A Case Study Report on Assessment of Eutrophication Status in Jiaozhou Bay, China

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Contents

1. Introduction and Objectives

Anthropogenic activities, such as the usage of fertilizer and discharge of human waste, have accelerated the fluxes of nutrients to coastal aquatic systems (Nixon, 1995). The Northwest Pacific region (parts of China, Japan, Korea and southeast Russia) is one of the most densely populated areas in the world and its coastal systems are also subject to significant human-induced nutrients modifications (NOWPAP CEARAC Report 2011).

Rapid development of Chinese economy in recent decades focused on manufacturing and urbanization, much of which is located in the coastal zone. This has resulted in a substantial increase in nutrient loads into estuaries and coastal areas through river flows, thereby stimulating phytoplankton growth (Shen, 2001). Nutrients loads have resulted in nutrient enrichment problems in coastal waters, including high nutrient concentrations. For dissolved inorganic nitrogen (DIN, summation of nitrate, nitrite, ammonia) and dissolved inorganic phosphorus (DIP), the benchmark of Class 4 according to the China's National Seawater Quality Standard (NSQS, 1997) were 0.5 mg/L and 0.045 mg/L, respectively. In the Bohai Sea, from 2007 to 2009, monitored DIN in most part of Bohai Bay and Laizhou Bay exceeded 0.5 mg/L, while monitored DIP in a major part of these two bays exceeded 0.045 mg/L.

Red tides and large-scale hypoxic conditions were some of the other eutrophication symptoms that took place in China coastal seas. In recent years, the occurrences of red tide events have become frequent in China coastal lines (Huang, 2003). Each year, more than 65 red tide events were observed in Chinese national marine waters from 2006 to 2009 (State Oceanic Administration of China, 2006 to 2009). An issue of concern in the Changjiang river estuary is the occurrence of hypoxia in near-bottom waters off the Changjiang estuary and its adjacent coastal waters (Li et al., 2002). Over the last two decades, minimum values of DO in the low oxygen region of the Changjiang Estuary have decreased from 2.85 to 1 mg/L (Xiao et al., 2007).

Since eutrophication has become a main ecological problem in coastal areas in China, the objective of the study is to assess the trophic status of a typical coastal area in NOWPAP region using revised Common Procedure.

1.1 Selection of assessment area

The Jiaozhou Bay, which is located in Qingdao, is a semi-enclosed bay in the North Yellow Sea of China. It is characterized by temperate waters: ice-free for all-year round and a temperature range of 2℃ (lowest) in winter to 28℃ (highest) in summer. The salinity in Jiaozhou Bay is around 32 psu. A few rivers flow into the bay and the discharge is about $2\times10^9 m^3/a$. Jiaozhou Bay covers an area of about 390 km^2 with an average depth of 7 m and is connected to the Yellow Sea via a narrow opening (2.5 km). The narrow mouth has led to an average water exchange time of about 52 days in Jiaozhou Bay.

In this case study, the Jiaozhou Bay was selected to be a target area for eutrophication assessment mainly because it is within the geographic scope of NOWPAP. Furthermore, the screening procedure applied to Jiaozhou Bay has indicated that high frequency of red tide events were recorded in inner Jiaozhou Bay and its adjacent coastal waters in the past three years. The Jiaozhou Bay ecosystem is a very typical marine ecosystem in China since it is impacted to a large extent by human activities such as port, aquaculture and riverine nutrient input. The effects of human activities on ecosystem are very significant. Jiaozhou Bay is fed by several rivers and among these, Haipo river takes the highest DIN load into the bay (about 3024 t in 2001, and accounts for 39% of the total DIN load into the bay), followed by the Dagu river (about 2295 t/a, Zhang and Sun, 2007).

On the whole, Jiaozhou Bay is a typical water body for eutrophication assessment in North Yellow Sea.

Fig. 1 The geographical location of the Jiaozhou Bay

1.2 Collection of relevant information

1.2.1 Information on the assessment area that is necessary and relevant to eutrophication assessment

i) Environmental monitoring/survey data:

The data on red tides or harmful algal blooms in Jiaozhou Bay was obtained from Bulletin of Marine Environmental Quality of Qingdao, Bulletin of Marine Environmental Quality of Shandong Province, and via some published researches in the Jiaozhou Bay (Wu et al., 2005). Bulletin of Marine Environmental Quality of China was also referred as supplemental information. Red tide data were collected from this area over the past 13 years (from 1997 to 2009). Whenever a red tide event occurred, the location was recorded using a global positioning system (GPS) and a sample was collected and analyzed immediately on board the monitoring vessel to identify the dominant algal species. Each record contained the location, area, start and finish time of the bloom, dominant species and the cellular abundance of the dominant species.

The nutrients, Chl-a, DO, COD, etc. were collected from the Jiaozhou Bay Marine Ecosystem Research Station, which implemented a long-term monitoring activities in

Jiaozhou Bay. Thirty years of data (form 1997 to 2009) were obtained from the monitoring station database and its publications (Sun et al., 2010; Sun et al., 2011).

ii) Pollutant sources:

Pollutant sources (e.g. municipal, industrial, agricultural, marine aquaculture, atmospheric deposition) were obtained through published references. Since no long time series pollutant sources were obtained, only pollution data (nutrients load) from riverine sources was considered in the assessment.

iii) Supplementary information:

The supplementary information (e.g. oceanography, meteorology, catchment area, population, wastewater management, fishery status) were obtained through published references. These information was used to interpret the assessment results.

iv) Information on methods of field measurement and chemical analysis:

At least four cruises were carried out annually in February, May, August and November in the Jiaozhou Bay, where 12 sampling sites were located (Figure 2). These sampling sites were selected according to their geographical location (e.g., some were located near the Sewage Treatment Plant, while some were near the aquaculture area). The four surveys were conducted from inner Jiaozhou Bay to the mouth and eventually, to the outside of Jiaozhou Bay. Indicators such as T, salinity, pH, DO, COD, nutrients (TN, TP, DIN and DIP), Chl-a, etc. in these 12 sites were monitored.

Fig.2 The sampling sites in Jiaozhou Bay

The methods of field measurement and chemical analysis for water quality and biological parameters were all standard methods specified by the Marine monitoring specification (GB 17378.4 - 1998), the Marine investigation specification (GB/T 12763.4 - 1991) and the National Standard (GB 13191 - 1991) and some published papers (Strickland et al., 1972).

1.2.2 Eutrophication related information/data from organizations:

i) Organizations that monitor water quality:

Organizations that monitor water quality for environmental conservation purposes includes: State Oceanic Administration (SOA) of China, Ocean university of China (located in Qingdao) and Jiaozhou Bay Marine Ecosystem Research Station, which is affiliated with the Chinese Academy of Sciences. Among these organizations, the Jiaozhou Bay Marine Ecosystem Research Station carried out a regular monitoring activity at a monitoring frequency of 4 – 12 times per year.

ii) Organizations that monitor harmful algal blooms:

Organizations that monitor HABs for protection of fishery resources includes: State Oceanic Administration, Qingdao Ocean and fishery Administration and North China

Sea Branch of SOA. Qingdao Ocean and fishery Administration and North China Sea Branch are regional-level monitoring stations for HABs which are affiliated with SOA and are part of the whole monitoring network for China coastal areas. The data were reported annually via Bulletin of Marine Environmental Quality and Bulletin of Marine Disasters, and survey frequency was not reported.

iii) Organizations that have supporting environmental information:

Organizations that have supporting environmental information (e.g. oceanographic data, meteorological data) includes: Jiaozhou Bay Marine Ecosystem Research Station. This organization monitored meteorological data on the coastal area of Jiaozhou Bay and the data were stored in the Jiaozhou Bay Marine Ecosystem Research Station Database.

The collected environmental monitoring/survey information are presented in Table1.

1.3 Selection of assessment parameters

1.3.1 Categorization of monitored parameters

From the selected environmental monitoring programs, all eutrophication-related parameters that are monitored within the assessment area were categorized into one of the following 4 assessment categories (Table 2):

i) Category I Parameters that indicate degree of nutrient enrichment

ii) Category II Parameters that indicate direct effects of nutrient enrichment

iii) Category III Parameters that indicate indirect effects of nutrient enrichment

iv) Category IV Parameters that indicate other possible effects of nutrient enrichment

1.3.2 Selection of assessment parameters for each assessment category

Considering assessment parameters that are recommended by the assessment procedure on the basis of their data reliability and continuity, assessment parameters were selected as follows (See also Table 2):

i) Category I: Parameters that indicate degree of nutrient enrichment include riverine input of DIN and DIP, TN and TP concentrations, annual mean DIN concentration, annual mean DIP concentration and annual mean DIN/DIP ratio. For all parameters of nutrients, surface data were used. Winter DIN or DIP was recommended by revised NOWPAP Common Procedure to assess the nutrient enrichment problems, for the simple reason that Biomass and uptake of nutrients by phytoplankton was the lowest and nutrient concentrations the highest in winter. Winter nutrient concentrations could reflect the nutrient pollutions or nutrient pressures without considering the impact (e.g. uptake) of phytoplankton biomass. But in Jiaozhou Bay, winter nutrient concentrations were the lowest in the four seasons according to monitoring data, and the nutrient enrichment problems could be underrepresented with the usage of only winter DIN. Therefore, in this case study, average values of four cruises data was used as annual mean DIN and DIP concentrations to substitute winter DIN and DIP.

ii) Category II: Parameters that indicate direct effects of nutrient enrichment, including maximum of Chlorophyll a (surface data), mean of Chlorophyll a (surface data) and red tide events (both *Diatom sp.* and *Flagellate sp.*)(See also Table 2).

iii) Category III: Parameters that indicate indirect effects of nutrient enrichment, including bottom DO, surface COD and fish kill incidents.

iv) Category IV: Parameters that indicate other possible effects of nutrient enrichment, including red tide events (*Noctiluca sp.* and *Mesodinium sp.*), shell fish poisoning incidents. *Mesodinium sp.* was also considered besides *Noctiluca sp.* for the simple reason that *Mesodinium sp.* was frequently observed in the bay in the past few years and the occurrence of *Mesodinium sp.* red tides events also were able to reflect the eutrophication effects in this area.

