International Council for
the Exploration of the Sea

C.M. 1986 / B:18
Ref. G .
Sess. V .

Digitalization sponsored by Thünen-Institut

# ASSESSMENT OF OPTIMUM MESH SIZE IN TRAWL'S CODEND FOR ARCTO-NORWEGIAN COD FISHERY

by

Blinov V.V.,

All-Union Research Institute of
Marine Fisheries and Oceanography
(VNIRO), Moscow, USSR

ABSTRACT

A new method is presented for the assessment of the optimum mesh size in trawl's codend. It is based on representation of relative fishing mortality at age as sum of four functions of age, one being of codend's selectivity. Selectivity and intensity parameters were changed in the model independently. Losses and gains in catches were calculated using selectivity cohort theory proposed by the author earlier. Calculations were made for North-Arctic cod fishery when varying mesh size values from 91 to 157 mm. Calculation variants were analysed using three criteria. The existing mesh size level for cod fishery B = 125 mm is proved to be optimum for the period of 1962-1990 years and must be thus "freezed".

RÉSUMÉ

Il est proposé une nouvelle méthode pour l'éstimation des dimensions optimum de maille des sacs de chalut. Elle est baseé sur la représentation de la mortalité rélative de pêche en fonction de l'âge sous forme de la somme des 4 fonctions d'âge des poissons, dont l'une représente la sélectivité du sac. Les paramétres de la sélectivité et de l'intensité de lapêche dans la modéle se changeaient de façon indépendante. Les pertes et les avantages dans les prises étaient calculées au moyen de la théorie de sélect'vité des cohortes proposée plus tôt par l'auteur. Les calculs sont faits pour la pêche à la morue arctique-norvégienne au changement des dimensions de maille de 91 à 157 mm. Les variantes des calculs étaient analysées a partir de trois critéres. Il est prouvé que les dimensions de maille existantes pour la pêche à la morue B = 125 mm est optimum pour la période 1962-1990, c'est pourquoi elles doivent être "congelées".

## INTRODUCTION

Selectivity and intensity of fishery as being its regulation factors should be considered as being parameters and functions that have to be optimized by using a certain complicated and structured model of the "stock-fishery" type. To get better accuracy and adequacy when modelling a system one should choose discrete type model. Regulation effects are usually seemed to correlate with variables and parameters responsible for abundance and biomass dynamics, and optimization of catch regulation parameters has to be followed by optimization of fishing and spawning stock parrmeters.

A method for optimization of trawl codend's mesh size has been developed in the papers (Hoydal,1977; Hoydal et al.,1980; Sparre, 1980). This method has not however taken into account for aspects of general and combined optimization of fishing and spawning stock sizes and catch.

New methods for estimation of effect of change in trawl fishery selectivity have been developed in the papers (Blinov,1981, 1984,1985a,b). Algorithms of those methods can be used in prognostic models to analyse and optimize stock size and catch level. The main problem is to separate adequately numerical variables of selectivity and intensity of fishery. A method for transformation of F(i) function is presented below that was brie'ly described earlier in the papers (Blinov,1985a,b). This approach gave a possibility to test, separately or in combination, factors of regulation of the Arcto-Norwegian cod fishery. Results of modelling and analyse of criteria over the set of variants of possible changes in cod fishery selectivity were given and optimum trawl codend's mesh size for cod fishery was determined.

## RELATIVE INSTANT FISHING MORTALITY

Different authors tried to find in different forms relationships between trawl selectivity parameters, fishing effort and fishing mortality rate F (see Beverton,Holt,1957; Pope,1974; Doubleday,1976). For example, Pope's and Doubleday's methods were based on proportionality of the type:

$$F = a \cdot S \cdot f \tag{1}$$

where $S$ - selectivity coefficient, $f$ - fishing effort, $a$ - constant.

As one can see from the expression (1), the selectivity coefficient written in the explicit form does not depend on age of fish and can be considered as a part of the whole constant $a$. To the author's mind it would be better to take into account for the selectivity process when forming a function F (i), where $i$ - age of the fishes, by the expression of the type (see Beverton,Holt,1957; Blinov,1981):

$$F = \mu \cdot F_{st} \tag{2}$$

where $F_{st}$ - stable F value that typically valid for middle and old ages, $\mu$ - a fraction of fishes at ages retained by trawl's codend. The function $\mu(i)$ was considered as being the cumulative one in the previous paper (Blinov,1981). Indeed, the point how to interpret the $\mu(i)$ function needs further study in the frame-work of trawl sampling theory.

