International Council for
the Exploitation of the Sea

C.M. 1986 / B:19
Ref. G .
Sess. V .

ASSESSMENT OF THE OPTIMUM MESH SIZE IN TRAWL'S CODEND FOR REDFISH S. mentella T. FISHERY IN THE NORTH ATLANTIC

by

Blinov V.V.,

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

ABSTRACT

The author's method proposed before for analysis of cod fishery selectivity was used in the present paper. Experimental selectivity data for trawl's codend with mesh sizes from 98 to 134 mm for the redfish (S. mentella T.) fishery in the North Atlantic were used in calculations. Three calculation runs were made that differ from each other by various functions of natural mortality rate at age M(i). Calculation variants were analysed by using five criteria which were put in order and optimum regions for them were determined from the Working Group data. The Pareto frontiers conception is also used in the analysis.

The optimum mesh size in trawl's codend B = 98 mm was recommended for the redfish fishery in the North Atlantic. Besides, a definite function of natural mortality rate at age of concave type for redfish was recommended for use instead of M = 0.1 for all ages that is used in the WG's practice.

RÉSUMÉ

La méthde proposé plue tôt par l'auteur pour l'analyse de la selectivité de la pêche à la morue arctique-norvégienne est utilisée dans ce travail. Les courbes de selectivité experimentalles des sacs de chalut au changement des dimensiones de maille de 98 à 134 mm pour la pêche à la perche (S. mentella T.) à l'Atlantique du Nord sont utilisée dans les calculs. Les trois cycles de calcul sont faite lesquelles se distingues par des fonctions differentes des taux de mortalité naturelle à l'age M(i). Les variantes de calcul étaient analysées à partir de cinq critères ayant placées par rang et les regions optima pour ces critères étaient determinées à la base des données de la Group du Travail. Il est aussi utilisée une conception de la frontier de Pareto dans l'analyse. La dimension optimum de maille des sacs de chalut B = 98 mm est recommandée pour la pêche à la perche à l'Atlantique du Nord. Outre cela, la fonction definie de taux de mortalité naturelle à l'age de la type concave pour des perche est recommandée pour l'utilisation à la place de la valeur M = 0.1 pour toutes les ages des poissons qu'est pris pour des calcules à la pratique de la Group du Travail.

INTRODUCTION

Total catch of the redfish S. mentella T. in the North-East Atlantic reached remarkable level in 1971 year (Anon., 1980, 1982a) and since 1974 to untill 1982 remained at relatively high level. As one can see from the fig. 1 peak of the total catch cccured to be in 1975 and 1976 and gradual lowering in catches is followed that speaks for a stable level of fishery. In that aspect the question is valid if the measures introduced earlier to regulate the NEA redfish fishery by setting definite levels of trawl's selectivity (codend's mesh size) and catch intensity (TAC level) should be appreciated to be optimum ones.

An estimate of optimum level of selectivity for redfish fishery in divisions IIa and IIb of the NEA and in the NWA was made in the present paper by using a new method applied preliminary to the NEA cod fishery (Blinov, 1986) that is mainly based on multicriterial analysis of modelling results for the system "stock-fishery".

MATERIALS AND METHODS

In the paper a method described in details earlier (Blinov, 1986) was used for assessment of stock and fishery optimum parameters (commercial and spawning stock sizes, total catch intensity and intensity when catching separate age groups of the stock, TAC, selectivity level of the fishery). The method realizes the following approach :

1. Splitting fishery regulation factors and representing them in a convenient (possibly universal) mathematical form. For one-type gear fishery (for example, trawl redfish fishery) one should tend to build universal base (B) year function $F_B(i)$, where F - fishing mortality rate, i - age of fish. This function is supposed to realize in its structure result of splitting fishing intensity and selectivity parameters. Numerous attempts for incorporating trawl selectivity parameters to the function F(i) in an explicit form have been made earlier (Pope, 1974;

Doubleday, 1976; Hoydal at al., 1980). Necessity of seaking for a function F(i) in the universal form was emphasized also in the Report of the WG (Anon., 1982b) and in the paper (Pope, Shepherd, 1983).

2. In order to take into account fishery selectivity process as being specific one and describing selective retention and sifting of fishes through trawl's codend meshes and returning them to the stock thereby, it is necessary to work out a method to estimate numbers of sifted and survived fishes entered the future stock and appeared in future catches. Account of the additional catch consisted of fishes that have been selectively sifted during the previous years of fishing permits to assess more accurately losses and gains in catches in every separate year within the prognostic period of fishery with changed trawl codend's mesh size. Such a theory has been developed by the author earlier (Blinov, 1 984).

3. Losses and gains in catches are usually estimated in per cents to the base year catch, i.e. when selectivity is changed, those values are calculated in per cents relatively to the catch in the last year of fishery with old mesh size.

4. Optimumness of exploitation of the system "stock-fishery" is understood as multiparametric optimization of basic parameters that describe stock and fishery. In other words, optimum level of TAC should be in agreement with the fishery selectivity and intensity optimum levels provided that commercial and spawning stocks are sustained at optimum levels as well while losses due to natural mortality being minimized. The criteria introduced below meet those requirements. Because optimumness of exploitation is usefully assessed within a certain prognostic period of years, so additive stock parameters are incorporated into criteria being writt-

en in cumulative form (criteria of cumulative type).

5. Optimization of fishery selectivity level should be made by the main criterion T_{fc} -period of full compensation of losses in catches. It is shown in the paper (Blinov, 1984) that the criterion T_{fc} means from the economical point of view the period of recoupment of the investment for the fleet being able to fish by using trawls with new selectivity.

6. In addition to the main criterion T_{fc} optimization of fishery selectivity level is also made by using the multicriterial analysis of Pareto frontiers and optimum regions of the criteria which the extreeme values can be obtained by analysis of fishery statistics for (Blinov, 1985a,b).

Initial relationships for modelling are given below (for details see Blinov, 1980).

I. Discret function F(i,j), where F - fishing mortality rate, i - age of fish, j - year of fishery, can be transformed to relative function FR by division of initial function by maximum F value that is chosen for one of the old ages of fishes:

$$FR(i,j) = F(i,j) \,/\, F_{max(j)} \qquad (1)$$

From the WG data (Anon., 1982a) the maximum F_{max} corresponds usually to 18 - 22-aged individuals of the NEA redfish.

The structure of the expression (1) gives an opportunity to introduce explicitly discret selectivity curve to the function FR(i,j). Represent this function to an additive form for a certain base year of fishery t_o :

$$FR(i,t_o) = SEL(i,t_o) + DISC(i,t_o) - GAP(i,t_o) - DISP(i,t_o) \qquad (2)$$

For detail explanation of the expression (2) see the paper (Blinov, 1986). The function DISC (i,t_o) is positive one if FR > SEL for young ages while DISC = 0 for middle and old ages. The function GAP(i, t_o) is both positive or negative depending on which of the inequalities FR $\gtrless$ SEL is valid in the range of middle ages. At last, if FR(i) is of dome-like form, then decreasing in right branch of the curve can be described by the function DISP(i), while DISP = 0 for young and middle ages of fishes. The function FR(i,1981) is given in the table 3 of the Annex.

