Statistical Investigation into the Effects of Climate and Eutrophication on the Occurrence of Cyanobacteria in Small Ponds and Reservoirs

小規模池沼や貯水池における藍藻の発生に対する気象および富栄養化の影響の統計学的研究

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Chapter 1 Introduction: Background and Aim of research

Chapter 2 Literature review

The dominant and excessive growth of cyanobacteria, called cyanobacterial bloom, has posed a considerable challenge for water treatment and management worldwide. In recent decades, the blooms of cyanobacteria have been dramatically accelerated by eutrophication and global warming. Besides the negative effects on the water quality, massive cyanobacterial blooms may contain cyanotoxins, which are among the most toxic natural compounds. In freshwaters, the most frequently reported cyanotoxins are microcystins (MCs), a family of extremely stable cyclic heptapeptide metabolites. Prolonged exposure to MCs can cause liver damage, tumor promotion, and many chronic diseases. *Microcystis*, which can produce MCs, is one of the best-studied genera during the past decades. MCs-producing *Microcystis* (toxic *Microcystis*) and non-MCs-producing *Microcystis* are well-documented to co-occurrence within the *Microcystis* population, together they can cause detrimental effects on both aquatic environment and human health. Therefore, accurate prediction of harmful cyanobacterial blooms, especially of *Microcystis*, has become critical for effective and proactive water management. However, there are some remaining challenges in cyanobacterial modeling due to both technical and financial reasons. The main purpose of this dissertation is to investigate into the effects of climate and eutrophication on the occurrence of cyanobacteria in small ponds and reservoirs.

Chapter 3 Investigation into cyanobacteria Microcystis in small lakes and reservoirs in Nagasaki Prefecture, Japan.

The data collected at 20 freshwater reservoirs in Nagasaki Prefecture (Japan) during May 2017 - May 2018 were used for the analysis. The proposed Bayesian hurdle Poisson models successfully handled zero-inflated *Microcystis* data in Nagasaki water bodies, resulting in the predictions of *Microcystis* presence probability, abundance, and alert-level exceedance probability. These results could be used as a quick reference for management decisions such as monitoring planning and testing. The principal predictor variables (air temperature, rainfall, TSI) could be quickly, easily, and flexibly obtained at a low cost, suggesting that the proposed models are convenient to operate and have competitive advantages over other predictive models. In addition, the results indicated that trophic state (TSI), but not air temperature and rainfall, had significant impact on the presence of *Microcystis*. However, once *Microcystis* occurred, high temperature, high TSI, and low precipitation were highly beneficial for the growth of total and toxic *Microcystis*. These findings were site-specific to Nagasaki Prefecture, however, they confirmed the results of other studies worldwide. Under climate change context, where harmful cyanobacterial blooms might occur earlier and longer, the proposed models here can be practical tools in cyanobacterial early-warning systems.

Chapter 4 Investigation into cyanobacteria *Microcystis* in small lakes and reservoirs in northern Thailand

The data collected at small ponds and reservoirs in northern Thailand during September 2009 - March 2010 were used for the analysis. The Bayesian hurdle Poisson models successfully handled zero-inflated *Microcystis* data in the sampling areas. Similar to the results of Nagasaki Prefecture (temperate region), the results from northern Thailand (tropical region) showed that trophic state (TSI), but not air temperature and rainfall, had significant impact on the presence of *Microcystis*. However, in case of the surveyed data in Thailand, temperature, precipitation, and TSI negatively effected the growth of total and toxic *Microcystis* in tropical area. These findings were different from the results of Nagasaki Prefecture, suggesting that the differences between temperate and tropical areas might have significant impacts on the proliferation of cyanobacteria, especially toxic genera. Further investigation should be conducted to clarify this point.

Chapter 5 Statistical analysis of the effects of environmental factors and fish species on class-sorted phytoplankton composition in aquaculture ponds in northern Thailand.

Data collected at 21 tilapia and 13 catfish ponds in September 2009 (wet season), December 2009 (cold season), and March 2010 (hot season) in northern Thailand were used for the analysis. The statistical analysis showed that TP (total phosphorus), PO4-P, and NH4-N concentrations in catfish ponds were significantly higher than in tilapia ponds ($p < 0.05$, Wilcoxon test). The cyanobacterial abundance in catfish ponds was significantly greater than in tilapia ponds ($p < 0.05$, Wilcoxon test). Multiple linear regression analysis was applied to elucidate the important factors for explaining cyanobacterial abundance. The analysis results clarified that season as explanatory variables had significant effects on cyanobacterial abundance. On the other hand, the results indicated that larger abundance of cyanobacteria proliferated in catfish ponds than tilapia ponds, whereas the effect of nutrients N and P was not significant. The results suggest that the effect of nutrients was insignificant because almost all aquaculture ponds were in hypertrophic state. In addition, the omnivorous tilapia may prey on cyanobacteria even when fed, resulting in fewer cyanobacteria in tilapia ponds than in the catfish ponds. Moreover, since the predation by tilapia may be promoted at high temperature condition, it was speculated that cyanobacterial abundance decreased in March of hot season in northern Thailand.

Chapter 6 Conclusion