BIODIVERSITY IN PLAYA WETLANDS IN RELATION TO WATERSHED DISTURBANCE

by

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Abstract

Playa wetlands are unique ecological systems crucial to the ecology of the western Great Plains of North America. Playas offer a variety of ecological goods and services: flood water retention; water quality improvement; habitat for a distinctive assemblage of resident and migratory biota; and primary recharge points for the Ogallala Aquifer. The major threat to the function of playas is caused by watershed disturbance and habitat loss, primarily through sediment accumulation that decreases playa hydroperiod, density, and size. Previous research focused on playas in the Southern High Plains in Texas and the Rainwater Basin of Nebraska, with little playa studies located in the Central Great Plains. My objectives were to (1) identify the number and level of functionality of existing playas in the Smoky Hill River watershed, (2) determine the relative contribution of playas to the biodiversity of the landscape and influences from watershed disturbance levels, and (3) assess relationships among avian community composition and environmental variables through a canonical correlation analysis (CCA). To assess playa functionality, I randomly selected 20% of the 3,310 historical playas in the watershed and confirmed playa presence and anthropogenic modifications through imagery analysis ($n = 608$). To achieve the last two objectives, I conducted breeding bird surveys using point counts in >25 playas with paired, nonplaya sites. I recorded avian relative abundance and species richness. Plant species occurrence was detected using step-point methods along transects. Species diversity was derived using Simpson's index. Approximately 22% of playas have been lost from the landscape. Of the remaining playas, only 3.15% were not affected by anthropogenic influences. Playas contribute greater than 40% and 16% greater avian species richness and diversity to the surrounding landscape, respectively. Playas located in grassland watersheds had a 63% and 35% greater avian species richness and diversity, as well as 57% and 66% greater floral species richness and diversity than playas located in croplands, respectively. CCA results identify playa soil moisture and watershed disturbance as significant influences to the playa avian community. It is important to reduce watershed disturbance and anthropogenic influence on playas to maintain biodiversity at local, regional, and continental scales.

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Dedication

This work is dedicated to Oscar David Jimenez Avila, a kind soul who passed away unexpectedly. I will always carry your adventurous heart with me.

"i carry your heart with me(i carry it in
my heart)i am never without it(anywhere
i go you go,my dear;and whatever is done
by only me is your doing,my darling)"

- ee cummings

Chapter 1 - Introduction

Since early European settlement, the United States has lost greater than half of the original wetland area (Dahl 2006). Playa wetlands (hereafter referred to as playas) are unique and complex ecological systems crucial to the ecology of the western Great Plains of North America. Playas offer a variety of ecological goods and services including flood water retention, water quality improvement, aquifer recharge, and provide critical habitat for a unique assemblage of resident and migratory biota (Smith et al. 2012). The declining number and function of playas in this semi-arid region could create major negative implications for biodiversity at local and global scales. The hydrology of a playa wetland, which is influenced by climate and landscape variables, drives the biotic community of the playa (Smith 2003).

The major threats to biodiversity of a playa wetland are caused by watershed disturbance (e.g., cultivation and playa modification) and habitat loss (Bolen et al. 1989, Webb et al. 2010, Tsai et al. 2012). Great Plains playas occur in one of the most agriculturally impacted landscapes of the Western Hemisphere (Johnson et al. 2012). Because a diverse species assemblage depends upon playas at various stages of their life-cycles, measuring biodiversity is an accurate way to assess the functionality of the playa wetland ecosystem (Johnson 2011). In an effort to maintain and evaluate the level of biodiversity that playas support in an agriculturally intense landscape, it is critically important to understand how watershed disturbance and environmental variation influence the biotic community composition and occupancy found in playas across landscapes.

My research is a component of a larger National Science Foundation project that aims to develop a human-landscape interaction model to predict the potential effects of land use, water use, and climate variation on the water supply and quality of the Smoky Hill River watershed in western Kansas, USA. In addition to being the predominant surface water feature, playas in the semi-arid High Plains region are critical freshwater sources for the Great Plains by serving as the primary recharge points for the underlying Ogallala aquifer (Bolen et al. 1989). Due to the lack of peer-reviewed scientific literature on playa wetlands in central High Plains, including the Smoky Hill River watershed of Kansas, this project will fill an information gap in literature as well as contribute to the larger research effort by providing information on the function of the playa wetlands in relation to surrounding land use and environmental variation using biodiversity as an index of the functional state of playas. The specific objectives of my project were to (1) identify the classification type, occurrence, size, and associated ecological state of the wetlands in the Smoky Hill watershed, (2) test for relationships among land use and playa hydrology through the biotic variables of the playa system, and (3) develop a framework to predict the effects of environmental variation on playa hydrology and associated biodiversity.

BACKGROUND AND LITERATURE REVIEW

Importance of Fresh Water Resources

Water is essential to life. The abundance and quality of water influences ecosystems as well as human activities and economics. Although the majority of the Earth's surface is water, only 1% is potable (Mansdorf 2010). Freshwater resources are challenged daily by increasingly unsustainable land use and water practices (Malmqvist and Rundle 2002). Agriculture is the top-ranked global activity consuming water, accounting for 75% of the total global consumption according to an Overview of the State of the World's Fresh and Marine Waters Report developed by the United Nations Environmental Programme (UNEP 2008). The quantity and quality of freshwater resources is declining due to loss and degradation of aquatic ecosystems, deforestation, urbanization, and agricultural chemical contamination (Gleick 1998, Malmqvist and Rundle 2002). While current natural and anthropogenic factors degrade freshwater ecosystems of the world, water availability will only decrease as demand grows and through predicted variation in future climate (Malmqvist and Rundle 2002).

The Great Plains region is no exception to the decline of freshwater resources. One of the most valuable freshwater sources in the region, playas and other wetlands have experienced an estimated 50-60% loss in Kansas since the 1780s (Kansas Water Office 2014). Continued decline in the quantity and quality of playas in the Great Plains will cause further declines in groundwater and surface water levels (Kansas Water Office 2014). In this region, playa wetlands are critically important as they are the primary source for aquifer recharge in the High Plains (Smith et al. 2011) and sites of ecological diversity in an intensely cultivated land (Bolen et al. 1989).

In arid and semi-arid regions, where land use is predominately agriculture and many soils are categorized as highly erodible, freshwater is an important resource for conservation actions. The High Plains occupy the western part of the Great Plains from roughly the 100th Meridian westward to the foothills of the Rocky Mountains. There are three subregions in the High Plains based on location (e.g., northern, central, and southern). Within the High Plains, playa watersheds are roughly categorized as three main watershed types (e.g., cropland, Conservation Reserve Program, and native grass) with land use having a strong relationship to the degree of watershed disturbance (Daniel et al. 2014). The Ogallala aquifer lies below much of the High Plains with the U.S. Geological Survey reporting that the Ogallala aquifer supplies water to 82% of the High Plains population (Dennehy 2000).

The western half of Kansas, including the Smoky Hill River watershed, depends largely on groundwater, compared to the eastern half of Kansas that depends largely on surface water

(Kansas Water Office 2014). The primary use of water in the Smoky Hill River watershed is for irrigation followed by municipal water use (Kansas Water Office 2009). An annual groundwater level monitoring program indicates that water level in the aquifer is being withdrawn at a faster rate than the recharge rate in many areas (Steward et al. 2013). Irrigation is the primary use of ground water, accounting for 94% of the water being used to grow crops in the High Plains (Kansas Water Office 2014). Since the beginning of irrigation in the High Plains, levels of saturated thickness have declined >33 m in many areas of the aquifer in Kansas (Kansas Water Office 2014). Kansas irrigation practices withdraw groundwater at a rate of 0.66 to 1.33 m per year, with a greater amount in some areas, whereas the Ogallala aquifer recharges, on average, only at a rate of 1.27 cm per year (Kansas Water Office 2014).

Playa Wetlands Offer a Freshwater Source to the Semi-arid Region

A playa is a unique type of wetland often incorrectly compared directly to other types of wetlands. Playas offer services such as surface drainage, contaminant filtration, floodwater storage, aquifer recharge, irrigation water for crops, and support for much of the High Plains biodiversity (Haukos and Smith 1994, Luo et al 1997, Smith et al. 2011). Playas are characteristically depressional and shallow, usually no greater than 1.5 m at the deepest point in the hydric-soil defined basin (Smith 2003). Playas are hydrologically isolated from other playas and water sources (Smith et al. 2012). The unique circular shape results from the geological formation process and persistence of the depression. Accumulation of water and organic matter in prairie depressions caused oxidation of organic matter over time, releasing carbon dioxide, which reacted with the water, forming carbonic acid that initiated the playa formation process. Carbonic acid readily causes the dissolution of the calcium carbonate deposit underlying the shallow topsoil. Caliche dissolution, or the calcium carbonate deposit dissolution, allows the land to subside, causing distinct playa edges and floors (Smith 2003). The persistence of playas results from wind deflation during dry periods (Osterkamp and Wood 1987, Haukos and Smith 2003). Playa basins develop in the surface depression of the watershed that collect and store runoff creating hydric soils through wetting and drying fluctuations over long periods of time (e.g., heavy vertisol clay; Osterkamp and Wood 1987, Luo et al. 1997, Smith 2003). Although aquifer recharge will occur via percolation through cracks in dry playa soils upon inundation by precipitation runoff prior to swelling and sealing of the playa floor, the primary aquifer recharge points occur around the dissolved caliche at edge of playas (Osterkamp and Wood 1987, Smith 2003).

Playa Hydrology

Hydrology is the primary driver influencing the function of playas and other wetlands (Euliss et al. 2008). Hydrology can affect habitat availability for wetland-dependent species, avian occurrence, water quantity and quality, and flood retention (Smith 2003). Abiotic factors are controlled by the hydrological processes with influences on soil anaerobiosis, organic matter accumulation, and nutrient availability (Osterkamp and Wood 1987, Luo et al. 1997). Variation within abiotic factors can also influence other biotic factors such as primary productivity, nutrient cycling, and species composition and richness. When wetland hydrology includes a pulsed hydroperiod with high water flows through the system, it allows for a high productivity in wetlands (Mitsch and Gosselink 2007). A slight change in the wetland hydrological conditions could result in altered species composition and alter the ecosystem productivity (Mitsch and Gosselink 2007).

Playa wetlands have a simple hydrological budget for the entrance and exit of water in its ecosystem. However, unlike most wetlands where inundation is the stable ecological state and drying during drought is a disturbance, the stable ecological state for playas is dry and inundation represents the primary disturbance (Albanese and Haukos 2016). Playas in the High Plains only receive water through direct precipitation and water runoff from the surrounding watershed (Smith et al. 2012). Playas will only lose water through aquifer recharge and evapotranspiration (Haukos and Smith 2003, Smith et al 2012). The hydrological system of playas creates a dynamic and changing availability of environmental states across the landscape (Albanese and Haukos 2016). The hydroperiod, known as the duration and timing of inundation of the playa, is unpredictable on spatial and temporal time scales (Haukos and Smith 2003). The hydroperiod is the key component of the hydrology of a wetland and drives the function of the ecosystem (Smith 2003). The hydroperiod is influenced through precipitation, evapotranspiration, surface flows, and groundwater fluxes. Playas can remain inundated for a few days to greater than a year, but may go years between inundation events (Bolen et al. 1989, Johnson et al. 2011). The hydroperiod influences the biota; however, native biota have adapted to the variable, unpredictable hydroperiods. Unmodified playas are typically inundated in late spring through fall depending upon frequency and intensity of precipitation events (Bolen et al. 1989). However, individual modified playas rarely stay inundated longer than a few months following a precipitation period without additional water inputs after the initial event. The hydroperiod of a wetland is critically important in relation to the recharge service as playas are the primary source of recharge for the Ogallala Aquifer in the Central and Southern High Plains. Not only does the hydroperiod affect infiltration of water through soil, biota must also be adapted to the variable and fluctuating hydroperiods, which also drive critical processes such as nutrient cycling and decomposition, resulting an overall energy flow.

Effects of Sediment Accumulation on Playa Wetlands

The main factors affecting the biotic community and function of the playa result from influences of watershed land use, specifically erosion and sediment accumulation from soils of the surrounding landscape (Smith 2003). The flow of sediment in run-off to the playa results from cultivation disturbances due to practices such as plowing and tilling of land, especially for highly erodible soils (Luo et al. 1999, Johnson et al. 2012, O'Connell 2013). Sediment accumulation in playas negatively affects the occurrence and function of playas as only a minor portion of sediment is naturally removed through wind action (Smith 2003). Sediment accumulation and organic matter in a wetland alters water flows and can affect the hydroperiod by decreasing the duration and frequency of the inundation of the wetland (Tsai et al. 2007). As sediment depth increases in a playa, water-holding volume will decline and cracks in the hydric clay layer will fill, disturbing the initial flow of precipitation to the aquifer and reduce the permeability of the soil (Bolen et al. 1989). The hydric-clay soil volume of depressional wetlands can fill from sediment in run-off during high precipitation events and through intentional "draining" and "filling" of the wetland from private land owners (Haukos and Smith 2003). While the rate of intentional filling of playas has declined in recent years (NRCS 2005), high sediment accumulation results from runoff of surrounding cropland, accounting for the majority of playa loss (Luo et al. 1997, Johnson 2011, Johnson et al. 2012, O'Connell et al. 2013, Daniel et al. 2014). Lack of legal protection accelerates loss of playas from the landscape as landowners can legally fill and use playas to grow commodity crops during the natural dry states of a playa or during drought (Haukos and Smith 2003, Johnson et al. 2012).

The structure and hydrology of a playa varies depending if it is located in a grassland, Conservation Reserve Program (CRP), or an agricultural landscape (Luo et al. 1997, Johnson et al. 2012, Daniel et al. 2014). Playas within cropland watersheds are at greater risk of losing their original basin volume by having a greater amount of sediment than playas with other watershed types (Luo et al. 1997, Smith et al. 2012, O'Connell et al. 2013). To protect highly erodible soil, the CRP gives landowners a yearly rental payment to remove their land from agricultural production and plant perennial grasses (Farm Service Agency, CRP 2014). Playas located in a CRP watershed have a lower sediment depth and volume loss than playas located in a cropland (Daniel et al. 2014). While playas located in CRP watersheds have a lower rate of sediment accumulation than when previously in cropland, the sediment yield from erosion of prior cultivated land remains in the playa. Playas in a grassland watershed have lower sediment depth and volume loss than CRP or cropland playas (O'Connell et al. 2013, Daniel et al. 2014). Potential water storage is also negatively affected by the accumulation of sediment resulting in increased flooding of surrounding areas such as croplands and roads (Luo et al. 1997, Smith et al. 2012). Playa hydroperiod is reduced by sediment accumulation, jeopardizing persistence of species that have evolved under historical hydroperiods (Smith 2003, Tsai et al. 2007).

Threats to Playas in a Grassland Watershed

Unmanaged grazing that typically occurs in native grassland watershed can affect the hydrology of a wetland. Unmanaged grazing reduces plant cover that may act as a buffer between cropland and playas as well as reduced vegetative cover that functions as wildlife habitat (Bolen et al. 1989). The greater soil erosion from watersheds due to unmanaged grazing will decrease perennial vegetation surrounding the wetland, which allows for more opportunities of sediment accumulation in the wetland and the runoff entering the playa is usually high in nutrients (Luo et al 1997, Smith 2003, Haukos et al. 2016). If there is a high amount of continuous discharge from the feedlots or pollution for urban areas into the wetland, the ecosystem supports limited aquatic vegetation (Bolen et al 1989, Haukos and Smith 2003). This altered hydroperiod affects the biotic community by changing the species composition and abundance (Smith 2003, Webb et al. 2010).

Other Threats to the Quantity and Quality of Playas

Urban areas have historically filled and drained playas to remove playas from the land for urban development (Haukos and Smith 2003, Smith 2003). Draining, however, is a difficult task in the Great Plains as playas do not have a direct drainage outlet. Filling is another option to remove the playa from the landscape by actively filling the playa with soil and other materials through intentional actions (Smith 2003).

Playa wetlands, typically located in a watershed containing erodible soil, are susceptible to contamination of metals, nutrients, and dissolved/suspended sediments during precipitation events from the surrounding watershed (Haukos et al. 2016). Chemical threats to playas include contamination from urban storm water runoff, pesticides, insecticides, herbicides, human wastewater, and fertilizers from surrounding land (Haukos and Smith 2003). Contamination of playas from chemical threats negatively affects migrating waterfowl causing death, decreases native flora and fauna, reductions in algae production, decreases water quality, and contaminates groundwater (Smith and Haukos 2002, Smith 2003, Venne 2006, Tsai et al. 2012, O'Connell et al. 2013). Anthropogenic alterations include physical modification of playa wetlands in practices such as concentration of water through excavated pits, diversion of runoff water, and road construction within the watershed and wetland (Haukos and Smith 2003, Smith et al. 2011).

Federal protection of playa wetlands in the Great Plains is currently nonexistent. Previously, federal protection for the majority of playas and isolated wetlands was covered under Section 404 of the Clean Water Act, prohibiting the dredging or filling of material into waters of the United States without issued permits (Haukos and Smith 2003, U.S. Environmental Protection Agency 2015). In 1986, the “Migratory Bird Rule” labeled waters that are used as habitat by migratory birds, including playas, in Section 404 of the Clean Water Act as a “water of the United States” and subject to regulations in Section 404 of the Clean Water Act (Haukos and Smith 2003, Johnson 2011). However, legal protection of playas and other geographically isolated wetlands was lost in 2001 when the Supreme Court declared that the use of wetlands by migratory birds do not constitute the land as a “water of the United States” in the *Solid Waste Agency of Northern Cook County (SWANCC) v. United States Army Corps of Engineers* case; thereby, eliminating legal protection for the majority of isolated wetlands (Haukos and Smith 2003, Johnson 2011). In an effort to provide protection for wetlands not subject to the Clean Water Act, the Highly Erodible Land Conservation and Wetland Conservation Compliance established provisions (Swampbuster) to the 1985 Farm Bill, with amendments in 1990, 1996, and 2002 (NRCS 2005). Swampbuster, an incentive program, reduced the amount of subsidies to landowners who alter the hydrology of a jurisdictional wetland to grow a commodity crop (NRCS 2005). However, this provision offers little protection as many loopholes exist for a landowner to cultivate the playa after a loss (e.g., burial) of hydric soils or during the natural dry periods of playas (Haukos and Smith 2003, Johnson 2011).

Furthermore, the current estimate of playa wetlands can be considered a threat to the future quantity and quality of wetlands. Anthropogenic changes to the land alter the function and presence of playa wetlands and current estimates of the number of playas does not take the recent loss of playas into account, giving a false representation of the correct number of functional and existing playa wetlands (Johnson et al. 2012). Landscape changes threaten the function and existence of playas, primarily through unsustainable sediment accumulation in playas, which decreases the function, size, and hydroperiod of individual playas (Luo et al. 1997, 1999; Johnson et al. 2012). In the Southern High Plains, a mere 0.2% of playas were not impacted by landscape changes (Johnson et al. 2012) Conservation plans and agencies depend on the current and historical estimates of playas and incorrect estimates will draw attention away from playas that need protection (Smith 2003). The current estimate of the loss of playas is conservative. Landscape changes have not been considered in the current estimates of playas due to low resolution (Bowen et al. 2010). Actively tilled playas are frequently not considered lost to the landscape; however, cultivation of a playa alters the hydric soil layer and other structural aspects resulting in functional loss of the playa (Johnson et al. 2012, O'Connell et al. 2013). To obtain an accurate estimate of playa loss, the current estimate of playa wetlands needs to be updated from prior estimates throughout the High Plains.

Flora and Avian Fauna in Playas

Playas have a unique assemblage of biotic communities adapted to the dynamic environment. The biotic community composition is influenced by the hydroperiod and responds to the altering dry and wet periods (Smith 2003). The playa structure, function, and biotic community can easily change within days (Smith 2003). Even when a playa is not inundated, it provides resources and habitat for resident wildlife, grassland passerines, and other migratory avian species. The disturbance defined by the unique wet and dry period fluctuations of a playa is necessary for organisms that depend upon this ecosystem (Smith 2003, Smith et al. 2012).

The fact that wetlands have different communities when wet or dry increases the biodiversity of these unique systems (Smith 2003). The playa system provides critical stopover sites for migrant birds, with additional critical habitats for nesting and feeding for dozens of species of birds including waterfowl, shorebirds, and passerines (Smith et al. 2012). Species richness and diversity is one way to assess the functionality of a playa wetland (Johnson 2011). Greater species numbers are required to maintain a stable level of ecosystem goods and services (Hooper et al. 2005). Therefore, it is critically important to understand how landscape management and climate variation will affect the biodiversity of playas in this semi-arid region where water is a valuable resource.

Disturbances in the surrounding watershed (e.g., cultivation and high soil erosion) affect dispersal, presence of exotics, competition, and predation of the biota using playa systems (Smith 2003). Species richness of playa plants is considerably less in playas with deeper sediments and playas affected by plowing also reduces richness (O'Connell et al. 2013). A hydroperiod that is affected by watershed disturbance alters the playa community as seen by more exotic species and less perennial vegetation species than grassland playas (Smith and Haukos 2002). Playas located in disturbed watersheds yield a greater number of exotic plants than grassland playas (Johnson 2011). Plant communities in playa wetlands with greater sediment accumulation or playas affected by plowing will shift to annual species, experience decreased habitat connectivity, and attract a greater number of exotic species (O'Connell et al. 2013, Albanese and Haukos 2016). Bioinvasion of exotics is commonly seen in cropland playas that have a disturbed hydroperiod (Smith and Haukos 2002). Because bioinvasion and community change is one of the largest threats to ecosystem functioning (Hooper et al. 2005), a change in the biotic community could indicate that these critical habitats are not functioning properly and may be lost to the landscape (Smith 2003).

Effects of Climate Change on Playa Function and Biodiversity

Climate and weather are the principal influences on the wetland hydrology (Bolen et al. 1989, Smith 2003). The future composition of the biotic community of playas will change in association with changes in playa function and services in response to future predicted changes in the environment. The most recent Intergovernmental Panel on Climate Change report reported that 1983-2012 was the warmest 30-year period of the last 1400 years (IPCC 2014). The global temperature is expected to continue to rise by 1-2° C by 2100. The Great Plains is not exempt from a prediction of average daily temperature on the rise. In Kansas, the temperature is expected to warm in all seasons; thus, affecting the hydrology of a wetland through an increase in evapotranspiration (Bolen et al. 1989, Brunsell et al. 2010, Cook et al. 2015). Along with predicted changes in average daily temperature, patterns of precipitation are predicted to change. Precipitation patterns are expected to be in the form of heavy, intense rain periods followed by extended periods of drought (Brunsell et al. 2010, IPCC 2014, Renton et al. 2015).

Increasing temperatures, combined with a change in the frequency and intensity of rain events will cause negative consequences to the frequency and duration of playa inundation. Intense precipitation events increase the sediment yield and nutrient pollution in the watershed runoff reaching the depressional wetland, resulting in a change of duration and frequency of the hydroperiod (Luo et al. 1999, Mitsch and Gosselink 2007, Kansas Water Office 2009). Large precipitation events, such as floods, increase the risk of soil erosion, leading to greater sediment accumulation and nutrient pollution in depressional wetlands (Luo et al. 1999, Burris and Skagen 2013, Haukos et al. 2016). The effects of large precipitation events will be observed in the declined function of the playa wetland to hold water and flooded playas will dissipate the flooded water onto surrounding lands, causing disturbances to cropland, homes, communities, and roads (Brunsell et al. 2010, Renton et al. 2015).

Further, future predictions indicate that the expected increase in sediment accumulation will result with nearly all playas filled by sediment in 100 years (Burris and Skagen 2013).

Playas in a cropland watershed, accumulating greater than twice the amount of sediment accumulation rate than grassland playas, will experience the negative impacts of predicted climate changes at a greater and faster rate, causing playas to be lost from the landscape at a faster rate (Burris and Skagen 2013). It has been shown that the future playa wetland system will be almost completely abolished due to high sediment yield with land use affecting sedimentation rates more so than future climate predictions (Smith et al. 2011, Burris and Skagen 2013).

