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Update on the By-catch in the NAFO Division 3M Shrimp Fishery, 1993-97

by

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Abstract

A fishery for shrimp, in existence since the late-1970s on the Labrador Shelf, and in the Hudson and Davis Straits expanded to the Flemish Cap (NAFO Division 3M) in 1993. As with the shelf fishery, the 3M grounds overlap with the distributions of other species resulting in a by-catch consisting primarily of small fish and invertebrates. A portion of the Canadian and Norwegian fleets carried fishery observers and the data collected by these individuals were used to examine the characteristics of the catch. This paper describes the changes that took place between 1993 and 1997 based on the observed portion of the fishery. Because of the use of small mesh gear and a complex local community structure, the by-catch in this fishery comprised about 125 species. The level and composition of by-catch was found to diminish over time due in part to the introduction of an excluding attachment, the Nordmore grate in 1994 and a reduction in bar spacing in subsequent years interacting with a changing community structure. Total by-catch was reduced from 33.26% of the catch in 1993 when no grate was in use to 4.29 and 3.44% in 1996 and 1997 respectively when 19 to 22 mm bar spacings were employed. In 1993 with no grate, redfish was dominant (28.5% of the total catch or 138 million fish) in the by-catch and along with other commercially valuable species namely wolffishes, skates, and turbot, comprised the majority of the catch. Other commercially valuable species taken in lesser amounts were capelin, witch, plaice, cod and roundnose grenadier. The by-catch mix changed significantly with introduction of the grate in 1994. Primarily small or thin fish about the width of shrimp that could fit through the bars of the grate were the main by-catch. However, redfish continued to make up the main by-catch until 1997 but at progressively reduced levels, specifically 19.0%, 1.1%, 1.0% and 0.6% of the catch by weight, equivalent to 89, 5, 18, and 4 million fish in 1994, 1995, 1996 and 1997, respectively. Redfish comprised mainly 2 to 8-year olds but the mix of year-classes was found to fluctuate from year to year. The majority were 5 and 6 year olds in 1993, 6 and 7 in 1994 and the same in 1995. However, there was an 18 fold decrease in numbers of redfish between 1994 and 1995 concurrent with a reduction of grate spacing from 28 to 22 mm. Although weight of redfish as a percent of total catch did not increase in 1996, numbers increased more than threefold. This was due to a large proportion of 2 year-olds taken in 1996, not encountered in other years. Age 2 redfish being as small as the shrimp were not excluded by the grate. In 1997, redfish (mainly 3 to 6 year olds) was no longer the main by-catch. A mix of lanternfish (Myctophidae), small pelagic species about the size of shrimp constituted the largest by-catch component in that year. Young redfish and eelpouts constituted most of the rest of the by-catch. Lost yield of redfish is estimated for a series of natural mortality levels. Using Canadian weight at age and assuming a constant natural mortality of 0.1 with $F_{0.1}$ of 0.124, the estimated lost yield relating to by-catch mortality in the shrimp fishery for 1993 to 1997 was 40,000 tons.

Introduction

A fishery for shrimp (*Pandalus spp.*) has existed on the Labrador Shelf and the Hudson and Davis Straits since the late-1970s (Parsons, 1994). For years, *P. borealis* was also known to be distributed on the Flemish Cap (Vasquez, 1989 and Sainza, 1995, Parsons *et al.* 1998 in press). However, it was not until 1993 that the shrimp grounds were extended to include the Flemish Cap (Fig. 1). Parsons *et al.* (1998 in press) reported that in 1993, two Canadian vessels were granted exploratory permits to fish for *P. borealis* in NAFO Div. 3M. Those vessels located commercial concentrations of shrimp and subsequently, the fishery expanded rapidly. The fishery has continued to be prosecuted in subsequent

years peaking in 1996 in terms of catch. To date, Canada, Denmark, Portugal, Spain, Estonia, Faroe Islands, Greenland, Iceland, Latvia, Lithuania, Norway, Russia, Honduras and St. Vincent have participated in the fishery taking an estimated 26 088, 24 324, 32 977, 51 163 and 25 000 (preliminary) tons of shrimp in 1993 through 1997, respectively.

The gear used to capture shrimp is a modified otter trawl with small mesh gear (average 43 mm, range 40-50 mm). This configuration results in the incidental capture of many species of fish and invertebrates other than shrimp. Kulka (1995) for Davis Strait the Labrador Shelf from data collected by fishery observers, showed that there was a significant by-catch of about 125 species (many more than are taken in other otter trawl gears), all of which was subsequently discarded. Because of the small mesh used, these by-catches are comprised mainly of small fish. With the introduction of an excluding device, the Nordmore grate in the early-1990s and its subsequent mandatory use, by-catch of larger fish taken with this gear has been reduced. However, where there are concentrations of very small fish (generally less than 20 cm) mixed with the shrimp, even with the grate, some of the smaller fish pass through the excluding device into the cod end.

In 1995, STACFIS raised concerns about the potential damage to the groundfish stocks, particularly redfish due to by-catch mortality in the then new shrimp fishery on the Flemish Cap. Kulka and Power (1996) analysed observer data for Canadian and Norwegian component of the 1993 to 1995 fishery. The observer estimates showed that high by-catches of redfish (*Sebastes spp.*) observed in 1993 were reduced by about one half in 1994. The reduction was concurrent with the introduction of the Nordmore grate in that year. A maximum bar spacing of 28 mm was made mandatory in 1994 for NAFO Div. 3M. Redfish and other species continued to be taken in 1995 but at greatly reduced levels when the maximum allowable bar spacing was set at 22 mm.

Detailed data were collected by fishery observers deployed to a portion of the Canadian fleet in 1993 and 1994 and the Norwegian and Canadian fleet in 1995 to 1997. Individual set records of catch and measurements of the redfish were used to examine by-catch composition, spatial distribution of the shrimp and redfish, and size and age distribution of redfish. This paper updates information previously reported by Kulka and Power (1996) on by-catches from the 1993 and 1994 shrimp fishery on the Flemish Cap. It also to examine the effect of the introduction of the Nordmore grate to the fishery and potential loss of yield of redfish due to the by-catch mortality.

Methods

Fishery observers deployed to a portion of the Canadian (1993-1997) and Norwegian (1995-1997) vessels fishing for shrimp in NAFO Division 3M recorded details of the catches on a set by set basis and this information was used to examine catch and subsequent discarding of by-catch for that period. One hundred percent of Canadian activity was observed but the percent observed for the total fishery ranged between 4.2 and 10.8%, the greatest coverage occurring in 1996 and 1997. A total of 10,402 shrimp directed sets were observed between 1993 and 1997.

The amount of each species taken in each set was estimated by methods outlined in Kulka (1996) and Kulka and Firth (1987). Specific to vessels directing for shrimp, discarding of the by-catch varies among vessels and may be handled by the crew in a variety of ways. Hence, instructions to observers during briefings on discard observation strategies were tailored to individual vessels and production shifts. Factors such as vessel configuration, discard sites, processing area layout, crew habits, discard practices and levels of discarding were taken into account when quantifying discards. Discard observation sites were combined where possible to minimize the number of locations at which observations were made thus maximizing the amount of fish viewed, weighed, or counted. On shrimp vessels, discarding was generally centralized taking place from the wet holding tank where redfish were floated off and on the sorting belt leading from this holding tank to the processing line and this was where catch estimation and fish removal for sampling took place.

Estimating discards was accomplished by either weighing or counting fish, or a combination of both depending on vessel conditions and amounts discarded. The general principle was to use the most direct method possible under the circumstances to estimate amounts discarded. The by-catch was weighed where amounts were small. Otherwise, the total amount discarded was estimated by taking a count of baskets of discard fish collected for the portion of the discarding period observed then extrapolating these counts to the total processing period. A weighed sample of baskets allowed conversion of basket counts to weights. Where weighing was not possible, discarded fish were counted then converted to weight by multiplying by the average weight of discarded individuals. Random sample of discarded fish from the set were weighed and measured and their mean length was calculated. A length/weight table was used to calculate average discard weight. Regardless of whether the discards were weighed or counted, the amount of fish viewed, counted, or weighed was maximized, all sites were observed and observations were spread over the entire production period.

Only sets where the observer estimated catch and discards were used in this study to calculate percent of by-catch (all of which was subsequently discarded). To account for unobserved sets, total by-catch amounts were estimated by multiplying the ratio of reported shrimp landings to observed shrimp kept weights by observed by-catch weight by species for each month (the finest breakdown available from the landing statistics). Eight length samples of redfish discards from 1994 and 11 from each of 1995, 1996 and 1997 were used to convert discard weight to numbers at length. Combined age-length keys from research vessel surveys in NAFO Div. 3M from 1978-1981 were used to estimate numbers at age.

