murawski and Serchuk, 1989) This means that productivity of the stock will be low, and that the sustainable yield for a fishery will be a very small fraction of the biomass.

In Nova Scotia there is a small inshore fishery that fishes ocean quahogs as well as other clam species, and a quahog processing plant operated in the 1960's in Port Medway. There has not been an offshore fishery on Canada's east coast, but an offshore fishery has operated off the Northeastern U.S. since the mid-1970's.

A series of exploratory surveys for offshore clams on the Scotian Shelf in 1980 -1982 showed ocean quahogs to be abundant on Sable Bank (Rowell and Chaisson 1983; Rowell *et al*. 1990), but there was little interest in developing a fishery at that time. The surveys did lead to the development of a fishery for the higher value Arctic surfclam (*Mactromeris polynyma*) on the adjacent Banquereau, where it was found to be abundant. With existing vessels and plants from the surfclam fishery and a growth in the use of quahogs in the U.S., there has been renewed interest in developing a fishery for ocean quahogs on Sable Bank.

In 2003 the Offshore Clam Industry entered into a Joint Partnership Agreement with DFO to fund a survey and research program program that will survey the various clam species and banks involved in the fishery, rotating through them on a 4-5 year cycle with each bank surveyed once per cycle. Since the 1980's survey data was over 2 decades old, and little was known about growth rates and other population parameters in Canadian waters, the first survey was for Sable Bank ocean quahogs, to estimate biomass and population parameters.

The present work describes the biomass, age structure, growth and longevity of ocean quahogs on Sable Bank. The intent of this study is to provide the basis for management of a sustainable quahog fishery.

2 – Methods:

2.1 – Survey Design:

To determine the optimal number of stations for the survey, the data of from the 1980-1982 surveys was used to estimate the expected variance for a quahog survey on Sable Bank. The variance in this data was used to examine the reduction in the standard error of the mean as sample size increased. Results showed that there was rapid decrease in the standard error as the number of stations increased up to 150 stations and that there was little reduction in the standard error as the number of stations was beyond 300 (Figure 1). The survey was based on 300 stations, randomly assigned within the 100 m contour on Sable Bank, excluding Sable Island. The tows were assigned with a minimum spacing of 3 km to ensure spread, and checked against the location of pipelines, power cables, wells, and two study sites, which were also excluded. Any stations falling on these locations were replaced (Figure 2).

2.2 – Survey Methodology:

The vessel used for the survey was the Cape Keltic, a 43 m, 360 GT side dragger built in 1967. For the survey it was equipped with a pump, towing frame and hydraulic clam dredge. The dredge was 226 cm wide and 445 cm long, with a 177 cm knife blade. The average bar spacing in the cage section was 23 mm on the top and sides, and 28 on the bottom. The depth of the knife was set to 14.33 cm below the runners. The electronics onboard the Cape Keltic included both a Microplot 7 navigation package (Sea Information Systems Ltd., Scotland, UK) used to measure tow distance and record the tow track; and a RoxAnn bottom discrimination system (Sonavision Ltd., Scotland, UK), used to determine bottom type before using the dredge. The RoxAnn system was calibrated against sites with known bottom types before the start of the survey.

2.3 – Tow procedures:

At each assigned station the bottom was first checked with the RoxAnn system to determine if the bottom was dredgeable. If it was, a 5-minute tow was then conducted. Data on the starting and ending time, latitude and longitude; bearing; depth; wave height; boat speed; and tow distance were recorded for each tow. The start of the tow was based on the vessel position when the winch stopped feeding out cable, and the end on the vessel position when the winch started hauling the dredge back.

2.4 – Catch processing

At each station the volume and weight of the catch was measured by shoveling the entire catch into plastic bushel baskets and counting and weighing the baskets. A Pols® motion-compensating marine scale was used for weighing the baskets. A sample of five bushels was selected and processed for catch composition. After weighing this sample, its components were separated down to species level where possible, as well as such items as empty shells, rocks, garbage, etc. A second sample of 20 bushels was taken and processed by picking out quahogs and all other major bivalves. The catch of major bivalves was thus based on a 25 bushel sub-sample, and catch of other components on a 5 bushel sub-sample. The sub-samples were selected periodically during the shoveling of the catch to minimize any possible effects of sorting of dredge contents either in the dredge or when dumped. The catch weight of any component can be calculated using the formula:

$$C_{tot}=C_S*W_S/W_{tot} \qquad 1$$

Where C_{tot} is the component catch weight in that tow; C_S is the component weight in the sub-sample; W_S is the weight of the subsample; and W_{tot} is the total weight of the catch. Catches were all standardized to a tow area of 1,000 m^2.

To estimate the length distribution of the quahogs, a sample of at least 100 quahogs from each tow was measured to the nearest millimeter.

For morphometrics and ageing, a sample of up to three clams from each 5 mm interval was collected during the length frequency measurements, and frozen for later processing in a DFO laboratory. Once in the laboratory, the morphometrics samples were thawed, and the length, width and height of each quahog was measured to the nearest mm. The weights, recorded to the nearest 0.01 g, were total wet weight (whole animal), total wet tissue weight (shell removed), wet foot weight, gutted foot weight (gonad and digestive gland removed), remaining tissue weight, and shell weight. For all these except total wet weight and total wet tissue, the dry weight was recorded after drying the sample at 90°C for 48 hours. During processing the gonad condition was visually classified into six maturity stages according to Ropes (1968). These were immature; fully spent; early active; late active; ripe; and spawning. The shell colour was also recorded, as the small light coloured shells may have a higher market value.

The age of a length stratified subsample of the quahogs processed for morphometrics was estimated using the acetate peel technique (Thompson *et al.* 1980a; 1980b; Ropes *et al.* 1984a; 1984b). The left valve was sectioned using a low-speed diamond saw, embedded in epoxy-resin, polished with silica carbide grinding powder of successively finer grit (240, 400 and 600), polished with a polishing compound, and etched with 1% hydrochloric acid for 1 minute. Acetate peels were then made by applying an acetate sheet (0.013 mm thick) over the etched surface, after flooding it with acetone. After a 1-hour drying period, the acetate was peeled off and sandwiched between glass slides for examination under a compound microscope. The internal growth bands were counted both in the hinge tooth and along the entire section. Although the number of bands was consistent in both the section margin and hinge area, the former was usually used because the growth bands were wider and thus provided higher resolution. A von Bertalanffy growth curve was fit by non-linear regression using the statistical package SPLUS:

$$L_t=L_\infty(1-e^{-k(t-t_o)}) \qquad 2$$

where L_t is the length at age t; L_∞ is the asymptotic length; k is a growth coefficient; and t_o is the theoretical age at zero length.
Ageing methods, especially those applied to such long lived organisms as ocean quahogs, require validation of the methodology used. The questions to address are: 1) Are the rings used for aging actually annual rings? and 2) Are the results of reading the rings an accurate measure of age, especially for older quahogs when the rings are closely spaced and difficult to read? There are several methods to answer the first question, i.e. marking and growing quahogs for a year or more to look at ring deposition, examining growth past the last ring through the year. Answering the second question with such a long lived species is more difficult. Obtaining known age specimens by growing them is not practical when you want to look at accuracy in aging specimens 100+ years old. A method that can be applied has been provided by the atmospheric testing of nuclear bombs, which started in the late 1950s. The atmospheric tests resulted in a marked and widespread increase in atmospheric ^{14}C, which was subsequently transferred to the oceans. This dramatic increase, and the subsequent decline with the banning of atmospheric tests, is incorporated into the carbon isotope ratio of carbon deposited during this period, including the carbonate shells of marine bivalves (Druffel 1989; Campana and Jones 1998). The age reading of the quahog shells that were growing during the 1950's and 1960's can thus be verified by comparing the dates back calculated from our aging for the $\Delta^{14}C$ peak in the shell, with a known $\Delta^{14}C$ chronology for the area. The $\Delta^{14}C$ chronology for the Scotian Shelf has been constructed with known age fish otoliths formed between 1949 and 2000 (Campana 1997; Campana et al. 2002). Kilada *et al.* (2007) used this method to successfully validate the aging of six quahogs from the Sable Bank survey. The results validate the accuracy of the aging results for quahogs up to 45 years old, and implies that the results for older quahogs are also accurate.

2.5 – Biomass estimation:

The lower depth limit for the survey was the 100 m contour around Sable, bounded on the west by the Western Bank Haddock Nursery Box, and excluding the Gully Marine Protected Area on the east. The upper limit of the depth range to use around Sable Island was determined by analyzing the survey data to determine the quahog minimum depth distribution around Sable Island.

Once the area was established, the biomass in the survey area was calculated by three methods:

1 Random sampling statistics:

$$B = A_s/A_t * \overline{C} \qquad 6$$

Where B = Biomass, A_s = survey area, A_t = Area of standard tow and $\overline{C}$ is mean catch per standard tow.

2 Areal expansion using inverse distance weighting with the ACON Data Visualization software package (Black, 1991).

3 Spatial analysis using kriging after modeling the spatial relationship with a variogram using the Surfer software package (Golden Software Inc., 2002).

The biomass estimates and distribution were compared to the estimates and distribution from the 1980-82 survey.

Other Studies:

2.6 – Selectivity:

A site was chosen for a selectivity study at the end of the first leg of the survey. The site was selected form stations which had a clean catch of quahogs with a large range of sizes, including sufficient quahogs in the 40 to 70mm size range. Dredge selectivity was determined by the covered-cage/codend method (Caddy 1971; Wileman et al. 1996). The dredge cage and codend were fit with a loose cover made of 38 mm shrimp mesh to retain quhogs passing through the dredge. Three tows were made, and the quahogs in the dredge and in the cover were measured to determine the length frequencies retained in each. The proportion at length retained in the dredge was fit by maximum likelihood to a Richards selectivity curve:

$$P = (e^{a+bL}/(1+e^{a+bL}))^{1/\delta} \qquad 3$$

where P is the proportion of quahogs of length L retained by the dredge, a, b and δ are parameters of the function. The mean length at which an individual clam has a 50% chance of being retained (L_{50}) can be calculated as:

$$L_{50} = (\log(0.5^{\delta}/(1+0.5^{\delta})) - a)/b \qquad 4$$

2.7 – Size and age at Sexual Maturity:

Samples for size and age at maturity were collected during the survey. Small quahogs were collected during the gear selectivity experiment, and from survey tows when they were found in the catch. Each animal was measured to the nearest mm and stored in 10% formalin in seawater. The preserved samples were transported to the laboratory, where the foot portion, which contains the gonad material, was separated for histological processing. Histology and staging was done by the Aquatic Diagnostic Services of the Atlantic Veterinary Collage at UPEI. Gonad sections were classified into six maturity stages (Ropes 1968, Rowell *et al.* 1990):1) early active; 2) late active; 3) ripe; 4) partially spent; 5) spent; and 6) immature. The proportion of mature individuals was plotted against size. A logistic curve was fit to the data using maximum likelihood:

$$P = e^{a + bL} / (1+e^{a + bL}) \qquad 5$$

where P is the proportion of mature individuals in the sample, L is the shell length (mm), a and b are constants. The quahog length corresponding to 50% mature was calculated as: $L_{50} = -a/b$. The shells were retained and aged with the same technique as used for the morphometrics samples, with the exception of very small shells, which were first completely embedded in epoxy to support them during sectioning and polishing. A logistic curve was fit to the age at maturity data using the same method used for the size at maturity data.

2.8 – Natural Mortality:

Since there has been no commercial fishery for quahogs on Sable Bank, the natural mortality rate (*M*) is equivalent to the total mortality rate (*Z*). The mortality rate was estimated using the catch curve method (Ricker 1975) which uses the slope of the regression between the natural log of the frequency at age and age. The minimum age to include in the analysis was based on the selectivity study to restrict the analysis to quahogs which were fully vulnerable to the sampling gear and thus on the descending right limb of the age frequency curve. The population age frequency for Sable Bank was estimated from the length frequency data with an age-length key constructed from the aged sample. The population age frequency was compared to that expected with a range of Z values. We compared the Z estimated from the catch curve method, that used for the U.S. quahog stock assessments (M = 0.02), and the best fit to the age frequency distribution.

2.9 – Yield Estimates:

With no times series of fishery data or biomass estimates, yield estimates are based on empirical equations relating biomass, growth and mortality to production. There are many equations that have been proposed, one commonly used in the past is Gulland's (1971) Maximum Surplus Production (MSY) = $0.5MB_0$, where M is the natural mortality rate and B_0 is the virgin biomass. The model is based on the assumption that the maximum population production occurs when the stock is reduced to 50% of the virgin level, and that at this level the yield is maximized when fishing mortality is equal to M. This was used by Rowell et al. (1983) to estimate yield from the 1980's survey estimate, but has fallen out of favor as stocks have collapsed when their fisheries have been based on MSY. It is currently used as an upper limit that triggers corrective action if this level is reached. Lower target yield levels such as 2/3MSY, F = M, and $F_{0.1}$ are more common in recent literature. More conservative equations such as Maximum Constant Yield (MCY) = xMB_0 (Annala 1993) are more recent and based on a strategy of setting a yield that is low enough to be sustainable at all probable biomass levels. The x in xMB_0 is usually set in the range of 0.25 - 0.33 and so can be very conservative. Yield estimates were calculated for MSY, MCY, F = M and $F_{0.1}$.

<u>3 – Results:</u>

Survey stations are shown in Figure 2. There were some un-dredgeable sites due to either bottom hardness or depth. The survey was divided into 2 trips with 219 sites successfully occupied and the selectivity tows completed during the first trip, from Sept. 9^th^ to 22^nd^. The second trip was conducted from Sept. 27^th^ to Oct. 2^nd^ and was interrupted by hurricane Juan, however, 74 sites were occupied, bringing the total occupied sites during the survey to 293. The shallow water limit of the survey area around Sable Island was defined with an analysis of the survey stations. Plotting the catch of major bivalves by species (Figure 3) shows that the catch changes abruptly from quahogs to Atlantic surfclams (*Spisula solidissima*) at the 30 m depth contour. The area for analysis was therefore taken as the area between the 30 and 100 m depth contours, bounded on the west by the Western Bank Haddock Nursery Box, and excluding the Gully Marine Protected Area to the east.

3.1 – Biomass:

Quahog total weight ranged between 0 and 93% of the total catch weight. Mean density was 114.3 kg/1000m^2 with a standard error of 14.7 kg, and when the tows at depths less than 30 m were excluded, the mean was 129.6 kg/1000m^2 with a standard error of 16.6. The quahog density per standard tow (1000 m^2) reached up to 2,425 kg for station 46, just south of Sable Island (Figure 4). Most of the quahogs were caught at depths of 30 to 50 m (Figure 5).

