A Case Study Report on
Assessment of Eutrophication Status
in Jinhae Bay, Republic of Korea

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1. Introduction and objectives

Masan-Jinhae Bay has been identified as one of the most polluted areas in Korea (Khim and Koh, 2011). During the last 40 years, the natural features of the bay have been dramatically modified by urban, industrial, and port developments, with its tidal wetlands having been reclaimed to accommodate the expansion of a large population and ever-growing industry (Ryu et al., 2011). As a result, the bay became quickly and heavily polluted by a variety of wastes, including untreated municipal sewage and industrial wastewater, which led to harmful algal blooms, sharp oxygen depletion, loss of aquatic life, and aesthetic problems. Hence, there has been public and regulatory concern about pollution problems in these areas since the 1980s.

There has been frequent oxygen deficiency/hypoxia and red tides giving adverse impact on fisheries and marine organisms, particularly, during summer season in Jinhae Bay, a well known frequent red tide area in Korea due to its geographical characteristics as a semi-closed bay and low water circulation (Hong, 1987; Lim et al., 2006; Lee et al., 2013). The number of red tide events in Jinhae Bay, showed a peak in the 1980s with the highest number in 1985 (21 events). Thereafter, the number decreased gradually ranging 10.3 and 8.9 in the mean annual events in 1990s and 2000s, respectively (Lee et al., 2013).

Since, eutrophication has become a ecological problem in coastal areas in Korea, the objective of this 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

In this case study, Jinhae Bay, located in the south eastern part of Korea, was selected to be a target area for eutrophication assessment because it is within NOWPAP geographic scope. Also, Jinhae Bay and its adjacent waters have been the most highly eutrophicated sea area in Korea with a high frequency of red tide and hypoxia, particularly, during summmer season since 1970s. On the whole Jinhae Bay is typical water body for eutrophication assessment in Korea. The geographical and oceonographical features including nutrient loads into the assessment area are as belows.

Geographical and Fisheries Features

Jinhae Bay is a semi-closed coastal embayment surrounded by several big (Masan and Changwon city) or small (Jinhae, Goseong, Tongyeong and Geoje) cities. A total of 1,530 thousands of population resides in the vicinity of Jinhae Bay comprising 1,080 thousands in Masan, Changwon and Jinhae city, 140 thousands in Tongyeong city, 250 thousands in Geoje city and 60 thousands in Goseong city. Jinhae Bay comprises several small bays such as Masan Bay, Haengam Bay, Jindong Bay, Gohyun Bay (Park et al., 1995). Forty small natural rivers flow into the bay which comprises 637㎢ of areas with water depths ranging from 5 to 20 m (Lee, 1998; Lee et. al., 2008).

The drainage basin (about 1,008㎢) of the Bay provides water for about 2.7% of the Korean population (a million people) for drinking and industrial uses, which eventually ends up in the Bay (Lee, 1998). The northern and eastern parts of the drainage basin (40% of total drainage basin), which include the cities of Masan, Changwon and Jinhae, are highly urbanized (81% of total population in the drainage basin, with an average population density of 1,362 persons per㎢) and heavily industrialized. The rest of the drainage basin is mostly rural (average population density of 194 persons per ㎢), with well developed agriculture including raising livestocks.

The topographic configuration of Jinhae Bay has three waterways, north and south of Gadeog Channel, and Gyeneryang Strait among which south of Gadeog Channel is the most major route for sea water exchange (about 90%) from outside (Kim, 1984). According to Oh et al. (2006), The velocity of the maximum tidal current in flood tide is 30~40 cm/s near Gadeog Island and flood tide flows westward near Jam Island. During the ebb tide, there are southward flow from Masan Bay and eastward flow at the in front of Goseong Bay at about 20 cm/s. The velocity of the minimum tidal current shows about 10 cm/s in the inner Jinhae Bay of small bays Masan, Wonmoon and Haengham. The residual current represents anti-clockwise circular flow in front of Gohyun Bay, showing a weak flow in the southward direction within the inner Masan Bay. At Masan Bay, there is a northward residual current occurring in the northern part of the bay, but it shows slight north-eastward current at the gate of the Masan Bay. For the west side of Masan Bay and the Hangam waters, such calculation is not viable due to their shallow water depth of less than 8 m.

Jinhae Bay with its excellent geographical conditions for marine life is one of the important places for fisheries resources and mariculture such as bivalves and finfish over the last few decades (Lee et al., 2008). Herein, aquaculture for oyster, sea squirt and ark clam is the most popular fisheries industry in Geoje and Tongyeong areas within Jinhae Bay. According to fisheries statistics of local government neighboring Jinhae Bay (Geoje, Tongyeong and Goseong local government in 2007), fisherman’s population is 32,248, and they have 10,743 ha of aquaculture farms with 45,310 MT of annual fisheries production, mostly targeting on invertebrate such as oyster, sea squirt and arch shell.

Nutrient Loads

After Masan industrial complex was constructed in 1960s, the marine ecosystem of surrounding areas started to be deteriorated drastically (Oh et al., 2006). The water quality of Masan Bay, adjacent to Jinhae Bay, has been seriously eutrophicated by the discharge of domestic and industrial sewage. Jinhae Bay has received a variety of waste, including untreated municipal sewage and industrial waste-water for more than 40 years, with an approximate daily average of $3X10^8$ liters/day (Ministry of Environment, 1991). The water quality of the Jinhae Bay depends on nutrient loads from the land for over 80%, and highly concentrated pollutant loads are carried into the Jinhae Bay by the rivers and streams, which lead to eutrophication problems in the coastal region. In Jinhae Bay, red-tide outbreaks have been reported after heavy rainfall through which amount of nutrients and growth promoting substances could inflow coastal waters from land runoff. There are six major cities neighboring Jinhae Bay, among which Masan Bay is the most major route for the introduction of pollutants loads (Shin et al., 2004). On the other hand, Chang et al.(2012) reported that the nutrient concentrations in Masan Bay, a highly eutrophicated Bay among other Bays in Korea, had shown decreasing trend since mid 2000s (Fig. 1).

1. 2 Collection of relevant information

Routine monitoring data

The nutrients (N, P, Chl-a, DO, COD) data in Jinhae Bay were obtained from the data set of NFRDI (National Fisheries Research and Development Institute), implementing coastal environment monitoring program seasonally (4 times a year) for the conservation of coastal environment. The data on red tides in Jinhae Bay was collected from the HAB occurrence report in Korean coasts based on monthly HAB monitoring program aiming at early warning and prediction of red tides to minimize fisheries impact. The data on incidence of shellfish poisoning was collected from the website of NFRDI (www.nfrdi.re.kr), implementing routine monitoring on shellfish poisoning aiming at early detection of shellfish toxin for food safety. Most of the data for this report were collected from those monitoring programs conducted by NFRDI targeting on Jinhae Bay (Table 1).

Table 1. Routine monitoring programs related to eutrophication in Korea

Survey area	Governing organization	Survey title	Aim	Survey period	Main survey parameters	Survey frequency	No. of survey points
Jinhae Bay including Masan-Haengam Bay	NFRDI	Coastal environment monitoring program	Conservation of coastal environment	1984-	Temp. Salinity Transparency. Nutrients COD, pH Chl-a pollutants	4/year	9-14
		HAB monitoring	HAB warning and prediction to minimize fisheries impact	1979-	Phytoplankton Nutrients Chl-a, etc.	1/month	15
		Shellfish toxins monitoring	Detection of shellfish toxin for food safety	1992-	PSP ASP DSP	1/month or 1-2/week (depending on toxin	19

						level)	

Note: NFRDI conducts long-term monitoring studies; universities conduct short-term and intensive studies.

Pollutant sources

Pollutant sources (e.g. municipal, industrial, agricultural, aquacultural sources) were obtained through published references. However, only nutrients load from riverine sources was used in this assessment.

Supplementary information

Supplementary information (e.g. oceanography, meteorology, fisheries including aquaculture, waste water management) were obtained through published references. However, this subsidiary data was not directly used in this assessment.

Information on field survey and sample analysis

Basically, all the data used in this assessement was based on four times (February, May, August, November) field survey results over 14 stations within Jinhae Bay (Table 2).

Table 2. Latitude and longitude of sampling stations

Sub-area	Name of Bay	Station	Latitude	Longitude
A	Jinhae Bay	1	35.02	128.46
A	Jinhae Bay	2	35.06	128.37
A	Jinhae Bay	3	35.05	128.29
A	Jinhae Bay	4	35.03	128.25
A	Jinhae Bay	5	34.54	128.26
A	Jinhae Bay	6	34.54	128.36
A	Jinhae Bay	7	35.02	128.31
A	Jinhae Bay	8	35.00	128.32
A	Jinhae Bay	9	34.58	128.28
B	Haengam Bay	1	35.07	128.41
B	Haengam Bay	2	35.08	128.41
B	Masan Bay	1	35.11	128.35
B	Masan Bay	2	35.09	128.36
B	Masan Bay	3	35.10	128.35

1. 3 Selection of assessment parameter

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 3):

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 (Table 3):

i) Category I: parameters that indicate degree of nutrient enrichment include riverine input of TN and TP concentrations, winter DIN concentration, winter DIP concentration and winter DIN/DIP ratio. For all parameters of nutrients, surface data were used.

