



Greenhouse Gas Fluxes and Carbon Storage Dynamics in Playa Wetlands: Restoration Potential to Mitigate Climate Change

Summary of Findings

Though playas occupy only 2-5% of the landscape, they may be of critical importance to the greenhouse gas budget of the Great Plains. Their capacity to provide climate mitigation services, however, may be threatened by cropland agriculture. Our goal in this study was to provide understanding of the potential climate mitigation services provided through playa conservation and restoration in the High Plains. Focus was placed on greenhouse gas (GHG) emissions from playas as well as identifying some of the drivers of GHG flux that are influenced by various land management practices. We also sought to understand how sediment removal from playa basins influenced C and N content as well as C sequestration services.

First, we evaluated the influence of two predominant conservation programs (the Wetlands Reserve Program, WRP, and the Conservation Reserve Program, CRP) on gas emissions (CO_2 , CH_4 , and N_2O) from 42 playas and associated uplands in the High Plains region of Nebraska. Because playa restoration through WRP is most prevalent in the Rainwater Basin (RWB), we studied 27 wetlands among reference condition, cropland, and WRP land uses. The CRP is the most common conservation program elsewhere in the High Plains. We studied 15 playas/uplands within native grassland, cropland, and CRP in the Western High Plains (WHP) of Nebraska. Overall, net $\text{CO}_2\text{-equiv}$ emissions were lower in playas/uplands in WRP, suggesting that benefits of playa restoration may

include climate mitigation as well as increased water storage capacity and biodiversity provisioning. In the WHP, playas in CRP also contributed less to net $\text{CO}_2\text{-equiv}$ emissions; however, the benefits of lower gas emissions must be weighed against tradeoffs of ecosystem services related to shorter hydroperiods as a result of reduced runoff into playas in CRP.

Next, we focused on how implementing a sediment removal practice in playa restoration influences soil carbon and nitrogen concentrations. Sixty playas (20 each from reference condition, cropland, and sediment removal restored land uses) were sampled to assess changes in C and N pools as well as to elucidate C sequestration services among land use types. Playas restored through sediment removal had 29% lower organic C and total N in the top 5 cm of soils compared to reference and cropland conditions. Overall, soil organic carbon (SOC) was similar among land uses to a 50-cm depth, indicating that sediment removal does not have a negative impact on C sequestration potential in playa soils. On average, SOC was 15% higher in playas compared to adjacent uplands, demonstrating the importance of playa wetlands to C sequestration services in the region. Paired with sediment removal within basins, playa watershed restoration can increase upland C storage by establishing permanent vegetation and concomitantly protecting wetland services from future degradation by preventing volume loss from watershed soil erosion.

Background

In 2007, the Society for Ecological Restoration International (SER) stated that global climate change is a real and immediate threat that requires action, and ecological restoration is one of the many tools that can help mitigate that change (SER 2007). Although restoring ecosystems in many cases, can contribute to removal of atmospheric C by sequestration in plant biomass and soils, there is concern that the full suite of ecosystem services provided through ecological restoration may be rarely considered (Emmett-Mattox et al. 2010). Furthermore, certain land management practices may increase provisioning of certain ecosystem services, while also reducing the provisioning of others (Euliss et al. 2011).

Wetland ecosystems provide a good example of the challenges that exist in balancing ecosystem tradeoffs, especially when considering climate mitigation (Euliss et al. 2011). Depending on climate and hydrology, wetlands can function as either net sinks or sources for atmospheric C (Whiting and Chanton 2001, Kayranli et al. 2010). Worldwide, peatlands store nearly one-third of all terrestrial soil C (Gorham 1991) but are also primary contributors to atmospheric CH_4 (Armentano and Menges 1986, Kayranli et al. 2010). Changing patterns of wetting and drying also influence N_2O emissions (Kasimir-Klemetsson et al. 1997, Smith and Conen 2003) providing an obstacle for wetland practitioners managing hydrology.

