Monitoring and Assessment of Eutrophication in Toyama Bay Using Remotely Sensed Chlorophyll-*a*

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Marine eutrophication has recently become a concern for all the world's oceans. There are over 415 areas worldwide identified as manifesting symptoms of eutrophication. Eutrophication causes deterioration of the coastal environment and often leads to the formation of harmful algal blooms and depletion of bottom oxygen, which may subsequently induce fish kills and/or ecosystem damage.

The Northwest Pacific region, which includes parts of northeast China, Japan, Korea and southeast Russia, is one of the most densely populated areas of the world, and its coastal systems can be expected to change with the high concentrations of human-induced nutrients. Thus, eutrophication is an emerging environmental problem in this region, where a significant number of red tides and hypoxic conditions have been reported in coastal waters - possibly due to anthropogenic influences such as extensive chemical fertilizer use and sewage effluent.

Chlorophyll-*a* concentration (Chl-*a*) is a parameter, among others, that reflects nutrient enrichment, since one of the responses to eutrophication is an increase of phytoplankton biomass. Therefore, Chl-*a*, as a proxy for phytoplankton biomass, can be utilized as a useful indicator of eutrophication. Chl-*a* has historically been measured in water samples retrieved *in situ*. However, *in situ* observations are often limited both in time and space. In the past decade, regular monitoring of Chl-*a* in coastal waters has been carried out by ocean color satellite sensors, especially after the success of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and a follow-on Moderate Resolution Imaging Spectroradiometer on board the Aqua satellite (MODIS-A) launched by NASA in 1997 and 2002, respectively. Remotely sensed Chl-*a* (satellite Chl-*a*) is a cost-effective indicator to simultaneously monitor dynamic changes in both marine and coastal waters on a daily basis.

Objectives of this study are to (1) propose a methodology for monitoring and assessment of anthropogenic eutrophication in marine coastal water using a consistent long term remotely sensed chlorophyll-a (satellite Chl-*a*) that can be used in the Northwest Pacific region, and then (2) evaluate influence of land-based sources of nutrients on seasonal and interannual variability of satellite Chl-*a* for management of water quality in Toyama Bay. Applicability of the proposed methodology to the other areas of the Northwest Pacific region is then discussed.

In Chapter 2, evaluation and quality check of satellite Chl-*a* were first conducted against in situ Chl-*a* and Level-2 flags. Evaluation of consistency between SeaWiFS and MODIS-A sensors were then carried out to make a long time series data for more than 10 years. A methodology for preliminary assessment of marine coastal eutrophication was then proposed by combining level of averaged satellite Chl-*a* and trend of annual maximum satellite Chl-*a* in the study period. Level of averaged satellite Chl-*a* was used to detect areas where urgent mitigation intervention is required, as excessive phytoplankton blooms immediately leads to degradation of water quality. In contrast, trend of satellite Chl-*a* in the study period was used to forecast future condition; worsen, recovering or not changing from a standpoint of preventive management. Toyama Bay was then classified into six eutrophication states: High-Increasing, High-No trend, High-Decreasing, Low-Increasing, Low-No trend and Low-Decreasing. The inner part to the eastern coast of Toyama Bay where classified as “High-Increasing” and “High-No trend ”was considered as a potential eutrophic zone, indicating high risk of eutrophication, in Toyama Bay.

In Chapter 3, a positive and significant correlation was found between satellite Chl-*a* and river discharge in the offshore area of Toyama Bay from May to October. It was suggested that land based sources of nutrients are likely to be transported to the outer areas of Toyama Bay. In the coastal area, satellite Chl-*a* was high in summer every year and an increasing trend was detected. High concentration of TN at Jinzu River from May to August was considered as a compelling cause of the increasing Chl-*a* in the coastal area. Monitoring the peak pattern and level of seasonal variability in satellite Chl-*a* was suggested for assessment and management of water quality, because a single and long summer peak pattern in Chl-*a* is correlated with symptoms of eutrophication.

In Chapter 4, applicability of the proposed methodology to the other parts of the Northwest Pacific region was discussed, including needs to improve accuracy of satellite Chl-*a* in turbid water and adjust threshold to determine the level of Chl-*a* that causes undesirable conditions in each assessment area.

Usefulness of the proposed methodology was demonstrated in Toyama Bay and applicability to other parts of the Northwest Pacific region was discussed. It is therefore revealed from this study that monitoring and assessment of eutrophication using satellite Chl-*a* will be a promising tool for conservation of water quality in Toyama Bay and other coastal waters. Future tasks remain in evaluating new ocean color satellite sensors to make consistent longer time series of satellite Chl-*a* as ocean color satellites in orbit will come to end of life some day in the future. Evaluation of new algorithms for turbid water is also required to apply the suggested methodology of preliminary assessment of marine coastal eutrophication to other parts of the Northwest Pacific region.