The multipli ative function for representation of F(i) has been used in the papers (Hoydal,1977; Hoydal et al.,1980; Sparre, 1980):

$$F = F_{max} \cdot \tau(i) \cdot \mu(i) \tag{3}$$

where $F_{max}$ - maximum fishing mortality rate that is usually occured for one of the oldest age group, $\tau(i)$ - fraction of fishes aged i being available for the fishery. The F value, in its turn, has been formed by such additive terms as landing $F_L$ and discard of fishes small in length $F_D$, i.e, $F = F_L + F_D$. These magnitudes as being all functions of age are then distributed among types of fisheries (and vessels as well). Such an approach signified progress in the problem owing to detalizing influence on F values of different types of fisheries and various mortality factor S for fishes. But multiplicative form of relationship (3), where functions $\mu(i)$ and $\tau(i)$ have both dome-like form, seems not to be evident enough.

To clarify the point it should be primarily said that the right decreasing part of the F(i) curve that is responsible for general availability of the fishery to the stock and for trawl's catchability in relation to the most aged fishes, is considered sometimes as being formed by selectivity processes. From methodological background trawl codend's ability to retain fishes of definite lengths (ages) despite of length composition of fished population before trawl's mouth provided fishes of all lengths (ages) do present there, that is usually considered as selectivity.

Fishes by the rest parts of bottom trawl for the exception of codend are treated by trawl's catchability theory. So fishing mortality curve as being a function of age of fishes can be constructed by using another background.

When analysing the ICES WG data on cod (see, for example, Anon, 1979,1986) onecan find that the F(i) function for cod in any year of fishery j has as a rule a dome-like form with maximum point that corresponds to the oldest fishes that can be likely explained by norwegian hand-line and long-line fisheries of the cod spawning stock. The function $F_j(i)$ being divided by its maximum value $F_{max(j)}$ is transformed to the function $FR_j(i)$ that changes from 0 to 1 and keeps domelike form (see Fig. 2,3).

Thus, the function

$$FR_j(i)=F_j(i)/F_{max(j)} \tag{3a}$$

is normalized and that form is the special one for the year $j$. The function $FR(i)$ can be represented in the form of sum of four functions in the following way:

$$FR_j(i)=SEL_j(i)+DISC_j(i)-GAP_j(i)-DISP_j(i) \tag{4}$$

Here $DISC_j$ signifies a function describing surplus catch of young fish over that determined by codend's selectivity curve. That is due to meshes in condends being blockaded by fish bodies and due to other reasons as well. But the most valuable constituent of the $DISC_j$ function is determined by amount of discarded fish. The function $GAP_j$ characterize averaged retaining ability of trawls relative to middle-aged fishes, $SEL(i)=\mu(i)$ - selectivity curve describing trawl codend's retention of fishes (it is usually applied to the fishery during a number of years that corresponds to fixed mesh size in trawl's codends). The function $DI$ describes a process of dispersion of old fishes among the stock and their relatively less availability to the fishery in the year of $j$.

Typical functions incorporated into the right side of the expression (4) are shown in the figs. 1a,b; 2,3. The $DISC$ function gives non-zero values for ages 1-3 only whereas $GAP$ and $DISP$ functions are often distributed over 5-9 ages. Transformations (3a) and (4) are made for $F(i)$ values obtained for instance, by the VPA method for a certain reference (base) year beginnning with that a retrospective or prognostic analysis is supposed to be carried out.

Thus, selectivity and intensity of fishery appeared to be splitted into separate parts as the expressions (3a) and (4) reveal: intensity of the fishery was separated by means of using multiplicative form of the expression (factor $F_{max}$), while selectivity function SEL (i) has an additive form. When changing the values of $F_{max}$ and SEL(i) as the fishery is modelled one can separately or jointly investigate intensity and selectivity effects produced onto the results of the fishery and their importance because as they can be considered stock and catch regulation parameters that need to be optimized.

## VIRTUAL POPULATION ANALYSIS REVERSED

The new method of cohort analysis reversed of selectivity (CAROS) has been proposed in the previous papers (Blinov, 1984, 1985a) to consider the selective part of a stock. This method is convenient for manual calculations but gives remarkable errors nevertheless, so there is need to improve it. The model and corresponding programm "ICES-3" always used below for calculation stock and catch numbers at age is the improved version of the problem. Here the VPA relationships in Gulland's form are used (Pope, 1972):

$$C_{ji} = N_{ji} \frac{F_{ji} \cdot (1 - exp(-(F_{ji} + M(i))))}{F_{ji} + M(i)} \quad (5)$$

$$N_{j(i+1)} = N_{ji} \cdot exp(-(F_{ji} + M(i))) \quad (6)$$

where $N_i, N_{i+1}$ - numbers of fishes aged $i$ and $i+1$, $F_{ji}$ - fishing mortality rate of $i$-th age group of the stock in $j$-th year of fishery, $M(i)$ - natural mortality rate of $i$-th age group of the stock.

The expressions (5) and (6) are used for calculations forward in time, i.e. fishes getting more aged are assessed in number by and by, it is plausible by analogy to CAROS method to call for the sake of definitness this direction calculations carried out in, as VPA reversed, or VPAR.

