Evaluating Method of the Marine Environmental Capacity for Coastal Fisheries and Its Application to Osaka Bay

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The methodology for the estimation of "the marine environmental capacity for coastal fisheries (E.C.)" is proposed. The characteristics of the methodology are as follows: 1) selecting and analyzing environmental factors affecting the growth and survival of fishery organisms at various developmental stages; 2) modeling the correlation of fishery organisms with their environmental factors on the basis of accumulated knowledge and experience; 3) estimating the fluctuation of fish population related to environmental conditions. For the above estimation, the environmental limits sustainable for the fisheries resources are determined by using models for the life cycle of fishery organisms. This methodology is applied to Osaka Bay. In this bay two factors are suggested to be essential to E.C. of marbled sole, *Limanda yokohamae*, which is representative of demersal fishes. One is the reclamation from the sea which makes narrower spawning and nursery grounds, and the other is the increased pollution load which results in a deficiency of dissolved oxygen in the bottom layer and reduces the biomass of benthonic organisms as food. The practical use of E.C. method as a tool for the environmental assessment is also discussed.

The developmental activities and utilizations of Japanese coastal seas have been increased recently. Consequently, the production of coastal fisheries, especially of those in enclosed seas, are considerably affected by artificial impacts such as reclamation from the sea and increased pollution load. Such impacts will be increased and become complicated further. Concerning preservation of marine environments including fisheries resources and their exploitation, it is important to quantify the environmental limits sustainable for fisheries resources and to analyze various impacts on marine environments. In this paper, we describe the methodology for estimation of "the marine environmental capacity for coastal fisheries (E.C.)", which is defined as the environmental limits, and its application to Osaka Bay. Conventionally, the factors relating to fisheries production are divided into two systems of natural science and social science. The object of this study is only for the former. In addition, this study forms part of the project for evaluating E.C. which is assisted by the Fisheries Agency, and is sponsored by the Japanese Fisheries Resource Conservation Association (JFRCA).[1)]

Methodology

The evaluation of E.C. involves the explanation of environmental impacts against coastal fisheries and their boundaries. It is important to understand the environmental factors on fishery organisms, because living organisms select specific habitats at various developmental stages. Therefore the methodology for evaluation of E.C. is as follows, selecting the representative species of commercial fishes, modeling the correlation of this species with its environmental factors, estimating E.C. of this species, and evaluating E.C. of fisheries resources on the basis of above estimation. The procedure of this method is shown in Fig.1 as a flow diagram, which can be summarized as follows: 1) select the major fisheries resources in relation to their production, commercial importance, coastal habitats, trophic levels, etc., and select a representative species of them; 2) review the ecological documents and environmental conditions of this species; 3) select and analyze physical, chemical and biological factors affecting the growth and survival of this species at various developmental stages; 4) build a structural diagram between the major selected factors and other environmental factors affecting them both directly and indirectly; 5) select the environmental impacts by load, developmental projects, fishery exploitations, accidents, etc., and formulate how to input such impacts to the structural diagram; 6) model the correlation of representative species with its environmental factors and each interrelation embedded in the structural diagram, and to make the mathematical stock analysis model that is able to estimate the fluctuation of fish population related to environmental changes (it is named "the life cycle model"); 7) estimate the environmental limits by using the life cycle model, and evaluate E.C. of the proposed fisheries resources on the basis of the estimation. For the above evaluation, accumulated fishery knowledge and related experience are put into practical use. The available data of

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environmental changes and the fisheries statistics are used for the life cycle models. The present evaluating method of E.C. is aimed to be objective, scientific and more practical.

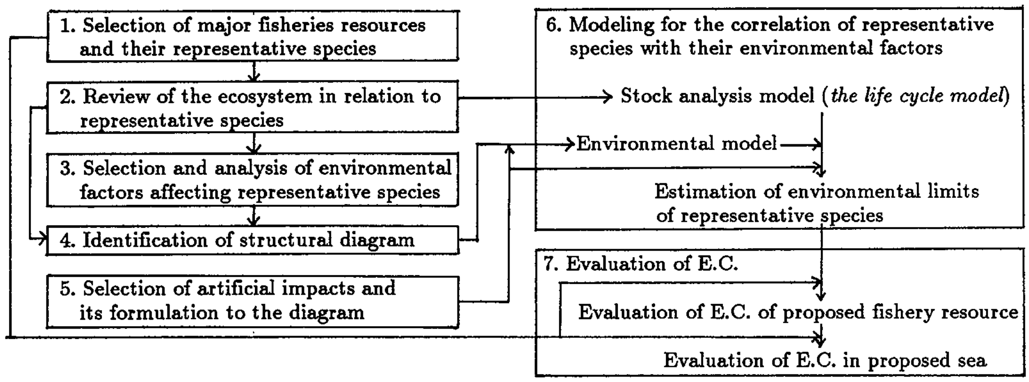

Fig.1 Procedure for the evaluation of E.C.

