学 位 論 文 要 旨

題　目：　Environmental management in semi-enclosed seas
（ 閉鎖性海域における環境管理 ）

氏　名　王　峰

Eutrophication has become a primary threat to many coastal ecosystems since the second half of last century. Following three or four decades of effort to revert this issue, evidences of ecosystem recovery are growing. Nevertheless, many ecosystems have not met their recovery potential yet. What's more, new problems have emerged in recent years, for instance, reductions in the annual fishery landings in some ecosystems due to decrease in the primary production. All of these suggest that our environmental managements need to be reviewed. The question of why different ecosystems response differently to nutrient loading reductions also need to be answered. Here we explored the region-specific water clarity and phytoplankton biomass baselines in the context of anthropogenic nutrient loading reductions in some semi-encolsed seas to obtain better environmental management targets. In addition, we assessed the potential of eelgrass bed recovery and its effectiveness in controlling phytoplankton in an eutrophic estuarine area.

Region-specific background Secchi depth (BSD) provides valuable information on light availability in aquatic ecosystems. We estimated BSD in Tokyo Bay and Ise Bay and the Seto Inland Sea based on monitoring data collected in the period 1981‑2015. BSD values were successfully obtained in 89‑96%, 67‑94% and 19-67% of monitoring sites in Tokyo Bay, Ise Bay and the Seto Inland Sea, respectively. Low BSD values were obtained in the innermost regions of these semi-enclosed seas, adjacent to the estuaries of large rivers. BSD was positively correlated with salinity in these seas, indicating that river-supplied substances, including tripton and/or colored dissolved organic matter, strongly influenced BSD values. Although the highest chlorophyll a concentrations were measured in the innermost sectors of these seas, the proportional contribution of phytoplankton to light attenuation was surprisingly low in comparison with other sectors. Moreover, the average estimated proportional light attenuation of phytoplankton was <40% in all these seas, indicating that background factors played a dominant role even in these highly eutrophic waters. Determinations of Secchi depth, BSD, and the proportional contributions of phytoplankton and background factors to light attenuation will improve understanding of the aquatic light environment, which in turn will inform the development of rational coastal management practices.

Water quality had been improved in most areas of the Seto Inland Sea, harmful algal blooms were still frequently observed in some regions of the sea. Based on a nonlinear perspective and an empirical approach with several natural environmental factors, a novel indicator, vulnerable index, was established to estimate surface chlorophyll a (Chl.a) concentration in the Seto Inland Sea with long-term monitoring records during the period 2003‑2012. Results suggested that models that included both salinity and water clarity were more predictive than that did not. The inclusion of distance to coast or water stability resulted in further improvement of model performance, whereas the improvements were limited. Highest Vulnerable Index were observed in the coastal regions of Osaka bay, Harima Nada, Hiroshima Bay and lowest Vulnerable Index in Aki Nada, Iyo Nada, offshore area of Suo Nada and two channels connecting the Pacific Ocean. We also found that the coastal areas

with highest Vulnerable Index coincide with the areas adjacent to highly populated watersheds, indicating that high natural potential for phytoplankton growth as well as high anthropogenic nutrient input from neighboring residences combined to result in the frequent red tide occurrence in the areas mentioned above. Vulnerable Index provide a simple and clearly defined way to identify vulnerable coastal zone in nature to phytoplankton growth. We suggest that vulnerable index be incorporated in future decision-making process and different management measures be implemented according to the property of VI in different water bodies of the Seto Inland Sea.

Water quality data from 1981‑2015 were used to elucidate the spatiotemporal distributions of Chl.a concentration and Secchi depth in the west-central Seto Inland Sea, Japan. The results revealed that salinity and distance from the northern coastline were the main factors for predicting Chl.a concentration and Secchi depth, respectively. Significant differences in both of these were observed between subareas in spring, summer and autumn; differences were insignificant in winter. Chl.a concentrations have decreased for the past 35 years, while their extent differed in the subareas. A greater rate of decrease in Chl.a concentration was observed in the innermost Hiroshima Bay in spring, compared with other subareas, while no significant difference in different subareas was found in other seasons. Secchi depth has increased for the past 35 years, but no significant difference in its rate of increase was found among different subareas in all seasons. Total nitrogen (TN) loading better explained changes in mean Chl.a concentration than total phosphorus (TP) throughout the west-central Seto Inland Sea. Phytoplankton's contributions to light attenuation were low in the west-central Seto Inland Sea, indicating that the nutrient loading reduction programme has been of limited effectiveness in improving water clarity.

Eelgrass beds are highly productive and support diverse faunal assemblages; they also take in nutrients from the water and prevent excessive phytoplankton growth in eutrophic coastal waters through the reduction of available nutrients. Despite its importance, the global distribution of eelgrass has declined worldwide. In eutrophic areas with high Chl.a concentrations, natural recovery of eelgrass beds after eutrophication is possible. To facilitate this, sufficient water clarity can be reached after a large enough decrease in phytoplankton concentration. In this study, we proposed a novel indicator for the maximum possible Secchi depth (MPSD), defined as the Secchi depth when the Chl.a concentration is equal to a reference Chl.a concentration. We applied the MPSD to evaluate water clarity improvements through the reduction of terrigenous anthropogenic nutrient loading. We found that phytoplankton did not control water clarity in the study area, which was instead controlled by background factors. Therefore, improvements in water clarity would not be expected after reducing terrigenous anthropogenic nutrient loading. The habitat of Zostera marina is determined by light availability, so we investigated a potential area with $\geq 20\%$ surface irradiance and Z. marina existed in 27% of it (100‑373 ha). The maximum recovery by Secchi depth improvements to the MPSD was estimated at 36 ha. The impact of eelgrass recovery and expansion on phytoplankton growth from May to September was evaluated by a mathematical model under two scenarios: the current eelgrass distribution (100 ha) and potential maximum eelgrass distribution (370 ha). The decrease in Chl.a concentration to 1.0‑3.0 μg l-1 was achieved in an area originally with 4.0 to 7.0 μg l-1 of Chl.a from May to July; this improvement decreased with time. These evaluation methods and findings could help us gain a better understanding of the nutrient management in seagrass-vegetated semi-enclosed seas subjected to anthropogenic nutrient input.