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Assessment of the Arctic Surfclam (*Mactromeris polynyma*) stock on Banquereau in 2010

Évaluation du stock de mactres de Stimpson (*Mactromeris polynyma*) du Banquereau en 2010

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ABSTRACT

A 2010 survey of the Banquereau Arctic Surfclam stock provided an estimate of the biomass of 1,150,585 t ± 20,643 of surfclams. This biomass is similar to that of the unadjusted 2004 survey estimate, but differences between the vessels and dredges used for the surveys means the estimates are not comparable. Indications are that the fishery, which started in 1986, has not had a large impact on the stock. 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. Catch per Unit Effort has increased and there are indications of good pre-recruit year classes. The Total Allowable Catch (TAC) could be increased from the present 24,000 t, but caution is advised as TACs and catch rates would be expected to decline as landings increase.

RÉSUMÉ

Un relevé du stock de mactres de Stimpson du Banquereau de 2010 a fourni une estimation de biomasse de 1 150 585 t ± 20 643 de mactres. Cette biomasse est semblable à celle de l'estimation de relevé de 2004 non corrigé, mais en raison des différences entre les navires et les dragues utilisés pour effectuer les relevés, les estimations ne sont pas comparables. Selon les indications, la pêche, qui a commencé en 1986, n'a pas eu une grande incidence sur le stock. La surpêche du potentiel reproducteur et de croissance n'est pas un problème dans cette pêche, grâce aux modèles d'engins de pêche sélectifs actuels. La taille des captures pour une sélectivité de 50 % est supérieure à la taille à la maturité et proche de la taille dans la biomasse maximale des cohortes. La capture par unité d'effort a augmenté et il y a des indicateurs de bonnes classes d'âges chez les pré-recrues. Le total autorisé des captures (TAC) pourrait augmenter par rapport aux 24 000 t actuelles, mais il convient d'être prudent étant donné les TAC et les taux de prise pourraient diminuer avec une augmentation des débarquements.

1.0 – 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. Commercial quantities of Arctic Surfclams, *Mactromeris polynyma*, were found on Banquereau during surveys conducted from 1980 to 1983 (Rowell and Chaisson, 1983; Chaisson and Rowell, 1985).

In 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 (Amaratunga and Rowell, 1986).

In 1987, a three-year Offshore Clam Enterprise Allocation (EA) Program was developed with industry consensus. Total Allowable Catches (TACs) and EAs were set for each of the three years of the program. TACs and EAs were based on biological information provided by the surveys and test fishery and an economic break-even analysis on the resources necessary for a viable vessel and processor. The TACs were set at 30,000 t for Banquereau 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 and the fishery expanded to Grand Bank. There were four licences with access to different areas under different EAs.

In 1990, the Offshore Clam Enterprise Allocation Program was extended for the five-year period 1990 to 1994. The TACs did not change, but the EAs were revised so all licences had equal access and allocations for all areas. Any changes in the TAC would also be equally split between the licence holders. The fisheries for the Scotia-Fundy and Newfoundland regions were combined under a single Integrated Fisheries Management Plan (IFMP).

The EA Program was continued for the 1998 to 2002 Integrated Conservation and Harvesting Plan (DFO, 1999), and up to the 2005-2009 Offshore Clams Integrated Fishery Management Plan. The industry has consolidated over time, so currently there is a single enterprise controlling the existing licences.

Three Industry-Department of Fisheries and Oceans (DFO) surveys of Banquereau have been conducted since the start of the fishery, in 1996-1997, 2004, and 2010. The 1996-1997 Industry-DFO survey of Banquereau resulted in a reduction of the TAC for Banquereau from 30,000 t to 24,000 t. Analysis of trends in the survey data is complicated by the fact that each survey has used different vessels and gear.

Fishing activity has switched between Banquereau and Grand Bank through time, with the most recent focus on Banquereau (Figure 1). Landings for the combined fishery are shown in Table 1 and Figure 1, and the landings and TAC for the Banquereau fishery are shown 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 catch for the fishery up to 2010 is shown in Figure 3, broken down into three time periods.

Landings have grown, but they have never reached the combined quota for both banks, although the Banquereau fishery has approached and levelled at the TAC for the last two years. Landings in 2009 were 24,692 t with a value of $51.7 million, and in 2010 were 22,845 t, with a value of $39.7 million.

2.0 – METHODS

2.1 – COMMERCIAL DATA

The main sources of data from the commercial fishery are the logbooks and a voluntary sampling program carried out on-board the vessels. There is also periodic coverage under the International Observer Program (IOP), which puts independent samplers on the vessels to monitor catch. The logbooks supply data on location, catch, and effort. The sampling programs provide data on length frequencies, by-catch, and conversion factors, as well as morphometric samples that are sent to DFO for processing.

The use of Catch per Unit Effort (CPUE) data has been complicated by the fact that Arctic Surfclams are sedentary, fishing effort varies in location over time, and the vessels are freezer-processors. During fishing, catch from the dredges is fed into a hopper system that continuously feeds the processing line. Catch weights are recorded as processed product weight at the end of the processing line, so it is difficult to accurately match a unit of catch to the effort that produced it. Since there are few vessels, and trips last up to 40 days, calculating CPUE on a trip basis results in few data points per year. For this analysis, trips were broken down into sub-trips by examining the logbook data for breaks in production in caused by storms, movement between areas, etc., of more than six hours, long enough to ensure all catch in the hoppers was processed. Sub-trips allow units of catch and effort to be matched on periods smaller than a full trip. CPUE was plotted by sub-trip and annual mean for the last four vessels that have been active in the fishery.

The by-catch data from the on-board sampling program is compared to data from the surveys and from the IOP that samples the catch composition on monitored trips.

2.2 – SURVEY DESIGN

<u>Number of Stations Required</u>

The variance in catch rate from the 2004 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 4, which indicates that there is a rapid decrease in the standard error as the number of stations is increased up to 200, and that beyond 300 stations there is little reduction in the standard error.

The vessel and dredge to be used in the 2010 survey differed from those used for the 2004 survey, resulting in the possibility of higher variability in the 2010 survey than 2004. Past experience had also shown that there would be areas where the dredge would not fish efficiently down to 100 m. For these reasons, and in anticipation that some tows would have to be dropped due to bottom roughness and other difficulties, it was decided to base the 2010 survey on 260 stations.

Using the ACON package (Black, 1991) and a new set of bottom bathymetry from Hydrographic Services; the area within the 90 m contour of Banquereau was calculated as 10,110 km^2. Using a total of 260 stations, this is one station per 39 km^2. The 2004 survey used a shallow limit of 40 m, which excluded the top of the eastern shoal, but there were stations along this contour that had good catches. For this reason, the 2010 survey incorporated all of the shoal area.

Two hundred and sixty (260) stations were randomly assigned within the 100 m contours on Banquereau. The assignment function allowed a minimum spacing of 2.0 km between tows. Additional stations were generated that could be used as alternates if original stations had to be dropped for some reason. An additional 35 stations from the 2004 survey were selected from areas where no fishing had occurred between the 2004 and 2010 surveys. These were to allow for comparisons between the surveys.

A plot of the station locations (Figure 5) indicated that all areas of the bank were adequately covered.

2.3 – SURVEY GEAR

The vessel used for the survey was the Tenacity 1, a 36 m, 353 GT stern dragger built in 1967. For the 2010 survey, it was equipped with a pump, stern ramp, 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 included both a Microplot 7 navigation package, used to measure tow distance and record the tow track, and a SeaScan bottom discrimination system, used to check the bottom for suitability before using the dredge. The SeaScan system was calibrated against sites with known bottom types before the start of the survey.

A ramp and runner system similar to that used on some of the commercial vessels was installed on the stern of the Tenacity 1. This system made handling the dredge much easier and safer than landing the dredge with a hoist system, but the back of the dredge was a cage and door system rather than the chain bag and codend used in 2004. This meant that the dredge used in 2010 had a lower capacity than that used in 2004, but it was felt that it would also retain less shell.

Tow distance is usually measured from the time 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. The clam survey dredge uses a sensor system 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 angles 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 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.

2.4 – TOW PROCEDURES

At each assigned station, the bottom was first checked with the SeaScan system to determine if it was fishable, i.e. not rocky. If the bottom was fishable, a three minute long tow was then conducted. As a precaution against dredge saturation effects, tow procedures were that if the cage came up full, the tow was to be repeated with the tow time reduced to two minutes, and that an area of high catches identified in the 2004 survey automatically had the tow time reduced to two minutes. 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 two second intervals during the survey, and the dredge sensor system data was recorded for each tow.

2.5 – CATCH PROCESSING

At each station, the volume and weight of the catch was measured by shovelling the entire catch into plastic bushel baskets and counting and weighing the baskets. A Pols® motion-compensating marine scale was used for weighing the baskets. A sample of five bushels was selected and processed for catch composition. After weighing the sample, its components were separated down to species level where possible, as well as debris items such as empty shells, rocks, garbage, etc. A second sample of 20 bushels was taken and processed by picking out clams and all other major bivalves. The catch of major bivalves was thus based on a 25 bushel sub-sample, and catch of other components on a five bushel sub-sample. The sub-samples were selected periodically during the shovelling 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:

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

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.

Catches were all standardized to a tow area of 500 m^2.

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

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.

During laboratory processing, the morphometrics samples were thawed, and the length, width and height of each clam were 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.

2.6 – CATCH COMPOSITION / BY-CATCH

By-catch from the survey was compiled for both the whole survey area and separately for those tows having a catch greater than 100 g/m^2, representing those areas likely to be fished commercially. By-catch was also compared to data from the industry and IOP sampling programs on the commercial vessels. The survey by-catch is recorded in more detail than either the IOP or on-board programs.

2.7 – AGEING

A length stratified, random sub-sample of clams processed for morphometrics was selected for ageing. As growth is initially rapid but levels off with the older ages there are many more ages present in the larger size classes. For this reason, the sampling consisted of 30 clams per 5 mm shell length interval up to 80 mm shell length and 150 clams per 5 mm interval for those over 80 mm. 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 0.6 mm. The section was then ground to its final thickness using increasingly finer grits (125 µm and 30 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 6). 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 of a sample from the reference set 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 6). 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. Ageing results were thus considered reliable as a 5% CV was used for a species with a lifespan of 50 years.

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

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

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 R statistical package (R Development Core Team, 2008).

2.8 – SELECTIVITY

During the second half of the survey, a site which had a clean catch of clams (i.e. little shell debris 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):

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

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:

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

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 was compared to that for the 2004 survey dredge and a commercial clam dredge (Roddick et al., 2007).

2.9 – COMPARISON OF 2004 AND 2010 SURVEYS

Since the vessel and dredge had both been replaced between the 2004 and 2010 surveys with no opportunity to do a comparison study, 35 comparison tows were carried out by repeating tows done during the 2004 survey, selected form areas where there had been no fishing activity between surveys. These were compared with Paired t and Wilcoxon tests and a Kolmogorv-Smirnov test of differences between cummulative distribution functions. They were also plotted against each other and a linear regression calculated.

As another means of comparison, logbook and Vessel Monitoring System (VMS) data were plotted to delineate areas that had not been fished between the 2004 and 2010 surveys. The biomass estimates for these areas were determined using the 2004 and 2010 survey tows and the two estimates compared.

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 2010 survey using the methods of Rago et al. (2006), and applied and modified since 1998 for the Northeast Fisheries Science Centre (NEFSC) Atlantic Surfclam and Ocean Quahog stock assessments (NEFSC, 2007a; NEFSC, 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; NEFSC, 2007a), Atlantic Surfclam (NEFSC, 2003; NEFSC, 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. In practice, estimating indirect effects has been problematic, as it is correlated with other parameters being estimated in the model and is dependent on assumptions about cell size. The current approach used in NEFSC assessments for surfclams and quahogs is to not try to estimate indirect effects (NEFSC, 2007a; NEFSC, 2007b).

A new approach to the patch model uses the same approach, but a finer grid of points (20 cm) to track the area dredged, and simulated annealing to fit the model. Tests using real and simulated data showed similar parameter estimates for the two methods, but the new method produces reduced variance for the estimates (Hennen et al., 2012). The data from the dredge efficiency experiment was analysed using both the latest version of the original Patch model code and by the new approach using the fine grid and simulated annealing.

The estimated dredge efficiency (E) is applied by multiplying the biomass by 1/E to produce an efficiency corrected biomass.

2.11 – BIOMASS ESTIMATION

The estimated survey biomass in the 2010 survey area was calculated by two methods:

1. Random sampling statistics:

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

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 for analysis, but the contour plots were done in t per km^2 for ease in interpretation.

Since the survey dredge retains smaller clams than the commercial dredge the survey biomass represents a higher biomass than the fishable biomass. To obtain an estimate of fishable biomass, a correction to the catch weight for each tow was calculated using the length frequency for that tow and the length-weight regression from the morphometrics sample for that tow. Millar (2010) has shown that the selectivity range for a gear estimated using paired tows will be higher than that estimated using a cover, especially when based on a low number of hauls. The commercial dredge selectivity was estimated using three paired tows, and has lower slope and higher selection range than the selectivity curve estimated from the survey dredge (Figure 7). Applying the difference in the two selectivity estimates would reduce the catch by an unrealistic amount. The approach used was to shift the survey dredge selectivity curve up so that the 50% selectivity size matched that of the commercial dredge. This was done by adding a term for the shift in size to equation 4.

$$P_{adj} = (e^{a+b(L\text{-}shift)}/(1+e^{a+b(L\text{-}shift)})^{1/\delta} \tag{13}$$

The numbers at length for each tow are then multiplied by $P_{adj}/P_{original}$ for each length. The length-weight regression for that tow is used to calculate weight at length for the original and adjusted numbers, and the percent difference in the sums over the tow is applied to the catch weight for that tow. For cases where there was missing data, the average correction for the survey was applied.

The selectivity adjusted catch weight was then used to provide a fishable biomass estimate in the same manner the original catch weight provided a survey biomass estimate.

2.12 – SIZE AND AGE AT SEXUAL MATURITY

Samples for size and age at maturity were collected during the surveys. Small clams were collected from survey tows after length frequency and morphometrics samples were taken. Each clam 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 College 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 Richard's 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 coated with or embedded in epoxy to support them during sectioning and polishing. A Richard's Curve was fit to the age at maturity data using the same method used for the size at maturity data.

2.13 – 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:

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

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_{∞} 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:

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

where $\bar{a}$ is the mean age above recruitment for those clams above the age of recruitment (a_r; i.e., mean of $a - a_r$ for clams over a_r), 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 Banquereau was estimated from the length frequency data using an age-length key 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 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 biomass estimate and landings provide an estimate of F, and the resulting M was compared with that used in the 2004 Banquereau Arctic Surfclam stock assessment (M = 0.08; Roddick et al., 2007).

2.14 – 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.

2.15– 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, Maximum Sustainable Yield (MSY) was used by Chaisson and Rowell (1985) to estimate yield for Arctic Surfclams on Banquereau, but has fallen out of favour 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) = $x\mathrm{MB}_0$ (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 $x\mathrm{MB}_0$ 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 a constant mortality rate based on the MCY approach be used. An F of 0.33M, slightly higher than MCY, was recommended, as all Canadian fisheries have some level of monitoring. This makes it equivalent to 2/3 MSY, when MSY is calculated as $0.5\mathrm{MB}_0$. 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 based on this fishing mortality applied to the most recent fishable biomass estimate was appropriate for Arctic Surfclams on Banquereau (DFO, 2007a; DFO, 2007b).

2.16 – 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 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.

2.17 – DATA FOR OTHER CLAM SPECIES

During the survey, data on Greenland Cockles (*Serripes groenlandicus*), Northern Propellerclams (*Cyrtodaria siliqua*), and Ocean Quahogs (*Arctica islandica*) are also collected, as there has been interest expressed in fishing these species. Catches of these species are recorded during the survey, length frequencies are taken and maturity samples collected. Due to limited freezer space full morphometric sampling cannot be done, and there have been no selectivity or dredge efficiency studies carried out for these species. With this data, the distribution and minimum biomass and some of their important life history parameters for these species can be estimated using the same methods as use for Arctic Surfclams. This gives important baseline data both in case fisheries for these species develop, and for tracking the effects that the Arctic Surfclam fishery may be having on these other large clam species.

3.0 – RESULTS

3.1 – FISHERIES DATA

The distribution of catch by one minute squares breaking the time period of the fishery into three periods is shown in Figure 8. The fishery initially concentrated on an area along the south-east slope of the shoal on eastern Banquereau; as this area was fished down, the fleet moved out to the central and western portions of the bank. The initial area had a large pulse of recruitment that was seen in the 2004 survey (Roddick et al., 2007). At that time, it was just starting to enter the commercial size range. As the recruits in the initial area grew, it has attracted fishing effort back to this area in the last few years. The densities are higher than elsewhere on the bank, but the fleet reports that growth is slower in the high density areas. This trend is currently under investigation.

The CPUE for Banquereau is shown in Figure 9. There has been a large increase in CPUE since 2006. Table 3 shows the catch effort and CPUE for all Banquereau, as well as inside and outside the high density area. CPUE in the high density area has increased more than three fold since 2004, but also doubled outside this area. In the early years of the fishery, as much as 85% of the catch came from this area. It now supplies about 1/3 of the catch and is likely to increase in the future as clam size increases.

3.2 – SURVEY STATIONS

There were 212 survey stations successfully completed during the survey. In addition, there were 27 stations identified as too rocky to tow and 22 that were too deep to successfully tow. Also completed were 19 tows for the dredge efficiency study, three for the selectivity study, and 35 comparison tows.

3.3 – SENSOR DATA

The dredge sensor data was used to determine tow distance. Figure 10 shows the sensor data for a typical tow. The ambient pressure goes up as the dredge sinks 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 of three degrees due to wave action or other factors 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.

3.4 – SELECTIVITY CURVES

Three selectivity tows with a mesh cover over the dredge were conducted during the survey. The shell sizes ranged from 35 to 95 mm with a mean of 55.4 mm in the cover, and 35 to 118 mm with a mean of 84.1 mm in the dredge. There were 322 clams retained in the dredge and 137 in the liner.

The resulting selectivity curve is shown in Figure 11. The size at 50% retention is 62.24 mm. This is similar to the 2009 estimate of 61.53 mm for the same dredge on Grand Bank (Roddick et al., 2011). However, it is smaller than the 87.4 mm estimate for the chain bag and codend dredge used on Banquereau in 2004, or the 85.6 mm estimated for a commercial clam dredge (Roddick et al., 2007).

3.5 – COMPARISON TOWS

During the 2010 survey, 35 tows from the 2004 survey were repeated. These tows were selected from areas where no fishing activity had taken place between the two surveys. Figure 12 shows a scatterplot of the catches from the comparison tows. A linear regression through the origin gives a slope of 0.634 (Standard error = 0.064 and $p < 0.001$). This indicates that the catch rate for the 2010 tows was only 63% of what it was in 2004. This would be due to the relative efficiencies of the two dredges, as a 37% drop in population densities would have been noticed by the fishery. A paired t-test and a Wilcox signed rank test, which makes no assumption of a normal distribution, both indicate significant differences between years ($p =$ 0.004 and 0.001, respectively).

A second method used to compare results, contrasts the biomass estimates for the areas where no fishing had taken place between surveys. Four discreet areas totalling 2,989 km^2 where no fishing activity took place between the 2004 and 2010 surveys were identified from logbook and VMS data (Figure 13). The 2004 and 2010 tows in these areas were used to produce stratified biomass estimates for the unfished area for each survey. The results are shown in Table 4. As the numbers of tows used is low, Satterwaite's effective degrees of freedom was used in calculating the confidence intervals (Cochran, 1963). The confidence intervals are wide and so the biomass estimates are not significantly different, but the 2010 survey biomass for these areas is only 89% of that for the 2004 survey.

These results show that the 2004 and 2010 survey biomass estimates are not directly comparable, and that the estimates cannot be used to indicate a change in biomass between surveys.

3.6 – DREDGE EFFICIENCY

Figure 14 shows the dredge tracks for the depletion study. The original patch model (Rago et al., 2006) 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 2010 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 15. The majority of the clams were fully selected by the gear, with only the left tail of the distribution smaller than the size for 90% retention.

There was good agreement between the two models used to estimate dredge efficiency. The new method for calculating the hit matrix, based on more precise accounting of the dredge location, rather than coarsely assigning it to a "grid cell", helps stabilize the likelihood behaviour. The k parameter was the only estimate that showed any difference between the two models, and k has been shown to be more unstable than the other parameter estimates in application.

