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# Assessment of the Arctic Surfclam (*Mactromeris polynyma*) Stock on Grand Bank

# Évaluation du stock de mactres de Stimpson (*Mactromeris polynyma*) du Grand Banc

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## ABSTRACT

A survey of the Grand Bank Arctic Surfclam stock on Grand Bank, Newfoundland was conducted to assess the biomass of the stock in this area. The survey was conducted in three parts in 2006, 2008 and 2009, and was also complicated by the use of two different vessels and three dredges. The survey provided a research vessel biomass of 1,140,662 t in an area of 49,473 km$^2$. 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 the size at maximum cohort biomass. The Total Allowable Catch (TAC) could be increased from the present 20,000 t applying the $F_{MCY}$ approach used for Banquereau, but caution is advised as a large portion of the biomass is in low density areas, and there continue to be uncertainties about the impact of dredges on overall benthic productivity.

## RÉSUMÉ

On a effectué un relevé pour évaluer la biomasse du stock de mactres de Stimpson du Grand Banc de Terre-Neuve. Ce relevé en trois volets (en 2006, 2008 et 2009) a été compliqué par le fait que trois dragues et deux navires différents ont été utilisés pour le réaliser. La biomasse recensée par le navire scientifique était de 1 140 662 t sur une superficie de 49 473 km$^2$. Il n'y a pas de problème de recrutement et de surpêche du potentiel de croissance dans cette pêche avec l'actuelle sélectivité de l'engin. La taille des captures pour une sélectivité de 50 % est supérieure à la taille à la maturité et à la taille dans la biomasse maximale des cohortes. Le total autorisé de captures (TAC) pourrait être augmenté par rapport aux 20 000 t actuelles si on appliquait la stratégie $F_{PME}$ actuellement utilisée sur le Banquereau, mais il convient d'être prudent étant donné qu'une forte proportion de la biomasse se trouve dans des zones de faible densité et que des incertitudes subsistent au sujet des incidences des dragues sur la productivité benthique générale.

# 1.0 – INTRODUCTION

## 1.1 – HISTORY OF THE GRAND BANK ARCTIC SURFCLAM FISHERY

The presence of Arctic Surfclams (*Mactromeris polynyma)* on Grand Banks was reported as early as 1885 (Chamberlin and Sterns, 1963), and K.N. Nesis (1963) mapped its distribution on parts of the Grand Banks. Following the development of a fishery for Arctic Surfclams on Banquereau in 1986, exploratory fishing on Grand Bank in 1987 and 1988 led to the expansion of the fishery to this area in 1989. Two exploratory licences and two exploratory permits were issued for one year for 3LNO (the Grand Banks), with a “precautionary” TAC of 20,000 t (DFO, 1999). The TAC was based on an economic Break-Even analysis, as there was little information on the available biomass in the area. In 1990 the TAC was rolled over for the 1990-1994 period, with access by 4 permanent licences. With no biological advice on biomass, and the TAC never being reached, the TAC has continued at the same level to the present.

Facing decisions on investment in the fishery and with DFO unable to obtain funding for surveys of the resource, Industry committed to funding a survey of Grand Bank and Banquereau in 1995-1997 under a multi-year Joint Project Agreement (JPA) program. With the demise of the scientist in charge, the results of the Grand Bank portion of the survey were never formally presented for review.

Industry has continued their commitment with a series of resource surveys under multi-year JPAs with DFO. The intent has been for the surveys to cycle through the fishing banks with a survey each year, and individual banks surveyed every 3 to 5 years. The survey series started with a quahog survey of Sable Bank in 2003, followed by Banquereau in 2004 and, due to the size of the area involved, Grand Bank was split into surveys in 2006, 2008 and 2009. Due to other financial commitments there were no surveys in 2005 and 2007.

The Scotian Shelf and Grand Bank offshore clam fisheries are managed under one plan, with the licence holders having equal access to quotas in both areas. Fishing activity has switched between the two areas through time, with the focus on Banquereau for the last few years (Figure 1). Landings for the combined fishery are shown in Table 1 and Figure 1, and the landings, value and TAC for the Grand Bank fishery in Figure 2. The fishery has used large freezer processor vessels since 1992. There were three vessels active for most years, fishing on both Banquereau and Grand Bank, but the fleet currently consists of two freezer processors. The distribution of logged effort for the fishery up to July, 2010 is shown in Figure 3. The fishery has concentrated on a small portion of the Bank.

# 2.0 – METHODS

## 2.1 – SURVEY DESIGN

### <u>Number of Stations Required</u>

The distribution of catch per tow from the 1995-97 survey is shown in Figure 4. The distribution is typical of survey data, where a large number of tows have little catch and a few have very high catches. A resampling approach was used to estimate the reduction in the standard error of the mean as the number of tows is increased. The reduction was estimated from the 1995-97 data by drawing 30 replicate samples of n tows, with replacement, and calculating the standard error. The results are shown in Figure 5, 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 300 stations there is little reduction in the standard error.

Since the data for the standard error analysis was old, and the vessel and gear to be used in the current survey differed from the original survey, there was the possibility that the variability in the current survey would be higher than the 1995-97 survey. Due to the possible difference in variance, and 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 of the southern half of Grand Bank on 350 stations. The same number of stations was assigned for the survey area of the northern half. Survey stations were randomly assigned within the survey area. The assignment function allowed a minimum spacing of 1 km between tows. Additional random stations were then assigned without reference to spacing from previous stations to aid in spatial analysis of variance at smaller distances. A plot of the station locations (Figure 6) indicated that all areas of the bank were adequately covered.

Using the Acon package (Black, 1991) and bottom bathymetry from the Canadian Hydrographic Service, the survey area was calculated as 49,473 $km^2$ (Figure 6).

The original design was to cover the Bank in 2 years, covering half the area each year. There were a number of vessel and equipment problems, and the stations were completed over 3 surveys in 2006, 2008 and 2009. The vessel changed after the 2006 survey, and there were differences in the design of the dredges used in all three legs. Stations from previous surveys were repeated in 2008 and 2009 to compare catch rates between surveys.

### 2.2 – SURVEY GEAR

The vessel used for the 2006 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 back of the dredge was a chain bag and codend, and the dredge was set and landed from the side of the vessel. The depth of the knife was set to 14.3 cm below the runners. The electronics onboard the *Cape Keltic* included both a MaxSea navigation package used to measure tow distance and record the tow track, and a SeaScan bottom discrimination system (Sonavision Ltd., Scotland, UK), used to check the bottom for suitability before using the dredge. The vessel used for the 2008 and 2009 surveys was the *Tenacity I*, a 36 m, 353 GT stern dragger built in 1967. The original dredge was showing signs of wear and so a new dredge was constructed based on the same design for the 2008 survey. There were problems landing the dredge over the stern during the 2008 survey, especially when it was full, and there were safety concerns. For 2009 a ramp and runner system similar to that used on some of the commercial vessels was installed on the stern. This system made handling the dredge much easier and safer, but the back of the dredge had to be changed from a chain bag and codend to a full cage. This reduced the capacity of the dredge, but it was felt that it would also retain less shell and sediment.

Tow distance is usually measured from when the winch stops paying cable out to when it starts hauling the dredge back. If the winch is paying out slower than the vessel's speed over bottom, the dredge may be on the bottom and fishing before the winch stops. If there is a lot of scope, the dredge may still be fishing for part of the time it is being hauled back. During the tow, wave action on the vessel or encounters with rocks may cause the dredge to lift or tilt so that it is not fishing for portions of the tow. A dredge sensor system was designed for the clam survey dredge to measure when the dredge was sitting flat on the bottom and fishing. The sensor system has X, Y, and Z accelerometers to measure the pitch and roll angle of the dredge, and ambient and manifold pressure sensors to measure the differential water pressure in the manifold. It also contains a temperature sensor for ambient temperature. The problem with the sensor system was that it could not stand the rough handling involved in setting and landing the dredge. It flooded at the start of the 2006 survey, and in 2008 internal parts repeatedly came loose eventually precluding repairs made at sea. With the smoother handling with the ramp and runner system in 2009, the sensor system worked for the whole survey, with the exception of the manifold pressure sensor which failed at the start of the 2009 survey.

The knife depth for different angles of the dredge off horizontal was measured on land to determine at what angle the knife would no longer be fishing. For each tow the amount of time the dredge was at more than this angle was calculated, and tow distance was adjusted for this time.

## 2.3 – TOW PROCEDURES

After checking the bottom with the SeaScan system, a 3 minute 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. Vessel position was recorded when the dredge was dropped, when the winch stopped feeding out, when the winch started retrieving the dredge, and when the dredge hit the surface. The vessel track was recorded at 2 second intervals during the survey.

## 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 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 sorted, taxa were identified 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 sorting and weighing all large bivalve species (Arctic Surfclams, Ocean Quahogs, Northern Propellerclams, Greenland Cockles, 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:

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

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 up to 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. The samples were then dehydrated in ovens set to 90°C for at least 48 hours after which the dry weights of the gutted foot, remaining tissue and shell were recorded. Also, both wet and dry weights were recorded for any sand found inside the clams. 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.

### 2.5 – CATCH COMPOSITION / BY-CATCH

By-catch was estimated for both the whole survey and separately for those tows having a catch greater than 100 g/m$^2$, representing those areas likely to be fished commercially. It was also compared to data from sampling programs on commercial vessels.

### 2.6 – AGEING

A length stratified, random sub-sample (150 clams per 5 mm shell length increment) of 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 polyester resin. 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 placed in a Petro-Thin® thin sectioning system and the shell section was ground down to approximately 0.3 mm. The section was then ground to its final thickness using three increasingly finer grits (30 µm, 15 µm, 6 µm) and a final polish of 0.3 µm aluminum oxide, which removed saw and grinding marks. The annuli were counted under an Olympus microscope using transmitted light at 40x magnification.

All personnel involved in ageing the clams (agers) went through training with a reference set and group ageing sessions to ensure consistency in ages assigned. Age determination bias between readers and against a set of consensus ages was assessed through the use of age-bias plots. This type of plot displays a reader's assigned ages against another reader or consensus ages in reference to an equivalence line where the reader has assigned the same age as the consensus or other reader's age. Specifically, for all animals with a given consensus age, the mean age and 95% confidence intervals of the ages assigned by the reader are plotted against the consensus age (Figure 7). Precision estimates were calculated by using the coefficient of variation (CV) as described by Chang (1982) and Morales-Nin and Panfili (2002):

$$CV_j = 100 * \frac{\sqrt{\sum_{i=1}^{R} \frac{\left(X_{ij} - X_j\right)^2}{R-1}}}{X_j} \qquad (2)$$

where Xij is the age estimate of the ith clam with consensus age j, $X_j$ is the consensus age j, and R is the number of clams of consensus age j. CV is then averaged across clams to produce a mean. CV is more flexible and statistically more robust than other measures of precision, such as percent agreement or Average Percent Error (Kimura and Lyons, 1991).

Each ager was tested by comparing their ages against a set of consensus ages, and had to achieve a CV less than 5% before they could do routine ageing of samples (Table 2 and Figure 7). There is no absolute rule for an acceptable CV for ageing studies, since the precision is affected by the species, its longevity, and the difficulty in reading the age structures. Laine et al. (1991) suggested a CV of 5% as the limit of precision for acceptable age readings for short lived species (<15 years). Campana (2001) states that 5% serves as a reference point for many fishes of moderate longevity and reading complexity, but shows in a review of 117 published precision values that CVs exceeding this are common. Our results were thus considered conservative as we have used a 5% CV for a species with a lifespan of 50 years.

The age data was fit to a von Bertalanffy growth curve:

$$L_t = L_\infty\,(1 - e^{-k(t-t_o)}) \qquad (3)$$

where $L_t$ is the length at age t; $L_\infty$ 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 R statistical package (R Development Core Team, 2008).

### 2.7 – SELECTIVITY

At the end of the 2009 survey, a site which had a clean catch of clams (i.e. little shell and by-catch) 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 was 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 curve (Millar and Fryer, 1999):

$$P = (e^{a+bL}/(1+e^{a+bL}))^{1/\delta}. \qquad (4)$$

where $P$ is the proportion of clams of length $L$ retained by the dredge, a, b and $\delta$ 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:

$$L_{50} = (\log(0.5^\delta/(1+0.5^\delta)) - a)/b \qquad (5)$$

The SELECT (Share Each Length class' 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.

The selectivity curve for Arctic Surfclams had alredy been determined for the old dredge design (Roddick et al. 2007), so the selectivity curves for the two dredge designs could be compared.

### 2.8 – COMPARISON TOWS

To compare the dredge and vessel differences 20 comparison tows were carried out in 2009, repeating tows done during the 2006 (8 tows) and 2008 (12 tows). The vessel followed the previous tow track as close as possible. These were compared with Paired Wilcoxon tests and a Kolmogorv-Smirnov test of differences between cummulative distribution functions.

## 2.9 – BIOMASS ESTIMATION

The biomass in the survey area was calculated by two methods:

1 Random sampling statistics:

$$B = A_s / A_t * \overline{C} \quad (6)$$

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 a tow area of 500 $m^2$.

## 2.10 – DREDGE EFFICIENCY ESTIMATES

Work is ongoing to estimate the dredge efficiency of the gear used in the surveys. A depletion experiment was conducted during the 2009 survey using the methods of Rago et al. (2006), and applied and modified since 1998 for the NEFSC Atlantic Surfclam and Ocean Quahog stock assessments (NEFSC, 2007a and 2007b). This model is referred to as the patch model, and has become a standard approach used in NEFSC stock assessment work for a variety of shellfish and sedentary demersal finfish, including Sea Scallops (NEFSC 2004b), Ocean Quahogs (NEFSC 2004a, 2007a), Atlantic Surfclam (NEFSC 2003, 2007b) and Goosefish (NEFSC 2005).

Although it is a depletion model based on the models of Leslie and Davis (1939) and Delury (1947), this model does not make the usual assumptions about complete mixing of the remaining population between samples: that all individuals have the same probability of capture; that the expected catch is proportional to the sampling effort; that the catch in a sample is dependent on the cumulative catch of the samples preceding it; and that all removals are known. Since clams are sessile organisms, the model takes a spatial approach in examining the area of overlap in successive tows of the dredge and the effect of this on the catch rate. It uses a Negative Binomial distribution to model the catch, and maximum likelihood to fit the model. It originally attempted to add indirect effects, where the sampling process affects the catchability and availability of some remaining individuals, i.e. dredging causes some individuals to burrow deeper into the bottom, beyond the capture depth for the dredge. This was done by allowing the parameter Gamma, nominally the ratio of dredge width to cell width, to include another term.

$$\gamma = ( w_{dredge} / w_{cell}) + \varepsilon \quad (7)$$

Where $w_{dredge}$ is the width of the dredge, $w_{cell}$ is the cell width and $\varepsilon$ is a factor related to indirect effects (Rago et al. 2006).

In practice, estimating gamma has turned out to be problematic, as it is correlated with other parameters being estimated in the model, and dependent on assumptions about cell size. The approach now used in the NEFSC assessments for surfclams and quahogs is not to try and estimate indirect effects, but to fix gamma at the ratio of dredge width to cell width (NEFSC 2007a, 2007b). A dredge efficiency study was done during the 2009 survey.

### 2.11 – SIZE AND AGE AT SEXUAL MATURITY

Samples for size and age at maturity were collected during the surveys. 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 Richards Curve was fit to the data using maximum likelihood (Equation 4). 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 Richards Curve was fit to the age at maturity data using the same method used for the size at maturity data.

### 2.12 – MORTALITY

Since there has been a commercial fishery for clams on Grand Bank, 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:

$$Z = 3/T_{MAX} \qquad (8)$$

where $T_{MAX}$ is the lifespan of the organism.

This is the method used by Amaratunga and Rowell (1986) for the initial estimate of M 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:

$$Z = (K(L_\infty - L_m))/(L_m - L') \qquad (9)$$

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 $L_\infty$ 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.

$$N_t = N_0 * e^{-Zt} \qquad (10)$$

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:

$$Z = \ln\left(\frac{1+\bar{a}-1/n}{\bar{a}}\right) \tag{11}$$

where *ā* 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 length frequency curve. The selectivity curve was used as the basis for this decision.

For the methods that require age frequencies (catch curve and C-R), the survey age frequency for Grand Bank was estimated from the length frequency data with separate age-length keys for each survey, constructed from the aged sample (approximately 150 surfclams from each 5 mm interval). This was to make sure the length-age key covered the full size range. The age-length keys were used to convert the survey length frequencies into age frequencies (Figure 8). The resulting population age frequency was used for the catch curve estimate of Z. The resulting Z was compared with that used in the Banquereau Arctic Surfclam stock assessment (M = 0.08, Roddick et al. 2007).

## 2.13 – 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:

$$N_{RA} = \frac{N_A}{e^{-Z(A-RA)}} \tag{12}$$

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 up to the maximum age well represented in the age frequency distribution. This provides an estimate of recruitment variability through time.

The assumption of constant mortality can be reduced, when a long time period is used, to that of assuming no trend in mortality. In other words, mortality can vary randomly during the time period, but should not have a continuously increasing or decreasing trend.

## 2.14 – 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, MSY was used by Chaisson and Rowell (1985) to estimate yield for Arctic Surfclams on Banquereau, but has fallen out of favor as stocks have collapsed when their fisheries were managed at 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, but some stocks have declined using these as well. 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 often set in the range of 0.2 - 0.3 for fisheries that will have little or no monitoring, 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 parameter $x$ set at 0.33, the higher level was recommended as all Canadian fisheries have some level of monitoring. This makes it equivalent to 2/3 MSY, when MSY is calculated as $0.5MB_0$. The 2007 Banquereau Assessment meeting recommended that with the lack of a time series of data, uncertainties with recruitment levels, and concerns over habitat impacts, that a TAC corresponding to the MCY level was appropriate for Arctic Surfclams on Banquereau. MCY for Grand Bank Arctic Surfclams was estimated using the methods outlined above.

### 2.15 – SENSITIVITY TO EXPLOITATION

There are life history parameters that can be compared with the selectivity pattern of commercial gear to gain insight to the population's sensitivity to exploitation. The most common is comparing the size or age at maturity to the commercial retention size. If the fishery is removing individuals from the population before they have a chance to reproduce than recruitment overfishing will be a concern, i.e. fishing effort is more likely to reduce the spawning stock biomass and thus reduce the level of recruitment to the fishery. Comparing the retention size to the size at maximum biomass per recruit indicates if the fishery is removing individuals from the population at a small size, before they have a chance to grow and thus increase individual yield. In this case growth overfishing will be a concern. Curves for maturity and biomass per recruit were fit to the data, and the age at the 50% values for the curves were compared to that for the selectivity curve for the commercial gear.

## 3.0 – RESULTS

### 3.1 – SENSOR DATA

Seven hundred and twenty-two (722) survey tows were completed over the 3 surveys. This amounts to one station per 65.6 $km^2$. The dredge sensor data was used to examine tow distance for the 2009 survey. Figure 9 shows the sensor data for a typical tow. The ambient pressure goes up as the dredge goes to the bottom, and the pitch drops as the dredge slides off the ramp and settles on the bottom. The dredge sits on the bottom as the cable pays out, and then there is a jump in the pitch and accelerometer readings, as the strain comes onto the towing hawser. The horizontal line shows the pitch angle below which the dredge is presumed to be fishing. At the end of the tow the pitch angle increases as the vessel speeds up and the dredge is hauled back. The raw tow distance is taken as the vessel distance from when the dredge starts moving to when the pitch angle indicates it is no longer fishing as it is hauled back. For the corrected tow distance, periods when the pitch exceeds the cut off angle due to wave action or other factor are subtracted from the raw tow distance. In deeper water, the period with the dredge sitting on the bottom at the start of the tow decreases, until it is absent from the deepest tows. Since we only had sensor data for the 2009 survey and a few of the 2008 tows, corrections from these tows were applied to the tow distances without sensor data. Where the tow distance was calculated using the navigation track data, the median correction from the sensor tows was used. There was a significant effect of depth on the correction factor (Figure 10, $p < 0.001$). There was also a significant depth effect where there was no navigation track data and tow distance was calculated from start and end positions ($p < 0.001$, Figure 11), and this was used to adjust the tow distance for survey tows where there was only end point distance available.

### 3.2 – SELECTIVITY CURVES

The selectivity curves for the new and old dredge designs are shown in Figure 12, along with that for a commercial dredge. The new dredge retains smaller clams than the old dredge due to the lack of a codend. We can bring the catches from the two dredges to the same standard by adjusting the 2009 dredge catches to the selectivity curve for the old dredge. This was done by taking the length frequency data for each tow and the length-weight regression from the laboratory samples for each tow, calculating the numbers for each 1 mm size increment, adjusting it for the difference in selectivity at that length, converting to weight and summing over all lengths for the tow:

$$\text{Adjusted weight} = \left(\sum_{L=L_{Min}}^{L_{Max}} \frac{S_{LO}}{S_{LN}} \times N_L \times W_L\right) / \left(\sum_{L=L_{Min}}^{L_{Max}} N_L \times W_L\right) \times \text{Catch Weight} \qquad (13)$$

Where $S_{LO}$ and $S_{LN}$ are the selectivity at length for the old and new dredge, $N_L$ is the numbers at length and $W_L$ is the weight at length. Since the laboratory weights have been frozen and thawed, the percentage difference was applied to the catch weight per tow which was a fresh weight.

