Evaluation of Primary Production Loads and Their Control in Enclosed Seas

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The primary production in eutrophic water bodies contributes greatly to water pollution as an organic pollutant. In this study, in order to evaluate quantitatively the organic pollution load originated from origin in the primary production in an enclosed water body (the internal organic pollution load), many methods for its evaluation that have been proposed up to the present, are investigated comparatively.
Though strict evaluation of the internal organic pollution load is difficult, its approximate evaluation is possible. For the control of this internal organic production, the reduction of inflowing nutrient loads such as nitrogen and phosphorus is necessary.
From the analysis of the relationships between nutrient loads to enclosed coastal seas in Japan and their nutrient levels, the eutrophic potential in each sea area is calculated with a simple procedure.
Though nutrients are essential for biological production, the excess of them creates many water quality problems. Therefore, for the control of nutrient impacts to the enclosed coastal seas in Japan, the following strategies are proposed.

1) an effective measure for nutrient load reduction in their originating stage, as a consequence of our structural analysis of nutrient budget in Japan.
2) waste water treatment for nutrient load reduction.
3) appropriate distribution of nutrient load impact based on the eutrophic potential of each coastal sea and each adjacent sea of Japan.

The sewer and sewage treatment system is an effective system for reduction and distribution of the nutrient load.

Evaluation of internal organic pollution in the eutrophic water body

Eutrophic potential in a water body

Eutrophic potential in a water body is estimated with the maximum phytoplankton production that can be calculated from the nutrient concentration (N or P) in that water body with the following formula for phytoplankton production (after Richard 1965).

$$106\ CO_2 + 16\ NO_3^- + HPO_4^{2-} + 122\ H_2O + 18\ H^+ + \text{light} + \text{trace elements}$$
$$= C_{106}\ H_{263}\ O_{110}\ N_{16}\ P\ +\ 138\ O_2$$

On the basis of this formula, the maximum production of TOC and TOD to be produced from 14 × 16 gr. of N or 31 gr. of P is 1272 gr. or 4416 gr. respectively.

Meanwhile, from the results of many phytoplankton cultures, the TOD value produced by phytoplankton (that is Internal production TOD, or IP TOD)is equivalent to 2-3 (2.26 on the average) times of the KMn04 COD values.

On the basis of this formula, the maximum production of TOC and TOD in the water body is shown as follows.

$$\text{TOC potential(mg/l)} = (1272 \div 16 \div 14) \times N\ (mg/l)$$
$$= (1272/31) \times P\ (mg/l)$$

$$\text{TOD potential(mg/l)} = (4416 \div 16 \div 14) \times N\ (mg/l)$$
$$= (4416/31) \times P\ (mg/l)$$

$$\text{KMn04 COD potential(mg/l)} = (4416 \div 16 \div 14) \div 2.26 \times N\ (mg/l)$$
$$= (4416/31) \div 2.26 \times P\ (mg/l)$$

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then, N : total Nitrogen concentration in the water body (mg/l)
P : total Phosphorus concentration in the water body (mg/l)

Evaluation of internal organic pollution

We cannot measure the internal organic matters such as TOC, TOD or COD index directly. Because TOC, TOD or COD values that are measured in the water body are the sum of the internal production part and the external coming part of these indexes, the direct and individual classification of these values is impossible. The external coming part means the part that is supplied from the land area and the other water body. For evaluation of this internal organic pollution, the following indirect methods are proposed.

(1) Indirect estimation of external coming COD
Internal production COD (IP COD) value is estimated by subtraction estimated external coming COD (EC COD) from measured total COD.

$$\text{IP COD} = \text{Measured total COD} - \text{Estimated EC COD}$$

EC COD is estimated indirectly as the minimum COD value in a year (⊿COD method), as a soluble COD value. The estimations are derived from the analyses of chloride ion concentration, chlorophyll concentration, simulation model, and so on.

(2) Indirect estimation of internal production COD
Internal production COD value is estimated from other water quality items such as particulate COD, chlorophyll-a, or from ecological model analysis.

