Chapter 7 ENVIRONMENTAL QUALITY STANDARDS FOR WATERS

--- NITROGEN AND PHOSPHORUS STANDARDS FOR ESTUARIES AND INLAND SEAS ---

1. Backgrounds

In 1970's, various efforts to study the mechanism of eutrophication, to develop strategies, technologies, laws and regulations was made to control the eutrophication of closed freshwater bodies. However, little attention has been directed to the similar problems observed in marine water. In recent years, similar phenomena as the eutrophication in lakes and reservoirs have been observed in many bays and inland seas. In spite of the strict regulation of organic loading such as the regulation of total maximum loads of COD, remarkable recovery of water quality has not been noted in closed marine waters such as Tokyo bay, Mikawa Bay and Seto Inland Sea as shown in Fig.7-1.

It is clear that, in these water bodies, the increase in nutrient discharge, either directly or through the inflow of river water, into the water in addition to organic loading resulted in the increase in the phytoplankton production and, subsequently, in the deterioration of water quality in terms of COD. Fig.7-2 shows percent contribution of internal production of COD out of total COD loading estimated by δCOD method and chlorophyll-a method. The contribution was high in summer (50 to 60%). Also percentages were dependent on the methods adopted, i.e. δCOD method gave higher value than chlorophyll-a method. Annual average contribution of internal COD production ranged from 40% to 50%. Eutrophication control, therefore, is essential to comply with the water quality standards in terms of COD.

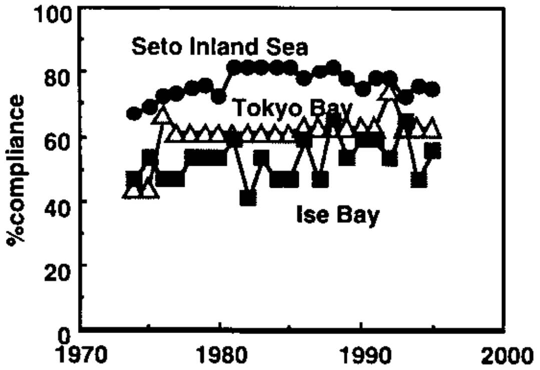

Fig. 7-1 Percent of compliance on COD in major estuaries.

To reduce COD loading, the Regulation of Total Maximum Daily Loads started in 1978 for three major estuaries, i.e. Tokyo Bay, Ise Bay and Seto Inland sea (see Chapter 11). However, by the increase in nitrogen and phosphorus loading, typical problems associated with eutrophication such as deterioration of water quality by the increase in primary production of phytoplankton has been frequently happened. Serious damage on aqua cultures by red-tide has been reported in these estuaries (Fig. 7-3). Also recreational use and scenery were damaged.

The massive growth of phytoplankton results in the increase in the concentration of organic matter, and decrease in dissolved oxygen concentration in bottom layer in summer. The DO deficit is known to be a cause of so-called blue-tide, and deteriorate bottom environment (See 7-4). Thus the increase in organic matter and, therefore, organic loading seemed to be a major reason of the unexpected low compliance of environmental water quality standards in terms of COD.

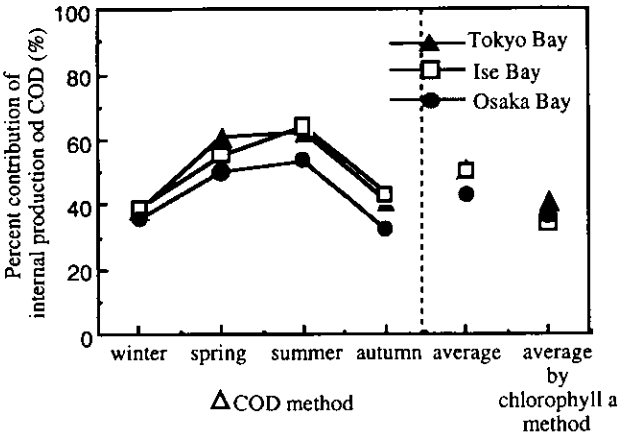

Fig. 7-2 Percent contribution of internal production of COD out of total COD loading.

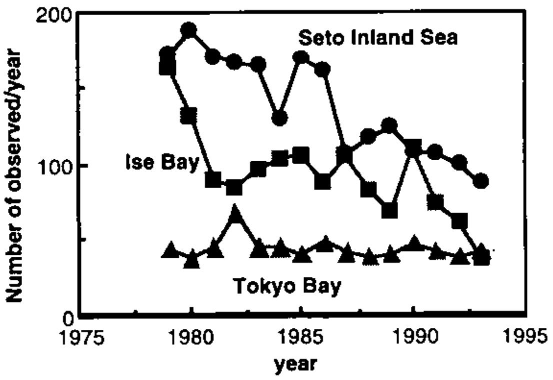

Fig. 7-3 Red-tide observed at three major estuaries.

