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Effects of persistent energy-related brine contamination on amphibian abundance in national wildlife refuge wetlands

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ABSTRACT

To inform sustainable energy development, it is important to understand the ecological effects of historical and current production practices and the persistence of those effects. The Williston Basin is one of North America's largest oil production areas and overlaps the Prairie Pothole Region, an area densely populated with wetlands that provide important wildlife habitat. Although historical disposal practices that released chloride-rich waters (brines) produced during oil extraction into the environment are no longer used, brine spills still occur frequently. We sampled 33 wetlands for three amphibian species in Montana and North Dakota during 2015–2017, primarily on National Wildlife Refuges, and used N-mixture models to determine how abundance varied with evidence of brine contamination. To provide insight into effects of historical versus contemporary contamination, we also estimated the association of well density and age with water quality and amphibian abundance. Abundance of boreal chorus frog (*Pseudacris maculata*) larvae declined most rapidly in response to increased chloride (range: 0.04–17,500 mg/L), followed by the northern leopard frog (*Lithobates* [*Rana*] *pipiens*) and barred tiger salamander (*Ambystoma mavortium*). Water quality and population- and community-level abundance of amphibians were more strongly related to nearby wells (≤800 m) installed before 1982 than to wells installed since 1982. These results suggest historical brine management practices were the primary driver of contamination and reduced amphibian abundance in wetlands we sampled, reflecting multi-decadal ecological effects. These persistent effects also underscore the critical need for tools to restore landscapes affected by brine contamination.

1. Introduction

Increasing demand has driven a global expansion for hydrocarbon-based energy sources (USEIA, 2017). Modern regulations and techniques have reduced contamination from oil and gas extraction compared to historical practices. Nonetheless, pollution events still occur, and the ecological effects from both legacy (historical) and more recent events are not well understood but could be long-lasting (Cozzarelli et al., 2017; Gleason and Tangen, 2014; Lauer et al., 2016; Souther et al., 2014). To ensure responsible energy development, it is important to understand the effects of contamination on ecological communities and the persistence of those effects.

Development of unconventional oil resources through advances in horizontal drilling and hydraulic fracturing techniques has led to large increases in energy production in many areas, including in North America's Great Plains. For example, the number of permitted wells in the USA portion of the Williston Basin—an area with a long history of conventional oil extraction—increased 53% from 2000 to 2013 (Figs. 1, 2). The Williston Basin overlaps with the ecologically-important Prairie Pothole Region, where > 35% of wetlands are ≤1 km from petroleum-related wells (Gleason and Tangen, 2014). Energy production occurs on a wide range of private and public lands in the USA, including on National Wildlife Refuges and other protected lands (Ramirez and Mosley, 2015). Protecting wildlife habitat while extracting energy resources presents management challenges (Northrup and Wittemyer, 2013; Ramirez and Mosley, 2015). Habitat loss from well pads, pipelines, and other infrastructure can directly or indirectly affect wildlife, by altering behavior, home ranges, and vital rates such as survival (Aldridge and

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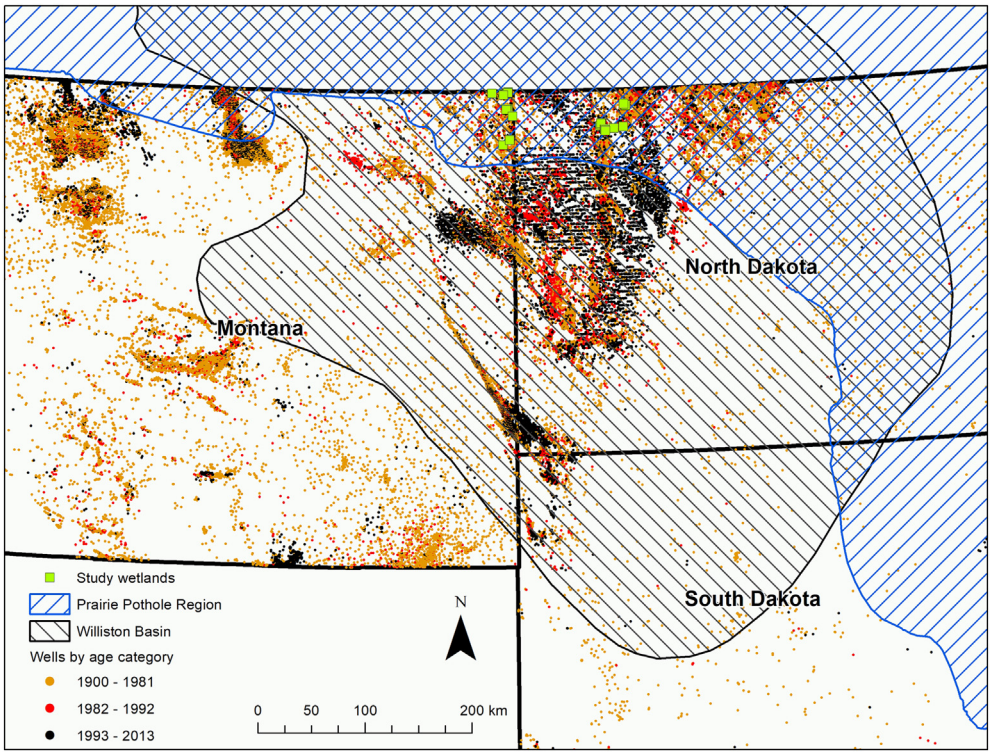