⊿COD method for evaluation of internal production COD

We assume that the seasonal variations of COD (Mn) in the eutrophic water body depend on the primary products. Therefore, the internal production COD produced in the eutrophic water body as a result of the primary production, is expressed as follows (Fig.1). We named this method as ⊿COD method.

$$\text{IP COD} = \text{Total COD} - \text{EP COD}$$

The minimum COD value in a year likely approximates the COD value derived from outside. And then,

$$\text{IP COD} = \text{Total COD} - \text{Min.COD}$$

$$\Delta \text{ COD} = \text{Annual average of total COD} - \text{Min.COD}$$

(IP COD on the annual average)

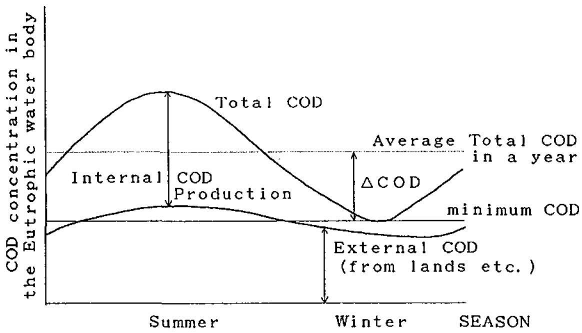

Fig.1. Evaluation of Internal Production COD (Δ COD Method)

IP COD value estimated in a water body is expressed as follows as a function of N or P concentration in that water body.

$$\begin{aligned}\text{IP COD (mg/l)} &= \text{COD potential(mg/l) for N} \times \alpha_N \\ &= (4416 \div 16 \div 14) \div 2.26 \times \text{N (mg/l)} \times \alpha_N \\ &= 8.7 \times \text{N (mg/l)} \times \alpha_N\end{aligned}$$

or

$$\begin{aligned}\text{IP COD (mg/l)} &= \text{COD potential(mg/l) for P} \times \alpha_P \\ &= (4416/31) \div 2.26 \times \text{P (mg/l)} \times \alpha_P \\ &= 63.0 \times \text{P (mg/l)} \times \alpha_P\end{aligned}$$

then,

α_N or α_P : Production rate (or Conversion factor) of internal production for N or P respectively.

α_N or α_P is a characteristic index that indicates a eutrophic situation in that water body. Between N and P, either which is the limiting factor for primary production, is adopted in these formulae. Examples of α_N or α_P are shown in Table 1.

Chloride ion method for evaluation of internal production TOD, TOC, COD etc.

The COD (TOD or TOC) load discharged into a coastal area is diluted with the sea water.

Therefore, EC COD (TOD or TOC) value can be expressed as a function of the chloride ion in the sea. The chloride ion method, that is proposed by the Japan Environmental Agency, is explained as Fig. 2. In Fig.2, COD (TOD or TOC) values in the vertical axis and chloride ion values in the horizontal axis are plotted for respective mesured point. The point for the inflowing water where chloride ion value is zero and the point for the open sea are combined with a straightline. Each COD value on the straight line indicate the external COD (TOD or TOC) value for each measured point.

Chlorophyll method for evaluation of internal production TOD, TOC, COD etc.
Chlorophyll-a values in the vertical axis and COD (TOD or TOC) values in the horizontal axis are plotted for respective measured point as Fig.3. And the regression line for the COD (TOD or TOC) values and the chlorophyll-a values is calculated. The COD (TOD or TOC) value at the point that the obtained regression line intersects with the vertical axis is regarded as EC COD (TOD or TOC) value in that water body.

Phytoplankton culture method for evaluation of IP TOD, TOC, COD etc.
Relationships between chlorophyll-a, pheophytine, TOD, TOC and COD values are measured in the progress of phytoplankton culture using phytoplankton in that water area. An example of the results is shown in Fig 4. By using the obtained relations, chlorophyll-a and pheophytine values measured in the water area are converted into TOD, TOC and COD values. However, the application of this method is complicated because these relations change with growth phase of the culture.

Examples of estimated internal production COD
From our and other studies, internal production COD ratios are estimated as shown in Table 2, where internal production COD ratios are estimated as a range of 10-70 % of total COD.

