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Assessment of the commercial fish stocks migrating along the continental slopes and shelves

by

V. K. Zilanov and A. A. Stroganov
All-Union Research Institute of Marine Fisheries and Oceanography (VNIRO)
Moscow, USSR

Trawling survey is presently one of the main methods of count for juvenile and groundfish abundance. This method was used for the first time by W.Hensen and K.Apstein (Hensen, Apstein, 1897) and has been successfully applied since, in particular for finding out fish productivity practically in a whole range of areas of the world ocean. Reviews of the method of direct count may be found in the works of S.V.Averintsev (1948), G.I.Monastyrsky (1952), G.V.Nikolsky (1974), T.F.Dementieva (1976) and others.

In spite of the fact that trawlings have become the main and integral part of fishery studies where bottom species are concerned, their results are used mainly to solve a limited number of problems connected with the count of juveniles, distribution of juveniles and large fish. The appliwation of trawling survey for evaluation of commercial part of the stock is limited due to purely technical reasons. The main condition for the use of trawling survey in order to evaluate the commercial part of the stock should be:

1. Synchronous work .
2. Stable distribution of fish during the survey.
3. Full coverage of the station with trawlings.
4. Availability of Catchability Rate.

In case these conditions are observed the method of trawling survey may be the most exact one for finding out stock abundance. However, the first condition cannot be observed in practice while the second one is only an assumption which cannot be proved.

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Thus, trawling survey on the continental slope and shelf in southeastern Atlantic (Komarov, 1969; Kudersky, 1973), central east Atlantic (Schmidt, 1972), northeast Atlantic (Maljkov, Nazarov, 1975) and northwest Atlantic (Zilanov and others, 1976), which last for hundreds of miles are usually carried out by one or two scientific research vessels and take several weeks during which time distribution of fish is constantly changing.

The surface of the stock station may account for dozens and hundreds of square miles, yet trawling operations can be carried out only at the narrow range of depths limited on the one side by even bigger depths inaccessible for trawlings and on the other side (in most areas of commercial fishery of the world ocean) by shallow areas belonging to coastal countries. Thus, Moroccan sardine (Domanevsky, 1971; Furnestin J., Furnestin M.-L., 1970) moves from coastal waters to shelf and continental slope only for feeding excursions. One of the stocks or round mackerel in Central east Atlantic (Bonnet, 1970) is for the most time dispersed in mid-water under big depths and only episodically concentrates over areas of continental slope.

To ensure synchronous works there has been applied aerial photography (Golenchenko, 1947, 1950) and lately particularly hydroacoustic survey (Shherbina, 1971; Berdichevsky and others 1973; Zaferman, Kiselev, 1974; Serebrov and others, 1975; Ehrenberg, 1972 and others). Application of instrumental methods is also limited since they are possible only in areas where one commercial species dominates (herring, capelin, sprat etc.). In this case identification of instrumental readings is carried out also with the help of control catches with trawls (Shatoba, Pohiljuk, 1976) or some other fishing gear.

Thus, at present time trawling survey (in the accepted version used as a method of assessment of the commercial stock abundance provides results rather distant from realistic and is applied mostly for accumulation of biostatistic material.

The following requirements made the foundation of the present method of assessment of commercial stock on the basis of trawling survey:

1. Shortest possible duration of trawlings.

2. Full coverage with trawlings of the area in which distribution of fish is possible at the moment.

3. Carrying out the survey at the moment when the studied concentration of fish stays at the depths where trawling is possible.

4. The count of stock migration as a whole and of its parts in particular.

Theory

A typical situation is studied:

- the stock consists of several concentrations;
- The structure of every concentration is known (assumption 1), gradient of density distribution points from the centre to periphery;
- density structure of the concentration is indicated with distribution of lines of equal density (with isoichthyas) from b_{max} to b_{min} and remains unchanged during the studied period (assumption 2);
- trawling survey is possible only between isobaths H_i and H_{i+1} (fig. 1a).

