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Resources estimation

AN ESTIMATION OF THE BALTIC COD STOCK PRODUCTION

OCENA PRODUKTYWNOŚCI STADA DORSZA BAŁTYCKIEGO

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In this paper, the author describes several "simple production models" as formulated by Schaefer (1954), Fox (1970, 1974), and Pella and Tomlinson (1969). On the basis of fishery statistics on Baltic cod the volume of the annual maximum sustained yield was estimated. This volume varies from 145 to 160 thousand tons depending on the model applied.

INTRODUCTION

The magnitude of a cod stock[1] supporting fisheries of coastal countries depends both on the species' biology and environmental "capacity" understood as an interaction of the space available, food, and shelter. When the stock reaches its maximum abundance capable of maintaining itself under given environmental conditions, its increase equals zero. A new individual can join the stock only if another one, a member of it so far, is eliminated. When the stock is reduced below its maximum abundance, possibilities of existence emerging for new individuals will make an impression of the stock striving to attain the maximum through an increase in reproduction and individual growth rate as well as a decline in the natural mortality. This reasoning leads to a conclusion that the

[1] As a stock the author considers a group of fishes spawning within the same area and time, the group being replenished by spawning and reduced as a result of mortality (not by emigration). Basic features such as growth rate, mortatity and recruitment are similar within the stock.

greatest absolute increase in the stock, further referred to as the "**stock production**", is characteristic of a certain stock magnitude lying between zero and the maximum abundance.

There is always a threat that the fishery, equipped with modern techniques, will reduce the stock below an abundance able to ensure the maximum production. A biological extermination of a stock is not likely to occur in most commercial species, it is nevertheless possible that a stock can be driven to a stage equal in practice to its non-existence. Given some time without any human interference, the stock will recover to a state when fishing is profitable again. If, on the other hand, the stock is not allowed to reach a certain abundance, an increasing fishing effort will not result in a rising catch, on the contrary: the catch will fall.

Thus the exploitation set at a level ensuring a permanent maximum yield has become the aim of man's activity since the time when he realised that catches of defined fish species were not only limited but also could be drastically reduced. In spite of the fact that the phenomenon of self-recovery is the feature of living marine resources, it has not been possible so far to control the process successfully.

Conclusions on trends in quantitative changes taking place in a stock, which we are able to draw, result from speculations based on application of the natural facts to invented situations. While engaging ourselves in this sort of speculations, we do not know and/or are not able to comprehend all the factors and laws governing the stock in nature. We, then, create a model of a stock and, by introducing the facts observed in nature to this model, calculate changes occurring, their results being interpreted so as if the stock conformed in its responses to the laws ruling our model. Our aim is to answer the question what measures proposed for regulating man's impact on the stock can bring about the greatest gains obtained through making use of the productive capabilities of the stock. The process of defining and exercising these measures is commonly known as the **rational management of living resources**[2].

A MODEL APPROACH TO CHANGES OCCURRING IN THE EXPLOITED FISH STOCK

Model approaches to quantitative evaluation of changes taking place in any fish stock can be divided into two groups. One of them comprises models treating a population (stock) as an entity, no account of its structure being taken, while the models dealing with a stock as with a sum of individuals differing in a number of their biological features make up the other group. In this case, factors increasing and decreasing the stock are

[2] In the present paper, the author's understanding of the rational management of living resources includes introduction of fishery-regulating measures that would ensure the potential maximum yield to be maintained over many years. An alternate point of view as to the object of fishery regulations concerns optimising the economic activity of fisheries exploiting a given stock rather than the biological resources protection directly.

expressed as exponents and as such permit a rate of instantaneous changes to be determined.

The present paper is an attempt to assess the impact of fisheries upon the Baltic cod stock using some of known models of the first group. These models are traditionally assumed more "primitive" as they give lesser chance to predict stock's responses of fishery when compared to the models of the other group, called also the analytical ones.

In the present author's opinion, the view as expressed above is justified only when the indices required by an analytical model can be realistically estimated. On the contrary, when the range of these indices is only speculated upon, the model is used as a mere mathematical exercise, in which case the results obtained are risky to be equalled to the really existing ones. This being the case, the "primitive" models of stock production may yield more reliable results to be possibly used when deciding on measures limiting the influence of fisheries upon the stock.