Application

The evaluating method of E.C. is applied to Osaka Bay, Japan, which is a semi-closed water body, with a surface area of approximately 1,500km^2 and mean depth of about 28m. In this bay, though environmental changes through coastal reformation, pollution load, etc. have been increased, the annual production per unit sea area is the maximum among eight fishing grounds of the Seto Inland Sea[2)]. Thus, it seems that commercial catch coexists with developmental projects in Osaka Bay. In recent years, since environmental assessments and monitorings such as those for the construction works of the Kansai International Airport have been carried out, significant information have been greatly documented through the ecological and environmental studies on both the commercial fishes and the fishing grounds. For the above reasons, the study of the evaluation of E.C. in Osaka Bay is executed.

Major fishery resource and its representative species:

Fisheries resources in Japanese inland seas are characterized by a large number of species but lower in production of each species.[3)] The commercial fishes in Osaka Bay are classified according to their life cycles, ecological habitats, and the trophic levels of the sea. From the view of productive and commercial points, it is identified that the environments of the fishery ground of both pelagic and demersal are important. The former has very great fluctuation in total yearly catch in the bay, because eggs spawned out of the bay or hatched larvae are transported from the spawning grounds to the bay. In case of the latter, it seems that population dynamics are closely related to the environmental changes in the bay, because many species live through whole stages in the bay. For stabilizing the fishing industry, we would attach importance to demersal resources, which are economically important and easy to be conserved and cultivated, rather than pelagic resources. Thus, E.C. of demersal resources is estimated the marbled sole, *Limanda yokohamae*, is selected as representative species of them. Because, it has a large catch, lives through all stages in the bay, and shows high trophic level. As its spawning and nursery grounds are in the inshore regin and it has demersal egg, the early stages will be therefore considerably affected by artificial impacts. Many ecological investigations have be carried out for this species. Hereafter the ecosystem on marbled sole is examined.

Structural diagram:

Many environmental factors having influence on fluctuation of fish population are collected comprehensively by questionnaire to fishery researchers in addition to already documented information. Consequently, some important information have been obtained on: 1) the environmental capacity and conditions of spawning and nursery ground; 2) non-available dispersion of eggs and hatched larvae; 3) density effect (intraspecific relation); 4) productions of predator, prey and competitor (interspecific relation); 5) water temperature, salinity and dissolved oxygen (having influence on metabolism of living organism); 6) fishing. It is known that the environmental conditions influence greatly on the fluctuation in fisheries resources at early stage. It is suggested that the serious environmental impacts relating to them are: 1) coastal reclamation; 2) pollution load; 3) water temperature; 4) fishing. Fig.2 shows the structural diagram to be assessed from such impacts to the marbled sole's population parameters.

