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Assessment of the Arctic surfclam (*Mactromeris polynyma*) stock on Banquereau, Nova Scotia, 2004

Évaluation du stock de mactres de Stimpson (*Mactromeris polynyma*) du banc Banquereau, Nouvelle-Écosse, en 2004

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ABSTRACT

A 2004 survey of the Banquereau Arctic surfclam stock provided an estimate of the biomass of 1,462,097 ± 24,944 t of surfclams. This biomass is higher than that of previous surveys. Indications are that the fishery, which started in 1986, has not had a large impact on the stock and it is still near the virgin biomass level. Recruitment and growth overfishing are not a problem in this fishery with the present gear selectivity pattern. Size at 50% selectivity is larger than size at maturity and near the size at maximum cohort biomass. The TAC could be increased from the present 24,000 t, but caution is advised as TAC's and catch rates would be expected to decine as landings increase.

RÉSUMÉ

Selon un relevé effectué en 2004, la biomasse du stock de mactres de Stimpson du banc Banquereau a été estimée à 1 462 097 tonnes, ±24 944. Cette biomasse est plus élevée que celle observée lors des relevés antérieurs. Il semble que la pêche, qui a débuté en 1986, n'a pas eu un impact significatif sur le stock, dont la biomasse se trouve toujours près de son niveau naturel. Le recrutement et la surpêche ne causent pas de problèmes dans cette pêche en raison de la sélectivité des engins de pêche utilisés. La taille, à une sélectivité de 50 %, est supérieure à la taille à la maturité et près de la taille à la biomasse de la cohorte maximale. Le TAC pourrait être accru par rapport aux 24 000 t actuelles, mais il convient de faire preuve de prudence du fait que les TAC et les taux de prise pourraient diminuer avec une augmentation des débarquements.

1 – Introduction

1.1 - History of the Banquereau Arctic Surfclam Fishery:

A fishery development plan was initiated in 1980 to determine the resource potential of the Ocean quahog (*Arctica islandica*) and other underutilized clam species in the Scotia-Fundy Region. Although these surveys, which took place from 1980 to 1983, found commercial quantities of Ocean quahogs on Sable Bank, there was no interest in developing a fishery at that time due to market constraints. The surveys also found commercial quantities of Arctic surfclams, *Mactromeris polynyma*, on Banquereau Bank, for which there was commercial interest (Rowell and Chaisson, 1983; Chaisson and Rowell, 1985). Due to the exploratory nature of the surveys, other areas of the Scotian Shelf could not be precluded from containing commercial quantities of Arctic surfclams.

Based on the survey results it was estimated that Banquereau Bank had a commercially exploitable biomass of surfclams of 561,000 t and an MSY of 16,821 t, (Rowell and Amaratunga, 1986). A three-month test fishery took place with three companies participating. Each company used chartered U.S. vessels, equipped with a single hydraulic clam dredge.

The results from the test fishery increased the previous estimates to an MSY of 24,000 t (Amaratunga and Rowell, 1986). The MSY estimates were based on the model MSY = 0.5 MB_o, (B_o = virgin biomass, M estimated by $M=3/T_{max}$, where T_{max} is the maximum age corresponding to the 95 percentile for the distribution of ages in the population). It was recognized that this approach makes some assumptions, especially that of equilibrium conditions, that probably do not hold. Furthermore, the estimates were based on very limited data. As a result, the estimate of MSY was probably not very accurate. Another approach used by Amaratunga and Rowell (1986) was to look at biomass as a finite resource, and not make any assumptions about natural mortality, growth or recruitment. In this way an annual level of exploitation is established that would, over a defined period of time, remove the existing biomass. For this analysis, assuming an initial biomass of 600,000 t, the level of annual removals required to have the resource last 10, 20 or 25 years were 60,000 t, 30,000 t and 24,000 t respectively.

In 1987 a three-year Offshore Clam Enterprise Allocation (EA) Program was developed with industry consensus. Total Allowable Catches (TAC's) and EA's were set for each of the three years of the program. They were based on biological information provided by the surveys and the test fishery, and an economic break-even analysis on the required resource to make a vessel and processor viable. The TAC's were set at 30,000 t for Banquereau Bank and 15,000 t for the rest of the Scotian Shelf. Details on the development of the fishery up to 1989 can be found in Roddick and Kenchington (1990).

In February 1989, Arctic surfclams officially became a regulated species under the Atlantic Fishery regulations. The fishery expanded to Grand Bank (NAFO area 3LNO) with the issuing of four exploratory licenses in 1989, with a "precautionary" total TAC of 20,000. These were issued to the three current participants plus a fourth, Newfoundland based company, in addition, access to the Scotian Shelf was expanded to include the new company, and the TAC for the Scotian Shelf outside of Banquereau Bank was increased to 20,000 t. Since this time there has been some exploration, but no sustained fishing, on the Scotian Shelf outside of Banquereau Bank.

In 1990 the Offshore Clam Enterprise Allocation Program was extended for the five-year period 1990 to 1994. In the spring of 1991, one company stopped fishing due to financial problems, and went out of business in 1992. Offshore Clam allocations were revised effective January 1, 1992, giving the remaining three offshore clam companies equal access and allocations on all banks. Any changes in the TAC would also be equally split between the license holders. Since early 1993 there have been 3 factory processors fishing year round. The enterprise allocation program was continued for the 1998 to 2002 Integrated Conservation and Harvesting Plan, and subsequent plans up to the current 2005-2009 Offshore Clams Integrated Fishery Management Plan.

During this time a 1996-1997 Industry-DFO survey of Banquereau resulted in a reduction of the TAC for Banquereau from 30,000 t to 24,000 t (Roddick and Smith 1999).

Looking at long term investments in the fishery, and wanting current estimates of the clam stocks, the Offshore Clam Industry entered into a Joint Partnership Agreement with DFO to fund a survey 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. The first survey of Banquereau in this program was conducted in 2004.

2.0 - Methods

2.1 –Survey Design:

The variance in catch rate from the 1996-97 survey was used to examine the reduction in the standard error of the mean as the number of tows is increased. The reduction was estimated from the data by drawing 30 replicate samples of n tows, with replacement, and calculating the standard error. The results are shown in Figure 1, which indicate that there is a rapid decrease in the standard error as the number of stations is increased up to 200 stations, and that beyond this point there is little reduction in the standard error.

The distribution of catch per tow from the 1996-97 survey is shown in Figure 2. The distribution is typical of survey data, where a large number of tows have little catch and a few have very high catches.

Since the data for the standard error analysis was old, and the vessel and gear to be used in the 2004 survey differed from the original survey, there was the possibility that the variability in the 2004 survey would be higher than the 1996-97 survey. For this reason, and the fact that it was anticipated some tows would have to be dropped due to depth, bottom roughness and other difficulties, it was decided to base the survey on 250 stations.

Using the ACON package (Black, 1991) and bottom bathymetry from the Canadian Hydrographic Service (Figure 3), the area within the 100 m contour of Banquereau Bank was calculated as 10,908 km^2. The 1996-97 survey used a shallow limit of 50 m, but there were a few stations along this contour that had good catches. For this reason the 40 m contour was used for a shallow limit in this survey. When the shoal area less than 40 m is excluded, the survey area is 10,265 $km^{2.}$ At 250 stations this is one station per 41 km^2.

250 stations were randomly assigned within the 40m -100 m contours on Banquereau Bank. The assignment function allowed a minimum spacing of 3.0 km between tows. Additional stations that could be used as alternates if the originals had to be dropped were generated at the same time.

A plot of the station locations (Figure 3) indicated that all areas of the bank were adequately covered.

2.2 - Survey Gear:

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 14.3 cm below the runners. The electronics onboard the Cape Keltic included both a Microplot 7 navigation package, used to measure tow distance and record the tow track; and a RoxAnn bottom discrimination system (Sonavision Ltd., Scotland, UK), used to check the bottom for suitability 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:

After checking the bottom with the RoxAnn system, a 300 meter long tow was conducted at each station. 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. A sample of five bushels was selected and processed for catch composition. After weighing this sample, all components were separated down to species level where possible and the weight of each component recorded. The weight of items such as empty shells, rocks, garbage, etc. were also recorded. A second sample of 20 bushels was taken and processed by picking out and weighing all major bivalves (Arctic surfclams, ocean quahogs, northern propellerclams, Greenland cockles, Atlantic surfclams, sea scallops, Iceland scallops). 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:

$$C_{tot} = (C_{S5+} C_{S20})*(W_{S5} + W_{S20})/W_{tot} \qquad 1$$

Where C_{tot} is the component weight in the entire sample; C_{S5} and C_{S20} are the component weights in the 5 and 20 bushel sub-samples; W_{S5} and W_{S20} are the weights of the 5 and 20 bushel sub-samples; and W_{tot} is the total weight of the catch.

To estimate the length distribution of the clams, a sample of at least 100 clams 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 clam 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; early active; late active; ripe; spawning; and fully spent.

A length stratified, random sub-sample (30/5mm shell length increment) of the clams processed for morphometrics was selected for ageing. Age was estimated using thin sections of the hinge area of the shell (Almeida and Sheehan, 1997). The left valve was sectioned using a low-speed diamond saw, and the side cut through the umbo was hand polished with silica carbide grinding powder (600 grit) to remove any saw marks. The section was then mounted, polished side down, on a microscope slide with epoxy. The slide was placed in a press to ensure it bonded flat and evenly to the slide and allowed to cure for several days. The slide was then mounted in a Petro-Thin® thin sectioning system and ground down for examination under a compound microscope. Final thickness varied with the section, but was approximately 0.3 mm. The annuli were counted in the section under a Nikon microscope using transmitted light at 40x magnification. The data was fit to a von Bertalanffy growth curve:

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

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. Curves were fit to both the raw sample data, and the sample weighted by the survey size frequency distribution in 5 mm increments. The curves were fit by non-linear regression using the statistical package S-PLUS (Insightful Corp., 2001).

2.5 – Biomass estimation:

The biomass in the survey area was calculated by two 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).

Catches were standardized to the average tow length of 329 m, which gives a tow area of 530 m^2.

Work is ongoing to estimate the dredge efficiency of the gear used in the survey. Two depletion experiments were conducted during the survey using the methods of Rago *et al*. (2006). These experiments encountered a problem with the confounding of gear efficiency and gear selectivity. The U.S. experience is that the efficiency of hydraulic clam dredges is high (NEFSC 2003, 2004) and so it was felt that a precautionary approach should be taken, and no efficiency correction was applied to the biomass estimates for this analysis.

The biomass estimates and distribution were compared to the estimates and distribution from the 1980-82 and 1996-97 surveys.

Other Studies:

2.6 - Selectivity:

Survey Dredge selectivity

At the end of the first leg of the survey, a site which had a clean catch of clams covering a wide size range was chosen for a selectivity study. 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. The catch escaping through the dredge was retained in the cover. Three tows were made, and the clams 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 Richard's selectivity curve (Millar and Fryer, 1999):

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

where P is the proportion of clams 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:

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

The SELECT (Share Each Length class's Catch Total) statistical model (Millar 1991; Millar and Walsh 1992) was used to derive curve parameters. This package uses maximum likelihood to fit the data, and the functions used were those developed for traditional covered codend experiments. The Richard's curve was used to fit the data as it allows for asymmetry in the curve and will reduce to the logistic curve if the fitted curve is symmetric (See equation 5).

