Utilization of the Biological Production in Eutrophicated Sea Areas by Commercial Fisheries and the Environmental Quality Standard for Fishing Ground

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The Seto Inland Sea, a typical enclosed sea in Japan, has been the most fertile and intense fishing ground. The fisheries have undergone an inevitable transformation which is attributable to cultural eutrophication of the waters resulted from rapid growth of Japanese economy.
Present paper briefly deals with the scientific researches in the past three decades; (1) quantitative expansion and degradation of fisheries production, (2) historical studies on the expansive utilization of the biological production by the commercial fisheries, and (3) the relation between nutrient level and commercial catch.

Transformation of the Inland Sea fisheries by the eutrophication of fishing grounds

The Seto Inland Sea, the largest enclosed coastal sea in Japan, has been known for its high fisheries productivity. Several archipelagoes with diverstities of topography are comprised in the fishing grounds. The Seto Inland Sea, which is less than 0.5% in area of the Japanese waters within a 200-miles, provide the areal extent of $19\times10^3 km^2$, yields about 5% of commercial catch around the islands of Japan (Tatara, 1981-1).(Fig. 1)

The boat fisheries catch weight had escalated during the rapid growth economy; increasing to 400×10^3m.t./year, or 21.1m.t./km^2/year (0.211m.t. ha^{-1} $year^{-1}$) by 170%, in the latter half of the 1960's (Tatara, 1981-1). (Fig. 2) Quantitatively speaking, this was the age of "overwhelming abundance." Contrary to the quantitative expansion, the qualitative degradation had become noticeable. This period overlaps with the fast growing

