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NOTE

Sustainment of epiphytic microinvertebrate assemblage in relation with different aquatic plant microhabitats in freshwater wetlands (South Korea)

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ABSTRACT

*In general, aquatic plants in shallow wetlands provide critical habitat and refuge for epiphytic microinvertebrates. We hypothesised that the density and diversity of epiphytic microinvertebrates would differ based on different types of aquatic plant species. We collected epiphytic microinvertebrate samples on the surfaces (stems and leaves) of diverse aquatic plant species at 2 shallow wetlands (Upo and Jangcheok, South Korea) from May to June 2011. The species diversity of epiphytic microinvertebrates tended to increase as the number of aquatic plant species increased. The highest epiphytic microinvertebrate density was found on elodeid and pleustophyte species, and a relatively low microinvertebrate density was found on helophyte and nymphaeid species. The results indicate that epiphytic microinvertebrates preferred elodeid and pleustophyte species over other plant types, because they support larger habitat spaces (*i.e.*, area of substrate) for foraging activity and predation inhibition. On the basis of the results, we recommend establishing diverse aquatic plant communities when wetlands are restored or created to assure high diversity of species that use aquatic plants as their habitat.*

Key words: aquatic plants types, β-diversity, shallow freshwater wetlands, epiphytic microinvertebrates, microhabitat, littoral zone.

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INTRODUCTION

Freshwater wetlands are important habitats that contain relatively diverse habitat structures and support high biodiversity. Among the biological organisms adapted to freshwater wetlands, microinvertebrates play important roles in processes such as the transfer of materials and energy in ecosystems. Microinvertebrates (typically consisting of rotifers, cladocerans, and copepods) behave like primary consumers and are food items for macroinvertebrates and juvenile fish (Sagrario and Balseiro, 2003). Therefore, the loss of microinvertebrates occasionally disturbs food web dynamics (O'Brien, 1979; Yan *et al*., 2002). Because of this potential effect, an understanding of microinvertebrate dynamics is fundamental to comprehending local biodiversity and food web dynamics in freshwater wetlands.

Empirical studies have shown that freshwater wetlands are dominated by epiphytic rather than planktonic microinvertebrates. An abundant substrate surface (*e.g.* stems and roots of aquatic plants) and sufficient food source are favourable conditions for epiphytic species (Zohary *et al*., 1994; Stefanidis and Papastergiadou, 2010). Planktonic species are preferred by consumers because they are easily pursued and captured in open-water areas (*i.e*., areas without aquatic plants; Perrow *et al*., 1999). When easy-to-exploit resources (*e.g*., planktonic microinvertebrates) are exhausted, epiphytic microinvertebrates can be used as alternative food sources for secondary consumers (Nicolle *et al*., 2010). Thus, research on epiphytic microinvertebrates is needed to understand biodiversity and food webs in freshwater wetlands. The distribution of epiphytic microinvertebrates relative to habitat supported by aquatic plants has been of particular interest to researchers (Scheffer, 1997; Warfe and Barmuta, 2004; Cazzanelli *et al*., 2008). The complex habitat provided by various aquatic plants can increase the density and diversity of microinvertebrate species through the control of ecosystem functions such as interactions between predators and prey (Harrel and Dibble, 2001; Gonzalez and Chaneton, 2002). However, because previous studies have primarily focused on predator–prey interactions or simple distribution patterns, the comprehensive distribution pattern of epiphytic microinvertebrates is not fully understood.

We expected a different distribution pattern of epiphytic microinvertebrates based on different types of aquatic plants. Aquatic plants in freshwater wetlands are classified into four types: helophytes, pleustophytes, nymphaeids, and elodeids. Each type has different inhabitation and morphological characteristics such as space occupation pattern (*i.e.* floating or substrate-based), length, width, and stem surface area based on species. Epiphytic microinvertebrates might adapt to the different conditions provided by different aquatic plants, resulting in distinguishable distribution patterns. Therefore, our goal was to verify whether aquatic plant type affects the density and diversity of epiphytic microinvertebrates in plant-dominated freshwater wetlands.

