

Marine Ecosystem Response to Nutrient Input Reduction in Jinhae Bay, South Korea

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We study on the dynamic interaction with a simulated physical-biological coupled model response to nutrient reduction scenario in Jinhae Bay. According to the low relative errors, high regression coefficients of COD and DIN, and realistic distribution in comparison to the observation, our coupled model could be applicable for assessing the marine ecosystem response to nutrient input reduction in Jinhae Bay. Due to the new construction and expansion of sewage treatment plant from our government, we reduce 50% nutrient inputs near Masan Bay and sewage treatment plant. COD achieves Level II in Korea standard of the water quality from the middle of the Masan Bay to all around Jinhae Bay except the inner Masan Bay remaining at Level III. When our experiment reduces 50% nutrient inputs near Masan Bay and Dukdong sewage treatment plant simultaneously, COD decreases to about 0.1-1.2 mg/L (128°30'~128°40' E, 35°05'~35°11' N). The COD from the middle of the Masan Bay to Jinhae Bay achieves Level II.

Key Words : Physical-biological model, Carrying capacity, Nutrient reduction, Jinhae Bay, Masan Bay

1. Introduction

Jinhae Bay is located in the southern part of South Korea. The northern part of the bay locates Masan city where lives in about one half million people. Within Jinhae Bay, there are number of small bays such as Masan Bay, Hangan Bay, Gohyun Bay. After the Masan industrial complex was constructed in 1960s, marine ecosystem started to worsen drastically. In recent years, rapid industrialization around Janhae Bay area such as Changwon City, Jinhae City and Masan City has imposed severe problems on the water quality of coastal areas resulting in damaged marine resources and human health (Fig. 1.).

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 which amount of nutrients and growth promot-

ing substances could inflow coastal waters from land runoff¹⁾.

There are lots of notions of environmental carrying capacity. In a point of traditional biological views, a carrying capacity features the limiting population supportable by the environment^{2,3)}. In a point of marine environment, suitable carrying capacity means the limit of the pollutants loads which begin to cause the contamination in aquaculture areas⁴⁾. To manage and control the water quality of coastal waters, it is essential for research scientists to set up the criteria of water quality for an appropriate usage, and to regulate total pollutants emission originated by point and non-point sources and inner production within self-clearing power⁵⁾. For the assessment of realistic carrying capacity, we consider various contents such as forestry, aquaculture, tourism, fisheries, etc. Among the different contents of the ecosystem, there is sustainable development within thresholds (Fig. 2.).

Due to new construction and expansion of sewage treatment plant from our government, we will focus on the dynamic interaction with a simulated physical-biological coupled model response to nutrient re-

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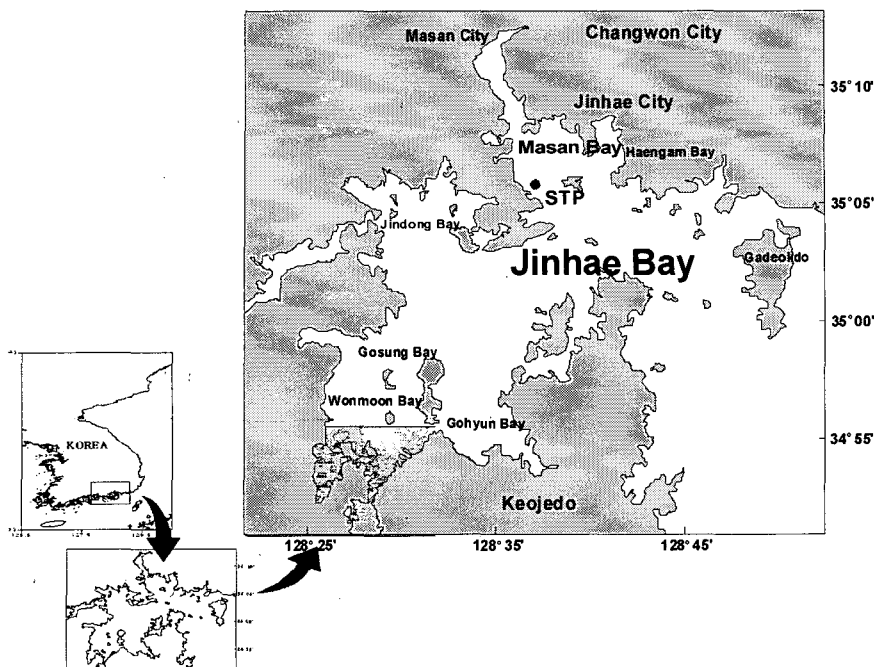


Fig. 1. Research site.

