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学位論文の要約

学位論文題名

Structural and functional assessments of hyporheic macroinvertebrates across multiple environmental gradients in rivers of Hokkaido, Japan　(北海道河川における複数環境傾度に沿った河床飽和間隙水域無脊椎動物の構造および機能評価)

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Knowledge of organisms' diversity pattern and their ecological drivers is central to ecology, which may vary at local to spatial scales. Rivers are composed of benthic habitat and a vertically saturated area below the riverbed which can be a habitat for diverse macroinvertebrate communities known as hyporheic habitat. In rivers, understanding the contribution of macroinvertebrates in ecosystem structure and function is largely limited for hyporheic habitat across multiple environmental gradients. This study tested the contribution of hyporheic habitat to total diversity of macroinvertebrates and demonstrated how macroinvertebrate's structural and functional responses vary across multiple environmental gradients in the hyporheic zone. The first part of the research was conducted in 15 river reaches within eight river segments consisting of five rivers in Hokkaido, Japan (Toyohira, Horonai, Sorachi, Tokachi, and Satsunai Rver). The latter parts were conducted only in Satsunai River.

The study first demonstrated the importance of habitat contribution from the hyporheic zone to the total diversity of macroinvertebrates and the factors that influence the contribution. Hyporheic and benthic samples were collected from August to November 2020 by installing colonization traps at 30 cm depth and a Surber sampler respectively. The macroinvertebrates were separated among segments, river reaches, and between benthic and hyporheic habitats. Habitat contribution (up to 25.9%) was most clearly detected at the reach scale, suggesting that habitat contribution should be recognized more at relatively small local scales. The higher alpha diversity of the benthic habitat and together with the dominance of turnover between habitats, suggested the presence of unique species in hyporheic habitat. The variable contribution pattern across reaches did not vary under variable environmental gradients. The number of hyporheic species predicted the contribution pattern across reaches and responded to environmental variables independently with the negative effect of fine sediment amount and positive effects of nitrate concentration, dissolved oxygen, and riverbed median particle size. Thus, the number of hyporheic species and their variable responses to the local environmental variables interactively cause varying contribution patterns across reaches. In the context of freshwater resource management and conservation, knowledge of the importance of

hyporheic habitat as a significant contributor to the total diversity of macroinvertebrates in rivers would signify the conservation priority of the habitat. Also, it provided information on the suitable scale at which the hyporheic habitat should be assessed, which could be crucial guidelines to set up the conservation importance of natural habitats. High contributions in Satsunai River calls an attention for hyporheic conservation and further research on the mechanical driver of the findings

The study then examined how fine sediment (particle size: <2 mm) influences the macroinvertebrates in hyporheic zone under different levels of nutrient pollution through experimental sediment addition in sites with different nutrient levels. The field survey and sampling were conducted in three sites in the Satsunai River and one of its tributaries in 2019. The amount of fine sediments varied between habitat treatment types, indicating that sediment addition effectively manipulated the hyporheic zone. The responses of hyporheic macroinvertebrates were predictable for the independent stressors. Higher nitrate increased the taxonomic richness and relative abundance. The interaction between two stressors was not apparent. Positive community structure organization was more promoted under the higher nutrient levels and any adverse effects of fine sediment were not apparent. This study would add the improved information on how field manipulation of fine sediments could affect the macroinvertebrates in the hyporheic zone under different nutrient gradients, which has been lacking and difficult through field observations and sampling often limited in providing cause-effect relationship. The hyporheic zone is as important as benthic zone since the biodiversity in the hyporheic zone plays important roles and shows variable responses to the environmental variables. A simultaneous quantitative measurement including benthic zone, with the functional responses could tell us further insight about the structural properties under multiple stressor effects in the hyporheic zone.

The study finally examined the effects of fine sediments and nutrients on hyporheic leaf litter decomposition rate and macroinvertebrates. The field survey and sampling were conducted in three sites in Satsunai River and one of its tributaries in 2019. The field experiment was conducted by measuring the leaf litter decomposition of dried *Alnus japonica* leaves in benthic and hyporheic zones with and without sediment treatments at four sites with a gradient of nitrate concentration; the same setups used in the previous chapter was used. The decomposition rate was comparable between the two zones but slowed down by sediment addition in the hyporheic zone. The leaf litter decomposition rate was highly predictable for the individual stressors. The detritivore invertebrate community was the main driving component of decomposition in the decreased leaf litter decomposition rate under higher sediment levels. Higher nitrate levels increased the leaf litter decomposition rate by stimulating microbe-driven decomposition and detritivore feeding. The adverse effects of fine sediment could be offset in the presence of nitrate and represented the additive effects of fine sediment and nitrate on leaf litter decomposition in the hyporheic zone. These findings provide two important implications to the predictions of how the hyporheic ecosystem may respond to sediment and nutrient stressors. First,

ecosystem functioning in terms of leaf litter decomposition rates is resistant to stressors because of counteracting responses. Second, the changes of ecosystem structure (community structure of macroinvertebrates and microbes) due to stressors may be substantial despite the functional changes appearing to be small. In other words, it is suggested that the functional resilience is maintained by the functional redundancy of detritivore invertebrates and microbes in the decomposition processes.

The findings estimated habitat contribution to the total diversity of macroinvertebrates and how environmental stressors affect the structure and function of macroinvertebrates in the hyporheic zone. The finding showed that hyporheic habitat could add unique species to river macroinvertebrate diversity in particular when examined at smaller reach scale. Moreover, hyporheic macroinvertebrates' structural and functional properties were influenced by the fine sediment and nutrients in the hyporheic zone, in which functional responses were adversely affected by the fine sediment with a decrease in detritivore abundance. Conservation of hyporheic species is important as they could provide essential roles (e.g., role in the food web) in hyporheic habitat. Detritivore invertebrates might not be unique species in the hyporheic zone, but their role is crucial for providing hyporheic functions. Thus, effective conservation measures can vary based on observed community structure including hyporheic species and taxa with more important functions, and multiple environmental gradients. The rich hyporheic zone with well mixed hydrological connectivity supported the higher diversity contribution from the hyporheic habitat in Satsunai River. Therefore, Satsunai River segments should be protected with great care by implementing the following steps. First, it is important to share the knowledge of current hyporheic macroinvertebrate diversity, distributions, and their contribution to the ecosystem structure and functions among stakeholders such as river managers and citizen. Second, the influence of environmental stressors on the macroinvertebrate structure and functions in the hyporheic habitat needs to be controlled to maintain a minimal level. Third, it is also important to assess whether ongoing river management activities such as, channelization and river regulation by dam etc. influence the community structure and function of hyporheic invertebrates, possibly including the hyporheic zone in the regular environmental monitoring activities.