METHODS

South Korea is located in the East Asia region and has a temperate climate. Four distinct seasons lead to a dynamic succession of biological communities in the freshwater ecosystems of Korea. Annual average rainfall is approximately 1150 mm, and freshwater ecosystems receive concentrated rainfall in the summer (more than approximately 60% of annual rainfall occurs from June to early September; Jeong *et al*., 2007). Therefore, ecological characteristics become relatively stable in the spring because of very low hydrological disturbance (for stability shift see Jeong *et al*., 2011).

The study sites were established in the Upo and Jangcheok wetlands, located in southeastern South Korea. The surface waters of the Upo and Jangcheok wetlands comprise 2.7 km^2 and 0.5 km^2, respectively. The dominant land cover surrounding the wetlands is agricultural, and non-point sources continuously influence the wetland ecosystems. Continuous nutrient loading to wetlands typically leads to eutrophication (Peterjohn and Correll, 1984; Jordan *et al*., 2003), and several reports at the study sites showed high nitrogen and phosphorus concentrations in those wetlands (Korea Ministry of Environment, 2006; Lee and Lee, 2010).

We collected epiphytic microinvertebrates in the Upo and Jangcheok wetlands from May to June 2011. We sampled 30 quadrats (0.5×0.5 m) along littoral areas at each study site (2-m minimum distance from shoreline) and counted all epiphytic microinvertebrates within each quadrat. We removed emergent organs above the water surface (*i.e.,* stalks and flowers) of all aquatic plants because microinvertebrates inhabit underwater environments. The plants were handled carefully to prevent the microinvertebrates from accidentally detaching. We divided the sampled aquatic plants into four life forms (helophytes, pleustophytes, nymphaeids, and elodeids) to distinguish the density and diversity of epiphytic microinvertebrates relative to aquatic plant type. In helophytes and nymphaeids, only a small part of the plant body is submerged, whereas in pleustophytes and elodeids, complex parts of the plant body are submerged. We measured the entire dry mass of floating or submerged plants in grams dry weight (gdw). The aquatic plant samples were dried at 60°C for 2 days. Intermediate preservation of epiphytic microinvertebrates was accomplished using filtered wetland water. Microinvertebrates were removed from 2-L of water using a plankton net (32-µm mesh size), and the filtered water was stored in 5-L tanks. This water was used as temporary storage for epiphytic microinvertebrates. We allocated one tank per aquatic plant species, so the number of tanks for every quadrat was determined by the number of sampled aquatic plants. The collected aquatic plants were shaken strongly more than 50 times in the tanks to detach all of the microinvertebrates (for the detaching process see Sakuma *et al*., 2002). The epiphytic microinvertebrates suspended in the water were filtered using a 68-µm mesh net and immediately fixed with sugar formalin (final concentration of 4% in the form of aldehyde). Densities of the epiphytic microinvertebrates attached to the plants were expressed as the number of individuals per gram dry weight of aquatic plants (ind.·gdw^{-1}). The sampled microinvertebrates were identified in accordance with Mizuno and Takahashi (1991) and counted under a light microscope (Nikon Axioskop 40; 100×). Several water quality parameters [temperature, dissolved oxygen percent saturation (DO % sat), pH, and turbidity] were measured in conjunction with epiphytic microinvertebrate sampling within each quadrat. We used a DO meter (YSI; Model 58) to measure water temperature and DO and a pH meter (Orion; Model 58) and turbidity meter (HF Scientific Inc.; Model 100B) to record pH and turbidity, respectively. Using the collected ecological data, we examined the relationship between number of aquatic plant species and epiphytic microinvertebrate diversity. First, we applied one-way ANOVA to identify any differences in epiphytic microinvertebrate density relative to aquatic plant type. An additional *post-hoc* test was conducted if the differences were statistically significant. The other statistical analysis was a simple regression to examine any patterns in epiphytic microinvertebrate β-diversity changes. The microinvertebrate samples were prepared for each aquatic plant species so that we could compare newly added epiphytic microinvertebrate species (*i.e.* β-diversity) as the number of aquatic plant species increased. The number of comparisons was determined by ${}_nC_a$, where n denotes the total number of aquatic plant species found in a wetland, and a indicates the number of compared aquatic plants. β-diversity values were estimated for each comparison number of the aquatic plants, and their averages were calculated. Regression analysis was performed using the average β-diversity based on the number of compared aquatic plant species. All statistical analyses were implemented using SPSS for Windows (version 20).

