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Dynamics of Optimum Fishing Intensity on Fish with Strong Fluctuations in Abundance

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Abstract

The analysis of the dynamics both of the commercial stock biomass and catches at differring values of fishing mortality rates and recruitment has indicated that under certain conditions (rate of natural mortality growth with age) the rate of biomass reduction is increasingly growing and rate of catches growth decreasing with a reduction of the commercial stock abundance. Further analysis has shown that under the given conditions the level of the optimum fishing intensity is not an invariable value, but changes depending on the stock size, the fluctuations of which are controlled by natural factors.

Introduction

The determination of the optimum fishing intensity with regard for specific conditions is one of the key problems of the rational utilization of the fish resources. At present, the assessment of the possible or total allowable catch (a term adopted by ICNAF) is made by using of a certain constant value of the fishing mortality rate(F), which is proportionate to fishing intensity and independent of the exploited stock state. Meanwhile, in the papers of some scientists it has long since been suggested that a correlation exists between the stock abundance and the fishing intensity rate(Boyko,1962; Katchina,Prokhorov,1967; Ponomarenko,1969). It was noted, that the latter may increase in the years of high abundance and vice versa. In the paper by Rikhter(1970), a model of the catch size is designed given different value of F and varying recruitment independent of the parential stock size. As a result of the analysis of the obtained data, a suggestion can be made that the optimum fishing intensity decreases with low recruitment.

Of course, the problem posed requires a more thorough study, which is necessiated by an extensive introduction of various regulatory measures to the oceanic fishery, primarily in the shelf regions. In the present paper an attempt is made to do so with the purpose of gaining of more reliable data concerning the influence of natural fluctuations of the fish population abundance on the optimum fishing intensity rate.

Materials and Methods

Although we have been used to a word" optimum" occurring in different context in conformity with the catches or fishing intensity, it is not quite clear yet what is meant by this term, whereas, an accurate estimate of any concept can be made only if its subject-matter is known.

It is hardly necessary to give a detailed review of all ever existing concepts of the optimum catch in the present paper. Such review, perhaps, might have been a subject for an independent research, therefore, we'll confine ourselves to a brief consideration of current status of the problem.

According to Gulland(1968), the F_{opt} rate can be considered as a point, which corresponds to the greatest economic effect. The author also suggested the way of estimating of that point, which seems to be very conditional. This, evidently, is the reason why the method has not been recognized, although its basic idea is correct. Another attempt made by Gulland and Boerema(1972,1977) is more noteworthy. Proceeding from the economical approach, the authors suggested that the so-called $F_{0.1}$ be used as the optimum fishing intensity rate. This method was first used by the ICNAF Scientific Council in 1972(ICNAF Redbook,1972,PartI STACRES Proceedings), and in 1976 the Comission approved of the recommendation that total allowable catches be estimated at the level approaching $F_{0.1}$(ICNAF Ann. Rep. Vol.26,1976). Since then, the Scientific Council has eliminated the usage of the term "optimum fishing intensity" or "optimum fishing mortality"(F_{opt}) having replaced it by an expression $F_{0.1}$. Certainly, the Gulland's method is convenient for its simplicity and ease of application, however, some limitations in thus determining of the $F_{0.1}$ cannot be disregarded.

In proceedings of the simposium on "Optimum sustainable yield as a concept in fisheries management" held in 1974(Spec.Publ.No.9 American Fish. Soc.WashingtonD.C.1975) a concept of the "optimum catch" is interpreted in many ways. Nevertheless, not a single interpretation can be used as a guide for developing of methods of assessment of the optimum fishing intensity rate. A Dawson's definition(1979) is also of a general character.

In this respect some possibilities can be gained from the paper by Baranov(1960), who suggests that the optimum exploitation level be estimated from a dependence between the fishing intensity which is proportionate to operation expenses and the catches. As is evident from the analysis of this dependence, the catch begins to markedly lag behind the fishing intensity from a certain moment. It is the fishing intensity level corresponding to a given moment that can be taken as the optimum value.

The Baranov's idea was applied by Rikhter in his paper(1970), who has estimated F_{opt} using a dependence between the rate of the catch growth and the rate of operation expenses. This method giving a definite idea of profitability of the fishery at varying exploitation level is considered in the present paper.