Table1 The collected environmental monitoring/survey information

Survey area	Governing organization	Survey title	Aim	Survey period	Main survey parameters	Survey frequency
China coastal water	State Oceanic Administration	Bulletin of Marine Environmental Quality of China	Survey and assessment of marine environmental quality	1990~2009	COD, nutrient, petroleum, heavy metals, PCB, BHC, DDT, diversity index, pollutant sources, red tides events	Not reported
China coastal water	State Oceanic Administration	Bulletin of Marine disaster of China	Survey and assessment of marine disaster	1990~2009	red tides events	Not reported
Jiaozhou Bay	Jiaozhou Bay Marine Ecosystem Research Station	Atlas of long-term changes in the Jiaozhou Bay ecosystem	Survey and assessment of marine environmental quality	1997~2009	COD, nutrient, petroleum, heavy metals, PCB, BHC, DDT, diversity index, pollutant sources, red tides	4-12 times/year
Jiaozhou Bay	Jiaozhou Bay Marine Ecosystem Research Station	Lakes, wetland and Bays ecosystem dataset of China: Jiaozhou Bay marine ecosystem	Survey and assessment of marine environmental quality	2001-2006	COD, nutrient, petroleum, heavy metals, PCB, BHC, DDT, diversity index, pollutant sources, red tides	4-12 times/year
Riverine input of DIN and DIP	Published papers	Published papers	Publishing of Riverine input of DIN and DIP	1980s.1999, 2001, 2005, 2008	DIN flux and DIP flux	Not reported

Table 2 Assessment parameters used in the Jiaozhou Bay

Category	Parameters recommended	Parameters in this report
Category I	Riverine input of TN, TP	Riverine input of DIN, DIP
	Annual mean TN, TP	√
	Winter DIN, DIP concentration	Annual mean DIN, DIP
	Winter DIN/DIP ratio	Annual mean DIN/DIP ratio
Category II	Annual maximum of Chlorophyll a	√
	Annual mean of Chlorophyll a	√
	Red tide events *(Diatom sp.*)	√
	Red tide events (*Flagellate sp.*)	√
Category III	Bottom annual mean DO	√
	Annual mean COD	√
	Fish kill incidents	√
Category IV	Red tide events (*Noctiluca sp.*)	*Mesodinium sp.* also considered
	Shell fish poisoning incidents	√

1.3.3 Setting subareas

According to the differences in the geographical characteristics of Jiaozhou Bay and the differences in water exchange capability (Liu, 2004), three sub-areas were divided. The sub-areas were demonstrated in Figure 3 in red polygon. Sub-area A represents inner Jiaozhou Bay, which has an average water exchange time of 50 days and was influenced by large amount of riverine nutrient load. Sub-area B points to the mouth of Jiaozhou Bay, which includes the narrow opening and has a shorter water exchange time of about 10 days. And sub-area C is the outside of the Jiaozhou Bay and is the near shore area of North Yellow Sea. In fact, although sub-area C did not belong to Jiaozhou Bay, it is adjacent to Jiaozhou Bay and thus, the eutrophication status was also assessed to fully recognize the trophic status of Jiaozhou Bay. Sampling sites 1 to 7 are located in sub-area A, while sites 8, 9 are located in sub-area B and sites 10, 12, 13 are located in sub-area C.

Fig. 3 Sub-areas of Jiaozhou Bay

1.3.4 Setting of assessment period

In order to assess the trophic status of the Jiaozhou Bay through both current status and trend, long-term monitoring data should be used in the assessment (At least more than 10 years recommended by the revised Common Procedure). In the Jiaozhou Bay case study, 13 years of data was set as the assessment period in accordance with the availability of reliable data. For bottom DO, only 6 years of data were collected and used in the assessment for current status and trend.

2. Data processing and Preparation of data sets

Concentration values of each assessment parameters were measured using commonly accepted methods. DIN concentration was based on the summation of ammonia, nitrite and nitrate (NH_4, NO_2 and NO_3). The evaluation concentrations used have been the annual mean values for DIN, DIP, Chlorophyll-a, DO (bottom) and COD. Also, annual maximum of Chlorophyll-a was used. The red tide data were represented by red tide events with a unit of times/year or times/3 years. The riverine DIN load and DIP load were obtained through published papers in which the riverine DIN and DIP load were calculated through the addition of DIN and DIP flux from different rivers.

With the exception of maximum of Chlorophyll a and red tide events, all parameters are based on annual mean values. The annual mean values were obtained by averaging the values of each parameter monitored in four cruises (February, May, August and November) of a year. The maximum of Chlorophyll a was the maximum value monitored in the four seasonal cruises. The annual mean dissolved oxygen was assessed for bottom concentrations.

3. Setting of assessment criteria

3.1 Setting of identification criteria of the assessment data

Eutrophication status based on each assessment parameter was assessed by identifying its current status and/or trend. Identification tools applied to each assessment parameter in Jiaozhou Bay were listed below (Table 3). The parameters of annual mean DIN, DIP, DIN/DIP ratio, COD, Chla and DO were identified by comparison and trend. The parameters of red tide events, shell fish poisoning incidents and fish kill incidents were identified by occurrence and trend. Comparison and occurrence were identified based on data in recent 3 years (2007-2009), while trend was analyzed based on data in all the years. Trend was identified by non-parametric Mann-Kendall test. If the data was not enough (>10), the linear regression was used for trend analysis.

Table 3 Identification tools applied to each assessment parameter in Jiaozhou Bay

Category	Assessment parameter	Units	Assessment value	Identification tools		
				Comparison	Occurrence	Trend
I	Riverine DIN, DIP	t/year	Annual			√
	TN, TP	μg/L or μM	Annual mean	√		√
	DIN, DIP	μg/L or μM	Annual mean	√		√
	DIN/DIP ratio	-	Annual mean	√		√
II	Maximum of Chlorophyll a	μg/L	Annual maximum	√		√
	Red tide events (*Diatom sp.* and *Flagellate sp.*)	time/3 years	Annual		√	√
	Mean of Chl-a	μg/	Annual mean	√		√

III	DO (Bottom)	mg/L	Annual mean	√		√
	COD	mg/L	Annual mean	√		√
	Fish kill incidents	time/3 years	Annual occurrence		√	√
IV	Red tide events (*Noctiluca sp.* and *Mesodinium sp.*)	time/3 years	Annual		√	√
	Shellfish poisoning incidents	time/3 years	Annual		√	√

3.2 Setting of classification criteria of the assessment parameters

According to the National Sea Water Quality Standard of China (NSQS, 1997), the thresholds and ranges of water quality parameters (DIN, DIP and COD) were presented in Table 4. In this study, the NSQS Class II was selected as criteria for each parameter for the reason that Class II was suitable for aquaculture water bodies. Jiaozhou Bay is an important Bay for shell fish aquaculture and a fairly large part of Jiaozhou Bay is covered by aquaculture farms. For TN and TP, no threshold values were assigned in NSQS (1997), and these criteria was set based on Japan Environmental water quality standard Type III and Fishery Type 2. For Chl-a and DO, several studies on Jiaozhou Bay and Chinese coastal eutrophication assessment (Chen et al., 2007; Yao et al., 2007; Su et al., 2008; Xia et al., 2012) and some international studies (Bricker et al., 2003) were referred. So 0.3 mg l^{-1} for DIN (21.4 μM), 0.03 mg l^{-1} for DIP (0.97μM), 0.6 mg l^{-1} for TN, 0.05 mg l^{-1} for TP, 20μg l^{-1} for maximum of Chl-a, 5 μg l^{-1} for mean of Chl-*a*, 2 mg l^{-1} for bottom DO, and 3 mg l^{-1} for COD were used as criteria of the assessment. As for DIN/DIP ratio, the Redfield value 16 was used in this study (Table 5).

Red tide events, fish kill incidents and shell fish poisoning incidents were rated as High or Low based on the occurrence of one or more incident, or no incident in the recent three years, respectively. This criteria was based on CEARAC Report in 2011.