Abundance of selectivity cohorts at age and catches taken from those cohorts are written by analogy to the expressions (5) and (6):

$$C_{ji(SEL)} = N_{ji(SEL)} \frac{F_{ji}\left(1 - \exp\left(-\left(F_{ji} + M(i)\right)\right)\right)}{F_{ji} + M(i)} \qquad (7)$$

$$N_{j(i+1)(SEL)} = N_{ji(SEL)} \exp\left(-\left(F_{ji} + M(i)\right)\right) \qquad (8)$$

Algorithm of selectivity cohort analysis is given in the paper (Blinov, 1984). If the expressions (5) and (6) in the paper (Blinov, 1984) were changed for the expressions (7) and (8) written above, we would have a method that can be called as VPA of selectivity reversed, or VPAROS.

## NATURAL MORTALITY RATE AND RECRUITMENT OF COD

ICES Working Group is well known to use constant and equal values for all ages of cod of natural mortality rates M (Anon., 1979, 1986). In 60-ies years M = 0.3 and in 70-ies - M = 0.2 have been taken whereas contemporary understanding of elimination of fishes from the stock due to natural causes (see, for example, Tiurin, 1972) is based on considering it as being a function of age of fish, i.e. a function $M(i)$ that is beleived to be of concave type. Values of that function over the regions corresponding to the youngest and oldest ages are reached or exceeded the level $M = 1.$, and the minimum being more often flatted hits to the middle ages of fishes.

In the paper by Borisov V.M. (1976) the computation by Tiurin's method of the abundance of cod individuals eliminated due to natural reasons has been made. In our work (Blinov, 1977) a model for such a type of elimination was delivered and some general type of the function $M(i)$ was proposed. Here again, coefficients of the function $M(i)$ were fitted on basis of the calculation results obtained in the cited work by Borisov V.M. In the present work one of the coefficients has been corrected that aimed getting results for the entire run provided that these results would not be in contradiction. The second part of the results obtained in that run has been presented in the paper (Blinov, 1985b).

We thus recommend for use the following function $M(i)$ for the arcto-norwegian cod:

$$M(i) = -\ln\left[6.9\left(\exp(-0.2\,i) - 1.1\exp(-0.3)\right)\right] \quad (9)$$

This expression was used in the modelling process as being an alternative to the constant value $M = 0.2$ that has been taken by the WG.

In his fundamental work Tretjak V.L. (1983) proposed the expression $M(i)$ that however gives very low values within wide range of cod age groups. This expression needs moreover to be set on a more rigorous theoretical basis. So in our calculations we have not taken Tretjak's expression.

As is well known (Anon., 1986) a number of year classes untill

1983 year were poor and cod recruitment was at a low level.– only several hundreds of millions of 3-year olds. During this run of modelling a constant low level of cod recruitment was used as it has been done by Ulltang (1979): we used $N_3$ = 310 mill. of individuals. Thus, the results of this run of modelling should be related to the state of the cod stock with constant multiyear recruitment of very low level.

## BRIEF DESCRIPTION OF ALGORITHM OF THE PROGRAMM "ICES-3"

The outputs of the model and the programm "ICES-3" are prognostic parameters of catch and stock (i.e. parameters of exploitation regimen of the stock) when changing (separately, or jointly) selectivity and intensity of the fishery and at the same time possibly changing in recruitment's level and natural mortality rate for fishes at different ages. The model and program can be used for retrospective analyses.

When taking the WG data on F(i) values for a certain "base" year of fishery, the function $F_{BASE}(i)$ is transformed by use of (3a) and (4). Calculations of stock and catch parameters by using the expressions (5) and (6) for prognostic years of fishery are made by the program "ICES-3" in two variants: 1) for fishery with existing (old) selectivity SEL(i)= $P_{OLD}(i)$ and 2) for fishery with new selectivity SEL(i) = $P_{NEW}$ (i), where $P_{OLD}$ (i) and $P_{NEW}$ (i)- values taken from old and new selectivity curves for fishes of i-th age. Any selectivity curve of trawl's codend that differs from that for base year (both for increasing or decreasing mesh size) can be taken to be valid to the calculation procedure.

The following variants of changing in intensity of fishery are taken into account: fishery with the same intensity that was observed in the base year; fishery with any constant intensity for all age groups of the stock; fishery with the intensity that is changed yearly by the value $\Delta F$ until it reaches constant (optimal, in a . case) level of $F_{opt}$ values for all age groups of the stock. The lather values that have been recommended by the WG for given selectivity of fishery (see Anon., 1979) were used in our calculations.

The WG data on numbers at ages for stock in the base year were used as start ones in the expressions (5) and (6). The rest of fishes in stock at the end of this year's fishery was calculated by the formula (6). Number of fishes eliminated by natural causes is determined as being the difference between initial number and sum of catch in number and the rest of the stock.

Spawning stock numbers at age are calculated using values of the maturity ogive by Ponomarenko V.P. et al., (1980). Spawning stock biomass at age and that for the entire unit are also calculated. For these purpose mean weights of fishes at age (Ancn.,1986) are used and biomass of fishes at age for catch, stock and amount of fishes eliminated due to natural causes are computed as well.