The concentration migrates at an angle to the continental slope following the trajectory marked in fig.1 with a dotted line and its position is fixed at five consecutive moments - from t_1 to t_5 (fig.1b - 1f). At the moments t_1 and t_5 the concentrations are situated out of the depths H_i - H_{i+1}, at t_2 and t_4 there are only two isoichthyas registered within its limits - the minimum one b_{min} and the intermediate one b_{int}. At t_3 nearly the whole concentration (with the exception of its insignificant part in the eastern and western peripheries) is situated in the area where trawling is possible (admittance 3).

From the analysis of fig. 1b - 1f there may be drawn a conclusion that the most reliable assessments of commercial abundance may be obtained only at the period $t_3 = t_{b_{max}}$; while at t_2 and t_4 the result obtained would be smaller than real and at t_1 and t_5 the survey will show no fish at all.

Constant survey when trawlings follow one another incessantly in order to catch the moment when concentrations move to an accessible depth cannot be carried out by a single survey vessel because of the enourmous time period needed for this.

The moment can be determined with the help of Space-Time Cartograms (STC) based on the results of commercial fishery (Stroganov, 1973). The way these cartograms are built is as follows

The points where isoichthyas cross with the line which traces the middle of the range $H_i \div H_{i+1}$ (marked in fig. 1b - 1f) are marked consecutively on a plane-table built on the plane φ t. By way of interpolating there are calculated the points of equal catches and isoichthyas are drawn. The obtained distribution is STC of concentration density (fig. 1g). Thus, from STC in fig.1g and having no fig. 1b - 1f, one should conclude that the survey should be carried out exactly at the moment $t_{b_{max}}$, when the density in the range $H_i \div H_{i+1}$ reaches its maximum.

Isobaths of the continental slope are directed along meridians only in some areas of the world ocean. Therefore STC may be built for Irish Shelf, central east and southeast Atlantic In this case to the ordinate of STC there is placed the vertical frame of the navigation chart built in Mercator projection. For the analysis of halibut distribution in the area of Canadian - Greenland Cascades in prespawning period there should be built Longitude - Time Charts (LTC) and on the horizontal frame there should be marked depths - isobaths in this area are practically parallel to meridian.

With these cartograms only there may be obtained the following information:

- time $t_{b_{max}}$ when the major part of the concentration stays within the depth range $H_i \div H_{i+1}$;
- latitude (or longitude) position of the concentration and its maximum;
- meridional migration speed;

- forcast for fish distribution for which isoichthyas are extrapolated for 1 - 2 time intervals (kinematic problem of Lagrange is to be solved).

When density distribution on a cartogram and the range of depths are known there may be easily calculated the abundance of each concentration and of the whole stock by numerical integration.

Therefore application of cartograms allows to realize the last two requirements stated above, i.e. to count fish migration and to determine the optimum period of survey. However it is impossible either to build LTC or to carry out trawling survey of the stock with the station of thousand square miles with the help of even 2 or 3 survey or scientific research vessels. Even less it is possible to answer the first two requirements.

Within the boundaries of the station, at the time when stock density is on commercial level, there usually operate commercial vessels in places where trawling is possible. Every vessel gives daily reports in which there are indicated: square, trawling depths range, daily catches by fish species, hours of trawling. By drawing average for every square there is calculated daily average density of concentration (in c per hour of trawling), the meaning of which makes the basis for building cartogram of density distribution. It is obvious that cartograms built on the basis of data provided by a group of commercial vessels are more reliable than those based on the research vessels' data, since the errors in average density are 5 - 10 times smaller in the first case compared to the second.

Information from the areas where commercial vessels do not operate should be provided by research vessels which will allow together with wide application of curvilinear interpolation to build with sufficient precision distribution fields on the plane φt (or λ t).

This way the use of considerable volume of commercial fishery information allows to answer the first two requirements formulated above: survey of each concentration is made during 1 - 3 days and their expanse is studied with a high number of trawlings.