The Baranov's approach to the determination of the optimum fishing intensity can be given the following wording:"Optimum intensity is such a level of commercial fishery, which, if exceeded, will result in a sharp reduction of the rate of the catch growth compared with the rate of the operation expenses growth".

Although this definition does not present an exhaustive explanation of the problem it allows to obtain a criterion for estimating of F_{opt} , which is indispensable for further modeling.

Modeling of catches of the fish with a relatively short life cycle(below 10 years) is based on the data on abundance of red hake(Urophycis chuss Walb.) age groups early in 1974(Rikhter,1977).

The maximum number of two-year-olds observed during all years of investigations(1965-1976) was taken as the initial recruitment level(R). Then the recruitment rate decreased to the minimum, which was also observed in the given period. Actually, a situation peculiar to species subject to strong fluctuations, when a depression is followed by a recruitment of poor year classes to the commercial stock a number of years running is modeled.

The instantaneous natural mortality rate(M) was taken as a coefficient increasing with age and decreasing as affected by the fishery. The size of the fish of 2-5 years old averaged 0.81 (Rikhter,1972). The examples of M increasing with age are given in the Ricker's paper(1975). Beverton and Holt(1957) note that M might change in both directions as the age is increased. According to theoretical calculations of Tjurin(1972), the natural mortality rate increases inevitably beginning from a certain age. As regards the change of M caused by a reduction of the commercial stock biomass which was induced by the fishery, this problem is still a question mark.

Nevertheless, all the assumptions appear to give a more precise estimate of the actual dynamics of abundance, commercial stock and catch sizes at varying fishing intensity and abundance than the models with a constant value of M.

The values of M used in our calculations are presented in table 1.

It is assumed that M remains unchanged under the influence of the fishery if the values of F are very small(0.1and0.2). Also the values of M remain constant for two-year-olds with increasing F. The explanation for the latter assumption appears to be based on the fact that actually the intensity of fishing of two-year-olds is considerably lower than that of older fish and is taken here as 25% of the total fishing mortality.

The following formulae were used in modeling:

a) $N_{i+1} = N_{i1}{-z}$ - for assessment of the commercial stock abundance

b) $C_i = N_i \frac{F}{Z} (1 - e^{-z})$ - for assessment of the catch size, where

N_i is the year class abundance at the beginning of the given year;

N_{i+1} is the year class abundance at the beginning of the following year;

C_i is the catch size from a year class in numbers;

Z is the total instantaneous mortality rate;

F is the instantaneous fishing mortality rate and

e is the natural logarithms base.

The numbers were converted to weight using the data on the mean weight of age groups.

A similar model was constructed for the population of fish with a long life history and strong fluctuations of year classes abundance. Directly applicable examples are the Atlantic-Norwegian herring and the Arctic-Norwegian cod. From the literaty data(Benko,1973;Borisov,1976;Vychrystjuk,1962;Maslov,1960;Garrod, 1967;ICNAF Redbook,1976, STACRES Proceedings) the parameters describing a certain hypothetical population possessing the characters of both stocks were selected. The fishery involves the individuals of 3 to 16 year-olds. The natural mortality rates are adopted from Borisov's paper(1976), the annual rate of loss in per cent being converted to the instantaneous mortality coefficients, Arbitrary coefficients of mortality for 3-5 and 15-16 year old fish were taken with regard for a trend towards their increase for first and last age groups(table2). The range of F varied from 0.10 to 0.50 at 0.05 intervals and an assumption was made that M decreases under the influence of the fishery. The initial abundance of age groups is taken as conditional(table3). The ratio, however, in some versions approximately corresponds to cod abundance in the Gulf of Saint Lawrence(ICNAF Redbook,1976, STACRES Proceedings). The initial(maximum) recruitment (number of 3 year old fish) was taken as 2500 conditional units and then it was assumed that the recruitment reduced continuously to the minimum level(100 units).