### 3.3 – PAIRED COMPARISON TOWS

During the 2009 survey, 20 tows from the 2006 and 2008 surveys were repeated, trying to follow the previous tow tracks. The full dredge tracks for the 2008 tows were available, and for the 2006 tows the start and end points were used. The surfclam catch for both the unadjusted and selectivity adjusted 2009 tows were compared with those made in 2006 and 2008 with the old dredge design. Figure 13 shows boxplots of the catches and Figure 14 the distribution of catches from the original 2006 and 2008 tows and for the 2009 comparison tows before and after adjustment for selectivity differences. Since the catches have a skewed distribution with mainly smaller catches and a few large catches, a two-sample Wilcoxon (or Mann-Whitney) test was used. This test only assumes a common continuous distribution under the null hypothesis. There were no significant differences between the 2006/08 and 2009 tows ($p = 0.5958$) or between the 2006/08 and selectivity adjusted 2009 tows ($p = 0.2162$). Emperical Cummulative Distribution Functions (CDF) for the three sets of catches are shown in Figure 15. A Kolmogorov-Smirnov test of differences between the pairs of CDFs did not show significant differences between the 2006/08 catches and the 2009 ($p= 0.8186$) or selectivity adjusted 2009 catches ($p = 0.3291$), although the p values are not exact due to the presence of ties in the data.

Although the differences were not significant with the analysis used, and there was no consistency in one set of the pairs being higher than the other, there is an obvious tendency for the 2009 catches to have less pronounced high outliers, and a slightly lower average. The procedure of trying to closely follow the old tracks may have confounded the results. The clam dredge is typically a very efficient gear, and the clams are sedentary, so there is the possibility the 2009 tows went over areas depleted by the previous tow. Although some re-distribution and growth was likely to have taken place between surveys, some effects of the first tow may still have been evident even after 1-3 years. There are other factors that could have produced differences over this time period, but with the slow growth rate it is unlikely that large population changes are the cause. Although more powerful statistical methods may find significant differences, the use of any correction factor would be questionable. Although there was no correlation between the 2006/08 and the 2009 estimates, the 2009 estimates tend to be lower. Thus, any error due to not correcting the 2009 estimates would be conservative. The 2009 catches were used without an additional correction for differences between dredge designs.

### 3.4 – BIOMASS ESTIMATES

Stations that showed as cobble and rocks according to the SeaScan system were periodically towed to ensure the SeaScan system was correctly interpreting the bottom type. These tows consistently filled the dredge with cobbles and rocks. 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 16 shows the relationship between the catch of rock and clams in the tows. High amounts of rock indicate the substrate is unsuitable for clams. In this respect, even 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.

The results of the simple statistical and ACON biomass estimates are shown in Table 3. The ACON package does not contour beyond the station boundaries. Since the station boundary was inside the survey boundry at some points, the area used is slightly less than that defined by the survey area (Figure 17 and Table 3). The catch rate is shown in Figure 17, contoured with the ACON package. For ease of interpretation the catch per standard tow was converted to $t/k^2$ for this map and the data table in the upper left corner.

### 3.5 – LENGTH FREQUENCIES

The total length frequency for the survey catch was estimated by prorating the length frequencies using the standardized 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 18. Previous surveys (Roddick et al 2007) had shown an artifact in the length frequencies with a higher 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 manual measuring board, there was an obvious bias in recording the last digit as a 0 or 5. An electronic measuring board has been developed and was used in the 2009 survey. This has eliminated this bias and also eliminated recording and transcription errors in the length frequency data. This effect was still present in the 2006 and 2008 data, and so the length frequencies were binned into 5 mm increments for analysis.

### 3.6 – BY-CATCH

The distribution of large clam species is shown in Figure 19. The southwest portion of the survey area was dominated by Ocean Quahogs, while Greenland Cockles were found along the eastern edge of the bank mixed with the surfclams and propellerclams. The surfclams and propellerclams were found along the eastern edge in the southern half of the survey area, but were more central in the northern half.

Over the three years of the Grand Bank survey 56.9 t of catch was processed for composition. When all material, including such things as shells, sand and rocks are included, Arctic Surfclams made up 4.24% of the catch by weight, with shell, shell and sand, rocks, sand dollars, Ocean Quahogs, and Northern Propellerclams, bringing it up to 87% by weight. This compares to the breakdown for tows with a catch of Arctic Surfclams of at least 100 g/m2, representing commercially viable areas, where Arctic Surfclams make up about 14% of the catch weight, second only to shell. Considering only living material for these tows (Table 4), surfclams made up 37% of the catch, followed by sand dollars at 27%, propellerclams at 18%, Greenland Cockles 10%, and sea cucumbers at 3%. All other taxa identified from the by-catch represented less than 1% of the total catch. The five most abundant groups together accounted for 95% of the catch of living organisms from the areas likely to be fished.

The high catch of sand dollars for Grand Bank is consistent with Nesis (1965) who found sand dollar densities up to 1.2 kg/m$^2$ for this area using grab samples.

At present, there are two sources of data on catch composition from the commercial fishery. The International Observer Program (IOP) occasionally has observers on commercial clam vessels, and there is a program of on-board sampling on the commercial clam vessels that uses crew members to sample the catch.

Through the IOP, observers were on-board for 3 trips on Grand Bank in 1995, 1 in 1996, 2 in 1997, and 1 in 2007. During these trips they recorded catch composition. They were requested to obtain the best estimate possible, but the method used, i.e. sub-sampling, visual observation etc., is not documented. (Joe Firth, DFO Nfld., pers. comm.). The catch composition for the commercial fishery from this data is shown in Table 5. The list does not include items like shell and rock. The proportion of Arctic Surfclams ranges from 20% to 94% of the catch. The low catch of surfclams in 2007 comes from a trip in which Greenland Cockles were the targeted species, and made up 76% of the catch. The higher percentage of surfclams in the IOP data may indicate that the fishery targeted areas with a higher catch of surfclams than the 100 g/m$^2$ used to delimit commercial grounds for the survey data, or that the commercial dredges retain less by-catch than the survey dredges. There also may have been a bias in the sampling. The list of species encountered in the IOP data was much shorter than that from the surveys, and contained more large, easily noticed organisms. For example, skates and finfish were more common than in the survey data while there were no small species such as worms, hydrozoans, etc. The difference in number of species recorded was probably reflective of both a smaller sample size and a bias for larger species, while the higher proportion of clams was likely a function of the areas targeted and gear used.

The on-board sampling was carried out by crew members. They were not trained observers, but were often the quality control staff and so had some science background. They were given some training and reference material to help in their sampling, but the sampling was in addition to their regular duties on the vessel. They periodically would take samples from the hopper on the vessels and sort them for catch composition. This data shows a smaller percentage of clams than the Observer data (Table 6). When Arctic Surfclams and Greenland Cockles are combined, the IOP data showed 90-95% of the catch by weight, while the on-board sampling showed 46% (54% when shell and rock were excluded), similar to the survey data for potential commercial areas at 48%. The species list was short, and did not contain any finfish, but the sample size was much smaller than the other sampling programs.

There were non-identified skate in the IOP list, and there were two unidentified skate in the 2006 survey data. Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has classified the Winter Skate (*Leucoraja ocellata)* population on George's Bank, Western Scotian Shelf, and Bay of Fundy as Special Concern; the population on the Eastern Scotian Shelf as Threatened; and the Southern Gulf of St. Lawrence as Endangered. The Northern Gulf-Newfoundland population was considered in 2005, but was classed as data deficient. Thorny Skate *(Amblyraja radiata*) are currently not listed, but are on the list for consideration by COSWIC. Currently, with the Grand Bank Winter and Thorny skates not listed, the skate by-catch is not an issue for the Grand Bank Surfclam fishery. If these species are listed, the skate by-catch is very low, but might become an issue.

### 3.7 – AGEING

The ageing results are shown in Figure 8. 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.

### 3.8 – SIZE AND AGE AT SEXUAL MATURITY

A total of 248 surfclams ranging in size from 17 to 118 mm were processed for maturity and sex, and 244 of these were aged, ranging in age from 3 to 55 years (Table 7). The resulting maturity data were fit with a Richards Curve using maximum likelihood. Figures 20 and 21 show curves fit to the size and age at maturity, respectively. The size at 50% maturity was 39.9 mm shell length, well below the 87.4 mm 50% retention size of a commercial dredge, meaning that the clams should have plenty of opportunities to spawn before entering the fishery. The age of 50% maturity was 5.3 years old. These values are smaller and younger than that of the Banquereau population, which were 47.2 mm and 6.7 years, respectively. (If the 50% age of maturity is 5.3 years it would be interesting to know what the 50% age at dredge retention was. This would allow us to replace 'plenty' with an actual average number of spawnings between maturity and capture.)

### 3.9 – MORTALITY

The simplest mortality estimate examined was that used by Amaratunga and Rowell (1986): $Z = 3/T_{max}$, 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 8) this is 49 years of age, and so 3/49 produces an estimate of Z = 0.06. This is lower than Amaratunga and Rowell's (1986) initial estimate for Banquereau (0.075). There was also no fishery at that time, and Z was considered to be equal to the natural mortality rate (M). The commercial fishery on Grand Bank has been concentrated in a small area and landings small in comparison to the biomass, thus M would be smaller than this estimate of Z, but the reduction would be slight.

Beverton and Holt's method (Equation 9) uses the length frequencies, and incorporates the growth curve parameters $L_\infty$ 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 12) shows that the size at 95% selectivity is 86 mm. This presents a problem in Equation 9, as the growth curve weighted by the population size frequency data (Figure 8) has an $L_\infty$ of 98 mm, while the mean size of clams above 86 mm is 97 mm. The Beverton and Holt equation does not work when the fully selected size approaches $L_\infty$.

For the catch curve analysis, the log of the age distribution is used. 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 12) and a wide spread of size at age (Figure 8), too high a cut off would leave few age classes in the analysis. Using the selectivity curves and the size at age distribution, a minimum age cut off of 30 years old was chosen for the 2006 and 2008 surveys, and 25 years for the 2009 survey. Since the survey took place over several years, each year was done separately to avoid errors introduced by trying to convert the data to a common year. Upper age limits were set as the first age group with no clams. Figure 22 shows the estimated age frequency distributions, along with a regression of the log of numbers at age versus age.

The slope of this regression gives an estimate of Z. The ages used to estimate Z are marked as filled dots. The separate Z estimates are 0.063, 0.087 and 0.148 for the three surveys, with an average weighted by the number of tows of Z = 0.100.

The Chapman and Robson mortality estimate in Equation 11 (Chapman and Robson 1960), again using 30 and 25 as the recruitment ages and running each year separately, gives estimates of Z = 0.079, 0.091 and 0.097 for 2006, 2008 and 2009, respectively, with a weighted average estimate of Z = 0.091 (Table 7). Mortality estimates are thus in the range of 0.06 to 0.10. Total mortality (Z) is made up of both natural mortality (M) and fishing mortality (F). Based on the survey biomass estimate, the present TAC of 20,000 t would produce an estimated fishing mortality rate of 0.0175. The fishery has not reached the TAC, and for 1989 to 2009 has landed an average of 6,515 t, which gives an F of 0.006. In light of these estimates of Z and F, the current estimate of M = 0.08 for the natural mortality rate appears to be reasonable.

### 3.10 – RECRUITMENT ESTIMATES

Using Equation 12 and converting the numbers at age shown for the catch curves in Figure 22 back to a common age for all three surveys (Age 25), gives the Age 25 recruitment patterns shown in Figure 23. Since the survey was done in 3 different years, the length-age key used to produce the numbers at age had to be done separately for each year. This meant that for any one age-length key there were approximately 50 clams aged per 5 mm increment. With the large range of age classes for lengths approaching $L_\infty$, this was not a large aged sample for this type of analysis. It did; however, provide our best information on past recruitment patterns.

The recruitment pattern differed for the three surveys, indicating either problems due to the number of clams aged (2,436 total), or real differences in recruitment by area over the bank. Since most bivalves recruit in “patches” of good settlement the latter would not be unexpected. Recruitment also appeared to vary greatly through time within each area, although it is likely that a larger aged sample would have smoothed out some of the peaks and valleys in the distribution. Taking the average recruits at Age 25 from each survey and weighting it by the number of tows for each survey, gives an overall average of 1,591 clams Age 25 per year. Since these numbers are based on those actually caught in the survey tows, it needs to be expanded to the survey area. Expanding to the survey area gives an estimate of average recruitment to Grand Bank of 208.7 million clams at Age 25 per year. This is a large number of recruits, but with the survey area so large it amounts to an average of just one recruit per 227$m^2$ over the whole survey area.

### 3.11 – DREDGE EFFICIENCY

Figure 25 shows the dredge tracks for the depletion study. Tows 1 to 3 are the initial set-up tows used to estimate initial density, then a series of overlapping tows are done. The model discounts the tow area for the number of cells that have been previously dredged to get an “effective area dredged”. In previous depletion experiments there was some confounding of the results due to the effect of dredge selectivity. If the area contains a large amount of partially selected clams, then a larger proportion of these clams should be caught by subsequent tows, reducing the estimated efficiency. Only those sizes with a high selectivity should be used to calculate the catch for the analysis. For the 2009 study, length frequencies were taken for each tow so the catch weight could be calculated based on the sizes of the clams caught. The size distribution in relation to the selectivity of the survey gear is shown in Figure 26. The majority of the clams were only partially selected by the gear, with only the right tail of the distribution larger than the size for 90% retention. The fit of the likelihood model using estimated catches of clams larger than the 90% retention size is shown in Figure 27. Runs were done using catches based on a range of sizes, but when residual plots of observed – predicted catches were examined they all had a negative slope (Figure 28). This indicated that the model was predicting a greater decline with subsequent tows than was observed, and thus underestimating dredge efficiency. Since the reduction in catch between the middle six tows and the last six was less than the drop between the first and middle six, runs were done using only tows 1 to 12. The initial depletion was most pronounced in these tows, while still including tows where there was overlap with previous tows. In these cases the efficiency estimate was consistently at the upper boundary limit. Even with an estimated efficiency of 1 the residual plot for observed – predicted catches had a negative slope. Since this could not be an underestimate it indicates the model was not working for this data set.

Work is ongoing on the dredge efficiency estimates, but in the meantime the conservative approach would be to assume an efficiency estimate of 1.

### 3.12 – INDIVIDUAL YIELD ESTIMATES

Individual lifetime yield was calculated with natural mortality as 0.08, the growth curve from Figure 8, and the commercial gear selectivity. Shell lengths were converted to weights with the weight-length regression shown in Figure 24. The individual yield for Grand Bank was much lower than that for the same species on Banquereau. The maximum yield for Grand Bank was 7.5 g while on Banquereau it was estimated as 16.5 g (Roddick et al., 2007). Since the same mortality rate was used, the difference in the two estimates was due to the lower growth rate and maximum size achieved on Grand Bank.

### 3.13 – SENSITIVITY TO EXPLOITATION

The commercial gear selectivity pattern from Figure 12 was converted to an age based curve using the growth curve in Figure 8. This was compared to the maturity at age and biomass per recruit curves to look at the sensitivity to growth and recruitment overfishing. The estimated age at 50% selectivity is 22.9 years, well above the 5.3 years for age at 50% maturity. This means that individuals should have over 17 years of spawning before they enter the fishery. Although there are no studies on the relative fecundity of young versus older surfclams, this should help ensure that recruitment overfishing does not occur. The age at 50% selectivity is also above the age of maximum biomass per recruit, making the fishery resistant to growth overfishing.

### 3.14 – BIOMASS DISTRIBUTION

The biomass estimate for Grand Bank is 78% of that estimated for Banquereau (Roddick et al., 2007), but this is for a survey area 4.8 times as large. A large part of the survey biomass for Grand Bank comes from a large area with a low density of clams. This is good for the clam population, as it means there is a large part of the population that will likely not be fished; but it means effort will be concentrated on higher density areas. We can compare the survey densities with those of the areas that have been fished.

The Catch Per Unit Effort (CPUE) for Banquereau and Grand Bank are shown in Figure 29. The CPUE shown is per vessel-trip, with trips being approximately one month long. CPUE has risen recently on Banquereau as a large recruitment pulse has entered the fishery. Taking the 1993 to 2006 period to avoid the recent increase, the average CPUE for Banquereau was 0.111 kg/m$^2$ fished (Std. Dev = 0.041, n = 222). CPUE for Grand Bank for 1993-2010 has been lower than Banquereau at 0.096 kg/m$^2$ (Std. Dev. 0.040, n = 172). Figure 30 shows the biomass distribution from the Grand Bank survey with the top three contour levels set to 0.075, 0.100, and 0.120 $kg/m^2$. The table in the upper left of the figure shows the biomass and area within these contour levels. Areas with a density less than 0.075 $kg/m^2$ contain 51% of the total biomass. If a fishery needs higher densities there is only 37% of the total biomass in areas with a density at least 0.10 $kg/m^2$, and 30% in areas with a density of 0.12 or more. At 0.10 $kg/m^2$ the fishery would concentrate on an area that is only 8% of the total survey area. With a long lived, sedentary species such as the Arctic Surfclam, once an area is fished down it will take a long time to recover.

## 4.0 – ECOSYSTEM AND HABITAT

DFO is committed to an ecosystem approach to fisheries management. The Department also has responsibilities and mandates that include fish habitat, species at risk, biodiversity conservation, and oceans planning and management.

The offshore clam fishery uses bottom contact gear that disturbs the seabed. As such it cannot help but have a large immediate impact on the substrate and benthic organisms as the dredges liquefy the sediment down to at least 8 inches (20 cm), remove many large organisms and cause sedimentation adjacent to the track. The question then becomes: what are the long term impacts on the habitat and benthic community of the fished areas? On Banquereau, the impacts are being studied at a site at 70 m depth. This is considered one of the most rigorous fishing gear impact studies done to date, and the site has been followed for 10 years (Gilkenson et al. 2003, Gilkenson et al. 2005), although the results for ten years post dredging are not available yet. The largest species impact is of course the removal of the large clams from the area, both from harvesting and from incidental mortality. Given the sedentary nature of clams and their slow growth rate, this is a long term impact. Furthermore, with an ongoing fishery, the population structure of the target species would not be expected to return to an unfished state. The experiment demonstrated immediate impacts on both habitat and non-target organisms within the first two years following dredging. In this timeframe, there was considerable recovery of the composition of non-target benthic species, such as echinoderms, with a shift in relative abundance of the species present. Visual methods such as still photos and video recordings could not discern the tracks after one year. The species composition in the dredged sites appeared to be dominated by colonizing species three years after dredging. Definite conclusions were complicated by similar changes in the reference sites, indicating an effect that extends well beyond the actual disturbed area, a large scale variation unrelated to the dredging, or a combination of both (Gilkenson et al. 2005).

There has been little recruitment of large bivalve species to the experimental study site over the 10 years, and sidescan sonar was still able to detect some of the tracks 10 years after dredging. The sidescan results infer that changes to the sediment structure caused by dredging can persist for 10 years or longer. It is noted that during the Sable Island Bank survey in 2003, out of 26 sampling sites that were surveyed with sidescan sonar 1 year later, only 6 deep sites still showed evidence of dredge tracks. This suggests water depth has a possible influence on track persistence, shallower areas having sediments that are more actively worked by waves and currents. Hydraulic clam dredge fisheries occur on fairly mobile, well-sorted sand, which may help mitigate the overall impact on some elements of the benthic community.

The long term impacts on overall benthic productivity are still unknown; the samples from the dredge impact study from ten years after dredging have not been analyzed, but may help to draw more definite conclusions.

Although clam dredges have a large immediate impact on the bottom, the impact of the fishery is usually ranked lower than other bottom contact gear, due largely to its current small footprint. The footprint of the fishery can be estimated using the “area swept” ($km^2$). With only 2 vessels currently active in the offshore clam fishery, the area impacted is relatively small compared to other fisheries, and the spatial extent of the target species. Since the Grand Bank surfclam fishery began in 1989, 1,132 $km^2$ have been swept, with most of this activity in the 1990-1998 period (Figure 3). This area swept is not corrected for overlap of tows, and still is only 2% of the area surveyed. There is considerable spatial and temporal variation of area swept over the timeframe of the fishery, with areas of high clam biomass fished more frequently and intensely than other sections, and periods when the fishery concentrated on Banquereau instead of Grand Bank. The average annual area swept during the last 5 years of the fishery (2005-2009) is approximately 26 km2, with low effort in that period.

## 5.0 – DISCUSSION

The Grand Bank Arctic Surfclam survey was complicated by vessel and gear changes, and being split into three parts spread over four years. As most of the changes were not planned for, there was no opportunity to do comparative work before they took place. Although there were some repeated stations, the sample size was small and the tows took place one to three years apart, confounding gear differences with other changes.

There have also been improvements with some of these changes, the present stern mounted ramp system makes deploying and retrieving the dredge fast, smooth and safe. The smoother action has also allowed the dredge sensor system to be used successfully, increasing the accuracy of the estimation of tow distance.