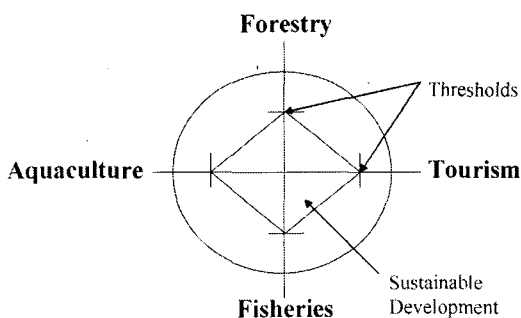


Fig. 2. Conceptual diagram of carrying capacity of an ecosystem.

duction scenario in Jinhae Bay. In this research, we use the COSMOS-EUTROP II model which is developed by Nakata⁶⁾. This model has been simulated the coastal marine ecosystem coupled with hydrodynamics at tidal flat ecosystem and assessment of water quality in lake^{7,8)}. Also, we will represent the characteristic between control model output and pollutant reduction results of the ecological parameters such as chlorophyll-a and dissolved inorganic components. In particular, the effects on the marine ecological water quality will be discussed by the construction of new sewage treatment plant and the expansion of the current facility.

2. Data and Method

In this research, the physical processes are described by the hydrodynamic model⁹⁾ which has a free surface, terrain following vertical z coordinate and a turbulence closure scheme for determining vertical mixing. Horizontal length of the model domain is about 40 km and the longitudinal length is about 35 km. The model has a horizontal and longitudinal resolution of 200 m in the domain $34^{\circ}42' \sim 35^{\circ}12' \text{ N}$ and $128^{\circ}18' \sim 128^{\circ}48' \text{ E}$ and 5 vertical levels. The model looks at tidal current of the flood and ebb tides from the final tide by computing 50 tides. The residual currents were computed by the integration of the final single tidal cycle period.

The biological processes are described by the eutrophication model⁹⁾, 3D ecological model. The biological variables in the model include organic parameters, inorganic parameters and water quality parameters. Biological variables for the simulation of eutrophication are phytoplankton (P), zooplankton (Z), particulated organic carbon (POC), dissolved organic carbon (DOC), dissolved inorganic phosphate (DIP), dissolved inorganic nitrogen (DIN), dissolved oxygen (DO) and chemical oxygen demand (COD) (Table 1).

In order to calculate pollutant loads more accu-

Table 1. Model parameters in biological model

| Item | Compartment | Abbreviation | Unit |
|-------------------------|-------------------------------|--------------|---------------------|
| Organic form | Phytoplankton | P | mg C/m ³ |
| | Zooplankton | Z | mg C/m ³ |
| | Particulated organic carbon | POC | mg C/m ³ |
| | Dissolved organic material | DOC | mg C/m ³ |
| Inorganic form | Dissolved inorganic phosphate | DIP | μg-at/L |
| | Dissolved inorganic nitrogen | DIN | μg-at/L |
| Water quality parameter | Dissolved oxygen | DO | mg/L |
| | Chemical oxygen demand | COD | mg/L |

rately from lots of streams and rivers near Jinhae Bay, every season we visited and investigated at about 50 rivers and streams. We have checked the width of the stream, the characteristics of the topography at the bottom and water velocity for the assessment. We also collected a sample of the water and the water quality parameter is analyzed in our laboratory for the model simulation input data. The basic data in sewage treatment plant for the simulation of the model has been obtained from the Ministry of Fisheries Affairs, South Korea^{10,11}.