Table 4 Thresholds of assessment parameters in the National Sea Water Quality Standard of China (NSQS, 1997)

Parameters	Class			
	I	II	III	Ⅳ
DIN(mg l^{-1})	0.2	0.3	0.4	0.5
DIP(mg l^{-1})	0.015	0.03	0.03	0.045
COD(mg l^{-1})	2	3	4	5

Table 5 Reference concentrations used in this study

Category	Parameters	Reference concentrations	References
I	TN	0.6 mg l^{-1} (42.9 μM)	Japan Fishery type 2
	TP	0.05 mg l^{-1} (1.61μM)	Japan Fishery type 2
	DIN	0.3 mg l^{-1}(21.4 μM)	NSQS Class II
	DIP	0.03 mg l^{-1}(0.97μM)	NSQS Class II
	DIN/DIP ratio	16	Redfield value
II	maximum of Chlorophyll a	20μg l^{-1}	Bricker et al., 2003
	mean of Chl-a	5 μg l^{-1}	Yao et al., 2007; Xia et al., 2012
	Red tide events (*Diatom sp.*)	1 event/3 years	CEARAC Report 2011
	Red tide events (*Flagellate sp.*)	1 event/3 years	CEARAC Report 2011
III	DO (bottom)	2 mg l^{-1}	Bricker et al., 2003
	COD	3 mg l^{-1}	NSQS Class II
	Fish kill incidents	1 event/3 years	CEARAC Report 2011
IV	Red tide events (*Noctiluca sp.*)	3 events/3 years	CEARAC Report 2011
	Red tide events (*Mesodinium sp.*)	3 events/3 years	CEARAC Report 2011
	Shell fish poisoning incident	1 event/3 years	CEARAC Report 2011

4. Assessment process and results

4.1 Assessment categories

Eutrophication assessment of Jiaozhou Bay was based on the data from the 12 sampling sites that were evenly distributed in Jiaozhou Bay. Each parameter of each sampling site in the study area was analyzed to assess the eutrophication status.

4.1.1 Assessment of Category I

Riverine input of DIN，DIP in the late 1980s, 1999, 2001, 2005 and 2008 were obtained through published research papers. Only three years of riverine input of DIP were collected to reflect changes in nutrient load. Since long-term monitoring data of riverine input of TN and TP cannot be collected, riverine inputs of DIN and DIP were used as indicators to reflect anthropogenic pressures in this study (Zhang and Sun, 2007; Wang, 2009). Riverine DIN loading in the recent twenty years showed an increasing trend and DIP loading in recent 10 years also showed an increasing trend, indicating increasing anthropogenic pressures to the Jiaozhou Bay. Riverine input of DIN and DIP was presented in Figure 4. The TN concentrations in most sites in recent 3 years were higher than reference values in sub-area A and C, while lower than reference in sub-area B. The TP concentrations in most sites in recent 3 years were all higher than reference values in the three sub-areas. In all sub-areas, Both TN and TP showed no obvious trend between 1997 and 2009 according to Mann-Kendall test. The DIN concentrations in sub-area A were higher than reference concentration in the recent 3 years and showed an increasing trend for all sampling sites from the years 1997 to 2009. On the contrary, the DIN concentrations in sub-area B and C were lower than reference values in the recent 3 years but showed no obvious trend according to the Mann-Kendall test. DIP concentrations in most sampling sites were higher than reference concentration in the recent 3 years and an increasing trend was observed in all sub-areas. The DIP concentrations in Jiaozhou Bay increased rapidly in recent years. At the same time, a decrease of DIN/DIP ratio was observed. Although decreasing trend observed, for most sampling sites in sub-area A, DIN/DIP ratio was higher than the Redfield value (a ratio of 16) in recent 3 years. The decreasing DIN/DIP ratio was also observed in the other two sub-areas. Annual mean concentrations of TN, TP, DIN, DIP and ratio of DIN/DIP in the recent 13 years were presented in Figures 5 to 9.

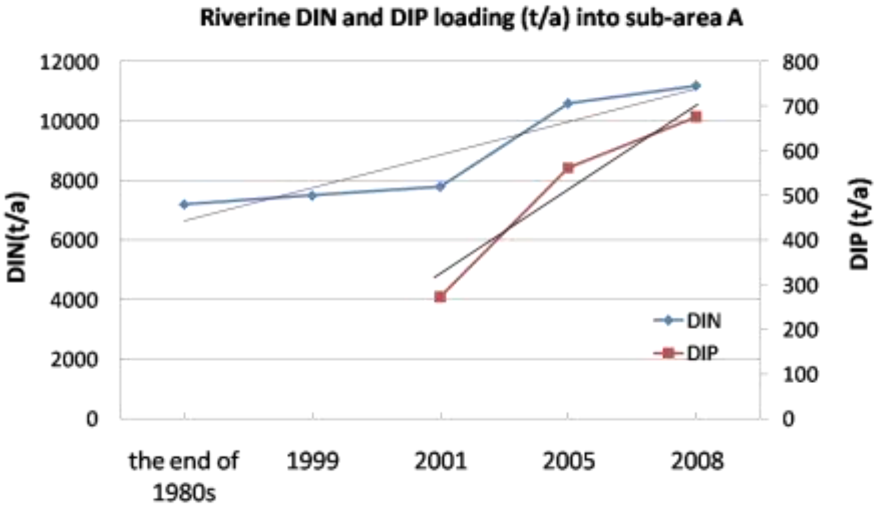


Figure4. Riverine DIN and DIP load in recent twenty years

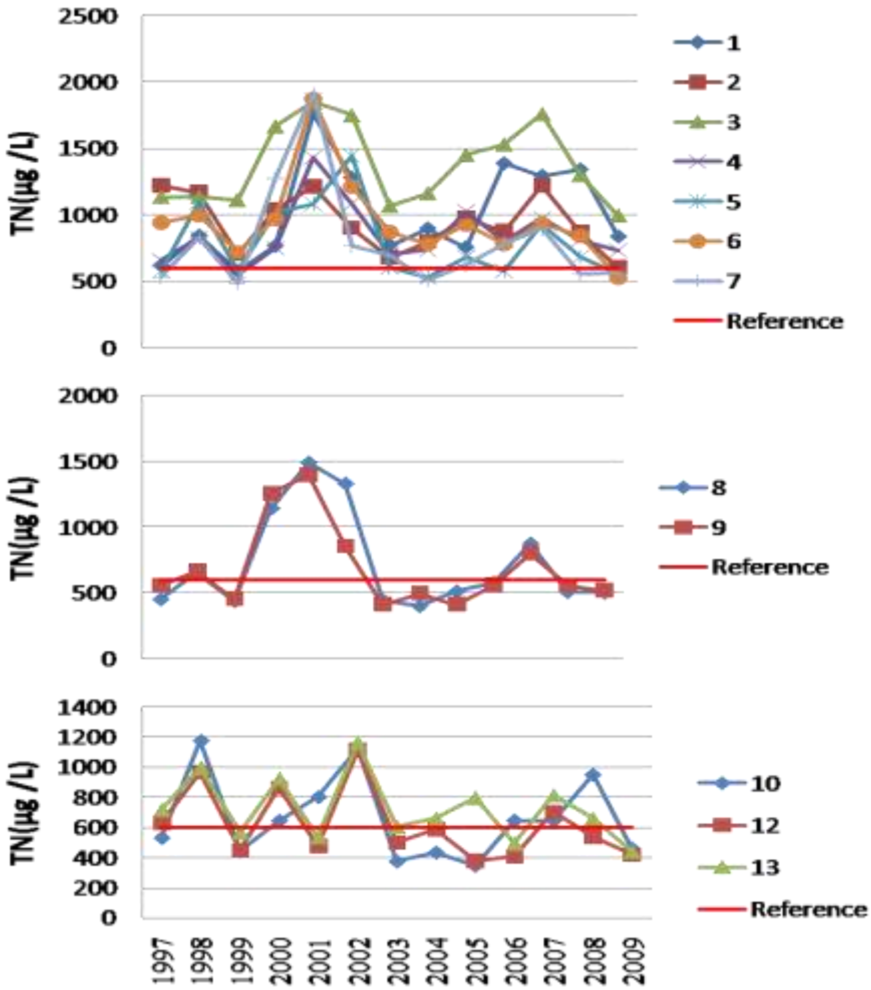


Figure 5 Long-term trend of annual mean TN concentration from 1997 to 2009 (Three sub-areas)

