Chapter 4

Fisheries Production

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FISHERIES PRODUCTION AND OPTIMUM YIELD

It is possible to utilize biological resources sustainably because of the quality they possess of self-renewability. In a lotus pond, for instance, farmers can harvest lotus plants sustainably every autumn if they plant in the spring a part of the lotus root harvested in the previous year.

It is the purpose of this section to describe the existing state of fishery production in the Seto Inland Sea, its resources and characteristics, and give suggestions for its future development.

Sustainable development

A sea area with its resources can be regarded as a single vessel. The capacity of this vessel is limited. An increase of a single species population over time under the condition that everything else remains constant is ordinarily shown using a logistic curve. This type of curve is called a sigmoid curve: the amount of change in population biomass per unit time is small at the initial and final stages, but large in between (Fig. 4.1). Surplus is calculated as the amount of increase (growth and recruitment) minus the amount of decrease (death), and it shows a domed-type curve when plotted against the population biomass. Therefore, if we utilize only the surplus, resources are not reduced and sustainable development can be maintained. In this case, the maximum sustainable yield (MSY) is achieved at one half of the maximum biomass. This is the most simple case of the surplus production model.

Although for a long time MSY was used as the criterion for resource exploitation management in the world of fisheries, this model was replaced by the maximum economic yield (MEY) and later the optimum yield (OY) models. An interpretation of the OY model depends, however, on the manager’s point of view.

The United States Magnuson Fishery Conservation and Management Act for instance defines the term “optimum”, with respect to the yield from a fishery, as the amount of fish:

(A) which will provide the greatest overall benefit to the Nation, with particular reference to food production and recreational opportunities, and

(B) which is prescribed as such on the basis of the maximum sustainable yield from such fishery, as modified by any relevant economic, social, or ecological factors.
Fig. 4.1. Logistic growth curve of a one-species population and the relationship between population biomass and surplus. $t$, $P$, $P_{\text{max}}$, and $Y_e$ indicate time, biomass, maximum biomass, and surplus, respectively.

Naturally, the managing criteria have changed so as to maximize yield, economic benefit, and national benefit, in turn. All of those three yields are sustainable, though their biomass levels may differ from each other. Society determines what is the appropriate level of resources to utilize. It is acceptable to have a certain level of exploitation as long as that level does not reduce the ability of the biomass to reproduce itself. However, in reality, maintaining a stable reproductive population has not often been achieved. This is particularly the case where the reproductive and recruitment mechanisms are not fully understood. A simple managing criterion to overcome this problem was proposed by Doi (1973). He noted that the biomass level achieving MSY fluctuates at around one half of the maximum biomass due to natural mortality, age of maturity, and other species specific parameters. Even in extreme cases, it is always larger than one third of the maximum biomass. Therefore, he divided the biomass levels at the time of exploitation into three phases: that greater than one half of the maximum biomass (favorable phase), that from one half to one third (monitoring phase), and that smaller than one third (unfavorable phase). He recommended to maintain fisheries resources at or above the monitoring phase.

In an analytical model using age specific parameters, MSY is achieved usually at a level of between one third and one half of the unexploited maximum biomass.
(Gulland, 1972). Allowable catches should, therefore, be reduced to keep the stock at a higher level when a more stable reproductive effort is desired. In multi-species management, the situation is more complicated, for example, to manage a species sustainably it may be necessary to restrain the exploitation of other species.

*The existing state of fishery production*

Under the present fisheries law promulgated in 1949, the Seto Inland Sea is defined as extending from the Kii-Channel to Iyo-Nada or Suo-Nada excluding the Bungo-Channel. We have divided the Seto Inland Sea into the East Area (eastward of Bisan-Seto) and the West Area (westward of Hiuchi-Nada) in the following analysis.

The total amount of fisheries’ yield in the Seto Inland Sea in 1992 was 668 thousand metric tons, consisting of 307 thousand MT by fishing and 361 thousand MT by aquaculture. Productions in the Seto Inland Sea comprises 23%, 19%, and 28% of the overall yield, the coastal fishing yield and the aquaculture yields for all of Japan, respectively. The averaged annual catch for the Seto Inland Sea by fishing was 16 MT/km². The main products of aquaculture are oysters (46%) and lavers (41%), the others being sea mustard, *Undaria pinnatifida* (7%), and fishes (6%: yellowtail 5%, red sea bream 1%). The production of lavers in wet weight amounted to 148 thousand MT, 39% of the total production in Japan. About 49 thousand people, engaged in the fishing and aquaculture industries, earning a total of 160 billion yen by fishing and 103 billion yen by aquaculture.

The production by fishing increased until 1986, and by aquaculture until 1988. Both productions have decreased in recent years. The production by aquaculture exceeded that of fishing in 1988.

Figure 4.2 shows the trend of fish catch classified by price per kg. It shows that 1) total catch of the high price fish is fairly constant, 2) the medium price fish catch increased slowly until the later half of 1970’s and stabilized thereafter, 3) the low price fish catch increased until 1982 and then decreased, 4) the seashell catch decreased after showing a peak in 1972, 5) the seaweed production decreased after 1984, and 6) the decrease of the low price fish catch and the seashell catch has resulted in the recent reduction of the total catch.

The mean catches by group for the period 1983–1992, with the coefficient of variation (C.V.; standard deviation/average) in parentheses, were as follows: high price fish 28,281 MT (4.1%); medium price fish 135,991 MT (4.0%); low price fish 174,094 MT (24.1%); seashells 37,149 MT (40.3%); seaweeds, 8,682 (24.8%), annual total catch 384,200 MT (14.9%). Namely, the high, medium and low price fishes, seashells, and seaweeds shared 7.4%, 35.4%, 45.2%, 9.7%, and 2.3% of the annual total catch by weight in the Seto Inland Sea for the last 10 years, respectively.

We next examined trends on the annual catch by species for the 41 year period from 1952 to 1992. The catches of sharks, pike eels, and hard clam have decreased steadily since 1952. In the last ten years, a big reduction was seen in the catches of hard clam, short-necked clam, ark shell (*Scapharca subcrenata*), sea cucumber, sea urchin, and sea mustard as well as sardine, anchovy, and cuttlefish.
Fig. 4.2. Trends of catches by species group classified by fish price per kg. The high price group: red sea bream, Spanish mackerel, bastard halibut, etc. The medium price group: jack mackerel, makerels, pike eel, hairtail, sea cucumbers, etc. The low price group: sardine, anchovy, shirasu, sand lance, etc.
We also examined levels and trends of the annual catch by species for the last ten years 1983–1992 (Table 4.1). Among the 47 species (or species groups), 27 (57%) were at a medium level range (the average catch for the last ten years being 0.7–1.3 times compared to that during the 41 years), 12 (26%) were at a high level (>1.3 times) and 8 (17%) were at a low level (<0.7 times). The number of species in which catch was increasing and those in which it was constant amounted to 5 (11%) and 8 (17%), respectively. On the other hand, 24 (51%) and 10 (21%) species showed decreasing and unstable trends, respectively. In other words, negative trends were seen in 34 (72%) species.

**Characteristics of the biological production**

The 47 species mentioned above (Table 4.1) and other four species statistically grouped as “other fishes”, such as conger eels, silver pomfret, gizzard shad, and mantis shrimp, were divided into three groups in terms of stock structure: 20 migratory species from the outer area (Pacific Ocean), 15 species native to the Seto Inland Sea, and 16 inshore species. The migratory species, about 40% in number, occupied 45% of the total catch in weight. In other words, about one half of the catch in the Seto Inland Sea depends on resources which migrate in from outside of the inland sea (Tatara, 1977).

