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Land use effects on sedimentation and water storage volume in playas of the rainwater basin of Nebraska

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ABSTRACT

A region dominated by cropland, the Rainwater Basin (RWB) of Nebraska, contains playa wetlands of international importance but estimates of historic wetland numbers suggest that approximately 90% of wetlands have been lost through draining and filling. To reverse these losses and restore their ecosystem services, >2000 ha of wetlands in the RWB have been enrolled into the US Department of Agriculture (USDA) Wetlands Reserve Program (WRP). Our goal was to compare water storage volume and sediment loads in RWB playas in surrounding cropland, reference condition, and restored (WRP) land uses. To do so, we measured characteristics of 48 playas that dictate water storage capabilities essential to their service provisioning (historic/current playa area, playa volume, and sediment depth to clay pan). Using historic wetland hydric soil footprints, we determined loss of historic area for wetlands in each land use type and using soil cores we estimated sediment depth and volume loss. Reference condition playas had 380% more functional wetland area and 8 times more volume than cropland playas, WRP playas were intermediate between reference and cropland playas. In addition, reference condition playas had lost the least amount of historic area (65%) followed by WRP (70%) and cropland (83%). Though cropland playas lost the greatest extent of historic wetland area, they had sediment depths (to Bt layer) similar to playas embedded in reference and WRP, indicating that all playas in the region have been impacted by watershed soil erosion. In order to increase the overall positive impact on wetland services provided by enrolling playas into the WRP, conservation practitioners should remove sediments down to the Bt layer in enrolled wetlands in the RWB and protect the immediate watershed to prevent further erosion.

Introduction

Soil erosion due to watershed cultivation is a threat to wetland services worldwide (Martin and Hartman, 1987; Luo et al., 1997; Craft and Casey, 2000; Junk et al., 2013; Daniel et al., 2014). Because depressional wetlands are the terminus in closed watersheds, increased sediment accumulation in depressional wetland basins can reduce wetland volume and hydroperiod (Luo et al., 1997; Tsai et al., 2007), subsequently reducing their value as biotic habitat (Smith et al., 2011). Also, incoming sediments can cover native egg and seed banks, effectively altering community structure (Jurik et al., 1994; Euliss and Mushet, 1999; Gleason et al., 2003). In addition, excessive nutrient and contaminant inputs into wetlands can coincide with upland erosion, especially from croplands, which favor the establishment of more competitive invasive plant species within the basin (Suding et al., 2005) and pollute wetlands and potentially groundwater (Belden et al., 2012).

Rates at which eroded watershed soils are deposited into wetlands depend on factors including precipitation, soil type, topography, and land use (Wischmeier and Smith, 1978). In the semi-arid Southern High Plains (SHP) of Texas, sediment accumulation rates of playa wetlands, predominately embedded in cropland watersheds with >2% slopes, were greater than rates reported for any other wetland system (Luo et al., 1997). Intense cultivation has resulted in the loss or degradation of approximately 95% of playas in the SHP (Johnson et al., 2012). Furthermore, cropland playas throughout the entire western High Plains had on average lost their entire historic water storage capacity due to watershed soil erosion (Daniel et al., 2014). For comparison, estimated loss of wetlands in the glaciated Great Plains (Prairie Pothole region, PPR) due to agricultural practices exceeds 50% (Dahl, 1991). Rates of sediment accumulation for cultivated wetlands in the PPR were found to average 80 mg/cm/yr (Martin and Hartman, 1987).

Cropland agriculture in the Rainwater Basin region (RWB) of Nebraska began approximately 50 years prior to widespread farming of the SHP and has served as one of the most productive cropland

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areas in North America (Musick et al., 1988; Olson, 1997; Smith, 2003). Of the approximately 4000 historic wetlands, to which the region receives its name, 90% have been drained or modified for agricultural purposes and thus, effectively removed from the landscape (Gersib, 1991). Because playas in the RWB are situated along a narrow corridor of the Central Flyway, they are critical stopover habitat for millions of migrating waterfowl and shorebirds each year (Bishop and Vrtiska, 2008). Losses in wetland area have reduced the region's waterfowl energetic carrying capacity (Bishop and Vrtiska, 2008) and hydrological degradation through sediment accumulation alters plant community structure (Beas et al., 2013), which in turn may affect other playa services such as seasonal carbon sequestration (Smith et al., 2011).

In response to the loss of wetlands, the US Department of Agriculture (USDA) Wetlands Reserve Program (WRP) was offered nationwide to promote the restoration of wetlands on private property (USDA, 2010). Today, the WRP offers permanent and 30-year conservation easements as well as a restoration cost-share agreement to private landowners who volunteer wetlands into the program. There are approximately 931,000 ha of wetlands nationwide enrolled in the WRP, in the High Plains, WRP property is concentrated in the RWB region (Smith et al., 2011). A variety of techniques are utilized to restore hydrology of WRP wetlands, including pit filling, drain plugging, sediment removal, and watershed restoration (USDA, 2010).