Using random statistics analysis the biomass is:

Number of tows used in analysis =	254
Surveyed area =	10,752 km^2
Survey Biomass (Ave catch per tow * #tows possible) =	1,393,016 t
95 percent confidence interval =	± 21,516 t

The ACON data visualization software (Black, 1991) takes into account the spatial distribution of the stations. It uses inverse distance weighting to estimate the value of intermediate points and contours the density estimates to produce the biomass estimate. In this case the tows shallower than 30 m were included for the contouring, and then for the biomass estimate the contoured area was clipped to the 30 m contour.

Spatial analysis using invers distance weighting:

Number of tows used in analysis =	293
Biomass =	1,265,686 t

The Surfer software package first has the user model the spatial correlation between pairs of data points with a variogram. It allows for different correlations in different directions (anisotrophy). The variogram for the Sable Bank survey is shown in Figure 6. This correlation was then used for the kriging analysis. A grid of points was estimated using the variogram and the grid was contoured, clipped to the survey area, and the biomass estimated.

Spatial analysis using kriging:

Number of tows used in analysis =	293
Biomass =	1,257,570 t

The biomass estimates were within 10% of each other, with the simple statistical method producing a larger biomass estimate than the spatial estimates, which were within 1% of each other. Since there did appear to be some spatial correlation in the data, the average of the two spatial analyses (1,261,628 t) was taken as the estimated survey biomass. Converting to an estimate of absolute biomass requires an estimate of dredge efficiency. Preliminary estimates of dredge efficiency were obtained from two depletion experiments done with the same dredge on Sable Bank in 2004. Using the procedure from Rago *et al*. (2006) the estimated dredge efficiency was 91.8%. This gives an efficiency corrected biomass estimate of 1,373,913 t.

3.2 – Length Distribution:

The length frequency samples were prorated to the total catch per tow using the quahog catch weight divided by the sample weight. The average size of quahogs caught during the survey was 75.9 mm (Figure 7). The mode of small quahogs at 15 mm shell length all came from one tow where a large number of small quahogs were retained in shell hash in the dredge. The distribution of quahogs by size category on Sable Bank is shown in Figure 8. Small quahogs (<60 mm) tend to be around the outside of the distribution, with larger quahogs towards the center. This type of distribution is common and is sometimes referred to as a Basin model. The quahogs do well where conditions are optimal, those towards the outside of the distribution are living in the least optimal conditions and more susceptible to changes in their environment. The outside of the distribution suffers more die-offs during environmental fluctuations, and thus tends to have a younger age and smaller size distribution.

3.3 – Gear Selectivity:

In the selectivity experiment, a total of 5,220 quahogs were retained by both dredge and the cover. About 81% by number were found in the cover and the rest (~19%) were retained by the dredge. Mean quahog shell size collected from the cover was 55.1 mm (± 11.6), while that collected in the dredge was 70.5 mm (± 14.5) (Figure 9). The fit of a Richard's selectivity curve to the proportion at length retained by the dredge is shown in Figure 10. The mean length at t which an individual clam has a 50% chance of being retained by the dredge, L_c, was derived from equation (3) and was found to be 69.6 mm.

3.4 – Morphometric Measurements:

Morphometric relationships for ocean quahogs were established from the samples collected from each tow and processed in the lab. The relationship between shell height and width versus shell length are shown in Figure 11, and the length – wet weight relationship in Figure 12.

Mean meat yield for the quahogs from the survey was 33.1% of the total weight (Figure 13). The relationship appears to be linear through most shell lengths, but not at the ends of the sampling distribution. A loess curve was also fit to the data, and its prediction shows a maximum meat yield of 36.5% occurs at a shell length of 53 mm.

The shell width versus length relationship can be compared to the selectivity analysis. The mean bar spacing on the bottom of the dredge was 28 mm. Plotting length against width gives a slightly curvilinear relationship. A linear regression did not provide an adequate fit to the data, so a loess regression was used to calculate the estimated length of a quahog that would fit through the bar spacing (Figure 14). Since quahogs have a hard shell and respond to disturbance by closing up, the selectivity of the dredge should be mechanical sorting. Since the survey dredge is not new, the bar spacing is not even, but the predicted value of 58.86 mm is well below the 50% selectivity point. This indicates that the selection in the survey dredge is taking place in the chain bag and codend which allow larger quahogs through than the bar spacing in the cage section of the dredge.

3.5 – Ageing:

A total of 335 quahogs were aged using the acetate peel technique, including those collected for the age/size at maturity study. The aged quahogs ranged between 2 and 210 years, and lengths of 8 to 118 mm. Growth rate was most rapid for quahogs < 25 yr old, declining to very low growth rates after 75 years of age (Figure 15). With such a wide range of ages a sample size of 355 does not produce a smooth and full age frequency. There are still gaps in the distribution that would take a large increase in aged shells to fill.

3.6 – Bycatch:

By-catch included 100 various items (Table 1). Ocean quahogs accounted for 31.3% of the catch by weight, while shell, rocks, sand and clay made up 52.7%. Sand dollars (*Echinarachnius parma*) were the second largest living component at 10.8%, followed by propellerclams (*Cyrtodaria siliqua*) and sea cucumbers (*Cucumaria frondosa*) at 0.9% each. The remainder of the items made up 3.4% of the catch.

3.7 – Natural Mortality:

The length frequency data was prorated to the total survey catch and converted to an age frequency using an age-length key constructed from the aging data. Since there were gaps in the age distribution it was decided to aggregate the data into 5 year intervals to smooth it out. The estimated age composition of the survey catch from Sable Bank was dominated by quahogs of between 25 - 55 years of age, although substantial numbers of animals up to 100 yr old were observed (Figure 16). Using our growth curve, the 50% selectivity size of 69.6 mm translates to an age of 28-29. The catch curve analysis of the aggregated data therefore used the age frequency distribution from 30 to 115 years of age to ensure it was based on quahogs retained by the gear. This resulted in an estimated total mortality (Z) of 0.026 (Figure 16).

The aggregated age frequency data was also plotted as frequencies proportional to age 30-35. The estimated reduction in numbers for a range of Z values was then compared to the resulting frequency distribution (Figure 17). The Z's chosen were 0.02, the value assumed for the U.S. fishery, 0.0277 from the catch curve analysis and those resulting from the best fit regressions using all points and all non-zero points. This analysis indicates that the value used in the U.S. stock assessments (Z = 0.02) does not fit the Sable population as almost all points fall below the line, and that a Z of 0.03 is more appropriate.

3.8 – Minimum Size and Age of Sexual Maturity:

Of the 76 quahogs processed for maturity, 31 were females, 25 were males, and 20 were immature. The latter ranged in size from 8 to 32 mm. There was no significant difference in the mean size of sexes within the sample.

The fit of a logistic curve to the proportion mature at size is shown in Figure 18, and by age in Figure 19. The 50% maturity level was reached at 30.96 mm and 8.2 years. This is well below the 50% selectivity size for the gear, and so quahogs should have approximately 20 years to reproduce before being vulnerable to the gear.

3.9 – Yield Estimates:

Constant yields were estimated using the survey biomass estimate as an estimate of the virgin biomass B_0, and the estimated total mortality (Z = 0.03) as the estimate of natural mortality (M). There are a number of methods that have been proposed for estimating sustainable yield in the absence of fisheries data. One of the earliest and simplest is Gulland's (1971) Maximum Sustainable Yield: MSY = $0.5MB_0$. This formula is based on surplus production modeling and is a "ballpark" estimate based on the assumptions that surplus production is maximized when a stock is fished down to roughly one half of its virgin biomass, and that sustainable yield at this level is maximized when fishing mortality is equal to natural mortality. This yield is generally felt to be too high, and there have been stocks that collapsed when managed with an MSY approach. A more conservative sustainable yield used today is 2/3MSY. For fisheries where there is the desire to keep monitoring costs low, an approach called Maximum Constant Yield (MCY) is used. The theory for this approach is that a constant yield is set at a low enough level to be sustainable during all probable biomass levels. This means that it is set low enough to be sustainable when the stock is at its lowest expected levels. It is a "set it and forget it" approach, and the formula for a data limited new fishery is expressed as MCY = xMB_0, where x varies with the parameters of the stock and is usually in the range of 0.2 to 0.33. Since it is expected that the quahog fishery will have monitoring in place, the upper end of this range is used.

In contrast to setting a constant yield, an approach used for a lot of developed fisheries today is to apply a constant fishing mortality (F). This approach removes a constant fraction of the population using a constant F, and so the yield will fluctuate with stock biomass. One method of determining the appropriate F is yield per recruit analysis. The most common target fishing mortality is $F_{0.1}$. This is below the maximum yield per recruit, but has both conservation and economic benefits. For the Sable survey data we cannot really model a commercial fishery, as we do not know the selectivity of the commercial gear, our growth curves and mortality estimates are still at the preliminary stage, and our weight at age data is from frozen and processed samples. As a demonstration of the approach, we can use the survey dredge selectivity estimate and the parameters as estimated here. We fit a von Bertalanffy curve to the weight at age data from the processed samples, used the survey gear selectivity curve, and the estimated M of 0.03. The yield per recruit curve is shown in Figure 20. For this analysis the recruits were recruits to the population, i.e. age 1, and not recruited to the gear. Yield is maximized at an F_{max} of 0.08, and the $F_{0.1}$ target is 0.04. Another constant F strategy, sometimes employed in data poor fisheries, is to set F equal to M. This will usually be more conservative than an F0.1 approach, but can be estimated with less data. In both these constant F strategies, the yield will initially be high as the biomass is around its maximum level, and will drop and the stock is fished down from the virgin state to a sustained fishing level. The yields produced by the different methods are shown in Table 2.

4 – Discussion

In comparing the present survey with the 1983 survey, the high biomass areas are generally in the same areas reported by Rowell and Amaratunga (1986). The current survey indicates a more continuous band in the 30-50 m depth range than the older survey. In the 1983 survey, the highest density on Sable Bank was 0.583[1] kg/m^2 (Rowell and Chaisson 1983) compared to 2.425 kg/m^2 recorded in the current survey. The 1983 survey covered both Sable and Western Banks, but most of the analysis focused on six areas with an estimated commercial density of at least 100g/m^2 (Rowell and Amaratunga 1986). Taking their areas 1,2,4,5 and 6 as Sable Bank (see Figure 2), they estimate an area of 2,071 km^2 which contained a biomass of 514,173 t. The present study estimates the area with a density over 100 g/m^2 as 3,147 km^2 with a biomass of 1,073,680 t (without a correction for dredge efficiency). Rowell and Amaratunga (1986) used MSY = 0.5MB_0 for their yield estimate, using M = 0.03 as in the present study, their estimate would be 7,713 t. but the difference in the biomass estimates results in a larger yield for the present study, even with the more conservative MCY and 2/3 MSY formulas. Restricting the estimate to the biomass in the area over 100 g/m2 (1,073,680 t) gives a 2/3 MSY of 10,737 t and an MCY of 10,629 t, still 50% higher than the 1986 estimate while using a more conservative method. There are two differences between the surveys that could account for the difference in biomass. The largest difference is in the survey gear used. The 1983 survey used the Delaware II, which is equipped with a dredge mounted electro-hydraulic pump for the water supply. It is towed with a combination power/tow cable, and so can keep the same scope at all depths as there is no water hose to handle. This system, however, has proven to be less efficient than the typical surface supplied commercial gear. The U.S. studies indicate that the Delaware II survey dredge has an efficiency of 16.5%, while the commercial dredges are highly variable, ranging from 15 to 100% with a median of 0.66% (CV = 14%). Preliminary estimates of the efficiency of the Sable Bank survey dredge are 92%. The higher efficiency for the dredge used in the present survey would be the main factor for the difference in catch rate and thus biomass estimates. A second, much smaller, factor is the method used to determine catch weight per tow. In the 1983 survey, the volume of clams in bushels and the total number of clams per tow was recorded. A length frequency sample was frozen for later length-weight determination. To estimate catch weight per tow, the length-weight relationship was applied to the numbers in each size class to obtain a mean weight per tow. This was then applied to the total number of clams caught per tow. This process could introduce errors in the calculation of catch weight. In the present study the catch weight is measured directly with a motion compensating marine scale.

The determination of a sustainable yield is the main focus of fisheries management. How large a catch can be taken from the stock on an annual basis without damaging its ability to maintain itself. The current approach is to use Reference Points (RPs) to guide the management of a stock. Target Reference Points (TRPs) and Limit Reference Points (LRPs) are set for each stock. The TRP is the level of fishing which is considered optimal, and towards which management attempts to guide the fishery. The LRP is a level that is bordering on being detrimental to the stock. When the fishery approaches the LRP, action is taken to direct it back towards the TRP. If this is unsuccessful and the LRP is reached, immediate and often drastic action is taken to reduce effort, including closure of the fishery. There is a wide choice of methods on which to base a TRP for a stock. The choice will depend on the amount, type and quality of the data available, the level of risk that is felt to be acceptable, and what stage of development the fishery is in. The methods range from simple empirical equations based on life history parameters and simple models of population growth, through models such as delay-

[1] Corrected according to errata sheet for Rowell and Chaisson 1983.

difference models that require a time series of catch, effort and size data, to methods requiring detailed data on the age or size structure of the catch over a number of years. The more complex methods also require the use of fishery independent data such as survey estimates. The ocean quahog population on Sable Bank in is a virgin state and there is no fishery data to use in a model. The survey program provides a direct estimate of the virgin biomass, something usually missing for a fished stock, and preliminary estimates of population parameters such as size and age at maturity, growth rate, and natural mortality.

Aspects of the life history that affect the management approach are shown in Figure 21. Cohort biomass (biomass per recruit with no fishing) reaches a maximum at 33 years of age, after which losses from natural mortality exceeds gains from growth. The age at 50% selectivity is much higher than the age at maturity, indicating that most quahogs will have many years of spawning before being captured by a fishery. This helps alleviate concerns about recruitment over fishing. The age of 50% selectivity is also near the age at maximum biomass per recruit, which reduces the potential of growth over fishing. Both of these are dependent on the commercial gear having a similar selectivity curve to the survey gear.

