TO THE EVALUATION OF THE POTENTIAL BIOLOGIC RESOURCES OF THE WORLD OCEAN

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Preface

This paper was written by Professor V.I. Belyaev (Head of the Department of Mathematical Modelling at the Institute of Biology of the South Seas, Sevastopol, USSR), during his visit with the Food and Agriculture Program at IIASA in July 1977.

Biological resources of the ocean have an important role in non-agricultural food production. Dr. Belyaev's task was to prepare a suggestion as to whether we should conduct inhouse research in this field or whether we should rely on the findings of other institutions. His paper describes the outlines of a method developed at his home institution to evaluate these special food resources. The method has not yet been applied to the whole scale but certain areas of the investigation show promising results.

Ferenc Rabar
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Abstract

An approach to the evaluation of the potential ocean bioproductivity on the basis of mathematical modelling is discussed. To determine the potential productivity of biomass of this species that may be removed annually from the area of its habitation during an indefinitely long period. Over the long term, this catch of marine organisms will act on the natural substance circulation in the sea at increasing spatial scales. It is proposed to model the bioproduction processes by successive evaluation of biogenic substance resources which take part in these circulations.

1. Introduction

Since 1971 the world fish catch has actually stopped increasing. One supposes that this fact is connected to the reaching of natural limits of fish catch caused by the ocean's ability for biologic production. Before this time, there was an annual increase in the fish catch. From 1950 to 1970 the increase in the total catch was approximately 7 percent per year. (The Fish Resources of the Ocean, 1971). Thus, the most intensive removal of marine products occurred during the last thirty years.

Those species utilized by man are elements of marine ecological systems. One may say they are produced by ecosystems. The function of an ecosystem is based on receiving solar energy from the sea's surface and on the circulation of organic and morganic substances. The latter is carried out by sea currents, turbulance, and additionally by chaotic and regular movement of living organisms and sedimentation of decaying organisms. In nature an approximate equilibrium exists between the in and outmigration of substances in all ocean layers. This equilibrium is supported by processes of substance transfers such as sea currents, turbulance, etc. The disturbance of this equilbrium was observed only when they are processes which were going on in geological time scales and which led to the creation of geological formation of marine origin.

The catch effect on marine ecosystems during the last decades is substantial but very transient compared to time periods which are typical for natural changes of marine ecological systems.

What will be the marine ecosystem's response to the removal of large numbers of fish, and how will the ecosystem behave in the future when faced with conditions of increasing catch? It is important to know the answer from the point of view of the ocean food resources evaluation. The answers to these questions are available from mathematical modeling of the behaviour of marine ecosystems at the set levels of their exploitation intensity.

The marine ecosystem productivity is caused, to a considerable degree, by the vertical circulation intensity. It is known that heightened biological productivity of the sea is observed in zones with intensive vertical circulations on the shelf and in upwelling zones. Biological productivity of the ocean is the property of ocean ecosystems to produce organic matter.

By 'biological productivity', marine biologists may mean different things. From the point of view of food problems, we shall consider the following value as the ocean biological potential productivity:

$$B = \sum_{i=1} B_i$$

B_i - maximum quantity of biomass of i-species that may be removed from the area of its habitation per year during an indefinitely long period;

$i = 1,...N$ - where N is the total number of species.

Another value that may indirectly characterize the ocean biological productivity is the species concentration expressed in biomass quantity or number of individuals per unit volume of water:

$$n_i = n_i\ (x,y,z,t) \quad ,$$

x,y,z - coordinates of space ,

t - time .

One may use the averaged value of n_i:

$$n_i^* = \int_{h_1}^{h_2} n_i\ (x,y,z,t)dz$$

where

h_1, h_2 - vertical boundary of species area.

All three values B_i, n_i, n_i^* are of interest for the ocean productivity evaluation.

2. The Evaluation of the Ocean's Potential Bioproductivity on the Basis of Mathematical Modelling

The whole ocean including living and non-living substances, together with its occurring processes and phenomena constitute the ecological system. This ecosystem may be separated into a number of parts or subsystems. A production subsystem corresponds to each exploited species. If the removal of a species is temporary and limited in respect to volume, the biomass concentration restores itself rapidly by borrowing from neighbouring layers. In this way the small scale system is motivated. Let F_i^t be the value of caught biomass of i-species during time t. The larger that F_i^t value and t-time is, the larger the ecosystem is which interacts with the catch. The continuing catch will have an influence on the substance circulation in the increasing scales of magnitude to the size of the whole ocean.

The F_i^t catch will always be limited from above by some limit which is determined by the principle of conservation of matter and the rate of its delivery by circulation into the zone of the exploited species "production". This condition will be valid with respect to limiting components that are used up in living matter creation.

When F_i^t is sufficiently big, the resources of the limiting component will be first used up in the limits of small-scale circulation and the corresponding subsystems of ecosystems. These resources will be replenished by circulations on larger scales.

As the resources of a component are exhausted in certain layers, the intensity of component delivery from neighbouring layers will first of all increase owing to concentration gradients increasing until it reaches a certain equilibrium value.

