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Effect of Abiotic Factors on Distribution of Young Shortfin Squids, Illex Illecebrosus (LeSueur, 1821)

by

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Abstract

The spatial distribution of shortfin squids in the area between the Gulf Stream and Nova Scotian shelf is analysed based on the data collected during the joint Soviet-Canadian cruise aboard the RTM "Belogorsk" in 1979. A detailed analysis of the hydrological data is made indicating a close correlation between the squid distribution and the structure of water masses in the area. Relationships between the squid distribution and oxygen minimum and temperature profile, as well as between the squid abundance and proportion (per cent) of the North Atlantic Central Water in the slope water masses are established. A method of estimating the young shortfin squid abundance in the given area based on T-S analysis of water masses is proposed. The hypothesis is suggested that larval squids are transported from the continental slope to the northern boundary of the Gulf Stream.

Introduction

The period of final maturation, spawning and growing of the youngs from larval to recruit stages has been given little consideration in the studies of the shortfin squid, Illex illecebrosus (Le Suer, 1821), biology, which is one of the most important commercial species of the Northwest Atlantic.

Many attempts have been made to discover the spawning squid aggregations on the Northwest Atlantic shelf using trawls but they were to no avail. It was in the recent years only that some records of larval and young shortfin squids on the shelf and continental slope of USA were obtained (Clyde F.E., Roper and C.C. Ly, 1978; M. Vecchione, 1978).

The main aspects of spatial distibution of shortfin squids at this stage of the life, beginning in laying eggs with neutral buoyancy (Durward R.D. et al., 1979) and ended by the post-larval stage (Dubinina, Froerman, in press), are likely to be controlled by the hydrological conditions of the species habitat.

The area considered in this paper is limited by the edge of the Nova Scotian continental shelf on the north-west, and by the Gulf Stream on the south and south-east. In the papers of McLellan et al. (1953); Gatien (1976); Smith et al. (1978); Stommel (1960) the structure, origin and dynamics of the water masses in the area are described.

Gatien (1976) showed that "warm slope water" and "Labrador slope water" can be distinguished in this region. In the present paper we shall use the term suggested by McLellan et al. (1953) who distinguished only one water mass in the given area, i.e. slope water.

Analyses of the hydrological data collected during the Soviet-Canadian cruise of RTM "Belogorsk" in 1979 showed that there is a close agreement between our data and the data presented in the paper of McLellan.

There are no data available on effect of abiotic factors on the distribution and behaviour of the young shortfin squids. The joint analysis of the hydrological and biological data showed that the distribution of the young shortfin squids observed in the area of survey depends considerably on the water structure and dynamics in the area. It means that the studies of peculiarities of dynamics and hydrological structure of the water masses in the area permit to reveal the possible ways of transport of the shortfin squid eggs and larvae and to determine the spawning area. The systematic investigations of the area during some years would allow to estimate the natural mortality rate and to build a model of the species abundance dynamics. In our view, the mortality at early stages of life history depends primarily on the environmental conditions and determines the year-to-year abundance of shortfin squids.

In this paper along with the study on the effect of abiotic factors on the youngs distribution the methods are proposed that can be used as the basis of the long-term forecasting of the shortfin squid stock size.

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Materials and Methods

Materials were collected during the Soviet-Canadian cruise on board the Soviet research vessel RTM "Belogorsk" in the period from 10 March to 13 April 1979.

The research activities were conducted between the continental shelf of Nova Scotia and the Gulf Stream (fig. 1). The stations were made at 50 or 25 mile intervals along the transects running from the shelf towards the Gulf Stream.

According to the range of activities the stations are subdivided as follows:

1. Seven-hour station including the hydrological activities, hauls with 400-mesh "Engel Trawl" (EMT) at 50, 100, 200, 300, 500 m depths, and oblique (200-0) and pre-surface step (10-5-1 m) hauls using plankton sampler "Large Bongo".

2. Two-hour station including two hauls (described in the previous item) with plankton sampler "Large Bongo", vertical measurements of the water temperature using XBTs within the depth range of 750-1 800 m.

3. Twenty-four-hour station: on completion of the seven-hour station the hauls using EMT were made at five depth levels every 4 hours.

4. EMT station involved hydrological observations and 1 to 3 hauls with EMT at 50, 100 and 200 m depths.

Hydrological work at the stations included the temperature measurements, sampling for salinity and dissolved oxygen content at 0, 10, 20, 30, 50, 75, 100, 150, 200, 300, 400, 500, 600 m depths.

Bathometers with reversed thermometers were used. Because of the loss of some bathometers at the beginning of the cruise, stations N 5-32 were occupied in two runs: 0-200 m and 200-600 m. The true depth of equipment immersion was determined by two pairs of depth-temperature recorders. Samples for salinity were processed by Canadian scientists ashore. The dissolved oxygen content was estimated by the Winkler's method aboard the vessel.

To analyse the data hydrological stations were combined by 8 transects oriented in normal to the shelf (fig. 1).

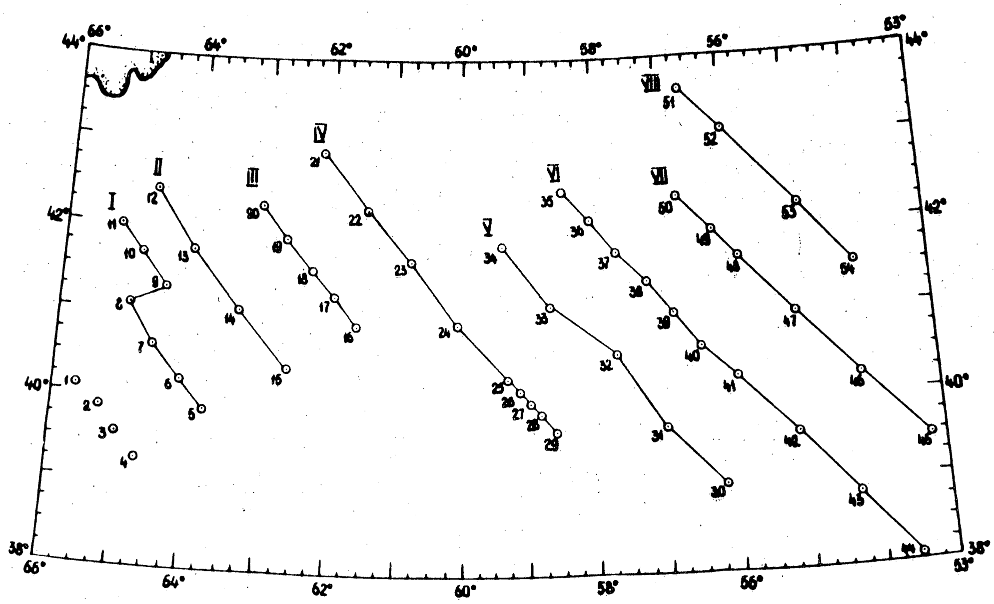

Fig. 1. The survey and hydrological stations conducted between 10 March and 13 April 1979. (The numbers of transects are given in Roman numerals).