In the High Plains region of the U.S., the ecosystem service delivery capabilities of playas are driven by their capacity to receive and store water

(Smith et al. 2011). Although threats to playa hydrology can include physical modifications such as irrigation reuse pits, drainage tiling, direct wetland cultivation, and road construction, the greatest threat to playa water storage capabilities is sedimentation resulting from watershed cultivation (Smith et al. 2011). Indeed, soil erosion into playas from cultivated watersheds has reduced functioning playa area and water storage volume in playas throughout the High Plains and in many instances, entire historic wetland footprints have been completely filled by upland sediment deposition (Luo et al. 1997, Daniel et al. 2014, Daniel et al. 2015). Because playa loss through sedimentation is a ubiquitous problem, any changes in land use or management practices that influence the movement of soils in or out of playa basins will ultimately alter ecosystem service provisioning.

Our goal was to provide understanding of the potential climate mitigation services provided through playa conservation and restoration in the High Plains. Focus was placed on greenhouse gas (GHG) emissions from playas as well as identifying some of the drivers of GHG flux that are influenced by various land management practices. We also sought to understand how sediment removal from playa basins influenced C and N content as well as C sequestration services.

Assessment Partnership

This project was funded by the EPA - 2011 Wetland Program Development Grant Program with additional funds provided by the USDA-NRCS CEAP - Wetlands National Assessment. It was conducted through collaboration among researchers with the Nebraska Games and Parks Commission (NGPC), U.S. Geological Survey (USGS), and Oklahoma State University. The primary investigators on this project were:

Loren M. Smith, Scott T. McMurry, and Dale W. Daniel (Oklahoma State University).

Ted LaGrange and Randy Stutheit (NGPC).

Brian A. Tangen and Charles F. Dahl (USGS).

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Assessment Approach (Method)

Greenhouse gas emissions were monitored on 42 wetlands in the High Plains. Twenty-seven wetlands in the Rainwater Basin (RWB) region and 15 wetlands in the Western High Plains (WHP) region of Nebraska were sampled. Wetlands included in the RWB were evenly split among reference, Wetlands Reserve Program (recently changed to Wetlands Reserve Easements within the Agricultural Conservation Easement Program in the most recent Farm Bill), and cropland watersheds. The WHP playas were split among native grassland, Conservation Reserve Program (CRP), and cropland watersheds. Wetland sites were selected at random from Rainwater Basin Joint Venture (RWB JV) GIS layers. In the RWB, very few playas still exist in undisturbed prairie catchments. For the purpose of this study, reference wetlands represent reference standard sites that are the least altered and that most closely resemble historic levels of functioning (Stutheit et al. 2004). Reference playas in the RWB were selected from a list of playas that had been classified as such by NGPC. Their suitability as reference condition playas (hereafter called "reference playas") was based on four criteria: 1) very negligible to no hydrologic modifications, 2) a natural vegetative 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 (R. Stutheit, pers. comm.).

Greenhouse gas emissions from each wetland were sampled every two weeks from April 1 - October 31, for two consecutive years in 2012 and 2013. Samples were collected using the static chamber method (Livingston and Hutchinson 1995). To account for variations in gas emissions across environmental gradients, four separate landscape positions were sampled at each site: (1) wetland center, (2) mid-distance between wetland center

and wetland edge, (3) wetland edge, and (4) upland slope (Gleason et al. 2009).

Gas sampling was conducted between 10 a.m. and 2 p.m. (local time). Gas emissions were collected for a 30-minute accumulation period, deemed sufficient based on previous samplings of greenhouse gas emissions from prairie pothole wetlands in the Glaciated Plains (B. Tangen, pers. comm). Flux values ($\text{g ha}^{-1} \text{ day}^{-1}$) for N_2O , CH_4 , and CO_2 were calculated for each collection chamber on each sample date using methods described by Parkin et al. (2003). To determine the impact of differing land use type on net radiative forcing from playa greenhouse gas emissions, the researchers standardized N_2O and CH_4 emissions into CO_2 equivalents using the Global Warming Potential (GWP) metric over a 100-year time horizon ($\text{N}_2\text{O}=296$, $\text{CH}_4=23$; IPCC 2001). CO_2 equivalents indicate the mass of carbon dioxide that the soil carbon pool would generate if completely converted to CO_2 .