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 and Flagellate species).

iii) Category III: parameters that indicate indirect effects of nutrient enrichment, including bottom DO, bottom 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.) and shellfish poisoning incidents. *Mesodinium* sp. was also considered in addition to *Noctiluca* sp. for the reason that *Mesodinium* sp. was frequently observed for the last decade in Jinhae Bay, and the occurrence of red tides by *Mesodinium* were one of the important factors to reflect the eutrophication in the Bay.

1.3.3 Setting of sub-areas

Based on the geographical and oceanograpical characteristics including sea water exchanges of Jinhae Bay, two sub-areas were divided in this report. Sub-area A represent inner Jinhae Bay having relatively good sea water circulation (30-40 cm/s) (Oh et al., 2006). Sub-area A includs many small Bays as Jindong, Goseong, Wonmoon and Gohyun Bays. Sub-area B includes Masan and Haengam Bay in which sea surface shows a relatively calm flow (20-30 cm/s) due to their shallow water depth and unique features of semi-closed embayment compared to sub-area A (Fig. 1). Nine and five sampling sites are located in sub-area A and sub-area B, respectively.

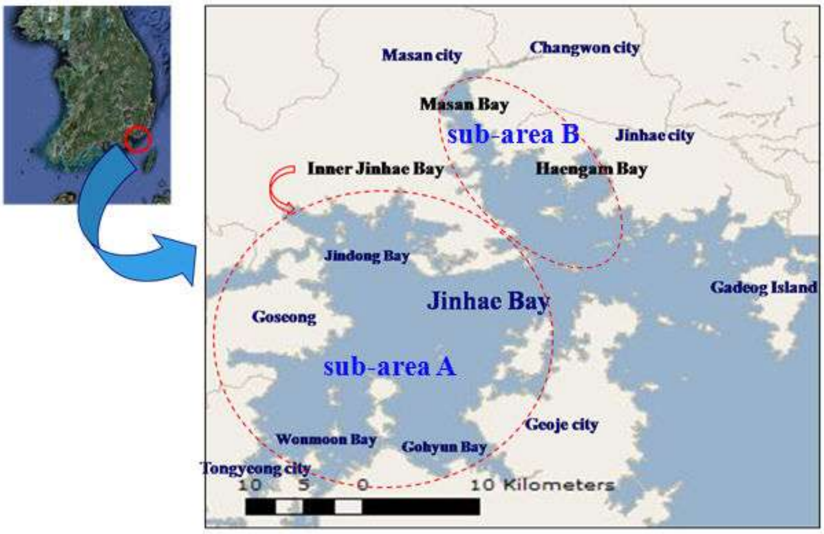


Fig. 1. Sub-areas of Jinhae Bay

1.3.4 Setting of assessment period

To assess eutrophication status in Jinhae Bay through current status and trend, long-term monitoring data (at least more than 10 years) was used in this report following the recommendation by revised Common Procedure of CEARAC/NOWPAP). The duration for the assessment of red tide events and environmental water quality was 1981~2011 and 2002~2011, respectively. The duration year for the assessment of riverine input(COD, SS, T-N, T-P) was relatively short (1995 and 1996) due to the lack of available data. Regarding reference values, background values for Gijang coast was applied as a contrast. 8 years data (2004-2011) for the background values were used in this assessment.

Table 3. Information of assessment parameters used in Jinhae Bay

Category		Assessment parameter	
Ⅰ	Degree of nutrient enrichment	Riverine input (COD, SS, T-N, T-P)	1995 - 1996
		Total nitrogen/Total phosphorus (T-N, T-P)	2002 - 2011
		Winter (DIN/DIP) concentration	2002 - 2011
		Winter N/P ratio (DIN/DIP)	2002 - 2011
Ⅱ	Direct effects of nutrient enrichment	Maximal chlorophyll-a concentration (surface)	2002 - 2011
		Mean chlorophyll-a concentration (surface)	2002-2011

		Red tide events (diatom and flagellate species)	2001 - 2011
Ⅲ	Indirect effects of nutrient enrichment	Dissolved oxygen (bottom)	2002 – 2011
		Fish kill events	1979- 2011
		Chemical oxygen demand (bottom)	2002 – 2011
Ⅳ	Other possible effects of nutrient enrichment	Red tide events (*Noctiluca* and *Mesodinium* species)	2001-2011
		Shellfish poisoning incidents	1980-

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). Basically, the annual mean values for DIN, DIP, Chlorophyll-a, DO (bottom) and COD (bottom) were used for the assessment except maximum of Chlorophyll a and red tide events. The red tide data were represented by red tide events with a unit of times/year or times/3 years. The riverine T-N and T-P load were obtained through published papers.

The annual mean values were obtained by averaging the values of each parameter monitored in four different seasons (February, May, August and November) of a year. The maximum of Chlorophyll a was the maximum value monitored in the four seasons. The annual mean dissolved oxygen (DO) and chemical oxygen demand (COD) were assessed for bottom values.

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. The parameters of annual mean DIN, DIP, DIN/DIP ratio, COD and Chla, and annual minimum 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 (2009-2011), while trend was analyzed based on data in all the years. Trend was identified by the linear regression due to the insufficient number of data.

3. 2 Setting of classification criteria of the assessment parameters

For the reference concentrations, background values were used in this report. Therein, water quality data in Gijang coast was applied as a contrast with Jinhae Bay and Masan-Haengam Bay. Gijang coast, about ten kilometers away to the east from Busan city, has a relatively least effect from anthropogenic activities and more influence by open sea than coast. Accordingly, the place shows quite constant salinities (33 psu) almost all the year round due to the strong influence by Tsushima warm current, a branch of Kuroshio current. Painting et al. (2005) reported that target area meets ‘ecological quality objective’ once assessment parameters don’t exceed 150% of background values. Following the standard suggested by Painting et al.(2005), this report classified eutrophication by two levels: ‘high’ when the value of current status shows more than 150% of background values and ‘low’ when the value of current status shows lower than 150% of background values. As for DIN/DIP ratio, the Redfield value 16 was used in this study. 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.

4. Assessment process and results

4. 1 Assessment categories

4.1.1 Assessment of Category Ⅰ

Riverine input

The information on reverine input of COD, SS, total nigrogen (T-N) and total phosphorus (T-P) of Jinhae Bay in the mid 1990s was collected through published research papers. Two years (1995 and 1996) data on riverine inputs of COD, SS, T-N and T-P into Jinhae Bay were used as indicators to reflect anthropogenic pressures in this study due to the lack of sufficient data. Based on the data by Cho and Chae (1998), the pollutants loads from Masan and Changwon city and from multi-port diffuser (effluents discharge) was estimated to be 80~90% and 20~25%, respectively. Table 4 shows seasonal variations of fresh water inflows and pollutants loads into Jinhae Bay from 1995 to 1996. The quantity of fresh water inflows shows critical seasonal variation by showing much higher in Summer than in Winter. The contribution rates in the introduction of COD of pollutants loads in Masan Bay, Haegam Bay and inner Jinhae Bay were 84%, 6% and 10%, respectively, without showing any remarkable seasonal changes. SS, also, showed similar pattern to COD by contributing 88%, 5% and 7% of pollutant loads in Masan Bay, Heangam Bay and inner Jinhae Bay, respectively (Fig. 2). Total nitrogen and total phosphorus, also, showed similar pattern likewise COD and SS representing that Masan Bay was the hot spot in the introduction of pollutants.

Table 4. Seasonal variation of freshwater inflows and pollutants loads in Jinhae Bay including Masan-Hangam Bay (Cho H. Y. and J. W. Chae, 1998)

	´95yr Summer	´95yr Autumn	´95yr Winter	´96yr Spring	´96yr Summer	´96yr Autumn	Average
Freshwater inflows	3,428.2	779.2	613.4	1,406.4	1,543.8	835.7	1,328.4
(x1000Ton/day)	(915.9)	(488.2)	(417.3)	(1,036.8)	(1,157.1)	(534.6)	(750.5)
COD loads	130.5	88.6	54.5	104.3	85.7	95.1	89.8
(x1000Kg/day)	(73.5)	(38.8)	(51.5)	(89.6)	(71.1)	(81.3)	(75.4)

SS	97.1	25.9	34.9	103.2	33.0	30.4	56.8
(x1000Kg/day)	(65.9)	(13.5)	(27.0)	(89.6)	(20.3)	(15.5)	(42.5)
Total-Nitrogen	32.1	29.7	28.8	32.9	26.5	27.3	29.7
(x1000Kg/day)	(17.8)	(19.2)	(21.5)	(23.7)	(17.2)	(20.2)	(20.5)
Total-Phosphorus	2.76	1.42	1.75	2.89	2.54	1.79	2.23
(x1000Kg/day)	(1.36)	(0.85)	(1.24)	(2.07)	(1.50)	(1.01)	(1.42)

Note: 1. average value was calculated by dividing into 4 at the sum of 4 season values
2. ( ): Total amount of freshwater inflows and pollutants loads in Masan and Haengam Bay.

