Northwest Atlantic Fisheries Organization

Serial No. N2252 NAFO SCR Doc. 93/68

SCIENTIFIC COUNCIL MEETING - JUNE 1993

Distributions of Juvenile Cod in NAFO Divisions 2J3KL During Fall, 1981-92, in Relation to Bathymetry and Bottom Temperatures

by

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1 Introduction

Very little is known about the distributions of juvenile cod within the 2J3KL management area. It has been hypothesized that the inshore areas (bays) are the primary nursery areas for 0-group cod (Templeman 1981, Lear and Green 1986). As cod develop, these juveniles would eventually return offshore to their original spawning areas (op. cit.).

The development of pre-recruit indices for 2J3KL cod has been one of the initiatives of the Northern Cod Science Program. As part of this work, I undertook an analysis of the Canadian fall research vessel survey data for young cod, ages 1-4 years, for the 2J3KL management area (Figure 1) to describe their general distributions during the fall, and how these varied over time. A comparison of these distributions is made to bathymetry and bottom temperatures. Preliminary results are presented in this paper.

2 Methods

The fall surveys are typically carried out in a series of cruises during October to December each year (minimum: 3 October; maximum: 19 December), except the 3L survey in 1984 which started on July 26 and apparently did not end until November 26. The surveys follow a random stratified design using an Engels 45 high-rise bottom trawl, towing for 30 minutes at each station. Bottom temperature and depth are measured and recorded for each tow. The Engels trawl is not designed to catch young cod (Godo and Walsh 1992). In this study I have assumed that 1 and 2 year cod are not quantitatively caught by the trawl, whereas 3 and 4 year old cod

are. Due to uncertainties in the application of the age length key to 1 and 2 year old cod, where their catches can be highly variable for a given area, I have confined my analysis to different length groups assumed to be representative of 1^+ to 4^+ aged cod caught during the fall surveys:

Age (yr)	Length Group	Lengths (cm)
1	LG2	9-17
2	LG3	18-26
3	LG4	27-35
4	LG5	36-44

To determine the general distributions of cod over all years, the surveyed area was gridded into quadrants of 20' latitude by 30' longitude. Examination of the data indicated that more than one tow per quadrant occurred in most cases. For 1 and 2 year old cod, if any fish were caught within each quadrant then a value of one was assigned, otherwise a zero. These results were then summed for each year, where the maximum value would be 12 (1981-92). Because all quadrants were not sampled each year, especially at the boundary, these results were averaged to remove any bias associated with undersampling a particular quadrant. For the the 3 and 4 year old cod, catch/tow were averaged within each quadrant for each year, and then averaged over all years. The final data sets for ages 1 and 2 were spatially integrated by gridding at 100x100 resolution using kriging interpolation, and then smoothed using a 2x2 matrix technique. For ages 3 and 4 the catch rates were $\log_{10}$ transformed, and then similarly gridded and smoothed. The final gridded data sets were contoured linearly.

To examine interannual variability I used the catch rates (catch/30 minute tow) each year for ages 2, 3 and 4 cod, $\log_{10}$ transformed, gridded, smoothed and contoured as described above. In this analysis the original tow locations were used. Total abundance was estimated for each age, each year, by converting the catch tow^{-1} into catch m^{-2} for each contoured interval and then multiplied by the total area occupied by each contoured interval. The total population abundance was the sum of the number of cod estimated for each contoured interval each year. Catchability for each age (length group) was estimated from Godo and Walsh (1992) for age 2 cod (18-26 cm) as 0.055, for age 3 cod (27-35 cm) as 0.25 and for age 4 cod (36-44 cm) as 0.45.

The average temperature for the entire time series, 1981-92, was estimated by calculating the average temperature for each 20' x 30' quadrant each year and then averaging each quadrant over all years. The final data set was contoured as described

above. Temperature each year was estimated from the bottom temperature recorded for each net tow, and contoured as described above.

Bathymetry was derived from a large data set originally digitized for each depth interval (eg. 50 m, 100 m, 150 m, etc.) from available bathymetric charts. This data set was decimated to achieve a manageable size and then contoured, as described above.

3 Results

3.1 Mean Distributions

One year old cod occurred most frequently in two locations: 1) off the southern Labrador/NE Newfoundland coast; 2) on the northern Grand Bank (Figure 2). Over all years, the highest probability of catching one year old cod was off the northern penninsula of Newfoundland. Notably, one year old cod were not caught offshore on Hamilton, Belle Isle or Funk Island Banks. The distribution of two year old cod occurred over a broader area and also occurred further offshore (Figure 3). Two year old cod were observed frequently on Hamilton and Funk Island Banks, on the nose of the Grand Bank and in the most southerly part of the survey area in the vicinity of the Virgin Rocks. The highest probability of catching 2 year old cod was off the southern coast of Labrador. Considering the data for 1 and 2 year old cod as probability of occurrence, it is noteworthy that the highest values for 1 year old cod is $\leq$ 0.2-0.3 and for 2 year olds is $\sim$ 0.6. Therefore, there was no single area in which 1 or 2 year old cod were caught each year, 1981-92.

The distributions of cod aged 3 and 4 years were very similar. Highest concentrations occurred in four distinct areas: 1) in the deep water ($>$ 300 m) on the shoreward and southern sides of Hamilton Bank; 2) in the deep water between Belle Isle and Funk Island Banks; 3) in the deep water south of Funk Island Bank and north of the Grand Bank; 4) on the Grand Bank at the southern limit of the surveyed area (Figure 4 and 5). On the NE Newfoundland Shelf (Figure 1, 2J3K), the abundance of 3 and 4 year old cod was notably lower in the surveyed area closest to shore where 1 and 2 year old cod were most abundant.

When the distributions are compared across ages, the 1 year old cod were distributed shoreward of the 3 and 4 year old cod on the NE Newfoundland Shelf, while the 2 year old cod overlaped these distributions. Therefore, it appears there is a gradual offshore spread in the distribution of cod from 1 to 3 years of age, afterwhich it did not change. On the northern Grand Bank there was a gradual southward shift in the distribution of cod from 1 to 3 years of age, afterwhich it did not change. In

both cases, the distribution of 1 year old cod was notably seperate from the older cod (ages 3 and 4).

3.2 Interannual Variations in Cod Distributions

There was notable variation in the annual distribution of 2, 3 and 4 year old cod each survey year. Plotted here are the annual distributions of 3 year old cod, for reference (Figure 6). The distributions of 3 year old cod demonstrated a considerable degree of interannual variation in both the areal extent of occurrence and areas of highest concentrations (Figure 6). Variations in the distributions may be due to either year effects or year-class (i.e. abundance) effects. However, from these plots it is apparent there is no evidence of a decadal change distribution; in particular, there is no southward shift in the distribution of 2, 3 or 4 year old cod.

3.3 Interannual Variations in Abundance

The total abundance of cod estimated for ages 3 and 4 fluctuated by approximately a factor of 5 during the fall surveys, 1981-92. Estimates for age 2 cod fluctuated by a factor of 19. There was notable variation in the estimates for each year-class, when comparing normalized data for among ages 2, 3 and 4 (Figure 7). However, there was no systematic pattern of one age estimating higher or lower year-class abundance for the time series. The average estimate of abundance for all ages combined (2, 3, 4 years) for each year-class indicates that the highest year-class occurred in 1982 while the lowest year-class occurred in 1984. Year-class abundance estimated for 1989 (ages 2 and 3 only) and 1990 (age 2 only) indicates recruitement for these year-classes may be the lowest recorded during this time series (Figure same).

