A Case Study Report

on Assessment of Eutrophication Status

in Jinhae Bay, Korea

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Contents

1 Introduction of Jinhae Bay

1.1 Geographical Features

Jinhae Bay, located in the south eastern part of Korea, is a semi-closed, coastal embayment surrounded by land and island (Fig.1.1). It is surrounded by big cities like Masan and Changwon city, also several small cities such as Jinhae, Goseong, Tongyeong and Geoje (Fig.1.2). 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 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. The residual current measured at 8 m below the sea surface shows a relatively calm flow and anticlockwise circular flow around Jam Island. 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 (Fig.1.3).

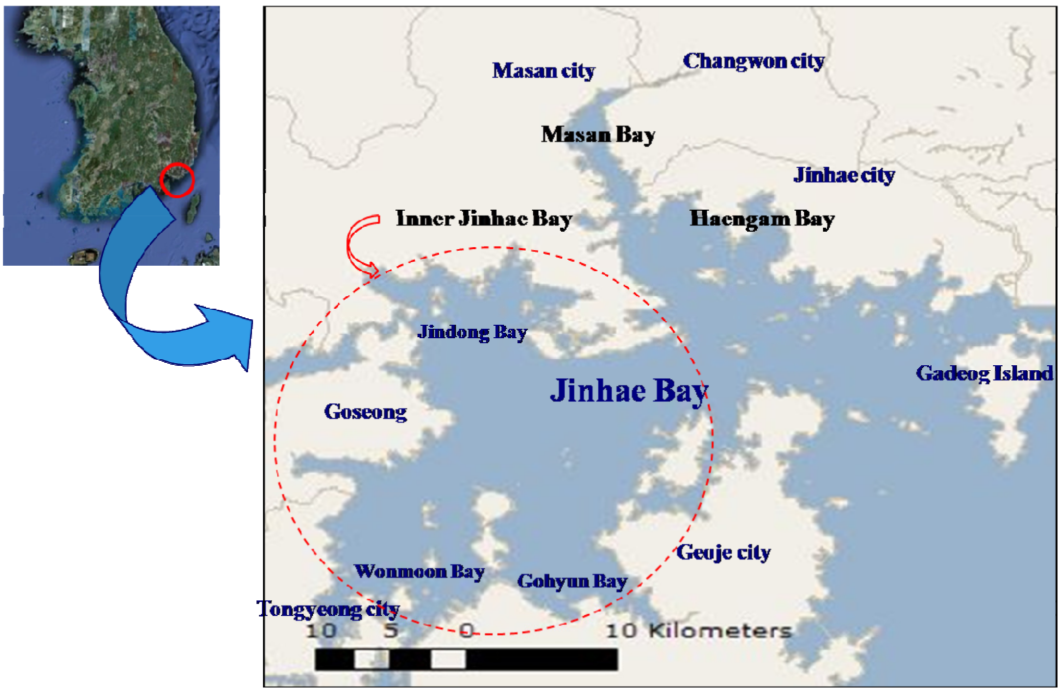
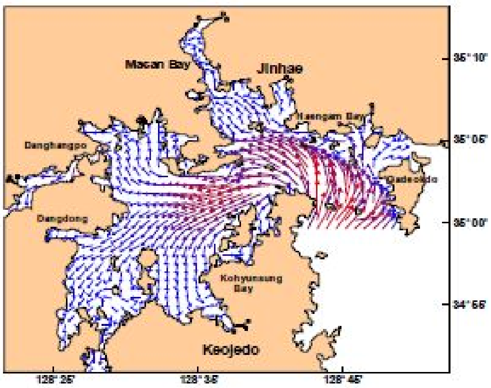


Fig. 1.1 The location of Masan, Haengam and Jinhae Bay.

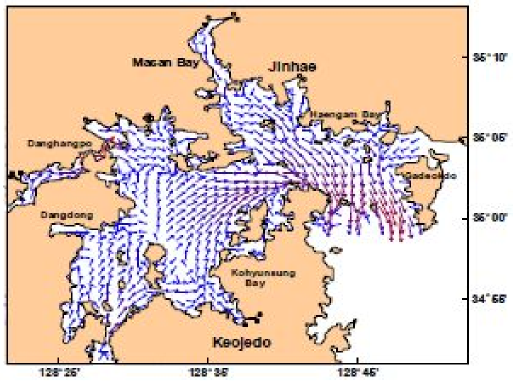
Masan City

Tongyeong City

Fig. 1.2　　Major cities neighboring Masan, Haengam and Jinhae Bay.



(A)



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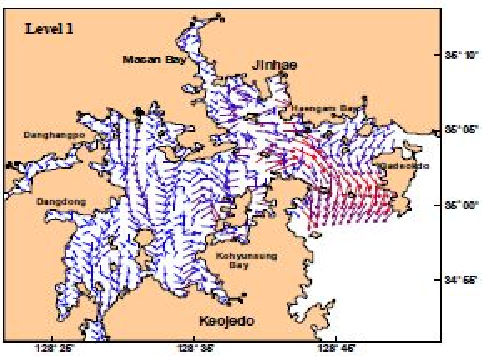

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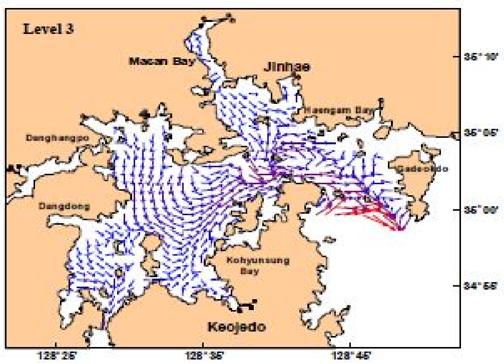

(D)

Fig. 1.3　　The distribution of simulated flood (A) and ebb tides(B), residual current at the sea surface(C), and residual current at the middle waters(D).

Data source: Oh et al. (2006)

1.2 Fishery Features

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 (Fig.1.4). 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 (Table 1.1).

(A) (B) (C)

Fig. 1.4 Aquaculture farms in Jinhae Bay (A, oyster culture farm by hanging system; B, pacific oyster, *Crassostrea gigas*; C, finfish cage culture).

Table 1.1 Fisheries statistics of local government neighboring Jinhae Bay (2007)

	Masan	Jinhae	Goseong	Tongyeong	Geoje	Total
Fisherman's population	3,957	6,677	3,684	9,082	8,848	32,248
Aquaculture farms (ha)	1496	559	1,975	4,539	2,174	10,743
Fisheries production (ton)	22,759	7,792	2,956	3,357	11,402	45,310

1.3 Variations of eutrophication status in Jinhae Bay

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 resulting in massive algal blooms from early 1980s. However, the water quality of Jinhae Bay has been improved with showing remarkable decrease of nutrient loading since Korean government designated Masan Bay as a special marine management area in 1982 under the revision of Korea Marine Pollution Prevention Law (Nam et al., 2005). Also, they divided into three stages of measures to address the environmental problems in Jinhae Bay based on the historical change of environment management policy and investment (Table 1.2).

Table 1.2 State changes and management of eutrophication in Jinhae Bay classified into three stages

1st Stage	*Perception of degradation of coastal environment*
late 1970s to 1983	− Urban development and sewage discharge into the bay were the main causes of water quality deterioration (MOMAF, 2002). − The occurrence of the first large-scale red-tide in Jinhae Bay − Designated the area as a special management area
2nd Stage	*Implementation of management measure*
1984 to 1999	− Construction of a sewage treatment facility with a treatment capacity of 280 thousand tons per day. − Polluted sediments in the bay were dredged and launched research and survey projects to secure scientific data. − Problems: insufficient experiences, lack of a problem-solving approach and a strategic action plan (Kang and Nam, 2003).
3rd Stage	*Introduction of watershed-based and integrated approach*
2000 to present	− The legal mechanism to control land-based activities, management capacity, and raise public awareness of the coastal stakeholders. − Established "Coastal Environment Management Plan of the Masan Bay" in December 2004. − Voluntary activities increased through the participation in the planning process.

1.4 Pollutants loads in Jinhae Bay

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 (Ministry of Environment, 1991). Jinhae Bay has received a variety of waste, including untreated municipal sewage and industrial waste-water for more than 30 years, with an approximate daily average of 3X108 liters/day (Ministry of Environment, 1991).

The water quality of the Jinhae Bay depends on pollutant 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). Cho and Chae (1998) carried out the quantitative analysis on the pollutants loads even though the observed pollutants loads data are not sufficient in the Jinhae Bay. The pollutants loads from Masan and Changwon city and from multi-port diffuser (effluents discharge) into Jinhae Bay amount to 80～90% and 20～25%, respectively.

Table 1.3 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 are 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. Total nitrogen and total phosphorus, also, showed same pattern likewise COD and SS representing that Masan Bay plays a key role in the introduction most of pollutants.

