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Origins of Phosphorus and Nitrogen in Ariake Bay, Japan

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Abstract

Origins of total phosphorus (TP) and total nitrogen (TN) were investigated in Ariake Bay, Japan, using the unit response function method. About 50 % of TP and 67 % of TN in Ariake Bay were found to have originated from the open ocean, 14 % of TP and 33 % of TN originate from rivers, 36 % of TP originated from sea sediments and 3.3 % of TN was emitted to the air via de-nitrification. The limiting nutrient for primary production in the head of Ariake Bay, that is the main occurrence area of red tides and oxygen deficient water, is phosphorus (Yanagi and Abe, 2005). We consequently suggest that it would be very difficult to prevent red tides and oxygen deficient water in Ariake Bay by managing land-derived TP, because its proportion (14 %) is not large. It may be possible to prevent red tides and oxygen deficient water by reducing the bottom release of TP (proportion of 36 %), by applying civil engineering method such as the placement of a sand cover over the present sea sediments.

Key words : *nutrients, phosphorus, nitrogen, unit response function, average residence time*

1. Introduction

Ariake Bay is a semi-enclosed shallow bay (average depth of about 20 m) located on the west coast of Kyushu, the southern-most of the main islands of Japan (Fig.1). It has suffered from frequent occurrences of red tides and oxygen deficient water masses in summer mainly owing to eutrophication from the 1990s (Fig.2, Fisheries Agency of Japan, 2010). It is necessary to dramatically reduce the phosphorus and nitrogen loads leaching from the land in order to prevent eutrophication in Ariake Bay. In order to establish effective countermeasures for reducing phosphorus and nitrogen from the land, it is important to know the ratio of land-derived phosphorus and nitrogen. These elements have three main sources: land, sea sediments and open ocean. A small portion of the phosphorus and nitrogen is air-derived; this amounts to about 5 % of that from the land in the case of Ariake Bay (Yanagi and Abe, 2005, 2006).

We have clarified the ratios of phosphorus and nitrogen derived from land, sea sediments and open ocean, using the unit response function method.

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2. Loads and concentrations

Total phosphorus (TP) and total nitrogen (TN) loads leaching from the land into Ariake Bay were estimated using river discharge and TP and TN concentrations in the rivers that empty into Ariake Bay. Measurements were made every month from July 2001 to January 2005 by the Ministry of Infrastructure and Transport, Japan (Fig.3). The Ministry of Environment, Japan monitored water temperature, salinity, and TP and TN concentrations in the surface and bottom layers at 20 stations in Ariake Bay (see Fig.3) four times a year (February, May, August and November) from 2002 to 2005.

All data were downloaded from the homepage of Ariake Bay Environmental Data Network Association (http://ay.fish-jfrca.jp/ariake/index.asp). We averaged observed water temperature, salinity, TP and TN concentrations for surface and bottom layers over the whole of Ariake Bay in order to calculate the averaged values in Ariake Bay.

Monthly variations in river discharge, TP and TN loads, water temperature in the bottom layer, salinity, and TP and TN concentrations in Ariake Bay are shown in Fig.4 (a) to (g). Large seasonal variations were evident in river discharge, TP and TN loads, salinity, water temperature in the bottom layer, and TP and TN concentrations. The large volume of river discharge from June to August corresponds to large TP and TN loads and high TP and TN concentrations in Ariake Bay. Yearly variations in these parameters were not great. Average river discharge was 578 x10^6 m^3 $month^{-1}$, TP load was 0.38 kg $month^{-1}$, and TN was 6.23 kg $month^{-1}$. Average salinity was 28.83, average bottom water temperature was 18.3 ℃, average TP was 0.050 mg l^{-1}, and TN was 0.30 mg l^{-1} over the observed period.

3. Method

We considered temporal variation in the standing stock of fresh water F_i (km^3) in Ariake Bay; this was estimated using the following formula,

$$F_i = V\frac{S_0 - S_i}{S_0} = \left(R_i + R_{i-1}e^{-b} + R_{i-2}e^{-2b} + \ldots + R_{i-7}e^{-7b}\right) \qquad (1)$$

where V denotes the volume of Ariake Bay (34 km^3), S_0 the salinity of open ocean (highest observed salinity in the bottom layer at Sta.Ang-5 in Fig.3; 33.83), Si the average salinity in Ariake Bay at month i (see Fig.4 (d)), Ri (km^3) the river discharge at month i (see Fig.4 (a)), b ($month^{-1}$) the