A general mathematical expression of a simple model of stock production assumes the increase of the stock in time, dP/dt, to result from a difference between the natural growth and exploitation rates (Schaefer, 1954, 1957; Fox, 1970)

$$dP/dt = P_t g(P_t) - P_t h(f_t) \tag{1}$$

where: P_t is a population in time t

$h(f_t)$ is fishing mortality caused by f_t fishing effort units

$g(P_t)$ is growth (production) rate of the population, combining the effects of reproduction, individual growth, and natural mortality.

Assuming a standardisation of nominal fishing effort such as $gf_t = F_t$ where F_t is the instantaneous fishing mortality coefficient and q is constant (coefficient of catchability), and equalling the differential equation to the difference of functions when Δt is one year over which the population attains a mean value of $\bar{P}$, we obtain

$$\Delta P/\Delta t = \bar{P} g(\bar{P}) - gf\bar{P} \tag{2}$$

When formulating the fundamentals of his model of changes in the stock growth Schaefer (1954) assumed the stock growth rate $g(\bar{P})$ to correspond to the logistic function of growth

$$g(\bar{P}) = k_1 (L - \bar{P}) \tag{3}$$

where: k_1 is a constant coefficient of the population growth rate

L is the environmentally controlled maximum volume of the population.

In case of the annual catch being equal to the stock size, the annual increase in the stock $\Delta P/\Delta t = 0$, to equation (2) takes on a form of

$$0 = k_1 (L - \bar{P}) - qf\bar{P} \tag{4}$$

If we assume that the catch per unit effort ($\bar{U}$) is proportional to the stock volume, the latter can be replaced by $\bar{U}/q$. As a result of transformations of the equation (4) we will obtain a linear equation relating the catch per unit effort to fishing effort under the equilibrium yield conditions

$$\bar{U}_e = a - bf_e \tag{5}$$

where: a and b are constants representing transformed constants L, q, and k of the equation (4).

The amount of equilibrium yield Y_e is a product of the righthand side of the equation (5) and f_e. To formulate a model in this way calls for the following simplifying assumptions:

1. At the constant rate of exploitation, a population will achieve a state where, on the average, it will not change in size or characteristic;
2. Regardless of peculiarities in the stock age distribution, the mortality rate resulting from a unit fishing effort applied does not vary;
3. Regardless of efficiencies exhibited by various fishing gear, the total fishing effort may be expressed in standard units.

If the catch and fishing effort statistics corresponding to several instances of equilibrium in the stock exploited are available, the coefficients a and b are easy to determine. There is, however, a difficuty emerging from the fact that the statistics available cannot be related to the actual period of stock equilibrium.

Schaefer (1957) proposed a method for estimating the equation parameters, making it possible to use data corresponding to a transient rather than stable status of the stock, the following assumptions being additionally adopted:

1. Changes in the stock bear an immediate effect on its growth. In other words, there is no time lag between a change in the stock volume and a change in the recruitment, growth rate, and natural mortality;
2. Alternations in the age structure of the stock have a negligible effect on its growth rate - $P_t g(P_t)$.

The method merely substitutes the difference between two equations for the differential equation (1), the next step being to solve these equations through successive approximations. Series of data collected over many years are required here, the method being very laborious when only a simple calculator is used.

Fox (1970) has postulated to adopt the Gompertz growth formula to express the self-regulated growth of the stock

$$g(\bar{P}) = k_1(\ln L - \ln \bar{P}) \tag{6}$$

In consequence, parallel to the Schaefer model the following equation is obtained:

$$U_e = a\,e^{-bf_e} \tag{7}$$

According to this approach a decrease in catch per unit of fishing effort is not in a direct proportion to an increase in fishing effort. The equilibrium yield curve is, on the contrary to the Schaefer model, asymmetric and, having reached its maximum, shows a slower decline with f_e increasing. Similar difficulties as in the Schaefer model are encountered when the values of a and b are being estimated.

Gulland (1969) states that data representing a transient state (and not that of the equilibrium) of the stock are possible to fit through measurements of the fishing effort which would correspond to the catch per unit effort values observed in calendar years, should the equilibrium be attained.

When we have in hand a series of data such obtained, we are able to determine parameters of the equilibrium equation on the basis of either the Schaefer or Fox model.

Pella and Tomlinson (1969) introduced a more flexible form of the equation (1) in which $g(P_t)$ was replaced by $HP_t^m - KP_t$; ; thus the equation is now

$$dP/dt = HP_t^m - KP_t - qf_tP_t \tag{8}$$

where: the constant m reflects interactions between individuals in the stock, and the constants H and K can be greater or less than zero, depending on m. Integrating the differential equation (8) and eliminating the variable t (the stock is assumed to have a tendency to compensate for the loss of its biomass and attain the equilibrium over the sufficiently long time t) we obtain the equilibrium yield equation

$$Y_e = qf\left(\frac{qf+K}{K}\right)^{\frac{1}{m-1}} \tag{9}$$

To estimate the parameters of this equation requires the usage of a computer with an ample memory. The method recommended by the authors of the model involves searching, through successive approximations, of the values that would minimalise the discrepancy between the observed catches and those predicted by the equation the parameters of which are being looked for.

