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WETLAND CONSERVATION EFFECTS RESULT IN ENHANCED PLAYA FUNCTIONALITY IN THE RAINWATER BASIN, NEBRASKA

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by

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WETLAND CONSERVATION EFFECTS RESULT IN ENHANCED PLAYA FUNCTIONALITY IN THE RAINWATER BASIN, NEBRASKA

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This study assessed the functionality level of wetland hydrology, hydrophyte and soil conditions, and then identified the restorable potential of conserved playas. The distribution of hydrology and hydrophyte were geospatially examined through annual tracking the quantity and quality of wetlands on historical hydric soil footprints under different conservation programs in the Rainwater Basin (RWB) in Nebraska, USA during 2004-2015. The results show that the historical hydric soil footprints with the conservation programs had significantly higher functionality of ponded water and hydrophyte than non-conserved wetlands. The yearly average of ponded water areas within footprints varies at 12.59% for the Waterfowl Production Areas (WPAs), 14.78% for Wildlife Management Areas (WMAs), 27.37% for Wetlands Reserve Program easements (WRPs), and 1.86% for non-conserved wetlands, respectively. The yearly average of hydrophyte coverage within footprints reaches at 77.51% for WPAs, 79.28% for WMAs, and 66.53% for WRPs, and 8.82% for non-conserved wetlands. Within conserved lands, Massie/Water soil series demonstrated the prominent ability to hold ponding water, especially in the ponded footprints with higher ponding frequency. Nevertheless, the proportion of Fillmore, Rusco or Butler soil series roughly decreased when the frequency of ponding water increased. The areas, with high likelihood to be restored, are the places between annual ponding/hydrophyte covered areas and eleven years' maximized ponding/hydrophyte areas. The identification of areas with restorable potential can offers valuable insights into prioritized planning in conservation strategies of playas.

Keywords

Playa Wetland; Conservation Programs; Historical Hydric Soil Footprints; Ponding; Hydrophyte; Rainwater Basin; Nebraska

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CHAPTER 1 INTRODUCTION

1.1 Introduction to Playa Wetlands

Playas are wind-blown shallow depressional wetlands with a clay pan. Playa wetlands are interspersed in semi-arid regions of the U.S. Great Plains (Smith 2003; LaGrange et al. 2015). Playas become inundated or saturated primarily via surface runoff from snowmelt or precipitation. The hydroperiod or duration of time when the wetland exhibits ponding conditions varies because of annual or multi-year dry/wet cycles. In addition, playa wetlands are isolated with each other having its own watershed and are not connected to groundwater (Luo et al. 1997; Bartuszevige et al. 2012). Playas lose moisture by evaporation, evapotranspiration and underlying ground water recharge, and they maintain a negative water balance because the evapotranspiration typically exceeds precipitation (Rosen 1996; Beas et al. 2014). The size of individual playas ranges from less than one acre to more than one thousand acres (LaGrange et al. 2005). Playa wetlands cycle through a wet/dry period with different hydrophytic vegetation communities ensures these wetlands provide the unique environments for physical, chemical, and biological processes to maintain productivity and biodiversity of wetland dependent plants and wildlife (LaGrange et al. 2005).

Playa wetlands provide significant ecological and societal benefits to the region: providing habitats for diverse plants and animal life, improving water quality, collecting and filtering runoff, recharging the aquifer, preventing flooding and preserving biodiversity (Bolen et al. 1989; LaGrange et al. 2005). Probably, the most important function of playas is providing foraging habitats for millions of waterfowl during their migrations, particularly in spring. However, studies have found playas are being lost and degraded at an alarming rate (Schildman and Hurt 1984; LaGrange et al. 2005). The playas are still negatively impacted by conversion to croplands, excessive sediment accumulation, spread of invasive plant communities, adverse hydrology alteration resulting from runoff diversion and prevalence of drainage, filling, pits, and other factors (LaGrange et al. 2005). Johnson et al. (2011) estimated that in the Southern High Plains, the number of playas decreased from 6,122 to 2,135 (65.1% decline), based on hydric soil presence. Nugent et al. (2015) reported that wetland historical hydric footprints were originally 830 km2 based on historical soil survey and approximately 90% of the original playa wetlands were destroyed or highly degraded in the Rainwater Basin (RWB) in south-central Nebraska. Daniel et al. (2017) pointed out that in the RWB, there once were 4000 playas and 90% of those playas have been lost because of human activities such as agricultural practices and road constructions. Tang et al. (2018) estimated that two-thirds of the historical hydric footprints in the RWB were no longer ponded in spring, and 83.2% of the total footprints were observed without hydrophyte in the past decade. All of these could decrease playa functionality level, and thus declined waterfowl use and availability of ecological services.

