Ecological Modelling at Osaka Bay Related to Long-Term Eutrophication

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Based upon the ecological model presented by Andersen & Ursin (1977), we constructed an adequate model which will quantatively evaluate the overall impact of industrial large-scale development on fisheries at Osaka Bay. It is expected that the patterns of changes in biomass of dominant species, which is caused by eutrophication, will be explained by the model we have established. The simulated results for two years, 1956−57, are as a whole comparable to the actual variations. However, the results for several species, including sea bass, flat fish, crab, mantis shrimp, and cuttlefish, differ significantly from observed data. It was attributed to the lack of accurate parameters of anabolism and catabolism for younger-aged stages of these species.

The general concept of the ecosystem

Many biological parameters are necessary to construct a dynamic ecosystem, such as food chain matrix, food consumption and density-dependent factors. Once the parameters are estimated, the mathematical model is not actually difficult. However, at present, enough parameters could not be estimations to conduct simulation which describe the actual state of the multispecies network.

Outline of the model adopted for species

Physical environment, primary production, the relationship between growth and food, starvation, reproduction, catch, migration, as well as, dynamics of inorganic materials are components of the ecosystem. The model, therefore, must consist of simultaneous differential equations to describe the ecosystem. Fundamentally modelling is based on changes in population numbers, changes in biomass, the flow of energy, the law of mass conservation, and biochemical reactions of carbon/nitrogen/phosphorus (Tiews, 1978; Ursin & Andersen, 1978; Ursin, 1979; Jorgensen *et al*, 1982).

The A-U model (Andersen & Ursin, 1977) treats quantities of phosphorus as index of biomass of each species as well as mass of inorganic matter, converted by phosphorus equivalents. Accordingly, the law of mass conservation for phosphorus plays an important role in ecosystem dynamics in this model. Based upon the A-U model, we constructed an adequate model which will quantatively evaluate the overall impact of industrial large-scale development on fisheries at Osaka Bay. It is expected that the patterns of changes in biomass of dominant species, which is caused by eutrophication, will be explained by the model we have established.

There are four basic time-related differential equations for each species.

Growth by anabolism and catabolism $$\frac{dW}{dt} = HW^m - kW^n$$

Population N $$\frac{dN}{dt} = -(F + M1 + M2)N$$

Catch Y $$\frac{dY}{dt} = FNW$$

Food consumption R $$\frac{dR}{dt} = fhW^p$$

(species suffix i is not written in the above equations)

where;

H = Coefficient of anabolism

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k = Coefficient of catabolism
F = Fishing mortality
M1 and M2 : Mortality by disease and by predation
f : Feeding level expressed by prey concentration
h : Coefficient of ingestion
m, n, p : constants

The coefficient of anabolism is described by the following equation:

$$H = (1-\alpha)\ \beta\ fh$$

α : Fraction of food loss in feeding catabolism
β : Fraction absorbed of food eaten

Although the above-described notations are not expressed explicitly by population sizes of prey and predator, they are functions of prey and predator. For example, feeding level, f, is a parameter related to prey biomass, expressed as follows.

$$\phi(i) = \text{Prey biomass of i-species} = \Sigma\, \rho(ij)\ g(ij)\ N(j)$$

where: $\rho(ij)$ = The vulnerability of species j to predation by species i
$g(ij)$ = Suitability of prey, that is, prey size preference as food for i eating j

Therefore the basic four equations are multi-dimensional and non-linear. In addition, there are a lot of biological parameters that need to be estimated before simulating. For this reason analytical or practical solutions can seldom be obtained.

Phosphorus contained in non-animal entities

Phosphate, phytoplankton, detritus, and also carcass are non-animal entities. The behaviour of phosphorus in these entities is similar. Phosphate is classified into two forms; phosphorus that is accessible to plants and phosphorus that is inactivated (polymerized) which is irreversibly inaccessible to plants.

Dynamic equations of non-animal entities, conceptually the same as the equations in the animal model, are symbolically written as

Change in time = (IN)−(OUT)

Food chain matrix

In order to construct equations in concrete and practical ecosystem problems, a food chain matrix of all the animal and non-animal entities is essential. After a food chain matrix is obtained, it is easy to fully formulate equations, introducing instantaneous phosphorus transport (IN) and (OUT) in the system.