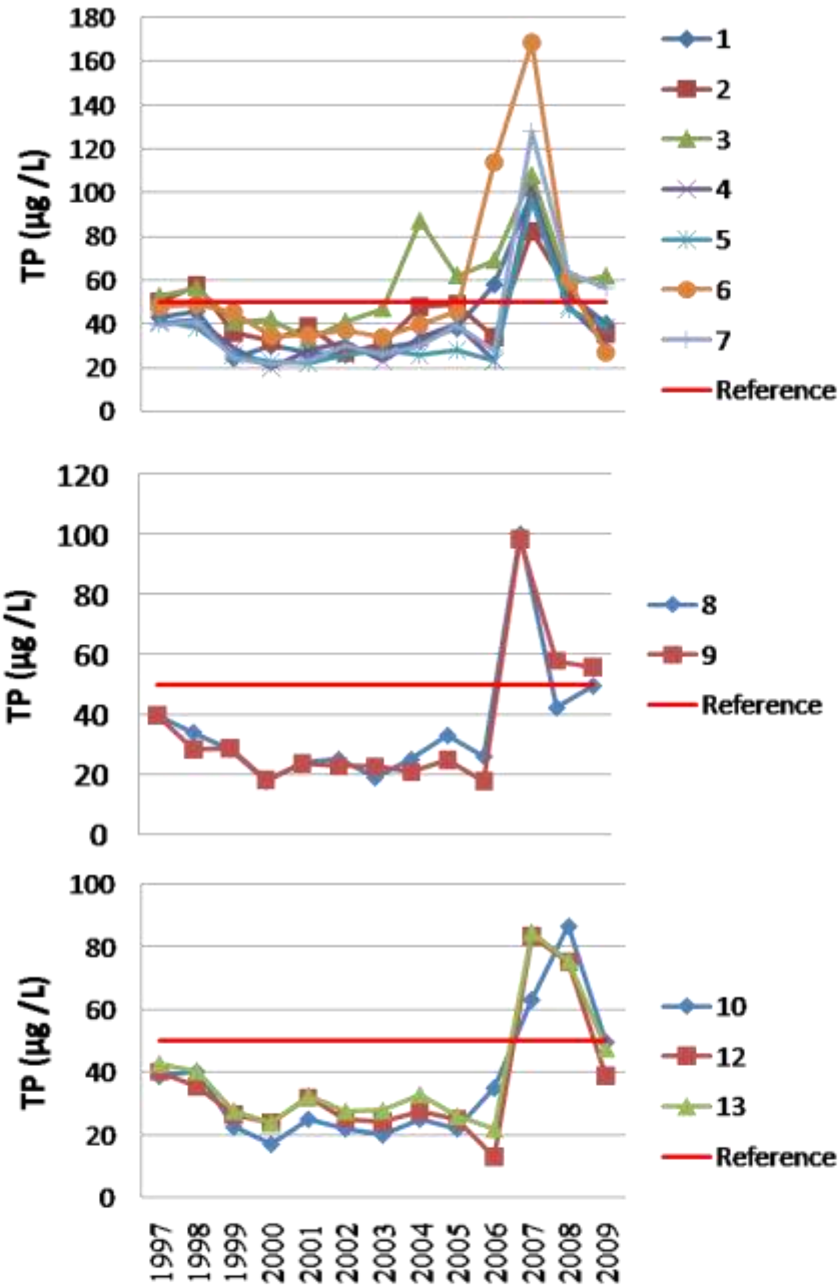


Figure 6 Long-term trend of annual mean TP concentration from 1997 to 2009 (Three sub-areas)

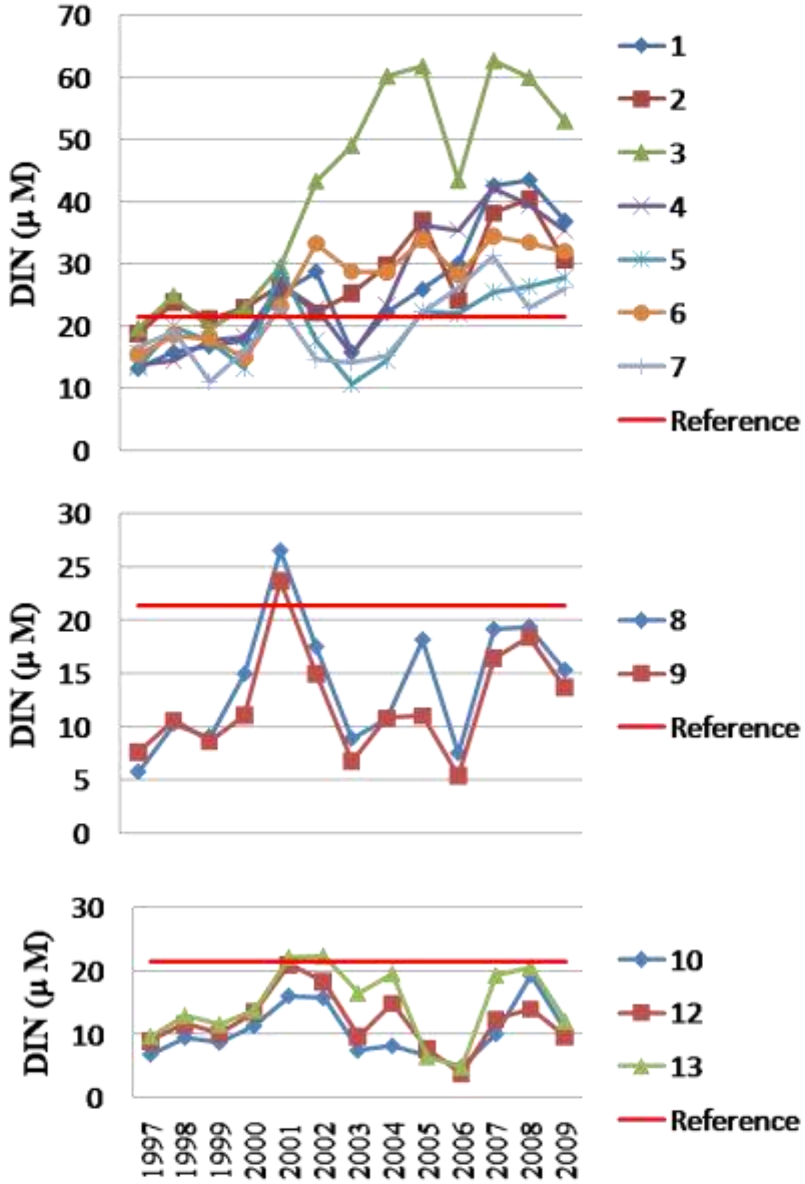


Figure7. Long-term trend of annual mean DIN concentration from 1997 to 2009 (Three sub-areas)

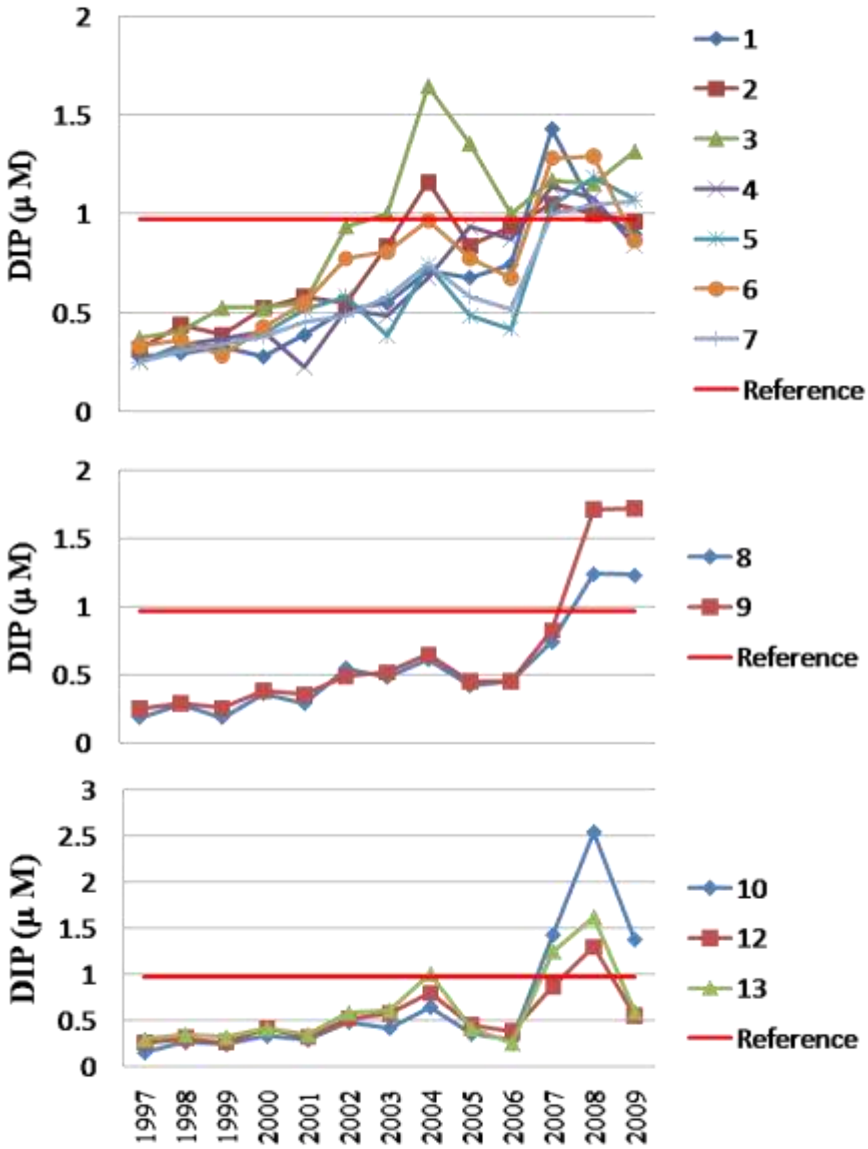


Figure8. Long-term trend of annual mean DIP concentration from 1997 to 2009 (Three sub-areas)