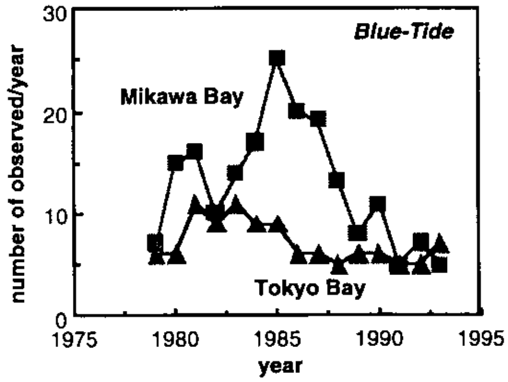

Fig. 7-4 Blue-tide observed at Tokyo Bay and Mikawa Bay in Ise Bay.

Main factors responsible for the above mentioned phenomena are inflow of nitrogen and/or phosphorus into estuaries. As shown in Fig.7-5, it is necessary to reduce nutrient loading as major factor of eutrophication in addition to conventional reduction of COD to restore marine environment.

The restoration of eutrophic water is hard task. Therefore, we must keep nutrient concentration as low as possible even in the waters with satisfactory environmental condition to prevent eutrophication and to conserve the environment to next generation. The environmental water quality standards for nitrogen and phosphorus are an allowable condition of water for the conservation of estuarine environment. The standard was legislated in 1993 based on "Basic Environment Law". Also effluent quality standards were legislated based on "Water Pollution Control Law".

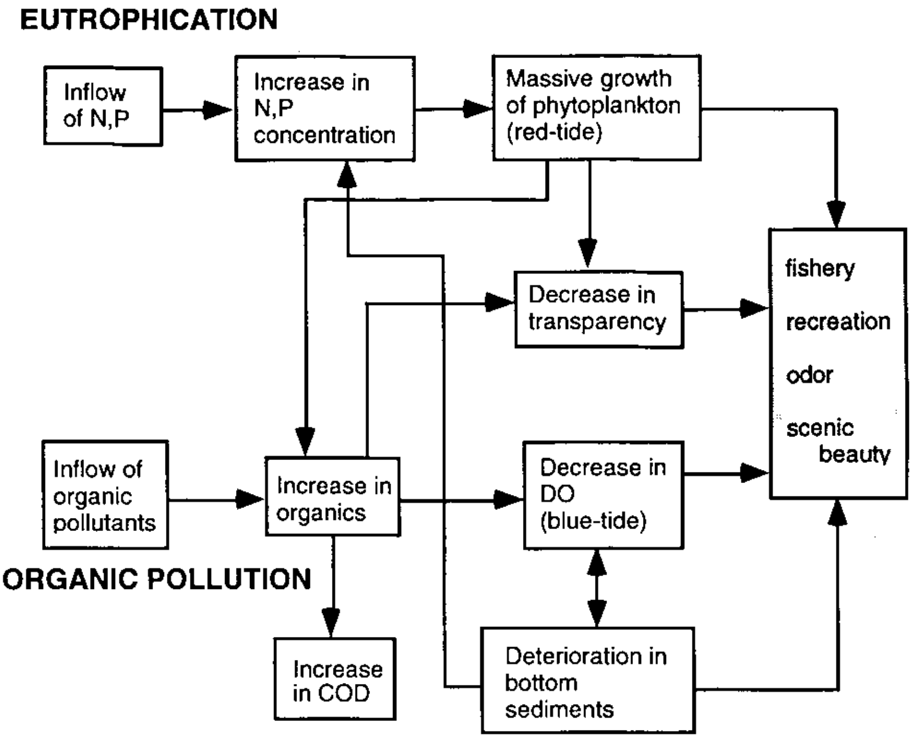

Fig. 7-5 Eutrophication and organic pollution.

2. Nitrogen and Phosphorus Standards for Estuaries

2.1 Limiting nutrients

Similar to the eutrophication in lakes and reservoirs, the identification of limiting nutrient has been one of the most important issues in the control of estuarine eutrophication. It is generally acknowledged that nitrogen and phosphorus are the most probable nutrient that limits phytoplankton growth both in freshwater and marine environment. However, the control and regulation of a single limiting nutrient are preferable. If only phosphorus is the limiting nutrient, we may install phosphorus removal process in wastewater treatment process.