The hydrological data are shown on the graphs of vertical and charts of horizontal distribution of temperature, salinity and oxygen. The results of T-S analysis of the water masses were used. The initial data on squid occurence at the stations are presented in the paper of Froerman (1980 a).

In all charts appended to this paper the number of squids at the stations is given with the time coefficient. Vertical distribution of temperature, salinity and oxygen is given in the paper based on the data obtained from the most typical transects (II, IV, V, VI).

Results

The young shortfin squids were found in the EMT catches from 30 out of 43 stations and in the plankton sampler hauls from 10 out of 50 stations (fig. 2). The catchability of EMT during the light and dark hours varied considerably. Therefore, the data on the shortfin squid distribution are given with regard for the time coefficient (fig. 2, 3) (Froerman, 1980 a).

The occurence and numbers of squids were the highest at the 100 m depth (fig. 3) within the zone 150-250 miles off the continental slope (fig. 2).

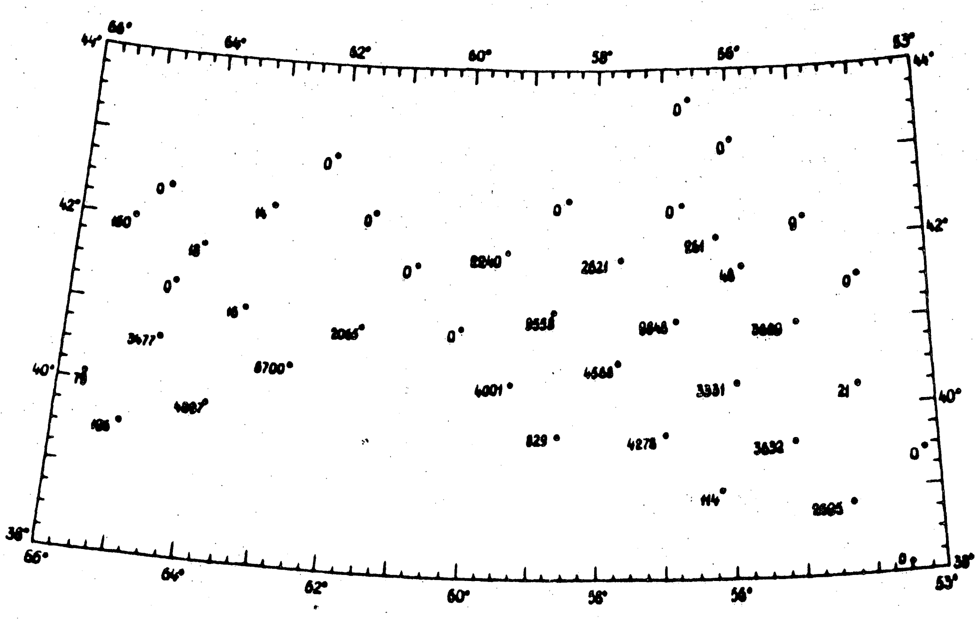

Fig. 2. Number of shortfin squid specimens (with the time coefficient introduced) at the survey stations .