There are several approaches to estimating yield, one common in the literature, and used for the analysis of the 1983 survey, is Gulland's (1971) formula for Maximum Sustainable Yield (MSY). It is based on surplus production modeling that says that when a population is at its carrying capacity, its rate of increase (growth and recruitment) are in balance with its rate of decrease (natural mortality) and the population is stable. When the population is reduced below its carrying capacity, growth and recruitment increase beyond what is removed by natural mortality (surplus production) and the population will increase. If a fishery just removes the surplus production, the population biomass will remain constant at its current level and that level of harvest will be sustainable into the future. Surplus production is zero when the population is at its carrying capacity, usually estimated as the virgin biomass level, and at its maximum when the population is approximately half that size. The theory also says that when the biomass is at $0.5B_0$, the surplus production is roughly equal to that removed by natural mortality, thus the formula MSY = $0.5MB_0$, and the F = M approach. Management with MSY targets have not been not very successful, and it has became evident that MSY is generally too high a target for a sustainable fishery. It was also found that economic returns from fisheries were usually better when the biomass was above $0.5B_0$. Target yield levels were therefore set below the MSY estimate, one sometimes used is 2/3 MSY. An alternative approach used in New Zealand for data poor fisheries is Maximum Constant Yield (MCY) (Annala 1993, Caddy 1998). MCY is defined as the maximum constant yield that is sustainable at all probable biomass levels with an acceptable level of risk. Setting it low enough level to be sustainable during the lowest of expected natural fluctuations in biomass makes it a very conservative yield. It is usually applied as a "set it and forget it" target. Set it low enough that it does not require monitoring and adjustments. New Zealand uses the formula MCY = $0.25F_{0.1}\,B_0$, or when $F_{0.1}$ is unknown MCY = $0.25MB_0$. In any Canadian fishery there would be monitoring and routine data collection, so yield levels would not have to be this conservative. A 2005 DFO expert opinion on the rationale for harvest advice for ocean quahogs (DFO 2005) recommended that a level of $0.33MB_0$ would be appropriate, making it identical to 2/3 MSY (Table 2). There is a big difference in the assumptions for MSY and MCY. MSY makes the assumption of equilibrium, the values it estimates are what would be expected after the system has adjusted to the rate of fishing, and it assumes constant growth and recruitment. The time for the system to come into equilibrium with such a long lived species as ocean quahogs will be beyond the lifespan of those involved in the fishery. The assumption of constant growth and recruitment is also generally false, nature is not constant and most species do not have constant growth or recruitment. The MCY approach does not make these assumptions. It assumes there will be fluctuations in the population, but attempts to set the yield low enough that it will be sustainable through the low periods.

A different approach than setting a constant yield is setting a constant fishing mortality. In this approach the fraction of the population removed by fishing is constant, and so as the biomass changes the yield changes along with it. For populations that undergo large fluctuations in biomass, a constant fishing mortality should give higher catches in the long term, as it will remove more during periods of high biomass than a constant yield approach would. For a long lived, slow growing species such as ocean quahogs, there is always a large number of year-classes present in the population. That means that the biomass does not undergo the same large fluctuations as seen in shorter lived species, where an exceptionally large or small recruiting year-class results in a big change in biomass. A common target fishing mortality is $F_{0.1}$. It is based on yield per recruit analysis, and similar to the current MSY approach, it is a target that is below the maximum for conservation and economic reasons. Yield per recruit addresses growth over fishing, but it does not ensure that recruitment over fishing is not taking place. The U.S. currently uses an $F_{0.1}$ approach to manage its ocean quahog fishery. It has had an offshore quahog fishery since 1976 and currently has a target reference point of $F_{0.1}$ = 0.028. When looking at the fisheries history, the biomass has always been above $0.5B_0$ and the fishing mortality has remained below $F_{0.1}$. Although the biomass has always been high and fishing mortality low, the biomass has steadily declined for the 30 year history of the fishery, and projections show it continuing to decline into the future. Recruitment is low and not keeping up with removals. It is hoped that recruitment will increase as the population declines, but the increased research on recruitment indicates that concern is growing. The MCY approach would produce stable catches and allow time for the collection of fishery and other data to refine the models and parameter estimates. Recruitment could be monitored to see how the biomass will respond to fishery removals.

Another consideration for an ocean quahog fishery is the period of time before the vessels have to return to previously fished areas. With the low productivity of ocean quahogs a fished area will not build back up to economic densities for a number of years. If the estimate of 100g/m^2 for commercial viability is correct, the available area is 3,147 km^2. Industry has estimated that a vessel would cover 165 km^2 per year. This means that a vessel would not have to return to the same grounds for 19 years. The 2002 expert opinion on the proposal for a quahog fishery on Sable and Western Bank (DFO 2002) estimated that the habitat would recover from dredging to an acceptable level in 20 years, so this rotation should help minimize long term impacts on the habitat. If the survival rate of undersized quahogs is high, and Murawski and Serchuk (1989) indicates it is, this would also be enough time for undersized quahogs to reach commercial size. The question would then be if recruitment would be steady enough to repopulate the beds. The U.S. experience is that recruitment events for ocean quahogs are sporadic, and there may be long periods of poor recruitment. Although age data for Sable is not extensive (Figure 16), there does appear to be periods of low recruitment that may span more than a decade. A low harvest rate would help carry a fishery through periods of poor recruitment. With a new fishery such as this one, it is warranted to take a cautious approach initially and to make adjustments as the fishery progresses and knowledge of the dynamics of the system increases. A catch level around the MCY level would be more appropriate than the higher levels.

The main source of error in this analysis is the survey catch rate. Tow distance is calculated as the vessel movement from the time the winch stops paying cable out until the winch starts hauling back. If the dredge is moving along the bottom before and after these points the tow distance will be underestimated. This would result in an overestimate of the biomass. In the U.S. surveys with the Delaware II when the winches were replaced with ones that had a different speed, the result was a change in catch rate. The other way that tow distance may be inaccurate is if the dredge is not fishing for all of the tow because it is being tilted or pulled up off the bottom due to vessel movement. This results in an overestimate of the area covered by the dredge and thus underestimates biomass. In addition, the dredge is not 100% efficient. We have preliminary estimates of the survey dredge efficiency based on two depletion studies done in 2004. These gave an estimated efficiency of 91.8%, but additional studies are required to see how it varies with factors such as depth and substrate.

There are attempts to address these sources of error. A sensor system for the dredge was purchased in 2006 that will tell when the dredge is sitting level on the bottom and fishing properly. This will address the question of tow distance. Examining how dredge efficiency is affected by factors such as depth and substrate will take either a large effort dedicated to dredge efficiency, or a number of years doing a few depletion experiments with each survey to build up a database that can be used to model dredge efficiency accurately.

5 – CONCLUSIONS

The estimated efficiency corrected survey biomass for Sable bank is 1,373,913 t. This is higher than the 1983 estimate. With an estimated natural mortality of 0.03 the MCY yield ($0.33MB_0$) is 13,602 t. The 50% selectivity size for the survey gear (70 mm) is well above the size of 50% maturity (31 mm). Growth rates show rapid growth up to age 30 with little increase in size after age 75. The oldest quahog from Sable Bank aged to date was 210 year old. By-catch is minimal for this gear, with sand dollars the only species besides ocean quahogs making up more than 1% of the catch weight. If a vessel covers 165 km^2/year the available area with a density above 100g/m^2 could be fished on a 19 year rotation. This would allow time for the benthos in the fished area to recover.

Bibliography

Abbott, R.T. 1974. American seashells. New York: Van Nostrand Reinhold Co. 663 pp.

Annala, J. H. 1993. Fishery assessment approaches in New Zealand's ITQ system. In Kruse, G. (Ed.), Proceedings of the International symposium on management strategies for exploited fish populations, Anchorage, Alaska, 21-24 October 1992, pp. 791-806.

Black, J. 1991. ACON Data Visualization Software User Manual [Internet]. Version 10.7.05. Dartmouth (NS): Fisheries and Oceans Canada, Maritimes Region; [Updated 2007 May 11; cited 2007 May 26]. Available from: http://www.mar.dfo-mpo.gc.ca/science/acon/.

Brey, T., Arntz, W.E., Pauly, D., and Rumohr, H. 1990. Arctica (Cyprina) islandica in Kiel Bay (western Baltic): growth, production and ecological significance. Journal of experimental Marine and Biological Ecology, 136:217-235.

Caddy, J.F. 1971. Efficiency and selectivity of the Canadian offshore scallop dredge. ICES CM, 1971/K:25. 8p.

Caddy, J.F. 1998. A short review of precautionary reference points and some proposals for their use in data-poor situations. FAO Fish. Tech. Pap. 379:30pp.

Chaisson, D.R. and T.W. Rowell. 1985. Distribution, abundance, population structure, and meat yield of the ocean quahog (*Arctica islandica*) and Stimpson's surf clam (*Spisula polynyma*) on the Scotian Shelf and Georges Bank. Canadian Industry Report of Fisheries and Aquatic Sciences, No. 155, Government of Canada Fisheries and Oceans, 1985: ix and 125 p.

DFO 2002. Expert opinion on Clearwater/Deep Sea Clam ocean quahog development proposal. DFO Maritimes Region Expert Opinion 2002/03.

DFO 2005. Expert opinion on the rationale for harvest advice on ocean quahogs (Arctica islandica). DFO Maritimes Region Expert Opinion 2005/04.

Golden Software Inc. 2002. Surfer 8 Contouring and 3D surface mapping for scientists and engineers User's guide. Golden Software Inc.. Golden CO. 640 pp.

Gulland, J.A. 1971. Science and Fishery management. J. Cons. Int. Explor. Mer. 33:pp. 471-477.

Insightful Corp, 2001. S-Plus 6 for Windows User's guide, Insightful Corp., Seattle, WA.

Kilada, R. W., Campana S. E., and Roddick, D. 2007. Validated age, growth, and mortality estimates of the ocean quahog (Arctica islandica) in the western Atlantic. ICES Journal of Marine Science, 64: 31–38.

Murawski, S.A., and F.M. Serchuk. 1989. Environmental effects of offshore dredge fisheries for bivalves. ICES C.M. 1989/K:27 23 p.

NEFSC (Northeast Fisheries Science Center) (2003) 37th Northeast regional stock assessment workshop (37th SAW) stock assessment review committee (SARC) concensus summary of assessments. NEFSC Ref. Doc. 03-16.

Nicol, D. 1951. Recent species of the veneroid pelecypod Arctica. Journal of Washington Acadamy of Science, 41:102-106.

Rago, P.G., J.R. Weinberg and C. Weidman. 2006. A spatial model to estimate gear efficiency and animal density from depletion experiments. Can. J. Fish. Aquat. Sci. 63: 2377-2388.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of Fisheries Research Board of Canada. (191) 382 pp.

Ropes. J.W. 1968. Reproductive cycle of the Surf clam, Spisula solidissima, in offshore New Jersey. Biol. Bull. 135:349-365.

Ropes, J.W., Jones, D.S., Murawski, S.A., Serchuk, F., and Jerald Jr., A. 1984a. Documentation of annual growth lines in ocean quahogs, Arctica islandica Linne. Fisheries Bulletin, 82:1-19.

Ropes, J.W., Murawski S.A., and Serchuk, F. 1984b. Size, Age, Sexual maturity, and sex ratio in ocean quahogs Arctica islandica Linne, off Long Island, New York. Fisheries Bulletin, 82:253-267.

Rowell, T.W. and T. Ameratunga. 1986. Distribution, Abundance, and preliminary estimates of production potential for the ocean quahaug (arctica islandica) and Stimpson's Surf clam (Spisula polynyma) on the Scotian Shelf. CAFSAC. Res. Doc. 86/56, 21p.

Rowell, T.W., and D.R. Chaisson. 1983. Distribution and abundance of the Ocean Quahaug (Arctica islandica) and Stimpson's surf clam (Spisula polynyma) resource on the Scotian Shelf. Can. Ind. Rept. Fish. Aquat. Sci. 142: v + 75p.

Rowell, T.W., D.R. Chaisson and J.T. McLane. 1990. Size and age of sexual maturity and annual gametogenic cycle in the ocean quahog, *Arctica islandica* (Linnaeus, 1767), from coastal waters in Nova Scotia, Canada. J. Shellfish Res. 9:195-203.

Thompson, I., D.S. Jones and D. Dreibelbis. 1980. Annual internal growth banding and life history of the ocean quahog *Arctica islandica* (Mollusca: Bivalvia). Mar. Biol. 57:25-34.

Thompson, I., D.S. Jones and J.W.Ropes. 1980. Advanced age and sexual maturity in the ocean quahog *Arctica islandica* (Mollusca: Bivalvia). 1980. Mar. Biol. 57:35-39.

Wileman, D.A., R.S.T. Ferro, R. Fonteyne and R.B. Millar (Eds.). 1996. Manual of methods of measuring the selectivity of towed fishing gears. ICES Cooperative Research Report 215. 126 pp.

Witbaard, R., Diuineveld, G., and de Wilde, P. 1999. Geographical differences in growth rates of Arctica islandica L. (Mollusca, bivalvia) from the North Sea and adjacent water. Journal of Marine Biological Association of UK, 79:907-915.

Table 1. Composition of the total dredge catch from the 2003 Sable Bank ocean quahog survey.

Species Name	Common name	Weight (kg)	%	Cumm. %
Arctica islandica	Ocean quahog	39,605.0	31.31	31.31
Clay	Clay	31,138.6	24.62	55.93
Shell	Shell	20,603.9	16.29	72.22
Echinarachnius parma	Sand dollars	13,709.1	10.84	83.06
Rocks and stones	Rocks and stones	13,596.5	10.75	93.81
Cyrtodaria siliqua	Propellor clam	1,153.4	0.91	94.73
Cucumaria frondosa	Sea cucumber	1,113.1	0.88	95.61
Sand	Sand	741.5	0.59	96.19
Aphrodita hastata	Sea mouse	713.0	0.56	96.76
Asterias vulgaris	Starfish	592.1	0.47	97.22
Placopecten magellanicus	Sea scallop	580.0	0.46	97.68
Rock and clay	Rock and clay	553.7	0.44	98.12
Spisula solidissima	Atlantic surfclam	379.3	0.30	98.42
Cancer borealis	Jonah crab	336.9	0.27	98.69
Mactromeris polynyma	Arctic surfclam	281.7	0.22	98.91
Lophius americanus	Monkfish	209.2	0.17	99.07
Cancer sp.	crab	139.5	0.11	99.19
Cancer irroratus	Rock crab	136.5	0.11	99.29
Chionoecetes opilio	Snow crab	129.7	0.10	99.40
Euspira heros	Moon snail	102.5	0.08	99.48
Raja ocellata	Winter skate	65.0	0.05	99.53
Pagurus sp.	Hermit crab	60.3	0.05	99.58
Caudina arenata	Rattail cucumber	58.5	0.05	99.62
Ensis directus	Atlantic Jackknife clam	58.2	0.05	99.67
Organic Debris	Peat, wood, coal	75.6	0.06	99.73
Chlamys islandica	Iceland scallop	41.3	0.03	99.76
Strongylocentrotus droebachiensis	Sea urchin	38.9	0.03	99.79
Serripes groenlandicus	Greenland cockle	32.1	0.03	99.82
Neptunea lyrata decemcostata	New England neptune	23.4	0.02	99.83
Limanda ferruginea	Yellowtail	23.3	0.02	99.85
Buccinum sp.	Waved whelk	20.9	0.02	99.87
Myoxocephalus octodecemspinosus	Longhorn sculpin	18.2	0.01	99.88
Colus sp.	Smooth whelk	15.4	0.01	99.90
Foreign articles, garbage	*Foreign articles, garbage*	12.7	0.01	99.91
Modiolus modiolus	Horse mussel	11.3	0.01	99.92
Mytilus edulis	Common mussel	10.8	0.01	99.92
Raja sp. eggs	skate egg case	10.5	0.01	99.93
Libinia emarginata	Portly spider crab	8.7	0.01	99.94
Ophiuroidea o.	Brittle star	7.7	0.01	99.95
Anthozoa C.	Sea anemone	6.0	>0.005	99.95
Ascophyllum nodosum	Rockweed	5.8	>0.005	99.95
Lithodes maja	Stone crab	5.7	>0.005	99.96
Hyas araneus	Toad crab	5.4	>0.005	99.96
Henricia sanguinolenta	Blood star	5.2	>0.005	99.97
Solaster endeca	Purple sunstar	4.4	>0.005	99.97
Mya truncata	Mya clam	3.9	>0.005	99.97
Clinocardium ciliatum	Iceland cockle	3.7	>0.005	99.98
Ammodytes americanus	Sand lance	3.1	>0.005	99.98
Porifera P.	sponge	3.0	>0.005	99.98
Crossaster papposus	Rough/Spiny sunstar	3.0	>0.005	99.98
Zostera marina	eel grass	2.8	>0.005	99.99

Table 1 continued. Catch composition of the dredge catch from the 2003 Sable Bank ocean quahog survey.

