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Assessment of the Banquereau Bank Arctic Surfclam, 1999

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Abstract

The Banquereau Bank fishery for Arctic surfclams has grown from landings of 29 t in 1986, to 24,951 t in 1998. The three vessels participating in this fishery exploit both Banquereau and Grand Bank. The fishery is managed with limited entry and a Total Allowable Catch (TAC) divided into Enterprise Allocations (EA's), but the TAC is based on sparse survey data from the early 1980's. Concerns for the future of this fishery led Industry to propose supplying three years of vessel time for a stock assessment survey of Banquereau and Grand Banks, if the Department of Fisheries and Oceans would design and carry out the biological assessment. The main survey was completed in 1996, and the opportunity to conduct additional stations was taken during the summer of 1997.

The combining of different year's data presented both opportunities to refine the assessment, and problems with how to combine data from the two different surveys.

The initial survey design, based on stratification from a RoxAnn survey, was not successful in delimiting areas of high and low abundance on Banquereau Bank. It could discriminate bottom that was too hard or soft to be suitable for surfclams, but as Banquereau Bank is one large sandbank it was not able to refine the density of surfclams on any finer scale. Analysis of logbook and observer data show that CPUE has started to decline as the vessels are fishing lower density areas and returning to some areas previously fished. The ability of the present fleet to keep moving around and leaving fished areas alone for the length of time needed for the area to recover will be dependent on the extent of areas with commercially viable catch rates both on Banquereau and on Grand Bank where they also fish. The use of rotational fishing areas is examined in light of the survey results.

Résumé

Les débarquements de la pêche de la mactre de Stimpson sur le Banquereau sont passés de 29 t en 1986 à 24 951 t en 1998. Les trois navires qui les produisent pêchent à la fois sur le Banquereau et sur les Grands Bancs de Terre-Neuve. Cette pêche est une pêche restreinte assujettie à un total autorisé de captures (TAC), divisé en allocations d'entreprise, qui est fondé sur de rares données de relevé remontant au début des années 1980. L'avenir de la pêche ayant suscité certaines inquiétudes, l'industrie a proposé de consacrer trois années de temps de mer d'un navire à un relevé d'évaluation du stock, si le ministère des Pêches et des Océans consentait à concevoir et effectuer le relevé biologique. Le relevé principal a été achevé en 1996, et on a saisi l'occasion d'échantillonner des stations supplémentaires en été 1997.

La combinaison de données d'années différentes a été à la fois une occasion de parfaire l'évaluation et une source de difficultés quant à la façon d'intégrer des données de deux relevés différents.

Le type de relevé initial, fondé sur une stratification d'après un relevé RoxAnn, n'a pas permis de délimiter les zones de forte et de faible abondance sur le Banquereau. Il a permis de différencier les fonds trop durs ou trop mous pour la mactre de Stimpson, mais comme le Banquereau est un vaste banc de sable, il n'est pas parvenu à établir la densité des mactres de Stimpson à une échelle très précise. L'analyse des journaux de bord et des données recueillies par les observateurs révèle que les PUE ont commencé à diminuer au fur et à mesure que les

navires se sont mis à pêcher dans des zones de plus faible densité et à revenir dans des zones qu'ils avaient déjà exploitées auparavant. La capacité de la flottille actuelle de continuer une rotation des lieux de pêche et d'éviter les lieux déjà exploités pendant le temps nécessaire au rétablissement du stock dépendra de l'étendue des zones où les taux de prises sont viables pour la pêche commerciale sur le Banquereau, ainsi que sur les Grands Bancs de Terre-Neuve où cette flottille pêche également. On étudie ici le recours à une rotation des lieux de pêche à la lumière des résultats du relevé.

Introduction

The offshore clam fishery has been operating on the Scotian Shelf since 1986, and the Eastern Grand Banks since 1989. Although it has developed into an industry with annual sales of $50 million, the lack of empirical information has forced the department to manage the fishery with a pre-emptive TAC.

The fishery has developed to the point where Industry must make decisions on capital investment, however, there is little information on the size of the resource. Furthermore, this is a fishery using highly efficient gear (Medcof and Caddy, 1974) to harvest a long lived, slow growing species. The lack of biological information means the Department does not know if the current harvesting rates are sustainable or if the resource is being "mined out" and heading for a collapse.

The lack of knowledge about the biomass and production of this resource has been a consistently identified concern during the development of the fishery, both by the Offshore Clam Advisory Committee (OCAC) and CAFSAC-AFRC (DFO, 1998). DFO does not have a vessel equipped to conduct a regular stock assessment survey and the costs of equipping a DFO vessel or chartering a commercial vessel are prohibitive. In 1994, Industry, recognizing this, proposed a three-year survey to cover both Banquereau Bank and Grand Bank. Industry said that they would commit to the estimated $1.3 million of vessel time if DFO would conduct the scientific assessment portion. This survey has been completed, and this paper presents the analysis of the survey results.

With a long lived sedentary organism it has been questioned if TAC's are the best method to manage this fishery. One alternative, that of a rotational fishery, is examined in light of the survey results.

History of the 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. During these surveys, which took place from 1980 to 1983, commercial quantities of Arctic surfclams, *Mactromeris polynyma*, were found on Banquereau Bank (Rowell and Chaisson, 1983; Chaisson and Rowell, 1985). Due to the exploratory nature of the surveys, other areas of the Scotian Shelf could not be precluded from containing commercial quantities of

Arctic surfclams, although these were not found. There has been no commercial interest in *Arctica islandica*, due to the lack of a market.

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

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

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

In February 1989, Arctic surfclams officially became a regulated species under the Atlantic Fishery regulations. Two exploratory licenses and two exploratory permits were issued for 3LNO in 1989, with a total “precautionary” TAC of 20,000. These were issued to the three current participants plus a fourth, Newfoundland based company, and the TAC for the Scotian Shelf outside of Banquereau Bank was increased to 20,000 t. Access to the Scotian Shelf was expanded to include the new company. Since this time there has been some exploration, but no sustained fishing, on the Scotian Shelf outside of Banquereau Bank.

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

Methods

The analysis presented here deals with two separate surveys, which were used as a two stage survey design. The complicating factor is that the two stages took place in different years.

Industry-DFO Surveys

1996 survey:

The offshore clam vessels have been equipped for several years with RoxAnn acoustic bottom classification systems and the captains have confidence in them, mapping out new areas before they start dragging. The RoxAnn system classifies the bottom type using two scaled indices derived from echo sounder acoustics returns. These indices are said to correspond to bottom hardness and bottom roughness. Industry conducted a RoxAnn survey of Banquereau and Grand Bank during 1994 and 1995, using the M.V. Atlantic Dauphin, a 34 m scallop vessel. Industry's data was loaned to DFO to use in preparing a stratified survey design for the two areas. The boxfile and RoxAnn data were used to classify the survey area into five bottom types:

Clams – Sand bottom with a high probability of clams
Clam Ground – Sand bottom with a moderate probability of clams
Seed and Shell – Sand bottom with a lower probability of clams, they occur, but are patchy or at low densities
Soft - Soft bottom, mud and silt, unlikely habitat for clams
Hard - Hard Bottom, unlikely habitat for clams

Optimal allocation of stations to the strata would be to assign stations in proportion to the product of the strata's area and variance. When the variance is not known the next best assignment is to allocate stations in proportion to the area of the strata. This ensures that the stratification scheme will do no worse than an unstratified random sampling design, and if the stratification works it can do better.

During July of 1996 the M.V. Atlantic Dauphin, which had been equipped with a 70-inch hydraulic clam dredge, and a diesel powered pump, conducted standard tows at the selected survey stations. At each survey station a tow of 0.3 nautical miles was done with the hydraulic clam dredge. For up to 20 bushels of catch, all catch was sorted for the main bivalve species (Arctic surfclams, Northern propellerclams, Ocean Quahogs, and Greenland cockles). For catches of more than 20 bushels a subsample of 20 bushels was taken. At each station two bushels were sorted completely to determine by-catch composition. At specified sites, selected to cover the Bank, length frequency samples were collected for Arctic surfclams, and frozen samples retained for morphometric analysis and aging.

Three additional tows were made with a loose bag of 1.5-inch shrimp netting over the dredge to look at selectivity (% retention) of clams entering the dredge. These tows were done in an area selected for having a good range of sizes, and little bycatch or trash to clog the dredge.

The arrival of Hurricane Bertha during the 1996 survey cut the number of stations that were done in the time available to 121 of a planned 200 survey stations.

1997 survey stations:

In 1997 Industry made the Atlantic Dauphin available for another 2-week period to do additional sampling on Banquereau Bank. Since the RoxAnn stratification had not improved the efficiency over that of a simple random design, it was decided to use a kriging analysis (Clark, 1979) of the 1996 data to map the variance estimate, and assign additional stations to areas with a high variance. In addition, 4 tows were done using a 40mm mesh liner in the dredge to look at the numbers of small clams in an area that was heavily fished in the late 1980's.

The survey stations were conducted with the same protocol as in 1996, but with length frequency and morphometric sampling at every station.

These additional stations improved the coverage of Banquereau and were assigned so as to reduce the variance of the biomass estimate. However, the fact that the survey now contained stations from two different years complicated the estimate of biomass that would now also have to incorporate the effects of fishing activity between the two years. We decided to combine the surveys in the following manner. Using current estimates of growth, the size distributions from the 1996 survey were projected one year forward with total numbers discounted by natural mortality to provide pseudo-1997 survey catches. Those stations from the 1996 survey that did not have length frequencies measured were estimated using a distance-weighted average of the length frequencies for the 8 closest stations in the survey. Growth rates were estimated from aged shells from the 1996 survey and natural mortality was assumed to be 0.08 (Amaratunga and Rowell, 1986). The pseudo-1997 stations were combined with actual stations from the 1997 survey to estimate the biomass by size-class of clams on Banquereau Bank in 1997. Commercial size ranges for the processed foot portion were provided by industry and converted to shell length using regressions from the morphometric data from the survey. The minimum commercial shell size was predicted from the foot data and used to along with the survey weight data to calculate the survey catch of commercial and pre-recruit size classes of clams.