For the evaluation of the physical-biological coupled model, we used the water quality data at the sea surface and bottom at the sea. This includes sea surface temperature, salinity, COD, DO, POC, DOC, DIN, DIP and Chl-*a* for 1999-2002. In this research, COD, Chl-*a* and DIN were adopted as an index of the bay water quality response to nutrient input. COD adopts as an indicator of the water quality criteria; Chl-*a* supports us the base of the Bay's food chain; and DIN gives us the effect of emission in the sewage treatment plant and sewage near big cities. In order to compare the results from the model to the analyzed observations, 7 stations were selected¹².

3. Results and Discussion

3.1. Characteristics of physical simulation

The physical model simulates 50 tidal cycle periods. We select the flood tide and ebb tide from the final tidal cycle. And residual currents were computed by the integration of the final tide. Fig. 3 represents the distribution of the simulated flood tide, ebb tide, residual current at the sea surface and residual current at the middle water. The velocity of the

maximum tidal current in flood tide is seen as 30-40 cm/s near Gaduk Island and flood tide flows westward. During the ebb tide, there are southward flow from Masan Bay and eastward flow at the in front of Gosung Bay at about 20 cm/s. The velocity of the minimum tidal current shows about 10 cm/s in the inner Jinhae Bay such as small bays of Masan, Wonmoon and Hangam.

The residual current represents the counter-clockwise circular flow in front of Gohyun Bay, showing a weak flow in the southward direction within the inner Masan Bay¹³. 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 counter-clockwise circular flow around Jam Island. For the west side of Masan Bay and the Hangam waters, such calculation is not viable due to their depth being less than 8 m.

The biological model is provided with tidal current from physical model as an input data. The biological model simulates 25 tidal currents, and those of parameters were computed by the integration of the final tide. Fig. 4 shows the comparison of COD and DIN between simulation and observation data in 7 stations of Jinhae Bay¹². Evidently, they are highly correlated. According to the low relative errors, high regression coefficients of COD ($R^2=0.9606$) and DIN ($R^2=0.7745$, $P<0.01$), we can deduce that our physical-biological coupled model could be applicable for assessing the response to nutrient input reduction in Jinhae Bay. Fig. 5 shows the simulated Chl-*a*, COD and DIN. The results of the biological model represent

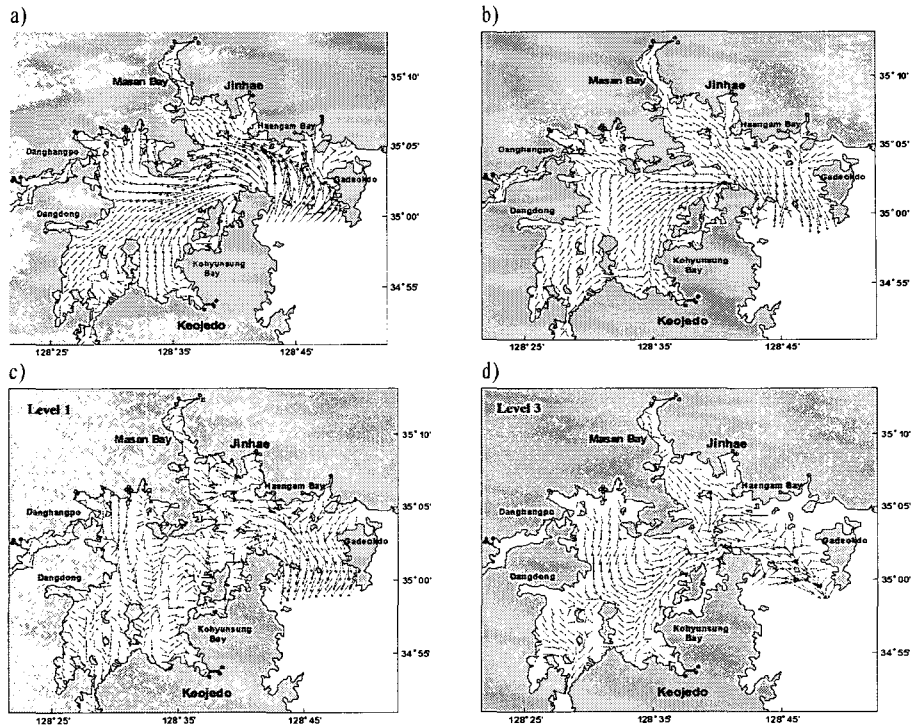


Fig. 3. The distribution of the simulated flood tide (a), ebb tide (b), residual current at the sea surface (c), and residual current at the middle waters (d).