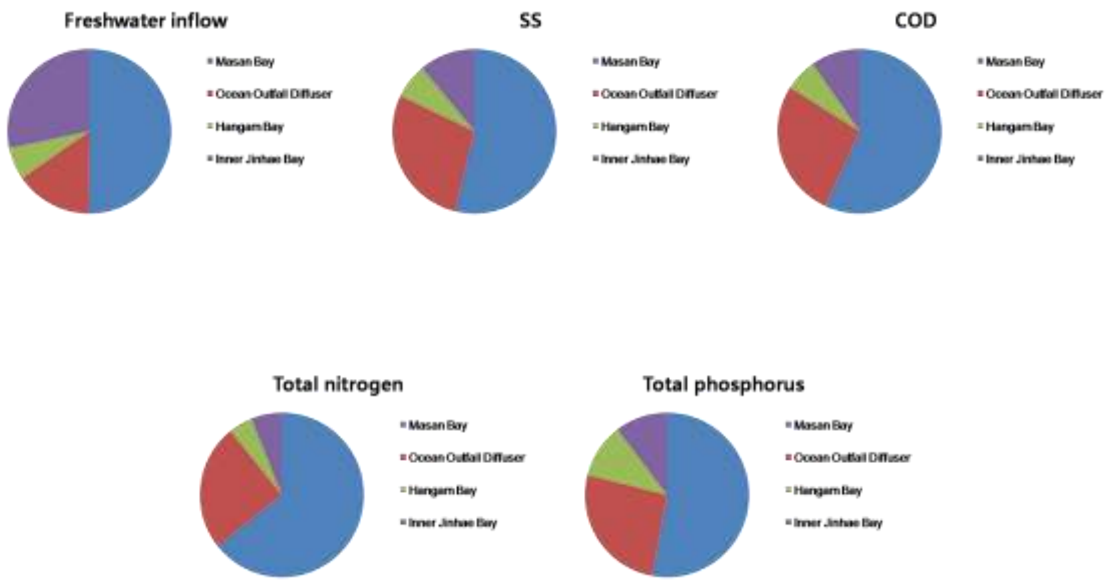


Fig. 2. Contribution rate in the introduction of freshwater inflow and pollutants loads in Jinhae Bay. (Data source:Cho H. Y. and J. W. Chae, 1998).

Meanwhile, Chang et al.(2012) analyzed water qualities in rivers during 2005-2010, targeting on COD, SS, T-N and T-P loads near sub-area B. Based on their reports over 14 sites in the inland rivers, riverine pollutant (COD, SS, T-N and T-P) loading has shown slightly decreasing trend during this period, particularly, with a significant reduction in COD and SS loads (Fig. 3). However, it was not possible to compare the values of riverine input in sub-area A and B with reference data due to the lack of data.

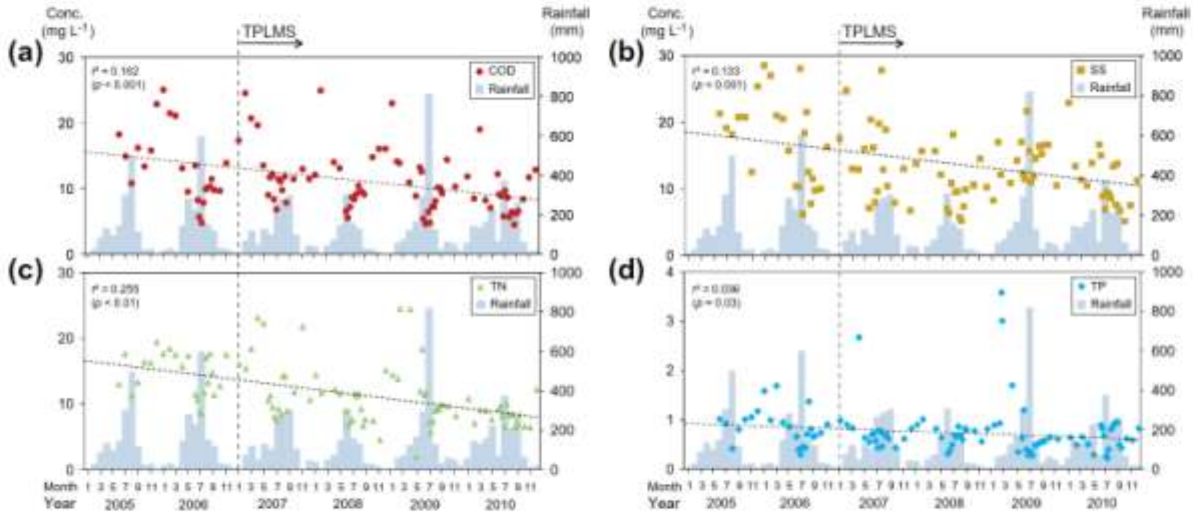


Fig. 3. Changes in concentrations (mgL^{-1}) of (a) COD, (b) SS, (c) TN, and (d) TP in freshwater measured from 14 sites (given as mean) in the inland revers over the six-year period (2005-2010), rainfall data (mm) was also given as background information. (Data source: Chang et al., 2012).

Total nitrogen/Total phosphorus

Fig. 4 shows the variation of annual mean and background values for T-N and T-P in the surface water of sub-area A during 2002-2011 with background value for Gijang coast. The annual mean values of T-N and T-P in sub-area A showed decreasing trend since 2002 with a range of 0.35~0.77㎎/L and 0.038~0.095㎎/L in T-N and T-P, respectively. Mean values of T-N and T-P in 2011 decreased 54% and 57%, respectively, compared to 2002 (Fig. 4). The annual mean values of T-N and T-P in sub-area B showed, also, decreasing trend since 2002 with a range of 0.37~0.96㎎/L and 0.048~0.152㎎/L in T-N and T-P, respectively. Mean values of T-N and T-P in 2011 decreased 52% and 68%, respectively, compared to 2002 (Fig. 5). In order to identify current status of eutorphication based on T-N and T-P values in Jinhae Bay, the value for Gijang coast was used as a reference value/background value. Annual ranges of T-N and T-P in the surface water for Gijang coast during 2004-2011 was 0.20~0.34㎎/L and 0.024~0.036㎎/L in T-N and T-P, respectively.

Overall, the concentrations of T-N and T-P showed higher value than that of background values both in sub-area A and B, in which the concentrations in sub-area B was slightly higher than that of sub-area A. However, the values showed obiously decreasing trend since early 2000s in both sub-areas. The T-N and T-P concentrations in recent 3 years were slightly higher than background values and showed decreasing trend.

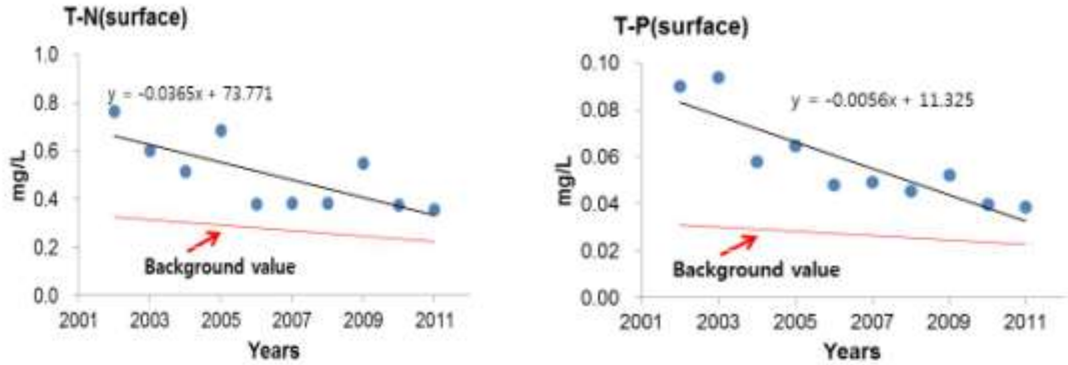


Fig. 4. Annual variation of T-N and T-P in sub-area A (2002~2011).

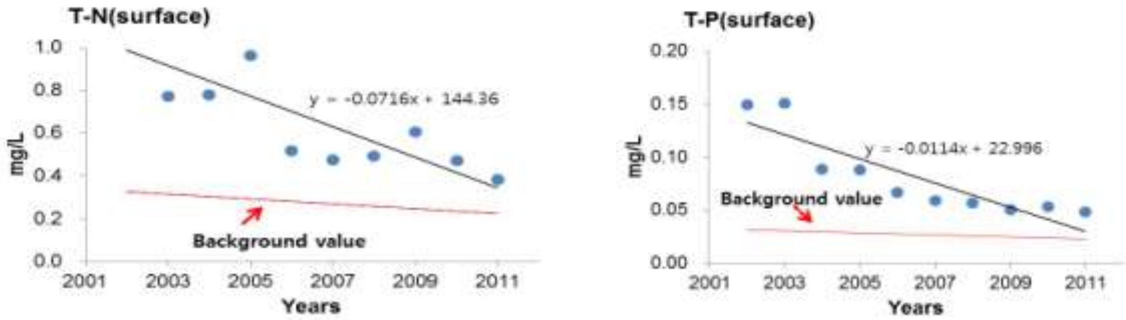


Fig. 5. Annual variation of T-N and T-P in sub-area B (2002~2011).