The formation of primary organic matter in the photosynthesis layer is the origin process at the ocean biologic productivity. The inorganic biogenic matter is used up by the organic substance molecules building in the definite ratio.

The Q_j value of phytoplankton biomass (averaged on different species) correspond to the definite quantity of biogenic component, which is delivered per unit of time into the specific area.

Let $j = \overline{1,M}$, where M is the number of inorganic substances, that take part in the photosyntesis. Let us designate as E_{oi} the ecosystem which directly produces the B_i species caught by man. Further, we designate by E_{1i}, E_{2i},..., E_{ni}, the circulation system in sequence of its increasing space scales until the E_{ni} system which envelopes the whole ocean.

When the biogenic component will be exhausted in the E_{oi} system it will be delivered first from the E_{1i} system. After the E_{1i} resources are exhausted this component will be delivered from E_{2i} system, etc.

We shall designate by $Q_{k,k+1,i,j}$ the flows of i-substance from $E_{k+1,i}$ system into E_{ki} system. These flows are bound to the restoration of component resources in E_{oi} system which have been consumed by the catch. $Q_{k,k+1,i,j}$ will be expressed in the proportioned quantity of phytoplankton biomass of i-species which is formed with the participation of j-substance.

As mentioned earlier, with increase in the duration of the catch, the catch will interact with the succession of E_{k1} systems with increasing space scales.

One may suppose the following inequality for flows will occur:

$$Q_{o,1,i,j} \leq Q_{k,k+1,i,j} \quad .$$

In this expression (k+1) is the number of the largest system which had taken part in the restoration of resources of j-substance on the time moment "t".

The value of the removed biomass F_i^t will not decrease with time if the quantity of outmigration substances is by the same quantity of substance which is delivered from the system of greater scales of magnitude.

According to the law of conservation of matter, F_i^t cannot exceed the min $Q_{k,k+1,i,j}$ at different j. This condition will determine the upper level for F_i^t values, i.e. for the value of ocean potential productivity B_i of species.

Another evaluation for B_i upper bound is derived from the ability of the exploited population to restore its number. This evaluation must be carried out on the basis of qualitative analysis of ecosystem stability taking into account its numerous links in the throphycal chains. However, in the future, the change in species number seems to be the most controlled parameter of marine ecosystems. It will be decreased by catch and increased by fish mariculture. There are some projects for creation of both anchored floating plants and coastal plants for reproduction of marine organisms.

At the present time, investigations in the field of mari-culture are being carried out and it is possible that this problem will be solved at the earliest in twenty years

For this reason, one may take into account two con-trolled variables in the models of marine ecosystems. These are the catch F_i and the artificial reproduction of marine organisms J_i. The maximum catch of exploited species will be reached at some level of these values. This maximum catch will be the potential productivity of the ocean B_i in respect to i-species.

The procedure for calculating for the B_i values begins with the use of M_{oi} model of E_{oi} ecosystem which includes the exploited i-species. Model M_{oi} envelopes the processes which determine the changebility parameters of i-species at its natural existence. The parameters of larger ecosystems E_{1i} are considered as set independent variables in the M_{oi} model of E_{oi} ecosystem. If, for time period "t" of the E_{oi} ecosystem the substance removed from E_{1i} ecosystem is substantial for the change of this system state, one must take into account the model M_{1i} which describes the interaction between ecosystems E_{oi} and E_{1i}. In a similar way, with the increase in scales of factor F_i action, one must take into account the model M_{2i} which envelopes the systems E_{oi}, E_{1i}, E_{2i}. This procedure may be prolonged up to the model M_{ni} which envelopes the whole ocean (Fig. 1).

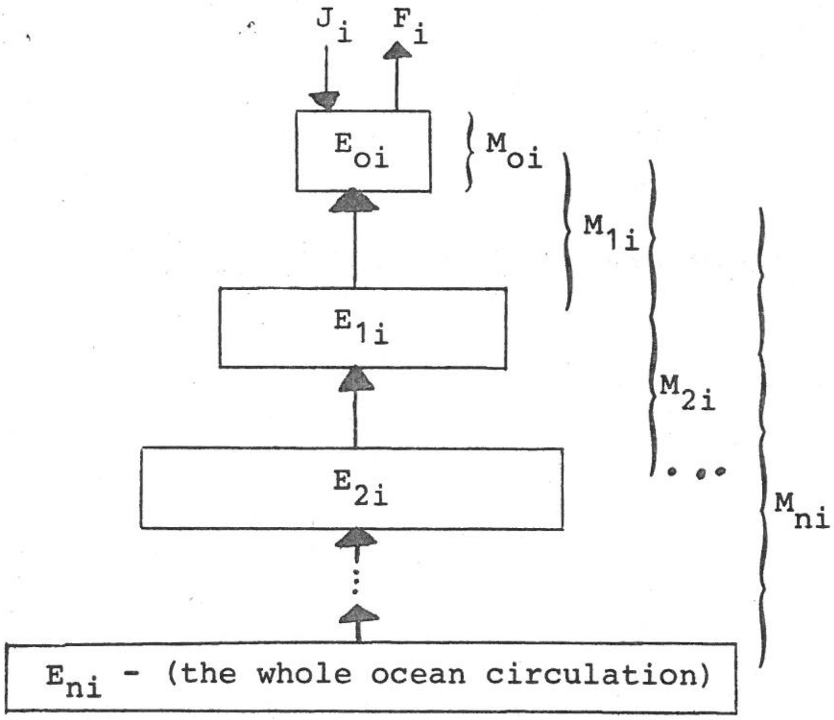

Fig. 1. The levels of modelling which are taken into account with time increase.

