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# Distribution of Eastern Scotian Shelf Cod With Respect to Age, Depth and Temperature

by

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## Abstract

The depth and temperature distributions at age of cod in NAFO Subdiv 4Vs and Div. 4W were investigated as part of a study of possible mechanisms for year-class targeting in commercial fisheries for cod. Using data from stratified random groundfish surveys, cumulative catch frequencies were calculated with respect to depth, temperature, and age. Older fish were found at progressively greater depths than younger fish over the entire age range studied (ages 1-12). The median temperature at capture decreased for ages 1-4 but remained stable for ages 5+. The depth and temperature distributions at age did not correspond with those observed in the survey area, indicating that cod sought areas with specific conditions. These results indicate significant age segregation in cod stocks thus allowing for year-class targeting by the commercial fishery. A general warming of bottom waters in Div. 4W corresponded with a reduction in the relative abundance of cod in this area.

COD SYMPOSIUM, SEPTEMBER 1991

## Introduction

Cod stock assessments in the Northwest Atlantic rely on age structured methods to arrive at stock abundance estimates and catch projections. An important part of the process is the estimation of the age specific exploitation pattern of the fishery, commonly referred to as partial recruitment (PR). PR has been used as an input parameter to cohort analysis (Rivard 1982) or it may be estimated as part of the analysis (Pope and Shepherd (1982), Gavaris (1988)). In either case, systematic interannual variation in PR is difficult to detect and it may lead to biased estimates of important assessment parameters. Rivard and Foy (1987) found that uncertainty in PR was an important factor in errors in catch projections used to set total allowable catches. A better understanding of the dynamics of PR could improve the assessment process.

Two factors are important in determining PR, the selectivity of the fishing gear and the availability of fish of different ages to the fishery. Regulation of mesh and hook size in commercial fisheries tends to limit the importance of selectivity changes on variations in PR except in years when new regulations are introduced. However, if the fish are segregated by age then the fishery could effectively target certain year classes thus making availability an important component in PR variation. One of my objectives in this study is to investigate the spatial distribution at age of cod in Subdiv. 4Vs and Div 4W and how this may be related to PR.

A second objective was to examine the distribution of cod with respect to temperature. I have concentrated on age specific variations in temperature distribution and on the possible effects of changes in temperature on cod distribution in the area.

Previous studies have studied the environmental occurrence of cod. In a study of several groundfish species on the Scotian Shelf in summer Scott (1982) identified preferred temperature, depth and salinities over the entire Scotian Shelf and all ages combined. Smith et al. (1991) investigated the influence of water mass characteristics on the spring distribution of age 4 cod on the eastern Scotian Shelf. Tremblay and Sinclair (1985) investigated the spatial and environmental distribution of different aged cod in the southern Gulf of St. Lawrence.

Materials and Methods

Data for this study were obtained from stratified random groundfish abundance surveys conducted on the Scotian Shelf (Figure 1) between 1970-1989 (Doubleday 1981). The basic data were obtained from the Canadian Department of Fisheries and Oceans Marine Fish Division, St. Andrews Biological Station, St. Andrews N.B. Catch at age of cod were calculated on a tow by tow basis according to a two stage sampling scheme described by Halliday and Koeller (1981). Catch per tow was adjusted to a standard tow length of 1.75 nm. Catches were weighted by the ratio of strata area ($N_h$) divided by the number of tows in each stratum ($n_h$) on an annual basis in accordance with the stratified random sampling scheme as suggested by Smith (1990). Additional information on bottom temperature and depth of tows were also extracted.

Cumulative frequencies of temperature and depth were used as an indication of the environmental conditions during each survey. The cumulative frequency in percent (F(t)) at any temperature $Y_{ih}$ was calculated as

$$F(t) = \frac{\sum_{h=1}^{L} \sum_{i=1}^{n_k} \frac{N_h}{n_h} \Delta\,(t-Y_{ih})}{\sum_{h=1}^{L} \sum_{i=1}^{n_k} \frac{N_h}{n_h}} 100 \qquad (1)$$

where

$L$ = the number of strata

$Y_{ih}$ = the observed temperature at set i in strata h

$$\Delta\,(t-Y_{ih}) = \begin{cases} 1 \text{ when } (t-Y_{ih}) \geq 0 \\ 0 \text{ otherwise} \end{cases}$$

The same was done for depth.

The cumulative frequencies of catch in relation to either temperature or depth were calculated as an indication of the distribution of different age groups in relation to these environmental variables. The following formula was used.

$$F(t) = \frac{\sum_{h=1}^{L} \sum_{i=1}^{n_k} \frac{N_h}{n_h} X_{ih} \Delta\,(t-Y_{ih})}{\sum_{h=1}^{L} \sum_{i=1}^{n_k} \frac{N_h}{n_h} X_{ih}} 100 \qquad (2)$$

where

$X_{ih}$ = the observed catch numbers in set i of strata h

The median temperature or depth was defined as that corresponding to the 50% point of the cumulative frequency. Cumulative frequencies were calculated for ages 1 to 12.

