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Stream macroinvertebrate communities across a gradient of natural gas development in the Fayetteville Shale

Erica Johnson [a], Bradley J. Austin [b], Ethan Inlander [c], Cory Gallipeau [c], Michelle A. Evans-White [b], Sally Entrekin [a,*]

[a] Department of Biology, University of Central Arkansas, 201 Donaghey Ave., Conway, AR 72035, United States
[b] 601 Science and Engineering, Department of Biological Sciences, University of Arkansas, Fayetteville AR, 72701, United States
[c] The Nature Conservancy, Ozark Highlands Office, 38 West Trenton Blvd., Suite 201 Fayetteville, AR 72701, United States

HIGHLIGHTS

- Gas well pad density and proximity related positively to turbidity and chlorophyll *a*.
- Gas metrics also related positively to macroinvertebrate densities.
- Filtering and gathering invertebrate densities related positively to gas activity.
- Natural gas activities may be altering macroinvertebrate community structure.

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ABSTRACT

Oil and gas extraction in shale plays expanded rapidly in the U.S. and is projected to expand globally in the coming decades. Arkansas has doubled the number of gas wells in the state since 2005 mostly by extracting gas from the Fayetteville Shale with activity concentrated in mixed pasture-deciduous forests. Concentrated well pads in close proximity to streams could have adverse effects on stream water quality and biota if sedimentation associated with developing infrastructure or contamination from fracturing fluid and waste occurs. Cumulative effects of gas activity and local habitat conditions on macroinvertebrate communities were investigated across a gradient of gas well activity (0.2–3.6 wells per km^2) in ten stream catchments in spring 2010 and 2011. In 2010, macroinvertebrate density was positively related to well pad inverse flowpath distance from streams ($r = 0.84$, $p < 0.001$). Relatively tolerant mayflies *Baetis* and *Caenis* ($r = 0.64$, $p = 0.04$), filtering hydropsychid caddisflies ($r = 0.73$, $p = 0.01$), and chironomid midge densities ($r = 0.79$, $p = 0.008$) also increased in streams where more well pads were closer to stream channels. Macroinvertebrate trophic structure reflected environmental conditions with greater sediment and primary production in streams with more gas activity close to streams. However, stream water turbidity ($r = 0.69$, $p = 0.02$) and chlorophyll a ($r = 0.89$, $p < 0.001$) were the only in-stream variables correlated with gas well activities. In 2011, a year with record spring flooding, a different pattern emerged where mayfly density ($p = 0.74$, $p = 0.01$) and mayfly, stonefly, and caddisfly richness ($r = 0.78$, $p = 0.008$) increased in streams with greater well density and less silt cover. Hydrology and well pad placement in a catchment may interact to result in different relationships between biota and catchment activity between the two sample years. Our data show evidence of different macroinvertebrate communities expressed in catchments with different levels of gas activity that reinforce the need for more quantitative analyses of cumulative freshwater-effects from oil and gas development.

1. Introduction

Natural gas and oil extraction using horizontal drilling coupled with hydraulic fracturing, currently unconventional methods (UOG), has expanded rapidly across the U.S. and is quickly becoming a more common land use in regions of the U.S. that have historical had little resource extraction (Lave and Lutz, 2014; US DOE/EIA, 2013). Natural gas and oil well extraction in shale basins has been shown to be close

* Corresponding author.
E-mail addresses: enlj12@gmail.com (E. Johnson), bjaustin@uark.edu (B.J. Austin), einlander@tnc.org (E. Inlander), cgallipeau@tnc.org (C. Gallipeau), mevanswh@uark.edu (M.A. Evans-White), sentrekin@uca.edu (S. Entrekin).

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to streams and pose multiple environmental threats to streams that include water flow alteration, sedimentation, and surface and groundwater contamination (Williams et al., 2007; Kargbo et al., 2010; Entrekin et al., 2011). The installation of infrastructure needed for natural gas extraction disturbs the landscape and can reduce core forest and riparian areas that decrease habitat and vegetation to buffer nearby streams from runoff (Drohan et al., 2012; Moran et al., 2015). Stream hydrology is often more flashy in catchments with altered riparian areas that can simplify stream habitat by sediment transport that scours the stream bed (Walsh et al., 2005; Roy et al., 2006) and increases sediment deposition, both of which reduce habitat for aquatic biota (Frissell et al., 1986; Wood and Armitage, 1997; Poff et al., 2006b). Associated infrastructure such as pipelines and roads for transporting equipment, fracturing fluids, or moving gas or oil also fragments landscape, increases impervious surfaces and increases the probability for cumulative effects from sedimentation, nutrient leaching, or contamination to receiving streams (Souther et al., 2014).

Sediment and nutrients are primary pollutants in streams in the U.S. most often associated with row crop agriculture, cattle grazing, and urban land development (Ryan, 1991; United States Environmental Protection Agency, USEPA, 2009). Increased sediment and associated nutrients can also occur from development associated with natural gas activity; however, there are few published studies quantifying cumulative impacts (but see Olmstead et al., 2013; Brittingham et al., 2014). Stream turbidity often correlates positively with sedimentation and has been shown to positively correlate with gas well density in stream catchments across the Fayetteville Shale in Arkansas (Burton et al., 2014; Entrekin et al., 2011). Stream water turbidity could also increase as a result of cumulative activities associated with natural gas well development similar to increases in streams draining agricultural and urban landscapes with elevated sediment concentrations (Walsh et al., 2005; Drohan et al., 2012). Direct measurements of sediment from recently placed gas pads quantified soil erosion on-pare to a construction site (Williams et al., 2007). Sedimentation to streams also occurs with new road construction and pipeline construction placed near or across streams when proper erosion control structures are not used (Walsh et al., 2005). More studies examining multiple sources of sedimentation at the landscape level are required for predicting water quality alterations associated with infrastructure development associated with oil and gas extraction.