Fishery resources in the Seto Inland Sea are characterized by a small scale stock with a large variety of species. Though the production of each individual stock is not large, high price species such as Spanish mackerel, silver pomfret, pike eel, butter fish, bastard halibut, kuruma prawn, and swimming crab are abundant. Juvenile and young are also abundant in the area, so the area has an important function as a nursery ground (Tatara, 1977).

Next, we compared the catches by species between the East and West areas of the Seto Inland Sea. Catches were larger in the East than in the West for pelagic fish such as sardine, mackerels, Spanish mackerel, and sand lance. On the other hand, demersal fish such as bastard halibut, red sea bream, and kuruma prawn as well as the benthic animals including sea urchin, hard clam, and short necked clam were larger in the West. The East is shallower and has lower salinity water than the West. It seems that differences in environmental conditions are responsible for the differences in abundance between the areas, and as a consequence these determine the fishery production by region.

Sardines are mainly phyto-plankton feeders when larger than 9 cm (Yasuda and Hiyama, 1957). Since almost all sardines caught in the Seto Inland Sea are larger than this, sardines are secondary producers in this area, like zoo-planktons. Therefore, roughly speaking, excluding sardines the low price fishes can be regarded as carnivorous species. Similarly the medium price fishes are generally the medium ~ large carnivorous animals, and the high price fishes are the large carnivorous animals. The catches by weight of medium price fishes and low price fishes excluding sardines were almost equal. As most of the low price fishes are native to the Seto Inland Sea, their production originates from this area itself. The medium price fishes are composed of mainly migratory species from the outer area such as mackerels, so only a part of their catch is supplied by the Seto Inland Sea.
Table 4.1. Average catches (MT), their coefficients of variation, catch levels, and overall trends for the period 1983–1992

<table>
<thead>
<tr>
<th>English name</th>
<th>Average</th>
<th>(C.V.)</th>
<th>Level/Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharks</td>
<td>226</td>
<td>(13)</td>
<td>Medium/Dec</td>
</tr>
<tr>
<td>Sardine</td>
<td>35321</td>
<td>(47)</td>
<td>High/Dec</td>
</tr>
<tr>
<td>Round herring</td>
<td>87</td>
<td>(122)</td>
<td>Low/Dec</td>
</tr>
<tr>
<td>Anchovy</td>
<td>58357</td>
<td>(44)</td>
<td>Medium/Dec</td>
</tr>
<tr>
<td>Shirasu</td>
<td>40968</td>
<td>(19)</td>
<td>High/Dec</td>
</tr>
<tr>
<td>Jack mackerels</td>
<td>4119</td>
<td>(22)</td>
<td>Medium/Unst</td>
</tr>
<tr>
<td>Scads</td>
<td>1809</td>
<td>(23)</td>
<td>Medium/Unst</td>
</tr>
<tr>
<td>Mackerels</td>
<td>6312</td>
<td>(36)</td>
<td>High/Inc</td>
</tr>
<tr>
<td>Yellow tails</td>
<td>681</td>
<td>(33)</td>
<td>Medium/Unst</td>
</tr>
<tr>
<td>Bastard halibut</td>
<td>854</td>
<td>(17)</td>
<td>High/Inc</td>
</tr>
<tr>
<td>Flounders</td>
<td>11221</td>
<td>(7)</td>
<td>Medium/Dec</td>
</tr>
<tr>
<td>Croakers</td>
<td>3142</td>
<td>(9)</td>
<td>High/Stb</td>
</tr>
<tr>
<td>Lizardfishes</td>
<td>4060</td>
<td>(22)</td>
<td>Medium/Dec</td>
</tr>
<tr>
<td>Butter fish</td>
<td>309</td>
<td>(96)</td>
<td>Low/Inc</td>
</tr>
<tr>
<td>Pike eel</td>
<td>545</td>
<td>(18)</td>
<td>Low/Dec</td>
</tr>
<tr>
<td>Hairtail</td>
<td>14153</td>
<td>(6)</td>
<td>High/Stb</td>
</tr>
<tr>
<td>Rays</td>
<td>487</td>
<td>(8)</td>
<td>Medium/Stb</td>
</tr>
<tr>
<td>Red sea bream</td>
<td>4047</td>
<td>(6)</td>
<td>Medium/Stb</td>
</tr>
<tr>
<td>Crimson sea bream</td>
<td>22</td>
<td>(50)</td>
<td>Medium/Unst</td>
</tr>
<tr>
<td>Black porgy</td>
<td>2088</td>
<td>(5)</td>
<td>Medium/Stb</td>
</tr>
<tr>
<td>Spanish mackerel</td>
<td>4127</td>
<td>(31)</td>
<td>High/Dec</td>
</tr>
<tr>
<td>Mullets</td>
<td>3290</td>
<td>(38)</td>
<td>Medium/Dec</td>
</tr>
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<td>Common sea bass</td>
<td>2564</td>
<td>(12)</td>
<td>Medium/Dec</td>
</tr>
<tr>
<td>Sandlance</td>
<td>31713</td>
<td>(28)</td>
<td>Medium/Unst</td>
</tr>
<tr>
<td>Oth. fishes</td>
<td>47685</td>
<td>(6)</td>
<td>Medium/Stb</td>
</tr>
<tr>
<td>Kuruma prawn</td>
<td>1164</td>
<td>(14)</td>
<td>Medium/Dec</td>
</tr>
<tr>
<td>Oth. shrimps</td>
<td>20861</td>
<td>(15)</td>
<td>Medium/Dec</td>
</tr>
<tr>
<td>Swimming crab</td>
<td>1594</td>
<td>(32)</td>
<td>High/Unst</td>
</tr>
<tr>
<td>Oth. crabs</td>
<td>1298</td>
<td>(19)</td>
<td>Medium/Dec</td>
</tr>
<tr>
<td>Cuttle fishes</td>
<td>2745</td>
<td>(21)</td>
<td>Low/Dec</td>
</tr>
<tr>
<td>Oth. squids</td>
<td>2612</td>
<td>(12)</td>
<td>Medium/Stb</td>
</tr>
<tr>
<td>Octopus</td>
<td>8456</td>
<td>(24)</td>
<td>Medium/Inc</td>
</tr>
<tr>
<td>Sea urchins</td>
<td>509</td>
<td>(31)</td>
<td>High/Dec</td>
</tr>
<tr>
<td>Sea cucumber</td>
<td>2291</td>
<td>(17)</td>
<td>Low/Dec</td>
</tr>
<tr>
<td>Oth. animals</td>
<td>10397</td>
<td>(10)</td>
<td>High/Stb</td>
</tr>
<tr>
<td>Abalones</td>
<td>364</td>
<td>(17)</td>
<td>High/Unst</td>
</tr>
<tr>
<td>Top shell</td>
<td>841</td>
<td>(29)</td>
<td>Medium/Inc</td>
</tr>
<tr>
<td>Hard clam</td>
<td>92</td>
<td>(43)</td>
<td>Low/Unst</td>
</tr>
<tr>
<td>Short-necked clam</td>
<td>22928</td>
<td>(62)</td>
<td>High/Dec</td>
</tr>
<tr>
<td>Mogai (Ark shell)</td>
<td>30</td>
<td>(260)</td>
<td>Low/Dec</td>
</tr>
<tr>
<td>Oth. seashells</td>
<td>12454</td>
<td>(30)</td>
<td>Medium/Unst</td>
</tr>
<tr>
<td>Sea mustard</td>
<td>647</td>
<td>(33)</td>
<td>Low/Dec</td>
</tr>
<tr>
<td>Agar-agar</td>
<td>1618</td>
<td>(14)</td>
<td>Medium/Dec</td>
</tr>
<tr>
<td>Glue plant</td>
<td>88</td>
<td>(19)</td>
<td>Medium/Dec</td>
</tr>
<tr>
<td>Oth. plants</td>
<td>6246</td>
<td>(32)</td>
<td>Medium/Unst</td>
</tr>
<tr>
<td>Fishery production by area</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average catches per square kilometer are shown for each region in the Seto Inland Sea in Fig. 4.3. Regional averages over the period of 1952 through 1992 become increasing from Iyo-Nada in the West to Osaka Bay in the East with the exception of Harima-Nada. The average value in the whole area of the Seto Inland Sea was 22.5 MT/km² for the last ten years. The maximum value was 46.2 MT/km² in Osaka Bay, followed by Kii-Channel, Hiuchi-Nada, and Bisan-Seto where average catches all exceeded 20 MT/km². Harima-Nada, Suo-Nada, Aki-Nada, and Iyo-Nada, all had values lower than 20 MT/km² with the minimum value of 9.7 MT/km² in Iyo-Nada. The values for the last ten years were less than those for 41 years in Bisan-Seto and Harima-Nada, the reduction being largest in Bisan-Seto.