The cumulative catch frequencies and median temperatures and depths were compared across ages and years, as well as to the observed temperature and depth frequencies to investigate possible differences in preferences and environmental conditions during these surveys.

## Results

The distribution of cod catches in the research surveys indicates a wide distribution of cod in the Subdiv. 4Vs and Div 4W area (Figure 2). Large catches of juvenile cod (ages 0-3) were made in Div. 4W on Middle and Sable Island Banks as well as on Emerald Bank. In Subdiv. 4Vs catches of this age group were high around the Gully and on eastern Banquereau Bank. Ages 4-6, which are partially recruited to the commercial fishery, overlapped considerably with the juveniles. However, there were relatively higher catches in northern Subdiv. 4Vs in the Misaine Bank area. This shift in distribution continued with older ages. At ages 10+ catches were almost exclusively from northern Subdiv. 4Vs.

The summer research surveys are stratified by depth, therefore the cumulative frequencies of depths sampled varied little among years. There was however a systematic difference in the cumulative frequency of catches at age by depth. Figure 3 presents box and whisker plots (Tukey 1977) of the median depths of capture of age 1 to 12 cod. The box represents the middle 50% of the distribution, the median value is given by the horizontal line within the box, and the range of observations is shown by the vertical line (the whisker). Extreme values are shown by separate circles. The plot indicates an increasing trend of depth distribution with age. The median depths sampled varied little among years and the median depths at age were both greater than and less than those sampled.

Annual median depths for ages 1, 5, and 9 are given in Figure 4. Values at age 1 vary between 40 and 100 m with no clear temporal trend. At age 5 the medians varied between 60 and 140 m. There is evidence of a decrease in the 1970's followed by relative stability in the early 1980's. The values for 1986-88 were among the highest in the series followed by a relatively low value in 1989. At age 9 the medians varied between 80 and 160 m. A decreasing trend was noted from a maximum in 1977-78 to a minimum in 1984. The last 5 values are relatively high and stable. No age 9 cod were caught in the 1976 survey.

Cumulative catch distributions at depth were calculated for each age group. The annual percent cumulative distributions were used as annual weights to represent average conditions for the ages and to reduce the influence of strong year classes on the calculations. The curves for ages 1, 5, and 9 indicate the age-specific differences

in the depth distribution of cod (Figure 5). As noted above, the cod are distributed deeper with age. The percentage of the catches in 50 meter depth intervals are given in Table 1. One can see that if fishing were concentrated in waters deeper than 150 m then age 5 fish would be less available to the fishery than if fishing were concentrated in waters less than 150 m.

Bottom water temperatures in summer on the Scotian Shelf have been described by McLellan (1954) and Scott (1976). The upper 50m is warmed in summer and temperatures may exceed 10°C. Deep areas of the central shelf west of Middle and Western Banks are bathed by relatively warm waters which commonly exceed 8°C. The deeper areas of Subdiv. 4Vs are colder with temperatures of less than 4°C. The coldest temperatures are on banks between 50-100m depth which are in contact with the intermediate cold layer which originates in the Gulf of St. Lawrence and the Labrador Current.

Median bottom temperatures observed during the time period support this description (Figure 6). Temperatures were always greater in Div. 4W than in Subdiv. 4Vs, ranging between 5-9°C in the former and between 1-4°C in the latter. While the time series is variable in Div. 4W, an increasing trend is evident between 1970-86 except for two cold years in 1982 and 1983. The median temperatures in the last three years were among the lowest observed. Median temperatures in Subdiv. 4Vs were relatively stable over the time period. Temperature data from the 1985 survey were not available at the time of writing.

Median temperatures at age was highest at age 1 and decreased to age 5 after which they were stable around 3°C (Figure 7). For the most part the adult cod (> age 6) were found at lower temperatures than observed indicating a preference for water less than 4°C. Younger cod showed preference for warmer waters.

Annual median temperatures for ages 1, 5, and 9 are given in Figure 8. At ages 5 and 9 the annual values were stable and varied little. At age 1 the annual values were higher, stable from 1970-78, increased to a maximum in 1981, and declined to 1989.

Cumulative catch distributions at temperature were calculated for each age as was done at depth. The curves for ages 1, 5, and 9 indicate that the younger fish are found, on average, at warmer temperatures than older fish (Figure 9). However, there is essentially no difference in the temperature distribution of fish age 5 and older. Approximately 75% of the catch of adult fish was taken in water less than 4°C while for age 1 fish about 15% was taken in the same range.