There is little question that phosphorus is the limiting nutrient in most freshwater. Nitrogen fixation may compensate nitrogen deficit and nitrogen will not be the limiting nutrient for phytoplankton growth. However, in marine waters, it is commonly accepted that nitrogen is the limiting nutrient. Contrary to freshwater, it is understood that the nitrogen fixation does not play significant role in marine waters. One of the exceptional case ever reported is in Baltic Sea where nitrogen input into the sea by the nitrogen fixation contribute similar amount as that by river inflow. The reason why nitrogen fixers cannot predominate in the nitrogen limiting marine environment is not well understood yet.

Table 7-1 shows intracellular N/P ratio for various marine phytoplankton obtained from various environmental conditions. The most referred number for the N/P ratio is so-called Redfield ratio; 16:1 in atomic ratio and 7.2:1 in weight ratio. Most of the ratios listed are similar to this value, whereas there are values as small as 2.0 and also as large as 43.5. As the supply side for phytoplankton growth, N/P ratios in Japanese estuaries are shown in Fig. 7-6. The ratio ranged from 5 to 20. Nitrogen might be a sole limiting nutrient if N/P ratio in marine water is always smaller than that in phytoplankton. On the contrary, phosphorus would be the limiting if N/P in water is always larger than that in plankton.

In Tokyo Bay, N/P was relatively large in winter (P limiting), whereas they were small in summer (N limiting). Fig. 7-7 shows seasonal variation of N/P in Hiroshima Bay. It is well known that seasonal variation in N/P in Chesapeake Bay is induced by the inflow of snow melt, i.e. phosphorus limitation by snow melt in early spring and nitrogen limiting in late summer. Hiroshima Bay is limited by nitrogen in most cases. However, large inflow of stormwater (limited by phosphorus) changed limiting nutrient from nitrogen to phosphorus. Thus, N/P ratio in water changes in time and space and that in phytoplankton also varies among species.

It is difficult, therefore, to identify one of these is always limiting phytoplankton growth. Both nitrogen and phosphorus are adopted as limiting nutrients to be controlled in the environmental standards for estuaries in Japan in 1993. Also we have little information on the change in ecosystem if we changed N/P ratio in estuaries to extremely high or low values. The uncertainty in the response of ecosystem was another reason to take both nutrients into consideration.

Table 7-1 Intracellular N/P ratio in marine phytoplankton

Algal species	N:P (mole)	source	remarks
CYANOPHYCEAE			
Agmenellum quadruplicaatum	10.6	BC	exp. phase
CHLOROPHYCEAE			
Dunaliella salina	6.1	BC	exp. phase
BACILLARIOPHYCEAE			
Chaetoceros affinis	7.9-43.5	BC	exp. phase
C. deblis	4.6	CC	N-limited
	12.0	CC	non-limited
Chaetoceros sp.	8.3	BC	exp. phase
Skeletonema costatum	7.7	BC	exp. phase
	4.8	CC	N-limited
	10.0	CC	non-limited
	5.5-29.4	BC	exp. phase
	5-20	CC	N/P changed
	9.1-26.0	N	
Thalassiosira graavida	2.0	CC	N-limited
	8.8	CC	non-limited
DINOPHYCEAE			
Ceratium tripos	12	SC	non-limited
	12	SC	P-limited
Prorocentrum minimum	15	SC	non-limited
	18	SC	P-limited
	14.8-17.4	SC	
RAPHIDOPHYCEAE			
Chattonella antiqua	11	BC	stationary phase
Heterosigma akshiwo	15.2	BC	stationary phase
	11.1-25	CC	N/P changed

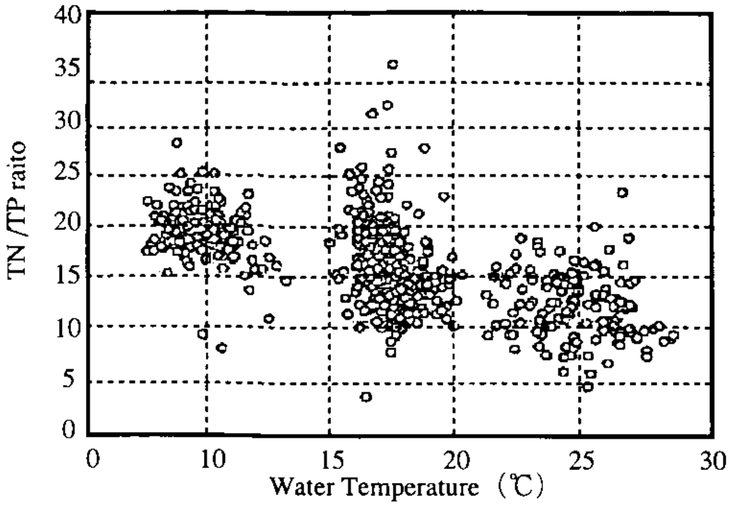

Fig.7-6 N/P ratio (weight) in Tokyo Bay (1986-1990)