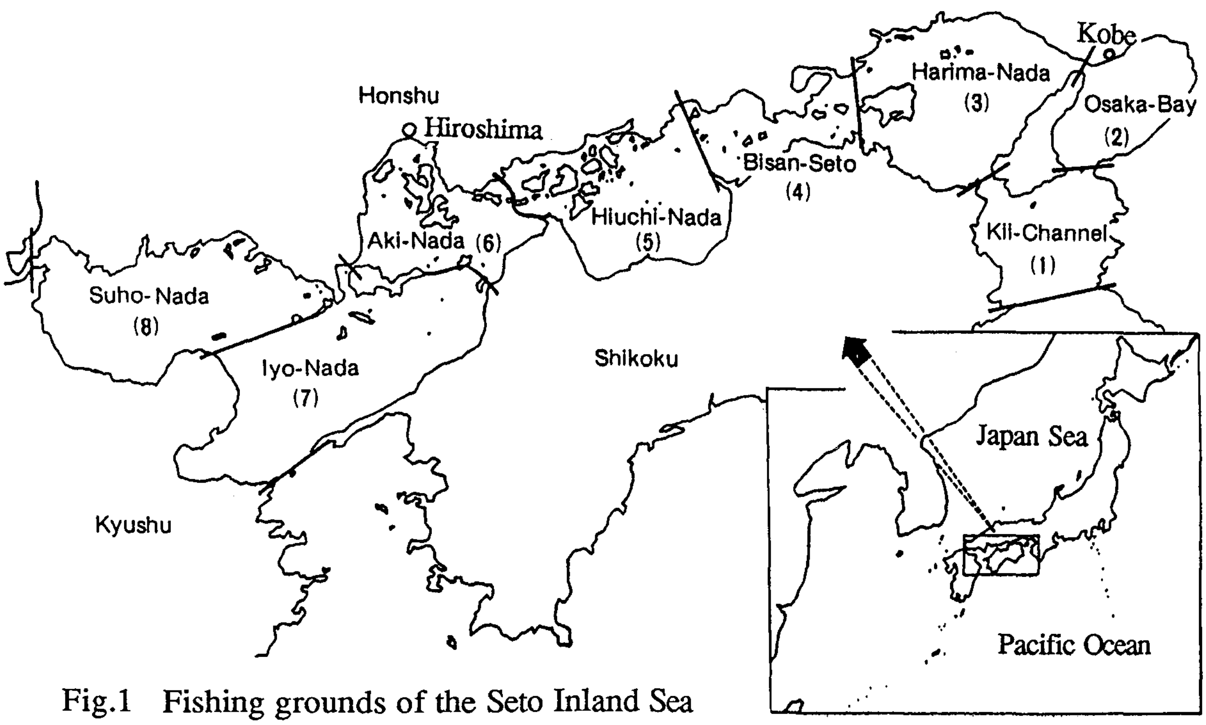

Fig.1 Fishing grounds of the Seto Inland Sea

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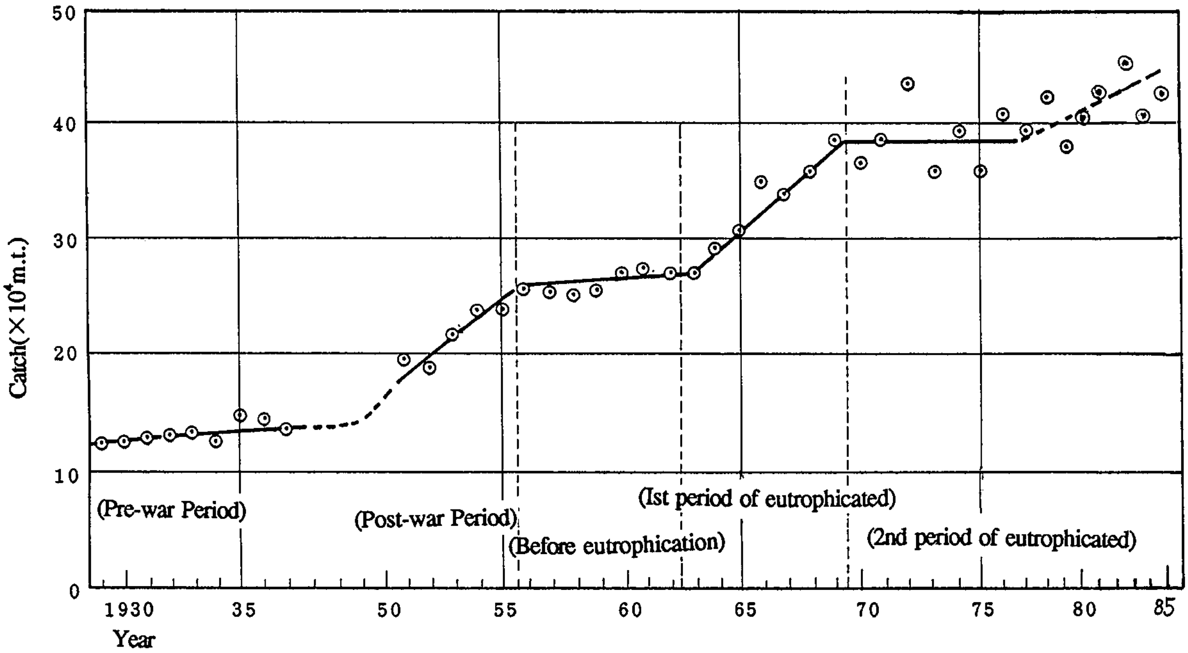

Fig.2 Change of catch amount by boat fisheries in the Seto Inland Sea

industrialization and urbanization along the coast of Inland Sea. In this period of Japan, due to the implementation of so called Regional Developement Policy, large-scale reclamations were promoted, and dumping of industrial and domestic waste waters were intensified, which caused a drastic environmental eutrophication in the fishing grounds. The complexity surrounding fisheries in the Inland Sea can be depicted as shown in Figure 3 (Tatara, 1981-2).

Although it was not evaluated quantitatively in one coherent method, the primary production in the fishing grounds had been inflated due to the eutrophication, thus causing the frequent Red Tides. These changes had influenced the ecosystem consistently and continuously; against the fisheries resources, predatory conditions of plankton feeders became fertile, but the degradation of nursery grounds damaged many other species.

