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River water quality assessment based on a multi-descriptor approach including chemistry, diatom assemblage structure, and non-taxonomical diatom metrics

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ABSTRACT

In the present study, the ecological status of four major South Korean rivers flowing near industrial complexes is assessed using physico-chemical analyses and various descriptors based on benthic diatom assemblages. Principal component analysis conducted with physical and chemical variables singled-out four sites as more severely impacted (higher concentration of metals and total nitrogen, higher conductivity and biological oxygen demand), while the remaining 12 sites indicated less impacted conditions, although showing nutrient enrichment. Less-contaminated sites based on physico-chemical properties showed higher cell densities, higher richness and diversity, a larger proportion of live and healthy-looking diatoms, lower production of lipid bodies (in terms of number and size) and fewer teratologies than more-contaminated sites. Non-taxonomical metrics (cell heath status, cell size, lipid bodies and valve deformities) were in good agreement with traditional taxonomical metrics (assemblage structure, richness, diversity). Overall, water quality assessment based on diatom assemblages and diatom-based metrics had a good fit with the available physico-chemical data and agreed on the most impacted sites. However, additional sites showed signs of degradation based on the diatom metrics used. This suggests that the use of biotic indicators provides useful complementary information on the health status at the selected sites.

1. Introduction

Industrialization and urbanization contribute to freshwater ecosystem degradation worldwide. Alteration and channelization of watercourses in urban areas result in progressive hydrological and hydrobiological degradation that may have serious impacts on the biotic and abiotic components of these systems. For example, urban watercourses may suffer from elevated and fluctuating concentrations of nutrients and contaminants (e.g., metals, pesticides, aromatic polycyclic hydrocarbons), causing changes in species assemblage composition, with increases in the number and abundance of pollution-tolerant species (Morin et al., 2012).

Water quality programs targeting chemical criteria alone have been criticized, as they do not provide information on the impacts of environmental stresses on organisms (Wolska et al., 2007; Lavoie et al., 2008). The aquatic biota, however, responds in a complex and dynamic manner to cumulative effects of various anthropogenic disturbances, and thus provides an integrated picture of the biological health of an ecosystem. Bioindicators therefore represent a crucial component for assessing overall ecological health (Ricciardi et al., 2009), and are a valuable complement to traditional physico-chemical measurements.

There is growing interest in studying the response of aquatic biota to various environmental stresses, its resilience, and its recovery trajectories. Due to its key ecological role at the base of the food web, sessile mode of life, cosmopolitan nature, and short life cycle, the algal component of biofilms is often selected for its sensitive and rapid response

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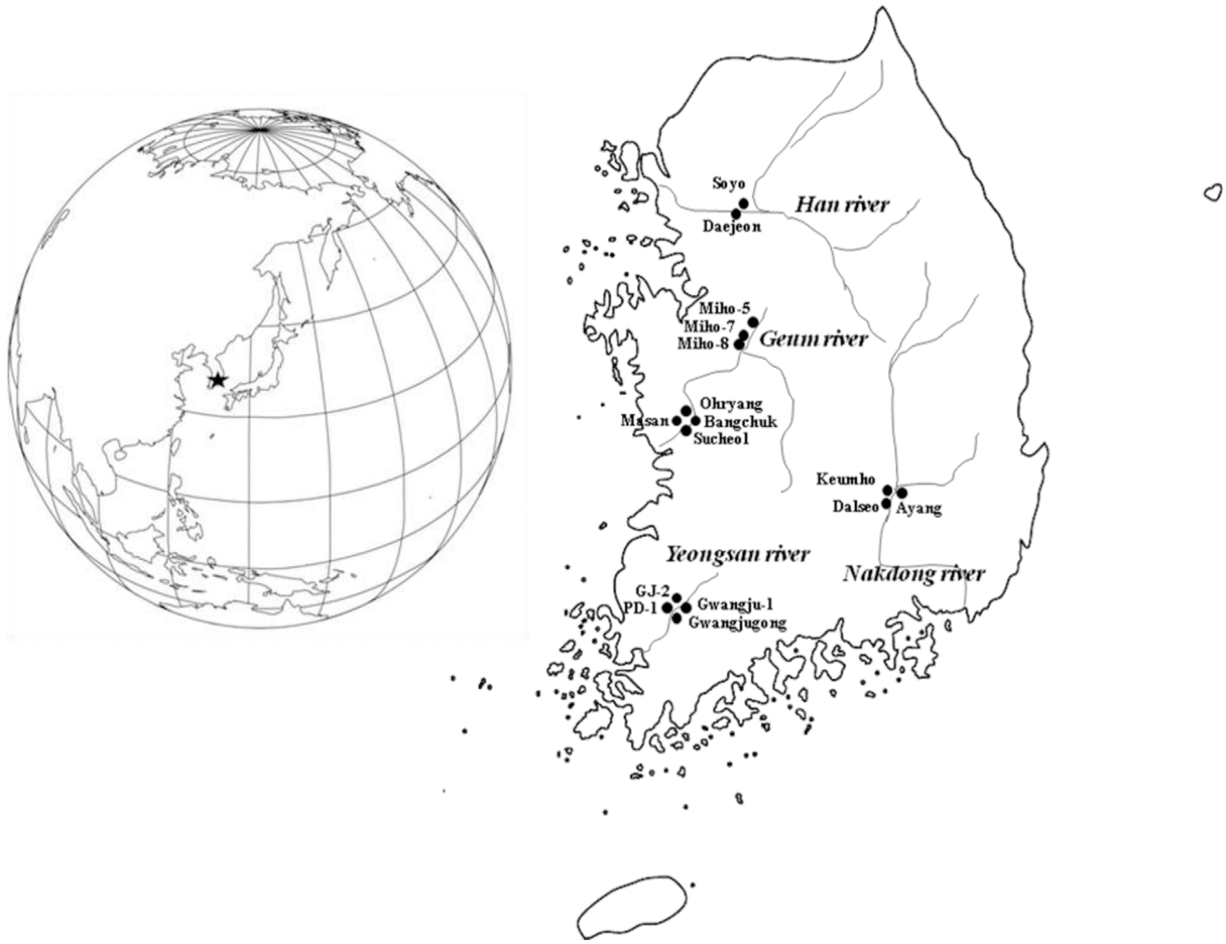