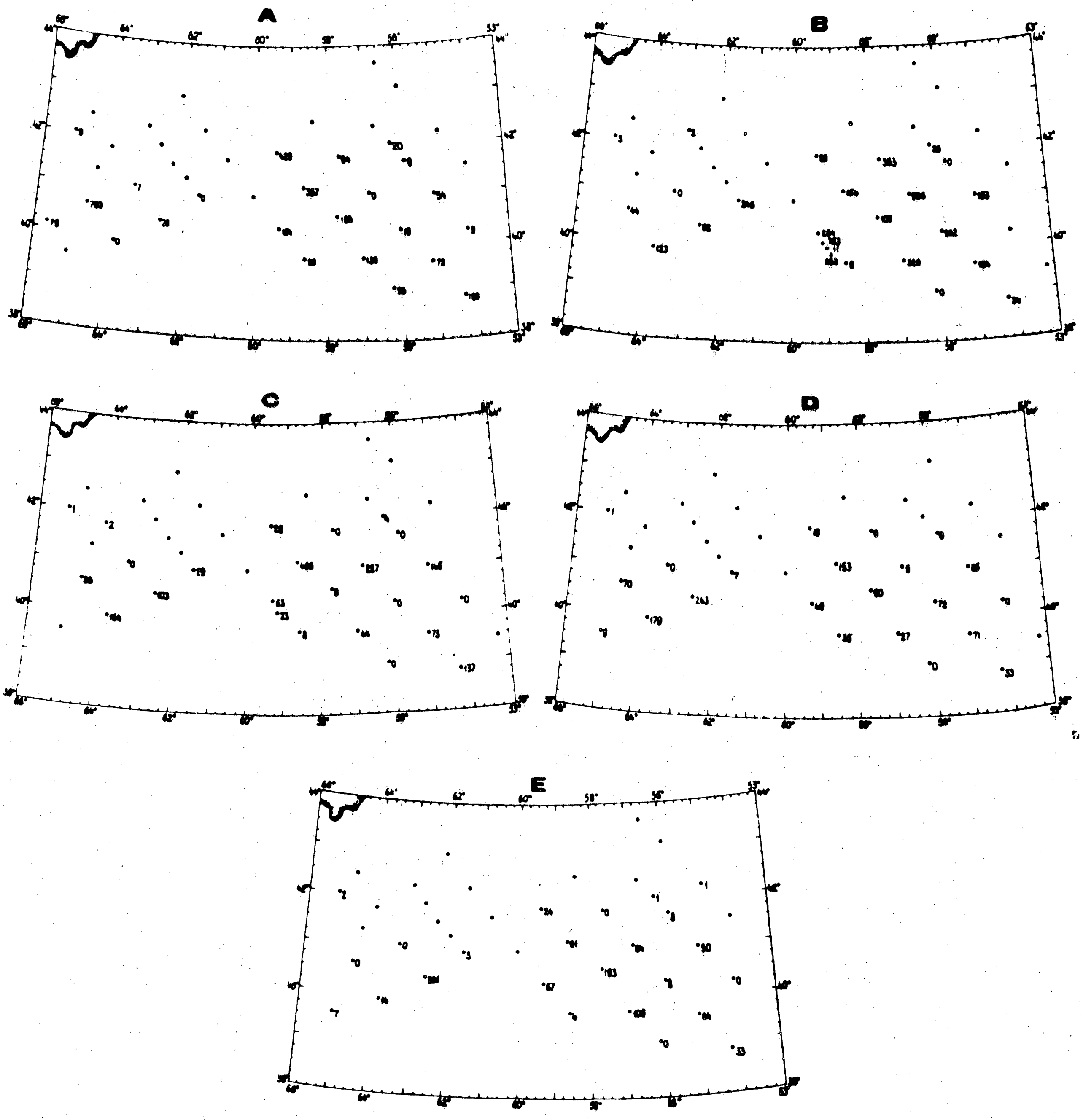

Fig. 3. Number of shortfin squid specimens (with the time coefficient introduced) at depths: 50 m - A, 100 m - B, 200 m - C, 300 m - D, 500 m - E.

The length of the youngs increases from the Gulf Stream in normal to the shelf (fig. 4). No considerable changes in the length composition were recorded in the survey area in the west to east direction (fig. 5).

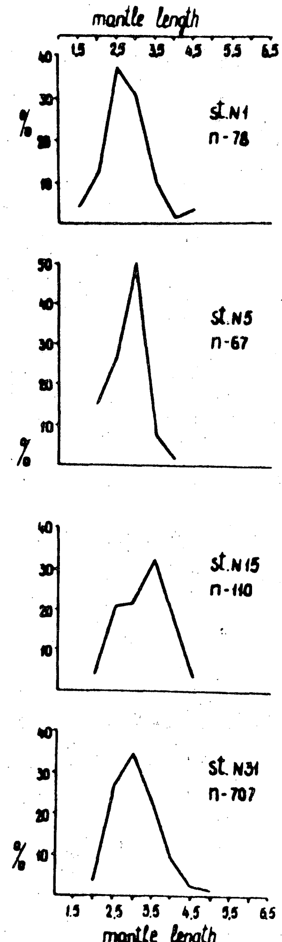

Fig. 4

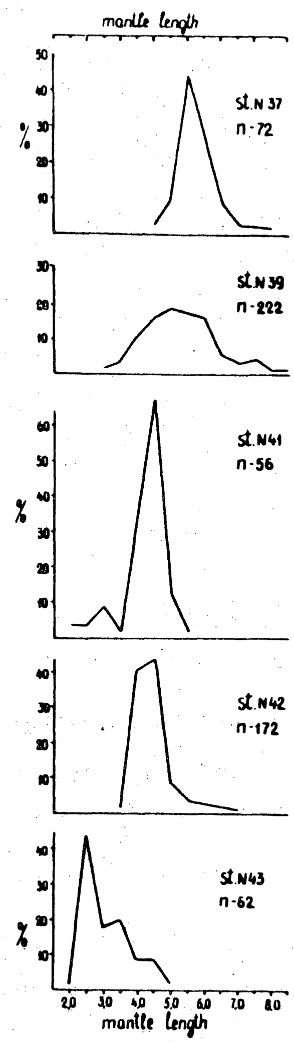

Fig. 5

Fig. 4. Variability of the length composition of the young shortfin squid in the north-west to south-east direction.

Fig. 5. Variability of the length composition of the young shortfin squid in the west to east direction.

The data on the vertical water mass distribution in the investigated area show that in the northern areas the upper layer down to about 100 m depth is occupied with the shelf waters with the temperature below 5°C and the salinity below 34.00‰. These waters penetrate into the deep ocean as far as 100-150 miles from the shelf edge. The slope water masses with the temperature over 10°C and the salinity over 35‰ at depths of 100-200 m lie deeper. They are directly adjacent to the continental shelf along the transects I-IV (fig. 6A and 6B). The same conclusion cannot be made in relation to other transects because the eastern transects (V-VIII) were begun at a considerable distance from the edge of the shelf (fig. 6C-6D). The slope water masses are distinctly separated from the upper layer of the shelf waters. The in-between temperature gradients are 0.2° per metre. The core of the slope water masses near the shelf is within the layer of 100-200 m deepening southwardly. Outside the boundary of the shelf waters the slope water masses rise to the surface and occupy the 0-400 m layer. According to McLellan et al. (1953), the slope water masses at the intermediate depths are the product of mixing of the subsurface Gulf Stream waters and the Labrador Current waters.

Along the transects of the vertical salinity distribution slope water masses are defined by the salinity maximum, which, although weak, is quite distinct along all the transects (fig. 7). This maximum lies within 100-450 m at the ends of the transects directed towards the shelf and deepens to 600 m near the Gulf Stream. There is no distinct boundary between the slope water masses and the North Atlantic Central Water (hereafter called NACW). Vertical T-S curves for slope water masses are practically straight lines.

Along the transects in the southern parts the Gulf Stream waters with the temperature over 15°C and salinity over 36‰ are well distinguished. The Gulf Stream waters in the given area in fact have the same T-S characteristics as the NACW, so the latter term will be used in the discussion below.

Isotherms in the southern part of almost all transects sharply deepen. These zones correspond to the maximum current velocities in the Gulf Stream. They were used to determine the Gulf Stream position.