Commercial Clam dredge selectivity

A commercial clam dredge selectivity study was conducted on the Ocean Concord in May of 1999. The Ocean Concord is a 67 m offshore clam vessel that tows two large hydraulic dredges. The selectivity study used paired hauls with one dredge lined with shrimp netting (1.75 inch mesh) and the other left unlined. This was chosen over the covered dredge method because it was felt that a cover would be torn off the dredge during the dumping process. The study took place on Banquereau, a bank off Nova Scotia Canada, where the Ocean Concord had been fishing (44.45° N, 57.9° W). Three paired tows were made and the entire catch from each dredge was shoveled into bushel baskets and weighed. A sub-sample of the baskets from each dredge (122 of 269 baskets caught) was sorted for clams, and from this, a sample of 3 bushels or the entire clam catch was taken for length frequencies. The length frequencies from each dredge in each tow were prorated up to the total clam catch. The length frequency data for the lined and unlined dredges were fit with a Richard's Curve.

The SELECT (Share Each LEngthclass's Catch Total) statistical model (Millar 1991; Millar and Walsh 1992) was used to derive curve parameters. The SELECT model for trouser-trawl or alternate-haul selectivity experiments incorporates an estimate of *p,* the relative fishing power (i.e., relative efficiency) of the gears being compared in addition to the standard Logistic or Richard's curve parameters. Relative fishing power is defined as the probability of a fish entering the test gear given that it entered the combined (test and control) gear (Wileman et al. 1996). This measure avoids bias in the selectivity estimates when unequal numbers of fish are retained in the two gear configurations by allowing the model implicitly to estimate the relative efficiency (*p*) of the two gears (Millar 1991; Millar and Walsh 1992; Wileman et al. 1996).

2.7 - Size and age at Sexual Maturity:

Samples for size and age at maturity were collected during the survey. Small clams 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 the University of Prince Edward Island. Gonad sections were classified into six maturity stages (Ropes 1968, Rowell *et al.* 1990): 1) early active; 2) late active; 3) ripe; 4) spawning; 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 clam length corresponding to a proportion of 50% mature was calculated as: $L_{50} = -a/b$. The shells were retained and aged with the same techniques 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 - Mortality:

Since there has been a commercial fishery for clams on Banquereau, it was assumed that the natural mortality rate (M) was equivalent to the total mortality rate (Z) minus the Fishing Mortality Rate (F). Several methods used for estimating mortality were examined. The first was :

$$Z = 3/T_{MAX}, \text{ where } T_{MAX} \text{ is the lifespan of the organism.} \qquad 6$$

This is the method used by Amaratunga and Rowell (1986) for the initial estimate for surfclams on Banquereau. The lifespan is usually described as the age at which 5% of the population remains alive. It is an approximation that requires very little data.

The second method was Beverton and Holt's (1956) method. This method takes the decline on the right hand side of the length frequency distribution, and uses the von Bertalanffy parameters to apply a time period for the animals to grow through a size range. Total mortality is estimated with the formula:

$$Z = (K(L_\infty - L_m))/(L_m - L') \qquad 7$$

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. This method requires length frequency data and a growth curve, but does not require a large sample to be aged.

The third method is the catch curve method (Chapman and Robson 1960, Ricker 1975), which takes a large aged sample and models the decline in numbers at age.

$$N_t = N_0 * e^{-Zt} \qquad 8$$

where N_0 is the initial number of individuals, t is the period of time (years), and N_t the number alive at time t. Z is estimated with a linear regression of the log transformed numbers at age.

The fourth method examined was the Chapman Robson (C-R) estimate of Z (Chapman and Robson, 1960). This method uses the mean age of animals above the recruitment age to estimate mortality:

$$Z = \ln\left(\frac{1 + \bar{a} - 1/n}{\bar{a}}\right) \qquad 9$$

Where $\bar{a}$ is the mean age (above the recruitment age) and *n* the sample size.

The last three methods require a decision on which sizes/ages to include, as they require the analysis to be based on individuals that are fully recruited to the sampling gear, and thus on the descending right limb of the frequency curve. The selectivity curve was used as a basis for this decision.

For the methods that require age frequencies (catch curve and C-R), the population age frequency for Banquereau was estimated from the length frequency data with an age-length key constructed from an aged sample. The sample consisted of 30 surfclams from each 5 mm interval randomly chosen from tows that had a catch rate ≥ 100kg per standard tow. This was to make sure the length-age key covered the full size range, and that it was done using clams in the areas that were likely to be commercially fished. The age-length key was used to convert the survey length frequencies into age frequencies. The resulting population age frequency was used for the catch curve estimate of Z. The resulting Z was compared with that used in previous stock assessments (M = 0.08).

2.9 – Recruitment Estimates:

An approximate estimate of recruitment can be obtained by taking the distribution of numbers at age and calculating the numbers at recruitment age using the estimated mortality rate:

$$N_{RA} = \frac{N_A}{e^{-Z(A-RA)}} \qquad 10$$

where N_{RA} are the numbers at recruitment age *RA*, N_A are the numbers at age A; and Z is the mortality rate. This assumes constant mortality, but produces an estimate of recruitment for the time period corresponding to the age of recruitment to the maximum age observed in the age frequency distribution. This provides an estimate of recruitment variability through time.

2.10 - Yield Estimates:

With no time series of fishery or biomass, yield estimates are based on empirical equations relating biomass, growth and mortality to production. There are many equations that have been proposed, ones examined here are the constant yield levels: Maximum Sustainable Yield (MSY), 2/3MSY, and Maximum Constant Yield (MCY); and the constant fishing mortality level $F_{0.1}$. MSY was used by Chaisson and Rowell (1985) 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 yield levels such as 2/3MSY 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 0.2 - 0.3 and so can be very conservative. For inshore ocean quahogs in Nova Scotia a DFO Expert Opinion (DFO 2005) recommended that MCY be used with the fraction (x) set at 0.33. This makes it equivalent to 2/3 MSY, when MSY is calculated as $0.5MB_0$.

Using the biomass, growth and mortality estimates, a Yield per Recruit analysis was done to provide F_{MAX}, $F_{0.1}$ and Spawning Stock Biomass estimates. These were done excluding and including the present estimated incidental mortality of small clams that pass through the dredge of 15%. Estimates of MSY and MCY were also produced using the methods outlined above.

2.11 - Production Estimates:

An estimate of production can be made with the data available. Production equals recruitment plus growth minus mortality.

$$P = R + G - M \qquad 11$$

$$G - M = \sum_{L}\left(N_L \bullet e^{-Z} \bullet \left[\left\{(L_\infty - L)\bullet\left(1-e^{-K}\right)\right\} - L\right]\bullet ae^{b} \bullet \frac{1}{(1-p_{wl})}\right) \qquad 12$$

$$R = N_R \bullet L_R \bullet ae^{b} \qquad 13$$

Where N_L are the numbers at length L, Z is mortality, L_∞ and K are von Bertalanffy growth coefficients, and a and b are length - weight regression coefficients. Since our growth data is from areas of commercial densities ($\geq$ 100 g/m^2), the production was also related to this area.

The total length frequency for stations within the 100g/m^2 density contour was used for numbers at size. The growth curve was used to calculate the length the following year (L_{t+1}). The length-weight regression from the morphometrics samples were used to convert size to weight, and the estimated Z was used to calculate survival to the following year. Recruitment was the estimated average age 20 recruitment from the catch curve analysis converted to weight. The length frequency data used for the present population production (growth – Mortality) was also restricted to ages $\geq$ 20. Since the weights for the regressions are the frozen and thawed morphometrics samples, they were adjusted for weight (water) loss using data from the fresh sample weights recorded during the survey versus the thawed weights in the laboratory (19.6%, Std. Dev. 6.1, n = 185).

3- Results:

3.1 – Survey results:

A total of 210 survey stations were occupied during the survey. During towing operations it was found that the dredge did not fish efficiently below 90m. At deeper depths the wear pattern on the runners showed that the dredge was not staying flat on the bottom. At depths shallower than 90 m the wear pattern was even over the length of the runners. For this reason the lower limit of the survey depth range was changed from 100 to 90 meters depth. There were also stations that the RoxAnn system showed were too rocky for the dredge and so these were not occupied.

3.2 – Biomass:

There were 210 stations dredged during the survey. There were 42 stations not occupied because they were classed as too rocky for the dredge, of which 27 were inside the 90 m contour.

All stations that showed as cobble and boulders according to the RoxAnn system were occupied, and these consistently filled the dredge with cobbles and boulders. From the calibration on known bottom types, the substrates of the unoccupied stations classed as rougher and harder than this consisted of large boulders and bedrock. Figure 4 shows the relationship between the catch of rock and clams in the tows. High amounts of rock indicate the substrate is unsuitable for clams.

This means that the stations that were classified as too rocky for the dredge and were thus not occupied provide information on the distribution of clams. For the analysis these were included as tows with a zero clam catch.

Figure 5 shows the average catch versus depth. The best catches were obtained between 50 and 65 m depth, and minimal catches would be expected at depths over 90 m.

Two stations on the 100 m contour were not occupied due to depth. There were 11 stations that were dredged but, by the wear patterns on the runners, were suspected not to have fished efficiently due to the depth (actually the combination of depth, currents and substrate). Of these 6 were on or inside the 90 m contour. For those tows suspected of not fishing properly, the average catch was 2.11 and 1.16 kg/tow for the 6 tows inside and 5 outside the 90m contour respectively. This can be compared to the average catch of 1.39 kg/tow for the 6 tows over 90 m that had no indication of problems.

It was decided to use the catches of the suspect tows as they were, but to test the sensitivity of the results by comparing the results to those obtained when multiplying the catch of the suspect tows by a factor of 10. A 10 fold increase in the catch of the suspect tows only resulted in a 0.9% increase in estimated biomass, demonstrating that the results are not sensitive to the catch of the suspect tows.

The results of the simple statistical and ACON biomass estimates are shown in Table 1. The simple statistical analysis was restricted to tows inside the 90 m depth contour. Tows outside the 90 m contour were used for the ACON analysis, but the area was then clipped to the 90 m contour for the biomass estimate. The ACON package does not contour beyond the station boundaries, as the station boundary was inside the 90 m contour at some points the area used is slightly less than that defined by the 90 and 40 m contours (Figure 6 and Table 1).

The catch rate is shown in Figure 6, contoured with the ACON package. For ease of interpretation the catch per standard tow was converted to g/m^2 for this map and the data table in the upper left corner.

3.3 - Length Frequencies:

The total length frequency for the survey catch was estimated by prorating the length frequencies using the surfclam catch weight divided by the length frequency sample weight for each tow and summing over the survey tows. The resulting length frequency distribution is shown in Figure 7. An obvious artifact in the length frequencies is the abundance of clams in intervals at units of 5 and 10 mm. Although the crew had been trained and cautioned about this, once they were measuring large numbers of clams with a measuring board there was an obvious bias in recording the last digit as a 0 or 5 (Figure 8). For most of the analysis involving length frequencies, lengths were aggregated to 5 mm increments to remove this effect.

3.4 - By-Catch:

The breakdown of the survey by-catch is shown in Table 3. Arctic surfclams made up 34% of the catch by weight, with rocks and stones, propellerclams, sand dollars, shell and sand bringing it up to 95% by weight. This compares to the commercial fishery, which targets areas of high clam abundance where Arctic surfclams make up about 80% of the catch weight. Sand dollars are the only non-bivalve species making up more than 1% of the survey catch weight. The next non-bivalve species is the sea cucumber (*Cucumaria frondosa*) at 0.942%, after which it drops to 0.157% for the sea mouse (*Aphrodita hastate)*.

3.5 - Ageing:

The ageing results are shown in Figure 9. The histogram of the length stratified sample and the survey size frequency distribution are shown with the fitted von Bertalanffy growth curve, the resulting age histogram for the aged samples, and the estimated survey age frequency distribution. The age frequency distributions indicate fluctuations in recruitment through time.