Fig. 1. Locations of the 33 wetlands surveyed (June and July 2015–2017; peridot green squares) to evaluate the effects of brine contamination on amphibians in Montana and North Dakota, relative to permitted and installed wells (1900–2013) in the Williston Basin (black hatching) and Prairie Pothole Region (blue hatching). Well locations are color-coded based on time periods that correspond to common disposal practices of wastewaters. Prior to 1982 (brown circles), brines were typically discharged into unlined reserve pits and often infiltrated into the groundwater. Liners were required in newly constructed reserve pits during 1982–1992 (red circles) but were often breached during remediation. Since 1992 (black circles), brines have primarily been removed via trucks or pipelines and re-injected below ground. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

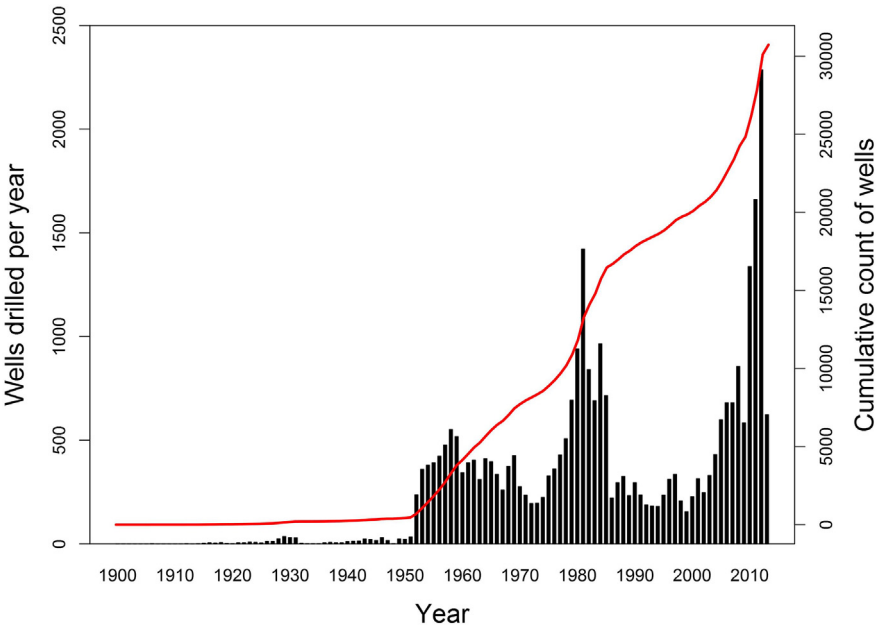

Fig. 2. Number of newly installed and permitted oil related wells in the Williston Basin (1900–2013; USA only) by year (left y-axis) and cumulatively (right y-axis). (Data source: Chesley-Preston, T. 2013. Petroleum related wells in Montana, North Dakota, and South Dakota; https://www.sciencebase.gov/catalog/item/528d0750e4b0c629af455a00.)

Boyce, 2007; Dyer et al., 2002; Sawyer et al., 2009). Fragmentation from roads and infrastructure can also magnify effects of habitat loss by increasing edge effects, causing light or noise pollution, and promoting establishment of invasive species (Northrup and Wittemyer, 2013; Preston, 2015; Thompson et al., 2015).

For wetlands and their associated species, improperly managed saline wastewaters that are produced as part of the extraction process are a potential threat in the Williston Basin and other oil and gas production areas. In the Williston Basin, the volume of brines can be > 10 times the volume of oil extracted (Gleason and Tangen, 2014; Reiten and Tischmak, 1993). These wastewaters (hereafter, brines) have high concentrations of sodium, chloride, and other pollutants such as heavy metals, volatile organic compounds, and hydrocarbons, that, if released into the environment, can alter water quality and persist in soils and wetland sediments (Beal et al., 1987; Cozzarelli et al., 2017; Lauer et al., 2016; Preston et al., 2014). Although releases of brines into the environment as a standard disposal practice has largely ended, wastewater spills still occur in the Williston Basin at a rate that exceeds that of many other major oil and gas production areas (Lauer et al., 2016; Maloney et al., 2017; Souther et al., 2014). Secondary salinization of aquatic environments from agricultural practices, drought, and road salts can alter ecological communities (Karraker et al., 2008; Nielsen and Brock, 2009; Sanzo and Hecnar, 2006; Smith et al., 2007). Secondary salinization and other forms of contamination from energy production also represent potential threats to freshwater environments (Gleason and Tangen, 2014; Maloney et al., 2017; Souther et al., 2014).