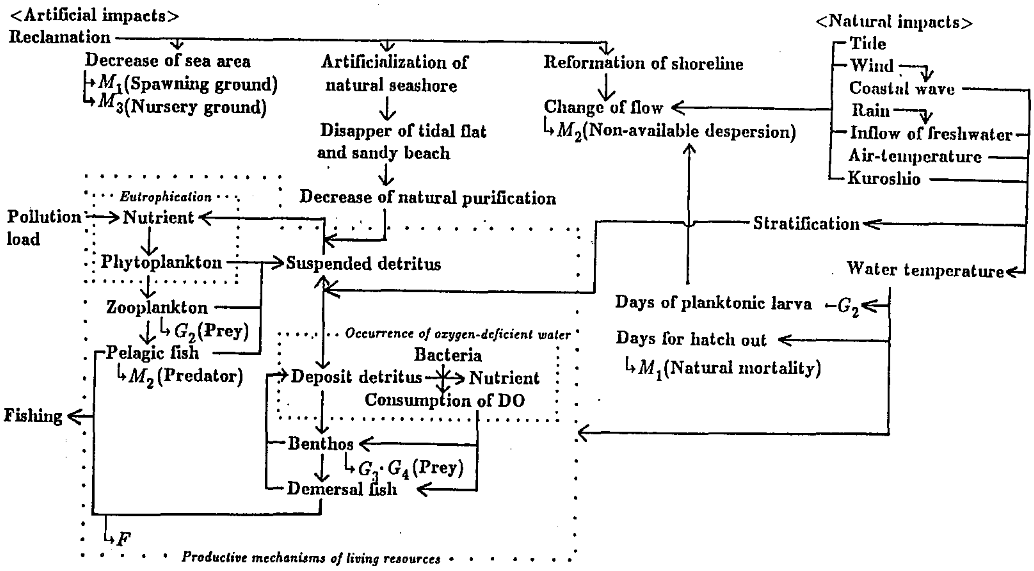

Fig.2 Structural diagram of the major system for marbled sole. The words in the barckets denote the contents of the factors affecting population parameters. M_i: natural mortality coefficient of i-stage (/year), F: fishing mortality coefficient (/year), G_i: growth coefficient of i-stage (/year). i is the periods of 1)egg, 2)larva, 3)juvenile and 4)immature and adult.

Life cycle model:

In consideration of the ecological habitat at various developmental stages, four stages, namely, the periods of 1) egg (spawning), 2) larva (pelagic), 3) juvenile (bottom-clinging) and 4) immature and adult (benthonic), are considered for the life cycle of marbled sole. The fluctuation of stock biomass can show both survival and growth curves of cohort. The modeling of the cohort's whole life is shown in the time scale below along with the differential equations for the model. As the formulae show, the model includes recruitment by reproduction, N_o and natural mortality coefficient at early stage by the effect of population density, $M_{o(A)}$. The former is determined with number N and body weight W, the latter is determined with N_o using the reproduction model of Beverton-Holt type.

0	7	30	180	360	720	2520 days (7 years)
egg i=1	larva i=2	juvenile i=3	immature i=4	adult (1+) i=5	adult (2+ to 6+) i=6 to 10	

$$\frac{dN_i}{dt} = -M_iN_i \text{ for } i = 1 \text{ to } 4, \qquad \frac{dN_i}{dt} = -(M_i+F)N_i \text{ for } i = 5 \text{ to } 10, \tag{1}$$

$$\frac{dW_i}{dt} = G_iW_i \text{ for } i = 1 \text{ to } 4, \qquad \frac{dW_i}{dt} = \alpha W^{\frac{2}{3}} - \beta W \text{ for } i = 5 \text{ to } 10, \tag{2}$$

$$\frac{dY}{dt} = F\sum_{i=5}^{10}(N_iW_i), \tag{3}$$

$$N_0 = \frac{1}{2}\sum_{i=5}^{10}(H_iN_iMTR_i), \qquad H_i = a\left(\frac{W_i}{c}\right)^{\frac{1}{3}} - b, \tag{4}$$

$$M_{0(A)} = -\ln\frac{1}{d+eN_0}, \tag{5}$$

where N_i: total number of i-stage, W_i: body weight of i-stage (g), Y: Catch (g), N_o: total count of spawned eggs, M_i: natural mortality coefficient of i-stage (/year), F: fishing mortality coefficient (/year), G_i: growth coefficient of i-stage (/year), α: assimilation coefficient ($g^{1/3}$/year), β: dissimilation coefficient (/year), H_i: fecundity of i-stage, MTR_i: rate of group maturity of i-stage, $M_{o(A)}$: natural mortality coefficient at early stage by effect of population density (/year), a,b,c,d,M_{4-10}: constants.

Here a box model is considered for Osaka Bay. As this species lives through whole stages in the bay, the emigration and immigration are not be considered. It is also assumed that F is a constant. That is, M_i and G_i (including α) are the dependent function of environmental factors (X_j: j=1,2,3, $\cdots$) at various development stages. The parameters for the model are determined from the specimens of 1975 trawled in Osaka Bay and on the basis of accumulated knowledge. The initial values of each parameter have been reported by JFRCA(1989). The calculated catch, Y using these parameters is consistent with the catch quantity of 1975 (370t/year). Such state is defined as the initial case. If it is assumed that the effect of environmental factors on a single parameter is independent of each other, it becomes possible to use simple multiplication as shown in the following formula.

$$z = z_1 \times z_2 \times \cdots \times z_m$$
$$= f_1(X_1) \times f_2(X_2) \times \cdots \times f_m(X_m)$$
$$= \prod_{j=1}^{m} f_j(X_j),$$

where z_j (j=1,2,3, $\cdots$) denote the deviating ratio of parameter on X_j in n-year from parameter in k-year (the initial case).