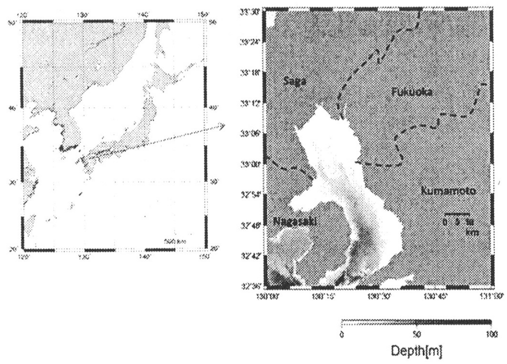

Fig.1 Ariake Bay

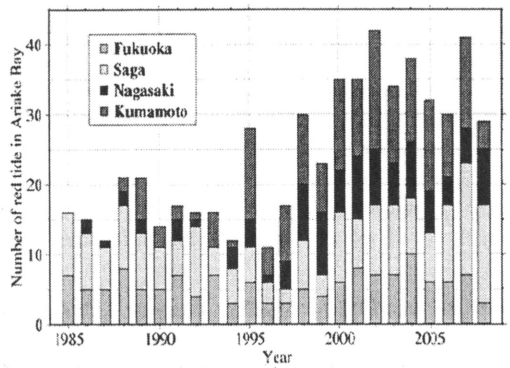

Fig.2 Variation between years in the occurrence of red tides in Ariake Bay.

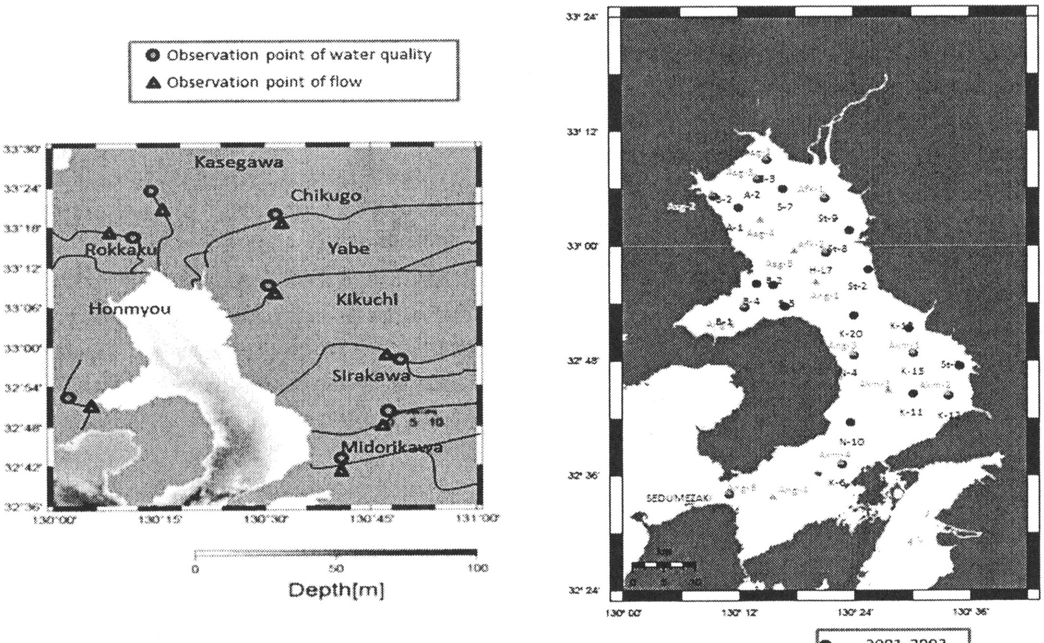

Fig.3 Rivers that empty into Ariake Bay and stations where river discharge and TP and TN concentrations were measured (left). Observation stations where water temperature, salinity, and TP and TN concentrations were measured (right).