Meanwhile, Chang et al.(2012) reported that COD, SS, T-N and T-P concentrations in Masan Bay (the sub-area B) showed decreasing trend both in the surface and bottom during 2005-2010 (Fig. 4). The result corresponds well with the trend in this report.

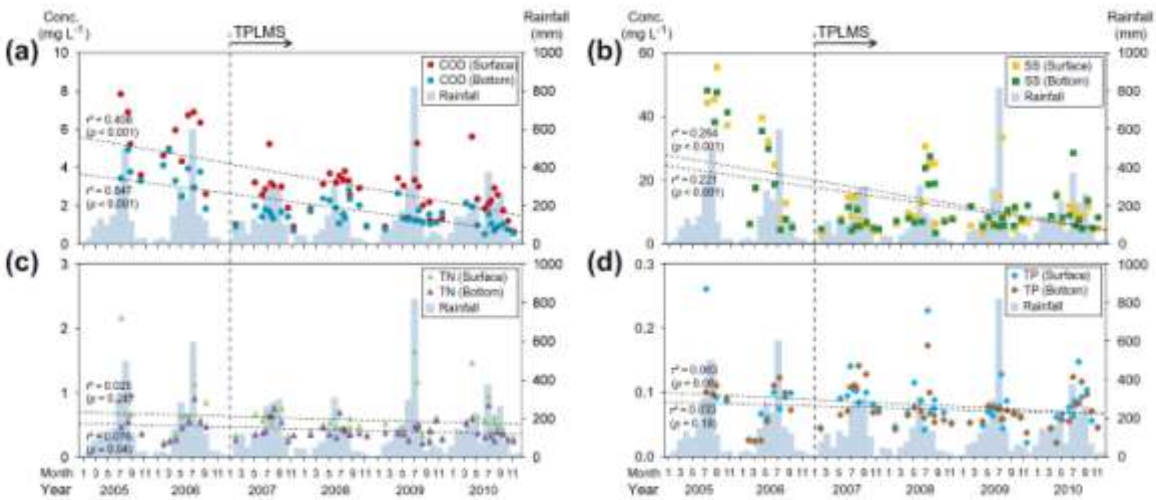


Fig. 6. Changes in concentrations (mgL^{-1}) of (a) COD, (b) SS, (c) TN, and (d) TP in sea water (surface and bottom) measured from 10 sites in the Masan Bay

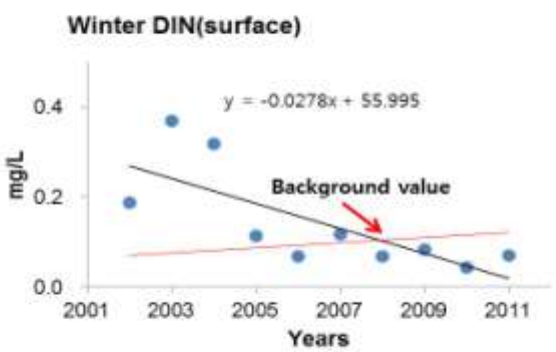
over the six-year period (2005-2010), rainfall data (mm) during the corresponding period was also given as background information. (Data source: Chang et al., 2012).

Winter DIN and DIP concentration

Inorganic nutrient levels of DIN and DIP are important factors for the identification of nutrient enrichment state in certain areas. These factors play a significant role in the regulation of phytoplankton growth as well. Generally, inorganic nutrient shows high level during winter season in the coastal and estuary areas of temperate region, where nutrient consumptions are much limited by the suppression of phytoplankton growth in winter season due to low water temperature and irradiance. Hence, DIN and DIP level in winter season, can be a key parameter in the identification of nutrient enrichment state.

Fig. 7 shows the annual variation of winter DIN and DIP in the surface of sub-area A during 2002-2011 with background value for Gijang coast. Winter DIN and DIP level in sub-area A, ranging 0.05˜0.36㎎/L and 0.005˜0.035㎎/L, respectively, showed decreasing trend since 2004. The mean values of winter DIN and DIP in 2011 decreased 57% and 68%, respectively, compared to 2002. Fig. 8 shows the annual variation of winter DIN and DIP in sub-area B during 2002-2011. Winter DIN and DIP level in sub-area B, ranging 0.05˜0.45㎎/L and 0.002˜0.068㎎/L, respectively, showed decreasing trend since 2004 likewise in T-N and T-P. The mean values of winter DIN and DIP in 2011 decreased 73% and 78%, respectively, compared to 2002. In order to assess eutorphication status, reference value/background value for Gijang coast was used.

The concentrations of DIN and DIP were higher than background value by 2006-2008 in both sub-area A and B. However, the concentrations showed lower values than that of background since 2006-2008 in both sub-areas. The concentrations of DIN and DIP showed obiously decreasing trend since early 2000s in both sub-areas. The concentrations in recent 3 years were lower than background values, but no obvious trend. Overall, the current eutrophication status based on winter DIN and winter DIP in sub-area A and B was classified as low with decreasing trend.



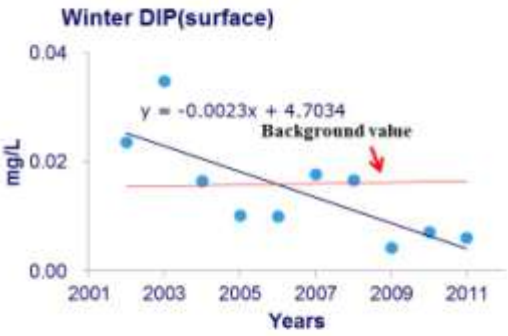


Fig. 7. Annual variation of winter DIN and DIP in sub-area A (2002~2011).

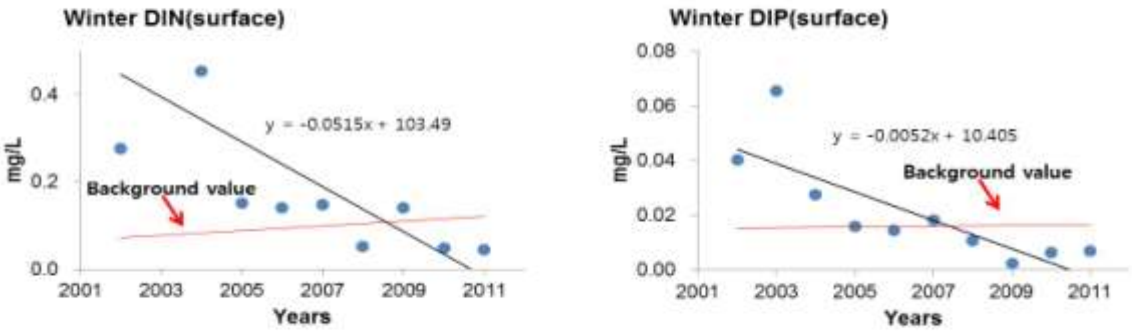


Fig. 8. Annual variation of winter DIN and DIP in sub-area B (2002~2011).

Winter N/P ratio (DIN/DIP)

The elemental composition of phytoplankton has indicated that the atomic ratio of nitrogen and phosphorus was about 16:1 in a spatially and temporally averaged value (Redfield, 1934). The limitation of P or N to phytoplankton and primary production in waters can be estimated. Also, the nutrient ratio in the seawater can change phytoplankton biomass and species composition (Smayda, 1990). It has been known that the increase of winter N/P ratio (compared to Redfield ratio=16) or excess of nitrogen in the seawater plays an important role in the species succession from diatom to flagellates.

Fig. 9 shows the annual variation of winter N/P ratio in the surface of sub-area A and B during 2002-2011 with background value for Gijang coast. The winter N/P ratio in both sub-area A and was slightly higher than background values of Gijang coast, and showed decresing trend in both sub-area A and B. The N/P ratios in recent 3 years was similar to background values, but no obvious trend in both sub-areas. Meanwhile, the increase of N/P ratio in recent 3 years, particularly, in sub-area A was related to the decrease of DIP concetrations rather than the increase of DIN concentrations in the region.

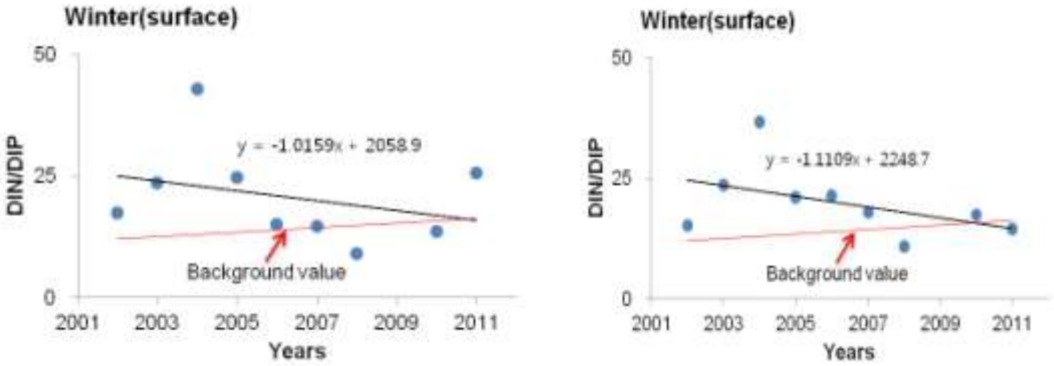


Fig. 9. Annual variation of winter N/P ratio in sub-area A (left) and sub-area B (right) during 2002~2011.

