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Development of a diatom index of biotic integrity for acid mine drainage impacted streams

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ABSTRACT

Acid mine drainage (AMD) resulting from extensive coal mining throughout Appalachia since the 1800s has caused a legacy of severe acid and dissolved metal loads to thousands of stream miles, which has critically impacted aquatic life and ecological attributes. Relationships of diatoms and macroinvertebrates with AMD have been established, but no index specifically designed to quantify AMD impacts using diatoms has been created, nor have the response of multiple organism groups been compared for their utility as indices assessing AMD severity.

For the purpose of developing an effective assessment and management strategy for AMD impacted streams, this study created and tested a multi-metric AMD-diatom index of biotic integrity (AMD-DIBI) and compared its response to AMD severity with an already established multi-metric macroinvertebrate community index (ICI). In 2006, 41 sites in southeast Ohio were sampled that represented an AMD impact gradient and non-AMD impacted reference sites. Metrics comprising the AMD-DIBI were selected based on their responsiveness to AMD and nutrient impacts. In the following year, the AMD-DIBI and its metrics were tested on a validation dataset consisting of 18 sites in an AMD impacted watershed. Results indicated a significant correlation between AMD-DIBI and ICI scores, and both indices and all metrics were strongly correlated with water chemistry variables indicative of AMD pollution ($P < 0.05$). Stepwise multiple regression selected alkalinity and conductivity as most influential to AMD-DIBI (adjusted $r^2 = 0.70$) and ICI scores (adjusted $r^2 = 0.66$). Narrative classes (e.g., Poor, Fair, Good, and Excellent) defined by index scores provided effective classifications of AMD severity. When tested on the watershed scale, AMD-DIBI and its metrics very successfully quantified AMD gradients and coal mining impacts as indicated by canonical correspondence analysis. This newly developed AMD-DIBI will be very useful for assessing impairment, sensitivity, and recovery of diatom communities in streams damaged or threatened by coal mining activities. In addition, because the AMD-DIBI was very responsive to a gradient of AMD pollution, it could be used in future studies measuring the long-term status of streams and effectiveness of various remediation methods. This study highlights the responsive power of diatom-based metrics.

1. Introduction

Acid mine drainage (AMD) often impacts streams in the Appalachian Mountains of North America (Office of Surface Mining, 1995). This AMD pollution is caused when pyretic minerals, naturally occurring in coal deposits, are exposed to oxygen and water during and after mining operations. Oxidation of these minerals generates sulfuric acid and produces conditions, in which many metals readily dissolve and flow through surface waters. Thus, AMD impacted streams are characterized by low pH, and high concentrations of sulfate and metals (Carroll et al., 2003). As the pH increases downstream by dilution, the dissolved metals, primarily ferric hydroxide ($FeOH_3$), precipitate and cover the stream substrata in *yellowboy* or *ochre*, a fine orange sediment (Younger et al., 2002). These changes to the physical environment, in addition to the chemical environment, may substantially alter species composition, abundance and biomass of all groups of organisms living in these waters.

Monitoring biological communities is an effective method for determining health and function of a stream (Karr, 1999; Lowe and Pan, 1996; Stevenson and Pan, 1999). As humans modify the landscape and discharge wastes into waterways, the organisms are subjected to stresses that alter species composition, abundance and function in ecosystem processes (Karr, 1999). Fish and macroinvertebrates have been used for over 30 years as tools for monitoring stream health by government agencies in the USA (Karr, 1999). In addition, the periphyton community, specifically diatoms, has been recognized as another powerful indicator of stream health/biotic integrity (Pan et al., 1996). Biological

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monitoring using these groups of organisms may be more effective than measuring water chemistry alone, because the organisms integrate chemical and physical properties of streams over time that could otherwise be missed by one-time water chemistry sampling (Winter and Duthie, 2000). Although these three assemblages may provide complementary information in some situations (Johnson et al., 2007), it should be noted that they do not always respond similarly to different environmental conditions, habitats, and types of stressors (Hering et al., 2006; Johnson et al., 2006; Carlisle et al., 2008).

Surveying macroinvertebrate communities in streams is a well-established method used by many state and federal agencies to monitor waterways (Karr and Chu, 2000). Stream invertebrates possess many traits that make them effective monitoring tools for stream condition (Gerhardt et al., 2004). First, they are rich in species and have varying degrees of pollution tolerance. They are permanent members of the system and cannot escape pollution events. Invertebrates inhabit many feeding niches including grazers, scrapers, filter feeders and predators, and changes in the abundance of these groups may signal disturbances within the system. In addition, they are relatively easy to sample, identify and store. Currently, the Ohio Environmental Protection Agency (OEPA) utilizes the invertebrate community index (ICI) as its principal tool for assessing streams in Ohio (DeShon, 1995). The ICI is a multi-metric index that uses 10 measures of taxonomic composition and functional groups to evaluate stream health.