Soil organic carbon and total nitrogen levels were measured in 60 playas (20 reference, 20 cropland, and 20 restored) and adjacent watersheds in the RWB to assess changes in C and N pools as well as elucidate C sequestration services among land use types. Soil at three depth intervals (0-5 cm, 5-25 cm, 25-50 cm) were collected from four landscape positions (1. wetland center, 2. half the distance between wetland edge and center, 3. wetland edge, and 4. upland) following a transect outward from the center of the wetland. Wetland zones were delineated based on changes in hydrophytic to upland vegetation. Bulk density was determined for all study playas and watersheds at each depth interval. Each soil core was oven dried at 105°C until dry and then weighed.

Following methods described by O'Connell (2012) organic C (%) was converted to soil organic carbon (SOC) (kg m^{-2}) using bulk density (d_b) measurements and depth intervals with the formula: $\text{SOC} = [(\%C \times d_b \times l_1) + (\%C \times d_b \times l_2) + \dots (\%C \times d_b \times l_n)] / 10$, where l_n is the depth of each sampled layer in centimeters. Dividing by 10 is needed to convert from g cm^{-3} to kg m^{-2} (Lal et al. 2001).

Study Area

Playas and uplands were sampled from the western High Plains (WHP) and Rainwater Basin (RWB) regions of Nebraska (LaGrange 2005). Playas in the WHP occupy all or part of 13 counties in the southwest corner of Nebraska, south of the Platte River (LaGrange 2005). The 13 counties coincide with the short-grass prairie ecoregion which receives low annual rainfall of 40–45 cm yr⁻¹ and high annual evapotranspiration of about 165 cm yr⁻¹ (Smith 2003). The region is characterized by nearly flat loess soils with the predominant hydric soil being Lodgepole (fine, smectitic, mesic Vertic Argiaquolls) series (USDA 2012). On average, playas in this region are less than 4 ha in size (Daniel et al. 2014). Producers typically grow wheat, corn, and soybeans on cropland in this region (USDA 2012), and playas in the region often dry up early in the year and are planted on (LaGrange 2005). The most common conservation program implemented in this region is the CRP, affecting more than 131,000 ha (USDA 2012).

The RWB is characterized by gently rolling loess plains historically dom-

inated by mixed-grass and tall-grass prairie (Stutheit et al. 2004). Annual precipitation in the RWB is greater than in the southwest playas and is, on average, 69 cm yr⁻¹. Hydric soils consist of Fillmore, Scott, and Massie series (fine, smectitic, mesic Vertic Argialbolls) that differ in their properties based upon their length of inundation, and in many cases all three soils may exist within a single playa basin (USDA 1981). Playas in this region range from 0.1 to 1,000 ha in size and from 1 to 5 m in depth (Kuzila 1984) so they have the potential to store large quantities of surface water; however, most of the smaller wetlands have been filled in with sediments (Tiner 1984, Gersib 1991, Smith 2003). Estimates of historic wetland numbers in the RWB suggest that approximately 4,000 wetlands covering 38,000 ha originally existed, but erosion due to agricultural practices in the region has filled in many of these playas so that by 1983 only 10% of the wetlands and 22% of the wetland area remained (Gersib 1991). As an area identified by the U.S Fish and Wildlife Service as one of nine areas of critical concern for wetland loss, the RWB relies on conservation programs of critical

importance and specifically designed for wetland restoration. Over 2,600 ha of playa wetlands in this region have been restored by WRP easements (N. Walker, pers. comm. 2015).