Table 1.3 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 (x1000Ton/day)	3,428.2 (915.9)	779.2 (488.2)	613.4 (417.3)	1,406.4 (1,036.8)	1,543.8 (1,157.1)	835.7 (534.6)	1,328.4 (750.5)
COD loads (x1000Kg/day)	130.5 (73.5)	88.6 (38.8)	54.5 (51.5)	104.3 (89.6)	85.7 (71.1)	95.1 (81.3)	89.8 (75.4)
SS (x1000Kg/day)	97.1 (65.9)	25.9 (13.5)	34.9 (27.0)	103.2 (89.6)	33.0 (20.3)	30.4 (15.5)	56.8 (42.5)
Total-Nitrogen (x1000Kg/day)	32.1 (17.8)	29.7 (19.2)	28.8 (21.5)	32.9 (23.7)	26.5 (17.2)	27.3 (20.2)	29.7 (20.5)
Total-Phosphorus (x1000Kg/day)	2.76 (1.36)	1.42 (0.85)	1.75 (1.24)	2.89 (2.07)	2.54 (1.50)	1.79 (1.01)	2.23 (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.

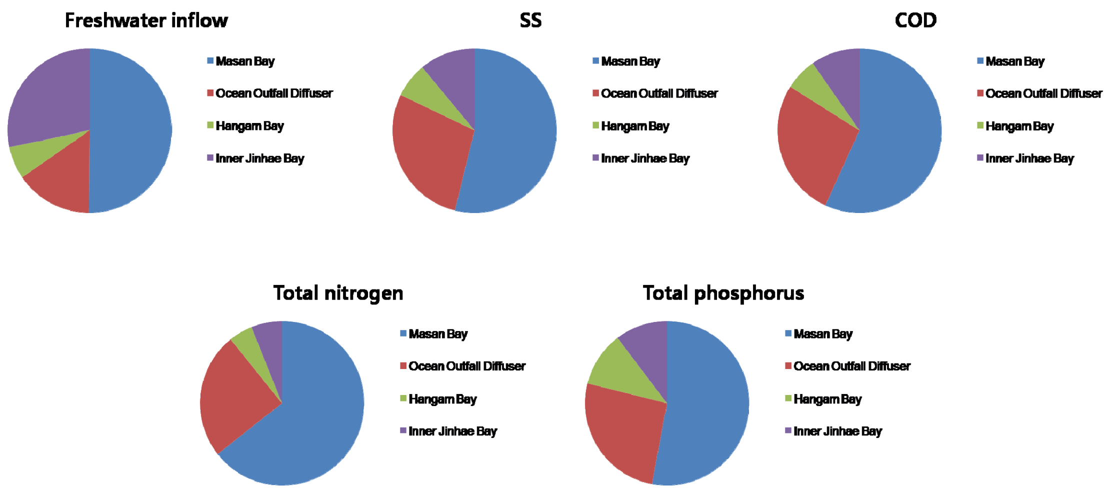

Fig. 1.5 Contribution rate in the introduction of freshwater inflow and pollutants loads in Jinhae Bay (Cho H. Y. and J. W. Chae, 1998).

2 Method

2.1 Data used in this report

There are many survey reports on the eutrophication of Jinhae Bay published by universities or research institutes. NFRDI(National Fisheries Research and Development Institute) is a key responsible organization conducting routine monitoring program related to the eutrophication of Jinhae Bay under which 'coastal environment monitoring' aiming at conservation of coastal environment since 1984, 'HAB monitoring' aiming at early warning and prediction of HAB to minimize fisheries impact since 1979, and 'shellfish monitoring' aiming at early detection of shellfish toxin for food safety since 1992 have been conducted (Table 2.1). Most of the data used in this report are from those monitoring programs conducted by NFRDI in Jinhae Bay.

Table 2.1 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 level)	19

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

Also, Table 2.2 shows the locality of 14 stations for coastal environment monitoring program.

Table 2.2 Latitude and longitude of sampling stations

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

Table 2.3 shows assessment parameters used in this report. All the available data collected by NFRDI was used for the assessment. The duration for the assessment of red-tide events and environmental water quality was 1981~2008 and 2002~2008, respectively. The duration year for the assessment of riverine input(T-N, T-P) was relatively short, from 1995 to 1996, due to the lack of available data.

Table 2.3 Information of assessment parameters used in Jinhae and Masan-Haengam Bay.

Category		Assessment parameter	
Ⅰ	Degree of nutrient enrichment	Riverine input (T-N, T-P)	1995 - 1996
		Total nitrogen/Total phosphorus (T-N, T-P)	2002 - 2008
		Winter (DIN/DIP) concentration	2002 - 2008
		Winter N/P ratio (DIN/DIP)	2002 - 2008
Ⅱ	Direct effects of nutrient enrichment	Chlorophyll-a concentration (field data)	2002 - 2008
		Chlorophyll-a concentration (remote sensing data)	Not applicable (low resolution)
		Ratio of area with high Chlorophyll-a concentration to the total area	2002 - 2008
		Red –tide events (diatom and dinoflagellate species)	1981 - 2009
Ⅲ	Indirect effects of nutrient enrichment	Dissolved oxygen (DO)	2002 - 2008
		Abnormal fish kill incidents	- 2008
		Chemical oxygen demand (COD)	2002 - 2008
Ⅳ	Other possible effects of nutrient enrichment	Red-tide events (Noctiluca sp.)	1981-2009
		Shellfish poisoning incidents	1980-

Eutrophication assessment for Jinhae Bay was obtained based on total mean value in Jinhae Bay including small Bays such as Goseong, Wonmoon, Jindong, Gohyun, Masan, Haengam Bays. However, degree of nutrient enrichment and direct effects of nutrients enrichment for Masan-Haengam Bay was added separately considering that Masan-Haengam Bay was relatively eutrophicated with the direct influence from land-based nutrient.

In addition, for the obtaining of background values as a contrast with Jinhae Bay and Masan-Haengam Bay, water quality data for Gijang coast was used in this report. Gijang coast, about ten kilometers away to the east from Busan city, is the place where has little effect from land-based nutrient source and facing open sea rather than embayment. Also, the place shows quite constant salinities more than 33 psu almost all the year due to the influence of Tsushima 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.

3 Results and Assessment

3.1 Category Ⅰ: Degree of nutrient enrichment

3.1.1 Total nitrogen/Total phosphorus

Fig. 3.1 shows the variation of annual mean and background values for T-N and T-P in the surface water of Jinhae Bay from 2002 to 2008. The annual mean values were obtained from the yearly average values for 9 stations within Jinhae Bay including small bays such as Goseong, Wonmoon, Jindong, Gohyun, Masan and Haengam Bays. The annual mean values for T-N and T-P in Jinhae Bay showed slightly decreasing trend since 2002, ranging 0.3~0.7 ㎎/L, 0.04~0.09 ㎎/L in T-N and T-P, respectively. Mean values of T-N and T-P in 2008 decreased 50% and 51%, respectively, compared to 2002. In order to identify current status of eutorphication in Jinhae Bay based on T-N and T-P, Gijang coast as contrast, was used for the background values.

Annual ranges of T-N and T-P in the surface water of Gijang coast from 2004 to 2008, targeted for background values, was 0.21~0.34 ㎎/L and 0.022~0.036 ㎎/L, respectively. In comparison with background values, current status of eutrophication in Jinhae Bay was classified as 'high' considering that the mean values of T-N and T-P in Jinhae Bay from 2004 to 2008 showed more than 150% of background values.

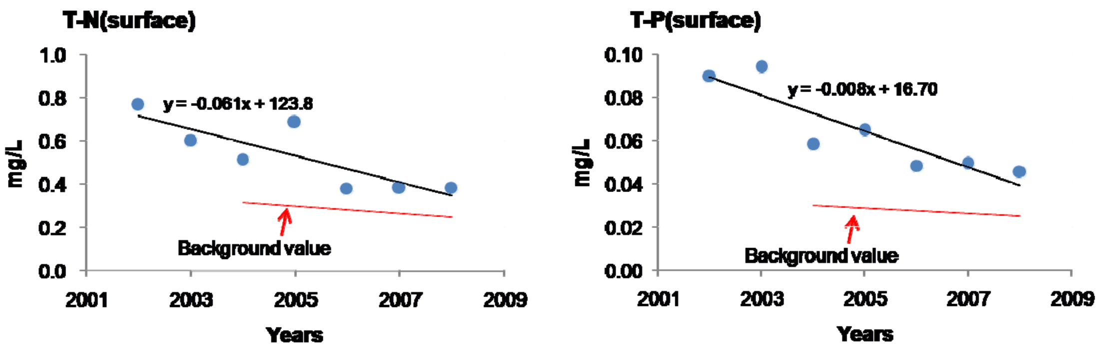

Fig. 3.1 The variation of Total-Nitrogen and Total-Phosphorus mean values in Jinhae Bay (2002~2008).