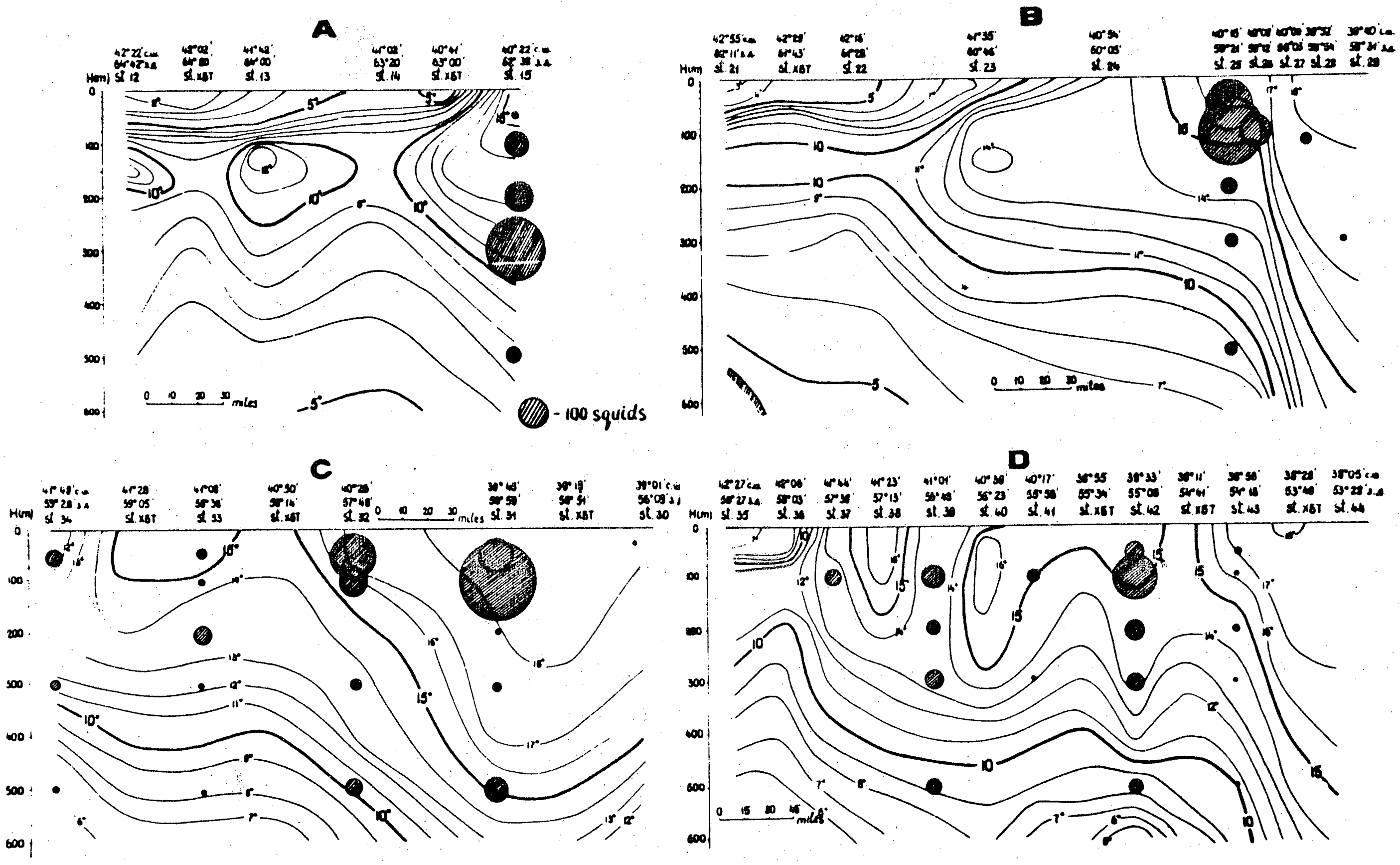

Fig. 6. Vertical distribution of the water temperature and the number of the young squids at different depths of EMT hauls.

A - transect II; B - transect IV;

C - transect V; D - transect VI.

Stations NN 13, 15, 22, 25, 31, 32, 34, 37, 39, 42, 44 were made in dark hours.

Stations NN 12, 14, 21, 23, 24, 29, 30, 33, 35, 41, 43 were conducted during the light hours of the day. (Dashed circles indicate the number of squids at the given depth of the EMT haul).