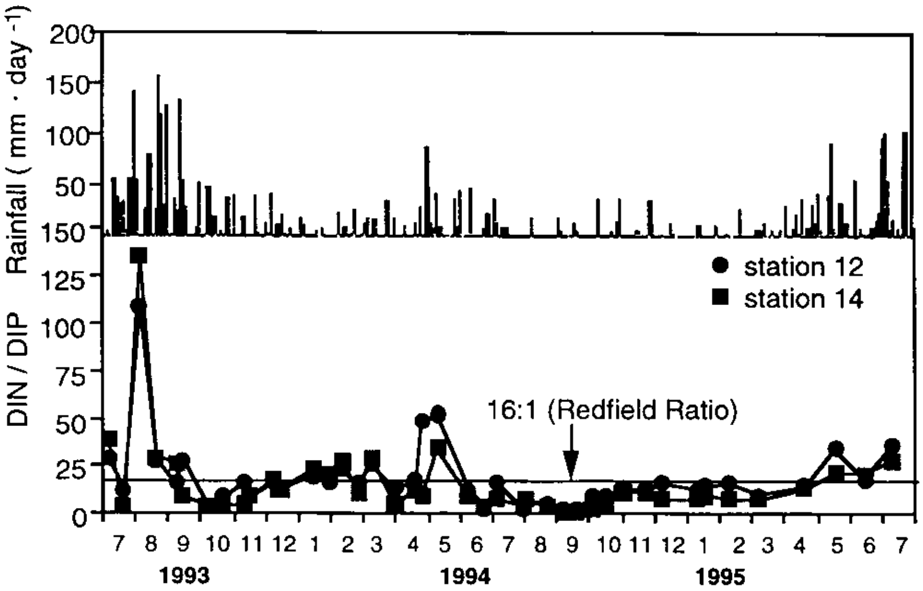

Fig. 7-7 Seasonal variation of DIN:DIP ratio at stations 12 and 14 in Hiroshima Bay

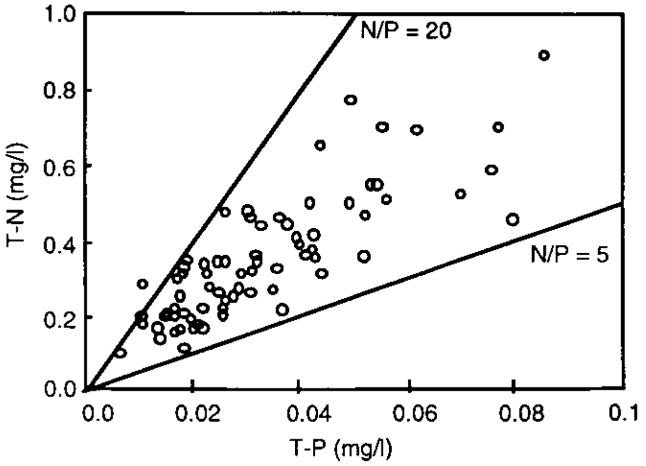

Fig. 7-8 N/P ratio in Japanese estuaries

2.2 Correlation between Water Use and Standards

The environmental standard for estuaries to control eutrophication was legislated in 1993 in addition to the former regulation on organic pollution (COD) and toxic substances (heavy metals). The standard values both for nitrogen and phosphorus were determined based on expected uses of estuarine waters. The uses presumed as a basis of the standard are:

1) Conservation of natural environment,
2) Marine recreation/bathing,
3) Protection of benthic organisms,
4) Fisheries: class 1, 2, and 3, and
5) Industrial water supply.

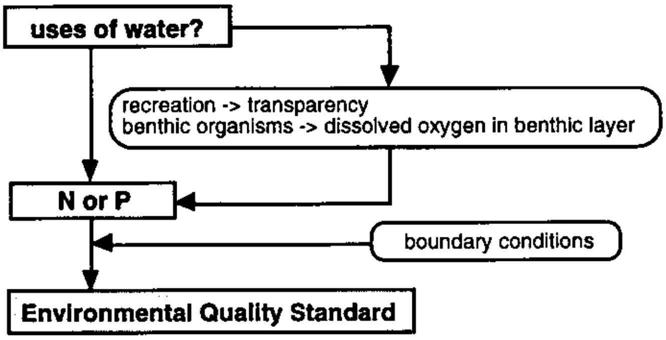

Fig. 7-9 Correlation between the use of water and environmental quality standards

Correlation between water quality parameters

The standard values are determined based on water use above mentioned. It is necessary to define or estimate concentrations of nitrogen and phosphorus that are appropriate or necessary to fulfill each water use.