RESULTS AND DISCUSSION

Results of the analysis of physico-chemical parameters showed no differences between the study sites in each wetland. Values at the Upo and Jangcheok wetlands were similar for water temperature (18.3±1.4 and 17.6±0.8, respectively), DO % sat (42.3±12.6 and 49.5±15.1, respectively), pH (8.4±0.5 and 8.1±0.4, respectively), and turbidity (15.6±3.4 and 17.5±4.2, respectively).

Species composition and dry weight of aquatic plants were also similar between the Upo and Jangcheok wetlands (Tab. 1). *Phragmites australis* dominated the Upo wetland, and the quadrats contained an additional 6 aquatic plant species: *Spirodela polyrhiza*, *Salvinia natans*, *Trapa japonica*, *Hydrocharis asiatica*, *Potamogeton crispus*, and *Ceratophyllum demersum*. *Paspalum distichum* dominated the Jangcheok wetland, and the quadrats contained an additional 5 aquatic plant species: *S. natans*, *T. japonica*, *H. asiatica*, *P. crispus*, and *C. demersum*. *T. japonica* had the highest dry weight among the aquatic plants, followed by *C. demersum*. No clear difference in the diversity and dry weight of aquatic plants was found between the 30 quadrats in each wetland. The results of β-diversity calculations for epiphytic microinvertebrates relative to the number of aquatic plant species revealed that the biodiversity of epiphytic microinvertebrates tended to increase as the aquatic plant species composition increased, converging at a certain level (Fig. 1). Both wetlands presented similar patterns, and regression analysis provided significantly high determination coefficients (Upo, 0.996; Jangcheok, 0.997; P<0.01). An increasing tendency in the β-diversity of epiphytic microinvertebrates was apparent when higher numbers of aquatic plants were available in both study sites. Increased biodiversity is primarily related to the presence of sufficient space for resident organisms. Expansion of the habitat area is significantly related to diversity of the resident species (Krauss *et al.*, 2004; Melles *et al.*, 2003; Tews *et al.*, 2004). In those cases, a mixture of various plant species implies that various types of microhabitats occur contemporaneously within a given space, which may attract different kinds of resident species. Consequently, a sufficient habitat space with rel-

Tab. 1. Dry weight between aquatic plant species in the Upo and Jangcheok wetlands.

Aquatic plant species	Upo wetlands (gdw)	Jangcheok wetlands (gdw)
Phragmites australis	26.4±12.5	-
Paspalum distichum	-	22.7±15.7
Spirodela polyrhiza	6.7±5.6	-
Salvinia natans	11.7±8.9	18.4±3.7
Trapa japonica	33.7±24.7	27.9±12.4
Hydrocharis asiatica	7.8±3.2	10.1±5.7
Potamogeton crispus	18.6±11.5	13.8±7.8
Ceratophyllum demersum	23.8±18.7	21.8±17.6

gdw, gram dry weight.