The -log likelihood profile for the efficiency estimate using clams larger than the 90% retention size is shown in Figure 16. The profile is rounded, rather than sharp, and that is reflected in the standard deviation for the estimate (Table 5). The best fit estimate of dredge efficiency was 45%. The shape of the likelihood profile produces a confidence interval that is large and skewed to higher values, resulting in a 95% confidence interval of 21-86% (Figure 16). The likelihood profiles for density and k are shown in figures 17 and 18. Figure 19 shows the catch per tow for the depletion tows. The low slope indicates either little overlap or a low efficiency. Figure 14 shows that there was considerable overlap between tows, meaning that the efficiency for the survey dredge was lower than the efficiency of offshore clam dredges used in the U.S. clam fishery, which are estimated to be around 80%, but above the survey dredge used in the U.S surfclam surveys which is 26% (NEFSC, 2010). Figure 20 shows the catch versus the effective area swept by the dredge. This is area swept corrected for overlapping tows and dredge efficiency. One explanation for the negative slope would be that the clams are buried deeper than the dredge is sampling. This would have the effect of higher than expected catches in areas that had previously been dredged, and would agree with the low efficiency estimate. Another explanation for the negative slope would be fine scale patchiness in the distribution of clams. Some of the tow tracks were outside the main area sampled, i.e. tows 3, 10, and 12 (Figure 14), but eliminating these still produced a negative slope.

The reason for the apparent difference in efficiency of the dredges used in 2004 and 2010 are unknown. There were also differences between the 1996-97 survey and that from 2004, which used the same, but modified, dredge. Conducting more depletion experiments or ground-truthing with direct sampling of dredge tracks would provide more confidence in the estimate.

3.7 – BIOMASS ESTIMATES

The results of the simple statistical and ACON biomass estimates are shown in Table 6. The ACON package does not contour beyond the station boundaries. Since the station boundary was inside the survey boundary at some points, the area used is slightly less than that defined by the survey area (Figure 21 and Table 6). The catch rate is shown in Figure 21, contoured with the ACON package. For ease of interpretation the catch per standard tow was converted to t/km^2 for this map and the data table in the upper left corner.

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. 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 biomass estimates are shown in Table 6. The survey biomass is based on the survey catches, standardized to 500 m^2 towed area. The selectivity adjusted catches are used to produce a fishable biomass estimate, and multiplying by the inverse of the dredge efficiency estimate provides efficiency corrected biomass estimates.

The survey biomass estimate (Table 6) is lower than that from the 2004 survey, which was 1,387,088 t. The difference is much more than could be explained as removals by fishing. The comparison tows and area study showed that the 2004 survey was catching significantly more clams than the 2010 survey. There was no dredge sensor system used during the 2004 survey, and we do not have a dredge efficiency estimate for the dredge used then. Without these it cannot be said with certainty the reason for the difference, but will discuss some possibilities.

Applying the efficiency correction of 1/0.4504 to the selectivity adjusted biomass estimate brings it up to 1,150,585 t (Table 6).

3.8 – LENGTH FREQUENCIES

The length frequency for the total survey is shown in Figure 22. There is a mode of small clams less than 50 mm shell length that was not observed in the 2004 survey. As the dredge used in 2010 retained smaller clams than that used in 2004, it cannot be said if this was not present in 2004 or if it is an effect of the gear changes.

3.9 – BY-CATCH

IOP data reports indicate that between 1995 and 2011, 8,744,639 kg of catch was observed on Banquereau. The observers are instructed to obtain the best estimate possible, but the method used, i.e. sub-sampling, visual observation, is not specified or documented (Joe Firth, DFO Newfoundland, pers. comm.). Table 7 shows the catch composition by year. Overall, Arctic Surfclams accounted for 77.71% of the total observed catch, while Northern Propellerclams, Greenland Cockles and Ocean Quahogs were 14.69%, 2.03%, and 0.11%, respectively. The most abundant non-bivalve species reported were Sand Dollars (3.76%), Whelk (0.21%) and Sea Cucumbers (0.18%). The year 2007 stands out for the low number of species; stone and shell were recorded in 2010 and 2011, but not previously. There are a number of non-specified groupings that vary in their use between years, i.e., Skate (NS), Sand Lances (NS) and scallop (NS). Winter Skate were recorded in 1995 but not since. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has listed the eastern Scotian Shelf population of Winter Skate as threatened. Thorny Skate are the most common skate identified. Thorny and Smooth Skate, which was also only reported in 1995, are presently under COSEWIC review and the reports are due in April 2012.

When the rock and shell categories are removed, sand dollars are the only non-bivalves that make up more than 1% of the catch. Arctic Surfclams make up 79% of the living catch overall, and range from 66 to 93% within years.

The on-board sampling of the catch is shown in Table 8. The number of items is between that of the IOP program and the survey sampling. The sampling is done by taking a one bushel sample of the catch and separating the components. The samplers are provided with reference materials, but have limited experience in species identification. Most of the components are at the genus level or higher, accounting for the shorter list than from the survey, where samples can be frozen for later identification. Arctic Surfclams are 49% of the catch or 60% of living material. Sand dollars are 14% of the living material, the only non-bivalve component making up more than 1% of the catch.

To compare the survey by-catch to the commercial catch, the by-catch for areas with a density of 100 g of Arctic Surfclams per m^2 was separated out (Table 9) The species composition is more extensive than the other sampling programs due to the detailed sampling and large sample size. During the survey, the five bushel subsamples used for catch composition amounted to 38 t of catch. There are eight species that make up more than 1% of the catch. sand dollars, sea mice and sea cucumbers are the only non-bivalve species, with sand dollars making up 36% of the catch. This is much higher than either of the programs sampling the commercial vessels and so could be a function of spatial distribution or gear.

3.10 – AGEING

The ageing results are shown in Figure 23. There are a large number of age classes present in the larger sizes; therefore, the aged sample consisted of a random stratified sample with approximately 30 clams per 5 mm shell length increment up to 80 mm and approximately 150 clams per 5 mm increment above 80 mm. Figure 23 displays the sample age versus length scattergram, fitted with von Bertalanffy growth curves for both the aged sample and weighted by population numbers at length. The length frequency histograms of the aged sample and the survey size frequency distribution are to the left of the scattergram, and the age frequency histograms for the sample and estimated for the population are shown below. The age frequency distributions indicate fluctuations in recruitment through time.

3.11 – 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. Taking the estimated size of 50% recruitment (62 mm) and the growth curve gives a recruitment age of 9. From the estimated age distribution (Figure 23) the upper 5% cut off is 50 years of age, and so 3/50 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 Banquereau has been operating since 1986, or about half the lifespan of the surfclams, thus M would be smaller than this estimate of Z, but not to the full extent of F.

Beverton and Holt's method (Equation 9) 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, which means the method does not work when the fully selected size approaches L_∞. The selectivity curve (Figure 11) shows that the size at 95% selectivity is 84 mm. This produces an estimated Z of 0.081912 using the Beverton-Holt method.

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 11) and a wide spread of size at age (Figure 23), too high a cut off would leave few age classes in the analysis. Using the selectivity curve and the size at age distribution, a minimum cut off age of 25 years old was chosen for the 2010 survey, the same used for the dredge for the 2009 Grand Bank survey. The upper age limit was set as the first age group with no clams. Figure 24 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 catch curve estimate of Z is 0.07905.

The Chapman and Robson mortality estimate in Equation 11 (Chapman and Robson 1960), again using 25 as the recruitment age, gives estimates of Z = 0.075501.

Mortality estimates are thus in the range of 0.06 to 0.082. 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 24,000 t would produce an estimated fishing mortality rate of 0.0135. The fishery has not reached the TAC, and for 1987 to 2010 has landed an average of 12,855 t, which gives an F of 0.007. 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 and, for consistency and compatibility with previous assessments, it was decided that there was no reason to change the M from 0.08.

3.12 – RECRUITMENT ESTIMATES

Using Equation 12 and converting the numbers at age shown for the catch curve in Figure 24 back to a common age (Age 25), gives the Age 25 recruitment pattern shown in Figure 25. The length-age key from the ageing sample shown in Figure 23 was based on approximately 150 clams per 5 mm increment for sizes above 80 mm. Although this is a larger sample than used in past assessments, it is not large when there are up to 80 age classes present in size groups around L_∞. This estimate provides the best information on hand of past recruitment patterns.

Recruitment appears to vary through time, 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 the survey, and weighting by the number of tows, gives an overall average of 2,329 clams per year at Age 25. Since these numbers are based on those actually caught in the survey tows, it needs to be expanded to the survey area and adjusted for the dredge efficiency. Adjustment for these factors provides an estimate of average recruitment to Banquereau of 493 million clams at Age 25 per year. This is a large number of recruits, but amounts to an average of one recruit per 20.5 m^2 over the surveyed area.

More recent recruitment pulses can be seen in the length frequency (Figure 22) and survey age frequency (Figure 23). The large year class centered on the eastern end of Banquereau has recruited to the fishery and is seen in Figure 23 as a mode of 20 year old clams. There is another mode around 15 years old that should be recruiting to the fishery over the next few years, and a mode of clams less than 50 mm that will recruit in approximately ten years.

During the 2007 framework assessment, two of the uncertainties identified were whether the recruitment pulse seen on the eastern end of Banquereau was a recurring process, and how such pulses might supplement any smaller, ongoing recruitment to the population. There is now evidence of three such pulses supplementing a lower background level of recruitment. Tracking these pulses as they move through the fishery will add to the knowledge of the recruitment process on Banquereau.

Overall, there appears to be a broad range of ages present in the population, which indicates that the fishery is not dependent on incoming recruitment.

3.13 – SIZE AND AGE AT SEXUAL MATURITY

A total of 87 surfclams ranging in size from 23 to 99 mm were processed for maturity and sex, and 84 of these were aged, ranging in age from 5 to 41 years (Table 10). The resulting maturity data were fit with a Richard's Curve using maximum likelihood. Figures 26 and 27 show curves fit to the size and age at maturity, respectively. The size at 50% maturity was 45.2 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 8.3 years old. These values are larger and older than that of the Grand Bank population, which were 39.9 mm and 5.3 years, respectively.

3.14 – YIELD PER RECRUIT ESTIMATES

The yield per recruit analysis can be seen in Figure 28. For this analysis, the selectivity of a commercial dredge was used and the fishing mortality includes an incidental mortality on small clams not retained by the dredge of 15% (Roddick et al., 2007). The estimate for F_{MAX} was 0.138 and F0.1 was 0.082. The levels of some common Spawning Stock Biomass per Recruit reference levels are also indicated. Fishing at $F_{0.33M}$ would reduce the standing stock biomass to 72% of what it would be in an unfished state, while fishing at $F_{0.01}$ and F_{MAX} would reduce it to 42% and 26% of the unfished state. This would have implications for the economics of the fishery through the impact on CPUEs.

3.15 – SENSITIVITY TO EXPLOITATION

To look at the Arctic Surfclam's sensitivity to growth and recruitment overfishing, the selectivity of the commercial gear can be compared to some of the clam's life history parameters. Figure 29 plots the Maturity at Age and Biomass per Recruit at Age along with the selectivity of the commercial gear converted to an age based curve using the population growth curve for Banquereau. The estimated age for 50% selectivity is 15.3 and the age at maximum Biomass per Recruit is 16.1. This should help prevent growth overfishing, as the present commercial gear is selecting for clams that have reached their maximum yield. The estimated age for 50% selectivity is also above the 8.3 years for age at 50% maturity. This indicates that individuals have 8 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.

3.16 –DISTRIBUTION OF OTHER MAJOR BIVALVES

The distribution of major bivalves on Banquereau from the 2010 survey data is shown in Figure 30. Data on the distribution of other species caught in the by-catch are also available, but based on smaller sample sizes. The length frequencies and maturity data are also available for other clam species. The distribution of Atlantic Surfclams (*Spissula solidissima*) on the shallow area on the eastern end of Banquereau is of interest, as this is the species that supplies the U.S. surfclam fishery. The population off the U.S. east coast has been declining at the southern end of its range, and this decline has been attributed to climate change (Weinberg, 2005; Marzec et al., 2010). With this baseline data on the current distribution on Banquereau, it will be interesting to see if this species expands from its present distribution in the future.

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 ten years (Gilkinson et al., 2003; Gilkinson 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 (Gilkinson et al., 2005).

There has been little recruitment of large bivalve species to the experimental study site over the ten years, and sidescan sonar was still able to detect some of the tracks ten years after dredging. The sidescan results infer that changes to the sediment structure caused by dredging can persist for ten 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 one year later, only six 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.

One of the aspects of habitat impact is the footprint of the fishery. The logbook data allows the estimation of the area towed per year. This estimate is a maximum as there is no correction for overlapping tows. Table 11 shows the area towed per year and the percentage of the area of Banquereau that it represents. The maximum annual footprint was 2.5% of the area of the bank. There are large areas that do not have the density to attract commercial effort, which will concentrate the effort on the high density areas. The area fished at the start of the fishery was not returned to for more than 15 years. Since the target species is one of the longer lived species in the benthos it will be one of the last species to recover from fishing. This should allow the shorter lived, faster growing species time to recover before the area is fished again.

Figure 31 shows the footprint of the fishery for the history of the fishery, the last ten years and the last two years. The foot print for the last two years should approximate the area where the shorter lived benthic species are still recovering from the effects of fishing.

5.0 – DISCUSSION

The Arctic Surfclam stock on Banquereau appears to be healthy. CPUE indicates that the biomass has increased since 2004, and the current fishing mortality is below the target F. Reference points are still being developed for this fishery. The recommended target F is $F_{0.33M}$ =0.0264. Setting a corresponding target biomass is difficult as there has been no stock recruit relationship established due to a lack of contrast in the data, i.e. no periods of high and low biomass. Most bivalves are broadcast spawners producing large numbers of eggs per individual, making environmental conditions more important than stock size at healthy biomass levels. The biomass per recruit analysis can be used to estimate a target biomass. The biomass per recruit analysis shows that fishing at $F_{0.33M}$ would reduce the biomass per recruit to 73% of the biomass per recruit with no fishing. This would make the target biomass $0.73B_0$. This is a conservative target, and can be compared to ones like the default Marine Stewardship Council default biomass target of $0.4B_0$. This means that the biomass is maintained at a higher level than would be with a more aggressive target, the trade-off being more stable landings and a higher CPUE against foregone landings that would result from the more aggressive target.

The 2007 assessment meeting recommended an F calculated as 0.33M be used as the target fishing mortality for Banquereau Arctic Surfclams. In applying this to the 2009 Grand Bank assessment, DFO Maritimes, Fisheries Management Branch further refined this by applying the target F to the biomass in areas with a density greater than 75 g/m^2. Grand Bank had large areas with a density less than this level. Applying the target $F_{0.33M}$ to the selectivity adjusted efficiency corrected biomass would result in a target TAC of 30,375 t. However, a contour plot of the selectivity adjusted efficiency corrected biomass estimate for Banquereau (Figure 32) shows that 92% of the biomass is in areas with a density above 75 g/m^2; therefore, applying the target F to just the biomass within this area would not make as large a difference as on Grand Bank.

Recruitment patterns indicated by back-calculation from the current age structure show fluctuations over time, typical of most bivalve populations. In 2004, the survey results and reports from the vessels showed that the area that had been fished heavily at the beginning of the fishery experienced a recruitment pulse several years later. The densities of Arctic Surfclams in this area were higher than observed anywhere else (Figure 8). The 2010 survey length frequencies show a pulse of pre-recruits less than 50 mm. Plotting the distribution of the catch of clams less than 50 mm on top of the aggregated catches from 1986-2010 (Figure 33) shows the current pre-recruits occur in areas that have been heavily fished, but also in areas without fishing effort. Since the fleet has by now had time to fully explore the bank, the distribution of effort probably reflects the productivity of the area.

The current biomass estimate of 1,150,585 t is slightly less than the 2004 estimate of 1,462,057 t. This cannot be attributed to an actual change in biomass as the CPUE indicates that biomass has increased during this time. Average catch for 2004 to 2010 was 18,569 t for an F of 0.016 compared to the target F of $F_{0.33M}$ = 0.0264.

The use of survey biomass estimates to track the health of the Arctic Surfclam stock is complicated by the changes in vessels and gear between surveys. The use of the dredge sensor system and efficiency studies will help to explain differences in surveys in the future, as it is likely that the next survey of this stock will use at least a different vessel. The reasons for the difference between the 2004 and 2010 surveys cannot be determined; there were large differences in the dredges and the way they were deployed, the winch used in 2004 was free spinning while that used in 2010 paid out under power, there was more hose used in 2004, and of course the different vessels.

6.0 – CONCLUSIONS

The Banquereau Arctic Surfclams stock is healthy, and CPUE indicates biomass has increased since 2004. 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. The differences in the surveys through time mean we cannot look at survey trends, but the current efficiency corrected biomass estimate is 1,150,585 t. Applying the target Fishing Mortality $F_{0.33M}$ recommended from the 2007 assessment would result in a TAC of 30,375 t.

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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
2010	286	22,559	0	22,845

Note: 1987 to 2009 from Offshore Clam Management Plan; 2010 from Statistics Branch Newfoundland Region.

Table 2. Testing results comparing readers results ageing sample from reference collection against consensus ages.

Age (y)	Count	% Agreement	CV %	Bias (y)	% Bias
7	1	100.0	0.0	0.00	0.0
8	1	100.0	0.0	0.00	0.0
10	2	50.0	3.4	-0.50	-0.5
13	4	100.0	0.0	0.00	0.0
14	9	55.6	2.2	0.00	0.0
15	6	100.0	0.0	0.00	0.0
16	2	100.0	0.0	0.00	0.0
18	2	0.0	3.8	0.00	0.0
19	9	55.6	1.6	0.00	0.0
20	4	50.0	1.7	0.00	0.0
21	5	100.0	0.0	0.00	0.0
22	3	66.7	1.0	-0.33	-0.1
23	5	60.0	1.2	0.40	0.1
24	6	83.3	0.5	0.17	0.0
25	6	66.7	1.4	-0.17	-0.0
26	4	75.0	0.7	0.25	0.0
27	5	80.0	0.5	-0.20	-0.0
28	1	100.0	0.0	0.00	0.0
29	3	66.7	0.8	0.33	0.0
30	2	100.0	0.0	0.00	0.0
31	2	50.0	1.1	-0.50	-0.1
32	2	50.0	1.1	0.50	0.0
33	2	50.0	1.1	0.50	0.0
34	1	100.0	0.0	0.00	0.0
35	2	50.0	1.0	-0.50	-0.0
36	4	0.0	2.4	0.75	0.1
38	1	0.0	1.8	-1.00	-0.1
39	3	100.0	0.0	0.00	0.0
40	2	0.0	1.7	1.00	0.1
41	1	0.0	3.4	-2.00	-0.1
42	8	50.0	1.0	0.63	0.0
43	4	75.0	0.8	-0.50	-0.0
44	2	0.0	4.0	1.50	0.1
45	1	100.0	0.0	0.00	0.0
46	2	50.0	3.8	-2.50	-0.1
47	4	25.0	1.5	0.50	0.0
48	1	0.0	1.5	1.00	0.0
49	1	100.0	0.0	0.00	0.0
50	1	0.0	1.4	-1.00	-0.0
54	1	0.0	3.9	3.00	0.1
56	1	100.0	0.0	0.00	0.0
59	1	0.0	2.4	2.00	0.1
76	2	0.0	2.3	0.50	0.0
Average		60.47	1.22		

Table 3. Catch Effort and Catch per Unit Effort (CPUE) for high density area on Eastern Banquereau.