3.4 Distribution in Relation to Year-class Size

Presently, this analysis has only been done for age 3 cod. There was a significant non-linear relationship between the area occupied by a particular year-class and its abundance (Figure 8). The data demonstrated that the lowest year-classes occurred in smaller areas, whereas there appeared to be an upper limit to the spatial distribution of juvenile cod for the most abundant year-classes. This relationship suggests that there is a limit to the available habitat for juvenile cod (age 3).

3.5 Bottom Temperatures

Average bottom temperatures for all years, 1981-92, demonstrated that the coldest waters ($\leq$ 0 °C) occurred in the shoreward area of the NE Newfoundland Shelf, off southern Labrador and the northern penninsula of Newfoundland, and on the

northern Grand Bank (Figure 9). Warm waters (> 3 °C) occurred at the shelfbreak while 2-3 °C water penetrated onto the NE shelf in the deep water channels between the banks. The pattern of bottom temperatures is clearly cross-shelf on the NE Newfoundland Shelf, whereas the Grand Bank was always cold with a temperature cline occurring at the shelfbreak. These consistent patterns in bottom temperatures suggest that variations in the oceanography of the NE shelf may be distinct from the Grand Bank.

The bottom area covered by cold water ($\leq$ 1 °C) increased from 1981 to a peak in 1985 (Figure 10). The smallest areal extent of cold water occurred in 1986 (51% of the survey area). Since then the bottom area covered by cold water has varied between approximately 55-69% of the survey area. The bottom area covered by the warmest water ($\geq$ 2 °C) decreased from 1981 to a 1985 minimum equivalent to 31% of the survey area followed by a peak in 1986 equivalent to 49% of the survey area (Figure). Since 1988 there has been a general decline in the area of warm water during the fall surveys. However, in 1991 and 1992 the bottom area covered by cold water is less than that observed in earlier years during the 1980's.

There were no simple relationships between the area occuppied by 3 year old cod and the extent of either cold (-1, $\leq$ 0, $\leq$ 1 °C) or warm ($\geq$ 2 °C) water. Simple correlations ranged between -0.10 and -0.31 and were not statistically significant.

4 Discusion

There appear to be two distinct areas occuppied by 1 and 2 year old juvenile cod within the 2J3Kl management area. One area occurs on the inner part of the NE Newfoundland Shelf off the coasts of southern Labrador and NE Newfoundland. These may represent different nursery areas for juvenile cod.

The surveys did not extend into the inshore bays of Newfoundland. Therefore, it is not known if high abundances of 1 and 2 year old cod also occur within the bays. However, several observations infer that they do: the gradient of occurrence increased moving from the shelf towards the inshore areas (Figures 2 and 3); cod were not caught all years, suggesting only the edge of their distributions were sampled; there was a progressive shift in the distribution of cod from 1-4 years of age.

The seperate distributions of 1 year old cod from 3-4 year old cod for both areas suggests different habitats are occuppied these age groups. The overlap of age 2 cod with these distributions suggests a gradual shift in habitat occurs during the second year of life. We know very little about the distribution of 0-group cod. However, if they occurred most abundantly within the inshore areas then there may be a gradual

shift in distribution from inshore to offshore areas during the first 3 years of life: Surveys in 1991 and 1992 demonstrated that 0-group cod occurred predominantly within the inshore bays along the NE Newfoundland coast while none occurred on the NE Shelf (Anderson and Dalley 1993, Dalley and Anderson 1993).

On the NE Newfoundland Shelf there was a clear association of cod distributions with both temperature and bottom depth. Cod 1 year old occurred predominantly nearshore in shallower water (< 200 m depth) which was cold (< 1 °C). This relationship was somewhat true for 2 year old cod, but less clear due to their broader distribution offshore. In contrast, cod 3 and 4 years old occurred predominantly offshore in deep water (> 300 m depth) that was relatively warm (≥ 2 °C). These distributions suggest an age-dependent seperation in distributions as a function of habitat; primarily bottom temperatures which are depth-dependent over the Shelf.

On the Grand Bank 1 year old cod were clearly seperate in distribution from 3 and 4 year old cod. However, there was no clear ontogenetic relationship with depth or temperature. Cod 1 year old occurred towards the shelf break but in shallow water (< 200 m depth) that was cold (< 0 °C). In contrast to the NE Shelf, 3 and 4 year old cod also occurred in shallow water (< 100 m depth) that was cold (≤ 0 °C). Therefore, while the distributions of 1 and 3-4 year old cod were demonstrably seperate on the Grand Bank it was not due to temperature, or depth. This suggests that some factor(s) other than temperature are responsible for the general separation of 1 year old cod from older ages.

Comparison of cod abundances, distributions and bottom temperatures during the period 1981-92 demonstrated that there has been no systematic change during this period of time. In particular, there has been no southward shift in the distribution of cod nor any increase in the amount of cold water these fish would be exposed to on the bottom during the fall. In addition, while the area occupied by 3 year old cod varied during this period there was no simple relationship with the areas of either cold or warm water, which also varied during this period.

Together, these observations suggest that temperature does not have a significant effect on the distribution of juvenile cod. Other factors relating to the obviously different distributions at age might include habitat cover to avoid predation, and food availability.

The non-linear relationship between the area occuppied by 3 year old cod and year-class abundance suggests that there is an upper limit to the available habitat for juvenile cod. Such a relationship would indicate that density dependence may occur at high abundances due to a limit of suitable habitat.

5 Summary

1. There appear to be two distinct areas occupied by 1 and 2 year old cod: one on the inner NE Newfounland Shelf off the coasts southern Labrador and NE Newfoundland; a second on the northern Grand Bank.

2. The distributions of 1 year old cod were distinct from 3 and 4 year old cod, whereas the 2 year old cod appear to be in transition between the younger and older cod.

3. One year old cod were clearly associated with the area of coldest bottom waters (< 1 °C) on the NE Newfoundland Shelf, whereas the 3 and 4 year old cod were found in association with the warmer waters. On the Grand Bank there was no similar association of cod with cold and warm water temperatures, due to the occurrence of cold water throughout the area. This suggests that factors other than temperature are responsible for the ontogenetic differences in distributions.

4. There has been no systematic change in abundance or distribution of juvenile cod, nor in bottom temperatures during the period 1981-92. In particular, there has been no southward shift in the distribution of cod nor any increase in the amount of cold water these fish would be exposed to on the bottom during the fall.

5. The area occupied by 3 year old cod varied each year but there was no simple relationship with variations in either cold or warm water.

6. The non-linear relationship between the area occuppied by 3 year old cod and abundance suggests there may be an upper limit to suitable habitat for juvenile cod.

