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Temporal dynamics of benthic macroinvertebrate communities and their response to elevated specific conductance in Appalachian coalfield headwater streams

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ABSTRACT

Coal mining in central Appalachia USA causes increased specific conductance in receiving streams. Researchers have examined benthic macroinvertebrate community structure in such streams using temporally discrete measurements of SC and benthic macroinvertebrates; however, both SC and benthic macroinvertebrate communities exhibit intra-annual variation. Twelve central Appalachian headwater streams with reference quality physical habitat and physicochemical conditions (except for elevated SC in eight streams) were sampled ≤fourteen times each between June 2011 and November 2012 to evaluate benthic macroinvertebrate community structure. Specific conductance was recorded at each sampling event and by in situ data loggers. Streams were classified by mean SC Level (Reference, 17–142 μS/cm; Medium, 262–648 μS/cm; and High, 756–1535 μS/cm). Benthic macroinvertebrate community structure was quantified using fifteen metrics selected to characterize community composition and presence of taxa from orders Ephemeroptera, Plecoptera, and Trichoptera. Metrics were analyzed for differences among SC Levels and months of sampling. Reference streams differed significantly from Medium-SC and High-SC streams for 11 metrics. Medium-SC streams had the most metrics exhibiting significant differences among months. Relative abundances of Plecoptera and Trichoptera were not sensitive to SC, as the families Leuctridae and Hydropsychidae exhibited increased relative abundance (vs. reference) in streams with elevated SC. In contrast, Ephemeroptera richness and relative abundance were lower, relative to reference, in elevated-SC streams despite increased relative abundance of Baetidae. Temporal variability was evident in several metrics due to influence by taxa with seasonal life cycles. These results demonstrate that benthic macroinvertebrate communities in elevated-SC streams are altered from reference condition, and that metrics differ in SC sensitivity. The time of year when samples are taken influenced measured levels and differences from reference condition for most metrics.

1. Introduction

The Appalachian coalfield covers >4.5 million hectares in West Virginia, Virginia, Tennessee, and Kentucky (USEPA, 2011a) and extends into adjacent states. Surface coal mining in Appalachia often occurs in upper watershed areas (USEPA, 2011a), influencing water quality in headwater streams (Griffith et al., 2012) and in downstream reaches (Lindberg et al., 2011).

Mining activity exposes un-weathered rocks to water and accelerated weathering, increasing total dissolved solids (TDS) in mine-influenced waters relative to background levels (Hartman et al., 2005; Merricks et al., 2007; Pond et al., 2008; Fritz et al., 2010; Timpano et al., 2010, 2015; Lindberg et al., 2011). In mine-influenced Appalachian waters, Ca^{2+}, Mg^{2+}, $SO_4{}^{2-}$, and $HCO_3{}^{-}$ are often the predominant major ions by mass (Pond et al., 2008; USEPA, 2011a,b; Timpano et al., 2015).

Elevated major ion concentrations can act as toxicants to sensitive freshwater taxa (Cañedo-Argüelles et al., 2013). Laboratory

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Table 1
Areas (mean ± standard error; and range) for watershed catchments defined by the study reaches.

Stream type	*n*	Mean[†] (km^2)	Range (km^2)
Reference	4	4.4 ± 2.6	0.8–12.3
Medium-SC	4	4.5 ± 0.8	2.7–6.7
High-SC	4	2.7 ± 0.6	1.1–4.2
Overall	12	3.9 ± 0.9	0.8–12.3

[†] Mean values do not differ significantly by stream type ($p < 0.05$).

toxicity tests confirm that elevated TDS levels lead to increased mortality and impaired reproduction and growth in freshwater invertebrates, although effect concentrations depend on selected test organisms, ions comprising TDS, and test duration (Mount et al., 1997; Kennedy et al., 2003; Soucek and Kennedy, 2005; Merricks et al., 2007; Chapman et al., 2000; Kennedy et al., 2004; Echols et al., 2010; Kefford et al., 2012; Kunz et al., 2013). Several studies of Appalachian streams have demonstrated strong associations between specific conductance (SC; electrical conductivity at 25 °C), an easily measured water parameter that is highly correlated with TDS, and benthic macroinvertebrate community metrics, suggesting causality or influence (Green et al., 2000; Freund and Petty, 2007; Pond et al., 2008; Gerritsen et al., 2010; Bernhardt et al., 2012; Cormier et al., 2013a). However, a variety of effect levels have been observed in field studies of SC-biota relationships.

When assessing effects of anthropogenic stressors, water managers should be aware of potential confounding by temporal variation of the targeted community that occurs naturally (Resh and Rosenberg, 1989; Linke et al., 1999; Šporka et al., 2006; Leunda et al., 2009; Álvarez-Cabria et al., 2010). Benthic macroinvertebrate community structure is influenced by seasonal growth and emergence patterns (Butler, 1984; Linke et al., 1999) which are related to dynamic environmental variables such as thermal regimes (Vannote and Sweeney, 1980; Sweeney et al., 1986) and resource availability (Hawkins and Sedell, 1981; Murphy and Giller, 2000). During some seasons, emergence patterns may cause decreased richness, density, or absence of particular taxonomic groups (Šporka et al., 2006).