Fig.3.2 shows the variation of annual mean and background values for T-N and T-P in the surface water of Masan-Haengam Bay from 2002 to 2008. The annual mean values for T-N and T-P in Masan-Haengam Bay showed slightly decreasing trend since 2002, ranging 0.49~0.21 ㎎/L, 0.06~0.15 ㎎/L in T-N and T-P, respectively. Mean values of T-N and T-P in 2008 decreased to 40% and 38%, respectively, compared to 2002. In order to identify current status of eutorphication in Masan-Haengam Bay based on T-N and T-P, Gijang coast as contrast, was used for the background values. Current status of eutrophication in Jinhae Bay was classified as 'high' considering that the mean values of T-N and T-P in Masan-Haengam Bay from 2004 to 2008 showed more than 250% of background values.

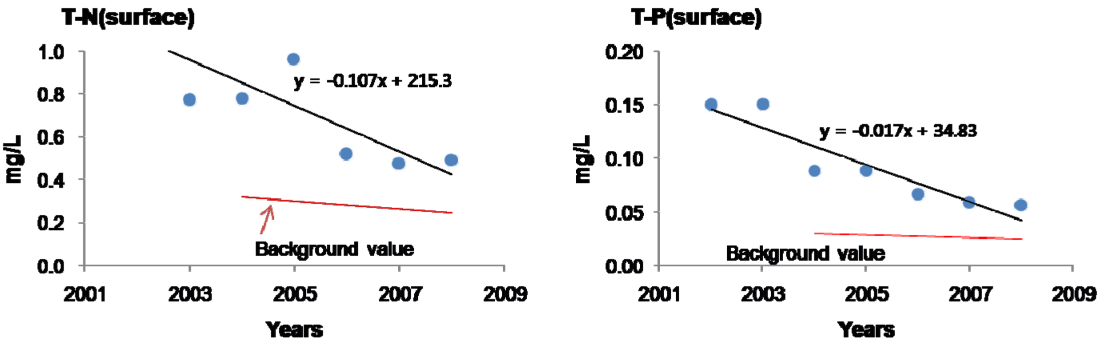

Fig. 3.2 The variation of Total-Nitrogen and Total-Phosphorus mean values in Masan-Hangam Bay (2002~2008).

Fig.3.3 shows spatial distribution of Total-Nitrogen and Total-Phosphorus mean values in the surface water of Jinhae Bay for 5 years from 2004 to 2008 (14 stations). The mean values of T-N and T-P showed high value in Masan Bay where is directly affected by nearby Masan city. However, the mean values of T-N and T-P in Jinhae Bay (less than 0.35 ㎎/L and 0.04 ㎎/L in T-N and T-P, respectively) was similar or slightly higher than background value in Gijang area of 5 years mean value (T-N, 0.28 ㎎/L; T-P, 0.027 ㎎/L).

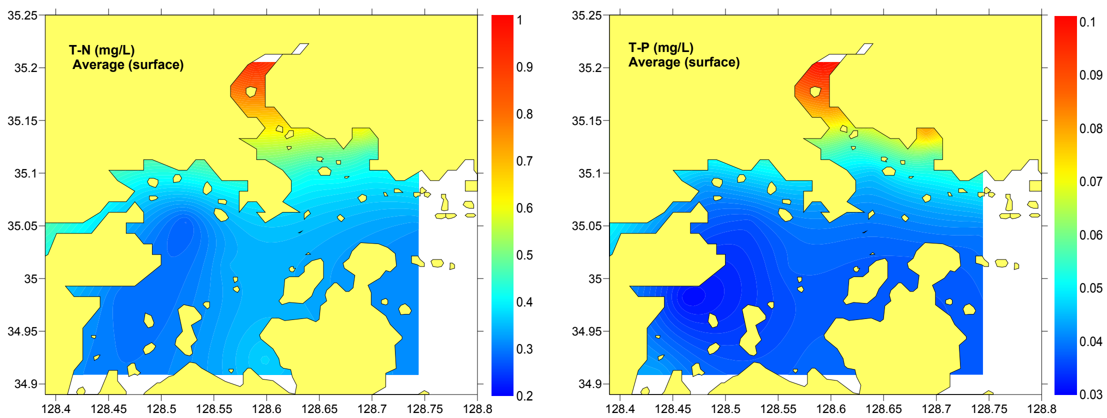

Fig. 3.3 The spatial distribution of Total-Nitrogen and Total-Phosphorus mean values in Jinhae Bay (2004~2008).

3.1.2 Winter DIN/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 an important role in the regulation of phytoplankton growth. 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/DIP level in winter, least affected season by biological activities, is a key parameter in the identification of nutrient enrichment state.

Fig.3.4 shows the variation of mean values of winter DIP/DIN in Jinhae Bay from 2002 to 2008 with the inclusion of background value. Annual DIN and DIP mean values were obtained from the average values for 9 stations in Jinhae Bay. Winter DIN and DIP level in Jinhae Bay, ranging 0.06~0.36 ㎎/L and 0.01~0.03 ㎎/L, respectively, showed decreasing trend over times since 2002 likewise in T-N and T-P. The mean values of winter DIN and DIP in 2008 decreased to 19% and 34%, respectively, compared to 2002.

In order to identify eutorphication status in Jinhae Bay based on winter DIN and DIP, background values for Gijang coast as a contrast were used. In comparison with background values for winter DIN and winter DIP, current status of eutrophication in Jinhae Bay was classified as ‘low’ considering that the mean values of winter DIN and winter DIP was similar or lower than that of background value since 2004 or 2005.

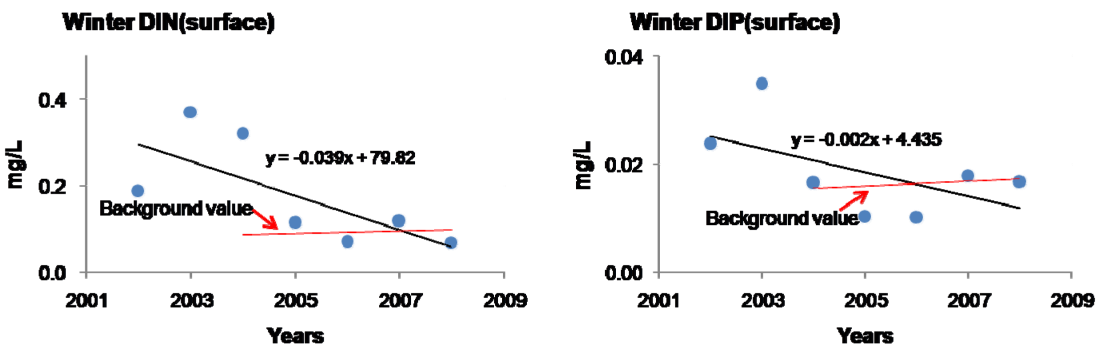

Fig. 3.4 The variation of winter DIN and DIP mean values in Jinhae Bay (2002~2008).

Fig. 3.5 shows the variation of mean values of winter DIP/DIN in Masan-Hangam Bay from 2002 to 2008 with the inclusion of background value. Winter DIN and DIP level in Masan-Haengam Bay, ranging 0.05~0.45 ㎎/L and 0.01~0.07 ㎎/L, respectively, showed decreasing trend over times since 2002 likewise in T-N and T-P. The mean values of winter DIN and DIP in 2008 decreased to 7% and 16%, respectively, compared to 2003.

In order to identify eutorphication status in Masan-Haengam Bay based on winter DIN and DIP, background values for Gijang coast as a contrast was used. In comparison with background values for winter DIN and winter DIP, current status of eutrophication in Masan-Haengam Bay was classified as 'low' considering that the mean values of winter DIN and winter DIP was similar or lower than that of background value since 2004 or 2005.

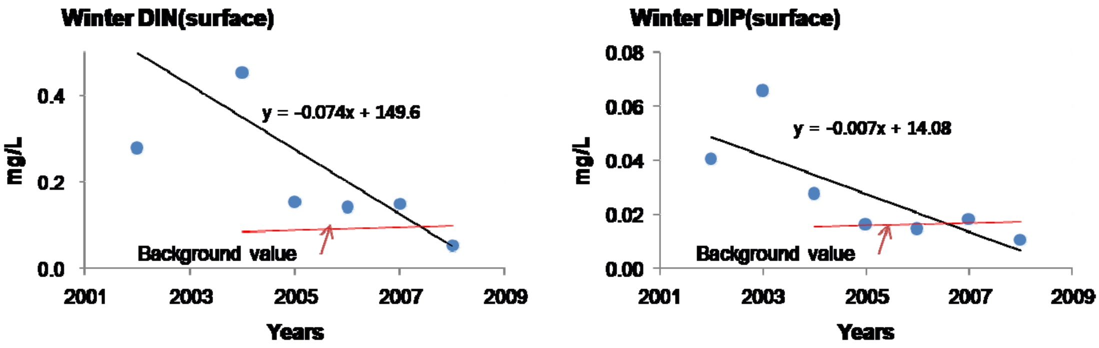

Fig. 3.5 The variation of winter DIN and DIP mean values in Masan-Haengam Bay (2002~2008).