Maps of fishing grounds were produced by converting point data, in this case set by set fishing locations to effort density surfaces using potential mapping in SPANS similar the methods described in Kulka *et al.* (1995). Similarly, potential maps of shrimp and redfish were produced from set by set estimates of catch per hour to illustrate distribution of the two species on the fishing grounds. Refer to Kulka (1998) for a description of how the potential maps were created in SPANS. A (model) matrix overlay of the fishing density and redfish density was used to show the spatial relationship between fishing location and redfish concentrations. Also, shrimp and redfish density maps were overlaid to show areas of high shrimp/low by-catch grading to low/shrimp high by-catch.

Loss of commercial yield of NAFO Div. 3M redfish due to 1993 to 1997 by-catches was calculated using the yield per recruit method described in Avila de Melo *et al.* (1997). However, the calculations presented in this paper differ from those of Avila de Melo *et al.* (1997) in that numbers at age were estimated using combined age-length keys from Canadian research vessel surveys and lost yield was estimated for the entire by-catch of redfish, not just the *S. mentella* component. Mean weights at age used in the yield per recruit calculation were obtained from Power and Atkinson (1990).

Results

Figure 1 illustrates the area fished for shrimp on the Flemish Cap based on set by set observations from the Canadian (1993-1999) and Norwegian (1995-1997) fleets. The fishing grounds for observed activity (10,402 sets) covered a total of 28,000 km² nearly circumscribing the Flemish Cap at depths between 151 and 715 m. The only unfished area was to the south-east where the slope of the bank was steep and preferred fishing depth range was narrow. Eighty-seven percent of the fishing activity occurred over a smaller area and narrower range of depths between 300 and 600 m covering about 18,200 km². Area fished differed among years covering only 11,600 km² and a narrow depth range in 1993, the first year of the fishery, expanding to 25,000 km² in 1996 then contracting to 21,00 km² in 1997 as reported fishing effort was reduced in that year. Expansion of the grounds after 1993 occurred mainly to the south-west due in part to the added coverage of the Norwegian fleet that also tended to fish slightly deeper than the Canadian vessels.

Perhaps more important than shifting fishing patterns, significant changes occurred in the configuration of the gear among years causing changes to the composition of the by-catch (described below). The Nordmore grate was introduced (made mandatory) in 1994 and changes were made to the grate spacing in 1994 and 1995 as shown in Figure 2. In 1994, 75% of the sets observed had a 28 mm spacing while 10%, 10% and 5% of the sets employed grates with 27, 26 and 25 mm bar spacings respectively. In 1995, the spacing was further reduced such that 61, 7 and 31% of sets had 22, 20 and 19 mm spacing. In 1996, Norway experimented with a range of grate spacings between 19 and 24 mm. Canada used 20 or 22 mm. In 1997, bar spacing was set at 19 or 22 mm, 22 mm or less being a regulatory requirement. Norway used a greater proportion of the smaller 19 mm grids.

Table 1 lists the estimated total catches by species based on the observed shrimp fishery adjusted to the total reported shrimp catches of all countries. The assumption in terms of estimates of by-catch is that proportions of by-catch in each year were similar among observed and unobserved fleets of the various countries that participated in the fishery. This is reasonable given similar mesh size used for the trawl and overlapping fishing grounds. Amount of by-catch by species varied greatly among years depending on changing levels of fishing effort, use and configuration of the Nordmore grate and species mix available to the gear. Proportion of by-catch of all species combined decreased over time, the biggest decrease occurring between 1994 and 1995. The by-catch dropped from 21.9% in 1994 to 2.6% of the total catch weight in 1995. In that year, the Nordmore grate bar spacing was reduced from 28 to 22 mm. Subsequently, the percentage of total by-catch remained low at 4.3% in 1996 and 3.4% in 1997 but the species mix continued to change (Note - The 1997 estimate of shrimp catch at 25,000 tons is preliminary and estimates of by-catch will change in proportion to the shrimp catch when final landings are known).

Redfish (*Sebastes spp.*, comprising mainly *mentella* and *fasciatus*) were found to be the main by-catch in the shrimp catches. Of about 125 species taken as by-catch with shrimp, only redfish exceeded 1% of the total catch in any year, dominating in all years except 1997 as shown in Figure 3. Redfish by-catch in tonnes accompanies the bar graph and weights and percentages for all species taken as by-catch are listed in Table 1. Redfish as a percent of total catch declined from 28.4% (11,970 tons) in 1993 to 1.03% (550 tons) in 1996 and 0.42% (155 tons) in 1997. Other species were a relatively minor component of the catch in all years. Only skates (*Raja spp*) and wolffishes (*Anarhichas spp*) exceeded an annual by-catch of 200 tons and only in the first year. However, species mix as well as proportion relative to shrimp changed as the Nordmore grate was implemented and bar spacing was reduced. In 1993, before introduction of the grate, in addition to redfish, in order of amount taken, wolffishes, skates, turbot (*Reinhardtius hippoglossoides*), lanternfishes (Myctophidae), capelin (*Mallotus villosus*) and plaice (*Hippoglossoides platessoides*) were common in most catches. Other commercial species taken in minor amounts were witch (*Glyptocephalus cynoglossus*), cod (*Gadus morhua*), roundnose grenadier (*Coryphaenoides rupestris*), silver hake (*Merluccius bilinearis*) and halibut (*Hippoglossus hippoglossus*). In 1995, with a smaller bar spacing, fish similar to the size (width) of shrimp became the dominant by-catch, namely young redfish, lanternfish and eelpouts (*Lycodes spp*). In 1997, a species (group) other than redfish, namely lanternfishes became the predominant by-catch.

Figure 4 illustrates the proportion of redfish in the catch with respect to grate size used. In 1994, percent of redfish was actually slightly greater with decreasing grid size between 26 and 28 mm but was lowest for sets where 25 mm spacing was used. In 1995, (only) 12 sets employing a 28 mm grid were observed. The by-catch rate for those sets was much lower than in 1994 at the same grid size but this number of sets is too small to draw any conclusions when comparing the two years. For the large majority of sets in 1995, the grids used were less than 23 mm apart and by-catch rates were less than 2%. In 1996 and 1997 the percentages continued to be low, less than 2% regardless of grate size used. However, except for the 12 sets in 1995, grate spacing for observed sets did not exceed 24 mm after 1994, concurrent with low by-catch rates. This pattern suggests that bar spacing set at less than 25 mm was much more effective in excluding redfish than wider spaced bars. Twenty-eight mm spacing allowed a far greater proportion of the redfish present with shrimp on the grounds to pass into the codend although what affect annual variation in fish sizes available to the gear had on the observed by-catch rates is unclear.

In 1996 and 1997, on average, redfish were taken at a rate less than 5 kg. per hour, equivalent to less than 600 fish per set over 95% of the total grounds. This is about 10 times less than in 1995 and in 1994 where 33% of the grounds yielded greater than 50 kg. per hour of redfish. Figure 5, upper left panel shows that the highest by-catches of redfish in 1996 occurred to the south-west but was more dispersed in 1997. The lower panels where darker shades depict areas of low redfish catches and high shrimp catch rates show that in both years that these areas were limited in extent. "Best fishing grounds" occurred only around the perimeter, mainly to the south (1996) and inner extent of the fishing ground. This suggests a considerable spatial overlap in the concentrations of commercial shrimp and redfish that were small enough to pass through the 19-22 mm grate spacing used in those two years. Thus, in order to achieve good catches of shrimp, small redfish could not be avoided.

Redfish catch rates at depth showed some significant trends within and among years. Figure 6 shows that catch rates in 1993 tended to decrease with depth although fishing was restricted to a narrow depth range in that year. In 1994, redfish catch rates peaked between 350 and 400 m. The pattern was somewhat different in 1995-1997 where catch rates peaked at a more shallow 300-350 m range. This range corresponded with the depths most consistently fished and where the shrimp catch rates were highest.

Samples of redfish from 1994 to 1997 were used to examine size of redfish caught and discarded from the shrimp fishery (Fig. 7). No sampling of redfish was carried out in 1993, thus 1993 sizes and numbers were estimated from 1994 frequencies but based on 1993 catch weight. Thus, the 1993 estimated numbers at length assumes similar sizes caught as in 1994. Table 2 provides a listing of numbers at length for the redfish by-catch. The size distributions were found to be uni-modal with narrow ranges in 1993 to 1995. The fish ranged from 13 to 21 mm with a mode at 18 mm in 1993, 1994 and 1995. Without grates in use in 1993, the size of fish may have actually been larger and the numbers taken smaller. In contrast, three modes at 7, 11 and 16 mm, varying in relative size among years were observed in 1996 and 1997.

Samples of redfish from 1994 to 1997 were used to estimate numbers at age discarded from the shrimp fishery (Fig. 8). It was estimated that of 138 million redfish taken with the shrimp in 1993, 95% were 6, 7 and 8 year olds (based on 1994 length samples). For the 1994 fishery it was estimated that 89.1 million redfish averaging 17.6 cm were taken. Ninety-four percent were age 6, 7 and 8. In 1995 the numbers caught were reduced to 4.8 million fish of which 88% were age 6, 7 and 8. This reduction in numbers of redfish occurred even though shrimp catches were up by 55% over

the previous year. In 1996, age 2 fish averaging 7 mm made up 42% of the redfish catch, most of the remainder being 3 to 7 year olds. In 1997, 75% were age 3 to 6 year olds. Over the life of the shrimp fishery, it is estimated that 253.5 million redfish, primarily 6 to 8 year olds (90%), have been removed on the Flemish Cap. Ninety percent of those estimated removals occurred in 1993 and 1994.