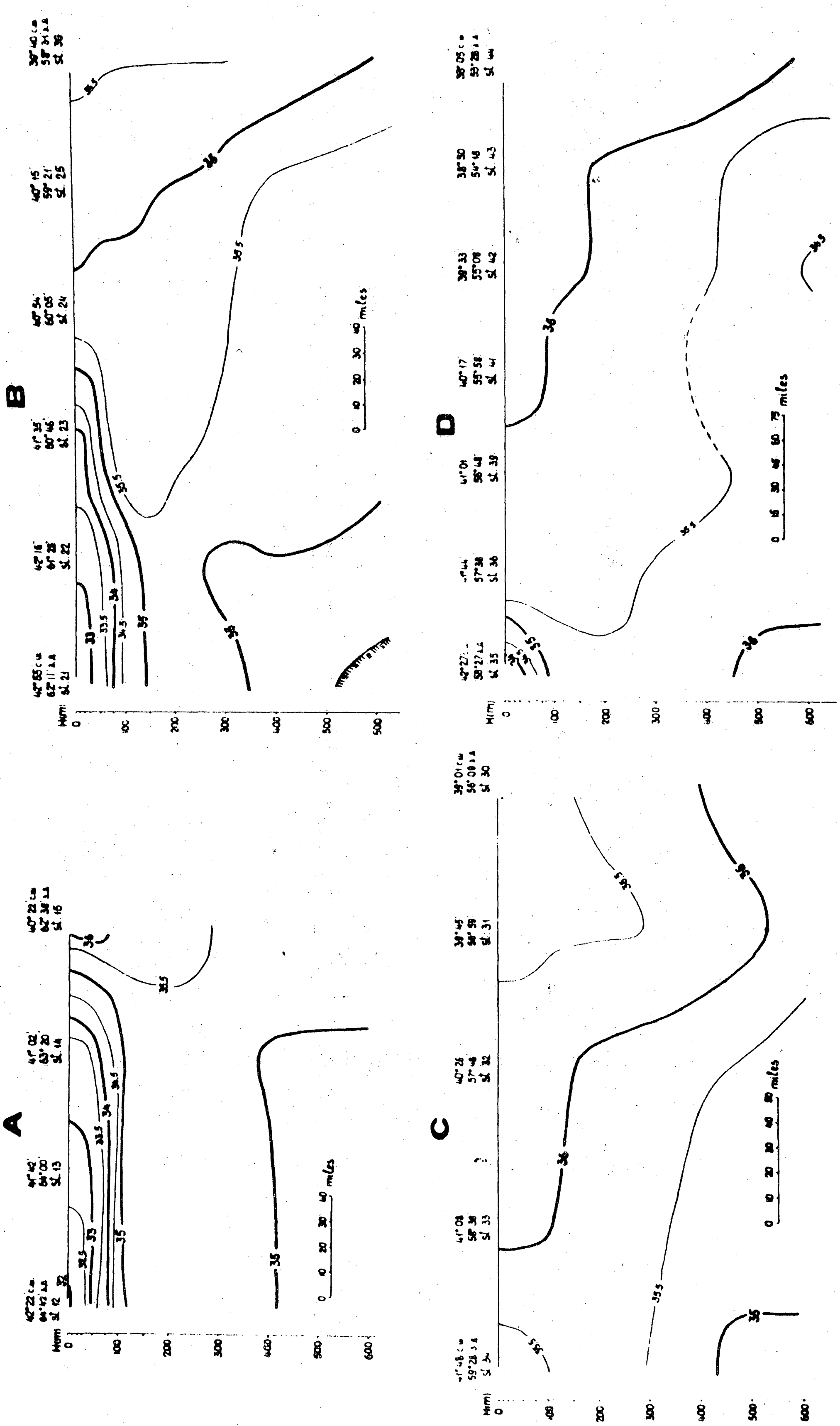

Fig. 7. Vertical distribution of salinity.

A - transect II; B - transect IV;

C - transect V; D - transect VI.

The pattern of isotherm positions along the transect VI (fig. 6D) somewhat differs from that along the other transects. It is of a more "broken" configuration. This can be explained by the fact that the given transect passes along the eastern boundary of incursion of the Gulf Stream waters (fig. 8).

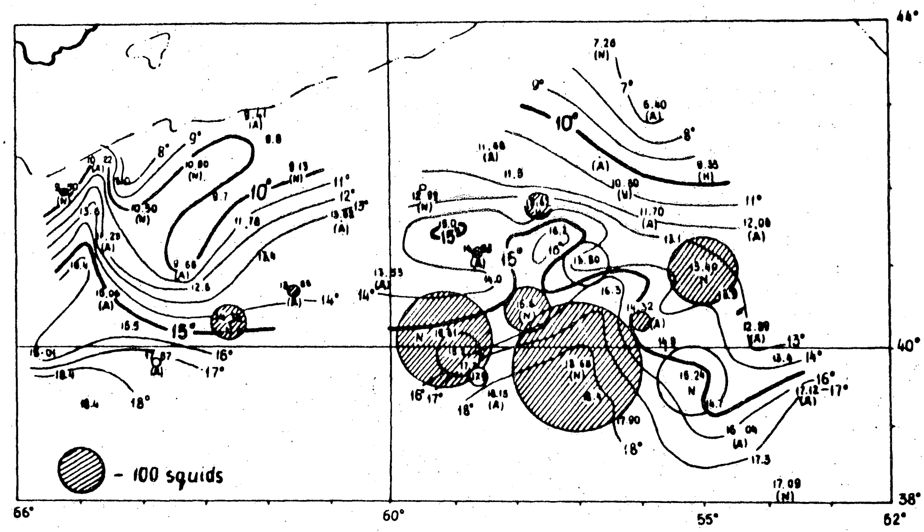

Fig. 8. The distribution of the water temperature and the number of squids at the stations at the 100 m depth without introduction of the time coefficient (Dashed circles indicate the number of squids at a given depth of the EMT haul). Hauling time: H - night, D - day.

The highest temperature variability by depth are observed within the 100-300 m layer. Below 300-400 m the changes in the hydrological characteristics along the transects are more plane.

From the analysis of spatial structure of the temperature field at the various horizons (in the given paper the chart for only 100 m horizon is presented in fig. 8) the following peculiarities are revealed:

a) general reguliarities of the horizontal temperature distribution persist between the surface and the 500 m depth;

b) penetration of cold Labrador waters from the north-east is most clearly observed from the 200 m horizon and deeper;

c) the presence of a marked incursion (the Gulf Stream meander) in the south-east part of the survey area.

Vertical and horizontal distribution of salinity is less variable than the temperature (fig. 7, 9).

According to the data of the hydrological survey there is a close agreement between the oxygen distribution and the water structure of this area. The surface shelf waters are rich in oxygen. Throughout the 100 m layer occupied with this water the content of dissolved oxygen exceeds 6 ml/l, the maximum on the surface reaching 8 ml/l. The oxygen content decreases towards the deep ocean (fig. 10). Along the transects the layer of the minimum oxygen content is strongly pronounced. This layer coincides with the slope water mass position. The oxygen content there is less than 4 ml/l. At the transects II, IV (fig. 10A and 10B) the centre of the oxygen minimum is clearly seen to be deeper than the slope water core by 60-100 m.

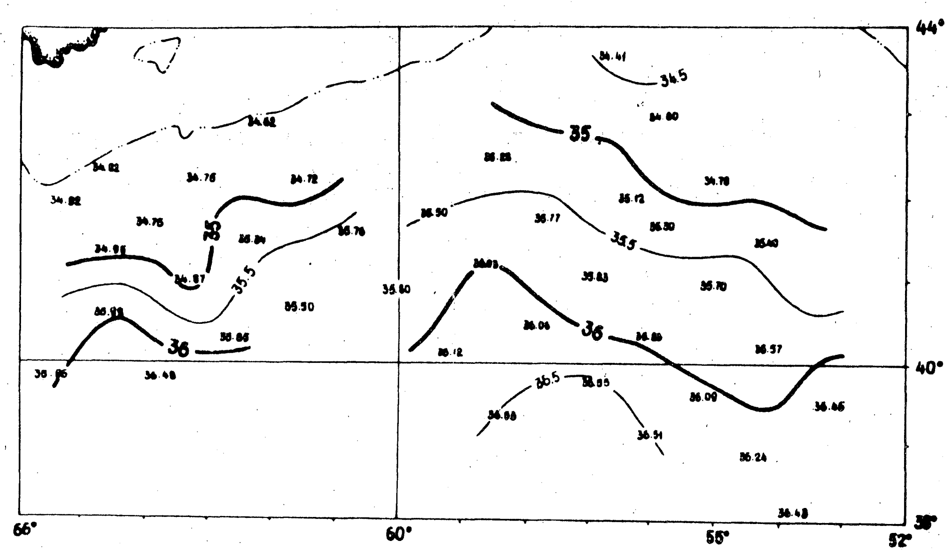

Fig. 9. Distribution of salinity at the 100 m depth.