The analysis of admittances shows that:

1. Preliminary fixing the structure of concentrations (assumption 1) and stability (assumption 2) cannot influence the process of determining the stock as any changes in density within the range of depths at which trawlings are made would be fixed on a cartogram. Even with a complete transformation of structure (the change of negative gradient to positive) or with stable distribution of fish (gradient is equal to zero) the direction of isoichthyas and their meanings would change, which is going to allow to find out maximum density, its stability in particular, and consequently $t_{b\ max}$.

2. Fish density in the part of concentration area (assumption 3) which at the time $t_{b_{max}}$ is situated out of the range $(H_i \div H_{i+1})$ b_{max} (fig.1d) is close to b_{min}, therefore the resulting error would be insignificant compared to other errors, like for example in case of determining Catchability Rate (g) and will not influence considerably the final result.

The problem of finding out the stock is formulated in general as follows:

$$W = \frac{1}{g} \int_0^{\bar{S}} b_{\bar{S}}\, d\bar{S} \qquad (1)$$

where $b_{\bar{S}}$ is the current meaning of fish density,
S - station surface.
With manual numerical integration formula (1) will transform to

$$W' = \frac{1}{g} \sum_{i=1}^{S} \bar{b}_i\, S_i \qquad (2)$$

where $\bar{b}i$ i s mean density in elementary area S_i.

Algorhythm of the method (fig.2)

Block 1. Treatment of daily data from commercial and research vessels.

Block 1a. Calculation of daily average of fish distribution $\bar{b}_{sq}$ for every square.

Block 1b. Determining borders of the trawled range of depths for each square. After calculation of $t_{b_{max}}$ (block 4) there is determined the range of depths during the period of maximum density of the concentration ($H_i + H_{i+1}$).

Block 2. Correction of commercial data with the materials of commercial fishery councils.

Block 3. Marking out cartograms of density distribution.

Block 3a. Building plane-table on the plane φ t (STC) or λ t (LTC).

Block 3b. Marking B_{sq} values on the plane-table.

Block 3c. Building distribution field for the density of the concentration by tracing isoichthyas. Fish concentration is a positive anomaly of its density field therefore in indefinite cases isoichthyas are traced through maximums (but not minimums) according to logics of the situation (fish migration, biota conditions etc.).

Block 3d. Identification of concentrations by separation of density maximums - nuclei of concentrations and of density minimums - the borders between them.

Block 4. Determining $t_{b_{max}}$ according to the data about the change of density in the nucleus of every concentration. At this instant there should be made a thorough analysis of statistic reliability of throw-outs.

Block 5. Building diagrams by formula $b_{max} = f(\varphi)$: points b_{max} of every concentration are connected with a flowing line. The points where it crosses with isoichthyas are projected onto a vertical axis of a plane-table, a diagram is built by formula $b_{max} = f(\varphi_1)$ - modification of density along the continental slope during maximum density of concentrations.

Block 6. Extreme isobaths $(H_i - H_{i+1})b_{max}$ are marked on a large scale chart to outline the station.

Block 7. From the diagram $b_{max} = f(\varphi_1)$ (block 5) the lines of minimum density are transmitted to the station - position of nuclei at the moment $t_{b_{max}}$.

Block 8. Calculation of commercial stock of the concentrations.

Block 8a. The area occupied by a concentration at the moment $t_{b_{max}}$ is subdivided into a number of subareas situated along the continental slope l in proportion to $\frac{\partial b}{\partial l}$. The surface of each of them is found.

Block 8b. With the help of diagram $b_{max} = f(\varphi_1)$ average density $\bar{b}_1$ is determined for each subarea.

Block 8c. By formula (2) there is calculated the stock of the concentration W_c.

Block 9. Determination of the whole commercial stock abundance is made by simple adding of the stocks of all the concentrations belonging to it.