Trends in the regional catches were re-examined by species groups in terms of habitat depth, type of migration, and type of feeding habit as reported by Tatara (1977). The analysis examining the habitat depth indicates that pelagic fishes were dominant in Osaka Bay and Hiuchi-Nada, while demersal fishes were dominant in Bisan-Seto and Suo-Nada. The two groups occurred evenly in Kii-Channel and Aki-Nada. The demersal fishes were marginally dominant in Harima-Nada and Iyo-Nada. The catch of pelagic fishes in Osaka Bay was 4.8 times as much as that in Harima-Nada, and 1.5 times for demersal fishes. The ratio of pelagic fishes to demersal was lower westward from Osaka Bay to Bisan-Seto, and higher eastward from Iyo-Nada to Hiuchi-Nada (Fig. 4.4).

Catches by type of migration are shown in Fig. 4.5. The widely migratory pelagic fishes among areas (PAA) includes sardine composed of a single stock for the entire area of Seto Inland Sea, while the migratory pelagic fishes between neighboring areas (PBN) including anchovy composed of more than two stocks. The individual groups were relatively well-balanced in Kii-Channel. In Osaka Bay, PAA were most abundant followed by PBN and the migratory demersal fishes between neighboring areas (DBN). In Harima-Nada, DBN was dominant followed by PBN. In Bisan-Seto, DBN was dominant followed by the migratory demersal fishes within an area (DWA), so the catch is largely dependent on demersal fishes. Most of the catch in Hiuchi-Nada were composed of PBN followed by DBN and DWA. The
Fig. 4.4. Regional average catches per km² by habitat depth for the period 1983–1992.
Fig. 4.5. Regional average catches per km² by type of migration for the period 1983–1992.
PAA; Pelagic fish among areas, DAA; Demersal fish among areas, PBN; Pelagic fish between neighboring areas, DBN; Demersal fish between neighboring areas, DWA; Demersal fish within an area.
individual groups were well-balanced in Aki-Nada, though PBN was slightly more abundant. The balance in Iyo-Nada was similar to Kii-Channel with the exception of the smaller fraction of PAA. Like Bisan-Seto, Suo-Nada was almost exclusively composed of DWA and DBN though the most dominant and second most dominant groups were reversed. Thus this area also showed a dependence on demersal fishes (Fig. 4.5).

Catches by feeding habit are shown in Fig. 4.6. The groups were fairly well-balanced in Kii-Channel and Iyo-Nada. The plankton feeders (PF) were dominant in Osaka Bay, and they were also comparatively abundant in Harima-Nada and Hiuchi-Nada. Each group was well represented in Aki-Nada but PF were slightly dominant. The crustacean-fish-seashell and the detritus-polychaete feeders were dominant in Bisan-Seto and Suo-Nada, respectively. The ratio of PF to the area total became lower westward from Osaka Bay to Bisan-Seto and higher eastward from Iyo-Nada to Hiuchi-Nada (Fig. 4.6).

Area specific catches occur as a combination of the production from that area’s own stock and migration of fish from other areas. The reason why the catches by groups were most balanced in Kii-Channel is possibly because it is geographically open to the outer area. In Osaka Bay, the fishes among areas and between neighboring areas are dominant, so the migration from other areas is large there. However, in Harima-Nada, the migration from other areas is small. Bisan-Seto is the inner most area in the East, so the fishes between neighboring areas are actually from the area’s own stocks. Therefore, the catches in Bisan-Seto are almost entirely from the area’s own stock. The reason why average catches per km² were higher in Bisan-Seto than in Harima-Nada may be due to the shallower average depth of water in Bisan-Seto. Similarly, as Hiuchi-Nada is the inner most area in the West, the catches are almost entirely from the area’s own stock there as well. The catches in Suo-Nada are also almost entirely from the area’s own stock.

Stock status and optimum yield

Next we review the stock status of three commercially important species. The red sea bream (*Pagrus major*) is highly prized in Japan. It is a long-lived species reaching more than 25 years, and stock in the Seto Inland Sea probably mingles with the Pacific Ocean stock with increasing size. The maximum age in the catch has declined from more than 18 in the 1930’s to about 11 in the 1980’s. Angling, the major gear used previously, has been replaced in recent times by “Gotami”, a type of surrounding seine net, and later by small sized trawlers. Angling was once the dominant fishing method in the spawning grounds, while the Gotami was used for the migratory schools. The small sized trawlers would catch this species incidentally. The average weight of the fish caught has declined as the major gear used changed. The average weight in the West was only 134 g in the 1980’s, just 9% of what it was in the 1930’s. Based on the yield per recruit analysis, it was calculated that yield per recruit value in the 1980’s was 40% of that in the 1930’s, and that the spawning biomass in the 1980’s was 20% compared to that of the unexploited stock. Therefore, the population level in the 1980’s was under an unfavorable phase.
Fig. 4.6. Regional average catches per km² by feeding habit for the period 1983–1992.
PF; Plankton feeders, FF; Fish feeders, CFSF; Crustacean-fish-seashell feeders, DPF; Detritus-polychaete feeders.
However, the recruitment level seems to be unchanged, at least since around 1980. The average catch for the last 10 years was about 4,000 MT which is equivalent to the equilibrium yield estimated using an analytical (age-structured) model. However, if fishing efforts are reduced, annual catch would actually increase (Table 4.2). This is because the production derived from growth is not fully exploited when a large quantity of small fish are caught (growth overfishing).

The anchovy (*Engraulis japonica*) is also a very popular fish in the Seto Inland Sea. The stock is a mixture of the spring brood coming from the outer area and the summer and autumn brood spawned in the Seto Inland Sea. The life span is short (two years). Anchovy is commercially captured at two sizes. Firstly, the anchovy is caught by boat seiners at the post-larval stage (shirasu) of 20–40 mm in T.L. The catch of shirasu includes sardine post-larvae and other species but these are negligible in the Seto Inland Sea. Secondly, the anchovy is caught by purse seiners and boat seiners at young and adult stages. Therefore, the shirasu fishery and the anchovy fishery share the same stock. Most of the anchovy are processed as "Iriko" used for making a fish soup. The catch ratio between shirasu and anchovy which was 1:25 40 years ago has become 1:1 in recent years. A one metric ton catch of shirasu is equivalent to a three metric ton catch of anchovy based on preliminary analysis. Thus the potential catch is the total of anchovy catch and three times the shirasu catch. This has decreased since 1986. At the same time, the average number of eggs per tow by net survey has decreased. In 1991, it declined to about 15% of the level compared to the average calculated for 1977 to 1991. Moreover, the size of the fish schools are declining in the wintering areas. Thus both the adults and recruits have reduced in biomass. The biomass is presently in an unfavorable phase, and the recruits are showing a downward trends (recruitment overfishing). As the excessive investment has been made into fishing vessels, fishing gears, auto-processing machines and a large scale dryers, high catch returns are necessary to pay back the investment. This over-investment has therefore had a detrimental effect on the anchovy stock, and subsequently led to hardship to amongst the fishermen. It is therefore necessary to initiate a catch or effort regulation policy immediately.