In the USA and elsewhere, government agencies enforce water-protection laws by monitoring benthic macroinvertebrate community structure and assessing multi-metric structural indices (Metcalfe, 1989; Gerritsen et al., 2000; Burton and Gerritsen, 2003). Agencies have recognized temporal variation of community structure by establishing specific index periods for regulatory compliance sampling (e.g., Burton and Gerritsen, 2003). However, it is possible that multi-metric index scores may vary within individual index periods, or between periods occurring in different seasons. Hence, improved understanding of benthic macroinvertebrate temporal variation is important to water quality management. To help address this need, we quantified temporal dynamics of benthic macroinvertebrate communities in Virginia coalfield headwater streams with varying SC levels and analyzed relationships of community metrics to, and their variability with, SC level.

2. Materials and methods

2.1. Stream selection

Eight test streams with elevated SC and four reference streams (Fig. 1 and Table 1) were selected from first- and second-order streams in the Virginia (USA) coalfield (Timpano et al., 2015). The study area is within Ecoregion 69, Central Appalachians, which extends into coal-bearing regions of Kentucky, West Virginia, Pennsylvania, and Tennessee (Omernik, 1987). Reference sites were selected based on relative absence of anthropogenic impacts and

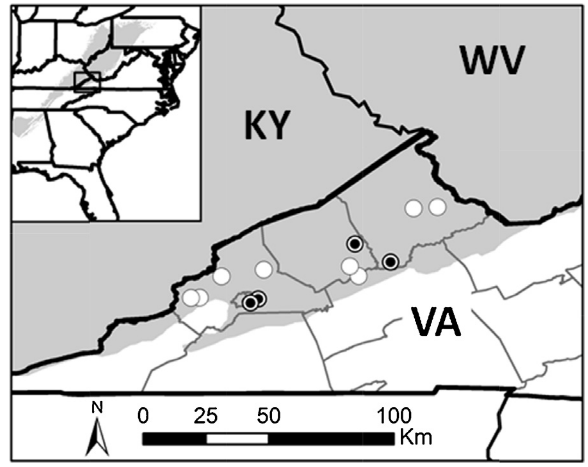

Fig. 1. Map of study streams in the coalfield of southwestern Virginia, USA, with state and county boundaries. Reference streams are shown as symbols with black centers and test streams as white symbols. The inset shows study-area location within eastern USA. The Appalachian coalfield's areal extent is denoted by gray background.

low levels of SC (Timpano et al., 2015). Test streams were selected to provide a continuum of SC levels and to differ from reference streams only in having elevated SC.

2.2. Field and laboratory methods

Stream reaches of 100 m with optimum benthic macroinvertebrate riffle habitat were sampled during base flow conditions. Each stream was sampled in June, August, September, October, and November of 2011; and in January, March, April, May, June, August, September, October, and November of 2012. During some months, some streams were not sampled because of low flows. A total of 151 benthic macroinvertebrate samples were collected.

Habitat quality was recorded at each sampling event using Rapid Bioassessment Protocols (Barbour et al., 1999). During each field visit, water temperature, dissolved oxygen, SC (referred to as discrete SC), and pH were measured by a calibrated Hanna Instruments 9828 Probe (Hanna Instruments, Smithfield, RI). Onset HOBO U-24 (Onset Computer Corporation, Bourne, MA) freshwater conductivity loggers were installed in each sampling reach between April and November, 2011, and recorded SC at fifteen-minute intervals until the end of the study period.

During each sampling visit, single grab samples of water were filtered with a nominal pore size of 0.45 μm using either (1) acid-rinsed cellulose ester filters and stored in acid-rinsed polypropylene bottles (June-August 2011) or (2) disposable syringe filters and stored in disposable sample bags (September 2011–November 2012). Water samples were transported to the laboratory on ice and stored at 4 °C until analysis. Samples to be analyzed for dissolved metals were amended with 1 + 1 nitric acid to decrease the pH to <2 for preservation (APHA, 2005). Samples were analyzed for Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, $SO_4{}^{2-}$, TDS, and total alkalinity using methods consistent with APHA (2005) and described by Timpano et al. (2015); and $HCO_3{}^-$ was calculated from alkalinity and pH measurements (APHA, 2005).

Benthic macroinvertebrates were collected using Virginia Department of Environmental Quality (VDEQ) (2008) protocols for single-habitat riffle-run sampling. A composite sample (approximately 2 m^2 of substrate) was made from six riffle samples per stream using a 0.3 m-wide D-frame kick-net with 500 μm mesh size. No mollusks or crayfish were retained. Samples were preserved in 95% ethanol until quantified in the laboratory. Benthic macroinvertebrates were sub-sampled in the laboratory to obtain