Fig. 1. Study area showing the 16 sites selected on four main Korean rivers.

to environmental fluctuations as compared with higher-level organisms. In particular, diatoms (Bacillariophyta) have been extensively included in water quality assessment for monitoring the biological integrity of lotic ecosystems under various stresses such as eutrophication, salinization, as well as metal and organic contamination (Gold et al., 2002; Debenest et al., 2008; Lavoie et al., 2014). Diatoms are a group of algae exhibiting a large diversity in terms of taxonomy, morphology and ecology, and are present in most aquatic and humid environments (Round et al., 1990). Diatoms have specific degrees of tolerance to environmental variables and have a rapid reproduction rate, which are among the characteristics making them excellent indicators of aquatic biological integrity (Kelly et al., 2008; Stevenson et al., 2008, 2010). Subtle changes in environmental conditions may cause a shift in assemblage structure; sensitive diatoms decrease in abundance, while tolerant species increase (Van Dam et al., 1994; Harding et al., 2005). The analysis of the diatom assemblage structure and species' autecology allows for the characterization of past and present environmental conditions and health status in a system (Kelly et al., 2008; Leira et al., 2015; Schallenber and Saulnier-Tablbot, 2015). Diatom-based monitoring is also gaining in popularity for the assessment of ecosystem rehabilitation to evaluate recovery success (e.g., Coe et al., 2009; Feld et al., 2011; Arini et al., 2012; Hamilton et al., 2015; Żelazna-Wieczorek and Nowicka-Krawczyk, 2015).

To adequately estimate the biological status of a system before and after alteration or rehabilitation, it is fundamental to develop appropriate biological metrics. An approach based on multiple descriptors may provide a more complete and integrated picture of the environmental conditions experienced by the diatoms, as compared with the more traditional taxonomic approach (assemblage structure) generally used in the development of diatom-based indices (Kelly and Whitton, 1995; Ponader et al., 2007; Coste et al., 2009; Lavoie et al., 2006, 2014). Multi-metric diatom indices have already been developed (Zalack et al., 2010), but generally include taxonomy-derived metrics such as % tolerant species, richness and chlorophyll *a* (Fore and Grafe, 2002). Various non-taxonomic diatom descriptors such as cell health status, motility, lipid bodies, cell density and teratologies (abnormal valves) are well documented as biomonitoring tools. For example, Morin et al. (2012) reviewed the response of diatoms to metal contamination from the individual level (e.g., size, growth form, and morphological abnormalities) to the assemblage structure level (turnover from sensitive to tolerant species). Similarly, Pandey and Bergey (2016) used various metrics to monitor the effect of chronic metal exposure (Cu and Zn) on benthic diatoms, and reported a reduction in diatom motility and cell size, as well as an increase in lipid body content and in teratology frequency.

In this study, benthic diatom assemblages from 16 sites selected along four major South Korean rivers flowing in close proximity to industrial complexes and municipal effluents were examined to evaluate their ecological status. For this purpose, multiple biological descriptors were used. First, more traditional metrics based on diatom assemblage composition, richness, diversity and cell density were examined. Additional biological metrics were also investigated: cell size distribution, diatom health status (live, unhealthy or dead), and the presence of lipid bodies and teratologies. Finally, we compared the information provided by the various diatom-based metrics examined with the estimation of the water quality status of each site based on a suite of physico-chemical characteristics.