3.6 - Selectivity

Survey dredge selectivity:

Four selectivity tows with a mesh cover over the dredge were completed during the survey. One tow was eliminated from the analysis as the entire catch consisted of small clams. The shell sizes ranged from 35 to 124 mm with a mean of 78.5 mm in the cover, and 54 to 135 mm with a mean of 101.3 mm in the dredge. There were 1,433 clams retained in the dredge and 813 in the liner.

The resulting selectivity curve is shown in Figure 10. The size at 50% retention is 87.4 mm.

Commercial dredge selectivity:

The three paired tows resulted in a total catch weight of 7,500 kg, of which 3,018 kg was Arctic surfclams. Most of the remainder of the catch weight was sand and shell. A total of 3,877 clams were measured for length, and this was prorated to a total catch of 25,064 clams. The sampling fractions by weight for the length frequency samples ranged from 9 to 64% of the clam catch per tow/dredge combination. The estimated parameters for the SELECT fit were: a = -2.7022, b=0.0517, δ = 0.2367 and p = 0.6614. The relative efficiency parameter (p = 0.6614), shows that the unlined dredge was more efficient in capturing large clams than the lined dredge. The curve fit is shown in Figure 11 and the deviance residuals in Figure 12. The residuals do not show any trend that would indicate problems with the fit.

The higher efficiency of the unlined dredge is probably due to the presence of the liner interfering with the movement of catch back into the cage of the dredge. Although the liner also prevents the finer material from passing out through the bars, causing the dredge to fill faster, the short tow distances used for this experiment prevented this from having an effect.

3.7 - Size and age at sexual maturity:

A total of 178 surfclams ranging in size from 22 to 79 mm were processed for maturity and sex, and 166 of these were aged. The resulting maturity data were fit with a logistic curve using maximum likelihood. Figures 13 and 14 show logistic curves fit to the size and age at maturity respectively. The size at 50% maturity was 47.2 mm shell length, well below the size at 50% retention of the dredge, and the age of 50% maturity was 6.7 years old.

3.8 - Mortality:

The simplest mortality estimate examined was that used by Amaratunga and Rowell (1986): Z = 3/Tmax, where T_{MAX} is the lifespan. Lifespan is usually taken as the cut off for the upper 5% of the recruited age distribution. From the estimated age distribution (Figure 9) this is 40 years of age, and so 3/40 produces an estimate of Z = 0.075. This is the same estimate as Amaratunga and Rowell (1986), but there was not fishery at that time and Z was considered to be equal to the natural mortality rate (M).

Beverton and Holt's method (Equation 7) uses the length frequencies, and incorporates the growth curve parameters L_∞ and K into the equation as an index of time. This method requires that only the fully selected portion of the length frequency distribution be used. The selectivity curve (Figure 10) shows that the size at 95 % selectivity is 115 mm. This presents a problem in Equation 7, as the growth curve weighted by the population size frequency data (Figure 9) has an L_∞ of 115.39 mm, while the size range goes up to 160 mm. The Beverton and Holt equation does not work when the full selected size approaches L_∞. The mean size of clams above 115 mm is 138 mm, so the numerator in Equation 7 will be negative for either the weighted or unweighted growth curve, producing negative estimates of Z.

For the catch curve analysis, ideally only those ages fully selected by the gear would be used in the analysis. With a low slope for both the top of the selectivity curve (Figure 10) and a wide spread of size at age (Figure 9), too high a cut off would leave few age classes in the analysis. A minimum age cut off of 20 years old was chosen based on the selectivity curve and the size at age distribution. Figure 15 shows the estimated age frequency distribution from Figure 9, along with a regression of the log of numbers at age versus age. The slope of this regression gives an estimate of Z, the total mortality rate, of 0.11. The ages used to estimate Z are marked as filled dots.

The Chapman and Robson estimate in Equation 9 (Chapman and Robson 1960), again using 20 as the recruitment age, gives an estimate of Z = 0.10.

Mortality estimates are thus in the range of 0.075 to 0.11.

Total mortality (Z) is made up of both natural mortality (M) and fishing mortality (F). Based on the survey biomass estimate, the present Total Allowable Catch (TAC) of 24,000 t would produce an estimated fishing mortality rate of 0.016. The fishery does not reach the TAC, and for the last ten years has landed an average of 17,517 t, which gives an F of 0.012. In light of these estimates of Z and F, the current estimate of 0.08 for the natural mortality rate appears to be reasonable, and is used for the production and yield estimates.

3.9 – Recruitment estimates:

Using equation 10 and converting the 2004 numbers at age to recruits at age 20 gives the age 20 recruitment pattern shown in the lower panel of Figure 15. The time period for the birth of clams aged 20 to 60 in 2004 is 1944 to 1984, so they were all born prior to the start of the fishery (1986). According to this analysis recruitment has varied over this period. The solution to the catch curve equation for age 20 gives 5,886 clams. Since this number is based on those actually caught in the survey tows, it needs to be expanded to the survey area. Expanding this to the area of commercial densities (>100 g/m^2 since this is what the aging data was based on) gives estimates of an average 185,616,162 clams recruiting at age 20 per year. Recruitment fluctuates, and periods of below average recruitment of 3 to 5 years duration have occurred during this period (Table 4).

3.10 - Yield estimates:

There are a number of common management approaches that can be used to estimate a sustainable yield using the data available. Table 5 gives the estimated yields for a range of these targets, along with the fishing mortality corresponding to the present TAC of 24,000 t. Constant yield estimates were made using the 2004 survey biomass estimate as B_0. This would be a conservative estimate since there has been a fishery operating on Banquereau, but the 2004 survey biomass is larger than those recorded previously. Natural mortality was taken as 0.08 and the selectivity of the commercial gear was used as the selectivity pattern. The Yield Per Recruit analysis was done with and without a 15% incidental mortality on small clams that pass through the dredge. The results for the Yield per recruit and Spawning stock biomass per recruit are shown in Figure 16. Incorporating the incidental fishing mortality reduces the estimates of F_{MAX} and $F_{0.1}$.

3.11 - Production estimates:

Using equation 11, the production from the present age 20^+ population, growth minus mortality, is 19,640 t. Using the average recruitment at age 20 from the catch curve analysis, recruitment at age 20 contributes an average of 19,100 t per year, for a total production of 38,740 t. This is a very rough estimate of production, and does not include any density dependent feedback to growth or mortality, but indicates that the 1987-2006 average landings of 11,200 t should not have had a large effect on the biomass.

4.0 Discussion:

In the biomass estimate it is logical to include the stations that were too rocky or deep to dredge as stations with zero catch. All indications are that this would be the true catch if they could be towed, and thus it is additional information that improves the result. The problem it presents from an analytical perspective is that you now have two different types of zero catch tows: true zero catches and estimated zero catches. We have no method of including a separate variance estimate for the estimated zero tows, as we have no data for them. For this analysis we felt that our best biomass estimate is produced by including the estimated zero tows and treating them as true zero catch tows. The present survey produces a biomass estimate that is much larger than previous surveys (Table 2). The two previous surveys give similar densities, however their coverage was very different. All three surveys were done with different vessels and gear. The original survey in the 1980's was done with the US survey vessel Delaware II, equipped with an electro-hydraulic dredge (Ameratunga and Rowell, 1986). Current work on Atlantic surfclams and ocean quahogs in the U.S. assessments have shown that this dredge is very inefficient, much lower than the commercial gear used in these fisheries (NEFSC 2003, NEFSC 2004). The 1996-97 Banquereau survey (Roddick and Smith 1999) used a different vessel but the same gear as the present survey, but the dredge had been modified between the surveys, mainly with the addition of more weight to keep it on the bottom. We would like to have a consistent vessel and gear through a survey time series, however, this is not going to be the case for the offshore clam surveys in the short term as the survey vessel that was used in 2004 is no longer available.

There are other differences between the past and present surveys. The older ones did not have scales that could give accurate weights at sea, and so the catch weights were estimated from length frequency samples and length-weight regressions from samples processed in the laboratory.

The variation in biomass estimates and the continuing changes in survey vessels shows the importance in getting a better understanding of the gear efficiency. The efficiency studies done with the Cape Keltic during the 2004 survey were confounded with gear selectivity. Research on estimates of dredge efficiency are ongoing. The current research plan was to integrate efficiency studies into the surveys, conducting a couple of depletion studies during each survey, and as the studies accumulated, look at effects of factors such as depth and substrate, which may have an effect. If there are going to be vessel and/or gear changes between surveys a different approach may be necessary, with more work on estimating dredge efficiency done during each survey.

Another critical factor in getting an accurate biomass estimate from the survey data is the measurement of tow distance. For the Banquereau survey the tow distance is taken as the vessel movement from when the winch stops paying out cable to when it starts to wind back in again. There is the probability that the dredge is fishing for a time before the winch stops and again when it is being hauled back. While this may underestimate tow distance, other factors such as wave action may cause the dredge to pull out of the bottom during the tow, resulting in an overestimate of the actual distance the dredge was fishing during the tow. Industry has invested in a sensor system for the dredge which will tell when it is on the bottom and effectively fishing. Accurate estimates of tow distance, dredge efficiency and selectivity should provide survey estimates of biomass that are accurate population estimates.

Figure 17 shows the selectivity curve of the commercial gear in relation to sexual maturity and biomass per recruit. The selectivity and maturity curves show that the surfclams have plenty of opportunity to spawn before they are recruited to the commercial gear. This is important, as it should prevent recruitment overfishing, capturing the clams before they have a chance to spawn and thus fishing out the spawning stock biomass. The biomass per recruit and selectivity curves show that recruitment to the commercial gear takes place near the maximum cohort biomass. This shows that growth overfishing, i.e. capturing clams before they have a chance to grow and contribute their maximum to the fished biomass, is also not a concern in this fishery. The selectivity of the present commercial gear is near optimal as far as the recruitment and growth overfishing are concerned.

A decision on target yield is still to be made for this fishery. The long term constant yield targets such as 2/3 MSY and MCY are similar, depending on the calculation of MCY (Table 2). They are long term targets that are set at a level that the population should be able to maintain through most fluctuations in biomass. More conservative levels of MCY are sometimes used that should be sustainable during all normal fluctuations in abundance. The more conservative levels are used as "set it and forget it" targets that allow a fishery to progress with little monitoring. $F = M$ and $F_{0.1}$ on the other hand are constant mortality targets, removing a set fraction of the biomass, and so the yield varies with fluctuations in population biomass. MSY is a constant yield target that used to be a common target, but is now considered too high to be sustainable in the long term, and now is usually considered a threshold which triggers measures to reduce fishing. Comparing the $F_{0.1}$ yield of 102,347 t to the average landings from this fishery, which are 11,200 t per year for 1987-2006 or 17,500 t for 1997 – 2006, indicates that the fishery has not resulted in a large reduction in biomass from the virgin state. This is supported by the production estimate (38,740 t). Although this estimate must be considered very approximate, it is in excess of the catches that have been taken from the fishery, and would allow the biomass to increase. Surplus production theory says that the virgin biomass level should be the maximum biomass the area will support under equilibrium conditions, and at this level surplus production (production greater than that required to sustain the stock at it's present level) should be zero. Surplus production theory says that as the population declines surplus production increases (Ricker, 1975) due to density dependent effects. The history of the fishery is still too short and stable to give us the data to estimate feedback effects such as a stock-recruit relationship. In comparison, the US experience with ocean quahogs shows a 30 year fishery with the biomass continuously declining as the fishery progresses, but the expected increase in recruitment in response to this decline has not been observed. On Banquereau we have seen a recruitment pulse in the area heavily fished in the early stages of the fishery (the high biomass area on the eastern side of Banquereau in Figure 6). The fishery was concentrated in this area from 1986-1990, and the 1996/1997 survey showed a large recruitment pulse had occurred in this area after the fishery left (Roddick and Smith 1999). Although this does provide some support for density dependent feedback on recruitment, and thus increased production in response to a decline in biomass, we have not observed this response in other heavily fished areas on Banquereau. Fishing down of the biomass should be done with care, either gradually over the bank, or if an experimental approach is desired, intensive fishing on selected small areas on the bank to observe the response of the local stock.