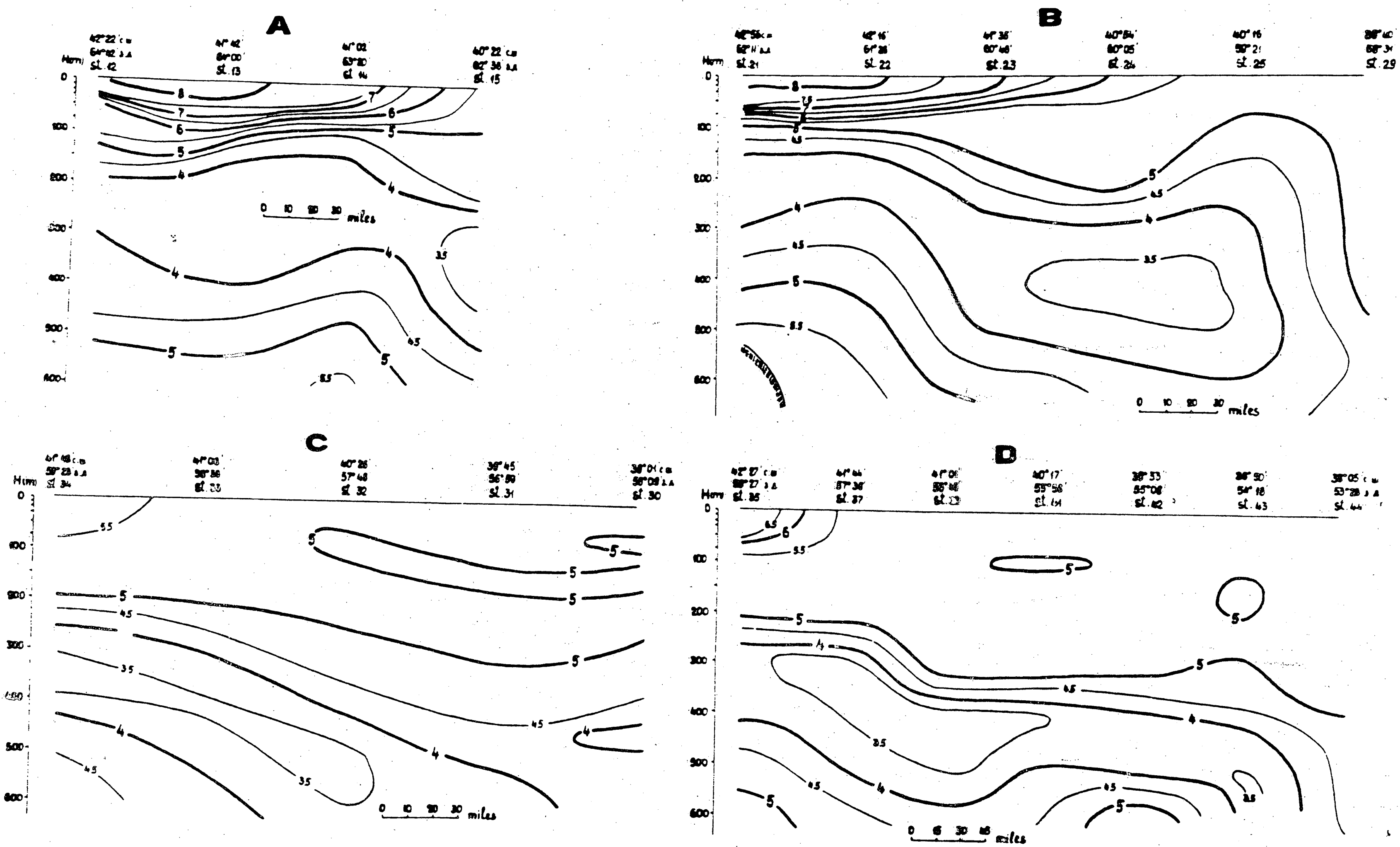

Fig. 10. Vertical distribution of oxygen (ml/l).

A - transect II; B - transect IV;

C - transect V; D - transect VI.

At all transects the layer of the minimum oxygen content in front of the Gulf Stream sharply deepens. Since the dissolved oxygen content in this layer decreases southwards, the origin of this minimum is supposed to be connected with the upwelling of the waters stretching under the Gulf Stream. This upwelling should almost closely border on the left edge of the Gulf Stream. Isopycnic analysis showed that the layer of the oxygen minimum for each transect lies on the same isopycnic surface, which proves its dynamic origin. A predominant role of the upwelling in the origin of slope water masses is also proved by the fact that there exists a good agreement between T-S curves for the slope water masses and NACW that lie 300-500 m deeper than the former. A theoretical substantiation of the upwelling was suggested by Rossby who applied the theory of the intruding stream to the Gulf Stream system (Stommel G., 1960).

Discussion

Slope water masses can be interpreted as the product of mixing of two water masses: the subsurface North Atlantic Central Water and Labrador Current water. The horizontal T-S graphs indicate a good horizontal intermixing in these water masses. Fig. 11 shows horizontal T-S graphs for the 100 m horizon. All T-S points practically lie on the same straight line. Linear dependence represented by this line is written as:

$$S‰ = 0.196 \cdot T + 33‰$$

The indices of the initial water masses chosen for NACW (A) and Labrador water masses (B) are T = 18.6°C, S = 36.80‰ and T = 6.5°C, S = 34.25‰ , respectively.

To determine the per cent proportions of each type of the water at the station the straight line was subdivided into 20 parts, i.e. 5% each. The per cent proportion of each water mass by the point can be easily read now from the graph. The analytical formula of mixing of two water masses can be used for more accurate calculations (Mamaev, 1970):

$$T = T_1 \cdot m_1 + T_2 \cdot m_2$$

$$S = S_1 \cdot m_1 + S_2 \cdot m_2$$

where T_1, S_1 and T_2, S_2 are the initial indices of water masses;

m is the index of the water mass in question. It is evident that $m_1 + m_2 = 100\%$.