A spherical variogram was fitted to the survey catch data using the MGAP Geostatistical Package (Rockware Scientific Software, 1994). The variogram was checked using various lag spacings and anisotropy was examined with directional variograms at 0, 45, 90 and 135 degrees. The resulting variogram model was then used to produce a regular grid at a 2 km spacing of the catch per standard 550 m tow. This grid was clipped to the survey area, and contoured using the ACON data visualization software (Black, 1993). Total biomass estimates for commercial and pre recruit size classes were then produced.

To examine the influence of removals between the surveys, logbook data was used to map the distribution of fishing effort between the survey periods in relation to the 1997 station locations.

The area containing commercial densities was estimated using the breakeven density from an economic study of the viability of the Offshore Clam fishery. This study, prepared by Gardner Pinfold Consulting Economists Limited, was done as an independent analysis (although financed by Industry) of the economic viability of the fishery. DFO had requested this before they would agree to close the fishery to new licenses for the 1998-2002 management plan. The Gardner Pinfold study estimated a breakeven density of 0.09 to 0.1 kg/m^2 at 1996 prices.

The fishery cannot economically dredge 100% of the bottom and therefore cannot remove 100% of the surfclam biomass on Banquereau Bank. To estimate the percent of the bottom that was covered, a high-resolution sidescan survey of an area that had recently been harvested was used to map out the coverage of the bottom. The estimate of percent coverage was applied to the biomass of the grounds within commercial densities to produce an estimate of harvestable biomass on Banquereau Bank.

Recruitment was examined using the pre-recruit estimates; the results from the lined tows in the previously fished areas, and information from logbooks and conversations with the vessel captains.

Logbook analysis:

In this fishery, logbook coverage is 100% and there is good co-operation from owners and captains. The only deficiency in the data is the lack of accurate discard information. This has improved for the main bivalve species, but as most of the initial sorting is mechanical, there is no visual observation of the composition of the discards. Log data are recorded on a 6 hour watch basis and log catches are prorated to sales slip information for the older data where logs are estimates of round weight. For the processing vessels this had little effect as the product is weighed as it is processed, so the captain has the actual information at hand. Dockside monitors have replaced the sales slip system, and so the logs are checked against both the dockside reports and the plant weighout tallies. Processed weights are converted to round weights using conversion factors of 5.37 and 6.51 applied to the raw and blanched Individually Quick Frozen (IQF) foot product. This differs from the official Statistics Branch numbers who have used various conversion factors over time (Roddick, 1996).

Catch and effort data from the commercial logs were aggregated by one-minute squares of latitude and longitude to examine the distribution of catch and effort on the bank. CPUE was also averaged over one minute squares and plotted to show the distribution of high CPUE areas.

Data on the percentage of the bottom dredged in each one-minute square were calculated from commercial log data. Area dredged was calculated from tow time, vessel speed (over bottom) and width of the gear. This was then aggregated over one minute squares, and the total plotted as a fraction of the bottom area of the one-minute square. This was done to show the cumulative effect of the dredging and to give an indication of how much more effort different areas of the bank could sustain in the short term.

CPUE was aggregated by month and plotted to show trends over time.

Results

The contouring of the standard error of catch per standard tow for the 1996 survey from the kriging analysis was used to select the additional station locations for the 1997 survey (Figure 1). The variogram model used for the kriging is shown in Figure 2.

During the 1997 survey 65 survey stations plus 4 tows with a lined dredge were completed. Some stations planned for the southern edge of the bank could not be dredged due to the depth of the bottom in that area.

The distribution of fishing effort for the time between the two surveys was examined (Figure 3) to estimate the influence of removals during this period. As the 1997 stations did not tend to fall in the fishing areas there was no need to correct for removals between the surveys.

The 1996 size frequencies were “aged” or “grown” to 1997 sizes using a von Bertalanffy growth curve (Figure 4) from an age study of the 1996 and some of the 1997 morphometric samples. The numbers of clams from the 1996 survey were reduced with a natural mortality of 0.08 (Amaratunga and Rowell, 1986). This produced a combined data set of length frequencies representative of 1997 conditions, with the exception that for the 1996 stations, clams that would be recruited to the selection size of the survey gear between surveys are not accounted for.

We were concerned that recruitment to the commercial sizes in 1997 that had not been detected by the 1996 survey would compromise our estimate of biomass of commercial size clams in 1997. Commercial samples of the foot portion were converted to shell height to give a minimum commercial shell height of 85 mm (Table 1). Results from a selectivity study with a small mesh bag over the dredge conducted during the 1996 indicated that the survey dredge had a 50% retention point at 76.5 mm shell height. Given the slow growth rate of these clams (Table 4), the survey should have detected clams at least one year before being recruited to the fishery. This means that recruitment to the commercial size between surveys was not a source of error.

The length frequencies were then converted to weights with a length weight regression from the survey samples, and the weight of commercial sized clams at each station for the combined 1996/1997 data set was calculated. This data set was then used to produce a kriged grid of kg/standard tow, which was then clipped to the survey area and contoured. The grid was also converted to densities and contoured to calculate the area containing different densities of clams, and the biomass within these areas (Figure 6, and Table 2). At the breakeven density of 90g/m^2 from the Gardner Pinfold study (1998), there are 2174 km^2 at commercial densities, with a biomass of clams above minimum commercial size of 344,000 t.

Side scan sonar was used in a recently fished area to estimate the coverage of the bottom by the gear (Figures 7 and 8). This area had been recently fished by the CFV Concordia when the sidescan track was recorded. Examination of logbook and RoxAnn records from the vessels showed that there had been no prior fishing of this area before the Concordia. Mapping of the tracks for two regions within the sidescan track showed 40 and 76 % coverage of the bottom. In talking to the vessel captains, they felt that this area would still be commercially fishable. The study was done in the summer of 1996 when catch rates were still high, and there were still many unfished high-density areas. They feel that catch rates that would have caused them to move on at that time are again becoming attractive as the highest density areas are fished down, and an area such as this would be fished again. When asked, after seeing the results of the sidescan analysis, what the bottom coverage would be to economically fish out such an area, they said that they felt it would be approximately 75%.

If this assumption is used, there is a harvestable biomass 258,000 t (0.75 x 344,000 t) available on Banquereau Bank in the 2,174 km^2 area of commercial grounds.

To examine recruitment over the Bank, the numbers of prerecruit size clams were also contoured (Figure 9). The 4 tows using a small mesh liner in the dredge (location shown in

Figure 6) had catches of 4,000 to 35,000 clams each. There was also an unlined survey tow with a catch of 56,000 clams, consisting mainly of small clams, 6 to 8 years old. In addition, one vessel captain also reported an area with a high abundance of small clams (location in Figure 6).

Logbook analysis:

The catch, effort and CPUE for each year from the logbook data are shown in Table 3. The catches increased to 1989 and then decreased as the fishery concentrated more on Grand Bank. In 1992 all fishing activity took place on Grand Bank; none on Banquereau. Since 1992 there has been increased effort on Banquereau Bank, and landings in 1998 were the highest on record, although still below the TAC of 30,000 t. CPUE has dropped since 1995, as the highest density areas have been fished down, the captains' report that they are now returning to areas where they have fished in the past.

Analysis of logbook data showed how the fishery has developed, first through exploratory fishing and then by concentrating effort in a small area of the bank where catch rates were good. Initial fishing effort concentrated on the southeastern end of the Bank but then moved to explore the western and central areas. The distribution of catch, effort and CPUE by one-minute square for the 1986 to 1992 period can be seen in Figure 10. Since 1993 fishing has concentrated in the central and western areas of the Bank, as can be seen in Figure 11.

The effort was aggregated by one-minute square and mapped as the percentage of the bottom area of the one-minute square (Figure 12), to show the total distribution of effort since the fishery began.

The plot of CPUE by month for 1986 to 1998 (Figure 13) shows the decline since 1994-95. The seasonal fluctuations were mainly due to weather conditions.

Discussion

In 1986 it was estimated that Banquereau Bank had an exploitable biomass of 600,000 t of clams in an area of 2,497 km^2 (Rowell and Amaratunga 1986, Amaratunga and Rowell 1986). It is interesting to compare these estimates to the present estimate of 344,000 t in an area of 2,174 km^2, and the removals over this time of 96,000 t. This comparison, however, only underlines the fact that the original estimates were based on sparse data, and that survey equipment and techniques have improved. The original calculation of commercial grounds was done by contouring the data by eye, and using a planimeter to calculate the area. The density estimate for one large area was based on 4 stations. In spite of these problems, the areas originally delimited as commercial, do in fact, correspond to areas that have been heavily fished since the fishery opened.

The current TAC of 30,000 t is about 10 % of the biomass, and does not appear to be sustainable in the long term for Banquereau Bank. With the current biomass estimate of 344,000 t, reducing the annual TAC to 24,000 t would result in an exploitation rate below the assumed natural mortality rate of 8%, and be in line with the original biological advice.

The estimate of harvestable biomass of 258,000 t represents 8.6 years of fishing with an annual TAC of 30,000 t, not including the effects of growth, natural mortality and recruitment.

An additional large factor that is not included is the fact that the vessels are not just dependent on Banquereau Bank. Grand Bank would have to be included in any overall analysis of this fishery.

This analysis has not examined the question of production of the surfclam population. It would be possible to do the calculations using the data now available and making some general assumptions, but the results would be questionable, and should not be used. The aging studies currently being done will provide better estimates of growth rates and population structure over Banquereau Bank. This will give a better understanding of the variability of recruitment and other processes involved.