	Banquereau			High Density Area			Banquereau outside HD Area			
Year	Effort (1000m^2)	Catch (t)	CPUE (kg/m^2)	Effort (1000m^2)	Catch (t)	CPUE (kg/m^2)	Effort (1000m^2)	Catch (t)	CPUE (kg/m^2)	% inside
1986	843	29	0.038	418	21	0.051	424	9	0.023	70.5
1987	16,059	1,210	0.081	3,156	234	0.081	12,903	976	0.080	19.4
1988	24,193	2,451	0.101	2,122	265	0.127	22,071	2,187	0.099	10.8
1989	84,478	9,134	0.109	62,736	7,800	0.125	21,743	1,334	0.061	85.4
1990	68,198	6,158	0.092	12,155	1,528	0.126	56,044	4,630	0.085	24.8
1991	9,716	715	0.076	0	0	0.000	9,716	715	0.076	0.0
1993	855	64	0.047	0	1	0.000	855	63	0.047	1.3
1994	39,469	5,313	0.136	112	5	0.048	39,357	5,307	0.136	0.1
1995	83,960	11,413	0.137	785	76	0.097	83,176	11,337	0.138	0.7
1996	153,515	19,254	0.122	233	17	0.070	153,282	19,237	0.122	0.1
1997	154,055	19,365	0.125	203	7	0.032	153,852	19,358	0.125	0.0
1998	236,829	24,536	0.104	567	51	0.089	236,262	24,485	0.104	0.2
1999	253,139	24,124	0.096	0	0	0.000	253,139	24,124	0.096	0.0
2000	233,206	20,224	0.087	0	0	0.000	233,206	20,224	0.087	0.0
2001	158,882	11,002	0.070	238	15	0.062	158,644	10,987	0.070	0.1
2002	148,994	12,479	0.085	9,592	844	0.088	139,402	11,635	0.085	6.8
2003	146,588	16,919	0.116	1836	162	0.088	144,751	16,757	0.116	1.0
2004	149,382	16,468	0.110	636	57	0.089	148,746	16,411	0.110	0.3
2005	141,479	14,321	0.101	1,657	209	0.126	139,822	14,112	0.101	1.5
2006	116,772	15,904	0.137	22,141	5,009	0.228	94,631	10,895	0.116	31.5
2007	103,892	17,846	0.173	26,808	6,658	0.247	77,083	11,188	0.147	37.3
2008	81,294	18,805	0.230	16,854	6,212	0.362	64,440	12,593	0.195	33.0
2009	97,855	24,135	0.248	29,487	9,042	0.307	68,369	15,094	0.222	37.5
2010	86,392	22,507	0.261	22,535	7,216	0.321	63,857	15,292	0.240	32.1

percent class 1 data Banquereau records = 96.7
percent class 1 data HDA records = 96.3
percent class 1 data Banquereau outside HDA records = 96.8

Table 4. Stratified estimate for unfished areas from 2010 and 2004 surveys.

A) 2010 estimate.

Area	n	Mean	Weight	Variance	Std. Dev	Std. Err
1	12	3.25	0.2088	12.2839	3.5048	1.0118
2	18	10.60	0.3235	109.4521	10.4619	2.4659
3	23	60.66	0.3807	1,847.5898	42.9836	8.9627
4	6	15.54	0.0870	636.3407	25.2258	10.2983

Stratified Mean	=	28.5567
Var of St. Mean	=	13.1277
St.Err of St. Mean	=	3.62322
Stratified Total	=	170,712
Var of St. Total	=	4.69139E+008
St.Err of St.Total	=	21,659.6
Effective df	=	23
95% Confidence Int.	=	± 44,813.8

B) 2004 estimate.

Area	n	Mean	Weight	Variance	Std. Dev	Std. Err
1	12	30.2693	0.2088	1,759.7873	41.9498	12.1099
2	14	28.0773	0.3235	2,675.2637	51.7230	13.8235
3	35	43.8185	0.3807	1,782.1604	42.2156	7.1357
4	3	1.3706	0.0870	1.9544	1.3980	0.8071

Stratified Mean	=	32.205
Var of St. Mean	=	33.7777
St.Err of St. Mean	=	5.8119
Stratified Total	=	192,521
Var of St. Total	=	1.2071E+009
St.Err of St.Total	=	34,743.3
Effective df	=	26
95% Confidence Int.	=	± 71,432.2

Ratio 2010 total/2004 total =170,712/192,521 = 0.89

Table 5. Parameter estimates for dredge efficiency model.

Parameter	Value	Std. Dev.
Efficiency	0.4504	0.4779
Density	0.2508	0.2355
k	5.8338	2.0798

Table 6. Biomass estimates from 2010 Banquereau offshore clam survey.

Survey Biomass Estimates	
Simple statistical model	
Average Catch per Standard Tow (kg)	39.47
Number of tows used in analysis	239
Area of survey (km^2)	10,110
Total Biomass Estimate (t)	798,085
95% confidence interval	± 17,891*
ACON estimate = areal expansion	
Number of tows used in analysis	239
Area within station boundaries (km^2)	9,025
Total Biomass Estimate (t)	744,864
Selectivity Adjusted Biomass Estimate	
Average Catch per Standard Tow (kg)	25.63
Number of tows used in analysis	239
Area of survey (km^2)	10,110
Total Biomass Estimate (t)	518,223
95% confidence interval	± 13,854
Selectivity Adjusted and Efficiency Corrected Biomass Estimate	
Average Catch per Standard Tow (kg)	56.9033
Number of tows used in analysis	239
Area of survey (km^2)	10,110
Total Biomass Estimate (t)	1,150,585
95% confidence interval	20,643

** Confidence intervals shown are that for the biomass estimate assuming the catch per tow values are correct, i.e. no additional variance for adjustments made is included.*

Table 7. International Observer Program (IOP) data on species caught for the Banquereau Arctic Surfclam fishery by year.

	2011	2010	2009	2007	1995	Total
Common Name			**Weight (kg)**			
Arctic Surfclam	535,352	1,010,002	1,894,933	1,390,114	1,964,746	6,795,147
Northern Propellerclam	128,150	28,089	707,588	238,313	182,521	1,284,661
Sand Dollars	60,445	36,810	227,994	3,795		329,044
Greenland Smoothcockle	9,194	129	61,257	99,488	7,493	177,561
Shells	53,310	8,260				61,570
Stone	33,975	4,600				38,575
Whelk	6,625	1,052	10,891			18,568
Sea Cucumber *(C. frondosa)*	430	5,345	910		5,516	12,201
Sea Cucumber NS *(Holothuroidea)*			3,221			3,221
Ocean Quahog	28	70	7,011		2,150	9,259
Snow Crab	112		2,937	58		3,107
Thorny Skate	25	1,046	87		1,788	2,946
Skates (NS)	2	1	961		104	1,068
Sea Star	19		1,286			1,305
Sea Star Lept Pol		341	41			382
Blue Mussel			1,045		174	1,219
Mussel		37				37
Green Sea Urchin	406	240	43		299	988
Seasnail (NS)					659	659
Sea Scallop	5	2	230			237
Scallop (NS)		416	33		113	562
Iceland Scallop	95	10	406		35	546
Atlantic Lyre Crab					253	253
Lyre Crab NS	15		72			87
Hermit Crab	106	16	102			224
Sand Lances (NS)	100	48				148
Yellowtail Flounder	8	45	97		41	191
Offshore Sand Lance			104		13	117
American Plaice		1	123		95	219
Winter Skate					112	112
Longhorn Sculpin		3	113			116
Witch Flounder			107			107
Atlantic Surfclam		100				100
Atlantic Cod			2		35	37
Monkfish					31	31
Soft Coral	4	7	1			12
Spiny Dogfish					7	7
Sculpins (NS)					6	6
Smooth Skate					3	3
Jonah Crab			3			3
Haddock					2	2
White Hake					1	1
Total Weight Observed	**828,406**	**1,096,670**	**2,921,598**	**1,731,768**	**2,166,197**	**8,744,639**

Table 8a. Catch composition estimated from the on-board sampling program 1999-2009.

Scientific Name	Weight (kg)	%	Cumulative %
Mactromeris polynyma	3722.21	49.01	49.01
Cyrtodaria siliqua	1215.99	16.01	65.02
Shell	1028.04	13.54	78.55
Echinarachnius parma	917.98	12.09	90.64
Rock	358.27	4.72	95.36
Serripes groenlandicus	112.75	1.48	96.84
Arctica islandica	73.90	0.97	97.81
Aphrodita hastata	35.33	0.47	98.28
Mytilus	24.67	0.32	98.60
Buccinum	20.51	0.27	98.87
Buccinidae	17.83	0.23	99.11
Neptunea lyrata decemcostata	14.12	0.19	99.30
Strongylocentrotus droebachiensis	13.35	0.18	99.47
Cucumaria frondosa	8.01	0.11	99.58
Asterias	5.97	0.08	99.66
Pagurus	5.08	0.07	99.72
Siliqua sp.	3.56	0.05	99.77
Colus	3.34	0.04	99.81
Cancer	2.56	0.03	99.85
Ammodytes	2.33	0.03	99.88
Ophiuroidea	2.27	0.03	99.91
Rajidae	1.70	0.02	99.93
Annelida	1.33	0.02	99.95
Placopecten magellanicus	1.26	0.02	99.96
Gastropoda	1.20	0.02	99.98
Bivalvia	0.58	0.01	99.99
Mesodesma arctatum	0.40	0.01	99.99
Chlamys islandica	0.27	0.00	100.00
Unidentified - worm like	0.20	0.00	100.00
Euspira heros	0.15	0.00	100.00
Total weight sampled	**7,595.10**		

Table 8b. Coverage on on-board sampling program 1999-2009.

Year	Total Trips (from logs)	Total Trips sampled on Banquereau	% Sampled
1999	24	1	4.1
2000	22	5	22.7
2001	14	3	21.4
2002	15	9	60.0
2003	16	13	81.3
2004	18	15	83.3
2005	19	6	31.6
2006	17	1	5.9
2007	20	0	0
2008	17	5	29.4
2009	21	17	81.0

Table 9. Catch composition for living components of catch from 2010 Banquereau survey tows where surfclam catch is greater than or equal 100 g/m^2.

Common Name	Scientific Name	Weight (kg)	%	Cumulative %
Arctic Surfclam	*Mactromeris polynyma*	5551.86	42.20	42.20
Sand Dollars	*Echinarachnius parma*	4670.60	35.50	77.70
Northern Propellerclam	*Cyrtodaria siliqua*	1118.73	8.50	86.20
Sea Mouse	*Aphrodita hastata*	292.40	2.22	88.42
Greenland Smoothcockle	*Serripes groenlandicus*	280.92	2.14	90.56
Common Sea Cucumber	*Cucumaria frondosa*	248.61	1.89	92.45
Ocean Quahog	*Arctica islandica*	142.79	1.09	93.54
Arctic Wedgeclam	*Mesodesma arctatum*	141.90	1.08	94.61
Thin Whelk	*Buccinium totteni*	128.16	0.97	95.59
Sinuous Whelk	*Buccinum plectrum*	99.59	0.76	96.34
Green Sea Urchin	*Strongylocentrotus droebachiensis*	78.73	0.60	96.94
Iceland Scallop	*Chlamys islandica*	68.00	0.52	97.46
Gilded Wedgeclam	*Mesodesma deauratum*	55.86	0.42	97.88
Whelk - Buccinum sp.	*Buccinum*	41.10	0.31	98.20
American Sand Lance	*Ammodytes americanus*	35.91	0.27	98.47
Hermit Crab NS	*Pagurus*	27.80	0.21	98.68
Blue Mussel	*Mytilus edulis*	26.88	0.20	98.89
Sea Scallop	*Placopecten magellanicus*	19.73	0.15	99.04
Bluish Whelk	*Buccinium cyanneun*	17.40	0.13	99.17
Waved Whelk	*Buccinum undatum*	13.09	0.10	99.27
Winter Skate	*Leucoraja ocellata*	12.67	0.10	99.36
Rough Razor	*Siliqua squama*	10.57	0.08	99.44
Snow Crab	*Chionoecetes opilio*	10.15	0.08	99.52
Sea Anemone NS	*Actiniaria*	7.72	0.06	99.58
Ventricose Whelk	*Colus terraenovae*	6.35	0.05	99.63
American Plaice	*Hippoglossoides platessoides*	5.97	0.05	99.67
Slender Sea Star	*Leptasterias*	5.47	0.04	99.71
Wrinkle Whelk	*Neptunea lyrata decemcostata*	5.13	0.04	99.75
Thorny Skate	*Amblyraja radiata*	4.75	0.04	99.79
Sea Strawberry	*Gersemia rubiformis*	3.08	0.02	99.81
Whelk - Colus sp.	*Colus*	3.02	0.02	99.84
Sponge	*Porifera*	2.46	0.02	99.85
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*	2.32	0.02	99.87
Ladder Whelk	*Buccinum scalariforme*	2.20	0.02	99.89
Disreputable Whelk	*Neptunea despecta*	1.84	0.01	99.90
Stimpsoni Whelk	*Colus stimpsoni*	1.38	0.01	99.91
Rough/Spiny Sunstar	*Crossaster papposus*	1.19	0.01	99.92
Daisy Brittle Star	*Ophiopholis aculeata*	1.10	0.01	99.93
Skate NS	*Rajidae*	1.04	0.01	99.94
Iceland Moonsnail	*Amauropsis islandica*	0.86	0.01	99.95
Smooth Brittle Star	*Ophiura sarsi*	0.72	0.01	99.95
Arctic Lyre Crab	*Hyas coarctatus*	0.62	<0.01	99.96
Winter Flounder	*Pseudopleuronectes americanus*	0.60	<0.01	99.96

Table 9. Continued.

Common Name	Scientific Name	Weight (kg)	%	Cumulative %
Grammaria Hydrozoa	*Grammaria*	0.55	<0.01	99.96
Grey Sole / Witch Flounder	*Glyptocephalus cynoglossus*	0.54	<0.01	99.97
White Burrowing Cucumber	*Stereoderma unisemita*	0.44	<0.01	99.97
Psolus phantapus	*Psolus phantapus*	0.42	<0.01	99.97
Featherduster Worm	*Sabellidae*	0.33	<0.01	99.98
Eyed Finger Sponge	*Haliclona oculata*	0.27	<0.01	99.98
Sertularia Hydrozoa	*Sertularia*	0.26	<0.01	99.98
Nephtyidae NS	*Nephtyidae*	0.25	<0.01	99.98
Atlantic Lyre Crab	*Hyas araneus*	0.23	<0.01	99.99
Starfish NS	*Asterias*	0.21	<0.01	99.99
Hairy Cockle	*Clinocardium ciliatum*	0.21	<0.01	99.99
Purple Sunstar	*Solaster endeca*	0.20	<0.01	99.99
Northern Moonsnail	*Euspira heros*	0.18	<0.01	99.99
Tunicate	*Tunicata*	0.18	<0.01	99.99
Sandbar Worm	*Ophelia limacina*	0.18	<0.01	99.99
Moonsnail NS	*Naticidae*	0.13	<0.01	99.99
Whelk NS	*Buccinidae*	0.12	<0.01	100.00
Razor Clam	*Siliqua*	0.11	<0.01	100.00
Lemonweed Bryozoan	*Flustra foliacea*	0.09	<0.01	100.00
Blood Star	*Henricia sanguinolenta*	0.09	<0.01	100.00
Mussel	*Mytilus*	0.07	<0.01	100.00
Nipple Sponge	*Polymastia*	0.06	<0.01	100.00
Thecate Hydroid NS	*Leptothecatae*	0.06	<0.01	100.00
Striped Shrimp	*Pandalus montagui*	0.05	<0.01	100.00
Atlantic Razor	*Siliqua costata*	0.01	<0.01	100.00
Hairy Whelk	*Colus pubescens*	0.01	<0.01	100.00
Sertularella tricuspidata	*Sertularella tricuspidata*	0.00	<0.01	100.00
Sea Fir	*Abietinaria abietina*	0.00	<0.01	100.00
Polychaete NS	*Polychaeta*	0.00	<0.01	100.00
Ragworm NS	*Nereis*	0.00	<0.01	100.00
Northern Cyclocardia	*Cyclocardia borealis*	0.00	<0.01	100.00
Wavy Liocyma	*Liocyma fluctuosum*	0.00	<0.01	100.00
Pericladium Hydrozoa	*Pericladium mirabilis*	0.00	<0.01	100.00

Table 10. Size (A) and age (B) at maturity data for Mactromeris polynyma from Banquereau 2010 survey.

A. Shell Length.

	Immature	Mature Male	Mature Female
Average	39.12	70.62	73.51
Std. Dev.	10.23	18.39	14.95
Minimum	22.7	42.3	43.1
Maximum	64.7	99.1	99.0
n	22	36	29

B. Age.

	Immature	Mature Male	Mature Female
Average	8.52	16.74	15.72
Std. Dev.	3.88	7.52	5.08
Minimum	5.0	7.0	6.0
Maximum	19.0	41.0	29.0
n	21	35	29

Table 11. Area dredged and footprint of the fishery by year. Footprint is area dredged from logbooks as the % of the area within the 100 m contour on Banquereau. It does not account for overlapping tows.

Year	Area Dredged (km^2)	% Area
1986	1.1	0.01
1987	16.1	0.16
1988	24.2	0.24
1989	84.5	0.84
1990	68.2	0.67
1991	9.8	0.10
1992	0.0	0.00
1993	0.9	0.01
1994	39.5	0.39
1995	84.0	0.83
1996	153.7	1.52
1997	155.5	1.54
1998	237.1	2.35
1999	253.1	2.50
2000	233.2	2.31
2001	159.0	1.57
2002	149.6	1.48
2003	147.2	1.46
2004	149.9	1.48
2005	141.5	1.40
2006	116.8	1.16
2007	104.2	1.03
2008	83.4	0.82
2009	97.9	0.97
2010	86.6	0.86
Total	**2,597.0**	**25.69**

9.0 – FIGURES

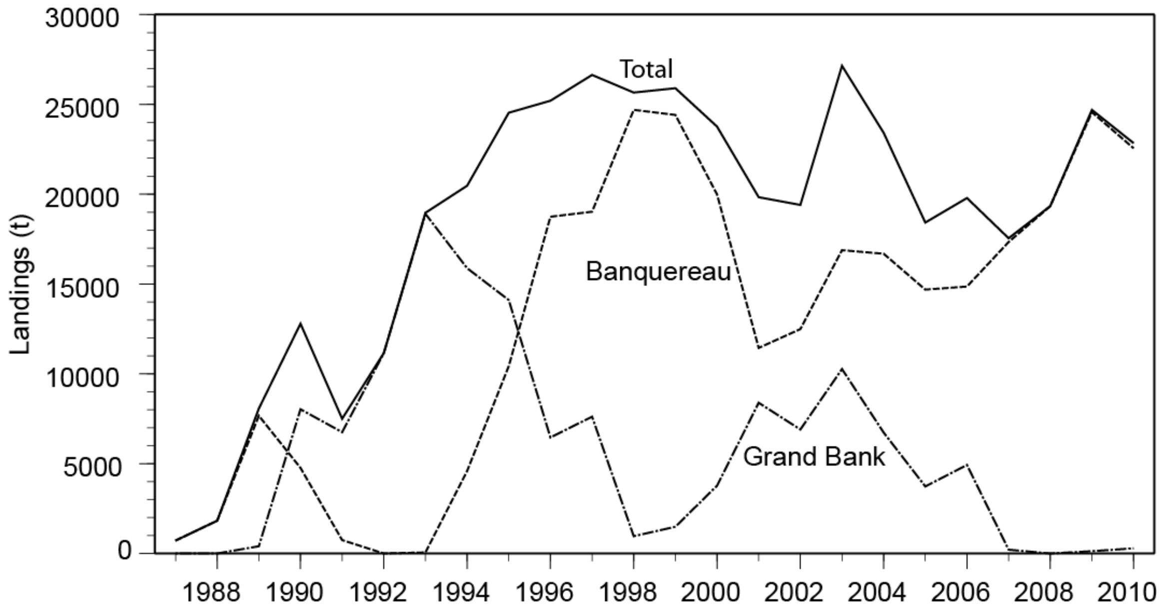

Figure 1. Landings of Arctic Surfclams from the Banquereau and Grand Bank fisheries.

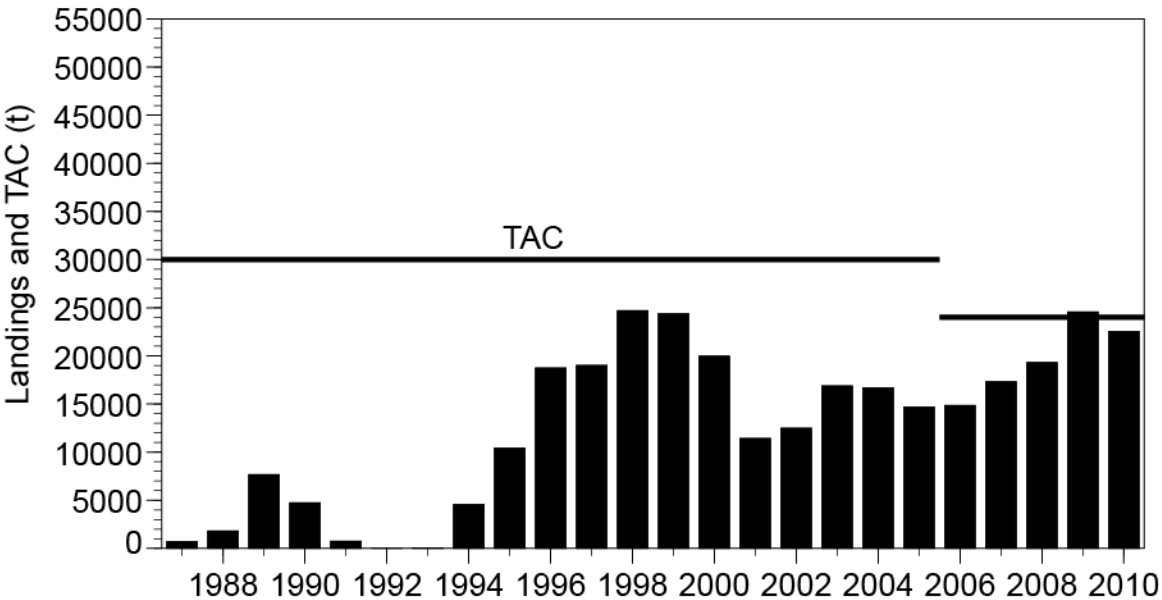

Figure 2. Landings and Total Allowable Catch (TAC) for the Banquereau Arctic Surfclam fishery.