There are still questions about the efficiency of the dredge. Adjusting the sizes and/or tows used for the efficiency calculation did not solve the problems with the Grand Bank efficiency study. The original intent was to conduct dredge efficiency experiments during each survey and thus building a data set that could be used to look at the effects of factors such as depth and sediment type. The changes in vessels and gear that have taken place over time prevent this approach. Since the vessel presently being used is an older vessel, it may be more useful to do a dedicated study of dredge efficiency, doing a number of trials over different depths and areas at one time. The results from this study could then be used until there were changes in the survey vessel or gear. The approach used for this analysis is to assume a dredge efficiency of 1. Since the actual efficiency must be less than this it is a conservative approach.

The life history of these species has implications for management. Arctic Surfclams are long lived and slow growing. The productivity of slow growing species is low, so sustainable TACs must be a small fraction of the biomass. If overfishing occurs, it will take a long time before the stock recovers.

The Offshore Clam Framework (DFO 2007a) recommended a constant F approach. A Science Expert Opinion Clarification (DFO 2007b) stated that as F approaches $0.5MB_{RV}$, increased stock risk could be expected, and that the Banquereau Surfclam assessment adopted $F_{MCY} = 0.33\ MB_{RV}$ as an appropriate F. This was considered a relatively risk-neutral point given the survey frequency and biological characteristics of the stock. An F target has not been selected for Grand Bank. Selection of a target F will depend on a range of factors, including the different growth and maturity rates for Grand Bank in comparison to Banquereau, the patchiness and variable density of clam beds, benthic impact, and by-catch issues.

*Example fishing mortality targets and yields for Grand Bank.*

| Harvest Strategy | F | (t) | Comment |
|---|---|---|---|
| $F_{MCY}$ | 0.026 | 30,114 | $0.33MB_{RV}$ |
| F current | 0.018 | 20,000 | Equivalent to the current TAC of 20,000 t. |

In addition to the target fishing mortality there should be thresholds, reference levels of F and/or biomass that indicate the stock is approaching an overfished state, and that trigger management actions to reduce the fishing mortality.

## 6.0 – CONCLUSIONS

The research survey biomass estimate for Banquereau Surfclams is 1,140,682 t. Current size at 50% selectivity is larger than size at maturity and 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. The population has not been heavily impacted by the fishery to date, and is probably still near the virgin biomass level. A large portion of the biomass is made up from a large area with a low surfclam density. A fishery based on the TAC calculated from the total biomass would be concentrated on the high biomass areas. The slow growth rate and sedentary nature of Arctic Surfclams means that areas that have been fished down will take a long time to recover.

There are concerns over the long term impacts of the gear used in this fishery. The results from the ten year sampling of the dredge impact study on Banquereau should help answer some of the questions on long term impacts.

With the movement towards an ecosystem approach, these are some of the considerations that Fisheries Management has to take into account when deciding on a target fishing mortality and TAC for Arctic Surfclams on Grand Bank.

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## 8.0 – TABLES

*Table 1. Landings for the Arctic Surfclam fishery in Atlantic Canada.*

| | Landings (mt) | | | |
|---|---|---|---|---|
| **Year** | **3LNO** | **Banquereau** | **Scotian Shelf** | **Total** |
| | | | | |
| 1987 | 0 | 717 | 1 | 718 |
| 1988 | 0 | 1,824 | 0 | 1,824 |
| 1989 | 402 | 7,666 | 0 | 8,068 |
| 1990 | 8,027 | 4,765 | 0 | 12,792 |
| 1991 | 6,753 | 746 | 0 | 7,500 |
| 1992 | 11,154 | 0 | 0 | 11,154 |
| 1993 | 18,905 | 60 | 0 | 18,965 |
| 1994 | 15,881 | 4,590 | 0 | 20,471 |
| 1995 | 14,108 | 10,427 | 0 | 24,535 |
| 1996 | 6,458 | 18,745 | 0 | 25,203 |
| 1997 | 7,614 | 19,025 | 0 | 26,639 |
| 1998 | 963 | 24,695 | 0 | 25,658 |
| 1999 | 1,487 | 24,413 | 0 | 25,900 |
| 2000 | 3,775 | 19,989 | 0 | 23,764 |
| 2001 | 8,389 | 11,443 | 0 | 19,832 |
| 2002 | 6,901 | 12,492 | 10 | 19,403 |
| 2003 | 10,265 | 16,883 | 0 | 27,148 |
| 2004 | 6,731 | 16,686 | 0 | 23,417 |
| 2005 | 3,732 | 14,689 | 0 | 18,422 |
| 2006 | 4,927 | 14,859 | 0 | 19,786 |
| 2007 | 211 | 17,337 | 0 | 17,548 |
| 2008 | 0 | 19,336 | 0 | 19,336 |
| 2009 | 127 | 24,565 | 0 | 24,692 |

**1987 to 2005 from 2005-2009 Offshore Clam Management Plan, 2006 to 2009 from Statistics Branch Newfoundland Region.*

*Table 2. Example age comparison table for comparison of aging results between two agers.*

| **Number Both Aged = 125** | | | | | |
|---|---|---|---|---|---|
| **Age (y)** | **Count** | **% Agreement** | **CV %** | **Bias (y)** | **% Bias** |
| 7 | 3 | 100.0 | 0.0 | 0.00 | 0.0 |
| 8 | 7 | 100.0 | 0.0 | 0.00 | 0.0 |
| 9 | 4 | 75.0 | 4.4 | 0.25 | 0.3 |
| 10 | 4 | 75.0 | 3.2 | -0.25 | -0.2 |
| 11 | 10 | 60.0 | 6.9 | 0.10 | 0.1 |
| 12 | 6 | 100.0 | 0.0 | 0.00 | 0.0 |
| 13 | 4 | 100.0 | 0.0 | 0.00 | 0.0 |
| 14 | 4 | 75.0 | 2.7 | 0.25 | 0.1 |
| 15 | 2 | 100.0 | 0.0 | 0.00 | 0.0 |
| 16 | 3 | 100.0 | 0.0 | 0.00 | 0.0 |
| 17 | 2 | 100.0 | 0.0 | 0.00 | 0.0 |
| 18 | 3 | 66.7 | 2.8 | 0.33 | 0.1 |
| 21 | 2 | 100.0 | 0.0 | 0.00 | 0.0 |
| 23 | 4 | 75.0 | 1.6 | 0.25 | 0.0 |
| 24 | 4 | 100.0 | 0.0 | 0.00 | 0.0 |
| 25 | 8 | 75.0 | 1.4 | 0.00 | 0.0 |
| 26 | 2 | 100.0 | 0.0 | 0.00 | 0.0 |
| 27 | 7 | 100.0 | 0.0 | 0.00 | 0.0 |
| 28 | 3 | 100.0 | 0.0 | 0.00 | 0.0 |
| 29 | 5 | 80.0 | 1.8 | -0.40 | -0.0 |
| 31 | 3 | 100.0 | 0.0 | 0.00 | 0.0 |
| 32 | 1 | 100.0 | 0.0 | 0.00 | 0.0 |
| 33 | 2 | 50.0 | 2.2 | 0.50 | 0.0 |
| 34 | 3 | 33.3 | 9.5 | -0.33 | -0.0 |
| 35 | 1 | 100.0 | 0.0 | 0.00 | 0.0 |
| 36 | 2 | 0.0 | 9.6 | -0.50 | -0.0 |
| 37 | 1 | 0.0 | 12.5 | 3.00 | 0.2 |
| 38 | 2 | 100.0 | 0.0 | 0.00 | 0.0 |
| 39 | 2 | 50.0 | 1.8 | -0.50 | -0.0 |
| 40 | 7 | 42.9 | 2.5 | -0.14 | -0.0 |
| 41 | 2 | 100.0 | 0.0 | 0.00 | 0.0 |
| 42 | 3 | 33.3 | 3.5 | 1.00 | 0.1 |
| 44 | 1 | 0.0 | 3.1 | -1.00 | -0.1 |
| 46 | 2 | 50.0 | 3.2 | 1.00 | 0.0 |
| 47 | 2 | 50.0 | 5.5 | -2.00 | -0.1 |
| 56 | 1 | 100.0 | 0.0 | 0.00 | 0.0 |
| 57 | 2 | 50.0 | 5.7 | -2.50 | -0.1 |
| 59 | 1 | 0.0 | 4.6 | -2.00 | -0.1 |
| Average | 76.00 | 2.23 | | | |

*Table 3. Biomass estimates from 2006 to 2009 Grand Banks Surveys.*

| Average Catch per Standard Tow (kg) | 12.04 |
|---|---|
| Simple statistical model | |
| Number of tows used in analysis | 722 |
| Total Biomass Estimate (t) | 1,140,682 |
| 95% confidence interval | ± 35,933** |
| Acon estimate = areal expansion | |
| Number of tows used in analysis | 722 |
| Area within station boundaries ($km^2$) | 47,360 |
| Total Biomass Estimate (t) | |

*** Confidence interval shown is simply that for the biomass estimate assuming the catch per tow values are correct. It does not carry forward the variance in the catch estimates and the correction factors that have been applied to the data*

*Table 4. Estimated catch composition from Grand Bank Arctic Surfclam survey tows where surfclam catch is greater than or equal 100 g/m2.*

| Common Name | Scientific Name | Weight(kg) | Percent | Cumm.% |
|---|---|---|---|---|
| Arctic surfclam | *Mactromeris polynyma* | 9,606.41 | 37.12 | 37.12 |
| Sand dollars | *Echinarachnius parma* | 6,889.62 | 26.62 | 63.73 |
| Northern propellerclam | *Cyrtodaria siliqua* | 4,687.40 | 18.11 | 81.85 |
| Greenland cockle | *Serripes groenlandicus* | 2,685.77 | 10.38 | 92.22 |
| Common sea cucumber | *Cucumaria frondosa* | 748.16 | 2.89 | 95.11 |
| Ocean quahog | *Arctica islandica* | 239.20 | 0.92 | 96.04 |
| Arctic roughmya | *Panomya norvegica* | 212.53 | 0.82 | 96.86 |
| Atlantic Lyre crab | *Hyas araneus* | 126.29 | 0.49 | 97.35 |
| Whelk - Buccinum sp. | *Buccinum* | 111.37 | 0.43 | 97.78 |
| Crenate barnacle | *Balanus crenatus* | 101.22 | 0.39 | 98.17 |
| Sand tunicate | *Molgula arenata* | 91.99 | 0.36 | 98.52 |
| Sea urchin | *Strongylocentrotus droebachiensis* | 50.97 | 0.20 | 98.72 |
| Slender armed sea star | *Leptasterias tenera* | 49.70 | 0.19 | 98.91 |
| Sea mouse | *Aphrodita hastata* | 26.63 | 0.10 | 99.01 |
| Arctic Lyre crab | *Hyas coarctatus* | 22.13 | 0.09 | 99.1 |
| Iceland scallop | *Chlamys islandica* | 21.30 | 0.08 | 99.18 |
| Truncate soft shell clam | *Mya truncata* | 21.04 | 0.08 | 99.26 |
| Sinuous whelk | *Buccinum plectrum* | 18.12 | 0.07 | 99.33 |
| Ventricose whelk | *Colus terraenovae* | 17.70 | 0.07 | 99.4 |
| Hermit crab | *Pagurus* | 16.07 | 0.06 | 99.46 |
| Snow crab | *Chionoecetes opilio* | 15.46 | 0.06 | 99.52 |
| American sand lance | *Ammodytes americanus* | 14.41 | 0.06 | 99.58 |
| Common seastar | *Asterias rubens* | 14.01 | 0.05 | 99.63 |
| Winter flounder | *Pseudopleuronectes americanus* | 11.71 | 0.05 | 99.68 |
| Sea urchins | *Strongylocentrotus* | 11.11 | 0.04 | 99.72 |
| Whelk - Colus sp. | *Colus* | 10.85 | 0.04 | 99.76 |
| Waved whelk | *Buccinum undatum* | 10.13 | 0.04 | 99.8 |
| American plaice | *Hippoglossoides platessoides* | 9.27 | 0.04 | 99.84 |
| Thin whelk | *Buccinium totteni* | 6.83 | 0.03 | 99.86 |
| Bluish whelk | *Buccinium cyanneun* | 6.23 | 0.02 | 99.89 |
| Starfish | *Asterias* | 4.02 | 0.02 | 99.9 |
| Yellowtail flounder | *Limanda ferruginea* | 3.33 | 0.01 | 99.92 |
| Disreputable whelk | *Neptunea despecta* | 2.94 | 0.01 | 99.93 |
| Discordant mussel | *Musculus discors* | 1.81 | 0.01 | 99.94 |
| Rough razor clam | *Siliqua squama* | 1.73 | 0.01 | 99.94 |
| Rough/spiny sunstar | *Crossaster papposus* | 1.59 | 0.01 | 99.95 |
| Finger sponge | *Haliclona oculata* | 1.38 | 0.01 | 99.95 |
| Thecate hydroid | *Leptothecatae* | 1.18 | <0.01 | 99.96 |
| Catworm | *Nephtys bucera* | 1.06 | <0.01 | 99.96 |
| Sea anemone | *Actiniaria* | 0.93 | <0.01 | 99.97 |
| Iceland moonsnail | *Amauropsis islandica* | 0.92 | <0.01 | 99.97 |
| Sandbar worm | *Ophelia limacina* | 0.89 | <0.01 | 99.97 |
| Sea strawberry | *Gersemia rubiformis* | 0.83 | <0.01 | 99.98 |
| Plant | *Plantae* | 0.56 | <0.01 | 99.98 |
| Nephtyidae | *Nephtyidae* | 0.55 | <0.01 | 99.98 |
| Northern moonsnail | *Euspira heros* | 0.48 | <0.01 | 99.98 |
| Whelk | *Buccinidae* | 0.35 | <0.01 | 99.98 |
| Black mussel | *Musculus niger* | 0.34 | <0.01 | 99.99 |

| Common Name | Scientific Name | Weight(kg) | Percent | Cumm.% |
|---|---|---|---|---|
| Sponge | *Porifera* | 0.34 | <0.01 | 99.99 |
| Flatfish - unid. | *Pleuronectiformes* | 0.32 | <0.01 | 99.99 |
| Sertularia hydrozoa | *Sertularia* | 0.30 | <0.01 | 99.99 |
| Bryozoan | *Ectoprocta* | 0.26 | <0.01 | 99.99 |
| Ladder whelk | *Buccinum scalariforme* | 0.26 | <0.01 | 99.99 |
| Grammaria Hydrozoa | *Grammaria* | 0.25 | <0.01 | 99.99 |
| Athecate hydroids | *Anthoathecatae* | 0.25 | <0.01 | 99.99 |
| Purple sunstar | *Solaster endeca* | 0.24 | <0.01 | 99.99 |
| Slender sea star | *Leptasterias* | 0.22 | <0.01 | 99.99 |
| White burrowing cucumber | *Stereoderma unisemita* | 0.21 | <0.01 | 100 |
| Dahlia anemone | *Urticina felina* | 0.17 | <0.01 | 100 |
| Featherduster worm | *Sabellidae* | 0.15 | <0.01 | 100 |
| Threadworm | *Lumbrineris fragilis* | 0.14 | <0.01 | 100 |
| Blue mussel | *Mytilus edulis* | 0.14 | <0.01 | 100 |
| Snail - unid. | *Gastropoda* | 0.12 | <0.01 | 100 |
| Polychaete - unid. | *Polychaeta* | 0.10 | <0.01 | 100 |
| Wavy liocyma | *Liocyma fluctuosum* | 0.09 | <0.01 | 100 |
| Club shaped tunicate | *Pelonaia corrugata* | 0.07 | <0.01 | 100 |
| Gilded wedgeclam | *Mesodesma deauratum* | 0.05 | <0.01 | 100 |
| Hairy cockle | *Clinocardium ciliatum* | 0.04 | <0.01 | 100 |
| Opal worm | *Arabella iricolor* | 0.03 | <0.01 | 100 |
| Bambooworm | *Maldanidae* | 0.02 | <0.01 | 100 |
| Stimpsoni Whelk | *Colus stimpsoni* | 0.02 | <0.01 | 100 |
| Hydrozoan - unid. | *Hydrozoa* | 0.01 | <0.01 | 100 |
| Fan tube worm | *Myxicola* | 0.01 | <0.01 | 100 |
| Sculpin | *Icelus* | <0.01 | <0.01 | 100 |
| Daisy brittle star | *Ophiopholis aculeata* | <0.01 | <0.01 | 100 |
| Travisia carneaá | *Travisia carneaá* | <0.01 | <0.01 | 100 |
| Total | | 25,882.30 | | |

*Table 5. Observer data on species caught for Grand Bank Arctic Surfclam fishery by year.*

| Year | Common Name | Scientific Name | Weight | % Weight |
|---|---|---|---|---|
| 1995 | Arctic Surfclam | *Mactromeris polynyma* | 238,182 | 59.79 |
| 1995 | Greenland Cockle | *Serripes groenlandicus* | 118,341 | 29.70 |
| 1995 | Propellor Clam | *Cyrtodaria siliqua* | 38,127 | 9.57 |
| 1995 | Toad Crab | *Hyas araneus* | 2,473 | 0.62 |
| 1995 | Toad Crab (ns) | *Hyas sp.* | 458 | 0.11 |
| 1995 | Shrimp | *Pandalus montagui* | 308 | 0.08 |
| 1995 | Offshore Sand Lance | *Ammodytes dubius* | 201 | 0.05 |
| 1995 | SKATE (NS) | *Raja sp.* | 154 | 0.04 |
| 1995 | Sea Urchins (ns) | *Echinoidea* | 60 | 0.02 |
| 1995 | Clams (ns) | *Myidae* | 51 | 0.01 |
| 1995 | American Plaice | *Hippoglossoides platessoides* | 23 | 0.01 |
| 1995 | Hermit Crabs (ns) | *Paguridae* | 13 | <0.01 |
| 1995 | Snow or Queen Crab | *Chionoecetes opilio* | 2 | <0.01 |
| 1995 | Icelandic Scallop | *Chlamys islandica* | 1 | <0.01 |
| 1996 | Arctic Surfclam | *Mactromeris polynyma* | 932,703 | 94.92 |
| 1996 | Propellor Clam | *Cyrtodaria siliqua* | 42,204 | 4.29 |
| 1996 | Greenland Cockle | *Serripes groenlandicus* | 7,015 | 0.71 |
| 1996 | Toad Crab | *Hyas araneus* | 640 | 0.07 |
| 1996 | Offshore Sand Lance | *Ammodytes dubius* | 106 | 0.01 |
| 1997 | Arctic Surfclam | *Mactromeris polynyma* | 107,706 | 57.02 |
| 1997 | Greenland Cockle | *Serripes groenlandicus* | 73,096 | 38.69 |
| 1997 | Propellor Clam | *Cyrtodaria siliqua* | 7,162 | 3.79 |
| 1997 | Toad Crab (ns) | *Hyas sp.* | 909 | 0.48 |
| 1997 | Icelandic Scallop | *Chlamys islandica* | 24 | 0.01 |
| 1997 | SKATE (NS) | *Raja sp.* | 8 | <0.01 |
| 2007 | Greenland Cockle | *Serripes groenlandicus* | 668,600 | 76.28 |
| 2007 | Arctic Surfclam | *Mactromeris polynyma* | 175,278 | 20.00 |
| 2007 | Sand Dollars (ns) | *Clypeasteroida* | 31,267 | 3.57 |
| 2007 | Snow or Queen Crab | *Chionoecetes opilio* | 445 | 0.05 |
| 2007 | Propellor Clam | *Cyrtodaria siliqua* | 309 | 0.04 |
| 2007 | Yellowtail Flounder | *Limanda ferruginea* | 155 | 0.02 |
| 2007 | American Plaice | *Hippoglossoides platessoides* | 152 | 0.02 |
| 2007 | Thorny Skate | *Raja radiata* | 135 | 0.02 |
| 2007 | Witch Flounder | *Glyptocephalus cynoglossus* | 130 | 0.01 |
| 2007 | Toad Crab | *Hyas coarctatus* | 21 | <0.01 |

*Table 6. Catch composition from on-board sampling of commercial clam vessels from 2002 to 2009 on Grand Bank.*

| Common Name | *Scientific Name* | Weight | % | Cumm. % |
|---|---|---|---|---|
| Arctic Surfclam | *Mactromeris polynyma* | 410.06 | 24.65 | 24.65 |
| Greenland cockle | *Serripes groenlandicus* | 351.63 | 21.14 | 45.80 |
| Sand dollars | *Echinarachnius parma* | 315.61 | 18.98 | 64.77 |
| Northern Propellerclam | *Cyrtodaria siliqua* | 304.71 | 18.32 | 83.09 |
| Shell | *Shell* | 200.17 | 12.04 | 95.13 |
| Rock | *Rock* | 50.05 | 3.01 | 98.14 |
| Cancer crabs | *Cancer* | 8.90 | 0.53 | 98.67 |
| Starfish | *Asterias* | 5.72 | 0.34 | 99.02 |
| Ocean quahog | *Arctica islandica* | 4.54 | 0.27 | 99.29 |
| Whelk - Buccinum sp. | *Buccinum* | 4.07 | 0.24 | 99.53 |
| Unidentified | *Unidentified* | 1.85 | 0.11 | 99.65 |
| Whelk - Colus sp. | *Colus* | 1.56 | 0.09 | 99.74 |
| Wrinkle whelk | *Neptunea lyrata decemcostata* | 1.45 | 0.09 | 99.83 |
| Sand lance (ns) | *Ammodytes* | 1.42 | 0.09 | 99.91 |
| Sea urchin | *Strongylocentrotus droebachiensis* | 1.27 | 0.08 | 99.99 |
| Hermit crab | *Pagurus* | 0.19 | 0.01 | 100.00 |