The prospects for future recruitment to the fishery appear to be better than previously thought (Roddick and Kenchington 1990). The young clams in the areas of high abundance appear to be 6 to 8 years old. In another 8 years they should be starting to enter the "Medium" commercial size class. The interesting point about the distribution and age of these clams is that they correspond both in time and location to the areas that were first heavily fished. Possible hypotheses for this correspondence could be that 1) fishing enhances recruitment success by reducing the biomass of filter feeders in the area and making more space available in areas suited for surfclam survival and growth, or 2) the action of the dredges on the bottom changes the geotechnical properties of the substrate making it more suitable for settlement. Future studies on the distribution of recruitment are needed to see if either of these hypothesis were true.

In the short term, the CPUE has started to decline. This is expected to continue as the fishery runs out of areas with a high virgin standing stock. They will have to target patches of lower density clams, and return to areas that they previously left, when average catch rates were higher, and fish them down further. As the accumulated biomass of older clams is fished out, the fishery will become more dependent on recruitment. The hydraulic dredges have a high efficiency for capturing commercial sized clams in their path, but will leave about 25% of the bottom area untouched. This means that there will be some broodstock left on the grounds as a source of future recruitment.

The commercial practice in general is to fish an area thoroughly and then move on, although there is some returning to high-density areas. This practice is good, as the effects of direct incidental mortality on small *Mactromeris polynyma* are not known for this area, but have been shown to be high for discards of adult *Spisula solidissima*, a closely related species fished with similar gear. Meyer et al. (1981) examined mortality rates for clams in two dredge tracks, and found they were 30 and 90% for large clams and 26 and 28% for small clams. This will be increased by the indirect effect of predation on small clams exposed on the surface (Kauwling and Bakus, 1979; Medcof and Caddy, 1974).

The average CPUE is still above the breakeven level from the Gardner Pinfold (1998) study. This study used the situation in 1996 as a basis however, and the main market for the clams is in Japan. The economic viability of this fishery is thus greatly influenced by the exchange rate between the Japanese Yen and Canadian Dollar. This has of course changed dramatically since 1996, to the detriment of Canadian companies exporting to Japan. The current breakeven level would be higher, but by how much is not known. This fishery is still limited by the market, as shown in 1998 when the vessels tied up at the end of the year when the market declined with the Japanese economy. The market for this clam is as luxury food item, mainly sushi and sashimi, and so is greatly effected by changes in the Japanese economy.

With the slow growth rates, unknown recruitment levels and probable high mortality of clams left on the bottom, the fishery would not be able to return to an area that had been fished out for at least 10-15 years and perhaps longer. Under these conditions, a TAC may not be appropriate. Other management techniques, such as a rotation of fishing grounds could be better suited to this type of fishery. The rotation of fishing areas would be on a schedule tied into the growth and recruitment pattern of the stock.

Using the data presented as a preliminary step and only considering Banquereau Bank, we have an estimate of harvestable biomass of 258,000 t in an area of 2,174 km^2. If we assume 15 years for new settlement to reach commercial size, it breaks down to 145 km^2 per year of grounds open, and a catch that would be approximately 17,000 t a year. If fishing is leaving small clams in the area, or the market will accept smaller clams, the rotational schedule could be shortened and the area opened each year increased.

Considerations for Rotational management schemes

The underlying issue for the sustainability of any fishery is to optimize harvesting with respect to the processes by which harvested biomass is replaced by population processes (MacCall 1990). These processes are recruitment of young, growth of adults and can also include immigration for highly mobile species (e.g., cod and haddock). For the case of highly mobile populations, harvests are assumed to equivalent effects on the population no matter where the harvesting occurs. However, in the case of sedentary benthic animals such as surfclams, mobility and immigration is minimal, if at all and harvesting will therefore have a very local effect. In this latter case, the replacement of biomass is simply a product of recruitment and growth in the local area.

MacCall (1990) has proposed that optimal harvesting of a relatively immobile population should be a function of the relative productivity in each area. In MacCall's approach each area has a specific suitability for the species in question with this suitability being reflected by the densities present. Further, the suitability of specific area will decline as populations increase in number with the lesser suitable areas reaching their carrying capacity at lower population sizes than the more highly suitable areas. The calculation of optimal harvests for each area needs to account for the suitability and carrying capacity specific to that area. In addition, specific assumptions concerning recruitment with respect to area and time need to be made.

On the other hand, Caddy and Seijo (1998) describe a simulation model in which a sedentary population is distributed in patches all with equal suitability. Recruitment processes can be constant or stochastic with respect to area and time. The results indicate that the optimum rotation period will be a function of the longevity and growth rate of the species being fished. In this type of approach, each area or patch is fished at a similar level in its rotation.

There are not very many examples of fisheries for which rotational plans or geographical optimal harvest plans have been developed and used for sedentary organisms. The geoduck clam (*Panopea abrupta*) fishery in British Columbia is managed on a three-year rotational period

(Campbell et al. 1998). Geoduck clams are long-lived species reaching ages of well over 100 years but appear to have their most rapid growth phase in the first 10 years of life.). The total fishing area is divided into three subareas for the rotational plan and fishing in each area is conducted at three times the quota that would have been permitted with annual fishing over the whole area. Over time, beds within subareas where greater than 50 percent of the original biomass has been harvested are removed from the fishery until stocks recover on these beds. Campbell et al. (1998) do not explain what the basis for the three-year period is nor comment on how long a bed takes to recover from high exploitation. Another example of a rotational fishery is the California red sea urchin (Botsford et al. 1993).

No matter what approach is chosen for structuring a geographical rotational fishery, many authors agree that commercial catch rate is a poor indicator of abundance for sedentary populations distributed in patches (e.g., Campbell et al. 1998, Prince and Hilborn 1998). Experiences vary but generally, catch rate will tend to decline at a slower rate than abundance while fishermen concentrate on the densest patches. Once these patches have been depleted, the catch rate will show a precipitous decline as lower density patches are fished. Research surveys that cover all areas in a standard way seem to be the best way of monitoring abundance changes.

Moving to a management strategy of rotational fishing areas, therefore, has benefits and problems. In a general sense it would be much as the fishery already operates, fishing an area down and then leaving it. In practice, to regulate this movement the distribution of biomass and production would have to be known in a lot finer detail, and be updated regularly. This implies a regular fine scale surveys of the area. The expense of this on Banquereau Bank alone would be large, but this fishery also takes in Grand Bank and is exploring others. To cover the entire fishing grounds in a regular survey could only be done at great expense, but would not have to be done on an annual basis. The use of rotational fishing areas without this knowledge means that the managers would have to rely heavily on information from the Industry on the status of the resource.

The most likely problems to be encountered with rotational fishing would be caused by the patchy distribution of the resource. The sidescan survey of the dredge tracks in a recently fished area indicated fishing was targeting areas on the scale of a few hundred meters. The analysis of the survey data is on a much larger scale and assumes that it is matching "average" conditions on that scale. With a rotational fishery, as the areas within the rotation decrease in size, the risk increases that these "average" conditions are not met. Without fine scale knowledge of the resource distribution, management of rotational fishing areas could only be done in close co-operation with Industry. It would have to have a system that could make changes quickly when problems are encountered, and it would have to rely on data from Industry to make decisions. This would then bring into question the idea that the fishery is being regulated at arms length.

Summary

The long-term future of this fishery remains unclear. If the fishery remains as dependent on Banquereau Bank as it has for the last two years, the catch rates will continue to decline as lower and lower density areas are targeted. The areas that were fished early on appear to have good recruitment, but are still years away from reaching commercial size. The survey analysis gives an estimate for Banquereau Bank of a harvestable biomass of 258,000 t, in an area of 2174 km^2. The analysis of harvestable biomass was based on breakeven values from 1996 when the market was in better shape. It is inevitable that at a lower market price the economically harvestable biomass is reduced. This indicates that the current TAC of 30,000 t for Banquereau Bank is not sustainable in the long term and should be reduced.

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Table 1. Predicted shell length for commercial size class from Banquereau Bank.

Predicted shell length at which clams enter each size class.

Size Class	Count	Blanched Foot Weight (g)	Raw Gutted Foot Weight (g)	Shell Length (mm)
SS	70	13.4	16.1	84.9
S	60	15.5	18.7	88.8
M	50	18.3	22	93.3
L	40	23.0	27.7	100.0
LL	35	27.0	32.5	105.0

Predicted shell length for average clam in each size class.

Size Class	Count /kilogram	Blanched Foot Weight (g)	Raw Gutted Foot Weight (g)	Shell Length (mm)
SS	70	14.3	17.2	86.6
S	60	16.7	20.1	90.8
M	50	20.0	24.1	95.9
L	40	25.0	30.1	102.6
LL	35	28.6	34.4	106.8

Table 2. Density contour levels and the area and biomass for clams >85 mm shell length within each contour level.

Kg/m^2	Area km^2	t * 1000
0.000	5200.117250	469.839032
0.015	4567.649897	466.089178
0.030	4107.020160	455.479590
0.045	3558.949186	434.869885
0.060	3033.559946	407.294816
0.075	2556.334190	375.057130
0.090	2173.564381	343.668155
0.105	1811.099452	308.251624
0.120	1484.157297	271.555834
0.135	1184.700557	233.399997
0.150	887.373846	191.061073
0.165	649.036002	153.755954
0.180	531.453117	133.555799
0.195	451.926443	118.681265
0.210	384.287587	105.005007
0.225	334.446492	94.170965
0.240	280.921122	81.749002
0.255	232.951849	69.868141
0.270	183.852327	57.002308
0.285	134.830497	43.427290
0.300	98.134501	32.710360

Table 3. TAC, Catch, Effort and CPUE for Banquereau Bank.