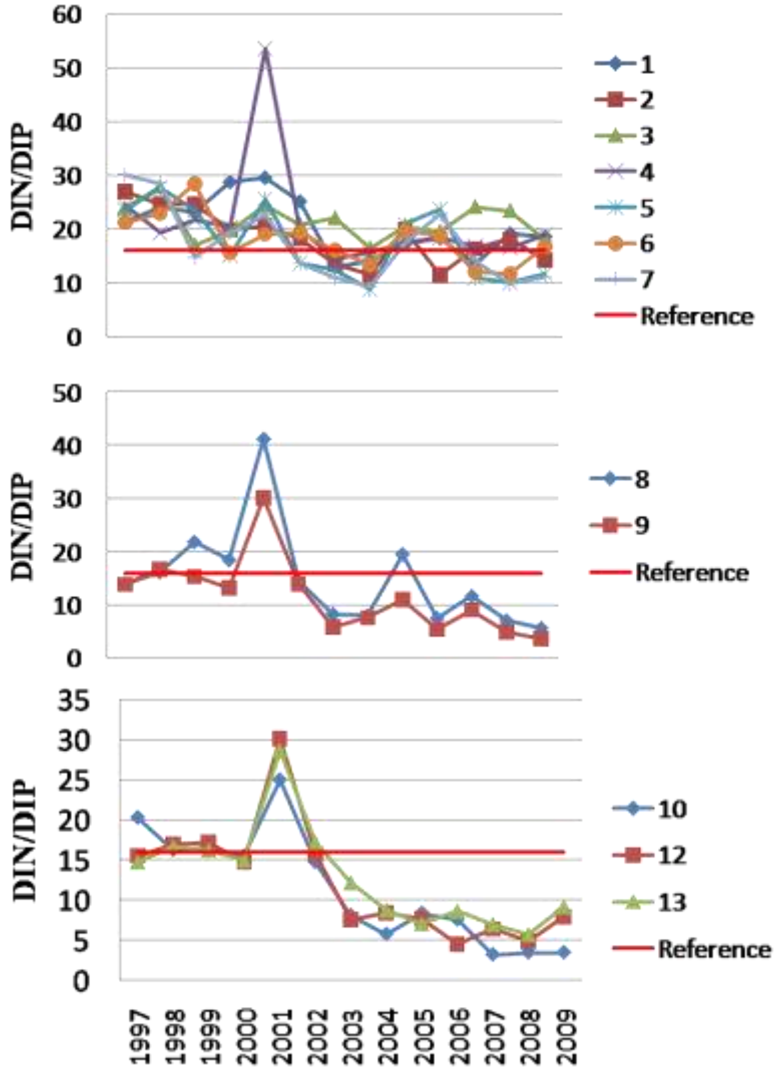


Figure9. Long-term trend of annual mean DIN/DIP ratio from 1997 to 2009 (Three sub-areas)

Results of liner regression and non-parametric Mann-Kendall test were presented in Table 6.

Table 6 Results of non-parametric Mann-Kendall test in all sampling sites

Parameters	Ranges of z value	p value	Overall trend
Riverine input DIN, DIP	liner regression	-	Increasing trend
TN (Sub-area A)	-1.5206 to 1.4032	All > 0.05	No trend
TN (Sub-area B)	-0.183 to – 0.4889	All > 0.05	No trend
TN (Sub-area C)	-1.159 to - 0.2440	All > 0.05	No trend

TP (Sub-area A)	0.1830 – 1.6472	Most > 0.05	No trend
TP (Sub-area B)	0.1222 – 1.2225	All > 0.05	No trend
TP (Sub-area C)	0 – 1.2859	All > 0.05	No trend
DIN (Sub-area A)	1.647-3.111	All <0.05	Increasing trend
DIN (Sub-area B)	1.159-1.525	All >0.05	No trend
DIN (Sub-area C)	0.305-0.427	All >0.05	No trend
DIP (Sub-area A)	3.355-3.966	All <0.05	Increasing trend
DIP (Sub-area B)	3.477-3.667	All <0.05	Increasing trend
DIP (Sub-area C)	2.989-3.056	All <0.05	Increasing trend
DIN/DIP ratio (Sub-area A)	-2.623 to -0.798	Most <0.05	Decreasing trend
DIN/DIP ratio (Sub-area B)	-2.989 to -2.379	All <0.05	Decreasing trend
DIN/DIP ratio (Sub-area C)	-3.355 to -2.623	All <0.05	Decreasing trend

4.1.2 Assessment of Category II

Maximum Chl-a, mean of Chl-a and red tide events (*Diatom sp. and Flagellate sp.*) were presented in Figures 10, 11, 12 and 13. In all three sub-areas, Maximum of Chl-a was generally lower than reference concentration in the recent 3 years with no obvious trend. Meanwhile, annual mean of Chl-a was lower than reference value in recent 3 years and again, with no observable trend. Red tide events (*Diatom sp.*) often occurred in sub-area A before the year 2004 and no events were recorded since then, showing a decreasing trend. Red tides (*Diatom sp.*) in sub-area C began to occur at a high frequency in the recent five years, displaying an increasing trend. One red tide event (*Flagellate sp.*) was recorded only in sub-area A in recent three years. For the mouth of Jiaozhou Bay (Sub-area B), no red tide event was recorded since 1997.

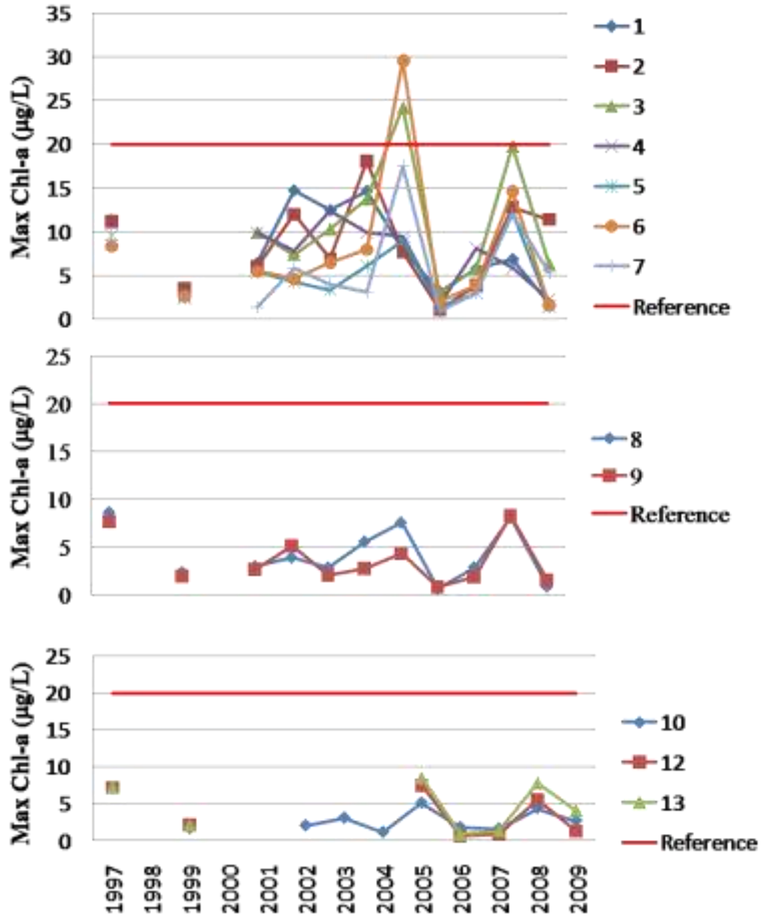


Figure10. Long-term trend of annual maximum Chl-a from 1997 to 2009 (three sub-areas)