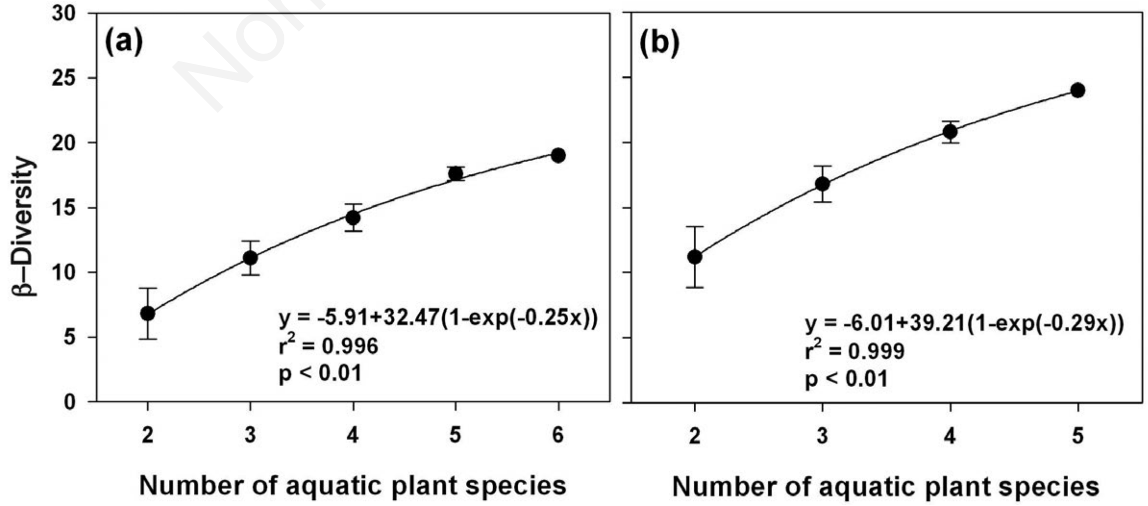

Fig. 1. β-Diversity of epiphytic microinvertebrate species relative to the number of aquatic plant species during the study period (May to June 2011). a) Upo wetland (n=15 for 2 aquatic plant species; n=20 for 3 aquatic plant species; n=15 for 4 aquatic plant species; n=6 for 5 aquatic plant species; and n=1 for 6 aquatic plant species). b) Jangcheok wetland (n=10 for 2 aquatic plant species; n=10 for 3 aquatic plant species; n=5 for 4 aquatic plant species; and n=1 for 5 aquatic plant species).

atively high heterogeneity (*i.e.*, different types of aquatic plants) can result in increased biodiversity. The β-diversity results of our study can be interpreted based on this concept. The diversity of the epiphytic microinvertebrates tended to converge at a certain level (Fig. 1). Typically, when a sufficient habitat is available, species richness tends to increase (Preston, 1962; MacArthur and Wilson, 1963). However, regression analysis revealed a converging pattern of β-diversity in these organisms. Spatially unbounded habitats may have a high probability of attracting resident species, which leads to an almost linear pattern of increasing biodiversity. However, the area containing the aquatic plants in this study was spatially limited, and both the aquatic plants and epiphytic microinvertebrates experienced spatial constraints. This limitation might result in a converging pattern of epiphytic microinvertebrate diversity. Epiphytic microinvertebrate densities were different relative to the aquatic plant species in both wetland systems (Fig. 2). In the Upo wetland, the highest epiphytic microinvertebrate density was found on the surface of *C. demersum* (average 2784±784 ind. gdw^{-1}), followed by *S. natans* (average of 2547±917 ind. gdw^{-1}). Results of the statistical analysis using one-way ANOVA showed that the epiphytic microinvertebrates on the surfaces of two plant species were clearly distinguished from those on the other plant species in both wetlands. *Phragmites australis* supported the lowest density of epiphytic microinvertebrates (average of 101 ind. gdw^{-1}). Epiphytic microinvertebrate density in the Jangcheok wetland was distributed largely on the surface of *S. natans* (average of 3516 ind. gdw^{-1}), followed by *C. demersum* (average of 2151 ind. gdw^{-1}). Among aquatic plants, *T. japonica* had the lowest density of epiphytic microinvertebrates (average of 252 ind. gdw^{-1}). The number of epiphytic microinvertebrate species exhibited a pattern similar to that of density distribution.