In most cases, both nitrogen and phosphorous concentrations do not directly relate with the use of water as shown in Fig. 7-9. For example, transparency would be the most important parameter to assess the quality of natural marine environment and bathing water. Dissolved oxygen concentration in the bottom in summer would be the critical parameter for the survival of benthic organisms. Correlation between water quality parameters was formulated to estimate corresponding nitrogen and phosphorus concentrations. Some examples of the correlation are shown in Fig. 7-10. All the basic data were monitored in coastal and estuarine waters in Japan.

2.3 Environmental Water Quality Standards for Each Water Use

1) Conservation of natural environment

The use specified for this category presumed the use of marine environment as recreational purpose such as sightseeing and diving. Water quality must be kept as natural as possible. Major parameter adopted in this category was transparency taking clear water would be the most important factor for this use. The data base used was water quality in marine parks in Japan. Table 7-2 summarize water quality parameters. T-P and T-N concentrations not determined in the monitoring were estimated from the above mentioned correlation (Fig. 7-10). The standard values both for T-N and T-P were determined to be less than 0.2 mg l^{-1} and 0.02 mg l^{-1}, respectively based on the correlation and taking the followings into consideration;

- Clear water is expected to have transparency more than 10 m,
- Better water quality than open seas around Japan can not be expected (Table 7-4).