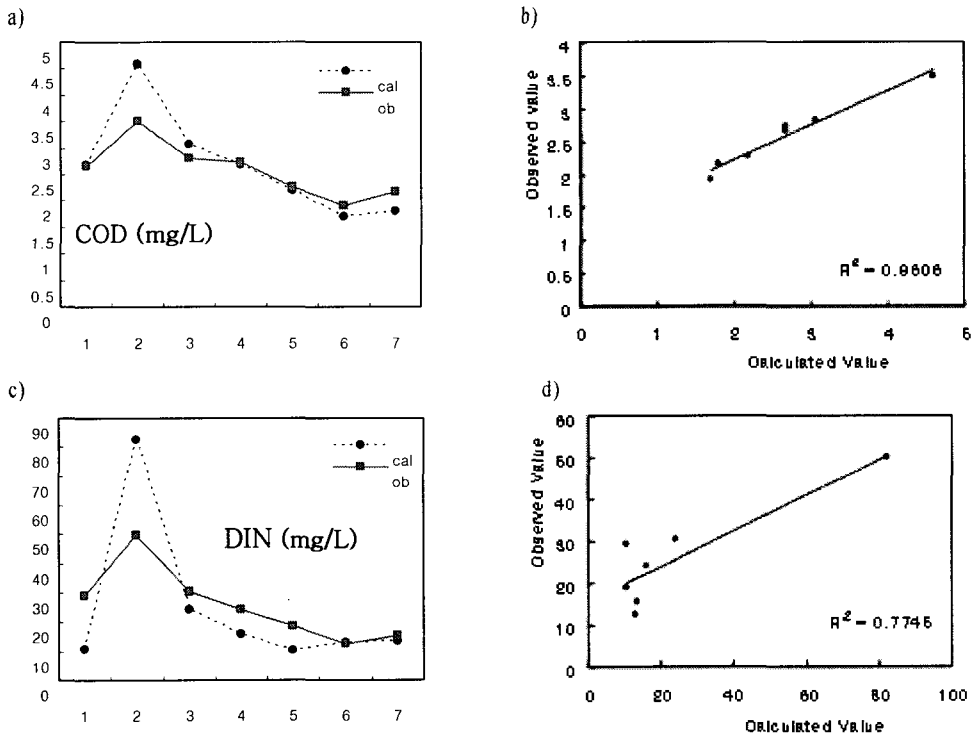


Fig. 4. Comparison between simulation and observation in 7 stations in Jinhae Bay ; COD values (a), coefficient correlation in COD (b), DIN values (c), and coefficient correlation in DIN (d).