The Spanish mackerel (*Scomberomorus niphonius*) is a migratory species. Its life span is about 7 years. Exploitation has occurred in three periods; big fishes were mainly caught in the 1960's (under-exploited), the catch increased by introducing net haulers in the 1970's (developed), the catch reached its maximum and thereafter decreased in the 1980's (fully-exploited ~ over-exploited). The present adult population level in the East was estimated at 24% compared to that of the unexploited stock (unfavorable phase). Furthermore, recruitment has become unstable in both the East and West. The present stock status seems to be in a serious situation (recruitment overfishing). It is desirable to restrain the annual catch at 1,000 MT for the whole area in the Seto Inland Sea and to continue monitoring.

The present fishing mortality in the Seto Inland Sea was assessed to be on average three times higher than the optimum ($F_{0.1}$) based on the assessment work for some commercially important species (Table 4.2). This means that the present fishing effort (the number of vessels or days fished) should be reduced to one third in the Seto Inland Sea.
<table>
<thead>
<tr>
<th>English name</th>
<th>Area</th>
<th>$F$</th>
<th>$F_{0.1}$</th>
<th>$F/F_{0.1}$</th>
<th>Optimum yield</th>
<th>Desirable management schemes (Remarks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchovy</td>
<td>Total</td>
<td>0.92</td>
<td>0.32</td>
<td>2.9</td>
<td>19000</td>
<td>Catch or effort regulation (Recruitment overfishing)</td>
</tr>
<tr>
<td>Shirasu</td>
<td>Total</td>
<td>0.96</td>
<td>0.66</td>
<td>1.5</td>
<td>220</td>
<td>Catch or effort regulation (Recruitment overfishing)</td>
</tr>
<tr>
<td>Bastard halibut</td>
<td>East</td>
<td>0.72</td>
<td>0.20</td>
<td>3.6</td>
<td>11000</td>
<td>Effort regulation and release of captured small fish (Management by species is difficult)</td>
</tr>
<tr>
<td>Flounders</td>
<td>Total</td>
<td>0.84</td>
<td>0.35</td>
<td>2.4</td>
<td>19000</td>
<td>Effort regulation and release of captured small fish</td>
</tr>
<tr>
<td>Frog flounder</td>
<td>East</td>
<td>0.79</td>
<td>0.41</td>
<td>1.9</td>
<td>400</td>
<td>Effort regulation and release of captured small fish</td>
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<td>West</td>
<td>0.41</td>
<td>0.17</td>
<td>2.4</td>
<td>1500</td>
<td>Effort regulation and release of captured small fish</td>
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<tr>
<td>Pike eel</td>
<td>Total</td>
<td>0.53</td>
<td>0.11</td>
<td>4.8</td>
<td>500</td>
<td>Release of captured small fish and effort regulation (Optimum yield was over-estimated in the East)</td>
</tr>
<tr>
<td>Hairtail</td>
<td>Total</td>
<td>0.45</td>
<td>0.20</td>
<td>2.2</td>
<td>14000</td>
<td>Mesh size increase and effort regulation</td>
</tr>
<tr>
<td>Red sea bream</td>
<td>East</td>
<td>0.88</td>
<td>0.20</td>
<td>4.4</td>
<td>4170</td>
<td>Effort regulation (East: 67%, West: 54%) (Recruitment is stable; Growth overfishing)</td>
</tr>
<tr>
<td>Spanish mackerel</td>
<td>East</td>
<td>0.59</td>
<td>0.27</td>
<td>2.2</td>
<td>620</td>
<td>Catch regulation (1.000 MT for the total area)</td>
</tr>
<tr>
<td>Tiger puffer</td>
<td>East</td>
<td>1.32</td>
<td>0.28</td>
<td>4.7</td>
<td>400</td>
<td>(Rate of recapture is high)</td>
</tr>
</tbody>
</table>

1) $F_{0.1}$ is the fishing mortality coefficient for which the slope of the yield per recruit curve is 1/10 of the slope at the origin. This coefficient, often called the optimum fishing mortality rate, is more conservative in maintaining the reproduction of a species.

2) The suffixal numerals of optimum yield indicate methods used: 1, Sustainable (or equilibrium) yield by multiplying yield per recruit value at $F_{0.1}$ and average of recruits; 2, Recruits was estimated from stock-recruitment relationships, and Method 1 was used; 3, $0.4 \times F_{0.1} \times$ the maximum biomass in recent years; 4, Adjusted average catches by considering a trend on catches for the period of 1983–1992.

3) Fishing mortality coefficients were expressed per month in case of anchovy, and per year for other species.
For the species not listed in Table 4.2, the average catch by species during the last ten years (Table 4.1) can be used to manage those resources for the time being.

**Trends of stock abundance and their reasons**

The sardine catches have decreased rapidly in the Seto Inland Sea for the last several years, in common with the resources around Japan which have shrunk rapidly. In the case of mackerels, the year class strength has increased in recent years, so the migratory schools entering into the Seto Inland Sea have increased.

Though the population size of spawning adults were not high for red sea bream and bastard halibut, fairly large number of the small sized fish of both species have been caught. Though the resources of these two species seem to have increased, the reasons for this increase are not fully clear. However, the release of farmed juveniles has been considered to be a major reason. Juvenile release has been carried out substantially since the late 1970’s for the red sea bream and from 1980 for the bastard halibut. Cultured red sea bream are numerous in stocks and probably to contribute to the reproduction of the natural stock. This possibility is now being studied using a genetics approach (Yokogawa, 1996).

Though the juveniles of kuruma prawn have been reared and released since 1977, the catch reached its maximum in 1985, and thereafter began to decrease. It was assessed that the loss of each 1 km² of tideland to reclamation resulted in a catch reduction of 6 MT of kuruma prawn (Doi et al., 1973). This figure was recognized as the total value affected by other factors including sea water pollution.

The catches have decreased remarkably in the case of sea cucumber, short-necked clam, ark shell, laver, agar-agar, and glue plant (*Gloiopectis*) due to the reduction of habitat by land reclamation and environmental deterioration. A rapid collapse occurred in the short-necked clam populations in Suo-Nada, the main fishing area for this species, after fishermen introduced a pump dredge net which was effective in harvesting the offshore large sized shells of the unexploited adults population.

In the sea cucumber (*Stichopus japonicus*) fishery, the cheaper black colored individuals have become more abundant than the blue colored individuals. Similarly, hardback shrimp, *Trachipenaeus curvirostris*, have become more abundant than the more expensive shrimps, cocktail (*Metapenaeopsis acclivis*) and kishi velvet (*Metapenaeopsis dalei*) in the small sized trawl fishery. The hardback shrimp is abundant in muddy ground environments, while the cocktail and kishi velvet are found in sandy ground environments.

Thus recently, the species composition has changed for the worse in terms of the commercial value. Though the fluctuation of a stock size is closely related to natural factors, fishing operations, and artificial environmental change, the importance of each individual factor is different for different species.