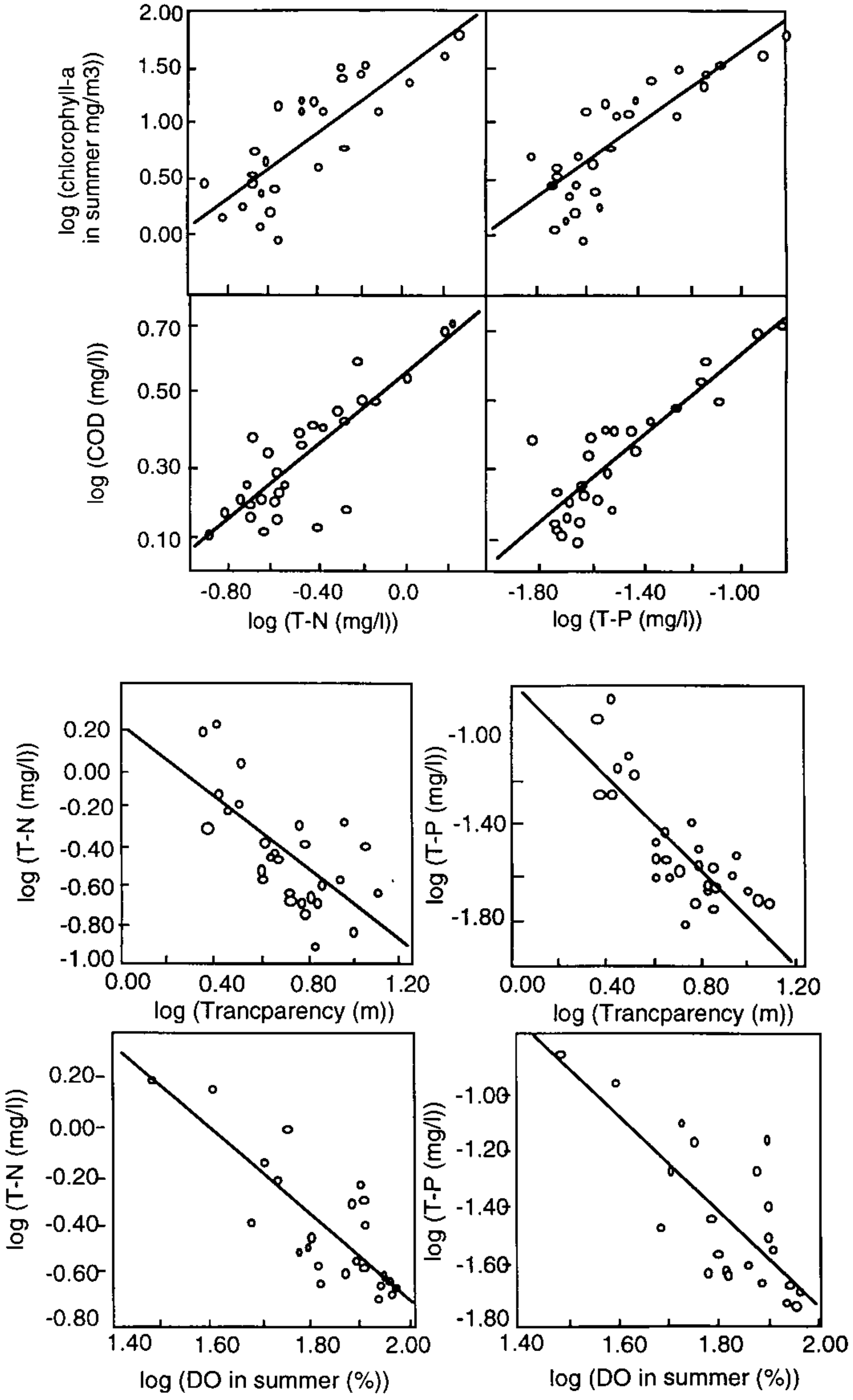

Fig. 7-10 Correlation between water quality parameters

Table 7-2 Water quality parameters in marine parks

parameter	no. of stations	no. of data	average	min.	max.	% less than std.*
T-N (mg/l)	6	16	0.16	0.07	0.24	88
T-N (calculated)	19	55	0.15	0.07	0.24	95
T-P (mg/l)	6	16	0.015	0.010	0.024	88
T-P (calculated)	19	55	0.013	0.008	0.024	96
COD (mg/l)	16	48	1.0	0.5	2.2	98
Transparency (m)	18	54	13	7	20	83

* standard value: T-N<0.2 mg/l, T-P<0.02 mg/l, COD<2 mg/l, Transparency>10 m

* * calculated from the correlation

Table 7-3 Water quality parameters in open seas

	oyashio		kuroshio		tsushima C.
station	A-6	B-2	C-3	D-2	E-4
T-N (mg/l)	0.08	0.09	0.08	0.08	0.09
T-P (mg/l)	0.02	0.01	0.01	0.01	0.01
COD (mg/l)	-	0.9	0.7	0.7	0.9

2) Marine recreation/bathing

The use specified for this category presumed the use of marine or coastal environment as recreational purpose for bathing/swimming. The data base used was coastal water quality around beach resorts for bathing and swimming in Japan. Only beach resorts in good condition were selected. Table 7-4 summarize water quality parameters. T-P and T-N concentrations not determined in the monitoring were estimated from the correlation.

The standard values both for T-N and T-P were determined to be less than 0.3 mg l^{-1} and 0.03 mg l^{-1}, respectively based on the correlation and taking the followings into consideration;

- Transparency more than 6 m is expected for comfortable bathing,
- Table 7-5 summarize water quality around beaches where bathing was abandoned due to excessive phytoplankton growth. Better water quality than these is expected.

Table 7-4 Water quality parameters around beach resorts

parameter	no. of stations	no. of data	average	min.	median	75%	max.
T-N (mg/l)	47	141	0.36	0.05	0.30	0.41	1.45
T-N (calculated)	86	257	0.33	0.05	0.29	0.38	1.45
T-P (mg/l)	48	144	0.027	0.008	0.023	0.030	0.12
T-P (calculated)	86	257	0.027	0.008	0.024	0.032	0.12
COD (mg/l)	101	302	1.4	0.5	1.4	1.7	6.9
Transparency (m)	76	227	6.7	2.0	6.2	8.6	16

* * calculated from the correlation

Table 7-5 Water quality parameters around beach resorts in trouble

parameter	no. of data	min.	max.
T-N (mg/l)	10	0.30	0.90
T-P (mg/l)	10	0.03	0.14
COD (mg/l)	10	1.7	3.6

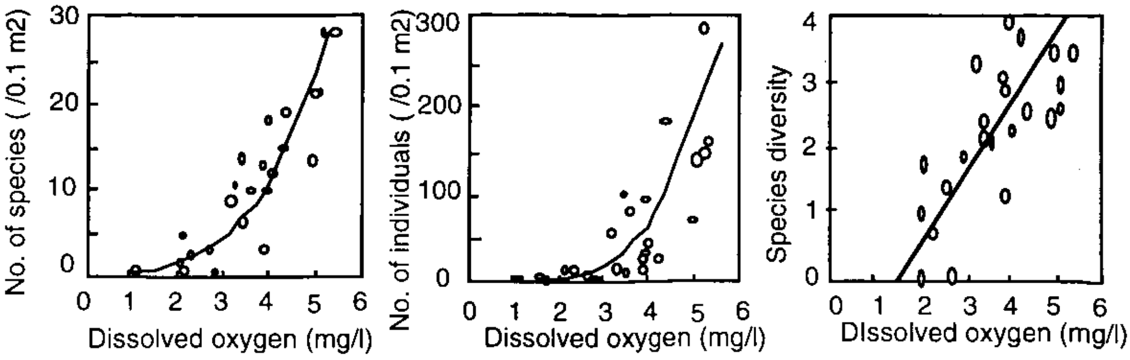

Fig. 7-11 Relationships between benthic community structure and dissolved oxygen concentration in the bottom

3) Protection of benthic organisms

Estuaries designated to this category guarantees minimum quality of water for the survival of benthic organisms. Eutrophication and associated internal production of organic matter decreases dissolved oxygen concentration in the bottom especially in summer. The most vulnerable organisms from the oxygen deficit are benthos.