The equation constans estimated in the above-mentioned way allow -- similarly to the Schaefer and Fox models to determine certain quantities characteristic for the stock and being of a considerable importance when fishery regulations are considered namely: the maximum sustained yield and optimal fishing effort making it possible to maintain the stock at the level that will ensure the maximum sustained yield.

If m equals 2, we are dealing with a specific case when the stock acts as predicted by the Schaefer model. When m is less than 2 and tends to 1, the equilibrium yield after its peak shows a slower decline with the fishing effort increase (the Fox equation). Conversely, when m is considerably greater than 2, the curve representing the equilibrium yield falls very steeply having reached its maximum.

The Pella and Tomlinson model is advantageous by its flexibility when treating a combination of factors affecting the stock response to a human influence.

When constructing the models described above, the stock's susceptiblity to fishing effort was assumed to be stock size independent (q = constant). Fox (1974) has proven that a situation is not impossible (and in fact observed in nature) when q alters with the stock size following the equation

$$q = rP^{-s} \tag{10}$$

When s differs from zero, the Pella and Tomlinson model equation describing the catch per unit effort/fishing effort relationship will, under the equilibrium conditions, adopt a complicated form of

$$f = a' \bar{U}^{b'} + c' \bar{U}^{d'} \tag{11}$$

where:

$$a' = \frac{H}{\left(\frac{s+2}{s+1}\right) r}$$

$$b' = (m-1-s)/(s+1)$$

$$c' = \frac{K}{\left(\frac{s+1}{s+2}\right) r}$$

$$d' = -s/(s+1)$$

Should s be less than zero (the effective catching ability of a unit fishing effort increases with the stock size decrease), the equilibrium yield curve would tend to zero having passed its maximum. Thus we are dealing with an additional critical point which is important to the fishery management.

This point corresponds to such level of fishing effort reached that afterwards only a dramatic reduction of catch would prevent the stock from extinction.

ESTIMATIONS OF BALTIC COD STOCK PRODUCTION

Parameters of simple production models for Baltic cod were estimated basing on fishery statistics over 1961–1973 published by Elwertowski and Netzel (1971), Table 1.

Table 1

Baltic cod catches statistics (Baltic proper with the Arkona region), after Elwertowski and Netzel (1975)

Year	Catch (t)	Catch per unit of fishing effort (t day fished of a 25 m boat) (days fished)	Total fishing effort (days)
1961	117 100	0.956	122 489
1962	121 685	1.135	107 211
1963	133 580	1.344	99 389
1964	106 549	1.056	100 898
1965	116 219	0.984	118 109
1966	139 472	1.214	114 886
1967	140 528	1.386	101 391
1968	168 695	1.466	115 071
1969	165 095	1.848	89 337
1970	162 294	1.962	82 718
1971	128 047	1.570	81 558
1972	153 755	1.896	81 094
1973	151 936	1.537	98 852

The authors were the first to estimate the maximum sustained yield for the Baltic cod fishery and the optimalised fishing effort, 146 000 tons and 80 000 fishing days of a 25 m boat, respectively, under the equilibrium yield conditions. The present author wishes to state here that in his opinion the effective fishing effort was actually greater towards the end of the period considered than that recorded in the statistics, which resulted from technical and organisational improvements accomplished in fisheries. Elwertowski and Netzel's paper does not state whether the authors consider changes in fishing power of a fishing effort standard unit over the period discussed. The equilibrium yield curve given by them is skew and, after reaching its peak, shows a slope not as steep as in its rising part (Fig. 1).

