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Concordance of diatom, macroinvertebrate and fish assemblages in streams at nested spatial scales: Implications for ecological integrity

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ABSTRACT

Understanding the concordance among different assemblages as well as their responses to the environmental gradients at multiple spatial scales is an important issue in conservation biology and in the assessment of ecological integrity. We examined the community concordance among diatoms, macroinvertebrates and fish in minimally disturbed streams on four nested spatial scales (i.e., national, catchment, sub-catchment and mountain or lowland at sub-catchment scales) in Korea. The results, based on non-metric multidimensional scaling, showed that diatoms, macroinvertebrates and fish displayed consistent patterns that were strongly structured along an altitude gradient at the national scale. However, the responses to all other influential environmental factors differed by assemblages. The community composition of fish closely reflected the gradients of larger scale environmental factors (i.e., geographical and hydrological variables), whereas macroinvertebrates mainly reflected the changes at relatively finer environmental scales (e.g., hydrological variables and substrate composition). Diatoms showed relatively weak relationships with environmental variables except for the altitudinal gradient. Community concordance based on Protest was significant at four nested spatial scales, although most cases of community concordances were relatively weak. Fish and macroinvertebrates showed high concordance at the national and catchment scales, whereas macroinvertebrates and diatoms showed high concordance at smaller scales (i.e., mountain or lowland at sub-catchment). Finally, our study demonstrated that community concordance among diatoms, macroinvertebrates and fish would be different according to spatial scales and even in the same scales and that use of a representative taxon to assess ecological integrity should be applied with caution.

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1. Introduction

Community concordance is a hot issue for designing cost-effective assessments of ecological integrity (Paszkowski and Tonn, 2000), presenting the similarity of different taxonomic groups across a set of sites based on species (i.e., community composition). Community concordance provides more comprehensive information about community similarity than studies based on species richness only (Su et al., 2004; Pawar et al., 2007). In addition, the concordance can be applied to evaluate the relationships between environmental gradients and each assemblage at multiple spatial scales (Paavola et al., 2006). The mechanisms of community concordance between different assemblages are influenced by many different factors, including responses among different taxonomic groups to the same environmental drivers, such as losses of sensitive species due to a certain environmental stress (Kilgour and Barton, 1999; Heino et al., 2005; Pawar et al., 2007; Heino, 2010; Dolph et al., 2011), biotic interactions (Jackson and Harvey, 1993; Heino, 2010; Johnson and Hering, 2010) and biogeographical and evolutionary history (e.g., life history traits of stream assemblages) (Mitter et al., 1991; DeChaine and Martin, 2005; Qian and Ricklefs, 2008; Virtanen et al., 2009).

Although different assemblages are concordant with each other, it has not been clearly proved whether they respond similarly to major environmental gradients and whether one or more assemblages can represent other assemblages as a 'surrogate'. To our knowledge, studies of these assumptions are still contradictory. For

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example, concordances between macrophytes and macroinvertebrates were strong in upland Welsh streams with acid gradients (Ormerod et al., 1994). In contrast, there was little concordance among benthic invertebrates, fish and bryophytes in headwater streams in a boreal watershed in northern Finland (Paavola et al., 2003). Community concordance of diatoms, macrophytes, macroinvertebrates and fish was higher in mountain streams than in lowland streams, with the strongest correlations between species-poor fish and macrophyte assemblages and between fish and invertebrate assemblages (Johnson and Hering, 2010).

Two contrasting studies were reported concerning the role of spatial scale in community concordance: Paavola et al. (2006) demonstrated that three different assemblages (i.e., bryophytes, macroinvertebrates and fish) represented a higher concordance at a large spatial scale including multiple drainages than at small scales, whereas Dolph et al. (2011) reported a stronger concordance between macroinvertebrates and fish at the smallest scale (i.e., the catchment scale) than at a large spatial scale (i.e., ecoregions and statewide). One reason why various studies yielded different results for the community concordance even between the same assemblages is the scale studied. If there is no community concordance at the spatial scales researched, it is not reasonable to evaluate or predict the condition or status of one assemblage based on the information from the other assemblage in the spatial scales researched. In addition, organisms should pass lots of filters (e.g., abiotic vs. biotic and actual vs. historical) across multiple spatial scales (e.g., continental, regional and local scales), resulting in differences in community compositions as well as biological traits (Poff, 1997; Statzner et al., 2004). Thus, an approach based on the spatially nested hierarchical model (Allen and Starr, 1982) can provide a useful framework for facilitating the examination of ecological characteristics, including community concordance, across a continuum of large to small and long to short spatial and temporal scales.