Yr	TAC (t)	Catch (t)	Effort (km Sq.)	CPUE Mean	CPUE Std. Dev.
86		29	0.37	0.10	0.10
87	30,000	1,220	8.86	0.15	0.10
88	30,000	2,836	25.08	0.11	0.06
89	30,000	8,350	75.49	0.11	0.06
90	30,000	5,629	68.10	0.09	0.04
91	30,000	731	9.68	0.08	0.03
92	30,000	0	0.00	-	-
93	30,000	60	2.10	0.04	0.02
94	30,000	5,329	38.17	0.15	0.08
95	30,000	11,490	83.92	0.15	0.08
96	30,000	19,231	155.34	0.13	0.06
97	30,000	19,527	159.18	0.13	0.13
98	30,000	22,925	217.41	0.11	0.14

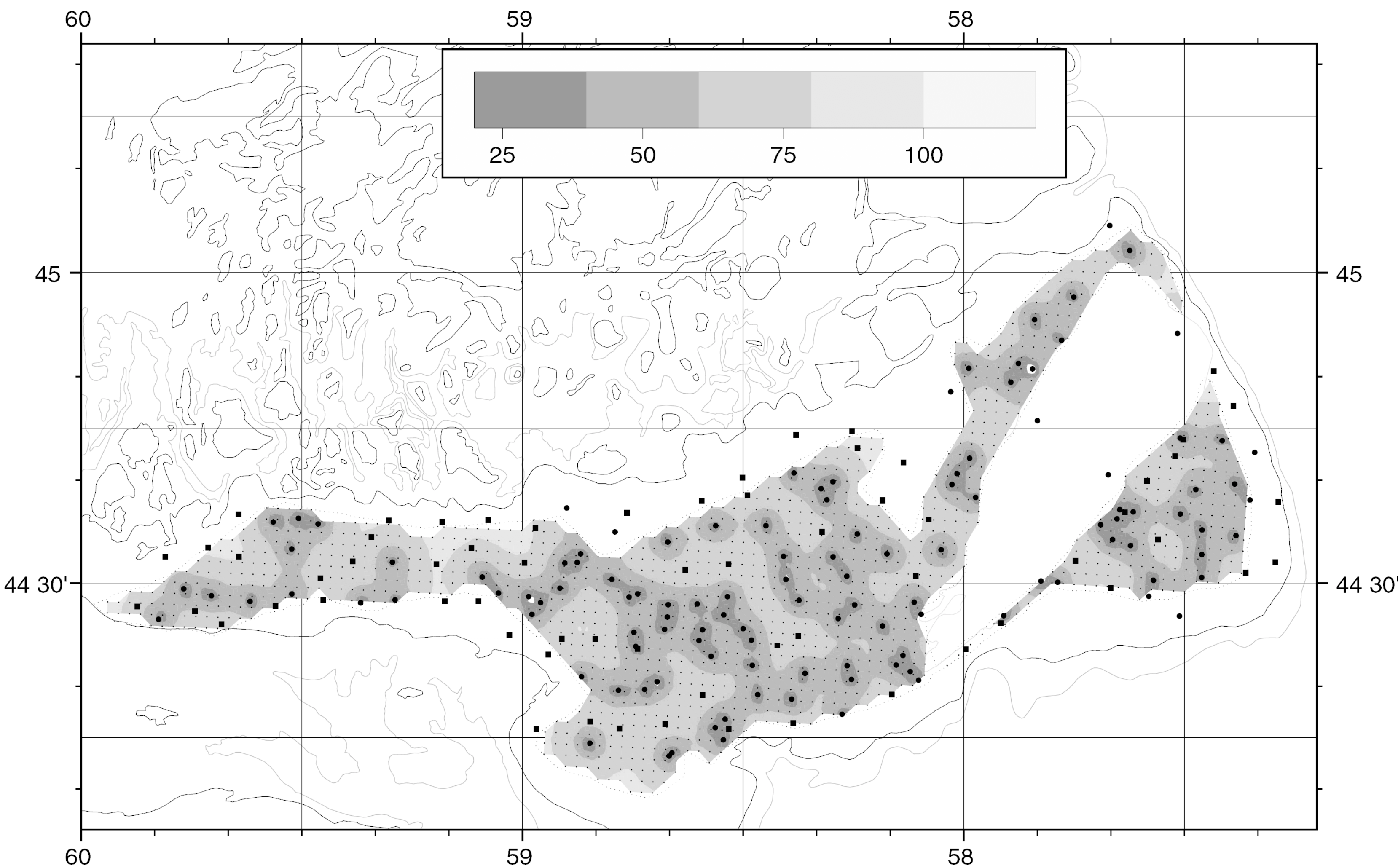
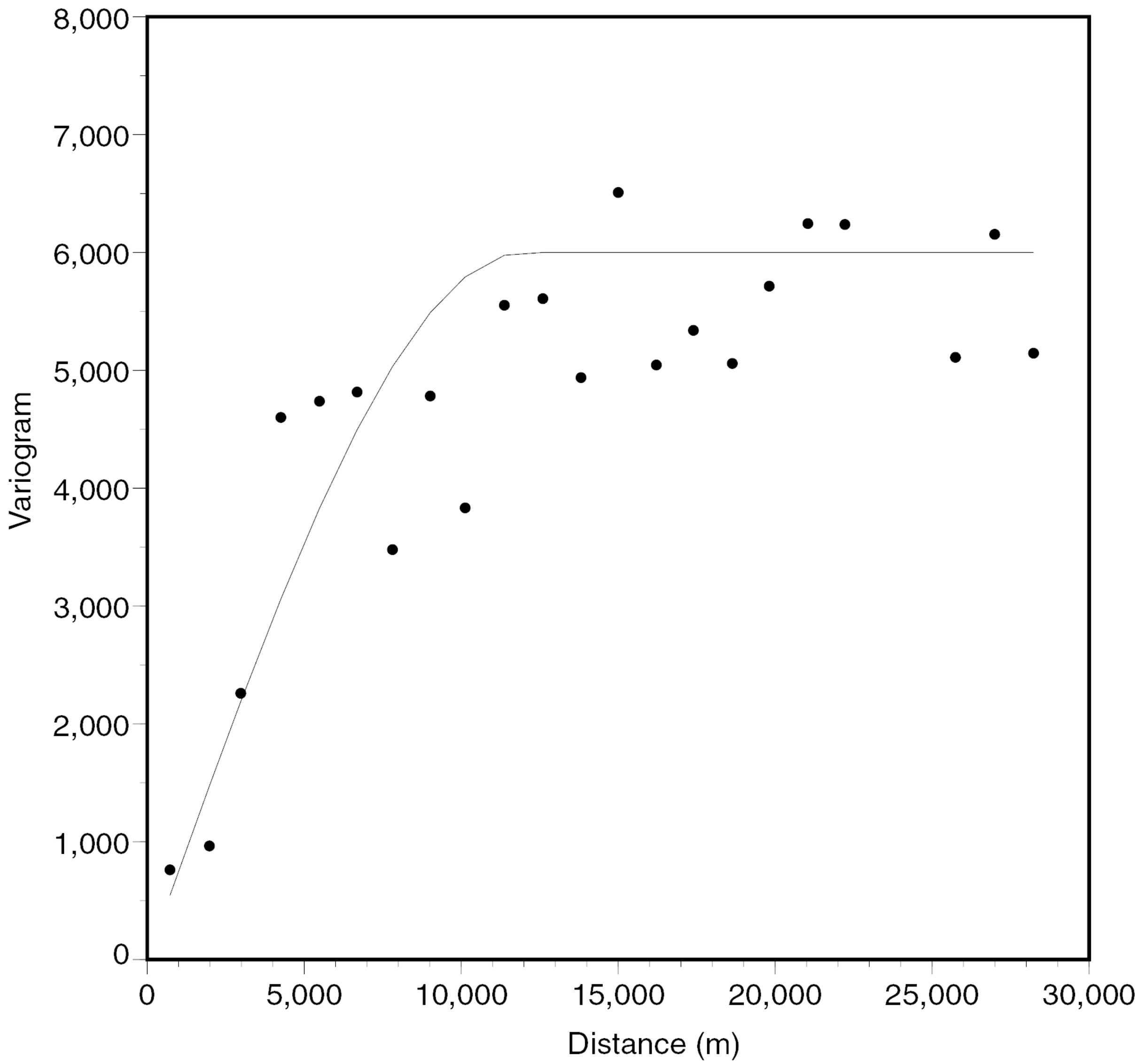


Figure 1. Contour plot of kriged grid of the standard deviations of catch rates (g/m^2) for the 1996 survey. Small dots are the grid nodes, large dots are the 1996 survey stations, and squares are the 1997 survey stations.



Parameters	Variable Limits	Model Information
# of pairs: 3,392	Min. 0.00	Nugget = 0.00
Direction: 0.0	Max. 375.20	Spherical Model:
Tolerance: 90.0	Mean: 76.12	Sill = 6,000.00
Bandwidth: MAX	Variance: 5,961.19	Range = 12,000

Figure 2. Variogram model used to krige the combined 1996-1997 survey data.