Aquatic plants are known to provide habitat for epiphytic microinvertebrates (Taniguchi *et al.*, 2003), and the habitat characteristics in freshwater wetlands are determined by the shape and structure of the aquatic plant species (Van der Putten *et al.*, 1997). Helophyte and nymphaeid species have a relatively simple morphology compared to other plants, but water is usually densely populated by pleustophyte and elodeid species (Hansen *et al.*, 2011). This pattern was also found in our study, and wetlands with pleustophyte and elodeid species supported high densities of epiphytic microinvertebrates (Fig. 2). Epiphytic microinvertebrates tend to attach to the leaves and stems of plants such as pleustophytes and elodeids because of their large surface areas in the water (Meerhoff *et al*., 2006), which increases the substrate area through complex distributions of leaves and stems (Manatunge *et al*., 2000). This supports an abundance of attached algae (periphyton), which are important prey items for epiphytic microinvertebrates (Jones *et al*., 1999).

CONCLUSIONS

In the present study, diverse aquatic plant species, especially the contemporaneous presence of different plant types in freshwater wetlands, could sustain the local diversity and density of epiphytic microinvertebrates. A

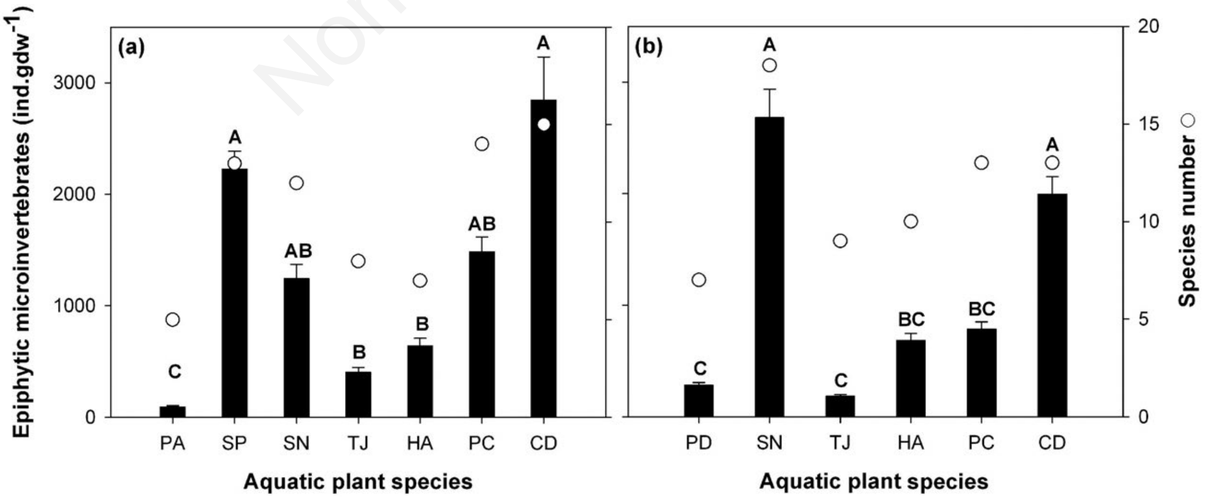

Fig. 2. Epiphytic microinvertebrate density (ind.·gdw–1) and species numbers relative to aquatic plant type during the study period (May to June 2011). Bars represent an average of replicates (±SD). Letters above the bars indicate statistically different mean values. a) Upo wetland. b) Jangcheok wetland. PA, *Phragmites australis*; PD, *Paspalum distichum*; SP, *Spirodela polyrhiza*; SN, *Salvinia natans*; TJ, *Trapa japonica*; HA, *Hydrocharis asiatica*; PC, *Potamogeton crispus*; CD, *Ceratophyllum demersum*.

high density and number of species of epiphytic microinvertebrates were found on elodeids and pleustophytes. In addition, we found that the habitat developed by diverse aquatic plant species could support a high density and diversity of epiphytic microinvertebtates. This study was partly limited in quantifying the degree of complexity provided by the aquatic plants. A relevant methodology should be developed in a further study.

In addition, we recommend establishing diverse aquatic plant communities when wetlands are restored or created to not only increase biodiversity in the wetlands but also sustain an ecologically healthy food web. Results showed that the increase of epiphytic microinvertebrate species was strongly related to the aquatic plant community, and this pattern is found in other animals (Tews *et al*., 2004). The convergence of animal species number implies its significance in determining an optimal level for aquatic plant community diversity to reduce the cost-benefit trade-off in wetlands restoration or management.

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