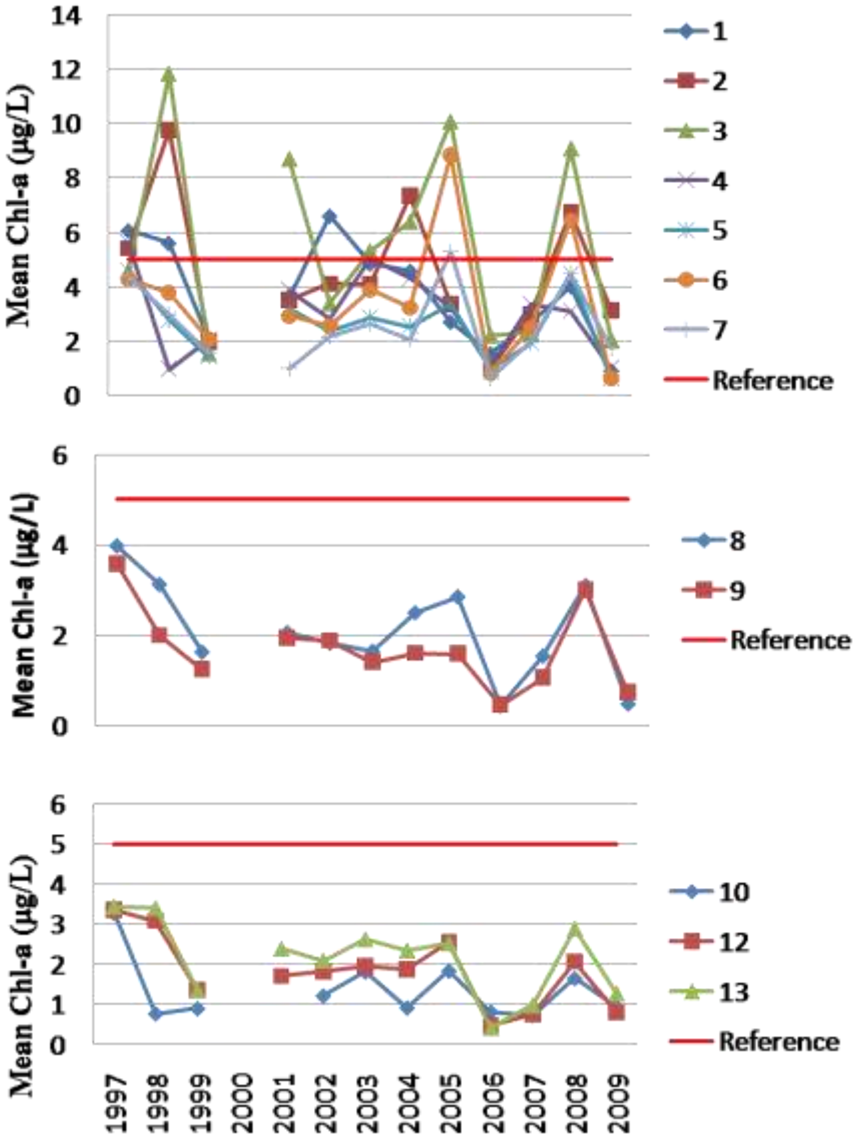
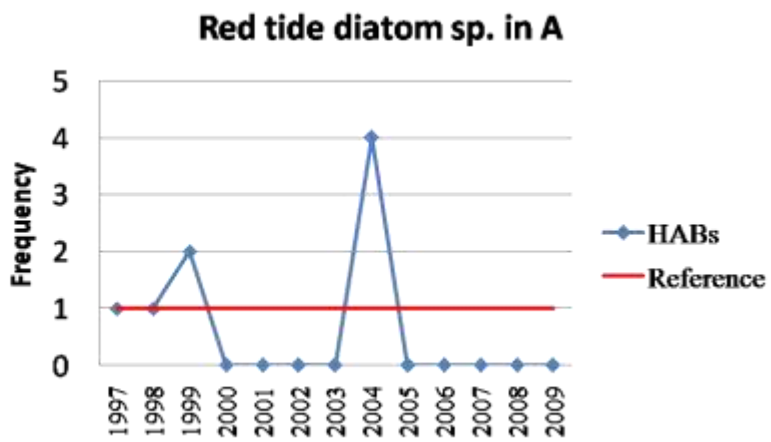


Figure11. Long-term trend of annual mean Chl-a from 1997 to 2009 (three sub-areas)



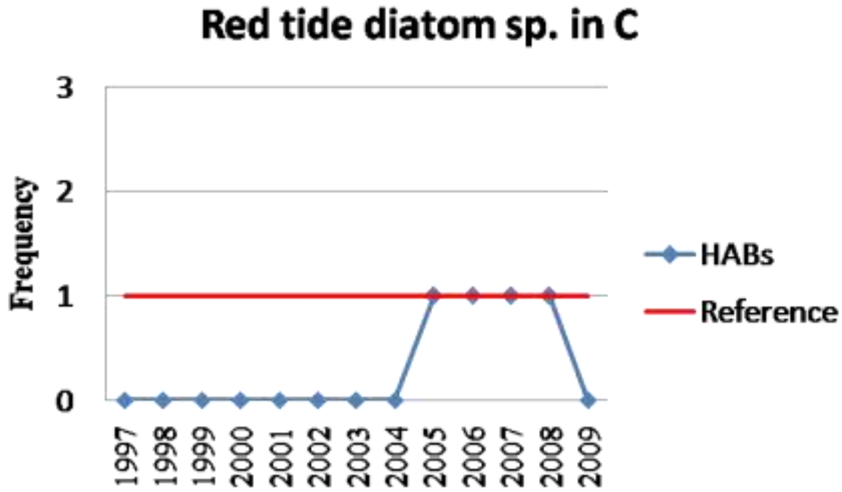


Figure12. Occurrences of red tides (*Diatom sp.*) from 1997 to 2009 in sub-area A and sub-area C

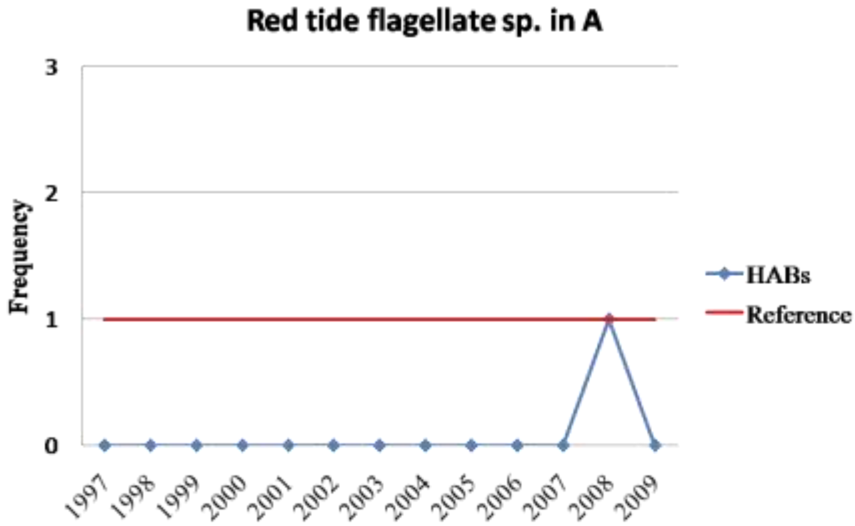


Figure13. Occurrences of red tides (*Flagellate sp.*) in sub-area A

Results of non-parametric Mann-Kendall test was presented in Table 7. Maximum Chl-a and Minimum Chl-a showed no obvious trend. There was a decreasing trend for red tide events in sub-area A and an increasing trend in sub-area C (Table 7). Red tide events (*Flagellate sp.*) in sub-area A showed no trend.

Table 7 Results of non-parametric Mann-Kendall test for Chl-a and red tide events in all sampling sites

Parameters	Ranges of z value	p value	Overall trend
Max Chl-a (Sub-area A)	-1.55to 0.6	All >0.05	No trend
Max Chl-a	-0.77 to -0.31	All >0.05	No trend

(Sub-area B)			
Max Chl-a (Sub-area C)	-0.17	>0.05	No trend
Mean Chl-a (Sub-area A)	-2.12 to -0.48	Most >0.05	No trend
Mean Chl-a (Sub-area B)	-1.98 to -1.44	All >0.05	No trend
Mean Chl-a (Sub-area C)	-1.44 to -0.311	All >0.05	No trend
Red tide events (*Diatom sp*) (A)	-1.38	<0.05	Decreasing trend
Red tide events (*Diatom sp.*) (C)	2.9687	<0.05	Increasing trend
Red tide events (*Flagellate sp.*) (A)	1.2026	>0.05	No trend

4.1.3 Assessment of Category III

The comparison and long term trend for COD, DO (bottom) and fish kill incidents were presented in Figure 14 and 15. In general, COD concentration in Jiaozhou Bay was lower than 3 mg l^{-1} for all sub-areas. COD values in a majority of sites showed no obvious trend in these 13 years in all sub-areas according to non-parametric Mann-Kendall test. Bottom DO concentration was generally higher than 2 mg l^{-1} for all sub-areas in these 6 years. Meanwhile, an increasing trend was observed for bottom DO. There were no fish kill incidents recorded from the year 1997 to 2009.

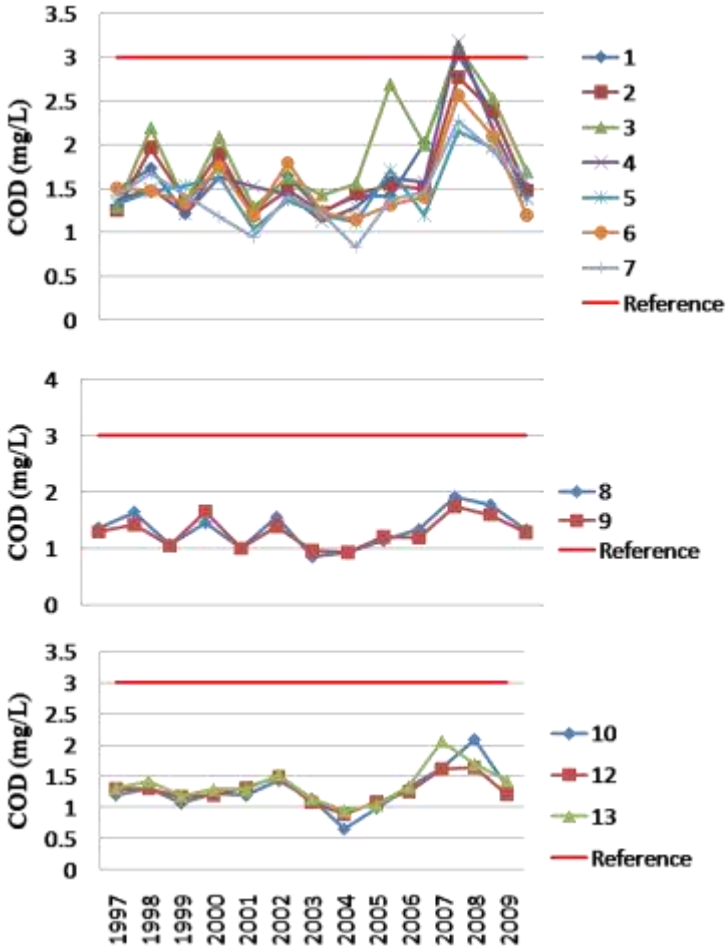


Figure14. Long-term trend of annual mean COD from 1997 to 2009 (three sub-areas)