Algae and diatoms are excellent indicators of stream health and water quality (Lowe and Pan, 1996; Stevenson and Smol, 2002). Algae are the primary producers in stream ecosystems and provide food and shelter for other organisms. Thus, any changes that affect the biotic integrity of the algal community may impact higher trophic levels as well. Although invertebrates are species rich, there may be hundreds of diatom species occurring on just a few square centimeters of rock (Lowe and Pan, 1996). This richness provides a high level of resolution and accuracy for multivariate statistical analyses. In addition, algal regeneration time is much shorter than macroinvertebrates, a few days compared to months, allowing the community composition to respond quickly to changes in environmental variables. Algae cannot be differentiated into feeding guilds like invertebrates, but they can be grouped based on their environmental tolerances (e.g., eutraphentic, acidophilic, motile) (van Dam et al., 1994). Diatoms respond directly to water quality characteristics including pH, salinity, light, nutrients, moisture, dissolved oxygen, metals, and siltation (van Dam et al., 1994; Hill et al., 2000a; Winter and Duthie, 2000; Soininen and Könönen, 2004). Species abundances within these tolerance groups can provide information about stream quality.

Algae and diatoms have become well established as biological indicators in European countries (Prygiel and Coste, 1993; Prygiel et al., 2002). Many of these countries have instituted algal-based monitoring programs, creating standard protocols for stream research and indices for assessing biotic integrity under the European Water Framework Directive (Furse et al., 2006), which focuses more on the ecological condition of rivers as measured by structure and function, rather than simply traditional measurements of specific pollutants and their effects (WFD, European Union, 2000). In the US, several states have begun using algae in their bioassessment protocols and several multi-metric indices based on stream algal communities have been developed. Using multiple metrics in an index or management framework can collectively describe the biotic composition or integrity as it is impaired by a variety of human activities. Hill et al. (2000b) introduced the Periphyton Index of Biotic Integrity (PIBI), which is comprised of 10 metrics chosen to indicate various stressors, but have not responded as predicted in all cases (Hill et al., 2000b; Hamsher et al., 2004). Wang et al. (2005) published the Diatom Index of Biotic Integrity (DIBI); this index is comprised of seven metrics and showed 80% accuracy when identifying reference sites in watersheds where eutrophication is the primary stressor and outperformed the PIBI.

Several European studies have examined the relationship between macroinvertebrates and periphyton in streams (Hill, 2002; Soininen and Könönen, 2004; Triest et al., 2001; Hirst et al., 2002). Triest et al. (2001) found that macroinvertebrates decreased in richness and diversity due to pollution while diatoms maintained diversity and richness, but changes in species composition were observed. Research conducted in Pennsylvania using species composition, not biotic indices, compared invertebrate and periphyton responses to chemistry and substrata quality in AMD impacted streams (DeNicola and Stapleton, 2002). They showed that water chemistry had a greater impact than the AMD precipitate on these organisms. With the exception of DeNicola and Stapleton (2002), macroinvertebrates and periphyton species composition have been utilized independently as indicators of AMD (Verb and Vis, 2000; Cherry et al., 2001); and, no diatom index specifically addressing AMD impact severity has been created and tested.

The present research was conducted over two sampling seasons with the goal of producing a diatom index of biotic integrity that would be sensitive to AMD, the prevalent stressor in southeast Ohio and Appalachian streams. The first year sampled streams along an AMD gradient within the Western Alleghany Plateau (WAP) and was used to select responsive diatom metrics and assemble them into a multi-metric index. In addition, the effectiveness of this index and a macroinvertebrate index (ICI) was assessed and compared. The second year of sampling focused on a single watershed with a range of conditions, to which the new index would be applied to ensure the index scores reflected AMD impacts.

2. Materials and methods

2.1. Development of AMD-DIBI

Forty-one stream segments from the unglaciated WAP were sampled July–September 2005 when consistent base flow conditions existed, which represent the typical conditions in our area (Fig. 1). Sites were chosen based on historical chemistry, macroinvertebrate and fish data to represent the range of conditions along an AMD gradient. Dissolved oxygen, conductivity, and temperature were measured at each site using a YSI model 85 system (YSI

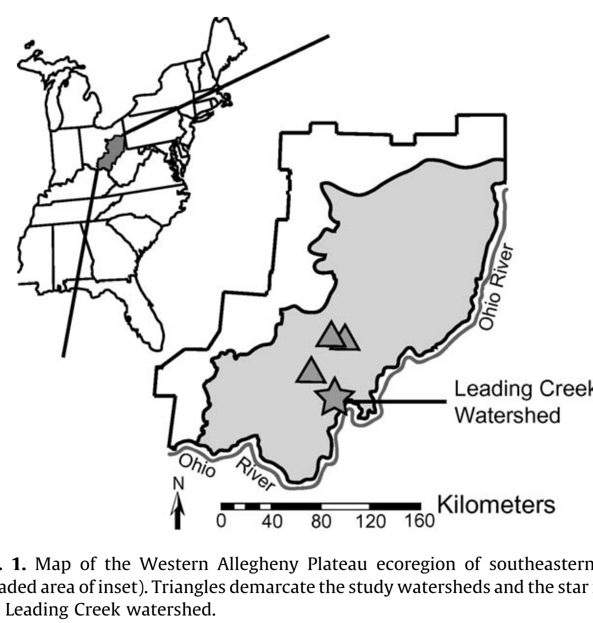

Fig. 1. Map of the Western Allegheny Plateau ecoregion of southeastern Ohio (shaded area of inset). Triangles demarcate the study watersheds and the star marks the Leading Creek watershed.