The annual cumulative temperature distributions for Subdiv. 4Vs and Div. 4W were examined to estimate the percentage of the survey area that was in a favorable temperature range for cod, taken here as 0-4°C. Annual values are presented in Figure 10. The y-axis of the graph is plotted in the log scale to present relative changes. There was little variation in the area of Subdiv. 4Vs outside the selected temperature range, except for 1984. In Div. 4W values for the early 1970's were in the order of 30-40%. These decreased in the late 1970's and early 1980's to less than 20% in 1977, 1979-81, 1984, and 1986. Recent values were comparable to those in the early 1970's. Thus, in the late 1970's and most of the 1980's there

was significantly less of Div. 4W that had temperatures favorable for cod.

Nominal catches for the management unit varied substantially since 1970 (Figure 11). The stock experienced low biomass and catches in the mid 1970's, recovered after the extension of fisheries jurisdiction in 1977, and recent catches have been reduced by TAC restrictions (Fanning and MacEachern 1990). Catches increased in both areas in the late 1970's, however there has been a substantial shift in catches to Subdiv. 4Vs in the 1980's. This corresponds with the warming of bottom waters in Div. 4W.

## Discussion

This study demonstrates significant age segregation of cod in Subdiv. 4Vs and Div. 4W. Research vessel survey catches of young cod (ages 0-3) came from shallow banks (Sable Island Bank, Middle Bank, Banquereau Bank, and Misaine Bank) (Figure 2). A shift in distribution with increasing age toward the northeast was evident. Tagging studies from the 1920-40's suggested that the management unit was composed of several stocks with separate components in the two areas (McKenzie 1956) and the distribution of juvenile catches reported here supports this. However the adult distribution is more homogeneous suggesting considerable mixing of older fish. Without more recent tagging information the origin of these older fish is not clear.

The tendency for older cod to occupy deeper water shown in Figure.3 has important implications in the interpretation of fisheries statistics. A shift of the commercial fishery to shallower waters will result in an increase in the availability of younger age groups and the opposite effect for older age groups. Mobile fisheries could follow strong year classes and thus partial recruitment could vary annually. Such a tendency could bias trends in CPUE at age used to calibrate sequential population analyses in stock assessments.

The age segregation in this management unit can also partly explain the large differences observed in partial recruitment to otter trawls and longlines (Sinclair 1986). Otter trawls catches younger fish than longlines and also have a dome-shaped partial recruitment pattern, ie. older fish are less recruited than middle aged fish. This latter observation is not consistent with the selectivity of the fishing gear. However, otter trawl effort for cod is concentrated on the shallow banks (Sinclair 1985) thus reducing the availability of older fish. Longline effort has been concentrated in relatively deeper water and the selectivity of the gear is toward older fish.

The distribution of cod with respect to temperature also varies with age. Median temperatures of capture of age 1-4 cod decline progressively with age. For ages 5+ the temperature distribution is consistent with median temperatures between 2-4°C. The decline in median temperatures with age for younger fish is consistent with their movement toward deeper waters. However, older cod remain in these relatively cold waters despite movement to greater depths. The bottom temperatures in areas > 100m in Div. 4W often exceed 7°C (Scott 1976) and thus it would seem that waters of these temperatures are not preferred by cod. If indeed this is the case it would explain the shift of cod toward Subdiv. 4Vs with increasing age. It may also explain the recent decline in the relative abundance of cod in Div. 4W which coincides with increasing bottom temperatures.

The temperature distribution of cod is important for the commercial fishery. Fishing for cod in waters warmer than 5° may not be as successful as in areas with colder temperatures.

Acknowledgements

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Table 1: Percent distribution of cod catches by 50 meter depth zones.

| Depth Zone | Age 1 | Age 5 | Age 9 |
|---|---|---|---|
| 0 to 50 | 37 | 12 | 4 |
| 50 to 100 | 41 | 34 | 23 |
| 100 to 150 | 20 | 41 | 36 |
| 150 to 200 | 2 | 7 | 22 |
| 200 + | 0 | 6 | 15 |