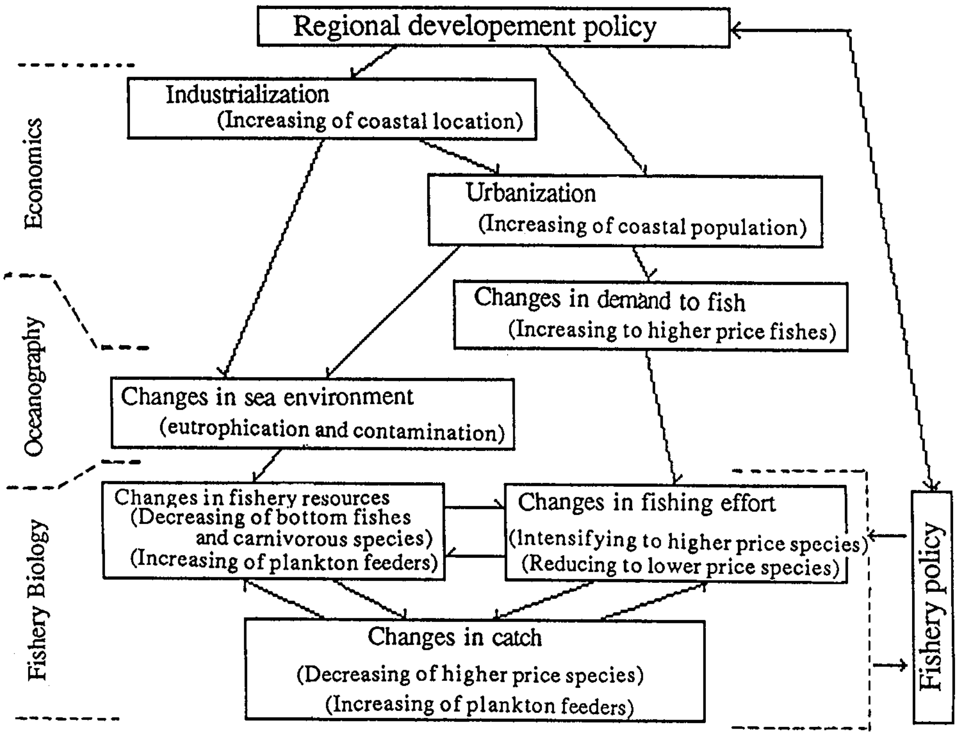

Fig.3 Schematic relation of the Changes in Social, Environmental and Fisheries around the Seto Inland Sea in modern age

By the urbanization of the Inland Sea areas, demands in fish market shifted to the higher commercial value species. This trend effected a inner reform of fisheries industry; the fishing effort exerted to the higher trophic level species such as sea breams and prawns, and slowed down to the plankton feeders such as sardines. These shifting in fishing pressures also changed the conditions of fishery resources severely.

Concerned chiefly with these degradation in environment and in fisheries of the Inland Sea, various measuresand administrative actions were initiated for the recovery. By 1973, the Law Concerning Special Measures for Conservation of the Seto Inland Sea was implemented by the Environment Agency, thus the degradation of the sea environment was decelerated. The Fisheries Agency had also taken many administrative actions to restoration of the nursery grounds and to regulate the excessive fishing effort. Despite of these efforts the fishery resources have not marked notable retrievals.

Utilization of the primary production in the eutrophicated waters by the commercial fisheries

Commercial fisheries do harvest a part of the biological production of marine ecosystem. All life of the ecosystem in fishing ground is supported by food chains beginning with phytoplankton and sea weeds (primary production). Phytoplankton become the food of fish through zooplankton. The trophic relations of the ecosystem of the Inland Sea can be schematized as in Figure 4 (Tatara, 1981-1). Thus the primary production flows into the higher trophic level, and the part of which, enclosed by solid lines, is utilized by the commercial fisheries shown as (PC) in the model equation.