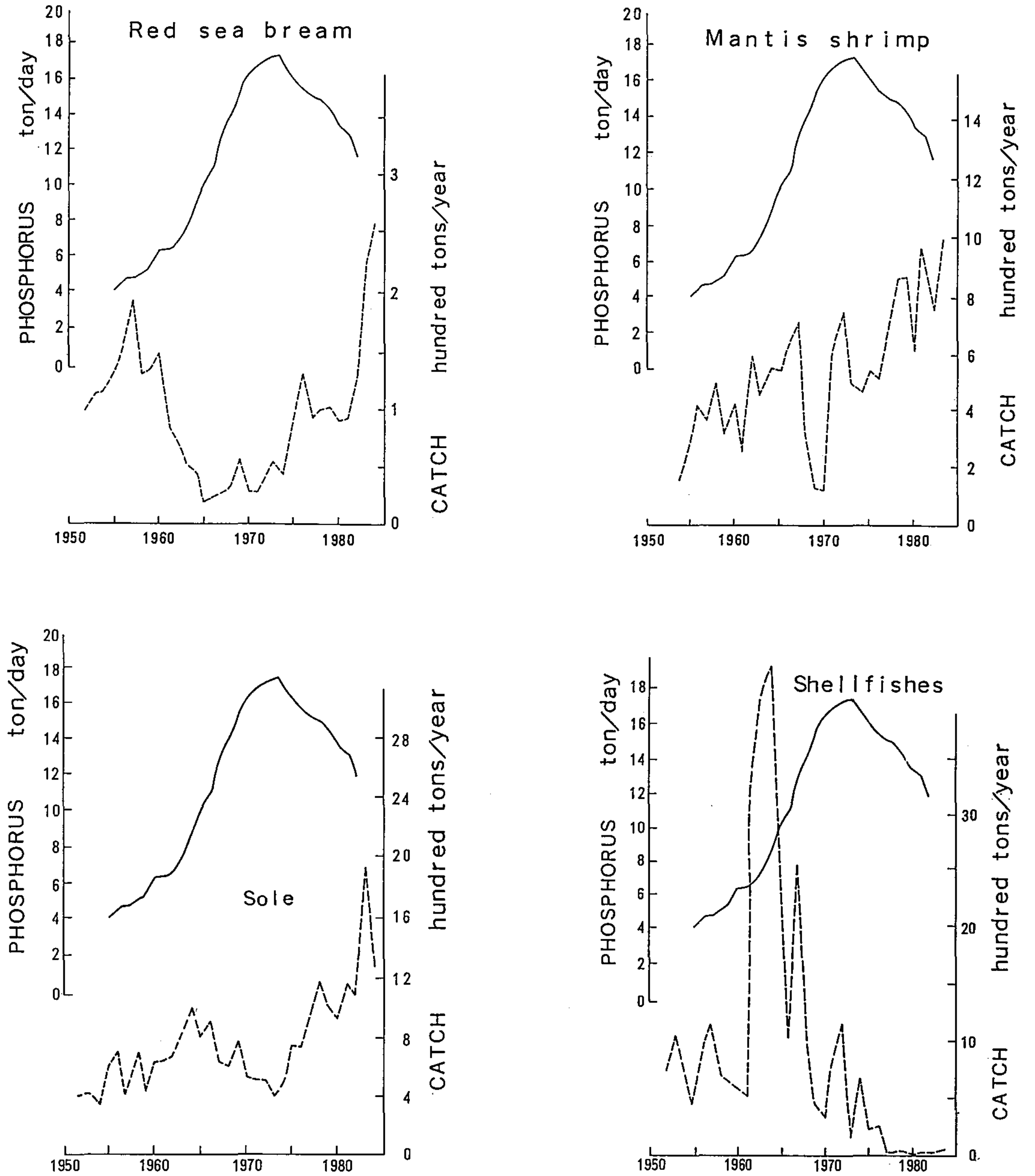
Simplification of the model

As a first approximation, because many parameters were impossible to obtain, we simplified the model as follows;

a. Phosphate, detritus and carcass are given.
   Therefore they do not change in time.
b. Zoo-plankton and benthos are given.
   Therefore variations of species in high trophic level are calculated.
c. The suitability of each species are given.
d. Reproduction mechanism of each species are assumed from the juvenile mortality of the species.