The method for M_{ki} model building has been described in our previous paper (V.I. Belyaev, 1976). Here, it is necessary to point out the difficulties which were caused by the circumstance that there was not sufficient data for calculations in certain ocean areas and some of the available data were not coordinated in time and space. For this reason, the models have to be built as block structures.

When the sub-models, which correspond to separate blocks, are more exact these blocks may be changed and the complete model will be repeated for making more precise calculations.

3. The Construction of Spatial Fields of Biomass Concentrations or Numerical Concentrations for Marine Organism Species on the Basis of Observation Data

As noted earlier, the construction of fields of biomass construction of fields of biomass concentration numerity concentrations for marine organisms is very important for solving the problem of potential biologic ocean productivity. Indeed, a model of marine ecosystems is intended for prediction of future states of these ecosystems in the conditions of the out factor influences. These models must describe the states of these ecosystems as presently observed.

The biomass numerity of any species is not calculated separately. As a result of calculations for modelling certain species we receive the rest of the parameters for the species and ecosystem components which are bound to the species in question. The comparison of all these data with their observed values may be used for model examination.

In the method we used for the oceanographic fields constructed on the basis of observed data (V.I. Belyaev (1973), A.A. Andrushchenko, V.I. Belyaev (1977)) the division of fields is made on regular and stochastic components. The regular component is usually derived by 'smoothing'. The stochastic component is considerable for oceanographic fields and it must be taken into account when field characteristics are evaluated.

In our calculations which were carried out for different areas of the ocean, the regular components were approximated for some surfaces with the parameters determined by data processing.

The stochastic components were restored by the use of algorithms for optimal interpolation and optimal coordination of the fields. The use of the first mentioned algorithms was carried out for data of only one field, and the use of the second one took place in the joint use of data for a number of fields which are bound together statistically.

For application of these algorithms it is necessary to know the statistic structure of study fields. For these aims, we undertook the study of oceanogrpahic fields for the Black Sea and the Atlantic.

At the present time, the described method is widely adopted in our research for the construction of the fields: sea temperature , salinity, St^{90} concentration, biomass and the number of zooplankton and other oceanographic values. The fields of biomass and number of zooplankton were restored on the basis of optimal coordination algorithms--their coordination was made with the sea temperature field. This led to more precise calculations.

The algorithms we formed are applicable for restoring two dimensional fields measured at only one moment in time. For the coordination of fields, data from different sea levels may be used when they possessed applicable correlation.

When the values of field parameters are restored in the nodes of regular grade, the errors of field restoration are calculated simultaneously. These errors are criteria for the modeling quality. They depend on the precision of measurement, the network configuration for measurement and the field statistic structure.

When the level of the field restoration errors is set, it is possible to solve the inverse problem to determine the network configuration for measurement which corresponds to the minimum expenditure (ussually these expenditures are proportional to the number of measurement points).

4. Outlook for Solving Problems of Evaluation for Potential Biologic Ocean Productivity

The evaluation of potential biological production of the ocean is one of the most complicated oceanographic problems. At the moment we do not have a sufficient quantity of data for reliably solving all areas of the World Ocean. Nevertheless, it appears necessary to begin solving this problem now on the basis of available data generalization and the application of mathematical modelling methods.

Attempting to model ecosystems for evaluation of ocean bioproductivity, in addition to its main aim, also provides the possibility for systematization of available notions about oceanographic processes. By this, one may determine which data are sufficient and which should be supplemented by additional data in future expeditions.
Only on the basis of preliminary mathematical modeling of the study processes is it possible to organize the rational system for the collection and processing of oceanographic data. For this reason, it is very important to carry out modelling of bioproductivity processes even for those ocean areas where the reliable data are unavailable. For this one may use approximate data and choose rough values based on the analogy to studied ocean areas

The evaluation of the potential biological productivity of the world ocean may be carried out by way of successive approximations as the notions about oceanographic processes which have been described by separate model blocks, are being made more exact.

These evaluations are necessary not only at present also for the future to solve problems relevant to the provision of food and industrial raw material. The rationalization of the world ocean resources exploitation in the future will be based on the control of marine ecosystem by catch and reproduction of marine organisms and by acting on other elements of systems, for example, on its hydrological elements. This control is impossible without mathematical modelling of the ecosystem production processes.

The problem of the ocean potential productivity evaluation is also relevant to the problems of the global processes modelling as for example the problems of weather, long-term prediction, etc. All of these problems are very important and sooner or later must be solved.

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