Numerous wetland-obligate species will be negatively affected by the future variation in hydrology as certain organisms (e.g., amphibians, invertebrates, and waterfowl) need specific hydroperiods to complete their lifestyle (Venne 2006, Renton et al. 2015). As playas fill with excess sediment, the proportion of exotic species will increase as hydroperiod and productivity decrease (Smith and Haukos 2002, Gleason et al. 2003, Tsai et al. 2007). Lower productivity will negatively affect the populations. Specifically, avian populations will experience a decrease in the quantity of available nutrients as excess sediment will suppress seedling and invertebrate emergences (Gleason et al. 2003) As there are many migrating birds that use playas as stop-over points, a change in the hydroperiod and community could influence biodiversity at a global scale.

While drought is a natural and common occurrence in Kansas, evidenced from the Dust Bowl and the "dirty thirties", the effects of drought may not be seen as quickly as a change in groundwater level (Kansas Water Office 2009). There is a large possibility of a delayed effect of animal populations having to either adapt or migrate to other land or face uncertainty in a change of habitat and water quality and quantity (Venne 2006, Cook et al. 2015). Community composition will change during the periods of greater sediment yield in the intense rain events, with more exotics and annuals able to adapt to the change (O'Connell et al. 2013). The increase in intense precipitation patterns will not outweigh the consequences resulting from the increased evapotranspiration rates from a rise in temperatures and evaporative demands.

Baseflow of many streams in the Smoky Hill River watershed, the volume of a stream that is recharged through groundwater, has experienced a decline in water level and flow rate as a consequence of the decline in groundwater levels that historically provided baseflow to these streams (Kansas Water Office 2014). As surface water and ground water are associated in a complex hydrologic system, ground water and surface water can influence each other in numerous ways. Therefore, as evapotranspiration is expected to increase, Kansas may see a positive feedback system where a decline in the groundwater continues to cause declines in base flow, which then continue to cause greater declines in the aquifer as increased usage of groundwater is needed for the agriculturally intensive land use of the region. Furthermore, as drought causes an increase in groundwater extraction, the predicted "megadrought" for the Central Plains will causes severe economic loss (Cook et al. 2015). In Kansas alone, the 2012 drought created over $3 billion in crop losses (Kansas Water Office 2014), illustrating the potential for a larger economic and monetary deficit in the near future.

OBJECTIVES AND HYPOTHESES

The main goal of my project was to identify the contributions to biodiversity that playas add to the Central Great Plains and how wetland biodiversity responds to changes in land use and cover. Specifically, my research objectives were to (1) identify the classification type, occurrence, surrounding land-use, impacts, and size of wetlands in the Smoky Hill watershed (Chapter II); (2) test relationships of land cover and wetland hydrology on biodiversity through the biotic variables of the playa (Chapter III); and (3) examine how surrounding land-use and inundation of soil influences the avian community (Chapter IV).

LITERATURE CITED

Albanese, G., and D.A. Haukos. 2016. A network model framework for prioritizing wetland conservation in the Great Plains. Landscape Ecology DOI 10.1007/s10980-016-0436-

Bolen, E. G., L. M. Smith, and H. L. Schramm Jr. 1989. Playa lakes: prairie wetlands of the southern High Plains. Bioscience 39:615-623.

Bowen, M. W., W. C. Johnson, S. L. Egbert, and S. T. Lopfenstein. 2010. A GIS-based approach to identify and map playa wetlands on the High Plains, Kansas, USA. Wetlands 30:675-684.

Burris, L., and S. K. Skagen. 2013. Modeling sediment accumulation in North American playa wetlands in response to climate change, 1940-2100. Climate Change 117:69-83.

Cook, B. I., T. R. Ault, and J. E. Smerdon. 2015. Unprecedented 21st Century drought risk in the American Southwest and Central Plains. Science Advances 1:e1400082.

Dahl, T. E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C.

Daniel, D.W., L. M. Smith, D. A. Haukos, L. A. Johnson, and S. T. McMurry. 2014. Land use and Conservation Reserve Program effects on the persistence of playa wetlands in the High Plains. Environmental Science and Technology 48:4282-4288.

Dennehy, K. F. 2000. High Plains regional ground-water Study. U.S. Geological Survey, 091-00, Washington, D.C.

Euliss, N. H. Jr, L. M. Smith, D. A. Wilcox, and B. A. Browne. 2008. Linking ecosystem processes with wetland management goals: charting a course for a sustainable future. Wetlands 28:553-562.

Farm Service Agency. 2014. Conservation Reserve Program. United States Department of Agriculture, http://www.nrcs.usda.gov/programs/crp.

Gleason, R. A., N. H. Euliss, D. E. Hubbard, and W. G. Duffy. 2003. Effects of sediment load on emergence of aquatic invertebrates and plants from wetland soil egg and seed banks. Wetlands 23:26-34.

Gleick, P. H. 1998. Water in crisis: paths to sustainable water use. Ecological Applications 8:571-579.

Haukos, D. A., L. A. Johnson, L. M. Smith, and S. T. McMurry. 2016. Effectiveness of vegetation buffers surrounding playa wetlands at contaminant and sediment amelioration. Journal of Environmental Management 181: 552-562.

Haukos, D. A. and L. M. Smith. 1994. The importance of playa wetlands to biodiversity of the Southern High Plains. Landscape and Urban Planning 28:83-98.

Haukos, D. A, and L. M. Smith. 2003. Past and future impacts of wetland regulations on playa ecology in the Southern Great Plains. Wetlands 23:577-589.

Hooper, D. U., F.S. Chapin, III, J. J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J. H. Lawton, D. M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setala, A. J. Symstad, J. Vandermeer, and D. A. Wardle. 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monographs 75:3-35.

Johnson, L. A. 2011. Occurrence, function, and conservation of playa wetlands: the key to biodiversity of the Southern Great Plains. Dissertation, Texas Tech University, Lubbock, USA.

Johnson, L. A., D. A. Haukos, L. M. Smith, and S. T. McMurry. 2012. Physical loss and modification of Southern Great Plains playas. Journal of Environmental Management 112:275-283.

Johnson, W.C., M.W. Bowen, and S.T. Klopfenstein. 2009. Kansas playa wetlands. Department of Geography, University of Kansas, Lawrence, Kansas, USA.

Johnson, W. P., M. B. Rice, D. A. Haukos, and P. P. Thorpe. 2011. Factors influencing the occurrence of inundated playa wetlands during winter on the Texas High Plains. Wetlands 31:1287-1296.

Kansas Water Office. 2009. Smoky Hill-Saline River Basin. http://www.kwo.org/Water%20Plan/KWP2009/Rpt_SHS_Entire_Basin_Section_KWP_2009.pdf.

Kansas Water Office. 2014. Kansas Water Plan 2014. http://www.kwo.org/Water%20Plan/KWP2014/Rpt_KWP_Volume_I_Draft_021913.pdf

Luo, H. R., L. M. Smith, B. L. Allen, and D. A. Haukos. 1997. Effects of sedimentation on playa wetland volume. Ecological Applications 7:247-252.

Luo, H. R., L. M. Smith, D. A. Haukos, and B. L. Allen. 1999. Sources of recently deposited sediments in playa wetlands. Wetlands 19:176-181.

Malmqvist, B. and S. Rundle. 2002. Threats to the running water ecosystems of the world. Environmental Conservation 29:134-153.

Mansdorf, Z. 2015. Sustainability: the water challenge. EHS Today 3:24.

Mitsch, W. J., and J. G. Gosselink. 2007. Wetlands. J. Wiley and Sons, Hoboken, New Jersey, USA.

Natural Resources Conservation Service. 2005. Wetland Conservation Provisions (Swampbuster).

O'Connell, J. L., L. A. Johnson, D. W. Daniel, S. T. McMurry, L. M. Smith, and D. A. Haukos. 2013. Effects of agricultural tillage and sediment accumulation on emergent plant communities in playa wetlands of the U.S. High Plains. Journal of Environmental Management 120:10-7.

Osterkamp, W.R., and W. W. Wood. 1987. Playa-lake basins on the southern High Plains of Texas and New Mexico: Part I. Hydrologic, geomorphic, and geological evidence for their development. Geological Society of America Bulletin 99: 215-233.

Pachauri, R.K. and L. A. Meyer (eds.). 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland. *IPCC* 151.

Renton, D. A. D. M. Mushet, and E. S. DeKeyser. 2015. Climate change and prairie pothole wetlands—mitigating water-level and hydroperiod effects through upland management. US Geological Suvery Scientific Investigations Report 2015-5004:21.

Smith, L. M. 2003. Playas of the Great Plains. University of Texas Press. Austin, Texas, USA.

Smith, L. M., and D. A. Haukos. 2002. Floral diversity in relation to playa wetland area and watershed disturbance. Conservation Biology 16 (4): 964-974.

Smith, L. M., D. A. Haukos, and S. T. McMurry. 2012. High Plains playas. Pages 299-311 in D.P. Batzer and A. H. Baldwin, editors. Wetland habitats of North America: ecology and conservation concerns. University of California Press, Berkley, USA.

Smith, L. M., D. A. Haukos, S. T. McMurry, T. G. Lagrange, and D. Willis. 2011. Ecosystem services provided by playas in the high plains: potential influences of USDA conservation programs. Ecological Applications 21:S82-S92.

Steward, D. R., P. J. Bruss, X. Yang, S. A. Staggenborg, S. M. Welch, and M. D. Apley. 2013. Tapping unsustainable groundwater stores for agricultural production in the High Plains Aquifer of Kansas, projections to 2110. Proceedings of the National Academy of Sciences of the United States of America 110:e3477-e3486.

Tsai, J. S., L. S. Venne, S. T. McMurry, and L. M. Smith. 2007. Influences of land use and wetland characteristics on water loss rates and hydroperiods of playas in the Southern High Plains, USA. Wetlands 27:683-692.

Tsai, J.S., L. S. Venne, L. M. Smith, S. T. McMurry, and D. A. Haukos. 2012. Influence of local and landscape characteristics on avian richness and density in wet playas of the southern Great Plains, USA. Wetlands 32:605-618.

United Nations Environment Programme. 2008. An Overview of the State of the World's Fresh and Marine Waters. Nairobi, Kenya: UNEP, 2.

United States Environmental Protection Agency. Section 404 permitting. 2015 [cited June 23 2015]. Available from http://water.epa.gov/lawsregs/guidance/cwa/dredgdis/.

Venne, L. S. 2006. Effect of land use on the community composition of amphibians in playa wetlands. Master of Science, Texas Tech University, Lubbock, USA.

Webb, E. B., L. M. Smith, M. P. Vrtiska, and T. G. Lagrange. 2010. Community structure of wetland birds during spring migration through the Rainwater Basin. Journal of Wildlife Management 74:765-777.

Chapter 2 - Our Essential Freshwater Source: Estimating the Occurrence and Function of Wetlands in Western Kansas

INTRODUCTION

Since early European settlement, the conterminous United States has lost greater than half of the original wetland area (Dahl 2006). The Great Plains region is no exception to the decline of freshwater resources. Wetlands, one of the most valuable freshwater sources in the region, have an estimated 50-60% loss in Kansas since the 1780s (Kansas Water Office 2014). Wetlands in the Great Plains offer a variety of ecological goods and services such as retention and slow release of flood water following periods of heavy rainfall; natural filters to cleanse water of contaminants while recycling nutrients; groundwater recharge; and provision of recreation, aesthetic, and wildlife viewing opportunities (Bolen et al. 1989, Haukos and Smith 1994, Smith 2003, Smith et al. 2011).

Wetland locations are generally defined by plants (the hydrophytes present), presence of hydric soils, and frequency of flooding (Mitsch and Gosselink 2007). However, due to the high diversity of wetland systems in the United States a systematic scheme is used to categorize and describe wetlands types (Cowardin et al. 1979), whereby wetlands are grouped into a classification system based on similar hydrologic, geomorphologic, chemical, or biological factors. Systems are then further divided into classes, based on substrate material or flooding regime.

Following the Cowardin et al. (1979) classification scheme, most wetlands in the Great Plains are found in either riverine, lacustrine, or palustrine systems. In the Smoky Hill River watershed of northwestern Kansas, palustrine freshwater emergent wetlands dominant, representing 99% of the wetland systems in the region (U.S. Fish and Wildlife Service 2016).

Greater than half of these wetlands are palustrine within the class emergent wetland, either temporarily flooded or semi-permanently flooded. Approximately 40% of the wetlands are in the class with aquatic beds and semi-permanently flooded.

Playa wetlands form the most common wetland type in the western region of the Smoky Hill River watershed (Smith et al. 2012). Playas are unique and complex ecological systems crucial to the ecology of the western Great Plains (i.e., High Plains) of North America. Relative to other wetland types, playas provide the unique function as the primary recharge points for the Ogallala Aquifer (Smith et al. 2012). Playa wetlands recharge the aquifer on an average of 7.6 cm per year (Gurdak and Roe 2009). Playas also act as a filter for water entering the aquifer by trapping sediment and attached contaminants as opposed to potentially contaminated water entering the aquifer through other sources (e.g., upland soils and center pivot wells; Gurdak and Roe 2009, Haukos et al. 2016). Besides aquifer recharge, playas provide a variety of ecological goods and services including floodwater retention, critical habitat for a unique assemblage of resident and migratory biota, and support for much of the biodiversity of the region (Smith et al. 2011, 2012).

Playas are characteristically depressional, shallow, recharge freshwater wetlands rarely exceeding 1.5 m at the deepest point in the hydric-soil defined depression (Smith 2003). Individual playas are hydrologically and geographically isolated from other playas and water sources (Smith et al. 2012). Their unique circular shape results from the geological processes during formation and development (Osterkamp and Wood 1987). The primary formation process is the oxidation of organic matter imported via precipitation run-off over time, releasing carbon dioxide, which reacts with water, forming carbonic acid during percolation of water through playas soils into the underlying substrate. The carbonic acid readily dissolved calcium carbonate and other deposits underlying the shallow topsoil. Caliche (calcium carbonate) dissolution results in land subsidence, causing distinct playa edges and floors (Smith 2003). The persistence of playas results from wind deflation during dry periods (Osterkamp and Wood 1987). Playa basins develop in surface depressions that collect and store runoff creating hydric soils (e.g., heavy vertisol clay; Osterkamp and Wood 1987, Smith 2003). Aquifer recharge from playa wetlands occur via percolation through cracks in dry playa soils upon immediate inundation by precipitation after a rainfall event. Once a playa becomes inundated, the hydric soil swells, sealing the cracks in the once dry soil, and, at that point, the primary aquifer recharge points occur around the dissolved caliche at edge of playas (Osterkamp and Wood 1987, Smith 2003).

Hydrology is the primary driver influencing the function of playas and other wetlands (Euliss et al. 2008). Many abiotic factors are controlled by hydrology, as the ecological state influences soil anaerobiosis, organic matter accumulation, and nutrient availability (Luo et al. 1999, Smith et al. 2012). Variation within abiotic processes, such as primary productivity and nutrient cycling, can also influence other biotic factors including species composition and richness. When the hydrology includes a pulsing hydroperiod with high water flows through the system, it allows for high productivity in wetlands (Mitsch and Gosselink 2007). A slight change in the wetland hydrological conditions could result in altered species composition and ecosystem productivity (Mitsch and Gosselink 2007).

Playa wetlands have a simple hydrological budget for the entrance and exit of water in its ecosystem. However, unlike most wetlands where inundation is the stable ecological state and drying during drought is a disturbance, the stable ecological state for playas is dry and inundation represents the primary disturbance (Albanese and Haukos 2016). Playas in the High Plains only receive water through direct precipitation and water runoff from the surrounding watershed and only lose water through aquifer recharge and evapotranspiration (Smith et al. 2012). The hydrological system of playas creates a dynamic and frequently changing ecological condition.

The hydroperiod, duration and timing of inundation of the playa, is unpredictable on spatial and temporal time scales (Smith et al. 2012). The hydroperiod is the key component of the hydrology of a wetland and drives the function of the ecosystem (Smith 2003, Tsai et al. 2007). The hydroperiod is influenced through precipitation, evapotranspiration, and groundwater recharge. Playas can remain inundated for a few days to greater than a year, but may go years between inundation events (Bolen et al. 1989, Johnson et al. 2011). Unmodified playas are typically inundated in late spring through fall depending upon frequency and intensity of precipitation events (Bolen et al. 1989). Individual playas rarely remain inundated longer than a few months following a precipitation period without additional water inputs following the initial event (Bolen et al. 1989).

As hydroperiod influences the ecological condition of playas, native biota have adapted to the variable, unpredictable hydroperiods (Smith and Haukos 2002, Webb et al. 2010, Tsai et al. 2012). The adaptable persistent biota responding to the variable hydroperiods results in a unique suite of flora and fauna supported by playas (Haukos and Smith 1994, 1997, 2004). The presence of a variety of biotic communities would not exist if playa habitats were not on the landscape (Smith and Haukos 2002, Albanese and Davis 2013). Furthermore, fluctuating hydroperiods drive critical processes such as nutrient cycling and decomposition, resulting in an overall energy flow within individual playas (Osterkamp and Wood 1987). The fluctuating hydrological condition, unpredictably shifting across the inundated to dry moisture gradient, allows for playas with varying ecological states to be present across the landscape at any point in time, allowing for coexistence of wetlands in a diversity of extreme and intermediate ecological states; thus, increasing the biodiversity of playas and surrounding areas (Haukos and Smith 1994, O'Connell et al. 2012, Tsai et al. 2012, Albanese and Davis 2015).

The major threats to the function of a playa wetland are caused by watershed disturbance (e.g., cultivation), playa modification, and habitat loss through hydroperiod alteration (Bolen et al. 1989, Webb et al. 2010, Johnson et al. 2012, Tsai et al. 2012). Anthropogenic changes to surrounding watersheds alter the function and presence of playa wetlands. Unfortunately, current estimates of the number of playas does not take into account the recent loss or modification of playas, giving a false representation of the correct number of functional and existing playa wetlands. Modification of playa wetlands continue to be a threat to the occurrence of playa wetlands as legal protection against modifying a playa is not effective in stemming continued physical or functional loss of playas (Haukos and Smith 2003, Johnson et al. 2011). A loss of playas on the landscape can cause negative implications at local, regional, and global scales. The loss of an individual playa causes negative effects to local populations by impeding movement by species among playas and decreasing landscape biodiversity (Albanese and Haukos 2016). The loss of an individual playa causes negative effects at a global scale when key playas that are heavily weighted in supporting ecological connectivity among playas are lost in the network system, which would reduce the occurrence of and occupancy of migrant shorebirds and other birds using the playa wetlands as a stopover site (Albanese and Davis 2015, Albanese and Haukos 2016).

Landscape change threatens the function and existence of playas, primarily through sediment accumulation, which decreases the function, size, and hydroperiod of individual playas (Tsai et al 2007, Johnson et al. 2012, Burris and Skagen 2013, O'Connell et al. 2013, Daniel et al. 2015). The transport of sediment in run-off to the watershed depression results from cultivation disturbances from practices such as cultivating watersheds, especially on highly erodible soils (Luo et al. 1999, Johnson et al. 2012, O'Connell et al. 2013). Culturally accelerated sediment accumulation in playas negatively affects the occurrence and function of playas as the unsustainable accretion of sediment is unlikely to leave the ecosystem except for the naturally minor portion of sediment removed through wind action during dry periods (Johnson et al. 2012). Sediment accretion in a playa alters water flow and negatively affects the hydroperiod by decreasing the duration and frequency of the inundation of the wetland (Luo et al. 1997, Tsai et al. 2007, Johnson et al. 2011, Burris and Skagen 2013, O'Connell et al. 2013, Daniel et al. 2015). As sediment depth increases in a playa, it may fill the naturally occurring cracks that develop during dry periods in the clay layer, interfering with recharge to the aquifer (Bolen et al. 1989). The physical threats and modifications to playa wetlands can be measured directly (e.g., sediment yield) and then to the function of the wetland.

The "filling" of a playa through sediment does not have to be intentional. While many playas have been filled with material to be able to farm or develop the wetland, unintentional filling can occur through an influx of sediment in runoff during periods of heavy rainfall from surrounding cropland. A high sediment yield significantly alters the hydrology of the playa, thus affecting all ecological functions and processes in the playa. Filling of playas with sediment decreases water storage volume; thus, reducing the hydroperiod and ecological function of the playa to hold water and provide wetland conditions (Tsai et al. 2007, Johnson et al. 2012).
The main issue with accelerated sediment accretion in playas is that there is no potential for sediment removal except through negligible effects of wind deflation or a costly excavation plan. The sediment will stay in the playa and increase in volume until the hydric-clay soil defined depression creating the playa is completely filled (Luo et al. 1997, Tsai et al. 2007, Johnson et al.

2011). The difficulty in removing sediment causes alarm to the future quantity and quality of playa wetlands. Further, future predictions also show that, not only will nearly all playas be filled by sediment in 100 years, but that future playas in cultivated watersheds will accumulate sediment at greater than twice the rate of playas located in a grassland watershed, causing those playas to be lost from the landscape at a faster rate (Burris and Skagen 2013). Without immediate action to slow sediment accumulation rates, all playas in the Great Plains will be filled within 100 years (Burris and Skagen 2013). It has been shown that the future playa wetland system will be almost completely abolished due to high sediment yield, with land use affecting sedimentation rates more so than future climate predictions (Smith et al. 2011, Burris and Skagen 2013).

The current estimate of the number and spatial distribution of playa wetlands can be considered an impediment to the future quantity and quality of wetlands as many conservation management and practices may be using an estimate of playa wetlands without considering contemporary physical and functional loss, with the false belief that many more functioning playa wetlands are present than actually exist. While playa and other wetland systems provide an immeasurable provision of ecological integrity to the Great Plains, estimation of the abundance and functional status of wetlands has been proven to be difficult and contradictory (Smith 2003, Johnson et al. 2012). The majority of playa wetland studies have been conducted in the Southern High Plains of Texas (e.g., Guthery and Bryant 1982, Osterkamp and Wood 1987, Haukos and Smith 2003, Tsai et al. 2007, Johnson et al. 2011). Johnson et al. (2012) reported a 17% physical loss of playa wetlands from the landscape in the Southern High Plains, with up to 60% functionally lost and only 0.2% of playas remaining at a full functioning ecological state.

The most recent approximation of the number and distribution of playa wetlands in Kansas is by Bowen et al. (2010), with an estimated 22,045 playas, doubling the previous estimate (Johnson and Campbell 2004). The majority of playas in western Kansas are <1 ha, with sizes ranging from a minimum of 0.03 ha to a maximum area of 345 ha, with an average of 1.65 ha (Bowen et al. 2010). However, the physical, ecological, or functional states of playas in Kansas were not considered when developing this estimate of plays in western Kansas. Bowen et al. (2010) also included landscape features that do not fit the strict definition of a playa wetland (Smith et al. 2012). The most current estimate of playas in western Kansas identified playas was based on five criteria, but did not include using hydric soils as a criterion (Bowen et al. 2010). These criteria to identify a depression as a playa wetland were comprised of the following conditions: 1) appropriate geographic position; 2) hydrologically isolated; 3) at the lowest elevation in a watershed; 4) no identifiable source of water outflow; and 5) having a circular form (Bowen et al. 2010). While all playas are depressions, not all depressions are playas. Playas are defined as having a characteristic hydric soil layer (Smith 2003). While playa wetlands have a specific landscape location, only scattering over the portion of western half of Kansas that overlies the Ogallala aquifer, this estimate may include an abundance of depressions in the landscape that do not fit the ecological description and services of a fully functioning playa wetland. If the current estimate is indeed an exaggeration, as I predict, conservation of playas is at risk due to the perception that there is an abundance of fully functioning playas in western Kansas.