Species Name	Common name	Weight (kg)	%	Cumm. %
Scomberesox saurus	Atlantic Saury / Billfish	1.6	>0.005	99.99
Glyptocephalus cynoglossus	Grey sole	1.5	>0.005	99.99
Hyas coarctatus	Lesser Toad crab	1.5	>0.005	99.99
Prionotus carolinus	Sea robin	1.4	>0.005	99.99
Merluccius bilinearis	Silver hake	1.3	>0.005	99.99
Solaster papposus	Sun star	1.1	>0.005	99.99
Unknown	Siphonid worm	1.0	>0.005	99.99
Buccinidae-Family, Eggs	whelk egg case	0.7	>0.005	99.99
Ctenodiscus crispatus	Mud star	0.7	>0.005	99.99
Hippoglossus hippoglossus	Atlantic halibut	0.6	>0.005	100.00
Unknown	flounder - unid.	0.6	>0.005	100.00
Unknown	snail - unid.	0.6	>0.005	100.00
Aporrhais occidentalis	Pelican's foot whelk	0.6	>0.005	100.00
Polychaeta - Class	polychaete worm	0.5	>0.005	100.00
Dipturus - Genus	skate - unid	0.4	>0.005	100.00
Arabella iricolor	Segmented red worm	0.4	>0.005	100.00
Raja laevis	Barndoor skate	0.3	>0.005	100.00
Astarte sp.	Astarte clam	0.3	>0.005	100.00
Buccinidae-Family	whelk - unid.	0.3	>0.005	100.00
Unknown	Unk purple worm	0.3	>0.005	100.00
Holothuroidea - Class	cucumber - unid.	0.3	>0.005	100.00
Coregonus canadensis	Whitefish	0.3	>0.005	100.00
Gymnolaemata - Class	marine bryozoan	0.2	>0.005	100.00
Gorgonocephalus sp.	Basket star	0.2	>0.005	100.00
Scophthalmus aquosus	Windowpane flounder	0.2	>0.005	100.00
Pentamera calcigera	white cucumber	0.1	>0.005	100.00
Fucus sp.	rockweed	0.1	>0.005	100.00
Desmerestia sp.	Horsetail	0.1	>0.005	100.00
Solemya borealis	Awning clam	0.1	>0.005	100.00
Geukensia demissa	Ribbed mussel	0.1	>0.005	100.00
Laminaria saccharina	Kelp	>0.05	>0.005	100.00
Euspira sp. eggs	moon snail eggs	>0.05	>0.005	100.00
Pandulus sp.	Pandalid shrimp - unid.	>0.05	>0.005	100.00
Mud	mud	>0.05	>0.005	100.00
Cyclocardia borealis	Northern cardita	>0.05	>0.005	100.00
Nemata - Phyllum	nematodes - unid.	>0.05	>0.005	100.00
Pelonaia corrugata	tunicate	>0.05	>0.005	100.00
UNID FISH AND REMAINS	fish vertebrae	>0.05	>0.005	100.00
Unknown	fish - unid.	>0.05	>0.005	100.00
Unknown	worm - unid	>0.05	>0.005	100.00
Unknown	tube worm	>0.05	>0.005	100.00
Unknown	Tunicate (purple)	>0.05	>0.005	100.00
Grand Total		126477.2	100.00	

Table 2. Input parameters and sustainable yield estimates for the quahog population on Sable Bank.

Input parameters:

- B_0 = 1,373,913 t
- M = 0.03
- $F_{0.1}$ = 0.039
- Weight at age from formula:

$$W_t = W_\infty(1-e^{-k(t-t_0)})$$

- Selectivity at age taking length at age from growth curve (Figure 15):

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

and selectivity at length (Figure 10):

$$P = (e^{a+bL}/(1+e^{a+bL}))^{1/\delta}$$

Yield estimates:

Method	Formula	Yield (t)
MSY	$.5*MB_0$	20,609
MCY	$0.33*MB_0$	13,602
F = M	$.03B_0$	41,217
$F_{0.1}$	$.04*B_0$	54,957**

** Based on survey gear and initial parameter estimates, may not apply to a commercial fishery. Initially high but declines with biomass.

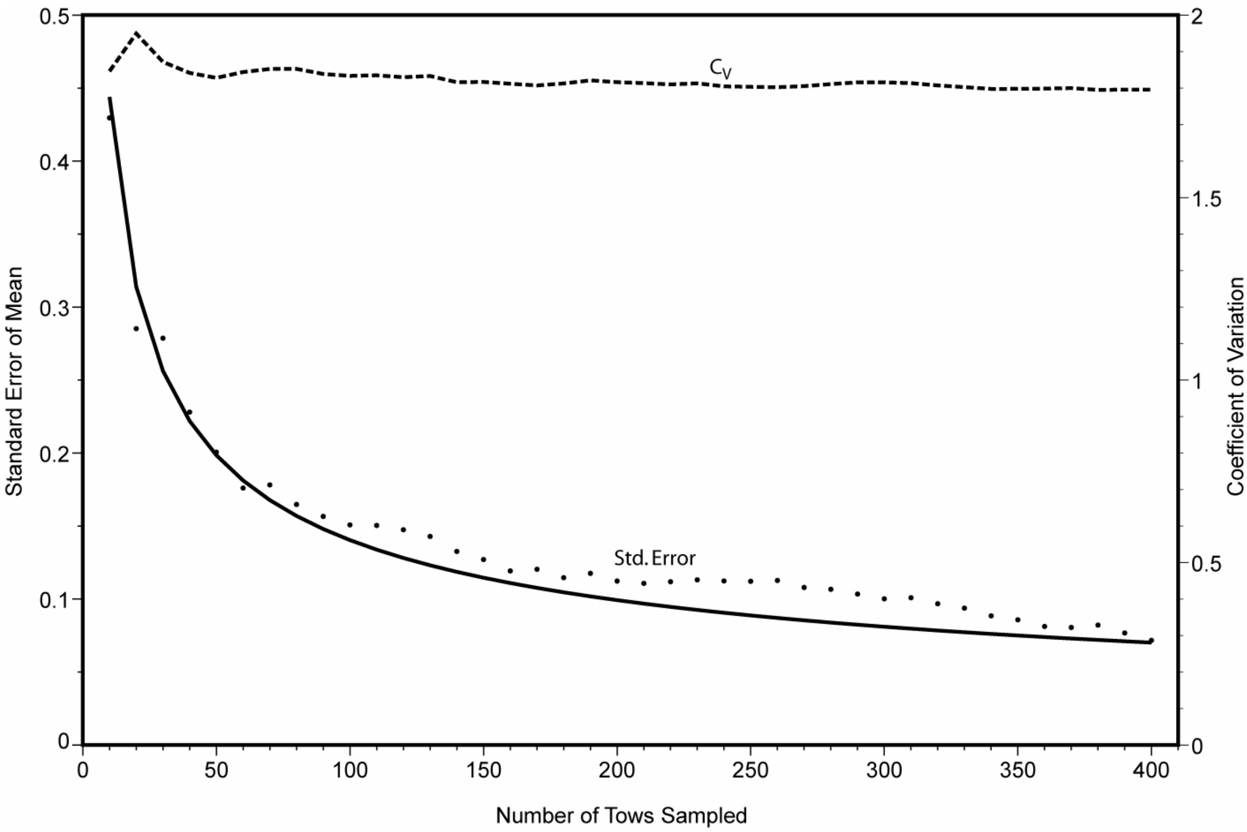

Figure 1. Estimated standard error of the mean from the 1981-82 Arctica survey on Sable-Western Banks. Points are standard errors from 30 replicates sampling with replacement from survey tows for the Figure specified number of tows. The solid line is the survey standard deviation over $\sqrt{n}$ where n is the number of tows, and the dashed line is the average Coefficient of Variation for the 30 replicates.

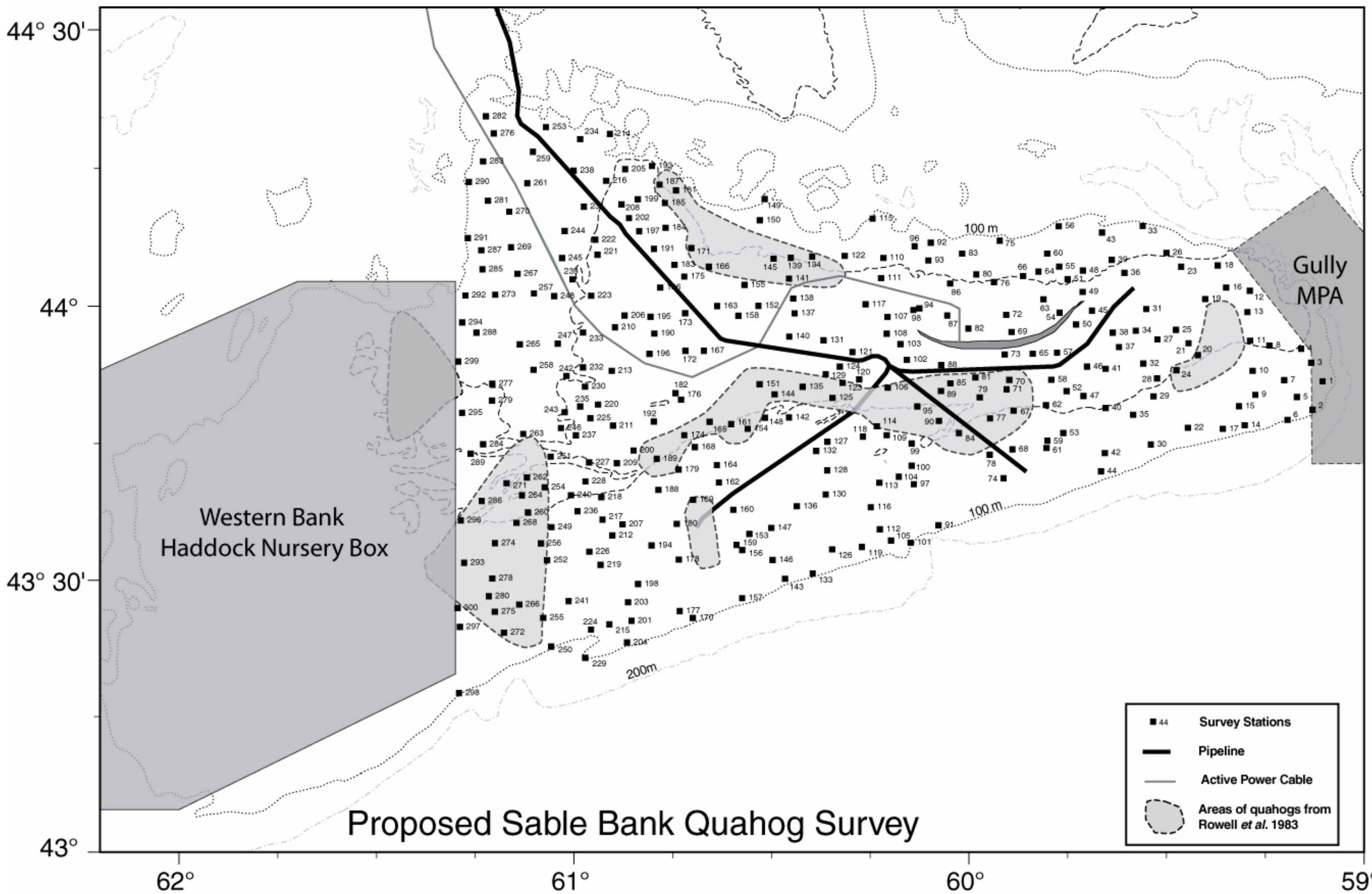

Figure 2. Station locations on Sable Bank showing areas of high quahog densities from Chaisson and Rowell (1985) and locations of other structures and areas that affect station locations for the 2003 ocean quahog survey.