Results/Discussion

Rainwater Basin playas and uplands
In the RWB, all playas restored through WRP were managed to maintain vegetation at early successional stages. Vegetation management in WRP playas resulted in lower above-ground biomass and a higher plant species richness, which likely helps explain why net CO₂-equiv emissions were 35% lower in WRP playas than in cropland playas (Figure 1). Indeed, increased deposits of upland soils and higher nutrient loads from upland runoff associated with cultivated watersheds, encourage establishment of productive, monotypic stands of vegetation that outcompete many native wetland plant species (LaGrange et al. 2011). Inherently fast growing plants such as *Typha angustifolia* (narrowleaf cattail) and *Scirpus fluviatilis* (river bulrush) flourish under higher nutrient concentrations and produce a substantial amount of root exudates. The high growth rate and the root exudates

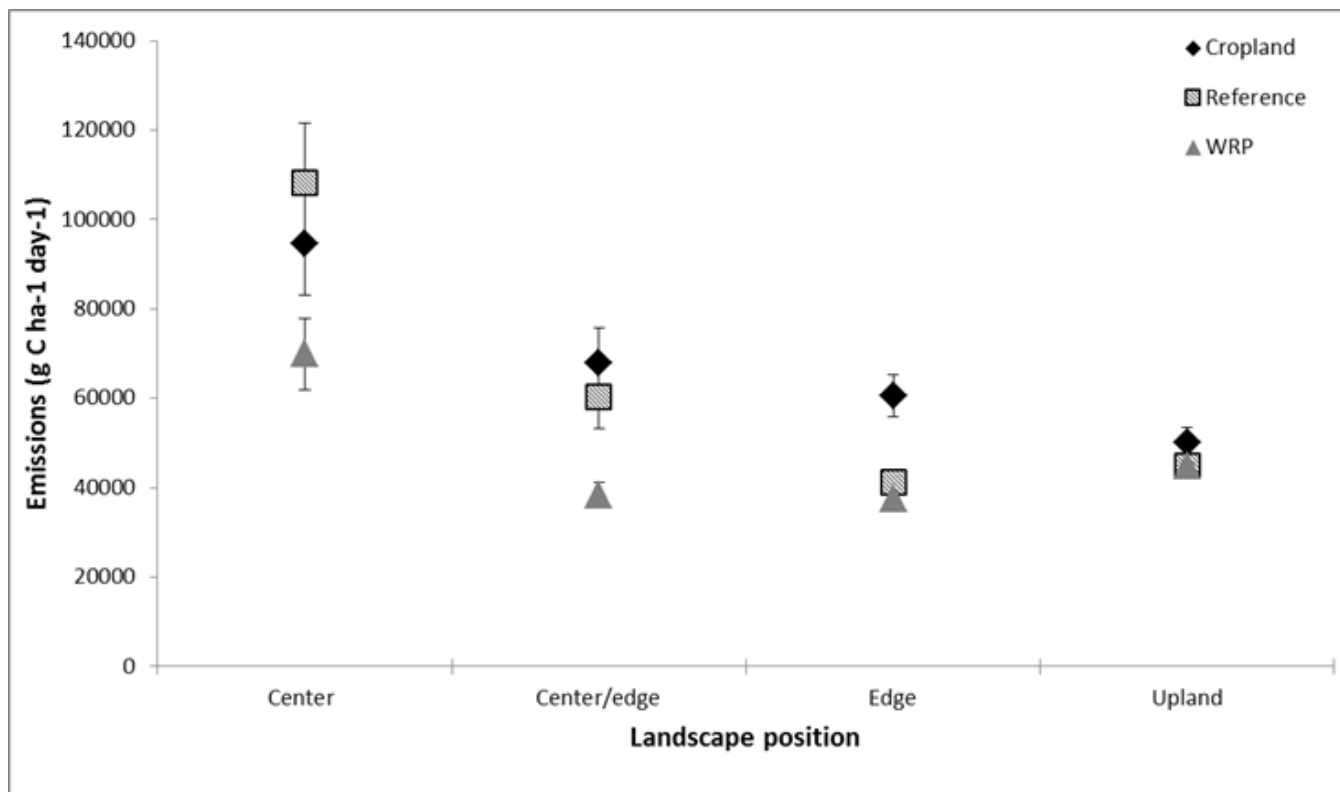


Figure 1. Mean (\pm SE) net CO₂-equiv emissions (g C ha⁻¹ day⁻¹) for playas and uplands in the RWB region of Nebraska.

