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Evaluation of stream ecosystem health and species association based on multi-taxa (benthic macroinvertebrates, algae, and microorganisms) patterning with different levels of pollution

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ABSTRACT

Benthic communities of macroinvertebrates, algae, and microorganisms were concurrently collected using a Surber sampler (30 × 30 m^2; 300 μm mesh), brush (5 × 5 cm^2), and syringe (100 mL; Denaturing Gradient Gel Electrophoresis), respectively, to determine the ecological integrity of streams with different levels of pollution. Macroinvertebrates provided a clearer representation of the gradient of pollution, while a broader scope of species distribution was observed for algae and microorganisms, including sites severely polluted with heavy metals. Species associations among different taxa were presented on the Self-Organizing Map (SOM) and Nonmetric Multidimensional Scaling (NMDS) based on environmental factors. After screening, indicator species visualized on the SOM represented a wider range of environmental impacts and were more illustrative with benthic macroinvertebrates in least polluted sites. In contrast NMDS presented species more closely associated with overall variance of communities with severe pollution, mainly in microorganisms and algae. Multi-taxa community analysis using SOM and NMDS in combination would provide a comprehensive assessment for addressing ecological integrity in streams.

1. Introduction

There is an urgent need for integrative assessment of water quality in aquatic ecosystems to enable their sustainable management (Allan and Castillo, 2007; Hellawell, 1986; Rosenberg and Resh, 1993). Considerable research has been conducted on revealing toxic effects of organic enrichment on different taxa (Hellawell, 1986; James and Evison, 1997; Rosenberg and Resh, 1993). In addition to organic enrichment, heavy metal pollution in stream ecosystems has been studied broadly in different taxa: fish (Demirak et al., 2006; Greig et al., 2010; Tariq et al., 1996), algae and micro-organisms (Bischoff, 1982; Gold et al., 2002; Richards and Mullins, 2013), and macroinvertebrates (Eyres and Pugh-Thomas, 1978; Iwasaki et al., 2013; Watanabe et al., 2008). Heavy metals also affected community functioning and food web structure in aquatic ecosystems by biomagnification processes (Solà et al., 2004; Watanabe et al., 2008).

On the basis of biodiversity and complexity of community functioning, the ecological integrity of a broad scope of diverse taxa in benthic aquatic communities, including producers (e.g., algae), consumers (e.g., macroinvertebrates), and decomposers (e.g., microorganisms), should be assessed. Since different biological organisms have their own ecological functioning patterns, integrative representation of the community can provide a comprehensive assessment of ecological health. However, due to difficulties in sampling (especially continuous sampling) and the extra research required to classify the collected organisms, not many surveys have been conducted to date.

Inter- and multi-taxa surveys to evaluate aquatic ecosystems were initiated in the 2000s (Olguin et al., 2004; Sagert et al., 2005). Olguin et al. (2004) provided integrated data for phytoplankton and zooplankton through an ecotoxicological assessment of highly polluted river water and reported that the best water quality had higher algal diversity and planktonic crustacean density. Soininen and Könönen (2004) investigated macroinvertebrates and diatoms to characterize the role of community structure in eutrophication concurrently and suggested

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that biological monitoring based on more than one taxon group would be more suitable for expressing water quality. Investigations with more than two taxa have also been conducted. Griffith et al. (2005) surveyed periphyton, macroinvertebrate, and fish communities to obtain metrics for comparison of their relative sensitivities to chemical and physical stressors. They reported that combining the matrix for taxa assemblages into a mixed assemblage index of biotic integrity may increase the utility of a multi-metric approach. Bae et al. (2011) analyzed fish, macroinvertebrate, and diatom assemblages concurrently in streams and identified differences in taxa associations. Specifically, significant correlations between fish and macroinvertebrates were observed when compared to the correlation between diatoms and macroinvertebrates. Their study enabled the visualization of the distribution of environmental impacts on a national scale for Korea. Although each taxon may represent ecological integrity and could convey some information regarding the target ecosystem separately, the integrative presentation of ecological integrity is necessary for comprehensive understanding of community functioning and ecosystem health pertaining to the sampling sites.

In previous studies, microorganisms such as decomposers have been seldom investigated along with other taxa in multi-taxa analyses of ecosystems. Song et al. (2005) analyzed microbial and macroinvertebrate communities and reported associations with both narrow and broad distributions between macroinvertebrates and microorganisms, as well as the usefulness of inter-taxa associations in defining the ecological integrity of an aquatic ecosystem. Three taxa groups, including producers, consumers, and decomposers together in the food chain, have never been extensively investigated for community patterns and species association in response to different levels of pollution.