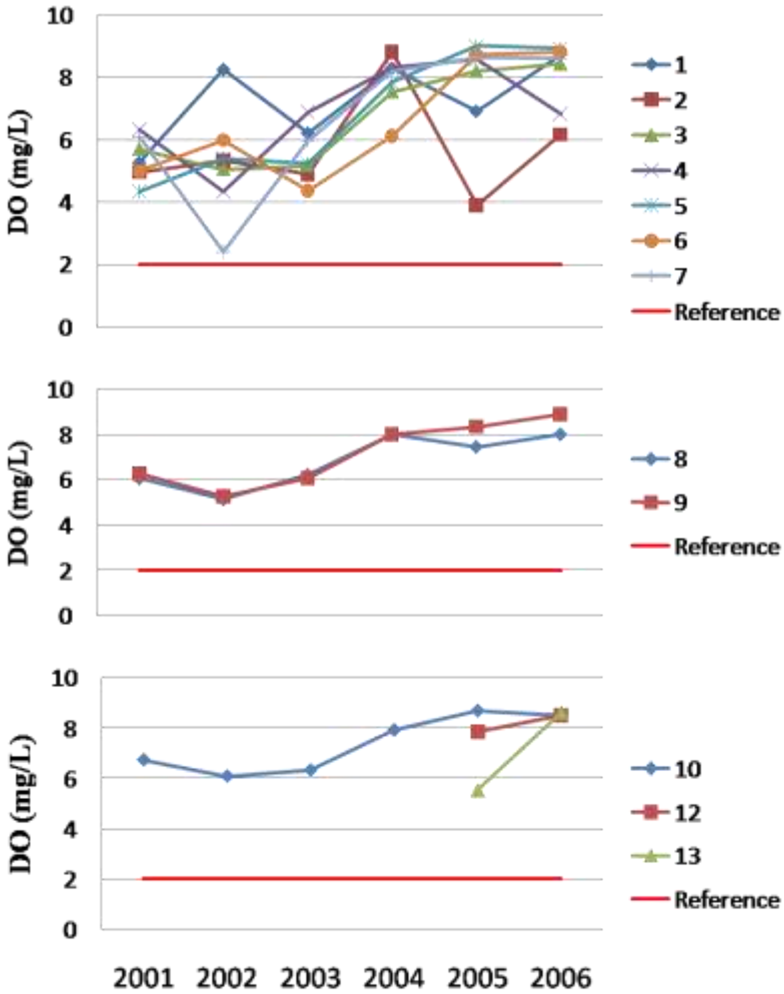


Figure15. Long-term trend of annual mean DO (Bottom) from 1997 to 2009 (three sub-areas)

Results of non-parametric Mann-Kendall test was presented in Table 8.

Table 8 Results of non-parametric Mann-Kendall test for COD and DO in all sampling sites

Parameters	Ranges of z value	p value	Overall trend
Bottom DO	Liner regression	-	Increasing trend
COD (Sub-area A)	0-1.711	Most >0.05	No trend
COD (Sub-area B)	0.06-0.305	All >0.05	No trend
COD (Sub-area C)	0.549-1.15	All >0.05	No trend

4.1.4 Assessment of Category IV

Occurrences of red tide events (*Noctiluca sp. and Mesodinium sp.*) in each sub-area were presented in figure 16.

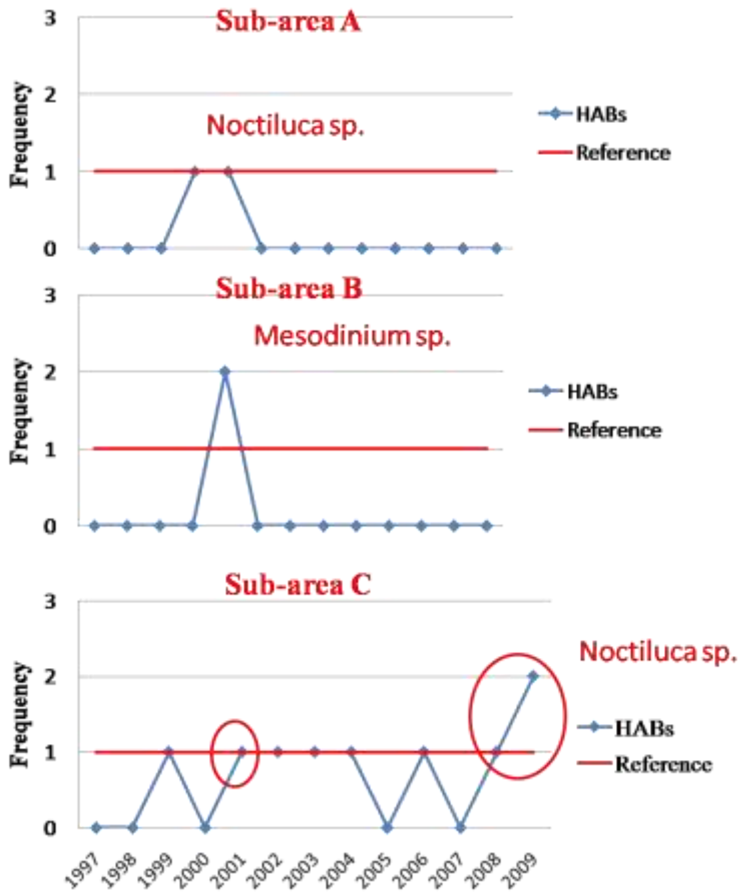


Figure 16. Occurrences of red tide events (*Noctiluca sp. and Mesodinium sp.*, only *Noctiluca sp.* events were indicated in sub-area C)

There was no shell fish poisoning incidents recorded in all sub-areas of Jiaozhou Bay from the year 1997 to 2009, and the shell fish poisoning incident was subsequently rated as low.

Results of non-parametric Mann-Kendall test for red tide (*Noctiluca sp. and Mesodinium sp.*) were listed in table 9.

Table 9 Trend analysis for red tide (Noctiluca sp. and Mesodinium sp.)

Parameters	Ranges of z value	p value	Overall trend
Red-tide (*Noctiluca and Mesodinium sp.*) (A)	-0.8882	>0.05	No trend
Red-tide (*Noctiluca sp. and Mesodinium sp.*) (B)	-0.4009	>0.05	No trend
Red-tide (*Noctiluca sp. and Mesodinium sp.*) (C)	1.5266	>0.05	No trend

4.2 Assessment results

The three sub-areas of Jiaozhou Bay exhibited different eutrophication status for the four assessment categories (category I to IV). This may be attributed to the geographical location, the hydrodynamic conditions and nutrient loads of the sub-areas.

For Category I, Riverine input of DIN and DIP into sub-area A showed increasing trends and was rated as “I”. Both TN and TP in three sub-areas were rated as “High” and “No trend” with the exception that TN in sub-area B was rated as “Low” and “No trend”. The DIN was rated as “High” with an “Increasing trend”. On the contrary, the DIN concentrations in sub-area B and C were lower than reference values in the recent 3 years with “No trend”. DIP was rated as “High” with “Increasing trend” observed in all sub-areas. The DIP concentrations in Jiaozhou Bay increased rapidly in recent years compared to DIN. A relatively mild increasing trend of DIN occurred as a result of a decrease in ammonia effluents (Sun et al., 2011). This has resulted in a decrease of DIN/DIP ratio, but for most sampling sites in sub-area A, DIN/DIP ratio was higher than the Redfield value (a ratio of 16) in the recent 3 years. The decreasing DIN/DIP ratio was also observed in the other two sub-areas. Considering the status of all the parameters, the Category I was rated as “HI” for sub-area A, “LN” for sub-area B and “HN” for sub-area C.

For Category II, in all three sub-areas, Maximum of Chl-a was generally lower than reference concentration in the recent 3 years with no obvious trend observed in 13 years. Meanwhile, annual mean of Chl-a was lower than reference value in the recent 3 years and again, with no observable trend. Both Maximum and Mean Chl-a were rated as “Low” and “No trend”. Red tide events (*Diatom sp.*) often occurred in inner Jiaozhou Bay before the year 2004 and showed a decreasing trend since then. Also in this sub-area, one red tide event (*Flagellate sp.*) was observed in 2008 and was rated as “High” and No trend. For the mouth of Jiaozhou Bay (Sub-area B), no red tide event (*Diatom and Flagellate sp.*) were recorded since 1997 and were rated both as “No trend” and “Low”. On the other hand, outside of Jiaozhou Bay (Sub-area

C), red tide events (*Diatom sp.*) begin to occur at a high frequency in the recent 5 years, demonstrating an increasing trend. Therefore, considering all the parameters in category II, the Category II was rated as “LN” in all three sub-areas.

