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Analysis of by-catches observed in the Scotian Shelf foreign fishery and their impact on domestic fisheries

by

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ABSTRACT

A study was conducted from 1977-1982 to investigate the Canadian Department of Fisheries and Oceans placement of the Small Mesh Gear Line (SMGL). From 1977 to 1979 vessels of Cuban and Soviet registration were permitted to fish on the shelf landward of the SMGL. This provided an unique opportunity to not only analyze the placement of the SMGL but to model the fishery's impact on recruitment to other domestic fisheries.

Geographic distributions of by-catches of cod, haddock, and pollock support the placement of the SMGL. In general, larger by-catches of all species were observed in areas landward of the SMGL. Calculation of potential yields to the domestic fisheries of cod and haddock caught by the foreign fleets offers insight into past fisheries. Of the total tonnage caught during 1977-1982, only 50% would have been returned to the domestic fleets during that period. This was due to availability and high natural mortality of these younger fish which is much greater than the fishing mortality exerted by the domestic fleets. Continuation of these projections for an additional 13 years gives a return to the domestic fishery of 1.9 and 1.2 times the reported 1977-1982 foreign catch of haddock and cod respectively.

A model evaluating future gains to the domestic cod and haddock fleets with no foreign fishery on the shelf showed that little benefit was realized. Increasing the codend mesh size of the foreign fleet from 60 to 90 mm resulted in a 1% increase in the TAC for haddock and no increase in the cod TAC (in fact a loss occurs). If the current level of fishing effort for silver hake is maintained at $F_{0.1}$, the foreign fleets must increase their effort by 30%. There appears to be little benefit to the silver hake stock. Further, there is minimal reduction in the cod and pollock by-catches while haddock by-catches could be significantly reduced.

In conclusion, the current management of the Scotian Shelf small meshed foreign fishery seems adequate to minimize by-catch and permit access to the silver hake stock.

Résumé

Une étude a été réalisée entre 1977 et 1982 pour faire le point sur l'établissement d'une ligne pour engins de pêche à petites mailles (LEPPM) par le ministère canadien des Pêches et des Océans. De 1977 à 1979, des bateaux de pêche immatriculés à Cuba et en Union soviétique ont été autorisé à pêcher du côté rapproché de la côte de la LEPPM. Cette situation a fourni une occasion unique non seulement pour étudier le bien-fondé de l'établissement de la LEPPM, mais aussi pour faire un modèle décrivant l'impact des pêches sur le recrutement dans d'autres pêcheries canadiennes.

La répartition géographique des prises fortuites de morue, d'aiglefin et de goberge viennent appuyer l'établissement de la LEPPM. En général, on a noté que les prises fortuites de toutes les espèces étaient plus importantes du côté rapproché de la côte de la LEPPM. Le calcul des rendements potentiels pour les pêches canadiennes des morues et aiglefins capturés par les flottilles de pêche étrangères permet de mieux comprendre les pêcheries antérieures. Sur le poids total des prises en 1977-1982, seulement 50 % seraient revenus aux flottilles canadiennes durant cette période. Cela est dû à la disponibilité et à la mortalité naturelle de ces poissons plus jeunes, qui est beaucoup plus élevée que la mortalité par pêche causée par les flottilles canadiennes. Si l'on établit des prévisions pour une période additionnelle de 13 ans, on constate que le gain pour les pêches canadiennes d'aiglefin et de morue serait respectivement de 1,9 et 1,2 fois les prises des flottilles étrangères signalées pour 1977-1982.

Un modèle établi pour évaluer les gains futurs pour les flottilles canadiennes de pêche à la morue et à l'aiglefin en l'absence de flottilles étrangères sur le plateau indique que les avantages seraient bien minces. Le fait d'augmenter la dimension des mailles des culs-de-chalut des flottilles étrangères de 60 à 90 mm a entraîné une augmentation du TPA de 1 % pour l'aiglefin, mais il n'y a pas eu d'augmentation du TPA pour la morue (en fait, il y a eu une diminution). Si l'effort actuel pour la pêche au merlu argenté est maintenu à $F_{0.1}$, les flottilles étrangères doivent augmenter leur effort de 30 %. Il semble qu'il y ait peu d'avantages pour le stock de merlus argentés. De plus, il y a une réduction minime des prises fortuites de morue et de goberge, tandis que les prises fortuites de l'aiglefin pourraient être réduites de façon importante.

En conclusion, la gestion actuelle de la pêche étrangère à l'aide d'engins de pêche à petits mailles sur le plateau Scotian semble appropriée pour réduire au minimum les prises fortuites et donner accès au stock de merlus argentés.

Introduction

The presence of a foreign fishery using small mesh gear for silver hake on the Scotian Shelf since the early 1960's has led to speculation that possible adverse effects on the recruitment to the cod and haddock stocks have occurred. Indeed there was supporting evidence, with large haddock catches were reported from this fishery in 1964 and 1965. Recruitment and eventually population size declined rapidly afterwards (Halliday 1971; Waldron 1980). Similarily for cod it was demonstrated that by-catches of young cod (1-2 years) of about 4,000 t annually could account for the reduced recruitment observed in the early 1970's (Anon. 1976a) and since then, the decline in the cod stock biomass has been attributed to growth overfishing by foreign fleets (Anon. 1977a; Maguire et al. 1982).

The Statistics and Research Subcommittee of the International Commission for the Northwest Atlantic Fisheries (ICNAF) reviewed the distribution of the silver hake fishery in relation to other groundfish at the Ninth Special Commission Meeting in December 1976 (Anon. 1977b). Three areas were identified as being actively fished for silver hake. In one area along the edge of the Scotian Shelf, Canadian research survey results indicated that the overlap of distributions of other important commercial species with silver hake was the least. The Subcommittee noted however that:

> "... the northern limit of this fishery area is critically important, as the haddock could be subjected to by-catch problems, particularly in the winter when they are aggregated in prespawning and spawing concentrations. These aggregations can occur to a depth of 155 m (85 fath.) in winter (November to March or April inclusive), depending on hydrological conditions. However, in summer (May to October inclusive), haddock occur in shallower areas, and fishing for silver hake along the edge of the Continental shelf in depths as shallow as 120 m (65 fath.) would avoid the main areas of haddock distribution".
>
> (Anon. 1977b)

Based on this advice, ICNAF agreed to a regulatory proposal allowing fishing with small meshed gear (60 mm) south and east of a line defined along the edge of the Scotian Shelf between April 15 and November 15 (Anon. 1976b). The line has become known as the Small Mesh Gear Line (SMGL) (Figure 1). The specific proposal resulted from negotiations between Canada, the originating nation, and the USSR and Cuba as the nations primarily involved in the silver hake fishery.

When Canada extended jurisdiction to 200 miles offshore in 1977 the ICNAF regulation was accepted and codified in the Canadian Foreign Vessel Fishing Regulations. In addition regulations were introduced to limit by-catch of haddock to less than 1% and that of other important commercial species to less than 10% of the total weight onboard the vessel. Enforcement of these regulations in part requires Canadian fisheries observers trained in both the fishing regulations and in techniques of biological sampling. These observers are deployed in the foreign fleets to collect information vital to monitoring and managing the small meshed fisheries (Kulka and Waldron 1983).

In the years immediately following 1977 the cod and haddock population biomasses rose rapidly providing the base for a new expansion of the Canadian inshore and offshore groundfish fisheries. To what extent the restriction of the small mesh fishery contributed to this "boom" may never be known. Important management lessons are to be learned, however, from exploring these issues. It is therefore not surprising that questions concerning the current small meshed fishery are being asked. These include concerns over the current by-catch levels and what the direct effects on the Canadian fisheries are. Do the current by-catch, mesh size, and fishing area/season regulations effectively reduce recruitment overfishing of cod and haddock stocks? Would the advancement of the silver hake fishing season permit the fleets to catch their allocations sooner avoiding by-catches of cod and haddock later in the season? Are there areas landward of the SMGL where acceptable silver hake catch rates with minimal by-catch could be obtained by the foreign fleets? Further, would it be more advantageous to employ the current by-catch regulations on an individual vessel or fleet basis.

This paper addresses the above issues using data from recent stock assessments and that collected by Canadian fisheries observers deployed on foreign commercial fishing vessels on the Scotian Shelf. It attempts to evaluate the current management system in relation to its benefits to all nations fishing on the Scotian Shelf.

Methods

Monthly nominal catch estimates for silver hake, squid, cod, haddock, and pollock by Cuba, USSR, and Japan for the years 1977-1982 were obtained from Northwest Atlantic Fisheries Organization (NAFO). Catches in 1983 were obtained from the Federal Licensing and Canadian Surveillance Hierarchical database (FLASH). Monthly by-catch rates for cod, haddock, and pollock were calculated from data collected through the Canadian International Observer Program (IOP) (Kulka and Waldron, 1983). By-catch rates were computed as percent of total observed catch and no distinction was made among directed fisheries. These by-catch rates were then applied to reported total finfish and squid nominal catches of Cuba, USSR, and Spain to estimate total catches of cod, haddock, and pollock. IOP data used in this analysis were available for the periods 1977-1979, 1982-1983. Data from the latter period were extensively edited and considered final. Data from the earlier period were not as extensively edited and may change with further editing.

Cuba and the USSR took the majority of the total silver hake catch on the Scotian Shelf and by considering only their catch a general picture of the monthly distribution of the silver hake fishery was obtained. Silver hake catch by these two countries was aggregated by 10' square and month over the years aforementioned and plotted. Shading of the boxes in these plots is in proportion to the maximum aggregated value in each plot (i.e. aggregated catch per box/largest aggregated catch for the plot). Squares with aggregated values less than 1% of the maximum value were not included in the plots.

Squid catch by Japan, Cuba, and the USSR were aggregated and plotted in a similar manner. These three countries consistently took the majority of the total squid catch.

By-catch rates of cod, haddock, and pollock in the Cuban and USSR fisheries were calculated from catch data aggregated by units (10' square) and month over all years. Only those squares where the total catch was greater than or equal to 1% of the maximum aggregated monthly total catch were plotted. The boxes were shaded to indicate critical by-catch levels.

The geographic distribution of mean age of haddock by-catch in the small mesh fisheries was determined using modal lengths. IOP length frequencies for 1982 and 1983 from Japanese, Cuban, and Soviet vessels were used. Using age length keys, three prominent length groups were found corresponding to age 1, 2, and 3+ fish. The thresholds used to determine age group were less than 25 cm for age 1, between 25-34 cm for age 2 and greater than 34 cm for age 3+. Individual length frequencies were summed by month and 30' of longitude along the shelf edge. The mean age group in each case was determined and plotted. A similar analysis was not possible for cod and pollock because the fish were too large to allow model analysis. Ageing of these samples was not extensive enough to allow the breakdown of age groups on so fine a geographic scale.

Removals at age for 4VsW cod (1978-1982) and 4VW haddock (1977-1982) are from Gagné et al., 1983 and for haddock, Mahon et al., 1983. Fishing mortalities at age presented in Gagné et al., 1983 and Mahon et al., 1983 were perturbed to reflect the domestic fishery using the method presented in O'Boyle et al., 1981. In the context of this paper two fleet components are considered, the foreign fishery (1) of OTB's using bottom trawls with 60 mm codends and the otter trawl domestic fishery using 130 mm codends (2).

Total F can be subdivided into;

$$F_1 = \frac{C_1 \times F_{TOT}}{C_{TOT}} \qquad (1)$$

for fleet component 1. Similarly for fleet component 2;

$$F2 = \frac{F_{TOT} \times (C_{TOT}-C_1)}{C_{TOT}} \qquad (2)$$

where C_{TOT} = total catch-at-age
F_{TOT} = total F-at-age
C_1 = catch-at-age for the foreign fishery
F_1 = fishing mortality at age for the foreign fishery
F_2 = fishing mortality at age for the domestic fishery

Using this new F value (F_2) in Baranov's catch equation (Ricker, 1975) provides a method to calculate the expected catch by the Canadian fishery of fish caught by foreign vessels during the 1977-1982 period. The method assumes no changes in availability or increases in observed effort (F). The mechanics of this are as follows:

Calculate the numbers of fish which are present at the start of the next year:

$$N_t = N_0 e^{-Z} \qquad (3)$$

where Z = (new fishing mortality calculated above) + M (where M = natural mortality = 0.2). These fish will be referred to as the survivors (S).