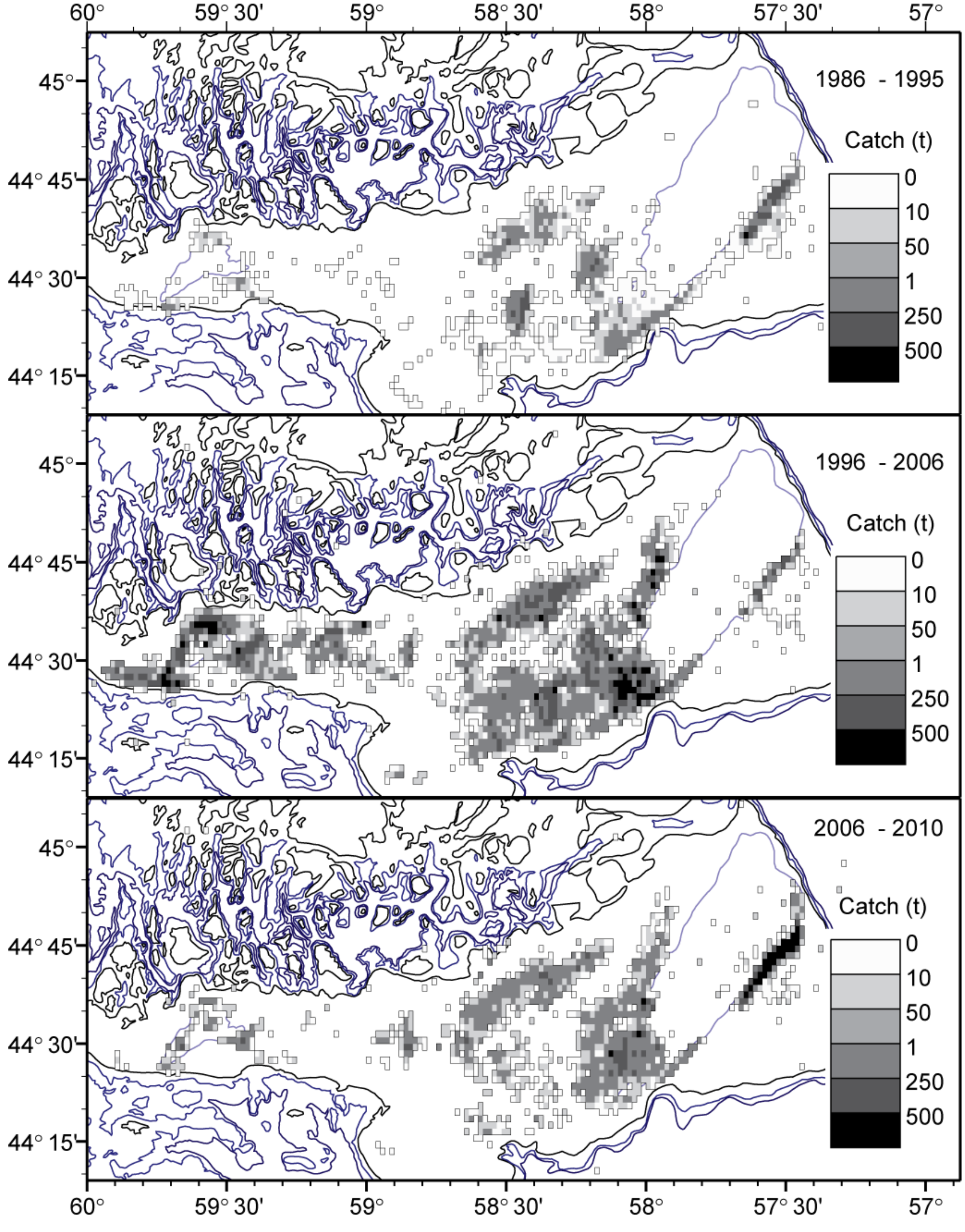

Figure 3. Distribution of Arctic Surfclam catch on Banquereau. Catch is aggregated by one minute squares for the period listed.

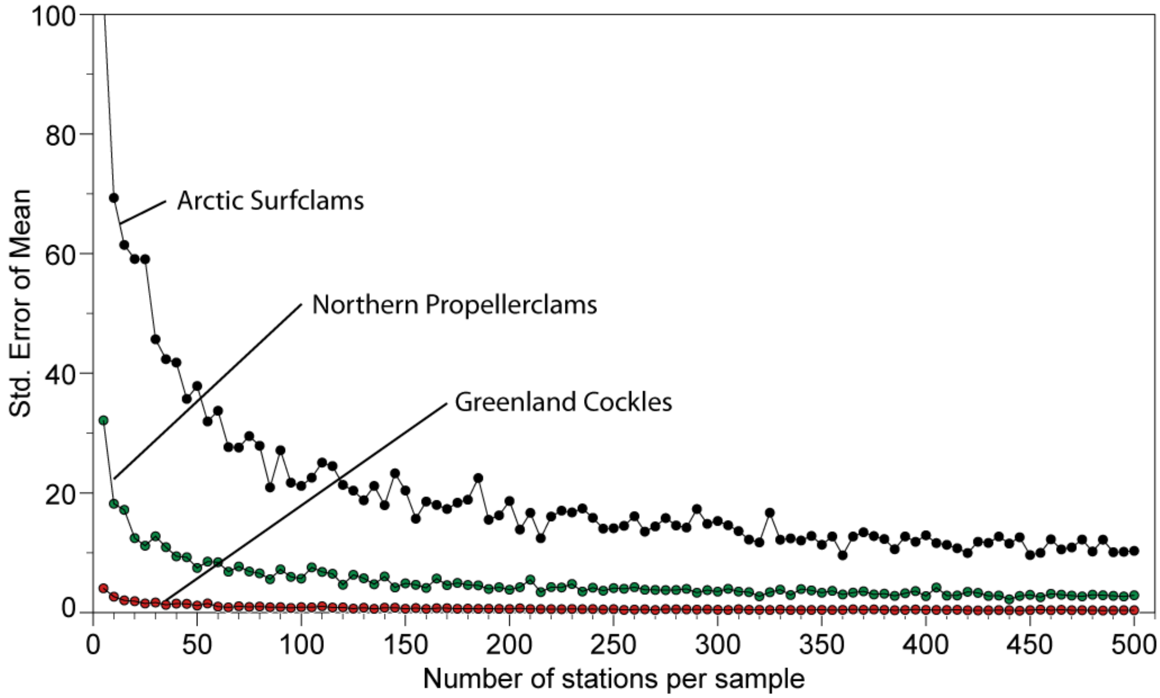

Figure 4. Change in standard error of the catch with number of tows for the three large bivalve species caught during the 2004 offshore clam survey of Banquereau.

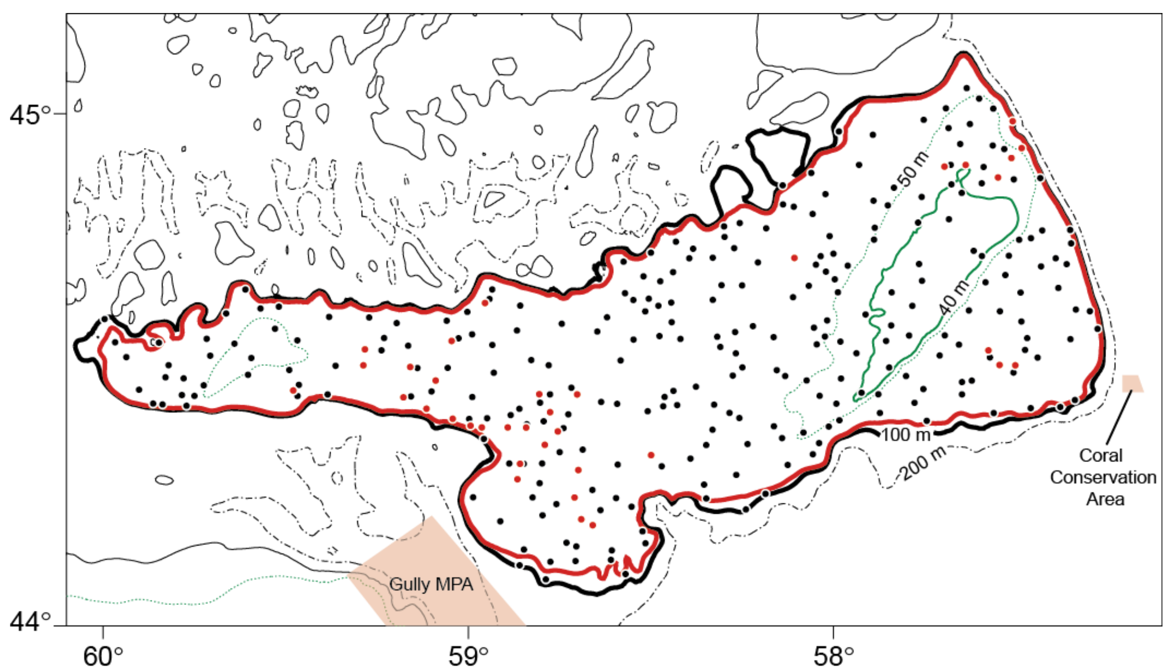

Figure 5. Station locations for 2010 Banquereau Arctic Surfclam survey. Red line is survey boundary, black dots are survey stations and red dots are repeated 2004 survey stations.

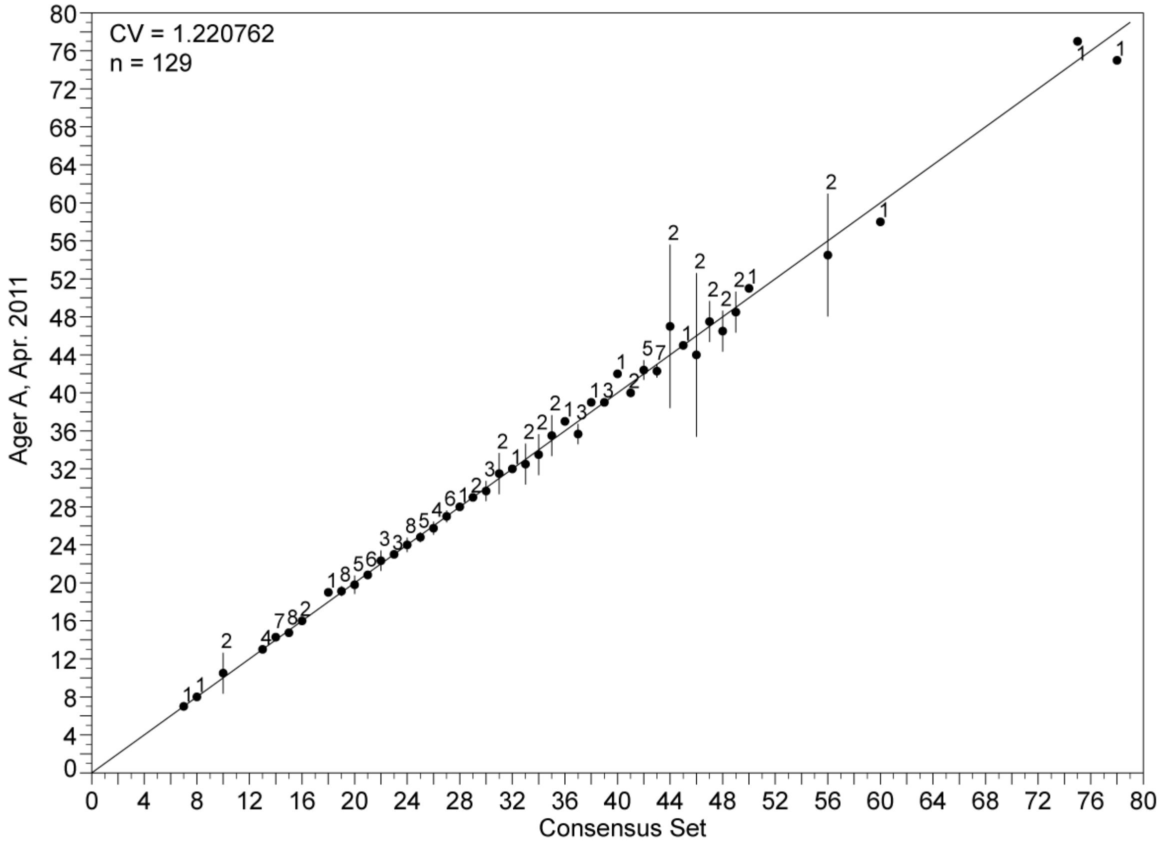

Figure 6. Testing of reader against consensus ages from reference collection. Vertical bars show range of ages assigned by the reader for clams of each consensus age. Numbers are the number of clams of that age in the test sample.

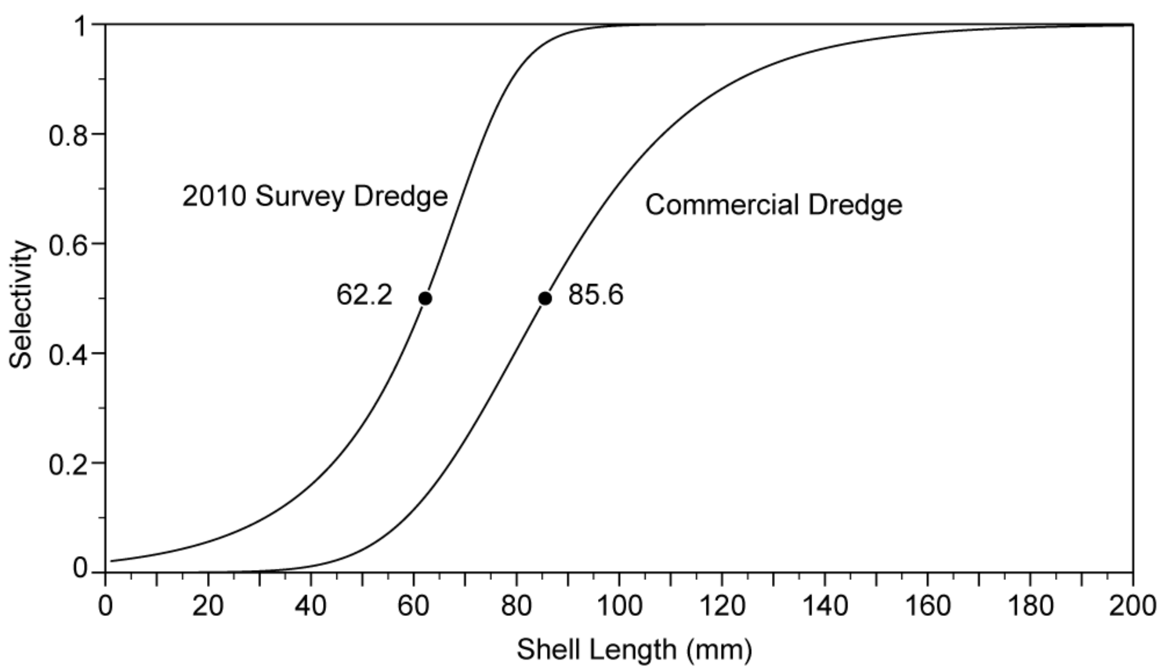

Figure 7. Selectivity curves for the 2010 survey dredge and a commercial clam dredge. Sizes at 50% retention are shown.

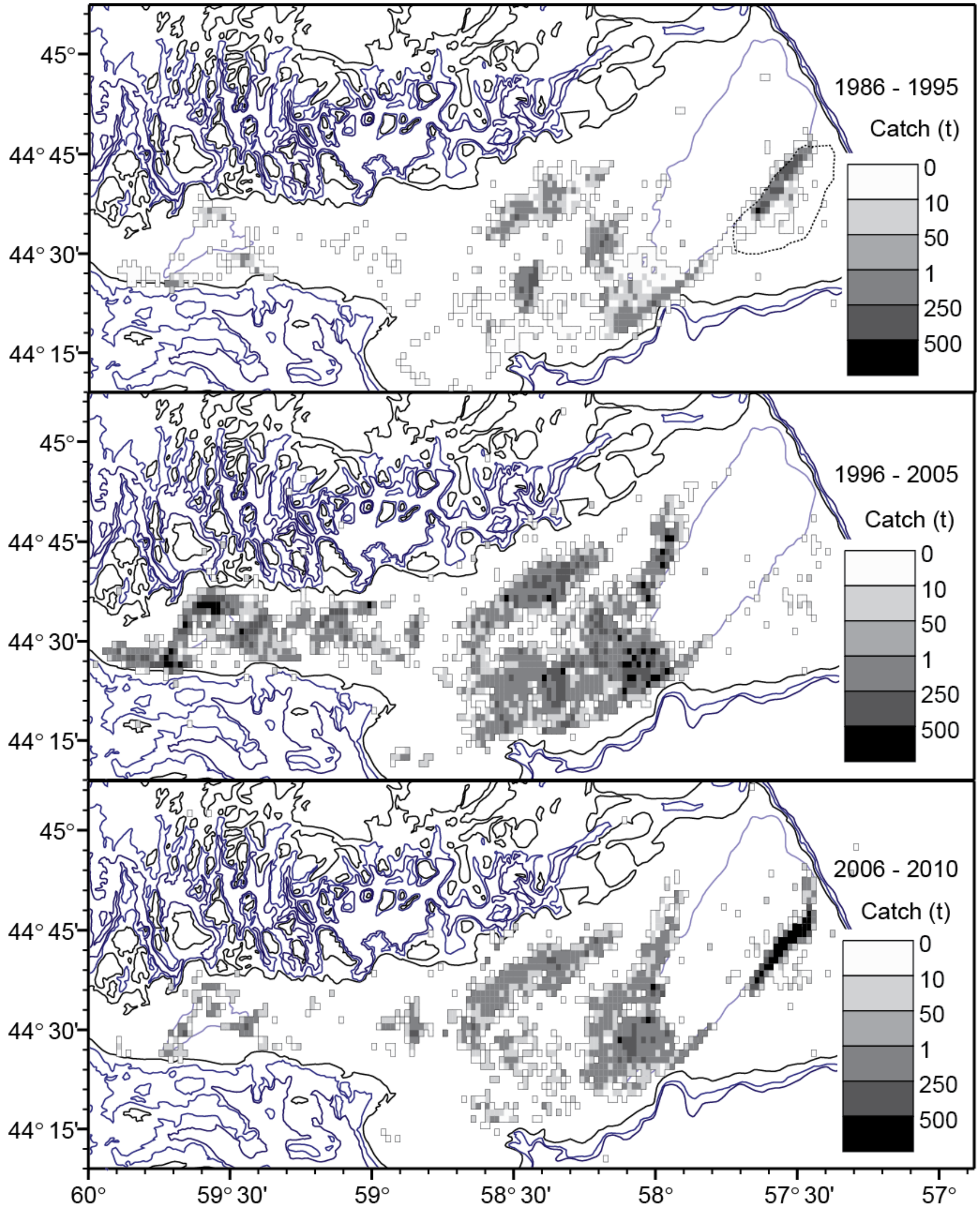

Figure 8. Distribution of catch from logbook data aggregated by one minute squares for three periods from 1986 to 2010. Dashed line in top figure shows area of high recruitment.