*Table 7. Size (A) and age (B) at maturity data for Mactromeris polynyma from Grand Bank.*

A. Shell Length

| | Immature | Mature Male | Mature Female |
|---|---|---|---|
| Average | 34.78 | 58.99 | 61.96 |
| Std. Dev. | 9.48 | 17.14 | 14.35 |
| Minimum | 15.2 | 18.6 | 30.1 |
| Maximum | 58.7 | 117.6 | 113.7 |
| n | 83 | 359 | 277 |

B. Age

| | Immature | Mature Male | Mature Female |
|---|---|---|---|
| Average | 7.52 | 13.93 | 14.44 |
| Std. Dev. | 3.67 | 8.25 | 7.48 |
| Minimum | 0.0 | 0.0 | 4.0 |
| Maximum | 23.0 | 55.0 | 38.0 |
| n | 54 | 166 | 126 |

*Table 8. Chapman Robson (C-R) estimate of Z (Chapman and Robson, 1960), for survey population age frequency data.*

| Survey | 2006 | 2008 | 2009 |
|---|---|---|---|
| Start Age | 30 | 30 | 25 |
| Z estimate | 0.0789 | 0.0914 | 0.0970 |

Weighted C-R estimate of Z = 0.0910

# 9.0 FIGURES

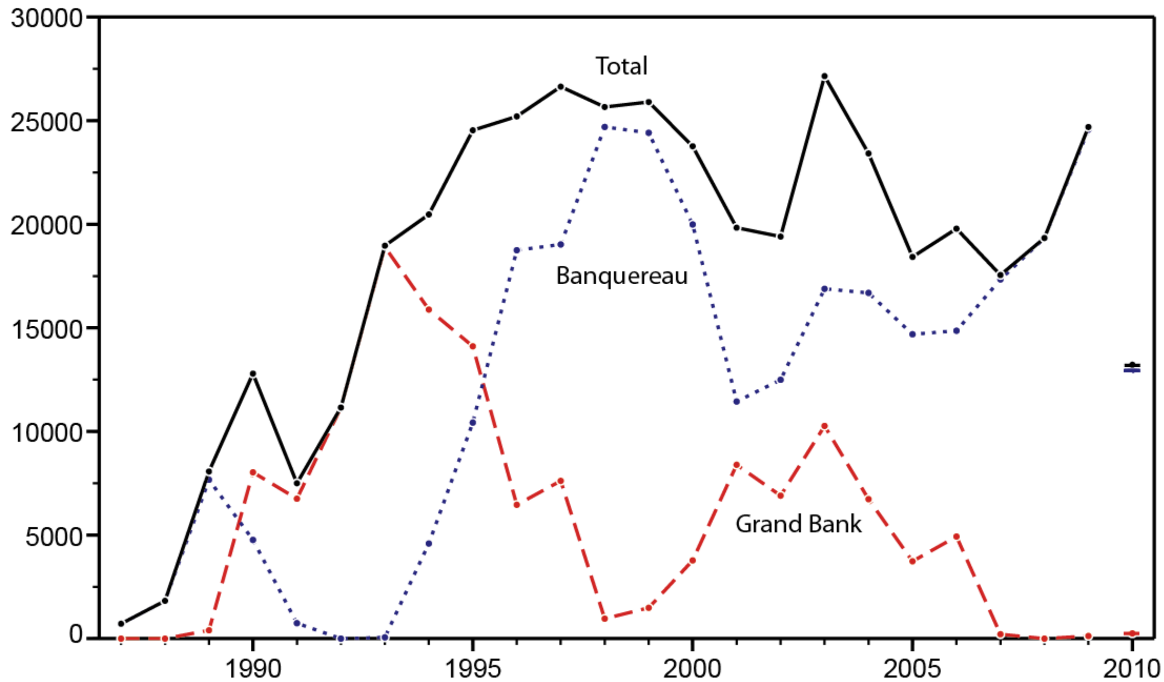


*Figure 1. Landings (t) for the Arctic Surfclam fishery on Banquereau and Grand Bank. 2010 landings to July 13, 2010, shown as short bars.*

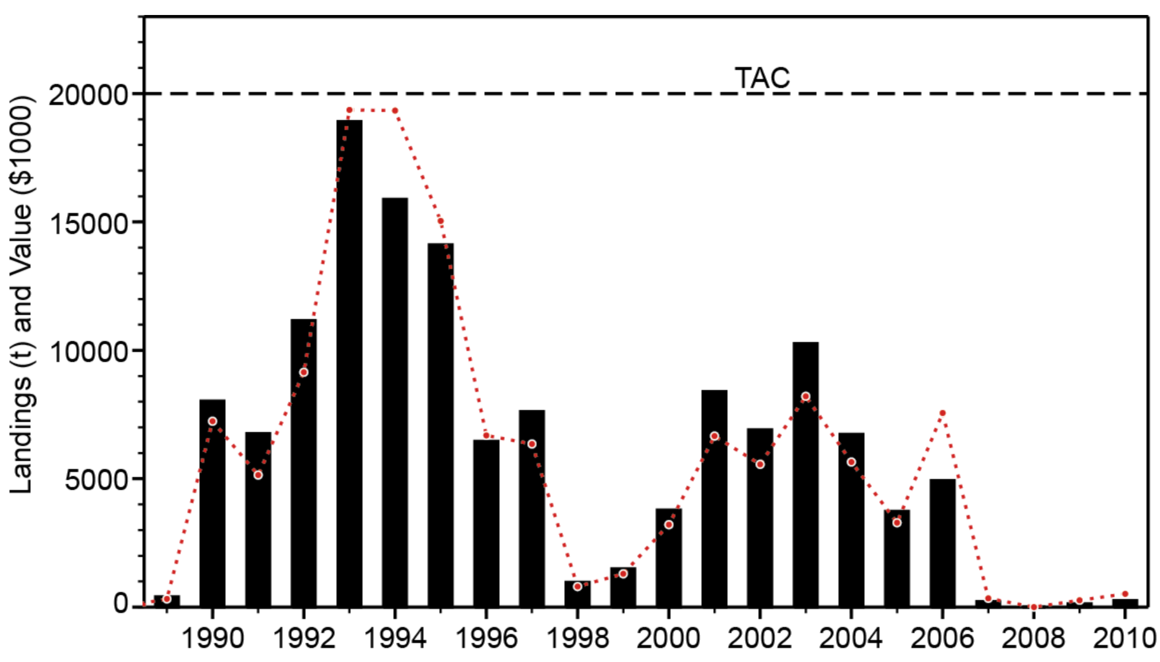


*Figure 2. Landings (bars) Total Allowable Catch (TAC) and landed value (dotted line) for the Grand Bank Arctic Surfclam fishery on Grand Bank. Values are from the 2005-2009 Offshore Clam Management plan for 1987-1984, and from Newfoundland Statistics Branch for 2005-2010. Values are total landed value prorated to Grand Bank landings. 2010 landings and value as of July 13, 2010.*

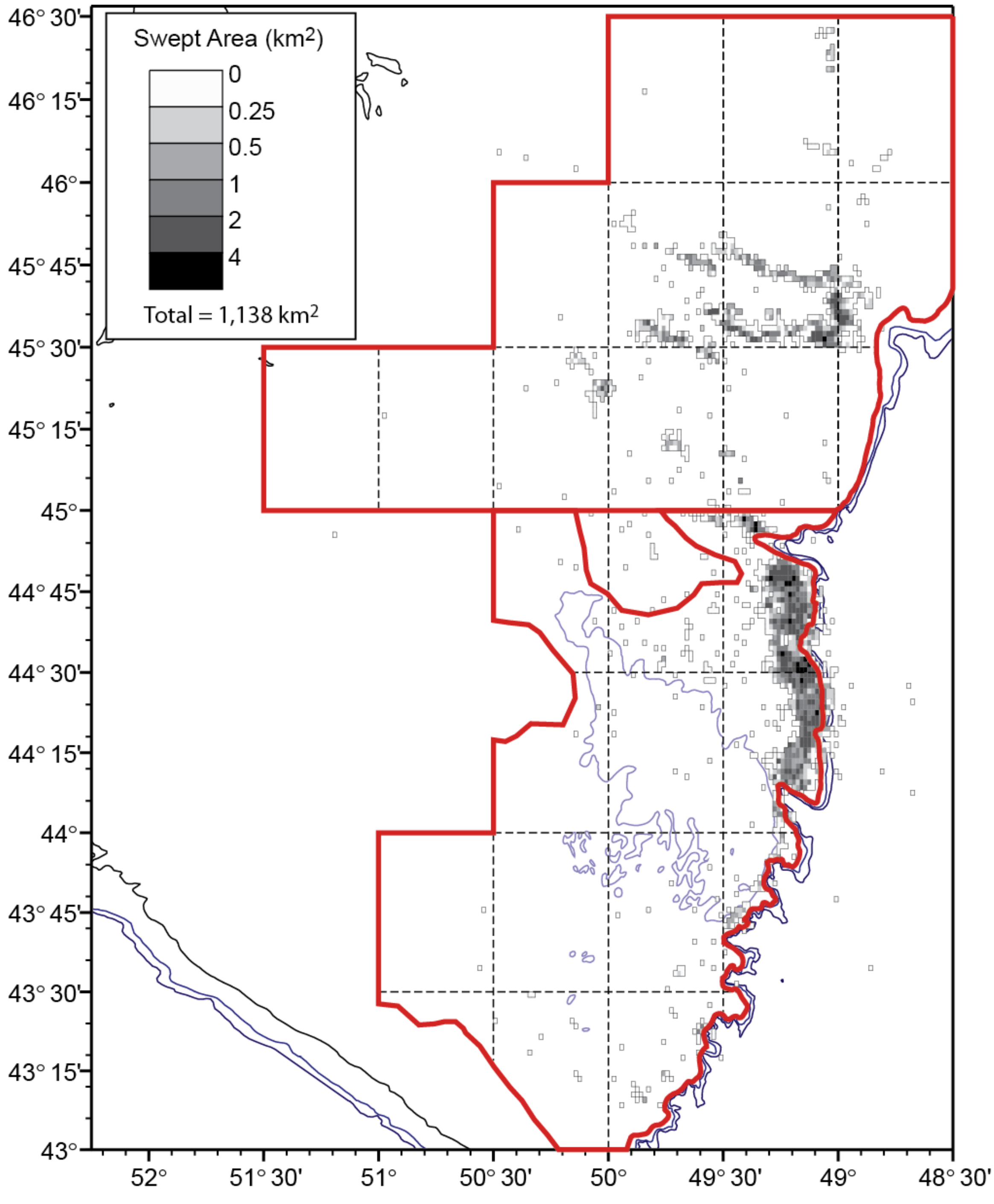


*Figure 3. Spatial distribution of effort (Area Swept in km²) for 1988 to July 2010 from log data. Total km2 swept is aggregated by one minute square, not correcting for overlap of dredge tracks.*

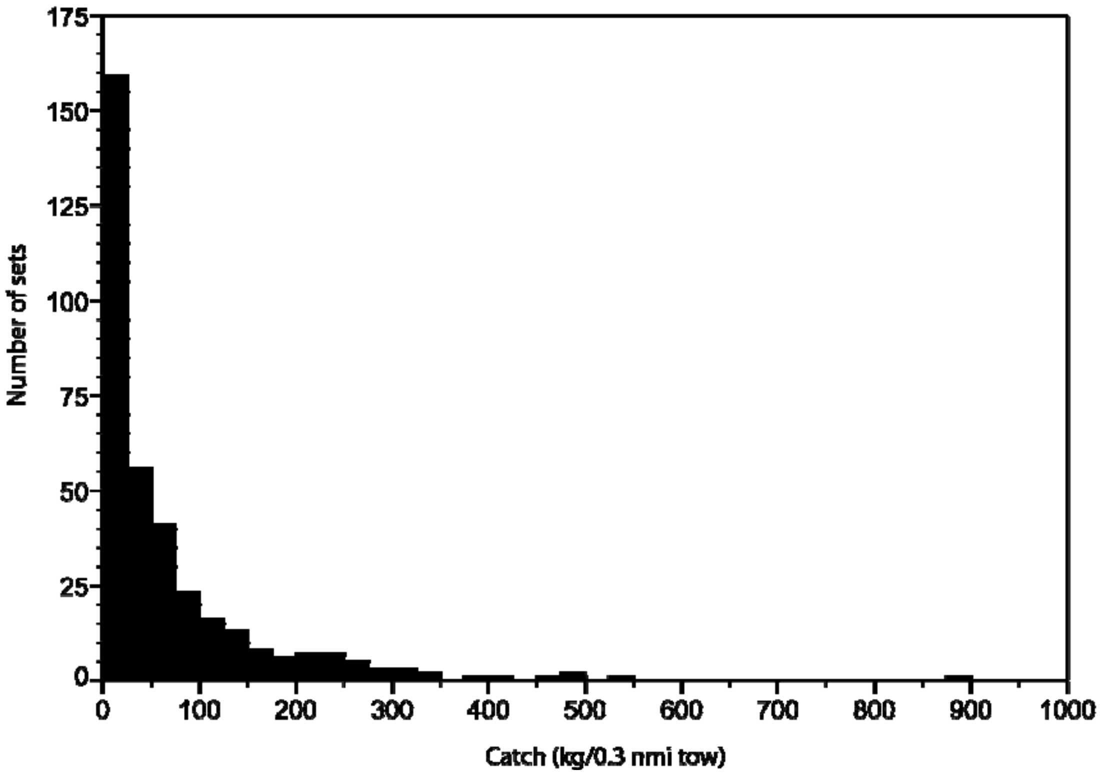


*Figure 4. Histogram of catch per standard tow from the 1996-98 survey stations within the proposed survey area on Southern Grand Bank.*

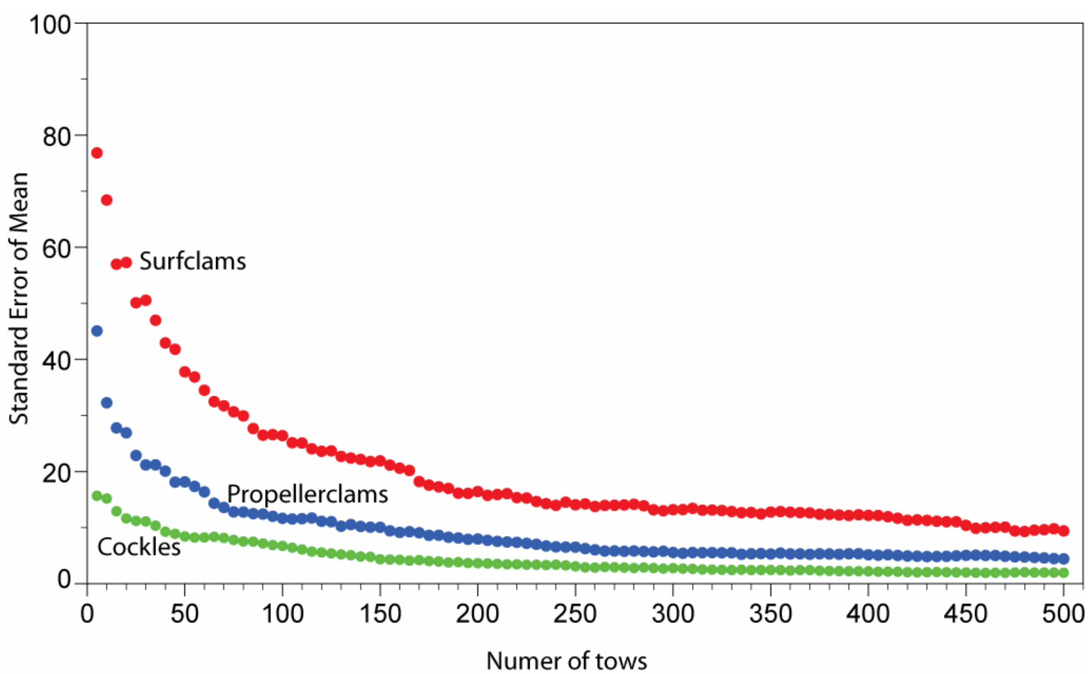


*Figure 5. Change in standard error of the catch with number of tows for the three large bivalve species caught during the Cape Dauphin clam survey of Grand Bank*

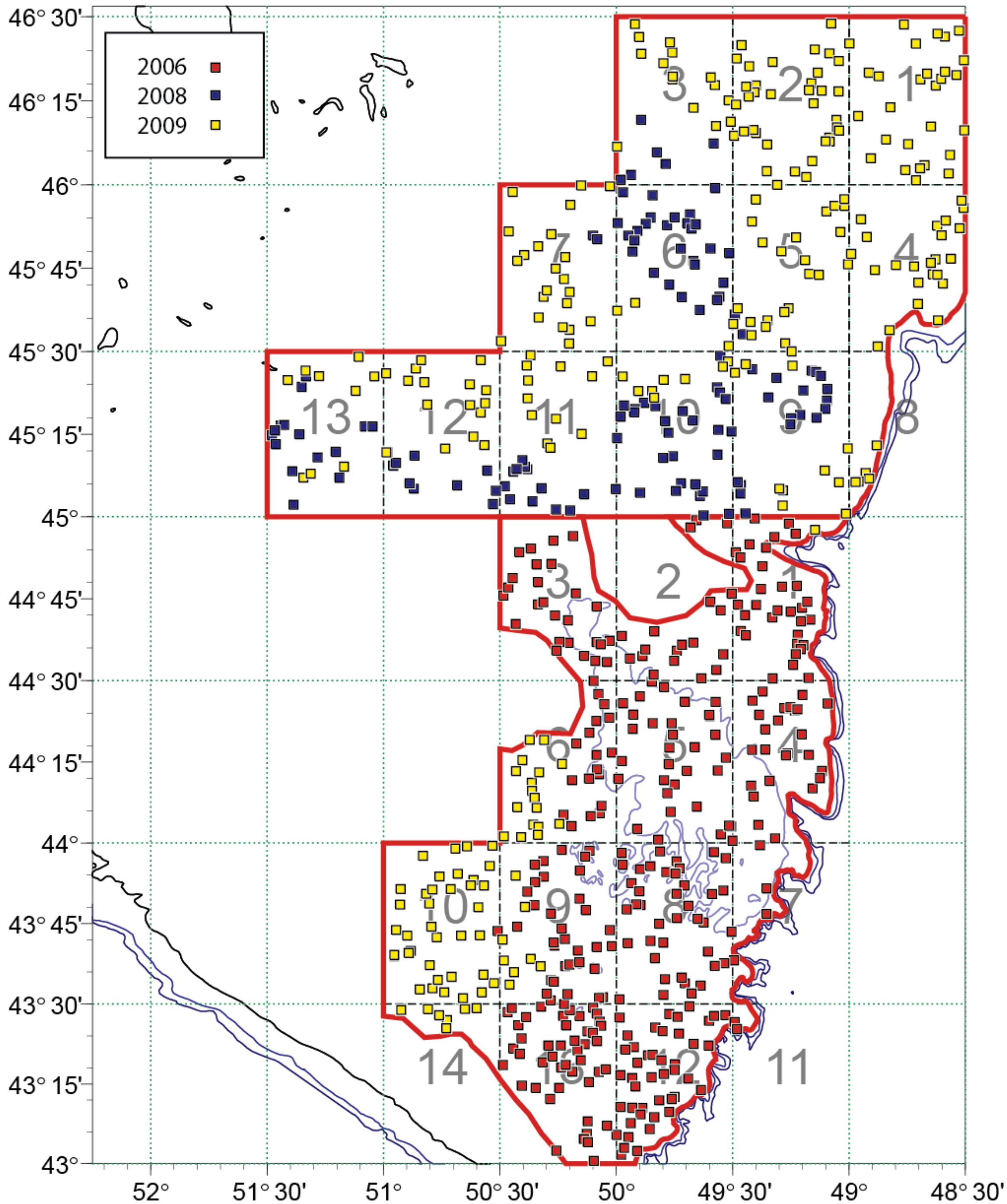


*Figure 6. Station map for 2006 to 2009 Grand Bank offshore clam survey. Stations are coloured by year they were completed.*