This mortality of pre-recruit redfish results in lost yield which was estimated for each of the years 1993 to 1997 assuming constant M of 0.1 and $F=0.124$ ($F_{0.1}$ from the yield per recruit curve). The loss of commercial yield pertaining to the entire by-catch of redfish (not just *S. mentella*) in the shrimp fishery was estimated at 40,413 tons (Table 3). Ninety-three percent of this can be attributed to the 1993 and 1994 by-catch. The 1997 by-catch contributed only 1%.

Discussion

By-catch species are of no commercial value to the shrimp industry. Their presence in the catches, particularly small redfish, makes it more difficult to process the shrimp and the accidental mortality raises significant conservation concerns. Thus, the shrimp industry prefers to avoid the by-catches. In an attempt to resolve the problem of incidental capture of small fish, the Nordmore grate, found to be effective for reducing by-catch in European shrimp fisheries was made mandatory in 1994 on the Flemish Cap. In this fishery, the large numbers taken in 1993 were reduced in 1994 with a larger grate spacing in use. Even greater reductions were observed in 1995-97 with a smaller grate spacing of 22 mm. The grate was found to be an effective excluded not only of redfish but also other commercially valuable species such as wolffish, turbot and skates.

For this paper, observed by-catch rates from only Canadian and Norwegian vessels were used to estimate total by-catch for the fisheries of all 14 countries combined. The analysis assumes that the observed portion of the fishery was representative of the whole fishery. It assumes that countries other than Canada and Norway used similar gear configurations and attachments, in this case the Nordmore grate. Since use of the grate with maximum 28 mm bar spacing in 1994 and 22 mm in 1995 was mandatory, it is likely that use of the grate by all vessels participating in the fishery was similar to the observed fleets. The assumption that observed by-catch composition was representative of all fleets is also supported by the similarity in the percent by weight of redfish reported in this paper for 1996 and 1997 (1.03 and 0.6%) with percentages for the same years (1.6 and 0.5%) as reported by Skuladottir (1997), for the Icelandic fleet.

The greatest reductions of the main by-catch, redfish were realised when the grate spacing was reduced from 28 mm to less than 23 mm. Bar spacing set at less than 25 mm appeared to be much more effective in excluding redfish than wider spaced bars. Thus, mandatory use of grates and a requirement for 22 mm (or less) spacing provides an effective approach for minimizing incidental by-catch in NAFO Div. 3M (and other shrimp grounds). The smallest individuals, about the width of shrimp are still found in the catch but these are a fraction of the numbers that enter the net. However, it is less than clear what proportion of the observed reductions are due to the affect of the grate or represent an actual reduction in numbers available to the gear. There are no data within years to compare by-catches with and without the grate. Also, changes in average size of the redfish available to the gear due to growth and incoming year-classes interacting with substantial changes in grate spaces between years further complicates the picture. For example, in spite of reduced grate spacing in 1996, redfish catch increased. The increased numbers was likely due to the presence of a large 1994 year-class (2 year olds in 1996) that are about the same size as shrimp). Excluding fishing from areas where small redfish are dense is not a viable approach for affecting by-catch reduction given the considerable overlap between shrimp and small redfish distributions on the Flemish Cap.

Given the limited area and the substantial removals of redfish particularly in 1993 and 1994, the shrimp fishery has been a significant contributor to redfish mortality in NAFO Div. 3M. What proportion of the population that these removals represent is uncertain. However, a comparison of estimated removals of redfish as by-catch in the shrimp fishery to reported catches in the directed fishery shows that the by-catch represented a substantial part of the fishing mortality. Combining directed fishery statistics with estimated by-catch weights to calculate total fishing mortality shows that in 1993, by-catch represented 29% by weight of the total redfish removals, 34% in 1994, 3% in 1995 and 9% in 1996. Proportion of removals by number would be much higher given the very young fish removed in the shrimp fishery.

Were these by-catch fish to survive to the sizes that they would be caught in a commercial fishery, the lost yield would be estimated at about 40,000 tons pertaining to the 1993 to 1997 shrimp fisheries (38,000 tons for 1993-1995). This number is higher than the 23,000 tons estimated by Avila de Melo et al. (1997) for 1993 to 1995 because their calculation was done only for the (estimated) *S. mentella* fraction of the total by-catch and their numbers at age

were derived using different ageing criteria. Avila de Melo et al. (1997) noted that *S. mentella* has its maximum abundance at depths greater than 300 m while the other two species prefer shallower waters less than 400 m. The shrimp fishery occurs at depths between 151 and 715 m (majority in 300 to 600 m). Thus, it is likely that a mix of species but primarily *S. mentella* comprised the shrimp by-catches. Thus, the numbers provided in this paper estimate total lost yield for all three species rather than just for one species. Regardless, the lost yield is significant when considered in terms of the magnitude of the reported catches from this area.

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Table 1 - List of species caught in the northern shrimp fishery in NAFO Division 3M, 1993 - 1997. Estimated amounts are based on the catch composition from Canadian (1993-1997) and Norwegian (1995-1997) vessels.

| Species | 1993 | | 1994 | | 1995 | | 1996 | | 1997 | | Total | |
|---------------------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|-----------|---------|
| | Catch | Percent | Catch | Percent | Catch | Percent | Catch | Percent | Catch | Percent | Catch | Percent |
| Shrimp | 28,088.0 | 66.74 | 24,325.0 | 78.15 | 32,980.0 | 97.41 | 51,163.0 | 95.71 | 25,000.0 | 96.56 | 161,556.0 | 86.67 |
| Redfish | 11,970.0 | 28.44 | 5,902.7 | 18.96 | 374.2 | 1.11 | 549.5 | 1.03 | 154.6 | 0.60 | 18,951.1 | 10.17 |
| Lanternfish | 70.2 | 0.17 | 63.6 | 0.20 | 144.7 | 0.43 | 296.5 | 0.55 | 191.9 | 0.74 | 766.8 | 0.41 |
| Eelpout | 38.5 | 0.09 | 82.4 | 0.26 | 75.8 | 0.22 | 292.3 | 0.55 | 125.3 | 0.48 | 614.3 | 0.33 |
| Turbot | 309.2 | 0.73 | 96.7 | 0.31 | 32.2 | 0.10 | 78.6 | 0.15 | 40.9 | 0.16 | 557.6 | 0.30 |
| Striped. Wolfish | 176.8 | 0.42 | 69.0 | 0.22 | 56.4 | 0.17 | 153.2 | 0.29 | 63.4 | 0.24 | 518.9 | 0.28 |
| ¹ Skates | 354.2 | 0.84 | 22.8 | 0.07 | 12.2 | 0.04 | 67.5 | 0.13 | 16.6 | 0.06 | 473.4 | 0.25 |
| Spotted Wolfish | 392.5 | 0.93 | 20.3 | 0.07 | 12.5 | 0.04 | 35.7 | 0.07 | 5.6 | 0.02 | 466.6 | 0.25 |
| Common Grenadier | 5.5 | 0.01 | 79.7 | 0.26 | 27.3 | 0.08 | 129.1 | 0.24 | 20.0 | 0.08 | 261.7 | 0.14 |
| Roughhead Grenadier | 15.8 | 0.04 | 75.9 | 0.24 | 7.8 | 0.02 | 60.0 | 0.11 | 1.1 | 0.00 | 160.5 | 0.09 |
| Barracudina | 4.0 | 0.01 | 15.9 | 0.05 | 7.3 | 0.02 | 60.1 | 0.11 | 43.4 | 0.17 | 130.7 | 0.07 |
| Viperfish | 10.1 | 0.02 | 19.6 | 0.06 | 5.7 | 0.02 | 60.2 | 0.11 | 14.0 | 0.05 | 109.7 | 0.06 |
| Longfin Hake | 14.1 | 0.03 | 24.6 | 0.08 | 5.8 | 0.02 | 46.7 | 0.09 | 14.0 | 0.05 | 105.2 | 0.06 |
| Greenland Shark | 46.6 | 0.11 | 50.1 | 0.16 | 0.0 | 0.00 | 7.6 | 0.01 | 0.0 | 0.00 | 104.3 | 0.06 |
| Snipe Eel | 10.4 | 0.02 | 15.9 | 0.05 | 2.1 | 0.01 | 45.9 | 0.09 | 26.8 | 0.10 | 101.1 | 0.05 |
| Capelin | 65.5 | 0.16 | 12.8 | 0.04 | 2.7 | 0.01 | 1.5 | 0.00 | 7.4 | 0.03 | 89.8 | 0.05 |
| Plaice | 59.9 | 0.14 | 11.1 | 0.04 | 6.4 | 0.02 | 7.1 | 0.01 | 1.8 | 0.01 | 86.3 | 0.05 |
| Northern Wolfish | 69.7 | 0.17 | 0.2 | 0.00 | 0.0 | 0.00 | 0.4 | 0.00 | 1.8 | 0.01 | 72.2 | 0.04 |
| Witch | 31.9 | 0.08 | 12.1 | 0.04 | 5.3 | 0.02 | 10.1 | 0.02 | 4.3 | 0.02 | 63.7 | 0.03 |
| Lancetfish | 24.5 | 0.06 | 3.0 | 0.01 | 6.1 | 0.02 | 23.9 | 0.04 | 0.5 | 0.00 | 58.0 | 0.03 |
| Roundnose Grenadier | 10.4 | 0.02 | 10.3 | 0.03 | 0.1 | 0.00 | 5.4 | 0.01 | 20.8 | 0.08 | 47.0 | 0.03 |
| Basking Shark | 35.3 | 0.08 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 9.3 | 0.04 | 44.7 | 0.02 |
| Cod | 18.9 | 0.04 | 2.3 | 0.01 | 0.3 | 0.00 | 0.1 | 0.00 | 0.1 | 0.00 | 21.7 | 0.01 |
| Silver Hake | 0.1 | 0.00 | 17.4 | 0.06 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 17.5 | 0.01 |
| Halibut | 8.0 | 0.02 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 2.0 | 0.01 | 10.0 | 0.01 |
| ² Other | 255.6 | 0.61 | 192.4 | 0.62 | 92.1 | 0.27 | 361.0 | 0.68 | 123.7 | 0.48 | 1,024.7 | 0.55 |
| Sum | 42,085.9 | | 31,125.8 | | 33,856.8 | | 53,455.3 | | 25,889.4 | | 186,413.3 | |

