Environmental Pollution 239 (2018) 722–732

Contents lists available at ScienceDirect

Environmental Pollution

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

Effects of brine contamination from energy development on wetland macroinvertebrate community structure in the Prairie Pothole Region☆

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ARTICLE INFO

Article history:
Received 15 December 2017
Received in revised form
10 April 2018
Accepted 20 April 2018

Keywords:
Williston Basin
Oil and gas
Coproduced water
Pollution
Freshwater salinization

ABSTRACT

Wetlands in the Prairie Pothole Region (PPR) of North America support macroinvertebrate communities that are integral to local food webs and important to breeding waterfowl. Macroinvertebrates in PPR wetlands are primarily generalists and well adapted to within and among year changes in water permanence and salinity. The Williston Basin, a major source of U.S. energy production, underlies the southwest portion of the PPR. Development of oil and gas results in the coproduction of large volumes of highly saline, sodium chloride dominated water (brine) and the introduction of brine can alter wetland salinity. To assess potential effects of brine contamination on macroinvertebrate communities, 155 PPR wetlands spanning a range of hydroperiods and salinities were sampled between 2014 and 2016. Brine contamination was documented in 34 wetlands with contaminated wetlands having significantly higher chloride concentrations, specific conductance and percent dominant taxa, and significantly lower taxonomic richness, Shannon diversity, and Pielou evenness scores compared to uncontaminated wetlands. Non-metric multidimensional scaling found significant correlations between several water quality parameters and macroinvertebrate communities. Chloride concentration and specific conductance, which can be elevated in naturally saline wetlands, but are also associated with brine contamination, had the strongest correlations. Five wetland groups were identified from cluster analysis with many of the highly contaminated wetlands located in a single cluster. Low or moderately contaminated wetlands were distributed among the remaining clusters and had macroinvertebrate communities similar to uncontaminated wetlands. While aggregate changes in macroinvertebrate community structure were observed with brine contamination, systematic changes were not evident, likely due to the strong and potentially confounding influence of hydroperiod and natural salinity. Therefore, despite the observed negative response of macroinvertebrate communities to brine contamination, macroinvertebrate community structure alone is likely not the most sensitive indicator of brine contamination in PPR wetlands.

1. Introduction

Wetlands in the Prairie Pothole Region (PPR) of North America support ecologically important aquatic macroinvertebrate (invertebrates hereafter) communities. Invertebrates comprise a taxa-rich group that serve as the principal connection between aquatic macrophytes and other primary producers, detritus, and higher order consumers (Murkin and Ross, 2000). Invertebrate community structure in PPR wetlands are less taxonomically rich than other freshwater systems (Euliss et al., 1999) and are influenced by hydroperiod (the time a wetland is covered by water) and salinity (Kantrud et al., 1989). Hydroperiod and salinity, in turn, are related to topographic position, interactions with local and regional groundwater flow paths, and extreme variability in precipitation (snowmelt and summer rain) and evapotranspiration across wet and dry cycles (Johnson et al., 2005). Generally, hydroperiod is extended and salinity increased along the gradient of groundwater recharge, flow-through, and groundwater discharge wetlands

☆ This paper has been recommended for acceptance by Dr. Harmon Sarah Michele.

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https://doi.org/10.1016/j.envpol.2018.04.088

(LaBaugh et al., 1987; Winter, 2003). Wetlands with shorter hydroperiods are often restricted to taxa possessing adaptations to withstand periodic desiccation. Wetlands with more permanent hydroperiods, have an expanded species pool and, correspondingly, greater taxonomic richness (Gleason and Rooney, 2018). Additionally, fresher wetlands generally support more diverse invertebrate communities whereas saline wetlands support fewer, salt tolerant invertebrates (Swanson et al., 1988).

The Williston Basin, a leading source of U.S. oil and gas (energy hereafter) production, underlies the southwestern portion of the PPR (Fig. 1). During energy production, large volumes of saline water (brine) are coproduced with oil and gas. While the amount of brine varies by well, traditional production methods have brine to oil ratios of approximately 10:1 over the lifespan of the well (Tangen et al., 2014). Furthermore, Williston Basin brines are among the most saline in the U.S. (Otton, 2006). Numerous pathways exist for brine to enter the environment with a major source being leachates that enter the groundwater system from legacy reserve pits used to store drilling fluids and brine during well construction (Beal et al., 1987; Murphy et al., 1988). Other contemporary sources include pipeline breaks, well failures, and spills. Therefore, brine is a potential environmental hazard from energy production in the Williston Basin (Preston et al., 2014).