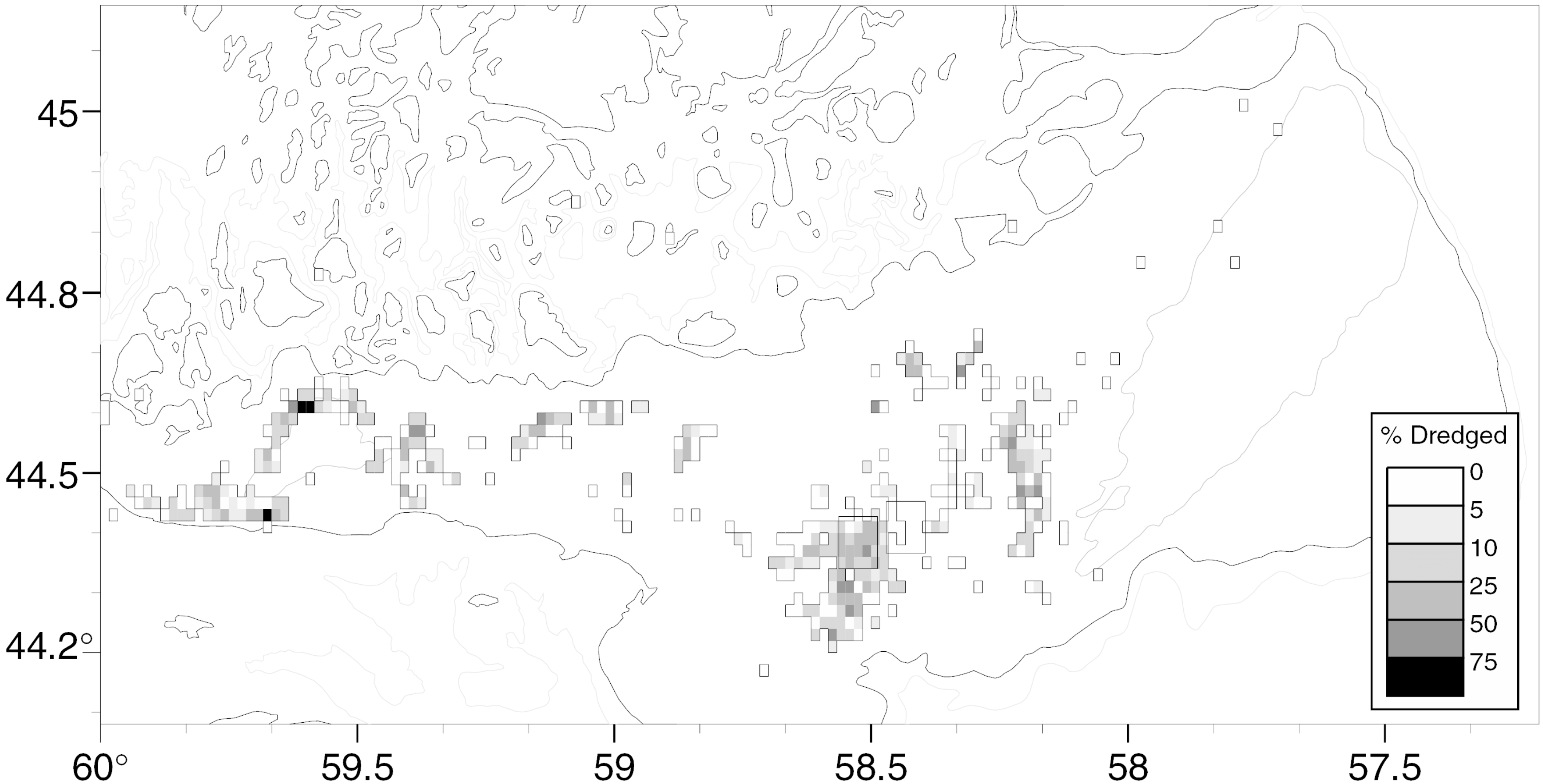


Figure 3. Distribution of fishing effort during the period between the surveys, July 1996 and September 1997.

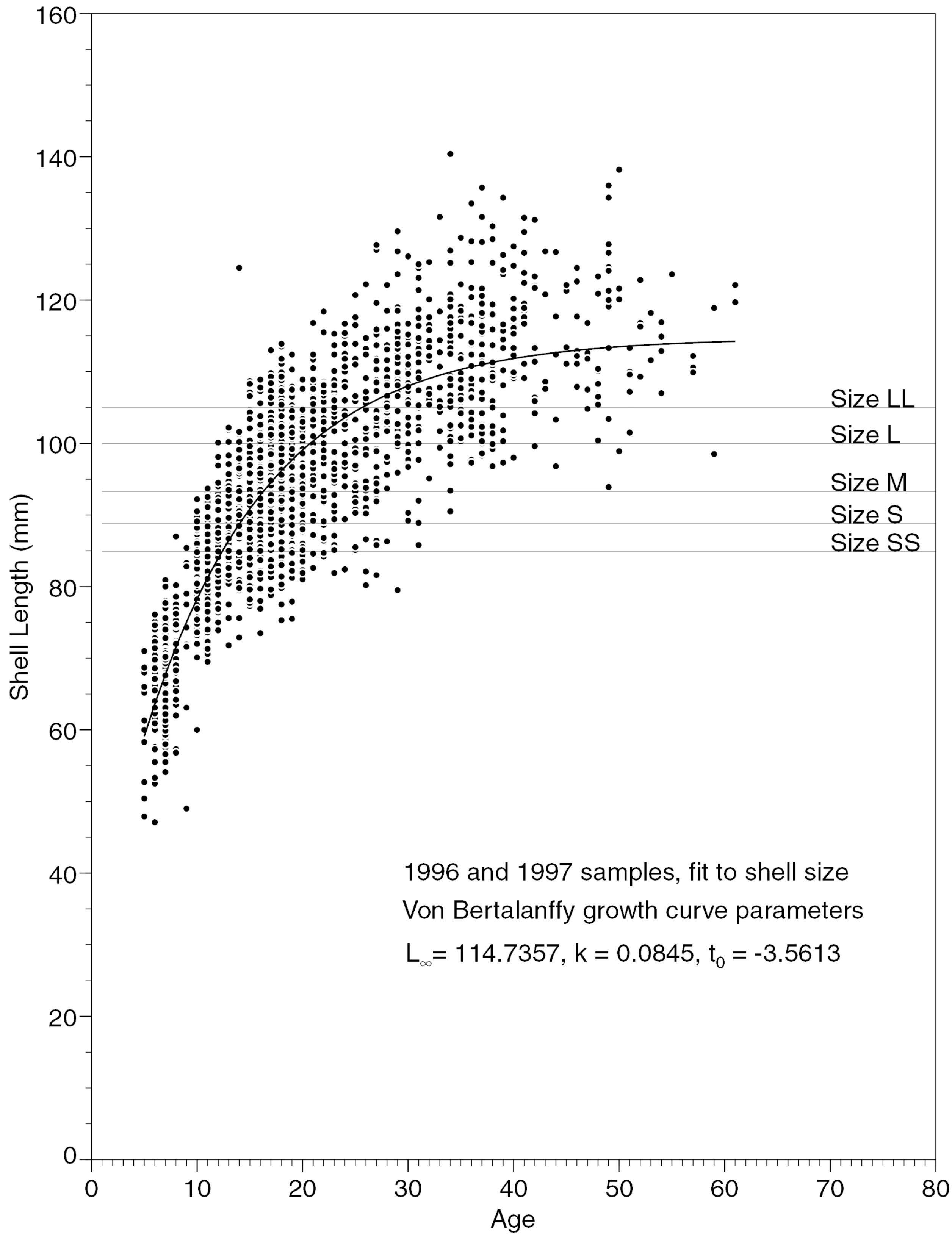


Figure 4. Shell length at age from 1996 and some 1997 shell samples, with Von Bertalanffy growth curve. Sizes are approximate commercial market sizes.

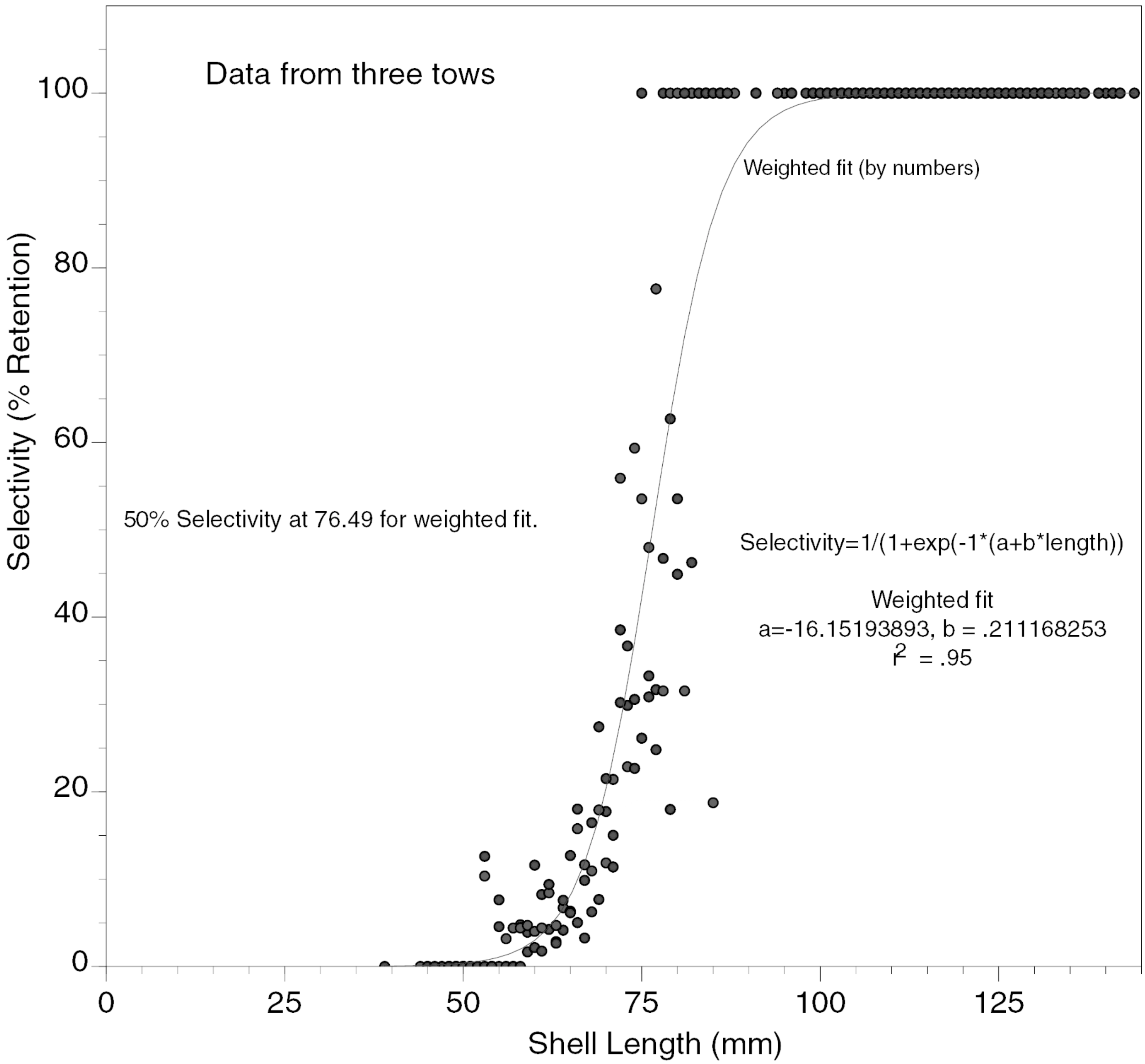


Figure 5. - Selectivity of dredge used on the CFV Atlantic Dauphin during the 1996 offshore clam survey.