can make an important contribution to soil C input (Bardgett et al. 2005) and consequently higher CO₂ output. Furthermore, vegetation may also have a direct influence on CH₄ transport (Whiting and Chanton 2001, Shannon et al. 1996, Joabsson et al. 1999) or indirect effects on evapotranspiration rates.

When sediment is removed from playa basins, accumulated nutrients and plant material are also removed from surface soils, resulting in organic C and total N in the top 5 cm being 29% lower in restored playas compared to reference and cropland playas. However, on an area basis, restored playas have more C in deeper horizons than either reference or cropland playas. The greater C level is likely due to sampling proximity to the Bt layer. Soils with high clay content generally have higher soil organic carbon (SOC) content, and C adsorption to clay particles is a crucial factor in SOC stability (Ingram and Fernandes 2001). Cropland and reference playas generally have higher sediment depths overlying Bt layers compared to playas restored through WRP, because sediment is usually removed from WRP playas during restoration (Daniel et al. 2015).

To a depth of 50 cm, restored playas contained levels of C (per unit area) similar to those of reference and cropland playas, indicating that the ecosystem service delivery capabilities gained from sediment removal may not need to be weighed against losses in C sequestration services (Figure 2). Furthermore, playa restoration through WRP (which can include sediment removal) changes the plant community composition, which likely contributes to reduced greenhouse gas emissions. Beas et al. (2013) found patterns of plant species composition in playas restored by sediment removal that were similar to those in the WRP playas sampled for the GHG study. By making sediment removal practices a priority in the RWB, the suite of playa ecosystem services can be increased, including water storage, biodiversity, and contaminant and climate mitigation (Smith 2003, Smith et al. 2011, Belden et al. 2012, Beas et al. 2013, Beas and Smith 2014, Daniel et al. 2015).

Adjacent watershed GHG emissions were similar among land use types and were only half the levels of net GHG emissions from playas. Although GHG emissions did not differ among land use types, restored and reference watersheds sequestered 34% more SOC than cultivated croplands (Figure 2). To maximize climate mitigation services from playa restoration projects, policymakers and conservationists should focus on protecting wetlands as well as surrounding watersheds. Paired with sediment removal hydrologic restorations within basins, playa watershed restoration can increase upland C storage and protect future wetland C sequestration capabilities from degradation by preventing volume loss due to watershed soil erosion.

Western High Plains playas and uplands

When playas become inundated after spring and summer rain events, they can quickly begin to emit GHGs. There were no differences in GHG emissions among land use types in 2012 likely because an extreme drought at the time limited microbial respiration. In 2013, rainfall totals were similar to historic averages, and cropland and grassland playas emitted 75% and 39% more CO_{2-equiv}, respectively, than playas in CRP (Figure 3). The dense, exotic vegetation associated with CRP decreases water runoff to CRP playas so they are inundated less frequently than playas in other land uses (Cariveau et al. 2011, O'Connell 2012) and therefore were smaller contributors to CH₄ and N₂O emissions in 2013. There were no differences in GHG emissions among land use types in the adjacent uplands (Figure 4).

Because CRP playas are inundated less often than native grassland and cropland playas, they are also smaller contributors to net CO_{2-equiv} emissions into the atmosphere. Furthermore, CRP enrollment increases C sequestration services in playas and watersheds (O'Connell 2012). Therefore, overall, CRP establishment on WHP playas and watersheds increases their climate mitigation services by reducing GHG emissions and increasing C storage.