As in the previous case, a partial recruitment was introduced. It was assumed that the recruitment process ends by 6 years, as it is observed in cod(Garrod,1967), and beginning from that age the fish are subject to total fishing mortality. The previous age groups are affected by the following fishing intensity rates (% of the total): 3-10,4-60,5-90. Such a partial recruitment rate is assumed for a cod stock of the Gulf of Saint Lawrence(ICNAF Redbook,1976,STACRES Proceedings). The numbers of fish were converted to weight using the data on the mean weight of the Atlantic-Scandinavian herring age groups(Benko,1973).

Results

The dynamics of the commercial stock biomass at varying fishing intensity and recruitment is shown in table4. As is evident from the data, the rate of biomass reduction is increased with decreasing abundance following an assumption that the natural mortality rate increases with age (table 1). Accordingly, an increase is observed in total mortality rate(Z) on older age groups. Simultaneously, the stock is replenished by more and more poor year classes(as is evident from the model) and grows older. The commercial stock exhibits the above-mentioned regularity as the total mortality rate increases. An example of variation of age structure of stocks at reduced abundance is given in table 5 for a randomly selected value of fishing mortality(F=0.7).

The dynamics of catches and the rate of their growth compared with the rate of operation expenses growth at different fishing intensity levels and different recruitment is shown in table 4. From these data a conclusion can be made that the rate of catches growth falls as the stock abundance reduces. This regularity is a logical outcome from the previous one and needs no comment.

Thus, a difference between the rate of exploitation expenses and catches growth increases with decreasing stock size. Taking into account the Baranov's idea(1960) and the given circumstances it can be suggested that a specific optimum fishing intensity might exist for every commercial stock abundance level.

Lagging of the rate of catches growth behind the rate of operation expenses by 30% was conventionally taken as a criterion for estimating of F_{opt}. As is evident from the data, the fishing intensity may be very high($F>1.0$) in the period of the highest abundance($R=350-300$), thus appreciably exceeding the mean value of natural mortality amounting to 0.81 for the population studied (Rikhter,1972). Subsequent limited recruitment(250,200,150,100 and 50) results in a decrease of F_{opt} to 1.0;0.8;0.6;0.5 and 0.4 respectively.

Identical analysis was made of a situation characteristic of the species with a long life history and strong fluctuations of abundance. The regularities revealed before were observed this time as well. Cumulative rate of exploitation expenses and catches growth is given in table 7. The same criterion(30% lagging behind) was used in assessment of F_{opt}. The analysis of the given data showed that the maximum recruitment size(2000 and 1500) might be consistent with the highest fishing intensity ($F>0.50$). As the recruitment size diminishes, the value of F_{opt} also decreases and constitutes 0.50, 0.35 and 0.30 at recruitment levels of 1000, 500 and 100 respectively.

So, a suggestion that there exists a dependence of the optimum fishing intensity on the stock state of the fish species characterized by strong fluctuations of the year class abundance under certain conditions is confirmed. As is evident from the previous analysis, the final result is greatly affected by assumptions as regards the dynamics of natural mortality rate, which help to bring closer the theoretical and real situations.

Discussion

In our opinion, the specific character of F_{opt} for different stock sizes proves to be consistent with biological principles.

High abundance of a parent stock provides normal reproduction at the fishing intensity considerably exceeding the value of $F_{0.1}$, determined from the catch curve constructed by Beverton and Holt (1957). It should be noted that the anomalously high stock abundance may provide conditions that adversely affect the recruitment stability. In terms of the optimum fishing strategy , in such cases a reduction of the stock to a certain average level promoting the highest reproduction stability is desirable. The views suggesting the existence of optimum biomass for each population had been set out in Herrington's papers(Herrington,1944,cited by Beverton and Holt,1957). Later, they were further developed by Ricker(1954 1975). Theoretical aspects of this strategy of fishery management were also considered in more recent papers by Canadian scientists (Doubleday,1976;Lett and Doubleday,1976).

All the above-mentioned considerations give rise to a logical conclusion that the fishing intensity should be increased when the stock abundance exceeds the given optimum level. On the other hand, a marked decrease of the exploitation rate during depression, when the stock is replenished with a number of poor year classes, might provide protection to minimum abundance of producers required for maintenance of stable reproduction.