As an illustration of this method there is studied the calculation of a part of Labrador stock of black halibut Reinhardtius hippoglossoidae (Walbaum). In the beginning of summer, following winter spawning, concentrations of mature fish of this stock move from big depths to the continental slope of South Labrador. In July - August there takes place migration to the north , to feeding areas. In August migrations come to an end, and halibut concentrated on the continental s o e of north and central Labrador where it feeds on shrimps and roundnose macrurus. Concentrations of the latter are timed to concentrations of feeding zooplankton which gathers in places of cyclonic eddies that are formed in the areas of canyons. Hence, in South Labrador, at places of halibut concentrations, following the spawning period most fish stays at depths inaccessible for trawling, while in feeding areas commercial fishery and trawling survey are hampered by heavy ground. Therefore survey may be carried out only during feeding migration in areas most accessible for trawling during the period when migration which follows spawning is over and the fish is cancentrated on the continental slope.

Identification of the Labrador stock of black halibut, determining its migration cycle and the calculations given below are made by the authors on the basis of the following data analysed:

1. Daily commercial reports and the materials of commercial fishery councils of BMRT of "Sevryba" trust which conducted fishery off Labrador coasts from 9.07 till 18.08.76.

2. Materials of exploratory BMRTs.

-	"Poliarnoe Sijanie"	9.07 - 18.08.76
-	"Suloy"	9.07 - 18.08.76

- "Zarnitsa" October - November 1975

The total of 2,802 trawlings by commercial and exploratory vessels was taken into account. Calculations were carried out by algorhythm given in fig. 2. Peculiarities of its application for this particular area and object are given below.

Block 3a. Continental slope of Labrador is placed at an angle to co-ordinates grid (fig.3). The lengths of its segments placed between parallels traced through every 20 min. are consecutively transferred to the vertical frame of STC (fig.4). Therefore vertical latitude frame is uneven. Horizontal time frame is built in the scale 1 day of 24 hours = 5 mm.

Block 3c. In the northern part of the area isoichthyas are drawn for every 2 c/hours of trawling, in the central part - for every 1 and in the southern part - for every 0.2 c/hour of trawling.

Block 3d. On the continental slope of Labrador there are subdivided 12 concentrations in halibut stock which are marked in fig. 4a with figures from I to XII and their migration is marked with arrows. More exact identification may be executed on the basis of the analysis of space structure of each concentration by materials of biological analyses made by research vessels.

Block 4. According to the data of the analysis of density modification of every concentration in time there is subdivided the period when it reached its maximum. These points are marked in fig. 4a with black circles and connected with dotted line AB.

Block 5. Building the diagram of density modification along the continental slope l in relation to latitude φ.

Block 6. Maximum and minimum isobaths at the period $t_{b_{max}}$ and $t_{b_{min}}$ are marked on commercial fishery charts.

Block 7. With the help of the diagram given in fig. 4b concentration areas schematically shown in fig. 3 are determined on commercial fishery schemes.

Block 8a. The area of each concentration is subdivided into subareas 2-10 miles long. The surface of each of them is found.

Block 8b. With the help of diagram shown in fig.4b mean density of fish distribution in subareas is found.

Block 8c. According to data of blocks 8a and 8b commercial stock of the concentration is found. Concentration X situated in gently sloping canyon of Central Labrador is determined by the trawling data obtained from 30.07 till 12.08.76 when maximum density was marked in neighbouring concentrations XIII, IX and XI.

Block 9. Abundance of certain part of the stock and of 12 concentrations belonging to it are given in the table. Catchability of trawls g is assumed to be 0,1 according to available literature (Marti, 1936; Lukashev, 1963, 1972; Ionas, 1967; Matsumiga, Tanaka, 1976; Chumakov, Serebrov, 1978 and others).

As it may be seen in the table, commercial stock of a certain part of Labrador population of black halibut determined by this method was equal to 281.2 th. tons in Labrador area in July - August 1976. The size of stock is 45.3 th. t bigger than that found by Chumakov and others (1978) for the same period by method of virtual population (stock 235.9 th. t) for the whole population of Labrador, Baffin Land and west Greenland.

The suggested method of determining commercial stock of populations has the following advantages:

1. Dynamism that allows to count fish migration and to fix the optimum period for carrying out the works.

2. Possibility of application in practical fishery to make prognosis of catches and distribution of concentrations.

In this case the principal block-scheme may have the form in which the fields of density distribution built by one of the methods of mathematical modeling (for example by objective analysis widely used in meteorology, physical and biological oceanology). Integrating the field allows to find out the size of the stock and its extrapolation enables to make a short-time prognosis of fish distribution which is later corrected according to oceanographic, biologic and other data supplied by research vessels.