Anthropogenic changes to the landscape alter the function and presence of playa wetlands and the current estimates of the number of playas does not take the recent loss of playas into account, giving a false representation of the correct number of functional and existing playa wetlands (Johnson et al. 2012). Conservation planning and resource agencies depend on the current and historical estimates of playas; incorrect estimates will draw attention away from playas that need protection. Information about what affects the functional state of playas will serve to assist conservation planners, such as ground-water resource managers and Playa Lakes Joint Venture, in prioritization of conservation actions (Smith 2003, Albanese and Haukos 2016). The current estimate of playas in western Kansas by Bowen et al. (2010) is unconventional by past playa estimates. A new estimate of playa wetlands needs to be conducted with increased restrictions on the occurrence and function of the playa to gain a more accurate estimate.

Landscape changes were not considered in the current estimates of playas. Actively tilled playas were not considered physically lost to the landscape if a depression remained on the landscape; however, tilling the playa floor causes a large negative ecological effect on the function of the playa as cultivation alters the hydric soil layer and other structural aspects resulting in functional loss of the playa (Johnson et al. 2012, O'Connell et al. 2013). To obtain an accurate estimate of playa loss, the current estimate of functional playa wetlands needs to be updated from prior estimates, including occurrence as well as any anthropogenic modifications or impacts that may affect playa hydrology and function. To assess how many functioning playas are present on the landscape in the Smoky Hill River watershed, my objectives were to (1) evaluate the proportion of playa and non-playa wetlands affected by anthropogenic modifications based on historical data, (2) evaluate the proportion of playa and non-playa wetlands lost to the landscape using historical numbers, and (3) determine the number of functioning wetlands in the Smoky Hill River watershed.

STUDY AREA

The study area was the Smoky Hill River watershed from Kanopolis Reservoir westward in Kansas (Figure 2.1). The Smoky Hill River watershed was located in the western two-thirds of Kansas, and center of the Central Great Plains. The Smoky Hill River basin has a drainage area of about 31,672.96 km^2 (Kansas Water Office 2009). The study area was 31,500 km^2, intersecting 32 Kansas counties (Figure 2.1). The majority of land cover encompassed two primary types: grassland and cultivated cropland. Grasslands were dominated by herbaceous vegetation. The watershed contains a gradient of mixed-grass prairie in the east to short-grass prairie in the west. Grasslands were used for livestock grazing. Cultivated cropland was used for the production of annual crops, actively tilled, and comprised of dry land and irrigated row crops. Major crops include wheat, sorghum, and corn (Kansas Water Office 2009). Cropland covered 48% of the land in the basin with grassland comprising 44% of the area (Kansas Water Office 2009). Playa wetlands were located in the western part of the Smoky Hill River watershed, primarily within the High Plains portion of the Central Great Plains west of the 100^{th} meridian. Playas were only found in the western 17 counties of the watershed (Figure 2.1).

METHODS

To characterize playas and other wetlands along with surrounding land use in the Smoky Hill River watershed, I developed a Geographic Information System (GIS) representation of the past and currently present wetlands. The method used to identify the occurrence of wetlands was adapted from Johnson et al. (2012), and created to identify the occurrence and functionality of playa wetlands in the Southern Great Plains.

Wetland Database Development

Playa Wetlands

A database containing the historical distribution of playa wetlands in western Kansas was created using spatial data provided by Playa Lakes Joint Venture (PLJV, Lafayette, Colorado). The PLJV spatial data for historic and probable playas in Kansas included locations compiled by William C. Johnson, Mark W. Bowen, and Scott T. Klopfenstein at the University of Kansas, who incorporated the analysis of the National Agriculture Imagery Program (NAIP) imagery by the University of Kansas (published in 2009, updated 2010; Bowen et al. 2010) and through hand-delineation by cross-referencing with Digital Raster Graphics (DRGs) and the Soil Survey Geographic Database (SSURGO) soils data from soil samples collected in the 1960s and 1970s (Johnson et al. 2009). The probable playas spatial data, created by Johnson et al. (2009) contains 22,045 probable playa wetlands in Kansas; specifically, the estimated of playa wetlands in the Smoky Hill River watershed was 3,310 probable playa polygons. Playa features >0.03 ha were included in these data. Because a unique playa was sometimes identified as multiple playas, due to additional classification codes or bisection of roads, polygons were aggregated if found within 50 m of another playa wetland.

The PLJV dataset contained 3,310 polygons representing probable playas in the Smoky Hill River watershed. I randomly chose 18.4 percent of the probable playas (n = 608) and assessed each individual playa wetland for physical presence and associated anthropogenic impacts following Johnson et al. (2012). To identify individual playas by latitude and longitude and area of each playa used in the imagery, I used the “calculate geometry” tool in ArcGIS 10.1 (ESRI 2011).

Non-playa wetlands

I used the National Wetlands Inventory (NWI) spatial data to develop a database that included wetland types excluding playa wetlands (U.S. Fish and Wildlife Service 2016). To remove playa wetlands from the non-playa wetland reference group, I used the “select by location” tool to find all playa wetlands shared between the NWI and PLJV spatial data and removed them from the non-playa wetland spatial dataset. I then removed all polygons identified as a river, lake or “other”. After removing the non-wetland polygons on the database, I then aggregated wetlands within a 50-m buffer using the “aggregate polygons” tool to eliminate wetlands that were considered multiple wetlands due to additional classification codes.

Categorization of wetland type followed the dichotomous approach created by Cowardin et al. (1979), which is used by the U.S. Department of Interior for the National Wetland Inventory. This classification of wetlands was based on predominant vegetation (hydrophytes), hydric soils, and frequency of inundation. To find the area, latitude, and longitude of each wetland, I used the “calculate geometry” tool. The resulting dataset contained 26,756 non-playa wetland types. I randomly chose 2% (n = 719) of non-playa wetlands and assessed each for physical presence and anthropogenic impacts. To test differences in sizes between historical and current wetlands, a t-test was performed ($\alpha = 0.05$) for both playa and nonplaya wetlands.

Quality Assessment

To examine if each individual wetland was present and record any associated anthropogenic features, the latitude and longitude of each wetland was entered into Google Earth (U.S. Department of State Geographer 2009). Google Earth uses Landsat TM imagery. After entering the mapped location of wetlands, I examined each location for the presence of the wetland and, if wetland was confirmed as present, I recorded any associated anthropogenic impacts. Recorded anthropogenic modifications included paved roads and dirt roads bisecting or intersecting the edge of the wetland, cultivation of the wetland, irrigation systems, oil rigs, fences, ditches, trenches, powerlines, railroads, and presence of trees.

To analyze the surrounding land use of selected wetlands, I created a 500-m buffer surrounding each wetland using the buffer analysis tool in ARCMap. Polygons representing wetlands and their respective buffer were then used to extract land cover data from the National Land Cover Database (Homer et al. 2011). Land cover categories were commercial/industrial, residential, urban-open land, irrigated row-crop (i.e., corn, soybean, sorghum, winter wheat, and alfalfa), non-irrigated row-crop, Conservation Reserve Program (CRP), warm- or cool-season grassland, woodland, and water. The Geospatial Modelling Environment (GME) provided by Spatial Ecology in ArcMap 10.1 was used to summarize the number of pixels for each land cover type for each polygon buffer (Beyer 2012). The information from GME was used to create an attribute table contained within the polygon shapefile by using the joins and relates option to combine data to the attributes contained within the polygon shapefile.

Quantity Assessment

To identify the number of playas that were physically lost or incorrectly identified as a wetland when there was no wetland present, I observed any wetlands that were recorded historically either through SSURGO data (Johnson et al. 2009) or NAIP imagery (Bowen et al. 2010) but are not currently present in the 2015 Google Earth imagery. A wetland was considered lost if there was no visible depression, visible hydric soil layer, and no change in the vegetative community from the surrounding upland (Johnson et al. 2012). A chi-squared test was used to test the difference between historical and current playa abundance by size category.

RESULTS

Playas

I assessed 608 of the 3310 polygons representing probable playas in the Smoky Hill River Watershed across 17 counties located in the western half of the Smoky Hill River watershed in western Kansas. The average size (±SE) of sampled playa wetlands across all land cover categories was 0.988 (±0.071) ha. The playa with the smallest area in the sample 0.039 ha; the area of the largest playa in the sample was 26.103 ha. Of this sample, 23.7% were 0-0.25 ha, 25.5% were 0.26-0.50 ha, 23.8% were 0.51-1.0 ha, 26.5% were 1.1-8.0 ha, and 0.5% were >8.0 ha. The dominant land cover category surrounding playas was 568 (93.4%) row-crop agriculture, 34 (5.59%) grassland, and 6 (0.99%) CRP (Tables 2.1, 2.2). Although CRP lands contained the smallest number of historical playas, playa wetlands in the CRP landscape historically had the highest average size of 1.46 (±0.527) ha (Table 2.2). The range of playa wetlands located in CRP was 0.127 - 3.46 ha. Playa wetlands in cropland landscapes historically had the second largest average size of playas at 1.003 (±0.076) ha with a range from 0.045 to 23.104 ha. Grassland playas had an average size 0.657 (±0.096) ha with a range of 0.039 - 2.511 ha (Table 2.2).

Of this sample, 33 (5.4%) of historical playas did not have any modifications present among all land cover type categories (Table 2.3). Playas in agriculture had the greatest number modified (97.4%), followed by CRP (66.7%), and grassland (52.3%; Table 2.3). The most common modification within a playa across all land cover types was tilling of playa soil (92.4%), followed by presence of actively growing crops and cultivation on the playa (91.3%), and dirt roads bisecting the playa or on playa edge (15.8%; Tables 2.4, 2.5)

The 608 historical playas had a confirmation rate of 77.96%, resulting in an estimated 474 depicted historical playas in the Smoky Hill River watershed sample; therefore, 22% of playas have been physically lost with no visible depression or presence on the landscape. There was no difference between the average size of playas found historically (0.988 ± 0.071 ha) on the landscape and the playas with a confirmed presence (1.057±0.080 ha) on the landscape (t_{1018} = 0.64, P = 0.52). The smallest size category had the greatest percentage of playa wetlands without a present confirmation (38.9% of playas 0-0.25 ha), followed by the largest size category (33.3% of playas >8.0 ha), the second size category (23.9% of playas 0.25-0.50), the third size category (13.1% of playas 0.5-1.0 ha), and the fourth size category (13.0% of playas 1.0-8.0 ha).

Considering only playas with no visible depression or presence (n = 134), the land cover contributing the most to lost playas was the row-crop agriculture watershed, contributing 129 (96.3%) with no visible depression or no longer present on the landscape, grassland watersheds contained 4 of 129 playas lost to the landscape (3.0%), and CRP-only contained one playa (0.8%) lost to the landscape across the other land cover types. After removing playa wetlands that had no confirmation of presence in Google Earth Imagery, there were 88 (18.6%) of playas in the smallest size category, 118 (24.9%) of playas were 0.26-0.50 ha, 126 (26.6%) of playas 0.51-1.0 ha, 140 (29.5%) of playas 1.1-8.0 ha, and 2 (0.4%) of playas >8.0 ha (Table 2.6). The distribution of playas by size was different between the historical assumed number of playas and the number left after assessing those remaining (X^2_9=5308, P<0.001); Figure 2.2). The average size of playa wetlands presently on the landscape is 1.057 (± 0.080) ha with a range of 0.039 - 26.103 ha. Of the remaining playas with physical confirmation on the landscape, only 15 (3.16%) of the remaining playas had no anthropogenic modifications (Table 2.6). Of the playas remaining on the landscape, the majority of playas continued to remain located in cropland watersheds (92.6%) with 6.3% located in a grassland and 1.1% located in CRP landscapes (Table 2.6).

Non-playa Wetlands

The dataset contained 718 randomly selected polygons representing historical wetlands in the Smoky Hill River watershed, after removing all riverine and lake habitats. Following the Cowardin et al. (1979) classification system, all wetland habitats were in the Palustrine system, with 363 (50.6%) in the emergent class, 298 (41.5%) in the aquatic bed class, 29 (4.0%) in the unconsolidated bottom class, 22 (3.1%) in the unconsolidated shore class, 4 (0.5%) in the forested class, and 2 (0.3%) in the scrub-shrub class (Tables 2.7, 2.8). The average size of playa wetlands 0.988 (± 0.071 ha) was almost 2.5 times greater than the average size on non-playa wetlands 0.397 (± 0.028 ha) (t_{794} = -7.74, $P < 0.001$). The area of the smallest non-playa wetland was 0.0014 ha; the area of the largest wetland was 7.857 ha. Of this sample, 18.7% were 0-0.06 ha, 17.9% were 0.061-0.1 ha, 21.6% were 0.11-0.2 ha, 22.7% were 0.21-0.50 ha, and 19.1% were >0.51 ha. The dominant land cover category surrounding the selected wetlands was 490 (68.2%) grassland, 224 (31.2%) row-crop agriculture, 2 (0.3%) developed, 1 (0.1%) pasture, and 1 (0.1%) forest (Table 2.8).

Only 53 (7.4%) of historical wetlands did not have any modifications present among all land cover type categories. All wetlands in the developed, pasture, and forest land cover types had the greatest number modified (100%), followed by row-crop agriculture (95.5%), and grassland (91.2%) (Table 2.9). The most common modification within a wetland across all land cover types was the presence of a ditch or pit (61.6%), followed by cultivation on the wetland (20.3%), presence of recent tilling (19.5%), and dirt roads bisecting or on the wetland edge (18.5%) (Tables 2.4, 2.10).

The non-playa wetlands had a confirmation rate of 90.1%, with only 71 (9.9%) wetlands having no visible depression or presences on the landscape. The smallest size category (0-0.06

ha) had the greatest number of wetlands without a present confirmation (20.2%), followed by the third size category of wetlands 0.11-0.21 ha (10.3%), the second size category (0.061-0.1 ha; 7.75%), the fourth largest size category of wetlands 0.21-0.5 ha (6.75%), and the largest size category of wetlands >0.51 ha (5.1%). The proportion of wetlands lost to the landscape varied among the different land use watersheds. The majority of non-playa wetlands lost to the landscape were located in a row-crop agriculture watershed, contributing 67.6% (n = 48) of all non-playa wetlands lost to the landscape, followed by the lack of presence of 22 wetlands (31.0%) in grassland, and 1 wetland (1.4%) in a developed land cover category. Of the remaining wetlands still present on the landscape after the wetland's confirmed presence, only 8.76% of waterbodies contained no anthropogenic impacts or modifications (Table 2.11).

DISCUSSION

The Smoky Hill River watershed has experienced considerable functional loss of playa wetlands, as almost every playa is impacted by various anthropogenic modifications. Even if one excludes the number of playa wetlands with a functional impairment, the watershed has experienced an alarming rate of physical loss of playas from the landscape. At a small scale, the loss of an individual playa wetland means a loss of a wetland habitat patch in a sea of agricultural patches. At a larger scale, the loss of a playa creates a loss of ecological goods and services to the regional and global landscape. The current estimate of playa wetlands in the Smoky Hill River watershed of western Kansas is an overestimate of the potential patches and abundance of playa wetlands occupy (Bowen et al. 2010). The rate of modification and physical loss of playa wetlands on the landscape in the Smoky Hill River watershed is consistent with modification and loss rates of playas in the Southern High Plains, where the largest density of playa wetlands is found (Johnson et al. 2012). Across the Great Plains, playa wetlands have experienced a >17% loss of the historical playas previously identified on the landscape with <6% of the playa wetlands in the Great Plains not influenced by anthropogenic modifications (Johnson 2011). The landscape now contains fewer playa habitat patches, thus causing negative implications on the wildlife demographics at local, regional, and global scales (Albanese and Haukos 2016).

Both wetland groups (i.e. playa wetlands and non-playa wetlands) have experienced a decrease in the quantity of individual wetland present on the landscape. Furthermore, between the two wetland groups, playa wetlands had greater than double the percent of individual wetlands with no confirmation of a presence any longer on the landscape, compared to wetland loss of non-playa wetlands. A major contribution to the difference in confirmation rate of wetlands between the two wetland groups is the difference of dominant land-cover types and hydrology characteristics. The difference in these attributes of wetland hydrology and dominant surrounding land cover between the two groups of wetlands is influenced by the longitudinal locations of the eastern non-playa wetlands and the western playa wetlands. The Smoky Hill River watershed experiences a precipitation gradient, with almost a 45% decrease in annual average precipitation from east to west. The eastern wetland classes are more likely to be inundated compared to the western half due to the increased precipitation as well as surface ground water. The wetland classes in the east are dominantly surrounded by grassland watersheds, a sharp contrast to the western playa wetlands. Playa wetlands are located in a landscape dominated by row-crop agriculture. The historic conversion of grassland to cropland in the western half of the Smoky Hill River watershed is attributed to the immediate proximity of the Ogallala Aquifer that underlies much of the Great Plains.

The surrounding land use of a playa plays the largest factor in determining if a playa becomes physically or functionally impaired. Playa wetlands in a cultivated watershed are more susceptible than those in grassland watersheds to accumulate excess sediment loads from cultivation practices such as plowing and tilling of land, impairing the playa physically and functionally (Luo et al. 1999, Johnson et al. 2012, O'Connell et al. 2013). Excess sediment loads, the leading threat to the persistence and occurrence of playa wetlands, increases volume loss, decreases total volume area, and forces flooded water to spread to other areas, further increasing water loss through evaporation (Tsai et al. 2007). Conservation programs can help to slow sedimentation rates in playa wetlands. The USDA Conservation Reserve Program removes cultivation practices on high erodible soils through the planting and maintenance of perennial grass cover, thus reducing anthropogenic effects to playas previously affected by cultivation practices. If playa wetlands continue to be physically and functionally altered by excess sediment yield, it can create a negative effect on local and regional biodiversity as playa wetland volumes and hydroperiod have been positively correlated with biodiversity and aquifer recharge (Smith et al. 2008, Gurdak and Roe 2009).

The type of modifications experienced by extant playas is associated with its surrounding upland land-use. Almost all playas in an agricultural watershed have been cultivated or tilled, negatively altering the characteristic hydric soil layer. Changes to the physical structure of a wetland, such as tilling, ditching and pitting, alter the function of the playa, acting in a similar way to that of physically filling and removing the playa from the landscape. Playa wetlands experience more anthropogenic impacts from cultivation of croplands than other wetland types due to the western location of playa wetlands in the Smoky Hill River watershed. Playa wetlands found in the agricultural landscape were nearly all modified, with almost half of that modification rate occurring in the grassland landscape. Playa wetlands found in a grassland landscape have a greater functional persistence than low functioning, near absent playa wetlands in an agricultural landscape.

The rate at which anthropogenic modifications occur is further related to the original volume of the playa wetland. In the Southern High Plains, small playas experience anthropogenic impacts more frequently than larger playas and have a greater percent loss of historical abundance on the landscape (Johnson 2011). Both categories of wetlands, playas and non-playa wetlands, experience the greatest likelihood of being lost to the landscape. Compared to large wetland basins, small wetland basins have a greater surface area to volume ratio. The increased surface area exposed along with the volume reduction of small wetlands are thus more likely to be filled with excess sediment faster and experience a greater evapotranspiration rate (Luo et al 1997, Tsai et al 2007). From a conservation perspective, larger wetlands should be given conservation priority to receive the greatest benefit of reducing further loss of playas from the landscape, specifically large playas in a grassland watershed. Further, conserving playas with the fewest modifications and thus the least altered, confirms previous management suggestions (Haukos and Smith 2003).

Since European settlement, North America has seen a consistent trend of loss of native grassland habitats coinciding with the growth of agricultural land. Converting native grassland to agriculture has profound negative effects on natural systems, such as loss of grassland ecosystems, increased soil erosion, greater usage of water for irrigation, as well as affecting our freshwater sources by adding extra nutrients to streams and filling wetlands with sediment (Edwards 2010, Schillings et al. 2015). Lack of legal protection does not help the increasing loss of freshwater playas from the Great Plains (Haukos and Smith 2003, Johnson et al. 2012). While the CRP will help compensate landowners if they wish to participate in the program, there still is sparse protection for playa wetlands, specifically when the wetland is dry, and therefore available to be legally modified. Lack of legal protection further removes playas from the landscape as landowners can legally fill and use playas to grow commodity crops during the natural dry periods of a playa or during drought (Haukos and Smith 2003, Johnson et al. 2012).

In the face of future climate change scenarios, watershed management is crucial to conserve playa systems. Playas in a cropland watershed, accumulating greater than twice the amount of sediment accumulation rate than grassland playas, will experience the negative impacts of predicted climate changes at a greater and faster rate, causing playas to be lost from the landscape at a faster rate (Burris and Skagen 2013). It has been shown that the future playa wetland system will be almost completely abolished due to high sediment yield with land use affecting sedimentation rates more so than future climate predictions (Smith et al. 2011, Burris and Skagen 2013). Fortunately, it has been shown that grassland buffers of 50 m maximize sediment and nutrient contaminant removal from precipitation runoff (Haukos et al. 2016).

With almost all playas in the watershed experiencing an impaired ecological function, or complete physical loss from the landscape, loss of individual wetlands needs to be considered within the spatial distribution of remaining functional wetlands (Albanese et al. 2012, Albanese and Haukos 2016). As playas are lost from the landscape, a change from clustered to isolated wetlands can occur (Albanese and Haukos *in review*). Isolated wetlands have a lower perennial richness and abundance (O'Connell et al. 2013). Clustered areas with a high density of playa wetlands on the landscape, however, are positively related to avian species richness, occurrence, abundance, and diversity (Haukos and Smith 2004, Albanese and Davis 2015). Individual playa wetlands lost to the landscape further diminishes the playa system as a whole, decreasing functional connectivity, and negatively impacting wildlife demographics such as movement, population dynamics, persistence of local populations, and decreased diversity (Albanese and Haukos 2016). Conservation efforts must be taken immediately to sustain the playa wetland system. If no actions are taken, biodiversity, and thus ecosystem function, will only decrease at local, regional, and global scales. Conservation efforts should include the following characteristics when considering playa wetlands for conservation and restoration efforts: (1) located in a grassland watershed, or a grassland buffer,, (2) exist in an area with a high density/cluster of playa wetlands, and (3) the wetland should be large in size to decrease the probability of the playa wetland to be lost from the landscape (Luo et al 1997, Johnson 2011, Johnson et al. 2011, Albanese et al. 2012, O'Connell et al. 2013, Albanese and Davis 2015, Albanese and Haukos 2016, Haukos et al. 2016).

LITERATURE CITED

Albanese, G., and C. A. Davis. 2013. Broad-scale relationships between shorebirds and landscapes in the southern Great Plains. Auk 130:88–97.

Albanese, G., and C. A. Davis. 2015. Characteristics within and around stopover wetlands used by migratory shorebirds: is the neighborhood important? Condor 117:328-340.

Albanese, G., C. A. Davis, and B. W. Compton. 2012. Spatiotemporal scaling of North American continental interior wetlands: implication for shorebird conservation. Landscape Ecology 27: 328-340.

Albanese, G., and D.A. Haukos. 2016. A network model framework for prioritizing wetland conservation in the Great Plains. Landscape Ecology DOI 10.1007/s10980-016-0436-

Albanese, G., and D. A. Haukos. 2017. toward a theory of connectivity among depressional wetlands of the Southern Great Plains: resiliency to natural and anthropogenic disturbance within a wetland network. In Press in E. Beever, S. Prange, and J. Franklin (editors). Disturbance Ecology and Biological Diversity: Context, Nature, and Scale. CRC Press/Taylor and Francis Group.

Beyer, H.L. 2012. Geospatial Modelling Environment (Version 0.7.3.0). (software). URL: http://www.spatialecology.com/gme

Bolen, E. G., L. M. Smith, and H. L. Schramm Jr. 1989. Playa lakes: prairie wetlands of the southern High Plains. Bioscience 39:615-623.

Bowen, M. W., W. C. Johnson, S. L. Egbert, and S. T. Lopfenstein. 2010. A GIS-based approach to identify and map playa wetlands on the High Plains, Kansas, USA. Wetlands 30:675-684.

Burris, L., and S. K. Skagen. 2013. Modeling sediment accumulation in North American playa wetlands in response to climate change, 1940-2100. Climate Change 117:69-83.

Cowardin, L. M., V. Carter, F. C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31. U.S. Fish and Wildlife Service, Washington D.C., USA.

Dahl, T. E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C.