Winter N/P ratio during 2002-2011 showed higher value than Redfield ratio (16:1) in both sub-area A and B. It was assumed that frequent algal blooms by mostly dinoflagellates such as *Heterosigma akashiwo*, *prorocentrum* spp. rather than by diatom since 2009 might be related to the increase of N/P ratio in this areas considering the assumption by Smayda (1990).

4.1.2. Assessment of Category Ⅱ

Maximum Chlorophyll-a

Phytoplankton has photosynthetic pigments such as Chlorophyll-a, b, c and accessory pigment, among which Chlorophyll-a has been used as a tool for the assessment of phytoplankton biomass.

Fig. 10 shows the annual variation of maximum chlorophyll-a concentration in sub-area A and B during 2002-2011. Maximum chlorophyll-a concentration in both sub-area A (6.54~50.82㎍/L) and B (19.25~52.46㎍/L) was much higher than that of background of Gijang (3.84~13.9㎍/L). The hightest values of maximum chlorophyll-a concentration in sub-area A (50.82㎍/L) and B (52.46㎍/L) were detected during the massive phytoplankton bloom in 2009. Overall, there was no obvious trend in the maximum chlorophyll-a concentration from 2002 to 2011. Current eutrophication status based on Chlorophyll-a concentration was classified as ‘high’ and ‘no trend’ in both sub-areas during the assessment period.

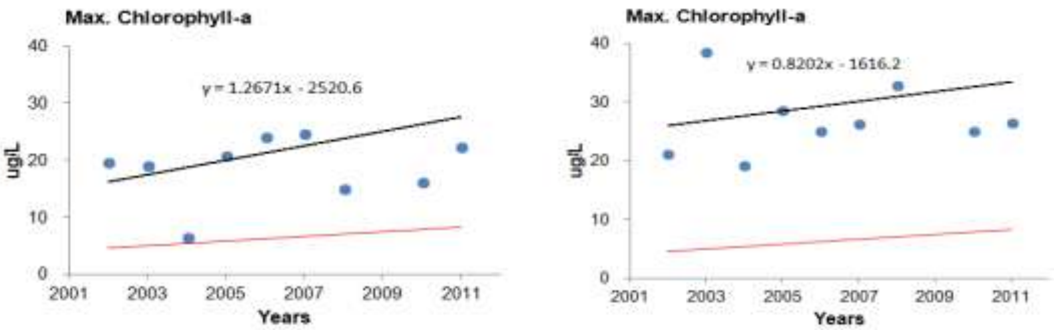


Fig. 10. Annual variation of maximum chorophyll-a in sub-area A and B

during 2002-2011.

Mean Chlorophyll-a

Fig. 11 shows the annual variation of chlorophyll-a concentration in sub-area A and B during 2002-2011 with background value for Gijang coast. overall annual chlorophyll-a concentration in both sub-area A and B was higher than background value. Herein, the chlorophyll-a concentration in sub-area B (8.75~20.25μg/L) was higher than sub-area A (5.08~10.18μg/L). High chlorophyll-a in sub-area B was related to the high frequency and long duration of red tides by dinoflagellates from spring to autumn season. Contrary to T-N, T-P, winter DIN and DIP, Chlorophyll-a concentration in sub-area A and B showed much higher value than that of background. This phenomenum was attributed to the relatively few red tides event in Gijang area used for background value even though dinoflagellate, *Cochlodinium* makes blooms occasionally during the summer season. There was no obvious trend in the chlorophyll-a concentration from 2002 to 2011. Accordingly, current eutrophication status based on Chlorophyll-a concentration was classified as 'high' and 'no trend' in both sub-areas during the assessment period.

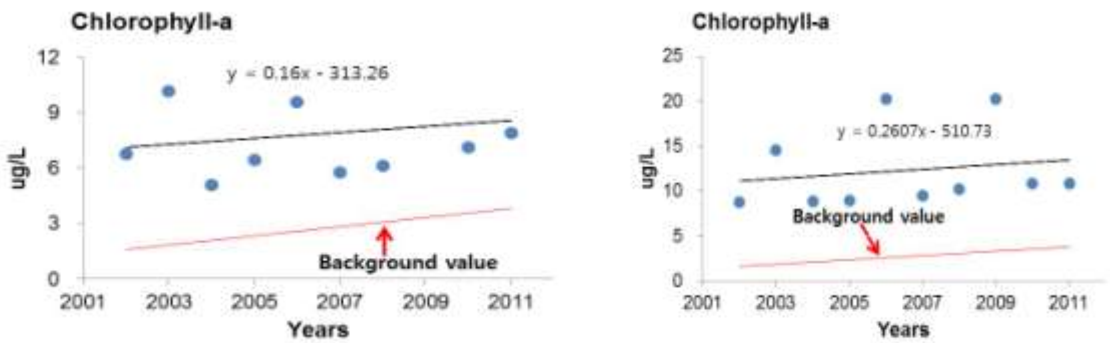


Fig. 11. Annual variation of chrorophyll-a in sub-area A (left) and sub-area B (right) during 2002~2011.

Red tide events

Fig. 12 shows the total number of red-tide events in sub-area A and B from 2001 to 2011. Red tide events showed obviously decreasing trend after showing a peak in 2002 (20 events). Flagellates were much more responsible for red tides than diatoms for a decade since 2001 by accounting for 55-100% in red tide number. Particularly, the percentage of red tides by flagellates sharly increased since 2006 by accounting for 83-100%.

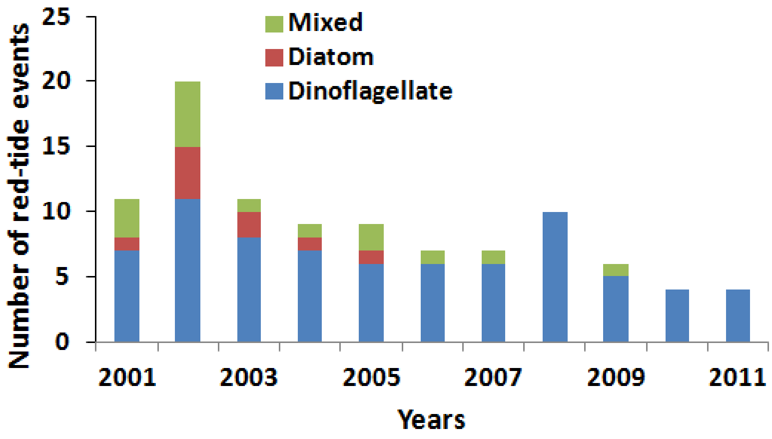


Fig. 12. Red tide events in Jinhae Bay during 1981-2011.

Fig. 13 shows the total number of red-tide events by diatoms in sub-area A and B during 2001-2011 . Overall, red tide events by diatoms were very few by showing 1 event (2001) and 1-4 events (2002-2005) in sub-area A and sub-area B, respectively for the assenssment period. The red tide number in sub-area A was lower than reference value (1 event). Also, the number in sub-area B was lower since 2006 even though the value was slightly high value during 2002-2003.Red tide trend by diatoms showed obviously decreasing trend both in sub-area A and B.
Fig. 14 shows the total number of red-tide events by flagellates in sub-area A and B during 2001-2011 . Overall, red tide events by flagellates were higher than reference value (1 event) by showing 1-7 events and 0-5 events in sub-area A and B, respectively, during the assessement period. Tne tred of red tide by flagellates showed no obvious trrend in sub-area A and decreasing trend in sub-area B for 11 years. Also, the red tide trend by and flagellates in recent 3 years was decreasing trend, particualrly in sub-area B.

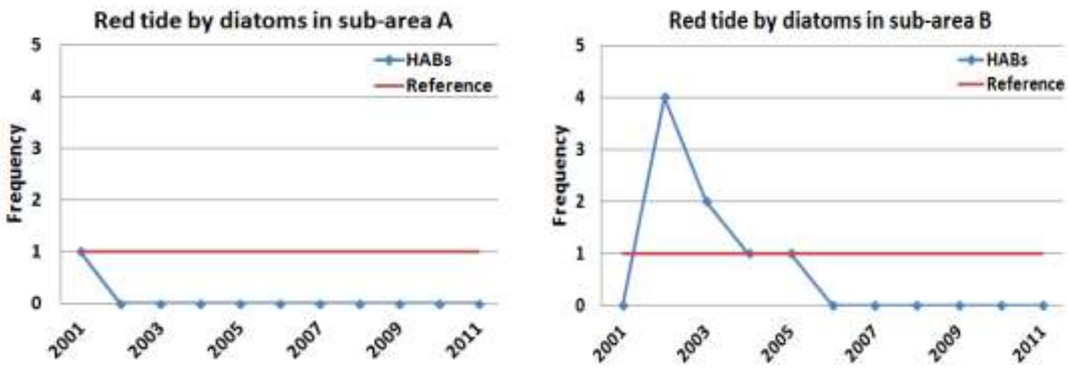


Fig. 13. Red tide events by diatoms in sub-area A and B during 2001-2011.

