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AN APPROACH TO ESTIMATING THE ECONOMIC EFFICIENCY OF ACOUSTIC SURVEYS

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INTRODUCTION

Acoustic survey is one of the methods of exploration of World Ocean biological resources. A survey gives information on stocks of commercial fish which, along with data of other investigations of resources, is used in planning international and national fishing operations. Annual expenses on carrying out acoustic surveys as well as economic return expected on the basis of intuition, amount to many millions of different currency units. In spite of heavy expenses and expected return, the conditions when the economic effect is positive as the result of an acoustic survey have not been clarified. Therefore, it is possible that some surveys are carried out in situations when they are economically unjustified and there may be situations when carrying out surveys is quite reasonable but no surveys are carried out. In both cases international and national fisheries sustain considerable losses. The cause of such a situation is that at the present time no approach to estimating the economic efficiency of acoustic surveys has been worked out. The authors paper have made an attempt to elaborate the basis of such an approach and to outline possible directions of its development. With this aim in view a number of assumptions and simplifying suggestions are made, and, as a matter of course a scheme of discussion is given which, in principle, can lead to the solution of this task.

The main idea of the paper can be formulated in the following way. Additional information on the stock of commercial fish obtained from the result of an acoustic survey allows errors in planning the catch next year to be reduced, which leads to decreasing losses inflicted on the fisheries. Economic effects of surveying is a reduction of losses minus surveying expenses. Carrying out a survey is justified if the expected economic effect is positive[1].

With the aim of estimating the value of losses due to errors in planning, the authors introduce the notion of economic significance of a population of commercial fish. The present day fishing is characterized by repeated exploitation of fish populations it is therefore proposed that the value of losses and the ultimate economic effect be estimated with regard to consequences of errors in planning during a number of years which will follow. The main aspects of estimating the economic efficiency of acoustic surveys are considered below. These are; planning the catch, estimation of planning errors, losses, economic return, expenses, and finally the ultimate economic effect.

PLANNING THE CATCH

When the abundance of a spawning stock decreases below a certain threshold the population productivity declines, which adversely tells on recruitment. This means that, as applied to each population, there is a maximum admissible value of annual withdrawal, the so-called Total Allowable Catch (TAC). If the requirement in a given species of commercial fish does not exceed the TAC, the real catch is determined by requirement. Such a situation occurs in decreasing frequency. At the present time requirements in all valuable fish species has exceeded the TAC of these species, however the real catch must not exceed the

TAC. With regard to these considerations it is assumed further on that maximal economic effect occurs when the annual catch is equal to the TAC.

Calculation of TAC value

This operation proceeds from the stock Q and optimal value of the coefficient of commercial withdrawal (K) by the formula

$$Y = QK. \tag{1}$$

To determine the TAC value for the next year it is necessary to know the forecast value of stock and the coefficient of commercial withdrawal.

Determination of optimal coefficient of commercial withdrawal

For the sake of simplicity it can be assumed that this characteristic is determined by mean lifetime of fish[2]. Dependence of the coefficient of commercial withdrawal on lifetime is given below and is used henceforth.

Mean lifetime, years	3	4	5	6	7	8	10	15	20	40
Optimal coefficient of commercial withdrawal, %	90	80	70	60	50	40	30	20	10	5

Forecasting the stock

This operation is made by biostatistical methods on the basis of analysis of population abundance dynamics. Estimates of the stock allowing its dynamics to be ascertained can be obtained with the help of ichthyological and fishing, or acoustical information. Both kinds of information have errors which lead to corresponding errors in forecasting the stock and in determining the value of TAC for the year to come.

ESTIMATION OF PLANNING ERRORS

In different conditions the degree of confidence of ichthyological and fishing, or acoustical estimates of the stock may vary markedly.