Table 2 shows that only a very conservative target would not result in an increase over the present TAC of 24,000 t. The choice of a constant yield or a constant mortality approach provides a wide range in the allowable catch to be taken from this fishery. Some caution in the approach is indicated. If the present population is near the virgin biomass level, the TAC resulting from a constant mortality approach is not sustainable in the long term. As the population is fished down to the level where the catch balances production, the TAC will decline as well. The fishery is capital intensive, the vessels and gear involved in fishing and processing are expensive. Management must take these factors into account to prevent over-capitalization of the fishery when it is near a virgin biomass level, to prevent economic problems in the fishery as the biomass and TAC decline.

Caution is also indicated by a 1998 economic study (Gardner Pinfold Consulting Economists Limited, 1998) of the offshore clam fishery. The study showed that the fishery was not excessively profitable at the catch rates at that time. This means that a large reduction in biomass may reduce the catch rate to an uneconomical level.

The fishery has never taken the full quota allowed it, as it has been limited by market demand. The present plans are for the stock to be surveyed every 4-5 years, so with either a constant mortality or constant yield approach, the allowable catch must be set low enough that the stock will not be overfished in the event of poor recruitment or other declines in biomass between fishery independent updates. There are also still some questions on the benthic impacts of this fishery. Although a lot of work has been done to address this, and indicates that it does not have a long term detrimental effect (Gilkinson, Gordon et al. 2003, Gilkinson, Fader et al. 2003, Gilkinson, Gordon MacIssac et al. 2003) there are still enough concerns about the impact of the gear to advise a cautious approach to expanding the fishery.

Along with targets, it is usual to set thresholds that indicate when a system is in an overfished state, and which when reached, trigger measures to reduce fishing mortality. Empirical thresholds are ones such as MSY for a yield threshold as stated above, and $1/4B_0$ as a biomass threshold. Others such as 20% of virgin spawning biomass are also used. The management plan should incorporate both targets and thresholds, as well and what management changes will take place.

5.0 Conclusions:

The research survey biomass estimate for Banquereau surfclams is 1,462,097 $\pm$ 24,944 t. Current size at 50% selectivity is larger than size at maturity and near the size at maximum cohort biomass. This means that recruitment and growth overfishing are not concerns with the present selectivity pattern. The estimated natural mortality rate of 0.08 appears to be reasonable. Applying estimated mortality, recruitment and growth rates to the survey population structure indicates that production exceeds the level of removals due to fishing. The population has not been heavily impacted by the fishery to date, and is probably still near the virgin biomass level. The TAC can be safely increased from the present level of 24,000 t, but caution is advised as under a constant F approach to management the TAC's and catch rates experienced at this point will not be sustained as the fishery expands.

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Table 1. Biomass Estimates for the Banquereau 2004 Arctic surfclam survey.

Ave catch per standard tow	81.82 kg
Simple statistical model	
Number of tows used in analysis	237
Total Biomass Estimate	1,462,097
95% confidence interval	± 24,944
Acon estimate = areal expansion	
Number of tows used in analysis	254
Area within station boundaries	9,259 km^2
Total Biomass Estimate	1,373,486

Table 2. Comparison of biomass estimate from 2004 survey with previous estimates.

Study	Survey Area (km^2)	Biomass (t)
Present Study	9,259	1,462,097
1996-97 survey	5,200	469,839
Ameratunga and Rowell, 1986	9,182	822,415

Table 3. Species composition for tows from the 2004 Banquereau offshore clam survey.

Scientific name	Common name	Weight(kg)	%	Cumm %
Mactromeris polynyma	Arctic Surfclam	17762.280	34.083	34.08
Rocks and stones	Rocks and stones	10128.899	19.436	53.52
Cyrtodaria siliqua	Northern Propeller Clam	7416.984	14.232	67.75
Echinarachnius parma	Sand Dollar	6524.559	12.520	80.27
Shell	shell	5742.284	11.019	91.29
Shell and sand	shell and sand	2037.172	3.909	95.20
Serripes groenlandicus	Greenland Cockle	700.388	1.344	96.54
Chlamys islandica	Iceland Scallop	551.070	1.057	97.60
Cucumaria frondosa	Sea cucumber	491.077	0.942	98.54
Arctica islandica	Ocean Quahog	221.904	0.426	98.97
Sand and gravel	sand and gravel	186.661	0.358	99.33
Aphrodita hastata	Sea Mouse	81.954	0.157	99.48
Buccinum sp.	Whelk - Buccinum sp.	40.563	0.078	99.56
Strongylocentrotus droebachiensis	Sea Urchin	37.379	0.072	99.63
Chionoecetes opilio	Snow Crab	31.460	0.060	99.69
Ophiura sarsi	Smooth brittle star	20.972	0.040	99.73
Placopecten magellanicus	Sea Scallop	20.905	0.040	99.77
Pagurus sp.	Hermit Crab	19.069	0.037	99.81
Amblyraja radiata	Thorny Skate	13.797	0.026	99.84
Caudina arenata	Rattail Sea Cucumber	11.140	0.021	99.86
Crossaster papposus	Rough/Spiny sunstar	8.687	0.017	99.87
Ammodytes americanus	American Sand Lance	7.665	0.015	99.89
Leptasterias tenera	Slender armed sea star	7.316	0.014	99.90
Anthozoa C.	Sea Anemone	6.284	0.012	99.92
Siliqua squama	Rough Razor Clam	5.613	0.011	99.93
Chone infundibuliformis	smooth tube worm	5.386	0.010	99.94
Solaster endeca	Purple Sunstar	4.220	0.008	99.94
Hyas coarctatus	Arctic Lyre Crab	4.052	0.008	99.95
Limanda ferruginea	Yellowtail flounder	3.653	0.007	99.96
Neptunea lyrata decemcostata	Wrinkle whelk	3.603	0.007	99.97
Mya truncata	Truncate softshell	3.136	0.006	99.97
Colus sp.	Whelk - Colus sp.	2.656	0.005	99.98
Seaweed	seaweed	2.193	0.004	99.98
Unidentified	unidentified	2.165	0.004	99.99
Gorgonocephalus arcticus	Basket Star	1.804	0.003	99.99
unidentified worms	unidentified worms	1.017	0.002	99.99
Cancer irroratus	Atlantic Rock Crab	0.995	0.002	99.99
Euspira heros	Northern Moonsnail	0.818	0.002	99.99
Thelepus cincinnatus	encrusted tube worm	0.708	0.001	100.00
Eunephthya rubiformis	Sea Strawberry	0.481	0.001	100.00
Asterias forbesi	Sea star	0.459	0.001	100.00
Panomya norvegica	Arctic roughmya	0.393	0.001	100.00
Raja sp. eggs	skate egg case	0.329	0.001	100.00
Unidentified tunicate	unidentified tunicate	0.247	>0.001	100.00
Ophiopholis aculeata	Daisy brittle star	0.057	>0.001	100.00
Buccinidae eggs	Whelk eggs (NS)	>0.01	>0.001	100.00
Laminaria saccharina	kelp	>0.01	>0.001	100.00
Nephtys bucera	rag worm	>0.01	>0.001	100.00
Ophelia limacina	Ophelia limacina	>0.01	>0.001	100.00
Pandalus montagui	Aesop shrimp	>0.01	>0.001	100.00
Pandalus sp.	shrimp	>0.01	>0.001	100.00
Pentamera calcigera	white cucumber	>0.01	>0.001	100.00

Table 4. Estimated recruitment at age 20 from numbers at age and estimated Z from catch curve analysis of 0.11.

Age	2004 Numbers at age	Estimated age 20 recruits
20	4036	4036
21	3476	3880
22	3936	4904
23	4202	5845
24	5933	9213
25	2562	4441
26	5056	9783
27	2393	5169
28	3004	7242
29	2912	7838
30	1265	3800
31	1175	3942
32	2428	9090
33	1333	5570
34	421	1964
35	2077	10817
36	1971	11455
37	1069	6938
38	650	4710
39	1230	9948
40	1268	11446
41	1214	12226
42	252	2835
43	242	3042
44	227	3181
45	1925	30107
46	110	1928
47	232	4529
48	197	4285
49	278	6742
50	226	6123
51	381	11524
52	198	6698
53	414	15625
54	204	8568
55	58	2720
56	81	4227
57	33	1909
58	97	6323
59	140	10244
60	42	3424
Average		7031
Std. Dev.		4972
Mean age 20 from catch curve		5886

Table 5. Estimated yields for different management targets for Banquereau Arctic surfclams based on the survey biomass estimate of 1,462,097 t.

Strategy	F	Yield
F = M	0.08	116,968
$F_{0.1}$	0.07	102,347
F_{MSY} = 0.5M	0.04	58,484
F_{MCY}	0.026	38,599
$F_{current}$	0.016	24,000

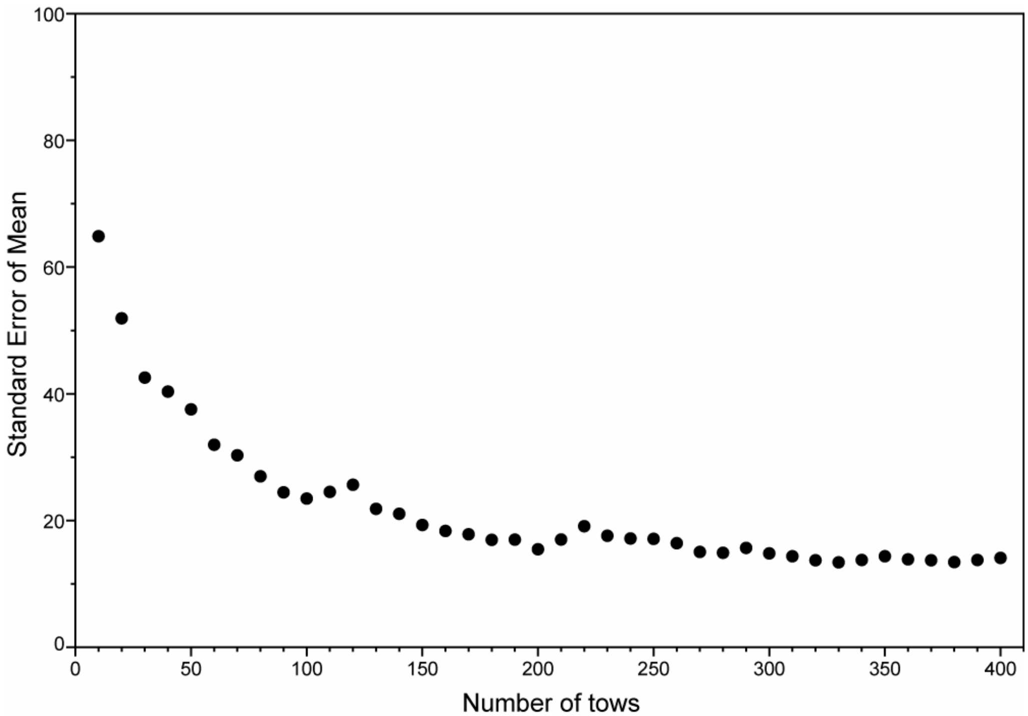

Figure 1. Estimated standard error of the mean from the 1996-97 Arctic surfclam survey on Banquereau Bank. Points are standard errors from 30 replicates sampling with replacement from survey tows for the specified number of tows.