¹Consists of approximately 95 percent Thorny Skate

²Other - comprises 110 other species caught in varying amounts.

Table 2 - Numbers at length of redfish bycatch in the Flemish Cap shrimp fishery, 1993-1997.

| Length | <i>1993</i> | <i>1994</i> | <i>1995</i> | <i>1996</i> | <i>1997</i> | <i>All Years</i> |
|---------------|--------------------|-------------------|------------------|-------------------|------------------|--------------------|
| 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 173,057 | 1,534 | 174,591 |
| 7 | 0 | 0 | 5,737 | 5,072,608 | 117,392 | 5,195,737 |
| 8 | 0 | 0 | 7,959 | 2,840,943 | 141,142 | 2,990,044 |
| 9 | 0 | 0 | 5,969 | 248,452 | 78,998 | 333,419 |
| 10 | 0 | 0 | 3,981 | 490,158 | 287,109 | 781,248 |
| 11 | 0 | 0 | 17,660 | 1,244,296 | 632,886 | 1,894,842 |
| 12 | 2,367 | 26,280 | 43,184 | 990,889 | 570,101 | 1,632,822 |
| 13 | 26,791 | 477,885 | 40,809 | 540,554 | 182,138 | 1,268,177 |
| 14 | 240,396 | 1,380,375 | 76,232 | 574,442 | 133,874 | 2,405,319 |
| 15 | 2,082,734 | 3,139,177 | 295,399 | 861,491 | 132,620 | 6,511,421 |
| 16 | 8,332,466 | 10,260,961 | 515,051 | 1,994,220 | 719,977 | 21,822,675 |
| 17 | 32,515,934 | 24,542,009 | 907,661 | 1,368,846 | 204,415 | 59,538,864 |
| 18 | 52,539,581 | 29,801,805 | 1,181,398 | 869,123 | 68,013 | 84,459,920 |
| 19 | 33,326,775 | 15,600,449 | 983,273 | 444,161 | 68,681 | 50,423,340 |
| 20 | 7,477,085 | 3,279,393 | 511,797 | 79,655 | 86,323 | 11,434,253 |
| 21 | 1,099,926 | 450,137 | 152,448 | 110,385 | 66,938 | 1,879,834 |
| 22 | 398,655 | 160,740 | 32,288 | 5,430 | 45,972 | 643,086 |
| 23 | 944 | 0 | 8,313 | 0 | 24,689 | 33,946 |
| 24 | 0 | 0 | 2,676 | 0 | 11,559 | 14,235 |
| 25 | 0 | 0 | 5,081 | 0 | 3,651 | 8,732 |
| 26 | 0 | 0 | 5,351 | 0 | 682 | 6,033 |
| 27 | 0 | 0 | 4,657 | 0 | 0 | 4,657 |
| 28 | 0 | 0 | 8,236 | 0 | 0 | 8,236 |
| 29 | 0 | 0 | 7,718 | 0 | 0 | 7,718 |
| 30 | 0 | 0 | 2,910 | 0 | 0 | 2,910 |
| 31 | 0 | 0 | 582 | 0 | 0 | 582 |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 138,043,655 | 89,119,209 | 4,826,373 | 17,908,710 | 3,578,693 | 253,476,639 |

Table 3 - Numbers at age and estimated loss of commercial yield due to bycatch removals from the shrimp fishery in NAFO Div. 3M, 1993-1997. Numbers at age is projected each year until age 25 with F0.1 (F=0.124).

| Age | 1993 | | | 1994 | | | 1995 | | | 1996 | | | 1997 | | | 1993-97 | | |
|----------|---------------------|-----------|-----------|---------------|-----------|-----------|---------------|-----------|-----------|---------------|-----------|-----------|---------------|-----------|-----------|---------------|-----------|-----------|
| | Bycatch (#'s) | Yield (t) | Yield (%) | Bycatch (#'s) | Yield (t) | Yield (%) | Bycatch (#'s) | Yield (t) | Yield (%) | Bycatch (#'s) | Yield (t) | Yield (%) | Bycatch (#'s) | Yield (t) | Yield (%) | Bycatch (#'s) | Yield (t) | Yield (%) |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 366 | 0 | 0 | 364,987 | 24 | 1 | 373,212 | 24 | |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 14,675 | 1 | 0 | 14,675 | 1 | 0 | 7,584,546 | 540 | 19 | 7,866,474 | 560 | |
| 3 | 195 | 0 | 0 | 2,167 | 0 | 0 | 16,765 | 1 | 0 | 16,765 | 1 | 0 | 1,213,829 | 96 | 41 | 1,750,090 | 138 | |
| 4 | 98,004 | 9 | 0 | 389,677 | 34 | 0 | 62,837 | 5 | 0 | 62,837 | 5 | 0 | 1,654,235 | 144 | 73 | 3,044,374 | 266 | |
| 5 | 1,688,139 | 166 | 0 | 3,061,298 | 300 | 0 | 225,815 | 22 | 0 | 225,815 | 22 | 0 | 1,593,324 | 156 | 54 | 7,122,256 | 699 | |
| 6 | 39,594,369 | 4,515 | 0 | 30,843,241 | 3,517 | 0 | 1,410,515 | 161 | 0 | 1,410,515 | 161 | 0 | 3,104,647 | 354 | 89 | 75,735,923 | 8,637 | |
| 7 | 66,647,415 | 8,886 | 0 | 39,488,339 | 5,265 | 0 | 1,956,160 | 261 | 0 | 1,956,160 | 261 | 0 | 1,840,427 | 245 | 50 | 110,306,732 | 14,706 | |
| 8 | 25,703,839 | 8,090 | 0 | 13,315,336 | 4,191 | 0 | 901,837 | 284 | 0 | 901,837 | 284 | 0 | 472,677 | 149 | 49 | 40,548,756 | 12,763 | |
| 9 | 3,755,980 | 1,419 | 0 | 1,768,285 | 668 | 0 | 174,575 | 66 | 0 | 174,575 | 66 | 0 | 69,055 | 26 | 21 | 5,823,278 | 2,199 | |
| 10 | 537,733 | 242 | 0 | 243,622 | 110 | 0 | 33,309 | 15 | 0 | 33,309 | 15 | 0 | 10,258 | 5 | 8 | 841,818 | 379 | |
| 11 | 17,963 | 10 | 0 | 7,245 | 4 | 0 | 6,688 | 4 | 0 | 6,688 | 4 | 0 | 725 | 0 | 3 | 38,759 | 21 | |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 5,245 | 3 | 0 | 5,245 | 3 | 0 | 0 | 0 | 1 | 6,741 | 4 | |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 4,401 | 3 | 0 | 4,401 | 3 | 0 | 0 | 0 | 0 | 4,839 | 4 | |
| 14+ | 0 | 0 | 0 | 0 | 0 | 0 | 13,182 | 12 | 0 | 13,182 | 12 | 0 | 0 | 0 | 0 | 13,370 | 12 | |
| All | 138,043,637 | 23,336 | 57.7% | 89,119,209 | 14,089 | 34.9% | 4,826,373 | 839 | 2.1% | 17,908,710 | 1,739 | 4.3% | 3,578,693 | 409 | 1.0% | 253,476,621 | 40,413 | 1.0% |
| % of Tot | 54.5% | | | 35.2% | | | 1.9% | | | 7.1% | | | 1.4% | | | | | |
| F0.1 | 1993-94 yield = 93% | | | | | | | | | | | | | | | | | |

