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Research paper

Evaluating features of periphytic diatom communities as biomonitoring tools in fresh, brackish and marine waters

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ABSTRACT

The aims of this study were to assess the biodiversity of periphytic diatom assemblages in fresh, brackish and marine waterbodies of Korea, and to assess the effect of environmental and anthropogenic factors on parameters such as the quantity and biovolume of lipid bodies and deformations of diatoms as early warning measures of anthropogenic impact. Diatom samples were collected from 31 sites (14 freshwater, 10 brackish and 7 marine), which included less impacted (upstream) and impacted (downstream) sites in each water type. Our results showed higher abundance and biodiversity of periphytic diatoms at the less impacted sites in terms of species richness, Shannon index, cell count and biovolume of the communities than at the impacted sites for freshwater and estuarine sites, but not for marine sites. 84 diatom species were noted in freshwater, 80 in brackish water and 40 in marine waters. In comparison to diatoms of the impacted sites, those of less impacted freshwater, brackish and marine sites had less lipid bodies (also less biovolume) and a lower percentage of teratological frustules, and showed more mobile forms in the community. Principal component analysis (PCA) also showed clear segregation of impacted from less impacted sites by the extent of the presence of lipid bodies (higher both in number and biovolume) and deformities in diatom frustules. Pearson correlation analysis revealed that lipid body induction and deformities were positively correlated with metals (Cd, Co, Cr, Cu, Fe, Pb and Zn) and nutrients (total phosphorus and total nitrogen), whereas they showed negative correlation with salinity, dissolved oxygen, suspended solutes and pH. Life-forms, lipid bodies and deformities in diatoms may be an effective biomonitoring tool for assessing biological effects of pollutants in non-marine aquatic ecosystems in Korea.

1. Introduction

Potentially dangerous substances are being introduced into aquatic environments as a consequence of industrial and human activities. Without proper risk assessment of chemicals and subsequent efforts to formulate effective (enforced) protective legislation, our aquatic ecosystems will be endangered by the thousands of chemicals derived annually from industrial and municipal sources (Mallick and Rai, 2002).

Traditionally, analytical chemistry has been used to provide quantitative information on the contaminants and to determine if the status of water samples is within the range allowed by regulatory standards but this analysis cannot be used *in situ* and needs costly and sophisticated instruments, such as, atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP; ICP-OES) and mass spectroscopy (MS; GC–MS and LC–MS). Furthermore, it is not possible to determine cause and effect relationships between inhabiting organisms and the causative agent using chemical methods alone (Wolska et al., 2007).

In contrast, organisms provide site-specific, integrated responses to exposure to the environmental variables, including chemicals. This is a key reason for introducing biomonitoring methods as part of a comprehensive approach to risk assessment of environmental pollution. Biomonitoring is widely employed to assess environmental threats posed by different classes of chemicals, in part because biomonitoring reduces the time and cost associated with blind chemical screening for a

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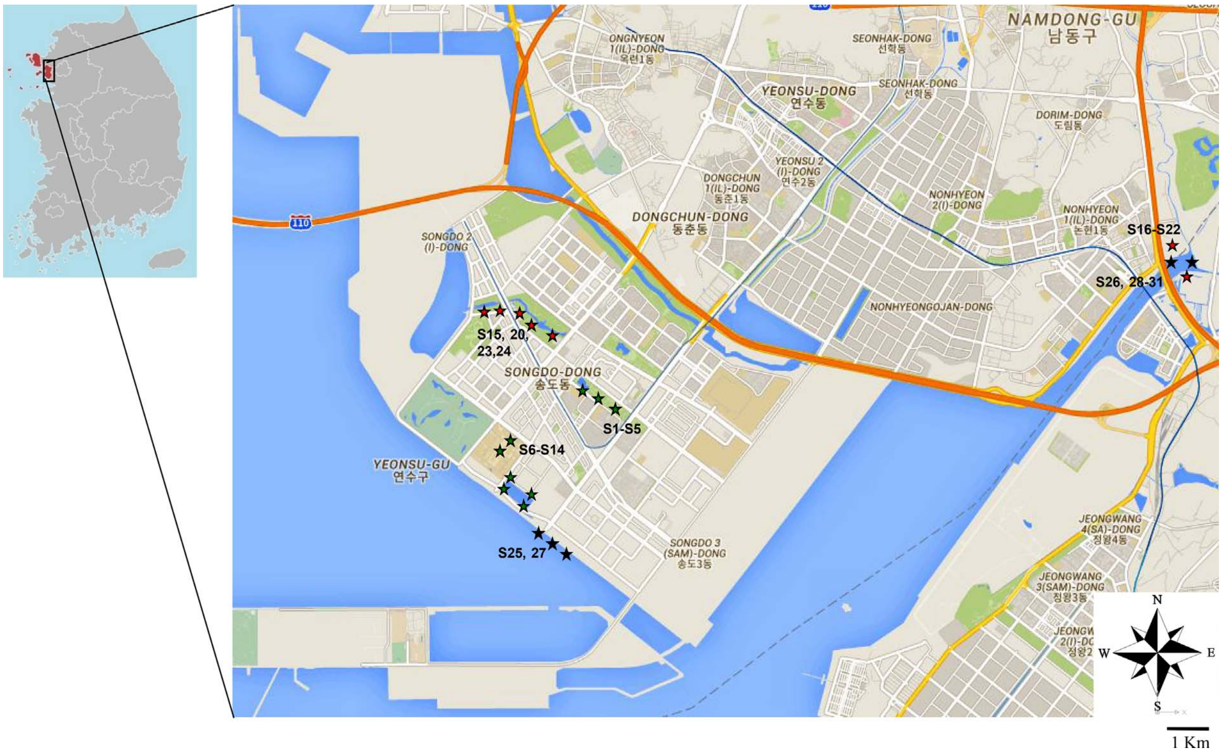