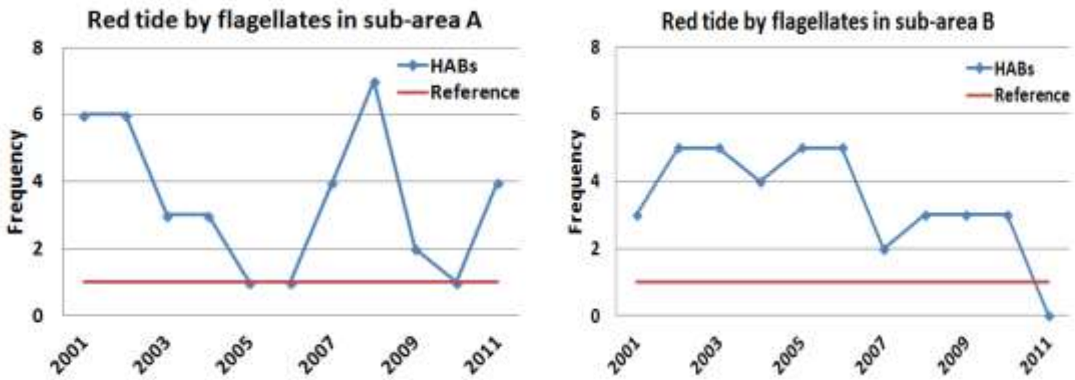


Fig. 14. Red tide events by flagellates in sub-area A and B during 2001-2011.

4.1.3. Assessment of Category Ⅲ

Dissolved oxygen (DO)

Dissolved oxygen level decrease in the process of decomposition when a large amount of organic substances are discharged into the coasts or massive algal blooms occur in the coastal areas. Hence, degree of oxygen depletion is widely used as indirect assessment parameters for nutrient enrichment. OSPAR (2005) notes that oxygen depletion can be induced by decaying algal blooms, long term nutrients and associated organic matter enrichment, especially in sedimentation areas, areas with long residence times and also in shallow areas with attached nuisance algae. Consequently oxygen depletion “during the growing season” is a category 3 effect under OSPAR, with 2~6 ㎎/L mg oxygen defined as a “deficiency” and less than 2㎎/L as “acute toxicity”. oxygen concentrations above 6㎎/L are considered to cause few or no problems to under OSPAR. There are several reports on the hypoxia caused by oxygen depletion in the bottom layer of Jinhae Bay mostly in summer season (Hong, 1987; Lim et al., 2006). The DO values in August shows a big variation whenever oxygen depletion phenomenon occurs in the Jihhae Bay. Considering that time and duration of oxygen depletion is quit variable depending on meteological and oceanographic condition rather than eutrophication itself in Jinhae Bay, minimum DO value in August was excluded in the data process to minimize noise.

Fig. 15 shows annual variation of bottom DO (Dissolved Oxygen) in sub-area A and B during 2002-2011 with background value for Gijang coast. DO level in the bottom layer of sub-area A and B ranged 2.58-6.99 mg/L and 2.44-6.07 mg/L, respectively. The DO level in both sub-area A and B was slightly lower than background value for Gijang coast.This level shows a bit lower than critical point (6㎎/L) under which marine animals are suffering from oxygen depletion that OSPAR (2005) reported. Also, there was no obvious trend for DO level from 2002 to 2011 in both sub-area A and B.

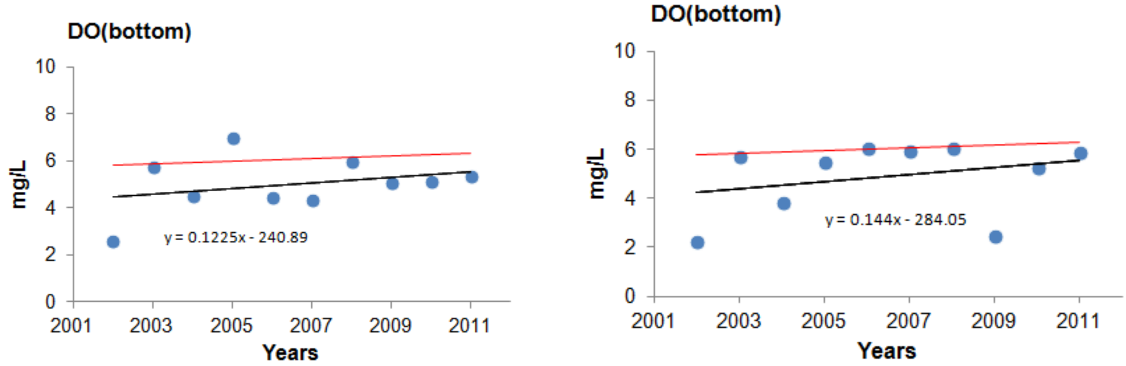


Fig. 15. Variation of annual minimum DO concentrations in the bottom of sub-area A (left) and B (right) during 2002-2011 (red line indicates background value).

Chemical Oxygen Demand (COD)

COD is defined as the number of oxygen equivalents consumed in the oxidation of organic compounds using strong oxidizing agents such as dichromate or permanganate. Chemical oxygen demand (COD) test is commonly used to indirectly measure the amount of organic compounds in water.

Fig. 16 shows the annual variation of COD values of bottom layer in sub-area A and B during 2002-2011 with background value for Gijang coast. The COD levels of bottom layer ranged 1.08-2.24 mg/L and 1.52-2.65 mg/L in in sub-area A and B, respectively. The COD levels in sub-area A and B were 2 times higher than background value (Gijang coast). Higher COD level was estimated to be related to high organic substances including phytoplankton biomass likewise in chlorophyll-a in Jinhae Bay. Meanwhile, a decreasing trend for COD was observed during 2002-2010. Particularly, the COD level showed obviously decreasing trend in recent 3 years in both sub-area A and B.

Fish kill incidents

There have been frequent fish kills in Korean coast mostly due to the red tide by *Cochlodinium polykrikoides* blooms since 1993. However, the fish killing species, *C. polykrikoides* has not made any high density blooms in Jinhae Bay. Therein, there was no any fish kill incidents in Jinhae up to date.

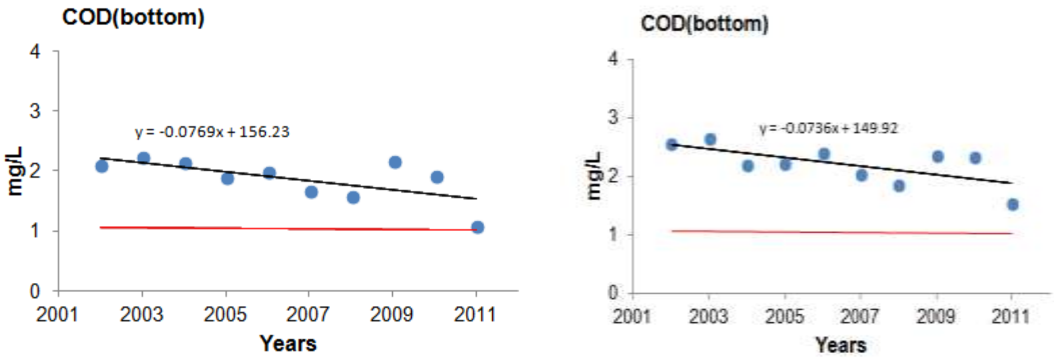


Fig. 16. Annual variation of COD concentrations in sub-area A (left) and B (right) during 2002-2011 (red line indicates background value).

4.1.4. Assessment of Category Ⅳ

Red tide by Noctiluca and Mesodinium species

Red tide causative species, *Noctiluca scintillans* forms red tide in inshore and offshore in Korean coasts. However, there was no any report on the occurrence of green *Noctiluca* in Korean coasts, which cause frequent red tide in tropical/subtropical areas. Hence, all of the red-tide events related to *Noctiluca* sp. in this report were targeted on *Noctiluca scintillans.* In addition to *Noctiluca scintillans, Mesodinium rubrum,* frequently forming red tide in inshore area was, also, included in this assessment.

Fig. 17 shows red tide event by *Noctiluca scintillans* and *Mesodinium rubrum* in sub-area A and B during 2001-2011. There were 3 red tide events (2002, 2006, 2008) in total by *Noctiluca scintillans* only in sub-area A during 11 years. The red tide by *Mesodinium rubrum* occurred 1 event in total only in sub-area B for 11 years. The number of red tide event by *Noctiluca scintillans* and *Mesodinium rubrum* was lower than reference value (1 event). No trend for the two red tide species was observed in recent 3 years in both sub-area A and B.