When all stock and catch parameters for two variants of selectivity of the fishery have been assessed, a comparison of these variants was performed by computing losses and gains in catches by means of the sub-program that realized the VPAROS method.

## SOME OPTIMIZATION CRITERIA FOR THE EXPLOITATION OF COMMERCIAL FISH STOCKS

A set of fish criteria for optimum exploitation of commercial fish stocks must surely include in explicit form such criteria that reveal variations in spawning stock abundance, biomass and structure.

The most simple criterion is keeping constant spawning stock biomass (provided given structure of the stock). The expression (4) permits to organize computational process of seeking for such a catch in the current season that the next year spawning stock would reach a certain given value. For that is used an increment

$$\Delta F_j(i) = \Delta F' \cdot FR_j(i) \qquad (10)$$

where $\Delta F'$ - varying computation step. Performing iterations a new value of fishing mortality rate $F_N$ is obtained by using the expression(from the old one $F_{OLD}$):

$$F_{N(j)} = F_{OLD(j)}(i) \pm \Delta F' \cdot FR_j(i) \qquad (11)$$

When using variable step $\Delta F'$ one can sustain calculation value for spawning stock biomass $B_{sp}$ to be at a given level within a certain fixed accuracy and finally to determine the allowable catch. This problem was solved by our optimization program "ICES-4".

Catch optimizing process for the prognostic year $j$ described above corresponds to the criterion $\zeta = Y \rightarrow max$ provided $B_{j+1}$ = = const, latter prognostic levels $B_{j+1}$ being thereby set from biological considerations.

Among outputs of the program "ICES-3" there are three ones being the most important: commercial $B_{st}$ and spawning stock $B_{sp}$ biomasses, biomass of catch $Y$. Concepts for rational exploitation should be evidently related to these parameters. Note that they are not independent and so criteria composed by using some combinations of these magnitudes do have to be single-valued.

As a basis to form criteria for option of optimum regimen of exploitation (optimization criteria) of the commercial fish stock bearing in mind that we deal with the complicated system it is reasonable to set the following qualitative considerations: 1) increasing in catches is limiting from above due to possible vulnarable impact to the stock while low catches may point out to irrational utilization of the stock due to the fact that elimination of fishes by natural causes is increasing; 2) rise in the commercial stock size without a corresponding rise in catches seems to be relatively high elimination of fishes due to natural causes and lowering in relative amount of feeding items and absolute one utilized by other species that are belived to be of high importance and rationally exploited; 3) decreasing in commercial stock size when catch is fixed, due to decreasing of spawning stock number and the reproduction system of the stock may therefore be violated; 4) sharp decreasing in the commercial stock size and catch may occur to be not profitable because the ecologic niche would be occupied by some other fish species (particularly by unexploited one); 5) increasing in spawning stock biomass should not coinside with decreasing of the commercial stock biomass that would inevitably result in sharp decreasing in catches; 6) decreasing of spawning stock biomass should not conside with increasing in catches.

Regulation measures that use fishery selectivity and intensity changes are well known to be directed to gain summed multiyear catch increased and simultaneously to save (or even enlarge) summed numbers of spawners over these years. So, among optimization criteria for exploitation regimen ought to be criteria of cumulative type that reveal properties of the system "stock-fishery" during a series of years.

For instance, the ratio

$$\varphi_n = \sum_{j=1}^{n} Y_j \Big/ \sum_{j=1}^{n} B_{sp(j+1)} \qquad (12)$$

where n - number of prognostic years (or time delay in years for retrospective analysis). As the criterion $\varphi_n$ is increasing, catches are relatively also increasing compared to spawning stock size that may result in overfishing. As the criterion $\varphi_n$ is on the contrary decreasing, catches are relatively decreasing accompanied by the more auspicious state of the spawning stock. However, drastic decreasing in $\varphi_n$ values would correspond to irrational exploitation of the stock (underfishing).

One may recommend another criterion of cumulative type that includes all three stock and catch parameters: $\omega_h$ criterion defined as ratio of catch and spawning stock biomass summed over a series of $n$ years of fishery to summed commercial stock biomass:

$$\omega_n = \sum_{j=1}^{n} \left[ Y_j + B_{sp(j+1)} \right] \Big/ \sum_{j=1}^{n} B_{cs(j)} \qquad (13)$$

where "$cs$" - commercial stock.

The expression (13) contains in the numerator a sum of catch and spawning stock biomasses to maximize which is the aim of fishery regulation. When the numerator in (13) is sustained constant (or near it) increasing in the commercial stock size would mean irrational exploitation of the stock. When the commercial stock is decreasing without decreasing in catches the spawning stock is also decreasing in size that may become dangerous for reproduction potential of the stock. When values of the criterion $\omega_n$ are lowering that results in decreasing in catches and biomass of the spawners while relatively constant level of the commercial stock size is sustained that also means irrational exploitation of the stock.