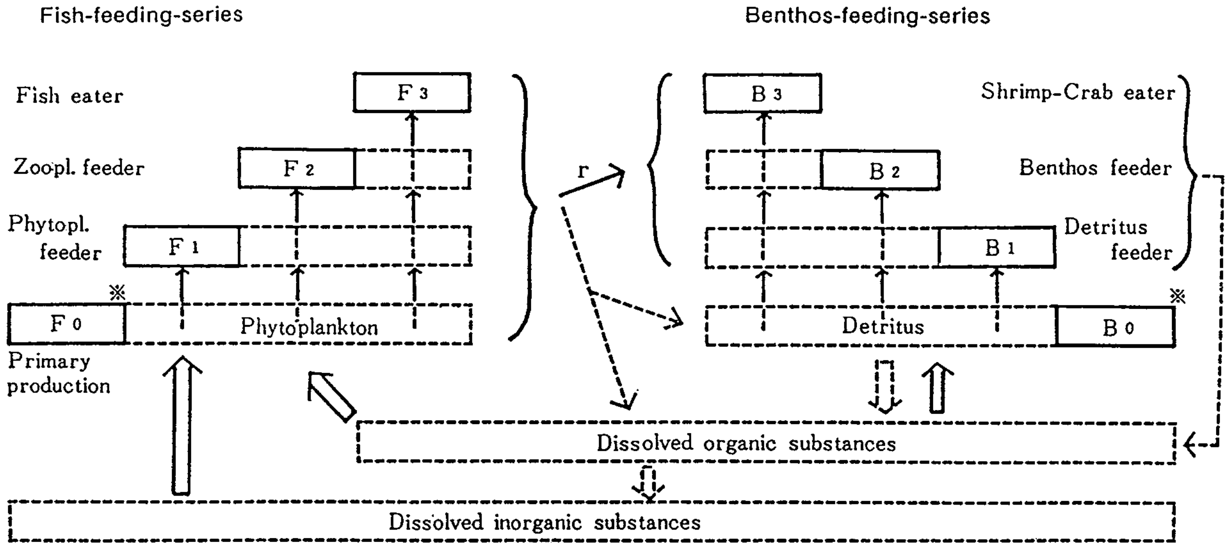

Fig.4 Utilization of primary production in the fishing ground by the commercial fishery (schematic)

$$(PC) = \sum_{i=0}^{3} (PF_i) + \sum_{i=0}^{3} (PB_i)$$

$$(PF_i) = (CF_i) / \prod_{n=0}^{i} g_n, \quad (PB_i) = r \cdot (CB_i) / \prod_{n=0}^{i} g_n$$

□ : Commercial catch
→ : Flows by feeding
⇒ : Flows by other than feeding
----→ : Flows by excretion and dead body
===⇒ : Flows by other than above mentioned
※ : Crops of sea weed was divided in phytoplankton and detritus.

where : PC : Total amount of primary production utilized through the total catch.
PF_i : Amount of primary production utilized through the catch of i-trophic level of fish-feeding series.
PB_i : Amount of primary production utilized through the catch of benthos-feeding series.
CF_i : Amount of commercial catch of i-trophic level of fish-feeding series.
CB_i : Amount of commercial catch of i-trophic level of benthos-feeding series.
G_n : Coefficient of assimilation from (n-1) -trophic level to n-trophic level.
r : Rate of dependence to the prey of fish-feeding series.

The historical relationship between the estimation of annual amount of primary production utilized through fishery (PC) and the annual catch amount is shown in Figure 5 (Tatara, 1981-2). It can be described as linear relationship from 1951 to 1974. As the eutrophication of the fishing grounds augmented, the catch weight almost doubled and (PC) increased by approx. 1.7 times from 15× 10^6m.t./year to 25× 10^6m.t./year. It seems that the utilization of the biological production of the eutrophicated waters was extended by intensifying the fishing efforts.