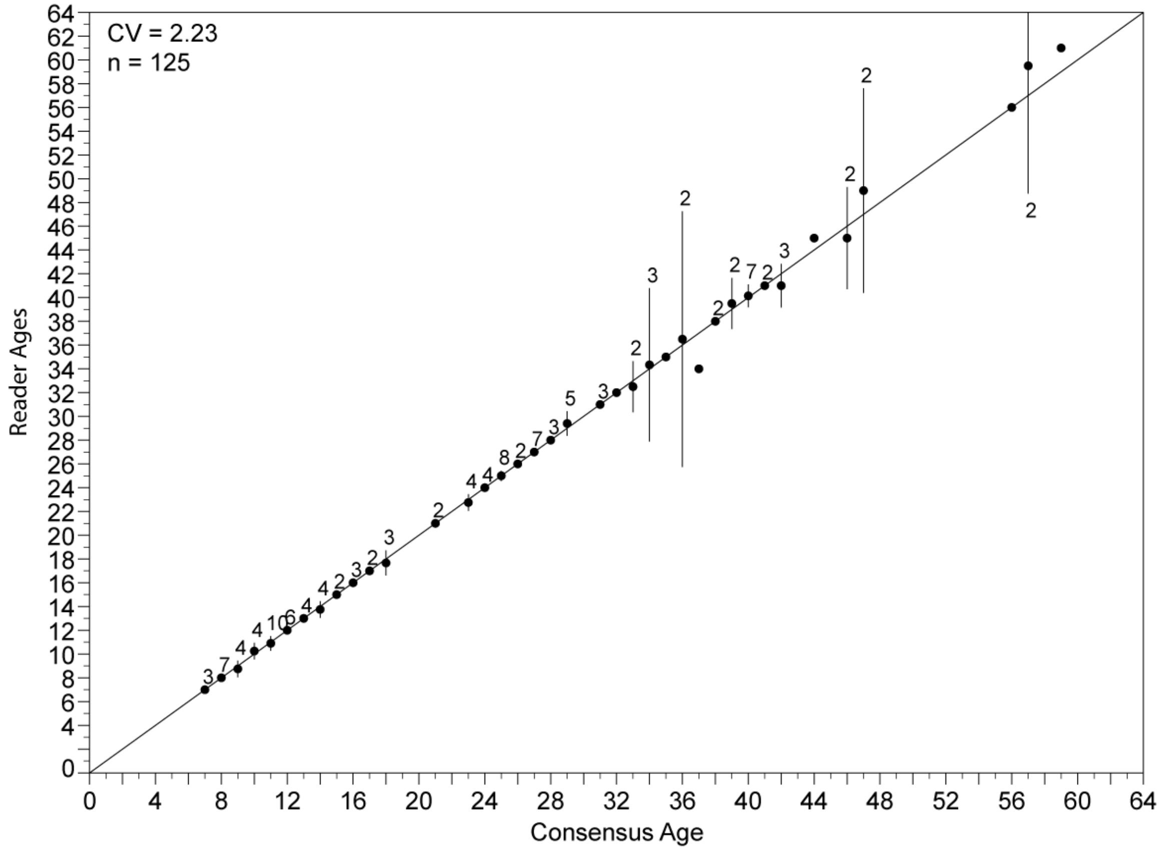


*Figure 7. Age bias plot for testing the results of an ager against the consensus ages assigned a sample of clams. For all clams of a given consensus age the results for the mean (dot) and range (vertical bar) of ages assigned by the ager being tested are shown.*

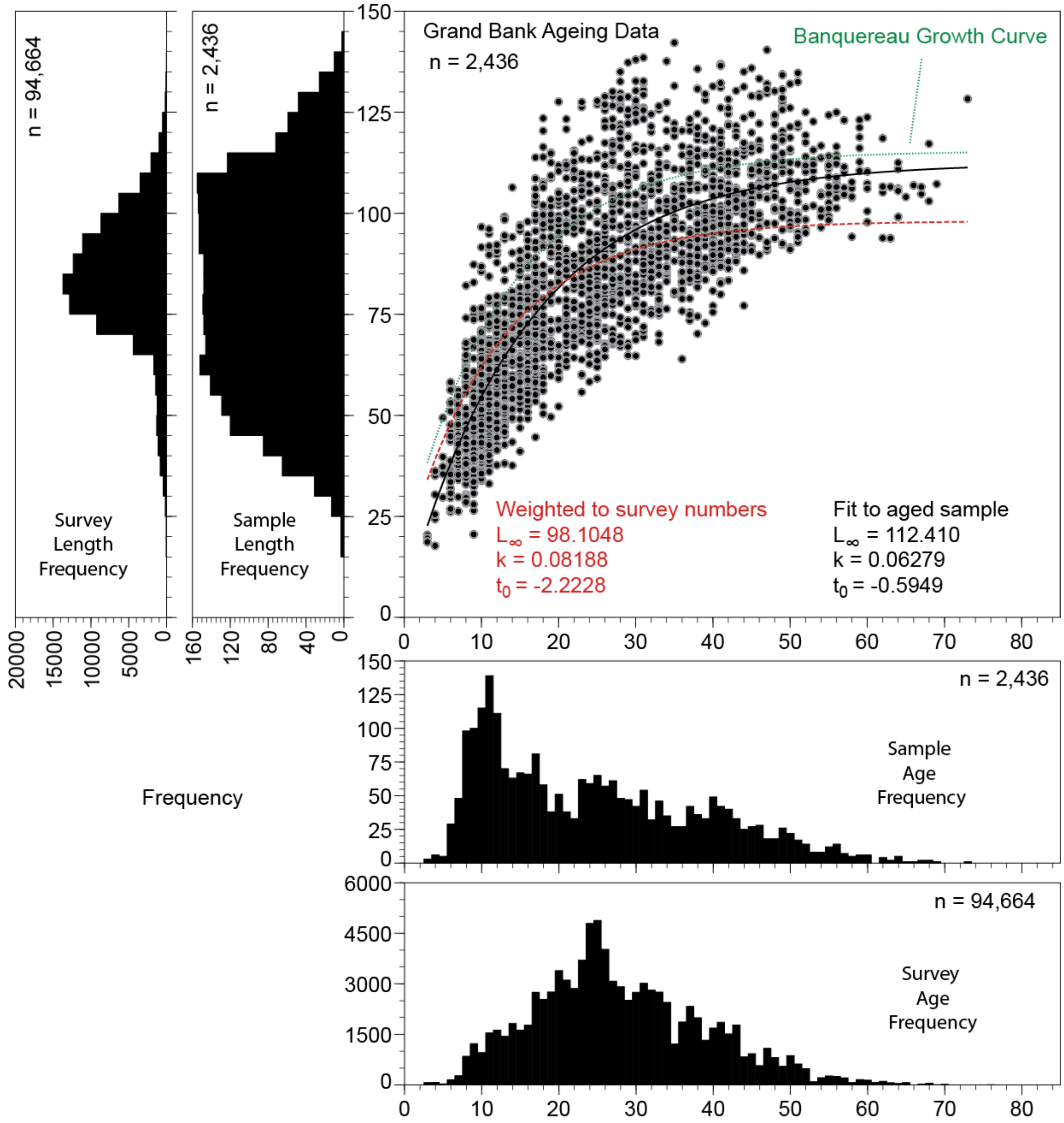


*Figure 8. Survey and sample length frequency, ageing results and sample and estimated survey age frequency results from the aging of a random sample of 2,436 clams from the 2006-2009 Grand Bank Arctic Surfclams survey.*

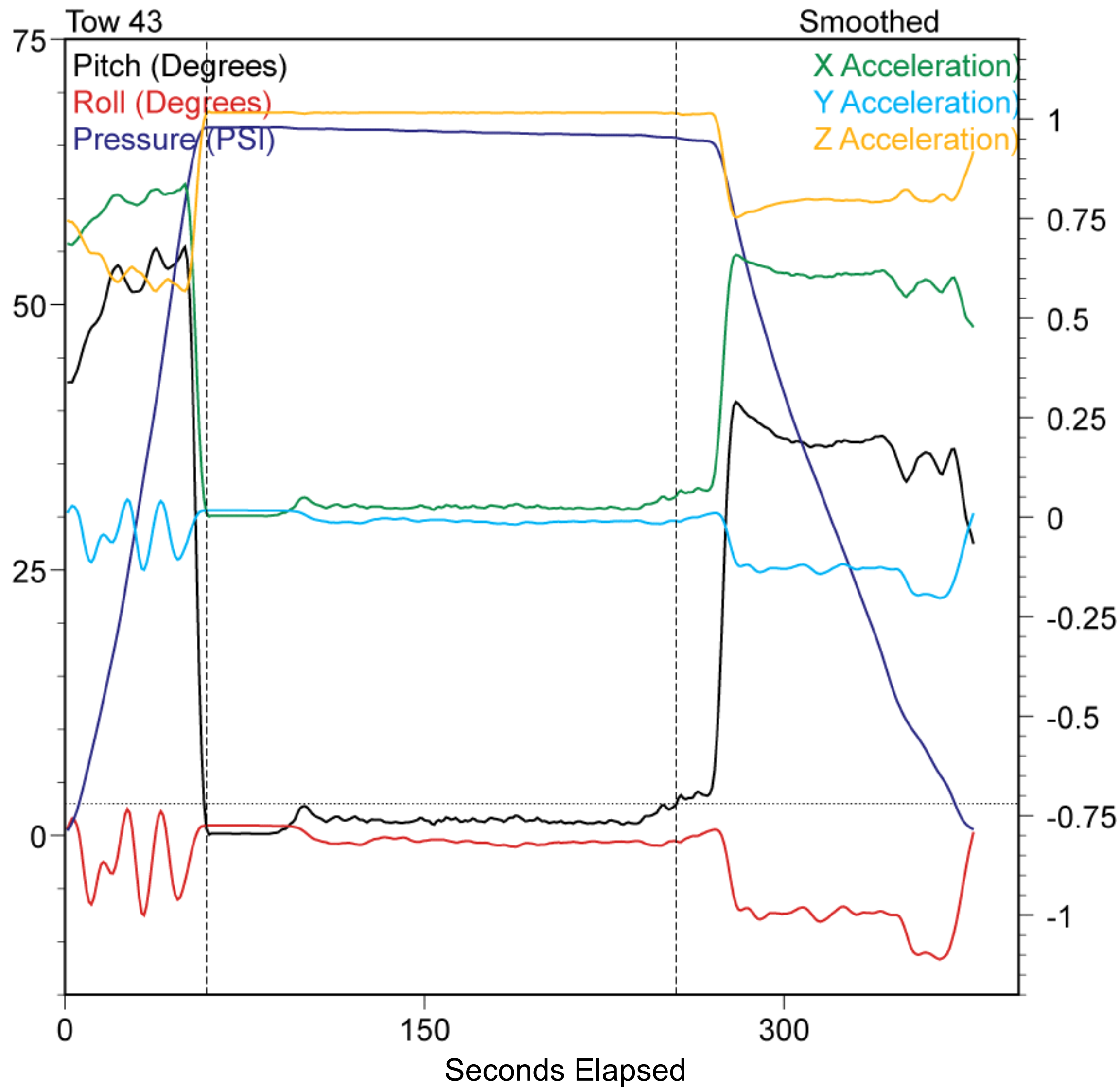


*Figure 9. Dredge sensor data from a typical tow during the 2009 Grand Bank Offshore Clam survey. The dashed vertical lines represent the points when the dredge touched bottom to when it stopped fishing as it was hauled up.*

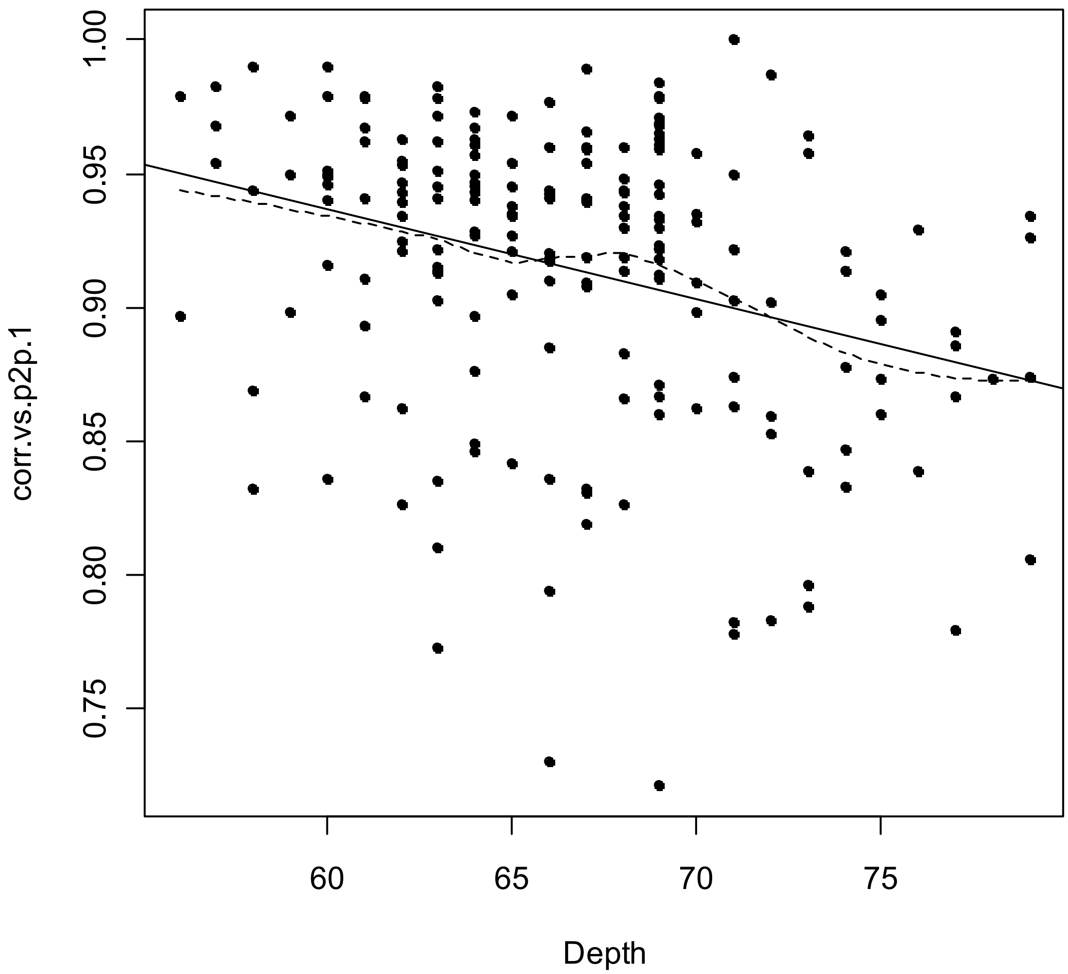


*Figure 10. Tow distance correction factor in relation to depth using the 2009 Grand Bank survey tows for which dredge sensor data was available. Uncorrected tow distance was smoothed navigation data recorded at 2 second intervals. Dashed line is LOWESS fit to data.*

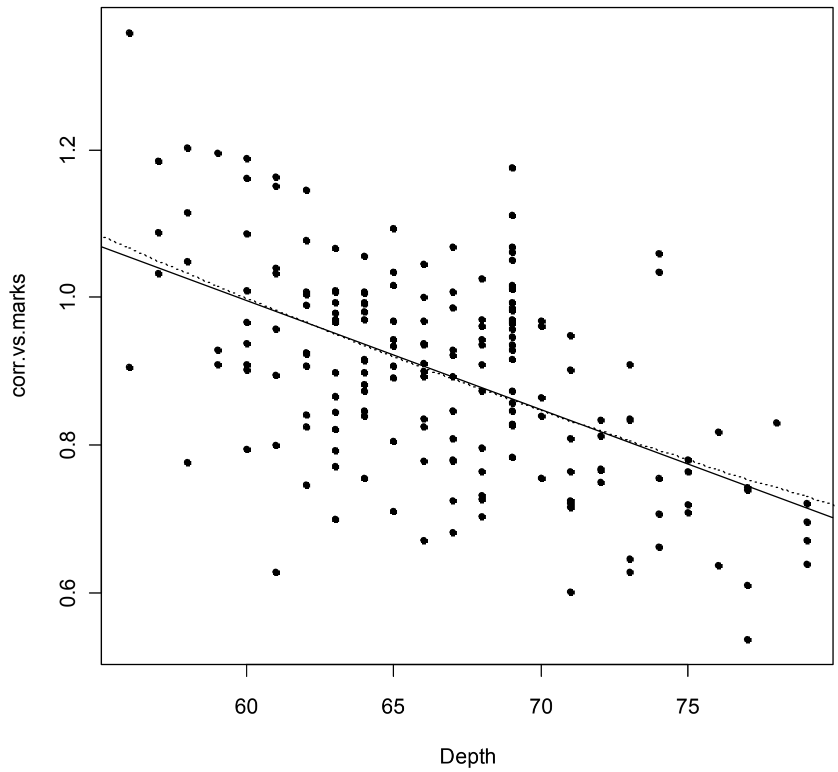


*Figure 11. Tow distance correction factor in relation to depth using the 2009 Grand Bank survey tows for which dredge sensor data was available. Uncorrected tow distance was distance between endpoints of the tow.*

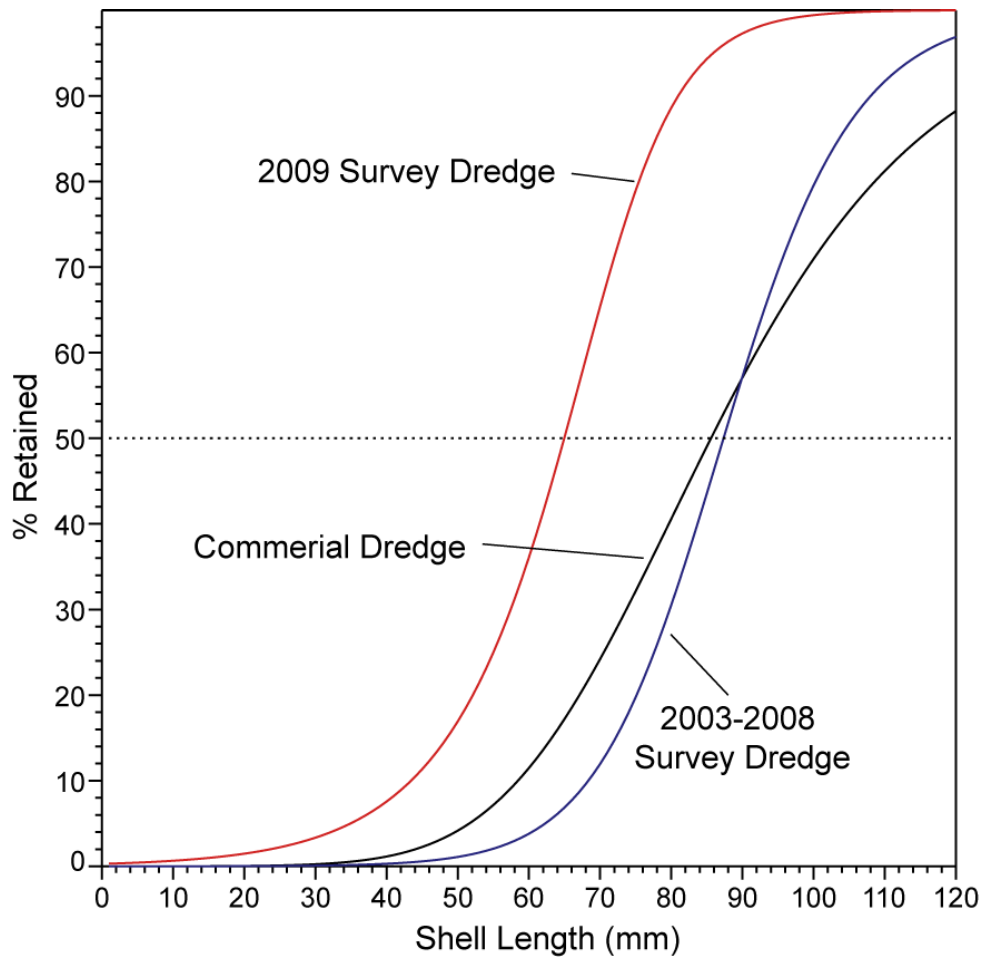


*Figure 12. Comparison of selectivity curves for the 2006 and 2008 survey dredge, the 2009 survey dredge and a commercial clam dredge.*

