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## 学位論文の要約

### 学位論文題名

A linkage between the underground and the land: insect-mediated resource fluxes and dispersals from the hyporheic zone of a gravel-bed river

(地下と地上のつながり：扇状地河川河床間隙水域からの昆虫を介した物質移送およびその分散)

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The hyporheic zone, locating below the riverbed, is a habitat for aquatic insects. Some insect larvae can temporarily live and some confine most of their mobility in this zone. The insects that span most of their lives as larvae in the hyporheic zone and have a terrestrial adult stage are known as amphibitic insects. Amphibitic insects bring out the resources originating from the hyporheic zone. There was no prior study on how much resources could be transferred from the hyporheic zone to the terrestrial ecosystem. The amphibitic insects were used as a conduit of resources to estimate how much resources the hyporheic zone could supply to the terrestrial ecosystem. The study also described the dispersal of amphibitic insects in the terrestrial ecosystem, which was not reported earlier. This study was conducted in about 18 km river section of a 4th order gravel-bed river, the Satsunai River locating in Hokkaido, Japan. A dominating amphibitic insect species was selected, *Alloperla ishikariana* (order: Plecoptera, family: Chloroperlidae), as a vector for supplying resources originating from the hyporheic zone. This species was chosen based on the previous study conducted in the same studied river section (Negishi et al., 2019a).

The study first demonstrated where the most hyporheic originating resources could be reached (Chapter 02). It estimated mean daily flux as dry biomass, carbon, and nitrogen during the early-summer to summer periods. The hypothesis was the hyporheic insects were an important contributor in total aquatic resources to the riparian zone. In 2017 and 2018, parallelly (May to August) and perpendicularly (June to October) oriented Malaise traps were set to catch the lateral and longitudinal directional dispersing winged adults of *A. ishikariana*, and other Ephemeroptera, Plecoptera, Trichoptera and Diptera from the river and estimated the directional fluxes of them. The directional fluxes were further split as moving away or back

to the channel (for lateral) and from down- to upstream or up- to downstream (for longitudinal). *Alloperla ishikariana* was similar to other Plecoptera species and differed clearly from Ephemeroptera and Trichoptera in directional characteristics of resources flux, suggesting that the extent and directions of hyporheic zone derived resource transfer depends on taxon-specific flight behaviors of hyporheic insects. Contributions of *A. ishikariana* to the riparian zone in total aquatic carbon and nitrogen transfer seasonally varied and were lower in May (5-6%) and August (2-4%) and the highest in July (52-70%). These conservative estimates largely increased (9% in May) after the supplementary inclusion of Diptera (Chironomidae and Tipulidae), part of which was considered hyporheic insects. Thus, the hyporheic zone could seasonally contribute a significant portion of aquatic resources to the riparian zone.

The study then attempted to understand how adult aquatic insects could disperse after reaching the riparian forest (Chapter 03). The hypothesis was the adult insects utilized the forest edge as a corridor to disperse along the river longitudinally. The predictions were the flying individuals along the channel in a longitudinal direction would be high in the riparian forest in relation to other areas such as water surface and gravel bars, and the individuals moving towards the upstream direction would be disproportionately common compared to those in the downstream direction in all the zones. The samples for this part of the study were collected in the period of June from 2017 to 2019. Six dominating taxa among Ephemeroptera, Plecoptera and Trichoptera were chosen based on their greater abundances. Chloroperlidae was one of the dominating taxa in which *A. ishikariana* comprised more than 95% in abundance. Most of Chloroperlidae and Hydrobiosidae reached the riparian forest rather than stayed on the open spaces of the river and the gravel-bar. After arriving in the riparian forest, most of the dominating taxa dispersed to the upstream direction. For upstream dispersal of Chloroperlidae the riparian forest is essential. By expressing the traveling distances of the insects in the riparian forest corridor, it might be possible to explore the extend of the linkage between the hyporheic zone and the terrestrial ecosystem.

In the final part of the study, it was reported how far *A. ishikariana* could disperse away from the channel (laterally) and along upstream or downstream (longitudinally) in the riparian forest of a gravel-bed river (Chapter 04). Malaise traps were set in June 2018 at various distances from the channel towards the riparian forest to estimate lateral dispersal distances. An elevated stable nitrogen isotope ratio in downstream larvae, caused by the influence of effluent from a wastewater treatment plant, was used to assess longitudinal dispersal by identifying and tracking adult movements. *Alloperla ishikariana* larvae were collected using colonization traps set below the riverbed from June to September in 2016, 2017, and 2018 for other ongoing studies. *Alloperla ishikariana* adults were hand-picked from

the riparian forest during June 2017 and July 2018. Laterally, 50th and 90th percentile dispersal distances were 11.66 and 35.09 m for female *A. ishikariana* and 20.59 and 59.20 m for male, respectively; this overlapped with distances for other aquatic benthic taxa. Longitudinally, 50th and 90th percentile dispersal distances were 0.74 and 1.43 km for females and 3.11 and 7.87 km for males, respectively. *Alloperla ishikariana* had one of the longest upstream traveling distances compared with other aquatic insects and the longest among Plecoptera taxa, where males exhibited a greater dispersal distance. A higher number of adults demonstrated upstream movement, suggesting an upstream bias in the longitudinal dispersal of *A. ishikariana*. Overall, the amphibitic stoneflies did not exhibit distinct dispersal characteristics compared with the results of previous reports on presumably benthic taxa.

This study is the first to report the amount of resources that could be derived from the hyporheic zone and to demonstrate how far the resources could be dispersed in the riparian zone. The findings supported an improved visualization of a multi-dimensionally connected river ecosystem in terms of material flow, including vertical connectivity. This study also showed the importance of the riparian forest edge for longitudinal dispersal of the hyporheic origin insects along the river. The amphibitic insects emerging from the hyporheic zone would utilize the riparian forest corridor to disperse upstream. Longitudinal and lateral dispersing distances comparison showed that the amphibitic insects could travel less away from the river than along the river. Therefore, maintaining vegetation cover in the riparian forest edge should be ensured for the continuous flow of resources via the hyporheic insects in the terrestrial ecosystem. The importance of the hyporheic zone as a supplier of aquatic resources to the terrestrial ecosystem revealed that it could demand worthiness in the freshwater resources management plan.