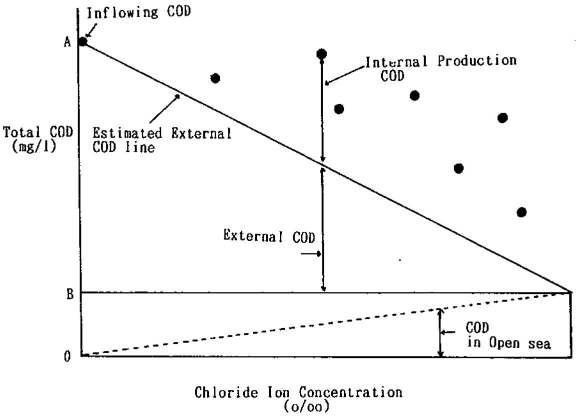

Fig.2. Evaluation of Internal Production COD (Chloride Ion Method) (Japan Environmental Agency)

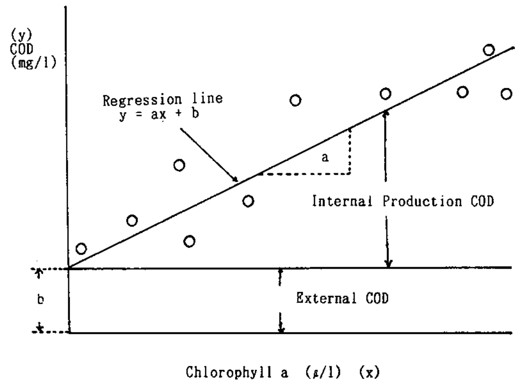

Fig.3. Evaluation of Internal Production COD (Chlorophyll Method)

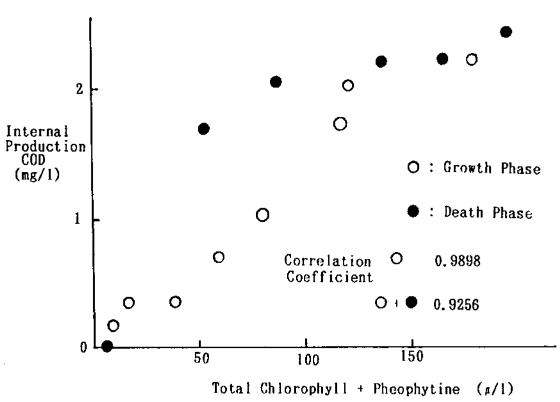

Fig.4. Evaluation of Internal Production COD (Phytoplankton Culture Method) Skeletonema Costatum Culture

Table 1. Examples of Production rate α_N or α_P

	Limiting factor	α_N	α_P		Limiting factor	α_N	α_P
OsaKa Bay	P	0.26	0.80	The sea of Suo	P	0.30	0.59
Kii Channel	P	0.36	0.49	Bungo Channel	P	0.45	0.38
The Sea of Harima	P	0.17	0.52	Seto Inland Sea	P	0.25	0.40
Bisan Seto	P	0.19	0.15	Tokyo Bay	N	0.54	0.43
The Sea of Hiuchi	P	0.08	0.23	Lake Biwa (South)	P	0.11	0.28
The Sea of Aki	P	0.17	0.25	Lake Kasumi	P	0.15	0.51
The Sea of Iyo	P	0.24	0.25				

Table 2. Internal Production COD Ratios

	Λ COD method	Simulation analysis	From Chlorophyll a	From Chloride ion
Tokyo bay	60 %		20-40 %	40 %
	100 %	300 %		
	38-62 %		41 %	
Ise bay	40-50 %		20-30 %	40-60 %
	39-64 %		36 %	
Mikawa bay	60-70 %		20-40 %	50-60 %
	50-69 %		47 %	
Osaka bay	50 %		30-40 %	30-40 %
	36-54 %		36 %	
Hiroshima bay	50-60 %		20 %	10-20 %
Tokuyama bay	33 %			
Seto Inland Sea	70	330 %		
Lake Biwa	53 %			
Lake Kasumi	45 %			
Lake Suwa	25 %			

Evaluation of the nutrient load impact to internal organic pollution

The nutrient impact to the enclosed sea and the eutrophic carrying capacity can be evaluated as follows.

Nutrient load impact to the enclosed sea

The nitrogen load or the phosphorus load per surface water area or per water volume (gr. N/m^2.day, gr. P/m^2.day, gr. N/m^3.day, gr. P/m^3.day) is an important impact index to the eutrophic water body.

Nutrient impact potential to the sea.

Nutrient impact potential is defined as the maximum phytoplankton production that can be produced in the water body by impacted nutrient load. This impact potential (gr. N/m^2.day, gr. P/m^2.day, gr. N/m^3.day, gr. P/m^3.day) can be calculated from the formula for phytoplankton production shown already in the preceding chapter.

