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Residual effects of lead and zinc mining on freshwater mussels in the Spring River Basin (Kansas, Missouri, and Oklahoma, USA)

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Abstract

Concentrations of selected trace elements in surface water and fluvial sediment were investigated as possible factors limiting the distribution and abundance of freshwater mussels in the Spring River Basin, a 6600 km^2 watershed overlapping a former Pb and Zn mining and ore processing district in the central USA. Mussel taxa richness surveys and supporting physical habitat assessments were performed in 23 stream reaches dispersed throughout the basin and above and below former mining sites. Quantitative mussel density surveys were performed in the Spring River at one upstream reference location and one downstream location. Concentrations of 16 trace elements in the soft tissues of mussels and Asian clams (*Corbicula fluminea*) were determined at most survey sites. Comparable analyses were performed on surface water samples collected during base flow and peak flow synoptic surveys and sediment samples collected during base flow periods. Sites on the Spring River immediately upstream of heavily mined areas supported at least 21–25 species of mussels, whereas sites near the lower terminus of the river yielded evidence of 6–8 extant species. Between the upper and lower quantitative survey sites, mean mussel and clam densities declined by 89% and 97%, respectively. Tributary reaches below heavily mined areas lacked evident bivalve communities and contained concentrations of Cd, Pb, and Zn that continually or sporadically exceeded hardness-dependent water quality criteria and consensus-based sediment quality guidelines (probable effect concentrations). In less contaminated stream reaches supporting bivalves, concentrations of Cd, Pb, and Zn in mussels and clams were correlated spatially with the levels occurring in surficial sediment ($0.50 \leq \text{tau} \leq 0.64$, $p \leq 0.03$). In non-headwater perennial stream reaches, sediment Cd, Pb, and Zn levels were related inversely to mussel taxa richness ($-0.80 \leq \text{tau} \leq -0.64$, $p \leq 0.004$). Metal contaminant burdens in mussels and clams fluctuated measurably in association with variable stream flow conditions and accompanying changes in surface water and sediment chemistry. Concentrations of Cd, Pb, and Zn in mussels approximately paralleled the levels measured in composite clam samples ($0.74 \leq \text{tau} \leq 0.79$, $p < 0.001$), implying *C. fluminea* could serve as a possible surrogate for native mussels in future metal bioaccumulation studies. Overall, streams draining heavily mined areas exhibited depauperate (or fully extirpated) mussel assemblages and correspondingly elevated concentrations of Cd, Pb, and Zn in water, sediment, and bivalve tissue. Other evaluated environmental chemistry parameters, and physical habitat conditions assessed at the stream reach scale, demonstrated little general relationship to the degraded status of these assemblages. We conclude that pollution attributable to former mining operations continues to adversely influence environmental quality and impede the recovery of mussel communities in a large portion of the Spring River Basin.

Keywords: Bioindicators; *Corbicula fluminea*; Ecological risk assessment; Freshwater mussels; Metals; Mining; Natural resource damage assessment; Sediment quality guidelines; Surface water quality standards

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1. Introduction

Freshwater mussels (Bivalvia: Unionoida) occur in many areas of the world but attain their greatest diversity in eastern North America (Bogan, 1993). Although this region historically supported nearly 300 mussel species, pollution, habitat alteration, and the introduction and spread of non-indigenous bivalves have led to the extinction of an estimated 35 endemic mussel taxa (Turgeon et al., 1998). Most surviving species now exhibit declining or increasingly fragmented geographical distributions, and mussels as a group are regarded as the continent's most imperiled freshwater organisms (Williams et al., 1992; Ricciardi et al., 1998; Strayer et al., 2004). Despite these recent trends, many perennial streams in the region continue to support a variety of native mussel species (*e.g.*, 10–40 or more; Vaughn et al., 1996; Roberts and Bruenderman, 2000; Miller and Lynott, 2006). In some favorable habitats, these animals still achieve impressive total densities (>50 individuals m^{-2}) and equal or exceed all other benthic macroinvertebrates in combined biomass and secondary production (Strayer et al., 1994; Smith, 2001).

Mussels play important functional roles in streams where they remain abundant. As filter feeders subsisting largely on bacteria, algae, and organic detritus, they participate directly in the transfer of nutrients and energy from the water column to the underlying substrate. Concurrently, nitrogenous wastes and other metabolic byproducts are excreted by mussels in forms readily assimilated by algae (Vaughn et al., 2004). Nutrient-rich feces and pseudofeces (materials removed from suspension but not ingested) are deposited by mussels on the streambed, where they are decomposed by benthic microorganisms or consumed by invertebrate detritivores (*e.g.*, Vaughn and Spooner, 2006). Mussel burrowing behavior facilitates the homogenization and aeration of the surficial sediment layer (McCall and Tevesz, 1979; Matisoff et al., 1985; McCall et al., 1995), and dense mussel beds may stabilize the bottom substrate during periods of high stream flow, providing refugia for other benthic organisms (*e.g.*, Strayer et al., 2004). Mussels also constitute an important source of food for many predatory fish and wildlife species, and their spent shells provide shelter and egg attachment sites for a diverse array of aquatic and semiaquatic animals (*e.g.*, Strayer et al., 1994; Smith, 2001).

In addition to their functional roles in freshwater ecosystems, mussels frequently are utilized in water and sediment pollution studies as indicators of contaminant bioavailability (*e.g.*, Renaud et al., 2004; Bonneris et al., 2005; Ravera et al., 2005). These bivalves are superior bioaccumulators of many chemical substances, tolerate handling and experimental manipulation, and provide ample tissue and shell material for chemical analysis. Because mussels are essentially sedentary, their body contaminant burdens normally can be attributed to local pollution sources or locally polluted water and sediment. In recognition of these factors, resident or transplanted adult mussels have been utilized in a number of studies to evaluate contaminant bioavailability and toxicity under field conditions (*e.g.*, Czarnezki, 1987; Oertel, 1998; Gagné et al., 2002). To date, larval and juvenile mussels have been applied primarily as test organisms in laboratory bioaccumulation and toxicological experiments (*e.g.*, Goudreau et al., 1993; Newton et al., 2003; ASTM, 2006).

Although many studies have evaluated the effects of selected contaminants on individual mussel species, few have addressed the aggregate impacts of water and sediment pollution on naturally occurring mussel communities. This is paradoxical, given that the application of these communities in freshwater pollution investigations would offer certain advantages over the use of other faunal assemblages. Unlike fish, which often migrate long distances in response to changing water levels and other stimuli, mussels spend their entire juvenile and adult lives in the same general location. The status of a local mussel community normally is indicative, therefore, of past conditions in the surrounding stream reach. Unlike most other freshwater invertebrates, mussels can live for years or decades, and estimates of species richness and total abundance are unaffected by the potential complications arising from rapid generational turnover (*e.g.*, seasonal emergence cycles in insects; *cf.*, Johnson et al., 1993; Resh and Jackson, 1993). The shells of dead mussels also can persist in an identifiable state for many years, in some instances permitting the evaluation of long-term changes in community composition and supporting environmental conditions (Layzer et al., 1993; Distler and Bleam, 1995).

In the USA, mussel community surveys incorporating data on local environmental contaminant concentrations and biological exposure levels would appear well suited to retrospective ecological risk assessments (ERAs) and natural resource damage assessments (NRDAs) performed under the Clean Water Act, the Oil Pollution Act, and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). ERAs focus primarily on the level of exposure of organisms to hazardous substances present in the environment, whereas NRDAs also consider the available evidence for natural resource injury. A declaration of injury under CERCLA, for example, would signify the occurrence of