Daniel, D. W., L. M. Smith, and S. T. McMurry. 2015. Land use effects on sedimentation and water storage volume in playas of the rainwater basin of Nebraska. Land Use Policy 42:426-431.

Edwards, R. P. 2010. Saving the world's grasslands an introduction. Great Plains Research 20:5-7.

ESRI. 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Euliss, N. H. Jr, L. M. Smith, D. A. Wilcox, and B. A. Browne. 2008. Linking ecosystem processes with wetland management goals: charting a course for a sustainable future. Wetlands 28:553-562.

Gurdak, J. J., and C. D. Roe. 2009. Recharge rates and chemistry beneath playas of the High Plains aquifer—a literature review and synthesis. U.S. Geological Survey Circular 1333, Washington, D.C.

Guthery, F. S., and F. C. Bryant. 1982. Status of playas in the Southern Great Plains. Wildlife Society Bulletin 10:309-317.

Haukos, D. A., L. A. Johnson, L. M. Smith, and S. T. McMurry. 2016. Effectiveness of vegetation buffers surrounding playa wetlands at contaminant and sediment amelioration. Journal of Environmental Management 181: 552-562.

Haukos, D. A. and L. M. Smith. 1994. The importance of playa wetlands to biodiversity of the Southern High Plains. Landscape and Urban Planning 28:83-98.

Haukos, D. A. and L. M. Smith. 1997. Common flora of the playa lakes. Texas Tech University Press, Lubbock, TX, USA.

Haukos, D. A, and L. M. Smith. 2003. Past and future impacts of wetland regulations on playa ecology in the Southern Great Plains. Wetlands 23:577-589.

Haukos, D. A. and L. M. Smith. 2004. Plant communities of playa wetlands. Special Publication 47, The Museum of Texas Tech University, Lubbock, TX, USA.

Homer, C.G., J. A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N. D. Herold, J. D. Wickham, and K. Megown. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing 81:345-354.

Johnson, L. A. 2011. Occurrence, function, and conservation of playa wetlands: the key to biodiversity of the Southern Great Plains. Dissertation, Texas Tech University, Lubbock, USA.

Johnson, W. C. and J. S. Campbell. 2004. Playa lakes: database of playa distribution in western Kansas. Data Access and Support Center, Kansas Geological Survey. Available via: www.kansasgis.org

Johnson, L. A., D. A. Haukos, L. M. Smith, and S. T. McMurry. 2012. Physical loss and modification of Southern Great Plains playas. Journal of Environmental Management 112:275-283.

Johnson, W.C., M.W. Bowen, and S.T. Klopfenstein. 2009. Kansas playa wetlands. Department of Geography, University of Kansas, Lawrence, Kansas, USA.

Johnson, W. P., M. B. Rice, D. A. Haukos, and P. P. Thorpe. 2011. Factors influencing the occurrence of inundated playa wetlands during winter on the Texas High Plains. Wetlands 31:1287-1296.

Kansas Water Office. 2009. Smoky Hill-Saline River Basin. http://www.kwo.org/Water%20Plan/KWP2009/Rpt_SHS_Entire_Basin_Section_KWP_2009.pdf.

Kansas Water Office. 2014. Kansas Water Plan 2014. http://www.kwo.org/Water%20Plan/KWP2014/Rpt_KWP_Volume_I_Draft_021913.pdf

Luo, H. R., L. M. Smith, B. L. Allen, and D. A. Haukos. 1997. Effects of sedimentation on playa wetland volume. Ecological Applications 7:247-252.

Luo, H. R., L. M. Smith, D. A. Haukos, and B. L. Allen. 1999. Sources of recently deposited sediments in playa wetlands. Wetlands 19:176-181.

Mitsch, W. J., and J. G. Gosselink. 2007. Wetlands. J. Wiley and Sons, Hoboken, New Jersey, USA.

O’Connell, J.L., L. A. Johnson, L. M. Smith, S. T. McMurry, S.T., and D. A. Haukos. 2012. Influence of land-use and conservation programs on wetland plant communities of the semi-arid United States Great Plains. Biological Conservation 146: 108–115.

O'Connell, J. L., L. A. Johnson, D. W. Daniel, S. T. McMurry, L. M. Smith, and D. A. Haukos. 2013. Effects of agricultural tillage and sediment accumulation on emergent plant communities in playa wetlands of the U.S. High Plains. Journal of Environmental Management 120:10-7.

Osterkamp, W.R., and W. W. Wood. 1987. Playa-lake basins on the southern High Plains of Texas and New Mexico: Part I. Hydrologic, geomorphic, and geological evidence for their development. Geological Society of America Bulletin 99: 215-233.

Schilling, K.E., P.J. Jacobson, and J. A. Vogelgesang. 2015. Agricultural conversion of floodplain ecosystems: implications for groundwater quality. Journal of Environmental Management 153:74-83.

Smith, L. M. 2003. Playas of the Great Plains. University of Texas Press. Austin, Texas, USA.

Smith, L. M., and D. A. Haukos. 2002. Floral diversity in relation to playa wetland area and watershed disturbance. Conservation Biology 16 (4): 964-974.

Smith, L. M., D. A. Haukos, and S. T. McMurry. 2012. High Plains playas. Pages 299-311 in D.P. Batzer and A. H. Baldwin, editors. Wetland habitats of North America: ecology and conservation concerns. University of California Press, Berkley, USA.

Smith, L. M., D. A. Haukos, S. T. McMurry, T. G. Lagrange, and D. Willis. 2011. Ecosystem services provided by playas in the high plains: potential influences of USDA conservation programs. Ecological Applications 21:S82-S92.

Smith, L. M., N. H. Euliss, D. A. Wilcox, and M. M. Brinson. 2008. Application of a geomorphic and temporal perspective to wetland management in North America. Wetlands 28: 563–577.

Tsai, J. S., L. S. Venne, S. T. McMurry, and L. M. Smith. 2007. Influences of land use and wetland characteristics on water loss rates and hydroperiods of playas in the Southern High Plains, USA. Wetlands 27:683-692.

Tsai, J.S., L. S. Venne, L. M. Smith, S. T. McMurry, and D. A. Haukos. 2012. Influence of local and landscape characteristics on avian richness and density in wet playas of the southern Great Plains, USA. Wetlands 32:605-618.

US Fish and Wildlife Service. 2016. National wetlands inventory website. US Department of the Interior, Fish and Wildlife Service, Washington D.C., USA.

Webb, E. B., L. M. Smith, M. P. Vrtiska, and T. G. Lagrange. 2010. Community structure of wetland birds during spring migration through the Rainwater Basin. Journal of Wildlife Management 74:765-777.

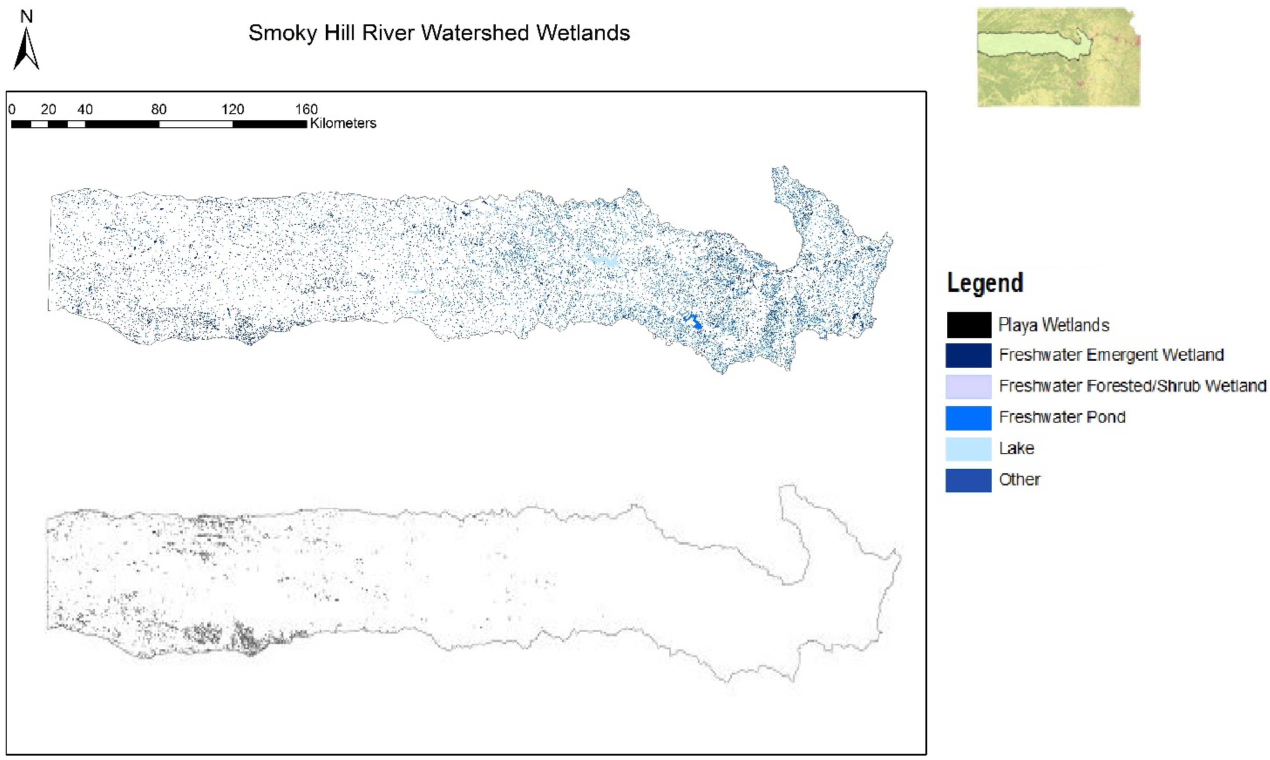

Figure 2.1 A geographical map of playa and other wetlands in the in the 3.13×10^6 ha Smoky Hill River watershed in western Kansas, USA.

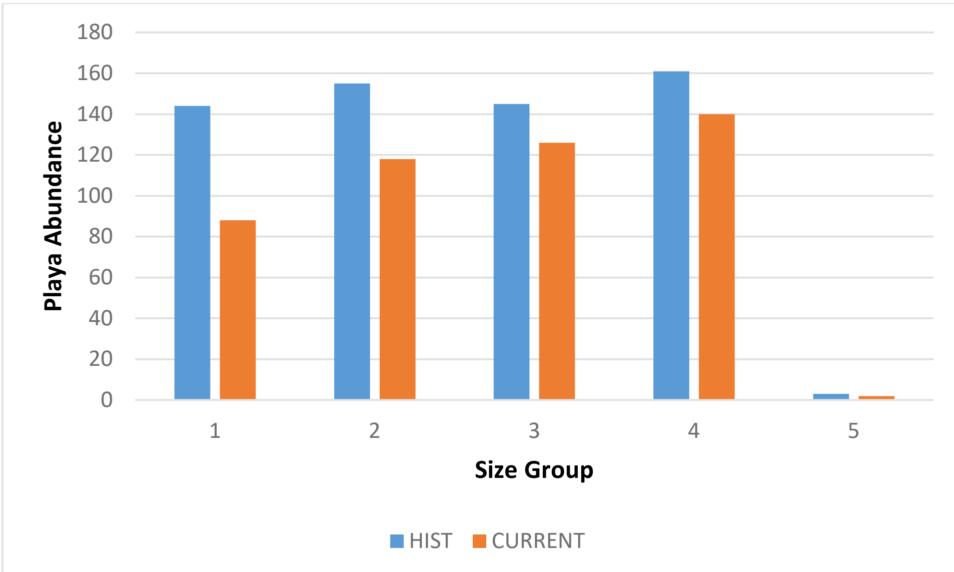

Figure 2.2 Size distribution (1 =0-0.25 ha , 2 =0.26-0.50 ha , 3 =0.51-1.0 ha , 4 =1.1-8.0 ha , 5 >8.0 ha) of 608 playas historically present in the Smoky Hill River watershed of western Kansas, USA, compared to playas physically present on the landscape during 2015.

Table 2.1 Kansas land cover patterns (2005, Level IV) created using remote sensing condition descriptions and assigned land cover categories present within a 500-m buffer of selected playa wetlands in the Smoky Hill River watershed of western Kansas, USA, during 2015-2016

Kansas Land Cover Patterns (2005, Level IV) Condition Description	Land cover Category
Urban Industrial/Commercial	Anthropogenic Development
Urban Residential	Anthropogenic Development
Urban Openland	Anthropogenic Development
Urban Woodland	Anthropogenic Development
Urban Water	Anthropogenic Development
Non-irrigated Corn	Row-crop Agriculture
Irrigated Corn	Row-crop Agriculture
Non-irrigated Soybean	Row-crop Agriculture
Irrigated Soybean	Row-crop Agriculture
Non-irrigated Sorghum	Row-crop Agriculture
Irrigated Sorghum	Row-crop Agriculture
Non-irrigated Winter Wheat	Row-crop Agriculture
Irrigated Winter Wheat	Row-crop Agriculture
Non-irrigated Alfalfa	Row-crop Agriculture
Irrigated Alfalfa	Row-crop Agriculture
Fallow	Row-crop Agriculture
Double-Crop	Row-crop Agriculture
Conservation Reserve Program (CRP) Land	CRP
Warm-Season Grassland	Grassland
Cool-Season Grassland	Grassland
Woodland	Woodland
Water	Water
Other	Other
Periodic Emergent Vegetation	Other

Table 2.2 Number of historical playas, average historical size, percent currently modified, and percent currently with no visible depression within Row-crop Agriculture, Conservation Reserve Program, and Grassland watersheds (n = 608) and by size (ha) (1 = 0-0.25, 2 = 0.26-0.5, 3 = 0.6-1.0, 4 = 1.1-8.0, 5 = >8.0) in the Smoky Hill River watershed of western Kansas, USA, during 2015-2016.

	Land cover											
	Row-crop Agriculture				Conservation Reserve Program				Grassland			
	Total	Size (ha)	%Mod	% Lost	Total	Size (ha)	%Mod	% Lost	Total	Size (ha)	%Mod	% Lost
Size group (ha)												
1	133	0.16(0.0)	96.2	40.6	1	0.13(0.0)	100.0	0.00	10	0.19(0.0)	40.0	20.0
2	150	0.36 (0.0)	99.3	24.0	0	0	0.0	0.00	5	0.34(0.0)	100.0	20.0
3	130	0.73(0.0)	98.5	13.9	3	0.85(0.1)	33.3	0.00	12	0.67(0.0)	41.7	8.3
4	152	2.23(0.1)	95.4	13.2	2	3.05(0.4)	100.0	50.0	7	1.53(0.2)	57.1	0.0
5	3	20.41 (2.9)	100	33.3	0	0	0.0	0.0	0	0	0.00	0.00
Total	568	1.00 (0.1)	97.4	22.7	6	1.46(0.5)	66.7	16.7	34	0.66(0.1)	52.94	11.76

Table 2.3 Contemporary condition of historical playas assessed for modifications and lack of visible depression within row-crop agriculture, Conservation Reserve Program, and grassland watershed land cover types in Google Imagery from the most recent imagery available (2012-2015) (n=608) and by size (ha) in the Smoky Hill River watershed of western Kansas, USA, during 2015-2016.

	Watershed Type											
	Row-crop Agriculture			Conservation Reserve Program			Grassland			All Land cover Categories		
Size Category (ha)	Total	Modified	Lost	Total	Modified	Lost	Total	Modified	Lost	Total	Modified	Lost
1 (0-0.25)	133	128	54	1	1	0	10	4	2	144	133	56
2 (0.26-0.50)	150	149	36	0	0	0	5	5	1	155	154	37
3 (0.51-1.0)	130	128	18	3	1	0	12	5	1	145	134	19
4 (1.1-8.0)	152	145	20	2	2	1	7	4	0	161	151	21
5 (>8.0)	3	3	1	0	0	0	0	0	0	3	3	1
Total	568	553	129	6	4	1	34	18	4	608	575	134

Table 2.4 Modification types recorded with number and percent of playas and non-playa wetlands with the given modification across all dominant watershed land cover types (playas: Row-crop Agriculture n = 568, Conservation Reserve Program n = 6, Grassland n = 34; non-playa wetlands: Row-crop Agriculture n = 224, Grassland n = 490, Developed n = 2, Forest n = 1, and Pasture n = 1) as observed in Google Earth from the most recent available data (2012-2015) for the Smoky Hill River Watershed of western Kansas, USA, during 2015.

Modification	*n* playas modified	Percent playas modified	*n* wetlands modified	Percent wetlands modified
Trees	10	1.64	390	54.32
Dirt Road	96	15.79	133	18.52
Paved Road	3	0.49	4	0.56
Ditch/Pit	29	4.77	442	61.56
Cultivation on playa	555	91.28	146	20.33
Fence	5	0.82	91	12.67
Oil	5	0.82	0	0
Edge of CP	26	4.28	0	0
Other	34	5.59	12	1.67
Buffer	8	1.32	103	14.35
Powerline	10	1.64	7	0.97
Tilled	562	92.43	140	19.5

Table 2.5 Number of playas affected by anthropogenic activities by land cover (Row-crop Agriculture, Conservation Reserve Program, and Grassland) by size (ha) (1 = 0-0.25, 2 = 0.26-0.5, 3 = 0.6-1.0, 4 = 1.1-8.0, 5 = >8.0) in the Smoky Hill River watershed of western Kansas, USA, during 2015-2016

	Row-crop Agriculture						Conservation Reserve Program						Grassland					
Size Group	1	2	3	4	5	Total	1	2	3	4	5	Total	1	2	3	4	5	Total
Trees	0	1	2	6	1	10	0	0	0	0	0	0	0	0	0	0	0	0
Dirt Road	12	17	24	39	2	94	0	0	0	0	0	0	0	1	0	1	0	2
Paved Road	0	0	1	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Ditch/Pit	2	5	6	14	1	28	1	0	0	0	0	1	0	0	0	0	0	0
Cultivation on playa	125	146	128	137	3	539	1	0	1	1	0	3	4	3	3	3	0	13
Fence	0	0	0	2	0	2	0	0	0	0	0	0	0	1	2	0	0	3
Oil	1	2	1	1	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Edge of CP	3	3	7	12	1	26	0	0	0	0	0	0	0	0	0	0	0	0
Other	5	6	8	14	1	34	0	0	0	0	0	0	0	0	0	0	0	0
Buffer	1	0	1	3	0	5	0	0	0	0	0	0	1	0	1	1	0	3
Powerline	1	2	2	5	0	10	0	0	0	0	0	0	0	0	0	0	0	0
Tilled	126	147	128	142	3	546	1	0	1	1	0	3	4	3	3	3	0	13
Total	276	329	308	377	12	1302	3	0	2	2	0	7	9	8	9	8	0	34

Table 2.6 Total number, average size, and number with no anthropogenic modifications of playas surveyed within Row-crop Agriculture, Conservation Reserve Program, and Grassland (n = 474) and by size (ha) (1 = 0-0.25, 2 = 0.26-0.5, 3 = 0.6-1.0, 4 = 1.1-8.0, 5 = >8.0) in the Smoky Hill River watershed of western Kansas, USA, during 2015-2016.

	Watershed Type											
	Row-crop Agriculture			Conservation Reserve Program			Grassland			All Land cover Categories		
	Total	Size (ha)	Unmod	Total	Size (ha)	Unmod	Total	Size (ha)	Unmod	Total	Size (ha)	Unmod
Size Category (ha)												
1 (0-0.25)	79	0.165(0.01)	5	1	0.127	0	8	0.180(0.03)	6	88	0.166(0.01)	11
2 (0.26-0.50)	114	0.359(0.01)	1	0	0	0	4	0.355(0.03)	0	118	0.359(0.01)	1
3 (0.51-1.0)	112	0.732(0.01)	2	3	0.845(0.06)	2	11	0.667(0.05)	6	126	0.729(0.01)	10
4 (1.1-8.0)	132	2.241(0.12)	7	1	2.643	0	7	1.531(0.21)	3	140	2.208(0.11)	10
5 (>8.0)	2	21.505(4.56)	0	0	0	0	0	0	0	2	21.505(4.56)	0
Total	439	1.081(0.09)	15	5	1.061(0.42)	2	30	0.697(0.11)	15	474	1.057(0.08)	32

Table 2.7 National Land Cover Database (NLCD 2011) condition descriptions and assigned land cover categories present within 500 m of randomly selected wetlands (n = 718) using remote sensing data in the Smoky Hill River watershed of Kansas, USA.

NLCD Condition Description	Land cover Category
Open Water	Water
Perennial Ice/Snow	Water
Developed, Open Space	Developed
Developed, Low Intensity	Developed
Developed, Medium Intensity	Developed
Developed, High Intensity	Developed
Barren Land (Rock/Sand/Clay)	Barren
Deciduous Forest	Forest
Evergreen Forest	Forest
Mixed Forest	Forest
Dwarf Scrub	Shrubland
Shrub/scrub	Shrubland
Grassland/Herbaceous	Grassland
Sedge/Herbaceous	Herbaceous
Lichens	Herbaceous
Moss	Herbaceous
Pasture/Hay	Disturbed Grassland
Cultivated Crops	Cropland
Woody Wetlands	Wetlands
Emergent Herbaceous Wetlands	Wetlands

Table 2.8 Number of historical wetlands, average historical size, percent currently modified, and percent currently lost to the landscape within Agriculture, Grassland, Forest, Developed, and Pasture watersheds (n = 718) and by size (ha) (1=0-0.06, 2=0.061-0.1, 3=0.11-0.20, 4=0.21-0.50, 5=>0.50) in the Smoky Hill River watershed of Kansas, USA.

	Landcover																			
	Agriculture				Grassland				Developed				Pasture				Forest			
Size Category (ha)	Total	Size (ha)	%Mod	%Lost	Total	Size (ha)	%Mod	%Lost	Total	Size (ha)	%Mod	%Lost	Total	Size (ha)	%Mod	%Lost	Total	Size (ha)	%Mod	%Lost
1 (0-0.06)	40	0.0375 (0.00)	90.00	32.50	94	0.0356 (0.00)	77.66	14.89	0	0	0.00	0.00	0	0	0.00	0.00	0		0.00	0.00
2 (0.061-0.10)	40	0.0804 (0.00)	92.50	20.00	88	0.0788 (0.00)	93.18	2.27	0	0	0.00	0.00	1	0.0676 (0.00)	100.00	0.00	0	0	0.00	0.00
3 (0.11-0.20)	61	0.1448 (0.00)	98.36	22.95	93	0.1427 (0.00)	93.55	2.15	0	0	0.00	0.00	0	0	0.00	0.00	1	0.131 (0.00)	100.00	0.00
4 (0.21-0.50)	49	0.3276 (0.01)	97.96	14.29	112	0.3252 (0.01)	94.64	2.68	2	0.3082 (0.07)	100.00	50.00	0	0	0.00	0.00	0	0	0.00	0.00
5(>0.50)	34	1.401 (0.19)	97.06	17.65	103	1.4280 (0.13)	96.12	0.97	0	0	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.00
Total	224	0.3448 (0.04)	95.54	21.43	490	0.4226 (0.04)	91.22	4.49	2	0.3082 (0.07)	100.00	50.00	1	0.0676 (0.00)	100.00	0.00	1	0.131 (0.00)	100.00	0.00

Table 2.9 Number of historical wetlands assessed for current modifications and physical presence within Agriculture, Grassland, Developed, Pasture, and Forest watersheds using Google Imagery from the most recent imagery available (2012, n = 718) and by size (ha) (1 = 0-0.06, 2 = 0.061-0.10, 3 = 0.11-0.2, 4 = 0.21-0.5, 5>0.51) in the Smoky Hill River watershed of Kansas, USA, during 2015.