In our model, the importance of recruitment as a factor influencing a shape of the catch curve is rather clearly pronounced (Fig.1), while Beverton and Holt(1957) never considered recruitment from this viewpoint. This is quite reasonable, for at any recruitment rate the curves constructed using a simple catch model at constant value of M, although occupying different levels are always strictly parallel. Therefore, the values of F_{opt} or $F_{0.1}$ found on one and the same curve will be identical to the rest curves.

From the above-stated it can be concluded that the yield equation of Beverton and Holt is not always applicable for the analysis of the fish populations with strong fluctuations of abundance. So, F_{opt} or $F_{0.1}$ obtained using this equation may appear to be under-or overstated depending on the commercial stock abundance, which will affect the value of the total allowable catch.

At present it is difficult to say anything definite on the possibility of practical application of the dependence of the value of F_{opt} on the exploited population state. The major difficulty lies in producing a criterion for estimating of F_{opt} at different recruitment. Nevertheless, there might be a way out if, proceeding from biological and economic considerations, a sought for criterion be expressed as a certain value of a lag of the rate of catches growth from that of operation expenses growth for each investigated species.

Conclusions

1. The optimum fishing intensity level is not a fixed value, but changes depending on the stock size, the fluctuations of which are controlled by natural reasons.

2. Application of fixed value of F_{opt} may cause erroneous assessment of the total allowable catch of the species subject to strong fluctuation of abundance. This will result in underexploitation, on the one hand, and overexploitation, on the other hand, with possible disturbance of the reproduction process.

3. The total allowable catch of the species subject to strong fluctuations of abundance should be estimated using the specific value of the optimum fishing intensity for each stock size.

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Table 1 Dynamics of M values depending on the age and fishing mortality(F)

Age(F)	2	3	4	5	6
0,1	0,6	0,7	0,8	0,9	I,I
0,2	0,6	0,7	0,8	0,9	I,I
0,3	0,6	0,65	0,75	0,85	I,05
0,4	0,6	0,6	0,7	0,8	I,0
0,5	0,6	0,55	0,65	0,75	0,95
0,6	0,6	0,5	0,6	0,7	0,9
0,7	0,6	0,45	0,55	0,65	0,85
0,8	0,6	0,4	0,5	0,6	0,8
0,9	0,6	0,35	0,45	0,55	0,75
I,0	0,6	0,3	0,4	0,5	0,7

Table 2 Dynamics of M values depending on the age and fishing mortality (F)

Age(F)	3	4	5	6	7	8	9	10	II	12	13	14	15	16
0,10	0,22	0,16	0,14	0,13	0,12	0,12	0,13	0,15	0,19	0,22	0,29	0,36	0,43	0,60
0,15	"	"	"	"	"	"	"	"	"	"	"	"	"	"
0,20	"	"	"	"	"	"	"	"	"	"	"	"	"	"
0,25	0,19	0,12	0,10	0,10	0,09	0.09	0,10	0,11	0,14	0,19	0,22	0,27	0,32	0,45
0,30	"	"	"	"	"	"	"	"	"	"	"	"	"	"
0,35	"	"	"	"	"	"	"	"	"	"	"	"	"	"
0,40	0,11	0,08	0,07	0,06	0,06	0,06	0,06	0,08	0,10	0,11	0,14	0,18	0,22	0,30
0,45	"	"	"	"	"	"	"	"	"	"	"	"	"	"
0,50	"	"	"	"	"	"	"	"	"	"	"	"	"	"

Table 3 The data used for modeling of the population of the fish with long life history

Indices	Age, years													
	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mean weight, g	165	190	228	264	304	316	343	364	375	383	387	389	394	398
Abundance, cond. units	2500	1000	850	750	500	400	150	200	100	40	50	25	10	5

Table 4 The rate of decrease of the commercial stock biomass at varying values of F and recruitment (%%)

R	0,I	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	I,0
300 –	–	3,5	2,2	2,3	1,6	2,0	2,7	1,4	1,8	2,5
250	–	5,5	4,0	2,8	3,2	2,5	3,3	3,2	2,3	2,6
200	–	6,8	4,0	4,0	4,5	3,8	2,6	3,8	3,0	2,9
150	–	7,5	5,4	4,0	4,6	4,1	3,6	3,9	3,1	3,6
100	–	9,2	5,5	4,8	4,2	4,8	4,0	4,4	4,1	3,3
50	–	11,0	5,5	6,0	5,2	6,2	4,2	5,0	4,1	3,6