Introduction of brine can alter wetland salinity and chemical compositions (Reiten and Tischmak, 1993). Across the PPR, wetlands have total dissolved solid (TDS) values ranging from <2500 to >95,000 mg/L (Swanson et al., 1988; Mushet et al., 2015); however, TDS is usually <11,340 mg/L (Tangen et al., 2014). Additionally, dominant anions are sulfate (62.4% of wetlands), bicarbonate (33.1%), and occasionally chloride (4.5%; Swanson et al., 1988). In contrast, Williston Basin brines have higher TDS values, ranging from 30,000 to >450,000 mg/L, and the dominant anion is chloride (Iampen and Rostron, 2000). Therefore, the introduction of brine can increase TDS and specific conductance and shift sulfate/bicarbonate dominated wetlands to chloride dominated wetlands (Preston et al., 2014). Brine can enter wetlands through surface runoff from spills or through groundwater flowpaths, with the latter being particularly important for flow-through and discharge wetlands. Brine contamination in groundwater is extremely persistent, remaining for over 50 years, and can migrate over 800 m from the source; therefore, brine can continue to accumulate in down-gradient wetlands long after the initial release (Rouse et al., 2013; Preston et al., 2014). Despite considerable research demonstrating deleterious effects of increased salinity from anthropogenic sources (e.g., road deicers) on invertebrate communities (e.g., Corsi et al., 2010), few studies have examined increased salinity from brine. This may be particularly relevant in portions of the PPR where brine contamination is widespread (Reiten and Tischmak, 1993; Lauer et al., 2016) and wetlands span a range of natural salinities (Tangen et al., 2014; Mushet et al., 2015). Therefore, our objective was to identify potential changes in invertebrate community structure in PPR wetlands resulting from energy-related brine contamination. Specifically, we examined taxonomic richness, diversity, evenness, and percent dominant taxa between contaminated and uncontaminated wetlands across hydroperiod and salinity gradients. A proximity analysis assessed wetland water quality based on adjacent well age and density. Cluster analysis and nonmetric multidimensional scaling placed changes in invertebrate communities into a regional perspective by grouping wetlands with similar invertebrate communities and identifying water quality and environmental parameters that best explained community composition.

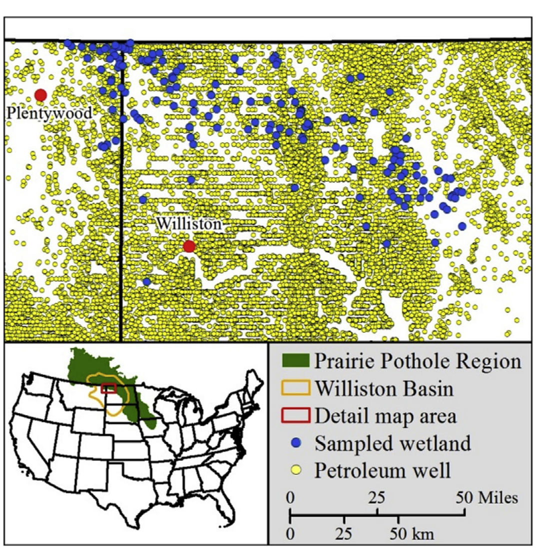

Fig. 1. Map showing the location of the Prairie Pothole Region and the Williston Basin. Detail map shows the locations of the 155 sampled wetlands and petroleum related wells.

2. Methods

Water quality and invertebrate samples were collected from 159 wetlands in northeast Montana and northwest North Dakota during 2014, 2015, and 2016 (Fig. 1). Water quality and invertebrate samples were generally collected together; however, 13 wetlands had samples taken on separate days. A total of 149 Waterfowl Production Areas (WPAs) within the Lostwood, Crosby, and Northeast Montana Wetland Management Districts were sampled in 2014 (116) and 2015 (33), with samples collected from the wetland in closest proximity to energy development. In 2016, wetlands adjacent to known brine spills were targeted to increase the number of contaminated wetland samples. These wetlands contained a mix of WPAs (3) and private lands (7). Uplands adjacent to sampled wetlands were generally mixed-grass prairie, with the exception of 30 wetlands that were partially surrounded by cultivated fields separated by grass buffers. Surrounding land use was not considered in this study; however, the relative percentages of contaminated (19%) and uncontaminated (20%) wetlands adjacent to agriculture were similar and land use is poorly correlated to PPR invertebrate communities (Tangen et al., 2003; Gleason and Rooney, 2017).

Water samples were collected from 21 May to 24 July in 2014, 21 May to 3 August in 2015, and 16 June to 2 July in 2016 using methods modified from Knapton (1985). Water depths were generally shallow and PPR wetlands are generally well mixed by wind-generated turbulence (Preston et al., 2012); hence, a single sample from each wetland was assumed to represent the entire wetland. Samples were obtained by wading to the wetland center and submersing acid-washed polyethylene bottles. Samples were analyzed by the Montana Bureau of Mines and Geology Analytical Lab, Billings, Montana, for major ions, trace elements, and metals following US Environmental Protection Agency (USEPA) methods 200.7 (USEPA, 1994a), 200.8 (USEPA, 1994b), and 300.A (USEPA, 1994c), respectively. Reiten and Tischmak (1993) empirically developed a Contamination Index (CI), calculated as the ratio of chloride concentration (mg/L) to specific conductance (μS/cm) in surface water, to determine the presence and magnitude of brine contamination in PPR wetlands, with values greater than 0.035 indicating contamination. The CI was used to classify all wetlands in this study as either uncontaminated or contaminated by brine.

Wetlands were further classified by hydroperiod and salinity class. Hydroperiods were determined from the National Wetlands