The qualitative analysis of the criteria (12) and (13) given above creates a basis for the maximin formulation of the problem, namely: maxmin $\varphi_n$ , maxmin $\omega_h$ as being the aims of stock size regulation for the period of $n$ years.

## ANALYSIS OF FISHERY SELECTIVITY FOR THE ARCTO-NORWEGIAN COD USING THE CRITERION $T_{fc}$

A set of retrospective and prognostic calculation runs has been carried out using the programm "ICES-3" in which stock and catch parameters for the arcto-norwegian cod have been determined when changing selectivity of the cod fishery. In all these calculations fishery intensity was kept at the base year level.

Input data for the calculations were taken from the following sources: codend's selectivity curves for the soviet trawls made of capron nets having mesh sizes as so B = 91, 98, 110, 120, 130, 200 mm (Anon., 1964; Treshchev, 1974), for B = 130 mm (Ponomarenko et al., 1978), for mesh sizes B = 125, 130, 140, 150, 157 mm - data obtained by PINRO.

The years of 1962, 1968 and 1978 are taken as the base ones: all materials of the WG (Anon., 1979), in particular, fishing mortality considered as function of cod age $F_{BASE}(i)$ , are used for the base years. Results obtained by application of the expressions (3) and (4) to the base year data (and for 1979 as well) are shown in the figs.: 1a,b; 2,3. For the base years 1962 and 1968 the calculations are retrospective ones. For the base 1978 year the prognostic regimen a rather great prognostic time interval $n$ = 20 years that was taken by analogy with Ulltang's computations (1979).

The following transitions of fishery selectivities corresponding to changes in mesh size from $B_0$ to the new one $B_1$ : 91 → 98, 91 → 110, 110 → 120, 110 → 130, 110 → 200 mm have been studied and the results have taken into account for all stock parameters that were really acted during the period of 1962-1968 years. In the prognostic regimen taking 1978 as the base year the following transitions have been studied: 120 → 125, 120 → 130, 120 → 140, 120 → 150, 120 → 157 mm. All these variants have been computed using both constant natural mortality rate $M$ = 0.2 and the function M(i) given by the expression (9).

To analyse variants of changing in cod fishery selectivities the criterion of full compensation of losses in catches $T_{fc}$ described earlier (Blinov, 1984, 1985a, b) has been used. The border value for $T_{fq}$ = 8 years was thereby used: if in a calculation variant the inequality $T_{fc} >$ 8 years appeared to be valid that transition variant was considered not to be advisable.

Calculation values of the criterion $T_{fc}$ for all variants of transition of the fishery when vessels began to use trawls with new codend's mesh size $B_1$ are shown in the Fig.4. The line that joints crosses corresponds to the calculation variants input data of which have been used in Treshchev's computations (1974). The only value for $B_1$ = 98 mm was obtained using data from (Anon., 1964). However, in all these cases $M$ = 0.3 and $F$ = 0.8 have been taken as the Working Group has used these years. As one can conclude from the description of the model the latter one allows to make calculations taking variable values of F(i) instead of the constant one F = 0.8. Results of these variants are shown by circles in the Fig.4. We see that the only transition 91 → 98 appeared to be advisable whereas for all other variants values of $T_{fc}$ were extremely high. One can conclude of that the value $M = 0.3$ has likely been then overestimated giving especially unrealistic results when the effect of change in fishery selectivity was calculated by Gulland's method.

The values of $T_{fc}$ criterion for prognostic variants of transition beginning from 1978 when the mesh size $B_0 = 120$ mm has been used to larger mesh sizes are shown in the Fig.4 by squares and triangles, the latter ones are thereby related to constant value of $M$ for all cod age groups, $M = 0.2$, and the first ones - to the function $M(i)$ given by the expression (9). As we see in both cases values of the $T_{fc}$ criterion increase while the new mesh size $B_1$ is increasing resulted in the most sharp increase for dots that correspond to the function $M(i)$.

In order to obtain values of the function $T_{fc}(B_1)$ in the region 100-120 mm, a set of retrospective calculations for the base 1962 and 1968 years has been performed with use of the expressions (3a) and (4) beforehand and the function (9) as well, i.e. provided $M = M(i)$ and $F = F_{BASE}(i)$ as if the above method was known those years. The results of these calculations are shown in the Fig.4 by transparent and half shaded rhombs. In both cases the input mesh size $B_0 = 91$ mm was taken. As we can see the transitions of the fishery to the mesh sizes $B_1 = 98$ mm and 100 mm epppeared to be true and valid. In this way the function $T_{fc}(B_1)$ became continued to the lower range of $B_1$-s.. The solid line that averages all dots in the Fig.4 crosses the border that was said about earlier in the range between $B_1 = 120$ and 125 mm. Thus, this is the range of optimum values of the criterion $T_{fc}$ , indeed. As far the $T_{fc}$ criterion reveals only technical and economical importance of the regulation measures when changing in fishery selectivity is concerned (see Blinov, 1984,1985), so in order to judge finally about cod fishery selectivity level it is necessary to draw to the analysis the criteria that reveal biological states of the stock.