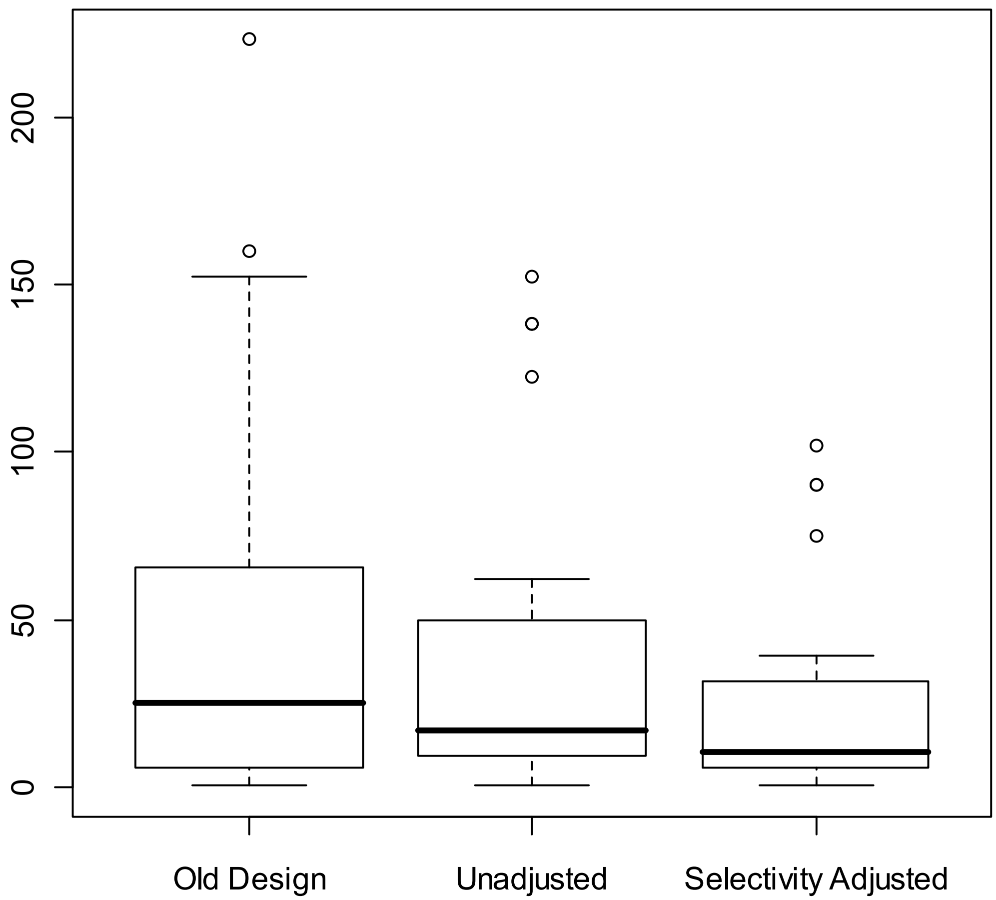


*Figure 13. Boxplots of standardized surfclam catch per tow (kg) for comparison tows done during the 2009 Grand Bank Surfclam survey. The plot labelled Old Design includes catches from the 2006 and 2008 surveys. The one labelled Unadjusted includes the unadjusted 2009 catches, the 2009 catches after adjusting for the selectivity differences are those labelled Selectivity Adjusted.*

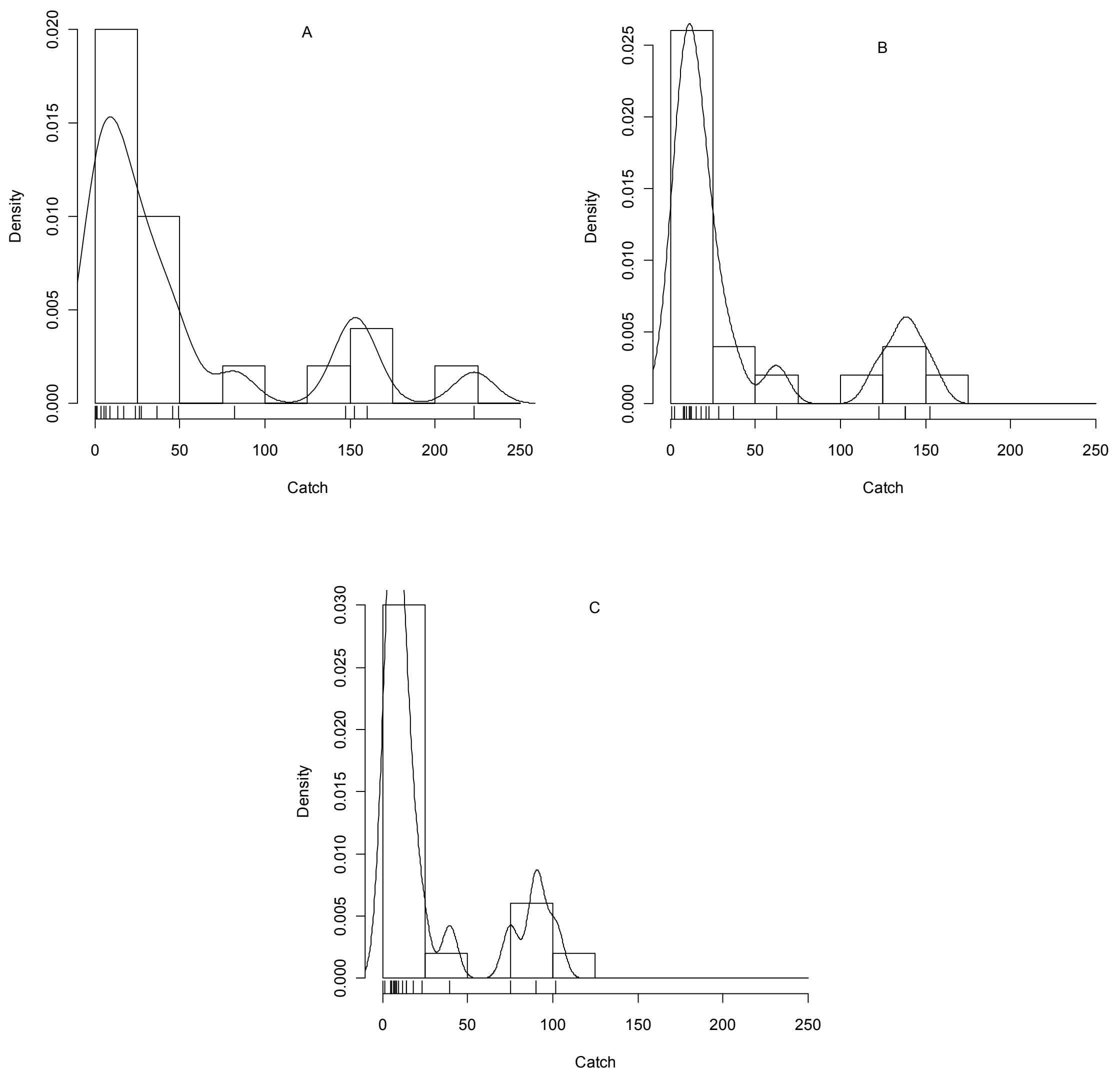


*Figure 14. Distribution of standardized catches from comparison tows done in 2009. Plot labelled A are catches from the 2006 and 2008 surveys done with the older dredge design. Plot B are the catches from repeating the tows in 2009, and C is the plot of the 2009 catches after adjusting for the difference in selectivity.*

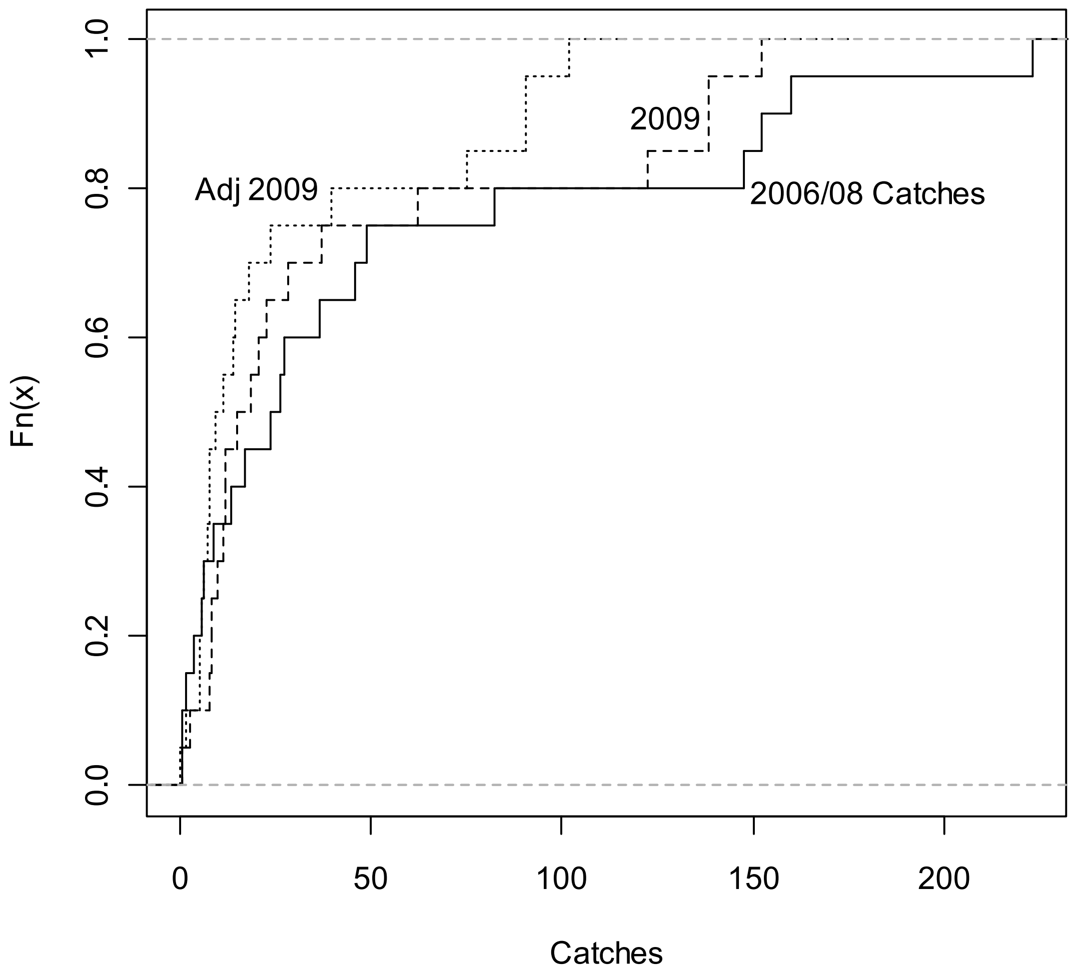


*Figure 15. Cumulative distribution functions for catches from the comparison tows.*

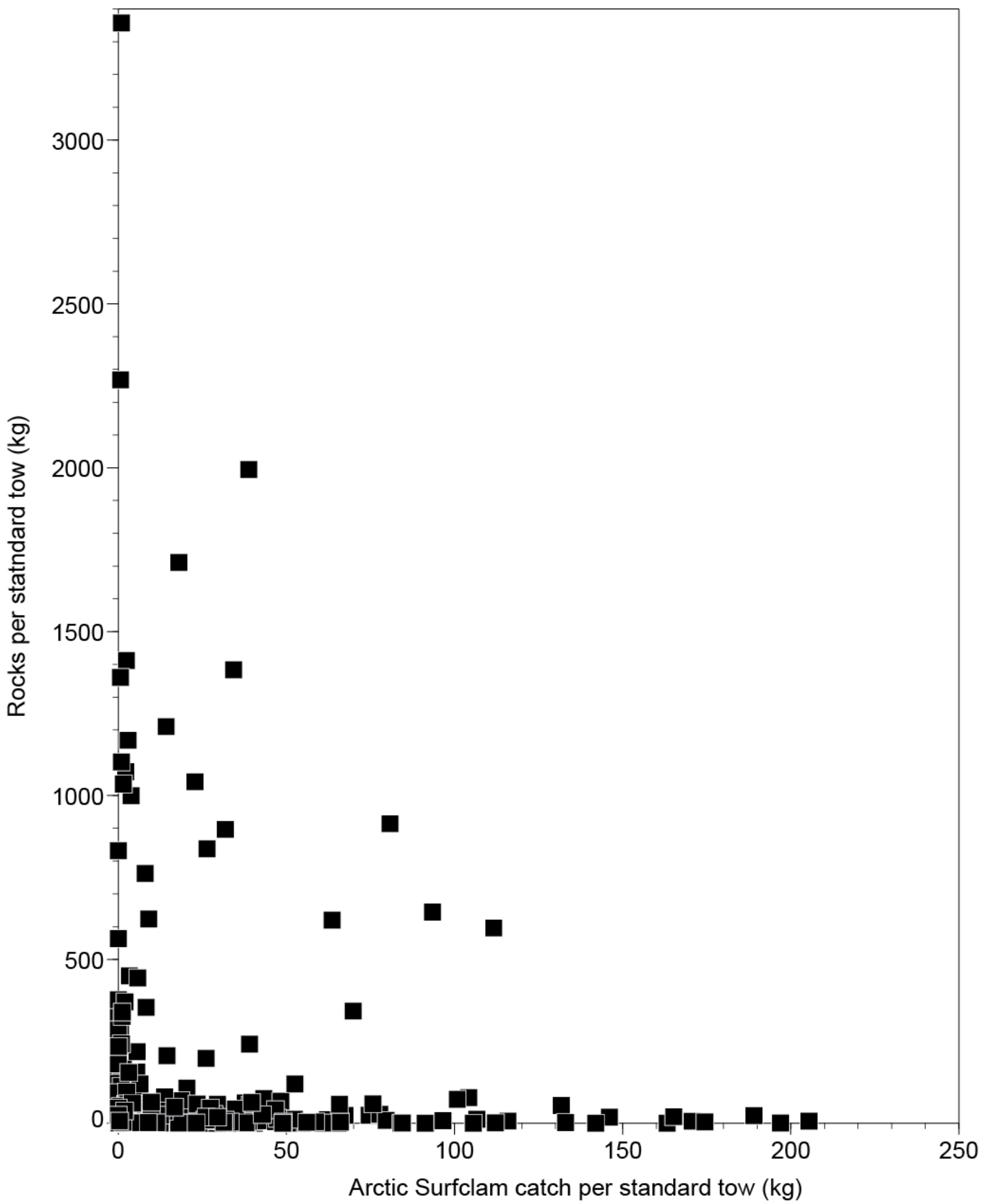


*Figure 16. Catch of Arctic Surfclams versus rocks in Grand Bank offshore clam survey tows.*

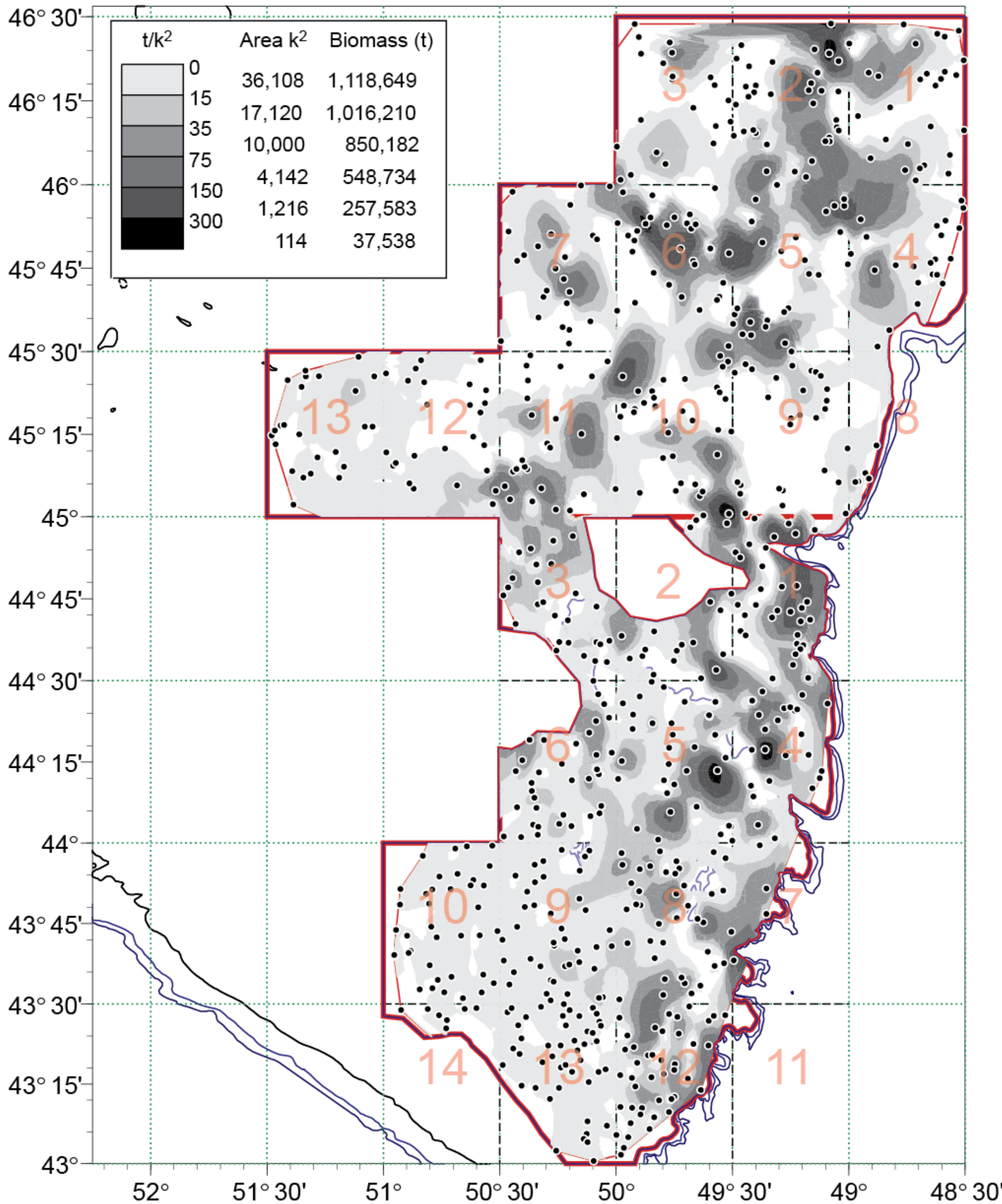


*Figure 17. Contour plot of biomass estimated from the 2006-2009 Grand Bank Arctic Surfclam survey. Table in upper left shows the area and biomass for increasing densities of Arctic Surfclams. For ease of interpretation contouring was done in tonnes per kilometre square instead of catch per standard tow. Black dots are tow locations.*

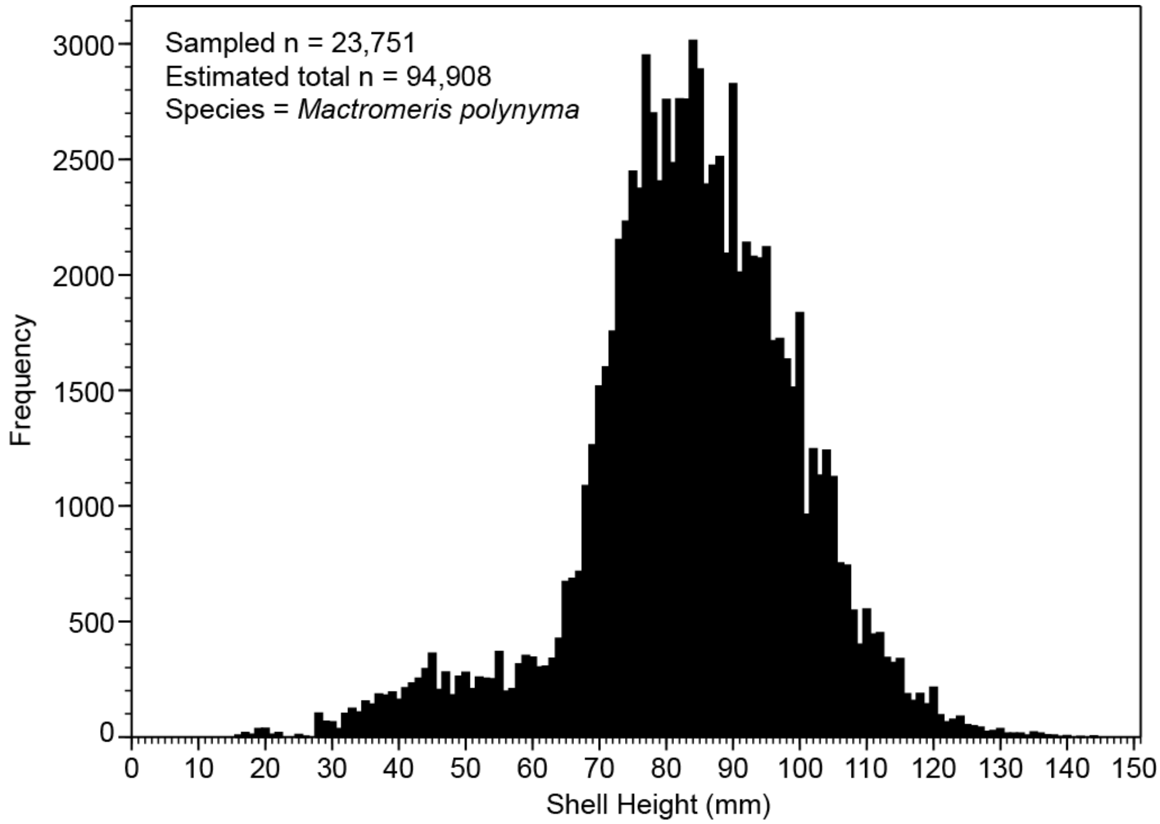


*Figure 18. Size frequency distribution for Arctic Surfclams caught during the 2006-2009 survey on Grand Bank.*