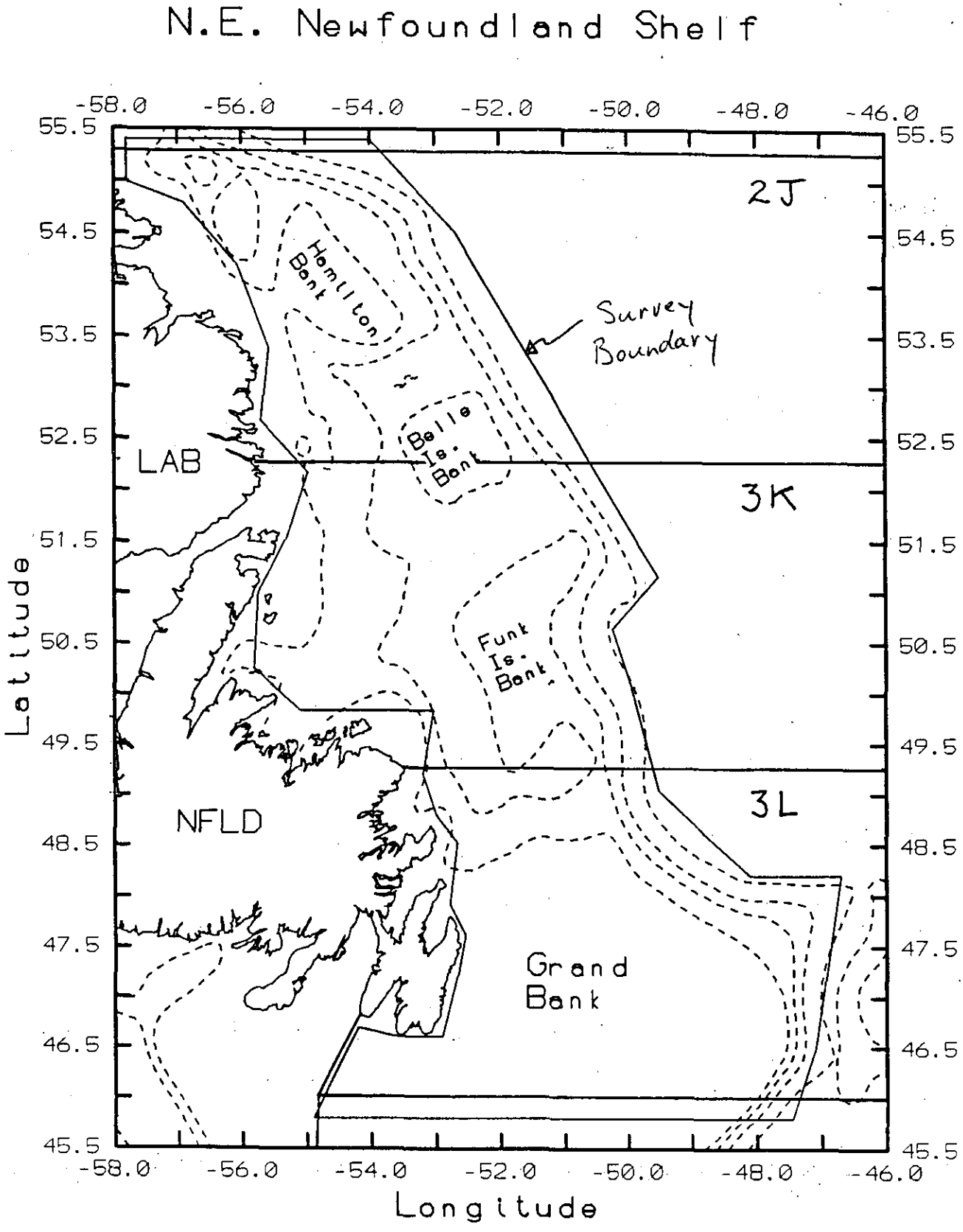


Figure 1. The 2J3KL management area, showing the major fishing banks and the boundary containing the survey area.

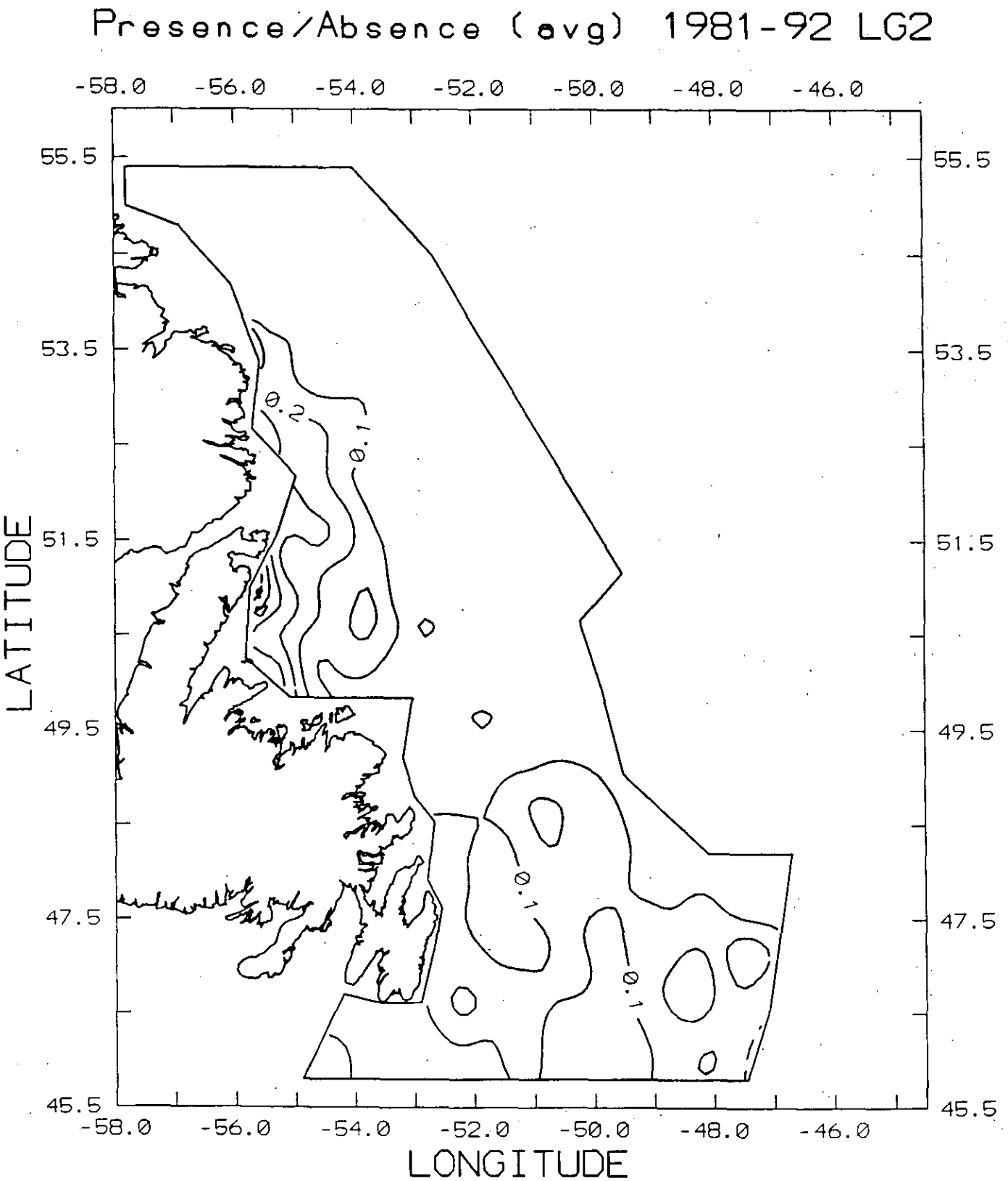


Figure 2. The distribution of 1 year old cod, based on the presence/absence of cod observed each year for the period 1981-92 and plotted as a probability of occurrence.