## ANALYSIS OF COD FISHERY SELECTIVITY USING THE CRITERIA $\varphi_n$ AND $\omega_n$

The criteria $\varphi_n$ and $\omega_n$ defined above reveal interdependency between parameters incorporated to these criteria and they belong besides to the relatioships of cumulative type, i.e. they accumulate multiyear information on changing of some model's outputs. Such criteria are very useful in assessment practice when one obtain digital parameter's level for the exploitation regimen of the commercial stocks and of the total allowable catches due to the fact that fishery changings that are concerned of young age groups of the stock do influence onto stock parameters during all subsequent years of their life in fishery.

The analysis of the modelling results obtained with the use of $\varphi_n$ and $\omega_n$ criteria in the maximin formulation is presented below. In our case there are two control parameters: new mesh size $B_1$ and the alternative $M = 0.2$ or $M(i)$ by the expression (9). For convenience sake consider a parameter $\sigma$ that chooses one of the alternatives, i.e. $\sigma = 1$ if $M = M(i)$ and $\sigma = 0$ if $M = 0.2$. The rule for the analysis is: the variants that hit into the cross-section region, which is formed by overlapping optimum regions of all criteria, should be treated as being the aim for stock size and fishery regulation. A variant of transition of the cod fishery to a new mesh size in trawl's codend $B_1$ when using criteria $\varphi_n$ and $\omega_n$ would be considered as being the optimum one if the optimum conditions determined by the criterion $T_{fc}$ are proved to be really fulfiled and the following expressions are valid:

$$\varphi_{n(opt)} = \max_{B_1} \min_{\sigma} \{\varphi_n\} \quad (14)$$

$$\omega_{n(opt)} = \max_{B_1} \min_{\sigma} \{\omega_n\} \quad (15)$$

Minimization of the criteria $\varphi_n$ and $\omega_n$ by the $\sigma$ parameter has the following sense. Values of natural mortality rate of fishes in the stock are redistributed over age groups, when the expression (9), instead of the constant value M = 0.2, is used in the modelling procedure, in the way: young and old ages are assumed to be eliminated with more high rate than that for the middle age groups. So, any averaging procedure by using the expression (9) (for example, with weighting by numbers at age) gives somewhat higher mean rate of cod elimination due to natural causes than that determined by the constant value M = 0.2. That means that provided the fixed values of $Y_j$ and $B_{sp(j+1)}$ the denominator in the expressions (12) and (13) should have the higher value resulting in lowering the values of $\varphi_n$ and $\omega_n$.

Calculation values of the criterion $\varphi_{20}$ for the 20-year forecast are shown in the Fig.5. As we see a value $B_1$ = 120 mm corresponds to the point of maximin according to the expression (14). All the rest, more higher, values of $B_1$ result in decreasing of the criterion $\varphi_{20}$ values. Thus, as the $\varphi_{20}$ criterion shows there no need to increase mesh size in trawl codends over 120 mm when cod fishery is carried out. The same conclusion one can produce if the $\omega_{20}$

criterion is considered (see the Fig.6.).

It also follows from the Fig.5 that if the spawning stock seems to have a somewhat better state, the latter is reached by means of valuable decreasing in catches. A family of curves $\omega_{20}(B_1, \sigma)$ decreases analogously to that of $\varphi_{20}(B_1, \sigma)$ that give rise to a conclusion, that during the period considered catch and spawning stock biomass are increasing with a significant lag compared to the commercial stock biomass. In these circumstances a fraction of fishes eliminated due to natural causes increases that gives an evidence for irrational exploitation of the commercial cod stock. As we can see from the Fig.6, this process takes place both for the variants determined by the value $M = 0.2$ (adopted by the WG) and for those determined while using the expression (9) that is recommended in the present work.

Thus, we can conclude that within the limits in which cumulative criteria $\varphi_{20}$ and $\omega_{20}$ take into account biological properties of the commercial cod stock, optimum values of these criteria appeal to the recommendation not to increase inner mesh size in trawl codends made of capron more than 120 mm when cod fishery is carried out by those gears. The mesh size of $B = 120$ mm is well known to be officially introduced since 1981, so the results of the present work should be understood as the proposition to "freeze" this regulation parameter at the existing level and perform cod fishery regulation by means of changing intensity of the fishery, i.e. changing in fishing effort exerted on the cod stock.

## CONCLUSIONS

1. The large scape of experimental material covering the

period of 20 years when the investigations of capron trawl codend's selectivity relative to the arcto-norwegian cod have been carried out by PINRO, was laid as inputs when system modelling of the process was performed using the special program "ICES-3". The criterion of full compensation of losses in catches was applied to the results of the modelling described to give the definite optimum range of mesh sizes in trawl codends: B = 120-125 mm.