Table 5 Abundance of age groups and mean age of the stock at varying recruitment

Age, years					Mean age
2	3	4	5	6	
300	160	37	15	4	2,57
250	138	51	11	4	2,63
200	115	44	15	3	2,69
150	92	36	13	4	2,72
100	69	29	10	4	2,82
50	46	22	8	3	2,98

Table 6 Cumulative rate of operation expenses and catches growth at varying values of F and recruitment (%%)

R		F: 0,I	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	I,0
	Rate of operation expenses growth	–	91	134	161	180	194	206	216	224	230
	Rate of catches growth										
350	–	–	93	139	171	191	210	225	237	248	257
300	–	–	84	126	153	168	184	196	206	214	219
250	–	–	79	117	144	160	175	185	192	199	204
200	–	–	76	115	139	153	167	178	184	190	195
150	–	–	76	112	136	151	164	173	179	185	190
100	–	–	72	108	132	147	159	168	174	179	183
50	–	–	70	108	130	144	154	163	169	174	177

Table 7 Cumulative rate of operational expenses and catches growth at varying values of F and recruitment (%%)

R		F: 0,10	0,15	0,20	0,25	0,30	0,35	0,40	0,45	0,50
	Rate of operation expenses growth	–	46	76	98	115	129	141	151	160
	Rate of catches growth									
2000		–	46,8	77,3	101,8	119,3	133,5	147,4	157,6	166,5
1500	–	–	41,6	67,6	92,7	106,3	116,8	131,5	138,2	143,6
1000	–	–	37,6	60,2	86,1	96,8	104,6	120,4	124,7	127,9
500	–	–	33,8	53,2	79,6	87,6	93,0	109,4	111,6	112,8
100	–	–	30,1	46,1	72,4	77,8	80,7	97,1	97,1	96,3

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Fig. 1. A dependence of the catch on fishing intensity(F) at varying recruitment.

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Addendum

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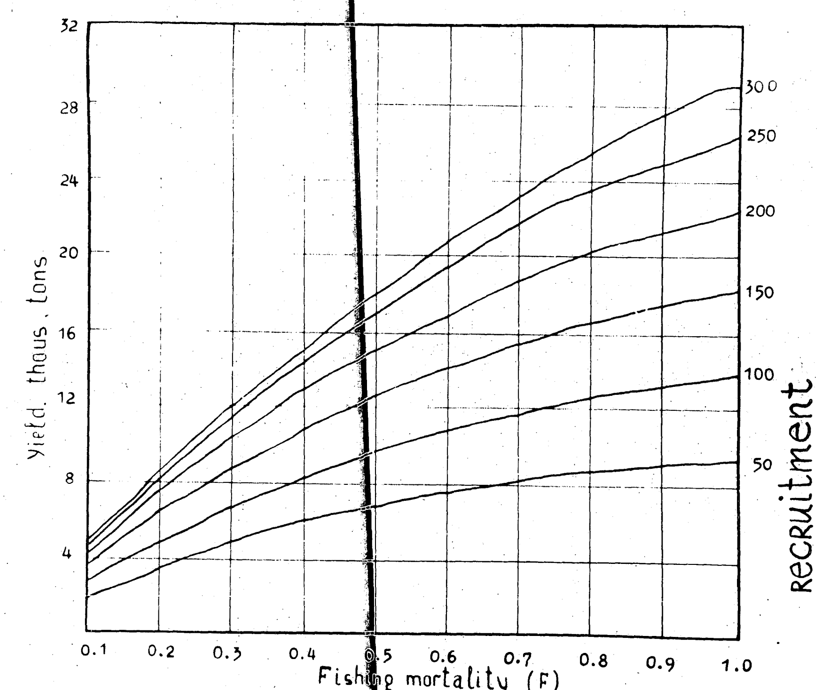
Please insert the following Fig. 1 on page 15 of SCR Doc. 81/VI/17.



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