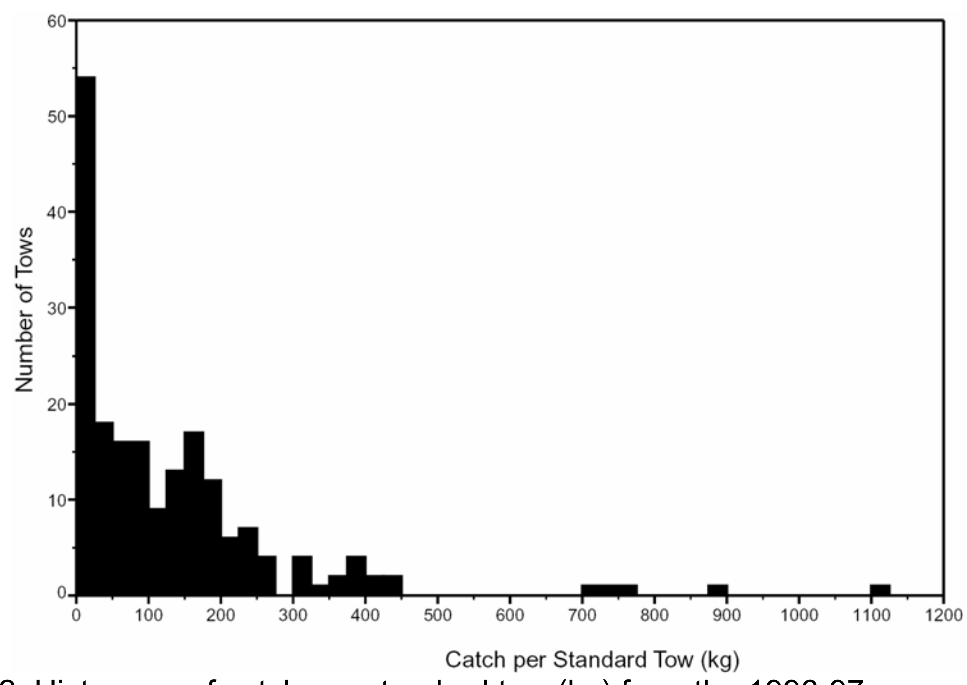

Figure 2. Histogram of catch per standard tow (kg) from the 1996-97 survey on Banquereau Bank.

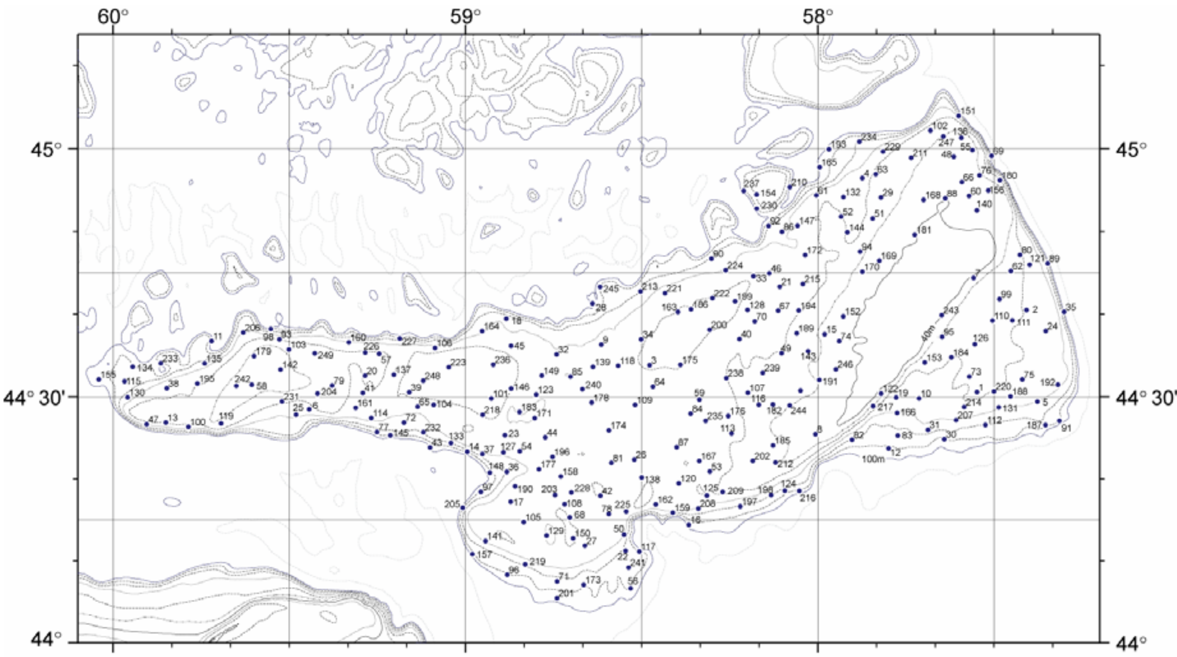

Figure 3. Station locations for survey of Banquereau Bank.

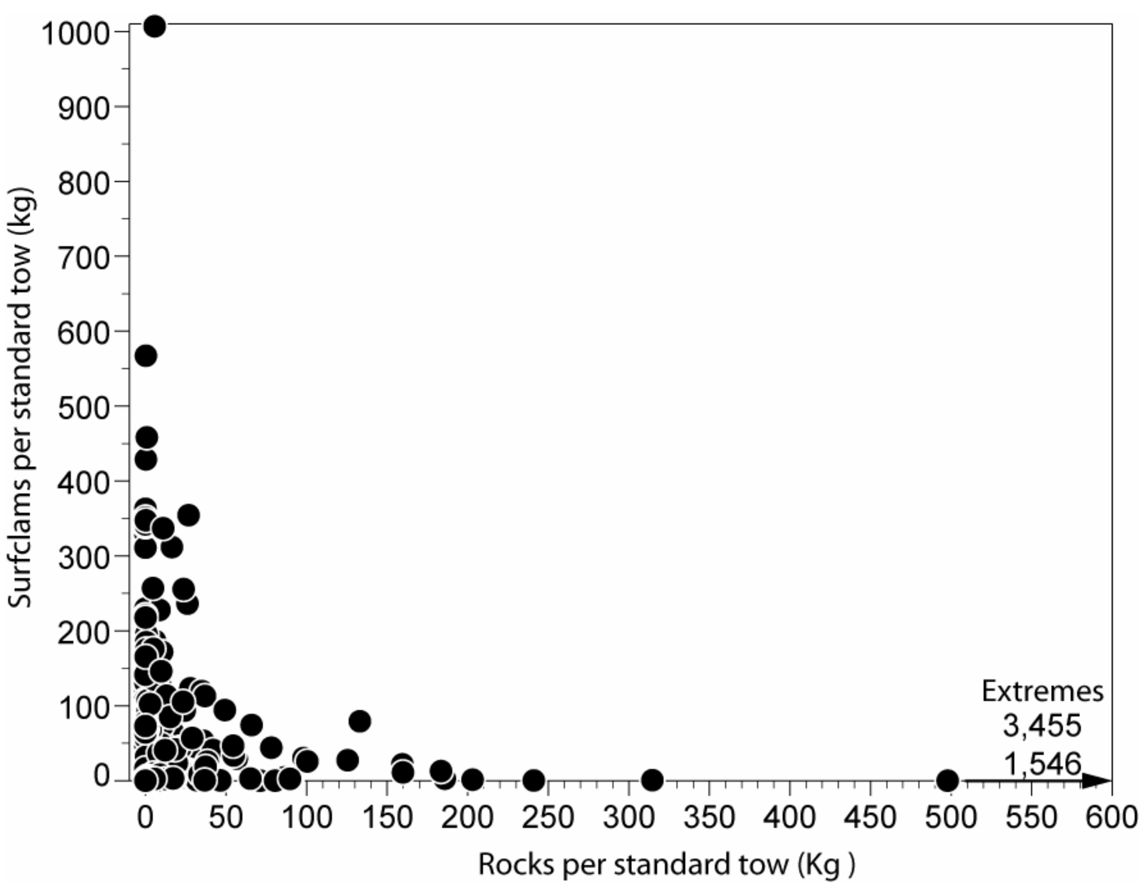

Figure 4. Catches of rock versus clams for stations occupied with a clam dredge in the 2004 Banquereau clam survey.

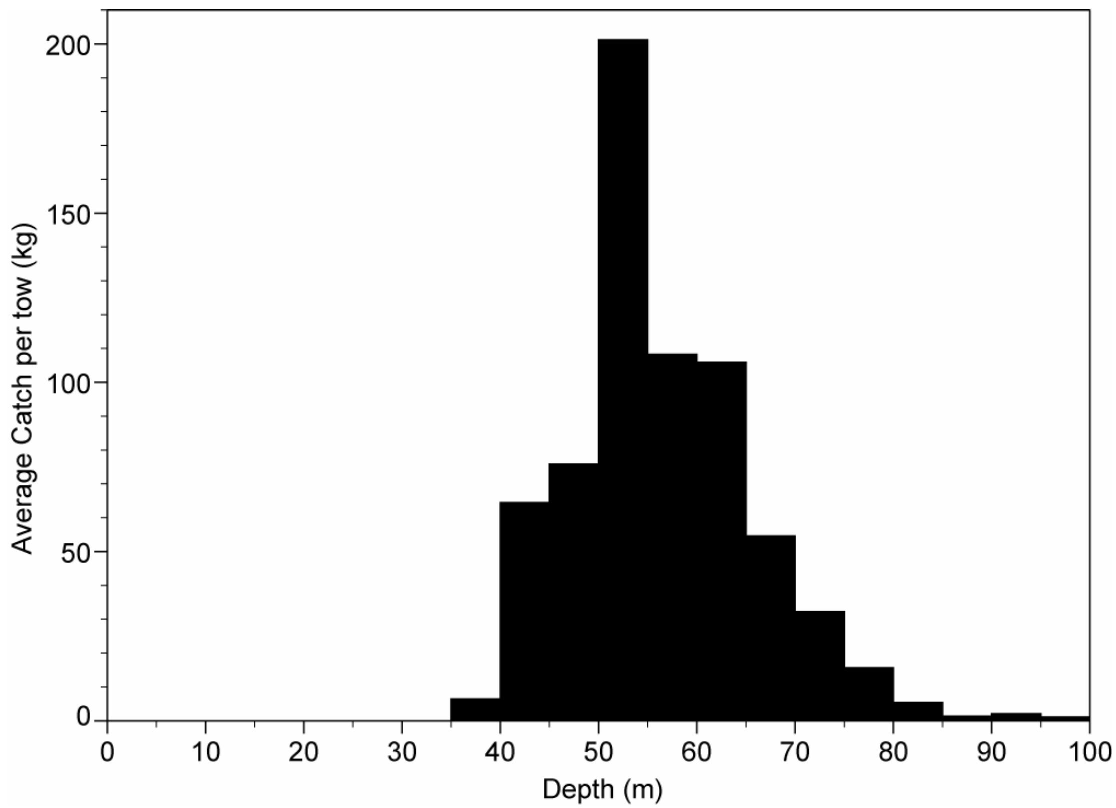

Figure 5. Average catch per tow versus depth for the 2004 Banquereau Arctic surfclam survey.