On the basis of this formula, eutrophic impact potential is shown as follows.

$$\text{TOC impact potential(gr./m}^3\text{.day)} = (1272 \div 16 \div 14) \times (\text{gr. N/m}^3\text{.day}) = (1272/31) \times (\text{gr. P/m}^3\text{.day})$$

$$\text{TOD impact potential(gr./m}^3\text{.day)} = (4416 \div 16 \div 14) \times (\text{gr. N/m}^3\text{.day}) = (4416/31) \times (\text{gr. P/m}^3\text{.day})$$

$$\text{KMn04 COD impact potential (gr./m}^3\text{.day)} = (4416 \div 16 \div 14) \div 2.26 \times (\text{gr. N/m}^3\text{.day}) = (4416/31) \div 2.26 \times (\text{gr. P/m}^3\text{.day})$$

Eutrophic conversion factor

We define as the eutrophic conversion factor, the ratio of the TOC, TOD or COD load produced actually in that water body to the TOC, TOD or COD impact potential. The eutrophic conversion factor is indicated as the product of ① the factor that indicates distribution in the water body of the inflowing N or P load (Dilution factor, d_N or d_P) and ② the factor that is indicates a ratio used for phytoplankton production of the inflowing N or P load (Production rate, or Conversion factor α_N and α_P).

$$\text{Internal production (TOD, TOC, COD) impact (gr./m}^3\text{.day or gr./m}^2\text{.day)} = \text{Impact potential (TOD, TOC, COD)} \times d_N \times \alpha_N$$
$$= \text{or Impact potential (TOD, TOC, COD)} \times d_P \times \alpha_P \quad (\text{gr./m}^3\text{.day or gr./m}^2\text{.day})$$

d_N or d_P : Dilution rate for N or P respectively.

Examples of estimated COD impact potential

COD impact potential in Japanese enclosed water area and marine coast is estimated as shown in Table 3. From these results, fundamental strategies for eutrophication control of enclosed inland and coastal water areas in Japan are suggested.

Strategies for reduction of pollution loads for COD, N and P discharged into the enclosed coastal sea in Japan

Pollution loads discharged into the marine coast in Japan are summarized in Table 4. For the reduction of pollution loads for COD, N and P, the following strategies are proposed.

The movement of N and P due to food relating matters has to be paid attention to and the management strategies to reduce their movement has to be taken seriously.

The most fundamental strategy for reduction of COD, N and P load discharged into water areas is to do it in each origin of their loads. This strategy has to be promoted strongly. Reduction of P content in synthetic detergent, treatment of garbage not as sewage but as solid waste, utilization of human and livestock waste as fertilizer and so on are good example for this purpose.

Adjustment of sewage treatment system has to be promoted strongly. In Japan, 92% of night soil and 45 % of miscellaneous sewage (except flush toilet waste) are treated in sewage treatment plants and night soil treatment plants, and 8 % of night soil is disposed in soil or others in 1989. Therefore, treatment of the rest 55 % of miscellaneous sewage is urged.

Remarkable good results in performances of night soil treatment plants or sewage treatment plants are obtained as shown in Table 5.

Industrial waste water had been improved strikingly for several years of 1970,s. As the remarkable improvement after that, however, has not recognized, more effort for reduction of pollution loads from industrial waste water is requested.

Judging from the eutrophic levels, the pollution load impact and the carrying capacities of pollutants in coastal seas and adjacent sea areas in Japan, selection of water areas to receive these pollution loads such as nutrient matters as COD, N, P is a very effective strategy for eutrophication control. Of course they are not toxic substances. After the discharging nutrient loads are treated, diversion of these nutrient loads from highly eutrophicated and enclosed water areas such as Tokyo bay, Osaka bay and Mikawa bay into the adjacent sea areas of Japan, where they have larger carrying capacities, might be recommend.