Fig. 3.6 shows the spatial distribution of mean values of winter DIP/DIN in the surface water of Jinhae Bay for 5 years from 2004 to 2008 (14 stations). Likewise in T-N and T-P, the mean values of winter DIN and DIP showed high value in Masan Bay where is directly affected by nearby Masan city. However, the mean values of DIN and DIP in Jinhae Bay (less than 0.15 ㎎/L and 0.018 ㎎/L in DIN and DIP, respectively) was similar or slightly higher than background value in Gijang area of 5 years mean value (DIN, 0.09 ㎎/L; DIP, 0.016 ㎎/L).

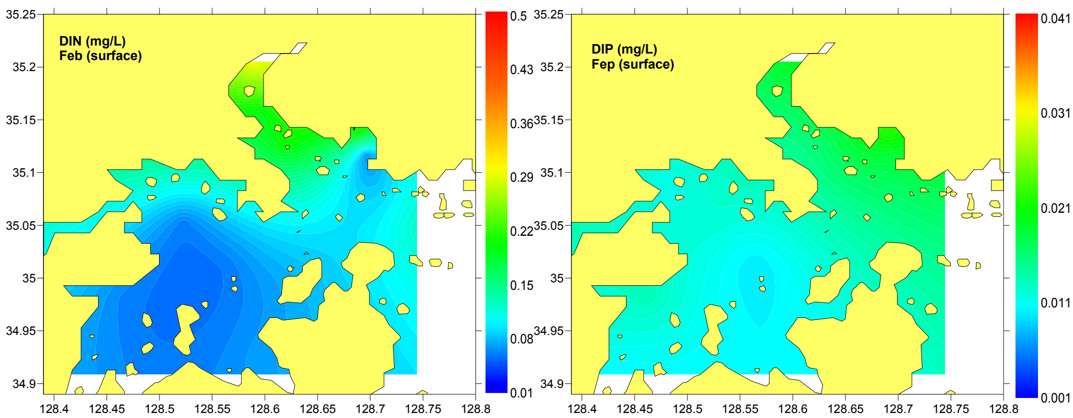

Fig. 3.6 The spatial distribution of DIN and DIP mean values in Jinhae Bay (2004~2008).

3.1.3 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). Thus 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 is 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. 3.7 shows the variation of winter N/P ratio in the surface water of Jinhae Bay from 2002 to 2008. The mean values of annual N/P ratio were obtained from the average values for 9 stations within Jinhae Bay including several small bays. Winter N/P ratio in Jinhae Bay has shown decreasing trend in recent years. Although winter N/P ratio showed higher value than Redfield ratio (16:1) during 2002-2005, it showed almost similar or slightly lower value thereafter. Accordingly, in comparison with background values for N/P ratio, current status of eutrophication in Jinhae Bay was classified as 'low'.

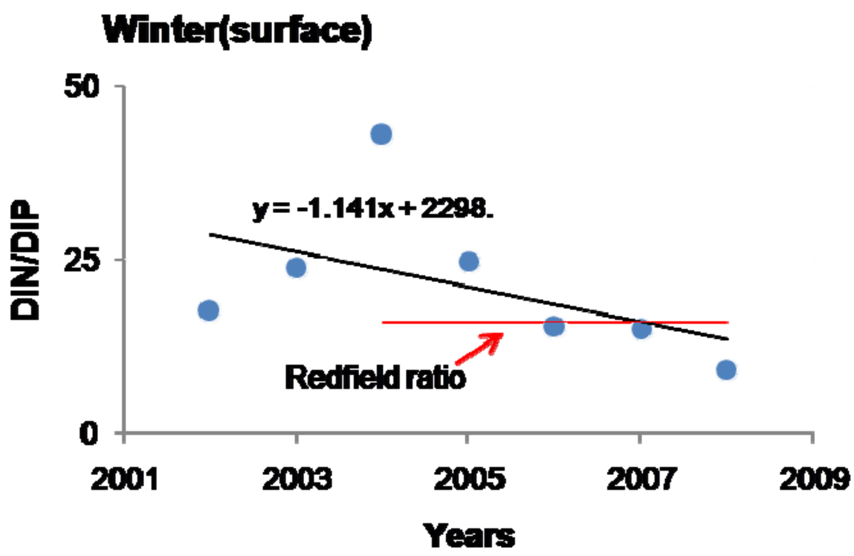

Fig. 3.7 The variation of winter N/P ratio mean values in Jinhae Bay (2002~2008).

Fig. 3.8 shows the variation of winter N/P ratio in the surface water of Masan-Hangam Bay from 2002 to 2008. Winter N/P ratio has shown decreasing trend in recent years. Although winter N/P ratio showed higher value than Redfield ratio (16:1) during 2003-2007, it showed almost slightly lower value thereafter. Hence, in comparison with background values for N/P ratio, current status of eutrophication in Masan-Hangam Bay was classified as 'low'.

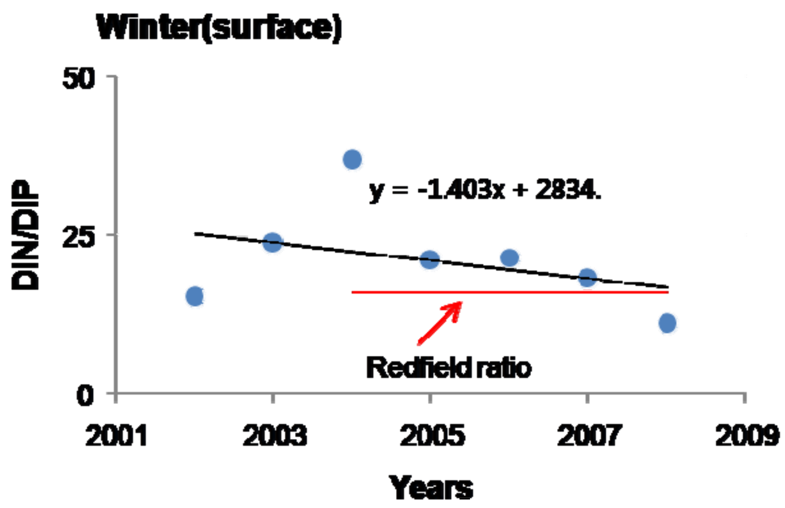

Fig. 3.8 The variation of winter N/P ratio mean values in Masan-Haengam Bay (2002~2008).

Fig. 3.9 shows the spatial distribution of winter N/P ratio mean values in Jinhae Bay for 5 years from 2004 to 2008 (14 stations). Winter N/P ratio showed much higher than Redfield ratio in Masan Bay where there were frequent red-tides by dinoflagellates such as *Heterosigma akashiwo*, *prorocentrum* spp. However, winter N/P ratio in inner-Jinhae Bay, ranging 11~17, shows similar or lower than Redfield ratio, which meets 'ecological quality objective' suggested by OSPAR (2001, 2002) at which winter N/P ratio is recommended not to exceed 25:1.

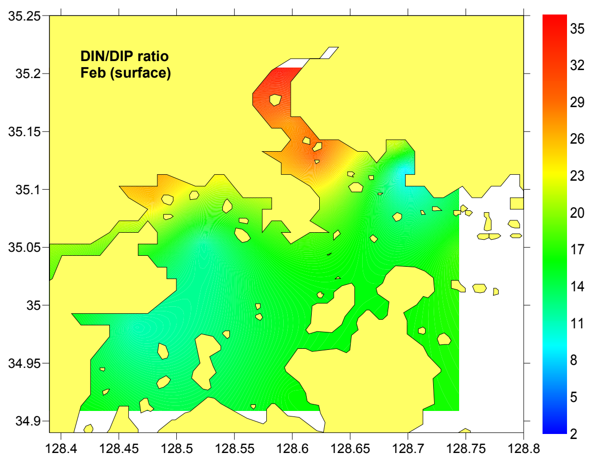

Fig. 3.9 The spatial distribution of winter N/P ratio mean values in Jinhae Bay (2004~2008).

3.2 Category Ⅱ: Direct effects of nutrients enrichment

3.2.1 Chlorophyll-a concentration (field data)

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. Phytoplankton chlorophyll-a concentration in relatively clear coastal and offshore waters are likely to be sensitive to management of nutrient inputs, but less so in water bodies where phytoplankton growth is limited such as light controlled such as grazing (Painting, 2005).