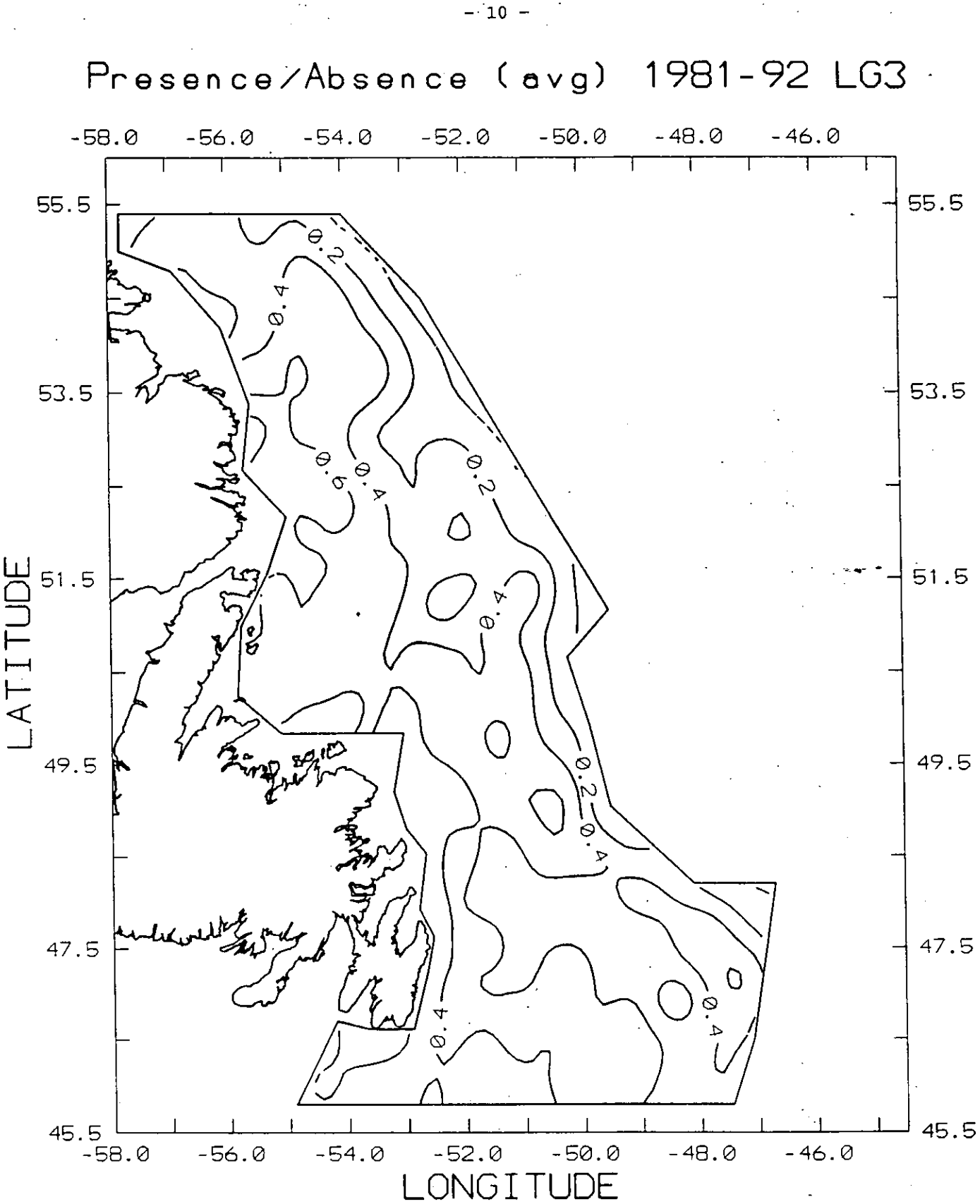


Figure 3. The distribution of 2 year old cod, based on the presence/absence of cod observed each year for the period 1981-92 and plotted as a probability of occurrence.

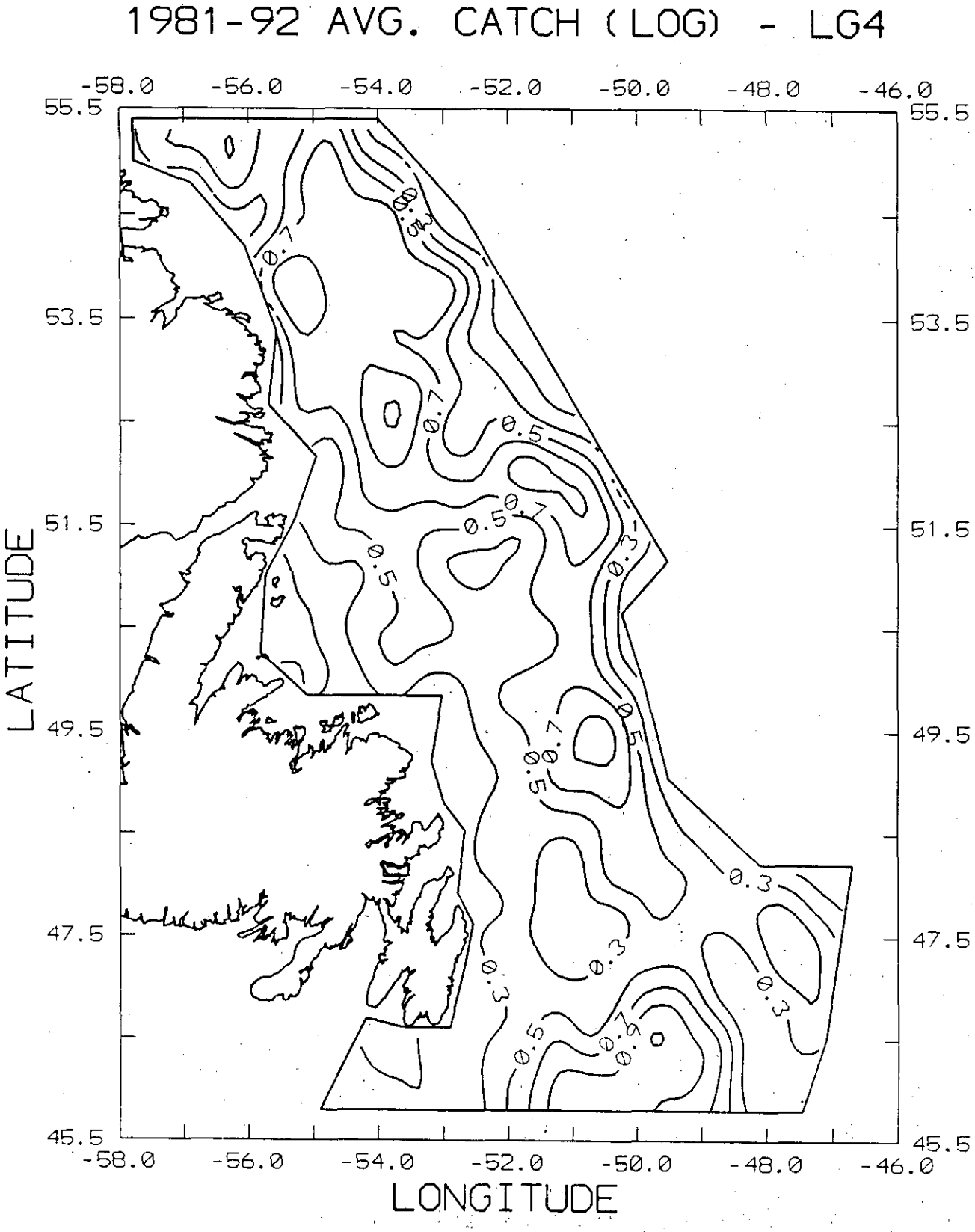


Figure 4. The distribution of 3 year old cod, based on the averaged catch rates ($\log_{10}$(cod)/tow) over all years 1981-92.