II. Calculation of stock numbers at age N_{ji} and catches C_{ji} for a prognostic period was performed by using well-known expressions :

$$C_{ji} = N_{ji} \frac{F_{ji} (1 - \exp(-(F_{ji} + M_i)))}{F_{ji} + M_i} \qquad (3)$$

$$N_{j(i+1)} = N_{ji} \exp(-(F_{ji} + M_i)) \qquad (4)$$

where j - year of fishery, i - age of redfish. Values of F_{ji} were calculated by the expression :

$$F_{ji} = F_{max(j)} \ FR(i, t_o, SEL(i,j)) \qquad (5)$$

where SEL(i,j) - age-specific fraction of redfish retained by trawl's codends with new mesh size, while the functions DISC, GAP,DISP remain the same, i.e. depending on i and t_o . Such a structure of the expression (5) allows to split fishery selectivity and intensity effects exerted to stock and catch in order to investigate them jointly or separately by using the model. (Note, that $F_{max(j)}$ is responsible for fishing intensity in the year j).

It is plausible the system of expressions (3) and (4) when one calculate forward in time to be called as virtual population analysis reversed (VPAR). As Sims (1982) has shown accuracy of calculations in runs forward and backward appeared to be the same.

III. To calculate numbers of fishes that have been released by selective sifting during the preceeding hauls and their numbers in catches considering them as being some additional catches (or by-catch of the same species) during forthcoming years one should apply expressions similar to (3) and (4) written correspondingly for the sifted or selected fraction of the commercial stock. A catch from the mentioned amount of fishes can be called as additional catch to the principal (main) catch in the base year of fishery. Calculation of selective sifting and subsequent return to the fishery is proposed to be made by using the procedure that we call VPAR of selectivity, or VPAROS, where the following expressions are used :

$$C_{ji(SEL)} = N_{ji(SEL)} \frac{F_{ji} \left(1 - \exp\left(-(F_{ji} + M_i)\right)\right)}{F_{ji} + M_i} \qquad (6)$$

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

Initial values of $N_{j_0 i(SEL)}$ (in the base year $t_0 = j_0$) are determined by difference between numbers at age in catches with old and new trawl codend's mesh sizes. Because during the last 30 years demersal fisheries in the North Atlantic have been generally developed in the direction of increasing in their selectivities, so every new mesh size in trawl codends B_1 was taken as a rule to be the greater than the previous one B_0 , i.e. $B_1 > B_0$. We consider then mesh size in the base year usually to be smaller of all others, so comparative calculations are made in this paper for increasing mesh sizes. Note that VPAROS procedure appears to be the further enhancement of the method proposed in the paper (Blinov, 1981).

IY. In all calculations recruitment numbers to the redfish stock were taken at age 6 and considered to be constant and equal to 420 757 thou. of individuals being the mean value for the period of 1965 - 1977 years (Anon., 1982 a).

Y. The experimental data on selective retention and sifting of redfish through different mesh sizes in trawl codends obtained by PINRO in 1977 - 1982 ys for divisions IIb ICES and 2H and 3M NAFO were used in calculations. Because selective retention and sifting of fishes by/through trawls are usually studed in relation to length and not to age of fishes, so selectivity data need to be treated beforehand by using age-length keys (ALK). In the present paper ALK was taken as being averaged over age samples for redfish obtained in divisions IIa and IIb ICES in 1980 - call it Norway - Bear Island- Spitzbergen key (NBIS key). The latter is shown in the fig. 2 (solid line). The trawl codend's selectivity data by PINRO are related to set of mesh sizes B = 98, 108, 116, 120, 125, 128, 134 mm. A large scope of laborous work on graphical treatment of those data by using NBIS key has resulted in selectivity curves P(i) which are shown in the fig. 3. Values of P(i) that have been used in the calculations are given in the table 1 of the Annex.

VI. In all calculations of the WG (Anon., 1980, 1982a) the only constant value M = 0.1 was taken for all ages of the redfish stock. In addition to the function of natural mortality rate M(i) = 0.1 the function of the type described in the author's earlier paper (Blinov, 1977) :

$$M(i) = -\ln\left[7.4\,(\exp(-0.05\,i) - \exp(-0.07\,i))\right] \qquad (8)$$

was used in the present paper. The curve M(i) corresponding to the expression (8) is shown in the fig. 4. As it is seen from the figure, values of the curve over middle age region are all within the range of the value M(i) = 0.1 while the left branch of the curve is likely rised too high that resulted in overestimating of M(i). So, in the third run of calculations for that reason another pattern was taken for the left branch of the curve M(i) : this one obtained graphically and dasignated as $M_1(i)$. Digit values from the curves M(i) and $M_1(i)$ are comparatively given in the table 2 of the Annex.

VII. In prognostic runs maximum of the fishing mortality rate for redfish was taken constant and equal to that value for 1981 (Anon., 1982a), i.e. $F_{max(j)} = F_{max(1982)} = 0.25$.

VIII. The main criterion to analyse calculation variants of fishing with new selectivity was taken T_{fc} (see Blinov, 1984, 1985a, 1986) that is defined as number of years after which all losses in catches during the latest years of fishery with new mesh size would be entirely compensated by additional catches due to selective sifting (and subsequent survival) of fishes during the whole transient period and especially during the recent years of fishing with new mesh size. It was suggested in all our papers (and in this one as well) that if $T_{fc} > 8$ ys then the exploitation regimen is claimed to be the irrational one.

IX. In order to optimize stock parameters for several prognostic years of exploitation one should formulate additional criteria that would express biomass ratios of commercial and spawning stock, catch and amount of stock biomass eliminated due to natural mortality (see Blinov, 1985b, 1986). Optimization process for a series of sequential years ought to be controlled by criteria of cumulative type that differs from situation when step-by-step optimization takes place. Such criteria which take into account general bilogical properties of catch and stock during the period of n years can be written :

$$\zeta_n = \sum_{j=1}^{n} Y_j \Big/ \sum_{j=1}^{n} B_{com.st.(j)} \tag{9}$$

$$\lambda_{n+1} = \sum_{j=1}^{n} B_{sp(j+1)} \Big/ \sum_{j=1}^{n} B_{com.st.(j)} \tag{10}$$

$$\chi_n = \sum_{j=1}^{n} B_{nat.mor.(j)} \Big/ \sum_{j=1}^{n} B_{com.st.(j)} \tag{11}$$

where Y_j - catch biomass in the year of fishery j, $B_{com.st.(j)}$- commercial stock biomass in the year of fishery j, $B_{sp.(j+1)}$ - spawning stock biomass just after the year of fishery j (at the beginning of the next year j+1), $B_{nat.mor.(j)}$ -biomass of eliminated fishes due to natural mortality in the year of fishery j.

One can form a set of complicated criteria on basis of the expressions (9) - (11) of which the most important are :

$$\varphi_n = \zeta_n / \lambda_{n+1} \tag{12a}$$

$$\psi_n = \varphi_n (\zeta_n + \lambda_{n+1}) \tag{12b}$$

Here : ζ_n - the criterion of catch biomass relative to stock size, λ_{n+1} - the criterion of relative spawning stock biomass, χ_n - the criterion of relative biomass eliminated due to natural mortality, φ_n - the complicated criterion that means relative catch comparatively to relative level of spawning stock biomass, ψ_n - complicated criterion that has the sense similar to that of the criterion φ_n but supplied with weight that is represented by sum of relative catch and spawning stock biomass. Weighting factor $\zeta_n + \lambda_{n+1}$ has a remarkable effect when ζ_n and λ_{n+1} change synphasicly.

The criteria (9) - (12) should be set in order by degree of importance, namely : ζ_n, λ_{n+1}, φ_n, ψ_n, χ_n.

In that series lowering in importance was meant. Calculation variants that are evaluated as being equivalent relatively to first four criteria are then analysed in relation to the condition $\mathcal{X}_n \longrightarrow$ min. Even simple analysis of general biological properties of fish stocks makes one to be convinced that the criteria ζ_n and λ_{n+1} ought to have optimum regions and the criteria φ_n and ψ_n - forbidden and allowable intervals of their values.