The relationship between the annual catch amount and the average trophic level of catch is shown in Figure 6 (Tatara, 1981-2). As the catch weight increased, the portion of lower trophic level species such as plankton-feeders expanded, thus the commercial values of catch were decreased during the period of continued eutrophication. It is not certain to what extent the relationship is reversible, between the catch amount and the average trophic level of the catch. But the catch amount seems to be extended by extensive fishing effort. However, the quantity of catch increases in reverse proportion to its quality. Here, the increase of catch depends upon the potentialities of the raising catch of lower trophic levels.

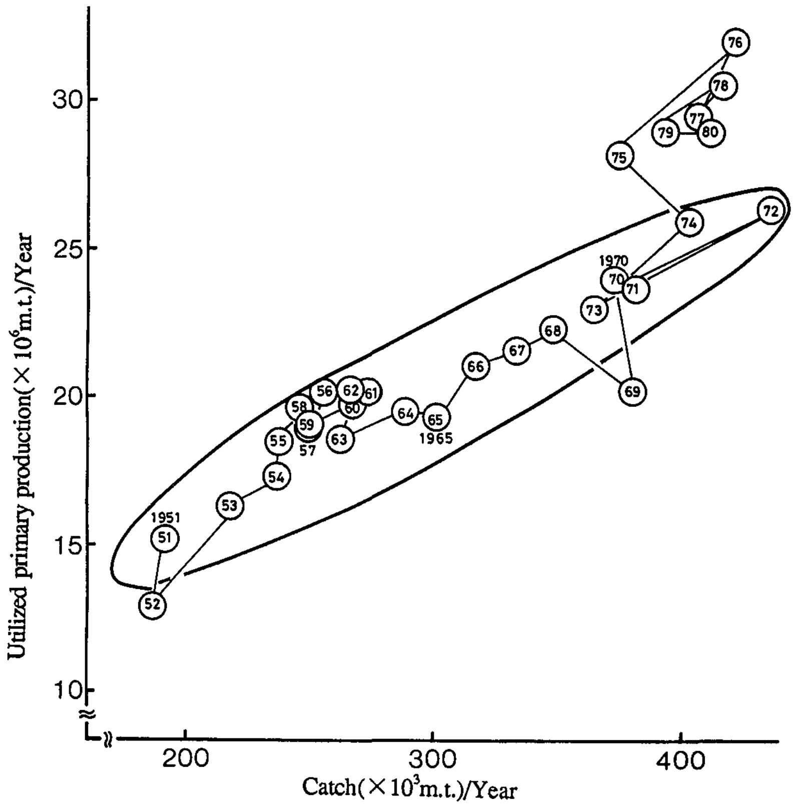

Fig.5 Annual catch amount and estimated amount of utilized primary production, in the Seto Inland Sea