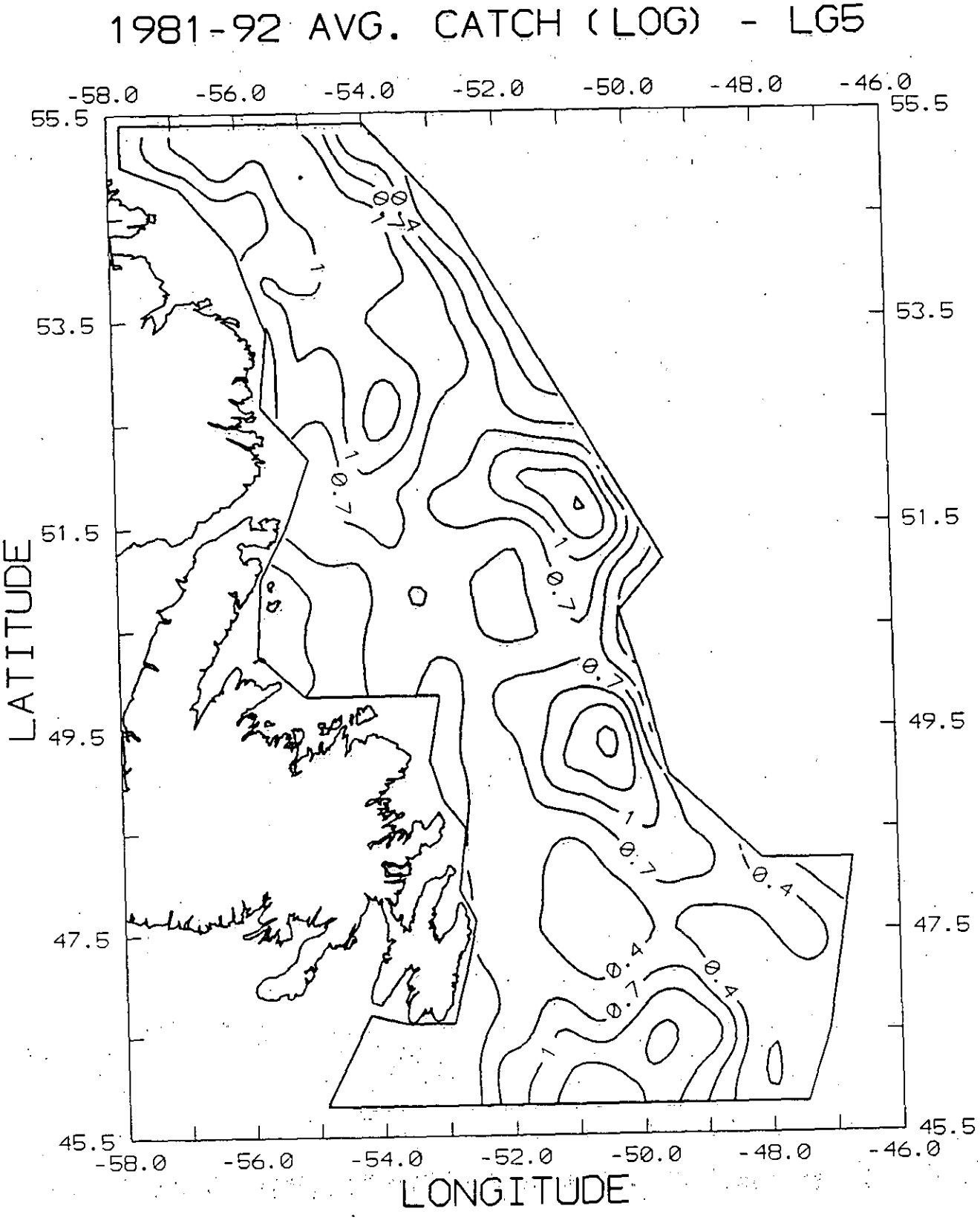


Figure 5. The distribution of 4 year old cod, based on the averaged catch rates ($\log_{10}$(cod)/tow) over all years 1981-92.

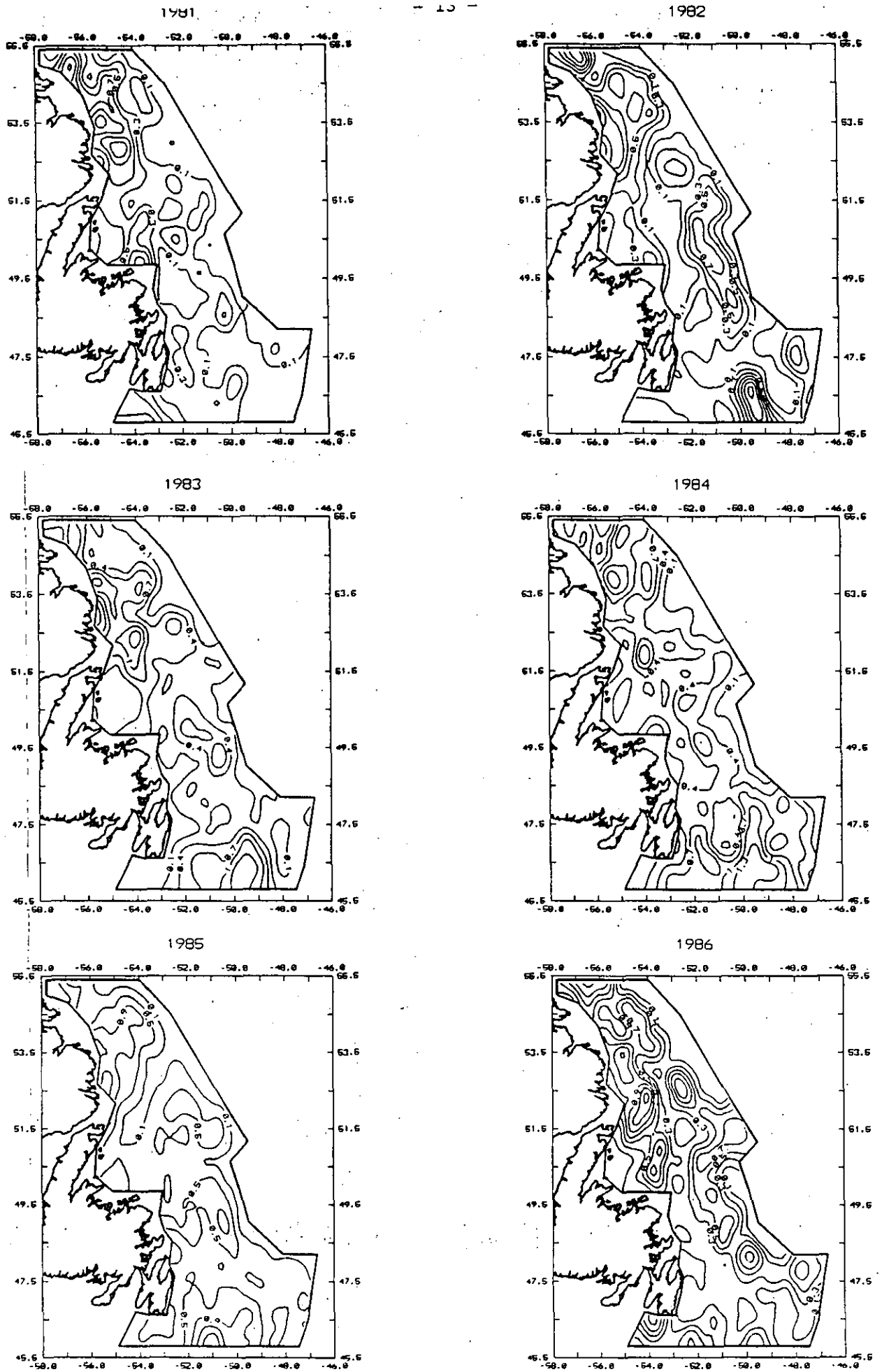
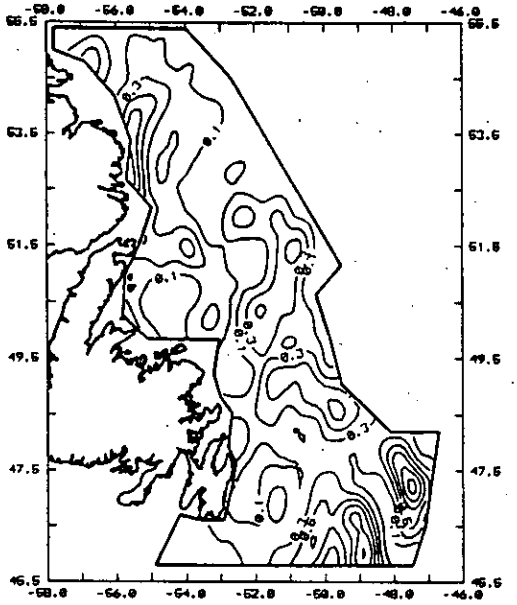