The main parameter adopted was dissolved oxygen concentration in the bottom during summer. A report based on the field survey in Seto Inland Sea to evaluate the relationship between benthic community structure and dissolved oxygen concentration in the bottom was adopted as the basis for the standard (Fig. 7-11).

The criteria adopted was 2 ml l^{-1} (= 2.9 mg l^{-1}) in DO in the bottom in summer. The standard values both for T-N and T-P were determined to be less than 1.0 mg l^{-1} and 0.09 mg l^{-1}, respectively based on the correlation and taking the followings into consideration;

- Detrimental effects are noted in some species at DO less than 4 ml l^{-1} (= 5.7 mg l^{-1}),
- Numbers of species, population density, and species diversity are extremely low if DO is less than 3 ml l^{-1} (= 4.3 mg l^{-1}),
- Most species were killed at DO less than 2 ml l^{-1} (= 2.9 mg l^{-1}).

4) Fisheries: class 1, 2, 3

It is known that the increase in primary production, i.e. phytoplankton production, increases the production of secondary and higher producers, i.e. fish production. Some circles claimed that nutrient control may decrease phytoplankton production and, hence, decrease fishery production. Although fishery production increased with the increase in primary production, it leveled of at a certain level of primary production and decreased if primary productivity is too high as shown in Fig. 7-12.

Not only the amount of fishery production, but also species changed drastically with the increase in the primary production. Remarkable decreases in the catch of all kinds of fishes were noted in Tokyo Bay by water pollution and eutrophication especially after 1970's. Even in the less polluted bays, total fish catch increased gradually. However, only free swimming plankton feeders such as sardine, anchovy, gizzard shad increased and remarkable decrease in clams, shrimps, crabs are noted probably affected by the dissolved oxygen deficit in the bottom.

Taking these relationships between fish catch both in quantity and quality and water quality in Tokyo Bay and other estuaries, the following three criteria on fishery and corresponding nitrogen and phosphorus concentration were determined.

[**Class 1**: T-N < 0.3 mg l-1, T-P < 0.03 mg l^{-1}]

Bottom fishes (black porgy), shrimps, crabs, octopus, squid, clams are rich. Especially, even those intolerable to oxygen deficit in bottom water are abundant. Estuarine ecosystem in this class are regarded to be maintained well and high in species diversity.

[**Class 2**: 0.3 mg l^{-1} < T-N < 0.6 mg l-1, 0.03 mg l^{-1} < T-P < 0.05 mg l^{-1}]

Both bottom and free swimming fish such as sardine, gizzard shad, sea bass, flatfish are abundant. However, catches for those intolerable to oxygen deficit such as shrimps and crabs are decreased. Environmental conditions are not suitable for bottom fishes.

[**Class 3**: 0.6 mg l^{-1} < T-N < 1.0 mg l-1, 0.05 mg l^{-1} < T-P < 0.09 mg l^{-1}]

Although catches for sardine, gizzard shad, sea bass is possible, most of them are sardines feeding phytoplankton. In estuaries such as Tokyo Bay, detritus feeders such as clams are major catches. Catches for bottom fish, crabs and shrimps are damaged. Organisms in low trophic level predominates and estuarine ecosystem is regarded to be unstable.

It must be noted that estuarine waters more polluted than class 3 are regarded to face with frequent depletion of dissolved oxygen and blue-tide.

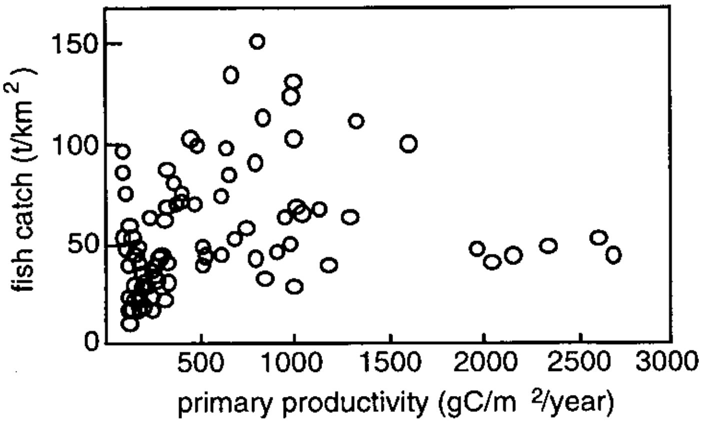

Fig. 7-12 Fish catch as affected by primary productivity

5) Industrial water supply

Major use of estuarine water for industrial purpose is cooling water. Some amount is used as raw material for salt production. Surveys on the water quality both for cooling water and raw water in use are summarized in Table 7-6. The standard values both for T-N and T-P were determined to be less than 1.0 mg l^{-1} and 0.09 mg l^{-1}, respectively based on the above mentioned use and the standard for organic pollution.

