Science of the Total Environment 541 (2016) 603–615

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Spatial and temporal relationships among watershed mining, water quality, and freshwater mussel status in an eastern USA river

Carl E. Zipper [a,*], Patricia F. Donovan [a], Jess W. Jones [b,c], Jing Li [d], Jennifer E. Price [a], Roger E. Stewart [e]

[a] Department of Crop and Soil Environmental Sciences, Virginia Tech, Blacksburg, VA 24061, United States
[b] U.S. Fish and Wildlife Service, United States
[c] Department of Fish and Wildlife Conservation, Virginia Tech, Blacksburg, VA 24061, United States
[d] China University of Mining and Technology, Beijing 100083, China
[e] Virginia Department of Environmental Quality, Richmond, VA 23218, United States

HIGHLIGHTS

- Surface coal mining has been conducted in the Powell River headwaters for >35 years.
- Mining-influenced water constituents in the Powell River exhibit increasing trends.
- The river's downstream areas serve as habitat for freshwater mussels.
- Freshwater mussels have declined in density over the period of mining influence.
- Linkages between water constituents and mussel status are poorly understood.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 23 July 2015
Received in revised form 19 September 2015
Accepted 20 September 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Coal mining
Conductivity
Major ions
Freshwater salinization

ABSTRACT

The Powell River of southwestern Virginia and northeastern Tennessee, USA, drains a watershed with extensive coal surface mining, and it hosts exceptional biological richness, including at-risk species of freshwater mussels, downstream of mining-disturbed watershed areas. We investigated spatial and temporal patterns of watershed mining disturbance; their relationship to water quality change in the section of the river that connects mining areas to mussel habitat; and relationships of mining-related water constituents to measures of recent and past mussel status. Freshwater mussels in the Powell River have experienced significant declines over the past 3.5 decades. Over that same period, surface coal mining has influenced the watershed. Water-monitoring data collected by state and federal agencies demonstrate that dissolved solids and associated constituents that are commonly influenced by Appalachian mining (specific conductance, pH, hardness and sulfates) have experienced increasing temporal trends from the 1960s through ~2008; but, of those constituents, only dissolved solids concentrations are available widely within the Powell River since ~2008. Dissolved solids concentrations have stabilized in recent years. Dissolved solids, specific conductance, pH, and sulfates also exhibited spatial patterns that are consistent with dilution of mining influence with increasing distance from mined areas. Freshwater mussel status

* Corresponding author.
E-mail address: czip@vt.edu (C.E. Zipper).

http://dx.doi.org/10.1016/j.scitotenv.2015.09.104

Specific conductance
Total dissolved solids

indicators are correlated negatively with dissolved solids concentrations, spatially and temporally, but the direct causal mechanisms responsible for mussel declines remain unknown.

1. Introduction

Impacts by mining to water resources occur worldwide (Younger and Wolkersdorfer, 2004). Surface mining disturbs geologic strata and soils, exposing disturbed materials to atmospheric oxygen and rainfall; and, as a consequence, often enables accelerated chemical weathering that releases soluble constituents that enter surface waters. Historically and globally, acids and acid-soluble metals released by oxidation of pyritic minerals have been primary mining-related water pollution concerns (Younger et al., 2002; Jacobs et al., 2014). However, even when acids are controlled, mining disturbances can release other constituents of environmental concern such as major ions and trace elements. Mining has been recognized as a source of elevated major ions and associated constituents in non-acidic surface waters of Australia (Hancock et al., 2005), Germany (Schreck, 1995; Bäthe (1997); Bäthe and Coring, 2011; Braukmann and Böhme, 2011), Spain (García-Criado et al., 1999; Cañedo-Argüelles et al., 2013), South Africa (Goetsch and Palmer, 1997), and eastern USA (Griffith et al., 2012).

Concerns for water resource impacts by mining are acute in eastern USA due to extensive surface coal mining in the Appalachian coalfield. Rivers draining Appalachian mined areas include the Powell River of southwestern Virginia and northeastern Tennessee, which hosts exceptional biological richness and a high diversity of at-risk species that include multiple freshwater mussels (Johnson et al., 2012; Ahlstedt et al., 2005). Freshwater mussels (Unionidae) occur worldwide but achieve their greatest diversity in North America, especially in southeastern USA (Lydeard et al., 2004). Freshwater mussels have experienced high rates of imperilment globally (Williams et al., 1993; Lydeard et al., 2004; Strayer et al., 2004; IUCN, 2015). Mussel declines have occurred in several North American rivers affected by watershed mining (Warren and Haag, 2005; Angelo et al., 2007; Johnson et al., 2014) as well as in the Powell River (Ahlstedt et al., 2015). There is interest in the region to identify specific toxicants that are responsible for the mussel declines that have been observed in streams draining the Appalachian coalfield (Warren and Haag, 2005; Jones et al., 2014) and to determine if such toxicants originate from mining.

