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Assessing change of environmental dynamics by legislation in Japan, using red tide occurrence in Ise Bay as an indicator

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ABSTRACT

Tokyo Bay, Ise Bay, and the Seto Inland Sea are the total pollutant load control target areas in Japan. A significant correlation between the incidence of red tides and water quality has been observed in the Seto Inland Sea (Honjo, 1991). However, while red tides also occur in Ise Bay and Tokyo Bay, similar correlations have not been observed. Hence, it is necessary to understand what factors cause red tides to effectively manage these semi-closed systems. This study aims to investigate the relationship between the dynamics of the Red Tide Index and nitrogen regulation as well as phosphorus regulation, even in Ise Bay where, unlike Tokyo Bay, there are few observation items, by selecting a suitable objective variable. The introduction of a new technique that uses the Red Tide Index has revealed a possibility that the total pollution load control has influenced the dynamics of red tide blooms in Ise Bay.

1. Introduction

Ise Bay and the marine area on the north part of the coast connecting Daiozaki at the southeastern end of the Shima Peninsula, the eastern area of Mie Prefecture, and Irako Cape on the Atsumi Peninsula of Aichi Prefecture are all subject waters use in regulation scrutiny. This current study focuses on Ise Bay (excluding Mikawa Bay to the east), which is a semi-closed area. The turnover of water through tides with the open sea is limited in the bay, and the occurrence of red tides, particularly during the summer is chronic. With the implementation of the government 5th directive concerning total pollution load control in 2001, some reduction of T-N and T-P has been recorded in Ise Bay.

Existing studies indicate a close relationship between red tide occurrence and total pollution load control. For instance, a "significant correlation between the number of red tide occurrences and total pollution load control is observed in the Seto Inland Sea" (Honjo, 1991). In contrast, a clear correlation between improved water quality and red tides has not been found in either Ise Bay or Tokyo Bay. Consequently, at that time, knowledge about the effect of water regulation on red tides remained unclear. However, Suzuki (2007, 2008, 2009a,b) clarifies the relationship between the red tide index (a water quality standard for red tides) and the implementation of the 5th total pollution load control directive. The relationship was made clear by using a new multiple regression model based on field surveys in Ise Bay.

This study focuses on clarifying the relationship between the red tide index and the regulation of N and P in Ise Bay. This study is based on existing methods, but with changes in the N and P contribution rates in relation to the red tide index. This new method is applied to a case study of Ise Bay, and despite fewer field observations than these of Tokyo Bay, the results are convincing.

2. Materials and methods

2.1. Data

Specific parameters were continuously monitored at permanent investigation sites at Aichi Prefecture, from which data were extracted for the current analyses (Fig. 1). A database was created from data collected from 1995 to 2006 at the permanent investigation sites based on the "investigation results of water quality in public waters (Aichi 1996–2007)" (Table 1). The database contained a complete information about health-related parameters and living-environment parameters, as stipulated by the Ministry of the Environment for the Aichi Prefecture study. However, particulate organic nitrogen (PON) was not measured, and this is unfortunate since this is the basis of the red tide index used by Ouchi (1982, 1986) and Suzuki (2008, 2009). The measurement of this parameter was optional, and was left to the discretion of each local government. Consequently, there may be major regional differences in this parameter, even when investigations focus on public waters. Even in instances where PON does not accumulate, a model with a high contribution ratio may be obtained by using PON as the objective variable. Since PON was not available for the use in the current study, chlorophyll-a (*Chl-a*), which has a similar index to PON, was selected as the objective variable, even though PON would have been a more reliable indicator. Suzuki (2008 and 2009) also used *Chl-a* as the index;

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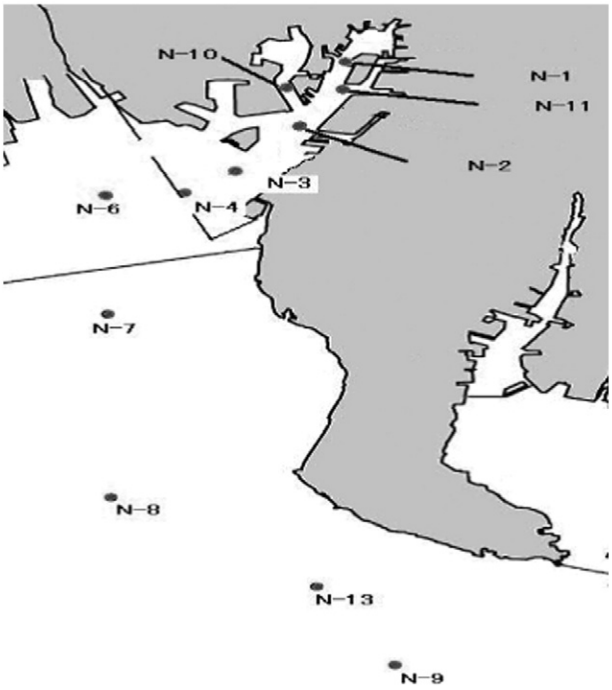

Fig. 1. Location of sampling sites in the inner area of Ise Bay, N-1–4, 6–10, 11,13.

hence the data of the current study could be compared with that previously obtained from Tokyo Bay.