Based on $M_{i,k}$, $G_{i,k}$ and $X_{i,k}$ of the initial case, the population parameter in a certain year (n-year) is shown in the following formula.

$$M_{i,n} \text{ (or } G_{i,n}) = M_{i,k} \text{ (or } G_{i,k}) \prod_{i=1}^{m} f_j(X_{j,n}) \tag{6}$$

Thus the fluctuation of catch Y according to the environmental changes X_j is predicted. As the fluctuation of catch in bottom trawl net correspond approximately to catch per unit effort, the fluctuation of catch Y is regarded as that of stock biomass.

Modeling the correlation of population parameters with environmental factors:

The correlations of the population parameters M_i, G_i with their environmental factors X_j are modeled on the basis of existing relevant information. If the informations have not been documented, especially those of the interactions in the biological domain, a simple empirical formulation scheme is made. The sensitivity of M_i and G_i are analyzed, and therefore some unknown quantities of the formulae are determined on the basis of following assumption: 1) the upper and lower boundaries for M_i and G_i exist within the limits of catch during the past thirty years; 2) M_i and G_i fluctuate relating to X_j based on observations during the same times; 3) the permissible fluctuations of M_i and G_i on X_j are determined gradually and objectively according to the magnitude of affecting the fishery resource. In view of influence of the environmental changes upon marbled sole resource, the available data on major environmental factors are selected and shown in Fig.3. The quantitative formulae of these relationship have been reported by JFRCA(1989). By inputting the multiple factors from X_1 to X_7 during the past thirty years, Y during the same years is calculated (Fig.4a). As a result, Y fluctuates within the limits of present catch. Consequently, it is judged that the relationship between M_i, G_i and X_j is good.

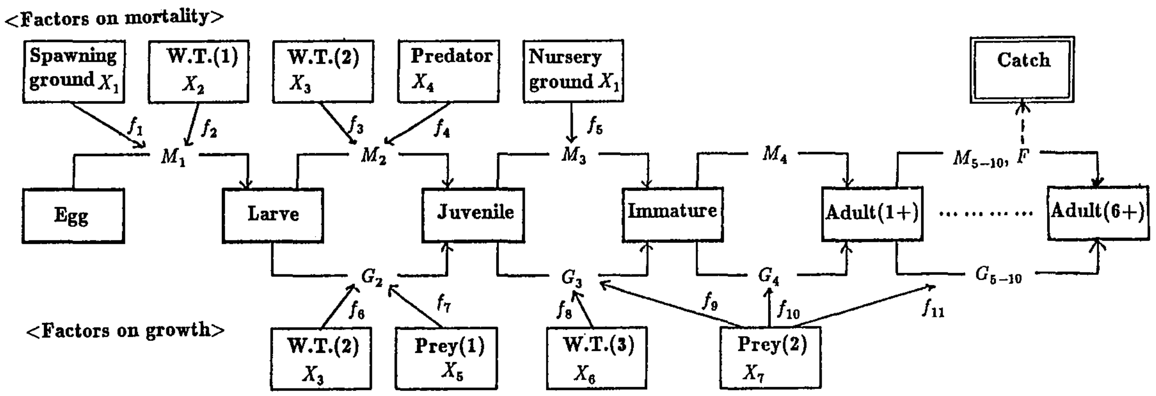

Fig.3 Diagram of the multiple environmental factors on parameters of marbled sole population. Coefficient of i=4 to 10 is a constant. M_i: natural mortality coefficient of i-stage (/year), F: fishing mortality coefficient (/year), G_i: growth coefficient of i-stage (/year), X_1: surface area shallower than 15m in depth, X_2: mean coastal water temperature in the bottom layer during the periods from Nov. to Mar., X_3: mean water temperature in the surface layer during the periods from Nov. to Mar., X_4: annual catch of pelagic fishes which feed on zooplanktons, X_5: mean transparency during the periods from Nov. to Mar., with indicator of phytoplankton production, X_6: mean coastal water temperature in the bottom layer during the periods from Jan. to Jun., X_7: sea area bellow 30% of dissolved oxgen saturation in the bottom layer, with indicator of benthos production.