Calculate the numbers of fish which are caught during the year;

$$C = \frac{FAN}{Z} = \frac{F \times (1-e^{-Z}) \times N_0}{Z} \qquad (4)$$

The survivors of year t are added to the foreign catch in year t+1 to give the new numbers available for fishing in year t+1.

$$N_{i(t+1)} = S_2 + N_{t+1} \qquad (5)$$

These new numbers ($N_{i(t+1)}$) are fished in year (t+1) and calculated in equation (3) where $N_0 = N_{i(t+1)}$. The survivors in N_{t+1} are added to the foreign removals, equation (5) and the process is repeated for each cohort until all of the fish caught prior to 1982 have gone through the fishery.

Would removing the foreign small meshed fishery from the Scotian Shelf have an impact on the haddock and cod stocks? This scenario was studied using equation (2) above with removals at age and F matrices for both cod (Gagné et al., 1983) and haddock (Mahon et al., 1983). Partial recruitment for only the domestic fleets were calculated, from equation (2), as the quotient of the F's at age divided by the F at full recruitment. A flat top partial recruitment curve was assumed after full recruitment, which was age 6 for both species.

Mean weights at age, population and catch numbers at age for 1982 as well as the recommended level of recruitment were taken from the above quoted papers for both cod and haddock. These were used as input parameters in the calculation of a new Y/R using the model of Thompson and Bell (Ricker, 1975). Projections at the recommended 1983 $F_{0.1}$ and the new $F_{0.1}$ levels for both cod and haddock (Anon. 1984) were made using the MPROJECT function of Rivard (1982).

Change in haddock and cod by-catch in the foreign fishery if the codend mesh size increased from 60 to 90 mm were calculated as follows.

O'Boyle *et al.* (1981) modified Pope *et al.*'s (1975) logistic equation for selectivity at length to be:

$$S(L) = \frac{1}{1 + \exp\left[\alpha + \beta\,(L/L50)\right]} \qquad (6)$$

where S(L) = fraction of fish selected at length (L)
α = intercept
β = slope
L = length of fish
L_{50} = 50% retention length (in units of L)

Equation 6 can be linearized as:

$$\ln \frac{1-S(L)}{S(L)} = \alpha + \beta\,(L/L_{50}) \qquad (7)$$

The 50% retention lengths were determined by the equations of Clay (1979a):

L_{50} = 3.63 m - 28.49 for haddock
L_{50} = 4.35 m - 87.62 for cod

where m = codend mesh size in mm. Values of m = 60 and 90 were used in this study for haddock and cod.

Equation 7 was solved using selection ogives for cod and haddock at mesh sizes of 76 and 100 mm from Hodder (1964). No ogives at 60 and 90 mm were available. It was assumed that the ratio of selectivity at 76 to that at 100 would be similar to the ratio of selectivity at 60 to that of 90 mm.

NAFO investigated the management option of increasing the mesh used in the silver hake fishery from 60 to 90 mm (Annon. 1980, 1981). This paper further investigates this scenario. Selectivity at length for 60 and 90 mm codends were calculated using the slope to intercept values from equation 7 substituted in equation 6. Observed length frequencies from the 1977 to 1983 (excluding 1980) foreign small mesh fishery were preturbed using the ratio of selection at length for 60 mm divided by selection at length for 90 mm codends. Both the observed and newly perturbed length frequencies were converted to weight at length using weight/length relationships from the foreign fishery for each year modeled. These weights at length were summed to give an observed and perturbed weight. The ratio of perturbed to observed weight gives the reduction in current by-catch levels for cod and haddock which could be expected if the codend mesh size was increased from 60 to 90 mm.

The impact on silver hake yields from a shift in codend mesh size from 60 to 90 mm was also studied. A new partial recruitment pattern for silver hake was calculated as below using data for 1982 from Waldron *et al.*, 1983.

$$PR_{90} = PR_{60} \times Sel_{90}/Sel_{60}$$

where PR_{90} = Silver hake partial recruitment at age if the fishery uses 90 mm codends.

PR_{60} = Silver hake partial recruitment at age calculated for the current fishery which uses 60 mm codends (Waldron et al., 1983).

Sel_{60} = The selectivity at age for silver hake when 60 mm codends are used in the fishery (Clay, 1979a).

Sel_{90} = The selectivity at age for silver hake if 90 mm codends were used in the fishery (Clay, 1979a). Sel_{90} is calculated using the partial recruitment pattern when 40 mm codends were used.

A Thompson and Bell yield per recruit model was employed to calculate a new $F_{0.1}$ for a 90 mm fishery. Catch and population numbers in 1982, average recruitment, mean weights, and $F_{0.1}$ at 60 mm utilized in the Rivard (1982) MPROJECT program were from Waldron et al. (1983).

Results

Silver Hake

Monthly catches of silver hake by Cuba and the USSR combined are given in Table 1. Since 1977 these catches have ranged from 35,000 t to 59,000 t. Peak catches are taken in the May to July period. Since 1977, these vessels have been restricted to fishing in the period April 15 - November 15. The first two weeks of the fishing period have been used to search for favorable concentrations of silver hake. Catch then increased through the months of May, June, and early July. By mid-July silver hake became less abundant in the area seaward of the SMGL (Figure 1) and subsequently the overall catch of the species declined.

The geographic distribution of observed silver hake catches by month is given in Figure 2. These plots include observation from the 1977-79 period when selected vessels were permitted to fish landward of the SMGL. The monthly trend in catches indicated that in April and May silver hake were found predominantly along the edge of the shelf. Good catches of hake were taken landward of the SMGL in June and July but most of the catch was still taken along the edge. From September to November most of the observed silver hake catch was taken on the shelf. This pattern closely resembles the movement of the Soviet fleet in the 1960s (Clay 1979b). Since 1980 fishing landward of the SMGL has been prohibited.

Catches of silver hake by Japan are given in Table 2. For the period 1977-81 these catches have been by-catch in the Japanese squid and argentine fisheries. In 1982 and 1983 Japan had a national allocation for silver hake. Overall silver hake catch by Japan has been minimal in comparison to that of Cuban and the USSR.

Squid

Monthly squid catches by Cuba and the USSR are given in Table 3. The highest yearly catch of squid by the two countries was in 1977 and since then the catches have declined to very low levels. Since 1978 squid catches peaked late in the season following the main silver hake fishery. Often the same vessels remained in the area for both fisheries and redirected their fishing to the increasingly abundant squid as silver hake abundance decreased.

Monthly squid catches by Japan are given in Table 4. The peak catch of squid by Japan was in 1979 and catches have decreased drastically since then. On a monthly basis peak catches were usually taken in August or September with the exception of 1978 when the highest catch was in October.

The monthly observed catch distribution of squid by Japan, Cuba, and USSR on the Scotian Shelf are given in Figure 3. Through the period April-June squid catches were much less than catches of silver hake with the highest catches being taken in association with high silver hake catches. In July, squid and silver hake were taken in comparable quantities and in similar areas seaward of the SMGL. Landward of the SMGL squid catches were small. For the period August to November squid catches dominated silver hake seaward of the SMGL and in the extended area (see Figure 1). In September-November the squid fishery was highly concentrated in the extended area.

By-catch

To estimate total by-catch levels for cod, haddock and pollock, by-catch rates calculated from IOP data were applied to total finfish nominal catches reported to NAFO. Monthly total finfish nominal catches for Cuba and USSR combined, and Japan are given in Tables 5 and 6 respectively.

Cod

Monthly reported catches of cod by Cuba and the USSR combined are given in Table 7. The highest reported catches come from the months of June through August. Yearly total reported catches ranged from 78 t in 1982 to 697 t in 1979. Most of these catches were reported from Division 4W and Subdivision 4Vs.

Monthly cod by-catch rates for Cuba and the USSR calculated from IOP data are given in Table 8. On a monthly basis the rates were never above 2% and were usually less than 1% of the total catch. Using the by-catch rates given in Table 8 monthly catches of cod were estimated to check the accuracy of the reported quantities. These estimates are given in Table 9. The largest differences between reported and estimated catches were in 1979 and 1981 when the reported catches were 274 and 231 t greater than the estimated catch respectively.

Monthly reported catches of cod by Japan are given in Table 10. The highest yearly reported catch was 14 t in 1980 and there was no apparent trend in monthly catches across years. Monthly by-catch rates calculated from IOP data are given in Table 11. None of the individual monthly values were above 2% and only 4 were above 1%. These by-catch rates and total finfish nominal catches (Table 6) were used to estimate monthly by-catch levels. The results are shown in Table 12. While most of the yearly totals for estimated and reported catch were in close agreement, a large discrepancy was found in 1978, notably in November. The estimated cod catch was 82 t while only 3 t were reported to NAFO. The total estimated catch for 1978 was 8 times that reported to NAFO.

The monthly geographic distributions of observed cod by-catch by Cuba and the USSR is given in Figure 4. In the months April-July there were very few units where the by-catch level of cod was above 1%. However, in August several squares had by-catch in the 3-10% range and in an unit by-catch was above 10%. By-catch was highest along the shelf edge and an area east of Emerald Basin landward of the SMGL. In the months of September-November the observed by-catch levels were below 1% in most units.

Haddock

Monthly reported catches of haddock by Cuba and the USSR combined are given in Table 13. Yearly total reported catches ranged from 34 t in 1977 to 292 t in 1983. Most of these catches were reported from Division 4W and Subdivision 4Vs.

Monthly haddock by-catch rates for Cuba and the USSR were calculated from IOP data and are given in Table 14. The highest by-catch rates, in July of 1983 (33.28%) and September of 1982 (10.67%) were observed in months of comparatively little fishing activity by these countries (Table 5) at a time when the year's fishery was coming to an end. Including these two months there were eight months when the observed by-catch rate of Cuba and the USSR was above the 1% regulated level. There was a tendency for haddock by-catch to be highest in the final month of the silver hake fishery.

Monthly haddock catches estimated using the observed by-catch levels (Table 14) and monthly reported finfish plus squid landings of Cuba and the USSR (Table 5) are shown in Table 15. The estimated total catches were greater than the reported catches in all years. The greatest difference was in 1977 when the reported haddock catch was 34 t and the estimated catch was 837 t. Since then, the largest difference was in 1983 when the estimated catch exceeded the reported catch by 289 t.

Monthly reported catches of haddock by Japan are given in Table 16. The highest yearly reported catch was 50 t in 1978 followed by 47 t in 1983. Monthly by-catch rates calculated from IOP data are given in Table 17. By-catch rates in 1983, 1982, and October of 1981 were all above the 1% regulated level. The highest monthly by-catch level was 4.53% in August of 1983. These high by-catch levels occurred when there was comparatively little fishing activity by Japan (Table 6) and when most of the fishing was of an exploratory nature, looking for squid.

Monthly estimates of haddock catches by Japan obtained using observed by-catch rates (Table 17) and reported total catches (Table 6) are given in Table 18. The highest yearly estimated catch was 55 t in 1983. The largest discrepancies between reported and estimated catches occurred in 1977 and 1981 when the reported catches were 23 t and 18 t less than the estimated catches respectively.

The geographic distribution of haddock by-catch by Cuba and the USSR is given on a monthly basis in Figure 5. In April by-catch has been very low with only one unit showing a rate in excess of 1%. In May by-catch in excess of 1% was experienced in the east-central portion of the shelf edge and in the area of Emerald Basin. In June-August haddock by-catch between 1-10% was experienced in many areas along the shelf edge. The highest levels of by-catch were found around Emerald Basin and to the east of the Emerald Basin landward of the SMGL. In September-November by-catch in all areas decreased but there remained areas where the rate was in excess of 1%.

Pollock

Monthly reported catches of pollock by Cuba and the USSR combined in 1977-1982 are given in Table 19. Most of the pollock catch came from the months of May and June. The highest yearly reported catch was 1072 t in 1979 and the lowest was 147 t in 1977.

Monthly pollock by-catch rates for Cuba and the USSR calculated from IOP data are given in Table 20. Generally pollock by-catch rates were observed to be highest in April-June, the early portion of the silver hake fishery, and lowest in the later months. While monthly by-catch rates were above 1% in 14 instances there were none greater than 10%.

Monthly pollock catches were estimated using the observed by-catch rates (Table 20) and monthly reported finfish plus squid landings of Cuba and the USSR (Table 5). The results appear in Table 21. There was close agreement between the reported and estimated yearly total catches for pollock. The largest difference between reported and estimated catches occurred in 1983 when the estimated catch exceeded the reported catch by 232 t.

Monthly reported pollock catches by Japan are given in Table 22. The highest yearly catch was 107 t in 1978 followed by 81 t in 1980. Monthly by-catch rates indicated very low by-catch levels in this fishery (Table 23) with an increase in recent years. All monthly values were less than 1%.

Monthly estimates of pollock catches by Japan obtained using Tables 6 and 23 are given in Table 24. The highest annual estimated catch was 68 t in 1978. The largest yearly difference between estimated and reported catch was in 1978 when the reported catch exceeded the estimated catch by 39 t.