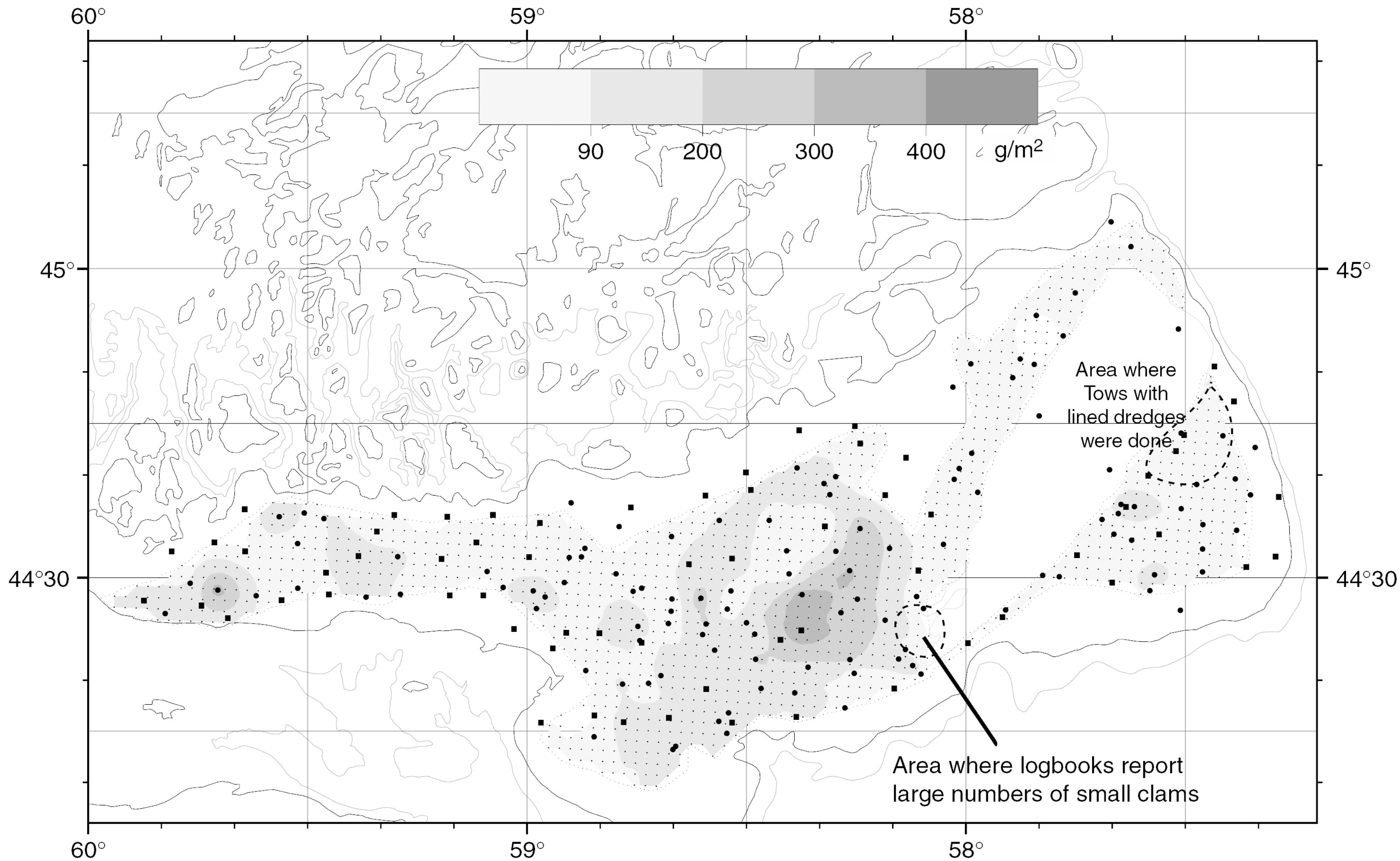


Figure 6. Contour plot of kriged grid of the density of clams (g/m^2) for the 1996 and 1997 surveys. Small dots are the grid nodes, large dots are the 1996 survey stations, and squares are the 1997 survey stations. 90 g/m^2 is the break-even commercial density from the Gardner Pinfold study.

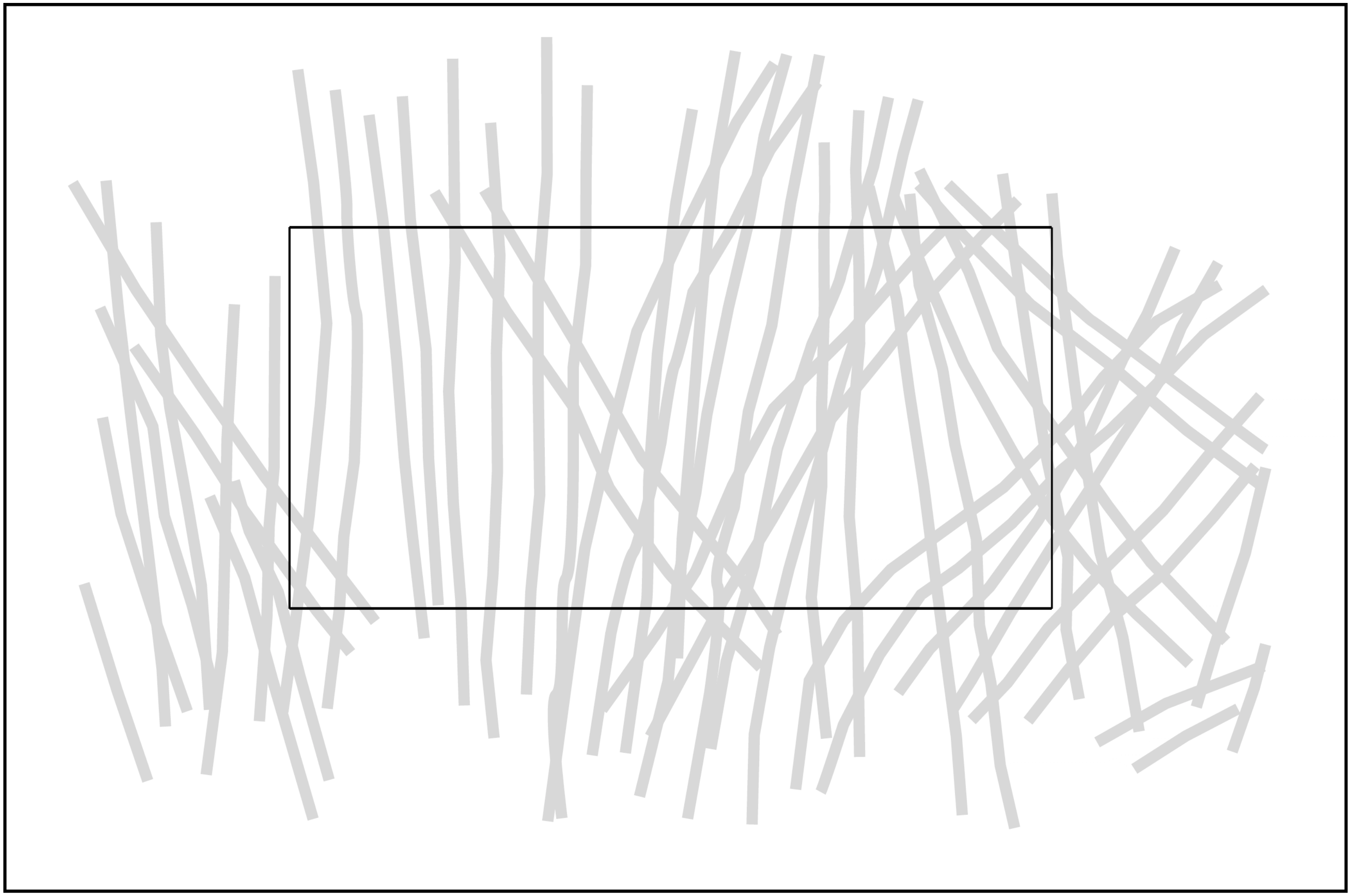


Figure 7. - Sidescan of clam dredge tracks from CFV Concordia in Area 1 North, Banquereau Bank 1996. Dredge track width scaled to 12 feet wide. Box used for area analysis is 250 m x 125 m, percentage of ground covered within box is 40.09%.