Filling water concentration pits is considered a best management practice for playas in the RWB (RBJV, 1994). Pit filling allows water to spread over a greater extent of the historic playa basin, increasing functional wetland area. However, property constraints and adjacent landowner land use practices limit the extent and effectiveness of restoration within a playa. In addition, though some eroded soils are excavated for pit filling, sediment removal is not always implemented in playa restoration projects. In a region depleted of wetland services and constrained by property lines, sediment removal from playas can increase functional wetland volume, thus increasing wetland value (Smith et al., 2011).

Water storage capacity and hydroperiod dictate much of the ecosystem service delivery capabilities of playas. For example, playas with greater wetland volumes and longer hydroperiods are greater contributors to biodiversity provisioning and potentially aquifer recharge (Smith et al., 2008; Gurdak and Roe, 2009). Because accumulation of eroded soils from watershed cultivation is the greatest threat to remaining playa wetlands and their associated services (Smith, 2003; Smith et al., 2011), our goal was to measure and compare water storage volume and sediment loads among playas in cropland, reference condition, and restored land use types in the RWB. Further, in an effort to elucidate the effectiveness of wetland conservation and restoration efforts as part of the Conservation Effects Assessment Project (www.nrcs.usda.gov, accessed 05.11.14; Smith et al., 2011), playas enrolled into the WRP were used as the restored wetlands.

Methods

Data collection and experimental design

We measured historic and current playa area, playa volume, and soil depth to Bt layer (water retaining clay pan) in playas embedded in reference condition, cropland, and WRP in the RWB region of Nebraska, in 2011, an area characterized by flat to gently rolling loess plains historically dominated by mixed-grass and tall-grass prairie (Kuzila, 1994) (Fig. 1). Locations of playas and surrounding land use information were compiled for 48 playas structured as triplets with 16 wetlands within each land use type. Reference playas were selected with assistance from the Nebraska Games and Parks Commission based on four criteria including: (1) very negligible to no hydrologic modifications, (2) a natural vegetation community with little to no invasive or problematic species of plants, (3) a watershed that is unaffected by physical alterations that would prevent runoff from reaching the basin, and (4) the correct water regime for the hydric soils present (Stutheit, personal communication). Reference playas were paired with nearby playas in WRP and cropland. Playas in the RWB have typically been mapped based on the presence of Fillmore, Scott, and Massie series hydric soils that reflect temporary, seasonal, and semi-permanent water regimes, respectively (USDA, 1981). Presence of these soils was determined for each catchment to distinguish water regime differences among land use types. Hydric soil signatures from historic soil surveys published between 1916 and 1934 in the RWB (LaGrange et al., 2011) have been compiled into a geospatial data layer (SSURGO) and metadata include soil type and area of each series signature within a given playa footprint. Using these data, we calculated original playa area and compared that to sampled playa area to determine loss of wetland area.

The area (±0.1 ha) of each sampled playa was determined by mapping the visual edge of the playa, defined as the shift from wetland to upland vegetation (Luo et al., 1997). Mapping was performed using either Trimble$^{\text{TM}}$ Series Geo XT or Geo XH GPS units with TerraSync software. Data were uploaded onto Trimble GPS Pathfinder$^{\text{TM}}$ Office software to post-process and correct GNSS data for Geographic Information System (GIS, ArcGIS 10) compatibility. The 48 surveyed playas were then combined into a GIS layer and overlaid onto the SSURGO hydric footprint layer to ensure that sampled playas were matched to the correct hydric footprint.

Unlike elsewhere in the High Plains, RWB playa soils have developed horizons (USDA, 1981), leading to differences in opinion and more subjective estimates of soil erosion impacts to playas. Using measurements of soil depths down to the Bt layer provides an objective measurement of soils overlying the impermeable clay pan of the playa basin, the essential water storage feature. Sediment depths overlying the Bt layer within existing playa basins were determined using JMC 42″ Dakota Probes so that measurements could be taken without destroying or mixing horizons upon sampling. Soil horizons (A, E, Bt) were distinguished by differences in soil color and texture. The topmost A horizon soils are a silt loam that has a darker coloration due to the higher organic matter content than the E horizon (leached layer) and both A and E horizons can clearly be distinguished from the gleyed, high clay content, Bt layer (USDA, 1981). Soil depths (±1 cm) were taken at the basin center and at five points approximately half the distance to the basin edge circling the center (Daniel et al., 2014).

To determine playa depth, elevation differences (±1 cm) between the center of the playa basin and eight locations (45° angles) around the visual edge were determined using a surveyor level and stadia rod (Tsai et al., 2007). The distance (±0.1 m) from the visual edge to the basin edge (point at which playa floor begins to slope upwards) was measured on opposing sides of the playa to determine slope of the playa edge. Playa volume was estimated using a series of equations using mapped playa area, slope of the playa edge on two opposing sides, and average playa depth (Luo et al., 1997; Daniel et al., 2014). The following equation was used to calculate playa volume of a half playa using each slope:

$$\frac{\Pi(R_{V1}^2 \times H_{v1} - R_{b1}^2 \times H_{b1})}{6}$$

where R_{v1} is the radius of the visible playa. H_{v1} is the visible cone height. R_{b1} is the radius of the playa basin. H_{b1} is the basin cone height.

The volume from each half playa calculation was then summed to determine total playa volume.