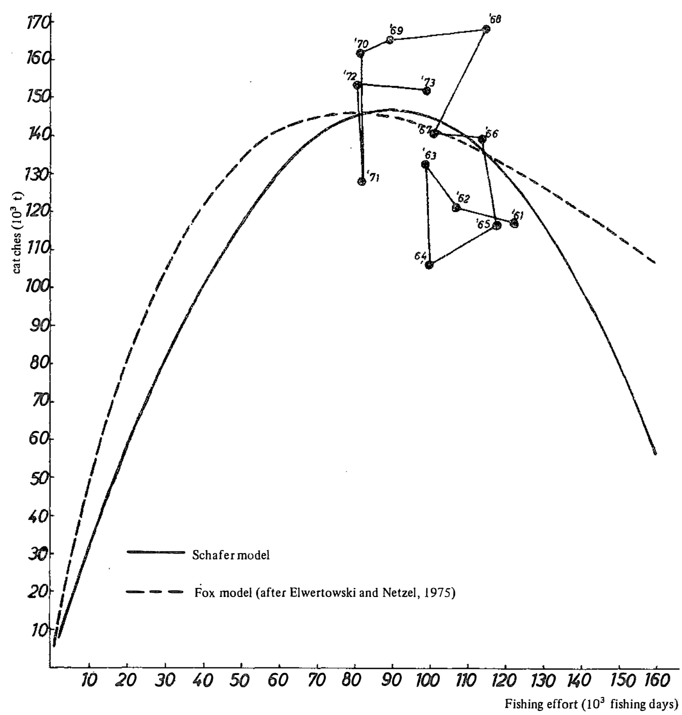

Fig. 1. Equilibrium yield curves for Baltic cod predicted by the Schaefer (1954) and Fox (1970) models

Basing on the above-mentioned catch statistics, the equilibrium yield equation parameters are estimated from the model proposed by Schaefer (1954). In this case, the maximum sustained yield of 148 000 tons can be produced during 89 000 fishing days of a 25 m boat; the equilibrium yield curve is symmetric here (Fig. 1).

The parameters of an equation describing the fishing effort/equilibrium yield relationship after the Pella and Tomlinson model of stock production (Pella and Tomlinson, 1969) were fitted by the GENPROD 2 program (Abramson, 1971) operated on a IBM 360 Model 40 computer. To take advantage of this program required is a number of data to be fed into the computer memory, the data corresponding to the anticipated extremal values of m, q, P_{max}, and U_{max}. The method can give satisfactory results provided the q value is chosen appropriately. In other words, obtaining representative estimates of m, K, H depends heavily on a proper range of q "guessed". Although the estimation of this kind is merely a guessing game, a wide range assumed nonetheless increases the computer's worktime.

The author wishes to draw the reader's attention to the fact of a limited application of the model resulting from the assumptions made when constructing the model.

In order to determine an approximate of q, the following procedure was adopted: basing on mean values of cod fishing mortality coefficients (M = 0.2) given by Kosior (1975) and on standardised fishing effort, a mean value of q over 1961–1973 was estimated at 0.0000075, its range being 0.00000596 0.00000895. When calculating the equation parameters fitting the Pella and Tomlinson model, the range of 0.00001--0.0000005 was assumed with m changing from 0.4 to 3.9.

At the first glance, the equilibrium yield curve of the parameters as follows: m = 1.6, q = 0.00000999, K = –3.3066, H = –0.001855 seems to be the best fit as far as the empirical data are concerned. In this case, the maximum sustained yield of 148 000 t can

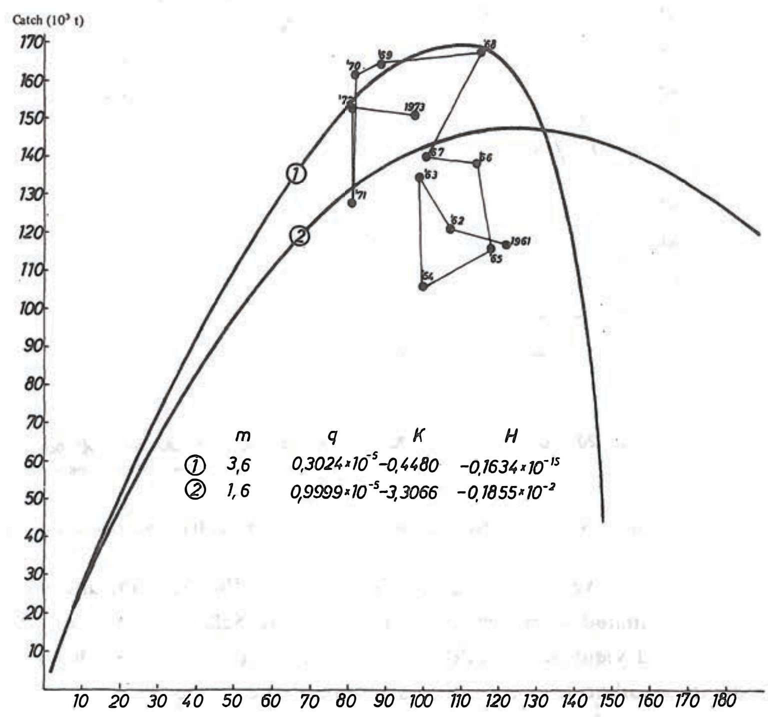

Fig. 2. Equilibrium yield curves for Baltic cod predicted by the general stock production model (Pella and Tomlinson, 1969)

be effected by the expenditure of 124 000 fishing days. The curve thus drawn (Fig. 2) is analogous in its slope to that resulting from the Fox model, the latter's maximum shifting to the right (towards a larger f).

