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Relationship between the natural abundance of soil nitrogen isotopes and condition in North Dakota wetlands

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ABSTRACT

A statewide condition assessment of North Dakota wetlands in the summer of 2011 was conducted as part of the U.S. Environmental Protection Agency's National Wetland Condition Assessment (NWCA). Two other wetland condition assessments, the Index of Plant Community Integrity (IPCI) and North Dakota Rapid Assessment Method (NDRAM), were also completed at each wetland. Previous studies have identified how the distinct signatures of stable isotopes can be used to determine different land uses, anthropogenic impacts, nutrient cycling, and biological processes. To evaluate if these relationships existed in northern prairie wetlands, the data collected from the wetland assessments were compared with the natural abundance of soil nitrogen ($\delta^{15}N$) isotopes. Wetland soil $\delta^{15}N$ was significantly higher (isotopically heavier) in wetlands surrounded by cropland compared to those surrounded by idle or grazed/hayed grasslands, possibly reflecting anthropogenic impacts and multiple nitrogen sources. Soil $\delta^{15}N$ was significantly correlated with floristic quality, IPCI scores, NDRAM scores, and average buffer width, indicating that soil $\delta^{15}N$ values may be representative of wetland condition. Soil $\delta^{15}N$ exhibited significant differences among wetland types, although limited sample sizes of certain wetland types may have affected this result. Additional studies on the natural abundance of wetland soil isotopes need to be performed in northern prairie wetlands. This study is the first step in exploring the potential applications of wetland soil nitrogen isotopes regarding wetland assessment and surrounding land use and provides important insight for future studies.

1. Introduction

The global nitrogen (N) cycle has important implications for human well-being (Millennium Ecosystem Assessment, 2005). Anthropogenic impacts to wetlands, whether through agriculture or urban development, have dramatically altered nutrient cycling with increased nutrient loads that originate from many different sources (Galloway and Cowling, 2002). Nutrient cycling is also affected by shifts in plant communities, disruption of soil/sediment, introduction of invasive species, and pollution. Northern prairie wetlands, found throughout the Great Plains of the United States, are important for water quality, climate regulation, and habitat, but are threatened by agriculture (Johnston, 2013). Due to concerns about the effects of anthropogenic impacts on natural wetland systems, wetland condition assessments have been implemented to measure changes in wetlands (U.S. Environmental Protection Agency, 2011).

One implication of anthropogenic impacts to natural systems is elevated nutrient levels, and stable isotopes may be used to indicate how nutrient cycling has been affected by particular anthropogenic activities (Elliott and Brush, 2006). N has two stable isotopes: ^{14}N and ^{15}N. Lighter isotope species (i.e., ^{14}N) are typically preferentially used during microbially- or plant-mediated chemical reactions (such as denitrification, respiration, or methanogenesis) creating distinct $^{14}N/^{15}N$ ratios. Furthermore, different sources of N (e.g., inorganic versus organic fertilizer) also have distinct isotope ratios. Because of these distinct signatures, the natural abundance of stable isotopes in the environment can provide valuable information about biogeochemical cycling and nutrient sources (Peterson and Fry, 1987). For example, the natural abundance of soil $\delta^{15}N$ may be an indicator of N processing, with denitrification having the most influence on the isotope enrichment factor, as N processing can result in an enrichment of soil $\delta^{15}N$ (Blackmer and Bremner, 1977; Billy et al., 2010; Chen et al., 2014). However, other factors such as the flow rate, depth of water and connectivity to other

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wetlands or waterbodies, can affect denitrification rates (Itoh et al., 2011; Racchetti et al., 2011).

Historically, the sources of N in wetlands have included biological fixation, mainly from plant and bacteria symbiosis, with some from lightening and wildfires (Viousek et al., 2002). Under natural conditions, the source of N is atmospheric, which has an isotope value of 0‰ (Elliott and Brush, 2006). Thus, $\delta^{15}N$ may be expected to range from 0 to +2‰ when derived from biological fixation. N sources from human inputs have distinct $\delta^{15}N$ values as well. Fertilizer ranges from −2‰ to +4‰ (Vitòria et al., 2004), atmospheric deposition ranges from −11‰ to +3‰ (Elliott and Brush, 2006), and manure and human wastewater ranges from +8‰ to +22‰ (Aravena et al., 1993; Elliott and Brush, 2006). The increased N from human activities has resulted in an increase in $\delta^{15}N$ values worldwide; urban ecosystems have been reported to have isotopically heavier $\delta^{15}N$ values than natural ecosystems (Elliott and Brush, 2006). Soil $\delta^{15}N$ can remain elevated up to a century or more after human disturbance has ceased, making N isotopes a good indicator of historic anthropogenic impacts (Koerner et al., 1999).

The anaerobic and carbon-rich environment typical of wetlands promotes denitrification, an important service by which excess N is removed from the landscape. Sutherland et al. (1993) found that denitrification and plant $\delta^{15}N$, were greater (isotopically heavier) in wet, depressional areas than in more elevated, drier landscape positions. However, cropped ecosystems have been shown to exhibit random spatial patterns of soil $\delta^{15}N$, indicating some difficulty in using soil $\delta^{15}N$ to indicate denitrification patterns in these types of landscapes (van Kessel et al., 1994).