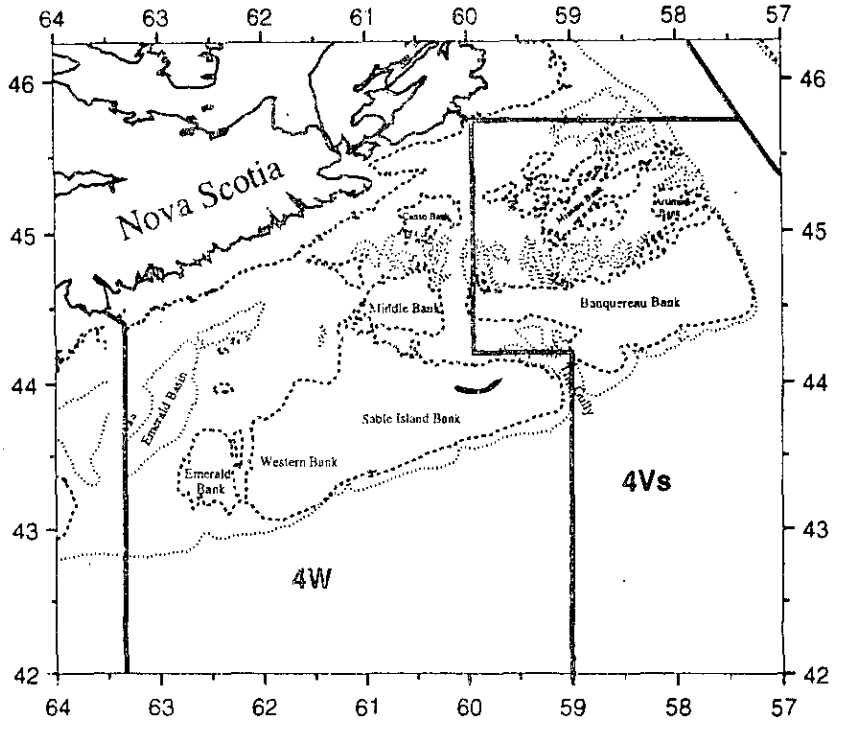


Figure 1: Map of the eastern Scotian Shelf showing NAFO Divisions.

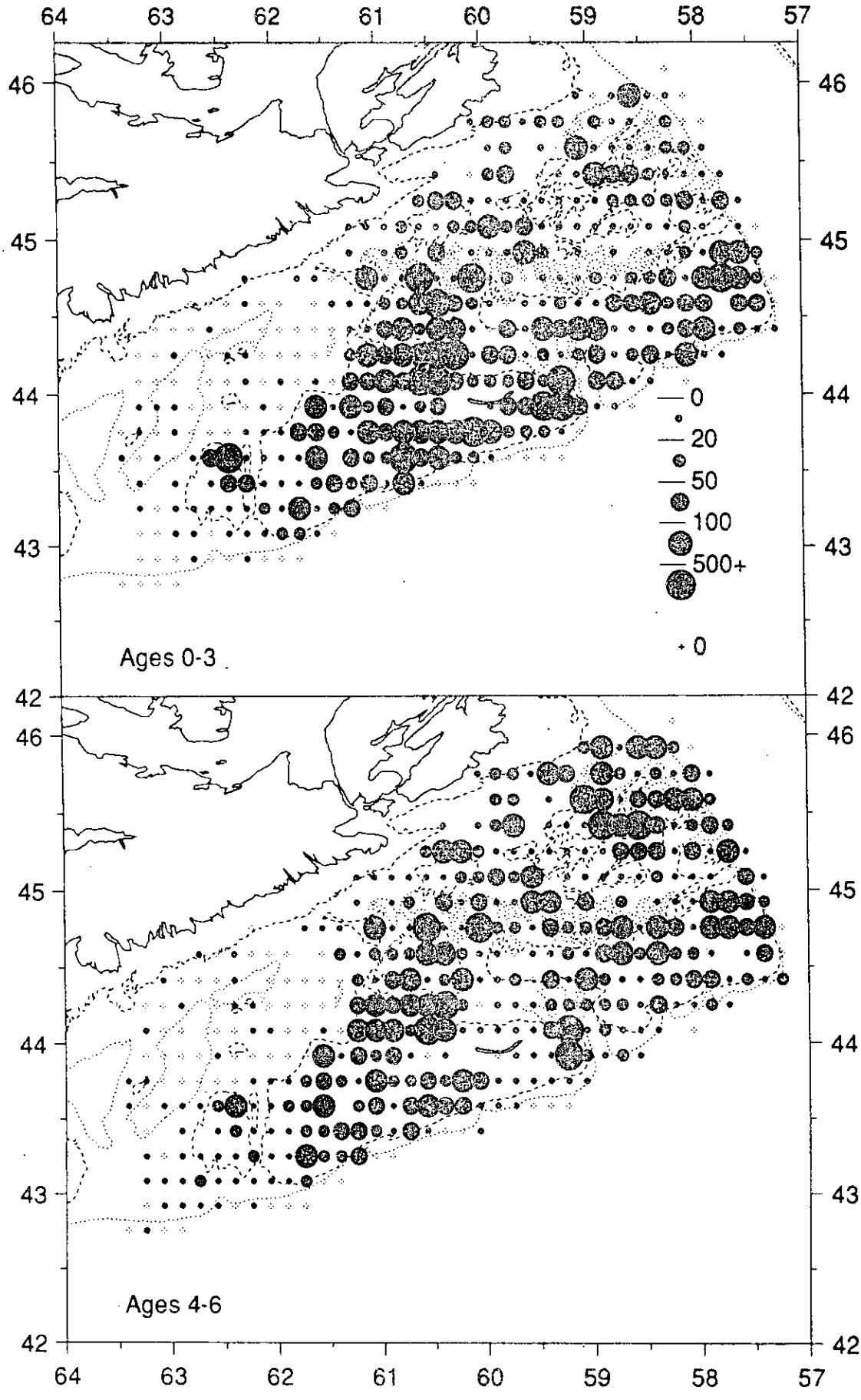


Figure 2: Cod catches from Scotian Shelf summer groundfish surveys 1970-89.