Table 7-6 Water quality for cooling water and raw water in use

use	parameter	no. of data	average	min.	median	75%	max.
raw water	T-N (mg/l)	8	0.15	0.57	0.42	1.00	1.5
	T-P (mg/l)	10	0.007	0.041	0.036	0.05	0.13
cooling water	T-N (mg/l)	28	0.1	0.79	0.78	0.88	3.9
	T-P (mg/l)	28	0.02	0.074	0.06	0.08	0.37

6) Water quality standard for estuaries

The standard for nitrogen and phosphorus mentioned above are summarized in Table 7-7. The corresponding qualities of water for other parameters are also shown in the table. The values of parameters were estimated from the correlation.

Table 7-7 Water quality standard for estuaries and related parameters

category	use of water	standard		related parameters		
		T-N (mg l^{-1})	T-P (mg l^{-1})	DO (ml l^{-1})	COD (mg l^{-1})	Transparency (m)
I	Conservation of natural environment and II, III, IV	< 0.2	< 0.02	> 5	< 1.7	> 7 - 9
II	Fisheries class 1, Marine recreation/bathing and III, IV	< 0.3	< 0.03	> 4	< 2.0	> 5 - 6
III	Fisheries class 2 and IV	< 0.6	< 0.05	> 3	< 3.0	> 3 - 4
IV	Fisheries class 3, Protection of benthic organisms, Industrial water supply	< 1.0	< 0.09	> 2	< 4 - 5	> 2 - 3

* all the standard values are applied on annual average basis

** Only waters where massive growth of phytoplankton are expected should be designated to a category mentioned above

3. Standard Values and Categorization of Estuaries

3.1 Estuaries to be Categorized

All the water bodies required to control nutrients are categorized either by national or prefecture government. The criteria on categorization are as follows;

1) Categorization is necessary for all the waters with high possibilities of eutrophication. However, hypertrophic waters at present and in near future should have high priority.
2)Previous water use must be taken into consideration as potential water uses in addition to present uses.
3)Deadlines to comply with the standards should be determined based on the prediction of water quality in future. The prediction should take water quality at present, changes in population and industrial production, and possible management strategies.

4. Criteria to Judge Compliance

4.1 Criteria

Different from the method for lakes and reservoirs' standards, the compliance for the standard is evaluated based on the average value of annual averages of all the environmental standard points (ESP).

Basic data to legislate nitrogen and phosphorus standards for estuaries were annual average values of water quality in 30 Japanese estuaries and their water use. If there were more than two environmental standard points, we adopted the average of all the points. The maximum values were not adopted because water quality of estuarine water shows large fluctuation by tidal motion and does not give representative information on water quality.

4.2 Allocation of environmental standard points

Allocation of ESPs has significant effects on percent compliance of environmental water quality standards. Because of the fact that the representative values are average of annual mean values of all the standard points in an estuary, allocation of ESPs in off-shore area with high water quality should result in higher rate of compliance. Thus the basic criteria for allocation are recommended by the government as follows;

1) Select central area as representative points for the quality of the estuary without direct effects of inflow water.

2) Use conventional ESP for COD to save monitoring efforts.
3) Select one point for the area raging from 30 to 140 km^2.
4) Select ESPs in the following small water body like harbors.
    -enclosed and independent water body form other area,
    -the area is more than 5 m^2,
    -the area has different water use from others.

5. Present water quality

Table 7-8 shows percent compliance of environmental water quality standards for nitrogen and phosphorus in estuaries in 1995. Number of estuaries that could comply with the standards corresponds to the number of estuaries where both nitrogen and phosphorus were satisfactory. Percent compliance for categories II and III where better qualities were expected were very low, 0 percent. Tokyo Bay was 33.3 % and all the area in Osaka Bay could not satisfy with the standards.

Table 7-8 Percent compliance of environmental water quality standards for nitrogen and phosphorus in estuaries in 1995

category	number of waters categorized	complied estuaries	percent compliance
I	-	-	-
II	2	0	0
III	2	0	0
IV	5	2	40
total	9	2	22.2