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Mountaintop removal mining reduces stream salamander occupancy and richness in southeastern Kentucky (USA)

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ABSTRACT

Mountaintop removal mining with valley fills (MTR/VF) is a ubiquitous form of land conversion in central Appalachia, USA and threatens the integrity of stream ecosystems. We investigated the effects of MTR/VF on stream salamander occupancy and overall community composition in southeastern Kentucky by conducting area constrained active searches for salamanders within first-order streams located in mature forest (i.e., control streams) and those impacted by MTR/VF. We found high mean species occupancy across 5 species at control streams, ranging from 0.73 (95% CI 0.41 to 0.96) to 0.90 (95% CI 0.77 to 0.98). Occupancy was lower at MTR/VF streams, with mean estimated occupancy probability ranging from 0.23 (95% CI 0.04 to 0.51) to 0.62 (95% CI 0.36 to 0.86). Additionally, the mean species richness for MTR/VF streams was 2.27 (±1.27 SD) whereas richness was 4.67 (±0.65 SD) for control streams. Numerous mechanisms may be responsible for decreased occupancy and species richness at MTR/VF streams, although water chemistry may be particularly important. Indeed, mean specific conductance was 30 times greater, sulfate (SO_4) levels were 70 times greater, and concentrations of dissolved ions (Ca, Mg, K, Na) were greater in MTR/VF streams than in control streams. Our results indicate that MTR/VF operations lead to significant decreases in salamander occupancy and species richness.

1. Introduction

Understanding the environmental impacts associated with mining has become an issue of global importance (Cooke and Johnson, 2002; Bridge, 2004; Litz et al., 2013). In central Appalachia (USA), mountaintop removal mining, a form of surface mining, has become the primary method for coal extraction. The coal seams are accessed by first removing forests, then clearing and stripping topsoil, and finally, using explosives, overlain rocks are removed to allow for excavation of coal (Palmer et al., 2010). The overburden material that is removed (i.e., mine "spoil") is pushed into an adjacent valley, burying portions of ephemeral, intermittent, and perennial streams located next to mining operations and creating a valley fill (Bernhardt and Palmer, 2011). When exposed to atmospheric conditions and surface runoff, the unweathered overburden material often leaches heavy metals along with high levels of salts into the partially buried streams (Griffith et al., 2012). Thus, water that emerges from the base of valley fills can exhibit altered pH, greater specific conductance, and elevated levels of total dissolved solids (i.e., sulfates (SO_4), calcium (Ca), magnesium (Mg)) compared to unaltered streams (Fritz et al., 2010; Palmer et al., 2010; Barton, 2011; Lindberg et al., 2011). Additionally, because of reduced vegetative cover and highly compacted soils on mined lands, streams impacted by mountaintop removal mining with valley fills (MTR/VF) typically have altered hydrology (i.e., decreased infiltration, increased peak flows) compared to streams within forested catchments (Negley and Eshleman, 2006). More than 1.1 million ha of forest land has been altered by surface mining in central Appalachia, USA (Bernhardt and Palmer, 2011). In the Commonwealth of Kentucky, approximately 2000 km of streams have been impacted by valley fills (Barton, 2011), and over 20% of streams in southern West Virginia are affected by runoff from surface coal mines (Bernhardt et al., 2012).

Streams influenced by MTR/VF are often characterized by diminished biological communities in comparison to reference streams. For example, macroinvertebrate richness in MTR/VF

Abbreviations: MTR/VF, mountaintop removal mining with valley fills; Ψ, occupancy; Θ, detection probability; u_i, species-specific mean probability of occurrence; v_i, species-specific mean probability of detection; U, uniform distribution.

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streams is significantly reduced compared to reference locations (Pond, 2010, 2012), and freshwater mussel diversity decreases as extent of surface mines increase within catchments of central Appalachian rivers (Warren and Haag, 2005). Additionally, fish species richness is reduced by 50% at sites downstream from MTR/VF (Ferreri et al., 2004). Amphibians, specifically salamanders, are important components of low-order stream ecosystems (Davic and Welsh, 2004); up to 9 species occur within central Appalachian streams (Petranka, 1998). Salamanders represent the dominant predators in low-order streams, and are responsible for driving many ecosystem-level processes (i.e., nutrient cycling; Davic and Welsh, 2004; Keitzer and Goforth, 2013). Although Wood and Williams (2013a) documented reduced abundances of stream salamanders in MTR/VF streams, investigations on the responses of stream salamander species' occupancy and communities to MTR/VF are lacking.

To evaluate the effects of MTR/VF on stream salamanders, we compared species' occupancy and community composition within streams located in mature, second-growth forest (i.e., control streams) to MTR/VF streams located on reclaimed mountaintop removal mined land. Specifically, we employed a multi-species hierarchical model to estimate species-specific and community-level responses of salamanders to MTR/VF while accounting for species-specific variation in detectability (Zipkin et al., 2009; Hunt et al., 2013). Additionally, we evaluated water chemistry attributes and other habitat characteristics of MTR/VF and control streams to determine mechanisms potentially responsible for species' occupancy and community composition. We hypothesized that MTR/VF would have a negative effect on species' occupancy probabilities and richness, and that MTR/VF streams would differ significantly in water chemistry and habitat characteristics from control locations.