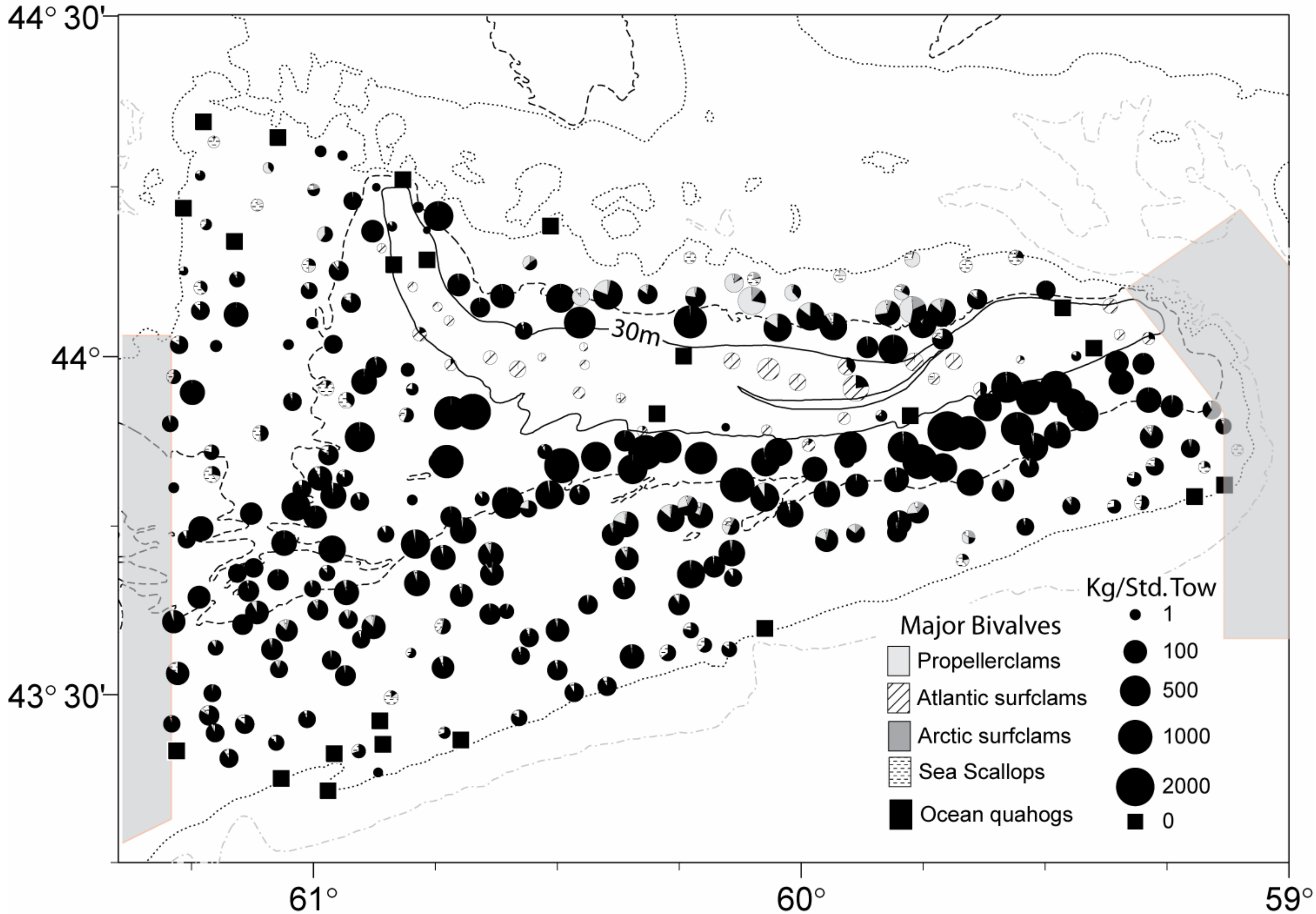

Figure 3. Catch of major bivalve species from 2003 Sable Bank Quahog survey.

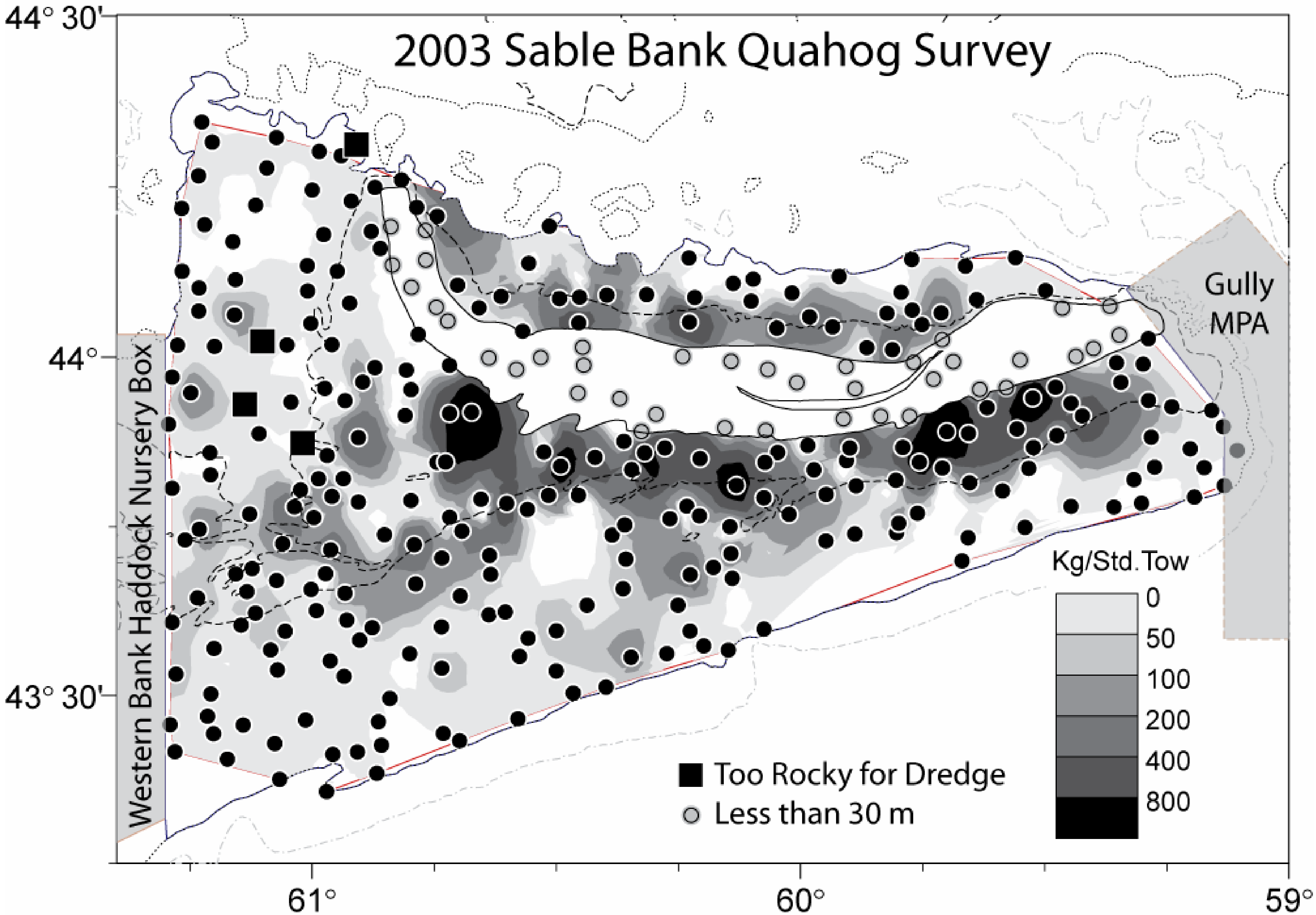

Figure 4. ACON biomass distribution in kg/standard (1000m^2) tow. Solid red line outlines area used for assessment.

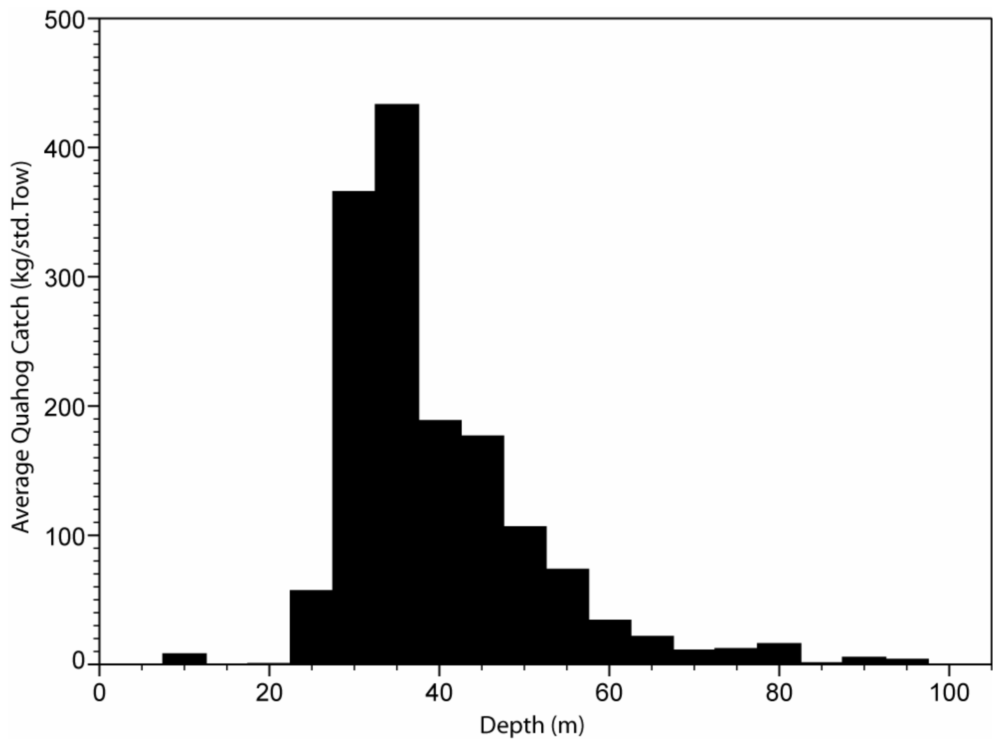

Figure 5. Average quahog catch per standard tow by depth for the Sable Bank quahog survey.

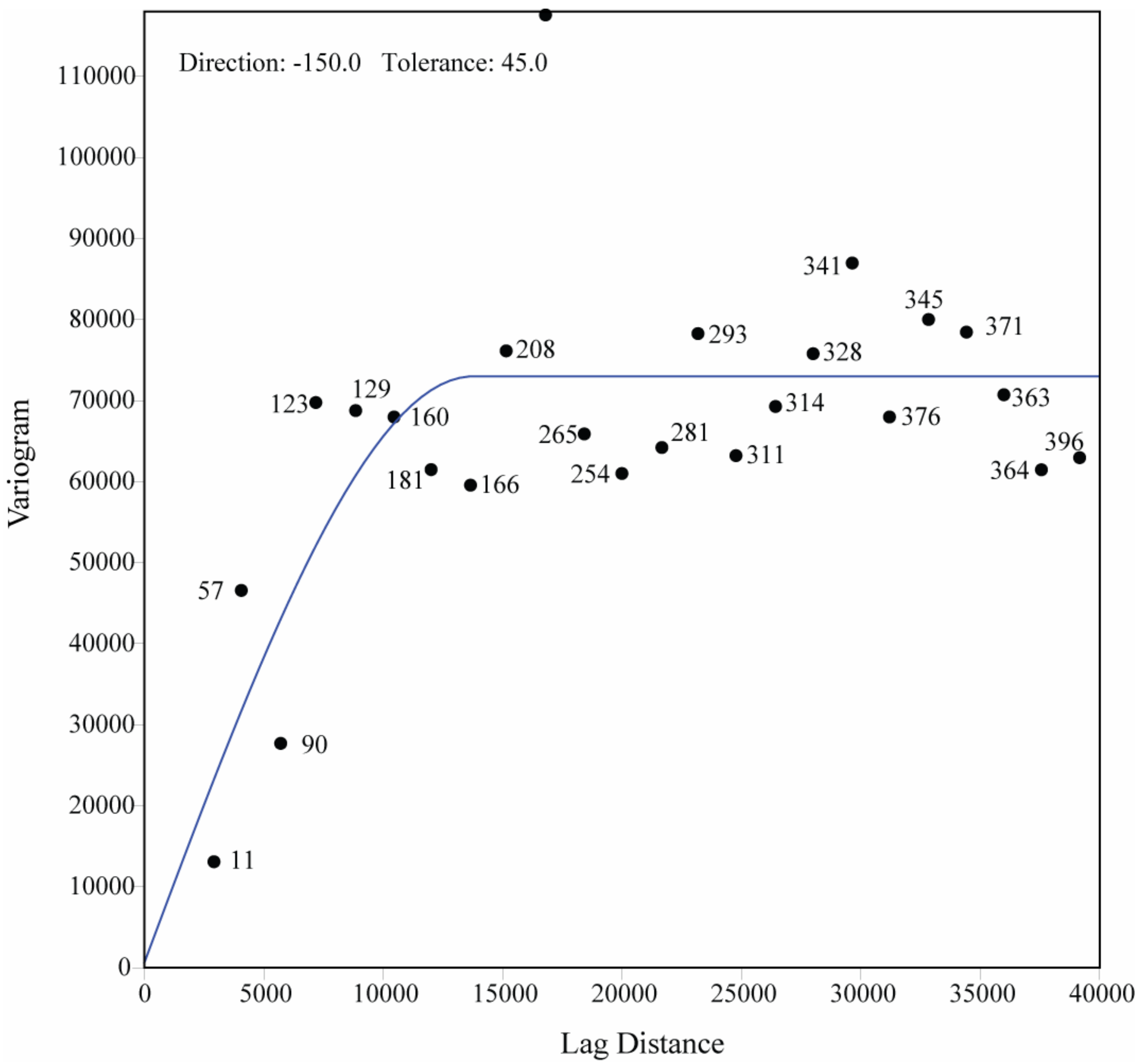

Figure 6. Variogram of spatial correlation used for kreiging analysis of survey biomass analysis.

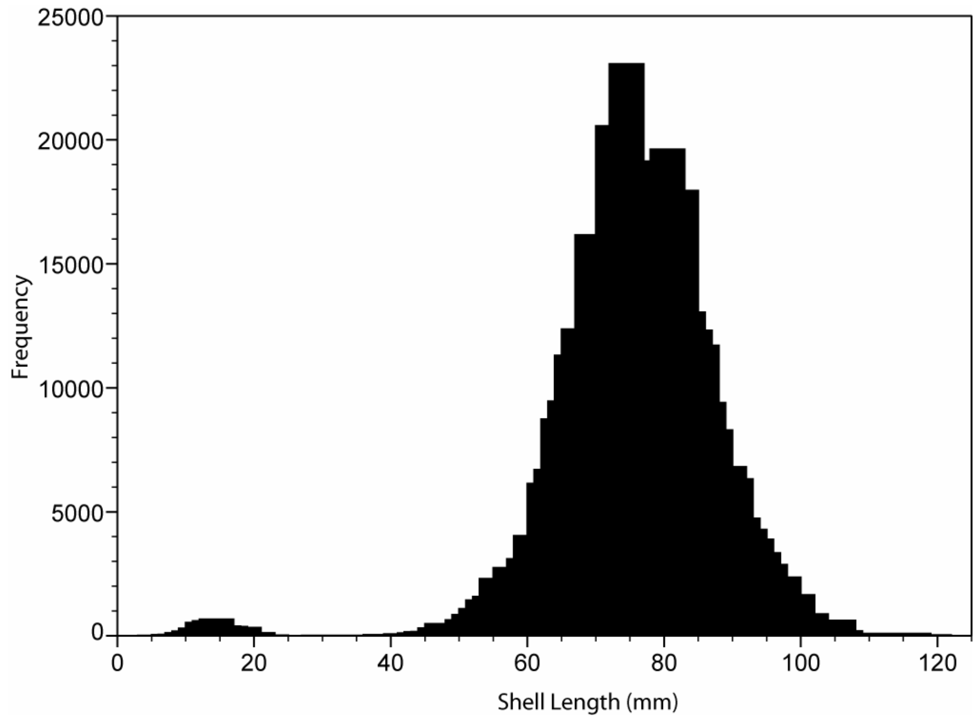

Figure 7. Quahog shell length frequency for Sable Bank quahog survey. All quahogs in the small mode at 15 mm shell length came from one tow.