Regional comparisons

Our study adds to a growing body of literature about land use change and

management influences on C and N influxes and effluxes from wetlands. Specifically, our study complements previous investigations on greenhouse gas emissions and carbon sequestration from cropland and restored wetlands in the Prairie Pothole Region, PPR (Euliss et al. 2006, Gleason et al. 2009). Making comparisons between the studies provides important insight into drivers of regional differences in C and N dynamics. Within the Wetland Continuum Concept, ecological processes including those associated with C and N cycling, are driven by hydrogeomorphology and climate (Euliss et al. 2004). Because the wetlands evaluated in Gleason et al. (2009) are likely similar to playas in basin morphology and water budget, differences in greenhouse gas emissions among regions may be primarily due to climate. Emissions of CO₂, CH₄, and N₂O were higher, on average, in RWB playas compared to PPR wetlands. It is likely that higher daily soil temperatures and extended growing seasons contributed to net emissions in the RWB playas, which were 34% higher than those in PPR wetlands. However, wetlands in lower latitudes, such as in the SHP, also have higher evapotranspiration rates and typically receive less annual rainfall, so warmer soils in these areas may not produce higher greenhouse gas emissions because they are often fairly dry. Indeed, emissions from WHP playas were about 33% and 50% lower than PPR and RWB wetlands, respectively. Other localized factors including soils, floral/faunal composition, and management practices could also have contributed to regional differences in emissions.

Carbon sequestration in the top 50 cm of playa soils in the RWB is similar to the amounts stored in the first 30 cm of PPR wetlands (Euliss et al. 2006). However, Euliss et al. (2006) did not limit their study to seasonal wetlands, and therefore it is likely that the study design included wetlands with longer hydroperiods and more complex hydrology than those of playas (Euliss et al. 2014). Indeed, the net C storage capacity of wetlands is, in part, due to lower rates of organic matter decomposition under anaerobic flooded conditions (Reddy and Delaune 2008). In addition to storing more C, semi-per-