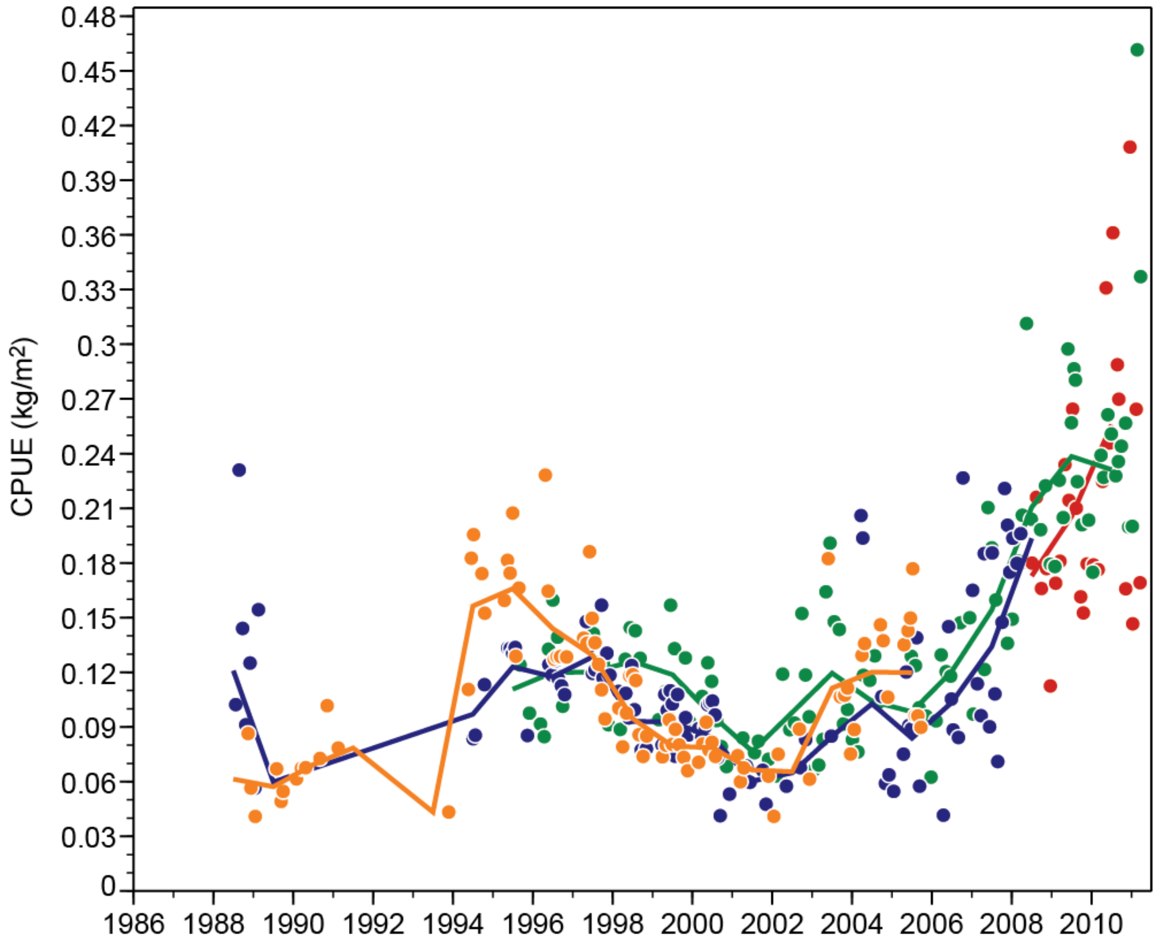

Figure 9. CPUE for the last four vessels active in the Arctic Surfclam fishery. Symbols are coloured by vessel, dots are CPUE by sub-trip, and lines connect yearly averages for vessels.

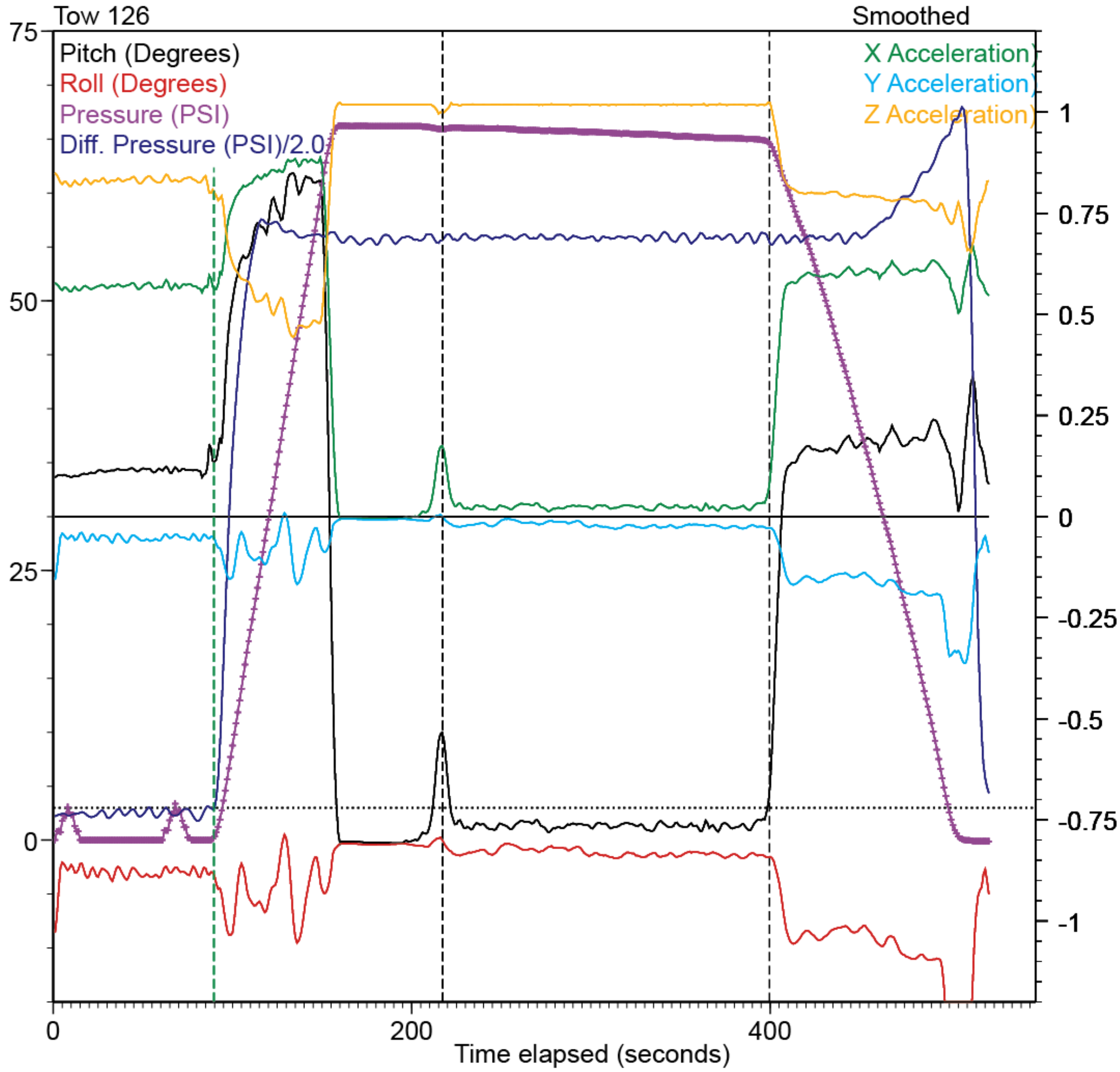

Figure 10. Dredge sensor data from a typical tow during the 2010 Banquereau offshore clam survey. The vertical green line is when the dredge was dropped and the black dashed vertical lines represent the points when the dredge started fishing and stopped fishing.

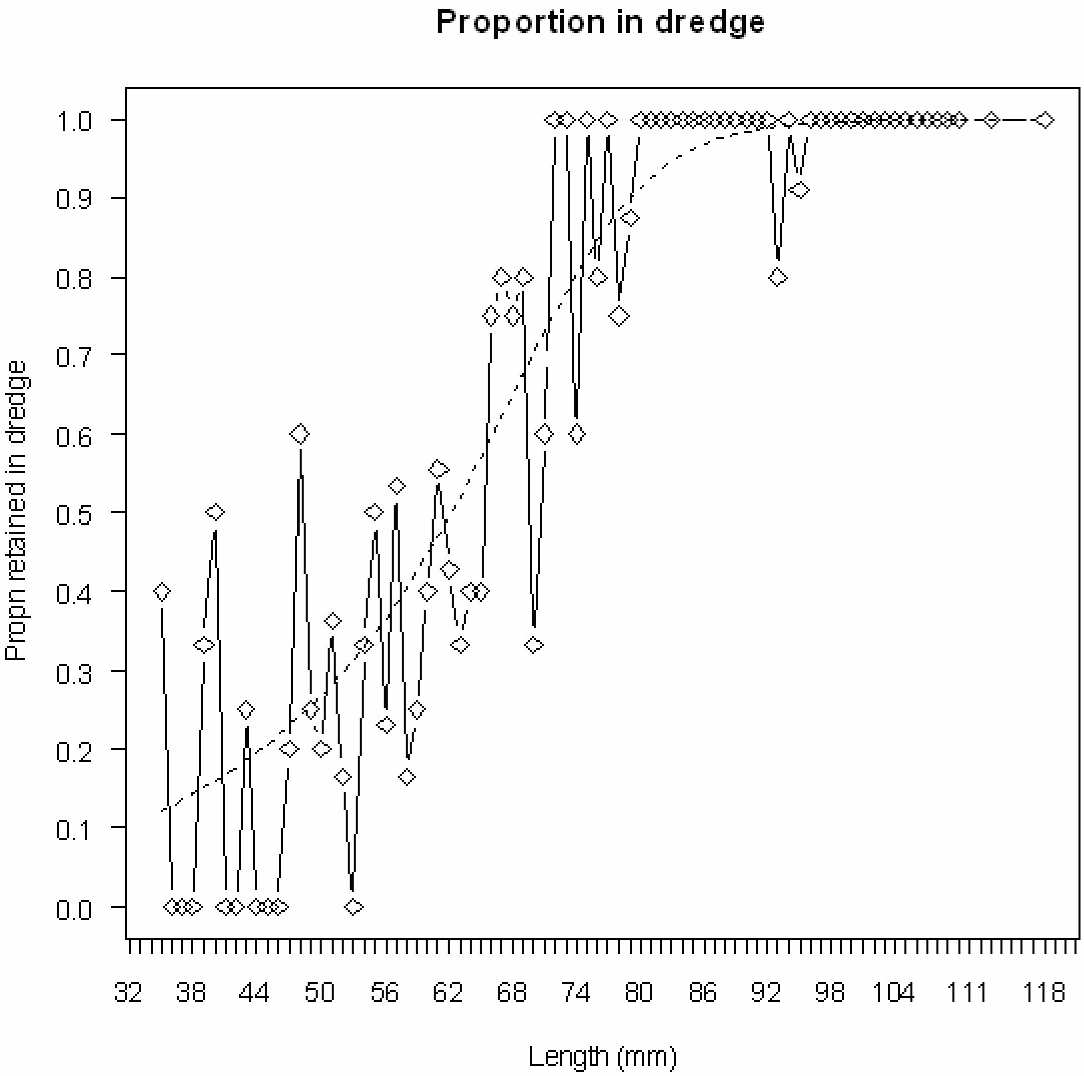

Figure 11. Fit of selectivity curve for Arctic Surfclams using the survey dredge used for the 2010 Banquereau offshore clam survey.

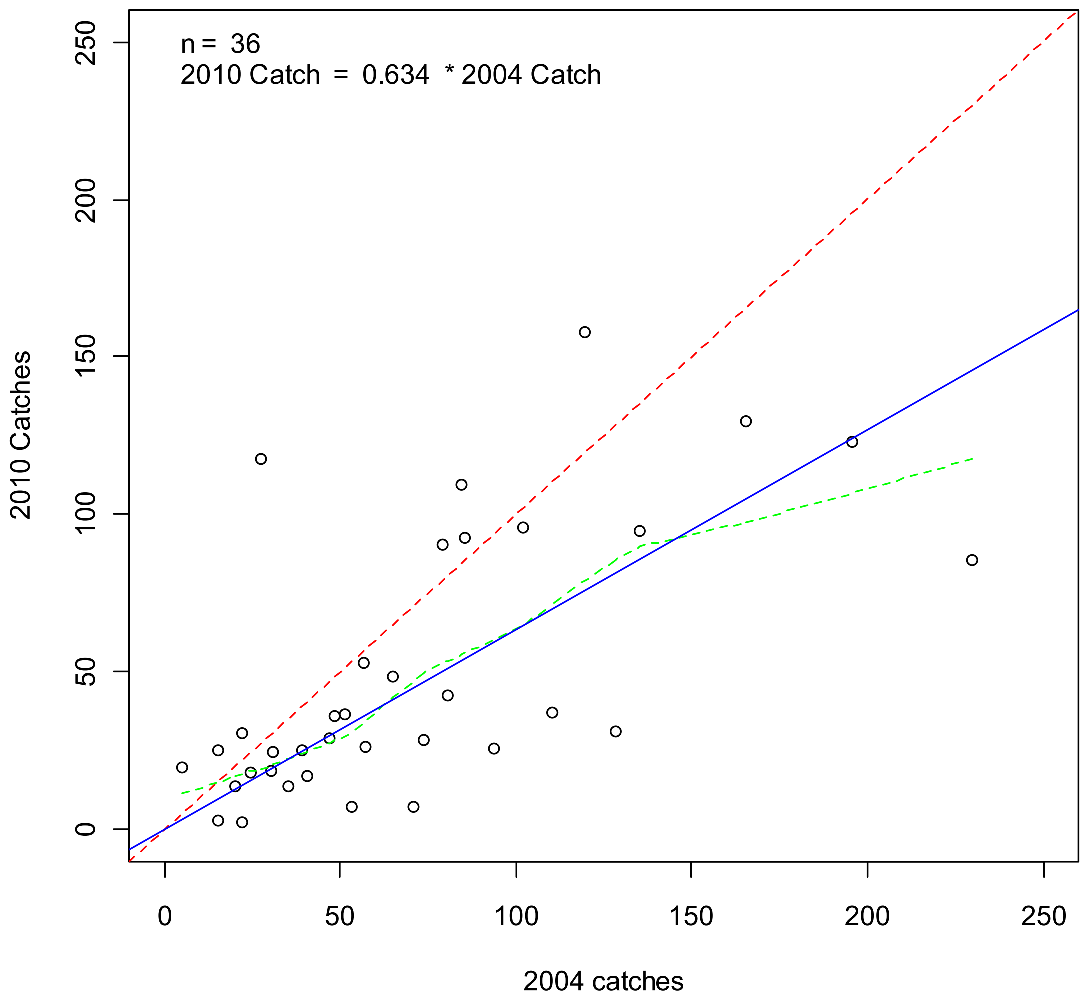

Figure 12. Scatterplot of catches from the 2004 and 2010 comparison tows. The equivalence line is the red dashed line, green dashed line is a LOWESS regression, and solid blue line is a linear regression through zero.

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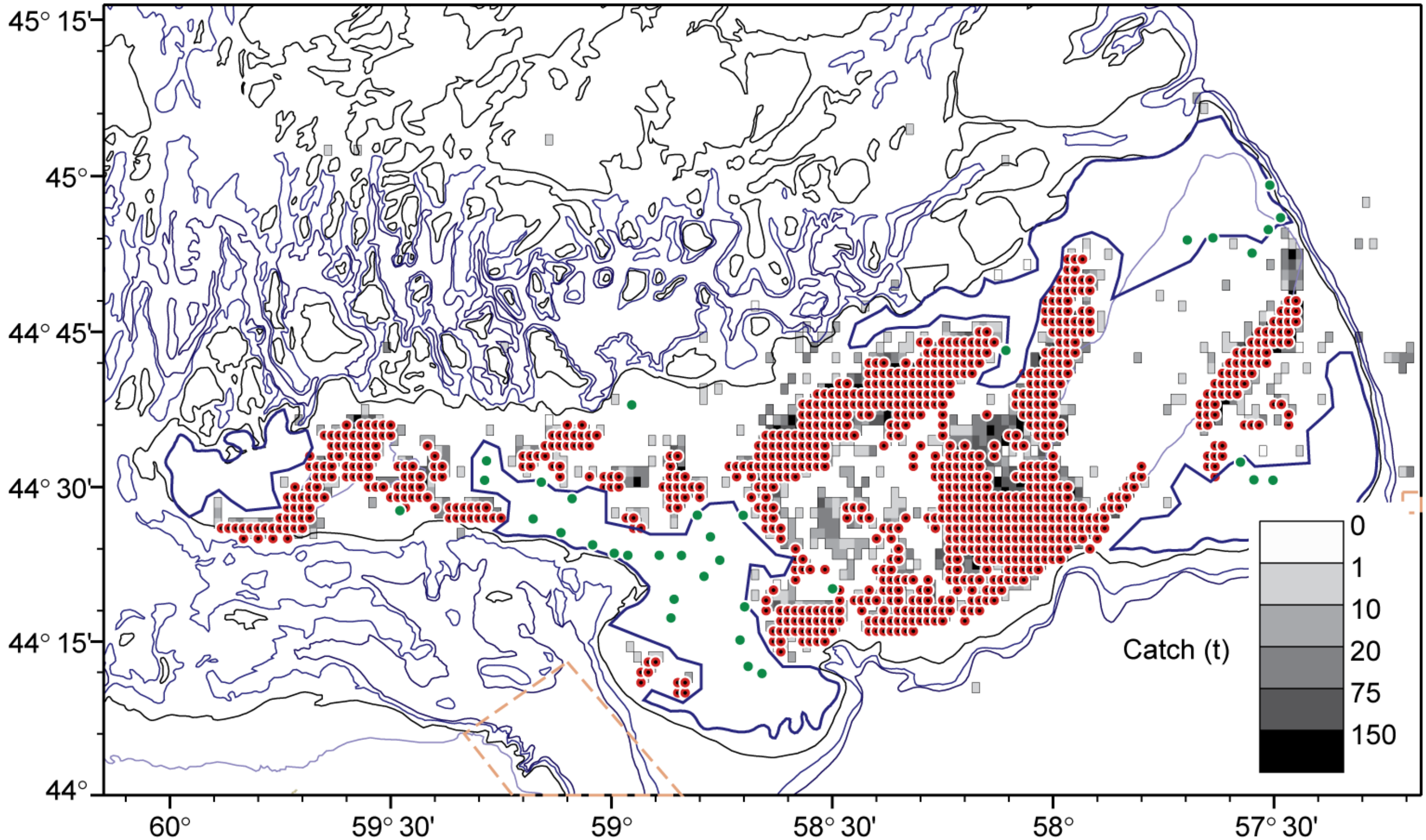

Figure 13. Plot of catch aggregated by one minute squares (grey squares) and Vessel Monitoring System data for estimated fishing activity (red dots) for June 26, 2004, to August 1, 2010, the time between the 2004 and 2010 surveys. Green dots are comparison tow locations and the blue outlined areas are the non-fished areas used for comparing biomass estimates between the two surveys.

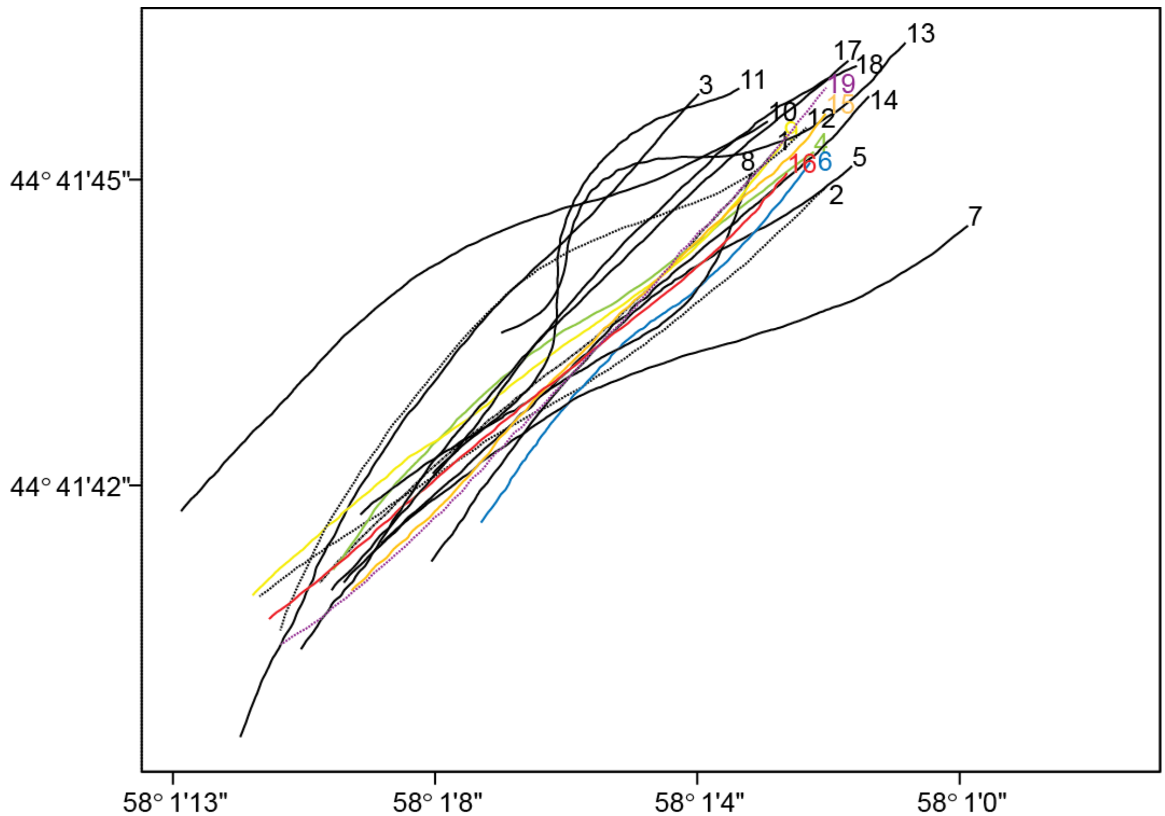

Figure 14. Vessel tracks for depletion study for dredge efficiency estimate. Start and end of the tows was determined with the dredge sensor system.