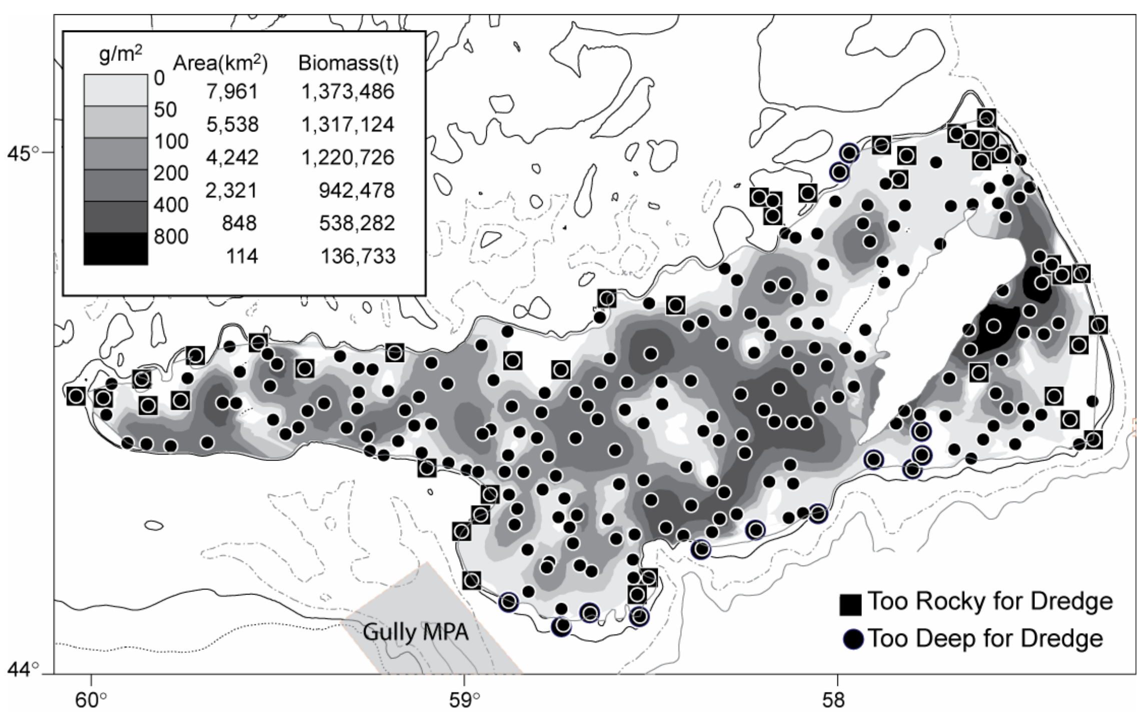

Figure 6. Contouring of surfclam catch (kg/ 500 m^2 tow) for the 2004 Banquereau Arctic surfclam survey.

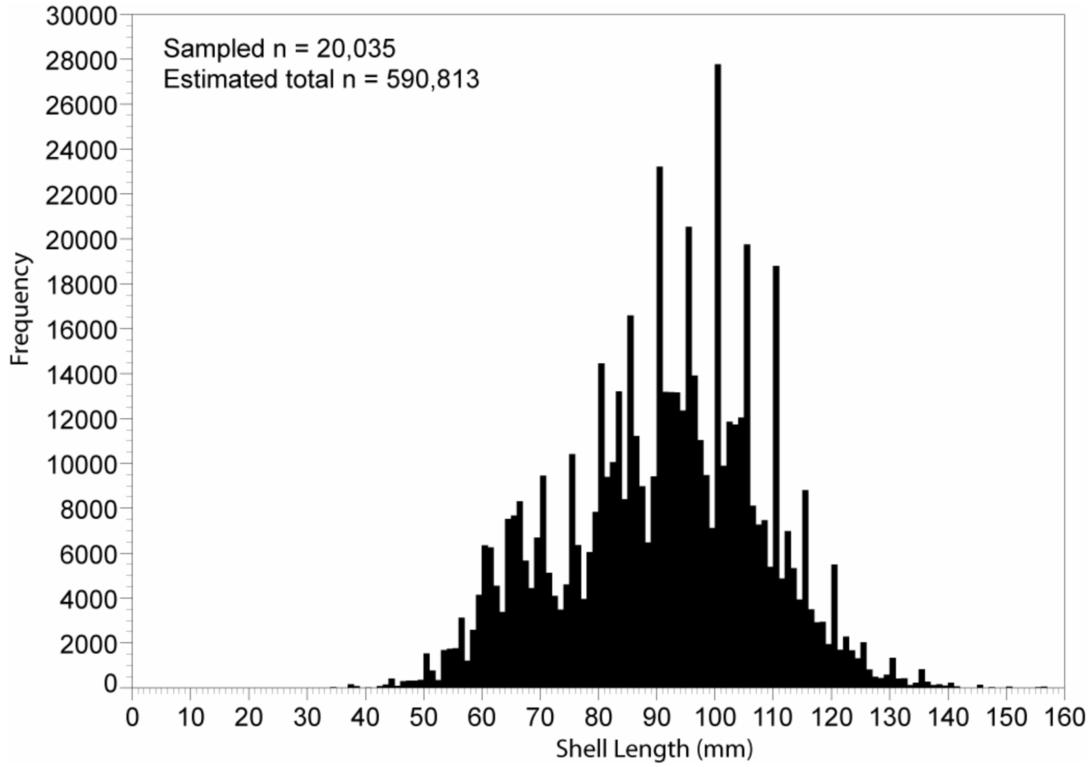

Figure 7. Estimated total length frequency for the surfclam catch for the 2004 Banquereau Arctic surfclam survey.

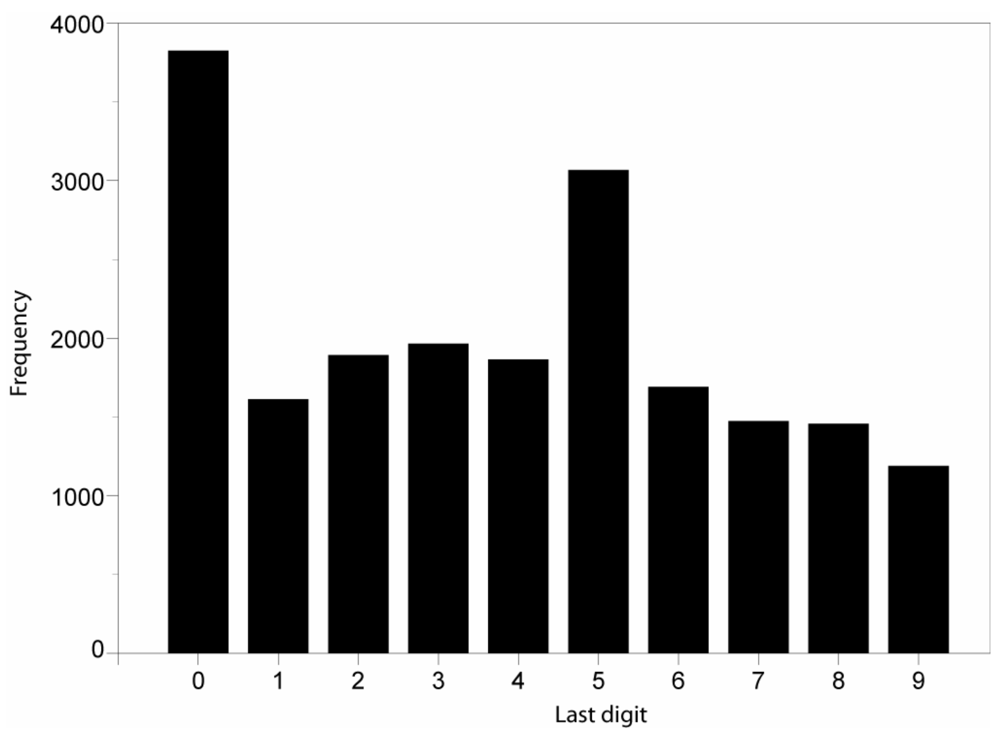

Figure 8. Frequency of last digit in length frequency shell measurements from 2004 Banquereau clam survey.

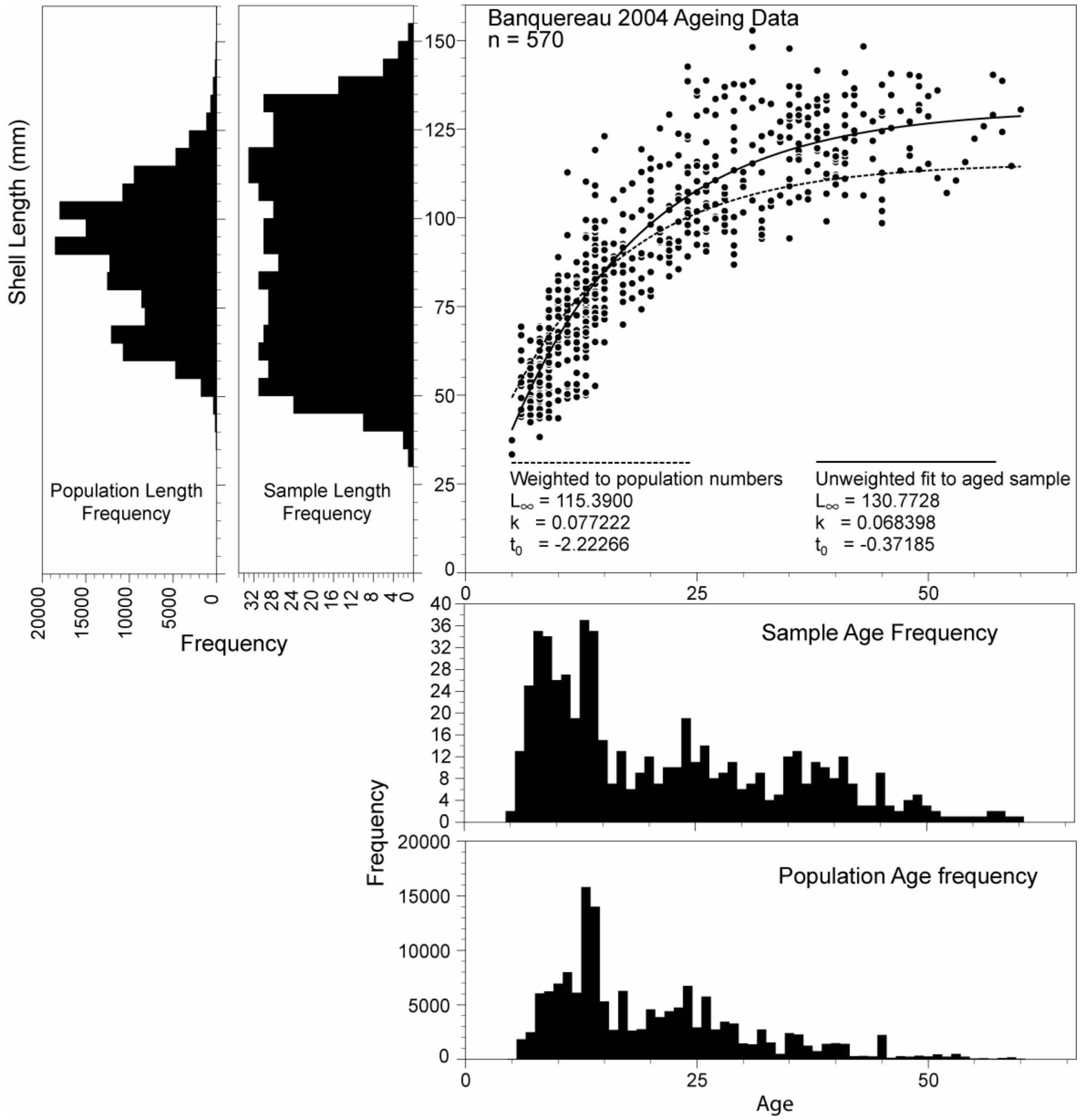

Figure 9. Aged surfclam samples from the 2004 Banquereau survey used for the construction of the age-length key. Histogram on the left is the size frequency of the aged sample. The center plot shows the age-length data and the fitted von Bertalanffy growth curve, and the bottom histogram is the resulting age histogram for the sample.