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Table 1. Commercial stock of black halibut concentrations of the Labrador population. July-August 1976.

No. of concentration	Square miles	Tons x 10^3
I	78	28.8
II	105	44.6
III	44	16.7
IV	43	14.5
V	61	17.3
VI	124	27.1
VII	39	6.9
VIII	157	21.6
IX	39	3.8
X	127	12.4
XI	495	81.6
XII	320	5.9
	1632	281 200 t

LIST OF FIGURES

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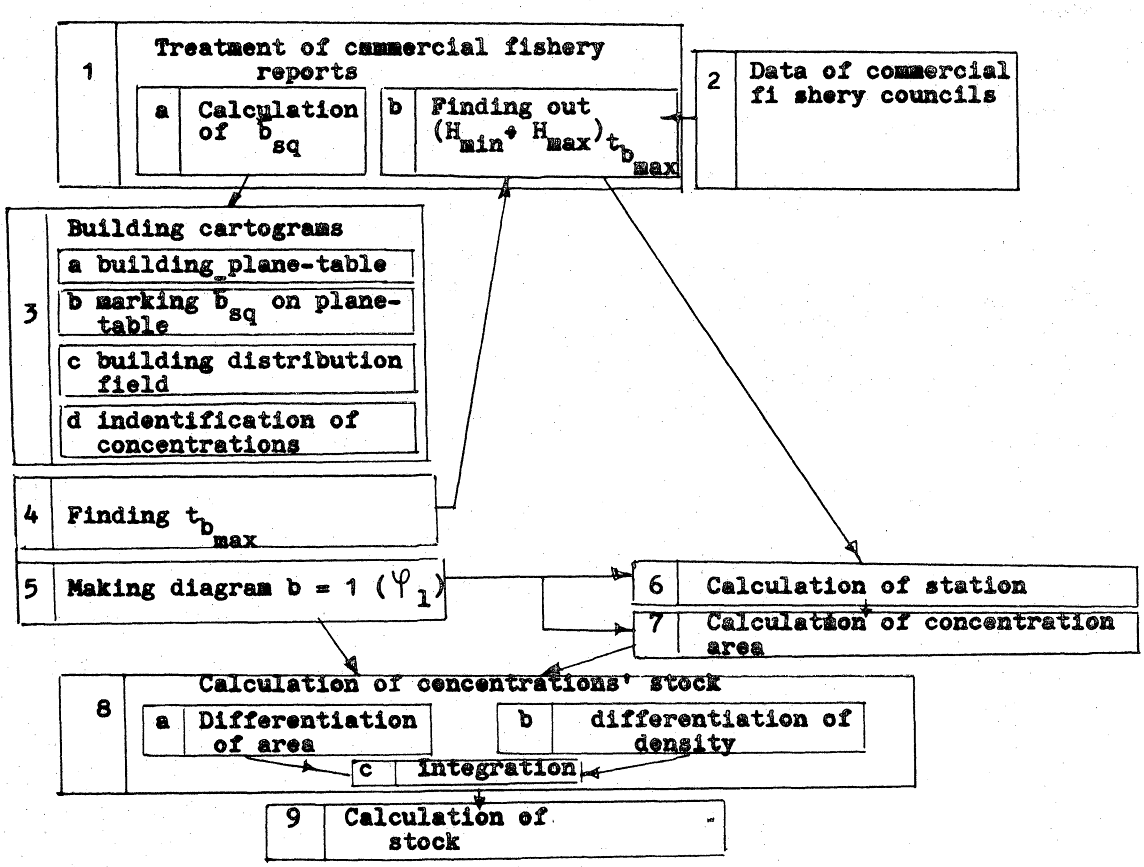

Fig. 2. Algorhythm of the method of determining commercial stock of migrating population.