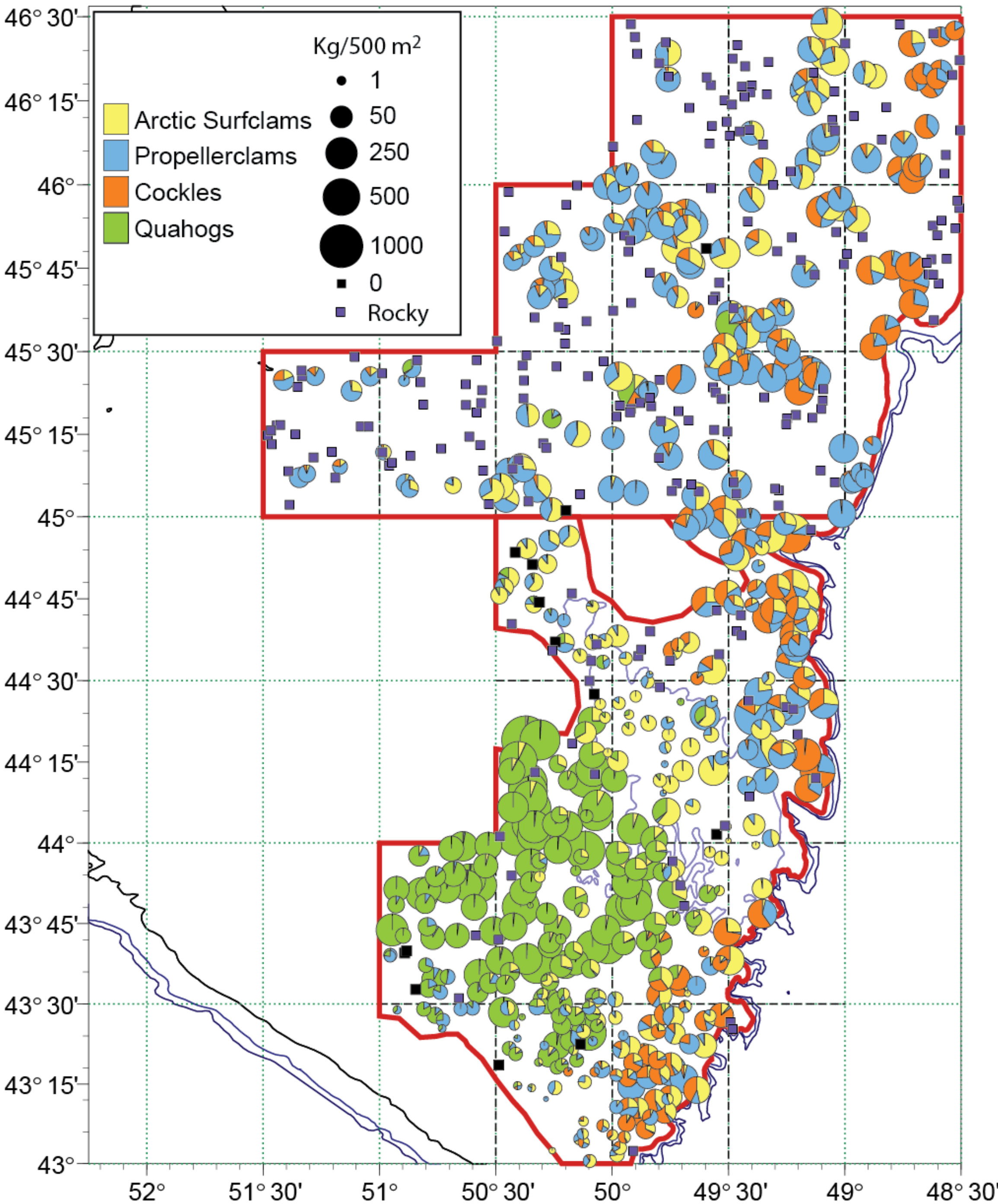


*Figure 19. Distribution of the major clam species from the 2006-2009 Grand Bank Arctic Surfclam survey on Grand Bank.*

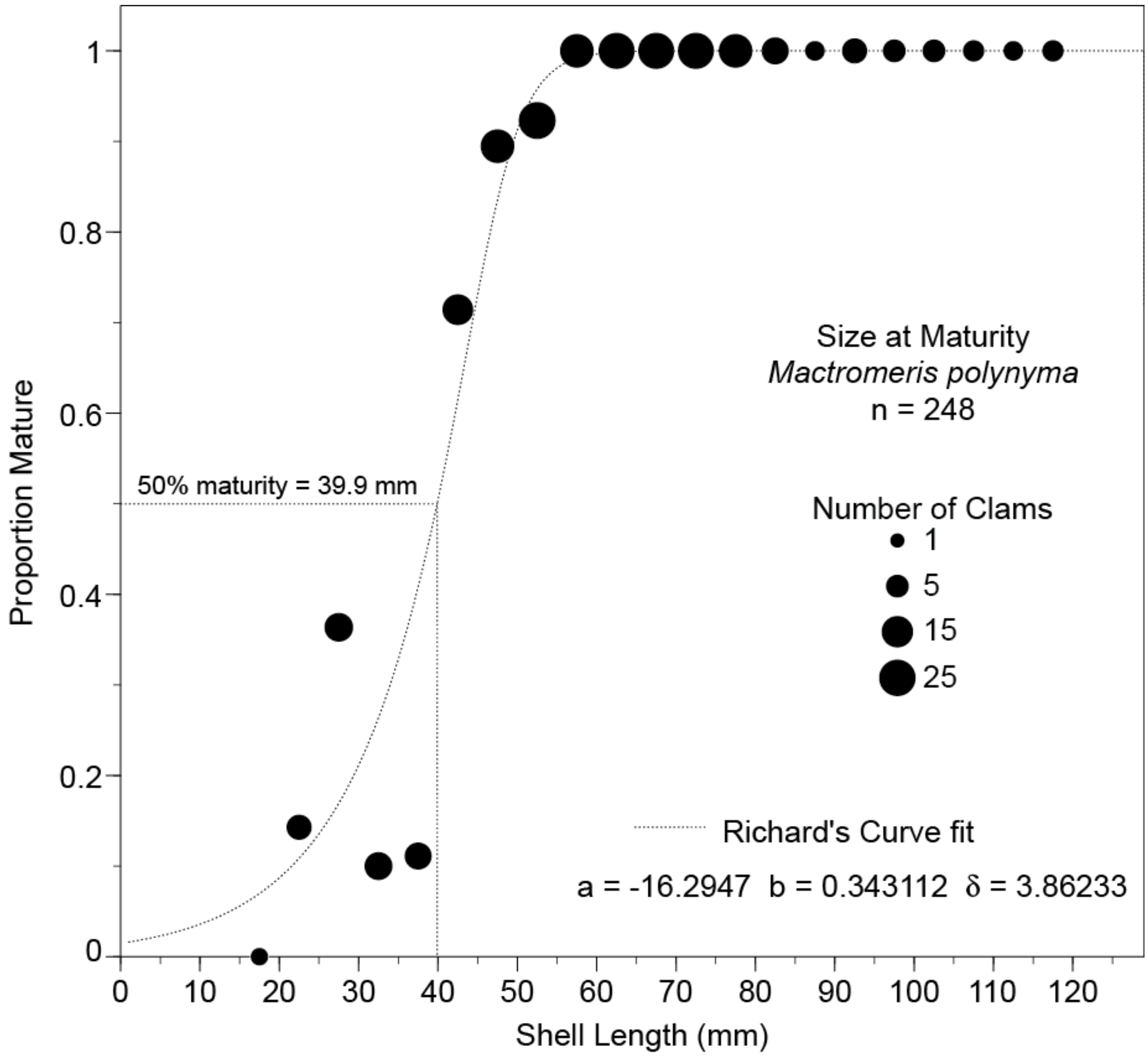


*Figure 20. Length at maturity for Artic Surfclam samples taken during the 2006-2009 survey on Grand Bank.*

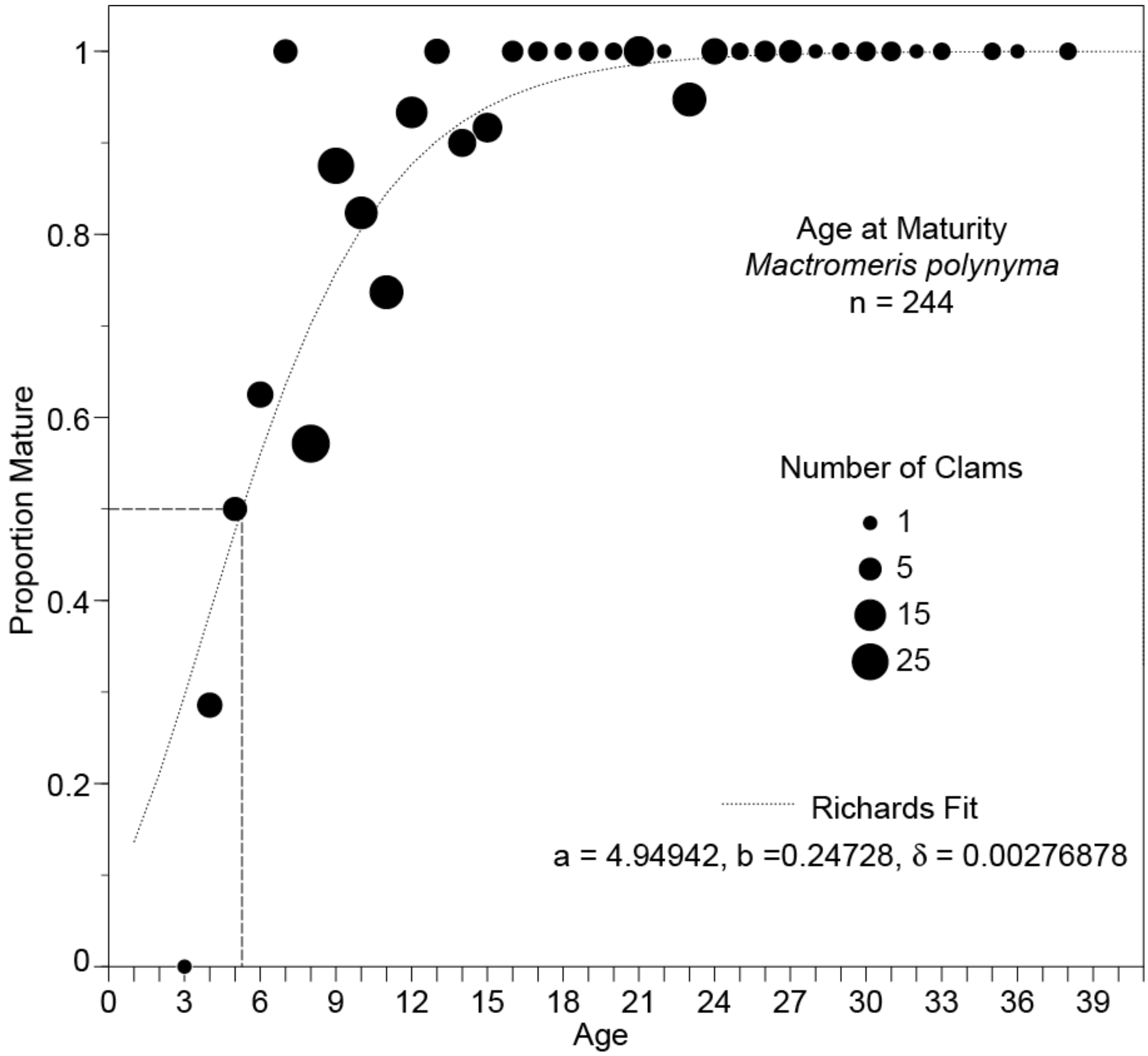


*Figure 21. Age at maturity for Artic Surfclam samples taken during the 2006-2009 survey on Grand Bank.*

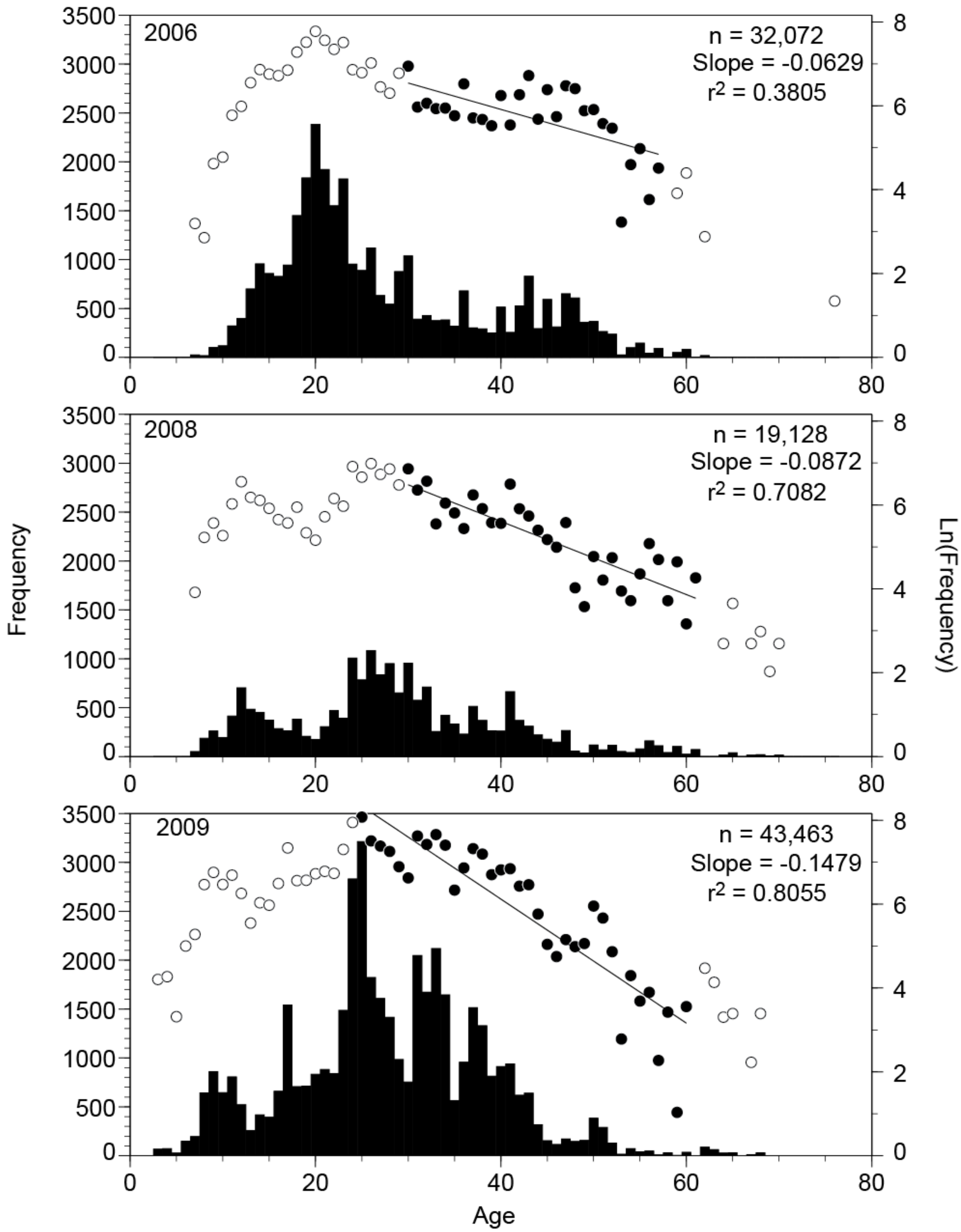


*Figure 22. Catch curve estimates of mortality for Grand Bank Arctic Surfclam surveys. Average estimate weighted by survey numbers is -0.1066.*

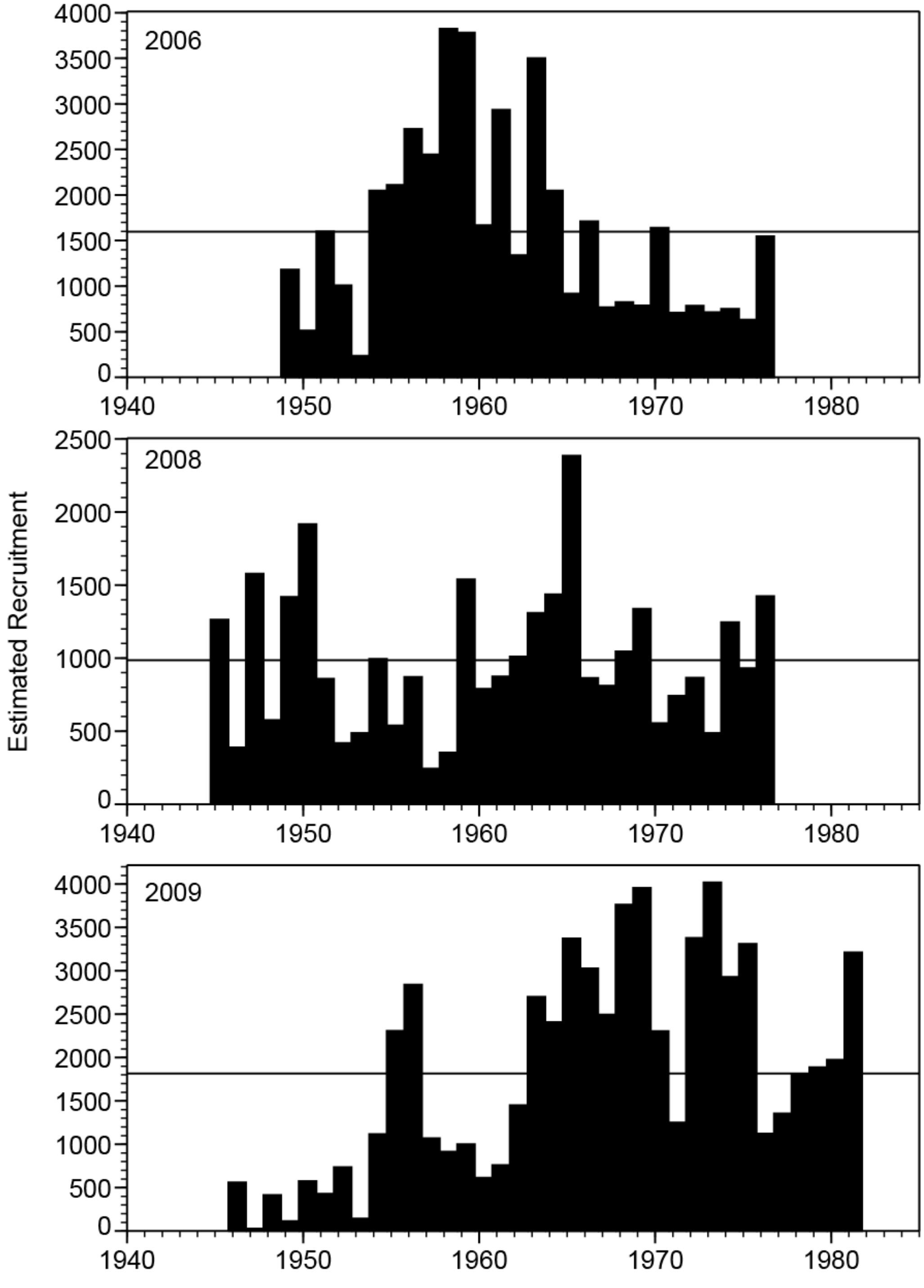


*Figure 23. Population recruitment patterns estimated by applying the estimated (constant) mortality rate to the estimated age structure for the 2006, 2008 and 2009 portions of the Grand Bank Arctic Surfclam survey.*

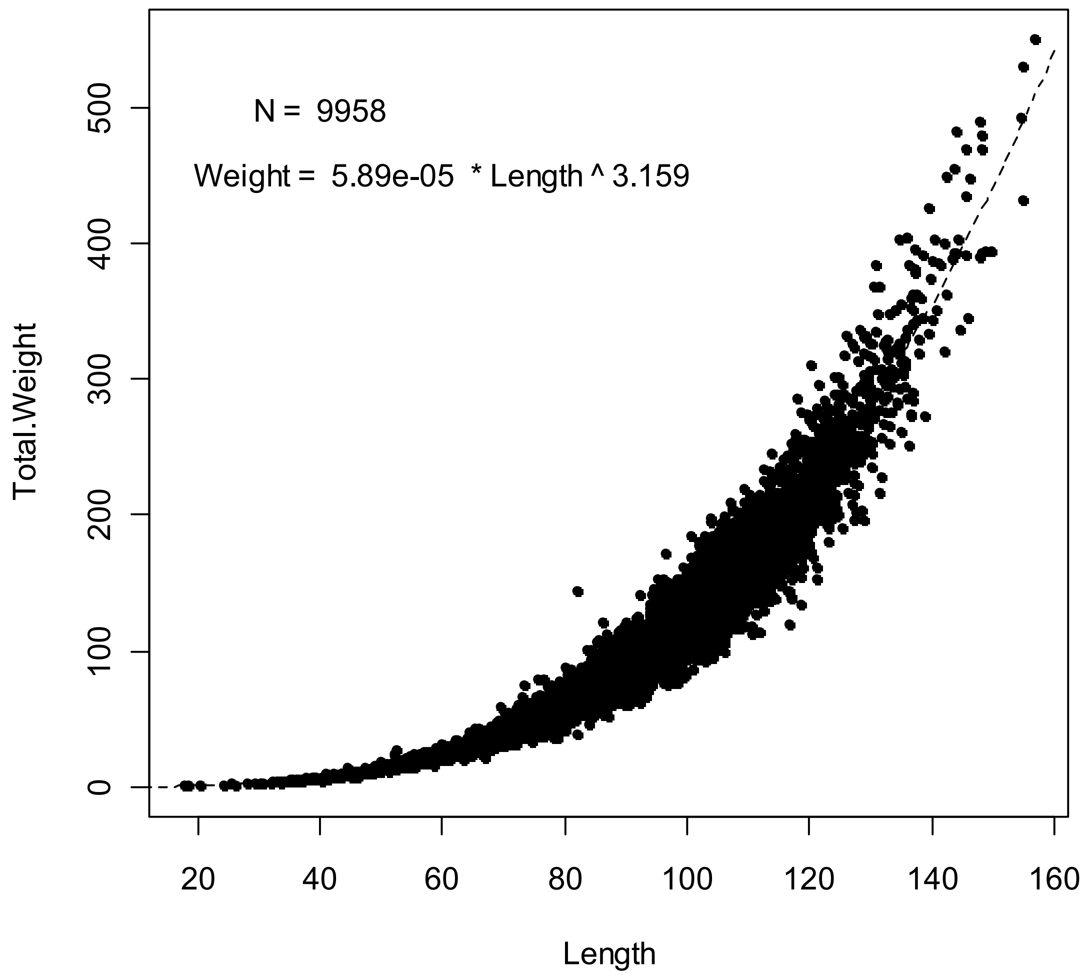


*Figure 24. Length versus total weight relationship for the samples form the 2006-2009 Arctic Surfclam survey on Grand Bank.*