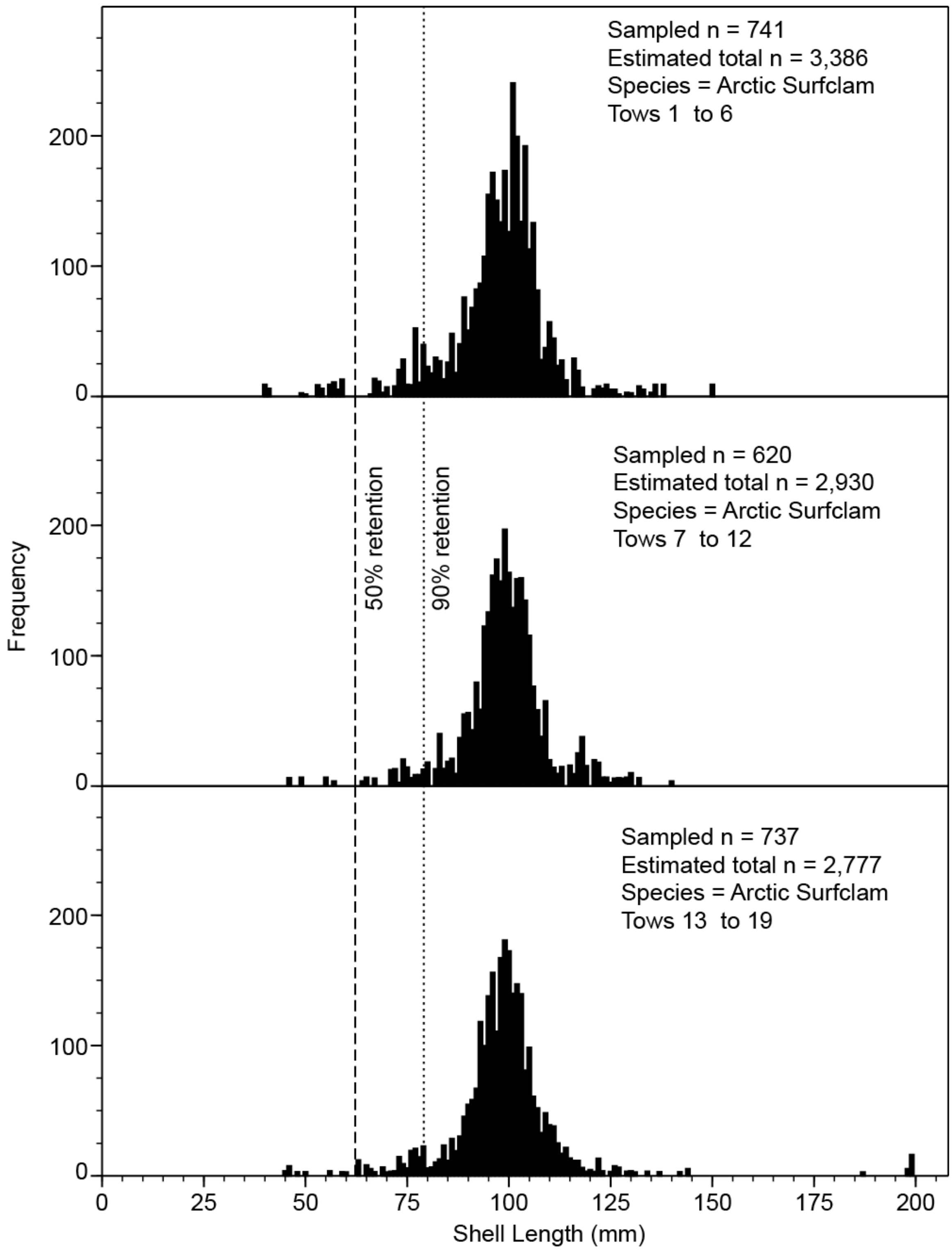

Figure 15. Length frequencies of Arctic Surfclams for tows from the depletion experiment during the 2010 offshore clam survey. The sizes at 50 and 90% selectivity for the survey dredge are indicated by the vertical lines.

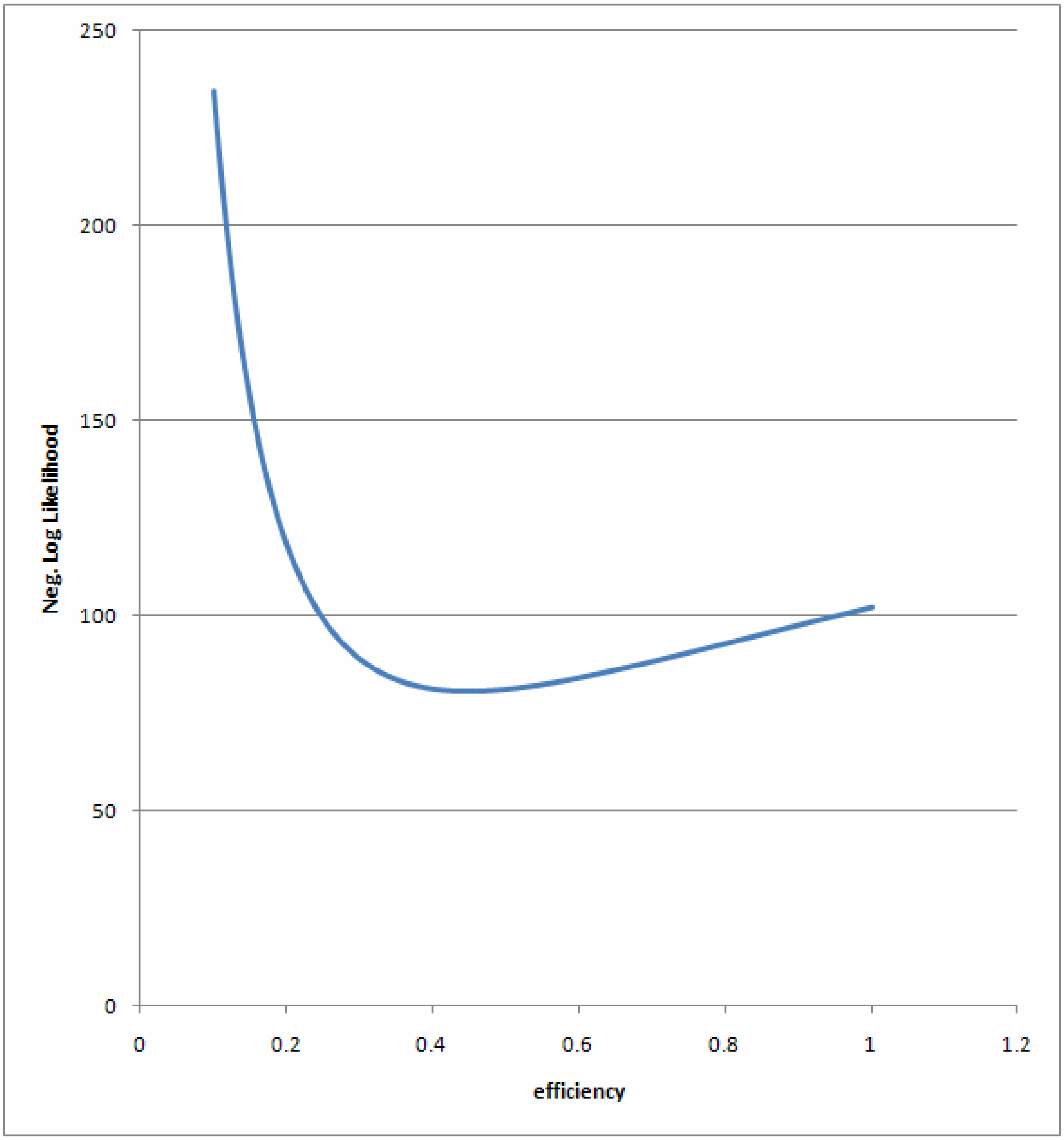

Figure 16. Likelihood profile for estimate of dredge efficiency from patch model.

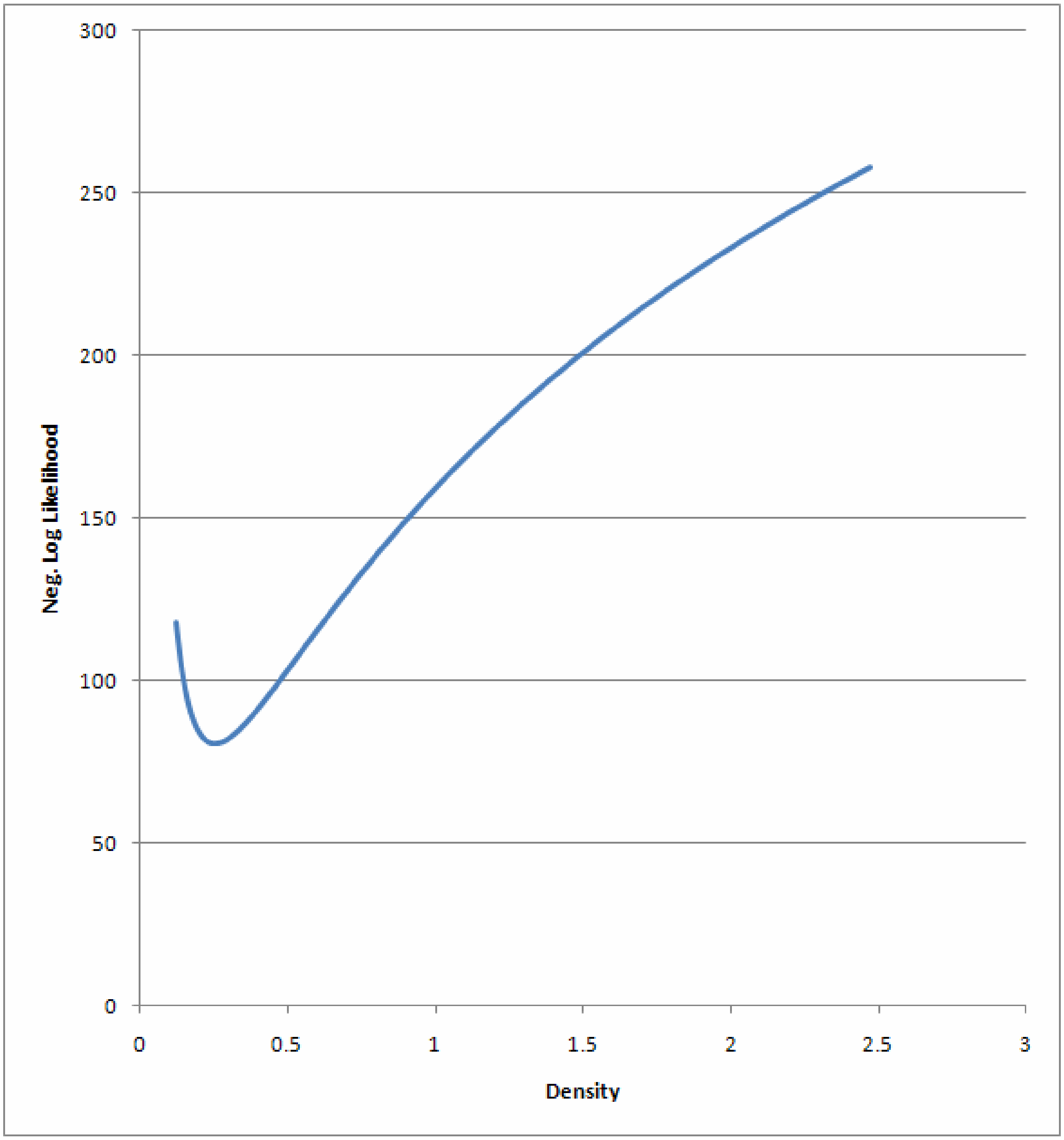

Figure 17. Likelihood profile for estimate of initial density from patch model.

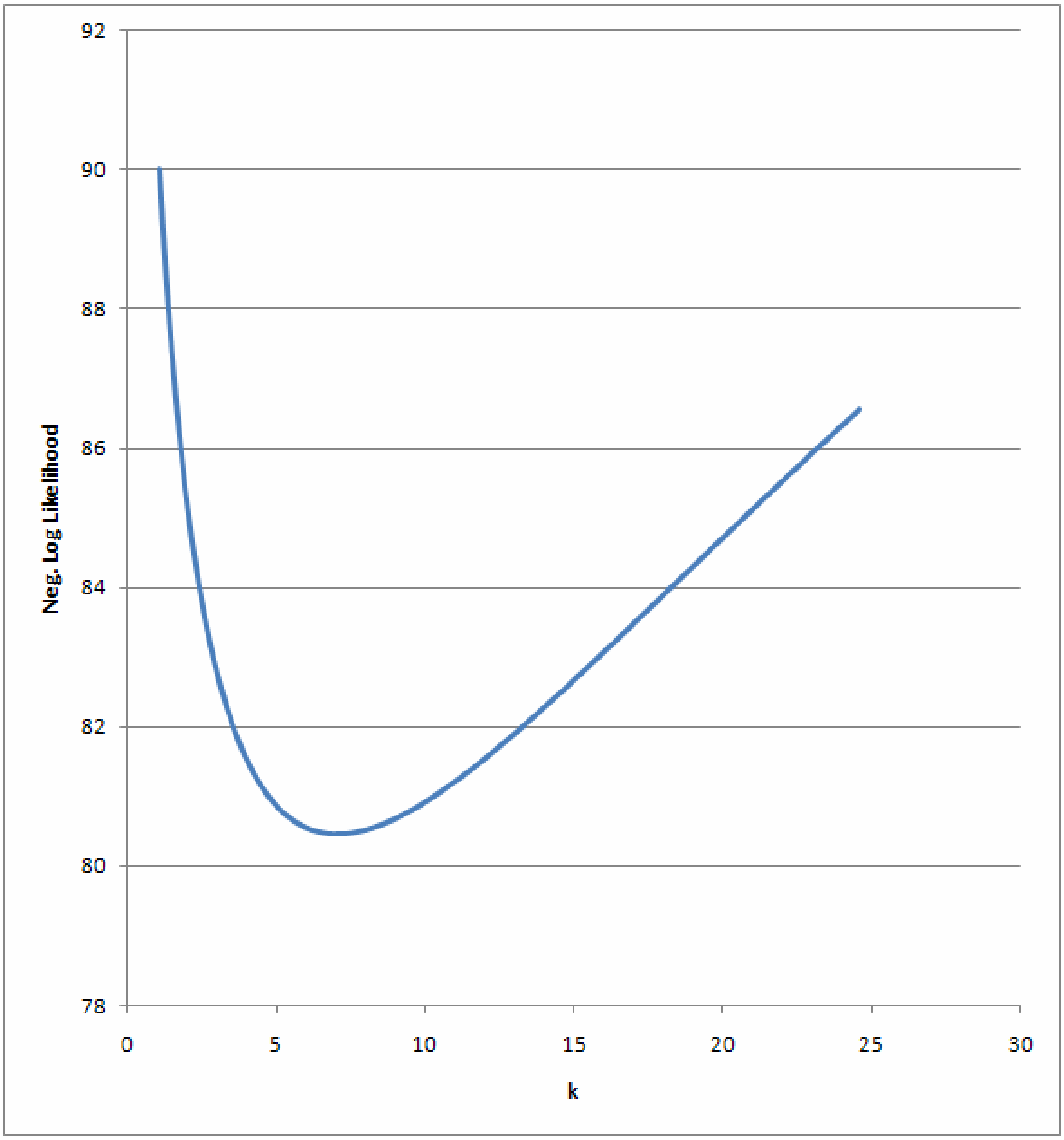

Figure 18 Likelihood profile for estimate of parameter k from patch model.

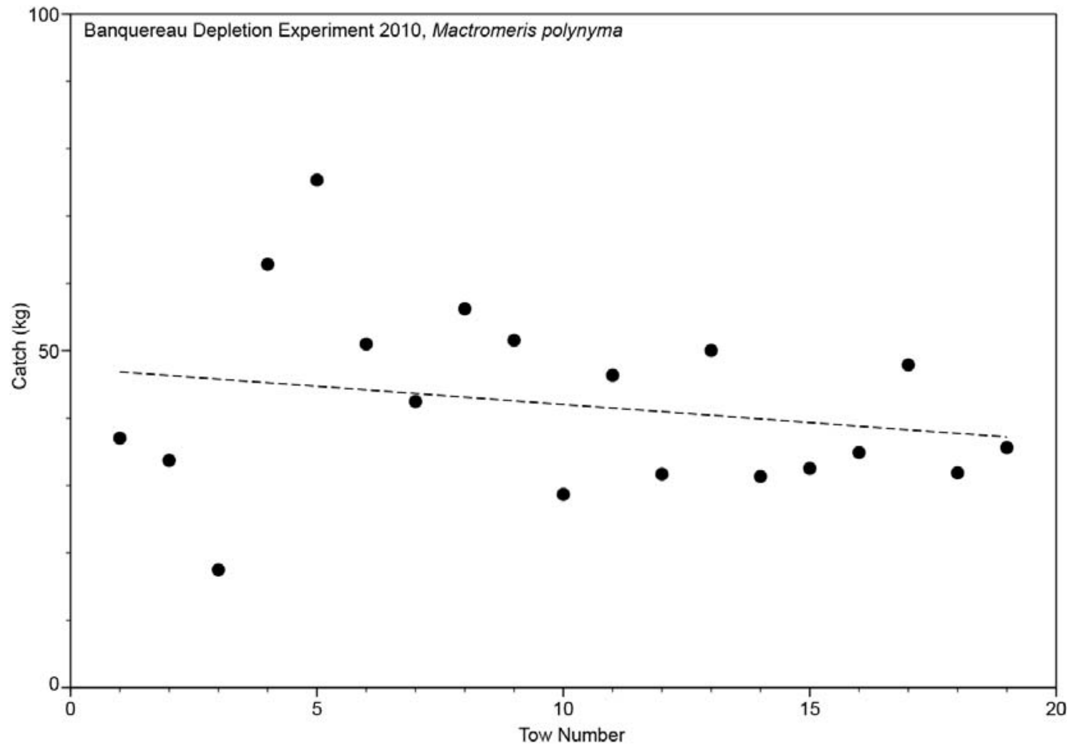

Figure 19. Catch versus tow for 2010 Banquereau depletion experiment. Linear fit to data is dashed line.

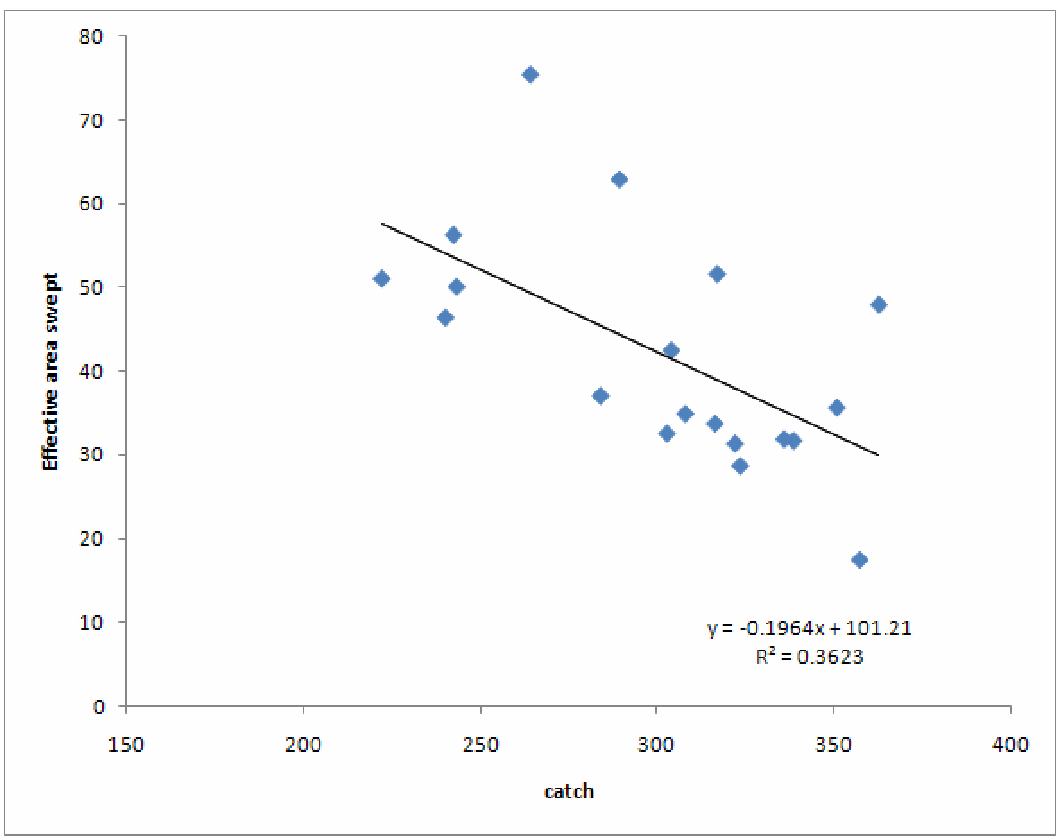

Figure 20. Plot of estimates of effective area swept versus catch for 2010 dredge efficiency data using the Patch Model. Line is for a linear regression fit to the data.