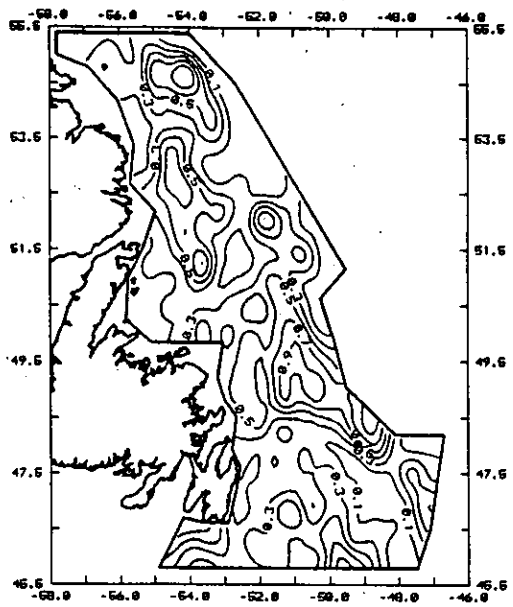
Fig. 6

Figure 6. The annual distribution of 3 year old cod ($\log_{10}$ (cod)/tow) sampled each year 1981-92.

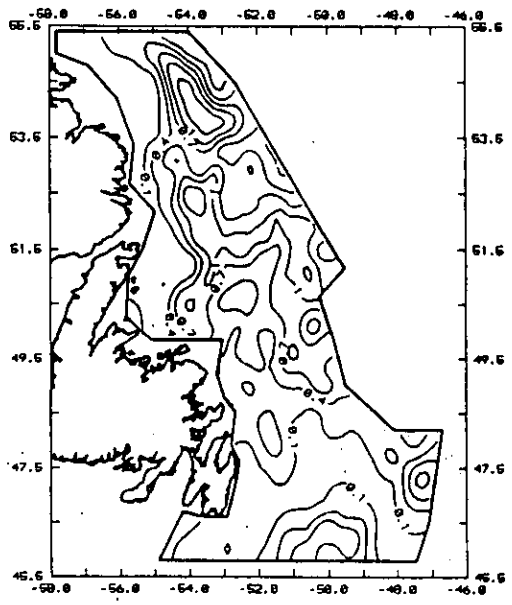
1987



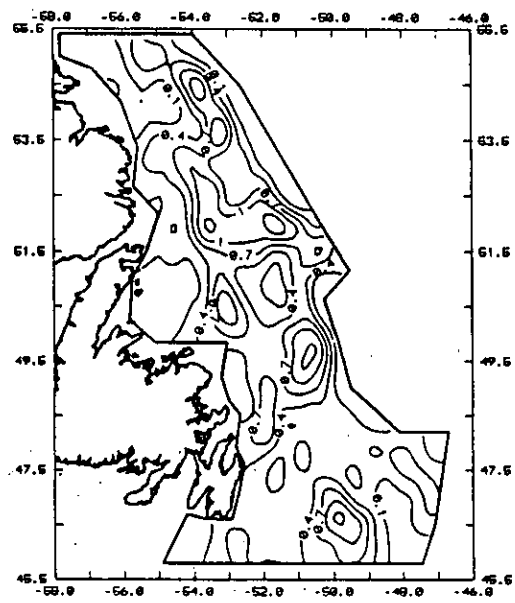
1988



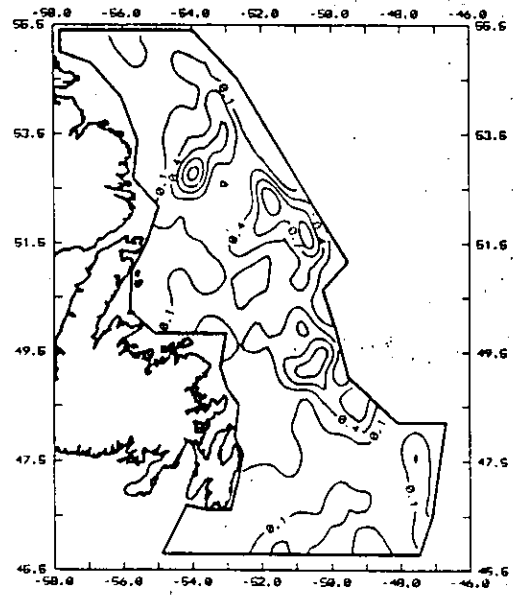
1989



1990



1991



1992

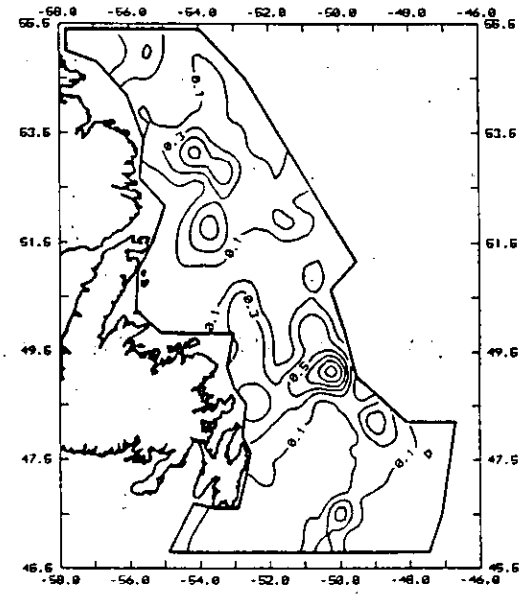


Fig. 6 (cont'd)