The geographic distribution of pollock by-catch by Cuba and the USSR is given on a monthly basis in Figure 6. In April, by-catches above 1% were observed in only three geographic units. In May and June there were higher by-catches on the shelf edge south of Emerald Bank and in the vicinity of Emerald Basin landward of the SMGL. In July-September by-catch was reduced in these regions but was higher in the eastern portion of the SMGL around the "Gully".

Mean Age of Haddock By-catch

The age distribution of haddock by-catch along the shelf edge was examined using sampling data from Japanese, Cuban, and USSR observer trips in 1982 and 1983. Modal analysis was used to separate 3 age groups, age 1, age 2, and age 3+. The mean age group by 30' of longitude was determined by month and plotted in Figure 7. The general trend demonstrated was that the mean age of haddock at either end of the SMGL was higher than in the middle region. Specifically, in the region of 61°-62°W longitude, south of Western and Sable Island Banks, the haddock tended to be younger then around 63°-64°W longitude and 60°W longitude.

Potential Domestic Yields from Foreign Removal of Cod and Haddock

Foreign removals of cod and haddock have been predominantly from the 4VsW and 4VW stocks respectively. Catch-at-age estimates of 4VsW cod by the USSR (1978-1982) and of 4VW haddock by all foreign countries (1977-1982) are given in Tables 25 and 26 respectively. For cod the removals were mainly composed of ages 3-5. For haddock in 1977-1979 ages 2-4 dominated and for 1980-1982 the removals were mainly at age 1.

Total fishing mortalities for 4VsW cod (Gagné *et al.* 1983) and 4VW haddock (Mahon *et al.* 1983) were perturbed to represent domestic fleet mortality only by the procedure outlined above. The resulting partial mortality tables are shown in Tables 27 and 28 for cod and haddock respectively. Potential domestic fleet catches of the foreign removal were calculated with the method outlined in equations 4 and 5.

From 1978-1982 the estimated USSR catch of 4VsW cod was 2,173 t (Table 29). The estimated potential domestic catch of these removals were 1,314 t for the same time period or 60% of the USSR catch. However, after 1982 the survivors would continue to provide yield to the domestic fishery. Assuming that for 1983 onward the domestic fleet fished at $F_{0.1} = .2$, the survivors would yield an additional 1,266 t over the next 13 years. In total, it was estimated that the USSR by-catch would yield 2,580 t to the domestic fishery over 19 years. This is 1.2 times the estimated foreign by-catch for 1978- 1982.

For 4VW haddock the estimated foreign catch from 1977-1982 was 1,733 t (Table 30). Over the same period, the estimated domestic catch of these removals was 1,006 t or 58% of the foreign catch. After 1982, the estimated yield of the survivors to the domestic fleet fishing at $F_{0.1}$ = .22 was 2,323 t. In total, the estimated domestic catch of the foreign removals was 3,329 t over 19 years. This was 1.9 times the estimated foreign by-catch.

The results of the Y/R analysis used to describe a change in yield if the foreign fishery was removed are presented in Tables 31 and 32 for haddock and cod consecutively. There is an average gain of 145 t/year for haddock and an average loss of 20 t/year for cod. The loss in cod catch is based on the very close similarity of the partial recruitment patterns for fish caught using 60 and 130 mm codends by the foreign and domestic fleets respectively. In fact very little of the foreign catch of cod would be transferred to the domestic fleet if such an increase in mesh size were to evolve. Overall in the long term projections, for haddock there is a net increase of roughly 1% and a loss of less than 1% for cod.

Yield Changes for the 4VWX Silver Hake Fishery

If the management measure of increasing the silver hake fishery codend mesh sizes from 60 mm to 90 mm is implemented the probable impacts on the silver hake fishery must be considered. Changes in the partial recruitment pattern from 60 to 90 mm codends causes an increase in fishing mortality at $F_{0.1}$ of 36% (Table 33). This change in fishing mortality from .418 to .568 results in an overall loss of 6162 t in catch over 8 years (Table 34, Figure 8). Since recruitment is held constant at 1.46 billion fish there is little difference between the estimated size of the population under fishing pressures at the two $F_{0.1}$ levels (Table 35, Figure 9).

Considering the unlikely scenario that the fleet would not increase its effort to a new $F_{0.1}$ level but remain at the same level indicates the loss is more severe. This loss in catch is estimated at 98,000 tons after 8 years on a yearly average of 12,300 tons per year. The losses of course are much larger in the first few years (Figure 8, Table 34).

The population biomass is as expected under the two new levels of $F_{0.1}$ (Figure 9). The different size of the population increases dramatically when the $F_{0.1}$ at 60 and 90 mm was compared to fishing mortality at 90 mm equal to that at $F_{0.1}$ for 60 mm gear. After 8 years, the net gain in this case is some 273,000 t or 34,200 t per year (Table 35).

By-catch Reduction for the 4VWX Silver Hake Fishery

Estimated reductions in by-catch of cod, haddock, and pollock if the small meshed silver hake fishery used 90 mm rather than 60 mm codends are presented in Figure 10. Changes in selectivity are most evident for cod and haddock but not pollock. Shape of these species is no doubt influencing the selectivity pattern. Cod less than 42 cm (or less than age 2, 3) are only partially selected with full selection of fish greater than 42 cm in length. Haddock are partially selected until 64 cm but in reality they are fully selected after a length of 52 cm (age 4-5). Pollock are partially selected to a length of 77 cm. Like haddock, they are really partially selected to a length of 53 cm (age 4-5).

Discussion

Since the extension of jurisdiction in 1977 segments of the Canadian fishing industry have continued to express the concern that the small mesh fishery on the Scotian Shelf still catches considerable quantities of cod, haddock and pollock. We have addressed this concern by collating the official reported statistics, examining by-catch rates from the IOP, and estimating by-catches for comparison with the reported data. The underlying assumptions has been that the observed monthly by-catch rates were indicative of the total fleet by-catch rates and that the total finfish plus squid nominal catches reported to NAFO are accurate. To the best of our knowledge these assumptions cannot be rejected.

Since 1977 the small mesh fishery catch of cod, haddock, and pollock has been minimal in comparison to the total stock catches. For 4VsW cod the reported catch in the small mesh fisheries was 5% of the total in 1977 and this decreased to less than 1% (Gagné et al. 1984) (in 1983 1,218 t were taken by Portugal under a non-surplus national allocation using 130 mm gear). For 4VW haddock the reported small mesh catch ranged from 1-5% of the total (Mahon et al., 1983) while for 4VWX+5 pollock the small meshed catch never exceeded 2% of the total. For these 3 species the differences between reported and estimated catches for Cuba and the USSR combined were never greater than 300 t for any 1 year. In 1983 the estimated haddock catch was 289 t greater than the reported catch (Tables 13 and 15). In 1979 the estimated cod catch was 274 t less than the reported catch (Tables 7 and 9). Given the low level of reported catch and the small differences between reported and estimated catches relative to the total catch one may conclude that the current management regime has been successful in limiting the catch of cod, haddock and pollock in the small mesh fisheries.

The plots of by-catch levels of cod and haddock (Figures 4 and 5) indicated higher by-catches landward of the SMGL. This supports the conclusions of ICNAF (Anon. 1977b) based on the results of Canadian summer research surveys. Recent work by Scott (1982) has indicated large concentrations of 0 and 1 group haddock on the banks just north of the SMGL. Thus it would be likely that a northward movement of the SMGL could result in increased by-catches of cod and haddock.

Examination of the mean age of haddock by-catch in the 1982 and 1983 small meshed fisheries revealed that younger fish were caught in the eastern portion of the area fished from approximately 61° to 62°

longitude. It is the catch of young haddock which has the greatest potential impact on Canadian fisheries. At the current levels of by-catch these impacts has been minimal. However any increases in by-catch of young fish will only increase these potential impacts.

The question of how much of the fish caught by the foreign fleets could have been caught by the domestic fleets was addressed using an age-structured model. Using this approach it was assumed that domestic effort and thus fishing mortalities would have remained the same in the absence of foreign effort, that the fish caught in the foreign fishery would have been equally available to the domestic fishery, and that the partial fishing mortalities used were indicative of the domestic fleet. The assessments for 4VsW cod (Gagné et al. 1983) and 4VW haddock (Mahon et al. 1983) indicate that perhaps the more recent F's were higher than those used here. However, this would have a minimal effect on the results.

The projected domestic catches of foreign removals indicated that in the period 1977-1982 the domestic fleet would have only caught a fraction of the weight caught by the foreign fleets, 60% for 4VsW cod and 58% for 4VW haddock. For 4VsW cod the Canadian catch was 221,410 t from 1978-1982 and the projected additional catch for the same time period from the foreign removals was 1,314 t, an addition of .6%. For 4VW haddock the Canadian catch was 60,977 t from 1977-1982 and the projected additional catch was 1,006 t or 1.7%. The survivors in 1982 would continue to yield catch to the domestic fishery into the 1990's. In the long term the USSR removals of cod were estimated to yield 2,580 t to the domestic fishery over a 19 year period. This was 1.2 times the estimated foreign catch for 1978-1982. The long term estimated yield of the foreign catch of haddock was 2,323 t or 1.9 times the 1977-1982 foreign catch. The reason for this higher estimated haddock yield is that the foreign catch was mainly of age 1-2 fish thus making the potential impact greater than for cod where the USSR removals were mainly age 3-5.

The argument that removing the foreign fishery would increase future yields is doubtful. This scenario was investigated using an age structured model which employed different selectivity patterns. The increase in $F_{0.1}$ for haddock of 2% is offset by an increase in the yield per recruit of 2% with a yield per unit of effort increase of 4%. The overall gain to the fishery is small, only 1%, for an increase in effort of 2%.

These effects, as well as those of the previous model, are so slight that the only conclusion one can draw is that there is little effect on the haddock or cod fishery whether the foreign vessels fish or not.

Clay (1979c) and Clay and Halliday (1980) suggested that the Scotian Shelf silver hake fishery could move from 60 mm to 90 mm codends with a subsequent small increase in the yield per recruit and average weight of fish. Clay (1979c) further points out that there would be a 10 to 30 percent increase in effort. The Thompson and Bell yield per recruit models used in our study agree with those observations and indicated that in order to maintain an $F_{0.1}$ fishing level, effort would need to be increased by 36%. The yield per recruit would not increase and the average weight would increase by only 1%.

Modeling the silver hake population at different levels of $F_{0.1}$ and mesh size results in the observation that both catch and population biomass at $F_{0.1}$ for 60 and 90 mm codends are similar (Figures 8 and 9). Within the models ability to predict and the fact that constant recruitment is assumed these estimates can be considered equal. No increase in effort with an increase in mesh size results in the population stabilizing at a level 10% higher than that estimated for a 60 mm fishery and the catch stabilizes at a level 12% below that estimated for 60 mm.

The constant effort case is an inefficient use of the silver hake resource. Although effort is not increased the loss in catch is very large in the first three years. As more fish escape the 90 mm trawl gear the population gains in strength relative to that estimated for a fishery using 60 mm gear. The impact of the increase in population is not considered within the context of this paper.

There seems little or no benefit to the silver hake fishery of an increase in codend mesh sizes. The only benefit may be in a reduction in by-catch of species such as cod, haddock, and pollock.

By-catch reductions are based upon the selectivity of 60 and 90 mm gears. Both cod and pollock by-catches would be reduced by less than 10% on the average. Haddock by-catches would be substantially reduced. This is the result of the small meshed fishery overlapping juvenile haddock rearing areas. Although, to some degree, there maybe a relationship between recruitment and reduction in by-catch, there could be some link to fluctuations in distribution of juvenile fish. This is no doubt due to an environmental parameter.

If the catch of silver hake is to be maintained at the current level after a switch to 90 mm gear effort would have to increase. This would mean greater exposure of cod and haddock to the gear and possibly cancel any reduction in by-catch due to changed selectivity.

Waldron and Gray (1978) conducted an experiment to investigate the appropriate combination of area and gear which would permit a viable squid fishery with minimal by-catches of cod and haddock. Four areas were selected: Emerald Bank; Sable Island Bank seaward of the SMGL; Sable Island Bank adjacent to Sable Island; and Banquereau Bank. Three gear types, otter trawl, off bottom bobbin, and off bottom chain were compared. In an area (area 3) to the landward side of the SMGL the most cod and haddock were caught. Otter trawls in general caught more of these two species with the off bottom chain gear catching least. Area 3 had the largest catches of cod and haddock while area 1 had the least. There was in particular a significant interaction between gear and area fished. Otter trawls fishing in area 3 (landward of the SMGL) caught more cod and haddock than any other gear - area combination.