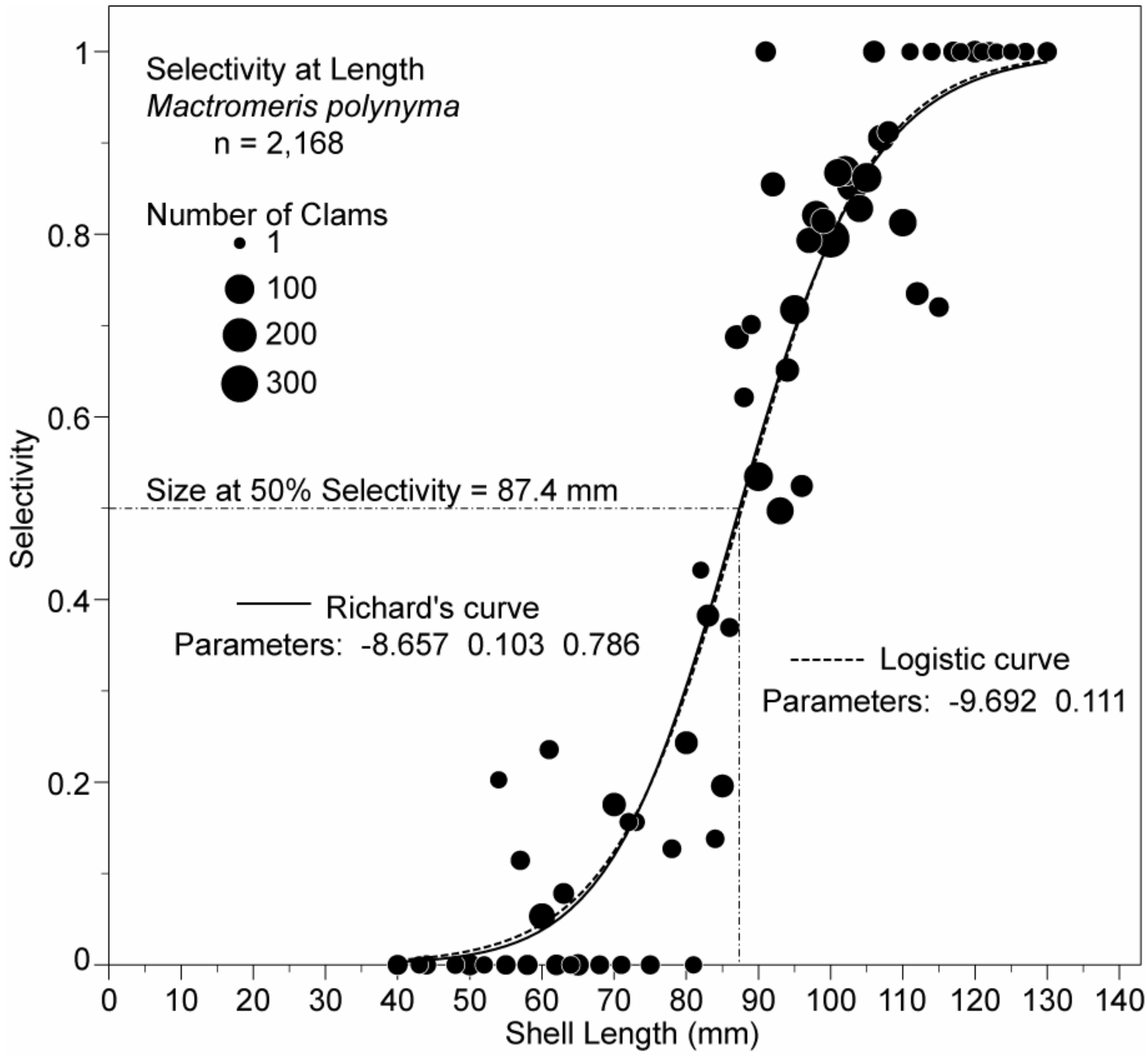

Figure 10. Selectivity curve for Mactromeris polynyma fit to data from 2004 Banquereau clam survey. Selectivity data was from a covered dredge experiment and fit was with the SELECT package using maximum likelihood.

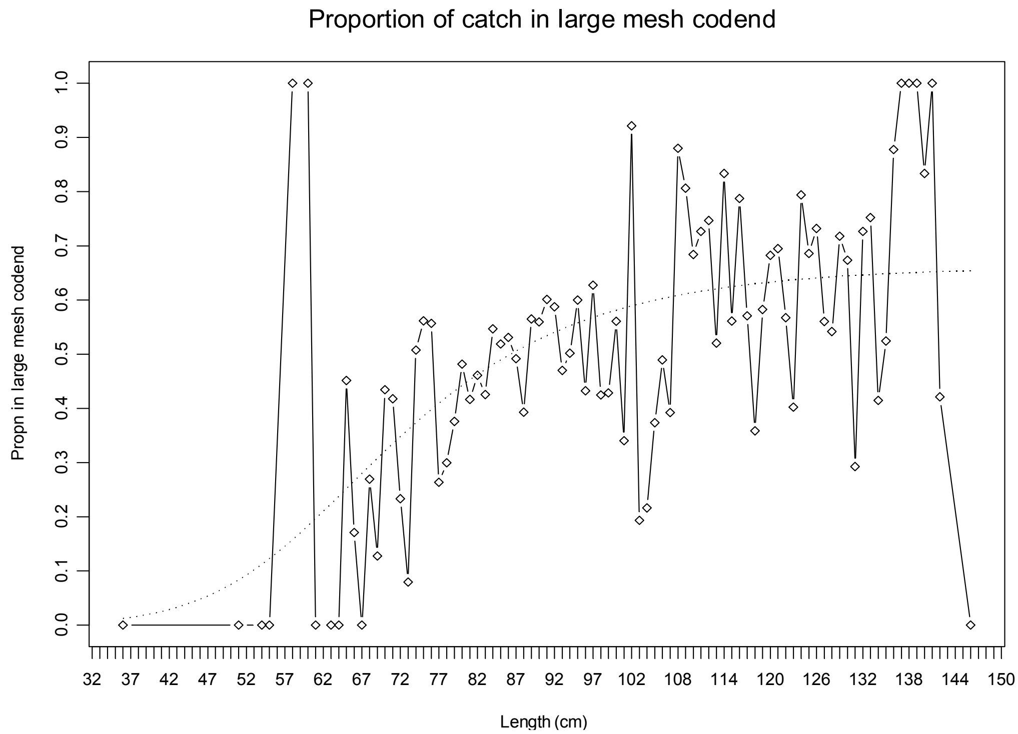

Figure 11. Fit of a Richard's curve to commercial surfclam dredge selectivity data. The selectivity experiment was done as a paired tow experiment with a lined and unlined dredge.

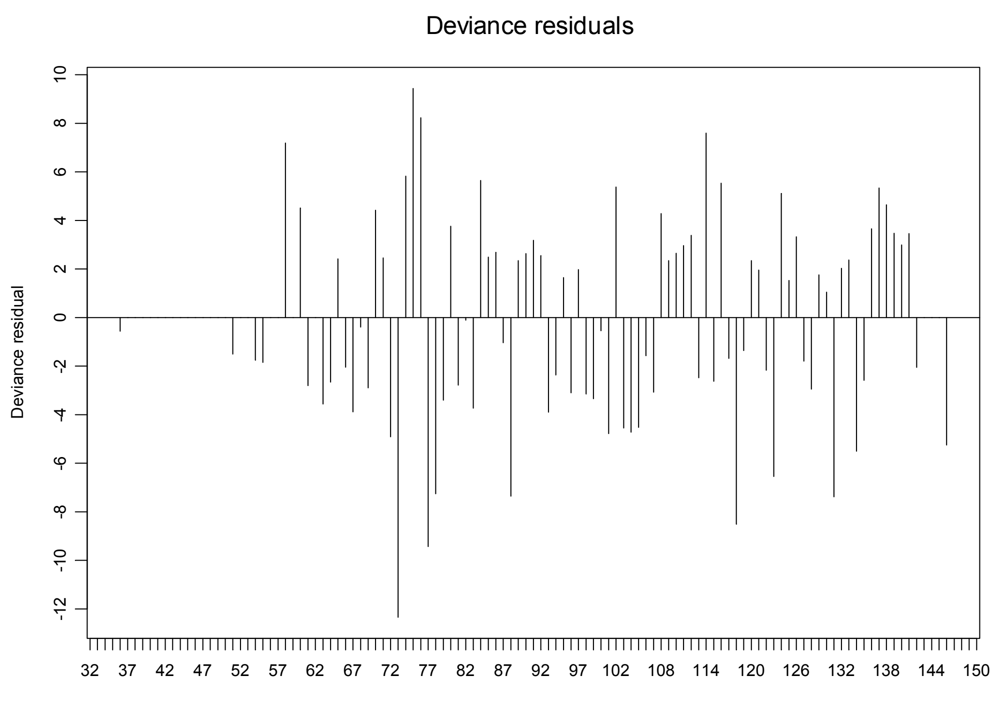

Figure 12. Deviance residuals for fit of Richard's Curve to commercial clam dredge paired tow data.

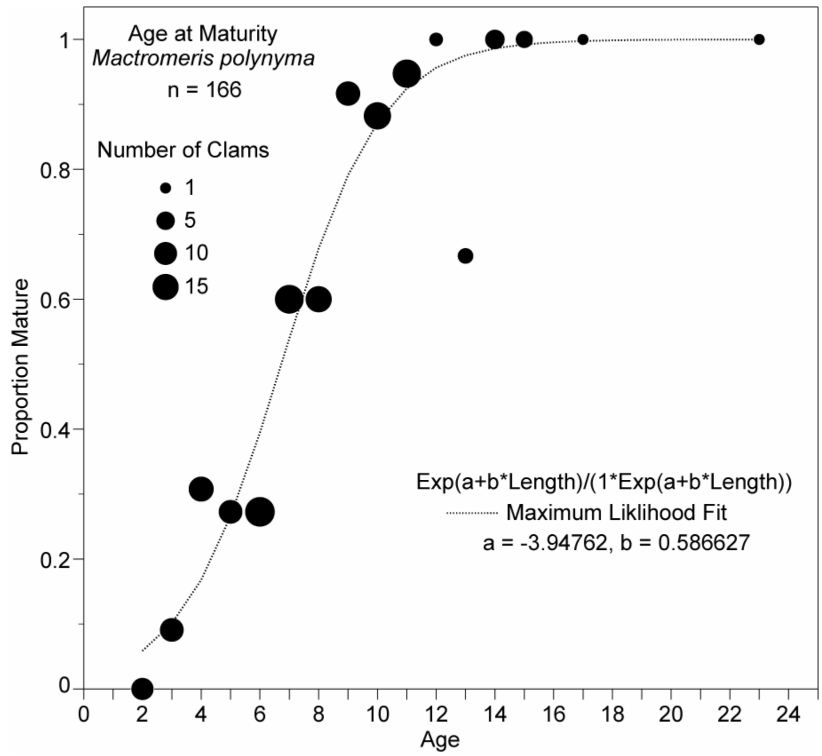

Figure 13. Age at maturity for Mactromeris polynyma collected during the 2004 Banquereau survey.