**A future direction for development**

A limited entry system by gear type (fishery) has been adopted in Japan as the main managing measure to adjust for friction between fishermen using different
gears. In addition, some other regulations on the fishing period, fishing area, and gears have also been adopted. However, the implemented regulations have not been able to prevent the substantial increase of fishing power derived from improvements in fishing vessels and gears used which have resulted in overfishing. In fact, the present fishing effort was assessed to be three times higher than the optimum level. It is difficult to reduce the number of vessels drastically at the present, for there are no new resources to exploit in the Seto Inland Sea. Further, as the government faces severe financial problems at the present, so it is probably impossible to compensate fishermen in order to reduce vessels.

Taking consideration of the present age composition of fishermen in the Seto Inland Sea, for better or for worse, the number of working fishermen will be reduced by one half in the next ten years because of the aging of fishermen and fewer younger aged fishermen finding employment in fishing. The stock status in this area may make a turn for the better at that time, if fishing effort is reduced in relation to the decrease in number of fishermen.

It is important to practice fisheries oriented resources management to maintain the reproduction stocks for various species. Further it is also important to raise the income and to reduce overheads of each individual fishery household by avoiding excessive investment and undue competition among fishermen.

**PRIMARY PRODUCTION CONSUMED BY FISHERIES**

Primary production is assimilated by predators at successively higher trophic levels in the food chain. It is therefore possible to estimate, from the amount of resources, the amount of primary production consumed by determining the assimilation efficiency at each trophic level (Tatara, 1981).

In the Tatara Model for estimating the amount of primary production consumed by fisheries in the Seto Inland Sea, this amount was calculated on the basis of the amount of fish caught, rather than the amount of resources, resulting in a minimum estimate of the amount of primary production. This section reports calculations for the period after 1978, using the Tatara Model. Also discussed are the estimated results for the period of 1963–1977, reported by Tatara (1981).

**Outline of the Tatara Model**

As shown in Fig. 4.7, in the Tatara Model, the total catch is divided into two bio-production series: the fish-feeding series and the bentho-feeding series. The latter obtains 50% of their food requirements from organisms belonging to the former series, and the remaining 50% is obtained from detritus derived from excretion and corpses.

Tatara (1981) first reviewed the published information on the feeding habits of the species caught. He then assigned the catch of each species to the corresponding bio-production series and feeding trophic level, according to its feeding habit. For example, the sardine is assigned to the fish-feeding series, and the quantity of its catch is divided into two halves on the assumption that it obtains 50% of its food from phytoplankton (feeding trophic level F1) and the remaining 50% from zooplankton.
Fig. 4.7. Consumption or primary production in the Tatara Model (modified from Tatara, 1981).
(F2). In the case of the hairtail, 50% of its catch is assigned to the fish-feeding level (F3) of the fish-feeding series, and the remaining 50% to the shrimp/crab feeding level (B3) of the benthos-feeding series.

There are four feeding trophic levels (F0–F3) in the fish-feeding series and also four (B0–B3) in the benthos-feeding series. The assimilation efficiency from one feeding level to another is assumed to be 0.3 for phytoplankton to zooplankton in the fish-feeding series, 0.3 for detritus to benthos in the benthos-feeding series, and 0.1 for all other cases. Conversion to primary production can therefore be achieved in the case of the fish-feeding series by multiplying the total catch at each feeding trophic level by the factors of 1.0 for F0, 3.33 for F1, 33.33 for F2 and 333.33 for F3, and summing up the results. For the benthos-feeding series, because the species belonging to the B1 to B3 feeding trophic levels obtain 50% of their food from organisms belonging to the fish-feeding series as stated above, the factors are 1.0 for B0, 1.67 for B1, 16.67 for B2 and 166.67 for B3.


**Consumption of primary production by fisheries**

The total annual catch in the Seto Inland Sea (Fig. 4.8) was almost stable at 260,000 tons on average between 1956 and 1963 (pre-eutrophication period). The annual catch increased dramatically during from 1964 to 1972 (the first period of eutrophication). Although some fluctuation occurred from 1972 to 1986 (high level catch stage in the second period of eutrophication), a large catch of 420,000 tons on average was maintained, with a peak of 460,000 tons in 1982.

However, the annual catch tended to decrease from 1987 to 1993 (low level catch stage in the second period of eutrophication), reaching a minimum of 260,000 tons in 1993, the same level as in the pre-eutrophication period. This significant decline in recent catches is unprecedented in the Seto Inland Sea, where the annual catch had only increased or at least remained stable prior to 1987.

The total amount of primary production consumed by fisheries in the Seto Inland Sea (Fig. 4.9) increased 1.7 times, from 19 million tons in 1963 to 32 million tons in 1976. The 1976–1986 period was characterized by little fluctuation, during which a high level of primary production consumption at 30 million tons, on average, was maintained. However, the consumption decreased steadily after 1987, reaching a minimum of 25 million tons in 1993. These figures demonstrate that the annual catch in the Seto Inland Sea and the amount of primary production consumed by the fisheries there share the same tendency.

**Primary production consumed per unit quantity of catch**

From the total fish catch in the Seto Inland Sea and the total amount of primary production consumed by the fisheries there, we have calculated the amount of consumption per ton of fish catch, hereafter referred to as unit consumption (Fig. 4.9).
Fig. 4.8. Changes in the amount of catch in the Seto Inland Sea (modified from Tatara, 1981).
Fig. 4.9. Total catch and unit amount of primary production consumed by fisheries in the Seto Inland (modified from Tatara, 1981).
Unit consumption decreased from 72 tons in 1963 to 61 tons in 1972, followed by a similar decreasing tendency from 76 tons in 1976 to 65 tons in 1982. However, following a minimum of 65 tons in 1985, unit consumption increased by 1.4 times to 93 tons in 1993. Thus, while the amounts of both fish catch and primary production consumed by fisheries increased and then decreased during the 1963–1972 and 1987–1993 periods respectively, unit consumption decreased and then increased during the respective periods.

For reference, the changes in unit consumption for both the fish-feeding and the benthos-feeding series are shown in Fig. 4.10. The unit consumption of primary production in the Seto Inland Sea has been higher overall in the fish-feeding series than in the benthos-feeding series.

The unit consumption by the fish-feeding series was 71 tons on average showing little fluctuation for the 1965–1985 period, but later increased to a maximum of 95 tons in 1993. On the other hand, the unit consumption by the benthos-feeding series, which was 58 tons on average during the 1964–1971 period, increased 1.6 times from 52 tons in 1972 to 84 tons in 1976. After 1976, it decreased two-thirds to a minimum of 59 tons in 1985, followed by an increase of 1.5 times to 89 tons in 1993. In summary, the unit consumption by the benthos-feeding series showed significant fluctuations after 1972, while the fish-feeding series was more stable.

Discussion

Endo (1970) proposed an estimate of 44 million tons/year for the total primary production in the Seto Inland Sea, based on a 1963–1966 survey. Uye et al. (1986) also proposed an estimate of 45 million tons/year, based on a 1979–1980 survey (using the conversion method employed by Yamamoto et al. (1994)). The amount of primary production consumed by fisheries, as derived from the Tatara Model, was 19 to 21 million tons/year for the 1963–1966 period, and 28 to 29 million tons/year for the 1979–1980 period, accounting for about 45% and 63% of the respective estimated total amounts of primary production. This agrees with the statement by Yamamoto et al. (1994) that these estimated amounts of total primary production in the Seto Inland Sea are sufficient to maintain the fisheries yields. They also stated, however, that these estimations may be slightly conservative, since aquatic organisms other than the species caught may be overwhelming in terms of biomass.