All gears caught more cod and haddock in areas landward and eastward of the SMGL (areas 2 and 3) when compared to fishing areas inside the SMGL. Such results supported the initial ICNAF reasons for establishing the SMGL as an area which would reduce by-catches of domestically desirable commercial species.

Interestingly, the area with the highest catch rates of silver hake was area 2, eastward of the SMGL. Further, otter and off bottom bobbin trawls were very similar in silver hake catch rates while off bottom chain trawls had a low catch rate for silver hake. Although the use of off bottom gear could reduce by-catches of cod and haddock they would also reduce substantially the catches of the target species silver hake.

It would seem most unreasonable to enforce a regulation favouring a change in gear used, from otter trawls to off bottom trawls, for the silver hake fishery. The analysis of Waldron and Gray (1978) further suggests that areas seaward of the SMGL, although perhaps not the best, have catch rates which are certainly adequate for the silver hake fishery.

Seasonal distribution patterns for the squid and silver hake foreign fisheries support the contention that areas seaward of the SMGL have the best catches of both squid and silver hake (Figures 2 and 3). In agreement with Waldron and Gray (1978) the highest catches of cod and haddock occur in areas landward of the SMGL (Figures 4 and 5). In those areas the by-catches can exceed the 10% and 1% limits for cod and haddock respectively.

There is one other note of caution when considering a change in the position of the SMGL. Scott (1982) delineates the north and southwest edge of Sable Island Bank and the shallows around Sable Island Bank as areas rich in juvenile haddock during the summer months. As there are very few adult haddock present in these areas Scott suggests these are specifically juvenile rearing areas. The selectivity pattern of the Scotian Shelf small meshed fishery is such that these juveniles being in close proximity to the silver hake fishery are vulnerable. In large catches of silver hake the juvenile haddock by-catch would be difficult to detect due to the similarity in shape, size, and colour when the two species are mixed together.

Again such observations favour a status quo with regard to the present placement of the SMGL. It would not be advisable to move the SMGL further landwards.

The question of advancing the season to April 1 from April 15 hinges on by-catches of spawning haddock and not increased silver hake catches. Distributional patterns of haddock catches in the foreign silver hake fishery do not suggest by-catches of haddock in excess of 1% are a major problem (Figure 5, Table 14). In fact, pollock presents many more possible problems in that its by-catch can be expected to exceed 10% (Figure 6 and Table 20).

The advantages of opening the silver hake fishing season on April 1 would be that the fleets could optimize their catches at a time of year when the silver hake catch rates are high. This has the attractive possibility of the various foreign fleets attaining their quotas before the by-catches of haddock and cod become a major problem in July. The authors favour a limited experimental fishery to test this theory.

The possibility of managing by-catches on an overall fleet rather than the current situation on a per vessel basis is attractive for the fishery managers. It could reduce the difficulties of enforcing a per vessel by-catch limit. Often a vessel can be in a by-catch violation situation after one or two tows. Under a strict adherance to the regulations this vessel should leave the fishery. Policy now provides the Department of Fisheries and Oceans with the option to request the vessel to leave the area of high by-catch (this is often done).

The monitoring of individual vessel by-catches, admittedly difficult, does and has averted potentially damaging by-catch situations. During the 1982 silver hake fishery a group of five vessels encountered a large concentration of juvenile haddock. Tows of 7-10 tons of juvenile haddock were recorded by Canadian observers. Before it was possible for the Department of Fisheries and Oceans or the fleets to react to the situation these vessels were in violation of the by-catch regulations. The fleet, however, was not. Continuation of this by-catch of juvenile haddock could have translated into a major problem for the future domestic haddock fishery. Instead, the Department of Fisheries and Oceans exercised its option and had the vessels move to another area. In a few days these vessels had caught enough silver hake to reduce the ratio of haddock to total catch below the 1% level and thus remain in the fishery.

This was a graphic example of the benefits of the current by-catch policy used by the Department of Fisheries and Oceans. The authors feel that this current mix of regulation and policy be maintained.

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Table 1. Catch of silver hake in NAFO Divisions 4VWX by Cuba and USSR.

Month	1977	1978	1979	1980	1981	1982*	1983*
1							
2							
3	3707						
4	8142	2118	2190	1558	618	2409	6990
5	5636	8760	13000	9777	13433	19482	16130
6	3026	13476	15264	13558	12375	24786	11133
7	10860	13906	12139	14474	13620	12450	542
8	2657	8838	2780	3894	829	93	
9	789	175	883	18	2	10	
10	112	193	375				
11	183	29	243	10			
12							
Total	35112	47495	46874	43269	40877	59230	34795

Table 2. Catch of silver hake in NAFO Divisions 4VWX by Japan.

Month	1977	1978	1979	1980	1981	1982*	1983*
1							
2							
3							
4							
5							
6	1	31					
7		12	122	10		157	
8	5	4	53	79	76	537	490
9	13	23	15	68	39	235	156
10		16	27	53	5		
11		20	2	29			
12		55					
Total	19	161	219	239	120	929	646

* Provisional

Table 3. Catch of squid (Illex) in NAFO Divisions 4VWX by Cuba and USSR.

Month	1977	1978	1979	1980	1981	1982*	1983*
1							
2							
3							
4	1						
5	809			9	1	7	
6	9877	77	2	50	38	22	3
7	9080	987	729	464	1650	182	3
8	1549	2714	1531	670	124	5	
9	940	2761	1026	396	17	1	
10		1735	73				
11		592	86				
12							
Total	22256	8866	3447	1589	1830	217	6

Table 4. Catch of squid in in NAFO Divisions 4VWX by Japan.

Month	1977	1978	1979	1980	1981	1982*	1983*
1							
2							
3							
4	2						
5	37						
6	74	9					
7	154	978	1277	395		95	
8	675	724	4054	5640	2876	108	357
9	1214	6029	10439	4798	2910	70	45
10	989	8342	8868	3864	273		
11		7533	2493	1978			
12		125	109				
Total	3145	23740	27240	16675	6059	273	402

* Preliminary

Table 5. Total finfish and squid catch (t) in 4VWX by Cuba and USSR reported to NAFO.

Month	1977	1978	1979	1980	1981	1982*	1983*
1							
2							
3							
4	2219	6514	2256	1927	13914	2410	7412
5	9565	6030	14684	12000	14595	19958	17278
6	14385	13098	16934	16000	14667	25260	12418
7	22734	19672	19292	19180	6637	13084	740
8	13495	4355	6907	7644	183	120	
9	3195	898	2672	544	17	24	
10	1988	133	537				
11	637	188	332	23			
12							
Total	68218	50888	63614	57318	50013	60856	37848

Table 6. Total finfish and squid catch (t) by Japanese trawlers reported to NAFO.

Month	1977	1978	1979	1980	1981	1982*	1983*
1							
2							
3							
4	10						
5	51						
6	5	97					
7	351	1421	968	413		259	
8	911	1210	3370	6222	3056	727	1076
9	2160	5912	9841	5374	3190	426	279
10	1689	8713	7769	4381	298		6
11		7631	1683	2150			
12		215					
Total	5177	25199	23631	18540	6544	1412	1361

*Preliminary

Table 7. Catch (t) of cod in NAFO Divisions 4VWX by Cuba and USSR reported to NAFO.

Month	1977	1978	1979	1980	1981	1982*	1983*
1							
2							
3	44						
4	18	3		2			17
5	16	42	30	75	22	12	145
6		18	109	176	345	36	91
7	20	27	372	189	237	29	7
8	22	140	186	51	61		
9		4				1	
10							
11							
12							
Total	120	234	697	493	665	78	260

Table 8. Observed cod by-catch rate (percent of total catch) for Cuba and USSR.

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4	1.48	.34		.15	.09	.03	.06
5	.49	.21	.28	.82	.32	.04	.41
6	.02	.14	.60	1.11	1.78	.10	1.03
7	.27	.62	1.05	.85	1.70	.56	1.68
8	.62	1.63	1.10	1.19	.48	1.50	
9	.18	.03	.04	.09		1.04	
10		.15	.09				
11		0	.03				
12							

* Preliminary

Table 9. Estimated cod catch (t) in 4VWX by Cuba and USSR.

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4	32.8	22.1		2.9	12.5	.7	4.5
5	46.9	12.7	41.2	98.4	46.7	8.0	70.8
6	2.9	18.3	101.7	177.6	261.1	25.3	127.9
7	61.4	122.0	202.6	163.0	112.8	73.3	12.4
8	83.7	71.0	76.3	91.0	.9	1.0	
9	5.8	.3	1.1	.5		.2	
10		.2	.5				
11			.1				
12							
Total	233.4	246.6	423.5	533.4	434.0	108.5	215.6

Table 10. Catch of cod (t) in NAFO Divisions 4VWX by Japan reported to NAFO.

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4							
5							
6							
7				1		1	
8		1	1	5			4
9		2		2	2	1	
10		2		2	3		
11		3	1	4			
12		3					
Total		11	2	14	5	2	4

Table 11. Cod by-catch rate (percent of total catch) for Japan fishing in NAFO Divisions 4VWX (from observer data).

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4							
5							
6							
7	.27	.63	1.05	.25			
8	.62	1.63	1.10	.07	.06	0	.46
9	.18	.05	.01	.08	.15	.12	.27
10		.15	.02	.04	1.30		
11		1.10	.01				
12							

Table 12. Estimated cod catch (t) in 4VWX by Japan.

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4							
5							
6							
7		.4	1.1	1.0			
8	.2	1.0	1.7	4.4	1.8		
9	1.7	.6	1.0	4.3	4.8		5.0
10		8.7	1.6	1.8	3.0	.5	.7
11		81.7	.2				
12							
Total	1.9	92.4	5.5	11.5	9.6	.5	5.7

Table 13. Catch (t) of haddock in NAFO Divisions 4VWX by Cuba and USSR reported to NAFO.

Month	1977	1978	1979	1980	1981	1982*	1983*
1							
2							
3	6						
4	20						17
5	4	7	50	61	27	24	98
6	2	28	38	77	135	35	153
7		54	21	126	37	33	24
8		137	8	31	2	2	
9	1	5	10				
10		6					
11	1						
Total	34	237	127	295	201	94	292

Table 14. Haddock by-catch rate (percent of total catch) for Cuba and USSR fishing in NAFO Divisions 4VWX. (from observer data).

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4	4.12	.14		.08	.07	.02	.12
5	6.54	.34	.58	.52	.31	.33	.80
6	.25	.54	.55	.63	1.67	.13	2.32
7	.18	.82	.24	.73	.58	.82	33.28
8	.29	1.78	.34	1.32	.13	.33	
9	.14	.25	.05	.10		10.67	
10		.11	.57				
11		1.07	.14				
12							

* Preliminary

Table 15. Estimated haddock catch in 4VWX by Cuba and USSR.

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4	91.4	9.1		1.5	9.7	.5	8.9
5	625.6	20.5	80.8	62.4	45.2	65.9	138.2
6	36.0	70.7	93.1	100.8	244.9	32.8	288.1
7	40.9	161.3	46.3	140.0	38.5	107.3	246.3
8	39.1	77.5	23.5	100.9	.2	.4	
9	4.5	2.2	1.3	.5		2.6	
10		.1	3.1				
11			.5				
12							
Total	837.5	341.4	248.5	406.2	338.5	209.4	681.5

Table 16. Catch of haddock - NAFO Divisions 4VWX by Japan.

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4							
5							
6		9					
7		6	5	2			
8		3	2	7	10	6	42
9	1	6	3	16	8	6	5
10		6	8	4	4		
11		6	1	8			
12		14					
Total	1	50	19	37	22	12	47

Table 17. Haddock by-catch rate (percent of total catch) for Japan fishing in NAFO Divisions 4VWX (from observer data).

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4							
5							
6							
7	.01	.18	.73	.56			
8	.09	.37	.06	.31	.54	1.18	4.53
9	1.07	.03	.02	.36	.53	1.47	2.33
10		.07	.12	.19	2.27		
11		.30	.03				
12							

Table 18. Estimated haddock catch in 4VWX by Japan.

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4							
5							
6							
7	0	2.6	7.1	2.3			
8	.8	4.5	2.0	19.3	16.5	8.6	48.7
9	23.1	3.5	2.0	19.3	16.9	6.3	6.5
10		6.1	9.3	8.3	6.8		
11		22.9	.5				
12							
Total	24.0	39.6	20.9	49.2	40.2	14.8	55.2

Table 19. Catch of pollock in NAFO Divisions 4VWX by Cuba and USSR.