X. All relationships written above have been incorporated to the program "ICES-3". Some initial data having been used in the calculation runs are given in the Annex.

RESULTS

Calculation runs were made for 24-year period of exploitation of the redfish stock in the North-East Atlantic. Such a large time interval was determined by not only the prolonged period of fishing life of the redfish S. mentella T. (more than 19 years) and also by the necessity of long-term prognostic analysis of exploitation regimen for the commercial redfish stock. There is evident need in prognostic estimates of stock state parameters. So, in the paper by Ulltang (1979) calculation prognostic period was taken 13 -15 years.

Three calculation runs have been made by using the program "ICES-3" for the base year 1981 and the minimum inner mesh size $B_0 = 98$ mm for the redfish fishery in order to study the effects that give larger mesh sizes. So, in every run the following transitions of the fishery to new mesh sizes have been investigated : 98 → 108, 98 → 116, 98 → 120, 98 → 125, 98 → 128, 98 → 134 mm. Two values for every five criteria in all 18 variants were calculated : for T = 8 and T = 20 years of prognostic exploitation of the stock with new mesh size in trawl's codend. Calculation results obtained by using the "ICES-3" program are given in the table 4 of the Annex.

Values of the T_{fc} criterion for two runs of calculations are shown in the fig. 5 which are related to conditions $M = 0.1$ and $M = M_1(i)$. As it can be seen from the figure, full compensation of losses in catches is reached in none of the variants earlier than after 16 years. Thus, because $T_{fc} > 8$ then none of the transitions to the larger mesh size can be recommended to be a variant for regulation of the redfish fishery.

In all variants of the second run when the $M(i)$ curve by the expression (8) has been used, negative long-term gaines in catches, i.e. long-term losses in catches were obtained. In other words, the values of T_{fc} for that run are equal theoretically to the infinity.

In the fig. 6 the transient curves of relative losses or gaines are shown that have been calculated for transitions of the fishery from the old mesh size 98 mm to larger mesh sizes, while the conditions $M = 0.1$ (fig. 6a) and $M = M(i)$ (fig. 6b) were valid. As it can be seen from the fig. 6a, during the first 7 years the redfish fishery would have significant losses and after 15 - 16 years of fishery gaines in catches are followed then. Despite of gaines that would increase to 20 - 34 % full compensation of losses in catches however would take place yet after a drastically long period. There are only losses in catches during the whole transient period in the second case (fig. 6b), and no gains the fishery would have up to the end of the transient period (it is equal to $T_{tp} = 20$ years) and further because $T_{fc} = \infty$ in that run.

One can say the criterion T_{fc} is of some "pragmatic" sense and gives an estimate of pure losses or gaines in catches relativeless to biological state of the stock. On the contrary, the criteria (9) - (12) give an opportunity to assess biological properties and consequences that would be effected by either choice of exploitation regimen of the stock. Thus, the criteria (9) - (12) are responsible for biological state of the stock in transient period.

Prognostic analysis of exploitation regimens for the redfish stock in the region I ICES while using the criteria (9) - (12) could be effectively made if values of the criteria would be adjusted to stock and fishery parameters by using the WG's data for 1971 - 1981 ys (Anon., 1982a). Such parameters are shown in the fig. 1, they include : commercial stock biomass, spawning stock biomass, total redfish catch in divisions IIa and IIb. Besides, values of the criteria ζ_1 and λ_1, i.e. for n = 1, for every year of fishery are given here that have been calculated by the expressions (9) and (10). As we see, relative catch of redfish reveals drastic variations. Such types of curves are dealt with in the field of analysis of oscillative signals transiting through complicated electric linear circuits (Itzhoky, 1969). The curve $\zeta_1(T)$ can be treated as being the response to the fishery that has increased stepwise in 1976 and oscillations of commercial stock biomass $B_{com.st.}$ and catch Y being superposed with each other. The values of the function $\zeta_1(T)$ fo the period 1978 - 1981 ys point out to the astatic type of the ζ_1 oscillations. Because of that it would be reasonable to assume the existance of an asymptote $\zeta_{1\infty}$ (when $T \rightarrow \infty$) that would hit in the range $0.12 \leqslant \zeta_{1\infty} \leqslant 0.14$. We consider the latter being the region of optimum values for the criterion ζ_1 (and by induction of ζ_n).

Biomasses of the commercial $B_{com.st.}$ and spawning $B_{sp.}$ redfish stocks in divisions IIa and IIb oscillate with phase shift that resulted in the complicated oscillation of the criterion ζ_1 values. For 1977 year the value of ζ_1 has corresponded to moderate level of B_{sp} and low value of $B_{com.st.}$. High level of the criterion λ_1 in the mentioned year is resulted by likely auspecious level of the spawning stock. This value $\lambda_1 = 0.325$ was taken for the upper frontier of the criterion λ_n : to keep biomass size B_{sp} higher than that level is unlikely reasonable. The lower frontier of λ_1 is less defined but it may be conventionally taken to be equal $\lambda_1 = 0.23$ considering that in 1978 the spawning biomass size of redfish B_{sp} has been lower than desirable level for the North-Atlantic redfish.

We assume that the optimum regions having been obtained above and shown in the fig. 1 would be valid for cumulative criteria (9) - (12) as well. Everyone of the latter should be taken for the period of T = 8 ys, i.e. border value of T_{fc} , and for T = 20 ys, i.e. for the end of the transient period at the beginning of which fishery selectivity has been changed.

Criteria ζ_8 and ζ_{20} versus to, correspondingly, λ_9 and λ_{21} are shown in the fig. 7. As we see, none of the calculation variants for T = 8 ys hits in the "optimum rectangle", but only dots that correspond to fishery selectivity with mesh size 98 mm have occupied the nearest positions to the rectangle's line.

One can conclude from the fig. 7a that when a stable state of the fishery with new trawl's mesh size would have been reached, the fishery should be evaluated as optimum one provided that elimination of redfish due to natural mortality is governed by the expression (8). Less optimum regimen of fishery is appeared to be that one for which the conditions $M = M(i)$ and $B = 98$ mm are valid. This plot proves the necessity to use in calculations a function $M(i)$ of concave type appropriately fitted beforehand. In this figure 7b one can draw the Pareto frontier (see Luce, Raiffa, 1957) that is shown by the dot-dashed line. The Pareto frontier goes just through those three variants with $B = 98$ mm that have been mentioned above. All the rest variants are then proved to be nonoptimum ones.

The complicated criterion φ in dependence on the simple criterion ζ is shown in the fig. 8. As we see from the figure, the optimum regions which cross each other form semistrips satisfying to the unequalities $\varphi > 0.4$ and $0.12 \leqslant \zeta \leqslant 0.14$.

As one can ascertain again from the fig. 8a, that only variants with $B = 98$ mm are located near the border of the semistrip of optimumness. As we see that properties of the curves $\Delta W(T)$ (see fig. 6) in the region to the right from the inflexion point have not yet made any influence. One can conclude from the fig. 8b that all variants with mesh size $B = 98$ mm are proved to be optimum or near to optimum ones. The Pareto frontier goes over three calculation points which correspond to the codend's mesh size $B = 98$ mm and different functions $M(i)$, and the only variant with $B = 98$ mm and $M = 0.1$ is appeared to be less poptimum than the others.