Fig. 1. Map showing the surveyed sites in Incheon, South Korea. Green, red and black colored star symbols showed fresh, brackish and marine sites. For complete information about sites see Table S1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

wide array of contaminants (Stevenson et al., 2010).

Various organisms have been used for biomonitoring practices. These organisms include protozoa, bacteria, fishes, aquatic macrophytes, algae, macroinvertebrates and zooplankton (Bettinetti et al., 2012). Algae, and diatoms in particular, have received global attention since diatoms are important primary producers of aquatic systems, playing major roles in food webs and in biogeochemical cycles, and constitute one of the most species-rich group of biological communities, making an important contribution to biodiversity and genetic resources of fluvial ecosystems (McCormick and Cairns, 1994; Stevenson et al., 2010). They inhabit almost all aquatic habitats including lakes, wetlands, oceans, estuaries, and even some ephemeral aquatic habitats. The key advantage of diatoms for use in ecotoxicology is that it is possible to examine the effects of toxicants at different levels of ecological organization, i.e., from individual cell to community levels (Debenest et al., 2013). In addition, the ease of sampling (simple scrapping of substrates), storing, observation of live features (photosynthetic apparatus and lipid bodies) and identification based on acid-cleaned frustules (mounted on permanent slides, which form a space-saving long-term record) are all features that make diatom bioassays more cost-effective than bioassays with other routinely used organisms (Pandey and Bergey, 2016; Pandey et al., 2018).

Toxicity research with diatoms has found that diatoms are more sensitive to heavy metal stress than other aquatic biota, responding characteristically through community shifts, i.e., replacement of sensitive species with more tolerant ones. For example, Hirst et al. (2002) reported that diatoms were more sensitive than macroinvertebrates for metal pollution, as indicated by a shift in diatom assemblage composition in upland streams of Wales and Cornwall. Similarly, De Jonge et al. (2008) concluded that the diatom community better explained the metal gradient (through analysis of species composition in the community) than macroinvertebrate communities in a Belgian river, the Dommel. Diatoms are also known for both rapid and chronic responses to heavy metal exposure. For example, Corcoll et al. (2012) used a translocation experiment to show that early (after 6 h and 24 h) metal toxicity was evident using chl a-fluorescence in combination with analysis of photosynthetic pigments, while chronic (3–5 weeks) toxicity of metals was better detected using cell biovolume or frustule deformity. Similarly, various researchers have reported deformities and size reduction in diatom frustules as phenomena associated with heavy metal stress (Falasco et al., 2009a; Luís et al., 2011; Pandey et al., 2014; Cantonati et al., 2014). Diatoms have short generation times and, therefore, reproduce and respond rapidly to environmental change, thus providing an early indication of biologically active heavy metal pollution.

Many environmental studies have been conducted using diatoms from separate entities of fresh, brackish and marine systems, but there is a lack of comparative studies of these three different types of waters. Furthermore, many live diatom features, such as life-forms, lipid bodies (LBs) and deformities (in live cells) have been little explored for biomonitoring purposes despite the fact that incorporation of these new live-diatom endpoints, combined with traditionally used metrics may increase the efficiency and reliability of diatom bioassays as a biomonitoring tool (Pandey and Bergey, 2016; Pandey et al., 2017).

The present study was undertaken to: (a) explore periphytic algal biodiversity from fresh, brackish and marine waterbodies of Incheon city, South Korea. (b) investigate the status of life-forms, lipid bodies and deformities in periphytic diatoms from the less impacted (upstream) and the impacted (downstream) sites and (c) recognize and evaluate the possibility to relate environmental or anthropogenic factors to these features of diatom assemblages.

2. Materials and methods

2.1. Studied area and sampling sites

The study areas were in the northwest portion of the city of Incheon, South Korea (Fig.1). The precise geographical location of sampling sites is 126°37′E, 37°28′N where fresh, brackish and marine waters adjoin (Table S1). The sampling periods were from October to December 2014.