2. When putting into comparison the old and new selectivity data for late and recent years if one uses the expression (9) it was proved that all calculation values of the $T_{fc}$ criterion have been surely put in order to give an evident and clear relationship which is of increasing type - the criterion $T_{fc}$ being as a function of the new mesh size $B_1$. On this basis the expression (9) is recommended to assess stock numbers and total allowable catches for the arcto-norwegian cod.

3. The maximin formulation of the $\varphi_n$ and $\omega_n$ criteria (expressions (14) and (15), when the analysis of changing in cod fishery selectivity is performed, allowed to take into account changes in biological parameters of the stock and catches. When examining optimum values of these criteria over the calculation variants obtained in the system modelling described above it was possible to digest the optimum mesh size in capron trawl codend's for cod fishery B = 120 mm.

4. If all three criteria are combined in the analysis it was possible to obtain the only value B = 120mm in the cross-section of the optimal criteria regions that have overlapped each other. Because the existing mesh size is officially taken as being B = = 125 mm, the main result of this paper is to "freeze" the existing

mesh size for cod fishery and further increasing in the value of $B$ is not advisable.

The mesh size value B = 120 mm should be considered as the minimum one in the optimum range when biological state of the stock is not getting worse. The mesh size value B = 125 mm should be treated as maximum allowable one when the level of rational fishery is yet sustained for a long time while biological and technical points are concerned. Thus, by the present work we recommend finally to "freeze" the present inner mesh size in capron trawl codends for cod fishery at the existing level of B = 125 mm.

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## LEGENDS TO THE FIGURES

Fig. 1. Fishing F and relative fishing mortality FR rates and the constituents of the FR depending on age of the Barents Sea cod for base years: a) 1962; b) 1968.

Fig. 2. Fishing F and relative fishing mortality FR rates and the constituents of the FR in dependence on age of the Barents Sea cod for the base 1978 year.

Fig. 3. Fishing F and relative fishing mortality FR rates and the constituents of the latter depending on age of fish (Barents Sea cod) for the base 1979 year.

Fig. 4. Criterion of full compensation of losses in catches $T_{fc}$, years, depending on new inner mesh size in trawl's codends $B_1$, mm.

Fig. 5. Criterion $\varphi_{20}$ in dependence on new mesh size $B_1$, mm, for two alternative functions of natural mortality rates for the Barents Sea cod: M = 0.2 and M = M(i) using the expression (9) of the present work.

Fig. 6. Criterion $\omega_{20}$ in dependence on new mesh size $B_1$, mm, for two alternative functions of natural mortality rates for the Barents Sea cod: M = 0.2 and M = M(i) given by the expression (9) of the present work.

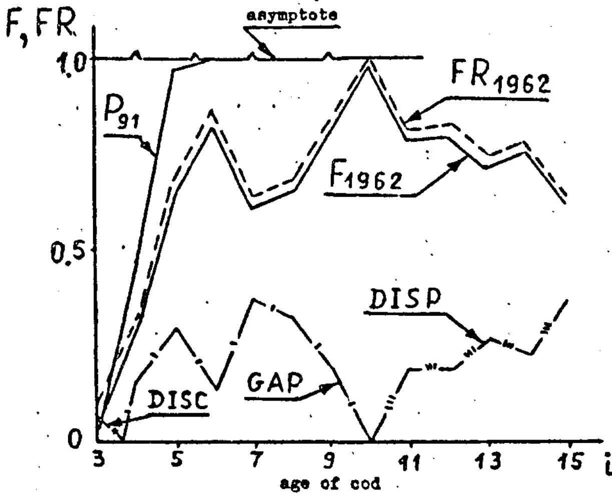
F, FR
asymptote
1.0
FR1962
P91
F1962
0.5
DISP
GAP
DISC
0
3
5
7
9
11
13
15
i,
age of cod

FIG. 1a

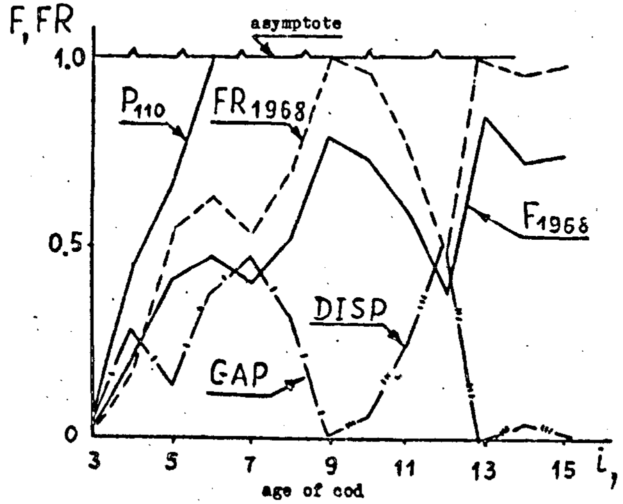
F, FR
asymptote
1.0
P110
FR1968
F1968
0.5
DISP
GAP
0
3
5
7
9
11
13
15
i,
age of cod