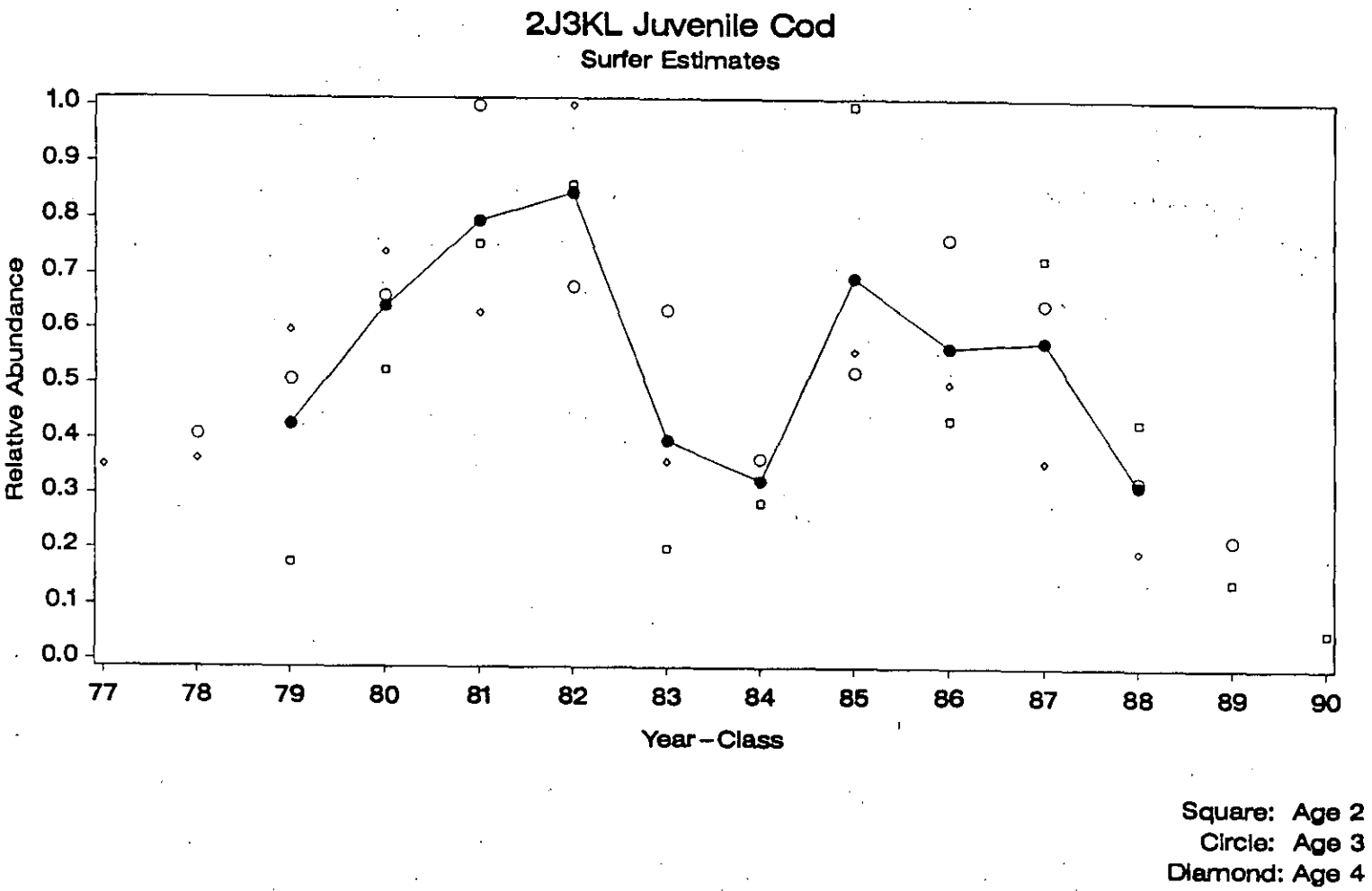


Figure 7. Year-class strength estimated for ages 2, 3 and 4 from the grided and contoured data, including the mean estimate for all three ages.

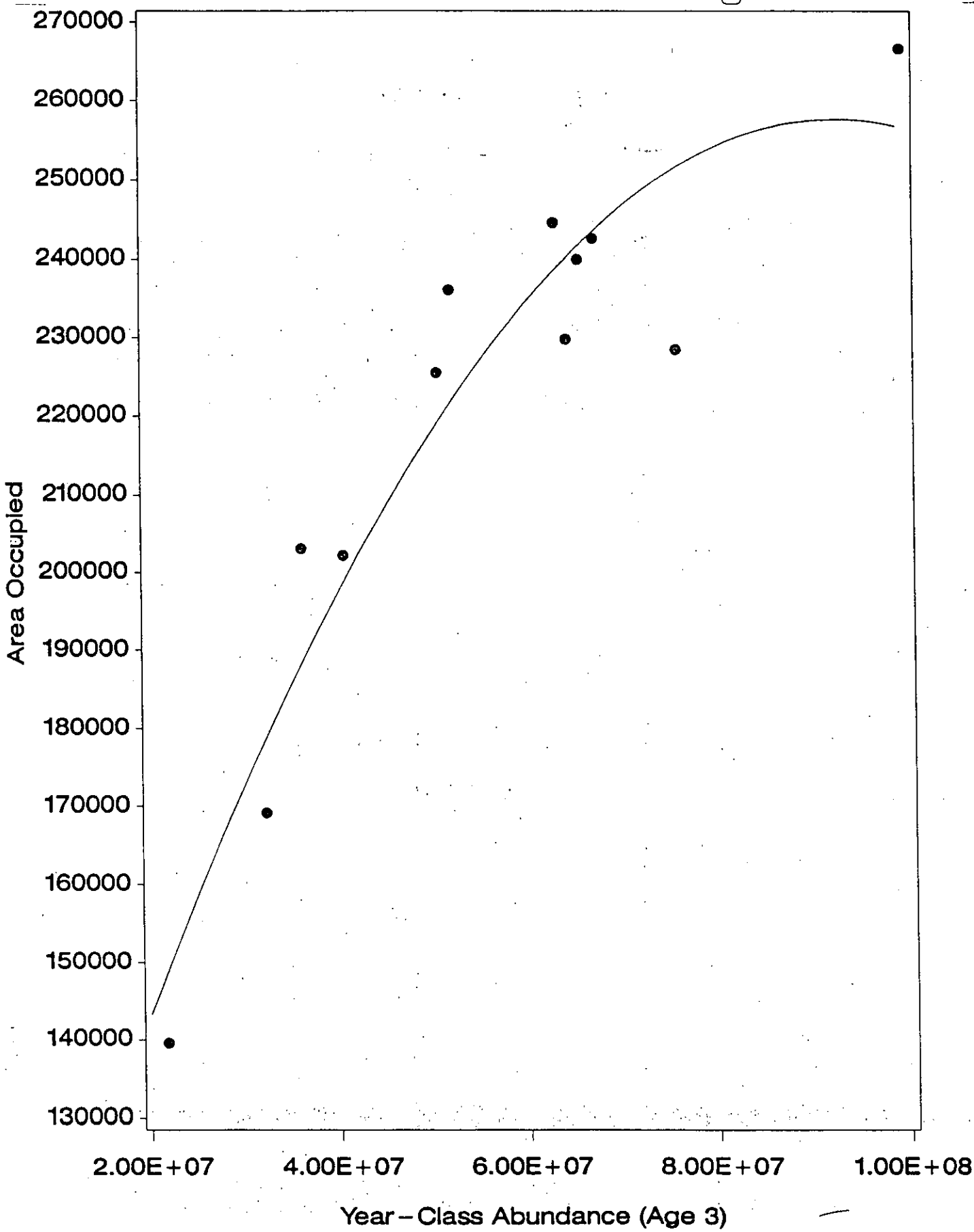


Figure 8. Area occupied by 3 year old cod (km^2) each year compared with the abundance estimated.