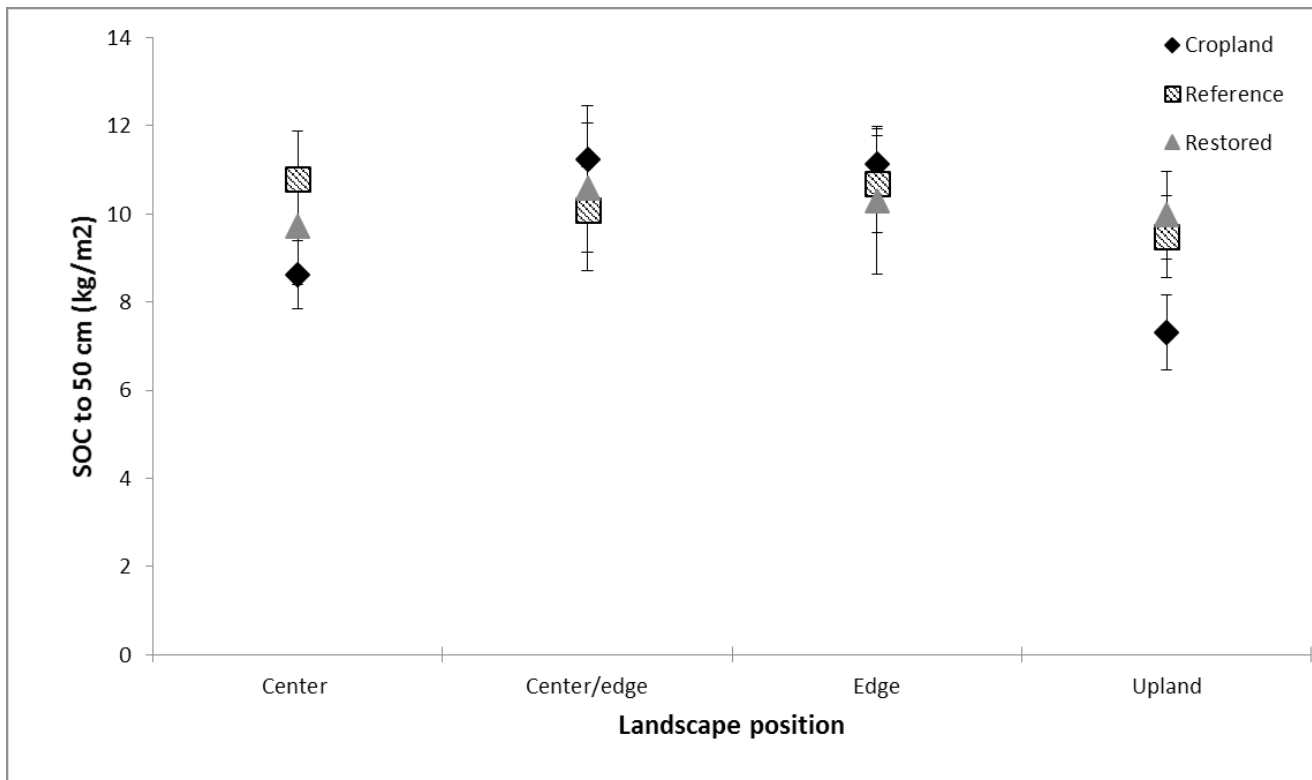


Figure 2. Mean (\pm SE) areal SOC (kg m^{-2}) to a depth of 50 cm in playas and uplands in the RWB of Nebraska.