Month	1977	1978	1979	1980	1981	1982*	1983*
1							
2							
3							
4	43	9	10	127	47		16
5	91	109	704	546	114	193	352
6	2	193	226	264	108	113	107
7	11	189	101	43	80	75	12
8		135	5	2	9		
9		5	26				
10							
11							
12							
Total	147	640	1072	982	358	381	487

Table 20. Pollock by-catch rate (percent of total catch) for Cuba and USSR fishing in NAFO Divisions 4VWX (from observer data).

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4	7.25	.16		6.39	.59		.62
5	1.69	.83	5.15	3.86	.07	1.26	2.21
6	.02	1.20	1.11	1.44	.38	.52	2.23
7	.03	.96	.27	.35	.01	.55	1.92
8	.11	1.21	.08	.14	.01	.01	
9	.02	.05	.60	.01	.01	.05	
10		.02	.27				
11		0	1.91				
12							

* Preliminary

Table 21. Estimated pollock catch in 4VWX by Cuba and USSR.

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4	160.9	10.4		123.1	82.1		46.0
5	161.6	50.0	756.2	463.2	10.2	251.5	381.8
6	2.9	157.2	188.0	230.4	55.7	131.4	276.9
7	6.8	188.9	52.1	67.1	.7	72.0	14.2
8	14.8	52.7	5.5	10.7			
9	.6	.4	14.2	.1			
10			1.4				
11			6.3				
12							
Total	347.7	459.7	1023.8	894.6	148.7	454.8	718.9

Table 22. Catch of pollock in NAFO Divisions 4VWX by Japan.

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4							
5							
6		15					
7		1		4			
8				12	5	1	6
9	1	1	15	9	8	1	
10		89	3	27	2		
11		2	1	29			
12		2					
Total	1	110	19	81	15	2	6

Table 23. Pollock by-catch rate (percent of total catch) for Japan fishing in NAFO Divisions 4VWX (from observer data).

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4							
5							
6							
7	0	.11	.03	.31			
8	0	.05	.02	.27	.32	.25	.60
9	.16	.04	.19	.21	.29	.04	.02
10		.65	.04	.42	.17		
11		.09	.03				
12							

Table 24. Estimated pollock catch in 4VWX by Japan.

Month	1977	1978	1979	1980	1981	1982	1983
1							
2							
3							
4							
5							
6							
7		1.6	.3	1.3			
8		.6	.7	16.8	9.8	1.8	6.5
9	3.5	2.4	18.7	11.3	9.3	.2	
10		56.6	3.1	18.4	.5		
11		6.9	.5				
12							
Total	3.5	68.0	23.3	47.8	19.5	2.0	6.5

Table 25. Foreign removals at age (numbers '000) for 4VsW cod (1983 is the average of 1977-82).

Age	1978	1979	1980	1981	1982
1	29	12	31	3	5
2	63	46	25	63	1
3	152	106	83	302	12
4	178	214	73	281	16
5	27	181	92	41	10
6	3	42	45	25	3
7	1	5	17	8	1
8	0	0	1	1	0
9	0	0	1	0	0
Sum 1+	453	606	368	724	48

Table 26. Foreign removals at age (numbers '000) for 4VW haddock.

Age	1977	1978	1979	1980	1981	1982
1	37	141	1	1015	1289	805
2	69	158	135	72	143	330
3	55	211	147	203	19	44
4	7	119	153	41	60	6
5	12	7	43	19	32	24
6	4	7	6	6	14	12
7	1	2	4	1	2	3
8	1	0	1	1	0	0
9	0	0	0	0	1	1
10	0	0	1	0	0	0
11	0	0	0	0	0	0
Sum 1+	186	645	492	1358	1560	1225

Table 27. Partial fishing mortality for the domestic fishery of 4VsW cod.

Age	1978	1979	1980	1981	1982
1	0.001	0.000	0.000	0.000	0.000
2	0.001	0.000	0.002	0.004	0.000
3	0.015	0.031	0.025	0.054	0.030
4	0.082	0.142	0.136	0.160	0.139
5	0.204	0.315	0.249	0.294	0.250
6	0.312	0.344	0.369	0.271	0.250
7	0.260	0.239	0.361	0.311	0.250
8	0.199	0.192	0.362	0.309	0.250
9	0.130	0.101	0.252	0.219	0.250

Table 28. Partial fishing mortality for the domestic fishery of 4VW haddock.

Age	1977	1978	1979	1980	1981	1982
1	0.000	0.000	0.000	0.000	0.000	0.000
2	0.003	0.000	0.000	0.000	0.003	0.001
3	0.080	0.032	0.014	0.052	0.040	0.065
4	0.191	0.264	0.066	0.246	0.159	0.172
5	0.258	0.316	0.117	0.293	0.525	0.272
6	0.413	0.672	0.176	0.520	0.503	0.398
7	0.483	0.788	0.256	0.479	0.900	0.399
8	0.595	0.704	0.095	0.396	0.564	0.399
9	0.371	0.567	0.120	0.460	0.676	0.394
10	0.841	0.441	0.135	0.309	0.782	0.400
11	0.453	0.626	0.176	0.504	0.578	0.400

Table 29. Projected potential domestic catch (t) of the 1978-1982 USSR catch of 4VsW cod. USSR catch weights were estimated using observed by-catch rates and total finfish reported catches.

Year	USSR Catch (t)	Potential Domestic Catch (t)	Cumulative Domestic Catch (t)
1978	375	28	28
1979	679	221	249
1980	421	332	581
1981	653	388	969
1982	45	345	1314
1983		290	1604
1984		253	1857
1985		205	2062
1986		161	2223
1987		118	2341
1988		81	2422
1989		54	2476
1990		37	2513
1991+		67	2580

Table 30. Projected potential domestic catch (t) of the 1977-1982 foreign catch of 4VW haddock. Foreign catch weights were estimated using observed by-catch rates and reported silver hake catches.

Year	Foreign Catch (t)	Potential Domestic Catch (t)	Cumulative Domestic Catch (t)
1977	134	14	14
1978	265	67	81
1979	425	61	142
1980	325	260	402
1981	304	350	752
1982	280	254	1006
1983		211	1217
1984		282	1499
1985		348	1847
1986		363	2210
1987		316	2526
1988		245	2771
1989		183	2954
1990		133	3087
1991+		242	3329

Table 31. Long-term projection of potential gains in catch (t) to the 4VW haddock fishery if the foreign fleets raised their codend mesh size from 60 mm to 130 mm.

Year	Projected Catch at $F_{0.1}$ = .220 and Current Mesh Sizes	Projected Catch at $F_{0.1}$ = .224 and Foreign Fleet at 130 mm	Potential Increase in Yield to the Total Fishery	Cumulative Increase in Yield to the Total Fishery
1984	11660	11711	51	51
1985	14529	14690	161	212
1986	16224	16412	188	400
1987	16151	16341	190	590
1988	14586	14745	159	749
1989	12310	12455	145	894
1990	10886	11008	122	1016

Table 32. Long-term projection of potential gains in catch (t) to the 4VsW cod fishery if the foreign fleets increased their codend mesh sizes from 60 to 130 mm.

Year	Projected Catch (t) at $F_{0.1}$ = .1623 and Current Codend Mesh Sizes	Projected Catch (t) at $F_{0.1}$ = .1621 and the Foreign Fleet at 130 mm Codend Mesh Size	Potential Increase in Yield to the Total Fishery	Cumulative Increase in Yield to the Total Fishery
1984	52975	52924	-51	-51
1985	58501	58461	-40	-91
1986	62879	62852	-27	-118
1987	65960	65944	-16	-134
1988	68192	68184	-8	-142
1989	69685	69684	-1	-143
1990	70917	70923	6	-137

Table 33. Silver hake Thompson and Bell Y/R calculations.

Age	1	2	3	4	5	6	7	8	9	10
Wt (kg)	0.051	0.140	0.202	0.263	0.322	0.387	0.522	0.683	0.844	0.923
60mm PR.	0.028	0.248	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
*90mm PR.	0.024	0.174	0.678	0.674	0.711	0.838	1.000	1.000	1.000	1.000
** Sel 90/60	0.850	0.703	0.678	0.674	0.711	0.838	1.000	1.000	1.000	1.000

Assume 60 mm Gear

	Fishing Mortality	Catch (Number)	Yield (kg)	Avg. Weight (kg)	Yield Per Unit Effort
	0.300	0.22394	0.054	0.241	1.000
$F_{0.1}$	0.413	0.26879	0.060	0.224	0.802
	0.600	0.31857	0.066	0.207	0.611
	0.900	0.37292	0.071	0.190	0.438
	1.200	0.40951	0.073	0.179	0.340
	1.500	0.43662	0.075	0.171	0.277
	1.800	0.45801	0.076	0.165	0.234
	2.100	0.47564	0.076	0.160	0.202
	2.400	0.49065	0.077	0.156	0.177
	2.700	0.50373	0.077	0.152	0.158
	3.000	0.51534	0.077	0.149	0.142
F_{MAX}	3.119	0.51961	0.077	0.148	0.137
	3.300	0.52579	0.077	0.146	0.129

* $PR_{90} = PR \times Sel_{90}/Sel_{60}$

** Clay, 1979 a.

Table 33. Continued.

Assume 90 mm Gear

	Fishing Mortality	Catch (Number)	Yield (kg)	Avg. Weight (kg)	Yield Per Unit Effort
	0.400	0.21642	0.053	0.245	1.000
$F_{0.1}$	0.568	0.26242	0.060	0.227	0.792
	0.800	0.30884	0.065	0.210	0.612
	1.200	0.36342	0.070	0.192	0.439
	1.600	0.40085	0.073	0.181	0.342
	2.000	0.42884	0.074	0.173	0.279
	2.400	0.45101	0.075	0.166	0.236
	2.800	0.46932	0.076	0.161	0.204
	3.200	0.48490	0.076	0.157	0.179
	3.600	0.49847	0.076	0.153	0.160
	4.000	0.51051	0.076	0.149	0.144
F_{MAX}	4.252	0.51745	0.076	0.147	0.135
	4.400	0.52134	0.076	0.146	0.131
	4.800	0.53119	0.076	0.143	0.120
	5.200	0.54023	0.076	0.141	0.110
	5.600	0.54860	0.076	0.138	0.102
	6.000	0.55638	0.076	0.136	0.095
	6.400	0.56367	0.076	0.134	0.089
	6.800	0.57051	0.075	0.132	0.084
	7.200	0.57697	0.075	0.130	0.079
	7.600	0.58308	0.075	0.129	0.075
	8.000	0.58888	0.075	0.127	0.071

Table 34. Long-term projections of yields to the 4VWX silver hake small meshed fishery if the current codend mesh size of 60 mm is increased to 90 mm in 1983 to 1990.

Year	Projected Catch at $F_{0.1}$ = .418 for 60 mm	Projected Catch at $F_{0.1}$ = .568 for 90 mm	Increase in Yield (t) at $F_{0.1}$ for 60 to 90 mm	Cumulative Increase in Yield (t) at $F_{0.1}$ for 60 to 90 mm
1982	53428	53428	-	-
1983	92156	90987	-1169	-1169
1984	89830	89100	-730	-1899
1985	82773	81934	-839	-2738
1986	78663	77766	-897	-3635
1987	76506	75869	-637	-4272
1988	75249	74684	-565	-4837
1989	74685	74048	-637	-5474
1990	74562	73874	-688	-6162

Table 35. Projected beginning of the year population biomass ('000 t) of 4VWX silver hake fishery for 60 and 90 mm codends at constant effort ($F_{0.1}$ = .418) and increased effort ($F_{0.1}$ = .568) in 1983 to 1990.