For Category III, in general, COD concentration in the Jiaozhou Bay was lower than 3 mg l^{-1} for all sub-areas. COD values in a majority of sites showed no obvious trend in these 13 years in all sub-areas according to non-parametric Mann-Kendall test and were rated as “Low” and “No trend” in all sub-areas. Bottom DO concentration was generally higher than 2 mg l^{-1} for all sub-areas. Meanwhile, an increasing trend was observed for bottom DO and finally DO were rated as “Low” and “Decreasing” in all sub-areas. This result indicated that Low DO or high COD were not the main eutrophication symptoms in the Jiaozhou Bay. There were no fish kill incidents recorded from the year 1997 to 2009 and the fish kill incidents was rated as “low” and “no trend”. Therefore, considering all the parameters in category III, the Category III was rated as “LN” in all three sub-areas.

For Category IV, there was no shell fish poisoning incidents recorded in all sub-areas of Jiaozhou Bay from the year 1997 to 2009, and the shell fish poisoning incident was rated as “low” and “no trend”. For red tide events (*Noctiluca sp. and Mesodinium sp.*), no events were recorded in sub-area A, B and were rated as “Low” and “No trend”. These two kinds of blooms occurred in sub-area C frequently since the year 1999, and was rated as “H” and “”. So the Category IV was rated as LN in sub-areas A, B and “HN-LN” in sub-area C.

The eutrophication assessment results of Jiaozhou Bay were presented in Table 10 to 12 for each sub-area.

Table 10 Identification of eutrophication status in sub-area A of Jiaozhou Bay

Category	Assessment parameter	Comparison	Occurrence	Trend	Parameter identification	Category identification
I	Riverine DIN loads	×	×	I	I	HI
	Riverine DIP loads	×	×	I	I	
	TN	H	×	N	HN	
	TP	H	×	N	HN	
	DIN	H	×	I	HI	

	DIP	H	×	I	HI	
	DIN/DIP ratio	H	×	D	HD	
II	Max of Chl-a	L	×	N	LN	LN
	Mean of Chl-a	L	×	N	LN	
	Red tide (*Diatom sp.*)	×	L	D	LD	
	Red tide (*Flagellate sp.*)	×	H	N	HN	
III	DO (bottom)	L	×	D	LD	LN
	COD	L	×	N	LN	
	Fish kill incidents	×	L	N	LN	
IV	Red-tide events (*Noctiluca and Mesodinium sp.*)	×	L	N	LN	LN
	Shell fish poisoning incidents	×	L	N	LN	

Table 11 Identification of eutrophication status in sub-area B of Jiaozhou Bay

Category	Assessment parameter	Comparison	Occurrence	Trend	Parameter identification	Category identification
I	Riverine DIN loads	×	×	×	×	LN
	Riverine DIP loads	×	×	×	×	
	TN	L	×	N	LN	
	TP	H	×	N	HN	
	DIN	L	×	N	LN	
	DIP	H	×	I	HI	
	DIN/DIP ratio	L	×	D	LD	
II	Max of Chl-a	L	×	N	LN	LN
	Mean of Chl-a	L	×	N	LN	
	Red tide (*Diatom sp.*)	×	L	N	LN	
	Red tide (*Flagellate sp.*)	×	L	N	LN	
III	DO (bottom)	L	×	D	LD	LN

	COD	L	×	N	LN	
	Fish kill incidents	×	L	N	LN	
IV	Red-tide events (*Noctiluca and Mesodinium sp.*)	×	L	N	LN	LN
	Shell fish poisoning incidents	×	L	N	LN	

Table 12 Identification of eutrophication status in sub-area C of Jiaozhou Bay

Category	Assessment parameter	Comparison	Occurrence	Trend	Parameter identification	Category identification
I	Riverine DIN loads	×	×	×	×	HN
	Riverine DIP loads	×	×	×	×	
	TN	H	×	N	HN	
	TP	H	×	N	HN	
	DIN	L	×	N	LN	
	DIP	H	×	I	HI	
	DIN/DIP ratio	L	×	D	LD	
II	Max of Chl-a	L	×	N	LN	LN
	Mean of Chl-a	L	×	N	LN	
	Red tide (*Diatom sp.*)	H	×	I	HI	
	Red tide events (*Flagellate sp.*)	×	L	N	LN	
III	DO (bottom)	L	×	D	LD	LN
	COD	L	×	N	LN	
	Fish kill incidents	×	L	N	LN	
IV	Red-tide events (*Noctiluca and Mesodinium sp.*)	×	H	N	HN	HN-LN
	Shell fish poisoning incidents	×	L	N	LN	

5. Evaluation of the refined NOWPAP common procedure

One of the most obvious improvement of the refined NOWPAP Common Procedure should be that the screening procedure before the Comprehensive Procedure. The screening procedure focused on three aspects which could reflect symptoms of eutrophication effects: low DO events, High concentrations of Chl-a and occurrence of red tide events.

In previous case study, the Changjiang river estuary, the screening procedure was not applied, and the final results indicated that the Changjiang river estuary had both a high degree of nutrient enrichment and a high level of direct ecological effects (high level of Chl-a and high frequency of red tides).

In the Jiaozhou Bay case study, screening procedure was applied. The improvement relies on the identification of eutrophic conditions or symptoms of the Jiaozhou Bay by both screening procedure and comprehensive procedure. The screening procedure had indicated that Jiaozhou Bay was a problem area of eutrophication, with high frequency of red tide events in the bay and its adjacent waterbody in recent years. However, the comprehensive procedure applied to Jiaozhou Bay indicated that in both 3 sub-areas, degree of nutrient enrichment were high, while ecological effects were relatively not obvious. For direct, indirect and other possible ecological effects, the status was almost “Low” category. Degree of other indicators may have covered the problems of red tides in the whole assessment results. This had indicated that without screening procedure, eutrophication problems may be not fully reflected only by final comprehensive assessment results. Both the screening procedure and the comprehensive procedure help to identify the evidence and degree of eutrophication.

Another important improvement in the Jiaozhou Bay case study compared to the previous Changjiang river estuary could be that the assessment parameters were more specific, which could reflect different stages and degree of eutrophication. In the Changjiang river estuary case study, only red tide event (total) was used, but in the

Jiaozhou Bay assessment, red tide events (*Diatom sp.*, *Flagellate sp.* and *Noctiluca sp.*) were used, respectively. These red tide events represent different stages and degree of bloom events, which can demonstrate the severity and degree of eutrophication conditions in the waterbodies. Besides the red tide events parameters, bottom DO was used to reflect indirect effects of eutrophication problems, which will avoid the contradictory when both surface DO and bottom DO were used, since surface and bottom DO concentrations may show quite different values.

6. Conclusion and recommendations

6.1 Conclusion

- Increasing nutrient enrichment pressures

The results of eutrophication assessment using revised NOWPAP Common Procedure indicated that nutrients showed an increasing trend in Jiaozhou Bay, especially inner the bay. Nutrient enrichment problems inner the bay were the most serious, followed by that outside the bay. The increase of DIP was apparent and was more serious than DIN, with high degree of DIP enrichment in all three sub-areas. Nutrient enrichment became a major problem of eutrophication in Jiaozhou Bay probably because more and more severe anthropogenic activities in coastal areas.

- No apparent direct/indirect effects of nutrient enrichment in Jiaozhou Bay

In Jiaozhou Bay, direct or indirect effects of nutrient enrichment were all not so apparent. The eutrophication symptoms were weak and degree of ecological effects was low. Especially in inner Jiaozhou Bay, red tide events occurred at a relatively low frequency after the year 2004. Also extremely high phytoplankton biomass or hypoxia were not detected. That is to say, high nutrient load and high nutrient concentrations did not result in severe ecological effects (high biomass, frequent HABs, low DO events.etc). In the Bohai Bay, decreasing frequency of red tide events may be mainly due to highly suspended particulate material according to investigation data (Qiao et al., 2011). But in Jiaozhou Bay, the reason for the reduction in frequency of red tide events still requires further investigation. One possible reason could be the shellfish aquaculture in inner the bay. Shellfish are filter-feeding animals that can suck red tide species out of the waters.

- Ecological effects of nutrient enrichment outside of Jiaozhou Bay became a new concern

On contrary to the unapparent effects of nutrient enrichment inner the bay, red tide events became a major eutrophication symptom outside the Jiaozhou Bay. Many types of red tide events (e.g. *Diotom. sp, Noctiluca. sp* and *Mesodinium sp.*) were frequent outside the Jiaozhou Bay. Relatively high nutrient concentrations, not so high turbidity and no filter of shellfish could be the possible reason that red tides frequently occurred in this area.

6.2 Recommendations

The results of eutrophication assessment of Jiaozhou Bay have indicated that the control of nutrient pollution into the bay is a major management strategy for eutrophication management of Jiaozhou Bay, especially in sub-area A. The mechanism on decrease of eutrophication symptoms (red tides or high biomass) in recent years should also be highlighted to eliminate eutrophication problems in the future.

Control of nutrient into outside of the bay from the sewage treatment plant is also essential, since in this sub-area, nutrient concentrations were also high and were able to stimulate eutrophication symptoms (e.g. occurrence of red tide events). Further research on the cause for increasing frequency of red tides in recent years outside of Jiaozhou Bay is needed to assist in the control of red tides. Strategies on emergency disposal of red tides are also needed to prevent ecological or economic losses.

Referring to the suggestions of the Common Procedure, since parameters had already been harmonized and universal reference of parameters should be recommended in order to compare eutrophication status in different areas.

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