Estimation of errors of ichthyological and fishing information

Values of errors greatly depend on how profoundly the fish is studied. Estimates of the stock of fish with a long lifecycle in which abundance of most age groups can be determined by fishing data are usually more precise than estimates of the stock of fish with a short lifecycle in which the main and at the same time the least studied part of the population is made up by recruitment. In expert opinion, errors in estimates of stocks of long lifecycle fish most often are within the range of 10-50% while in short lifecycle fish they are within 50-100%. Henceforth it is assumed that as applied to a population on which an acoustic survey is planned to be made, the error of ichthyological and fishing estimates of the stock δ_{IF} is known.

Estimation of errors of acoustic information

The error of estimating the stock is made up by methodological error (error of the acoustical method of determining concentration density) and tactical error (error accounted for by the sampling from all possible density values). The methodological error mainly ensures from how the reflectivity of the surveyed fish are studied, and from the quality of applied devices, conditions and character of registration. Henceforth the value of this error δ_M is assumed to be known[3]. The tactical error depends on the size of the surveyed area, the degree of non-uniformity of the random concentration density field in this area, and the density of the grid of tracks[4]. The value of this error in fractions of one can be determined by the formula

$$\delta_T = \left(\frac{r\nu}{l}\right)^2, \tag{2}$$

where l is typical size area, ν = coefficient of variation of concentration density, r = distance between tracks.

Since the methodological and tactical components are statistically independent the expression for the ultimate error of acoustic estimates of the stock can be as follows:

$$\delta_A = \sqrt{\delta_M^2+\delta_T^2} = \sqrt{\delta_M^2+\left(\frac{r\nu}{l}\right)^4}. \tag{3}$$

ESTIMATION OF LOSSES

Let us introduce the notion of economic significance of a population as profit from the catch obtained from a given population during one year and equal to the TAC. The economic significance of a population can be calculated by the formula

$$ES = YP = QKP, \tag{4}$$

where P is profit per tonne of marine products which henceforth is conventionally taken as constant.

As a result of the fishing fleet implementing erroneous recommendations, the real catch in the given year differs decreasingly or increasingly from the true value of TAC. In other words, either undercatch or overcatch takes place which reduces the summary catch during the given year and a number of years that will follow. The value of losses incurred depends on the economic significance of the population and the degree of decrease in the summary catch. Now estimation of the effect of undercatch or overcatch on the value of catch in the years to come can be made only on the basis of expert opinion.

Estimation of undercatch consequences

In this case the situation is close to the situation when no fishing is carried out - the value of the stock is limited by environmental factors, by the food base in particular. Therefore it is believed that undercatch in the given year only slightly increases the future stock as compared with the stock which would exist if the catch were equal to the TAC. The catch in the years to come remains approximately the same as it would be in the absence of undercatch.

Estimation of overcatch consequences

As the result of overcatch, not only the commercial stock decreases but the abundance of the spawning stock declines as well. The first factor will be felt beginning from next year until overfished generations are the main component of the catch. The duration of the effect of the second factor is approximately the same as that of the first one but the second factor will be felt with a shift in time equal to the period from the birth of the fish until their entry into the commercial stock. The ultimate effect will be observed during a period approximately equal to the mean lifetime of fish. It can be conventionally assumed that the degree of reduction of the summary catch during the years that will follow is proportional to the degree of overfishing in the given year. It means that overestimation of the stock results in greater losses than equidimensional underestimation; further consideration is made in the application to overestimation. Proceeding from the above assumptions the following expression for calculating the value of losses is obtained:

$$EL = QKP\left[t-(1+\delta)-\frac{t-1}{1+\delta}\right], \tag{5}$$

where t is mean lifetime of fish, δ is error in fractions of one.