2. Methods

2.1. Study sites

We investigated salamander occupancy and community composition at 23 first-order streams located in the interior rugged section of the Cumberland Plateau in Breathitt and Knott Counties, Kentucky USA. This region has seen extensive changes in land-use over the last 30 years; more than 194,000 ha of eastern Kentucky has been affected by surface mining (C. Barton, personal communication). We sampled salamanders at 11 MTR/VF first-order streams located on the reclaimed Laurel Fork surface mine (4144091.438 N 307635.435 E Zone 17) and 12 control first-order streams in approximately 80-yr-old, second-growth forest on the University of Kentucky's Robinson Forest, which shares a northeast border with the Laurel Fork surface mine. Robinson Forest is a 5983 ha teaching, research and extension experimental forest composed of eight discontinuous properties. Our control streams were located with the main block of Robinson Forest comprising approximately 4200 ha. Land-cover within catchments of control streams consisted of typical, mixed mesophytic forests of the region; dominant tree species included white oak (*Quercus alba*), tulip tree (*Liriodendron tulipifera*), Eastern hemlock (*Tsuga canadensis*), and chestnut oak (*Quercus prinus*) (see Phillippi and Boebinger, 1986).

During the mid-1990s, approximately 607 ha of the 890 ha Laurel Fork watershed, was mined for coal. The catchments of the MTR/VF streams sampled in our study were mined in the late 1990s and reclamation occurred in the early 2000s. Bond release, indicating that reclamation was satisfied, was issued in November of 2007. All of the streams used in this study were partially buried by overburden (i.e., valley-filled); all VFs had perimeter drains, which collect seepage and runoff from around the VF and direct the runoff into the original stream channel. Dominant vegetation cover of the MTR/VF catchments included the nitrogen-fixing herb Sericea lespedeza (*Lespedeza cuneata*) and grasses (tall fescue; *Schedonorus arundinaceus*), with autumn olive (*Elaeagnus umbellate*), Virginia pine (*Pinus virginiana*), white oak (*Q. alba*) and black locust (*Robinia pseudoacacia*) scattered throughout the landscape. Despite low forest cover within catchments, all MTR/VF stream riparian zones and adjacent terrestrial habitat was primarily forested. See Fritz et al. (2010) for additional information on the Laurel Fork study site.

2.2. Data collection methods

Area-constrained active searches were used to sample salamanders at each stream, in a single, 10-m sampling transect. Transects were chosen on the basis of similarity of width, depth and current velocity. Additionally, all transects included a pool, run and riffle section. Streams impacted by MTR/VF were generally sampled at the base of the VF. Although previous studies on stream salamanders have utilized longer transects (i.e., 100 m (Lowe et al., 2004)), the 10-m length of our sampling transect was chosen because of logistical reasons (i.e., dense salamander populations; large number of cover objects) and to provide data comparable to previous studies of stream salamander occupancy in the eastern US (i.e., Grant et al., 2009; Price et al., 2011).

We used a combination of systematic dipnetting and bank searches to capture salamanders (see Price et al., 2011). Dipnetting consisted of one person, moving from downstream to upstream, actively searching for salamanders around and under submerged rocks, logs, and other cover within the 10-m sampling transect. One person also conducted bank searches, which included searching under rocks, logs, leaf litter and other material within 1 m of the wetted width of the stream. In general, dipnetting sessions took approximately 30 min and bank searches took 15 min to finish. All salamanders captured were held in containers until the search was complete. After the active search, we recorded each species and the associated life stage (adult or larva) prior to release. Each 10-m transect was sampled four times (i.e., usually monthly) from March through June 2013. All searches were conducted during day light hours in base flow conditions.

We recorded several variables before each active search. Prior to sampling, we measured the wetted width and depth at the start, middle, and end of each 10 m sampling transect and counted the number of cover objects within the wetted width of our sampling transects. Specifically, we considered rocks >50 mm in diameter as well as logs and other debris cover objects of importance to salamanders. Also, we recorded air temperature (°C), water temperature (°C), wind speed, degree of cloudiness, and the date of last precipitation. Additionally, a 50 mL water sample was collected prior to each sampling event and placed on ice. The samples were analyzed for concentrations of Ca, Mg, SO_4^{2-}, potassium (K), sodium (Na), total organic carbon (TOC), pH and specific conductance; sampling, preservation, and analytic protocols were performed in accordance with standard methods (Greenberg et al., 1992).

Finally, we used a geographic information system (ArcGIS 10.1 ESRI) and Watershed tool in ArcToolBox to calculate the catchment area and percent of catchment in forest cover of each of study stream. To calculate catchment area, we used post-mining, high resolution (0.6 m), digital elevation model (DEM) data as our base layer for catchment delineation. Forest cover was obtained via 2013 United States Geological Survey 7.5-min image map for Noble, KY quadrangle; we considered both mature and younger forest classes as forest cover in our analysis of each stream catchment.