In spatially nested habitats, although all of the components are interconnected across various scales, the influence of a particular component can change based on the spatial scales researched. In other words, the events that are components at a certain scale can alter a potential habitat at smaller scales, whereas the influence of the same events can be minor at larger scales. For instance, geographical topography and climate can control physiology, vegetation type, land use (e.g., agriculture, urbanization and mining) and soil types at catchment scales (Fig. 1). Vegetation and soil types restrict the lower levels such as channel-forming factors (e.g., magnitude, frequency and duration of water flashing, discharge, sediment input, sediment transport, stream bank and slope), and the channel-forming factors influence habitat condition at the lower levels of the hierarchy structure such as sediment input and transport, water velocity, refugia, substrate composition and water quality (Parsons et al., 2004). Finally, these factors determine the distribution and occurrence of species.

The selection of a particular scale limits the understanding of the component patterns as well as processes in stream ecosystems. In addition, biotic filters including competition, prey-predator relationships and community diversity of other taxonomic groups can limit dispersal and influence the establishment and colonization of certain taxonomic groups (Oster et al., 2009). In particular, the influence of biotic filters can be more strengthened in minimally disturbed areas, which can possess relatively shorter environmental gradients than anthropogenically perturbed areas (e.g., Johnson and Hering, 2010). Therefore, studies of the community concordance with various environmental factors across various scales (e.g., local, catchment and national scale) as well as biotic metrics are necessary to evaluate whether ecological integrity based only on a specific surrogate is justified.

In this sense, we focused on evaluating the community concordances of three different taxonomic groups (diatoms, macroinvertebrates and fish) in minimally disturbed streams at

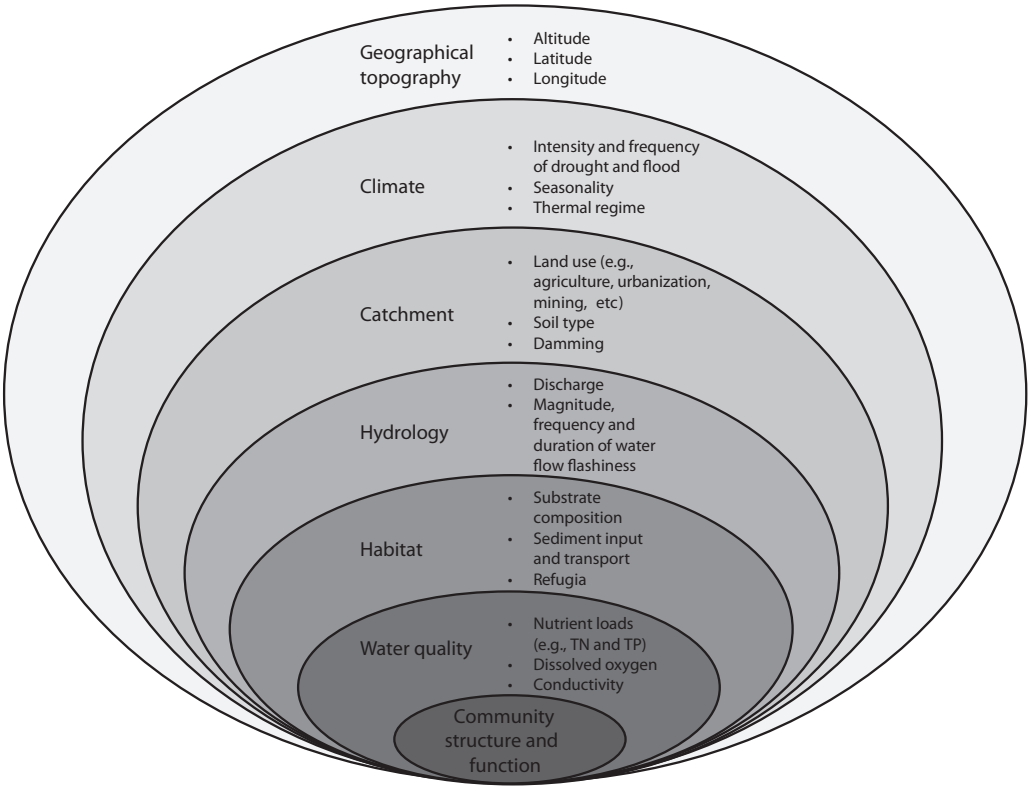

Fig. 1. Conceptual illustration of the relationship between environmental variables and stream community structure.

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