Fig. 3.10 shows the variation of mean values of chlorophyll-a concentration in Jinhae Bay from 2002 to 2008. Annual Chlorophyll-a mean values were obtained from the average values for 9 stations within Jinhae Bay including several small Bays. Chlorophyll-a mean values in Jinhae Bay has shown gradual decreasing trend over time since 2002. Chlorophyll-a mean values ranged 6.2~10.2 ㎍/L for 7 years with showing relatively high value in 2003 and 2006. Contrary to T-N/T-P and winter DIN/DIP, Chlorophyll-a showed slightly higher value than background value obtained from Gijang area. High chlorophyll-a value in Jinhae Bay was estimated to be closely related to the frequency and long duration of red-tides formed by various dinoflagellates frequently from spring to autumn. However, red-tides are very few in Gijang area even though dinoflagellate, *Cochlodinium* sometimes makes bloom in summer season.

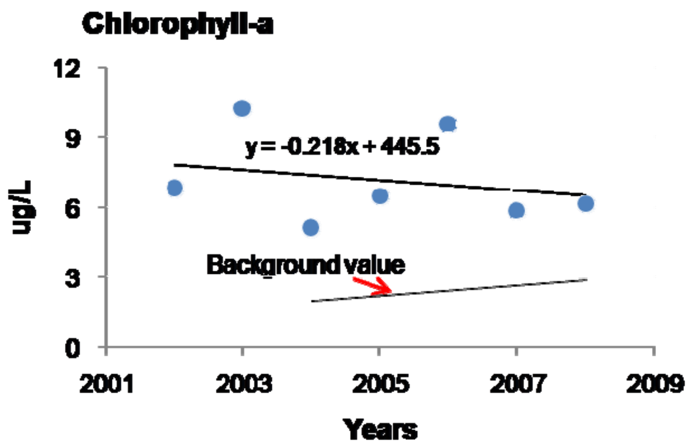

Fig. 3.10 The variation of chlorophyll-a concentration mean values in Jinhae Bay (2002~2008).

Fig. 3.11 shows the variation of mean values of chlorophyll-a concentration in Masan-Haengam Bay from 2002 to 2008. Overall, chlorophyll-a mean values in Masan-Haengam Bay didn't show any remarkable trend during the period. Chlorophyll-a mean values ranged 8.8~20.2 ㎍/L for 7 years with showing relatively high value in 2007. Contrary to T-N/T-P and winter DIN/DIP, Chlorophyll-a showed higher value than background value obtained from Gijang area. Accordingly, in comparison with background values for chlorophyll-a, current status of eutrophication in Masan-Haengam Bay was classified as 'high'.

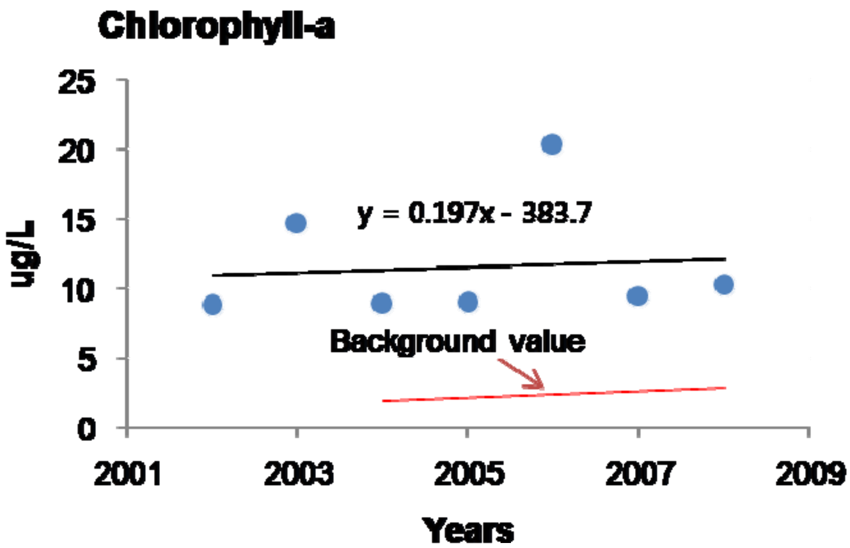

Fig. 3.11 The variation of chlorophyll-a concentration mean values in Masan-Haengam Bay (2002~2008).

3.2.2 Ratio of area with high chlorophyll-a concentration to the total area

Fig. 3.12 shows the spatial distribution of chlorophyll-a concentration in Jinhae Bay for 5 years from 2004 to 2008 (14 stations). Likewise in nutrient (T-N/T-P and winter DIN/ DIP), chlorophyll-a mean values showed high value (8~14 $\mu g/L$) in Masan Bay where is directly affected by Masan city and suffering from frequent red-tides. However, chlorophyll-a mean values in Jinhae Bay with a range of 1.6~3.2 $\mu g/L$ showed similar level to background value in Gijang area. In addition, the highest chalorophyll-a concentration was showed in Masan Bay. The ratio of area with high Chorophyll-a concentration to the total area was less than 5%.

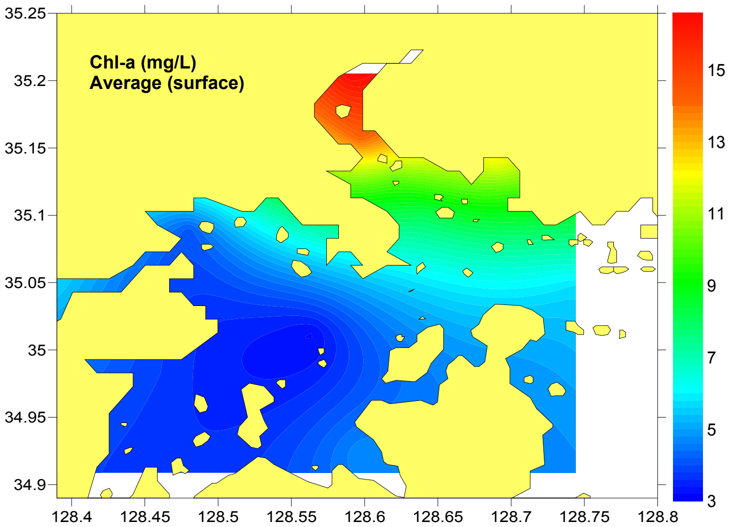

Fig. 3.12 The spatial distribution of chlorophyll-a concentration mean values in Jinhae Bay (2004~2008).

3.2.3 Red-tide events (diatom species)

Fig. 3.13 shows the variation of red-tide events in Jinhae Bay from 1981 to 2008. Red-tide events showed higher number in 1980s (11~21 events, mean 14.7 events) than in 1990s (5~21 events, mean 10.6 events) and 2000s (2-13 events, mean 8.9 events) with showing the highest in 1985 (21 events) and the lowest in 2008 (2 events). Concerning red-tide causative organisms, dinoflagellate was more responsible for red-tide than diatom for the three decades from 1981 to 2008. Annual diatom red-tide events were 0~9 times in the same period. Bloom occupation rate by diatom for the three decades has gradually decreased by showing 8~50% (mean 29%), 0~29% (mean 17%) and 0~43% (mean 13%) in 1980s, 1990s and 2000s, respectively.

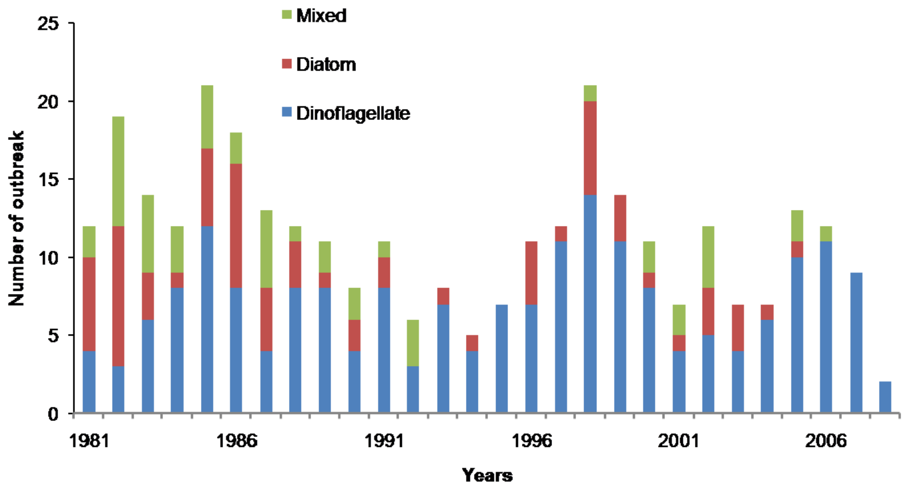

Fig. 3.13 Number of redtide events in Jinhae Bay from 1981 to 2008.