During the 1963–1972 and 1987–1993 periods, the amounts of both fish catch and primary production consumed by fisheries first increased and then decreased, while the amount of primary production per ton of catch (unit consumption) decreased and then increased, representing a reverse tendency. This will be owing to that the increase or decrease in the annual total catch for the Seto Inland Sea is mainly due to changes in the catches of some species at lower feeding trophic levels (F1–F2 in the fish-feeding series; B1 in the benthos-feeding series), such as anchovy, sand lance and short-necked clam from 1963 to 1972, and sardine, anchovy, anchovy larva (shirasu) and short-necked clam from 1987 to 1993.
Fig. 4.10. Unit amounts of primary production, by bio-production series, consumed by fisheries in the Seto Inland Sea (modified from Tatara, 1981).
The annual catch in the Seto Inland Sea has tended to decrease significantly since 1987, mainly due to great reductions in the catches of sardine, anchovy, anchovy larva and short-necked clam. In addition, the fishing efforts in the Seto Inland Sea have also decreased due to reduced number of persons engaged in fishery and the aging of the work force. Consequently, future trends regarding the annual catch in the Seto Inland Sea must be monitored carefully.

FISHERIES AND OPTIMAL ENVIRONMENTAL CONDITIONS

For a few decades after World War II, high price fishes such as red sea bream and Spanish mackerel were abundant in the Seto Inland Sea. Recently, while their populations have decreased and some species disappeared entirely, the catches of low price fishes such as sardine (spotlined sardine) have increased. In the Seto Inland Sea, domestic or industrial waste water has caused water pollution, and reclamation of shallow areas has reduced fishing grounds and eliminated some spawning or nursery grounds. These events have affected the Seto Inland Sea fisheries in various ways.

In this section, the relationship between eutrophication and fishery production is examined, and we discuss what environmental conditions are required to sustain these fisheries in the future.

What is “eutrophication”?

“Eutrophication”, originally a word from the field of limnology, has come to be used in oceanography as well. Generally, with the exception of fixed nitrogen and phosphorus, nutrient substances are dissolved in sea water in more than sufficient quantities to support biological production. If a large amount of nitrogen and phosphorus in domestic and industrial waste water is supplied to an area of coastal waters, they promote the growth of phytoplankton and other algae. This in turn causes an increased production of zooplankton, zooplankton feeders and fish feeders in the food chain. Dead plankton assemblages which have not been grazed accumulate on the sea bottom and are decomposed by bacteria. By this process, oxygen is consumed in the near bottom waters. Heavy accumulation of organic matter in the near bottom waters can induce an oxygen deficiency or anoxic conditions, finally leading to hypertrophic or saprobic (rotten water) conditions. This process is referred to as “eutrophication”. Eutrophication has a marked influence on coastal marine ecosystems, decreasing the number of species and the abundances of various organisms, and increasing the abundance of some specific species well adapted to high nutrient levels. Of the nutrients in sea water which are temporarily taken up by phytoplankton, after death and decay of the phytoplankton, part of these nutrients will be re-mineralized into inorganic substances by bacteria during the sedimentation process. These recycled inorganic substances are then available to the phytoplankton again. In this way, the dissolved nutrients are re-cycled in the coastal waters. New nutrient enter into the sea through rivers and add to this nutrient circulation, accelerating the eutrophication process.
How much does “eutrophication” damage the fisheries?

The term “Red Tide” is defined as the phenomenon where, under eutrophic conditions, certain species of phytoplankton grow at an extraordinary rate, staining the sea water red. In the Seto Inland Sea, the number of outbreaks of red tides per year reached a maximum (299 cases) in 1976 and thereafter has decreased to 100 cases in 1992, approximately one third of the 1976 maximum. In 1992, 55% of the red tide outbreaks occurred in the Kii-Channel, Osaka Bay and Harima-Nada, and 30% occurred in Suo-Nada and the Bungo-Channel. This indicates that outbreaks are more frequent in the eastern area than in the western area. There was a tendency for red tides in the western area to occur in the areas adjacent to the open sea. The incidence of damage, mainly to cultured yellowtail, reached a maximum of 39 cases in 1972, and then decreased to 18% of that maximum incidence. As an example of the damage caused by red tides, a red tide in 1972 killed about 14 million cultured yellowtail, causing damage amounting to 7.1 billion yen, the heaviest damage that the Japanese fishery industry has ever experienced.

Shellfish poisoning caused by red-tide phytoplankton consists of paralytic and diarrhetic types. In western Japan, paralytic shellfish poison retained by oysters and short-necked clams has become a major health problem. When oysters or short-necked clams feed on the toxic algae, *Alexandrium tamarense* and *A. catenella*, they accumulate neurotoxins such as saxitoxin or gonyautoxin into their bodies. When a person eats these shellfish, the toxins cause numbness of the lips, hands and/or legs, and sometimes in the worst cases death may occur. At present, the occurrence of toxic plankton and the level of toxicity in shellfishes are examined prior to sale of the shellfish. If the toxicity exceeds a designated upper limit, putting shellfish on the market is restricted and the administrative agency recommends people not to catch and eat the shellfish.

In Harima-Nada, hypertrophication has occurred continuously from the early 1980’s, inducing an oxygen deficiency in the near bottom waters and deoxidation of the bottom sediments (Manabe et al., 1994). Recently, a diatom, *Coscinodiscus wailesii*, has become abundant in autumn through spring in this area. This diatom consumes large quantities of nutrients, temporarily causing low nutrient conditions in the sea water, which can result in discolored (low quality) seaweeds to occur. Furthermore, “Nuta”, aggregations of the suspended matter form around the core of the dead large diatoms, and these attach to fishing nets of trawlers, which hinders commercial operations at times.

In the Seto Inland Sea, the recent proliferations of *Ulva* had damaged the beauty of the seashore and obstructed small trawlers in some cases. Large numbers of ctenophores or comb jellyfish have occurred recently as well, which also obstruct net-fishing.

Development of eutrophication and its effects on fisheries

Concentrations of nitrogen and phosphorus derived from eutrophication are reflected in the phytoplankton abundance and are thus indirectly associated with the water transparency. Therefore, the level of eutrophication between different periods
can be determined based on trends in the transparency. This relationship between water transparency (eutrophication) and the main fish species caught has been examined for Hiroshima Bay and Osaka Bay by Nagai (1995).

Three periods were recognized in Hiroshima Bay: before 1962 when the annual mean transparency was 7 m or more (high-transparency period), from 1963 to 1975 when transparency decreased to from 7 m to 5 m (low-transparency period), and from 1976 to 1990 when the transparency increased temporarily but then decreased.