Year	$F_{0.1}$ = .418 60 mm	$F_{0.1}$ = .568 90 mm	Change Constant Effort (60-90)	Change Increased Effort (60-90)	Cumulative Change Constant Effort	Cumulative Change Increased Effort
1982	490	490	-	-	-	-
1983	516	516	-	-	-	-
1984	486	487	22	1	22	1
1985	461	462	35	1	57	2
1986	446	448	41	2	98	4
1987	439	441	43	2	147	6
1988	435	438	44	3	185	9
1989	432	436	44	4	229	13
1990	431	435	44	4	273	17

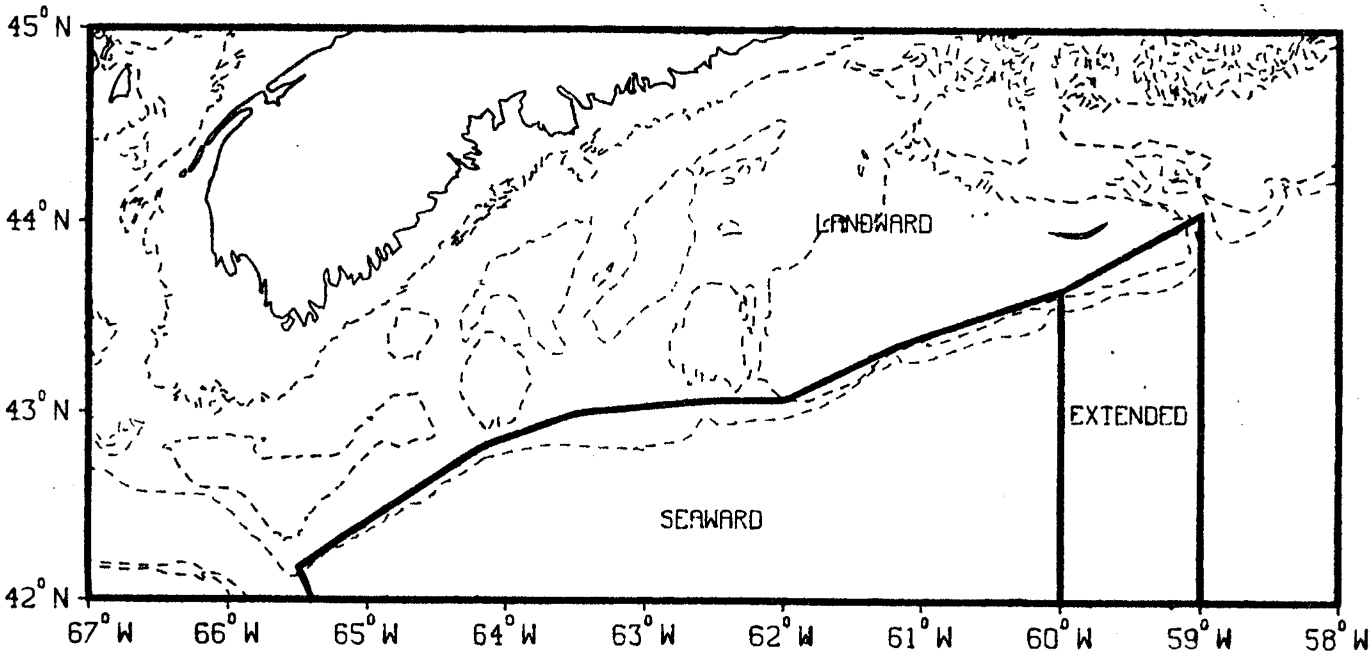

Figure 1. The Scotian Shelf small meshed gear line (SMGL) used to manage the the silver hake, squid and argentine fisheries.

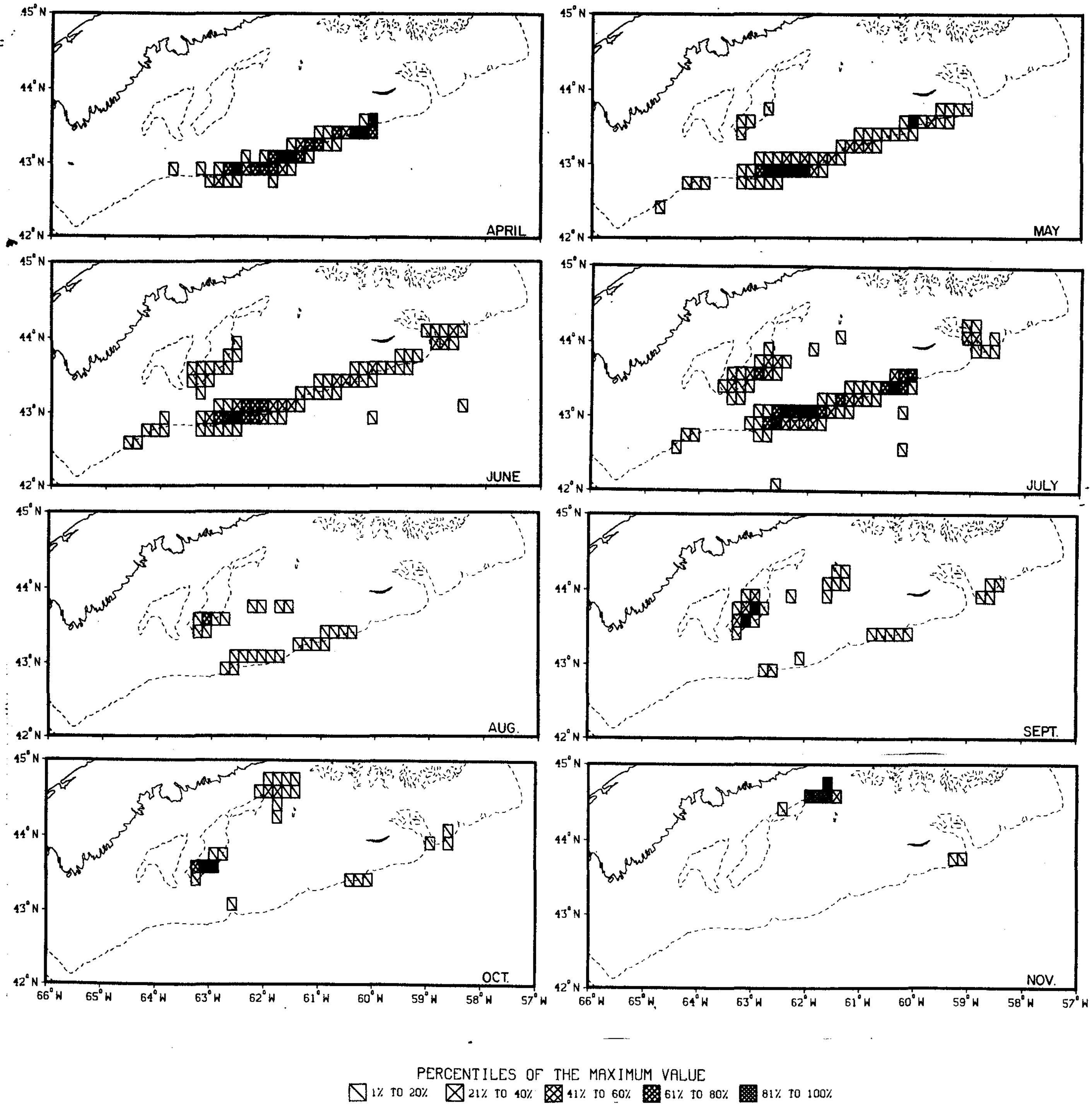

Figure 2. Seasonal distribution of observed silver hake catches from the small meshed fishery aggregated by ten minute squares. Shading is done in proportion to the maximum aggregated value.

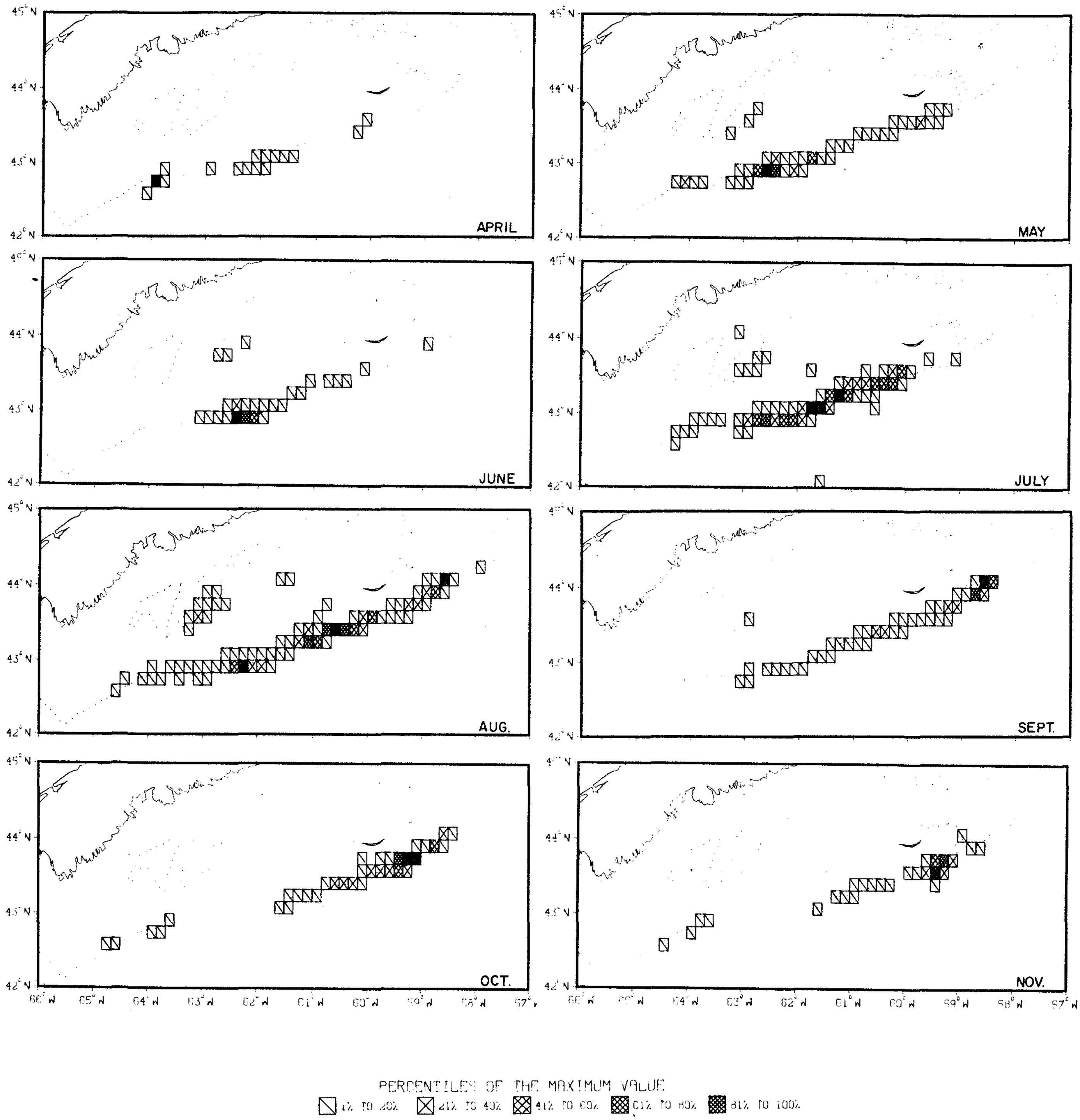

Figure 3. Seasonal distribution of observed squid catches from the Cuban, Japanese and Soviet small meshed fishery aggregated by ten minute squares. Shading is done in proportion to the maximum aggregated value.

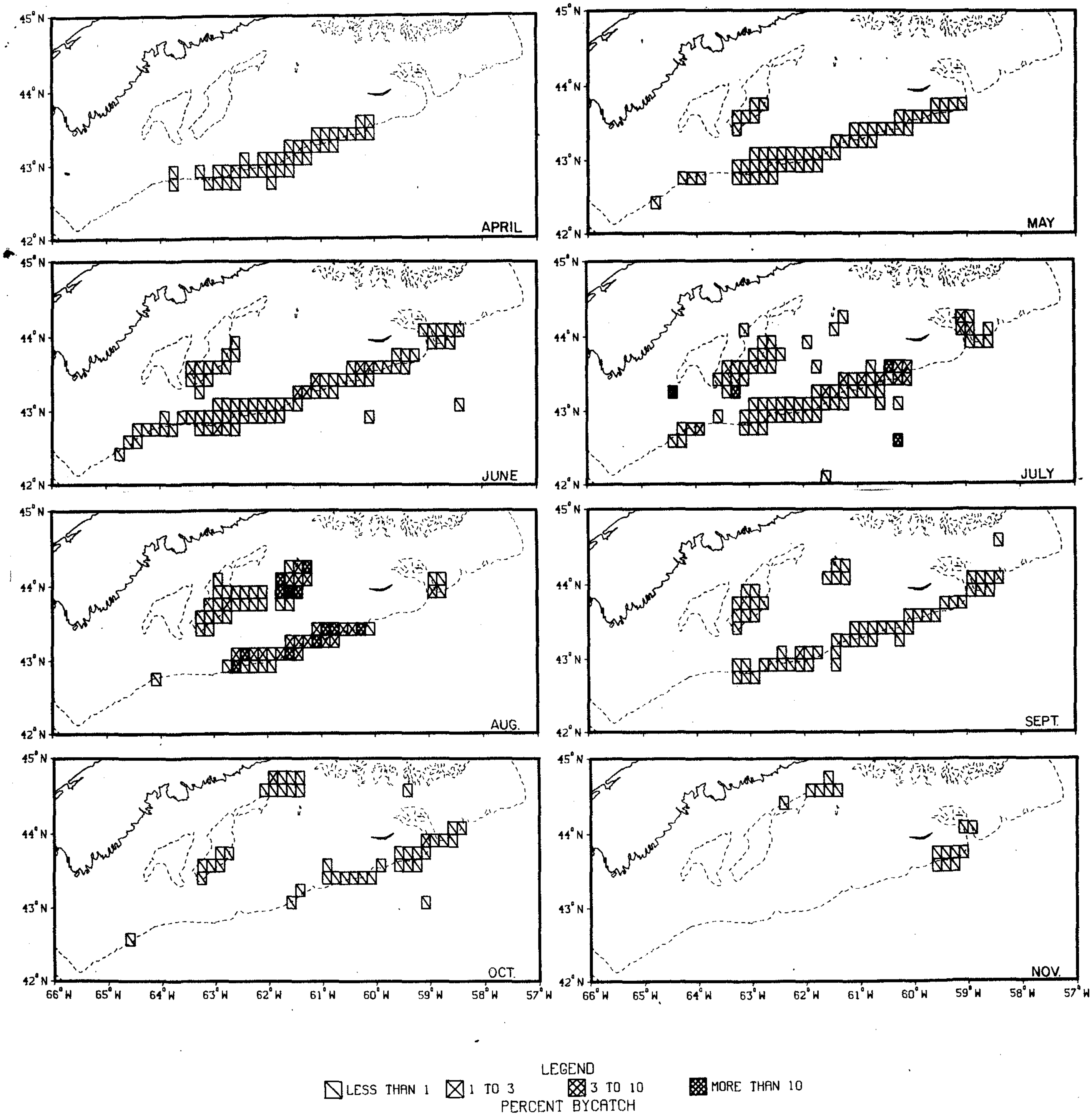

Figure 4. Seasonal distribution of observed cod by-catch from the small meshed fishery aggregated by ten minute squares. Shading indicates by-catch levels.