	Land cover																	
	Agriculture			Grassland			Developed			Pasture			Forest			All Land cover Categories		
	Total	Modified	Lost	Total	Modified	Lost	Total	Modified	Lost	Total	Modified	Lost	Total	Modified	Lost	Total	Modified	Lost
Size Category (ha)																		
1 (0-0.06)	40	36	13	94	73	14	0	0	0	0	0	0	0	0	0	134	109	27
2 (0.061-0.10)	40	37	8	88	82	2	0	0	0	1	1	0	0	0	0	129	120	10
3 (0.11-0.20)	61	60	14	93	87	2	0	0	0	0	0	0	1	1	0	155	148	16
4 (0.21-0.50)	49	48	7	112	106	3	2	2	1	0	0	0	0	0	0	163	156	11
5(>0.50)	34	33	6	103	99	1	0	0	0	0	0	0	0	0	0	137	132	7
Total	224	214	48	490	447	22	2	2	1	1	1	0	1	1	0	718	665	71

Table 2.10 Number of wetlands impacted by anthropogenic activities by land cover (Row-crop Agriculture, Developed, Pasture, and Grassland) by size (ha) (1=0-0.06, 2=0.061-0.10, 3=0.11-0.2, 4=0.21-0.5, 5>0.51) in the Smoky Hill River watershed of Kansas, USA, during 2015.

	Landcover																													
	Agriculture						Developed						Forest						Grassland						Pasture					
Size Category	1	2	3	4	5	Total	1	2	3	4	5	Total	1	2	3	4	5	Total	1	2	3	4	5	Total	1	2	3	4	5	Total
Dirt Road	8	9	13	10	12	52	0	0	0	1	0	1	0	0	0	0	0	0	9	19	13	19	19	79	0	1	0	0	0	1
Paved Road	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	0	0	0	0	0	0
Cultivation	25	21	37	22	19	124	0	0	0	1	0	1	0	0	0	0	0	0	12	4	1	3	0	20	0	1	0	0	0	1
Ditch/Pit	10	13	28	27	16	94	0	0	0	1	0	1	0	0	1	0	0	1	37	69	75	84	81	346	0	0	0	0	0	0
Trees	9	12	15	22	16	74	0	0	0	1	0	1	0	0	1	0	0	1	46	55	61	74	78	314	0	0	0	0	0	0
Fence	4	4	7	6	6	27	0	0	0	0	0	0	0	0	0	0	0	0	14	13	14	9	14	64	0	0	0	0	0	0
Tilled	23	19	35	20	19	116	0	0	0	2	0	2	0	0	0	0	0	0	13	4	2	3	0	22	0	0	0	0	0	0
Veg Buffer	5	6	7	8	7	33	0	0	0	0	0	0	0	0	1	0	0	1	4	14	13	16	22	69	0	0	0	0	0	0
Powerline	0	1	1	0	1	3	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	1	3	0	0	0	0	0	0
Other	1	1	0	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1	1	8	0	0	0	0	0	0

Table 2.11 Number of wetlands with a confirmed physical presence, the currently present average size, and number of physically present wetlands with no anthropogenic modifications for row-crop agriculture land cover, grassland land cover, other land covers (Developed, Hay, and Forest), and all land cover categories (n = 647) and by size category in the Smoky Hill River watershed of Kansas, USA, during 2015.

	Land cover											
	Row-crop Agriculture			Grassland			Other			All Land cover Categories		
Size Category (ha)	Total	Size (ha)	Unmod	Total	Size (ha)	Unmod	Total	Size (ha)	Unmod	Total	Size (ha)	Unmod
1 (0-0.25)	27	0.036(0.0)	4	80	0.037(0.0)	21	0	0	0	107	0.037(0.0)	25
2 (0.26-0.50)	32	0.081(0.0)	3	86	0.079(0.0)	5	1	0.068	0	119	0.079(0.0)	8
3 (0.51-1.0)	47	0.147(0.0)	1	91	0.147(0.0)	5	1	0.131	0	139	0.144(0.0)	6
4 (1.1-8.0)	42	0.335(0.0)	1	109	0.323(0.0)	6	1	0.373	0	152	0.327(0.0)	7
5 (>8.0)	28	1.276(0.2)	1	102	1.365(0.1)	4	0	0	0	130	1.35(0.1)	5
Total	176	0.343(0.0)	10	468	0.421(0.0)	41	3	0.252(0.1)	0	647	0.399(0.0)	51

Chapter 3 - Avian and Floral Biodiversity in Playa Wetlands in Relation to Watershed Disturbance

INTRODUCTION

Playa wetlands are unique and complex ecological systems crucial to the ecology of the western Great Plains of North America. Playas offer a variety of ecological goods and services including flood water retention, water quality improvement, aquifer recharge, and provide critical habitat for a unique assemblage of resident and migratory biota (Smith et al. 2012). Because playa wetlands support critical stop-over sites for long-distance migrant birds of the Central Flyway, playas have the potential to influence biodiversity at a local, regional, and global scale. In many areas, including the Smoky Hill River watershed of Kansas, playas have been lost from the landscape at an alarming rate (Chapter II; Johnson et al. 2012). The declining number and function of playas in this semi-arid region could create major negative implications for biodiversity at various temporal and spatial scales.

Biodiversity can be used as an indicator of the ecological function of an ecosystem (Hooper et al. 2005). Maintenance of biodiversity is crucial to the stability of the ecosystem, as losses of playa biodiversity are associated with increasing disturbance and decreasing habitat (Smith and Haukos 2002, Tsai 2007, Tsai et al. 2012, O'Connell et al. 2013). Conserving biodiversity in ecosystems thus ultimately conserves ecosystem stability and resilience (Tilman and Downing 1994, Cardinale et al. 2012). Resilience, the resistance ability to recover from disturbances, allows an ecosystem to remain stable and present on the landscape, whereas unstable ecosystems will see declines in productivity, the driving force of most ecosystems (Tilman and Downing 1994, Cardinale et al. 2012). Biodiversity can be typically defined by either species richness or use of an index that combines species richness and species evenness

(Peet 1974). Biodiversity indices are a numerical value representing how the abundance and proportion of species are represented in a community (Peet 1974). Biodiversity of a community can be assessed at different scales, from a small area to a whole landscape. Generally, the positive relationship between species and playa area have been supported, so biodiversity may vary depending on the scale from which it is calculated (Webb et al. 2010, Tsai et al. 2012).

To measure diversity of a population, the Shannon's *H* diversity formula is typically used as it is sensitive to rare species in the sample and relatively easy to interpret (Peet 1974). Shannon's *H* diversity index provides important information about the possibility that a random individual selected from the population is rare or common in the community, accounting for both abundance and evenness of species present in the community. Specifically, Shannon's *H* diversity index is the negative sum of the proportion of species *i* relative to the total number of species (p_i), then multiplied by the natural logarithm of the species' proportion. The resulting equation is: $H = -\sum_{i=1}^{S} p_i \ln(p_i)$ Relative levels of biodiversity can tell us if an ecosystem is stable, moving to a more disturbed or stable state, or if it might becoming nonfunctional (Huston 1979). Not only does biodiversity specifically indicate the relative stability and resilience of an ecosystem, this metric is frequently correlated with other landscape metrics, providing a bigger picture of ecosystem stability (Hooper et al. 2005).

Biodiversity in playa wetlands can be analyzed at various spatial scales. Because individual playas form a connective system, measuring biodiversity at various spatial scales will help understand the contribution of individual playa wetland to a watershed's biodiversity but also how the playa system is impacting the biodiversity in the Smoky Hill River watershed (Albanese and Haukos 2016). Biodiversity of individual systems, such as an individual playa, may be influenced by species interactions such as competition, predation, and disease transmission (Huston 1979). Landscape features have also been correlated with the distribution and abundance of avian populations (Block and Brennan 1993).

Major threats to biodiversity of the playa wetland system arise from disruptions in the natural hydrological pulses caused by watershed disturbance (e.g., cultivation and playa modification) and habitat loss through hydroperiod alteration (Bolen et al. 1989, Webb et al. 2010, Tsai et al. 2012). Anthropogenic impacts that result in hydrological modifications influences the hydroperiod (timing and duration of playa inundation), sediment yield, and volume of playas. When the normally-fluctuating hydrological condition experiences these modifications, it does not allow for playas to enter into the varying wet-dry ecological states of inundation, decreasing the biodiversity of playas and surrounding areas (Haukos and Smith 1994, O'Connell et al. 2012, Tsai et al. 2012, Albanese and Davis 2015).

The biotic community of playa wetlands is drastically influenced by anthropogenic modifications to playa hydrology (Smith and Haukos 2002, Tsai 2007, Webb et al. 2010, Tsai et al. 2012, O'Connell et al. 2013). Size, surrounding land use, and inundation state of playa wetlands (i.e., hydroperiod) can affect community composition (e.g., Tsai 2007). Factors associated with land use surrounding a playa also influence avian community composition, specifically due to the past conversion of native prairie to cropland (Whited et al. 2000, Tsai 2007). Cropland watersheds have negative impacts on playa hydrology by decreasing the hydroperiod, volume of playa, and a loss of hydric soils (Luo et al. 1997, Tsai et al. 2007, Johnson 2011). Cropland watersheds also influence the vegetation community, as cropland playas have more exotic floral species and fewer perennials than playa wetlands in a grassland watershed (Smith and Haukos 2002, Tsai et al. 2012, Chapter III). Greater sediment yields, common for playas in a cropland watershed, also decrease plant richness in small sized playas (O'Connell et al. 2013). Human disturbances of cropland playas, specifically plowing of the wetland, not only removes perennial plants from the vegetative community, but decreases overall plant community connectivity to nearby playa wetlands (O'Connell et al. 2013). Excessive sediment accumulation in the playa wetland further reduces volume and water depth in playa wetlands; a lower water depth in playa wetlands also reduces hydroperiod, which negatively influences plant communities in relation to plant richness, diversity, and cover (Tsai et al. 2012). Negative implications of reduced water depth are even more apparent in wetland-dependent plant communities, perennial richness, and cover (Tsai et al. 2012). Runoff from surrounding cropland contains excess sediment, metals, nutrients, and dissolved/suspended sediments that accumulate in playas (Haukos et al. 2016). Further, reduced vegetative cover is not effective in buffering these materials entering the playa wetland (Haukos et al. 2016). As avian communities in playas depend upon the vegetation communities (Smith et al. 2004), understanding how land use can affect avian community composition is important for conservation and management of the avian diversity in the Great Plains.

The playa hydroperiod is unpredictable and influenced through precipitation, evapotranspiration, and groundwater recharge (Smith 2003, Tsai et al. 2007, Smith et al. 2012). Native biota have adapted to the variable, unpredictable hydroperiods (Smith et al. 2002, Webb et al. 2010, Tsai et al. 2012). The adaptable persistent biota responding to the variable hydroperiods results in a unique suite of flora and fauna supported by playas (Haukos and Smith 1994, 1997, 2004). Because playas can occur in multiple ecological states of varying inundation levels, upland plants can persist in a playa basin; however, many plant species occurring in playas are wetland dependent and will not occur beyond the playa boundary (Smith and Haukos 2002).

Water depth, while influenced by surrounding land-use (Luo et al. 1997, Burris and Skagen 2013) is also shown to be a factor influencing avian community composition (Tsai 2007). Water depth in wetlands has been used as an indicator for the occurrence of wetland-dependent birds (Elphick and Oring 1998, Tsai 2007). Hydroperiod is also an indicator for amphibian species richness and community composition, which is an important food resource for a number of avian species (Venne 2006, Beas et al. 2014). Wetland-dependent birds using playa wetlands as stop-over sites during migration greatly depend on vegetation and invertebrates as a main part of their diet; thus, water depth can indirectly influence habitat use of birds during migration (Davis and Smith 1998, Anderson and Smith 2004).

Furthermore, many avian species depend on habitats created by playas transitioning among the various ecological states. This creates the opportunity for several different communities being supported by individual playas. While biodiversity and organization of communities influence the functional state of an ecosystem, biodiversity itself is an ecological service (Cardinale et al. 2012).Without the variable wet-dry ecological state changes found in highly disturbed playas, biodiversity would greatly decline (Smith and Haukos 2002, Albanese and Davis 2013). Further, anthropogenic impacts can create a loss of the natural variation in hydroperiod leading to local extinctions of immobile species (e.g., plants and invertebrates) and cease of use by mobile species (e.g., birds) (Smith and Haukos 2002, Smith et al. 2004, Venne 2006, Tsai et al. 2010, Webb et al. 2010, Tsai et al. 2012, O'Connell et al. 2013). Past conversion of native grasslands to the highly erodible cropland created an excess sediment yield in runoff, collecting in the playa basin; thus, reducing the quality of playa system and use by native biodiversity.

Disturbance in general drives ecosystem variation regarding the spatial and temporal heterogeneity in community composition (Sousa 1984). Unlike most wetland types where flooding of the wetland is the natural state, playa wetlands are typically in the dry state until a intense precipitation event occurs, creating the disturbed flooded state (Albanese and Haukos 2016). The disturbance of inundation influences wetland productivity creating heterogeneous vegetation communities, which then influences relative abundance and composition of avian communities (Tsai 2007). After the initial flooding of a playa, invertebrates and seeds in the soil will begin to emerge (Smith et al. 2012). Inundation initiates a series of successional states that influences emergence of invertebrates and plants and vertebrate response (Anderson and Smith 2000, Haukos and Smith 2004). As certain species experience an increase in population growth rate in response to the inundation disturbance, community composition will change due to a change in competition (Huston 1979). Understanding how local and regional landscape variables influence the avain community composition in playa wetlands will elucidate the relationship among avian community compositions and the ecological state of a playa wetland.

Numerous studies have reported the effects of land use on the function and occurrence of playa wetlands, but the effect that playas have on the ecological function of the landscape is not clear (Luo et al. 1997, Luo et al. 1999, Tsai et al. 2007, Johnson et al. 2011, Johnson et al. 2012, Burris and Skagen 2013, Haukos et al. 2014, Haukos et al. 2016). By definition, a landscape and habitat are scale dependent. Habitat is defined as “the resources and conditions present in an area that produce occupancy—including survival and reproduction—by a given organism” (Hall et al. 1997). Habitat must be defined in relation to a specific species, either pertaining to an individual or population with the area’s corresponding abiotic and biotic characteristics, and at specific spatial and temporal scales (Mitchell 2005). The context of scale is a key component of understanding how an ecosystem works. Whereas a habitat is an area with resources and environmental conditions to sustain occupancy, a species will occupy different habitat types during various stages of its life cycle (Dennis et al. 2003). Requirements of a species change temporally and spatially, as does the availability of habitats with variable resources and conditions. It is important to consider a multitude of scales when assessing contributions of systems to biodiversity because, at times, individual-level and population-level measures of habitat quality are not correlated due to density-dependence factors affecting population growth and reproductive rates (Boves et al. 2015). There are examples of avian species choosing habitat at different scales to maximize their fitness (Chalfoun and Martin 2007). At large spatial scales, the Brewer's sparrow (*Spizella breweri)* selected for habitats with high individual densities and more cover. At finer scales, the Brewer's sparrow selected habitats that maximize nest success by choosing habitats with a low predation rate (Chalfoun and Martin 2007). The various spatial scales where a species utilizes habitat and landscape influences overall biodiversity in different ways as changes in habitat quality and landscape composition has a significant influence on local and regional diversity (Block and Brennan 1993, Chalfoun and Martin 2007).

Landscapes that include playas should have greater biodiversity than those lacking playas at a larger scale perspective. Therefore, watershed biodiversity should include the species and abundance of the flora and fauna directly using the playa wetland, but also from the surrounding upland that directly influences the playa wetlands hydrology and function. The influence of watershed condition can be compared when assessing the influence of playas on landscape biodiversity in the Great Plains. Because a diverse species assemblage depends upon playas at various stages of their life-cycles, measuring biodiversity is an appropriate way to assess the functionality of the playa wetland ecosystem (Johnson 2011). In an effort to maintain and evaluate the biodiversity that playas support in an agriculturally intense landscape, it is critically important to understand how watershed disturbance and environmental variation influence the biotic community composition and occupancy found in playas across landscapes. Understanding how playas specifically influence landscape biodiversity provides a novel understanding of what would happen to the biodiversity in the Great Plains if playas continue to disappear on the landscape (Chapter II).

Prior studies have focused on local habitat characteristics affecting avian communities in the Southern High Plains, but similar work has yet to be done for playa wetlands in western Kansas (Smith et al. 2004, Tsai 2007, Webb et al. 2010). Understanding how local environmental factors can influence an avian diversity and community composition is key for creating conservation plans specific to habitat characteristics supported by playas. Further, environmental conditions among different regional areas throughout the range of playa occurrence may affect avian community compositions in different ways For example, playas in the southern Great Plains experience an east-to-west regional transition between prairies to the Chihuahuan Desert that may influence community composition differently than the transitional region of prairies to irrigated row-crop land-use in the central Great Plains (Johnson 2011). Thus, comparing these influences on avian community composition in playas of western Kansas to other playa areas is needed to determine if there are regional differences in avian community composition response to physical and environmental conditions. To characterize how local habitat characteristics influence the avian community composition in playas of western Kansas, my objectives were to (1) determine a relationship between diversity and the presence of a playa in the watershed, including effects of watershed land-use, (2) examine how surrounding land-use influences the avian community composition in playa wetlands between grassland and cropland watersheds, (3) examine how inundation state of playa soils (dry, moist, or flooded) influences the avian community composition in playa wetlands, and (4) compare my results to studies in other regions. Relative to each objective, I hypothesized that (1) grassland watersheds with a playa wetland will have a greater avian and floral species diversity and species richness than cropland watersheds with and without the presence of a playa (2) playas in cropland watersheds will have a higher proportion of exotic and non-native species than playas in grassland watersheds, (3) playas with a flood soil moisture will have a higher proportion of wetland-dependent birds than dry or moist playa soils, and (4) due to the agriculturally-intensive landscapes of the Central Plains and southern High Plains, diversity results will be similar to current literature.

STUDY AREA

The study area was the Smoky Hill River watershed from Kanopolis Reservoir westward in Kansas (Figure 3.1). The Smoky Hill River watershed was located in the western two-thirds of Kansas, and center of the Central Great Plains. The Smoky Hill River basin covered approximately 3.13 x 10^6 ha with a drainage area of about 31,672.96 km² (Kansas Water Office 2009). The study area was 31,500 km^2, intersecting 32 Kansas counties (Figure 3.1). The majority of land cover encompassed two primary types: grassland comprised 44% of the area and cultivated cropland covered 48% (Kansas Water Office 2009). Grasslands were dominated by herbaceous vegetation. The watershed contained a gradient of mixed-grass prairie in the east to short-grass prairie in the west corresponding to the precipitation gradient. Grasslands were used for livestock grazing. Cultivated cropland was used for the production of annual crops, actively tilled, and comprised of dry land and irrigated row crops. Major crops included wheat, sorghum, and corn (Kansas Water Office 2009). Playa wetlands within the High Plains portion of the central Great Plains were located west of the 100th meridian. The surrounding land use of playa wetlands in the Smoky Hill River watershed was dominantly row-crop agriculture, with >93% of playa wetlands located within a cropland watershed (Chapter II). Playas were only found in the western 17 counties of the watershed (Figure 3.1). Playas in western Kansas are typically 91% and 67% smaller in size than playas in the Southern High Plains, for playas in a grassland and cropland watershed, respectively (Johnson 2011). The majority of playas in western Kansas are <1 ha, with sizes ranging from a minimum of 0.03 ha to a maximum area of 345 ha (estimates from USGS Digital Raster Graph of topographic map). Current estimate of the average area of playas in western Kansas is 1.65 ha (National Agriculture Imagery Program, Bowen et al. 2010).

METHODS

My study was conducted on 28 playa wetlands over two years in the Smoky Hill River Watershed. Eight playas were located in a grassland watershed and 20 were surrounded by a row-crop agriculture watershed. At each sampled playa, I conducted avian and vegetative cover surveys to measure species occurrence and abundance. I established avian point-count surveys at the playa wetland and a randomly paired point within a 500-m buffer outside of the playa area in the surrounding watershed to record species occurrence and relative abundance. I measured plant species occurrence and relative abundance using transects within each playa.

Biotic field data were used to estimate species richness and calculate a Shannon's *H* Diversity Index, both of which served as an index of wetland function. Relative abundance, richness, and diversity index were then related to the surrounding land use. Estimates of species richness and biodiversity were estimated for each individual playa wetland and for all playas combined. Soil moisture condition of the playa wetland at the time of the survey was recorded as dry, moist, or flooded (Haukos and Smith 2004). To estimate species richness and diversity at the watershed level, species richness and biodiversity were estimated combining biotic data from inside of the playa wetland and a paired non-playa area to include all species and relative abundance in the watershed. Paired non-playa sites were randomly were selected from a random direction and distance no greater than 500-m away from the playa boundary. Avian and vegetative surveys follow methods that Webb et al. (2010) created for small isolated wetlands from the Rainwater Basin playas and Smith and Haukos (2002) used in Southern High Plains playas.

Multivariate ordination methods are useful tools in assessing community composition through the use of reducing dimensionality and visualizing patterns in multivariate data (Anderson and Willis 2003). Canonical correspondence analysis (CCA) is particularly useful as axes are organized to maximize correlation relationships with quantitative predictor variables (Anderson and Willis 2003). Ordination is a popular method in ecology to test relationships between environmental conditions and avian species composition (e.g., Tsai 2007).

Avian Breeding Surveys

At each sampled playa, I conducted avian surveys at pre-established points. Surveys were conducted for three consecutive days in early summer (May to June) and again in late summer (July to August), with each playa surveyed three times on consecutive days during each survey period. Before entering the wetland, all visible birds in the playa area were recorded from an initial vantage point. I then proceeded to the pre-established point(s) to survey avian species not visible in the initial vantage observation. Survey bouts lasted 10 minutes at each point location (vantage points, playa points, and paired non-playa points) and all visible species and abundance were recorded. In large wetlands, where a single observation point was not sufficient to detect all birds, I varied the number of point counts at each playa to increase the detection of birds (Webb et al. 2010). In flocks <100 birds, I recorded each species and abundance. In flocks >100 birds, I recorded species and visually estimated abundance of individuals of each species. Any bird sighted inside of the playa boundary was included. Species flying over the playa were excluded from analyses unless the individual bird utilized the playa area by searching for food or other resources (Webb et al. 2010, Tsai et al. 2012). To identify avian species, I used binoculars and a scope to identify avian species and Sibley (2014) as the authority used to identify avian species.

Flora Surveys

I assessed plant communities in each playa using the protocol developed by Haukos and Smith (2004). Vegetation composition data were collected twice in each sampled playa, once to detect early summer (May to June) plant communities and then for late summer (July to August) plant communities. Plant species occurrence was detected using step-point sampling, recording species approximately each 1 m along transects. Step-point methods were used along two transects. The first transect began in the southeast boundary of the playa and proceeded at a 45 degree angle to the west boundary of the playa basin; the second transect began on the west side of the playa boundary and proceed at a 45 degree angle to the northeast boundary of the playa basin. At each point, plant species or bare ground was recorded. To identify plants, I used Barkley (1983), Haukos and Smith (1997), and Haddock (2005) to identify recorded species.

Statistical Analyses

Because species richness consisted of counts, I used a generalized linear model with Poisson regression to test for differences in flora species richness between years (2015, 2016) and watershed type (cropland, native grassland). I used Poisson regression to test for differences in season-long avian species richness between years (2015, 2016), watershed type (cropland, native grassland), and survey location (playa, nonplaya). The assumption that the occurrence of each species in independent is met due to the timing of the breeding bird surveys, where breeding birds establish independent breeding territories, where species occurrence is independent of other species occurrences. Results from the Poisson regressions are presented as $\beta \pm$ SE. I ranked transformed the flora Shannon diversity values and compared mean values between year and watershed type using a nonparametric two-way factorial analysis of variance. I ranked transformed the season-long avian Shannon diversity values and compared mean values between year, watershed type, and survey location using a nonparametric three-way factorial analysis of variance. I used linear regression to test the influence of playa size on flora and avian species richness. Statistical significance was established at $\alpha = 0.05$.

An ordination analysis was used to assess relationships among avian community composition and environmental considerations. A CCA was performed using two matrices: an avian response matrix and an explanatory habitat characteristic matrix. To perform a CCA, the following packages were used in Program R: vegan, BiodiversityR, labdsv, and MASS. The response matrix was a species matrix indicating the occurrence and abundance of each avian species for all playa wetlands from the avian surveys performed during this study. To follow CCA assumptions that communities respond in a unimodal fashion to environmental variables, community data were log-transformed (Borcard et al. 2011). To test the significance of the CCA, 1000 permutation tests were performed on the CCA results. To test the significance of each axis, 1000 permutation tests were performed on each axis. The explanatory matrix identified each playa with its surrounding land-use, inundation of soil, and year of study.