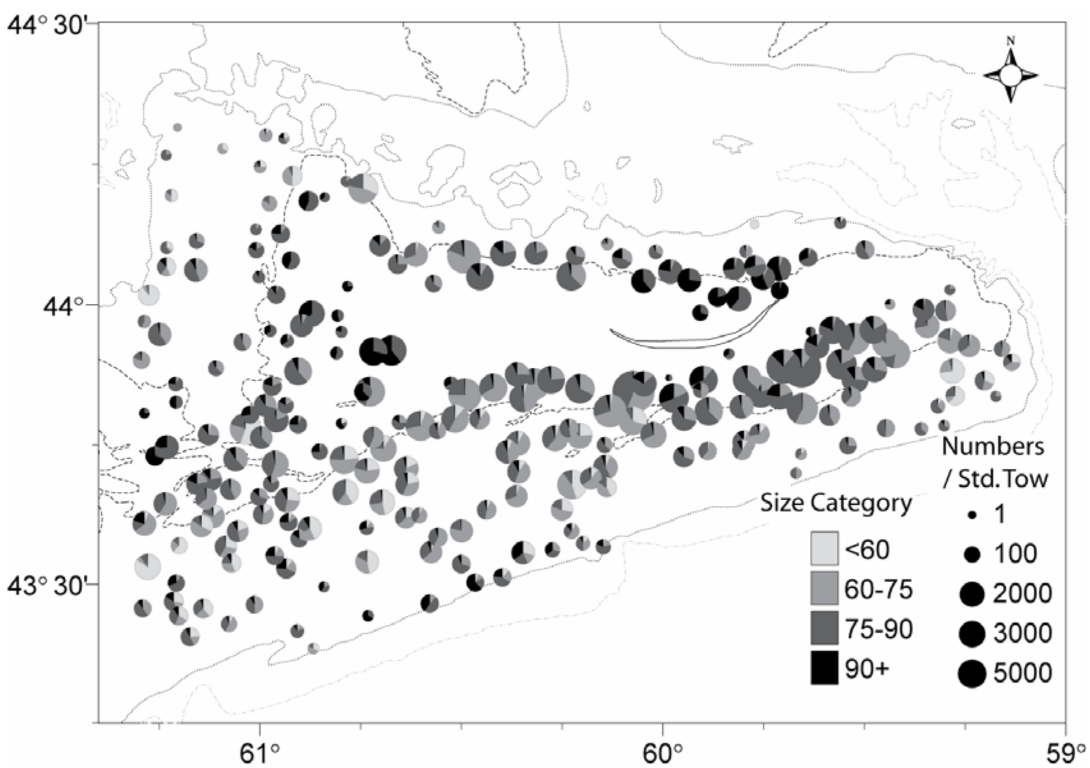

Figure 8. Size distribution and numbers per tow for ocean quahogs from the 2003 Sable Bank survey.

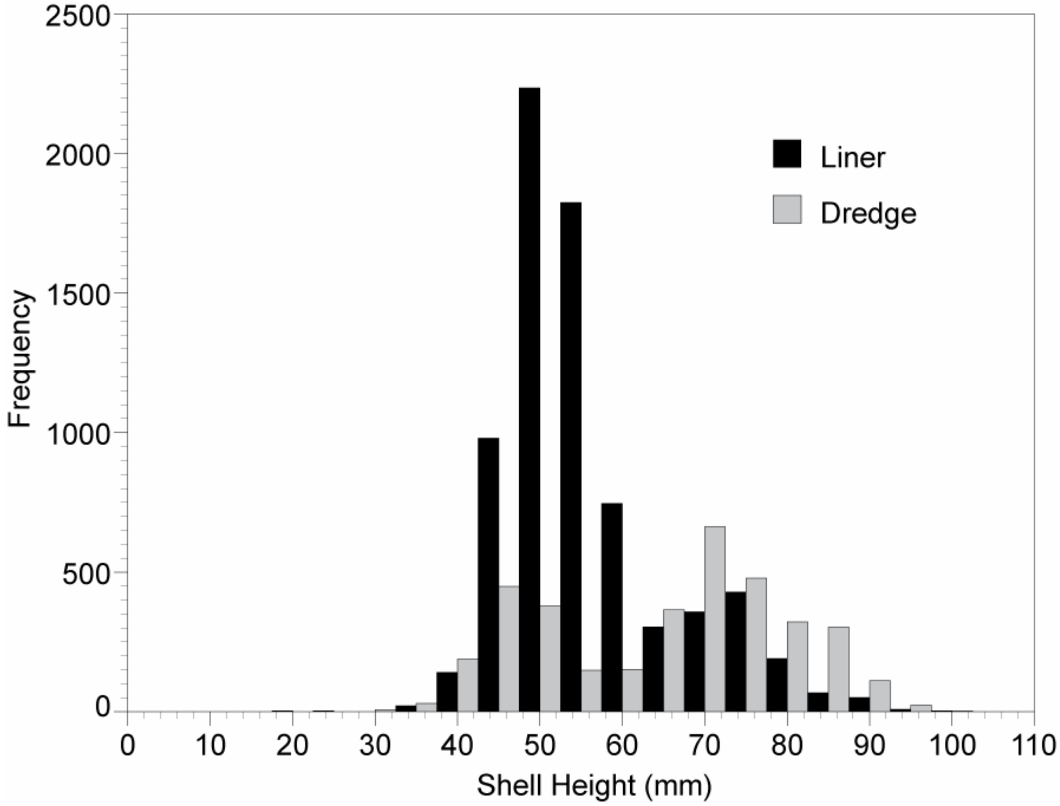

Figure 9. Shell length frequencies of quahogs retained by the dredge (Black) and the cover (Gray) during selectivity tows on Sable Bank.

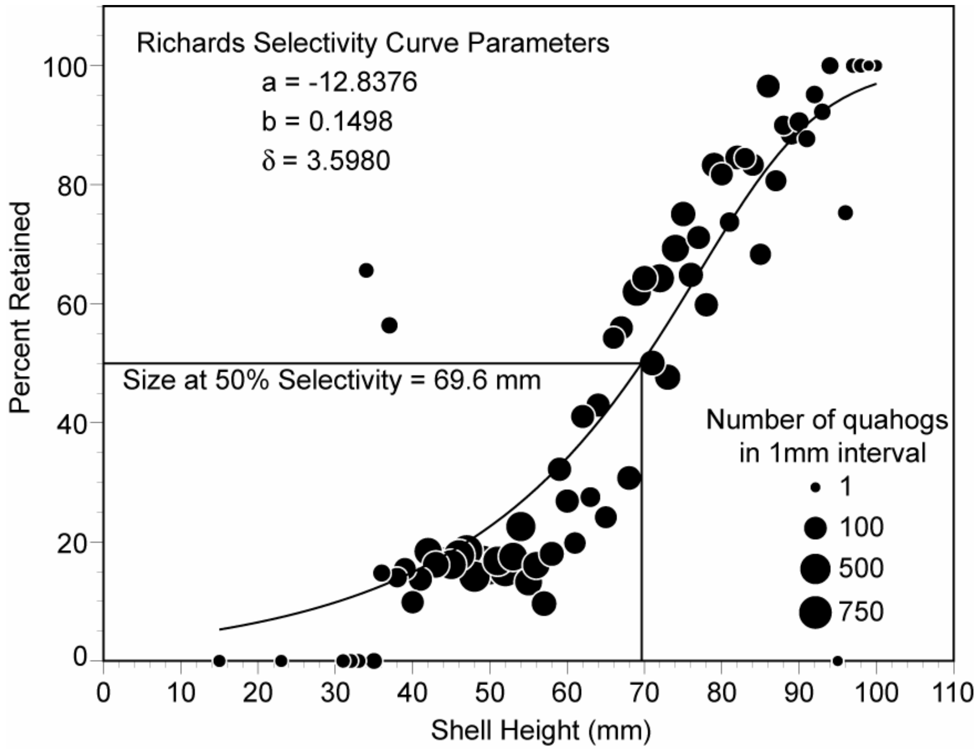

Figure 10. Selectivity analysis for quahogs using survey dredge. Curve is Richards selectivity curve fit by maximum likelihood.

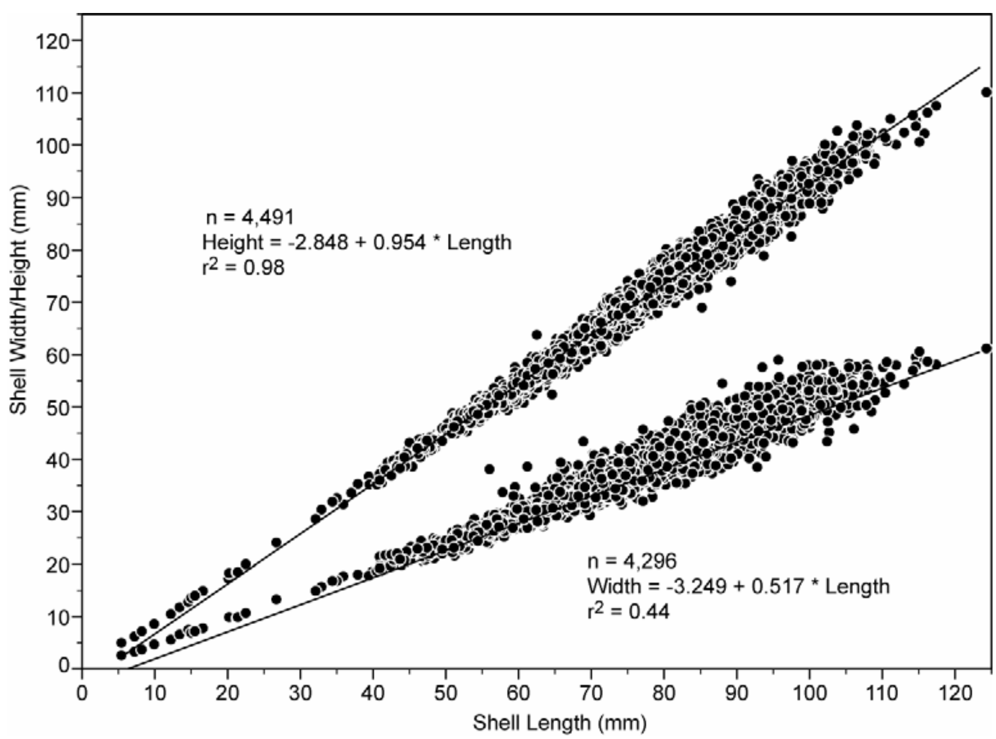

Figure 11. Quahog shell length versus shell hight and width for quahogs collected from Sable Bank.

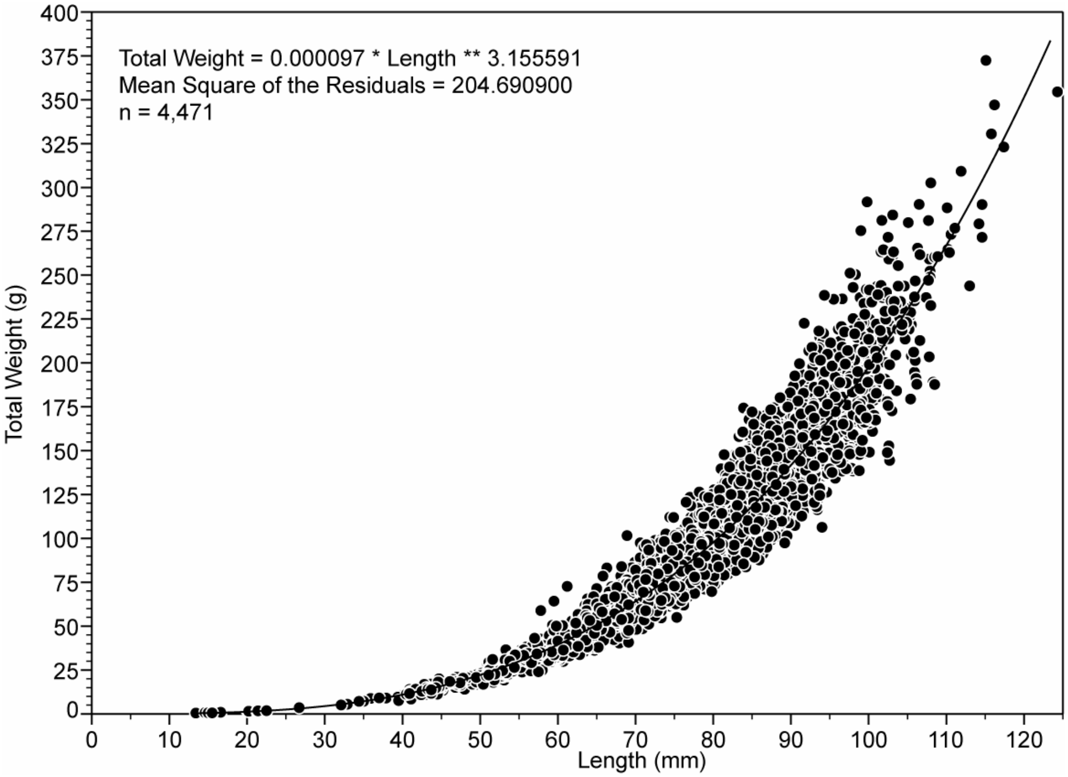

Figure 12. Length-Total wet weight relationship for quahogs from Sable Bank, Frozen and then processed in the laboratory.