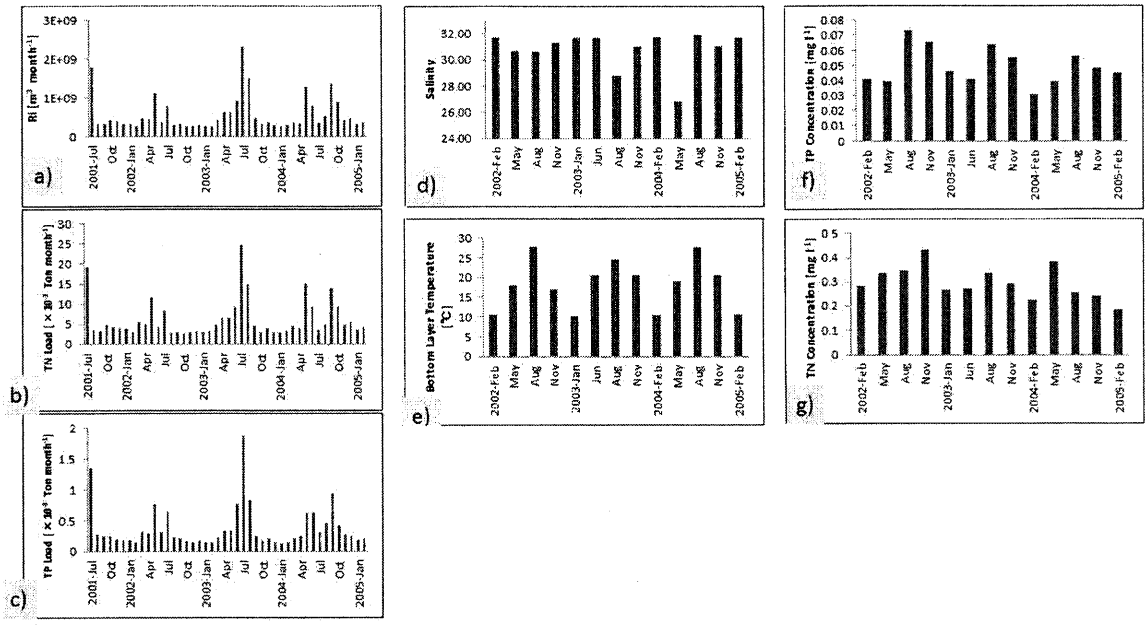

Fig.4 Monthly variations in river discharge (a), TN load (b), TP load (c), salinity (d), bottom temperature (e), TP concentration (f) and TN concentration (g) in Ariake Bay.

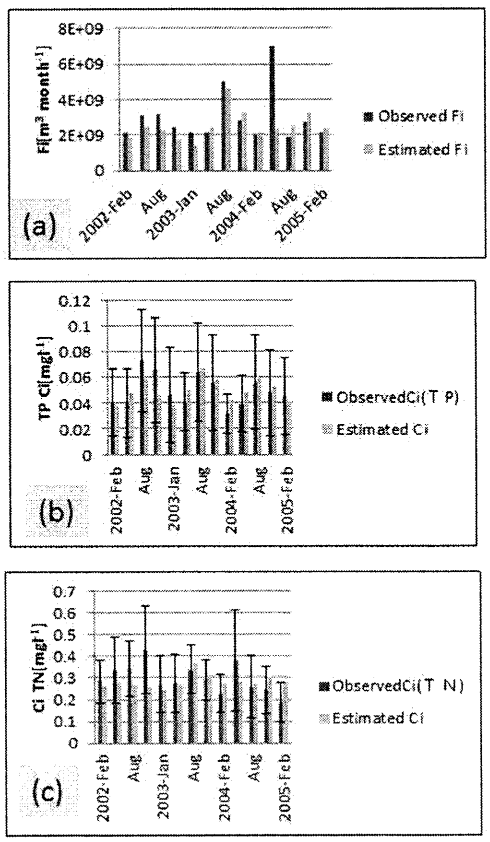

Fig.5. Comparison of observed and estimated freshwater standing stocks (a), TP concentrations (b) and TN concentrations (c) in Ariake Bay. Vertical bar indicates standard deviation.

decreasing gradient of the exponential function. We included the effect of river discharge seven months previously on the standing stock of fresh water in Ariake Bay because the average residence time of fresh water near the head of Ariake Bay was estimated to be 2.1 months (Yanagi and Abe, 2003).

The terms on the right hand side of Eq.(1) express the unit response function for the unit river discharge. The unknown in Eq.(1) is only b and we were able to estimate the most suitable value of b by the least-square method using 13 equations from February 2002 to February 2005 (see Fig.4 (d)).