Inundation of soil was identified as "dry" if the soil was not moist during any survey for each year. Soil was identified as "moist" if the soil held water during the time of survey. Soil was identified as "flooded" if the center of the playa held >15 cm of water for an extended period of time longer than the duration of the surveys. If species weights in the ordination were overlaying each other, I expanded the area to include all species that were previously hidden by overlaying species into a circle directed to the side of the ordination.

RESULTS

During 2015 and 2016, I surveyed 40 playas with cropland watersheds and 15 grassland watersheds for flora and avian richness and diversity. Playa size range ranged from 0.14 – 93.48 ha. After removing the 93.48 ha outlier, average playa size was 5.21 ha (SE = 1.25). I identified 57 flora (Table 3.1) and 70 avian (Table 3.2) species. I recorded occurrence of avian species in 65% and 35% of playa surveys with dry and moist/inundated ecology states, respectively. Of the 27 playas sampled in 2015, 15, 9, and 3 playas had inundation characteristics of dry, moist, and flooded, respectively. Of the 28 playas sampled in 2016, 21, 2, and 5 playas had the soil inundation characteristic of dry, moist, and flooded, respectively.

Floral metrics

Flora species richness changed little between the two survey periods (Table 3.1). Species composition turnover between early and late surveys was 63% for playas with cropland watersheds and 53% for playas with grassland watersheds. Flora species richness did not differ between years for the early season survey (β =-0.38 ± 0.35; P = 0.29), late season survey (β =-

0.01 ± 0.32; $P = 0.96$), or entire season survey ($\beta = -0.12 \pm 0.09$; $P = 0.16$). Flora species richness differed between watershed type for the early season survey ($\beta =- 1.30 \pm 0.35$; $P = 0.0002$), late season survey ($\beta =-0.91 \pm 0.32$; $P = 0.004$), or entire season survey ($\beta =- 0.96 \pm 0.09$; $P < 0.001$). Playas with grassland watersheds had approximate three times greater species richness than those with cropland watersheds (Figure 3.2).

Flora Shannon's species diversity was similar between the two survey periods (Table 3.1). There was not an interaction between year and watershed type for flora diversity for the early season survey ($F_{1,50} = 1.07$, $P = 0.30$), late season survey ($F_{1,48} = 2.72$, $P = 0.11$), or for both surveys combined ($F_{1,50} = 0.02$, $P = 0.90$). Flora diversity did not differ between years for the early season survey ($F_{1,50} = 2.17$, $P = 0.15$), late season survey ($F_{1,48} = 0.09$, $P = 0.76$), or for both surveys combined ($F_{1,50} = 0.46$, $P = 0.50$). However, flora diversity differed between watershed types for the early season survey ($F_{1,50} = 31.08$, $P < 0.001$), late season survey ($F_{1,48} = 25.20$, $P < 0.001$), and for both surveys combined ($F_{1,50} = 27.69$, $P < 0.001$: Figure 3.3).

Flora species richness was related to playa size ($F_{1,39} = 4.67$, $P = 0.04$). Although playa size did not have much predictive capacity ($r^2 = 0.11$), there was a clear trend of increasing species richness with playa size (Figure 3.4).

Avian metrics

I counted 1,074 individuals of 35 avian species in 2015 and 2,112 individuals of 65 species in 2016; with a total of 70 avian species. Of the 70 species, 32 were wetland-dependent species and 38 were non-wetland dependent species. Of the 35 species in 2015, four were wetland dependent species and 31 were non-wetland dependent species. Of the 65 species counted in 2016, 32 were wetland dependent species and 33 were non-wetland dependent species

(Table 3.2). Avian species richness for individual playas ranged from a maximum of 42 species and a minimum of three species.

I was most interested in the total contribution of playas to landscape avian species richness and biodiversity, thus I present the mean avian richness and diversity values of playa areas compared to the mean avian richness and diversity values of nonplaya areas for the early and late surveys by watershed condition (Table 3.2). Average avian species richness for the entire season did not differ between 2015 (8.42 ± 0.41) and 2016 (7.88 ± 0.80; $\beta = -0.08 \pm 0.07$, $P = 0.21$). Avian species richness for the entire season differed between watershed type ($\beta = 0.51 \pm 0.07$, $P < 0.001$) and playa and nonplaya areas ($\beta = 0.26 \pm 0.07$, $P < 0.001$). However, when comparing playa to nonplaya avian richness, patterns differed between watershed types. For playas with cropland watershed types, average season long species did not differ between playa and nonplaya areas ($\beta = 0.11 \pm 0.08$, $P = 0.17$; Figure 3.5). However, for playas for grassland watershed types, avian species richness in playas was nearly double that of associated nonplaya areas ($\beta = 0.50 \pm 0.11$, $P < 0.001$; Figure 3.5).

Avian diversity had a greater difference between playa and nonplaya locations for grassland watersheds compared to cropland watersheds (Table 3.2). There were no interactions among year, watershed condition, and location (i.e., playa vs. nonplaya) (all $P > 0.11$). There was no difference in species diversity between years ($F_{1,102} = 1.85$, $P = 0.18$). Avian species diversity differed between watershed category ($F_{1,102} = 41.62$, $P < 0.001$) and location ($F_{1,102} = 3.92$, $P = 0.05$) (Figure 3.6). For playas with cropland watersheds, there was no difference in avian species diversity between playa and nonplaya locations ($F_{1,78} = 0.11$, $P = 0.74$; Figure 3.6). However, avian species diversity differed between playa and nonplaya locations for playas with grassland watersheds ($F_{1,28} = 7.07$, $P = 0.01$; Figure 3.6)

Avian species richness was marginally related to playa size ($F_{1,41} = 3.22$, $P = 0.08$). However, playa size had little predictive capacity ($r^2 = 0.07$) for total avian richness, but there was a trend of increasing species richness with playa size (Figure 3.7).

CCA Results

Permutation tests show that the additive model including all environmental variables (land use, soil inundation, and year) was significant to explain the variability in the avian community (ANOVA, $F_{4,50} = 4.25$, $P = 0.001$). The model explained 25% of the total variability (total mean squared contingency coefficient = 3.115, unconstrained mean squared contingency coefficient = 0.791) in the avian community matrix. The first two axes explained 65% of the constrained variability and were the only axes deemed significant in the model ($F_{1,50} = 10.241$, $P = 0.001$; $F_{1,50} = 3.724$, $P = 0.010$). The level of soil inundation, represented by the first axis CCA1, was the most significant variable in explaining the avian community variability and explained 47% of the constrained variability ($F_{2,50} = 5.224$, $P = 0.001$; Figure 3.8 and 3.9). Surrounding land use (i.e. grassland or cropland), represented by the second axis, CCA2, significantly explained 17% of the constrained variability in the avian community ($F_{1,50} = 5.313$, $P = 0.003$).

The five most common grassland species among all avian communities included the Horned Lark followed by Red-winged Blackbird, Western Meadowlark, Lark Bunting, and Mourning Dove with abundances of 444, 384, 255, 212, and 207 individuals, respectively (Figure 3.10, Table 3.3).

DISCUSSION

It is clear that both watershed cover type and the presence of playas on the landscape influences biodiversity of the Smoky Hill River watershed. Playas with cropland watersheds contribute little to richness and diversity beyond nonplaya areas, whereas playa wetlands in a grassland watershed contribute almost double the number of avian species richness than what would be expected without playas occurring on the landscape. If playa wetlands continue to be lost at an alarming rate (Chapter II), the Great Plains will experience a drastic decrease in the capacity of the landscape to support the historical number of species and overall avian diversity. Reduction in expected species richness and diversity is associated with an ecologically unstable ecosystem from negative effects such as increased possibility of invasion of exotic species and disease spread in populations (Isbell et al. 2011, Hooper et al. 2005). Management to conserve diversity in the Great Plains should therefore include watershed management and maintenance of playas on the landscape.

Watershed condition had a greater influence on avian diversity than location (i.e., playa and nonplaya). In grassland watersheds, the presence of playas not only significantly increased the number of avian species and diversity compared to the surrounding landscape, but was also contributing much more species richness and diversity than playa wetlands located in a cropland watershed. As individual playas fill with sediment in a cropland and loses ecological function as the hydrology becomes negatively influenced by high sediment yields (Luo et al. 1997, Luo et al. 1999), species richness and diversity declines to levels similar to nonplaya areas within the surrounding watershed. Playa wetlands in a grassland watershed are critically important for maintenance of natural levels of diversity in the Smoky Hill River watershed.

Floral species richness and diversity of playa wetlands differed dramatically between watershed conditions. Less disturbed grassland playas supported three times the extent of floral diversity and richness than playas surrounded by cropland watersheds. As most playa wetlands in croplands are subject to watershed cultivation and tilling, the high seasonal turnover rate seen in the floral communities in croplands indicate the lack of persistence of cool-season plants through the summer season. The trend of cropland playas containing a greater percentage of non-native plants than native plants is seen in the playas in western Kansas as well as in the Southern High Plains (Smith and Haukos 2002). However, unlike playa wetlands in the Southern High Plains, cropland playas did not have a higher species richness than grassland playas (Smith and Haukos 2002). Following tilling practices, plant communities can become established and begin growing in the playa if the floral seed bank has not been too drastically destroyed (Smith and Haukos 2002, Tsai et al. 2012, O'Connell et al. 2013). Typically, plants that are able to grow from bare ground of a tilled cropland include invasives and annuals instead of the typical perennials of well-functioning playa wetlands (Smith and Haukos 2002). Floral communities in grassland watersheds are not exposed to such a drastic soil disturbance cycle and therefore, are represented by native perennial plants (Smith and Haukos 2002, Tsai et al. 2012, O'Connell et al. 2013).

Large playas, specifically those greater than 0.5 ha (Chapter II) need to be selected for playa conservation. Large playas are associated with increased avian density and richness (Webb et al. 2010, Tsai et al. 2012, Albanese and Davis 2013, Albanese and Davis 2015). Large playas are also less susceptible to filling of sediment, thus persist on the landscape longer than smaller playas (Luo et al. 1997, Johnson 2011, others).Playa size also impacts inundation occurrence (Johnson et al. 2011)

Identifying habitats that support a unique assemblage of species is key to conservation of playa wetlands in the Great Plains. Results from ordination analyses indicate that grassland playas support a unique assemblage of avian species dependent on watershed type and soil moisture. Playas with grassland watersheds experience the natural wet-dry fluctuation common of playa wetlands; thus, functioning at a greater ecological level than cropland playas, allowing more unique species to persist in grassland playas.

Surrounding land use of the playa explains variation in the avian community composition as well as avian diversity. Playa wetlands in a grassland watershed had a highly variable avian community composition with the community composition showing a dependence to playa soil moisture. The playa avian community composition surrounded by cropland, however, was constrained and did not show as much variability in the community composition compared to the communities in grassland watersheds. When a playa wetland becomes inundated, the avian community composition shifts to include unique wetland-dependent species that do not occur at other moisture levels (i.e. dry or moist playa soils). Further, the soil moisture gradient from flooded to moist to dry soils shows variable avian community compositions associated with each moisture regime, adding unique assemblages of avian species in grassland playas. The two dimensions of land-use and playa inundation affecting the avian species composition are important factors to consider for conservation and management plans targeting a specific group of avian species.

Other disturbances influencing the ecological state of playa wetlands is related to watershed disturbance, where excess sediment will accumulate in the playa and is the main threat to existence of playas (Smith 2003, Tsai 2007, Johnson 2011). As disturbances influence the ecological state of the playa, communities will experience a direct effect on survival, abundance, and diversity of species (Svensson et al. 2007). Different disturbance levels/intensities will be favored by different community compositions (Tsai 2007). The variable hydroperiod of playas correlates highly with the various species composition (Tsai 2007, Webb et al. 2010, Tsai et al. 2012). This is of important consideration in an effort to identify and predict species distributions as the spatial and temporal distribution of species change in relation to the variable environmental factors.

While the majority of playa wetlands in the Smoky Hill River watershed were located in a cropland watershed, communities originating from cropland sites only support a limited number of species relative to grassland watersheds. The majority of species were negatively associated with cropland watersheds, indicating that playa wetlands in grasslands are important for maintaining the variable inundation periods to which native species respond.

It is clear that the greatest abundance of wetland-dependent birds were associated with a flooded regime in playas in the Smoky Hill River watershed, with 97% of the species considered to be wetland-dependent. Flooding regime directly influences the vegetative community as high water levels inhibit growth of many non-wetland plant species, potentially decreasing the vegetation in the basin of the flooded playa until submergent plant communities develop, but a unique assemblage of vegetation surrounding the playa edge will develop where water has drawn down (Smith and Haukos 2002, Haukos and Smith 2004, Tsai 2007, Webb et al. 2010, O'Connell et al. 2013). After flooding events, a critical period occurs as the playa wetland dries, a requirement for the reestablishment of many plant species (Smith 2003). Species will utilize these transition periods and provide yet another unique assemblage of species. Communities of shorebirds have been known to rapidly react to the unpredictable environment of wetlands in the Great Plains, occurring almost immediately in flooded wetlands (Skagen and Knopf 1994). As avian use of playas change, so does the distributions of these shorebirds, decreasing density in areas of clustered playas, spreading out and using more flooded habitats (Tsai 2007).

There is a unique assemblage of species in each of the soil moisture regimes. The group associated with flooded playas in a grassland watershed can be associated with the species that drove those playas to have a greater species richness and diversity than playas with other moisture regimes or watershed types. This group of species includes: field sparrows, ferruginous hawk, lark sparrow, mountain plover, and Swainson's hawk. In addition, there is a unique assemblage of species associated with undisturbed moist sites: American robin, Baltimore oriole, Eurasian-collared dove, European starling, house sparrow, rock pigeon, and yellow-headed blackbird. The remainder of the recorded species occurred ubiquitously near the origin, just selecting grassland playas without regard to inundation status. There was one clustered section in the dry soil moisture regime that was strictly avian species only occurring in cropland. The species that were only found in a cropland included a single observation of the following conspicuous species: a lark sparrow, ferruginous hawk and a mountain plover. While more than one observation was observed for the following more social birds, still only observed in a cropland playa: Swainson's hawks and field sparrows. This shows that while dry croplands do support a different community composition, it includes a different assemblage of species, particularly only generalist species are able to occupy habitats associated with dry croplands, such as the species found in all watershed types and soil moisture regimes: horned lark, red-winged blackbird, and mourning dove.

The presence of functional playas capable of responding to the wet-dry fluctuations is critically important. Grassland playas offer a unique assemblage of species that respond to the environmental variables of watershed disturbance and soil moisture regime, whereas species found in dry croplands are clustered together in a small group, identifying grassland playas as a key source of diversity in the avian community composition in the Great Plains. Further, in the face of future climate change scenarios, watershed management is crucial to conservation of the playa system. The local climate change predictions of increased daily average temperatures, coupled with more intense and less frequent precipitation events, will cause changes to the frequency and duration of playa inundation (Bolen et al. 1989, Brunsell et al. 2010, Cook et al. 2015, Renton et al. 2015). Intense precipitation events increase the sediment yield and nutrient pollution in the watershed runoff reaching the depressional wetland, resulting in a change of duration and frequency of the hydroperiod (Luo et al. 1999, Mitsch and Gosselink 2007, Kansas Water Office 2009*)*. Large precipitation events, such as floods, increase the risk of soil erosion, leading to greater sediment accumulation and nutrient pollution in depressional wetlands (Luo et al. 1999, Burris and Skagen 2013, Haukos et al. 2016). The effects of large precipitation events will be observed in the declined function of the playa wetland to hold water and flooded playas will dissipate the flooded water onto surrounding lands, causing disturbances to cropland, homes, communities, and roads (Brunsell et al. 2010, Renton et al. 2015).

Further, future predictions indicate that the expected increase in sediment accumulation will result with nearly all playas filled by sediment in 100 years (Burris and Skagen 2013). Playas in a cropland watershed, accumulating greater than twice the amount of sediment accumulation rate than grassland playas, will experience the negative impacts of predicted climate changes at a greater and faster rate, causing playas to be lost from the landscape at a faster rate (Burris and Skagen 2013). It has been shown that the future playa wetland system will be almost completely abolished due to high sediment yield with land use affecting sedimentation rates more so than future climate predictions (Smith et al. 2011, Burris and Skagen 2013).

Negative influences to playa hydrology by disturbed watersheds threaten the avian community composition. Communities located in cropland watersheds do not seem to be influenced by environmental variables with little variation in the community composition across soil moisture conditions; thus, not adding any unique diversity contribution to the landscape and decreasing the potential species richness and diversity that undisturbed playa watersheds offer. Many ubiquitous and generalist avian species were not affected by the soil moisture regime or watershed type, and will thus appear in any playa condition. Even that being said, when the playa hydrology experiences natural dry-wet pulses, common in grassland watersheds where there is not an excess of sediment in the playa, there are several unique groups of species that playa wetlands support that the surrounding landscape does not. Numerous wetland-obligate species will be negatively affected by the future variation in hydrology as certain organisms (e.g., amphibians, invertebrates, and waterfowl) need specific hydroperiods to complete their lifestyle (Venne 2006, Renton et al. 2015). As playas fill with excess sediment, the proportion of exotic species will increase as hydroperiod and productivity decrease (Smith and Haukos 2002, Gleason et al. 2003, Tsai et al. 2007). Lower productivity will negatively affect the populations. Specifically, avian populations will experience a decrease in the quantity of available nutrients as excess sediment will suppress seedling and invertebrate emergences (Gleason et al. 2003) As there are many migrating birds that use playas as stop-over points, a change in the hydroperiod and community could influence biodiversity at a global scale.

There is a large possibility of a delayed effect of animal populations having to either adapt or migrate to other land or face uncertainty in a change of habitat and water quality and quantity (Venne 2006, Cook et al. 2015). Community composition will change during the periods of greater sediment yield in the intense rain events, with more exotics and annuals able to adapt to the change (O'Connell et al. 2013). The increase in intense precipitation patterns will not outweigh the consequences resulting from the increased evapotranspiration rates from a rise in temperatures and evaporative demands.

Watershed condition greatly influences the avian and floral richness and diversity in the Great Plains. Conservation plans need to address the quantity of watershed disturbance to protect these critical stop-over sites used by migrating species. The quality of nonbreeding habitat can cause demographic consequences through cross-seasonal effects causing a difference in body condition, or affecting the migration travel, which influences future reproductive success (Pulliam 1988, Norris 2005). Many measured population attributes are likely a function of prior habitat condition (Mitchell 2005), which furthers the need to include watershed condition in management plans. By continuing to lose playa wetlands, many avian populations in North America may drastically decrease, thus effect the landscape ecological function as a whole. The transformation from grassland to cropland in watersheds has a tremendous effect on the ability of the playa system to support biodiversity. Therefore, conservation efforts should focus on conservation of playa wetlands located in a grassland watershed to support the various flora and fauna using playa wetlands in the Great Plains.

LITERATURE CITED

Albanese, G., and C. A. Davis. 2013. Broad-scale relationships between shorebirds and landscapes in the southern Great Plains. Auk 130:88–97.

Albanese, G., and C. A. Davis. 2015. Characteristics within and around stopover wetlands used by migratory shorebirds: is the neighborhood important? Condor 117:328-340.

Albanese, G., and D.A. Haukos. 2016. A network model framework for prioritizing wetland conservation in the Great Plains. Landscape Ecology DOI 10.1007/s10980-016-0436-

Anderson, J. T., and L. M. Smith. 2004. Persistence and colonization strategies of playa wetland invertebrates. Hydrobiologia 513:77-86.

Anderson, M. J., and T. J. Willis. 2003. Canonical analysis of principal coordinates: a useful method of constrained ordination for ecology. Ecology 84:511-525.

Barkley, T. M. 1983. Field Guide to the common weeds of Kansas. University Press of Kansas, Lawrence, Kansas, USA.

Beas, J. B., L. M. Smith, T. G. LaGrange, and R. Stutheit.2014. Effects of sediment removal on vegetation communities in Rainwater Basin playa wetlands. Journal of Environmental Management 128:371-379.

Block, W. M. and L. A. Brennan. 1993. The habitat concept in ornithology: theory and applications. Current Ornithology 11:35-91.

Bolen, E. G., L. M. Smith, and H. L. Schramm Jr. 1989. Playa lakes: prairie wetlands of the southern High Plains. Bioscience 39:615-623.

Borcard, D., P. Legendre, and F. Gillet.2011. Numerical Ecology with R. Springer Science Business Media, New York, NY, USA.

Boves, T. J., A. D. Rodewald, P. B. Wood, D. A. Buehler, J. L. Larkin, T. B. Wigley, and P. D. Keyser.2015. Habitat quality from individual- and population-level perspectives and implications for management. Wildlife Society Bulletin 39:443-447.

Bowen, M. W., W. C. Johnson, S. L. Egbert, and S. T. Lopfenstein. 2010. A GIS-based approach to identify and map playa wetlands on the High Plains, Kansas, USA. Wetlands 30:675-684.

Cardinale, B.J., J. E. Duffy, A. Gonzalez, D. U. Hooper, C. Perrings, P. Venail, A. Narwani, G. M. Mace, D. Tilman, D. A. Wardle, A. P. Kinzig, G. C. Daily, M. Loreau, J. B. Grace, A. Larigauderie, D. S. Srivastava, and S. Naeem. 2012. Biodiversity loss and its impact on humanity. Nature 486:59-67.

Chalfoun, A. D., and T. E. Martin. 2007. Assessments of habitat preferences and quality depend on spatial scale and metrics of fitness. Journal of Applied Ecology 40:983-992.

Davis, C. A., and L. M. Smith. 1998. Behavior of migrant shorebirds in playas of the Southern High Plains, Texas. Condor 100:266-276.

Dennis, R. L. H., T. G. Shreeve, and H. V. Dyck. 2003. Towards a functional resource-based concept for habitat: a butterfly biology viewpoint. Oikos 102:417-426.

Elphick, C. S., and L. W. Oring. 1998. Winter management of Californian rice fields for waterbirds. Journal of Applied Ecology 35:95-108.

Haddock, M. J. 2005. Wildflowers and grasses of Kansas: a field guide. University Press of Kansas, Lawrence, KS, USA.

Hall, L. S., P. R. Krausman, and M. L. Morrison. 1997. The habitat concept and a plea for standard terminology. Wildlife Society Bulletin 25:173-182.

Hanson, G. C., P. M. Groffman, and A. J. Gold. 1994. Symptoms of nitrogen saturation in a riparian wetland. Ecological Applications 4:750-756.

Haukos, D. A. and L. M. Smith. 1994. The importance of playa wetlands to biodiversity of the Southern High Plains. Landscape and Urban Planning 28:83-98.

Haukos, D. A. and L. M. Smith. 1997. Common flora of the playa lakes. Texas Tech University Press, Lubbock, TX, USA.

Haukos, D. A. and L. M. Smith. 2004. Plant communities of playa wetlands. Special Publication 47, The Museum of Texas Tech University, Lubbock, TX, USA.

Haukos, D. A., L. A. Johnson, L. M. Smith, and S. T. McMurry. 2016. Effectiveness of vegetation buffers surrounding playa wetlands at contaminant and sediment amelioration. Journal of Environmental Management 181: 552-562.

Hooper, D. U., F.S. Chapin, III, J. J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J. H. Lawton, D. M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setala, A. J. Symstad, J. Vandermeer, and D. A. Wardle. 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monographs 75:3-35.

Huston, M. 1979. A general hypothesis of species diversity. The American Naturalist 113:81-101.

Isbell, F., V. Calcagno, A. Hector, J. Connolly, W. S. Harpole, P. B. Reich, M. Scherer-Lorenzen, B. Schmid, D. Tilman, J. van Ruijven, A. Weigelt, B. J. Wilsey, E. S. Zavaleta, and M. Loreau. 2011. High plant diversity is needed to maintain ecosystem services. Nature 477:199-202.