One can draw analogous conclusions if a complicated criterion ψ would be put in dependence on the simple criterion ζ (fig. 9). As in the case above, all calculation variants except of fishery regimen applying $B = 98$ mm appeared to be located aside from the region of optimumness. When using the ψ_{20} - ζ_{20} coordinates (see the fig. 9b) we can notice that calculation dots for the fishery applying the selectivity level of B = 98 mm have formed the Pareto frontier and the two of those have hit in the semistrip of optimumness (variants with M(i) and $M_1(i)$).

It is clear, the criterion χ_n depending in no wise on putting in order the other four criteria ought to take thus the last place because the process of elimination of fishes due to natural causes is in general of independent character and yet partly depends on the level of elimination due to the fishery. The decisive rule for choice by using the criterion χ_n is given by the verbal formula : if there is a set of variants being equivalent to each other in relation to the criteria of superior range , a variant is then chosen which $\chi_n \longrightarrow \min$ is valid for. The preceeding analysis shows that for the redfish fishery in divisions IIa and IIb ICES the regimen is recommended which the trawl codend's mesh size is equal to B = 98 mm for and thereby the regularity for elimination of redfish due to natural causes ought to be have taken by using the expressions of the type (8) or corrected dependence of type $M_1(i)$ (see the table 2 of the Annex). From the fig. 10 we can finally call the optimum regimen for the redfish fishery of the North-Atlantic : take B = 98 mm and consider the process of elimination of redfish due to natural mortality as being described by the regularity $M_1(i)$.

DISCUSSION

The regions of optimumness for the criteria ζ_1 and λ_1 in the fig. 1 appear to be rather appropriate and they form a fairly good basis for analysis of different exploitation regimens of the redfish S. mentella T. commercial stock in the North-East Atlantic. Since 1978 the redfish fishery has reached a new stable level comparatively to the period of 1971 - 1975 ys. It is likely the fishery by trawls with larger mesh size (B = 120 mm) that resulted in rising intensity level of redfish fishery and catches.

Despite of the irregular character that a family of experimental curves giving fractions of retention of redfish by trawl's codend with different mesh size has revealed, the optimum regimen for fishery of the North-Atlantic redfish has been clearly established in the present paper yielding the optimum mesh size B_{opt} = 98 mm ; an additional result was also obtained, namely : when assessing stock and fishery of the North Atlantic redfish the ICES WGs is recommended to use values for natural mortality rate at age for redfish that are given by the regularity $M_1(i)$ (see the table 2 in the Annex).

Such a result was induced by gently sloped selectivity curve of trawl's codend relatively to redfish (see the fig. 3). Note for comparison selectivity curves for the Arcto-norwegian cod are in general significantly steeper.

Fishery selectivity factor is probably to have divisional or regional pecularities. So, to account for them it is necessary to have a set of selectivity curves for commercial trawl codends and age-length keys for every separate stock in the division or subdivision under consideration. Clear it is a heavy problem accompanied by little hope that we shall obtain significant discrepances of B_{opt} values. Because of large scope of initial data required it would be difficalt to obtain them experimentally, so we decided in the present cycle of modelling to use all available curves $P_B(l)$, where l - mean length of redfish, that have been obtained in different parts of the North Atlantic and to treat them by the unique age-length key (NBIS key) (see the fig. 2).

For the Arcto-norwegian cod (Blinov, 1985a,b ; 1986) the criterion T_{fc}, due to more regular character of trawl codend's selectivity curves, appeared to be the main discriminant criterion for optimumness of mesh size in trawls while a set of criteria (9) - (12) has carried out a certain subordinated function. Indeed, in the present work the dependence of the criterion T_{fc} on new mesh size B_1 for redfish fishery makes us to draw the general conclusion : transition of the fishery from the mesh size B_0 = 98 mm to any larger size is not advisable (see the fig. 5). The criteria (9) - (12) in those cases give some additional information to the problem and bear discriminant function.

The fact that for the criterion ζ_n exists a strip of optimumness signifies that to take a great relative catch from the stock is hardly substantiated from biological point of view while low exploitation level of the stock is surely irrational one. The strip of optimumness of the criterion λ_{n+1} gives an evidence that biomass size of mature redfish being less than that of given by the value for the left border of the criterion (see the fig. 7) is even dangerous for the population to be existed while the value of λ_{n+1} to the right from the right border is responsible for excess amount of spawners which would be rational to be catched. As one can clearly see from the fig. 7 levels of catches provided any values B > 98 mm are low in comparison to the optimum one while spawning stock biomass sixe is likely higher than the optimum one.

The Pareto frontiers of optimumness (see Luce, Raiffa, 1957) gave the opportunity to separate an optimum regimen of exploitation of the redfish stock in divisions IIa and IIb (and to the author's mind, in the whole region of the North Atlantic). The Pareto frontiers appeared to be in good agreement with regions of optimurness for the criteria under considerations the latter being obtained on the basis of the WG's data (Anon., 1982a).

The method of modelling and optimizing fish stock parameters used in the present work does not contain, to the author's mind, drawbacks of Andersen-Hoydal's approach (Hoydal, 1977 ; Hoydal et al., 1980) and can be recommended to the ICES WGs to assess selectivity levels for fisheries of demersal species in the North Atlantic.

CONCLUSIONS

1. All available data on selective retention and sifting of redfish by trawl's codends for fishery in the North-East and North-West Atlantic obtained by PINRO have been used in the present paper to assess optimum mesh size by using the approach for modelling proposed by the author. This approach overcomes difficalties introduced by irregular character of selectivity curves for redfish.

2. The program "ICES-3" worked out by the author has been used to compute abundances of the main and selective parts of the stock by applying the VPA expressions for calculations forward in time. The procedures VPAR and VPARCS have been defined

in this way.

3. To analyse if optimumness of the stock and fishery parameters exists multicriterial approach used into the theory of games and research of operations has been applied and a system of criteria of cumulative type has been formulated as being relative magnitudes that was considered as exploited stock parameters. The pragmatic criterion T_{fc} was also used in the analysis.

4. The calculated values of the criterion T_{fc} for all investigated variants of changing trawl codend's mesh size from 98 mm to larger ones appeared to be significantly greater than the frontier value $T_{fc(f)} = 8$ years for which transition of the fishery to the new mesh size is avaluated to be yet rational one. The North Atlantic redfish fishery should use mesh size $B = 98$ mm whichever function M(i) is thereby chosen.

5. Analyses by pairs of cumulative criteria that have been put in order (fig. 7 - 10) have shown that the Pareto frontiers for a set of calculation variants aimed to study exploitation regimens of the Nort Atlantic redfish stock are in good agreement with the criterion optimum regions that have been obtained by using the ICES WG's data. The Pareto frontiers in all cases when they might be drawn at all appeared to be consisted of points being corresponded to the fishery regimen with $B = 98$ mm. The more detailed analysis for degree of optimumness belonging to those regimen due to taking different kinds of the function M(i) has shown that preference ought to be given to the fishery regimen for which $B = 98$ mm and $M = M_1(i)$ are valid that differs from the value $M = 0.1$ assumed by the ICES WG.

6. To the author's mind in the present work and the paper

(Blinov, 1986) a fair efficiency of the proposed method for mathematical modelling of the system "stock-fishery" has been clearly shown. This approach is recommended to use in the WG's practice to assess stock sizes and elaborate options for regulation of fisheries in the North Atlantic.

REFERENCES

Anon., 1980. Report of the Working Group on Redfish and Greenland halibut in Region I. ICES C.M. 1980 / G:4.

Anon., 1982a. Report of the Working Group on Redfish and Greenland halibut in Region I. ICES C.M. 1982 / Assess:5.

Anon., 1982b. Report of the Arctic Fisheries Working Group. ICES C.M. 1982 / Assess : 1.