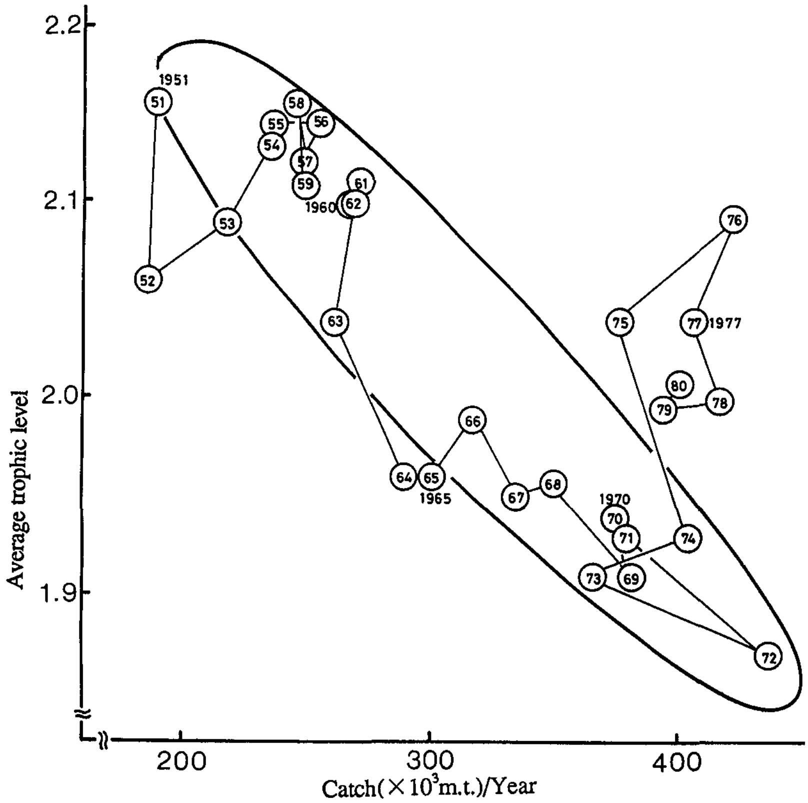

Fig.6 Annual catch amount and average trophic level of catch, in the Seto Inland Sea

Nutrient load and the fisheries production

Osaka Bay, located in the eastern part of the Seto Inland Sea, is a fishing ground of large nutrient loads from the surrounding cities (Joh, 1986). In this area, the studies have been done concerning the relationship between nutrient levels and fisheries production. As is shown in Figure 7, the annual catch amount of certain species from 1957 to 1973 were maximized under certain levels of nutrient (phosphorus) which was loaded one or two years before (Kurata, 1989). Total value of catch was also maximized in a certain phosphorous level. Daily phosphorous load levels substantiated the maximum annual catch are shown in Table 1 (Hattori, et al., 1989).

It has been clarified in the Inland Sea ecosystem, that a considerable part of luxuriant growth of plankton can not be used to form fish production but only used up in the side loops near the beggining of food chain fruitlessly (Anraku, et al., 1987). However, the above mentioned relationships suggested that the commercial catch may be maximized by regulating the nutrient level. The nutrient level is figured out by the capacity of fishing ground corresponded to the loads. So the concept of capacity is essential for establishing the environmental quality standard based on the management purposes.

For prescribing the environmental quality standard

Studies in Osaka Bay showed that the nutrient levels which make the catch weight maximize varied according to a species. Consequently, the target nutrient level would vary with the species intended. Inner-most part of Osaka Bay has been eutrophicated heavily, and has produced commercial

Table 1. Amounts of daily Phosphorous load corresponded to the maximum commercial catch in Osaka-Bay

Name of fish	Phosphorous load (m.t./day)
Red sea bream	less 4
Black sea bream	less 4
Common octopus	less 4
Kuruma prawn	less 4
Shrimps	less 4
Ground fishes	6
Shell fishes	7
Mullets	7
Soles and flounders	7
Sea weeds	9
Mantis crab	10
Sea urchins and Sea cucumbers	10
Sea bass	11