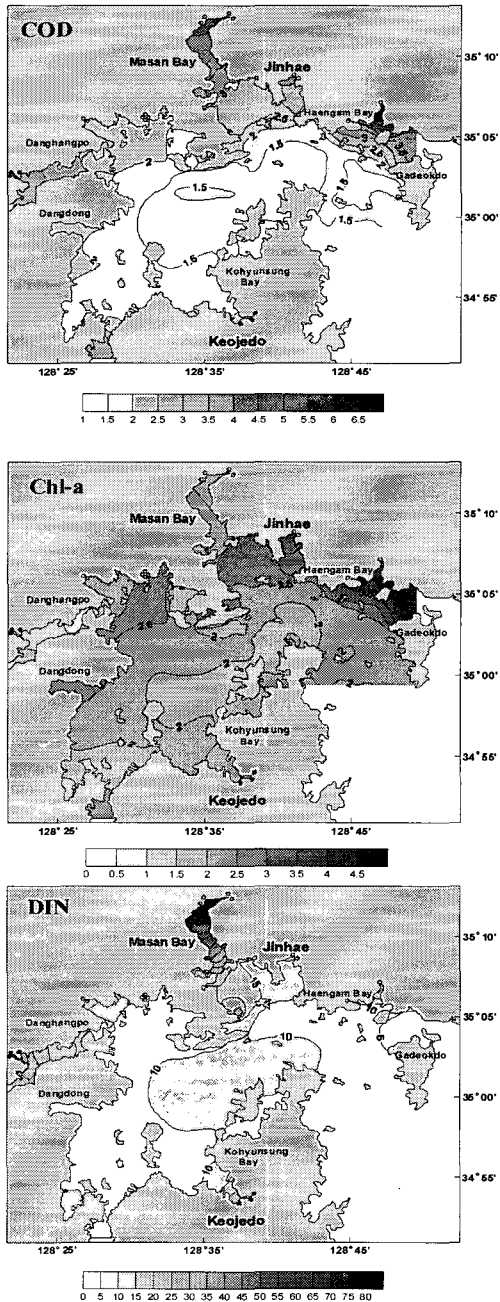


Fig. 5. The simulated results of COD, Chl-*a*, and DIN.

realistic distribution in comparison to the observation. The simulated water quality of the inner small bays of Masan, Hangan and Wonmoon shows Level III water quality standard of Korea in COD. The other region's water quality shows below Level II in COD.

Furthermore, the distribution of Chl-*a* simulates well the internal productivity inside the marine ecol-

ogy and it shows a similar distribution as COD¹⁴⁾. The simulated Chl-*a* was higher at the inner part of the Masan and Hangan Bay and lower in the outer bay. This result indicates concentration of Chl-*a* is considerably dependent on the pollutant loads from land. For DIN, the maximum is seen around Dukdong Sewage Treatment Plant (STP) located near the mouth of Masan Bay and the concentration in the neighboring areas decreases gradually. As going towards the inner area from the mouth of Masan Bay, gradual increase in DIN concentration is noticed. Biological parameters for the model simulation were getting through the normalized observation data and paper investigation; growth rate: 0.49, phytoplankton death rate: 0.020, zooplankton death rate: 0.045¹⁵⁾.

3.2. Characteristics of biological simulation

In order to confirm the discrepancies and the affected regions by the reduction of nutrient inputs, we have categorized into 4 major regions where pollutant loads flowing into Jinhae Bay are different; Masan Bay neighbors (R1), Gosung Bay neighbors (R2), Gohyun Bay neighbors (R3), and sewage treatment plant (STP) in Dukdong (R4) (Fig. 6). When we reduced the pollutant loads in each region, differences between control and reduction experiment in R2 and R3 are very small. R1 and R4 pair shows much larger differences between control and reduction experiment than R2 and R3 pair. This is because more than 80% of the pollutant loads entering Jinhae Bay are

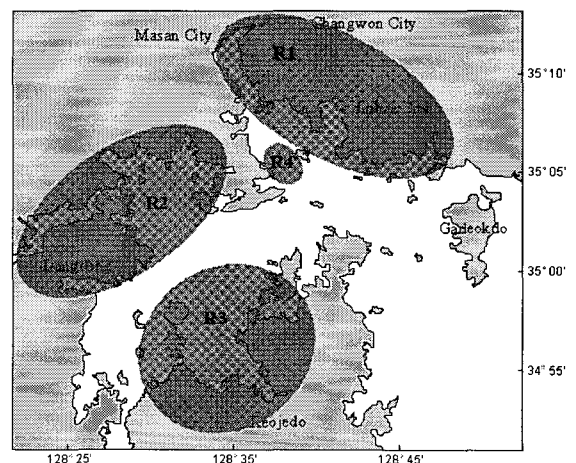


Fig. 6. Categorization of 4 major regions where pollutant loads flowing into Jinhae Bay.

from the neighboring waters of Masan Bay where urbanization and industrialization are occurring. On the other hand, the pollutant loads are relatively low in R2 and R3 where most lands are for the farming purposes.