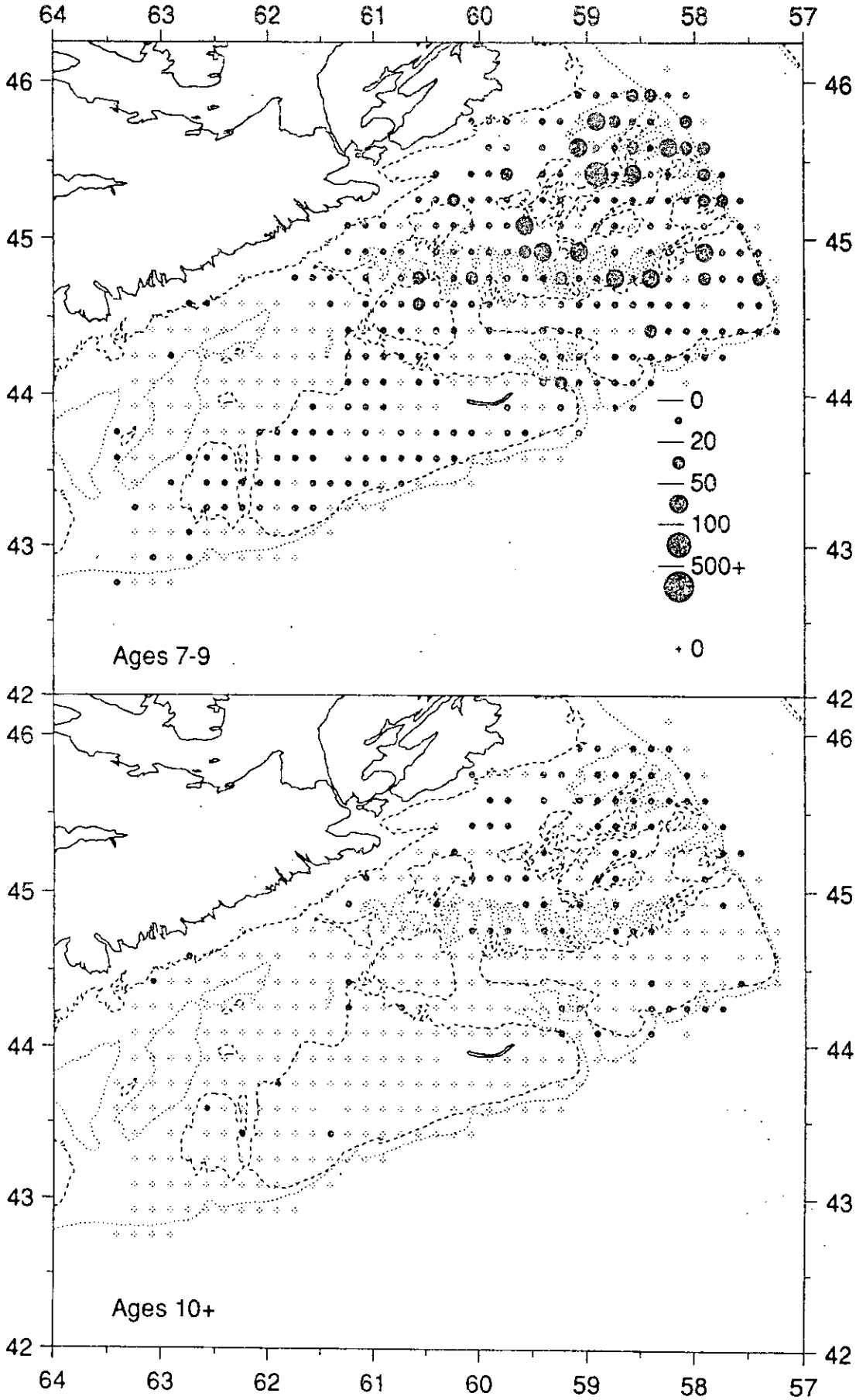


Figure 2: Con't.

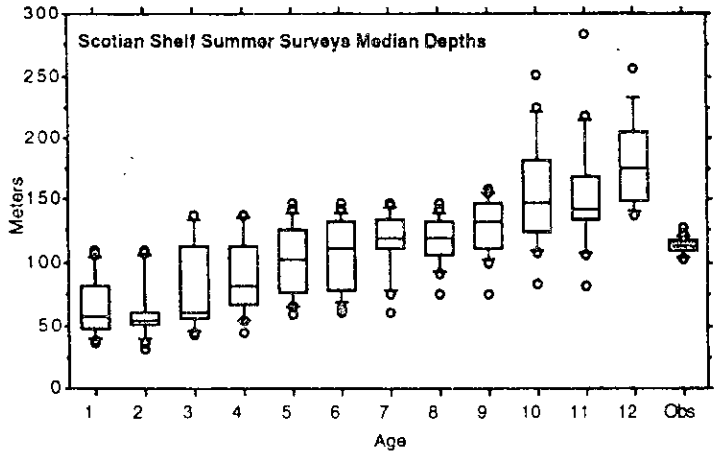


Figure 3: Box and whisker plots of annual median depths of capture of NAFO Subdiv. 4Vs and Div. 4W cod for the period 1970-89.