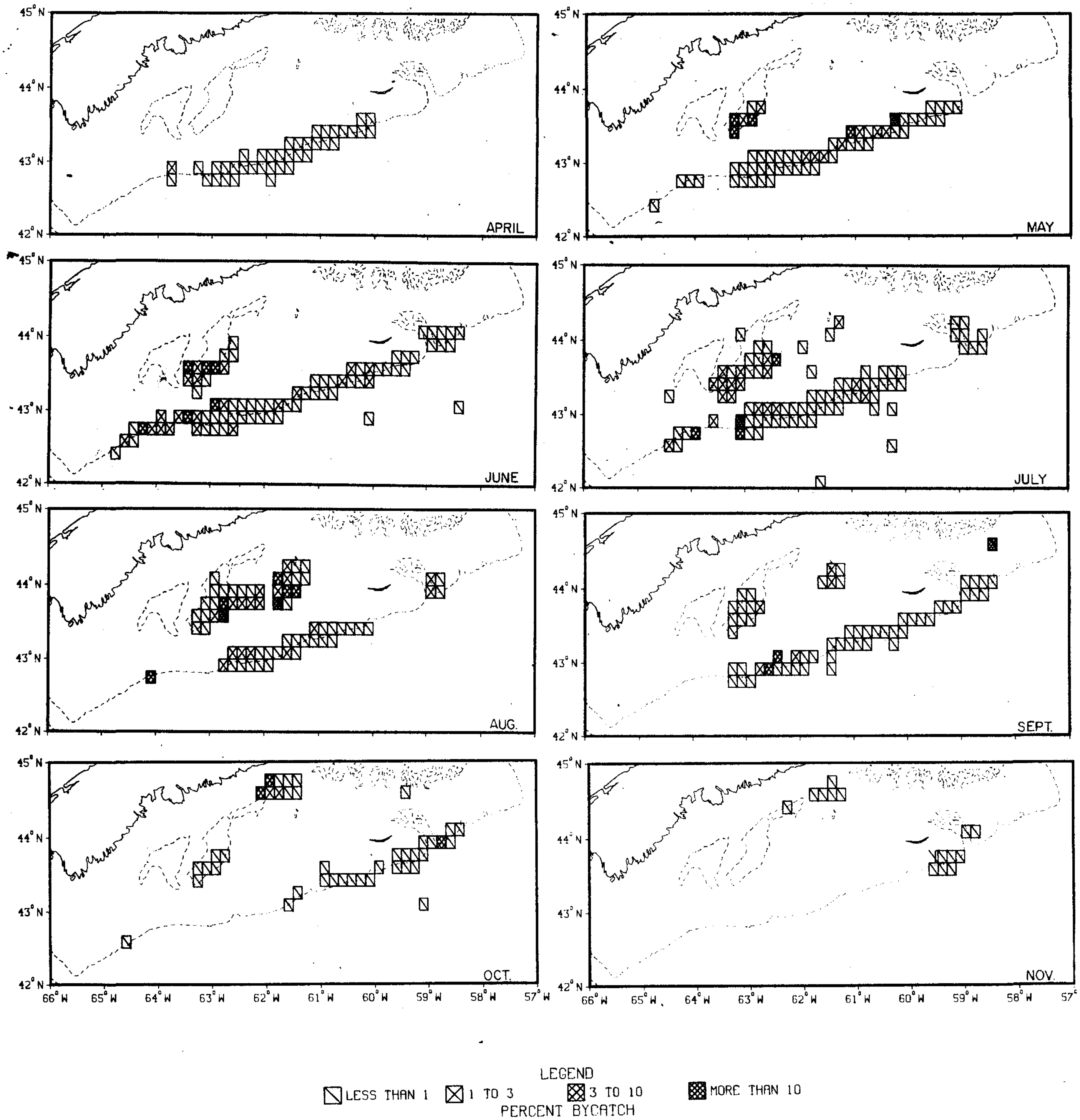

Figure 5. Seasonal distribution of observed haddock by-catch from the small meshed fishery aggregated by ten minute squares. Shading indicates by-catch levels.

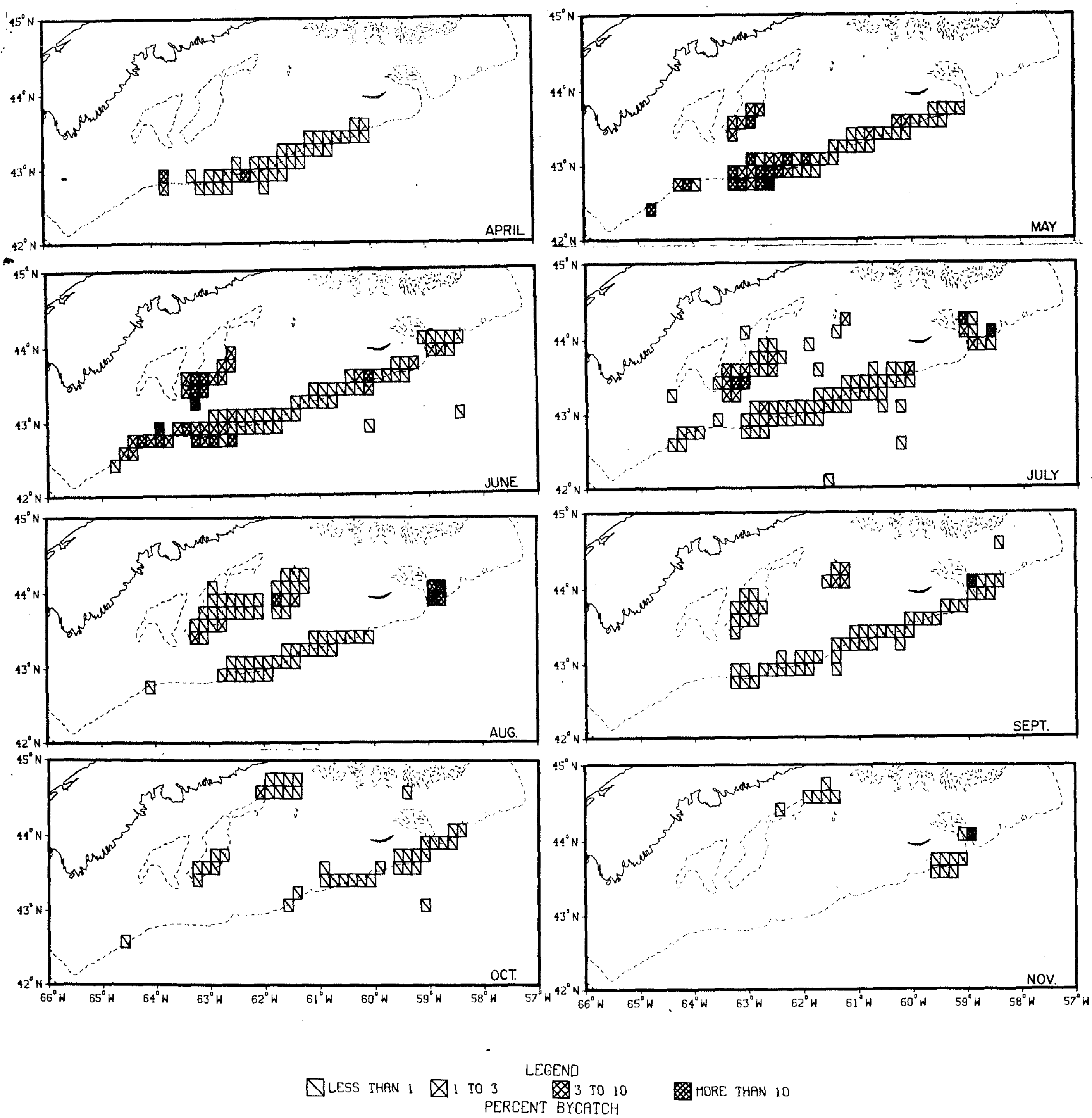

Figure 6. Seasonal distribution of observed pollock by-catch from the small meshed fishery aggregated by ten minute squares. Shading indicates by-catch levels.

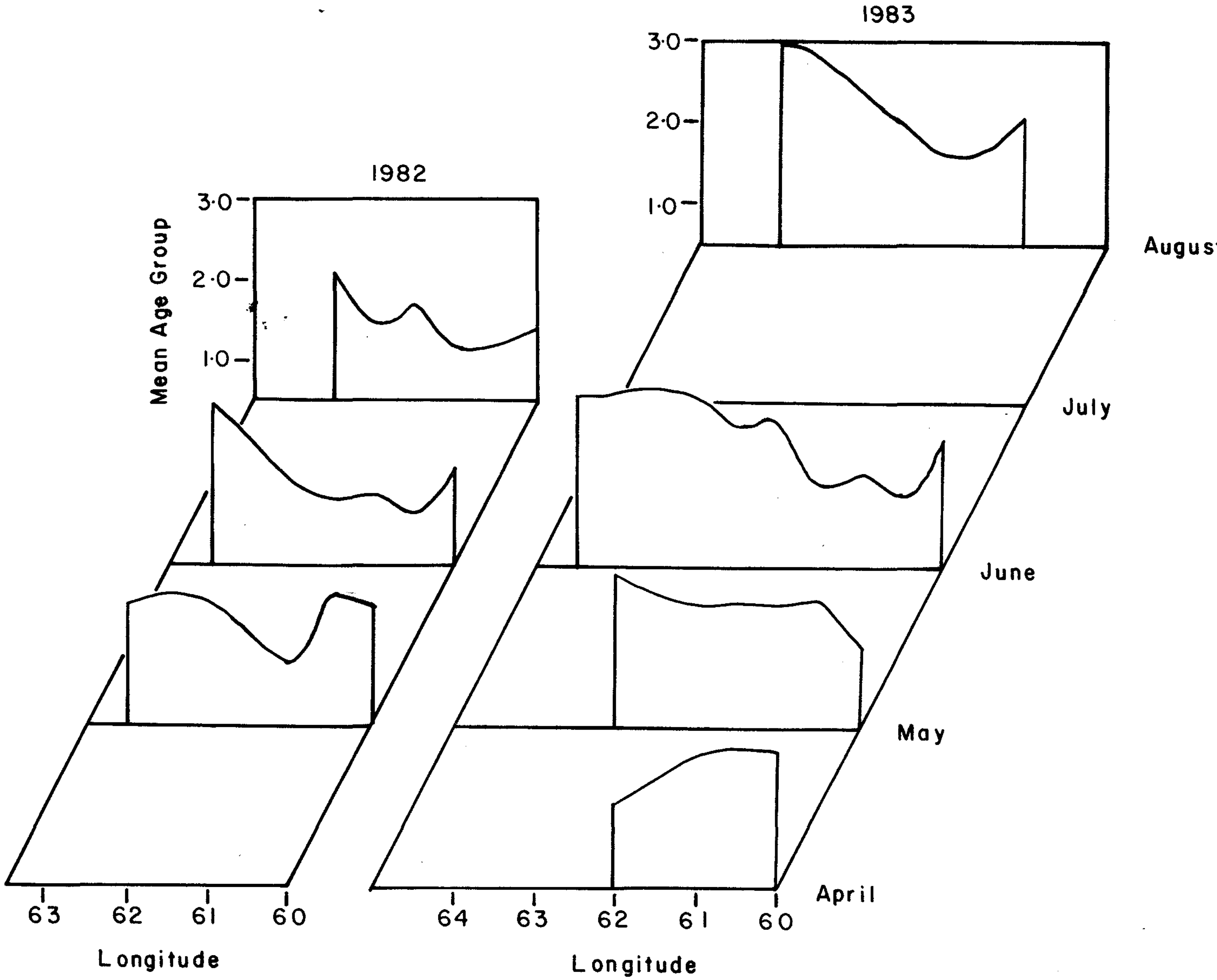

Figure 7. Mean age by longitude and month of haddock sampled from the Scotian Shelf small meshed fishery in 1982 and 1983.