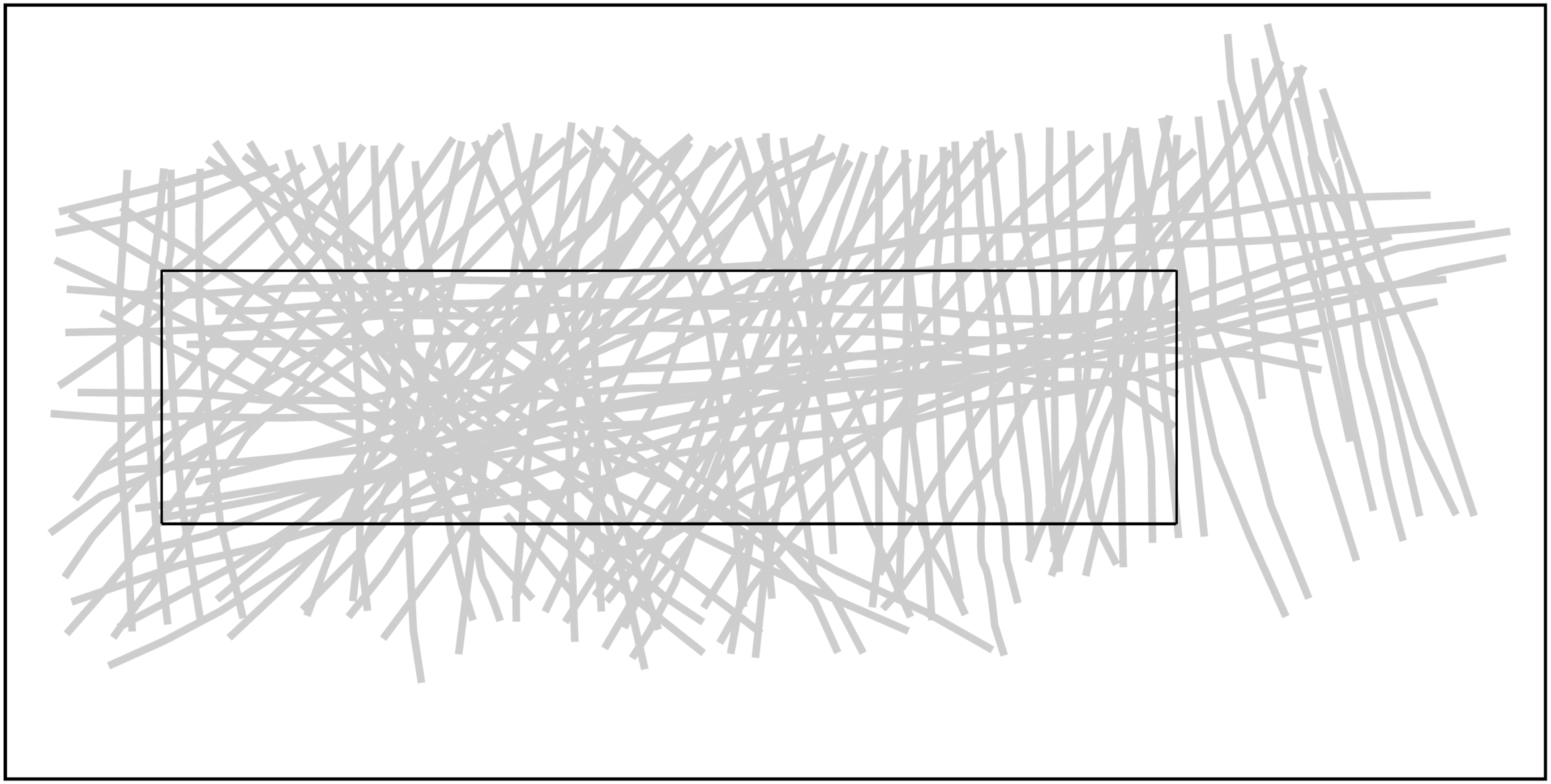


Figure 8. - Sidescan of clam dredge tracks from CFV Concordia in Area 2 North, Banquereau Bank 1996. Dredge track width scaled to 12 feet wide. Box used for area analysis is 500 m x 125 m, percentage of ground covered within box is 67.42%.

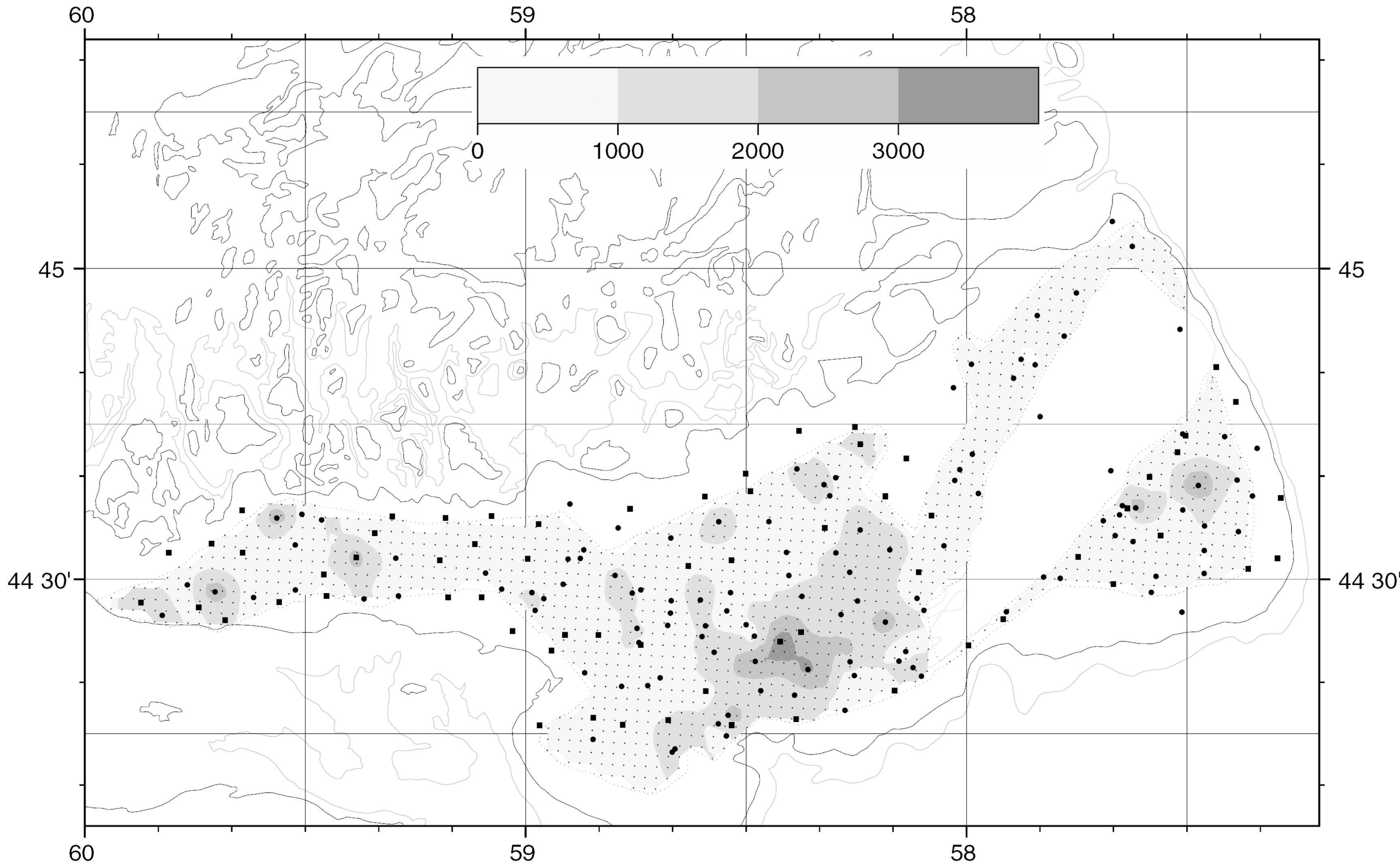


Figure 9. Kriged grid of the number of pre-recruit (<85 mm shell length) surfclams per standard tow for the combined 1996-1997 survey data.

