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Research papers

Drought-induced recharge promotes long-term storage of porewater salinity beneath a prairie wetland

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ABSTRACT

Subsurface storage of sulfate salts allows closed-basin wetlands in the semiarid Prairie Pothole Region (PPR) of North America to maintain moderate surface water salinity (total dissolved solids [TDS] from 1 to 10 g L^{-1}), which provides critical habitat for communities of aquatic biota. However, it is unclear how the salinity of wetland ponds will respond to a recent shift in mid-continental climate to wetter conditions. To understand better the mechanisms that control surface-subsurface salinity exchanges during regional dry-wet climate cycles, we made a detailed geoelectrical study of a closed-basin prairie wetland (P1 in the Cottonwood Lake Study Area, North Dakota) that is currently experiencing record wet conditions. We found saline lenses of sulfate-rich porewater (TDS > 10 g L^{-1}) contained in fine-grained wetland sediments 2–4 m beneath the bathymetric low of the wetland and within the currently ponded area along the shoreline of a prior pond stand (*c.* 1983). During the most recent drought (1988–1993), the wetland switched from a groundwater discharge to recharge function, allowing salts dissolved in surface runoff to move into wetland sediments beneath the bathymetric low of the basin. However, groundwater levels during this time did not decline to the elevation of the saline lenses, suggesting these features formed during more extended paleo-droughts and are stable in the subsurface on at least centennial timescales. We hypothesize a "drought-induced recharge" mechanism that allows wetland ponds to maintain moderate salinity under semiarid climate. Discharge of drought-derived saline groundwater has the potential to increase the salinity of wetland ponds during wet climate.

1. Introduction

Millions of prairie wetlands throughout the ~750,000 km^2 Prairie Pothole Region (PPR) of the glaciated North American Great Plains (Fig. 1a) serve as critical habitat for amphibians and migratory waterfowl (Batt et al., 1989; Dahl, 2014). Although situated in a semiarid climate where annual potential evaporation is almost double annual precipitation (Rosenberry, 2003), wetlands occupying small topographic depressions on low permeability glacial till support surface water ponds that capture snowmelt runoff in the spring and subsequently drawdown during the open-water season (van der Kamp and Hayashi, 2009). The salinity of surface ponds influences habitat suitability for aquatic biota and varies widely (total dissolved solids [TDS] from < 0.5 g L^{-1} to > 50 g L^{-1}) among proximal wetlands due to complex hydrological controls driven by landscape position and climate (Eisenlohr et al., 1972; Euliss et al., 2004; Hayashi et al., 2016).

Wetlands at higher topographic positions within hummocky glacial landscapes typically have small "seasonal" or "temporary" freshwater ponds that fill and dry annually and receive salt inputs from atmospheric sources and surface runoff. Alternately, those occupying lower landscape positions with greater catchment areas tend to be larger and have saltier "semipermanent" ponds that fill and dry in response to multi-annual trends in precipitation and receive salt inputs from atmospheric sources, surface runoff, and groundwater discharge (Stewart and Kantrud, 1971). Pond salinity is dominated by sulfate salts generated from the oxidation of pyrite in the clay-rich till. Groundwater in the till varies from low salinity Ca-HCO_3 facies in recharge areas to high salinity Mg-Na-SO_4 facies