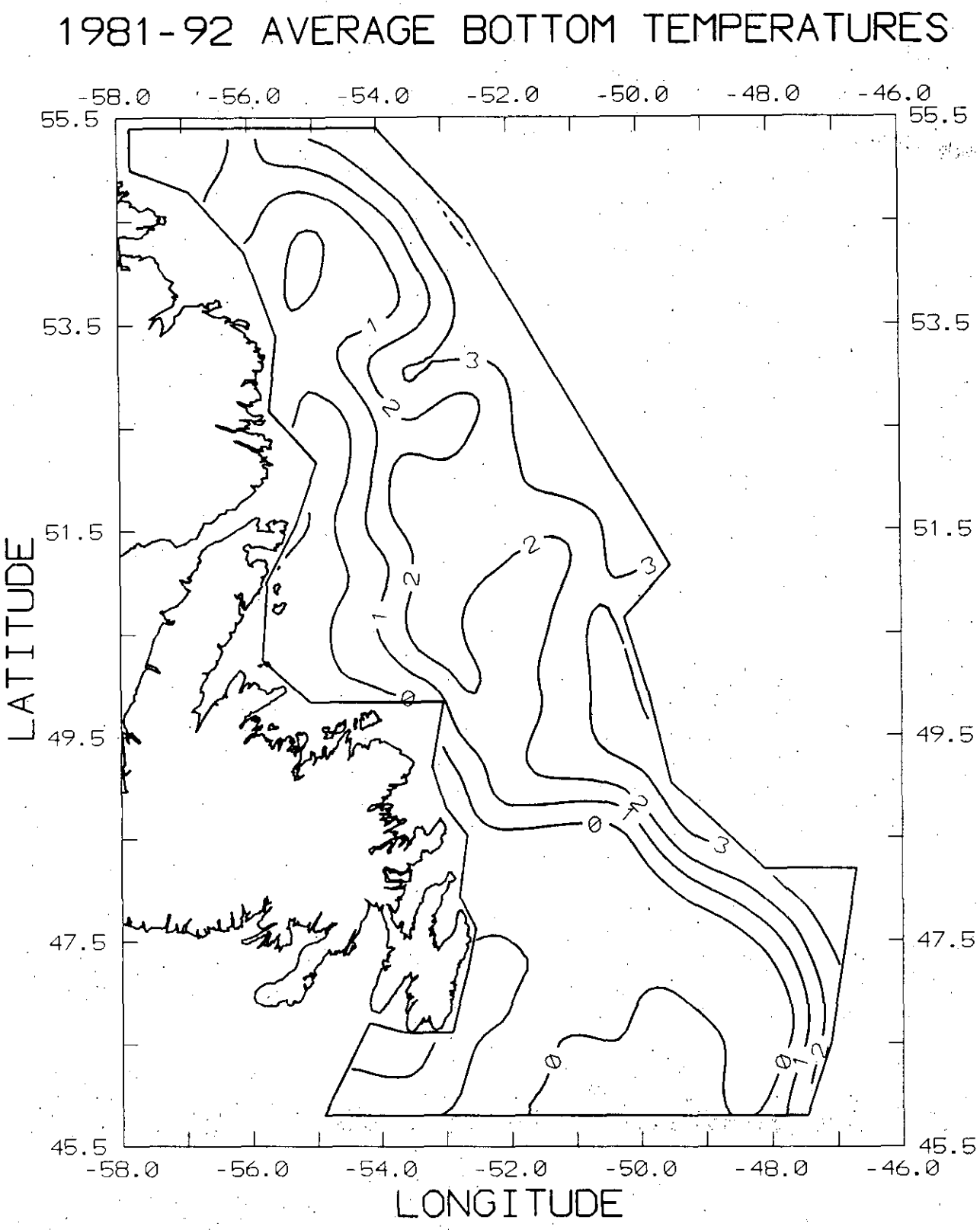


Figure 9. Mean bottom water temperatures (°C) measured during the fall surveys, 1981-92.

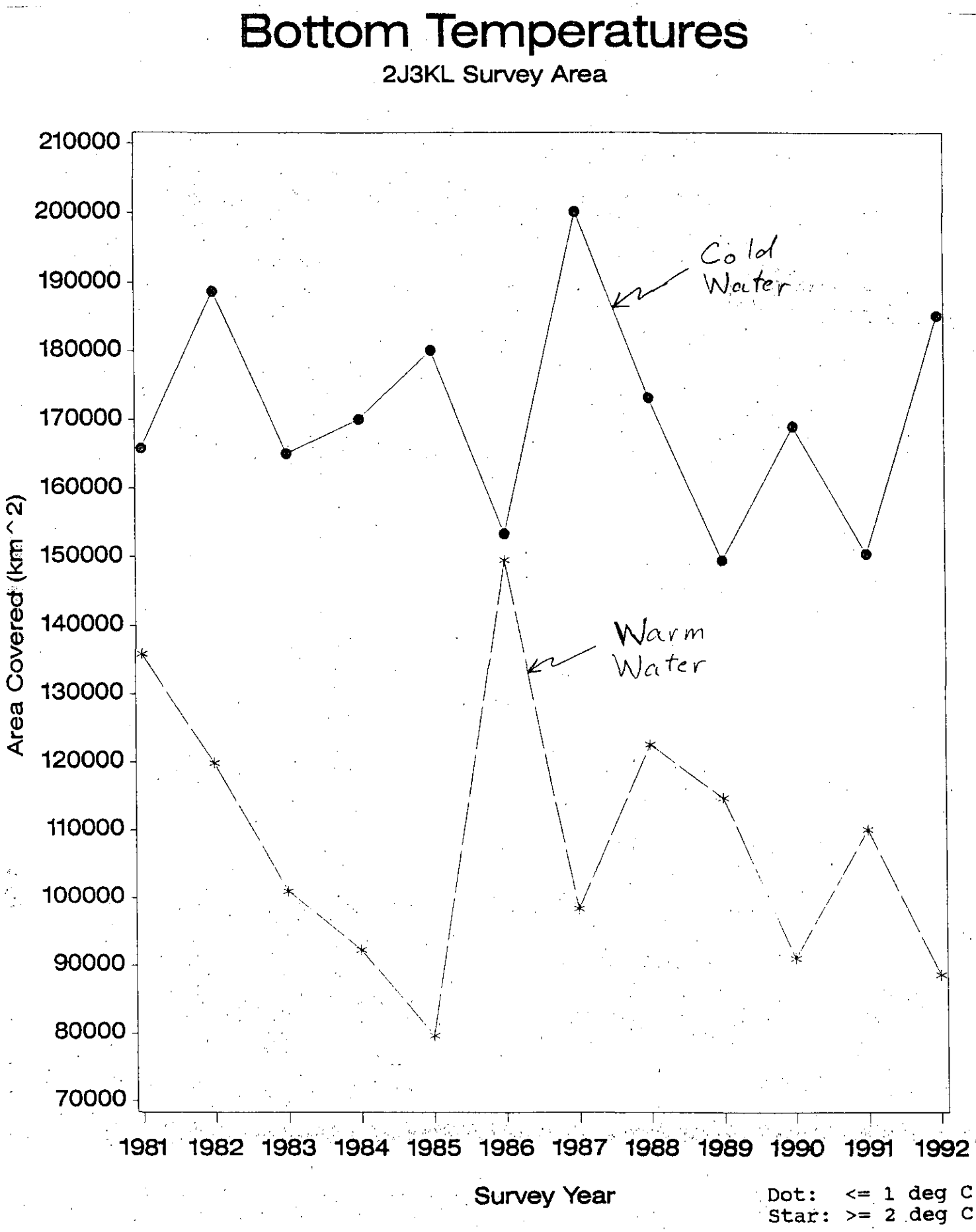


Figure 10. Bottom area (km^2) of cold ($\leq$ 1 °C) and warm ($\geq$ 2 °C) water each year.