The temporal variation in average concentration of TP or TN Ci (mg l^{-1}) in Ariake Bay was estimated using the following formula,

$$C_i = C_0 + \frac{1}{V}\left(L_i + L_{i-1}e^{-b} + L_{i-2}e^{-2b} + \ldots + L_{i-7}e^{-7b}\right) + \alpha T_i \quad (2)$$

where C_0 (mg l^{-1}) is the TP or TN concentration in the open ocean, Li (kg) is the TP or TN loads from rivers in month i (see Fig.4 (b) and (c)), α (mg l^{-1} °C^{-1}) is the TP or TN concentration released from sediments in the case of TP or sediment (release minus de-nitrification) in the case of TN. We assumed that release from sediments was proportional to water temperature in the bottom layer Ti (°C) in month Ii(see Fig.4 (e)). The unknowns in Eq. (2) are C_0, b and α, and we were able to estimate these by the least-square method using 13 equations from February 2002 to February 2005 (see Fig.4 (f) and (g)).

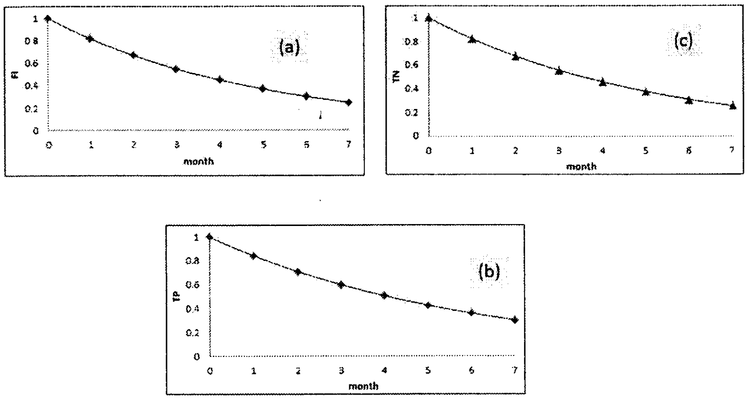

Fig.6. Estimated unit response function of fresh water (a), TP (b) and TN (c).

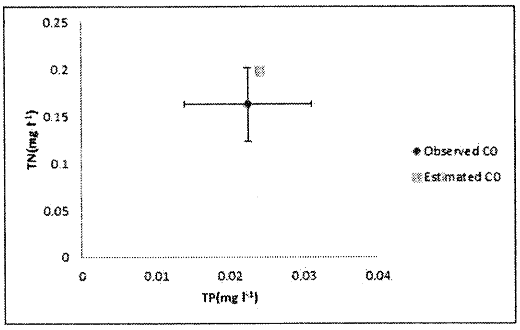

Fig.7. Estimated and observed C_0 for TP and TN. Vertical and horizontal bars indicate standard deviation.

The average residence times (τ) of fresh water, TP or TN were calculated using the following equation (Takeoka, 1984).

$$\tau = \int_0^{+\infty} e^{-bt}\, dt = \frac{1}{b} \tag{3}$$

4. Results

We compared observed and estimated temporal variations in the standing stock of fresh water (Fi) (see Fig.5 (a)): our observations and estimates agreed well. The estimated unit response function for unit river discharge is shown in Fig.6 (a). The estimated most suitable value of b was 0.2 month^{-1}. Using Eq.(3), this meant that the estimated average residence time of fresh water in Ariake Bay was 5.0 months.

We compared observed and estimated temporal variations in average concentration of TP (see Fig.5 (b)): these agree well. The estimated TP concentration in the open ocean was 0.023 mg l^{-1}. The estimated unit response function for unit TP load is shown in Fig.6 (b). The estimated value of b was 0.17 month^{-1}, meaning that the estimated average residence time of TP in Ariake Bay was 5.9 months.

We compared observed and estimated temporal variations in average concentration of TN (see Fig.5 (c)): these agree well. The estimated TN concentration in the open ocean was 0.20 mg l^{-1}. The estimated unit response function for unit TN load is shown in Fig.6 (c). The estimated value of b was 0.196 month^{-1}, meaning that the estimated average residence time of TN in Ariake Bay was 5.1 months.

We compared estimated TP and TN concentrations in the open ocean with observed concentrations in the bottom layer at the bay mouth station (Sta.Ang-5 in Fig.3) (see Fig.7). Estimated values are a little larger than observed ones but within their standard deviations. Such results indicate that our unit response function method is reasonable.

The ratios of TP and TN in Ariake Bay derived from open ocean, rivers and sea sediments are shown in Fig.8. About 50 % of TP and 67 % of TN in Ariake Bay was found to originate from the open ocean, 14 % of TP and 33 % of TN originated from rivers, 36 % of TP originated from sea sediments, and 3.3 % of TN was emitted to the air via de-nitrification.