Table 3. Estimation of Nutrient Load Impact

	Nutrient load impact (kg/km²/Y)		Nutrient impact Potential (TOC kg/km²/Y)		
	N	P	from N	from P	Applied Potential
Reservoir (Ave.,n=60)	16.57	1.157	92.8	64.8	65
Lakes in Open Land					
Lake Biwa	7.04	0.596	39.4	33.4	33
Lake Biwa (South)	19.00	2.329	106.4	130.4	106
Lake Kasumi	25.25	2.721	141.4	152.4	141
Lake Suwa	95.00	17.210	532.0	963.8	532
Nakaumi,Shinji	13.91	1.405	77.9	78.7	78
Lake Kojima	129.38	20.075	724.5	1124.2	725
Lake Inba	169.39	15.664	948.6	877.2	877
Lake Taga	547.71	88.161	3067.2	4937.0	3067
Average	124.25	18.680	695.8	046.1	696
Enclosed Seas					
Tokyo Bay	89.25	10.689	499.8	598.6	500
Ise Bay	43.41	5.775	243.1	323.4	243
Seto Inland Sea	8.18	0.816	45.8	45.7	46
Average	46.95	5.761	262.9	322.6	263
Ariake Sea	16.59	1.416	92.9	79.3	79
Hakata Bay	25.86	2.479	144.8	138.8	139
Oomura Bay	2.73	0.171	15.3	9.6	10
Adjacent Sea					
Okhotsk Sea*	0.350	0.0354	1.96	1.98	2.0
(Okhotsk Sea)	0.350	0.0354	1.96	1.98	2.0
Pacific Ocean*	0.313	0.0313	1.75	1.61	1.6
(Pacific Ocean)	1.559	0.1559	8.73	7.93	7.9
Japan Sea*	0.189	0.0189	1.06	1.04	1.0
(Japan Sea)	0.405	0.0405	2.27	2.23	2.2
Average*	0.286	0.0286	1.60	1.54	1.5
(Average)	0.759	0.0759	4.25	4.11	4.1

Adjacent Sea
( ) : Within 200 nautical miles. * : Within 500 m depth.

Table 4. Nutrient Loads Discharged into the Marine Coasts in Japan
(Nakanishi,Ukita, et al.)

	1970 (10^3t/Y)		1984 (10^3t/Y)		note
Origin	N	P	N	P	
Residential	281(32.9)	43.7(46.5)	315(38.7)	32.4(43.3)	reaching-ratio
Food-processing	55(6.4)	9.7(10.3)	44(5.4)	8.0(10.7)	N:83%
Chemical fertilizer production	128(15.0)	22.0(23.4)	77(9.5)	16.8(22.4)	P:81% (reaching-ratio for industries
Stockbreeding	32(3.7)	8.8(9.5)	26(3.2)	8.0(10.7)	that located at coastal area,
Agricultural land	213(24.9)	6.5(6.9)	213(26.2)	6.5(8.7)	such as Chemical fertilizer,
Coal,petrochemical	33(3.9)	-	26(3.2)	-	Coal,petrochemical, and
Other natural organic matter	12(1.4)	3.2(3.4)	12(1.5)	3.2(4.3)	Precipitation is set to 1.0)
Precipitation	100(11.7)	-	100(12.3)	-	
Total	854(100%)	94.0(100%)	813(100%)	74.9(100%)	

Table 5. Performances in Biological Treatment Plants

An example of an industrual waste water treatment plant(fermentation industry)

	Raw water mg/l	Treated water mg/l	Removal ratio %	
COD	3000	900	70	Activated sludge process. Treated
T-P	40	12	70	water is discharged after being
T-N	1200	480	60	diluted with 12 times cooling water.
	Raw water	Treated water	Removal ratio	
COD	170	54	68	Activated sludge method.
T-P	3	1	66	
T-N	140	120	14	

An example of a Night soil treatment plant (1975)

	Raw water mg/l	Treated water mg/l	Removal ratio %	
COD	7000	2100	70	Activated sludge process. Treated
T-P	340	240	30	water is discharged after being
T-N	5000	3500	30	diluted with 19 times fresh water.
BOD	13500	600	95	

An example of a Night soil treatment plant (1984)

	Raw water mg/l	Treated water mg/l	Removal ratio %	
COD	7000	60	> 99	High loading activated sludge process
T-P	340	2	> 99	with UF membrane for separation.
T-N	5000	40	> 99	Treated water is discharged after
BOD	13500	20	> 99	being diluted with 1 times fresh water.

An example of a sewage treatment plant

	Raw water mg/l	Treated water mg/l	Removal ratio %	
COD	76	5	93	Biological nitrogen removal process.
T-P	3.6	0.1	97	
T-N	29	6	79	
BOD	200	1 >	99	

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