Discharge of phosphorus into Osaka Bay and changes of catch

Fig. 1 shows the relationships between long-term variations of enormous amounts of phosphorus discharged into Osaka Bay and catches of red sea bream, sole, prawn, mantis shrimp, shellfishes, during the period 1955−1982. We can recognize that the long-term phosphorus discharge influenced upon the variation of catches. Ecosystem modelling is expected to become usefull in interpreting such relationships between environment and aquatic resources.



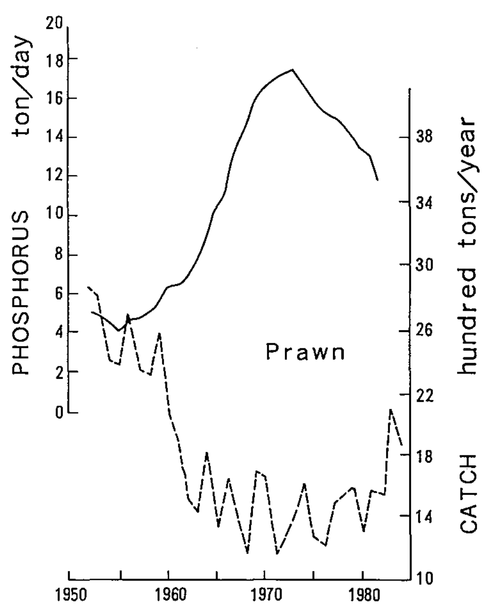


Fig.1. Relationships between long-term variations of phosphorus discharged into Osaka Bay (solid line) and catches of five species (dotted line)
Ordinate(left): amount discharged ton per day
Ordinate(right): catch hundred tons per year
Abscissa: year 1950–1985

Entities treated at Osaka Bay

Commercial species caught at Osaka Bay, include more than 80. We adopt the following 23 species in simulating the ecosystem model.

KONOSIRO, gizzard shad *Clupanodon punctatus*
IKANAGO, sand lane *Ammodytes personatus*
SUZUKI, sea bass *Lateolabrax japonicus*
HIRAME, flounder *Paralichthys olivaceus*
KAREI, sole *Pleuronichthys cornutus*
MOGAI, ark shell *Scapharca subcrenata*
ASARI, short-neck clam *Ruditapes philippinarum*
EBI, southern rough shrimp *Trachypenaeus curvirostris*
KANI, wimming crab *Portunus trituberculatus*
SYAKO, mantis shrimp *Oratosquilla aratoria*
TAKO, octopus *Octopus vulgaris*
MAIWASI, sardine *Sardinopis melanostictus*
KATAKUTIIWASI, anchovy (spring) *Engraulis japonica*
KATAKUTIIWASI, anchovy (summer) *Engraulis japonica*
SABA, mackerel *Scomber japonicus*
SAWARA, spanish mackerel *Scomberomorus niphonius*
ESO, lizard fish *Saurida undosquamis*
TATIUWO, ribbon fish *Trichiurus leptturhs*
BORA, mullet *Mugil cephalus*
MADAI, red sea bream *Pagrus major*
ANAGO, conger *Conger myriaster*
GUTI, croaker *Argyrosomus argentatus*
KOOIKA, cuttle fish *Sepia esculenta*

Considering the food behaviour and growth-stage, several species were divided into three entities. At last 51 entities were finally analyzed in the simulation.

Rapid calculation

The relationships between phosphorus and catches, as shown in Fig. 1, must be theoretically explained by the established ecosystem model. There are long-term period data nearly 30 years. However, because of limited financial conditions, we regreted that we can only present here the two year simulation from 1956—57, when oxygen defficent water mass begun to appear.

There are many problems with the input data. Each animal entity has more than ten necessary parameters including growth, mortality, feeding habitat, spawning, imigration, fishing, and initial condition. Such tremendously large number of parameters that were collected from various papers and reports, are important and useful in further advanced studies, although uncertainties in parameters are inevitable which are examined and checked in future.