Fig. 3.14 shows the decadal succession of red-tide causative species in Jinhae Bay since 1970s. In 1970s, *Skeletonema coastatum, Chaetoceros spp., Pseudo-nitzschia spp. and Leptocylindrus danicus* in diatom were the key red-tide causative species by occupying more than 80% of total red-tide events. However, there has been succession of red-tide causative species since 1980s. *Heterosigma akashiwo* and *Prorocentrum* spp. and *Ceratium* spp. in dinoflagellate, which had been minor red-tide causative species in 1970s by occupying less than 20% of total red-tide events, became the key red-tide causative species in 1990s and 2000s with showing more than 45% of occupancy of total red-tide events.

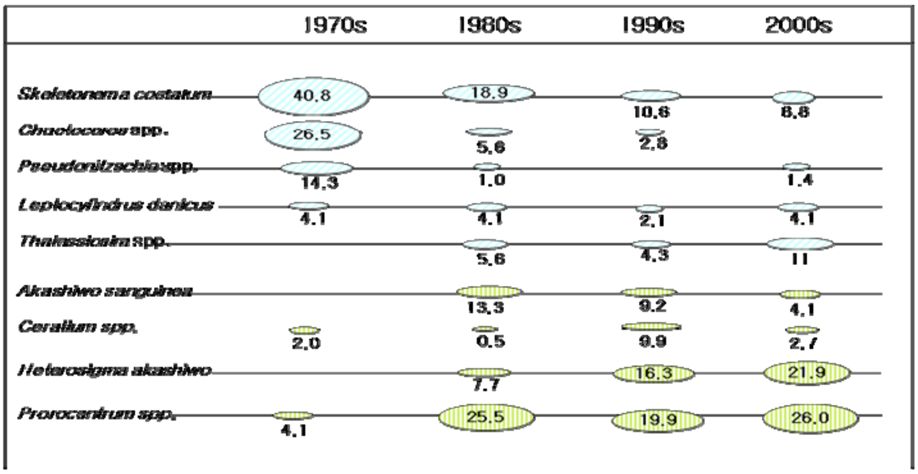

Fig. 3.14 Decadal succession of redtide causative species in Jinhae Bay.

Fig. 3.15 shows species succession of red-tide causative diatom in Korean coasts since 1999. *Skeletonema costatum* and *Thalassiosira* spp. were still major red-tide causative diatoms with showing 46% and 23% of red-tide occupancy, respectively, among other diatom species for 2004~2008. Also, it was remarkable that red-tide by *Chaetoceros* spp. and *Rhizosolenia* spp. sharply decreased, and on the contrary, red-tide by *Pseudo-nitzschia* spp., well known to be amnestic shellfish poisoning species, drastically increased to 23% in 2004-2008 from 7% in 1999~2003.

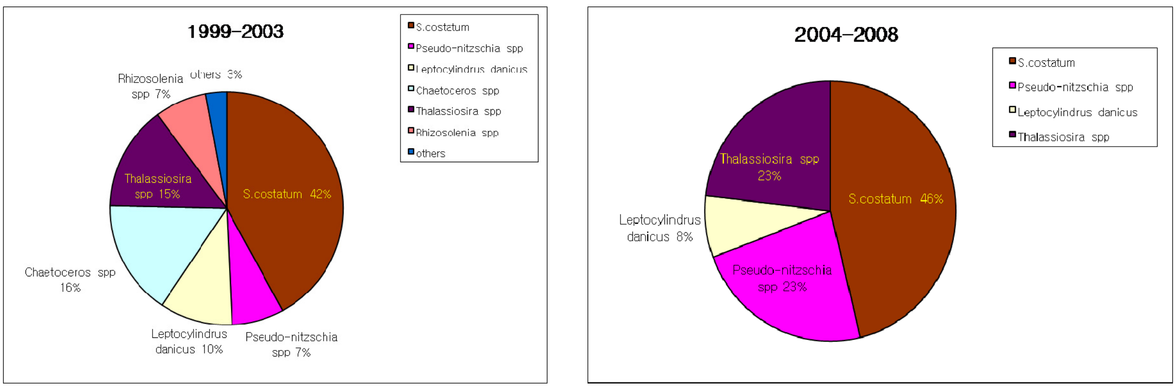

Fig. 3.15 Species succession of redtide causative diatom in Korean coast since 1999.

3.3 Category Ⅲ: Indirect effects of nutrients enrichment

3.3.1 Dissolved oxygen

Major factors that affect on the variation of dissolved oxygen are biological activity and hydrodynamic process of sea water in the coasts. Generally, 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 coasts. Hence, degree of oxygen depletion is widely used as indirect assessment parameters for nutrient enrichment. Also, hypoxia condition occurs in the bottom layer from spring to summer season. These low oxygen concentrations may, in turn, result in changes in fish behavior or kills in zoo-benthos and/or fish species (Painting et al., 2005). The revised common procedure for the identification of the eutrophication status of the OSPAR maritime area (OSPAR, 2005), identifies oxygen depletion as an indirect effect of nutrient enrichment. OSPAR 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 (2005).

Fig. 3.16 shows the variation of mean value of DO (Dissolved Oxygen) in the surface of Jinhae Bay from 2002 to 2008. The annual mean values of DO were obtained from the average values for 9 stations in Jinhae Bay including several small Bays. DO level in the surface layer showed slightly increasing trend. Mean values of DO was higher in surface than in bottom by ranging 8~10 ㎎/L, which shows more than critical point of 6 ㎎/L under which marine animals are suffering from oxygen depletion suggested by OSPAR (2005).

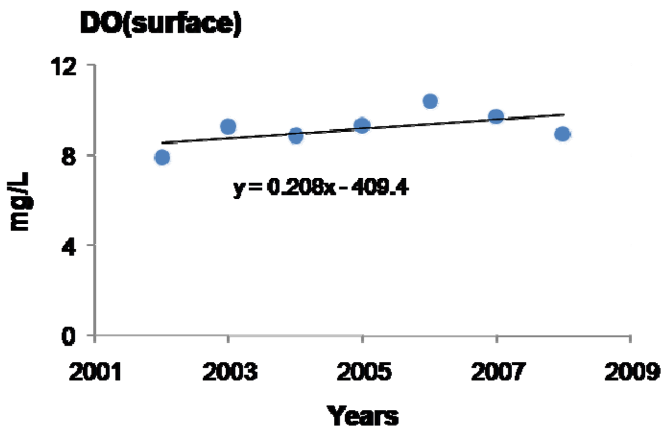

Fig. 3.16 Variation of mean values of DO concentrations in Jinhae Bay (2002~2008).

Fig. 3.17 shows the variation of mean value of DO (Dissolved Oxygen) in Masan-Haengam Bay from 2002 to 2008. Likewise in Jinhae Bay, DO level in the surface layer showed slightly increasing trend. Mean value of DO in the surface layer ranged 8~10 ㎎/L showing higher level than critical point of 6 ㎎/L under which marine animals are suffering from oxygen depletion suggested by OSPAR (2005).

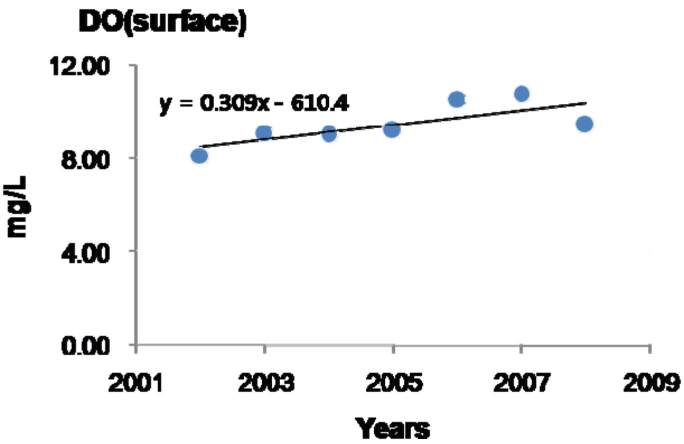

Fig. 3.17 Variation of mean values of DO concentrations in Masan-Haengam Bay (2002~2008).

Fig. 3.18 shows spatial distribution of DO values in Jinhae Bay for 5 years from 2004 to 2008 (14 stations). DO values was the highest (surface, 7.8~10.4 ㎎/L) in Haegam Bay where is directly influenced by off-shore water among other areas within Jinhae Bay. The rest of the areas, also, showed relatively high DO values with showing more than 8 ㎎/L in the surface.