To compare with the differences between control simulations and pollutants reduction experiments, we reduce the pollutants in 10~90% in steps of 20% for each of R1~4 areas. The more we reduce the pollutants loads, the more COD, Chl-*a*, and DIN that determine the water quality gradually improve. But due to the residual current, the effecting region is limited to only the neighbors of the areas that have reduced the pollutant loads.

When we reduce 90% nutrient inputs near R1, COD improves to about 0.2-1.6 mg/L in the inner Masan Bay. Fig. 7 shows three types of experiments based on model control, reduction and the difference between the two. The water quality in most of the Masan Bay achieves Level II (less than 2 mg/L) water quality standard in Korea. But the water quality in

35°10' N regions and inner Hangam bay is of Level III (more than 2mg/L and less than 4 mg/L). The concentration of COD in the regions of the Hangam Bay has reduced to about 0.2-0.6 mg/L and Jinhae neighboring areas have the concentration reduced to about 0.4 mg/L. The area where the COD improvement is particularly effective has a structural character that the water enters weakly into the land, and the applicable area is the northern waters of Masan Bay.

When we reduce 90% nutrient input near sewage treatment plant in Dukdong (R4), COD improves to about 0.1-0.3 mg/L (128°36'~128°40' E, 35°05'~35°10' N). This is a smaller effect compared to the effect of reduced loads in R1, the effect is almost negligible in the northern waters of Masan Bay (Fig. 8.). Due to the residual current, the maximum difference is seen at the mouth of the Masan Bay. The effect of R4 reduction experiments did not affect the inner Masan Bay as well as R2 and R3 regions due to the southward residual current in the inner Masan Bay.

COD
R1 90% Reduction

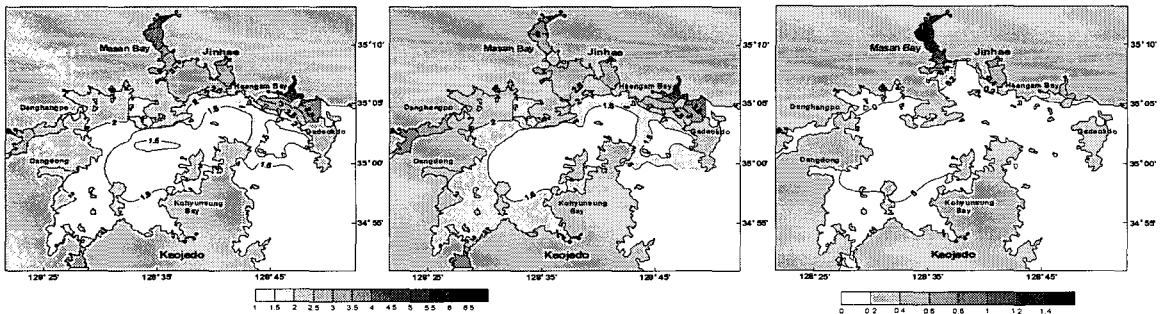


Fig. 7. Distribution of COD in R1 reduction experiment ; control simulation (left), 90% nutrients reduction simulation (center), and differences between control minus reduction (right).

COD
R4 90% Reduction

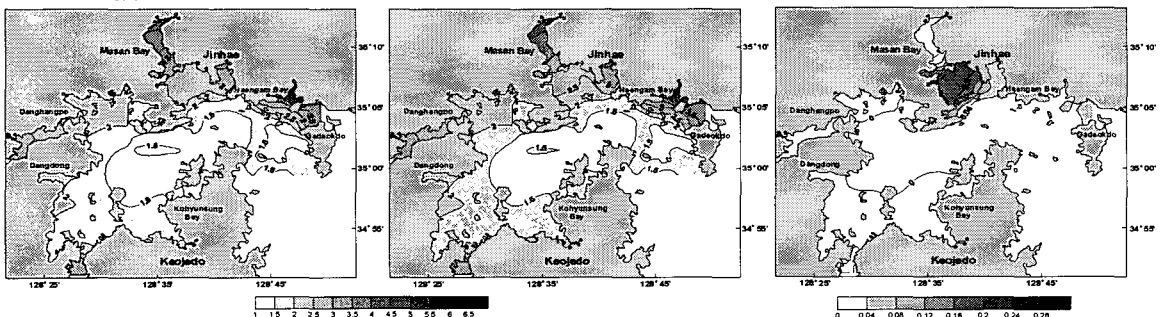


Fig. 8. Distribution of COD in R4 reduction experiment ; same as Fig. 7. panel.