Blinov V.V., 1977. Modelling of natural mortality rate at age for young fishes. Voprosy ichtiol., n. 3,pp. 572 - 573.

Blinov V.V., 1981. The estimation method of the effect on catches of changes in trawl's selectivity. NAFO SoR Doc. 81 / VI / 58, Ser. N 342.

Blinov V.V., 1984. On improving of methods for estimation and optimization of fishery selectivity. Rybnoje hozjajstwo, N 3, pp. 55 - 57.

Blinov V.V., 1985 a. Estimation of the optimum mesh size in trawl's codend on basis of mathematical modelling of "stock - fishery" systems. Rybnoje hozjajstwo, N 5, pp. 62 - 64.

Blinov V.V., 1985 b. Long-term exploitation of the fish stocks as being optimized by using system modelling methods. In : "Theory of commercial fishery and fishing gear designing", Moscow, VNIRO, pp. 105 - 128.

Blinov V.V., 1986. Assessment of optimum mesh size in trawl's codend for Arcto-norwegian cod fishery. ICES C.M. 1986 / B : 18.

Doubleday W.G., 1976. A least squares approach to analysing catch at age data. ICNAF Res. Bull., N 12, pp. 69 - 81.

Hoydal K., 1977. A method of Mesh Assessment Making it Possible to check Growth Parameters and Evaluate Effective Mesh size in operation. ICES C.M. 1977 / F : 51.

Hoydal K., Rørvic C.J., Sparre R., 1980. A metod for estimating the effective Mesh sizes and effects of changes in Gear parameters. ICES C.MA 1980 / G : 28.

Luce R.D., Raiffa H., 1957. Games and Decisions. Introduction and critical survey. NY, J. wiley and Sons; L., Chapman and Hall.

Pope J.G., Shepherd J.G., 1983. A comparison of the performance of various methods for tuning VPAs using effort data. ICES C.M. 1983 / G : 9.

Sims S.E., 1982. Algorithms for solving the catch equation forward and backward in time. Can. J. Fish. Aquat. Sci., v. 39, pp. 197 - 202.

Ulltang Ø., 1979. Some comments to the problem of adjusting TACs to mesh size changes. ICES C.M. 1979/G : 56.

ANNEX

Table 1. Fraction of redfish retained by commercial trawl codends $P_B(i)$ when using different codend's mesh sizes B, mm. The PINRO data $P_B(l)$ were treated by using age-length key for the redfish of divisions IIa and IIb ICES (details in the text).

Age, years	P_{98}	P_{108}	P_{116}	P_{120}	P_{125}	P_{128}	P_{134}
6	0.665	0.031	0.091	0.273	0.166	0.000	0.030
7	0.692	0.050	0.156	0.330	0.210	0.024	0.100
8	0.745	0.092	0.228	0.385	0.264	0.170	0.215
9	0.825	0.290	0.311	0.448	0.326	0.330	0.320
10	0.890	0.510	0.407	0.518	0.408	0.480	0.438
11	0.940	0.670	0.520	0.594	0.475	0.611	0.530
12	0.968	0.830	0.629	0.690	0.555	0.720	0.610
13	0.982	0.933	0.737	0.775	0.650	0.810	0.678
14	0.994	0.972	0.830	0.846	0.750	0.877	0.740
15	1.000	0.992	0.900	0.923	0.830	0.934	0.790
16	1.000	1.000	0.936	0.976	0.890	0.980	0.830
17	1.000	1.000	0.960	1.000	0.940	1.000	0.865
18	1.000	1.000	0.973	1.000	0.980	1.000	0.893
19	1.000	1.000	0.982	1.000	1.000	1.000	0.930
20	1.000	1.000	0.990	1.000	1.000	1.000	0.960
21	1.000	1.000	0.995	1.000	1.000	1.000	0.975
22	1.000	1.000	1.000	1.000	1.000	1.000	0.990
23	1.000	1.000	1.000	1.000	1.000	1.000	1.000
24	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 2. Natural mortality rate for the North-Atlantic redfish as being the function of age : $M(i)$ is given by the expression (8), $M_1(i)$ after the left branch of the $M(i)$ curve having been corrected.

Age of redfish, years	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
$M(i)$	0.478	0.384	0.310	0.252	0.206	0.171	0.143	0.123	0.108	0.099	0.094	0.092	0.095	0.100	0.108	0.119	0.131	0.146	0.163
$M_1(i)$	0.214	0.195	0.179	0.164	0.143	0.134	0.113	0.102	0.102	0.099	0.094	0.092	0.095	0.100	0.108	0.119	0.131	0.146	0.163

Table 3. The f FR(i, 1981) function for the redfish fishery in divisions IIa and IIb in 1981.

Age of redfish, years	6	7	8	9	10	11	12.... 24
FR(i, 1981)	0.008	0.032	0.112	0.440	0.680	0.920	1.000...1.000

Table 4. Resulting values of the criteria ζ, λ, $\varkappa$, φ, ψ based on three modelling runs of the system "stock - fishery" for the redfish S. mentella T. of divisions IIa and IIb in the NEA.

Mesh size, B, mm	Period, T_{fc}, years	ζ		λ		$\varkappa$		φ		ψ	
		ζ_8	ζ_{20}	λ_9	λ_{21}	$\varkappa_8$	$\varkappa_{20}$	φ_8	φ_{20}	ψ_8	ψ_{20}
The first calculation run when it was suggested that $M(i) = 0.1$											
98	-	0.142	0.143	0.348	0.357	0.088	0.088	0.408	0.402	0.200	0.201
108	16	0.115	0.122	0.371	0.395	0.089	0.089	0.309	0.308	0.150	0.159
116	17	0.101	0.110	0.397	0.428	0.090	0.090	0.254	0.258	0.125	0.139
120	18	0.108	0.116	0.387	0.414	0.090	0.089	0.280	0.281	0.139	0.149
125	18	0.095	0.106	0.409	0.441	0.090	0.090	0.234	0.240	0.118	0.131
128	18	0.108	0.116	0.385	0.411	0.090	0.089	0.280	0.282	0.138	0.149
134	18	0.097	0.106	0.407	0.440	0.090	0.090	0.237	0.241	0.119	0.132
The second calculation run with $M(i) = -\ln\left[7.4(\exp(-0.05\,i) - \exp(-0.07\,i))\right]$											
98	-	0.140	0.127	0.362	0.322	0.175	0.189	0.387	0.395	0.194	0.177
108	∞	0.118	0.109	0.380	0.353	0.173	0.183	0.311	0.310	0.155	0.143
116	∞	0.106	0.101	0.407	0.383	0.170	0.179	0.261	0.262	0.134	0.127
120	∞	0.112	0.105	0.397	0.371	0.171	0.181	0.283	0.284	0.144	0.135
125	∞	0.101	0.097	0.418	0.396	0.168	0.177	0.241	0.245	0.125	0.121
128	∞	0.112	0.105	0.394	0.368	0.171	0.181	0.285	0.285	0.144	0.135
The second calculation run when it was suggested that $M(i) = M_1(i)$											
98	-	0.140	0.136	0.349	0.337	0.123	0.125	0.401	0.402	0.196	0.190
108	24	0.114	0.115	0.370	0.373	0.124	0.124	0.310	0.308	0.150	0.151
116	31	0.101	0.105	0.396	0.404	0.123	0.122	0.256	0.259	0.127	0.132
120	33	0.108	0.110	0.386	0.391	0.123	0.123	0.281	0.283	0.139	0.142
125	31	0.096	0.101	0.407	0.418	0.123	0.122	0.237	0.242	0.119	0.125
128	23	0.108	0.110	0.383	0.389	0.123	0.123	0.282	0.283	0.139	0.141
134	31	0.097	0.101	0.406	0.417	0.123	0.122	0.239	0.242	0.120	0.125

LEGENDS TO THE FIGURES

Fig. 1. Catch, commercial and spawning stock biomasses, criteria ζ_1 and λ_1 for the redfish of divisions IIa and IIb in North-East Atlantic for years 1971 - 1981.