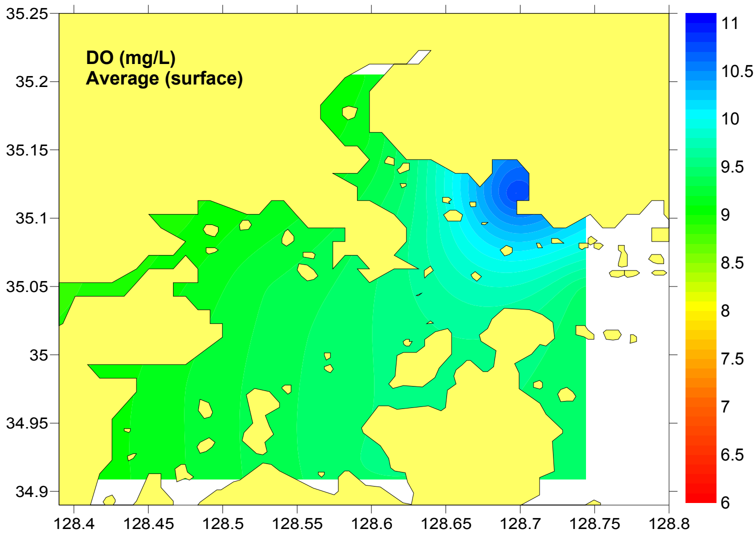

Fig. 3.18 The spatial distribution of DO values in Jinhae Bay (2004~2008).

3.3.2 Abnormal fish kill incidents

There have been frequent fish kills in Korean coast due to the red-tide mostly by *Cochlodinium polykrikoides* since 1993. However, the fish-killing species, *C. polykrikoides* never made any dense blooms in Jinhae Bay. Herein, there has not been any fish kill incidents in Jinhae since 1970s.

3.3.3 Chemical oxygen demand (COD)

The value of COD shows the oxygen equivalent of the organic content that can be oxidized by potassium dichromate ($K_2Cr_2O_7$) using silver sulfate (Ag_2SO_4) as a catalyst under acidic conditions (APHA, 1999). 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. 3.19 shows the variation of COD mean values in Jinhae Bay from 2002 to 2008 and background value. The annual mean values of COD were obtained from the average values for 9 stations in Jinhae Bay including several small Basys. COD level in the surface layer of Jinhae Bay showed slightly decreasing trend during 2002-2008 likewise in T-N/T-P. Overall, COD values in surface of Jinhae Bay showed about two times higher than background value in Gijang area of contrast. Accordingly, in comparison with background values for COD, current status of eutrophication in Jinhae Bay was classified as 'High'. The high COD values in Jinhae Bay compared to background values was estimated to be related to the high amount of organic substances including phytoplankton biomass likewise in chlorophyll-a.

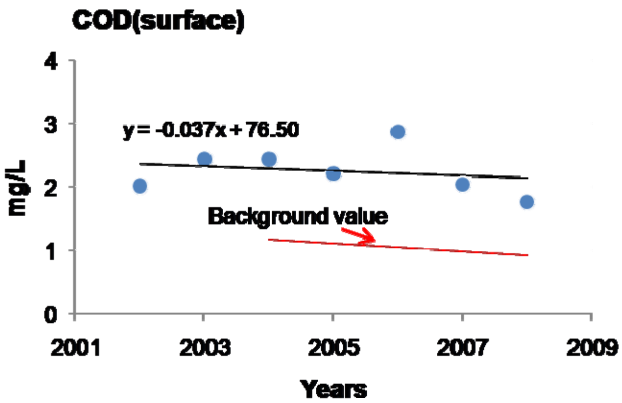

Fig. 3.19 Variation of mean values of COD concentrations in Jinhae Bay (2002~2008).

Fig. 3.20 shows the variation of COD mean values in Masan-Haengam Bay from 2002 to 2008. There was no any remarkable trend in COD mean values in Masan-Haengam Bay for 7 years excluding year 2008 when showed slightly decreased value than previous year. Overall, COD values in the surface of Masan-Haengam Bay showed about two times higher than background value obtained from Gijang area of contrast. Hence, in comparison with background values for COD, current status of eutrophication in Masan-Haengam Bay was classified as 'High'. Overall, higher COD values in Masan-Haengam Bay than background values was estimated to be related to higher amount of organic substances including phytoplankton biomass likewise in chlorophyll-a.

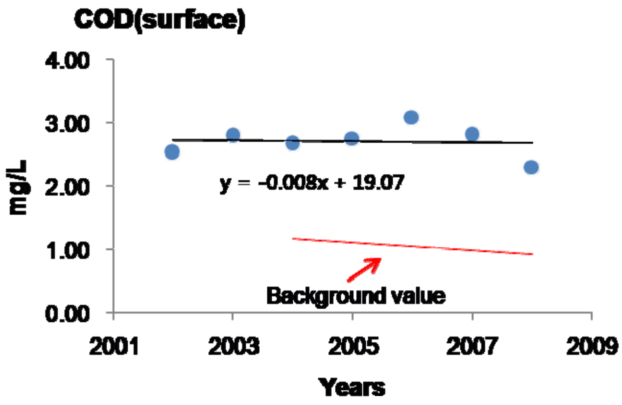

Fig. 3.20 Variation of mean values of COD concentrations in Masan-Haengam Bay (2002~2008).

Fig. 3.21 shows spatial distribution of COD values in Jinhae Bay for 5 years from 2004 to 2008 (14 stations). COD showed highest value in Masan Bay where is directly influenced by Masan city likewise other parameters such as T-N/T-P, winter DIN/ DIP and chlorophyll-a. Mean while, COD in Jinhae Bay (surface, 2.0 ㎎/L) showed higher values than background values in Gijang area (surface, 1.0 ㎎/L).

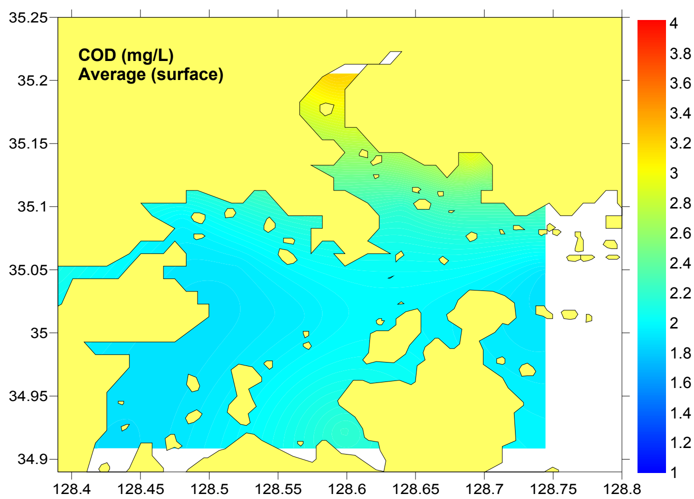

Fig. 3.21 The spatial distribution of COD values in Jinhae Bay (2004~2008).

3.4 Category Ⅳ: Other possible effects of nutrient enrichment

3.4.1 Red-tide (Noctiluca sp.)

Red-tide causative species, *Noctiluca scintillans* frequently 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.*

Fig. 3.22 shows annual red-tide events by *Noctiluca scintillans* in Jinhae Bay from 1985 to 2008. Annual red-tide events during the period ranged 0~4 events. The number of annual red-tide events before 2000 was relatively high (0~4 events) with showing highest number in 1993 (4 events). However, the red-tide number has sharply decreased since 2001 with showing at best one event a year. Particularly, there were only 3 events (2002, 2006, 2008) during 2001-2008. Hence, the trend of red-tide events by *Noctiluca scintillans* in Jinhae Bay has been decreasing since 2000s.

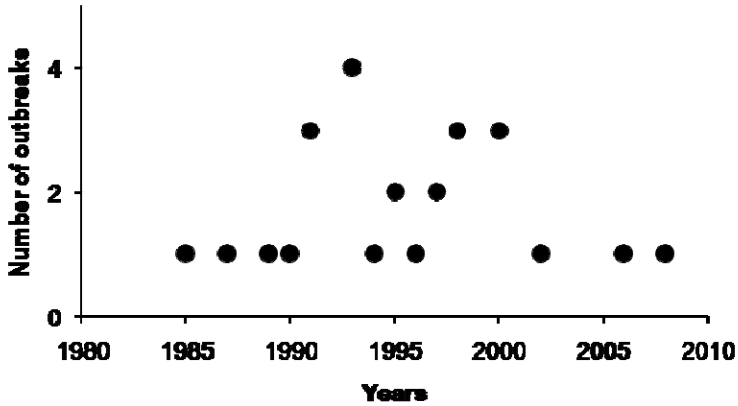

Fig. 3.22 Number of redtide events by *Noctiluca scintillans* in Jinhae Bay from 1985 to 2008.