FIG. 1b

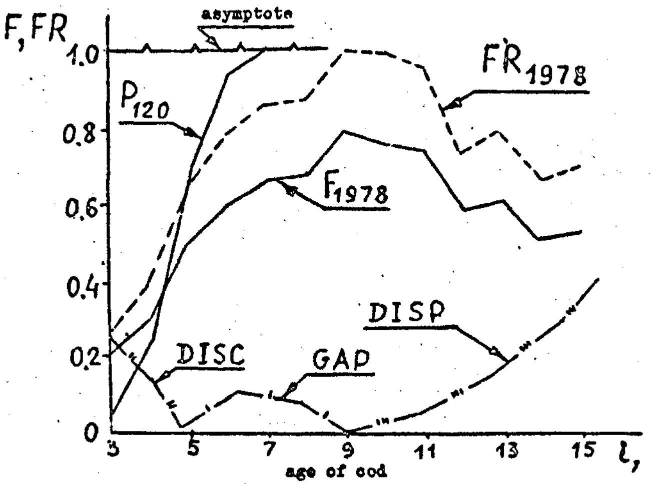
F,FR
asymptote
1.0
0.8
0.6
0.4
0.2
0
$P_{120}$
$FR_{1978}$
$F_{1978}$
DISP
DISC
GAP
3
5
7
9
11
13
15
i,
age of cod

FIG. 2

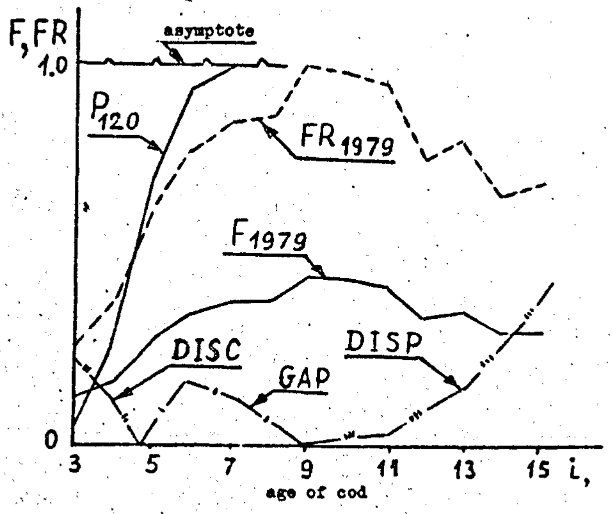
F,FR
asymptote
1.0
0
$P_{120}$
$FR_{1979}$
$F_{1979}$
DISC
DISP
GAP
3
5
7
9
11
13
15
i,
age of cod

FIG. 3

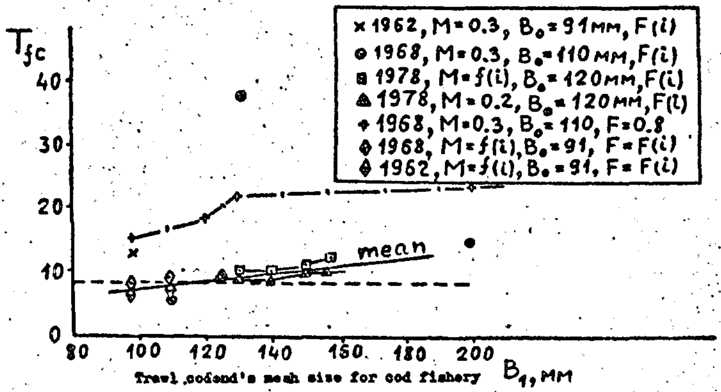


FIG. 4

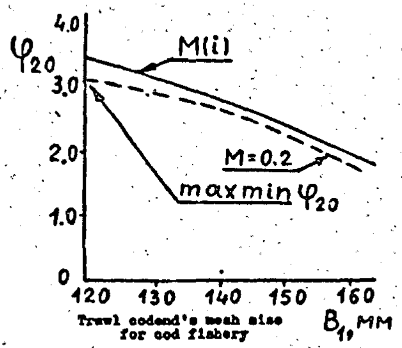


FIG. 5

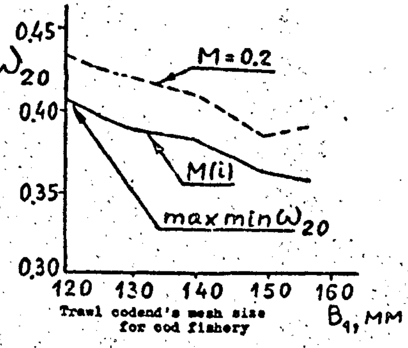


FIG. 6

Подписано к печати 27/УI 1986 г. Заказ 324
Объем I,75 п.л. Формат 60х84 I/I6 Бесплатно Тираж 265

Ротапринт ВНИРО
I07I40. Москва, Верхняя Красносельская, I7