Estimation of environmental limits on artificial impacts:

In case of marbled sole, if it is assumed that the minimum stock level for fishery can regard as the minimum catch (200t/year) during the past thirty years, E.C. will be determined by the environmental impacts below this level. Two factors as artificial impacts are suggested to be essential to E.C. of this species. One is the reclamation from the sea which makes narrower spawning and nursery grounds, and the other is the increased pollution load which results in a deficiency of dissolved oxygen in the bottom layer and reduces the biomass of benthonic organisms as food. Using the life cycle model, the stock biomass is calculated from two environmental impacts. One is the surface area shallower than 15m in depth, X_1, and the other is the sea area below 30% of dissolved oxygen saturation in the bottom layer, X_7. As results, E.C. is judged as follows: 1) the reclaimed sea area of 83km^2 corresponding to a decrease of 23% of X_1 in 1985, when X_1 is used as input at the same rate of annual decrease (0.5%) as the past twenty years; 2) the pollution load maintaining X_7 at 350km^2, corresponding to about 1.3 times as large as the mean of X_7 during the past ten years, for twenty consecutive years. Fig.4b shows the fluctuation of calculated Y from above two impacts. As a result, E.C. on such multiple impacts is estimated both reclaimed sea area of 21km^2 and pollution load maintaining X_7 at 350km^2 for twelve consecutive years. Concerning the occurrence of oxygen-deficient water in the bottom layer, the horizontal distribution of dissolved oxygen in the bottom layer can be predicted in relation to the magnitude of pollution load such as COD, total phosphorus and total nitrogen by using the simulation model.[1)]

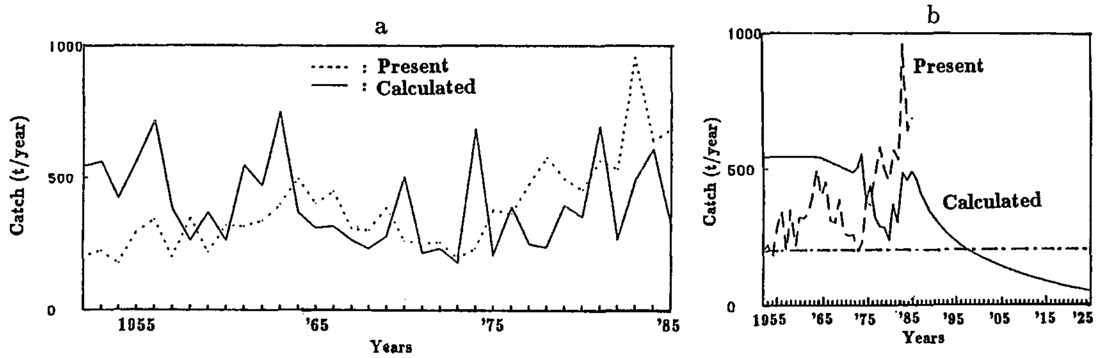

Fig.4 Yearly fluctuation of calculated catch from some environmental impacts by using the life cycle model of marbled sole. a) The multipal impacts of X_1 to X_7 during periods from 1952 to 1985, shown in Fig.3. b) Two impacts of X_1 and X_7 : until 1985, accumulated factors; after 1986, annual decrease of 0.5% of X_1 in last year and an increase of 20% of X_7 in 1975 (the initial case).

Discussion

The marine environments are very active and extremely complicated in structure, where the productive mechanisms of living resources are involved. The evaluating purpose of E.C. is to explain the structure of ecosystem and the functional change caused by the environmental impacts. It also shows how to estimate more quantitative fluctuation of fish population, which is affected by multiple impacts of environmental factors throughout the life history. It is considered that the present method makes it possible to estimate the environmental limits on multiple factors by using the life cycle model. Several methodologies for environmental assessment of coastal fisheries have been advocated,[4)] but none of them is found effective. The major reason is the problem of quantifying the interaction between the biological and environmental states. About this problem, Nakata and Hirano (1989a,b) advocated a method using a structural model in which a simple empirical formulation scheme was proposed as a means for quantifying each environmental factor. However, this method has several limitations when handling feedback process, evaluating plus effects, etc.. The life cycle model is made with reference to the principles of the structural model. Furthermore, it is emphasized to select the environmental factors on fishery organism and to quantify indicative states in relation to environmental impacts. It also shows the fluctuation of stock biomass affected by the multiple environmental impacts. On the other hand, as the present model has a limitation to model a comprehensive system including physical, chemical and biological factors, it is necessary to incorporate more simulation models. For the future, the practical use of the life cycle model including the structural and other simulation models, as a tool for the environmental assessment for coastal fisheries, would be established.

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