An example of biological information for sea bass is shown in the following :

[**sea bass,** young]

anabolism(mean)	H	951	$g^{1/3}$/year
catabolism	k	0.945	/year
ingestion	h	78.05	$g^{1/3}$/year
natural mortality	M1	0.08	/year
half saturation level of available food	ϕ,	$Q = 1.36 \times 10^{12}$kg	

suitability of prey g(ij) for i eating j

i = sea bass j = food for i eating j

j	g(ij)
zooplankton	.8
gizzard shad(young)	.4
sand lane	.8
ark shell	.8
short-neck clam	.8
shrimp	.8
crab (young)	.8

mantis shrimp (young)	.8
octopus (young)	.8
anchovy (summer)	.8
mullet (young)	.4

spawning period	January
egg weight ω	5.316×10^{-4} g
mortality in stage of larva	8.5722 /year
fishing mortality F	0
initial abundance (January 1, 1955)	839,660 kg

Results obtained

In numerically solving simultaneous differential equations, shorter time steplength is important to avoid accumulated errors in sumulations. For our simulation, calculations were carried out using a time step legth of one day. Accordingly, due to insufficient financial limitation, longer perid test run could not be conducted, although our initial plan was to carry out simulation during 30 years. Only the two years from 1956 to 1957 could be barely conducted.

Verification of test runs are usually checked by means of comparability of simulated results to actual changes. Despite the potentially insufficient short two-year period, considerably acceptable results, as summerized below, were obtained.

a. The two-year simulated results are presented in Table 1, only for catch, in order to compare the actual and the calculated. Here omitting biological information of body weight, length composition, etc..
b. Simulated results are as a whole comparable to actual variations.
c. The results for several species, including sea bass, flat fish, crab, mantis shrimp and cuttlefish, differ from observed data.
d. Inferring from the above-described results obtained, from a first approximation, the model can be considered theoretically acceptable.
e. The non-satisfactory results mentioned in article b, are attributed to the lack of accurate parameters of anabolism and catabolism for younger-aged stages of these species.

Table 1. Actual variations of and calculated values for catch (in tons)

Species	Acutual		Caluculated	
	1956	1957	1956	1957
KONOSIRO	88	55	113	61
IKANAGO	4701	3650	4217	1552
SUZUKI	180	150	278	61
HIRAME	3	2	3	2
KAREI	682	400	2905	1971
MOGAI	1248	3077	1650	5212
ASARI	884	568	1103	999
EBI	2714	2361	6038	347
KANI	663	510	268	1
SYAKO	0	5	29	171
TAKO	1035	882	3346	2384
MAIWASI	0	21	0	11
KATAKUTIIWASI	25353	31337	17398	6040
SABA	968	443	165	72
SAWARA	90	60	89	65
ESO	424	217	6153	1591
TATIUWO	68	8	3	1
BORA	120	98	220	200
MADAI	198	214	348	431
MAANAGO	440	617	652	2066
GUTI	146	123	137	110
KOOIKA	521	326	131	202

Summary and brief discussion

1. Ecosystem modelling is not well developed world-wide, although several methods have been presented.
2. Andersen-Ursin model is a theoretically advanced model, because, based upon food chain matrix, <IN> and <OUT> of phosphorus contained in animals and non-animal entities are accurately represented by simultaneous differential equations.
3. Many parameters are necessary in any ecological model. Accordingly, it is very dificult to apply such models to practical situations.
4. Food chain matrix plays a vital role in ecosystem modelling.
5. In this report, the ecosystem of Osaka Bay is analysed by a simplified model which is based on the Andersen-Ursin model. Simplification and modification are maily done in the non-animal entities such as phytoplankton, detritus, carcass.
6. Twenty-three species, selected from more than 80 commercial kinds of fish, were adopted in this analysis. Considering the growth stage, they were classified into 51 entities.
7. Calculations were carried out only for 2 years, 1955—56, because of financial limitations. Environmental data, as well as biological information, for an approximate 30-year period, were collected, which will be useful for future model simulation.
8. Verification was done by a comparison of calculated results with the actual changes of catch and body weight over time. Calculated results and actual changes for most species were well-fitted; however, for several species, such as sea bass, sole, ribbon fish, crab, cuttlefish, results did not coincid with actual changes. The reason for such discrepancies were attributed to unreliable feeding parameters and spawning mechanisms.
9. Ecosystem fluctuations, impacted by environmental changes (for instance, discharge of phosphorus) can be, principally and as a first approximation, explained from the model, although a practical application will be expected to be achived in the 21st century.

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