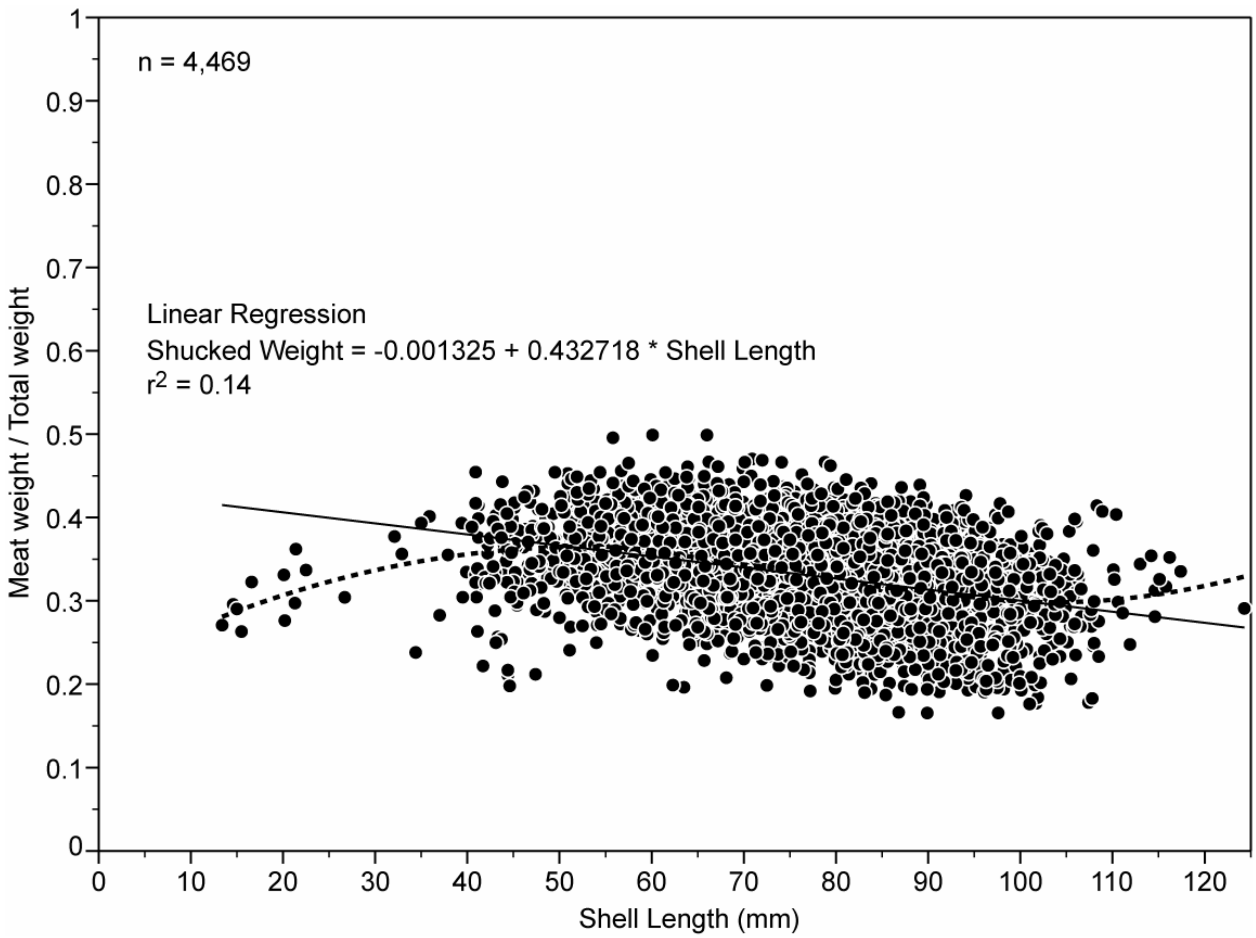

Figure 13. Meat yield versus shell length for quahogs collected from the Sable Bank survey. Both linear (solid) and loess (dashed) regression lines are shown.

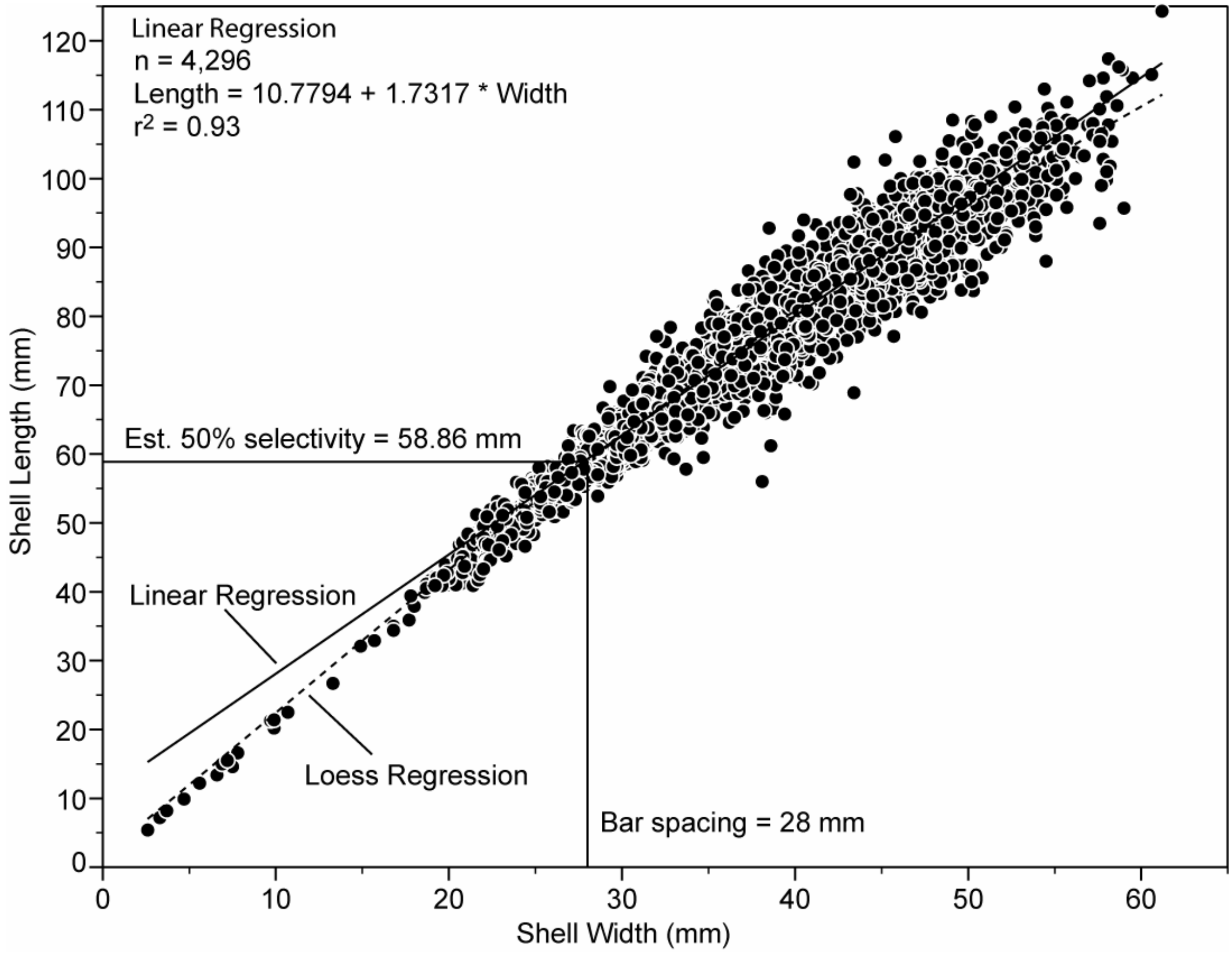

Figure 14. Quahog shell width versus shell length relationship from Sable Bank. Linear regression and Loess regression lines shown. Estimated shell length for quahogs fitting through a 28 mm bar spacing is 58.86 mm.

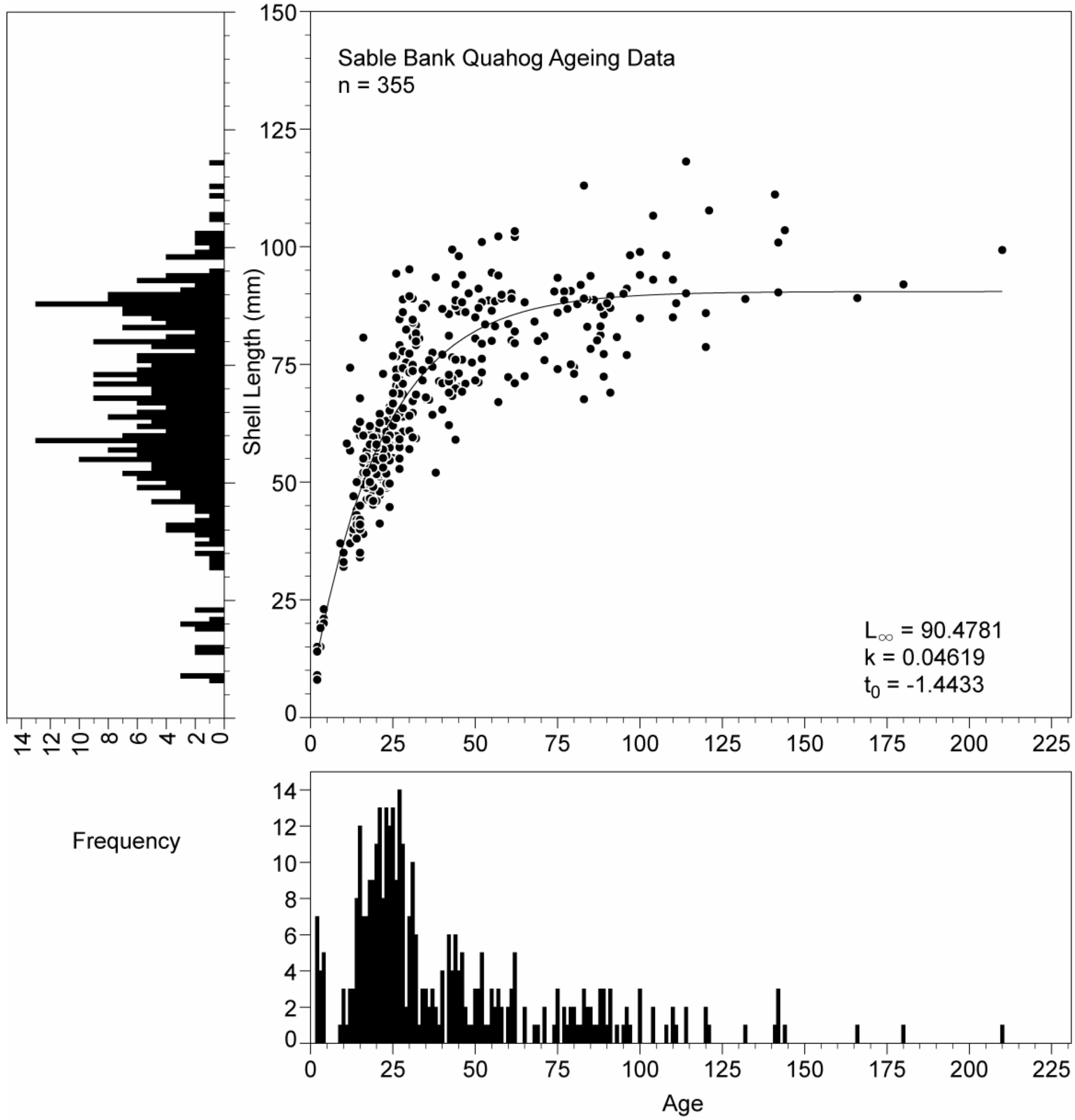

Figure 15. Ageing data for 2003 Sable Bank Quahog survey. Age and size (Shell Length) frequency histograms and plot of the fit of a von Bertalanffy growth curve to the data.

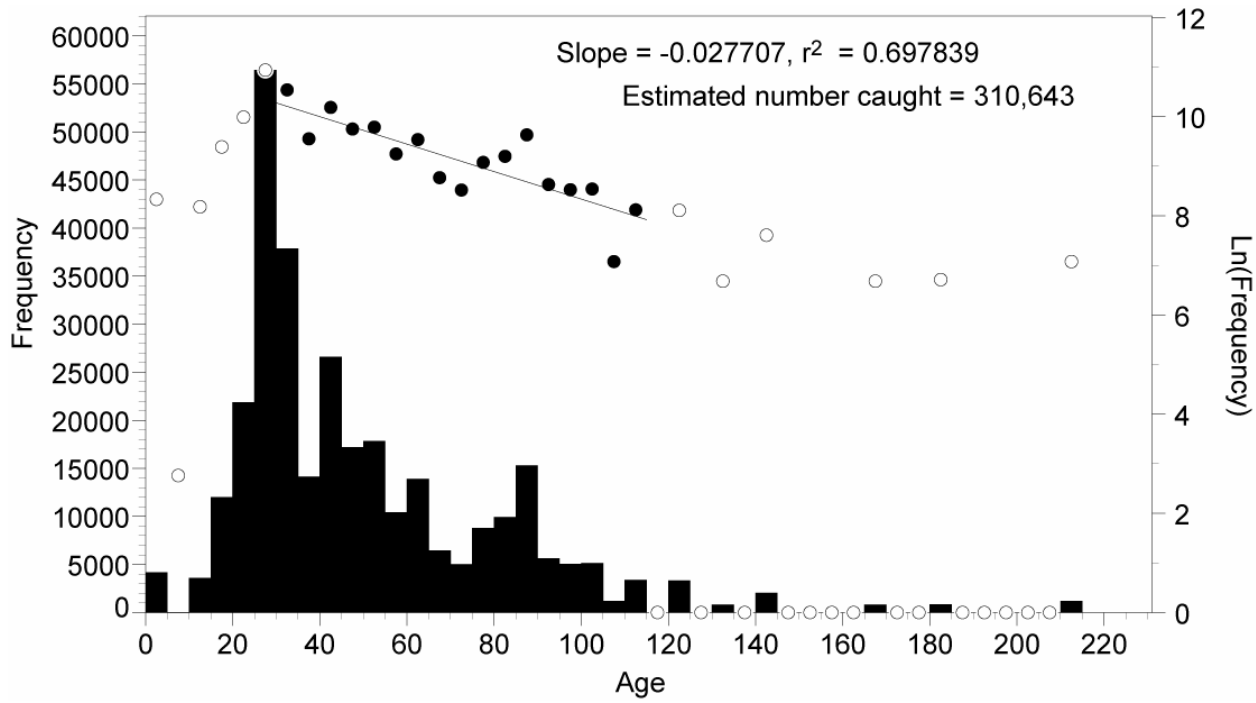

Figure 16. Age frequency distribution aggregated into 5 year intervals constructed from length frequency data and age-length key from aged sample. Line is catch curve analysis for mortality estimate.