Shellfish poisoning incidents

Only the Paralytic shellfish poisoning (PSP) of shellfish poisoning incidents occurrs in Jinhae Bay. Hence it is a routine work for NFRDI to monitor more than 20 regular monitoring stations around shellfish culture farms within Jinhae Bay, and to ban fisherman from shellfish harvest when PSP toxin level exceeds regulatory level (80ug/100g meats). It has been reported that *Alexandrium tamarense* and *A. catenella* are the major PSP causative species in Korea. Particulary, A*. tamarense* plays a key role as a PSP toxin producer in Jinhae Bay during spring season. Shellfish harvest has been banned for a few cases from March to May since 2004 in sub-area A rather than sub-area B. Any obvious trend of PSP incidents in both sub-area A and B was not observed based on the accessable data from the shellfish monitoring program. In addition, there have not been any offical reports on the patient suffered from PSP intoxication in Jinhae Bay area since 2001.

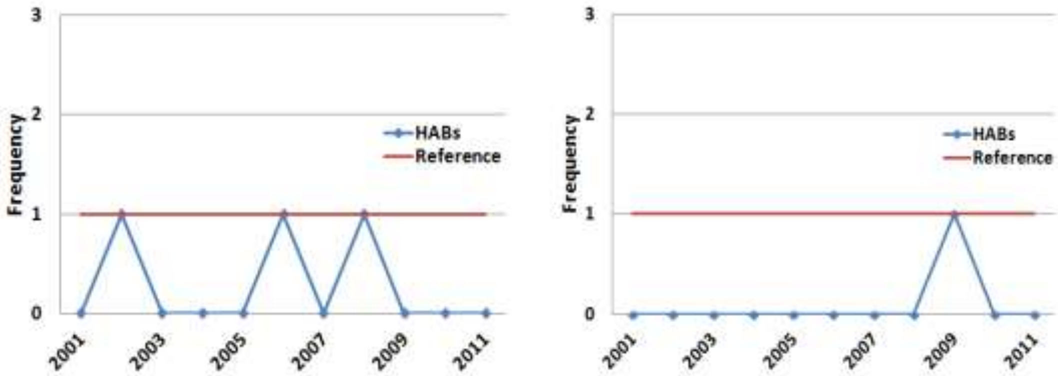


Fig. 17. Number of redtide events by *Noctiluca scintillans* (left in sub-area A) and *Mesodinium rubrum* (right in sub-area B) during 2001-2011.

4. 2. Assessment results

Table 5 and 6 show the results of eutrophication assessment for Jinhae Bay following the assessment procedures (Category I to IV) of CEARAC/NOWPAP. Overall, there were no any remarkable differences between the two sub-areas of Jinhae Bay in the eutrophication status.

For Category I, riverine input of T-N and T-P into sub-area A and B showed decreasing trend and was rated as ‘D’. Both T-N and T-P concentrations showed decreasing trend with higher value than that of background, and were rated as ‘H’ and ‘D’ for both sub-areas. Winter DIN and DIP showed lower value than that of background, and showed decreasing trend. Accordingly, winter DIN and DIP were rated as ‘L’ and ‘D’ for sub-area A and B. The decreasing trend for DIN/DIP ratio was observed in both areas although the value was slightly higher than that of background. Hence, the DIN/DIP was rated as ‘H’ and ‘D’. Considering the status of all the parameters, Category I was rated as ‘HD’ for both sub-area A and B.

For Category II, maximum of Chl-a concentration showed higher value than that of background with no trend for both areas, and was rated as ‘H’ and ‘N’. Mean Chl-a, also, showed higher value than that of background without any distinguishable trend, and was rated as ‘H’ and ‘N’ for both areas. Red tide events by diatoms in both sub-area A and B were lower than reference value (1 event), and showed decreasing trend. Accordingly, enturophication status was rate as ‘L’ and ‘D’. Meanwhile, red tide events by flagellates in both sub-area A and B were higher than reference value (1 event). Although red tide event by flatellates in sub-area B showed decreasing trend, there was no distinguishable trend in sub-area A. Accordingly, red tide status by flagellates was rate as ‘H’ and ‘D’ in sub-area B and ‘H’ and ‘N’ in sub-area A, respectively. Considering the status of all the parameters, the Category II was rated as ‘HN’ in sub-area A and ‘HD’ in sub-area B, respectively.

For Category III, DO (bottom) concentration showed almost similar or slightly higher value than that of background without any distinguishable trend in both sub-area A and B, and was rated as H’ and ‘N’ for both areas. COD (bottom) concentrations in both sub-area A and B were higher than those of background with decreasing trend. However, it was regarded that the COD level was not so absolutely high considering the ranges (1.08-2.24 in sub-area A and 1.52-2.65 in sub-area B). The COD status was rated as ‘H’ and ’D’ for both areas. There was no any report about fish kill incidents in Jinhae Bay during 1993-2011, and the fish kill incidents was rated as ‘L’ and ‘N’ in both sub-area A and B. Considering the status of all the parameters, the Category III was rated as ‘HN’ for both sub-areas.

For Category IV, red tide event by *Noctiluca scintillans* and *Mesoninium rubrum* was low with a record of totally 3 events (2002, 2006, 2008) only in sub-area A and totally 1 event (2009) only in sub-area B, respectively. Accordingly, red tide event by the two species was rated as ‘L’ and ‘N’ in both areas. For shellfish poisoning incidents in Jinhae Bay, Paralitic Shellfish Poisoning (PSP) occurs from March to May repotedly from the shellfish monitoring program targeted on more than 20 regular sampling stations within Jinhae Bay. However, the PSP incidents exceeding regulatory level (80ug/100g meats) was a few case, and there has been no any official reports on the incidents of patient suffered from PSP intoxication in Jinhae Bay since 2001. So, shellfish poisoning incidents was rated as ‘L’ and ‘N’ for both areas. Therefore, the Category IV was rated as ‘LN’ in both areas.

Table 5. Identification of eutrophication status in sub-area A of Jinhae Bay

Category	Assessment parameter	Comparison*	Occurrence	Trend	Parameter identification	Category identification
I	Riverine T-N loads	-	-	D	D	HD
	Riverine T-P loads	-	-	D	D	
	T-N	H	-	D	HD	
	T-P	H	-	D	HD	
	Winter DIN	L	-	D	LD	
	Winter DIP	L	-	D	LD	
	Winter DIN/DIP ratio	H	-	D	HD	
II	Max Chl-a	H	-	N	HN	HN
	Mean Chl-a	H	-	N	HN	
	Red tide (Diatoms)	-	L	D	LD	
	Red tide (Flagellates)	-	H	N	HN	
III	DO (bottom)	H	-	N	HN	HN
	COD (bottom)	H	-	D	HD	
	Fish kill incidents	-	L	N	LN	
IV	Red tide events (*Noctiluca, Mesodinium*)	-	L	N	LN	LN
	Shellfish poisoning incidents	-	L	N	LN	

※ * Comparison : all of the values were compared with background value targeted on Gijang area excluding red tide event (reference value: 1 event) and DO level (reference value: 6mg/L, following OSPAR).

Table 6. Identification of eutrophication status in sub-area B of Jinhae Bay

Category	Assessment parameter	Comparison*	Occurrence	Trend	Parameter identification	Category identification
I	Riverine T-N loads	-	-	D	D	HD
	Riverine T-P loads	-	-	D	D	
	T-N	H	-	D	HD	
	T-P	H	-	D	HD	
	Winter DIN	L	-	D	LD	
	Winter DIP	L	-	D	LD	
	Winter DIN/DIP ratio	H	-	D	HD	
II	Max Chl-a	H	-	N	HN	HD
	Mean Chl-a	H	-	N	HN	
	Red tide (Diatoms)	-	L	D	LD	
	Red tide (Flagellates)	-	H	D	HD	
III	DO (bottom)	H	-	N	HN	HN
	COD (bottom)	H	-	D	HD	
	Fish kill incidents	-	L	N	LN	
IV	Red tide events (*Noctiluca, Mesodinium*)	-	L	N	LN	LN
	Shellfish poisoning incidents	-	L	N	LN	

※ * Comparison : all of the values were compared with background value targeted on Gijang area excluding red tide event (reference value: 1 event).

5. Evaluation of the refined NOWPAP commom procedure

One of the most obvious improvement of the refined NOWPAP Common Procedure is the application of screening procedure before the comprehensive procedure. The screening procedure was focused on three aspects (nutrients input a nd their residence time, high Chl-a concentrations and frequency of red tide events) which could reflect symptoms of eutrophication effects.