3.3. Simulation of nutrients inputs reduction

For the improvement of water quality, we need to reduce R1 and R4 pollutant loads simultaneously. If we construct the new sewage treatment plant near Masan Bay and expand the sewage treatment plant in Dugdong, we can reduce about 50% nutrient inputs in R1 and R4 regions (Masan City, 2002). According to new construction and expansion of sewage treatment plant from our government, we will focus on coupled

model response to nutrient reduction scenario in Jinhae Bay.

In 50% nutrient inputs reduction experiment near R1 and R4 simultaneously, COD decreases to about 0.1-1.2 mg/L (128°30'~128°40' E, 35°05'~35°11' N). The COD from the middle of the Masan Bay to Jinhae Bay achieves Level II whereas the inner Masan and Hangan Bay remaining at Level III (Fig. 9 a.). The effecting regions are Masan and Hangan

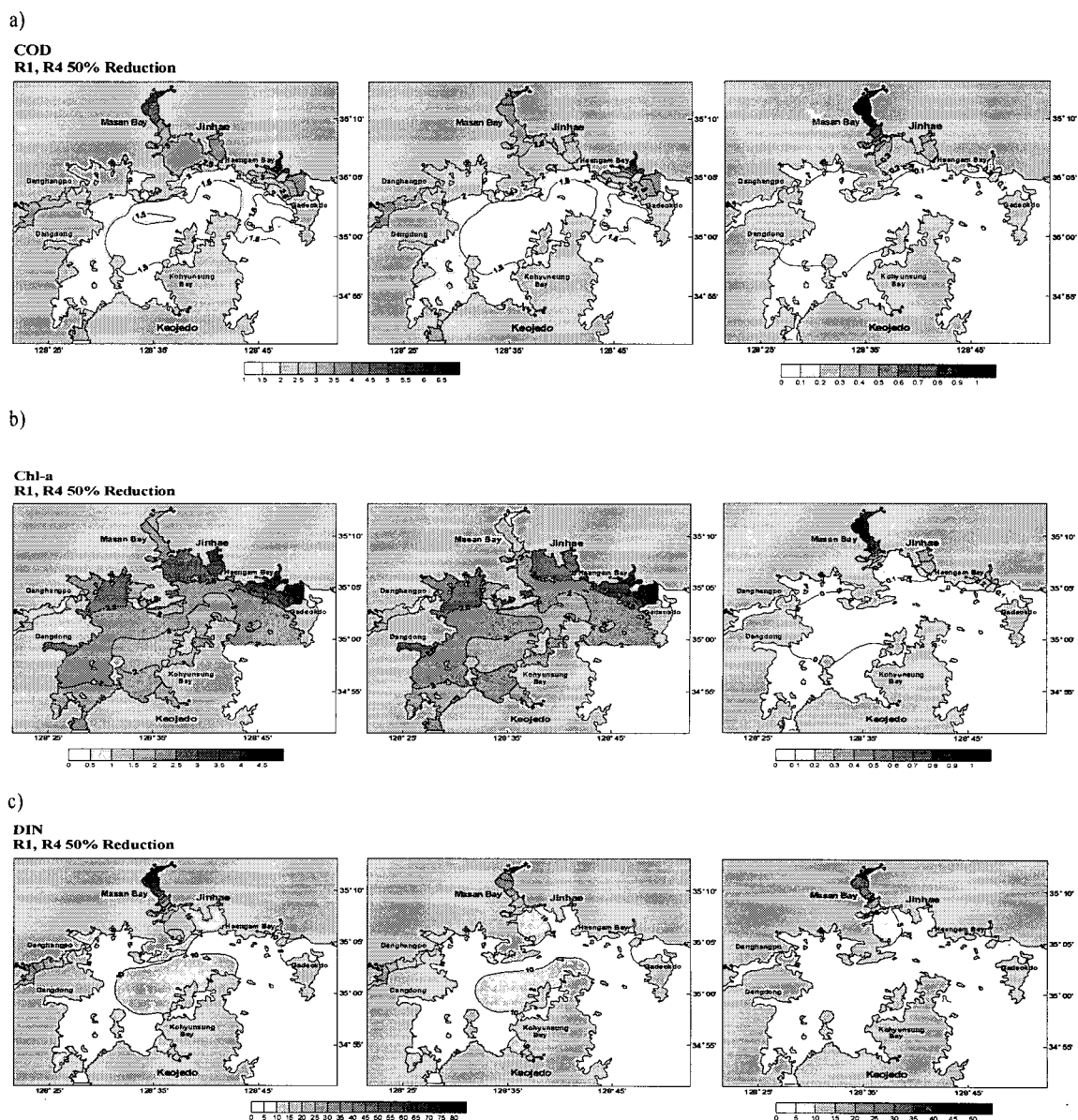


Fig. 9. Distribution of COD, Chl-a, and DIN in R1&R4 reduction experiment ; same as Fig. 7. panel in COD (a), Chl-a (b), and DIN (c).

is 0.1-0.2 mg/L and the maximum is seen at around 35°10' N due to the current characteristics. Inner Masan Bay is showing the reduction effect from R1 and the mouth of Masan Bay is a part of the region where the improvement is increasing due to the effect from the simultaneous reduction in R1 and R4.

When we reduce 50% nutrient inputs near R1 and R4, Chl-*a* represents less primary reduction at about 0.1-1.0 µg/L, showing a similar COD distribution. From the Chl-*a* results, COD difference is showing a close correlation for the inner Masan Bay, and that coincides with the region where there is the maximum concentration of COD (Fig. 9b). We deduce that 50% decreased level in DIN and DIP during summer might attribute to the gradation of primary production with an evidence of Chl-*a*. At the outer waters of Masan Bay the difference between Jamdo Island and the mouth of Masan Bay is as minuscule as 0.1-0.2 µg/L. From Duckdong Sewage Treatment Plant to the inner Masan Bay the difference is gradually increasing.