ESTIMATION OF ECONOMIC RETURN

The number of estimates of the stock minimally required for forecast is determined by the dynamics of the stock. As a rule, a series of acoustic surveys are made in the fisheries area. If the number of surveys in the series considerably exceeds the minimally required number of estimates of the stock, it can be assumed that each survey results in an economic return. Using acoustic information on the stock instead of ichthyological and fishing data results in increasing the accuracy of determining the TAC and decreasing losses, only if acoustic information is more accurate than ichthyological and fishing data. Such a situation may take place in particular as applied to pelagic fish with well studied target strength and to fish with a short lifecycle. The formula for calculating the economic return is as follows:

$$ER = QKP\left(\frac{t-1}{1+\delta_A} - \frac{t-1}{1+\delta_{IF}} + \delta_A-\delta_{IF}\right) \tag{6}$$

ESTIMATION OF EXPENSES

Expenses on an acoustic survey are the cost of running a research vessel during an expedition with an acoustic survey in view. Expenses on an expedition are made up by duration of the survey, time taken by getting from the home port to the surveyed area and back, and time expenses on force majeure. The duration of a survey is determined by the summary length of tracks and speed of the vessel. The length of tracks depends on the size of habitat under survey and the chosen distance between tracks. The speed depends on vessel type and the weather. Time taken from home port to survey area is determined by remoteness of the area from the home port. It can be assumed that time expenses on force majeure comprise a certain part of the time taken by the expedition depending on weather conditions. The expression for calculating the forecast expenses on carrying out an acoustic survey as applied to parallel tracks is

$$EE = \frac{C}{v}(1+k)\left(\frac{S}{r} + 1 + L\right), \tag{7}$$

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where S is area of habitat surveyed, L = length of passage to surveyed area and back, v = admissible speed of vessel, k = coefficient with allowance for force majeure time expenses, C = cost of running the vessel per day.

ESTIMATION OF ECONOMIC EFFECT

From expressions (6), (3), and (7) it follows that the value of the economic effect, obtained as a result of an acoustic survey, depends on distance between tracks and can be determined by the formula

$$\text{EFFECT} = QKP\left[\frac{t-1}{1+\sqrt{\delta_M^2 + \left(\frac{rv}{l}\right)^4}} - \frac{t-1}{1+\delta_{IF}} + \sqrt{\delta_M^2 + \left(\frac{rv}{l}\right)^4} - \delta_{IF}\right] - \frac{C}{v}(1+k)\left(\frac{S}{r} + 1 + L\right). \tag{8}$$

The distance between tracks with which the economic effect is maximum is optimal and must be taken as a basis for planning the grid of tracks of the acoustic survey.

EXAMPLE

Arctic-Norwegian population of cod. Mean lifetime t = 15 years. Habitat area S = 70 000 square miles. Typical size of habitat l = 265 miles. Coefficient of variation of concentration of density v = 3.0. Error of acoustic method of estimation of density δ_M = 40%. Error of ichthyological and fishing estimates of stock δ_{IF} = 50%. Stock Q = 2.0 million tonnes. Coefficient of commercial withdrawal K = 20%. Profit per tonne of catch P = 80 rubles. Distance covered from Murmansk to surveyed area and back L = 400 miles. Vessel speed v = 8.0 knots. Coefficient with allowance for force majeure time expenses k = 10%. Cost of running vessel per day C = 7 000 rubles.

Dependence of the economic effect on distance between tracks calculated by formula (8) and shown in Figure 1 indicates that the acoustic survey is economically justified with 3<r<46 miles. Optimal distance between tracks r = 20 miles. Corresponding tactical error δ_T = 5%, survey expenses EE = 4.0 million rubles, economic return ER = 18.6 million rubles, ultimate economic EFFECT = 14.6 million rubles.

CONCLUSION

The accuracy of estimates of economic efficiency of acoustic surveys with the use of the suggested approach is determined by degree of confidence of initial information. It is quite natural that on the basis of expert estimates of the accuracy of ichthyological and fishing information and the extent of influence of overfishing on the catch in the years that will follow, only tentative economic estimates can be obtained.

The value of error of ichthyological and fishing estimates of the stock will be established as the general problem of raising the accuracy of these estimates will find solution. The main direction of this problem is further studying the influence of the environment on the efficiency of fish reproduction, ascertainment of such regularities as applied to established populations, improvement of stock-taking of young generations as a basis for forecast recruitment of the commercial stock, and enhancing the accuracy of all initial information used in estimating stocks, improving methods of information treatment.