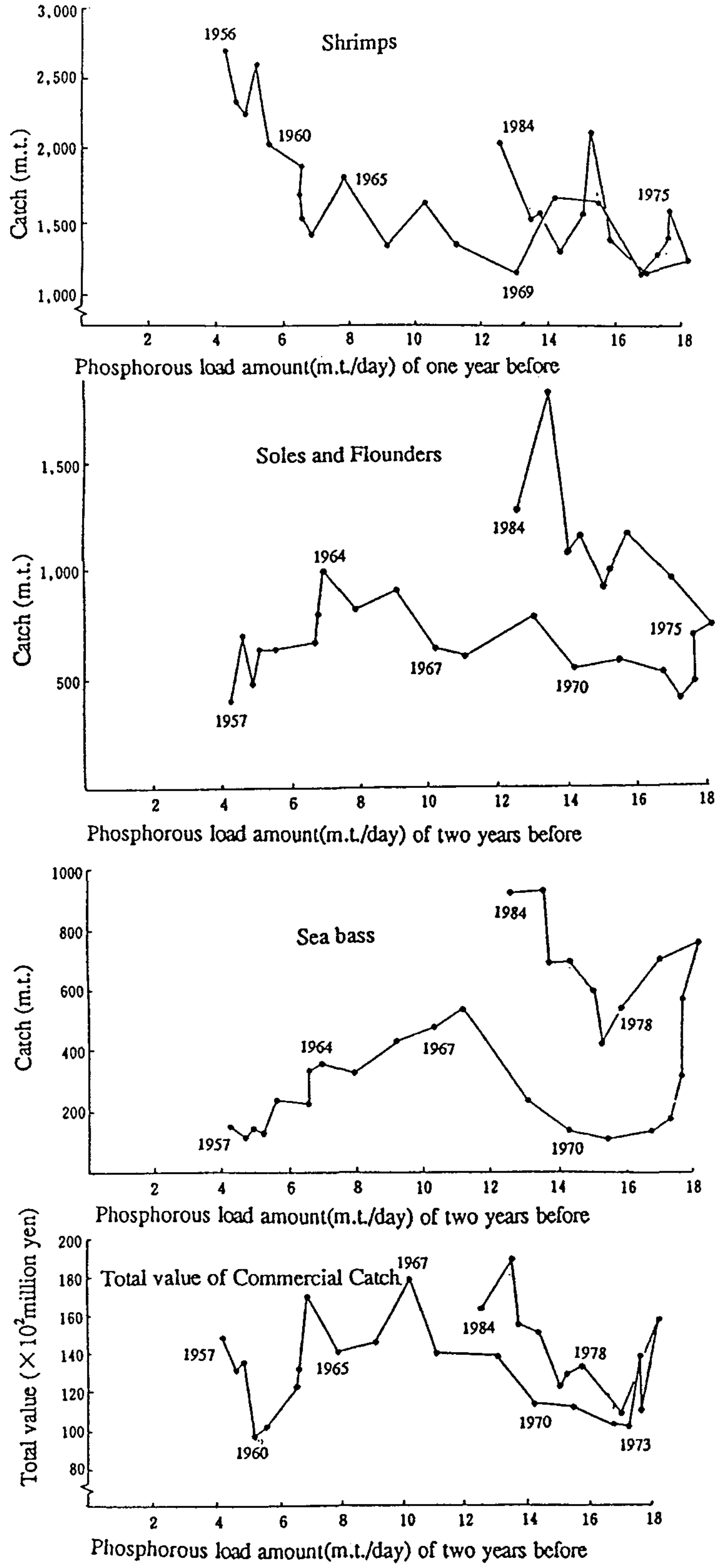

Fig.7 Relations between Phosphorous load amount and the amount of commercial catch or of money

catch, such as sardines, most abundantly in the Inland Sea. The evaluation for this profitable fishing ground, however, would be different according to the social appreciation for the sardine harvests. The value in this sense might be the foundamental element in establishing the environmental quality standard. However, it is very difficult in most cases to form a social consensus for the evaluation of environment, due to various points of view of concerned groups and users such as conservationists, fisheries and manufacturing industries and so on. The social adjustment function is still infirm for this purpose among the competing clusters even in heavily exploited shallow seas in Japan.

For the fisheries side, the recent state of eutrophication in Seto Inland Sea seems too excess to keep the balance of living species along with its variety in the inner-most fishing grounds. It is true that the general condition of the fishing ground is improving in recent years owing to various administrative efforts: but the statistics show that the improvement of catch and its quality are slow, then our efforts should not be interrupted. On the other hand, however, in most of sea laver culturing grounds, the recent eutrophic levels are believed to be much more favourable than somewhat oligotrophic conditions before the period of rapid growth of economy in late 1960's (Saito & Suto, 1984). Thus, it seems difficult for us to agree on a matter of eutrophication level even inside the fisheries.

Thus the "environmental quality standard" should not be established formally for the coastal area in general, but be prescribed as the actual contents of utilization plan of the waters. In other words, environmental quality standard is not an absolute indication, but a relative one of which the administrators and marine scientists should pursue, all the time, to meet the needs and interests of the time.

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