The author, however, having cosidered the possibility of the remaining parameters reflecting realistically the stock response to human activities, is inclined to question the value of the parameters as true characteristics of the Baltic cod stock dynamics. The catchability coefficient, being very high, would indicate an optimal population size (provided that the population complies to the assumptions of the model) to be 120 000 t, which is less than the maximum sutained yield. The fact of the curve passing, in its certain section, between the points corresponding to observed values of catch and fishing effort is by no means a convincing evidence of the model expressing a true behaviour of the stock. Of the remaining nine values of m, for which the computations were made, only the curve of m = 3.6 passes in its part between the points reflecting the empiric values.

In this latter case, the maximum sustained yield is 171 000 t corresponding to 106 000 days fished. To reach this yield, the total size of the stock must be 529 000 t, the inadequacy of the model still being evident when the curve is compared to the distribution of points representing the really-existing situation.

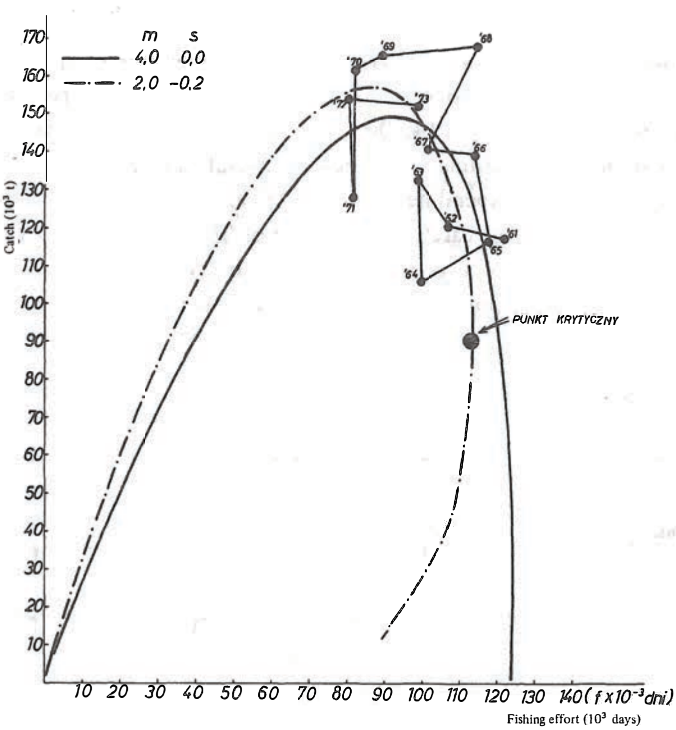

Fig. 3. Equilibrium yield curves for Baltic cod predicted by a model involving catchability coefficient variability (Fox, 1974)

Under such circumstances, the author decided to use a model taking into account the catchability coefficient q variability dependent on the stock size (Fox, 1974). The parameters were calculated similarly to the procedure proposed by Pella and Tomlinson (1969), that is through repeated calculations for a number of arbitrarily selected values of m and s; then the values were chosen that, in the author's opinion, would provide the best fit of the equilibrium yield curve to empirical data interpreted as representing the transient stage of the stock. Out of hundreds of parameters combinations two were chosen so as to reflect in the best way possible the stock's response to human exploitational activities. It is author's opinion that the catchability of the Baltic cod is related to the stock size and the catchability coefficient probably increases ($s < 0$) when the stock is at a low level. Consequently, having passed the maximum catch (160 000 t) the exploitation proceeding with a growing intensity leads to a quick drop in yields; should the critical point (114 000 fishing days) be passed, a catastrophic decrease is imminent unless the fishery is radically restricted (fig. 3).

When we assume the catchability coefficients independent of the stock size ($s = 0$), the best fit of a curve is observed for $m = 4.0$ (maximum sustained yield of 150 000 t); in such case the stock behaves according to the Pella and Tomlinson model assumptions.