Table 1 Estimated parameters

	Fresh water	TP	TN
Average residence time τ(month)	5.0	5.9	5.1
C_0 (mg/l)		0.024	0.20
Bottom release (mg/l)		0.018	
Denitrification − bottom release (mg/l)			0.013
Ratio of open ocean and land derived nutrients		0.40:0.14	0.71:0.25

The estimated parameters are shown in Table 1. The

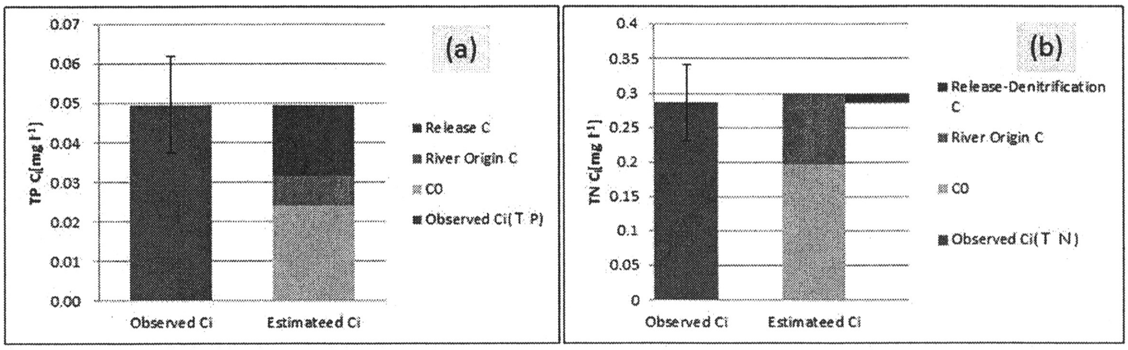

Fig.8. Observed and estimated TP concentrations (a) and observed and estimated TN concentrations (b) in Ariake Bay. Vertical bar indicates standard deviation.

average residence time of TN (5.1 month) is a little longer than that of fresh water (5.0 month), perhaps due to the nutrient trapping effect (Takaoka and Hashimoto, 1988), and a little shorter than that of TP (5.9 month) due to de-nitrification. The ratios of land-derived TP and TN to open ocean derived TP and TN were both 35 %.

5. Discussion

TN/TP mole ratio in Ariake Bay is 13.0 (Fig.8) but DIN (Dissolved Inorganic Nitrogen) / DIP (Dissolve Inorganic Phosphorus) mole ratio in the head of Ariake Bay, that is the main occurrence area of red tides and oxygen-deficient water, is 16.7 (Yanagi and Abe, 2005). This suggests that the limiting nutrient for primary production in the head of Ariake Bay is phosphorus (Yanagi and Abe, 2005).

We consequently suggest that it would be very difficult to prevent red tides and oxygen deficient water in Ariake Bay by managing land-derived TP, because its proportion (14 %) is not large and we cannot control ocean derived TP (50 %). It may be possible to prevent red tides and oxygen deficient water by reducing the bottom release of TP (proportion of 36 %), by applying civil engineering method such as the placement of a sand cover over the present sea sediments.

6. Conclusions

The origins of phosphorus and nitrogen in Ariake Bay, Japan, were investigated using the unit response function method. About 50 % of TP and 67 % of TN in Ariake Bay was found to originate from the open ocean, and only 14 % of TP and 33 % of TN originated from rivers, and 36 % of TP originated from sea sediments.

References

1) Fisheries Agency of Japan (2010) Occurrence of red tides in Kyushu, 20p.
2) Takeoka,H. (1984) Fundamental concepts of exchange and transport time scales in a coastal sea. Continental Shelf Research, 3, 311-326.
3) Takeoka,H. and T.Hashimoto (1988) Average residence time of matter in coastal waters in a transport system including biochemical processes. Continental Shelf Research, 8, 1247-1256.
4) Yanagai,T. and R.Abe (2003) Year-toyear variation of water exchange in Ariake Bay. Oceanography in Japan, 12, 269-275 (in Japanese with English abstract and captions).
5) Yanagi,T. and R.Abe (2005) Year-to-year variations in salinity and in the budgets of dissolved inorganic phosphorus and dissolved inorganic nitrogen in the head of Ariake Bay. Oceanography in Japan, 14, 21-33 (in Japanese with English abstract and captions).
6) Yanagi, T. and R.Abe (2006) Nitrogen budget change in Ariake Bay between 1979 and 1999. Oceanography in Japan, 15, 67-75 (in Japanese with English abstract and captions).