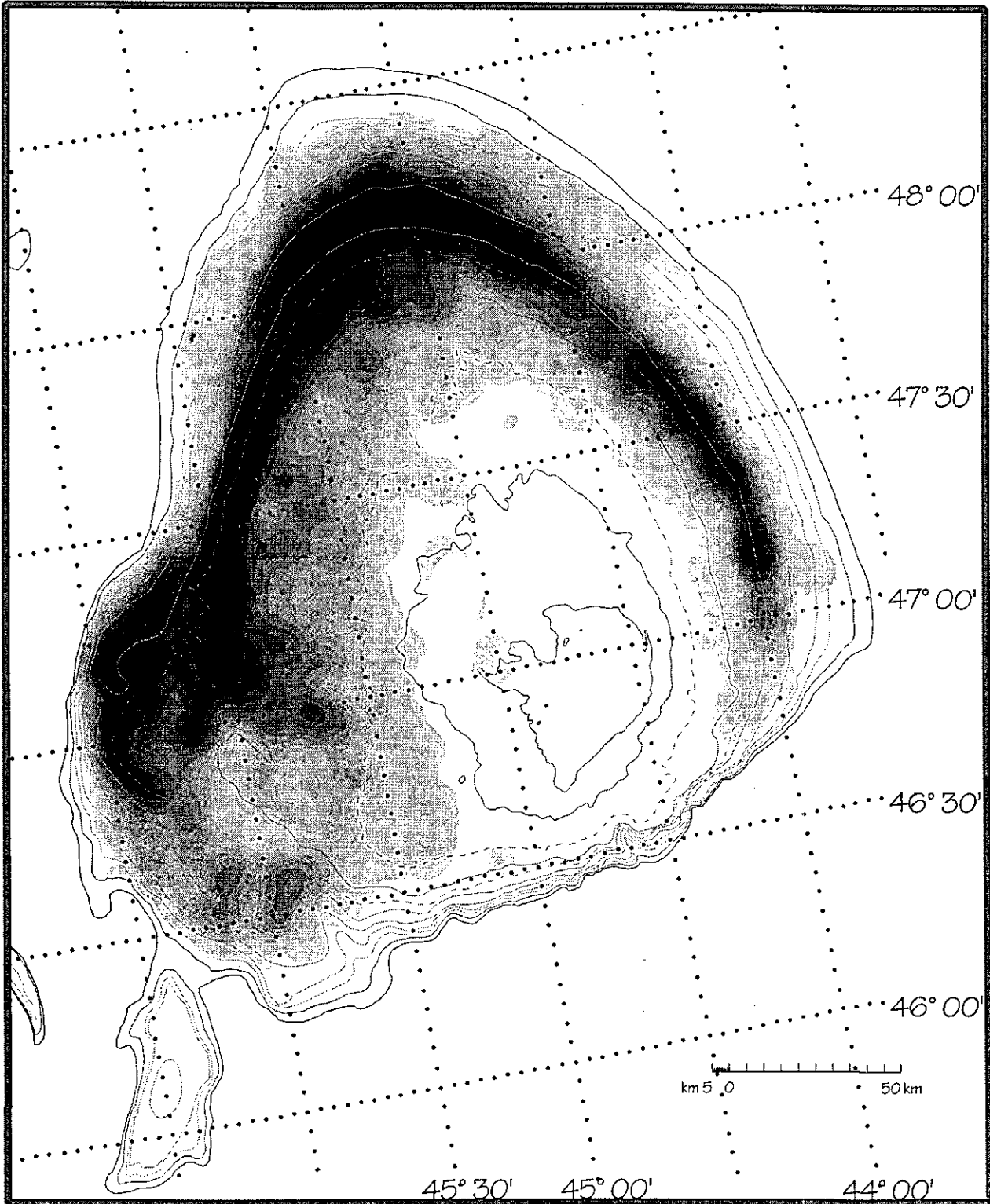


Figure 1 - Fishing grounds (1993-1997 observed) and bathymetry of the Flemish Cap. Increasingly dark grey shades depict more intensively fished areas. Bathymetry lines are 150 to 400 m at 50 m intervals, 400 to 800 m at 100m intervals plus 1000 m.

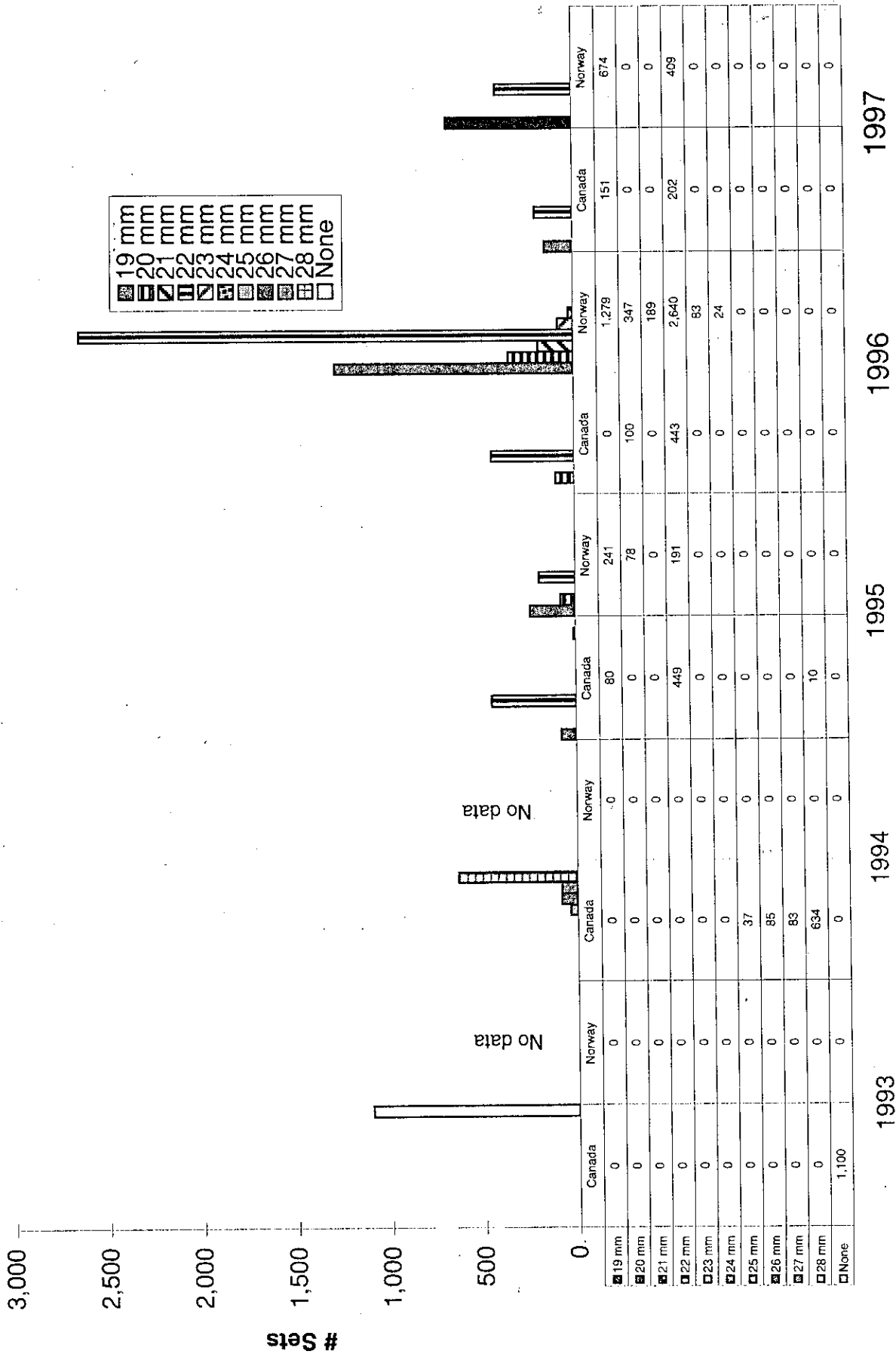


Figure 2 - Observed Nordmore grate usage for observed Canadian and Norwegian shrimp fishery on the Flemish Cap, 1993-1997.