Table 4.3 shows the main fish species caught during each of these three periods of eutrophication in Hiroshima Bay. High price fishes and then middle price fishes were caught during the high-transparency (before eutrophication) period and the low-transparency (eutrophication) period, respectively. On the other hand, low price fishes were caught in the recovery/aggravation period with a few middle price species and some species that were farmed. Although the total catch in the Bay did not decreased throughout the three periods, the main fish species caught in each

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<tbody>
<tr>
<td>Inner part</td>
<td>Kuruma prawn</td>
<td>Lizardfishes</td>
<td>Mackerels</td>
</tr>
<tr>
<td></td>
<td>Swimming crab</td>
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<td>Round herring</td>
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<td></td>
<td>Hard clam</td>
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<td></td>
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<tr>
<td></td>
<td>Short-necked clam</td>
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<td></td>
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<tr>
<td>Central part</td>
<td>Ark shell</td>
<td>Egg cockle</td>
<td>Anchovy</td>
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<td></td>
<td>Hard-shelled mussel</td>
<td>Sea cucumber</td>
<td>Flounders*</td>
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<td></td>
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<td>Short-necked clam</td>
<td>Hairtail*</td>
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<td>Black porgy**</td>
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<td></td>
<td>Bastard halibut**</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Kuruma prawn**</td>
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<tr>
<td>Both areas</td>
<td>Red sea bream</td>
<td>Oyster</td>
<td>Shirasu***</td>
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<td></td>
<td>Common sea bass</td>
<td>Croakers</td>
<td>Spotlined sardine</td>
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<td>Pike eel</td>
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<td></td>
<td>Common octopus</td>
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Price |
---|---|---|---|
High | Medium | Low |

*Medium price fishes; **Released juveniles of the species; ***Substantially composed of anchovy post-larvae (20–40 mm in total length).
1) Periods of eutrophication were divided by transparency: before eutrophication, >7 m; eutrophication, 5–7 m.
2) The catch by species was noted when it reached its maximum.
period changed. The annual catch of each species was examined for when it reached its maximum during the period of 1955–1990. Analysis was made for parts of the Bay using catches in every fourth year. The number of species with peak catches in their respective fisheries, was highest in 1960 in both areas, 16 in the inner part and 11 in the central part, respectively. This suggests that the diversity of species was at its highest in Hiroshima Bay around this year.

In Osaka Bay, Nagai (1995) found four periods of eutrophication: before 1950 when transparency was high, from 1951 to 1975 when transparency was low, from 1976 to 1980 when transparency recovered slightly and after 1981 when transparency decreased again. In all periods, the total catch in the entire Bay was dominated by that in the inner part, where the percentage increased with time. The total catch in the Bay decreased temporarily but has recently increased because of increases of spotlined sardine, gizzard shad, and mackerels. Because the total catch is dominated by pelagic fishes, this suggests that the catch has not been significantly influenced by water pollution and reclamation of shallow areas. However, the diversity of species was highest prior to 1950 in Osaka Bay.

In both Bays, high price fishes were abundant during the high transparency period and during this period also the diversity of species was high. At present, we can not return the coastal environment to the conditions of high species diversity as seen in the pre-eutrophic period, but we should maintain the abundance and diversity of fisheries resources at an appropriate level.

Eutrophication and ecosystems

Recently, elimination of phosphorus from waste waters and the use of synthetic detergent without phosphorus have caused a decrease in the phosphorus concentration in the Seto Inland Sea. However, it has not been possible to remove the nitrogen from waste water due to technological problems. As a result, the ratio of nitrogen and phosphorus concentrations (N:P ratio) has increased, and exceeds 100 in some cases. This can have a strong influence on the ecosystems of coastal waters. In Osaka Bay, the average N:P ratio increased by 5 both in the surface and near bottom waters during the 1970's (Joh, 1991). A preliminary analysis for Tokyo Bay suggests that the number of species caught decreased around 1965 and the late 1980's when the N:P ratio increased. In the 1970's, the ratio decreased and the number of species recovered to their previous levels (Shimizu, 1993). This relationship in the Seto Inland Sea as a whole remains to be analyzed.

Some reports have indicated that eutrophication may greatly affect the ecosystem in the Seto Inland Sea. On the basis of observations of phytoplankton from 1979 to 1991 in Osaka Bay, fluctuations of the phosphorus concentration corresponded with the dominance of the diatom, Skeletonema costatum, in the phytoplankton community (Yamochi, 1993). Growth rates of this diatom were not affected by the N:P ratio in culture medium (Yamaguchi, 1992), implying that the phenomenon observed in Osaka Bay is affected by the concentration levels of each nutrient rather than by the N:P ratio.

Eutrophication and the resulting increase of the N:P ratio may cause shifts in the
predominant group in a phytoplankton community from a diatom dominant to a non-diatom (e.g. flagellates or dinoflagellates) dominant system, although this mecha-
nism is not fully clear. Since some non-diatom phytoplankton are not eaten by herbivorous zooplankton, any increase in population size of these phytoplankton may not be utilized in the planktonic food chain. As a result, these non-diatom phytoplankton will sink to the bottom after death and be decomposed by bacteria, and thus increasing the energy flow in the microbial food chain. Furthermore, most of the non-diatom phytoplankton are too small to be grazed by the large zooplankton, so the small zooplankton (e.g. microzooplankton) which are able to feed on the non-diatom phytoplankton increase and then are consumed by the jellyfishes which are not size-selective for foods. Consequently, the energy flow from primary production to the higher trophic levels via grazing food chain decreases, causing a decrease in fish production (Takahashi, 1977; Uye, 1993). This means that the food chain system which is typical of the Cenozoic era has become emaciated and may regress to that of the Mesozoic era.

What is the environmental capacity for fisheries?

Joh (1991) showed that the phosphorus concentration is the main limiting nutrient for biological production in Osaka Bay by examining changes in the N:P ratio. He also showed the optimal load of phosphorus entering the Bay for the production of each fish species. The value is 3 tons/day for shrimps or crabs, 4 tons/day for common octopus, 13 tons/day for flounders and 14 tons/day for mantis shrimp; thus the optimal level differs for each species.

Grouping fish species by feeding habit is one approach to determine the optimal level of nutrient loads for the Bay as a whole. The primary production which fish and shellfish in Osaka Bay formerly utilized was estimated by back calculation based on fish and shellfish catch data, and the relationship between the results obtained and phosphorus loads was examined (JAFRCA, 1989; Joh, 1992). The amount of primary production utilized by the detritus feeding group (detritus feeders, benthos feeders and shrimp/crab feeders) was at its maximum with a phosphorus load of 8–9 tons/day, corresponding to the loading conditions around 1965 (Fig. 4.11). Joh and his colleagues considered that as the phosphorus load changed following 1965 from this optimal load, the catches of the detritus feeding group began to decrease. While this level of loading is not enough to cause any oxygen deficiency in Osaka Bay except for a limited section of the inner Bay, the direct effect of P loading on plankton feeders is not clear. The environmental conditions in the inner part of the Bay where red tides due to diatoms occur frequently and sea water is highly stagnant are suitable for Japanese anchovy and spotted sardine. These conditions require phosphorus concentrations in surface water of more than 2.5 μg-at/l (0.078 mg/l). However, this level of phosphorus loading also causes oxygen deficiency in the inner part of the Bay, which in turn influences the environment in the central part of the Bay. Hence, Joh et al. recommended a lower concentration of phosphorus be established in the inner part of the Bay of 1.5 μg-at/l (0.047 mg/l), which is in water Rank III of the environmental quality standards, set by the Environment Agency. This concentra-
Fig. 4.11. Relationship between phosphorus load and primary production in Osaka Bay (Joh, 1992). The amount of primary production was back-calculated from the catch data as a minimum estimate.

tion, which does not induce any oxygen deficiency in the central part of the Bay, is equivalent to the load of 8–9 tons/day.

In the south-eastern coastal area of Osaka Bay, the abundance of benthic organisms decreased drastically when the DO concentration in the bottom layer diminished to under 3 ml/l (Osaka Pref. Fish. Exp. Stat., 1977). In general, the number of species and abundance of benthic organisms is strongly associated with the DO concentration in the near bottom water (Imabayashi, 1983). Oxygen deficiency in the near bottom waters not only influences indirectly the species composition and abundance of fishes and shellfishes on the bottom due to changes in food diversity and abundance, but also directly restricts their habitats.