Fig. 2. Mean length of age groups for the redfish stock of divisions IIa and IIb in the NEA (NBIS key).

Fig. 3. Fraction of redfish at age retained by commercial trawl codends with different mesh size.

Fig.4. Natural mortality rate at age for redfish of the NEA stock.

Fig. 5. Dependence of the criterion T_{fo} on new mesh size if the redfish fishery in divisions IIa and IIb of the NEA would be transited from the codend's mesh size B_o = 98 mm to larger ones.

Fig. 6. Curves of relative losses or gaines in catches during transient period for redfish of divisions IIa and IIb in the NEA if the fishery would be transited from the codend's mesh size B_o = 98 mm to larger ones : a) provided that $M = 0.1$; b) provided that $M = -\ln\left[7.4 \cdot (\exp(-0.05\,i) - \exp(-0.07\,i))\right]$.

Fig. 7. Dependence of the criterion ζ_{cn} on λ_{n+1} in calculation variants for the redfish fishery in divisions IIa and IIb of the NEA : a) when n = T = 8 years - $\zeta_8 - \lambda$; b) when n = T = 20 years - $\zeta_{20} - \lambda_{21}$.

Fig. 8. Dependence of the criterion φ_n on ζ_n in calculation variants for the redfish fishery in divisions IIa and IIb of the NEA : a) when n = T = 8 years - $\varphi_8 - \zeta_8$; b) when n = T = 20 years - $\varphi_{20} - \zeta_{20}$.

Fig. 9. Dependence of the criterion ψ_n on ζ_n in calculation variants of the redfish fishery in divisions IIa and IIb of the NEA : a) when n = T=8 years - $\psi_8 - \zeta_8$; b) when n = T = 20 years - $\psi_{20} - \zeta_{20}$.

Fig.10. Dependence of the criterion ζ_{20} on χ_{20} for red-fish fishery in divisions IIa and IIb of the NEA.

DRAWINGS OF THE DOTS IN THE FIGURES 7 - 10

Mesh size, B , mm	Natural mortality rate at age, M (i)		
	M = 0.1	M = M(i)	M = M_1(i)
98	⧗	◇	○
108	⬙	Φ	□
116	◒	⊖	△
120	⬓	⊠	●
125	◭	×	■
129	⌖	σ	▲
134	♉	⧓	◆

— · — · — Pareto frontier

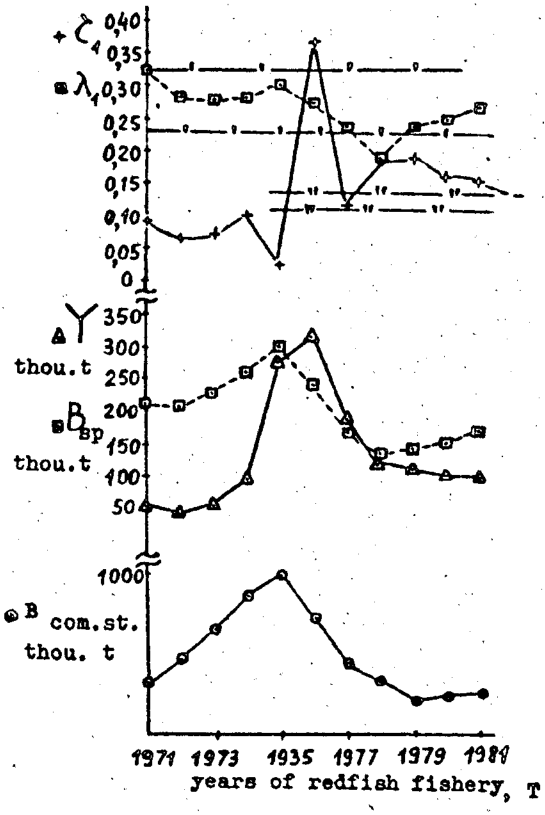
+ ζ₁
0,40
0,35
λ₁
0,30
0,25
0,20
0,15
0,10
0,05
0
Y
thou.t
350
300
250
200
B_BP
thou.t
150
100
50
1000
B com.st.
thou. t
1971
1973
1935
1977
1979
1981
years of redfish fishery, T

FIG. 1

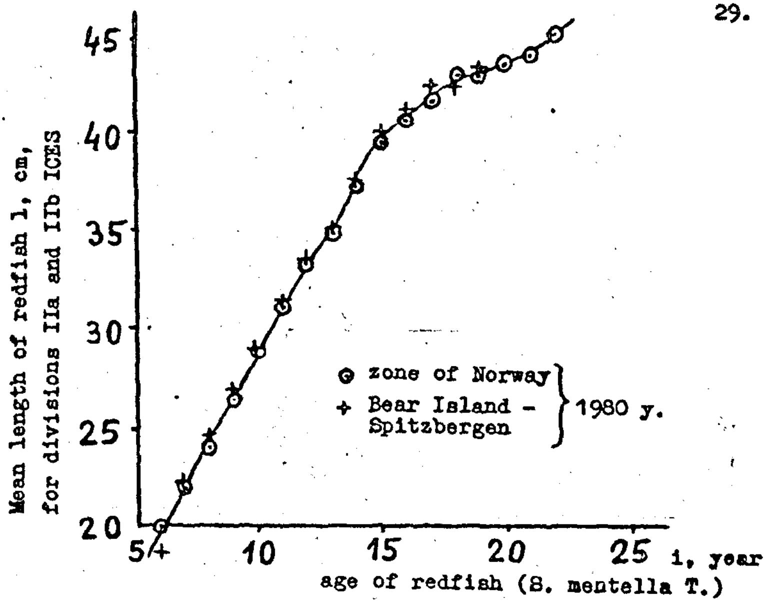
Mean length of redfish l, cm,
for divisions IIa and IIb ICES
45
40
35
30
25
20
5
10
15
20
25
i, year
age of redfish (S. mentella T.)
zone of Norway
Bear Island - Spitzbergen
1980 y.

FIG. 2

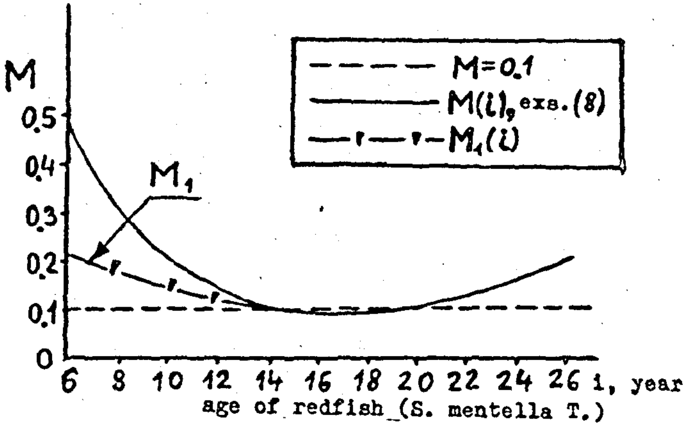
M
0,5
0,4
0,3
0,2
0,1
0
M=0.1
M(i), exs. (8)
M1(i)
M1
6
8
10
12
14
16
18
20
22
24
26
i, year
age of redfish (S. mentella T.)