It should be noted that on horizontal T-S graphs for the 200, 300, 500 m horizons T-S points also lie on the straight lines which are practically parallel.

The per cent proportion of NACW at each station was compared with the number of shortfin squid specimens within the 50-500 m layer over the area of 0.003 sq. miles.

The number of squids was estimated by means of interpolation between the adjacent horizons; a time coefficient was introduced showing the catchability of the trawl depending on the time of the day (Froerman, 1980 a).

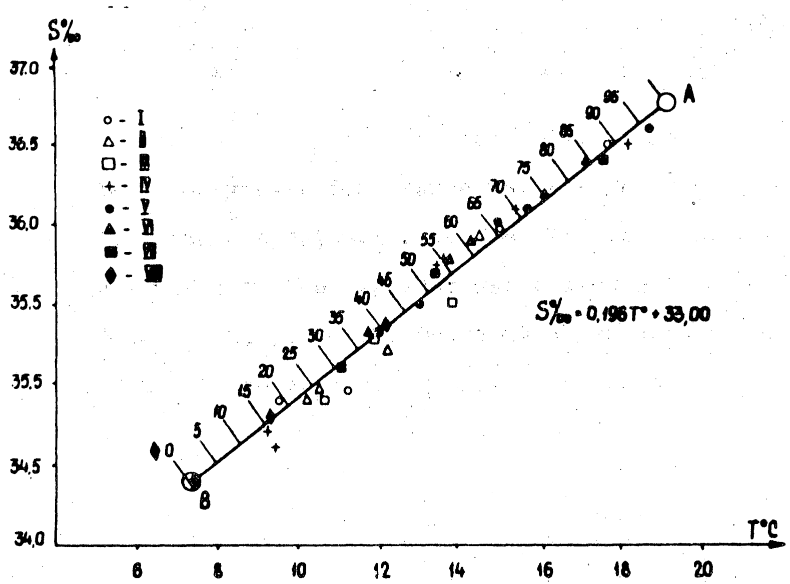

Fig. 11. Horizontal T-S graph for the 100-m depth.

I-III - symbols for transects. A - index of the North Atlantic Central water masses (T=18.6°C; S=36.80‰).

B - index of the Labrador water masses (T=6.5°C; S=34.25‰) 0, 5, 10 ... 95, 100% - per cent proportion of the North Atlantic Central water masses.

A dependence obtained shows a close relationship between the occurence of shortfin squids and per cent proportion of NACW at each station (fig. 12).

The chart of the horizontal distribution of the per cent proportion of NACW was also constructed for the 100 m horizon (fig. 13). The shaded zone indicates the optimum conditions of the young squid habitat, i.e. to the area of the largest catches. This zone is limited by the 60% and 80% isolines. Configuration of the isolines repeats the isotherm positions at the 100 m horizon in general outline, the northern border of optimum zone (60% isoline) roughly coinciding with the 15% isotherm. A dotted line in fig. 13 shows the position of the Gulf Stream, which was determined from the zones of maximum horizontal temperature gradients along the transects of the vertical temperature distribution.

Experimental points in fig. 12, enclosed in triangles correspond to the stations occupied outside the Gulf Stream. Although

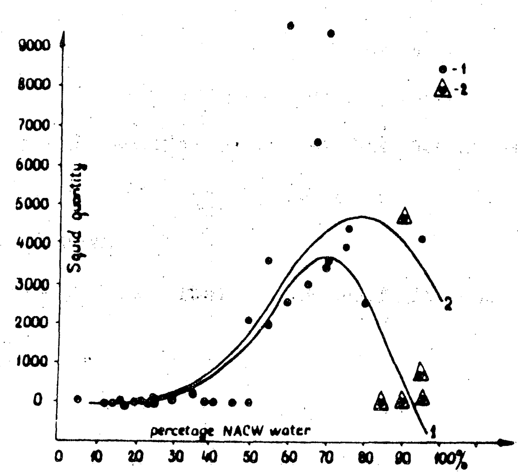

Fig. 12. The number of shortfin squids within the 50-500 m layer in relation to the per cent proportion of the North Atlantic Central water at the 100 m depth.

1 - stations between the continental slope and Gulf Stream.

2 - stations outside the Gulf Stream.

T-S characteristics of the water at the 100 m horizon at stations 29, 30, 31 are close to the optimum conditions of young squid habitat, the catches taken there were negligible. This means that the northern edge of the Gulf Stream is the limit bordering the distribution area for the young squid feeding in the slope waters. Station No. 5, where the squid abundance was the largest, is the exception.

The experimental data were approximated by a polynom of the third power using the method of least squares. In the first version of the calculations (curve 1, fig. 12) all points were used. The dependence obtained is written as

$$K = 1918 - 289x + 9.3x^2 - 0.07x^3,$$

where K is the number of squids within the 50-500 m layer calculated by the above method, x is the per cent proportion of NACW.

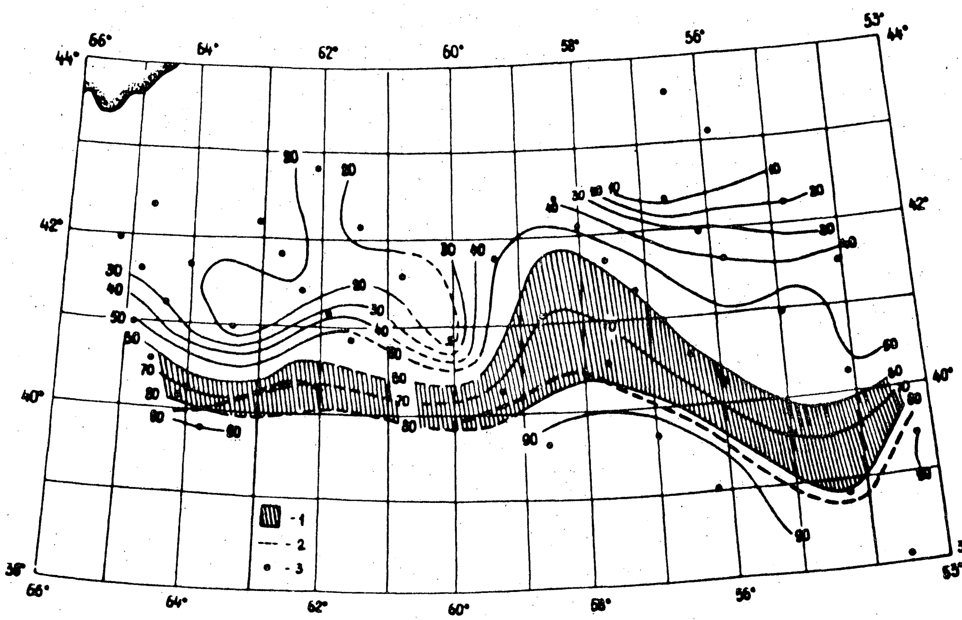

Fig. 13. Per cent proportion of the North Atlantic Central water masses at the 100 m depth

1 - maximum squid abundance region;

2 - northern cdge of the Gulf Stream;

3 - stations.