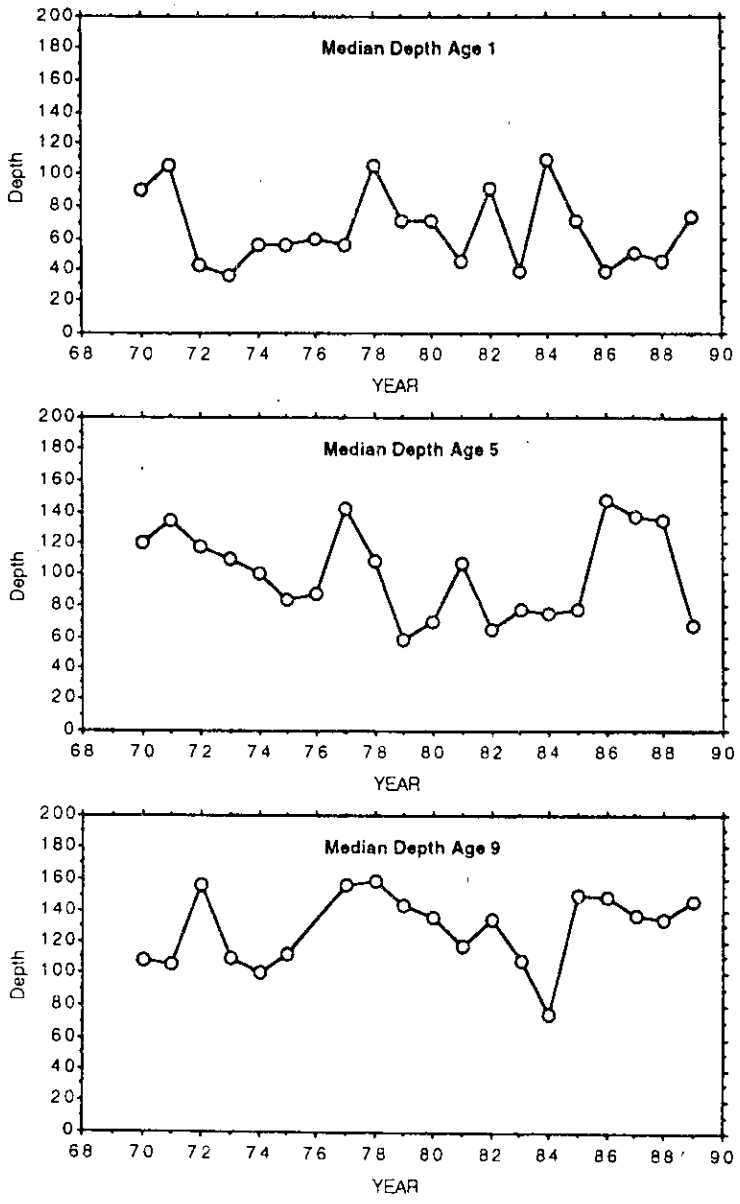


Figure 4: Trend in median depths of age 1, 5, and 9 cod in NAFO subdiv. 4Vs and Div. 4W.

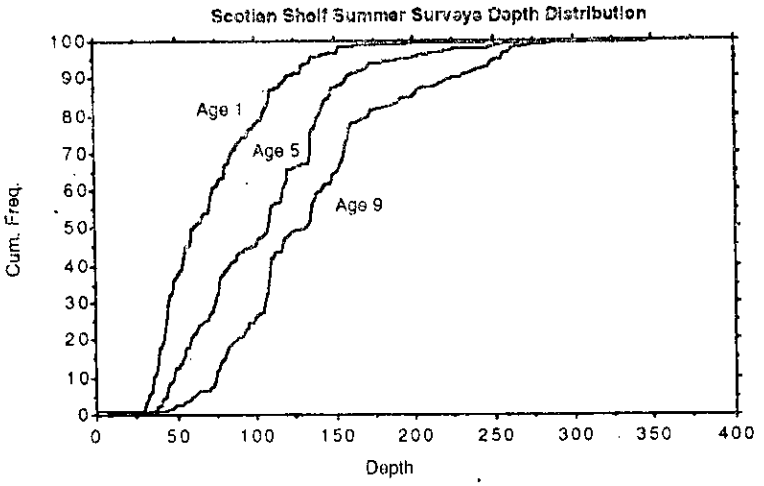


Figure 5: Cumulative frequency distribution at depth for age 1, 5, and 9 cod in NAFO Subdiv. 4Vs and Div. 4W for the period 1970-89.

