Assessing global regionalized impacts of eutrophication on freshwater fish biodiversity

Zhou, J.

Summary

Freshwater biodiversity has been threatened by eutrophication due to excessive nutrients in the environment. Releasing the freshwater species from such pressures requires efforts from industry and manufacturers to avoid emissions to vulnerable and high-risk regions. The first step is to know which nutrient influences where and the effects thereof on species loss. These impacts can be assessed by methods of life cycle impact assessment (LCIA). This thesis contributes to such knowledge by improving the LCIA method, for instance, by developing more regionalized and comprehensive indicators as well as adding the consideration of both phosphorus (P) and nitrogen (N) and which of these two nutrients is limiting. To achieve this research goal, this thesis put forward four questions (Q):

Q1: What is the pattern of regionalized nutrient fate, and how do drivers affect the nutrient fate over the global freshwater?

Q2: How can retention equations improve model performance?

Q3: What is the pattern of the regionalized effect on fish species loss across the global freshwater ecosystem?

Q4: What is the impact of eutrophication on global fish species loss in freshwater ecosystems?

To answer the first question, Chapter 2 embedded N into the assessment of the eutrophication impacts on the freshwater system as a complement nutrient to P, which is at the focus of present studies. Based on the Integrated Model to Assess the Global Environment–Global Nutrient Model (IMAGE-GNM), it developed a spatially explicit approach to global fate factors (FFs) for nutrients from direct emissions, diffuse sources, and erosion to freshwater systems at half-degree resolutions. This study underlines the relationship between FFs and hydrological conditions. The results reveal that high FFs mostly exist in retention-dominated regions, while low FFs mainly occur in advection-

dominated regions. The FFs allow life cycle assessment (LCA) practitioners to estimate the fate of nutrients to the downstream locations from the inventory, and its pattern can provide a concept of where the impacts of nutrient emissions are most harmful.

Next to the study about FFs, Chapter 3 goes further into the improvement of the accuracy of simulated nutrient fate. This study evaluated the performance of empirical retention models in IMAGE-GNM by using the mean-Normalized Root Mean Square Error (NRMSE) and Pearson's r in comparison with validation data. We also applied one-way Analysis of variance (ANOVA) and post hoc analyses to check the under- or overestimates of different retention models. We find that the retention models of Behrendt and Opitz considering specific runoff perform the best for predicting riverine retention of P and N, while De Klein's retention model is the best choice for simulating P retention in lakes and reservoirs. The results reveal that empirical equations perform better for N than P globally. The hydraulic-load-driven equations predict lower retention than specific-runoff-driven models. The hydraulic driver in the retention model is more important than function forms and coefficients that affect the simulation of N/P concentrations. The assessment on the global and geographical-zone scale can suggest the best empirical retention equations for nutrient model developers. The analysis of the driving force allows better development of retention models for waterborne eutrophication-related studies. This can further help to improve the accuracy of global nutrient models.

In Chapter 4, we took N as an example to regionalize the quantitative relationships between nutrient concentration and freshwater fish species loss. This study also complements the existing studies on the effect of P in freshwater ecosystems. We calculated the freshwater species sensitivity distributions (SSDs) of hundreds of ecoregions, which goes beyond previous studies that included a few geographical zones only. The SSDs for all the ecoregions with sufficient data display good performance. We provided average and marginal effect factors (EFs). The pattern of EFs reflects the sensitivities of ecosystems to nutrient emissions at a half-degree resolution. The results reveal the high possibility of species loss in the tropical zone and the vulnerability of cold regions. The SSDs can be utilized for research on evaluating the site-specific species richness loss due to excess nutrients, and EFs can be implemented in characterization factors (CFs) for LCA practitioners.

In Chapter 5, we developed regionalized CFs for freshwater eutrophication at a half-degree resolution and put forward a method to integrate nutrient limitation information with CFs to decide which nutrient has most influence where. The eutrophication impact on global freshwater fish was assessed by coupling the CFs considering nutrient limitation with nutrient emissions and land use information. The estimation of global species loss using our CFs (13.8%) and the conclusion of erosion as the main contributor is in line with the present studies of species loss due to water pollution and erosion. Our work thus can reflect the fish species loss due to freshwater eutrophication and exemplifies how to consider nutrient limitation in eutrophication-related studies. This study provides indicators that allow industry and stakeholders to assess the eutrophication impact on regional and global species richness. The consideration of comprehensive nutrient-species effects and nutrient limitation can be further applied in developing regionalized CFs for eutrophication issues in other ecosystems.

Based on these chapters, this thesis addresses the objective of quantifying the impact of freshwater eutrophication on global fish biodiversity. These studies provide methods to regionalize the nutrient fate, the effect on species richness, and eventually the CFs. The thesis also elaborates on which nutrient affects fish biodiversity where and applies the nutrient limitation in CFs to evaluate the global eutrophication impact.

In future studies, the thesis suggests improving the data availability and global nutrient models, since these are the main reasons that cause uncertainties in such studies of regionalizing eutrophication impact. In particular, an improvement in fish occurrence data can reduce the bias of high uncertainty in cold regions due to the current lack of observations. We also recommend using a process-based model, IMAGE-DGNM, to replace IMAGE-GNM when it is available for a global assessment.

In conclusion, this thesis advances the understanding of 1) the nutrient fate and effect of N that also plays an important role in freshwater eutrophication, 2) the improvement of accuracy of global nutrient predictions through choosing the best-fit retention models, 3) the relationship between potential species loss and nutrient content at freshwater ecoregion level, 4) the improvement in regionalization of FFs, EFs, and CFs, and 5) the severeness of freshwater fish species richness as affected by eutrophication globally (13.8% global species loss). The thesis, therefore, provides insight into the freshwater eutrophication impact on biodiversity loss. It also proposes methods for future research to assess eutrophication-related impact in terrestrial and marine ecosystems, and can support the stakeholders to mitigate eutrophication-induced biodiversity loss and support decision-makers to formulate the environmental strategies that relate to Sustainable Development Goals 6.3 and 15.1 and Kunming-Montreal Global Biodiversity Framework target 7.