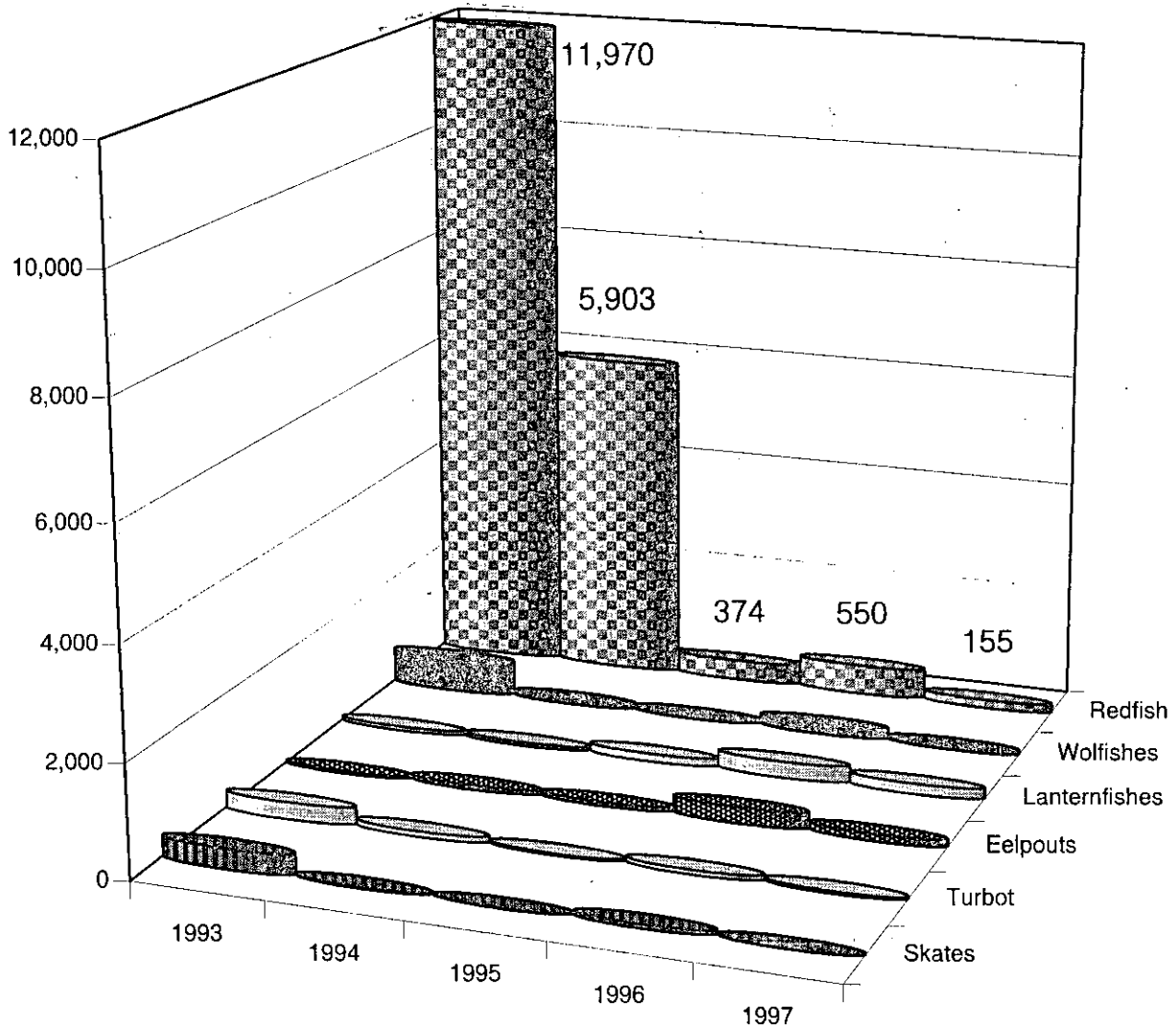


Figure 3 - Catch of the six most common species or species groups taken as bycatch in the observed Flemish Cap shrimp fishery between 1993 and 1997. Labels for redfish are estimated tonnes taken as bycatch.

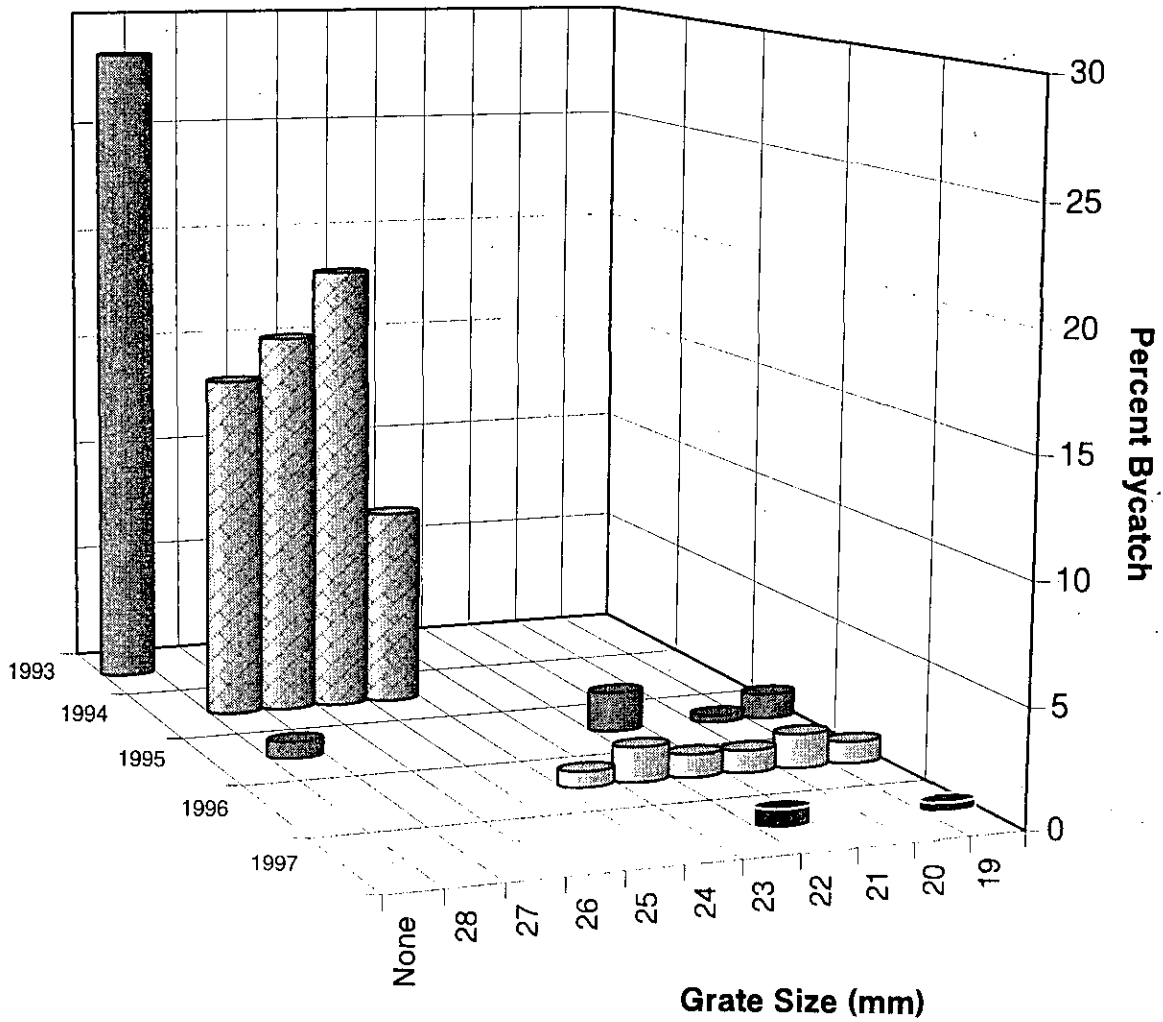


Figure 4 - Redfish as a percent of the total catch in the Flemish Cap shrimp fishery by grate size and year, 1993-1997.