In this case study, screening procedure was applied before the comprehensive procedure for the accessement unlike previous case study targeted on the same area of Jinhae Bay. The improvement relies on the identification of eutrophic conditions or symptoms of the Jinhae Bay by both screening procedure and comprehensive procedure. The screening procedure had indicated that Jinhae Bay was a problematic area of eutrophication having high nutrients input high Chl-a concentrations and frequent red tide events in the bay since 1980s. However, the comprehensive procedure applied to Jinhae Bay (sub-area A and B) indicated that ecological effects were not so obvious in spite of relatively high nutrients level compa red to the background area, and the eutrophication status was identified as almost 'Low' based on the assessment for indirect and other possible ecological effects. Degree of other indicators from category I to category IV may have covered the problems related to low DO events and frequent red tide events in the whole assessment results. This results indicate that screening procedure, generally, reflecting representative factors can be a useful tool for the understanding of eutrophication problems by the comparison with the final comprehensive assessment results. Therefore, both the screening procedure and the comprehensive procedure help to identify the evidence and degree of eutrophication.

Another improvement in this case study compared to the previous study was the assessment parameters that reflected different stages and degree of eutrophication more specifically. In this case study, red tide events were assessed along with red tide index species or taxonomic group (Diatoms, Flagellates, *Noctiluca scintillans, Mesodinium rubrum*) even though only the total number of red tide events were included in the previous case study. In general, the red tide events along with taxonomic group represent different stages and degree of bloom events, which can demonstrate the severity and degree of eutrophication conditions in the waterbodies. In addition, the bottom DO and COD instead of surface were used for the assessement of indirect effects of eutrophication (Category III) in this case study. Because those values in the bottom can reflect well rather than those in the surface for the assessment of eutrophication status considering that the levels of DO and COD in the bottom are, in general, worse than in the surface (low DO and high COD values in the bottom), particularly, in summer season when shows quite different values between them.

6. Conclusion and Recommendations

6. 1 Conclusion

Based on the assessment results using the revised NOWPAP Common Procedure, the degree of nutrient enrichment (riverine loads, T-N, T-P, DIN, DIP, DIN/DIP) in Jinhae Bay showed decreasing trend. However, the nutrient concentration of T-N and T-P were still higher than background value even though DIN and DIP concentration were lower than background value in recent years. In particular, T-P concentration in sub-area B was higher than that in sub-area A where Masan and Changwon mega city is located nearby.

The direct effect of nutrient enrichment (Chl-a and red tide events) in Jinhae Bay were higher (in max and mean Chl-a) than background value although red tide events have been steadily decreasing in recent years.

In the indirect effect of nutrient enrichment (DO, COD, fish kill incidents), overall, eutrophication symptoms were not so apparent and degree of ecological effects was low. However, the COD (bottom) level was higher than background value even though the value showed continuously decreasing trend.

In the other possible effects of nutrient enrichment (red tide events by index species, shellfish poisoning), there was no apparent eutrophication symptoms. Along with the decreasing trend of red tide events, the red tide events by the index species (*Noctiluca scintillans* and *Mesodinium rubrum*), also, showed very low number of events unabling to state trend.

Based on the consideration of 4 categories (Category I through Category IV), the eutrophication status of Jinhae was indicated as ‘Low state’ and ‘No trend’ in sub-area A and ‘High state’ and ‘Decreasing trend’ in sub-area B, respectively. In addition, the eutrophication status for sub-area B where Masan and Changwon mega city is located nearby was relatively higher than sub-area A where is comprised of many small Bays such as Jindong, Goseong, Wonmoon and Gohyun Bays with several small cities nearby.

6. 2 Recommendation

The eutrophication status of Jinhae Bay assesed by the revised NOWPAP Common Procedure indicated that sub-area B was relatively higher than sub-area A even though the status was not regarded as so serious and, also, showing steadily decreasing trend. The relatively high eutrophication status in sub-area B was attributed to the strength of anthrophogenic activities and reverine nutrient loads in the area. Considering the report by Cho and Chae (1998) that more than 80% of nutrients in Masan Bay could be land-based source pollutants, higher eutrophication status in sub-area B would be closely related with this geographical characteristic of the area where there are big cities nearby, one of the heavily industrialized cities in Korea.

Korean government has been working intensively towards reducing landbased pollution in Masan Bay since the 1990s by the increase of wastewater treatment plant and intensive dredging activity to remove polluted sediments in the bay during 1990-1994. More recently, a total pollutant load management system (TPLMS) was launched for Masan Bay in 2007 (MLTM, 2008). The main purpose of the TPLMS was to reduce the organic matter from point sources in the watershed and to reduce nitrogen and phosphorus related nutrients through regulating diffuse sources across the watershed by 2020. Based on the report by Chang et. al. (2012), the the water quality of Masan Bay has been steadily improved (Fig. 3 and Fig. 5) since the mid 2000s by the benefit of those policy.

Neverthless, the eutrophication status of Jinhae Bay for several parameters (T-N, T-P, COD and Chl-a) are still showing high level compared to the background values. However, considering the steadily decreasing trend of the eutrophication status in the area, it is anticipated that the water quality of Jinhae Bay will be improved year by year under the ongoing national water quality management activities.

Therefore, it is recommended to implement the national water quality management plan of ‘total pollutant management system (TPLMS)’ on scheduled with a great concern and investment without cessation.

References

Chang, W.K., Ryu, J.S., Yi, Y.J., Lee, W.C., Lee, C.W., Kang, D.S., Lee, C.H., Hong, S.J., Nam, J.H. and Khim J.S, 2012. Improved water quality in response to pollution control measures at Masan Bay, Korea. Marine Pollution Bulletin 64, 427-435.

Cho H. Y. and J. W. Chae. 1998. Analysis of the Characteristics of the pollutant load in Chinhae-Masan Bay. Journal of Korean Society of Coastal and Ocean Engineers. 10(3): 132-140 (in Korean).

Hong, J.S., 1987. Summer oxygen deficiency and benthic biomass in the Chinhae Bay system, Korea. The Journal of the Oceanological Society of Korea 22, 246–256.

Khim, J.S., Koh, C.-H., 2011. Integrated assessment of trace pollutants associated with the Korean coastal environment: exampled from the sediment TIE and triad approaches. Toxicol. Environ. Health Sci. 3 (2), 59–68.

Kim J. H. 1984. Seawater exchange in Chinhae bay Pukyong Nat'l Univ. MS Thesis. 36 pp (in Korean).

Lee, C.K., Park, T.G., Park, Y.T., Lim, W.A., 2013. Monitoring and trends in harmful algal blooms and red tides in Korean coastal waters, with emphasis on *Cochlodinium polykrikoides*. Harmful Algae 30, 3–14.

Lee J. H. 1998. Policy issues and management framework of Chinhae Bay, Republic of Korea. Ocean & Coastal Management. 38: 161-178.

Lee I. C., Y. J. Oh and H. T. kim. 2008. Annual variation in oxygen-deficient water mass in jinhae bay, Korea. J. of. kor. Fish. soc. 41(2): 134-139 (in Korean).

Lim, H.S., Diaz, R.J., Hong, J.S., Schaffner, L.C., 2006. Hypoxia and benthic community recovery in Korean coastal waters. Marine Pollution Bulletin 52, 1517-1526.

Ministry of Land, Transportation and Marine Affairs (MLTM, South Korea), 2008. Basic plan for coastal TMDL in Masan Bay, a special management area (in Korean).

NFRDI, 2013. 2013 annual technical report on fisheries resource and marine environment, Southwest Sea Fisheries Research Institute/National Fisheries Research & Development Institute.

Oh H. T., W. C. Lee. S. E. Park, S. J. Hong, R. H. Jung and J. S. Park. 2006. Marine ecosystem response to nutrient input reduction in Jinhae Bay, South Korea. Journal of Environmental Sciences. 9: 819-827.

OSPAR, 2005. Revised common procedure for the identification of the eutrophication status of the OSPAR Maritime Area. Ref. Numb. 2005-3. OSPAR Commission.

Painting S. J., M.J. Devlin, S.I. Rogers, D.K. Mills, E.R. Parker, H.L. Rees. 2005. Assessing the suitability of OSPAR EcoQOs for eutrophication vs ICES criteria for England and Wales. Marine Pollution Bulletin 50: 1569–1584.

Park S. C., K. W. Lee and Y. I. Song. 1995. Acoustic characters and distribution pattern of modern fine-grained deposits in a tide-dominated coastal bay: Jinhae bay, Southeast Korea. Geo-Marine Letters. 15: 77-84.

Redfield A.C. 1934. On the proportions of organic derivatives in sea water and their relation to the composition of plankton. In: Daniel, R.J. (Ed.), James Johnstone Memorial Volume. University of Liverpool Press, Liverpool, UK, pp. 176-192.

Ryu, J., Leschine, T.M., Nam, J., Chang, W.K., Dyson, K., 2011. A resilience-based approach for comparing expert preferences across two large-scale coastal management programs. J. Environ. Manage. 92, 92–101.

Shin S. Y, C I Lee, S-C. Hwang and K. D. Cho. 2004. Relationship between pollutuion factors and environmental variation in waters around Masan Bay. Journal of the Korean Society of Marine Environment and Safety. 10(2): 69-79 (in Korean).

Smayda, T.J. 1990. Novel and nuisance phytoplankton blooms in the sea: evidence of a global epidemic. In: Grane´ li, E., Sundstrom, B., Edler, L., Anderson, D. (Eds.), Toxic Marine Phytoplankton. Elsevier, pp. 29-40.