Johnson, L. A. 2011. Occurrence, function, and conservation of playa wetlands: the key to biodiversity of the Southern Great Plains. Dissertation, Texas Tech University, Lubbock, USA.

Johnson, L. A., D. A. Haukos, L. M. Smith, and S. T. McMurry. 2012. Physical loss and modification of Southern Great Plains playas. Journal of Environmental Management 112:275-283.

Kansas Water Office. 2009. Smoky Hill-Saline River Basin. http://www.kwo.org/Water%20Plan/KWP2009/Rpt_SHS_Entire_Basin_Section_KWP_2009.pdf.

Knoll, L. B., M. J. Vanni, and W. H. Renwick. 2003. Phytoplankton primary production and photosynthetic parameters in reservoirs along a gradient of watershed land use. Limnology and Oceanography 48:608-617.

Luo, H. R., L. M. Smith, B. L. Allen, and D. A. Haukos. 1997. Effects of sedimentation on playa wetland volume. Ecological Applications 7:247-252.

Luo, H. R., L. M. Smith, D. A. Haukos, and B. L. Allen. 1999. Sources of recently deposited sediments in playa wetlands. Wetlands 19:176-181.

Mason, C. F., and S. M. Macdonald. 2000. Influence of landscape and land-use on the distribution of breeding birds in farmland in eastern England. Journal of Zoology 251:339-348.

Mitchell, S. C. 2005. How useful is the concept of habitat? A critique. Oikos 110:634-638.

National Agriculture Imagery Program. Farm Service Agency. Available via: www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/index.

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Norris, D. R. 2005. Carry-over effects and habitat quality in migratory populations. Oikos 109:178-186.

O’Connell, J.L., L. A. Johnson, L. M. Smith, S. T. McMurry, S.T., and D. A. Haukos. 2012. Influence of land-use and conservation programs on wetland plant communities of the semi-arid United States Great Plains. Biological Conservation 146: 108–115.

O'Connell, J. L., L. A. Johnson, D. W. Daniel, S. T. McMurry, L. M. Smith, and D. A. Haukos. 2013. Effects of agricultural tillage and sediment accumulation on emergent plant communities in playa wetlands of the U.S. High Plains. Journal of Environmental Management 120:10-7.

Peet, R. K. 1974. The measurement of species diversity. Annual Review of Ecology and Systematics 5:285-307.

Pulliam, H. R. 1988. Sources, sinks, and population regulation. The American Naturalist 132:652-661.

Shutler, D., A. Mullie, and R. G. Clark. 2000. Bird communities of prairie uplands and wetlands in relation to farming practices in Saskatchewan. Conservation Biology 14:1441-1451.

Sibley, D. A. 2014. The Sibley guide to birds. Second Edition. Second edition. Knopf Doubleday Publishing Group, New York, New York, USA.

Skagen, S. K. and F. L. Knopf. 1994. Migrating shorebirds and habitat dynamics at a prairie wetland complex. Wilson Bulletin 106:91-105.

Smith, L. M. 2003. Playas of the Great Plains. University of Texas Press. Austin, Texas, USA.

Smith, L. M., and D. A. Haukos. 2002. Floral diversity in relation to playa wetland area and watershed disturbance. Conservation Biology 16 (4): 964-974.

Smith, L. M., D. A. Haukos, and R. M. Prather. 2004. Avian response to vegetative pattern in playa wetlands during winter. Wildlife Society Bulletin 32:474-480.

Smith, L. M., D. A. Haukos, and S. T. McMurry. 2012. High Plains playas. Pages 299-311 in D.P. Batzer and A. H. Baldwin, editors. Wetland habitats of North America: ecology and conservation concerns. University of California Press, Berkley, USA.

Sousa, W. P. 1984. The role of disturbance in natural communities. Annual Review of Ecology and Systematics 15:353-391.

Svensson, J. R., M. Lindegarth, M. Siccha, M. Lenz, M. Molis, M. Wahl, and H. Pavia. 2007. Maximum species richness at intermediate frequencies of disturbance: Consistency among levels of productivity. Ecology 88:830-838.

Tilman, D. and J. A. Downing. 1994. Biodiversity and stability in grasslands. Nature 367:363-365.

Tsai, J. S., L. S. Venne, S. T. McMurry, and L. M. Smith. 2007. Influences of land use and wetland characteristics on water loss rates and hydroperiods of playas in the Southern High Plains, USA. Wetlands 27:683-692.

Tsai, J. S., L. S. Venne, S. T. McMurry, and L. M. Smith. 2010. Vegetation and land use impact on water loss rate in playas of the Southern High Plains, USA. Wetlands 30:1107-1116.

Tsai, J.S., L. S. Venne, L. M. Smith, S. T. McMurry, and D. A. Haukos. 2012. Influence of local and landscape characteristics on avian richness and density in wet playas of the southern Great Plains, USA. Wetlands 32:605-618.

US Fish and Wildlife Service. 2016. National wetlands inventory website. US Department of the Interior, Fish and Wildlife Service, Washington D.C., USA.

Venne, L. S. 2006. Effect of land use on the community composition of amphibians in playa wetlands. Master of Science, Texas Tech University, Lubbock, USA.

Voldseth, R. A., W. C. Johnson, T. Gilmanov, G. R. Guntenspergen, and B. V. Millett. 2007. Model estimation of land-use effects on water levels of northern prairie wetlands. Ecological Applications 17:527-540.

Webb, E. B., L. M. Smith, M. P. Vrtiska, and T. G. Lagrange. 2010. Community structure of wetland birds during spring migration through the Rainwater Basin. Journal of Wildlife Management 74:765-777.

Whited, D., S. Galatowitsch, J. R. Tester, K. Schik, R. Lehtinen, and J. Husveth. 2000. The importance of local and regional factors in predicting effective conservation: Planning strategies for wetland bird communities in agricultural and urban landscapes. Landscape and Urban Planning 49:49-65.

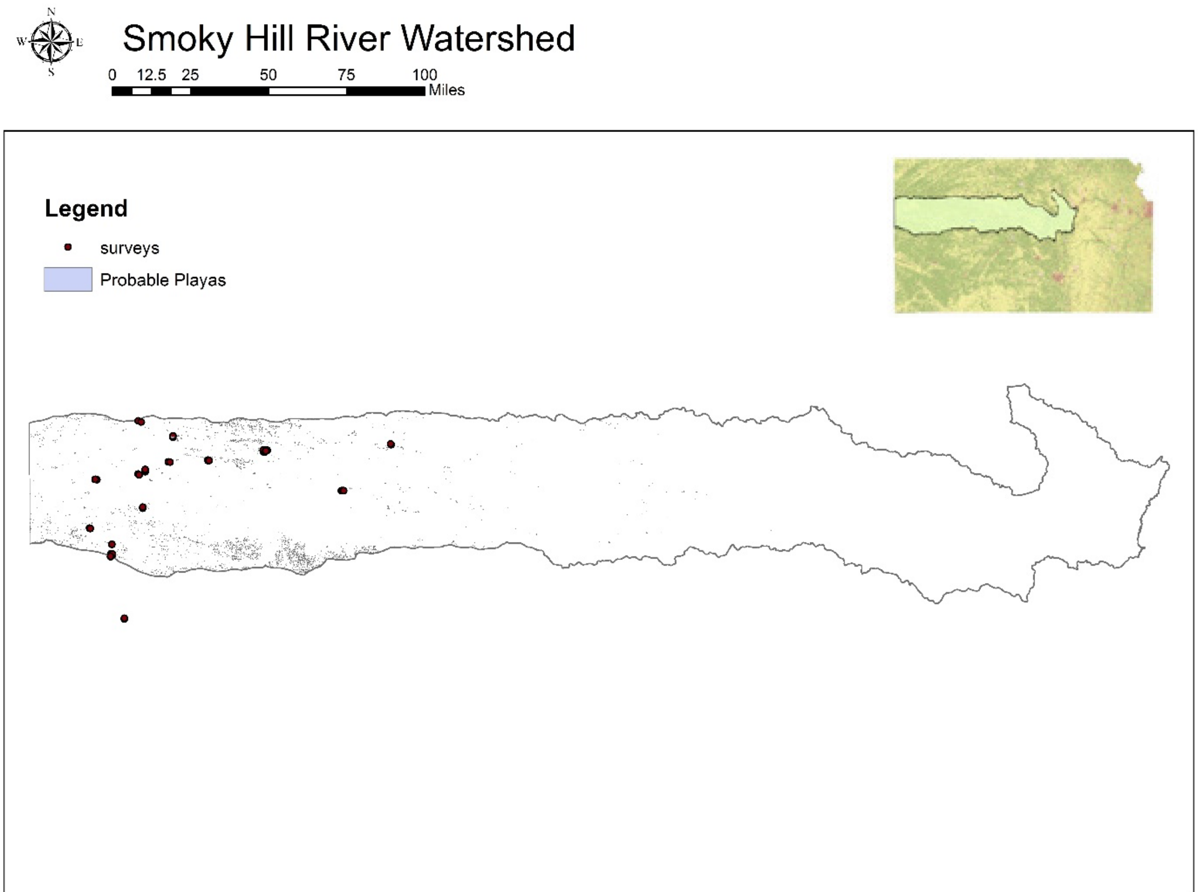

Figure 3.1 A geographical map of playa wetlands and surveyed playas in the 3.13 x 10^6 ha Smoky Hill River watershed in western Kansas, USA.

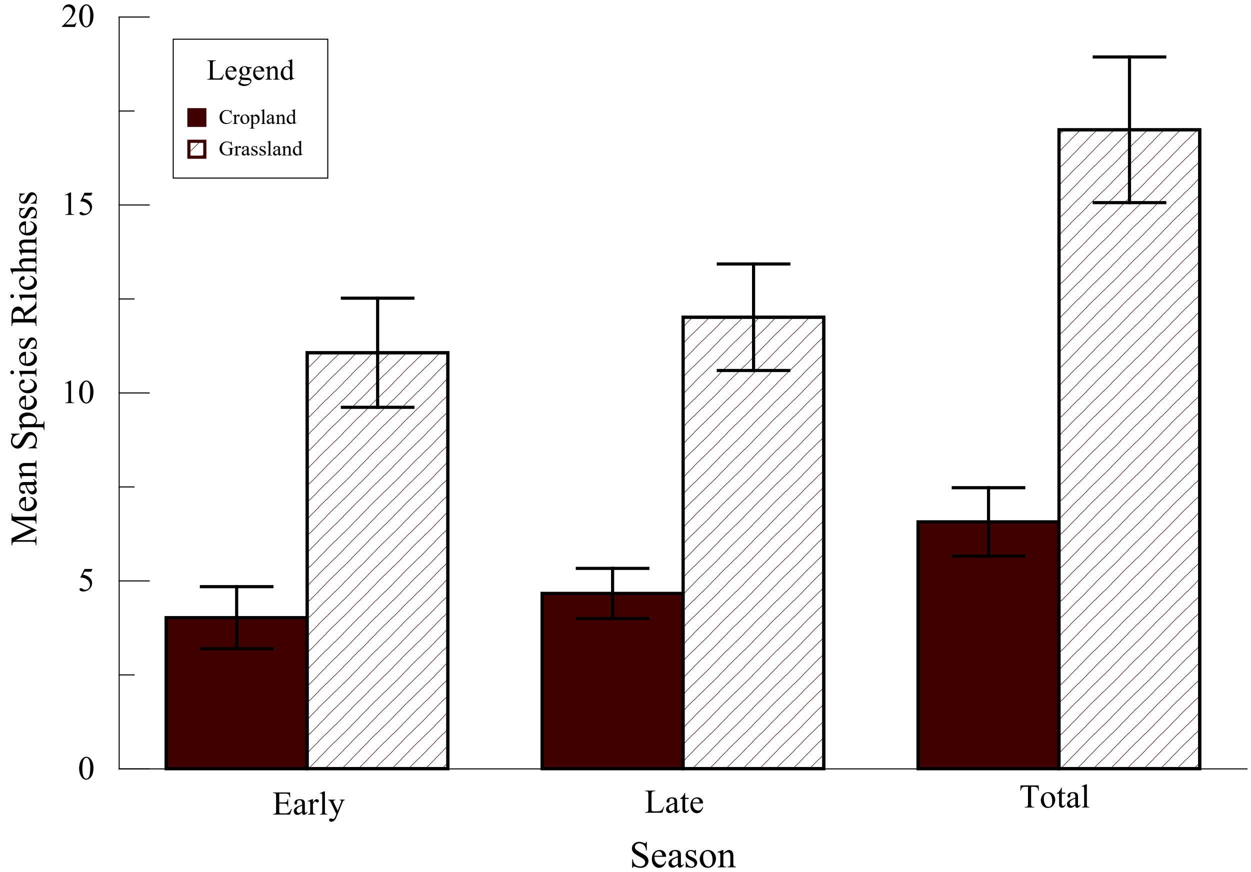

Figure 3.2 Early season (May-June), late season (July-August), and total flora species richness for playas with cropland (*n* = 40) and grassland (*n* = 14) watersheds in the Smoky Hill River watershed of western Kansas, USA, during 2015-2016. Average species richness differed ($P < 0.05$) between cropland and grassland watersheds for each season and overall season.

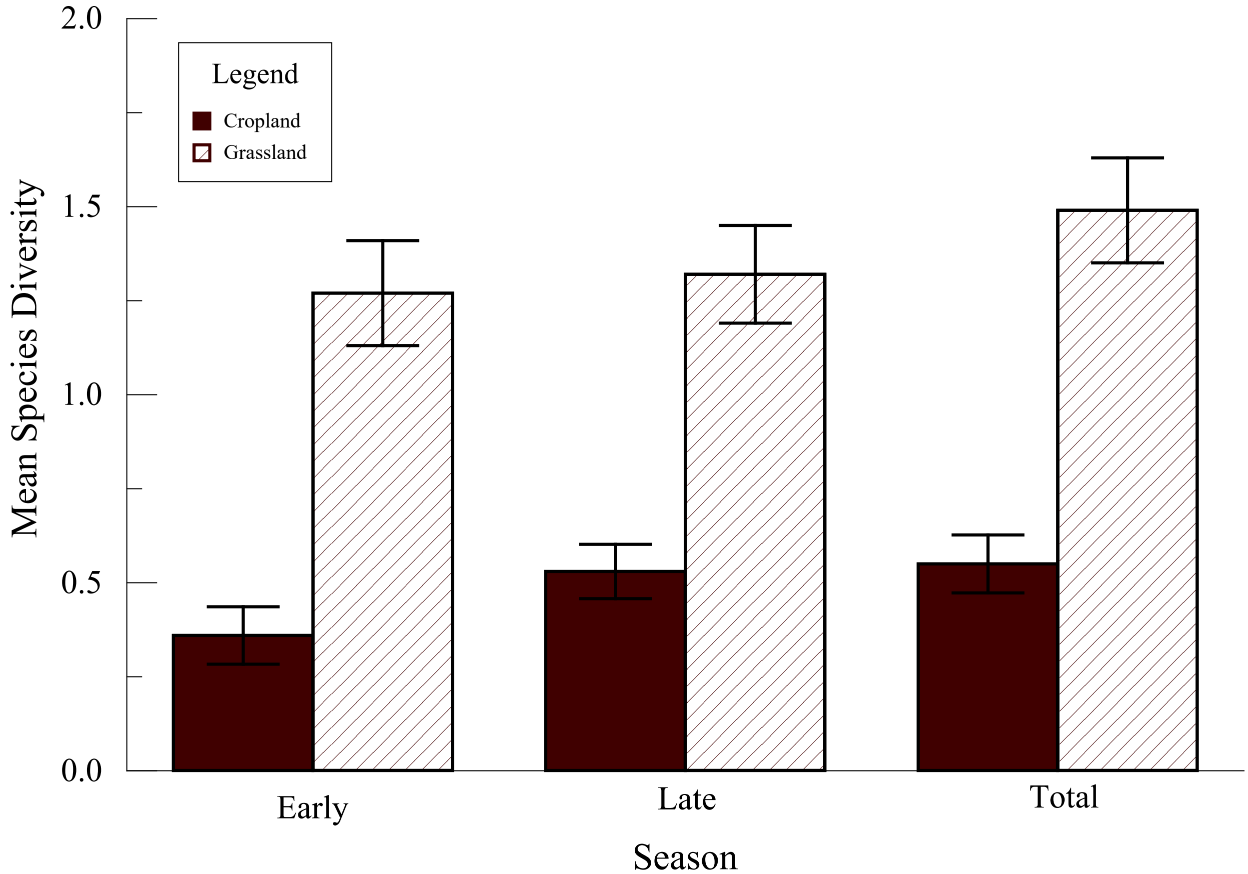

Figure 3.3 Early season (May-June), late season (July-August), and total flora species diversity for playas with cropland (*n* = 40) and grassland (*n* = 14) watersheds in the Smoky Hill River watershed of western Kansas, USA, during 2015-2016. Average species richness differed ($P < 0.05$) between cropland and grassland watersheds for each season and overall season.

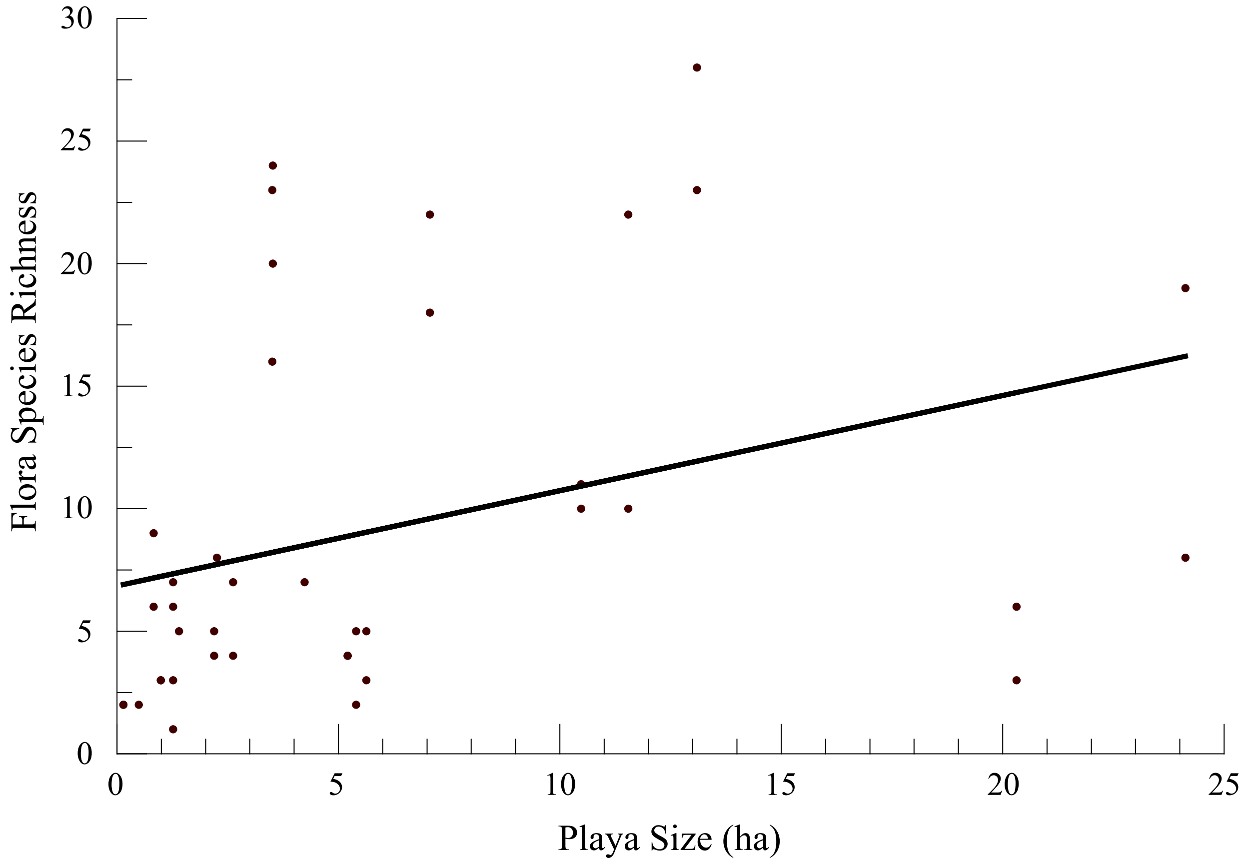

Figure 3.4 Relationship between flora species richness and wetland size for 54 playas surveyed during 2016-2016 in the Smoky Hill River watershed of western Kansas, USA.

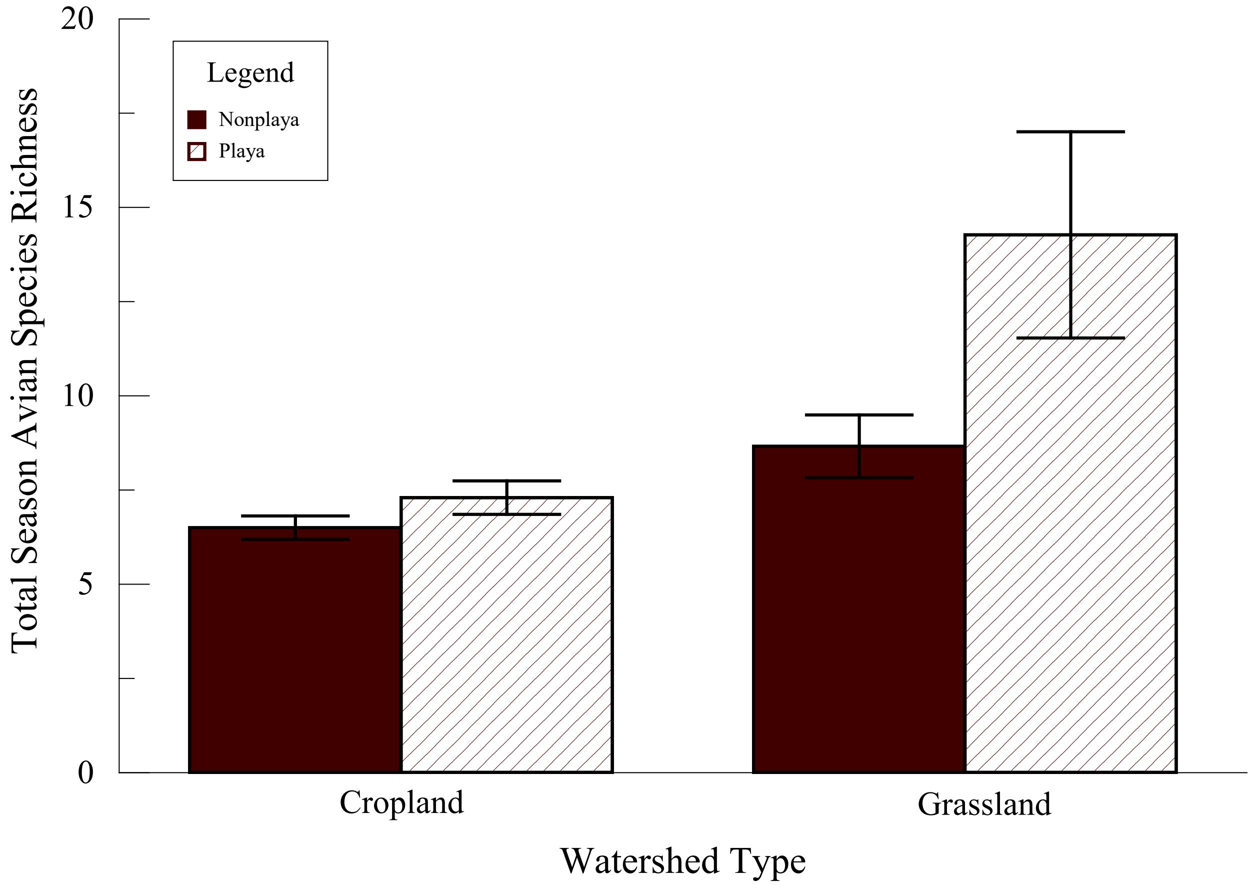

Figure 3.5 Season-long average avian species richness comparison between playas and nonplaya areas for playas with cropland (*n* = 40) and grassland (*n* = 14) watersheds in the Smoky Hill River watershed of western Kansas, USA, during 2015-2016. Average species richness did not differ ($P > 0.05$) between playa and nonplaya areas with cropland watersheds, but did differ ($P < 0.05$) between playa and nonplaya areas with grassland watersheds.