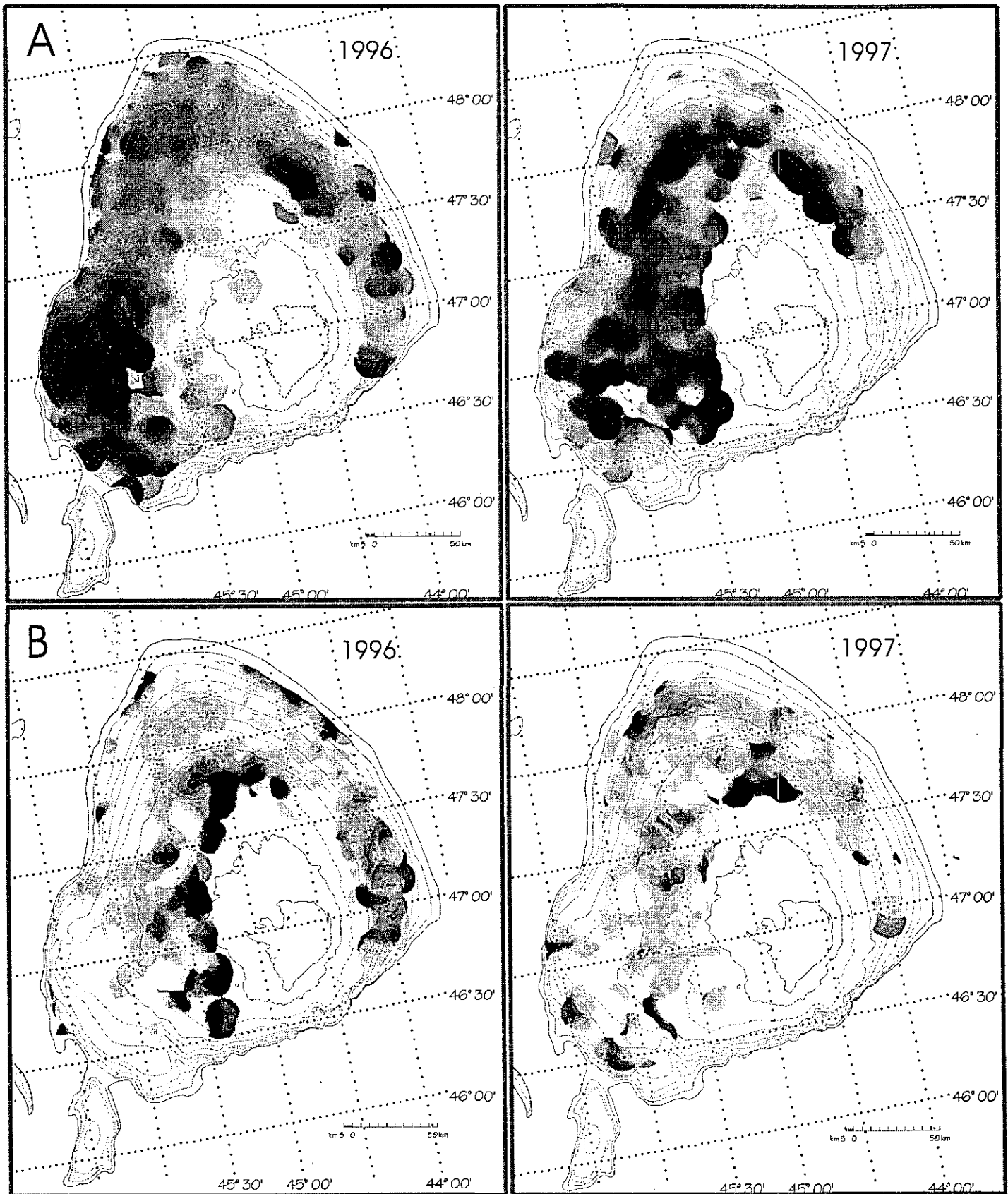
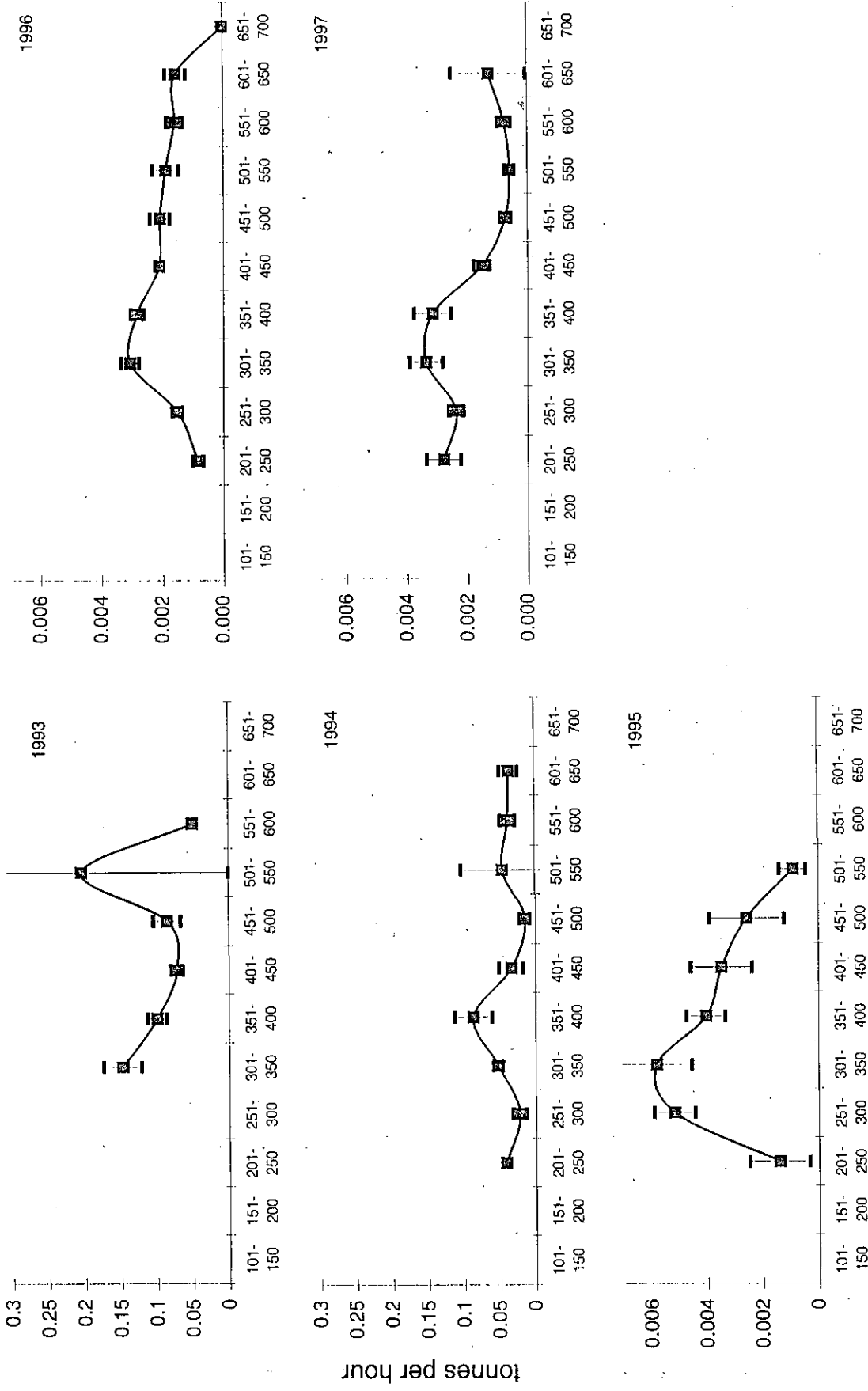


Figure 5 - Upper panels (A) Catch rate of redfish taken as bycatch in the Flemish Cap shrimp fishery. Lower panels (B) Darker shades represent areas where both redfish bycatch is low and shrimp catch rates are high. Conversely, lightest areas show where redfish bycatch is moderate to high and shrimp is moderate to low.



Depth Range (m)

Figure 6 - Catch per hour of redfish bycatch in the NAFO Div. 3M shrimp fishery. Vertical bars are 95% confidence intervals.