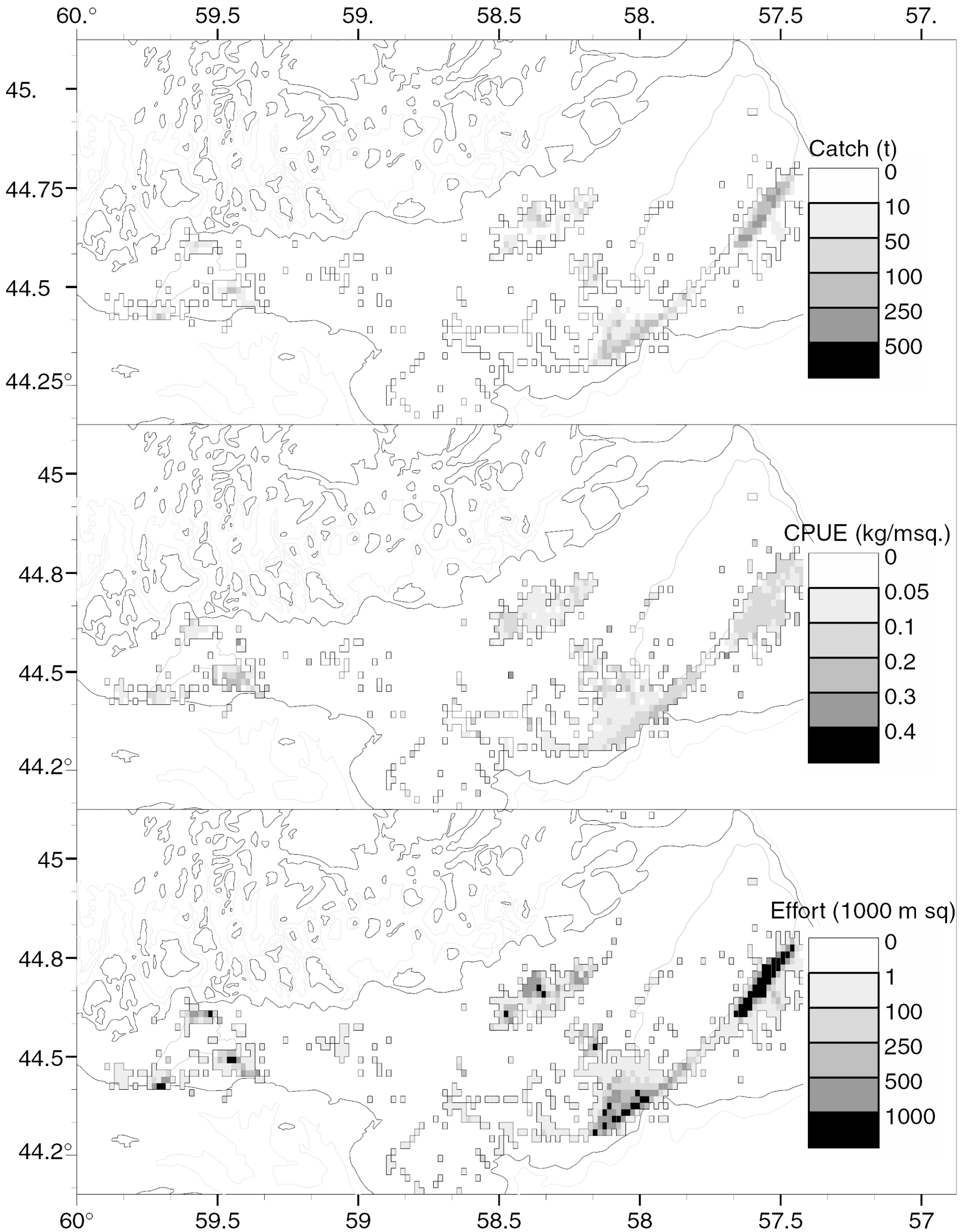


Figure 10. Catch, effort and CPUE for the surfclam fishery from 1986 to 1992. Catch and effort are totals in the one minute squares, CPUE is the average within the one minute square.

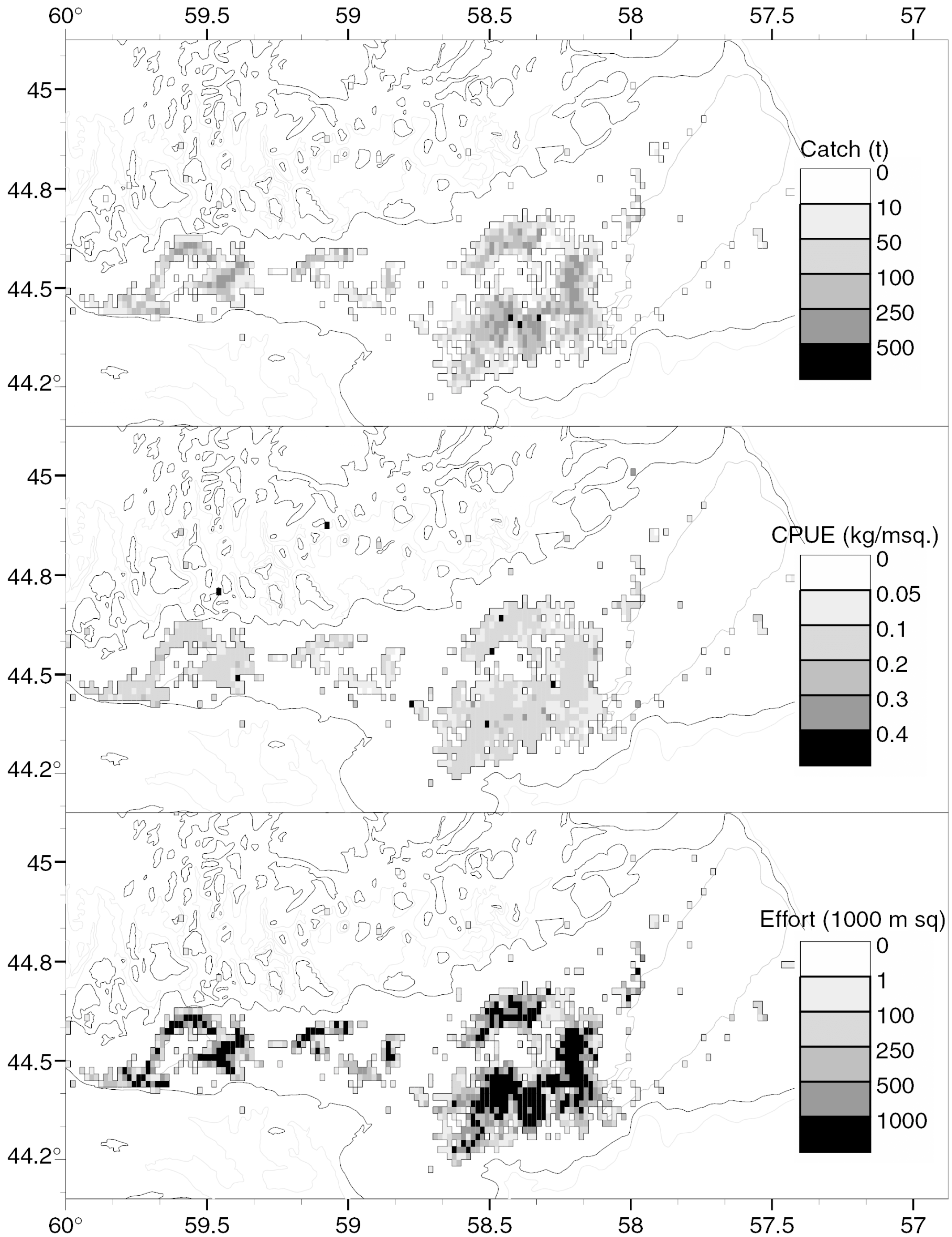


Figure 11. Catch, effort and CPUE for the surfclam fishery from 1993 to 1998. Catch and effort are totals in the one minute squares, CPUE is the average within the one minute square.

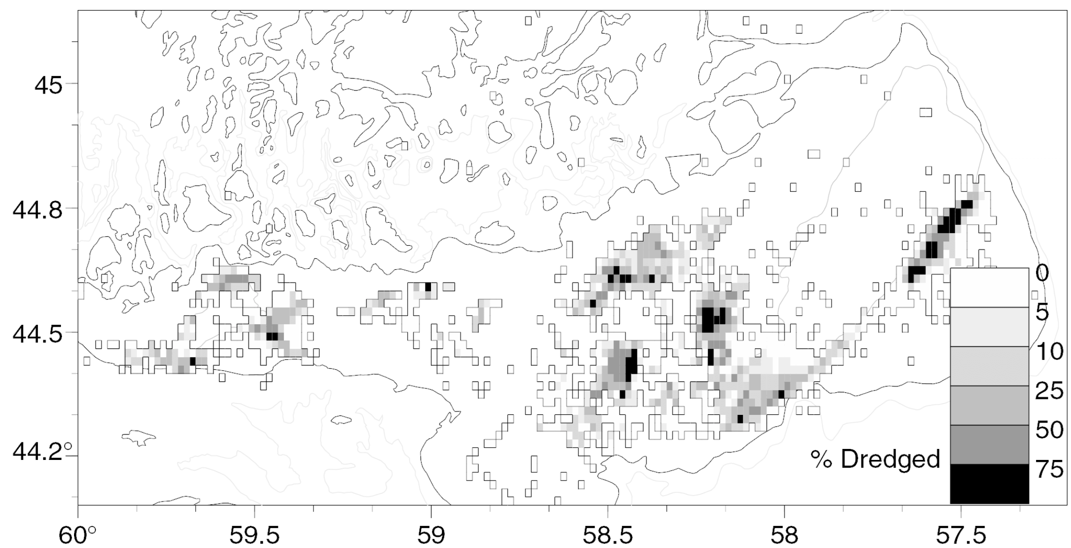


Figure 12. Effort (m^2) aggregated by one minute square and summed as the percentage of the area of each one minute square for the 1986 to 1998 period.

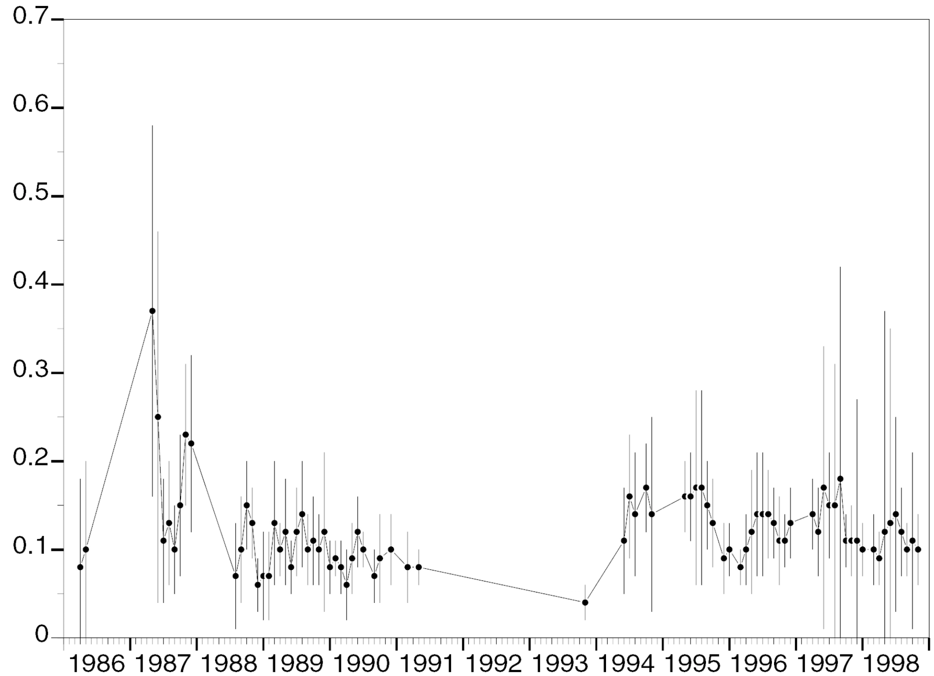


Figure 13. CPUE (kg/m^2) by month for 1986 to 1998 for surfclam vessels on Banquereau Bank. Verticle bars are standard deviations.