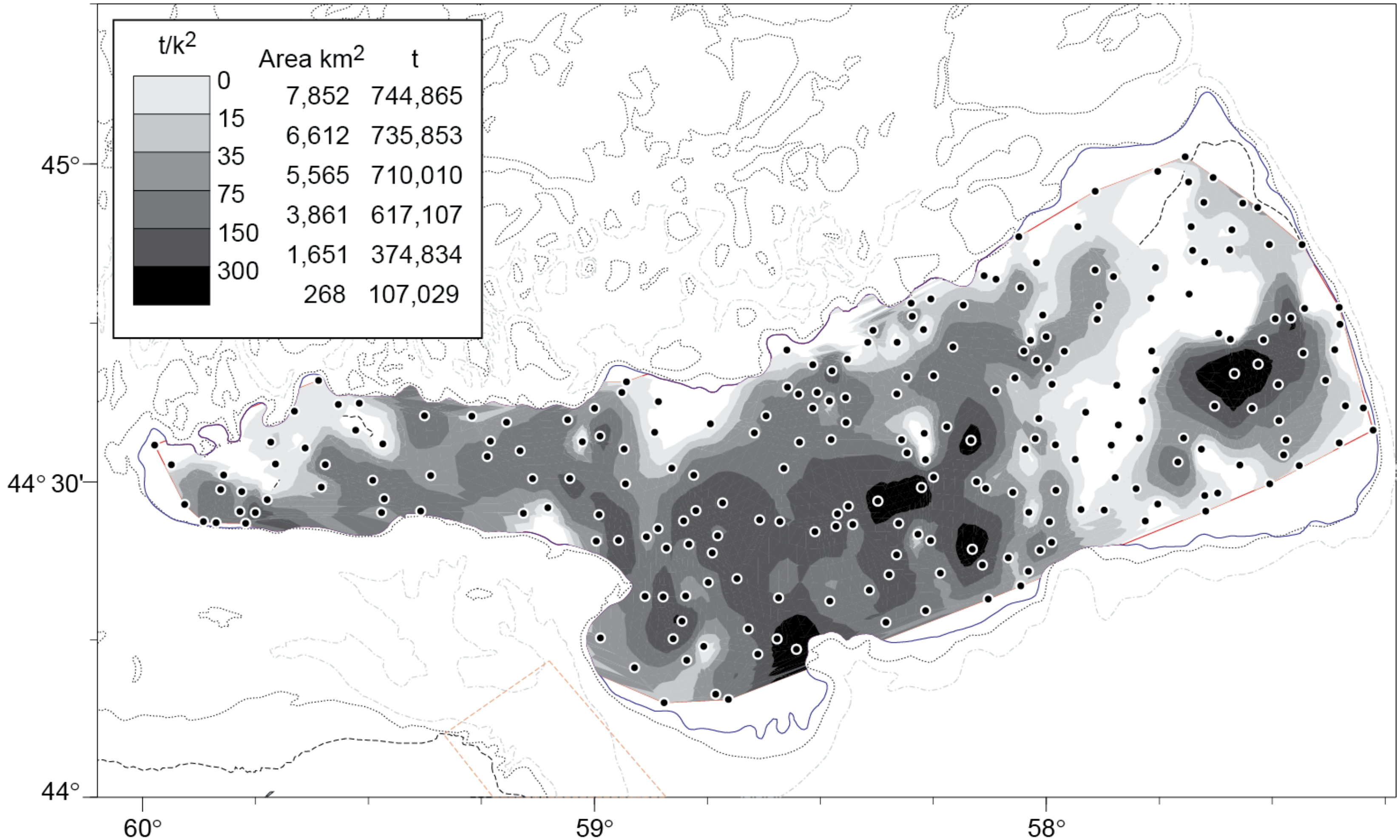

Figure 21. Contour plot of Arctic Surfclam biomass estimated from the 2010 Banquereau offshore clam survey. Table in upper left shows the area and biomass for increasing densities of Arctic Surfclams. For ease of interpretation, contouring was done in tonnes per kilometre square instead of catch per standard tow. Black dots are tow locations.

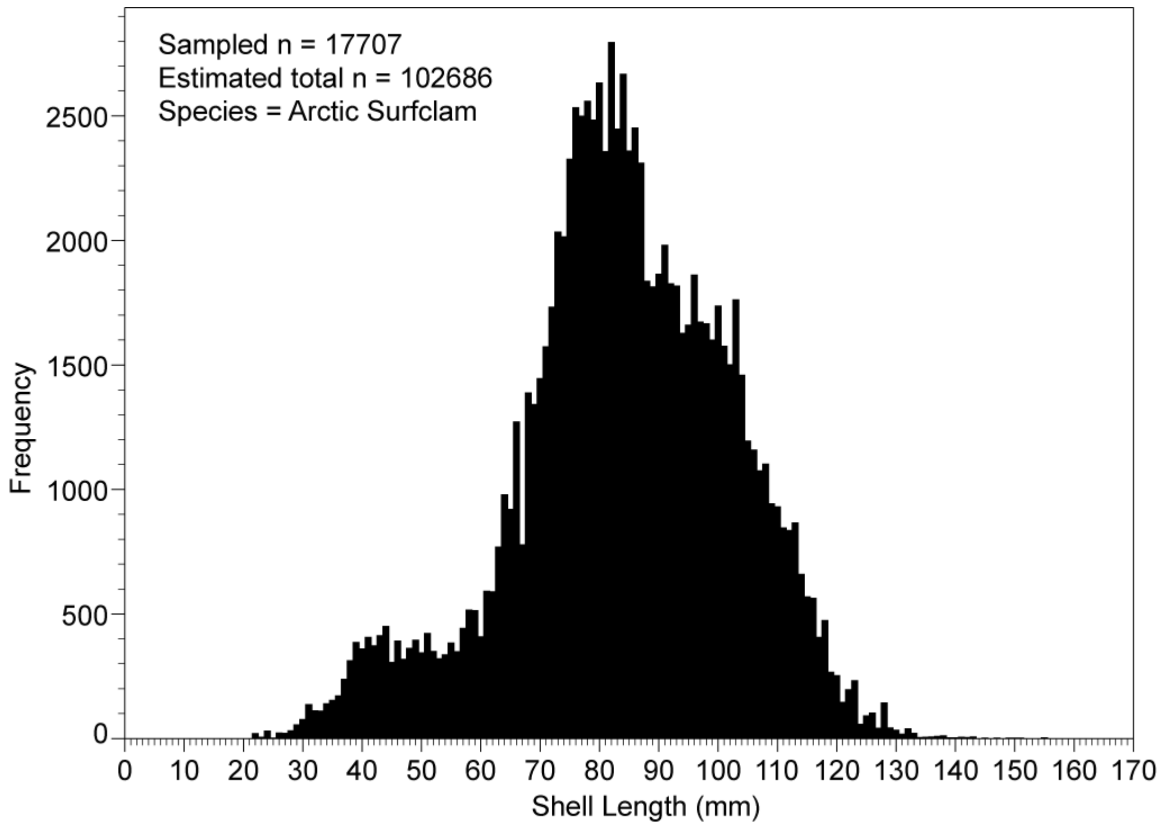

Figure 22. Length frequency for Arctic Surfclams caught during the 2010 Banquereau survey. The length frequency for each tow has been scaled to the catch for that tow and then the length frequency summed over all tows.

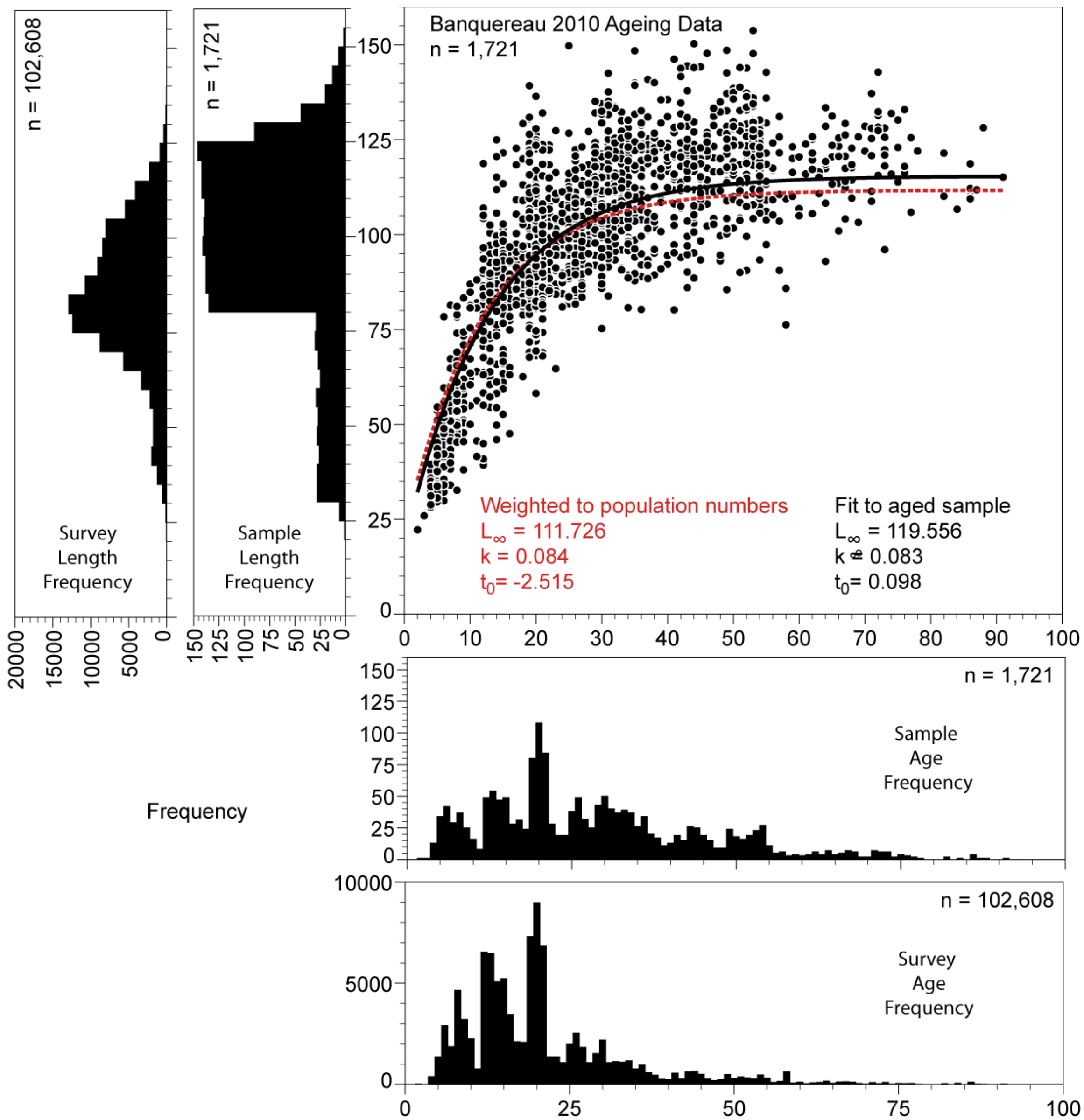

Figure 23. Survey and sample length frequency, ageing results and sample and estimated survey age frequency results from the ageing of a random sample of 1,721 Arctic Surfclams from the 2010 Banquereau offshore clam survey.

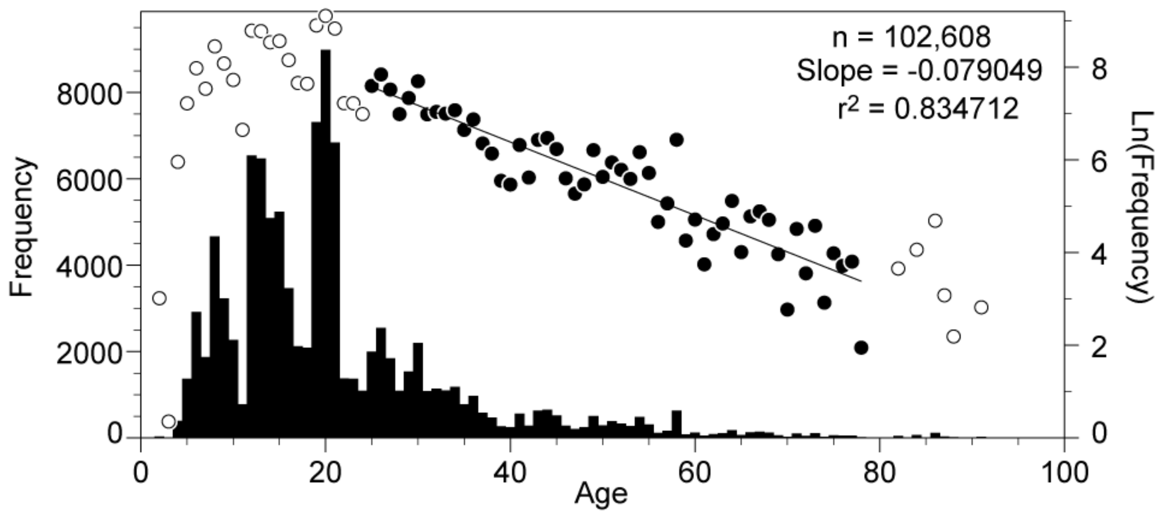

Figure 24. Catch curve estimates of mortality Arctic Surfclams from the for Banquereau 2010 survey data.

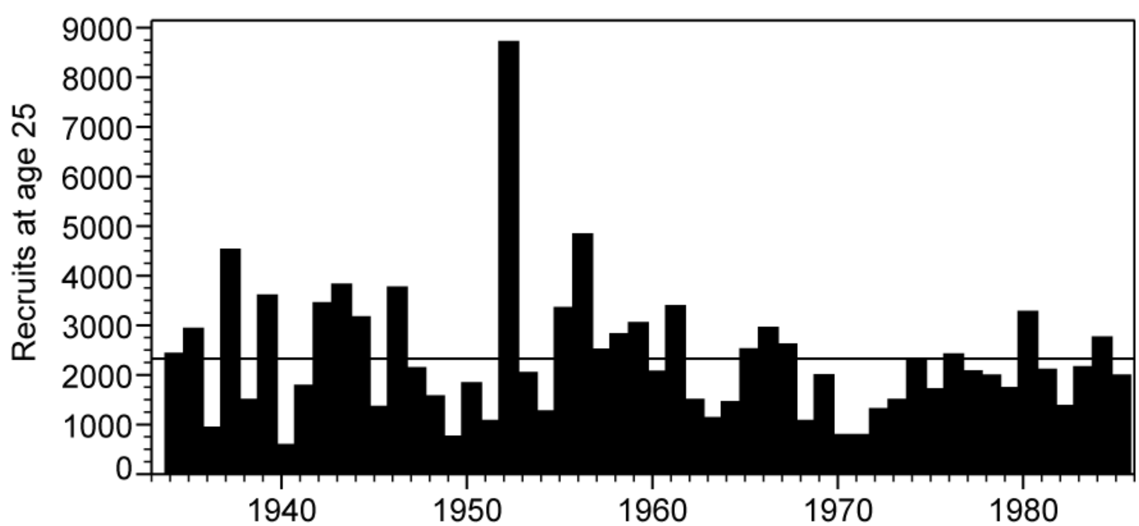

Figure 25. Population recruitment patterns estimated by applying the estimated (constant) mortality rate to the estimated age structure for 2010 Banquereau Arctic Surfclam survey.

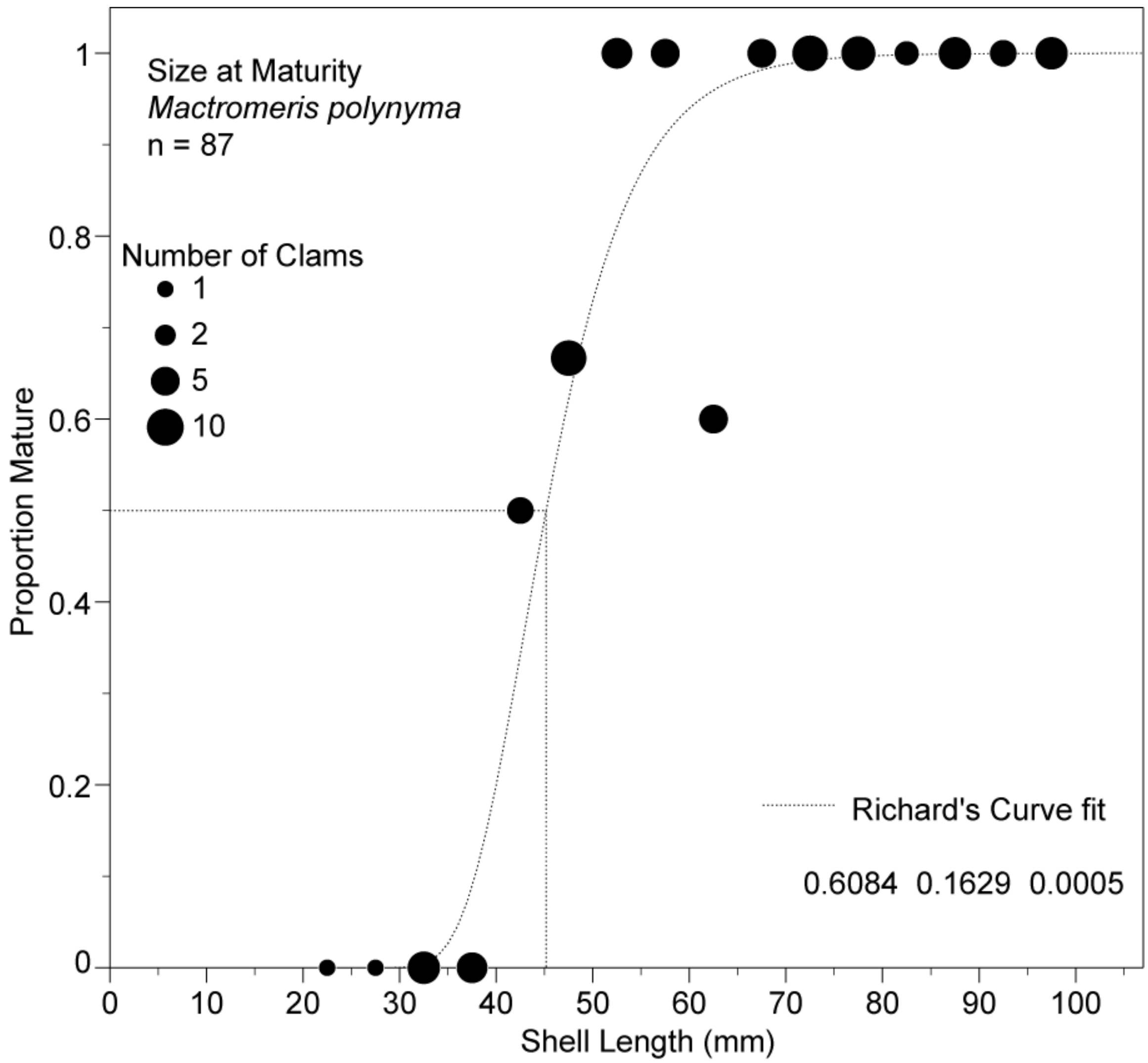

Figure 26. Curve fit to size at maturity data for samples from the 2010 Banquereau survey.