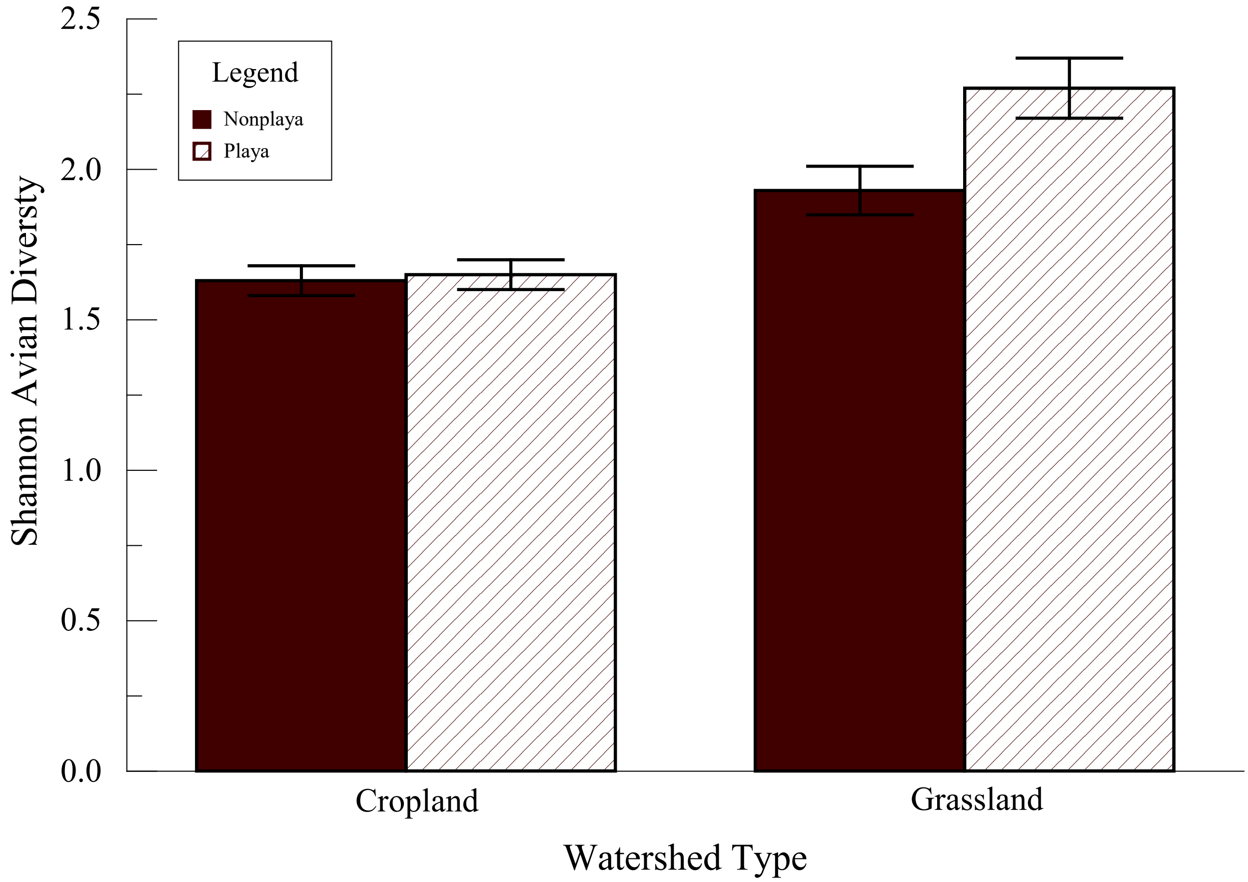

Figure 3.6 Season-long average avian species diversity comparison between playas and nonplaya areas for playas with cropland (n = 40) and grassland (n = 14) watersheds in the Smoky Hill River watershed of western Kansas, USA, during 2015-2016. Average species diversity did not differ ($P > 0.05$) between playa and nonplaya areas with cropland watersheds, but did differ ($P < 0.05$) between playa and nonplaya areas with grassland watersheds.

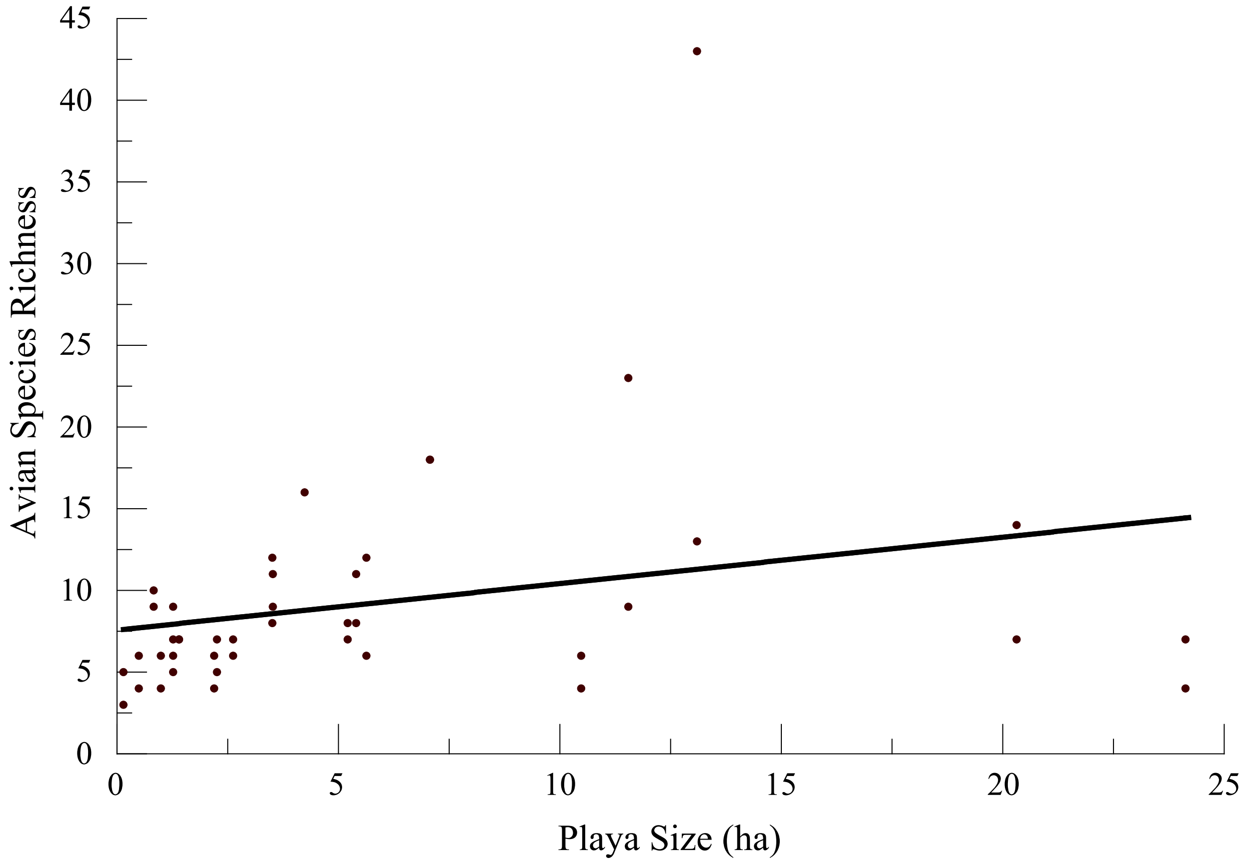

Figure 3.7 Relationship between avian species richness and wetland size for 54 playas surveyed during 2016-2016 in the Smoky Hill River watershed of western Kansas, USA.

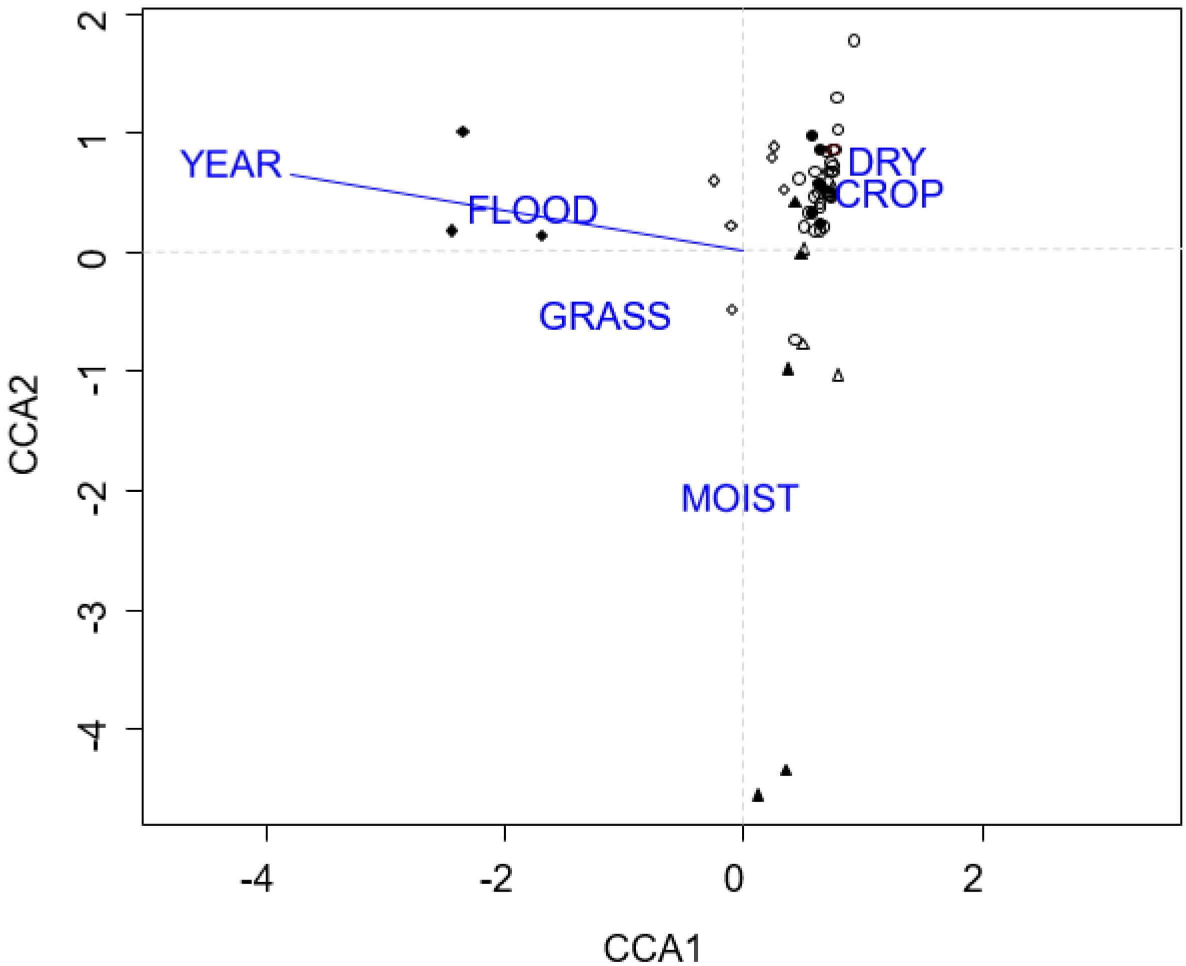

Figure 3.8 Canonical Correspondence analysis of 54 playa sites and environmental variables in the Smoky Hill River watershed in western Kansas, USA, during 2015-2016 categorized by watershed variables (grassland and cropland) and soil moisture regime (flooded, moist, dry). Shapes with a black fill indicate grassland sites whereas shapes with only a black outline and no fill indicate cropland sites. Different site shapes indicate soil moisture of site where a diamond shape indicates a flooded site, triangles indicate a moist-soil, and circles indicate dried soils.

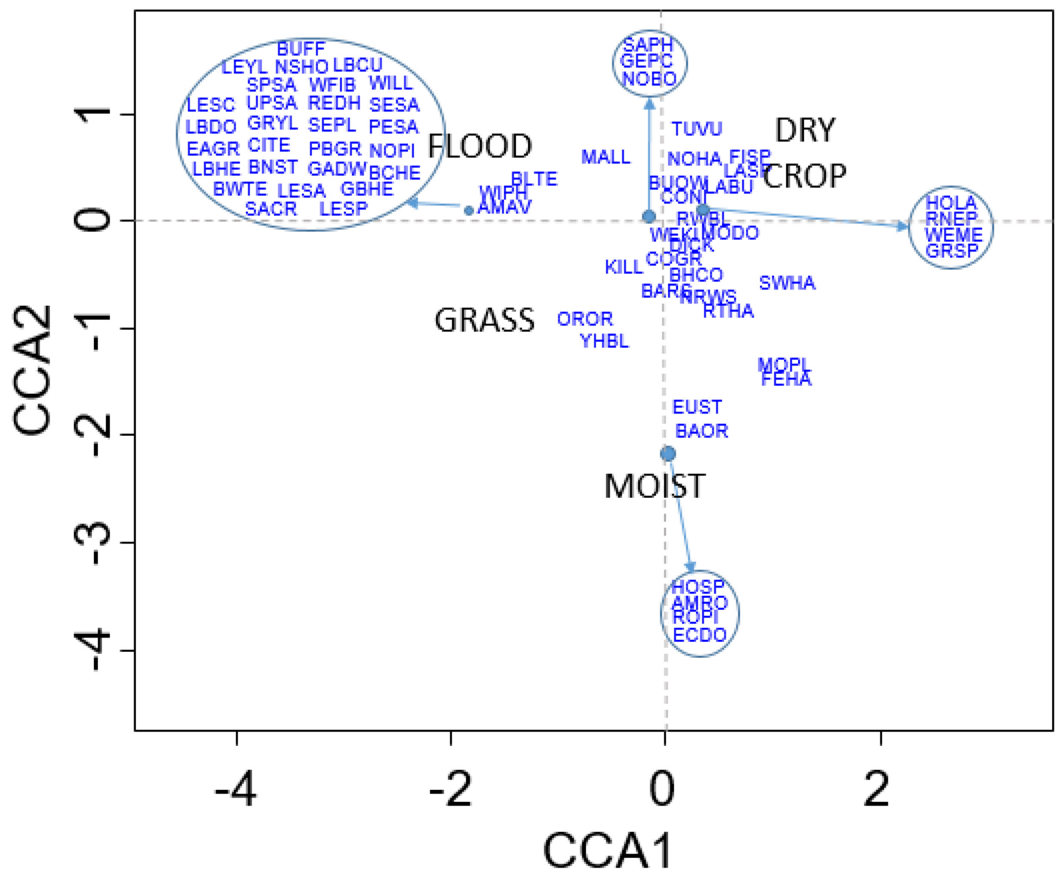

Figure 3.9 Canonical Correspondence analysis of percent composition (natural-log [y + 1]) of different avian species and environmental variables of watershed land use (grassland and cropland) and soil moisture (flooded, moist, dry) associated with 54 playas in the Smoky Hill River watershed in western Kansas, USA, during 2015-2016. Species are labeled according to the four-letter bird code. Circles represent a group of species located in the same ordination space, thus were expanded to show all species associated with the shared area.

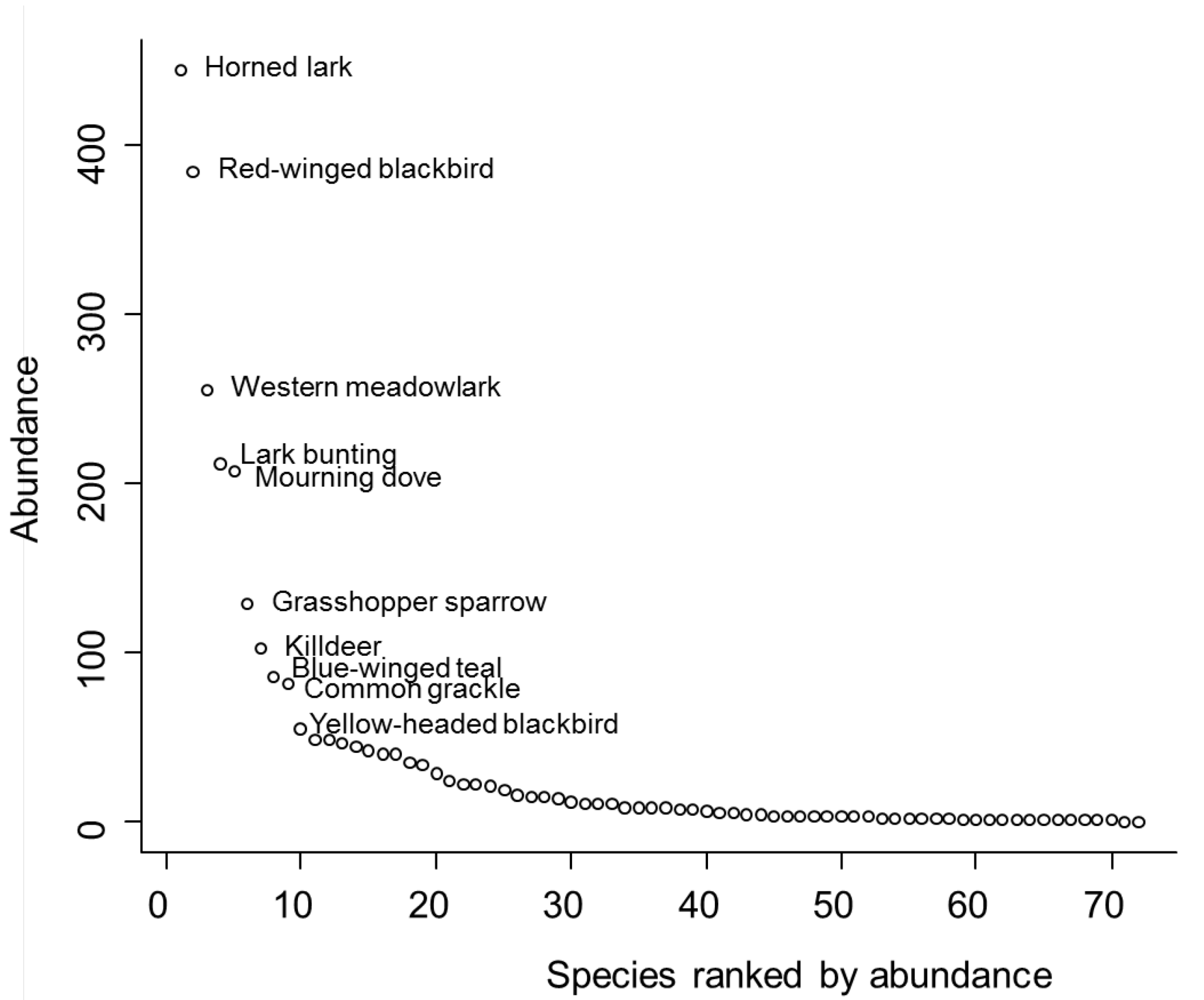

Figure 3.10 The abundance of each species of the avian community found in 54 playas in the Smoky Hill River watershed in western Kansas, USA during 2015-2016, with species labels for the top ten most abundant species.

Table 3.1 Mean (SE) species richness and Shannon diversity index for flora surveys during early (May/June) and late (July/August) surveys in 54 playa wetlands in the Smoky Hill watershed of western Kansas during 2015-2016.

Watershed Type/Season	Species Richness $\overline{x}$ (SE)	Species Diversity $\overline{x}$ (SE)
Cropland		
Early	4.02(0.83)	0.36(0.08)
Late	4.67(0.66)	0.53(0.07)
Total	6.57(0.91)	0.55(0.08)
Grassland		
Early	11.07(1.45)	1.27(0.14)
Late	12.13(1.42)	1.32(0.13)
Total	17.00(1.94)	1.50(0.14)

Table 3.2 Mean (SE) species richness and Shannon diversity index for playa and nonplaya avian surveys during early (May/June) and late (July/August) surveys in 54 playa wetlands in the Smoky Hill watershed of western Kansas during 2015-2016.

Watershed Type/Season	Species Richness		Species Diversity	
	Playa $\bar{x}$ (SE)	Nonplaya $\bar{x}$ (SE)	Playa $\bar{x}$ (SE)	Nonplaya $\bar{x}$ (SE)
Cropland				
Early	5.90(0.37)	5.26(0.31)	1.49(0.06)	1.46(0.06)
Late	4.78(0.39)	4.22(0.24)	1.23(0.07)	1.21(0.06)
Total	7.30(0.44)	6.50(0.31)	1.65(0.05)	1.62(0.05)
Grassland				
Early	10.00(1.52)	6.87(0.76)	1.99(0.09)	1.75(0.09)
Late	11.13(1.90)	6.20(0.54)	2.04(0.10)	1.61(0.09)
Total	14.27(2.37)	8.67(0.83)	2.27(0.10)	1.92(0.08)

Table 3.3 Grouping of avian species based presence in grassland or cropland watersheds, soil moisture regimes, and relative abundance from the results of canonical correlation analysis of the avian community composition found in 54 playas in the Smoky Hill River watershed in western Kansas, USA, during 2015-2016.

		Land use		Soil moisture		
Common name	Abundance	Grass	Crop	Dry	Flood	Moist
Barn Swallow	34	x	x	x	x	x
Brown-headed Cowbird	11	x	x	x	x	x
Burrowing Owl	21	x	x	x	x	
Common Grackle	81	x	x	x	x	x
Common Nighthawk	14	x	x	x	x	x
Dickcissel	49	x	x	x	x	x
Greater Prairie-Chicken	3	x		x		
Grasshopper Sparrow	129	x	x	x	x	x
Horned Lark	444	x	x	x	x	x
Killdeer	102	x	x	x	x	x
Lark Bunting	212	x	x	x	x	x
Mourning Dove	207	x	x	x	x	x
Northern Bobwhite	2	x		x		
Northern Harrier	7	x	x	x	x	
Northern Rough-winged Swallow	8	x	x	x	x	x
Red-winged Blackbird	384	x	x	x	x	x
Ring-necked Pheasant	22	x	x	x	x	x
Say’s Phoebe	1	x		x		
Turkey Vulture	2		x	x	x	
Western Kingbird	40	x	x	x	x	x
Western Meadowlark	255	x	x	x	x	x
American Avocet	24	x	x		x	
Black-necked Stilt	1	x			x	
Black tern	40	x	x		x	
Blue-winged Teal	86	x	x		x	
Bufflehead	3	x			x	
Cinnamon Teal	5	x			x	
Eared Grebe	7	x			x	
Gadwall	3	x			x	
Great Blue Heron	2	x			x	
Greater Yellowlegs	47	x	x		x	
Little Blue Heron	4	x			x	

Least Sandpiper	19	x			x	
Lesser Scaup	42	x			x	
Lesser Yellowlegs	45	x			x	
Long-billed Curlew	1	x			x	
Long-billed Dowitcher	1	x			x	
Mallard	34	x	x	x	x	x
Northern Pintail	7	x			x	
Northern Shoveler	22	x			x	
Pectoral Sandpiper	11	x			x	
Pied-billed Grebe	1	x			x	
Redhead	3	x			x	
Sandhill Crane	1	x			x	
Semipalmated Plover	3	x			x	
Semipalmated Sandpiper	16	x			x	
Spotted Sandpiper	10	x			x	
Upland Sandpiper	1	x			x	
White-faced Ibis	14	x			x	
Willet	1	x			x	
Wilson’s Phalarope	48	x	x		x	
American Robin	3	x				x
Baltimore Oriole	2	x				x
Eurasian-Collared Dove	9	x				x
European Starling	15	x	x	x		x
House Sparrow	28	x				x
Rock Pigeon	8	x				x
Yellow-headed Blackbird	55	x	x		x	x
Ferruginous Hawk	1		x	x		
Field Sparrow	6	x	x	x		
Lark Sparrow	1		x	x		
Mountain Plover	1		x		x	
Swainson’s Hawk	3		x	x		