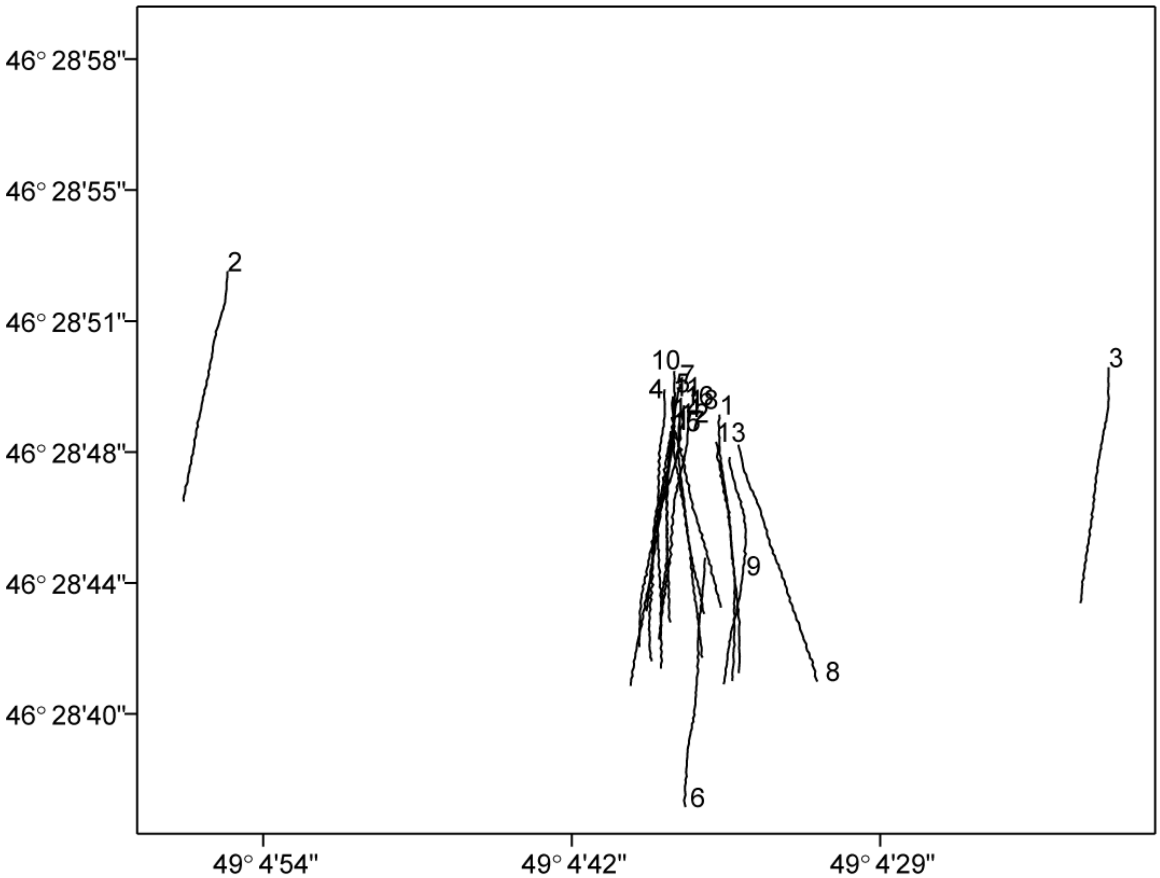


*Figure 25. Vessel tracks for depletion tows done during the 2009 Grand Bank Clam survey.*

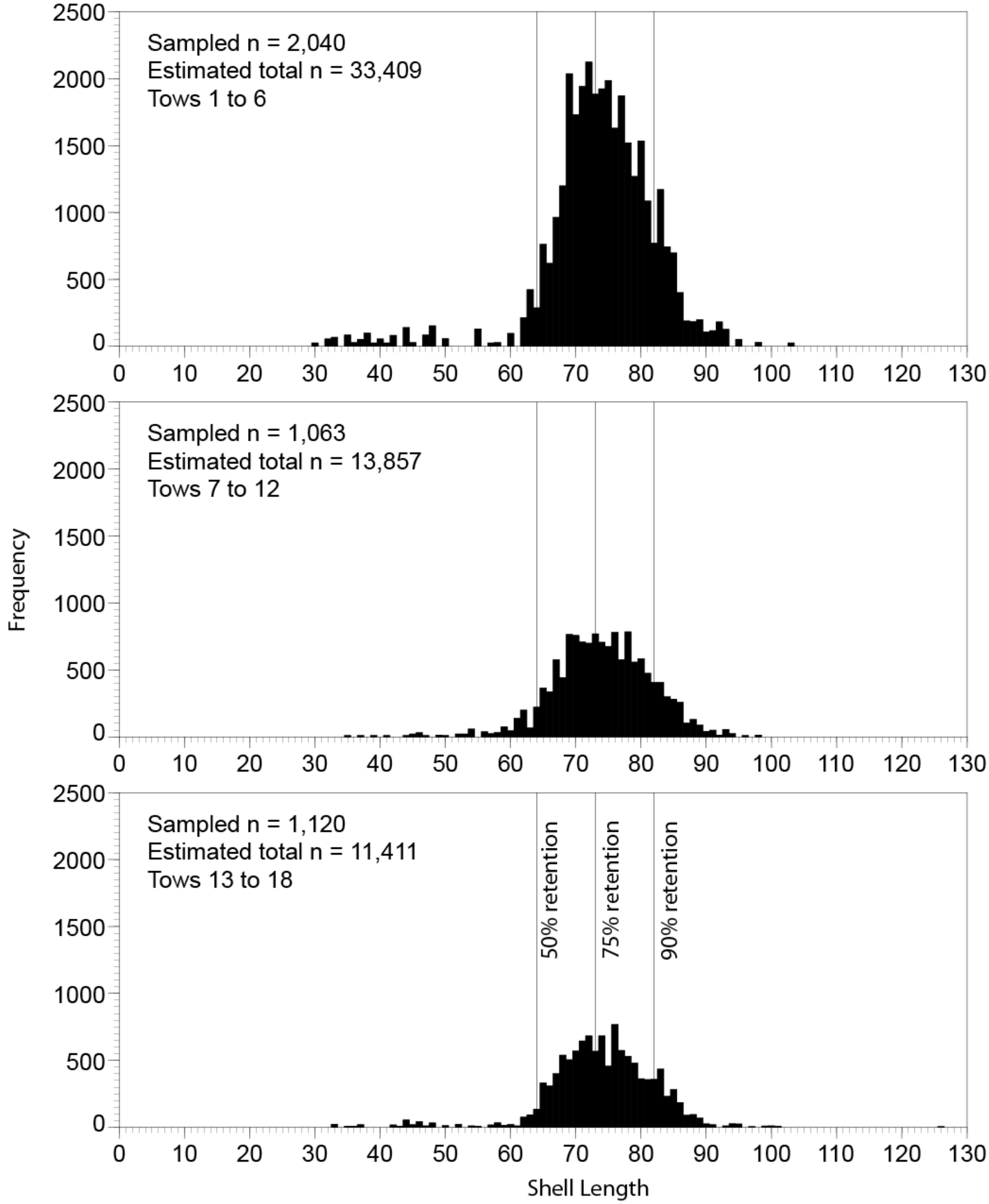


*Figure 26. Length frequencies from depletion experiment tows grouped by tow. Vertical lines are the 50, 75 and 90% retention sizes from the selectivity curve.*

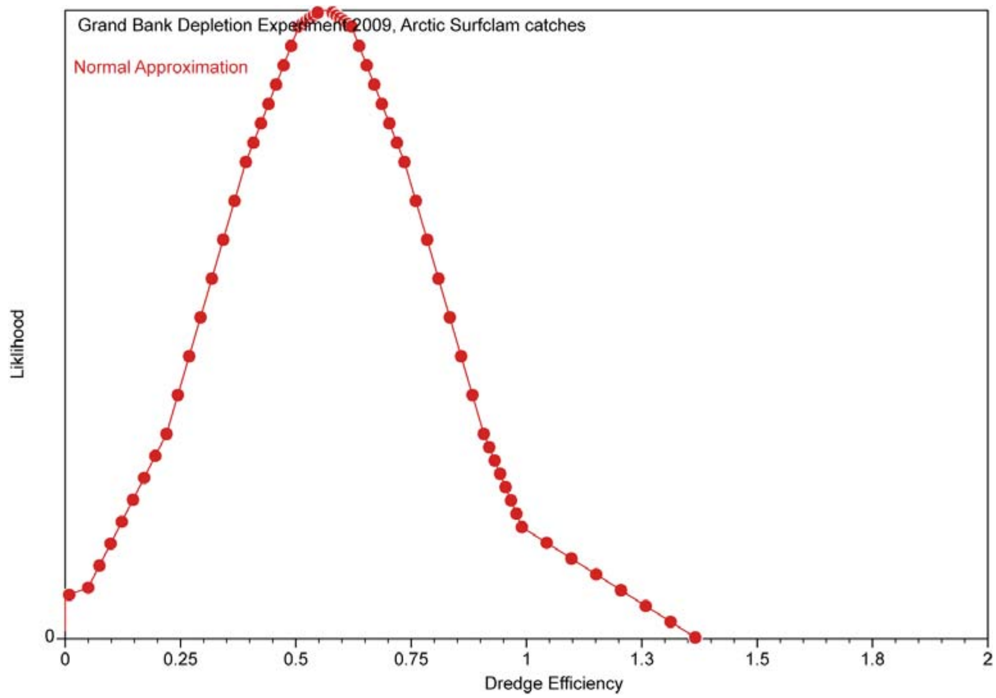


*Figure 27. Liklihood results from the estimate of dredge efficiency from the 2009 Grand Bank dredge efficiency study.*

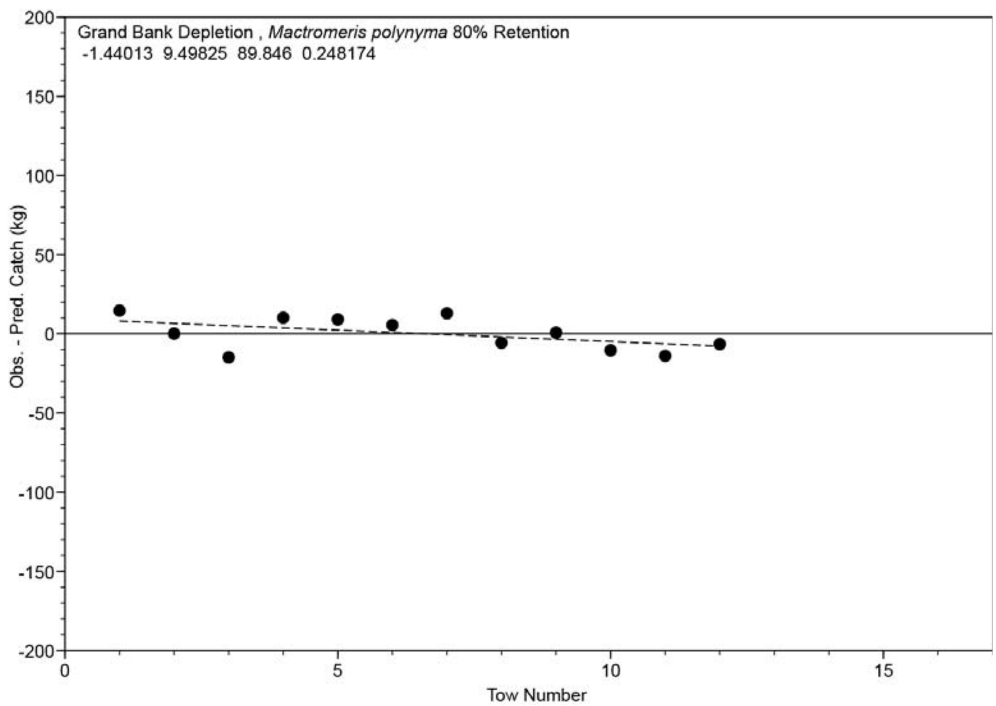


*Figure 28. Residual plot of observed – predicted catches for the depletion study on Grand Bank Arctic Surfclams. Catches were for clams at or above the size of 90% retention for the survey gear.*

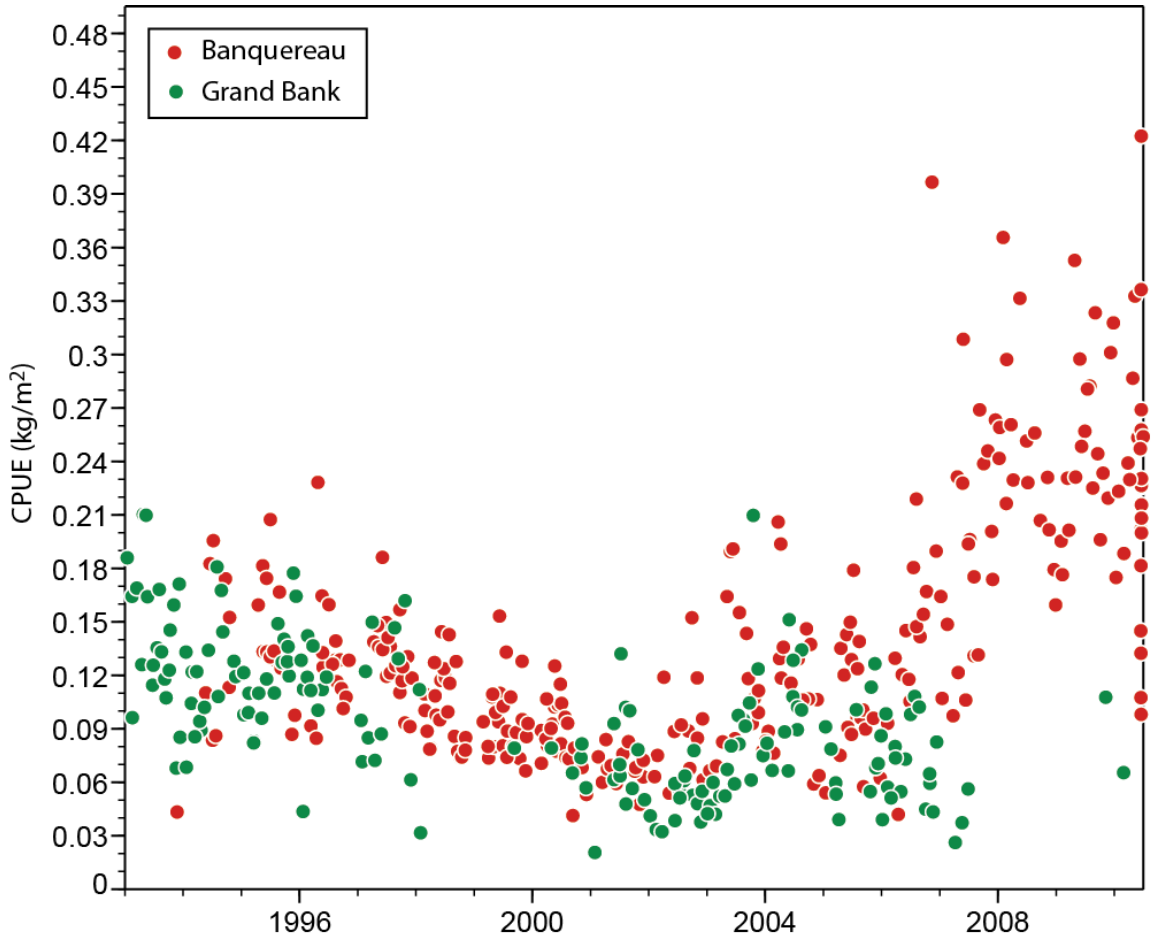


*Figure 29. CPUE (kg/m2 dredged) for the Arctic Surfclam fishery. CPUE is calculated on a trip basis.*

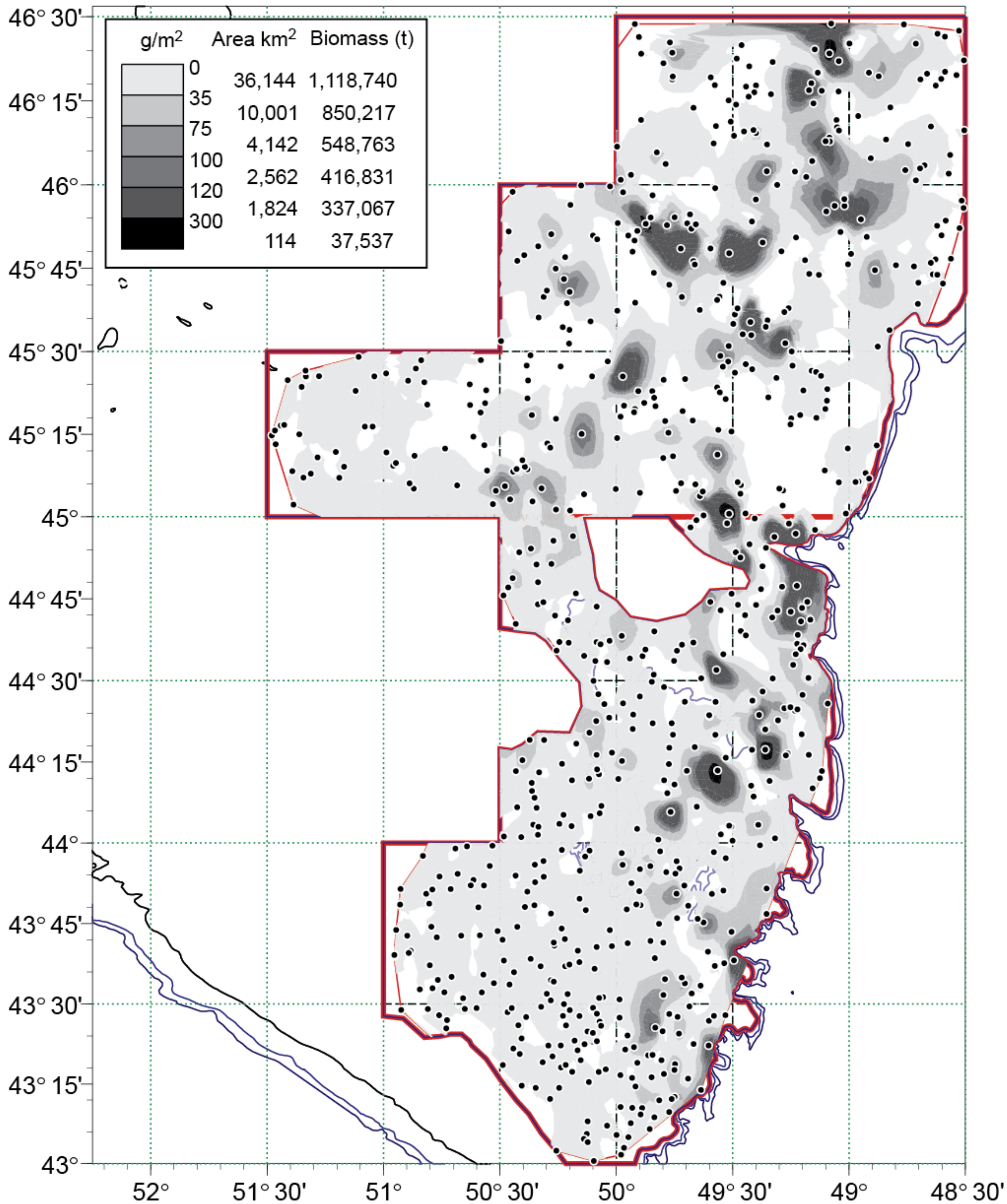


*Figure 30. Biomass contours with the three highest levels set to span the range of densities being fished.*