Total dissolved solids, metals, and organic compounds may also increase in streams in close proximity to UOG activities from accidental spills and leaks associated with the process of hydraulic fracturing and subsequent production (Preston et al., 2014; Rozell and Reaven, 2012). The probability of accidental spills is uncertain but will increase with greater activity (Rahm and Riha, 2014). Contamination events from UOG will be mostly acute where it is unlikely an event would be detected in most small streams unless monitoring is occurring or biological communities are examined before and after an event. Streams that have experienced chronic stress from construction activities or acute contamination events will have altered biological communities that reflect these stressors over several generations (Weigel, 2003; Burton et al., 2014).

Macroinvertebrate community composition represented as functional composition and tolerance to stressors provides metrics to assess changes in trophic status and organization from catchment-scale stressors (Merritt et al., 2008; Barbour et al., 1999). For example, a majority of collector-gathering macroinvertebrates would indicate an abundance of fine benthic organic matter and likely high frequency and intensity of habitat disturbance (Boulton et al., 1992; Resh et al., 1988; Whiles and Wallace, 1992). More collector-filterers would indicate greater delivery of suspended organic sediment and more scrapers are indicative of greater benthic primary production. Density-weighted tolerance of a community provides a more comprehensive indication of overall degradation to water quality that could be a result of contamination from myriad catchment-level alterations. Differences in macroinvertebrate communities and individual taxa in similar streams and rivers allow scientists and managers to predict effects of catchment-level alterations integrated over time (Merritt et al., 2008; Poff et al., 2006a).

Our primary objective was to identify differences in aquatic macroinvertebrate communities in receiving streams draining catchments with recent and on-going UOG extraction activities embedded in a landscape of pasture and forest. We predicted greater tolerant taxa and collectors and fewer sensitive taxa, such as shredders represented by Ephemeroptera, Plecoptera, and Trichoptera (EPT) in catchments with more UOG.

2. Methods

2.1. Study area

We sampled 10, 4th–6th order streams in north-central Arkansas in the Arkansas River Valley with catchments that ranged from 14 to 84 km^2 (Fig. 1). Sites were selected to achieve a gradient of gas well densities (Table 1). Catchment area was calculated for each site using ArcHydro Tools 9 version 1.3 (an ArcGIS extension). For each catchment, gas well data points were accessed from the Arkansas Oil and Gas website (ftp://www.aogc.state.ar.us/GIS_Files/) and well density was calculated as the sum of spud, active, and plugged wells divided by the catchment area (Table 1). Gas well densities across all catchments ranged from 0.2 to 2.2 wells per km^2 in May 2010 and 0.6 to 3.6 wells per km^2 in May 2011. Land use was estimated for each catchment and dominated by forest and pasture (Table 1). The total length of paved and unpaved roads within each catchment was divided by catchment area to calculate density. Natural gas pads were digitized from USACE (U.S. Army Corps of Engineers) aerial photography from June 2009 at 0.3 m resolution as well as 2009 and 2010 USDA (U.S. Department of Agriculture) NAIP (National Agriculture Imagery Program) aerial photography at 1 m resolution. Where there were active gas wells from the AOGC data for these years, but pads were not visible on the 2009 or 2010 aerial photography (i.e. pads from 2011, 2012, 2013), a standard pad size of ~1 ha was used to generate pad polygon. The distance from gas pads to a stream was measured as the path water would flow using ArcHydro Tools 9 version 1.3 (ArcGIS, ESRI, Redlands, CA). Flowpath distances were then inverted and summed to calculate the inverse flowpath length (IFPL) of gas pads as an index of the total proximity of gas pads to streams in a catchment. The gas variables (gas well and pad density and IFPL) were updated annually. Land cover and road variables could not be updated annually.

2.2. Macroinvertebrate benthic sampling

Macroinvertebrates were sampled two years in spring from May 7–9 in 2010 and again from May 16–17 in 2011. At each of the 10 ten streams, we delineated 200 meter upstream reaches and used a random number generator to identify sampling locations within each reach. Macroinvertebrates were sampled in five pools with a 650 cm^2 d-frame kick net (250 μm mesh), standardized to 1 m with three sweeps along the stream bottom (Snyder et al., 2002). Macroinvertebrates were also sampled in five riffles using a 32-cm diameter Hess sampler (250 μm mesh, Delong and Brusven, 1998). All macroinvertebrates were preserved in 95% ethanol.

In the laboratory, macroinvertebrates in each sample were separated into 1-mm and 250-μm size classes using stacked sieves. Macroinvertebrates >1 mm were sorted by eye, while macroinvertebrates <1 mm but >250 μm were subsampled using a sample splitter with an adequate subsample having at least 100 individuals (Waters, 1969) and sorted with using a dissecting microscope. Chironomids were classified as Tanypodinae predators or non-Tanypodinae and all other invertebrates were identified to genus using Merritt et al. (2008), Stewart et al. (1993), Thorp and Covich (2001), and Wiggins (1996). All individuals