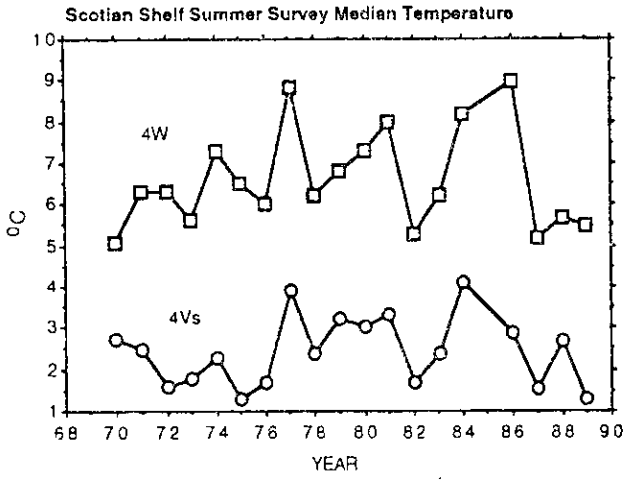


Figure 6: Median bottom temperatures observed in NAFO Subdiv. 4Vs and Div. 4W during summer groundfish surveys.

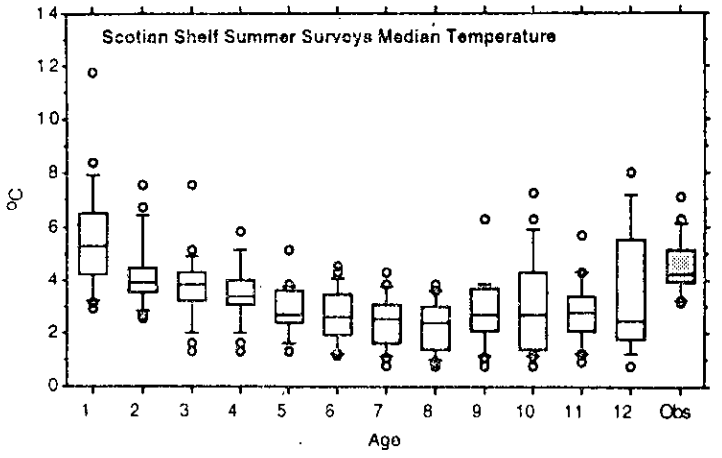


Figure 7: Box and whisker plots of annual median temperatures of capture of NAFO Subdiv. 4Vs and Div. 4W cod for the period 1970-89.

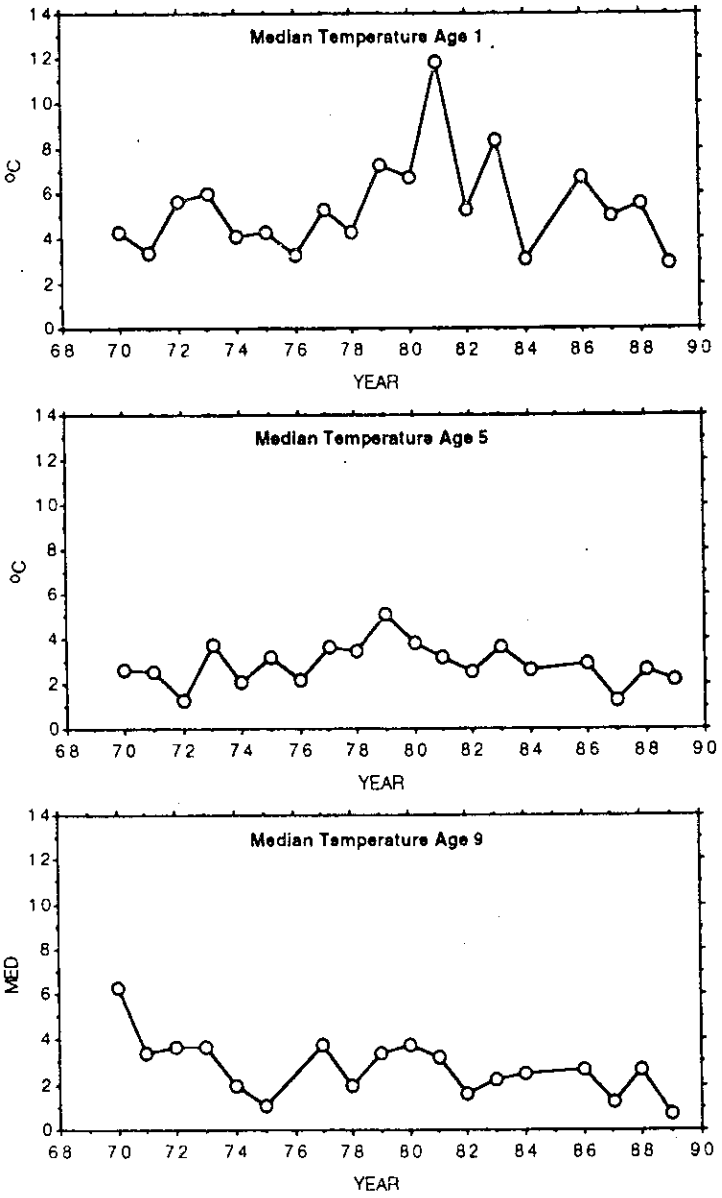


Figure 8: Trend in median temperatures of age 1, 5, and 9 cod in NAFO subdiv. 4Vs and Div. 4W.