FIG. 4

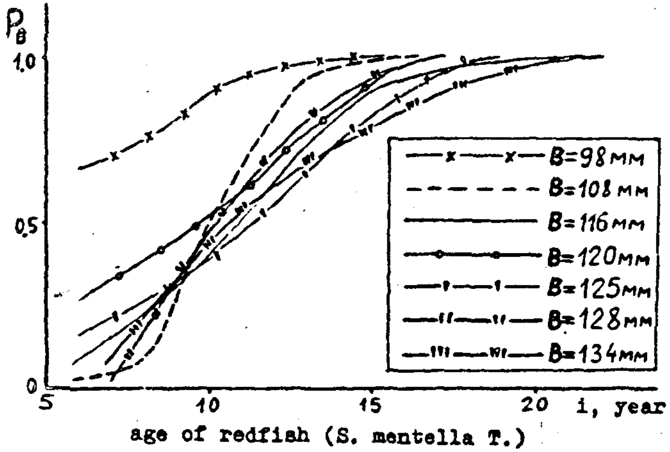
P_B
1,0
0,5
0
5
10
15
20
i, year
age of redfish (S. mentella T.)
B=98мм
B=108мм
B=116мм
B=120мм
B=125мм
B=128мм
B=134мм

FIG. 3

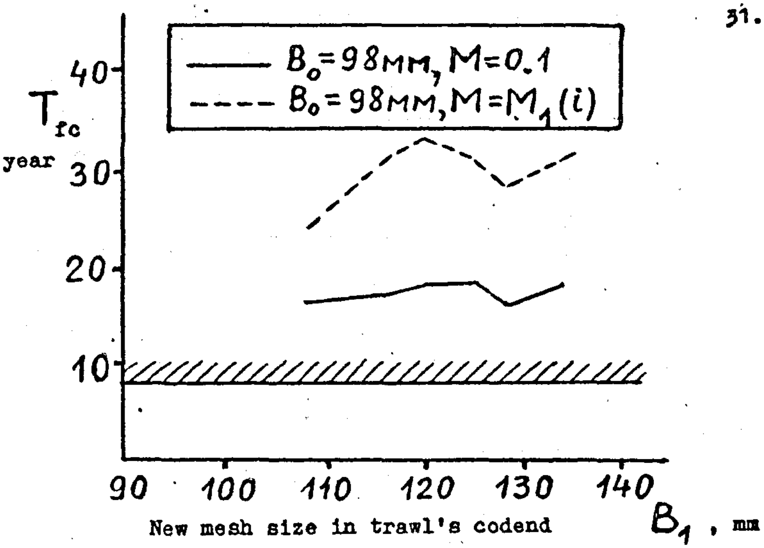
B_o=98мм, M=0.1
B_o=98мм, M=$M_1(i)$
T_{fc}
year
40
30
20
10
90
100
110
120
130
140
New mesh size in trawl's codend
B_1, mm

FIG. 5

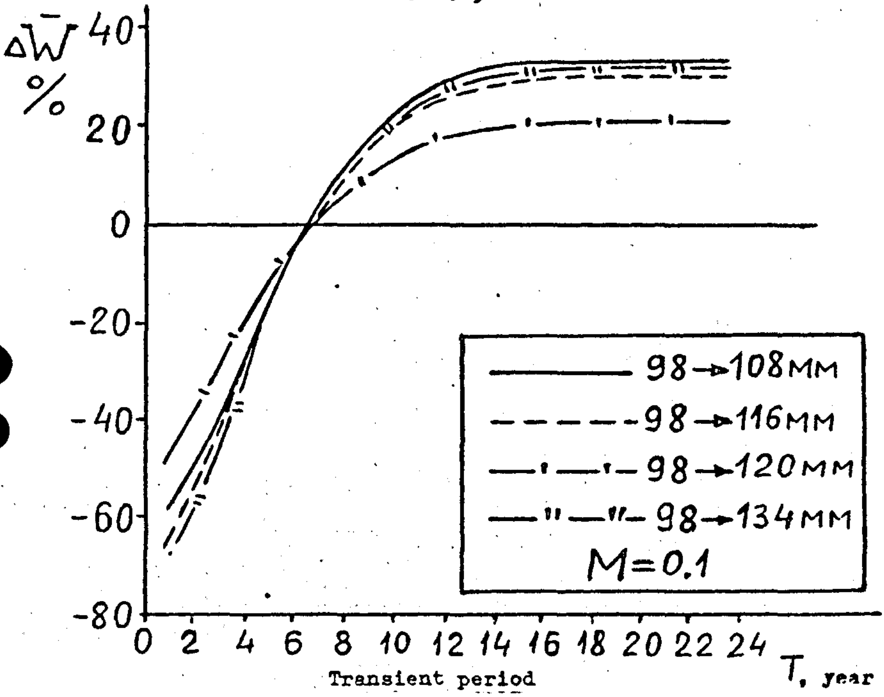
$\Delta\bar{W}$
%
40
20
0
-20
-40
-60
-80
98→108мм
98→116мм
98→120мм
98→134мм
M=0.1
0
2
4
6
8
10
12
14
16
18
20
22
24
Transient period
T, year

FIG. 6a

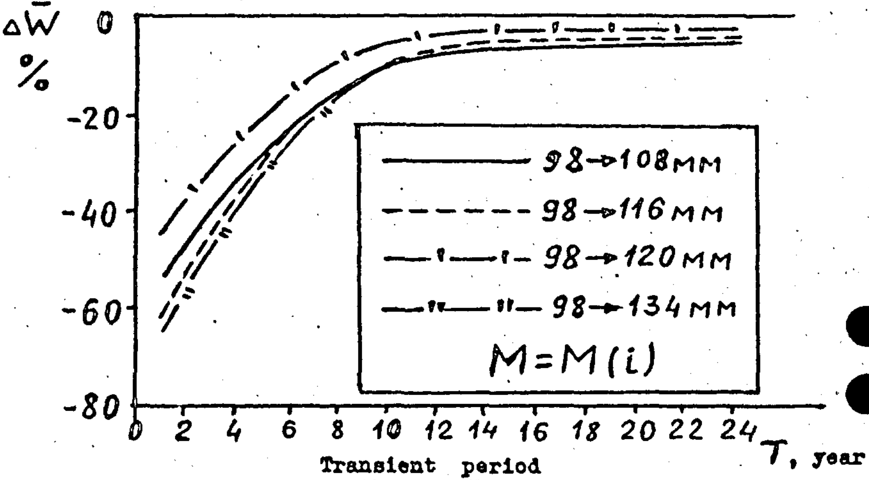
ΔW̄ %
0
-20
-40
-60
-80
0 2 4 6 8 10 12 14 16 18 20 22 24
Transient period
T, year
98→108 MM
98→116 MM
98→120 MM
98→134 MM
M=M(i)