JAFRCA (1989) concluded that the following conditions are required to maintain the habitats of benthic fish and shellfish in Osaka Bay. The lower limit
concentration of dissolved oxygen (DO) should be 3 ml/l in the inner and central parts of the Bay, and the upper limit of phosphorus loading from Osaka Prefecture should be 8–9 tons/day (the load level in 1965).

In general, from the point of the fisheries production, the desired nutrient level in the inner Bay areas is that which corresponds to the lower limit of DO concentration (3 ml/l) in the near bottom waters which is defined as the environmental capacity for the fishery.

**Environmental quality standard, 1993**

In June 1993, the Environment Agency submitted a report on the new environmental quality standards for nitrogen and phosphorus concentrations and the types of use of the water areas to prevent any further increases in eutrophication levels (Table 4.4).

The basic idea behind the new standard is assess areas on the level of DO concentration in the near bottom water affecting the habitats of organisms in embayments. The degree of influence of DO concentration on the benthic community are classified as follows: Rank II (the first rank for fisheries) refers to a DO concentration of less than 4 ml/l where some species are influenced to some extent; Rank III (the second rank for fisheries) less than 3 ml/l, where the number of species and their density (the diversity of species) decreases drastically; Rank IV (the third rank for fisheries) less than 2 ml/l, where almost all the species are influenced. The environmental quality standard also regulates the concentrations of total nitrogen (TN) and phosphorus (TP) in surface waters. TN and TP standard values for each of the ranks described above were estimated using the correlation between the TN (or TP) and the DO concentrations in the near bottom water.

The Central Council for Environmental Pollution Control, one of the deliberative assemblies of the Environment Agency, reported the types of water in Tokyo Bay and Osaka Bay in December 1994, and proposed a tentative goal to reduce the nutrient loading over the next 5 years. Using results from the monitoring of water quality, subsequent goals will be determined every four years in general. As was done in Osaka Bay, in order to improve the present eutrophic conditions in the Seto Inland Sea, each prefecture will work with the Agency to determine the type of water on the water front of each prefecture and at the boundary areas between prefectures where the possibility of major blooms of phytoplankton is greater. By regulating nitrogen and phosphorus loads entering the sea water in this way, the DO concentrations in the near bottom waters are expected to be maintained or recover to an appropriate level.

**Desired rank of water qualities**

I have examined the present water environment conditions on the basis of DO concentrations in August. Oxygen deficient conditions where the DO concentration was at or was less than 2 ml/l (equivalent to more than Rank IV) were observed in three regions: the inner parts of both Osaka Bay and Beppu Bay and the offshore area of Himeji City in Harima-Nada. DO concentrations of 2–3 ml/l (equivalent to Rank
Table 4.4. Environmental quality standards for nitrogen and phosphorus concentrations and the types of use of the water areas as proposed by the Environment Agency in 1993

<table>
<thead>
<tr>
<th>Standard (rank)</th>
<th>Type of water area use</th>
<th>Total nitrogen (TN; mg/l)(^2)</th>
<th>Total phosphorus (TP; mg/l)(^2)</th>
<th>Other water quality (for reference(^1) only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Natural environment conservation area</td>
<td>0.2&lt;</td>
<td>0.02&lt;</td>
<td>5&lt; 1.7&lt; 7&lt;</td>
</tr>
<tr>
<td>II</td>
<td>Swimming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The first rank for fisheries(^3)</td>
<td>0.2~0.3</td>
<td>0.02~0.03</td>
<td>4<del>5 1.7</del>2 5~7</td>
</tr>
<tr>
<td>III</td>
<td>The second rank for fisheries(^3)</td>
<td>0.3~0.6</td>
<td>0.03~0.05</td>
<td>3<del>4 2</del>3 3~5</td>
</tr>
<tr>
<td>IV</td>
<td>The third rank for fisheries(^3) Critical environment for benthic organisms(^3)</td>
<td>0.6~1.0</td>
<td>0.05~0.09</td>
<td>2<del>3 3</del>4.5 2~3</td>
</tr>
<tr>
<td>IV&lt;</td>
<td>(Anoxic water, blue tide)</td>
<td>1.0&lt;</td>
<td>0.09&lt;</td>
<td>2&gt; 4.5&lt; 2&gt;</td>
</tr>
</tbody>
</table>

1) Reference values were estimated from the relationship between elements of water quality.
2) TN, TP, and COD are annual means in surface waters, while DO is the summer value at the bottom layer. Transparency is the annual mean. The value of COD in the surface waters is roughly equivalent to 75% of the average of the total water column.
3) Theses ranks indicate biological phases: the first rank, high species diversity of catches; the second rank, clear downward trend for shrimps and crabs; the third rank, a bias of most of the catches to specific species such as spotlined sardine and short-necked clam; the critical environment, the lowest conditions for benthic organisms to survive all the year, respectively.
Fig. 4.12. Horizontal distribution of DO concentration in the near bottom water of the Seto Inland Sea in August during 1982–1986. The map was drawn using data from the Fishery Agency.
Fig. 4.13. Horizontal distribution of total nitrogen (annual mean) in the surface water of Seto Inland Sea during 1984–1987. The area of 0.25–0.3 mg/l of TN was shown as II' for convenience. The map was depicted based on data from the Environment Agency.
IV) were observed in the central parts of Osaka Bay, Harima-Nada, Suo-Nada and the inner part of Hiroshima Bay. In the outer part of Osaka Bay, western and eastern parts of Harima-Nada, eastern part of Hiuchi-Nada, central part of Hiroshima Bay and most parts of Suo-Nada, DO concentrations ranged from 3 ml/l to 4 ml/l (equivalent to Rank III). DO concentrations in other areas of the Seto Inland Sea were at or more than 4 ml/l (equivalent to Rank II or less) as is shown in Fig. 4.12. The inner part (Rank IV) and central part (Rank III) of Hiroshima Bay have the same water ranks as the central part and outer part of Osaka Bay, respectively.

Figure 4.13 shows the distribution of total nitrogen in the surface water of the Seto Inland Sea. In Osaka Bay, we see a rank of IV or more occurs in the inner part, a rank of IV in the central part and a rank of III in the outer part.

A rank of III in the inner part and a rank of II in the central part were observed in Hiroshima Bay, the same ranks as in the outer area of Osaka Bay and the Kii Channel, respectively. The rank difference between Hiroshima Bay and Osaka Bay was two grades on the basis of nitrogen concentration, while it was one grade on the basis of DO concentration. This indicates that the DO concentrations in the near bottom waters in Hiroshima Bay is lower than the level predicted from observations in Osaka Bay. Similar tendencies were observed in other areas. These area specific characteristics should be examined in detail in the future.

In anticipation of the work to reduce the effects of eutrophication, which will be initiated by the Environment Agency, I would like to propose the following values as optimal levels in terms of fishery production. In Osaka Bay, I suggest that we follow the report of the Environment Agency described above. In other areas, we should keep or work to attain a rank of III (the second class for fisheries), i.e. DO concentration of at least 3 ml/l, in coastal waters near cities, the rank of II (the first class for fisheries) where many species are able to produce stable populations in offshore areas, and the rank of I (natural environment conservation area) in oceanic areas.

However, as observed in Hiroshima Bay, the relationship between total nitrogen and phosphorus concentrations and DO concentration in the near bottom water does not always correspond to that of the environmental quality standard. Furthermore, considering the fact that nitrogen reduction is more difficult than that of phosphorus, I propose that we improve the present ranks illustrated in Fig. 4.13, each area to a higher rank in quality (lower concentration) for the whole of the Seto Inland Sea as the desired rank for water quality (for examples, IV → III; III → II'; II' → II).

REFERENCES