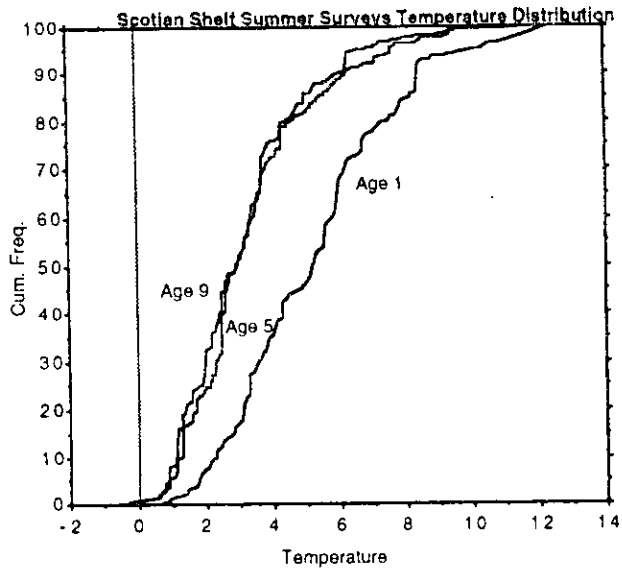


Figure 9: Cumulative frequency distribution at temperature for age 1, 5, and 9 cod in NAFO Subdiv. 4Vs and Div. 4W for the period 1970-89.

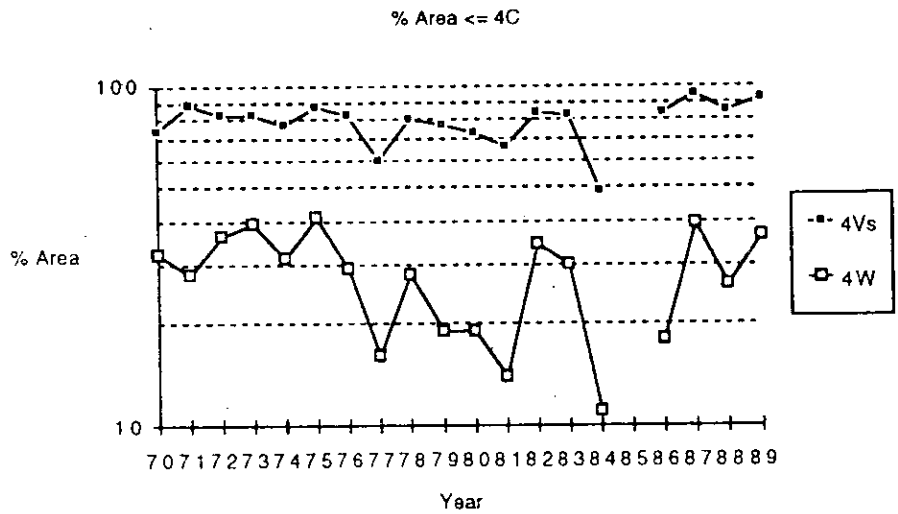


Figure 10: Percentage of survey area with bottom temperatures between 0-4°C.

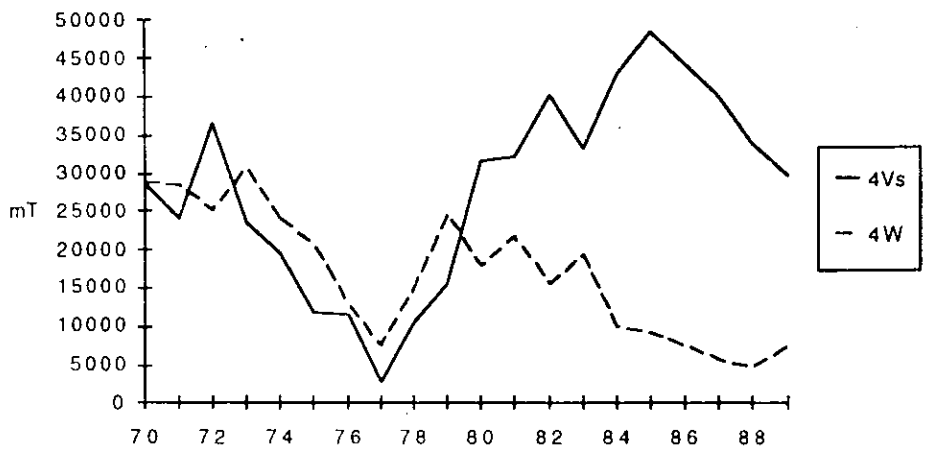


Figure 11: Nominal catch of cod in Subdiv. 4Vs and Div. 4W (from (Fanning and MacEachern 1990)).