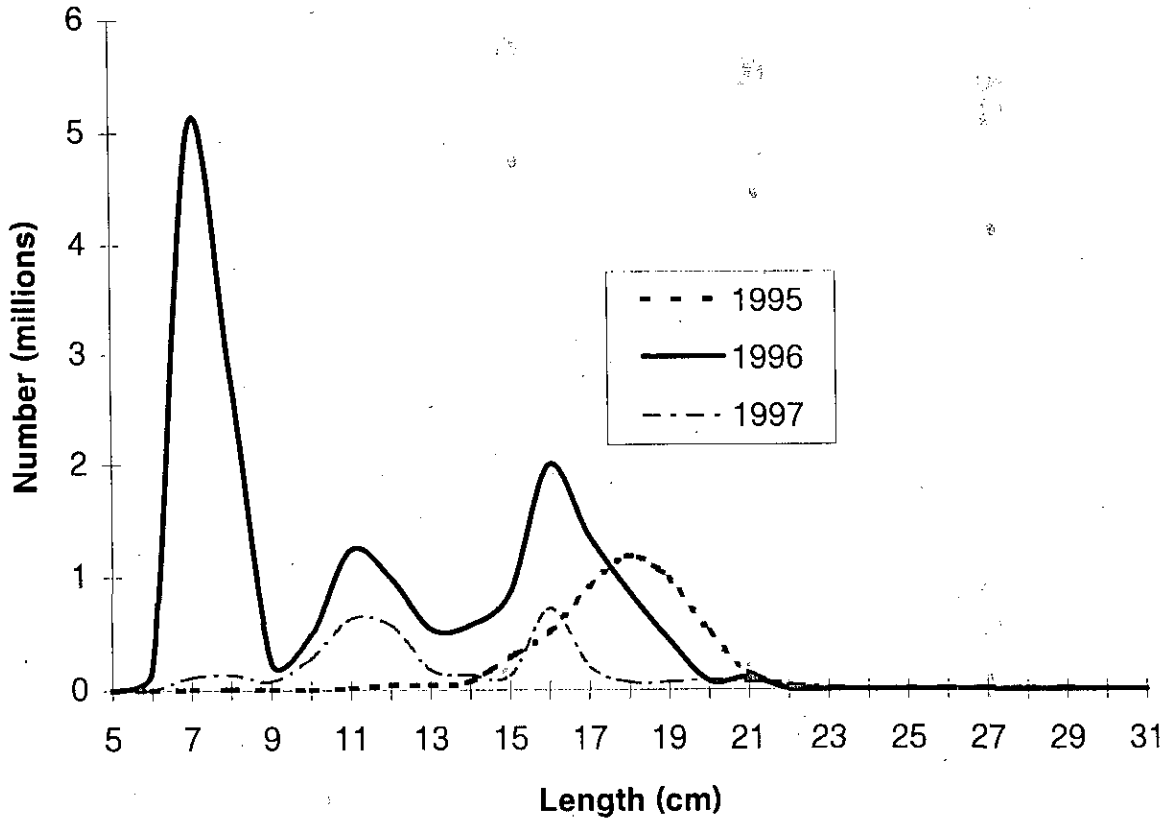
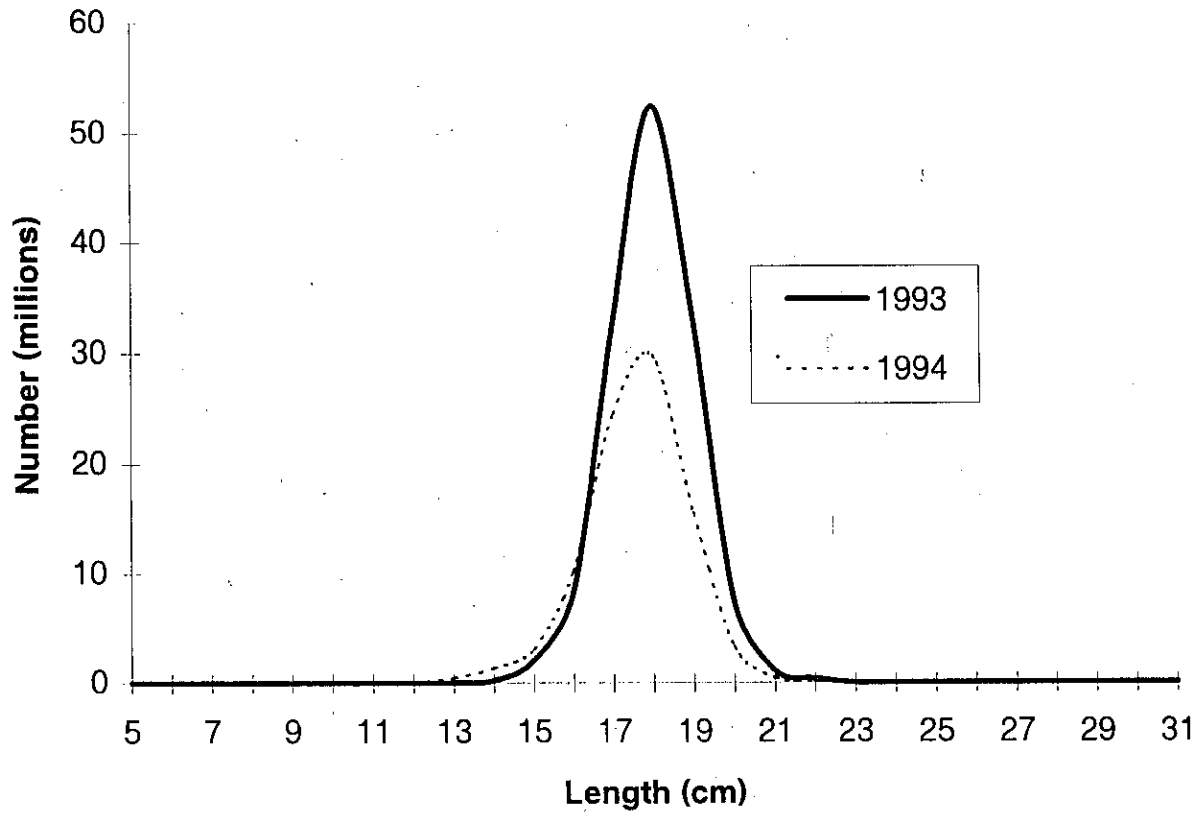
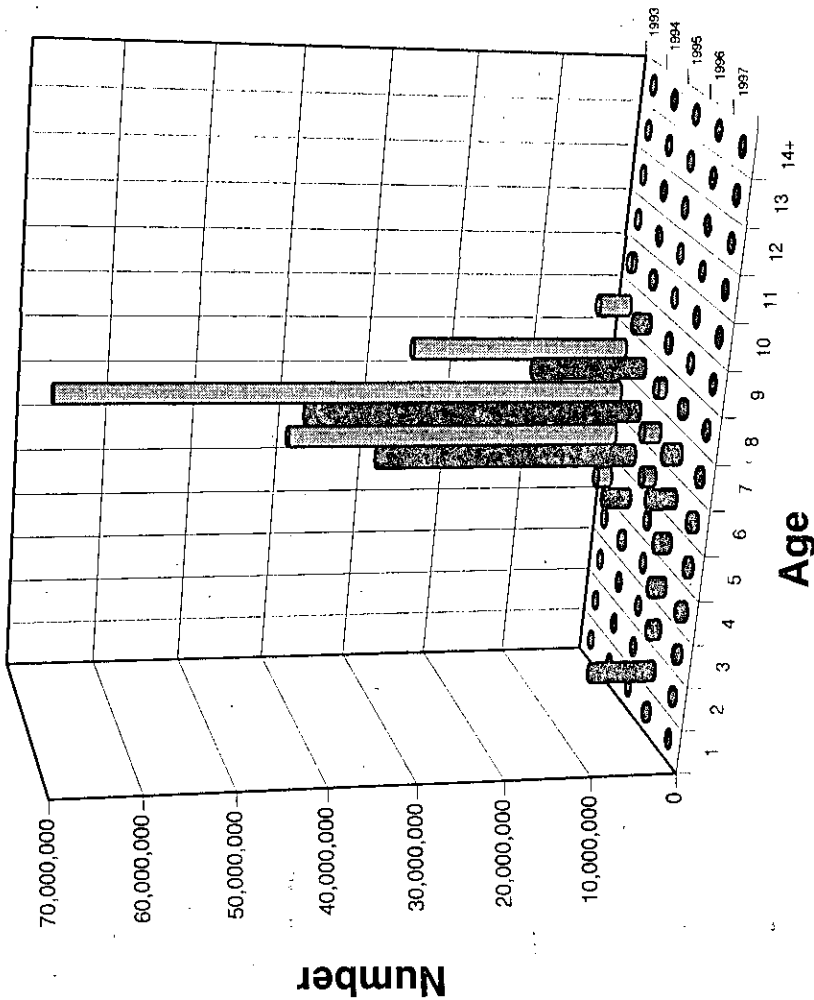


Figure 7 - Numbers at length of redfish taken as bycatch in the Flemish Cap shrimp fishery. Upper panel shows years when no grate was used. Lower panel shows years when the grate was used.

| Percent | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ |
|-----------|------|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|
| 1993 | 0.0% | 0.0% | 0.0% | 0.1% | 1.2% | 28.7% | 48.3% | 18.6% | 2.7% | 0.4% | 0.0% | 0.0% | 0.0% | 0.0% |
| 1994 | 0.0% | 0.0% | 0.0% | 0.4% | 3.4% | 34.6% | 44.3% | 14.9% | 2.0% | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% |
| 1995 | 0.0% | 0.3% | 0.3% | 1.3% | 4.7% | 29.2% | 40.5% | 18.7% | 3.6% | 0.7% | 0.1% | 0.1% | 0.1% | 0.3% |
| 1996 | 2.0% | 42.4% | 6.8% | 9.2% | 8.9% | 17.3% | 10.3% | 2.6% | 0.4% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% |
| 1997 | 0.2% | 7.5% | 14.5% | 23.5% | 15.5% | 21.9% | 10.5% | 4.3% | 1.5% | 0.5% | 0.2% | 0.0% | 0.0% | 0.0% |
| All years | 0.1% | 3.1% | 0.7% | 1.2% | 2.8% | 29.9% | 43.5% | 16.0% | 2.3% | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% |



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ |
|------|---------|-----------|-----------|-----------|-----------|------------|------------|------------|-----------|---------|--------|-------|-------|--------|
| 1997 | 7,858 | 267,253 | 517,133 | 839,670 | 553,680 | 783,151 | 374,392 | 155,066 | 55,383 | 16,896 | 6,138 | 1,495 | 438 | 188 |
| 1996 | 364,987 | 7,584,546 | 1,213,829 | 1,654,235 | 1,593,324 | 3,104,647 | 1,840,427 | 472,677 | 69,055 | 10,258 | 725 | 0 | 0 | 0 |
| 1995 | 366 | 14,675 | 16,765 | 62,837 | 225,815 | 1,410,515 | 1,956,160 | 901,837 | 174,575 | 33,309 | 6,688 | 5,245 | 4,401 | 13,182 |
| 1994 | 0 | 0 | 2,167 | 389,677 | 3,061,298 | 30,843,241 | 39,488,339 | 13,315,336 | 1,768,285 | 243,622 | 7,245 | 0 | 0 | 0 |
| 1993 | 0 | 0 | 195 | 98,004 | 1,688,139 | 39,594,369 | 66,647,415 | 25,703,839 | 3,755,980 | 537,733 | 17,963 | 0 | 0 | 0 |

Figure 8 - Estimated numbers of redfish at age taken as bycatch in the Flemish Cap shrimp fishery, 1993-1997.