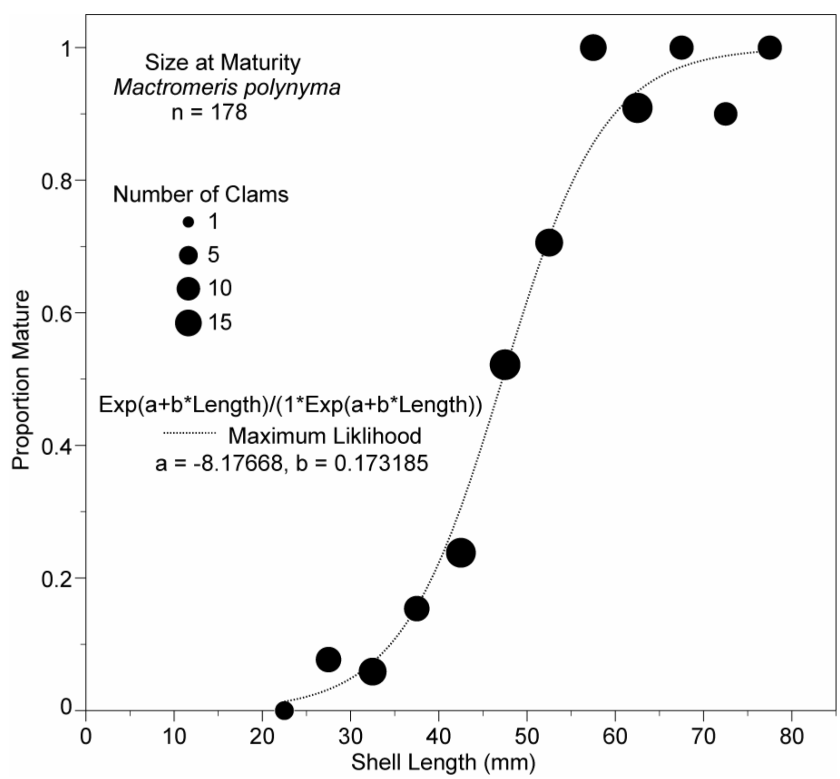

Figure 14. Size at maturity for *Mactromeris polynyma* collected during the 2004 Banquereau survey.

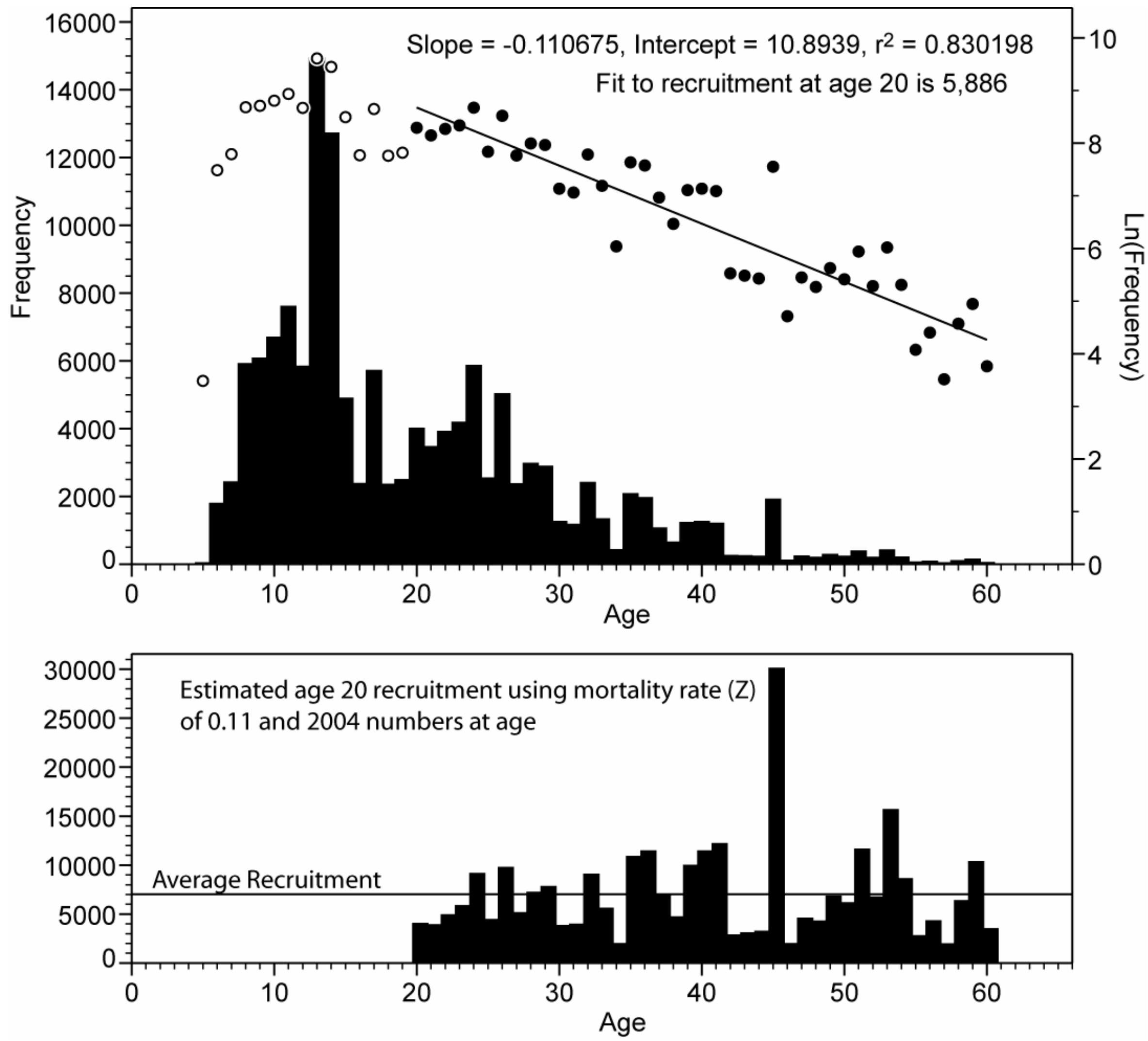

Figure 15. Age distribution for Banquereau survey numbers at age. Catch curve estimates of total mortality (Z) are done using log transformed numbers at age (top linear regression, filled circles are points used for the regression). Estimated recruitment at age 20 using the numbers at age and estimated Z from catch curve are shown in lower panel.

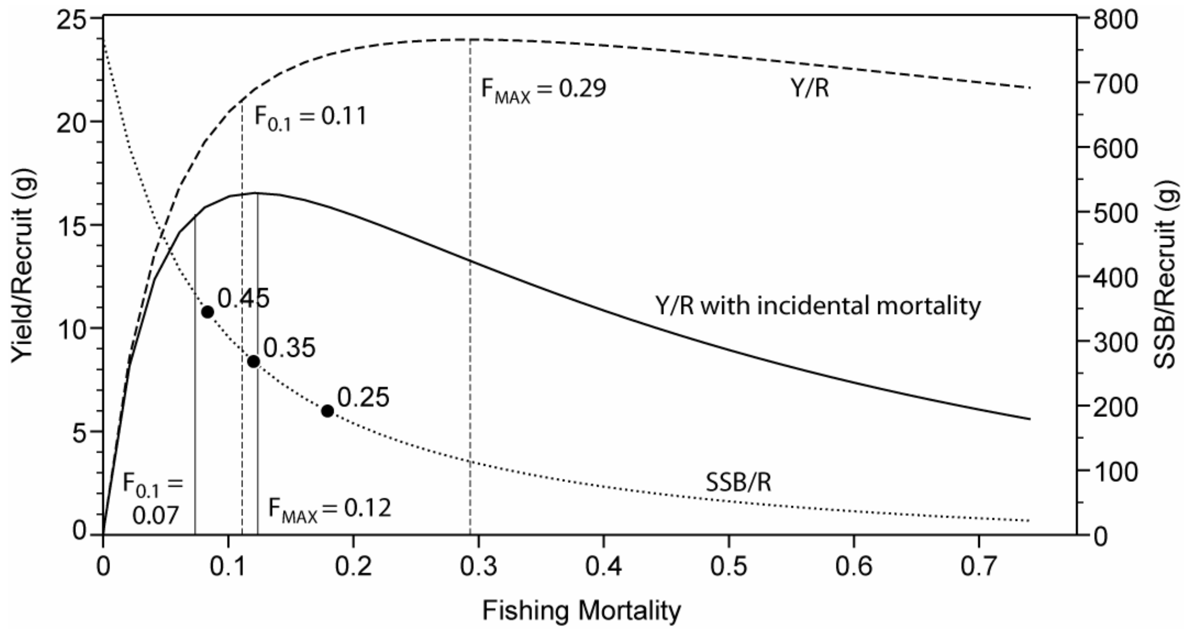

Figure 16. Yield and spawning stock biomass (SSB) per recruit for *Mactromeris polynyma* on Banquereau. The top dashed yield per recruit curve is with no incidental mortality. The lower curve is with a 15% mortality of small clams that pass through the dredge. The SSB curve is with the 15% incidental mortality included.

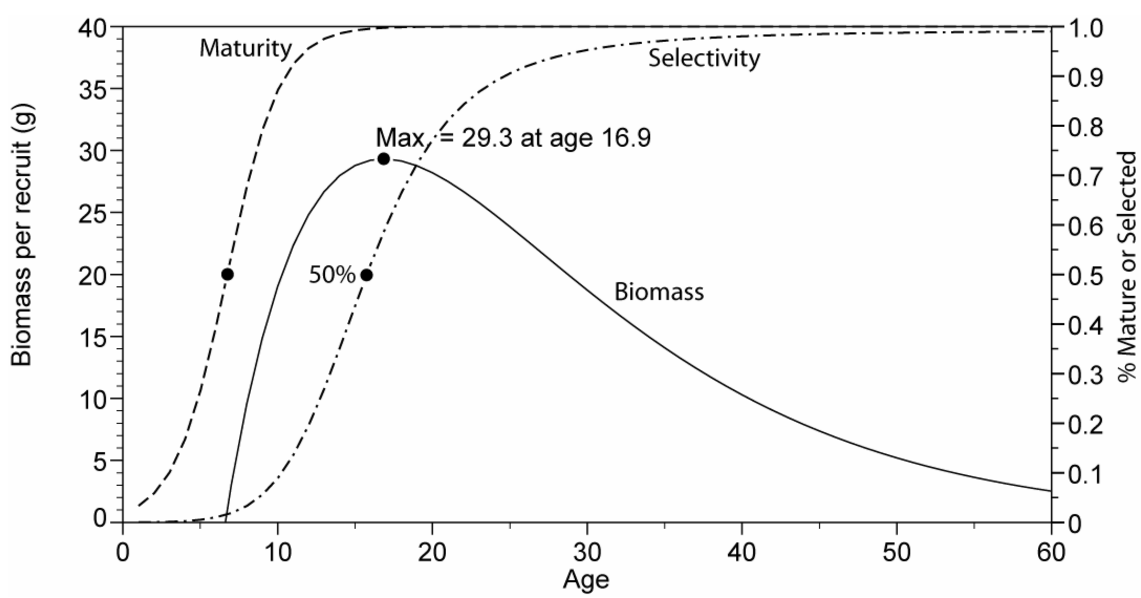

Figure 17. Selectivity at age of the commercial gear in relation to age at maturity and biomass per recruit for *Mactromeris polynyma* on Banquereau.