Changes in land use have affected wetlands and nutrient cycling globally (Millennium Ecosystem Assessment, 2005; Elliott and Brush, 2006). Natural abundances of stable isotopes have been used as an indicator of anthropogenic inputs into ecosystems (Hoffman et al., 2012; Xu and Zhang, 2012), and elevated nutrient levels have been correlated with high human impact (Elliott and Brush, 2006). Therefore, stable isotope levels in wetland soils can be used to indicate changes in land use and nutrient inputs into natural systems (Chang et al., 2002; Elliott and Brush, 2006; Merlo-Galeazzi and Zambrano, 2014).

The objective of this study was to explore the relationship between the natural abundance of stable N isotopes associated with landscape position, wetland soil characteristics, wetland type, differing surrounding land use, and wetland condition in northern prairie wetlands. Wetland condition in this study was defined as the current state of a wetland compared to a reference (U.S. Environmental Protection Agency, 2011). Reference wetlands are characterized by high quality physical, chemical, and biological characteristics. Specifically, we hypothesized that (1) soil $\delta^{15}N$ in samples collected from uplands (or from wetlands without soil hydric indicators) would be isotopically lighter than those collected from wetlands with soil hydric indicators (Sutherland et al., 1993; Billy et al., 2010); (2) wetland types characterized by saturated surface soils most of the year would have greater soil $\delta^{15}N$ than those characterized by long periods of drawdowns; (3) soil $\delta^{15}N$ would be higher in wetlands surrounded by cropped land use compared to wetlands surrounded by idle or grazed/hayed grasslands (Elliott and Brush, 2006); and (4) because there is an expected relationship between wetland condition and surrounding land use, soil $\delta^{15}N$ would also be higher in lower condition wetlands.

2. Methods

2.1. Study sites

This study was conducted in conjunction with the U.S. Environmental Protection Agency's National Wetland Condition Assessment (NWCA) during the summer of 2011 (Kentula et al., 2011; U.S. Environmental Protection Agency, 2011). Assessment areas (AAs) of 0.5 ha were established at 51 wetland points, which may or may not have included the whole wetland ecosystem, in the state of North Dakota (Fig. 1). These were sampled as an intensification of and a contribution to the nationwide NWCA. This was the first NWCA survey completed and provides baseline data for future surveys. Wetland points were chosen using a probability design based upon the Fish and Wildlife Service's Status and Trends Plots so results could be reported by wetland area across the nation (Olsen and Peck, 2008; Dahl, 2011). A hydrogeomorphic (HGM) class was assigned to each AA (Brinson, 1993; Smith et al., 1995). Of the 51 wetland points, 32 were classified as closed depressions (CD), 5 as open depressions (OD), 5 as upper perennial riverine (UPR), 4 as lacustrine fringe (LF), 3 as organic soil flats (OSF), and 2 as topographic slopes (TS). The NWCA protocol called for one day field visits to each wetland point to collect data associated with buffer, vegetation, soils, hydrology, water quality, and algae.

At the same established wetland AAs used for the NWCA, two regional-specific assessments to evaluate the condition of the wetland were performed: (1) the Index of Plant Community Integrity (IPCI) and (2) the North Dakota Rapid Assessment Method (NDRAM, Hargiss et al., 2008; Hargiss, 2009). The IPCI was utilized to assess the vegetation, and the NDRAM was used to rapidly assess wetland characteristics, such as wetland buffer, hydrology, vegetation, soils, habitat, management, wetland potential, and overall condition. Surrounding land use was defined as cropped, idle, or grazed/hayed for the NDRAM. Cropped wetlands were planted through or up to the wetland, or were surrounded by cropland and had a very narrow (i.e., less than 100 m) buffer. Idle wetlands did not have an active management practice (such as cropping, grazing, etc.) in or around the wetland. Grazed/hayed wetlands were wetlands that were managed with vegetation removal by domestic grazing and/or haying. Of the 51 wetland points, 14 were cropped, 18 were idle, and 19 were grazed/hayed.

2.2. Sampling methods

2.2.1. National Wetland Condition Assessment

At each designated wetland point, the NWCA field protocol was conducted according to the methods outlined in U.S. Environmental Protection Agency (2011). Upon arrival at the wetland point, an AA was established, with less than 10% of the AA in upland or in water over 1 m deep. The standard AA was established as a 0.50 ha circle; however, in some cases, the circle was adjusted to fit the shape of the wetland or the AA area was reduced (to a minimum of 0.10 ha) if the individual wetland ecosystem in which the point fell was less than 0.50 ha in area. Non-standard AAs were established at 31 of the 51 wetland points in this study. The mean AA was 0.42 ha in area, and only a single site was established with the minimum area of 0.10 ha. With the exception of buffer data, all data were collected within the established AA.

The buffer was established using 100-m transects along each cardinal direction (N, S, E, W) from the perimeter of the AA. As part of the general NWCA buffer protocol, the presence of stressors in prescribed plots along the transects were recorded to characterize the buffer; however, additional "research" protocol was conducted in the buffer as part of United States of America Rapid Assessment Method (USA-RAM, U.S. Environmental Protection Agency, in review), which was being tested in conjunction with the NWCA. One metric that was collected as part of USA-RAM and used as part of this study as an indicator of condition was buffer width. Buffer width was collected primarily using aerial satellite imageries acquired in 2011. Eight 100-m transects were drawn from the perimeter of the AA along the cardinal and ordinal (NE, SE, SW, NW) directions. The distance between the AA perimeter and the point at which the line intercepted any type of non-buffer land cover was