In the same experiment as 50% nutrient inputs reduction experiment near R1 and R4, DIN improves to about 5-50 µg/L from the mouth to the northern part of Masan Bay. The effecting regions include the inner Masan Bay and around, also the maximum is shown in the inner Masan city (Fig. 9c). Although the affecting regions of COD and Chl-*a* include Masan and Hwang Bays, that of DIN only applies to Masan Bay. This can be interpreted as at Masan Bay, the effecting regions of R1 are much larger than that of R4.

4. Conclusion

In this research, we simulate the physical-biological coupled model for the response to the nutrient inputs reduction in Jinhae Bay. The simulated models are fairly in good agreement with the observed values for the years 1999-2002. The simulated ecosystem in Jinhae Bay indicates that COD is below Level II around Jinhae Bay except for the inner Masan and Hwang Bays of Level III. When we reduce 50% nutrient inputs near Masan Bay and sewage treatment plant, COD achieves Level II from the middle of the Masan Bay to all around Jinhae Bay except the inner Masan Bay remaining at Level III.

When the nutrient input of R1 and R4 regions that constitute over 80% of the pollutant load is reduced,

results of reduction is observed to be a lot greater than R2 and R3 regions. COD of the inner waters of Masan Bay improves to 0.2-1.6 mg/L when 90% of the nutrient input around R1 region is reduced. COD improves to 0.1-0.3 mg/L when 90% of the nutrient input, around R4 region is reduced. If the pollutant loads are simultaneously reduced at both R1 and R4 regions, COD improvement effect at the mouth of Masan Bay is 0.1-0.3 mg/L and the maximum is apparent near 35°10' N by the current characteristics. The inner Masan Bay takes the reduction effect of R1 whereas at the mouth, the reduction effect of R1 and R4 simultaneously are applied.

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