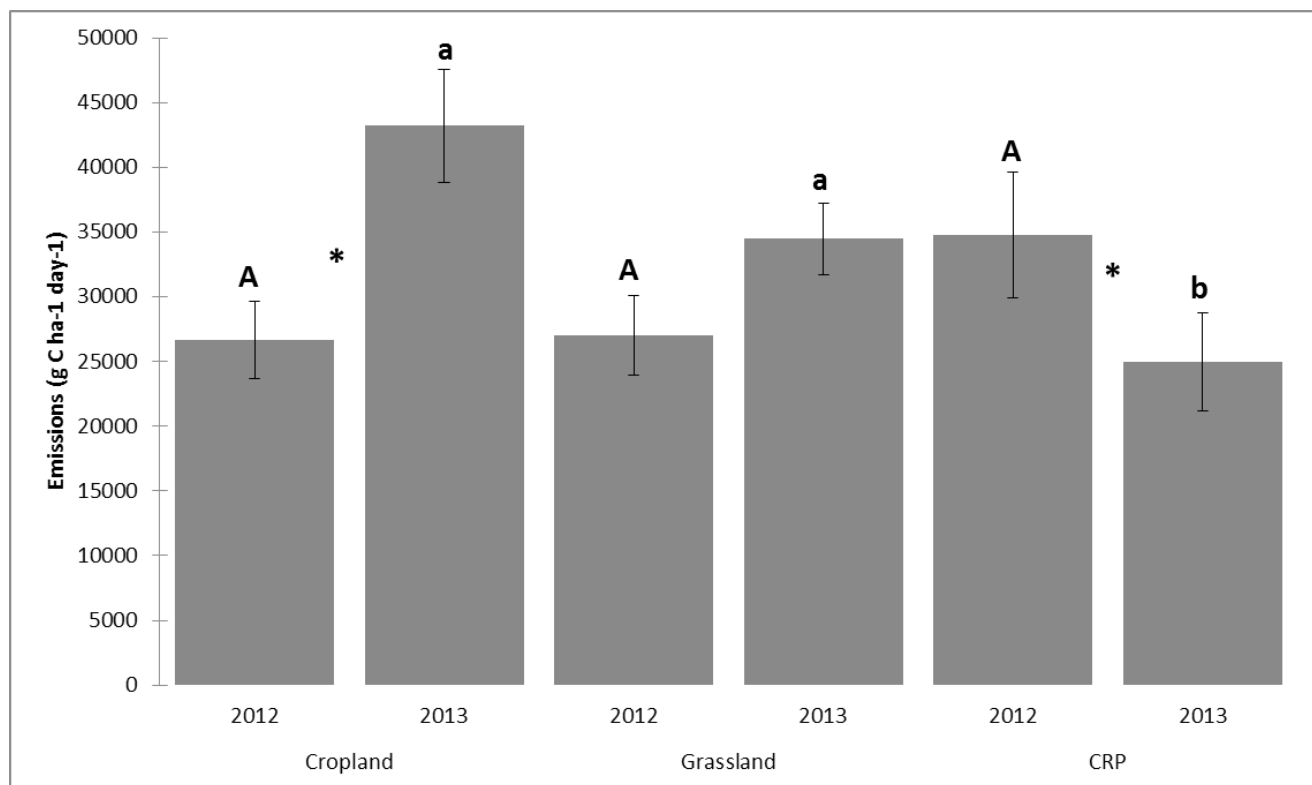


Figure 3. Mean (\pm SE) net CO₂-equiv emissions ($\text{g C ha}^{-1} \text{ day}^{-1}$) in 2012 and 2013 for playas in the WHP region of Nebraska. Capital letters represent differences among land use types for 2012 and lowercase letters designate differences among land use types for 2013. Asterisks denote differences between years within a land use.

manent wetlands in the PPR receive groundwater discharge and have higher concentrations of SO_4^{2-} (Euliss et al. 2014), which may hinder CH_4 production from those wetlands.

Conclusions

When considering potential climate mitigation services, and indeed most other ecosystem services, provided by playa conservation/restoration, it is important that the focus is on returning historic hydrological functioning. Debate within the wetland conservation science community has arisen concerning whether restoring wetlands for C offset projects may shift focus away from other important wetland services (Emmett-Mattox et al. 2010). Indeed, not all wetland restorations make viable ecological offset projects for industries seeking to reduce their C emissions, and those that do may not always occur in areas where wetland restoration funding is needed the most.

The RWB region of Nebraska is listed as one of nine areas of critical concern for wetland loss in the U.S. About 90% of historic playas have already been lost (Gersib 1991) and remaining playas represent a fraction of their historic extent (Daniel et al. 2015). Because proper hydrologic restoration may return historic wetland functioning and increase playa services, including climate mitigation, playa restoration in the RWB may be an attractive option for mitigating anthropogenic greenhouse gas emissions.

In the WHP and SHP, playas conserved in the CRP provide climate mitigation services but fail to function as they did historically. Climate mitigation services contributed by playas in CRP should be appropriately weighed against the loss of services related to less frequent flooding. Using native species rather than exotics in CRP plantings will provide additional ecosystem services such as biodiversity and aquifer recharge to be measured as this will help restore hydrological function.

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Conservation Effects Assessment Project: Translating Science into Practice

The Conservation Effects Assessment Project (CEAP) is a multiagency effort to build the science base for conservation. Project findings will help to guide USDA conservation policy and program development and help farmers and ranchers make informed conservation choices.

One of CEAP's objectives is to quantify the environmental benefits of conservation practices for reporting at the national and regional levels. Because wetlands are affected by conservation actions taken on a variety of landscapes, the Wetlands National Component complements the national assessments for cropland, wildlife, and grazing lands. The wetlands national assessment works through numerous partnerships to support relevant assessments and focuses on regional scientific priorities.

This project was conducted through collaboration among researchers with the Nebraska Games and Parks Commission (NGPC), U.S. Geological Survey (USGS), and Oklahoma State University. Primary investigators on this project were Loren M. Smith, Scott T. McMurry, and Dale W. Daniel (Oklahoma State University), Ted LaGrange and Randy Stutheit (NGPC), and Brian A. Tangen and Charles F. Dahl (USGS). This Science Note was written by Drs. Dale W. Daniel, Loren M. Smith, and Scott T. McMurry, Oklahoma State University. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by USDA.

For more information, see <http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap>, or contact Bill Effland (william.effland@wdc.usda.gov) or Mari-Vaughn Johnson (mjohnson@brc.tamus.edu).

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