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Review

The use of diatoms in ecotoxicology and bioassessment: Insights, advances and challenges

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A B S T R A C T

Diatoms are regularly used for bioassessment and ecotoxicological studies in relation to environmental and anthropogenic disturbances. Traditional taxonomical diatom parameters (cell counts, biovolume estimates, species richness, diversity indices and metrics using sensitive and tolerant diatom species) are regularly used for these studies. In the same context, very less focus was given on new endpoints of diatoms (life-forms, nuclear anomalies, alteration in photosynthetic apparatus shape, motility, lipid bodies, size reduction and deformities), in spite of their numerous merits, such as, their easiness, quickness, cheapness, global acceptation and no especial training in diatom taxonomy. In this review we analyzed 202 articles (from lab and field studies), with the aim to investigate the bioassessment and ecotoxicological advancement taken place in diatom research especially in terms of exploring new endpoints along with the traditional taxonomical parameters in a perspective which can greatly enhance the evaluation of fluvial ecosystem quality for biomonitoring practices.

Contents

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1. Introduction

Globally, diatoms are used to assess the ecological status of aquatic systems because diatoms have a cosmopolitan nature, short life span and quick response to environmental and anthropogenic disturbances (Stevenson et al., 2010). Such use of diatoms is meaningful, given that diatoms are the chief primary producers in waterbodies, contributing 40% of the primary productivity of the oceans and contributing approximately 20% of global carbon fixation (Hildebrand, 2008). Various organisms (macroinvertebrates, fishes, macrophytes and algae, including diatoms) have been used for biomonitoring around the world, but among these organisms, diatoms are the most suitable for assessing the chemical status of waterbodies (McCormick and Cairns, 1994; Stevenson et al., 2010). For example, Hering et al. (2006) found that diatoms were sensitive to nutrient and organic matter contamination, whereas fishes, macroinvertebrates and macrophytes were more sensitive to hydrological changes in aquatic ecosystems. Indeed, the high sensitivity of diatoms to organic toxicants (atrazine, metolachlor, simazine, phenols and PAHs) (Blanco and Bécares, 2010), organic matter (especially nutrients, nitrate and phosphate) (Stevenson et al., 2010; Stevenson, 2014; Morin et al., 2016) and inorganic contamination (heavy metals) (Hirst et al., 2002; De Jonge et al., 2008; Morin et al., 2012) has been reported from different parts of the world. A major advantage of using diatoms in environmental studies, including ecotoxicology, is that diatom assemblages are specious and can be used to investigate the effects of toxicants at different levels of ecological organization (community, population, and individual levels) (McCormick and Cairns, 1994; Debenest et al., 2013; Stevenson, 2014). Because of these characteristics, a variety of national and international agencies have recommended diatoms as a biomonitoring tool for assessing the ecological status of rivers and streams (Kelly, 1998; Stevenson et al., 2010).

Diatoms are characterized by their robust, ornamented, species-specific siliceous frustules, which are preserved and dependably replicated in successive generations (Falasco et al., 2009). Species identification is based on these siliceous frustules. Even in fossilized form, diatom frustules are a useful tool to assess the paleoclimatic conditions (Mackay, 2007). Although used for biomonitoring worldwide, few studies have related diatom diversity in Polar Regions to global climate change (Anderson, 2000; Bopp et al., 2005; Alvain et al., 2013).

In spite of their diversity, beauty, ecological importance and biomonitoring potential, diatoms are globally underutilized as a tool for risk assessment and for evaluating management options for fluvial ecosystems (Stevenson et al., 2010). The main reason behind this underutilization is the limited types of metrics traditionally used in bioassessment. Traditional metrics for diatoms include biovolume, cell density and relative abundance (with special reference to indicator species), whereas the newer behavioral, physiological and functional metrics are rarely used. These newer metrics have advantages in understanding the dynamics of biological communities (Giddings et al., 2002), especially because these metrics demonstrate sublethal effects that are not apparent in diatom counts (the basis of traditional metrics).

Community structural metrics are useful for predicting possible adverse effects of chemicals at the population and community level, thus they are directly linked to biodiversity. According Knauer and Hommen (2012), two common metrics - species richness and Shannon-Wiener index (H') - showed low bioassessment value for community structure, whereas total abundance and the abundance of the dominant species demonstrated high sensitivity.

High diatom community variability is an inherent characteristic of complex test systems, such as in experimental micro- and mesocosm studies, and consequently, this variability complicates interpretation of studies (Campbell et al., 1999). Therefore, evaluation of test systems is preferably not based on biodiversity metrics alone, but is complemented by other parameters (e.g., functional metrics) that are quick, easy and can be used globally. Functional metrics are pertinent because they are closely linked to some regulatory and supporting ecosystem services, and may be less variable among replicates. Furthermore, even if the structural integrity of the community is altered, some functional parameters (such as primary productivity and nutrient cycling) may be unaffected and vice versa. Combining information from both structural and functional metrics enhances the sensitivity and predictive power of studies aimed at bioassessment and risk assessment. Indeed, the use of both structural and functional parameters provides sensitive and powerful early warning tools for evaluating sub-lethal effects of exposure to toxins (Renzi et al., 2014). However, structural metrics (cell counts and biovolume, species composition and abundance) had high variation due to variation among replicates, which resulted in statistically weak relationships with the studied stressors (Kraufvelin, 1998; Knauer et al., 2005). Varying division rates of individual diatom species (which is often related to their size; Lavoie et al., 2006) is a prime reason for high variation among test replicates, in part because accurate quantification of diatom frustules is still a major constrain for ecotoxicological studies. Thus, there is an urgent need to develop or incorporate more sensitive metrics for assessing early exposure to stress, specifically metrics that measure physiological or morphological changes in diatom species, making functional metrics a priority for further research (Renzi et al., 2014).

For bioassessment and ecotoxicological practices several new diatom parameters have been reported in the last decade; parameters that are very promising but sporadically used or reported. These parameters are nuclear anomalies (Debenest et al., 2008; Licursi and Gómez, 2013), alteration in the cell membrane, cytoplasmic content and photosynthetic apparatus (Chang et al., 2011; Armbrecht et al., 2014; Wood et al., 2014), changes in lipid body formation (Pandey et al., 2015) and the classification of diatoms using various life-forms and ecological guilds (Passy, 2007; Rimet and Bouchez, 2011). Relationships among these unconventional parameters have been found in some studies. For example, diatom motility was associated with the size/number of lipid bodies (Wang et al., 2013), size reduction can be associated with frustule deformity (Hasle and Syversten, 1996), lipid bodies metrics and frustule deformities may vary with cytoplasmic anomalies (Renzi et al., 2014) and frustule deformity is associated with lipid body characteristics (Pandey et al., 2015). This correlation among unconventional metrics demonstrates shared sensitivity and indicates their efficiency in measuring responses to toxicants, especially early