3.4.2 Shellfish poisoning incidents

Paralytic shellfish poisoning (PSP) frequently occurs in Jinhae Bay. Hence it is a routine work for NFRDI to monitor shellfish culture farms over 100 regular monitoring stations and to ban fisherman from shellfish harvest when PSP toxin level exceed 80ug/100g meats. It has been reported that *Alexandrium* species such as A. *tamarense, A. catenella, A. leei* are major PSP causative species in Korea. Particulary, A. *tamarense* plays a key role as PSP toxin producer in Jinhae Bay during spring season. Shellfish harvest has been banned for about one or two months mostly from March to May every year since 2004. Also, it was not possible to seek any trend of PSP incidents over times based on the data from the shellfish monitoring program. In addition, there was no any patient reported suffering from PSP intoxication in Jinhae Bay area since 1992.

4 Summary and Review of results

It was analyzed that eutrophication status in Jinhae Bay, based on the assessment parameters guided by CEARAC/NOWPAP, became, overall, improved year by year since 2002. In 2008, the value of T-N and T-P, one of the key factors determining the degree of nutrient enrichment showed almost similar or slightly higher level than background value (Gijang area) with decreasing up to 50% and 51% in T-N and T-P, respectively, compared to year 2002.

Particularly, the value of winter DIN and DIP in Jinhae Bay has shown sharp decrease since 2007 with showing slightly less value than background value in 2007 and 2008. Winter N/P ratio in Jinhae Bay has, also, shown decreasing trend in recent years likewise T-N/T-P and winter DIN/DIP by showing similar or lower level than both Redfield ratio (16:1) and background value since 2006. However, chlorophyll-a concentration, one of the key parameters indicating direct effects of eutrophication, still showed relatively higher level than background values, although it showed slightly decreasing trend after 2006. Conclusively, it was summarized that eutrophication status of Jinhae Bay was 'Medium status' and 'decreasing trend considering all the eutrophication assessment parameters including the degree of nutrient enrichment (Table 4.1, 4.2, 4.3). The eutrophication status and trend between Jinhae Bay and of Masan-Haengam Bay was overall similar although Masan-Haengam Bay showed slightly higher level in some eutrophication parameters(Table 4.4, 4.5, 4.6).

Masan-Haengam Bay neighboring Masan city, one of the heavily industrialized cities in Korea, showed relatively high eutrophication status among other bays where more than 80% of land-based pollutants are loaded via Masan Bay. Korean government has implemented various policies such as 'Total Pollution Load Management System' including financial supports to improve water quality of Masan Bay after designation of Masan Bay as a special marine management area in 1982. Masan-Haengam Bay is, now, under the third stages of eutrophication management, started from 2000, targeting on 'Introduction of watershed-based and integrated approach' with the establishment of 'Coastal Environmental Management Plan of Masan Bay'. Therein, the water quality of Masan-Haengam Bay has been improved with showing remarkable decrease of nutrient loading since 1990s. It is expected that the water quality of Masan-Haengam Bay, still showing relatively high eutrophication status than any other bays, will be improved year by year under the ongoing national water quality management implementation activities.

Table 4.1　Summary of assessment values along with parameters in Jinhae Bay

Category	Assessment parameter	Assessment value	Identification tools			Year
			Comparison	Occurrence	Trend	
□	Riverine input T-N T-P	Annual mean: 29.7ton/day 2.23ton/day			- -	1995~1996
	Total nitrogen Total phosphorus	Annual mean: 0.3~0.7mg/L 0.04~0.09 mg/L	High High		Decrease Decrease	2002~2008
	Winter DIN Winter DIP	Winter mean: 0.06~0.3mg/L 0.01~0.03mg/L	Low Low		Decrease Decrease	2002~2008
	Winter N/P ratio	Winter mean: 9~42.7	Low		Decrease	2002~2008
□	Chlorophyll-a concentration (field data)	Annual mean: 6.2~10.2ug/L	High		Decrease	2002~2008
	Ratio of area with high Chlorophyll-a concentration (field data) to the total area	Annual mean: less than 5% to total area			Non-detectable trend	2002~2008
	Red-tide events (diatom species)	Annual Occurrences		0~9 times	Decrease	1981~2008
□	Dissolved oxygen (DO)	Annual mean: 8~10mg/L	>6mg/L*		Increase	2002~2008
	Abnormal fish kill incidents	-		No	-	1970-present
	Chemical oxygen demand(COD)	Annual mean: 1.5~2.8mg/L	High		Decrease	2002~2008
□	Red-tide events (Noctiluca sp.)	Annual occurrences: 0~4 times/yr		0~4 times	Decrease	1981~2008
	Shellfish poisoning incidents	Annual occurrences		No	-	1992-present

※ 1. Comparison : compare annual mean value in 2008 between Jinhae Bay and background value of Gijang area

2. *: define oxygen deficiency level when DO level lower than 6mg/L following OSPAR(2005).

Table 4.2 Classification of eutrophication status by assessment parameter in Jinhae Bay

Status	Assessment parameter
HD (Current status high but decreasing trend)	Total nitrogen Total phosphorus Chlorophyll-a concentration (field data) Chemical oxygen demand
HN (Current status high but no decreasing or increasing trend)	-
HI (Current status high but increasing trend)	Dissolved oxygen
LD (Current status low but decreasing trend)	Winter DIN Winter DIP Winter N/P ratio
LN (Current status low but no decreasing or increasing trend)	-
LI (Current status low but increasing trend)	-

Table 4.3 Classification of eutrophication trend by assessment parameter in Jinhae Bay

Trend	D (Decreasing trend)	N (No decreasing or increasing trend)	I (Increasing trend)
Assessment parameter	Red-tide events (diatom species) Red-tide events (Noctiluca sp.)	-	-

Table 4.4 Summary of assessment values along with parameters in Masan-Haengam Bay

Category	Assessment parameter	Assessment value	Identification tools			Year
			Comparison	Occurrence	Trend	
□	Riverine input T-N T-P	Annual mean: 20.5ton/day 1.42ton/day			- -	1995~1996
	Total nitrogen Total phosphorus	Annual mean: 0.5~1.2mg/L 0.05~0.15 mg/L	High High		Decrease Decrease	2002~2008
	Winter DIN Winter DIP	Winter mean: 0.05~0.7mg/L 0.01~0.07mg/L	Low Low		Decrease Decrease	2002~2008
	Winter N/P ratio	Winter mean: 10.9~36.7	Low		Decrease	2002~2008
□	Chlorophyll-a concentration (field data)	Annual mean: 8.6~20.2ug/L	High		No trend	2002~2008
	Ratio of area with high Chlorophyll-a concentration (field data) to the total area					
	Red-tide events (diatom species)					
□	Dissolved oxygen (DO)	Annual mean: 8~11mg/L	>6mg/L*		Increase	2002~2008
	Abnormal fish kill incidents	-		No	-	1970-present
	Chemical oxygen demand(COD)	Annual mean: 2.5~3.1mg/L	High		No trend	2002~2008
□	Red-tide events (Noctiluca sp.)	Annual occurrences: 0~1 times/yr		0~1 times	Decrease	1981~2008
	Shellfish poisoning incidents	Annual occurrences		No	-	1992-present

※ 1. Comparison : compare annual mean value in 2008 between Masan-Hangam Bay and background value of Gijang area
2. *: define oxygen deficiency level when DO level lower than 6mg/L following OSPAR(2005).

Table 4.5 Classification of eutrophication status by assessment in Masan -Hangam Bay

Status	Assessment parameter
HD (Current status high but decreasing trend)	Total nitrogen Total phosphorus Chemical oxygen demand
HN (Current status high but no decreasing or increasing trend)	Chlorophyll-a concentration (field data)
HI (Current status high but increasing trend)	Dissolved oxygen
LD (Current status low but decreasing trend)	Winter DIN Winter DIP Winter N/P ratio
LN (Current status low but no decreasing or increasing trend)	-
LI (Current status low but increasing trend)	-

Table 4.6 Classification of eutrophication trend by assessment parameter in Masan-Hangam Bay

Trend	D (Decreasing trend)	N (No decreasing or increasing trend)	I (Increasing trend)
Assessment parameter	Red-tide events (Noctiluca sp.)	-	-

5 Conclusion and Recommendation

Based on the assessment results and literatures, it was concluded that current eutrophication status of Jinhae Bay including several small bays was, overall, **'Low state'** and **'decreasing trend'**; Eutrophication status of Masan-Haengam Bay was **'High state'** and **'decreasing trend'.**

Therein, it is recommended to increase sewage treatment facilities and/or dredge up bottom sediments to improve water quality in Masan-Haengam Bay. Particularly, considering that Masan Bay, among other bays, is relatively high eutrophication status area with frequent algal blooms, it is encouraged to apply tertiary water treatment system to remove inorganic nitrogen and phosphorus level within the treated water substantially.

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