FIG. 6b

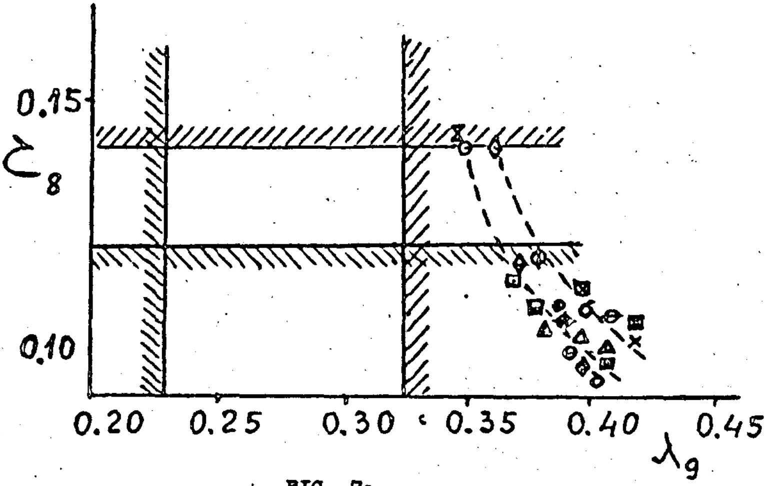
0.15
0.10
ζ₈
0.20
0.25
0.30
0.35
0.40
0.45
λ₉

FIG. 7a

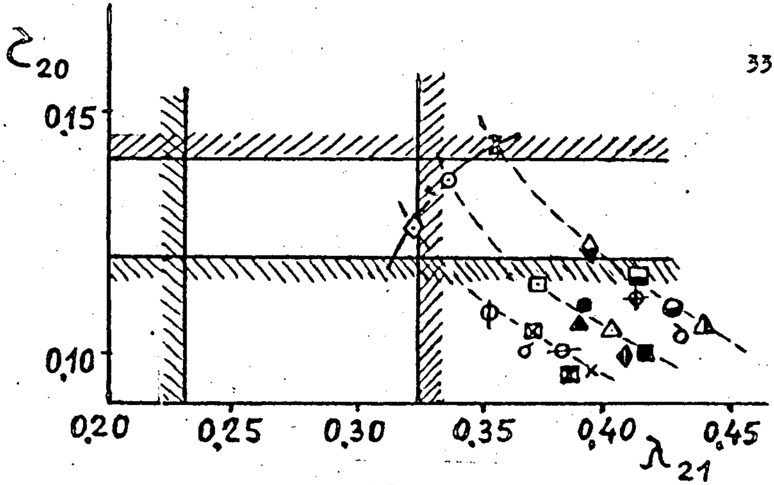
ζ_{20}
0,15
0,10
0,20
0,25
0,30
0,35
0,40
0,45
λ_{21}

FIG. 7b

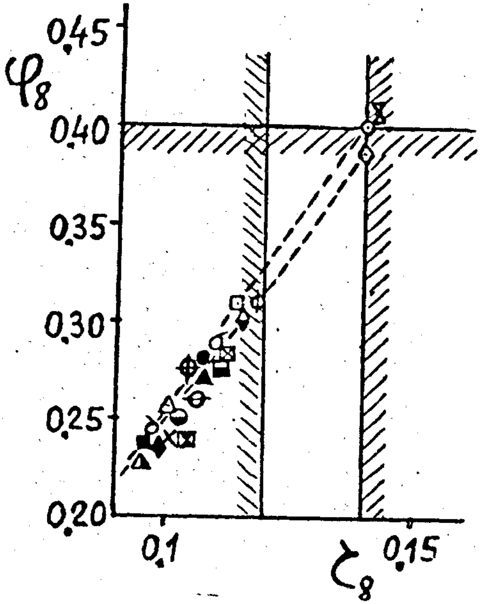
φ_8
0,45
0,40
0,35
0,30
0,25
0,20
0,1
ζ_8
0,15

FIG. 8a

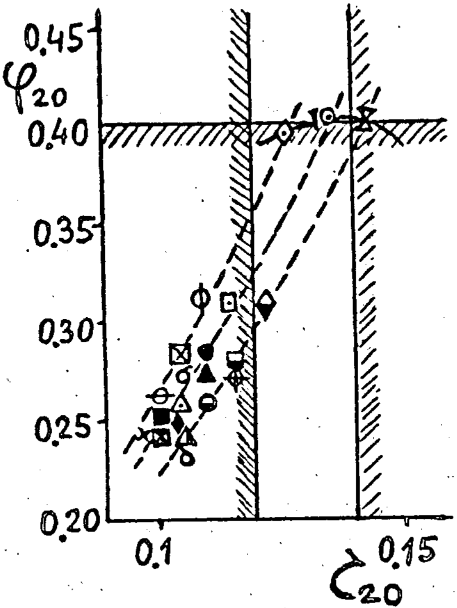
0.45
φ_{20}
0.40
0.35
0.30
0.25
0.20
0.1
0.15
ζ_{20}

FIG. 8b

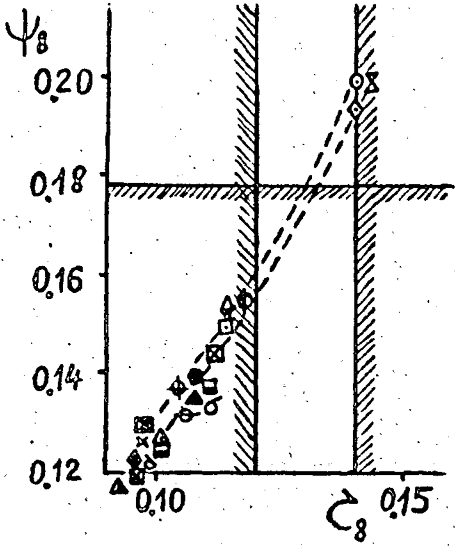
ψ_8
0.20
0.18
0.16
0.14
0.12
0.10
ζ_8
0.15

FIG. 9a

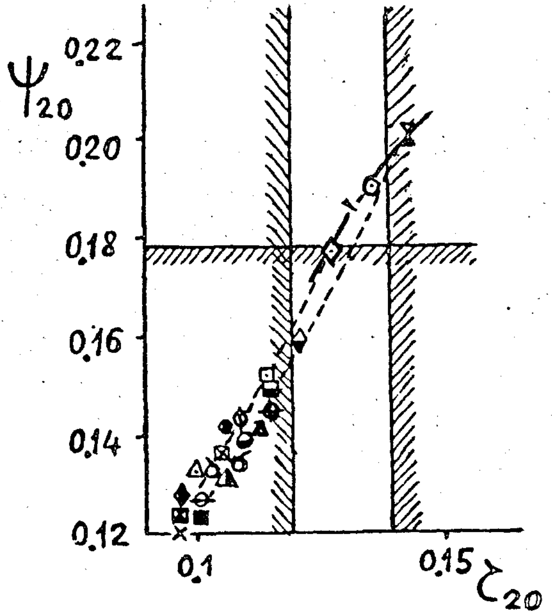
ψ_{20}
0,22
0,20
0,18
0,16
0,14
0,12
0,1
0,15
ζ_{20}

FIG. 9b

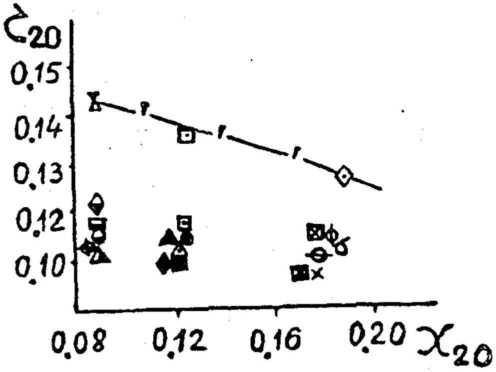
ζ_{20}
0,15
0,14
0,13
0,12
0,10
0,08
0,12
0,16
0,20
χ_{20}

FIG. 10

Подписано к печати 27/УI I986 г. Заказ 323
Объем 2,25 п.л. Формат 60х84 I/I6 Бесплатно Тираж 265

Ротапринт ВНИРО
I07I40. Москва, Верхняя Красносельская, I7