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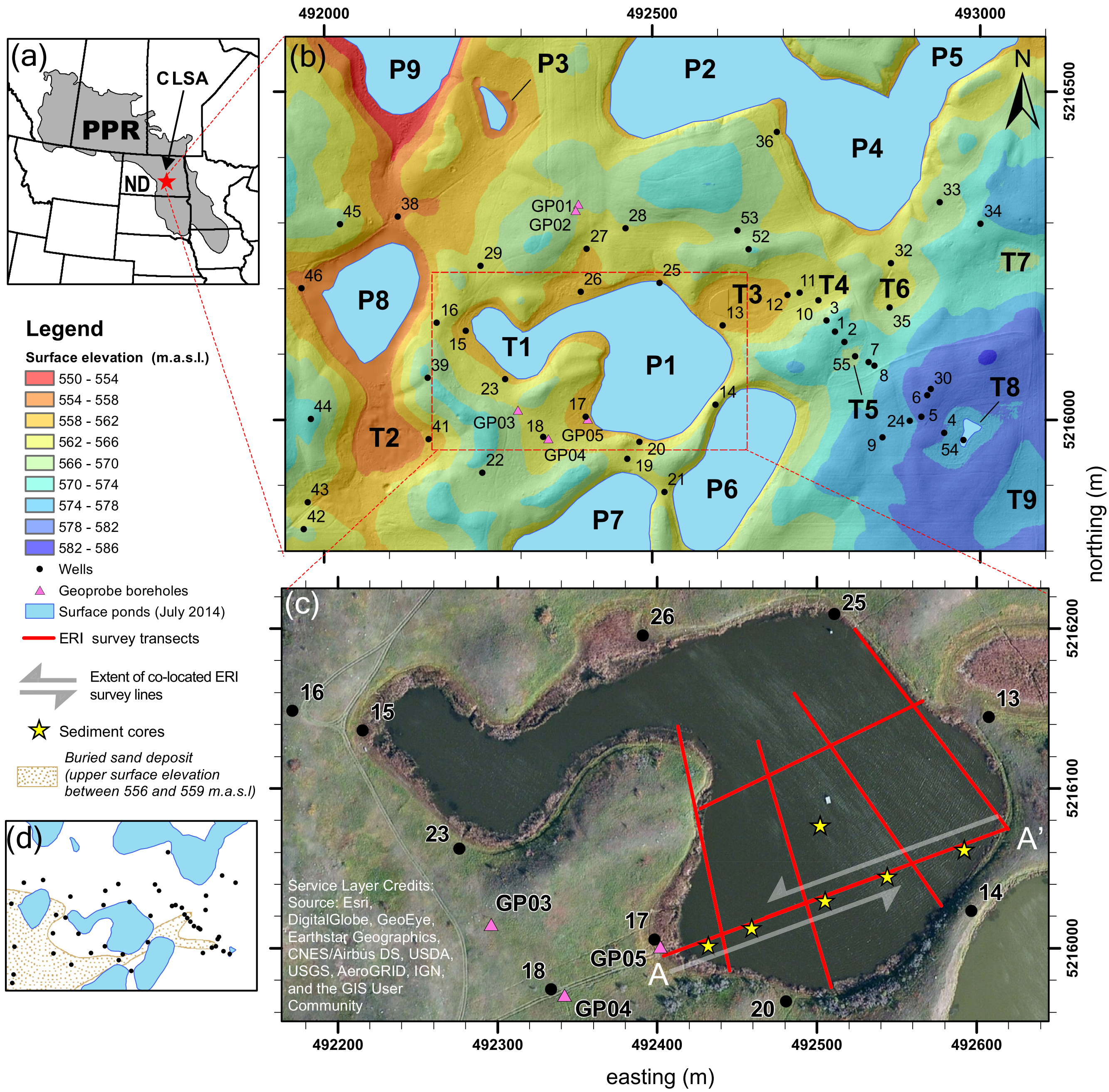

Fig. 1. (a) Location of the Cottonwood Lake Study Area (CLSA) within the Prairie Pothole Region (PPR). (b) CLSA basemap with hypsometric tint showing locations of main study wetlands (P = semipermanent pond, T = seasonal pond), groundwater wells, and locations of Geoprobe borehole conductivity measurements. (c) Inset of satellite photograph of P1/T1 basin (July 2015) showing locations of ERI survey lines and sediment cores. An evaporation platform is visible near the center of P1. (d) Map of CLSA showing the extent of a large, buried sand body (modified from Winter, 2003). All map coordinates are in UTM (zone 14T).

in discharge areas (Goldhaber et al., 2014). Wetland ponds occupying higher landscape remain fresh by recharging surface waters and solutes into underlying fractured till (Hayashi et al., 1998a,b; Berthold et al., 2004; Parsons et al., 2004) and overflowing (i.e. fill-and-spill) into adjacent lower-elevation wetlands (Shaw et al., 2012). In contrast, salts accumulate in low-lying "closed-basin" wetlands that lack surface drainage outlets and are enclosed by surroundings hummocks where elevated groundwater levels create a hydraulic barrier against out-migration of salinity from the basin (van der Kamp and Hayashi, 2009). While some wetlands and lakes in the PPR evolve hyper-saline surface waters (e.g. Last and Ginn, 2005), many closed-basin wetlands maintain surface ponds of moderate (i.e. brackish) salinity (TDS from 1 to 10 g L^{-1}) (e.g. LaBaugh et al., 1998; Heagle et al., 2013).

Atmospheric dry-wet cycles drive complex hydrological processes that control surface-subsurface exchanges of salinity in closed-basin wetlands. Seasonally, transient drawdown of the water table by transpiration of fringing phreatophytes (e.g. cattails, willows) in the summer can induce outseepage around the pond margins, forming "saline rings" of solute-rich porewater and evaporite crystals in peripheral wetland sediments (Meyboom, 1966; Hayashi et al., 1998a,b; Winter and Rosenberry, 1995; Nachshon et al., 2013). During more extended droughts when semipermanent ponds dry, sulfate concentrates by evaporation in the shallow subsurface causing gypsum to precipitate and accumulate in wetland sediments (Eisenlohr et al., 1972; Arndt and Richardson 1989; Heagle et al., 2013; Pennock et al., 2014). During wet times, enhanced runoff from uplands, expanded pond areas, and water-