The red tide index was used as the objective variable in this study, while the measurement item *Chl-a* was used as the objective variable after case analysis, due to its regular use as the standard for the red tide index.

2.2. Case analysis of cells

The life-cycle of microorganisms, including microalgae and bacteria, includes an induction phase, a logarithmic growth phase, a non-proliferation phase, and a non-active proliferation phase. In this chapter, a case analysis of data was conducted using both *Chl-a* and pheo-pigments, the degradation products of microalgae and bacteria. However, the induction phase of these microorganisms falls in the period when red tides do not occur, and the time span of the logarithmic growth phase is very short. In addition, in the case study of Tokyo Bay, Suzuki (2008) found that the contribution rate is high and stable when using data from the non-active proliferation phase in the model.

Thus, it was considered appropriate to prepare a model using data from a period that had no red tide (i.e., a non-active proliferation phase containing a phytomass background) to understand the trend of red tides. The current study followed the index used by Suzuki (2008), which was based on the proportion of *Chl-a* and pheo-pigments (1 or higher for the active proliferation phase and 0–0.9 for the non-active proliferation phase). Of the 1576 total datapoints collected from 1995 to 2006, the database for the non-active proliferation phase included 402 points.

2.3. Method

The best fitted multiple regression equation was determined using the following method.

1) The following items were excluded from the base items for multiple regression analysis; the items included deficit data, physically meaningless items, and items which do not show normal distribution after transformation.
2) In consequence, the following seven items were selected; air temperature(Temp.), water temperature(W.Temp.), pH, dissolved oxygen(DO), total nitrogen (T-N), total phosphorus (T-P) and salinity (Sal.).
3) A total of 127 multiple regression models were generated using all possible combinations of the seven variables. These were narrowed down by step-wise method (Kimiyama, 2004) with a threshold criteria of $\alpha = 0.15$.
4) The model for multiple regression analysis was obtained using a combination of five variables; T-N, pH, DO, Temp., and T-P.
5) The explanatory variable in the selected model indicated that VIF was <10. This result provided undisputed evidence that multicollinearity does not occur in this model.
6) From the statistical precondition result (later description: Figs. 2–4), I confirmed that this model was acceptable.

The electronic database containing 226 points for the non-active proliferation period for 2001–2006 was separated into two parts, with October 2002 serving as the divide before and after water regulation. Hence, 49 and 177 datapoints were available before and after regulation, respectively. The transition of the contribution rate in the multiple regression equation, using the red tide index *Chl-a* as the objective variable in both datasets, validated a change in the red tide index

Table 1
List of survey items for water quality measurement of Ise Bay.

Weather	W.d. (direction m-digitizing)	Temperature (Temp.) (°C)	Water temperature (W.Temp.) (°C)
Flow (m^3/s)	Depth (m)	Total depth (m)	Color
Odor	Transparency (m)	Conductivity (m)	High water time (t·s)
Low water time(t·s)	Wind direction	Wind velocity (m)	DO (mg/L)
Water color	pH	COD (mg/L)	SS (mg/L)
n-hexane (mg/L)	T-N (mg/L)	T-P (mg/L)	T-Zn (mg/L)
Cd (mg/L)	Cyanide (mg/L)	Zn (mg/L)	Cr (VI) (mg/L)
As (mg/L)	Ag (mg/L)	Methylmercury (mg/L)	PCB (mg/L)
Dichloromethane (mg/L)	CCl_4 (mg/L)	1,2-Dichloroethane (mg/L)	1,1-Dichloroethene (mg/L)
Cis-1,2-dichloromethylene (mg/L)	1,1-Trichloroethane (mg/L)	1,1,2-Trichloroethane (mg/L)	Trichloroethylene (mg/L)
Tetrachloroethylene (mg/L)	1,3-Dichloropropene (mg/L)	Thiram (mg/L)	Simazine (mg/L)
Thiobencarb (mg/L)	Benzene (mg/L)	Selenium (mg/L)	Cd (mg/L)
NO_2-N (mg/L)	F (mg/L)	B (mg/L)	Phenols (mg/L)
Cu (mg/L)	Fe(mg/L)	Mn (mg/L)	Cr (mg/L)
Zn (mg/L)	Trihalomethane (mg/L)	Chloroform (mg/L)	Bromodichloromethane (mg/L)
1,2-Dichloroethane (mg/L)	Tribromomethane (mg/L)	NH_4-N (mg/L)	MBAS (mg/L)
NO_3-N (mg/L)	O-N (mg/L)	DTN (mg/L)	DON (mg/L)
PO_4-P (mg/L)	Electrical conductivity (A·V-1·m-1)	Cl^- (mg/L)	Sal.
EPN (mg/L)	*Chl-a* (mg/L)	Pheopigment (mg/L)	Coliform group bacteria (MPN/100 mL)