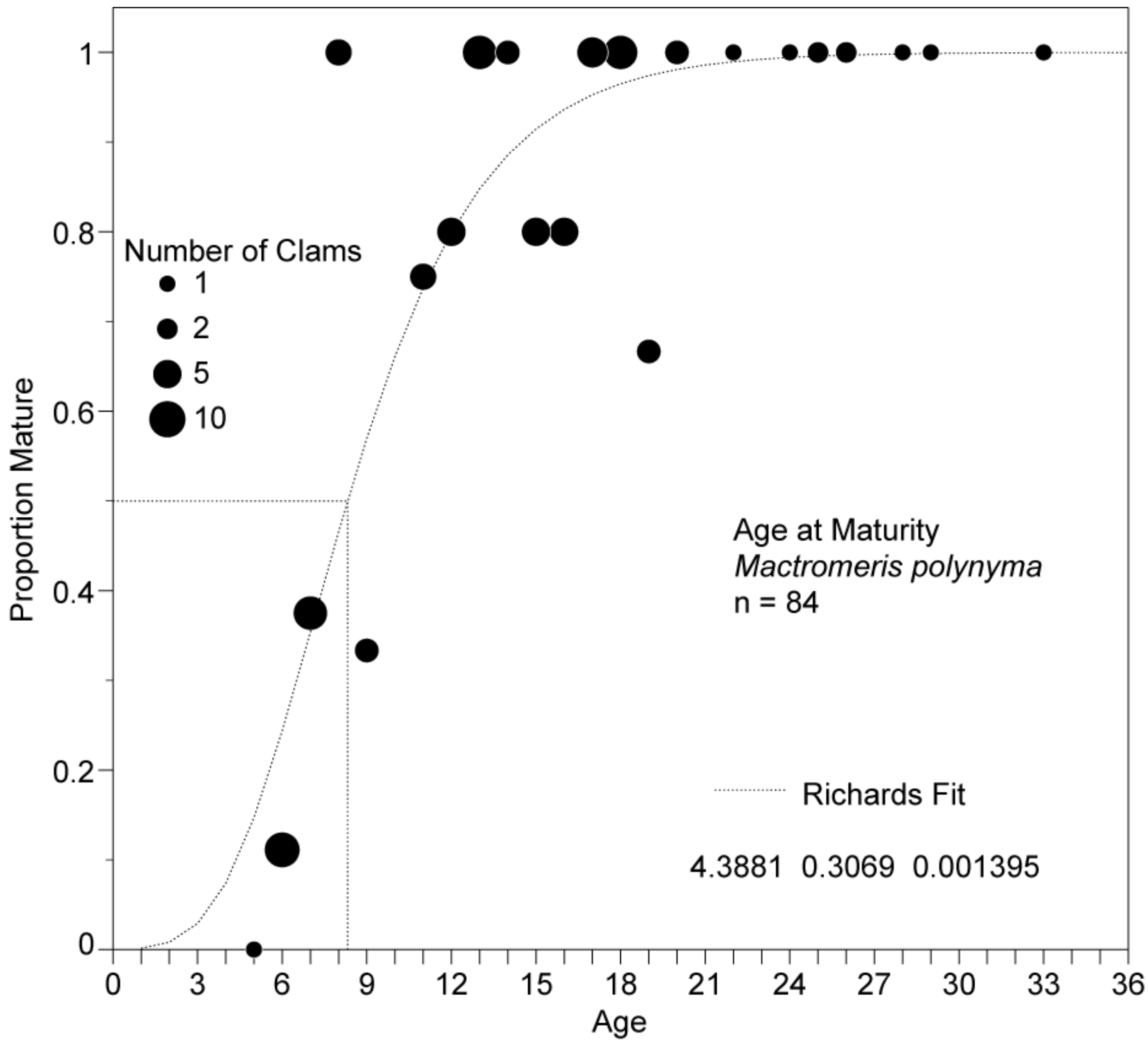

Figure 27. Curve fit to age at maturity data for samples from the 2010 Banquereau survey.

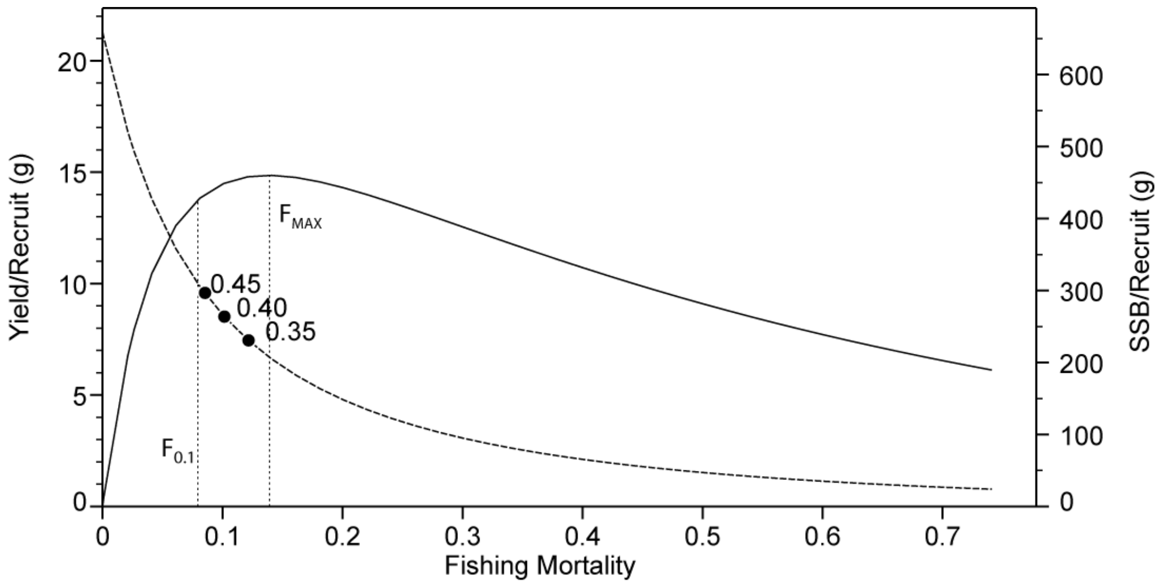

Figure 28. Yield per recruit for the Banquereau Arctic Surfclam fishery. Selectivity used was that from a commercial dredge, and fishing mortality includes a 15% mortality on small clams not retained by the dredge.

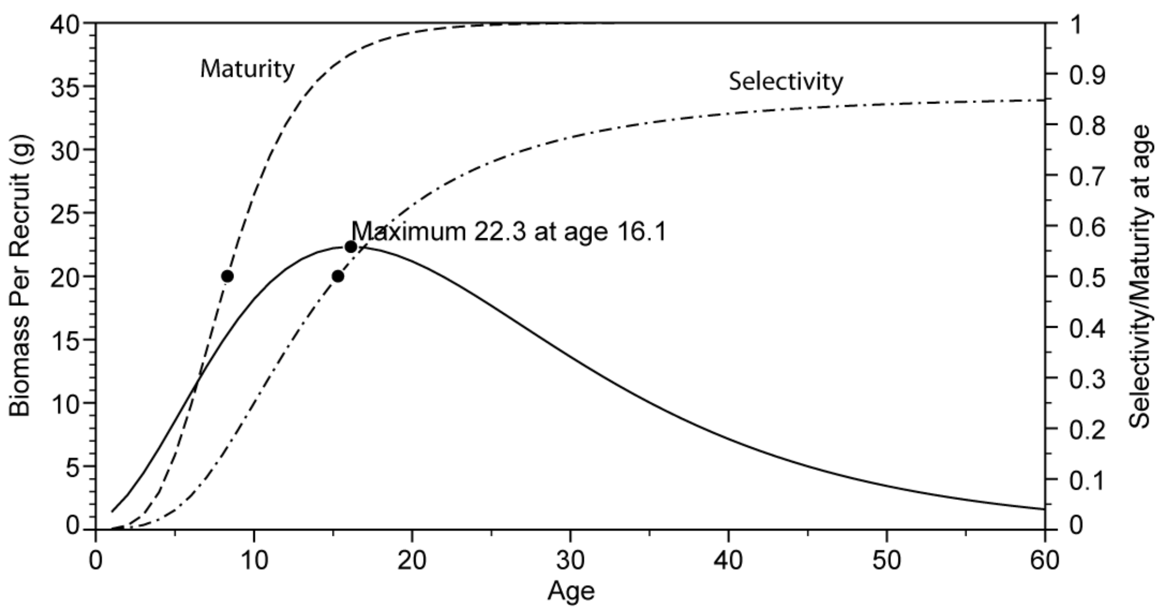

Figure 29. Plot comparing selectivity, maturity, and biomass per Recruit at age for Arctic Surfclams on Banquereau. Selectivity is for a commercial dredge, and indicates it selects for clams near their maximum Biomass per Recruit and above the age at 50% maturity.

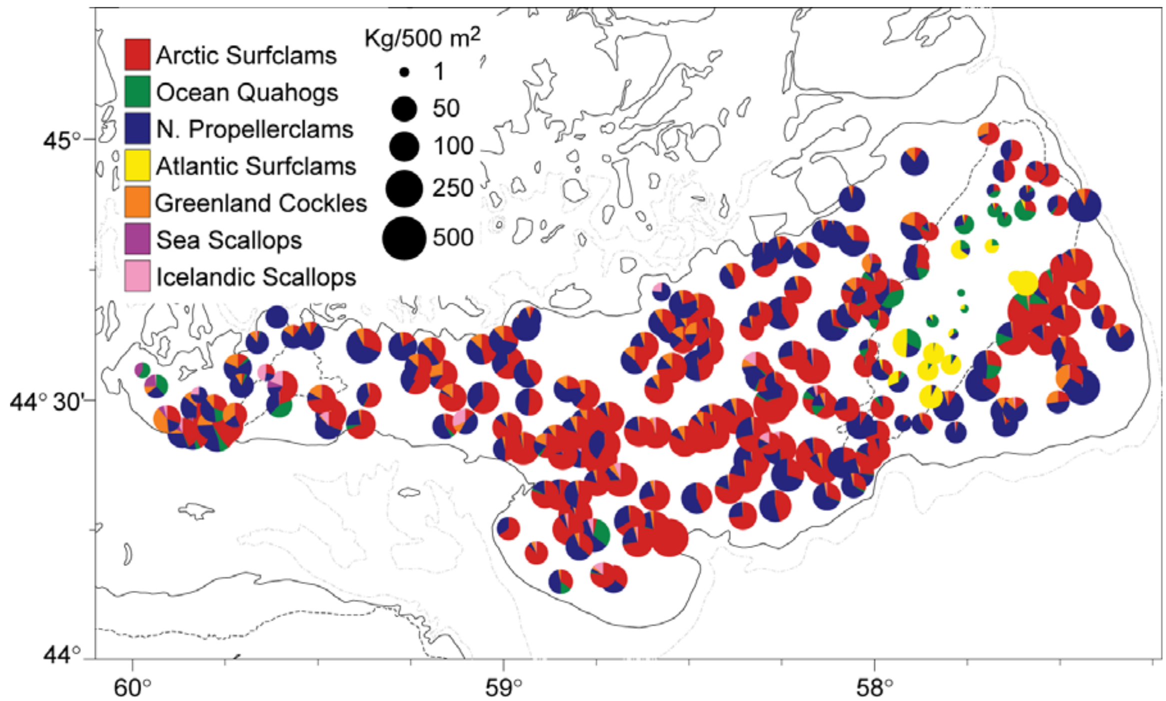

Figure 30. Distribution of major bivalve species on Banquereau from 2010 offshore clam survey.

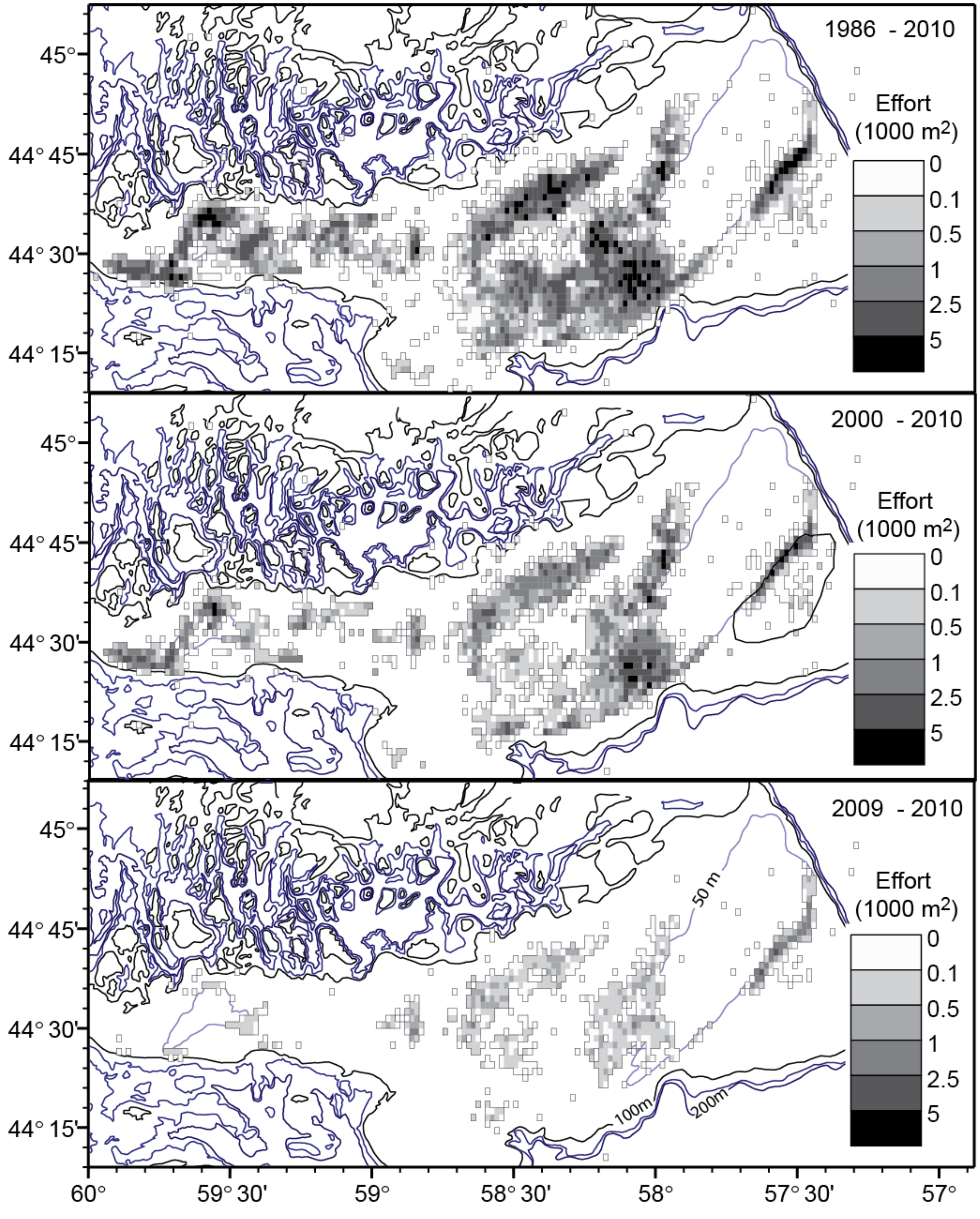

Figure 31. Aggregated effort (m^2 towed) for the entire fishery (top), last ten years (middle) and last two years (bottom). Area towed is not corrected for overlapping tows.

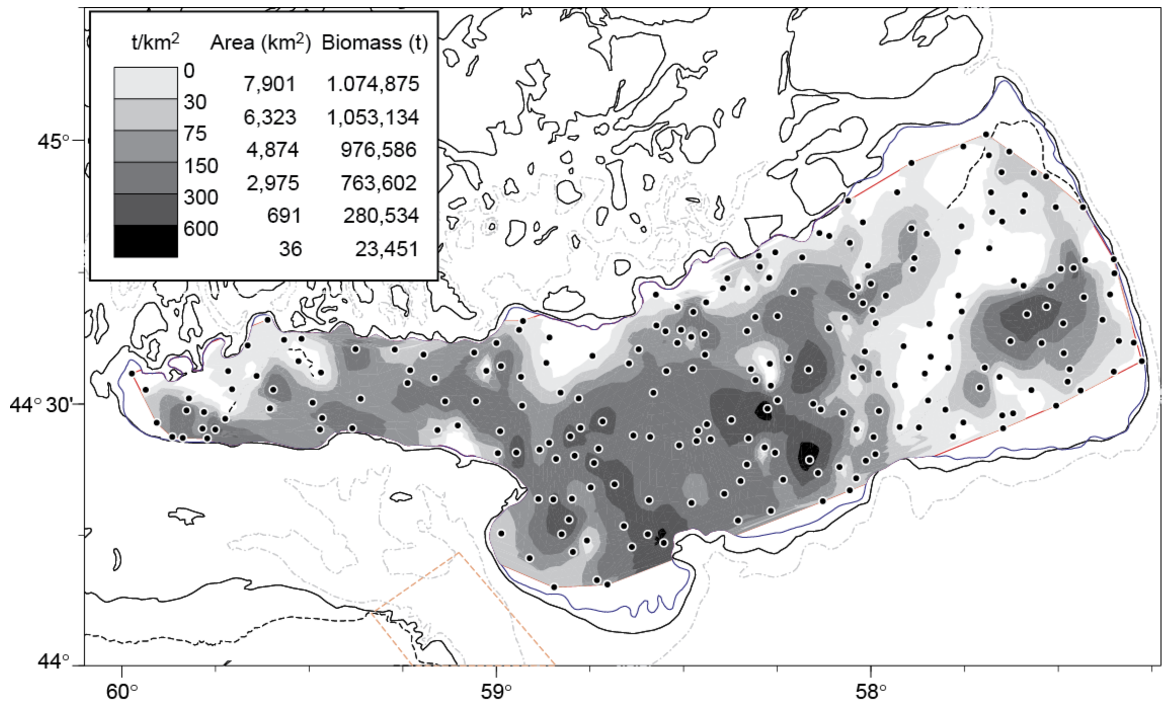

Figure 32. Contour plot of Arctic Surfclam selectivity adjusted, efficiency corrected biomass estimated from the 2010 Banquereau offshore clam survey. Table in upper left shows the area and biomass for increasing densities of Arctic Surfclams. For ease of interpretation contouring was done in tonnes per kilometre square instead of catch per standard tow. Black dots are tow locations.

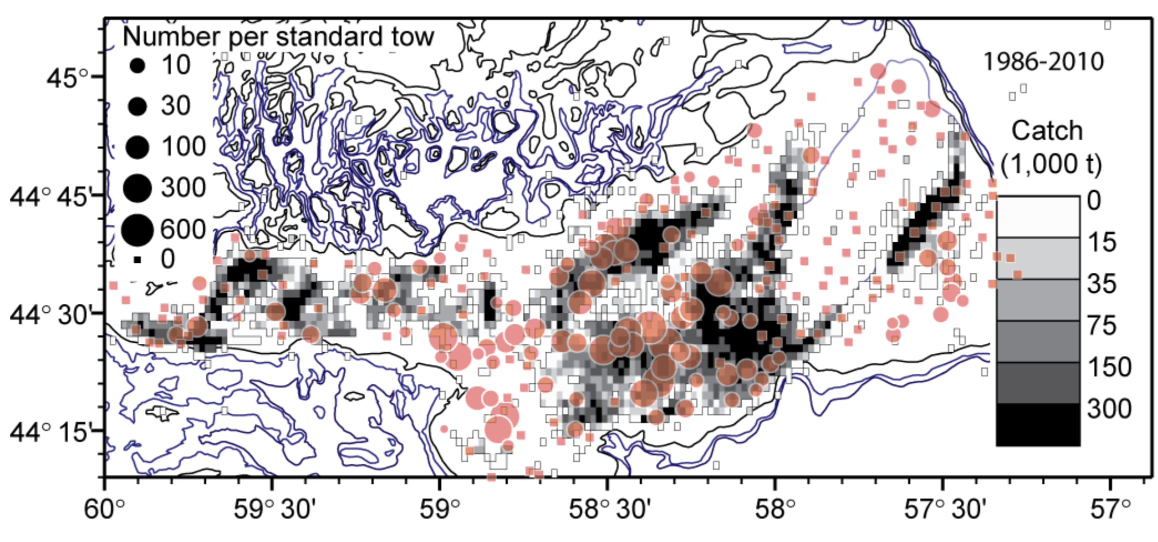

Figure 33. Distribution of catches of Arctic Surfclams less than 50 mm shell length from 2010 Banquereau offshore clam survey (red circles) and catch aggregated by one minute square for 1986 to 2010.