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The dependence of future catch on the degree of underfishing or overfishing can be established by a mathematical simulation of the population and fishing. With this in view it is necessary that, by varying the intensity of fishing as applied to one and the same population, the strength of age groups of all generations simultaneously engaged in fishing be traced for a number of years. Thus, it is possible to ascertain the effect of intensity of fishing on future commercial stock and the strength of the spawning stock, which in its turn determines the yield of new generations. Finally the degree of influence of intensity of fishing on the value of future catch will be established.

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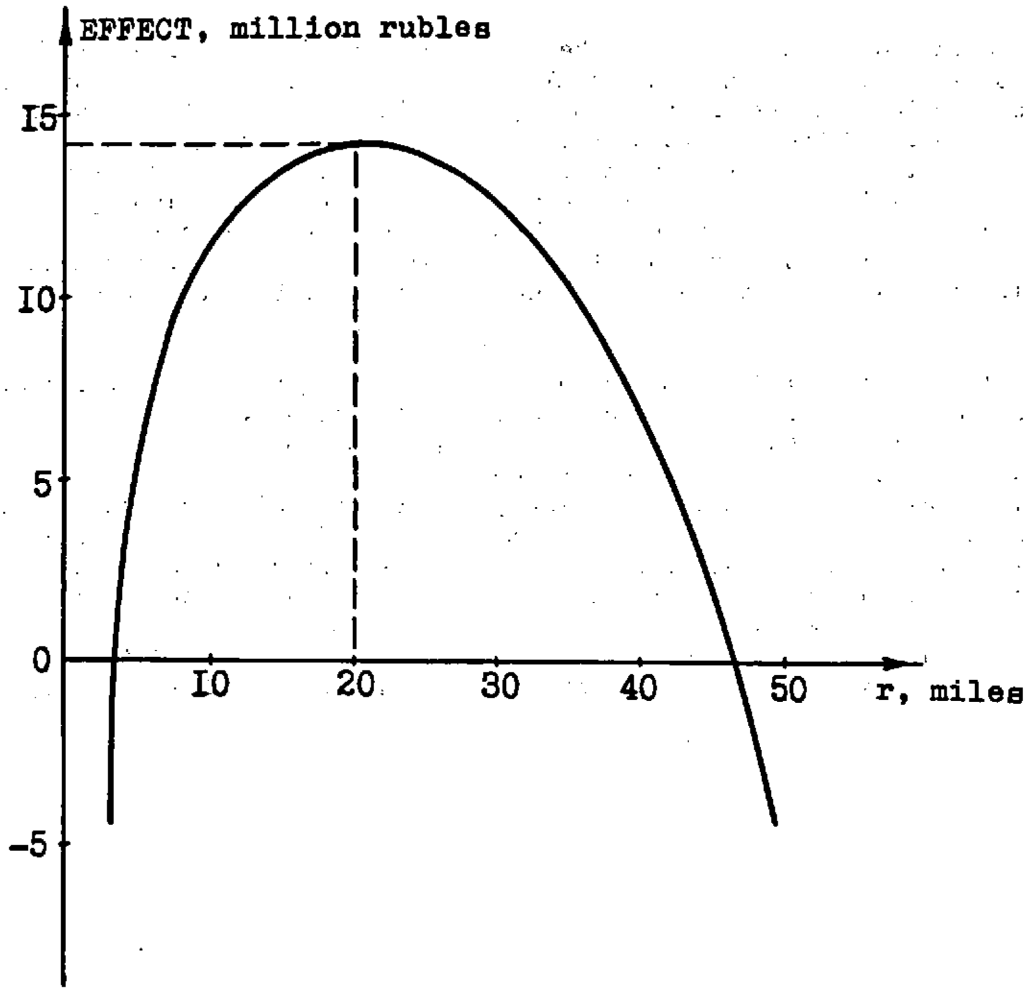

Figure 1 Dependence of economic effect of acoustic survey on distance between tracks.