Due to legal protections (Zipper, 2000), the acidic waters that characterize coal mining drainages in other world regions are no longer a major concern throughout much of the Appalachian coalfield. Yet, a number of studies have documented stressed biotic resources in the region's mining-influenced rivers and streams. Water salinity, measured as specific conductance (SC) and/or total dissolved solids (TDS), is often elevated in such streams (Bryant et al., 2002; Hartman et al., 2005; Merricks et al., 2007; Pond et al., 2008; Wood and Williams, 2013; Gangloff et al., 2015; Pond et al., 2014; Timpano et al., 2015), and recent research has linked elevated salinity with biotic impacts. Depressed richness of benthic macroinvertebrate communities often occurs in mining-influenced low-order streams with elevated SC (Green et al., 2000; Hartman et al., 2005; Pond et al., 2008; Cormier et al., 2013a, 2013b; Pond et al., 2014; Timpano et al., 2015). Recent studies have also found fish assemblage structure (Hitt and Chambers, 2014), salamander abundance (Wood and Williams, 2013) and richness (Muncy et al., 2014), and microbial community composition (Bier et al., 2015) to be altered in salinized mining-influenced streams; and freshwater mussel richness and densities to be depressed in salinized river segments (Johnson et al., 2014). Water borne trace elements often occur at elevated concentrations in association with elevated salinity in such waters (Pond et al., 2008; Lindberg et al., 2011; Pond et al., 2014) and are also of concern due to potential biotic impacts (Palmer et al., 2010; Johnson et al., 2014). Depressed aquatic communities have also been observed in salinized freshwater bodies of other world regions (Cañedo-Argüelles et al., 2013).

Freshwater mussels are long-lived mollusks that are sensitive to water- and bed-sediment quality. Juvenile mussels burrow into sediments, and are sensitive to sediment and interstitial water quality (Yeager et al., 1994; Cope et al., 2008). Mature mussels are filter-feeding organisms that process large volumes of water to extract suspended organic particles for sustenance. Laboratory studies have documented freshwater mussels' sensitivity to water and sediment contaminants that include major ions (Keller et al., 2007, Gillis, 2011; Kunz et al., 2013) and dissolved metals (Havlik and Marking, 1987; Jacobson et al., 1993, 1997; Naimo, 1995; Keller et al., 2007; Cope et al., 2008; Wang et al., 2010) such as those occurring in Appalachian coal mine drainages; but mussel-specific toxic effect levels for most of these constituents are not known. Mussels are also sensitive to other constituents that occur in the Powell River, including ammonia and chlorine from sewage effluents (Goudreau et al., 1993; Augspurger et al., 2003; Mummert et al., 2003; Wang et al., 2007) and polycyclic aromatic hydrocarbons (Wang et al., 2013).

With understanding of that background, we investigated relationships among surface coal mining land disturbance, water quality, and mussel status in the Powell River. Our research objectives were to determine spatial and temporal patterns of water quality change; determine correspondence of those changes with known spatial and temporal patterns of watershed disturbance by mining; and determine relationships of mining disturbance and corresponding water quality change to changes of freshwater mussel status in the Powell River, Virginia and Tennessee.

2. Materials and methods

The research focus was spatiotemporal change. Factors of primary interest were watershed disturbance by mining, water quality in the Powell River, and status of the river's mussel assemblages. The spatial dimension of interest was the Powell River's linear extent as it connects headwater mining with monitored mussel populations located >100 km downstream. Both watershed mining and mussel declines have occurred over multi-decadal time periods.

The Powell River is a largely free-flowing tributary of the upper Tennessee River which drains to the Mississippi River and the Gulf of Mexico. The Powell River originates in the Appalachian Plateaus ecoregion (US EPA, 2015) that is heavily mined for coal and flows into the Ridge and Valley ecoregion where its watershed is primarily forested and agricultural (Fig. 1).

2.1. Mining

Mining disturbance within the Powell River watershed was assessed by accessing data generated by Li et al. (2015a, 2015b). These authors analyzed 24 Landsat satellite, each covering ~90% of the watershed's coal-bearing areas, to identify surface mined areas by location and by year of most recent disturbance for the 1984–2011 period. New mining disturbances could not be assessed for the years 1991, 1996, 2006, and 2009; but they interpreted new disturbances for the years following as representing the two years of mining. They also reported that the 1984 image detected more “new” mining disturbance than any other year, which they interpreted as representing mining disturbances over multiple prior years.

We characterized 2011 landcover for four nested Powell River watersheds, each defined water monitoring location: Virginia DEQ's