The largest deviation of the experimental data from the obtained curve is 2587; the relative approximation error is 0.42; the standard deviation is 1010. In the second version of the calculation (curve 2, fig. 12) the points outside the Gulf Stream were excluded. The dependence is written as

$$K = 1398 - 216x + 9.3x^2 - 0.047x^3,$$

The largest deviation for this curve is 2786; the relative error is 0.45; the standard deviation is 1065. It should be noted that for the approximation of the experimental data in tabulated form the squid abundance falling into 5% gradation was averaged. Curve 2 (fig. 12) seems to be more consistent with the real distribution of the squid abundance, because it takes into account the absence of the youngs outside the Gulf Stream.

Using the obtained dependence and the chart of the horizontal distribution of the water masses the young squid abundance in this area can be easily estimated. The formula for calculating abundance is as follows:

$$Q = \sum_{i=30\%}^{i=100\%} P_i \cdot K_i$$

where Q is the squid abundance estimate,

P_i is the area in square miles occupied with the water with the i-th per cent proportion of NACW,

K_i is the squid abundance in the water masses with the i-th per cent proportion of NACW.

The value of K can be taken from the graph (fig. 12, curve 2) or calculated using the above formula.

The summation can be started not from zero, but from 30%, because the young squids are practically absent from the slope water masses with the lowest per cent proportion of NACW. The upper limit of summation is determined by the Gulf Stream position.

The calculations were made using the given methods. The estimate obtained was approximately 70×10^9, which is quite consistent with the estimate obtained by means of the horizontal interpolation method (Froerman, 1980).

The region of the slope waters considerably varies in terms of hydrology. In particular, McLellan (1953) pointed out that the slope water masses can occupy the distance 20-120 mile wide in different years. In this connection the conditions of the young squid feeding change accordingly. The abundance of squids in this area finally determines the abundance of the commercial stock on the Nova Scotian shelf in the summer period.

The maximum squid catches were recorded at the 100 m horizon. From the analysis of the hydrological data it can be suggested that this peculiarity of vertical distribution is related to the formation of the slope water masses. As it was stated above, the origin of the oxygen minimum seems to be associated with the upwelling of NACW along the left edge of the Gulf Stream. The upwelled waters are usually rich in nutrients but short of oxygen. Unfortunately, we have no data on nutrients for this area, so we are guided by general reguliarities of their distribution and succession in the ocean. The upper boundary of the oxygen minimum usually lies within the 100-200 m depth (fig. 10). The vertical gradient of the dissolved oxygen content along the upper boundary is rather high, therefore, immediately over the oxygen minimum layer there lie the water masses rich in nutrients with the oxygen content almost same as at the surface and with the temperatures optimal for the young squids.

A more detail analysis shows that at the stations where the upper boundary of the oxygen minimum layer is deeper than 300 m (fig. 10D, stations 39,42) or even 500 m (station 31, transect V, fig. 10C) the catches taken from these depths are large. On the contrary, where the hauling depth coincides with the oxygen minimum layer or is below the catches from these depths are considerably smaller, for example, from station No. 37, transect VI (fig. 10), station 33, transect V (fig. 10C).

All pre-spawning and spawning females and males of shortfin squids occurred in near-bottom shelf waters and continental slope waters at the depths of 300 m. No spawning aggregations of shortfin squids have been yet detected outside the continental slope. From the comparison of this fact with the discovery of the young shortfin squids of the minimum sizes 150-200 miles off the shelf edge it follows that egg layings and larvae are transported from the shelf towards the Gulf Stream. Such a transport apparantly occurs from the Nova Scotian continental slope all along its length. This is confirmed by the stable length composition in a "west-east" direction all over the survey region. At present we cannot ascertain yet the depth of the transport. However, it is likely to occur at depths of 600-1 000 m, and the larvae rise to the surface layers in the upwelling zone off the left edge of the Gulf Stream. In our opinion, the transport dynamics is the main factor which determines the natural mortality of the species and, accordingly, the year class strength.

To examine the hypothesis of the larvae transport complex investigations should be regularly carried out in the area between the shelf edge and the northern boundary of the Gulf Stream within the US and Canada zones. It is desirable that the research activities in this area be conducted all the year round. The December-April period is most important. The program of investigations should include the trawl survey using a midwater trawl (most likely Engel Trawl) and plankton sampling by the methods used during the Soviet-Canadian cruise aboard the RTM "Belogorsk" in 1979; bottom and midwater hauling on the shelf and continental slope down to 1 000 m; hydrological stations down to 1 500-2 000 m depths for the temperature, salinity, oxygen and nutrient determinations.

Conclusion

1. The distribution of the young shortfin squids in the area between the Nova Scotian shelf and Gulf Stream is related to the dynamics and structure of the water masses in the region.

2. The relationship exists between the squid abundance and the per cent proportion of NACW in the slope water masses. The maximum abundance corresponds to the water mass consisting of NACW by 60-80%, i.e. to the salinity of 35.80-36.25‰ and the temperature of 14.3-16.3°C.

3. The Gulf Stream is the dynamic boundary of the young shortfin squid distribution to the south and south-east.

4. Vertical distribution of the young shortfin squids is correlated with the position of the oxygen minimum and vertical temperature profile.

5. The young shortfin squid abundance estimated by the methods based on the T-S analysis of the water masses proposed in this paper was about 70 billion sp., which is consistent with the estimate obtained from the horizontal interpolation method.

6. Conduction of biological and hydrological work proposed in this paper will provide enough data to build the model of the young shortfin squid abundance dynamics with regard for the environmental factor effect.

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