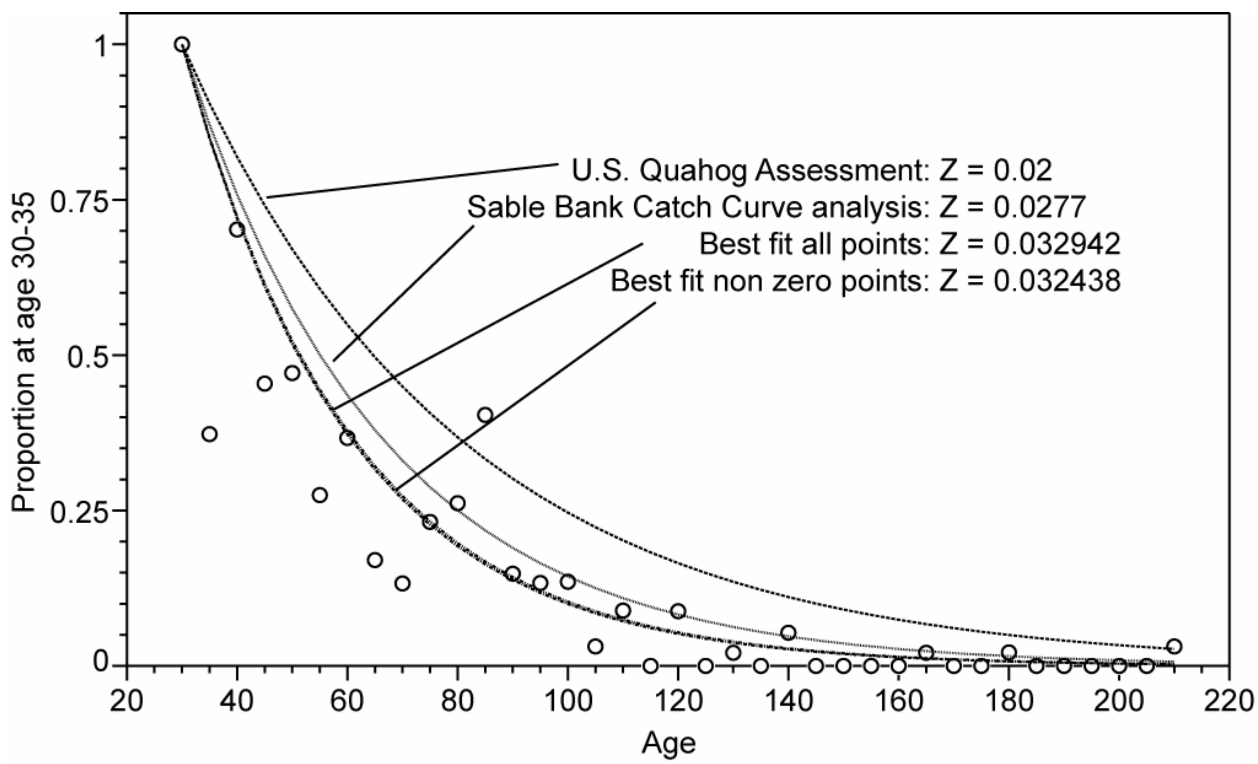

Figure 17. Total mortality (Z) curves plotted against age frequencies as proportion of numbers at age 30 to 35.

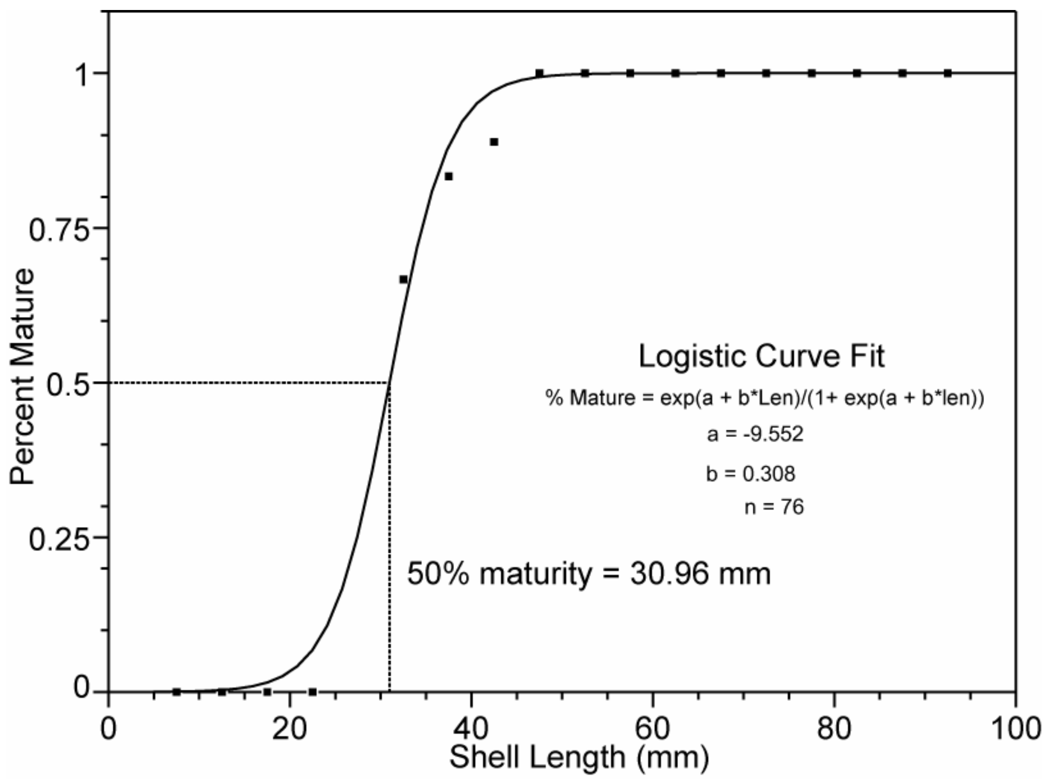

Figure 18. Size at maturity for ocean quahogs on Sable Bank, Nova Scotia.

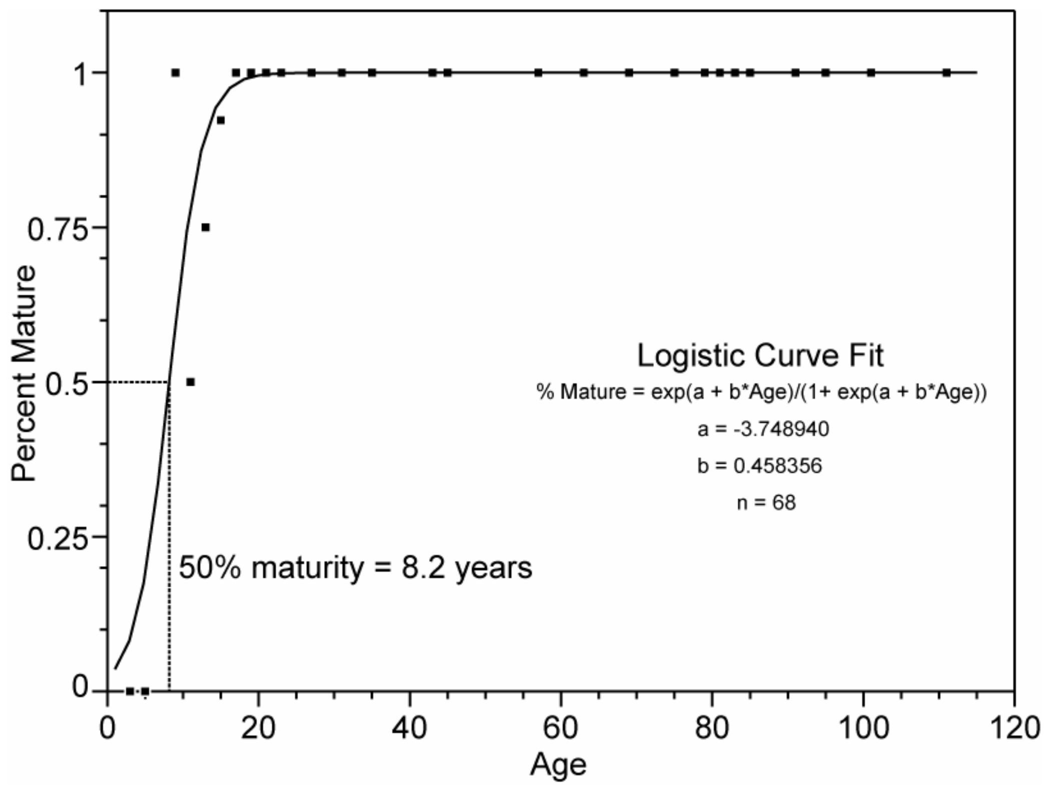

Figure 19. Age at maturity for ocean quahogs on Sable Bank, Nova Scotia.

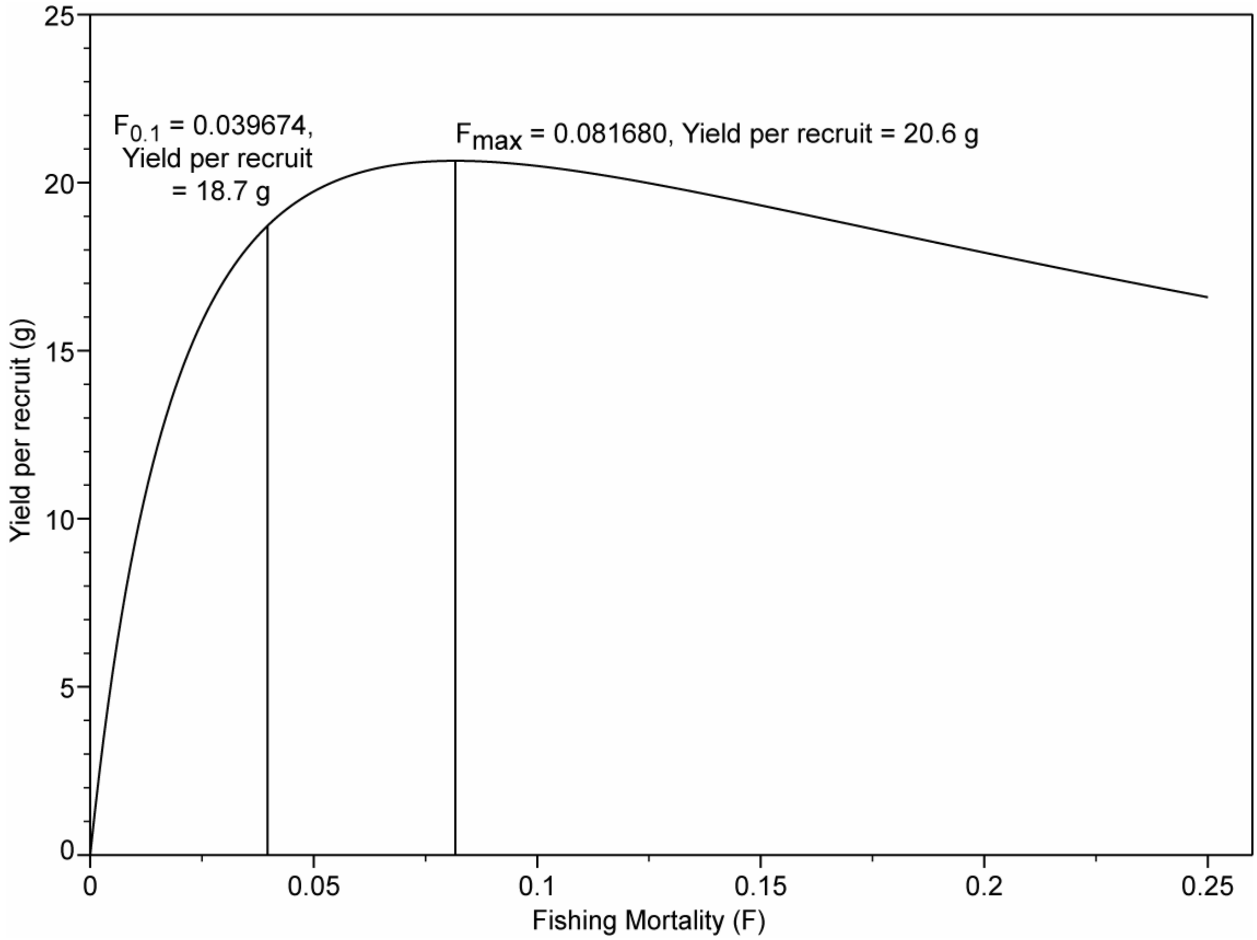

Figure 20. Thompson-Bell Yield per recruit analysis for ocean quahogs on Sable Bank. Recruitment was to the population (age 1+), and selectivity was based on the survey gear.

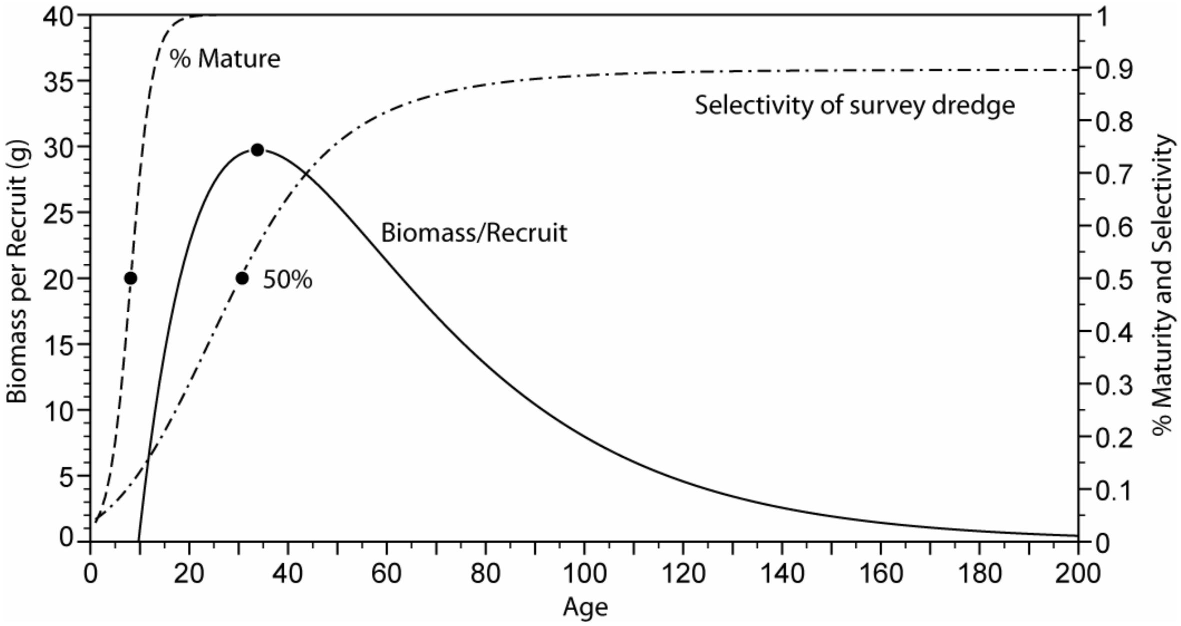

Figure 21. Biomass per recruit with no fishing and percent maturity for ocean quahogs on Sable Bank. The size at 50% selectivity for the survey gear is also shown.