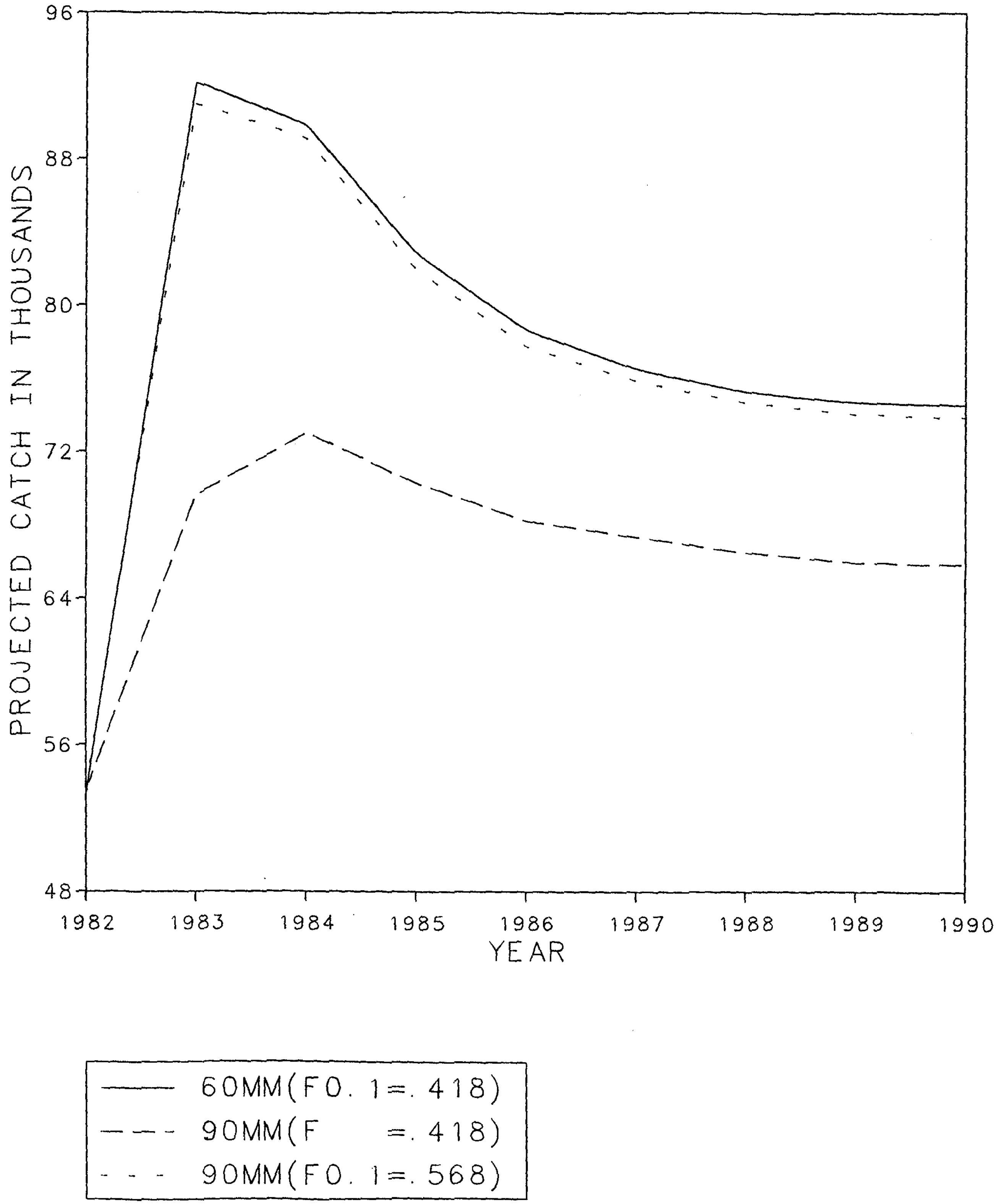

Figure 8. Projected small meshed catches (t) of Scotian Shelf silver hake for 60 mm. and 90 mm. codend selectivities.

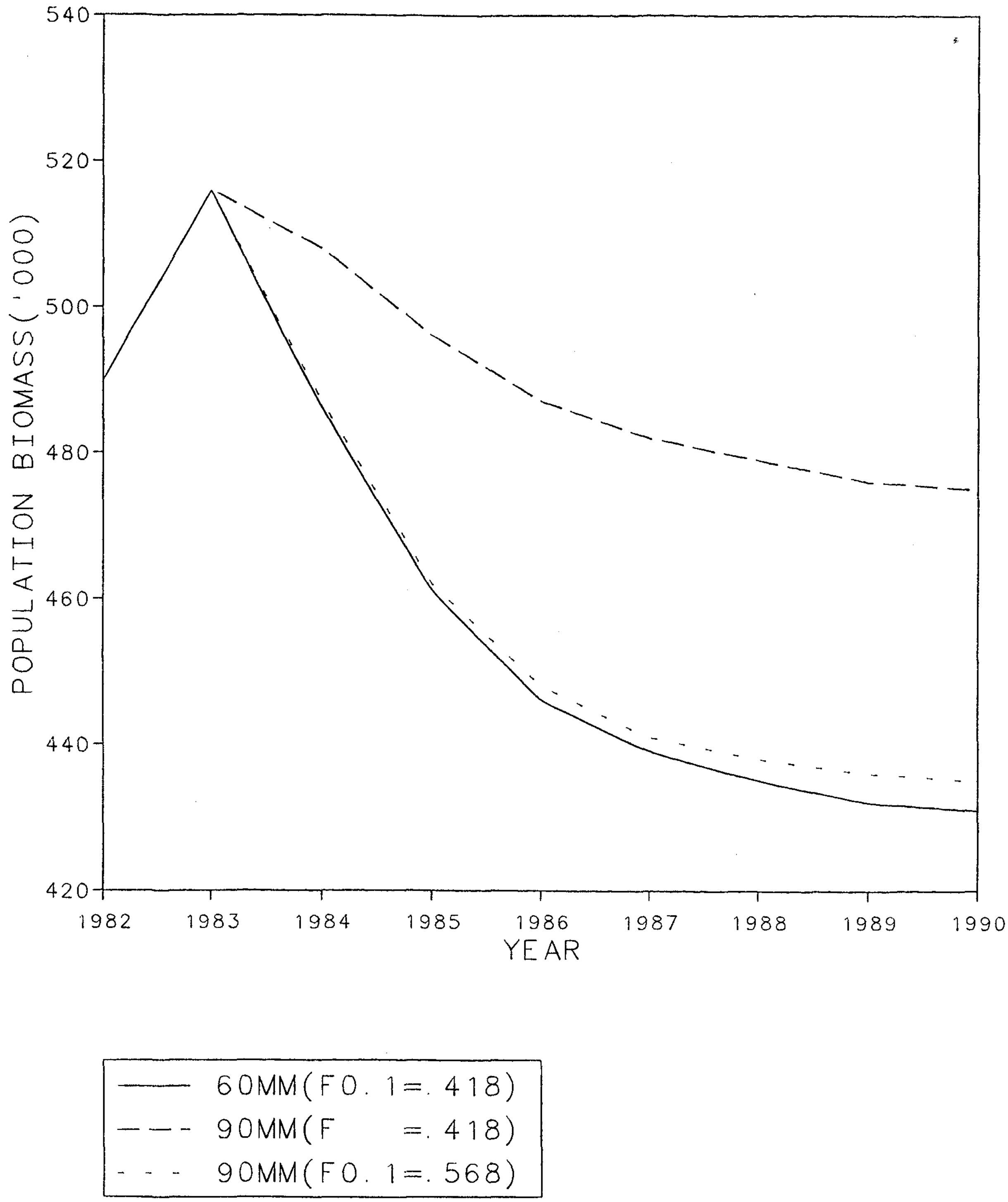

Figure 9. Projected beginning of the year population biomass (t) of Scotian Shelf silver hake fishing at different levels of F and with different mesh sizes.

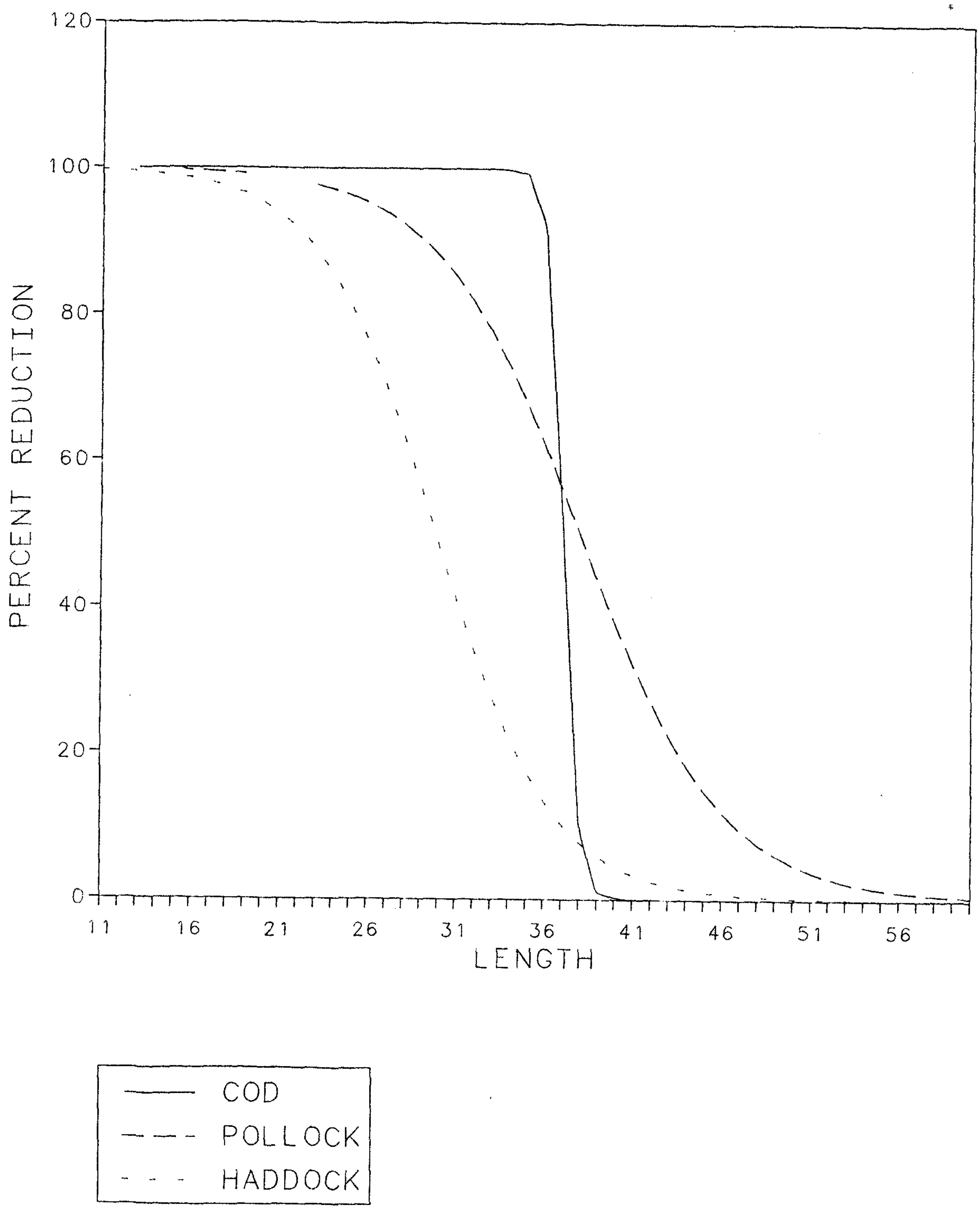

Figure 10. Percentage reductions of observed cod, haddock and pollock catch numbers at length if the small meshed fishery used 90 mm rather than 60 mm codends.