DISCUSSION OF RESULTS

The above-mentioned results of calculating the parameters characterising both the size and response of the Baltic cod stock to fisheries evidence a capability of the stock to ensure a stable catch ranging within 145 000 -160 000 t p.a. (Table 2). Assuming average environmental conditions governing the stock's survival and growth a catch such as indicated can be attained by expending 80 000–115 000 fishing days. If the upper limit of fishing effort is exceeded, no catch stability is possible; on the contrary: the catches may be lower. This threat is of a considerable probability when the decisive effect of abiotic environmental factors upon young cod survival is taken into account.

Table 2

Indices of the Baltic cod stock exploitation under equilibrium yield conditions

Model		Maximum sustained yield (t)	Optimal fishing effort (days)	Critical values for:	
				fishing effort (days)	Catch (t)
Schaefer	(1954)	147 000	89 000	–	–
Fox	(1970)	146 000	80 000	–	–
Pella and Tomlinson	(1969)	148 000	124 000	–	–
Fox	(1974)	158 000	88 000	114 000	90 000

The available fishery statistics are not accurate enough to employ efficiently other mathematically – refined models. Thus the results obtained using general models of stock production in studies on the Baltic cod should be treated with due caution. Any assessment of a true fishing effort aimed at the Baltic cod stock over the recent 30 years is not likely to be accurately performed. Therefore the array of models available needs broadening, so does the number of indices with which to correlate the fisheries intensity and a true productive ability of the stock.

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OCENA PRODUKTYWNOŚCI STADA DORSZA BAŁTYCKIEGO

Streszczenie

W pracy scharakteryzowano podstawowe założenia przyjęte przy konstrukcji ogólnego modelu produktywności stada ryb. W oparciu o te założenia zaprezentowano najistotniejsze cechy czterech wybranych modeli sformułowanych przez Schaefera (1954), Foxa (1970, 1974), Pelle i Tomlinsona (1969).

Na podstawie statystyki połowów za lata 1961–1973 oszacowano wartości parametrów modeli zastosowanych przez autora do ilustracji zachowania się stada dorsza bałtyckiego na zmiany intensywności połowów.

Wielkość maksymalnego zrównoważonego połowu waha się w granicach 145–160 tysięcy ton, w zależności od przyjętego w rozważaniach modelu. Znacznie większą rozpiętość wykazuje wielkość optymalnego nakładu pracy połowowej (80–120 tysięcy standardowych dni połowowych).

Wyniki dotychczasowych badań nad dynamiką populacji dorsza bałtyckiego jak i te otrzymane w niniejszej pracy nasuwają wniosek, że wskaźniki eksploatacji stada określone na podstawie prostego modelu produktywności stada należy traktować z rezerwą. Do powyższego wniosku skłaniają autora następujące fakty: stosunkowo niewielka liczba lat dla których istnieją zapisy połowów jak i nakładu pracy połowowej, znana z badań innych autorów podatność stada na wpływ abiotycznych czynników środowiska, które w warunkach Bałtyku ulegają częstym zmianom.

Б. Драганик

ОЦЕНКА ПРОДУКТИВНОСТИ СТАДА БАЛТИЙСКОЙ ТРЕСКИ

Р е з ю м е

В работе приводится характеристика основных положений, принятых во внимание при составлении общей модели продуктивности стада рыб. На основе этих положений представлены наиболее существенные характеристики четырёх избранных моделей, составленных Шэфером (1954), Фоксом (1970, 1974), Пелле и Томлинсоном (1969).

На основе статистики уловов за 1961-1973 гг. определены величины параметров моделей, использованных автором для иллюстрации поведенческой реакции стада балтийской трески на изменения интенсивности лова.

Размеры максимального равномерного лова колеблются в границах от 145 до 160 тыс. т в зависимости от применённой при этом модели. Значительно больший диапазон имеет размер оптимальной промысловой затраты труда (80--120 тыс. стандартных промысловых дней).

Результаты проведенных до сих пор исследований над динамикой популяции балтийской трески и результаты, полученные в ходе этих исследований, приводят к выводу о том, что к показателям эксплуатации стада, полученным на основе простой модели продуктивности стада, следует относиться осторожно. К такому выводу автор приходит на основе следующих фактов: относительно небольшое количество лет, в течение которых учитывались размеры промысла и промысловой затраты труда; известная из исследований других авторов податливость стада к влиянию абиотических факторов среды, которые в Балтийском море подвергаются частым изменениям.

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