Because communities consist of multiple-taxa, which vary widely under environmental constraints, it is difficult to address the non-linearity and dynamic nature of communities by using conventional multivariate methods (Chon et al., 1996, 2001; Lek and Guegan, 1999, 2000; Recknagel, 2003); therefore, the SOM can be utilized to analyze multi-taxa community data. The feasibility of using SOM for patterning community data has been demonstrated in assessment of ecosystem quality (Lek and Guegan, 1999, 2000; Recknagel, 2003), patterning complex relationships (e.g., Huntingford and Cox, 1997; Lek et al., 1996; Recknagel, 2003; Tuma et al., 1996), predicting community dynamics (Céréghino et al., 2001; Recknagel et al., 1997; Tan and Smeins, 1996), and comparing with other statistical techniques (e.g., principal component analysis) (Giraudel and Lek, 2001). SOM has been further used for analysis of communities consisting of different taxa, including benthic macroinvertebrates with microorganisms (Song et al., 2005), and benthic macroinvertebrates with diatoms and fish (Bae et al., 2011). We examined the species association of three taxa groups by concurrently visualizing community data using the SOM trained by environmental factors and screened indicator species across different degrees of pollution.

To reveal the association of species between different taxa, the nonmetric multi-dimensional scale (NMDS) was also employed (Clarke, 1993; Kruskal and Wish, 1978; McCune et al., 2002). The NMDS technique has been reported to be feasible for use in ordination when compared to other multivariate techniques in application to ecological data (Bettinetti et al., 2000; Kenkel and Orloci, 1986; Kwon et al., 2009).

In this study, we selected three taxa groups in benthic communities representing producers (algae), consumers (macroinvertebrates), and decomposers (microorganisms) in streams and utilized the SOM and community parameters i) to address community compositions for different taxa in response to pollution levels, ii) to compare the abundance distribution of species (e.g., broad or narrow) reflecting the environmental impact, and iii) to reveal overall species associations among the three taxa groups based on the SOM and NMDS in response to anthropogenic disturbances.

2. Methods

2.1. Study sites

Eight sampling sites in three streams in two river basins, the Nakdong and Suyong river basins, were selected to represent the differential levels of the impact of pollution in the metropolitan Busan area, Republic of Korea (Fig. 1). The Nakdong river basin (506.2 km) is the longest river system in the Southern peninsula of Korea, while the Suyong river basin (28.6 km) covers most of eastern Busan. Two tributaries of the Nakdong River, the Daechon and Hakjang streams, were selected to survey the impact of pollution. Daechon stream is located in a mountainous resort area; however, the sampling sites were characterized by high levels of pollution produced from the large number of nearby restaurants (DKS and DDK). We selected four sampling sites along the longitudinal axis of the Daechon stream (DUK (35°14′27.25″N 129°3′24.66″E)), (DAG (35°15′5.64″N 129°2′36.65″E)), (DKS (35°14′59.32″N 129°3′24.30″E) and DDK (35°14′59.32″N 129°3′24.30″E)) across different levels of pollution (Fig. 1). The sampling sites have been reported to present community response to disturbances since 2003 (Song et al., 2006). While the Daechon stream was mainly exposed to organic sewage pollution, the Hakjang stream in the Nakdong river basin was heavily polluted with residential sewage and industrial waste from Busan (Fig. 1). Two sampling sites (SSI (35°8′46.04″N 128°58′32.27″E) and HJD (35°8′30.31″N 128°59′0.66″E)) were selected to present the levels of severe domestic sewage and heavy metals in the Hakjang Stream. Since the stream is short and heavily polluted along the longitudinal axis, we were unable to find a clean site in this stream. Therefore, one site from the Onchon stream of the Suyong river basin was selected to represent least polluted state (OCU (35°16′46.78″N 129°4′47.38″E)). Another site (ONS (35°16′40.26″N 129°5′9.65″E)) was also chosen in the same stream to present severe organic pollution in the Busan residential area (Fig. 1).

2.2. Sampling

Three major taxa groups, algae, benthic macroinvertebrates and microorganisms were collected concurrently either by sampling across the stream's width or at locations at 5–10 m intervals along

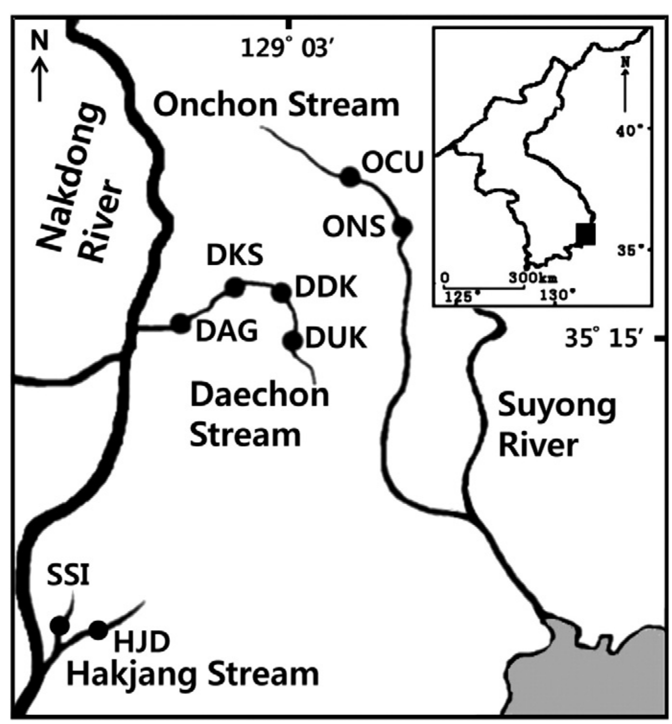

Fig. 1. Location of sampling sites in streams in Busan across different levels of pollution.