1.2 Conservation Efforts of Playa Wetlands

With numerous losses and threats facing playa wetlands, the conservation community has leveraged significant financial resources to protect, restore and enhance sufficient habitats and food resources for wetland birds. Easement and fee-title acquisition programs have had a profound effect and have increased the number of functioning acres as well as the distribution of wetlands across the landscape.

1.3 Evaluation of Conservation Programs

Many studies have investigated the effects of conservation strategies on wetland function, including biodiversity preservation, water and air quality improvement, wildlife habitat protection, and soil erosion reduction. (Skagen et al. 2008; O’Connell et al. 2012; Haukos et al. 2016; O'Connell et al. 2016). Several kinds of field research have provided qualitative measurements to evaluate the ecosystem services delivered by conservation programs and practices on private lands through fieldwork and modeling, such as Conservation Effects Assessment Program (Duriancik et al. 2008) and Environmental Benefits Index (USDA 2017).

In addition, studies have contributed to our better understanding of ecological function of restored playas with conservation programs. Smith et al. (2002) pointed out that conservation efforts play a critical role in preserving flora diversity and native plant communities on playas. They found playas with conservation efforts had fewer exotic species, lower diversity of perennial species than the playas with cropland watersheds. Moreover, Smith et al. (2011) have found that conservation strategies have greatly improved playa hydrological function, which is heavily affected by accumulated sediments. Beas et al. (2014) found restored playa wetlands in the RWB provide the most reliable water availability for amphibians. Amphibian species richness averaged almost two times greater in restored playas than cropped playas during a drier year than average year. Braza et al. (2017) established a spatial econometric method by propensity-score matching and estimated that approximately 14.6% of the protected lands would have been converted to agriculture production areas without conservation easement programs. Daniel et al. (2014) measured the effect of CRP on sediment deposition and concluded

CRP playas have 40% lower sediment depth and 57% lower water volume loss than cropland playas. Smith et al. (2011) found the WRPs have the greatest potential to restore playa hydrological function because the program encourages sediment removal. Tang et al. (2016a) used Landsat data and Google Earth engine to map ponded water distribution, and concluded that conservation easements covered 4.29% of the total footprints, while providing 20.82% of the total ponding area of footprints in the past three decades. These studies have documented the value of conservation programs and practices on playa wetlands.

1.4 Temporal-Spatial Pattern of Conserved Playas Functionality

However, there have been few studies systematically investigating the contemporary condition of playa functionality with different conservation programs. Measuring variations in playa function over space and time allows us to assess the effectiveness of different conservation programs and help policy makers plan wetland management as well as prioritization of conservation practices. Monitoring and assessment for the dynamic change of hydrology (ponded area) and functional hydrophyte (distribution of wetland vegetation community) on historical hydric soil footprints is a necessary step to understand the effectiveness of conservation programs. When the locations once were observed with functional features (ponding water or functional hydrophyte), those places theoretically have the ability to be functional wetlands and could be maximized to achieve the fully restoration. Hydric soils with the greatest restoration potential can be identified by comparing functional areas of footprints over a timespan of several years. Thus, the temporal-spatial patterns of playa functionality condition in terms of hydrology function and functional hydrophytic vegetation have important implications for the effects of each type of conservation program on playa function restoration.

1.5 Research Questions and Objectives

To identify the functionality and restorable potential of playa wetlands within conserved lands, this study used hydrological features and hydrophytic vegetation, along with hydric soils, as multi-indicators to assess the associated wetland functionality level within each conserved land on historical wetlands footprints, which serve as technical criteria to delineate wetlands. This study is trying to answer the following research questions: (1) What is the temporal-spatial pattern of the playa functionality? And restorable potential? (2)What is the functionality level of hydrophyte and hydric soil? (3) What insights do the findings have into policy recommendation?

Three specific objectives are addressed in this study:

(1) Evaluate the annual hydrology function on site level by temporal-spatial mapping of ponding frequency on the RWB historical hydric soil footprints of conserved lands and non-conserved lands.

(2) Investigate the hydrophyte presence and quality on historical hydric footprints during the same period, as well as determine the current functionality level of hydrophyte within conserved lands according to the vegetation types.

(3) Analyze dominant soil types on ponded footprints with different ponding frequency, as well as ponding/hydrophyte covered footprints on each type of conservation property.

CHAPTER 2 METHOD

2.1 Study Area

This study focused on the playa wetland complex in the RWB in south-central Nebraska (Figure 1), covering 15,907 km2 land across 21 counties. This region is globally well-known as the crucial staging habitats for millions of waterfowl and 500,000 shorebirds in spring migratory seasons (RWBJV 2013). However, ever since European Americans settled there, playa wetlands have experienced significant alterations. Wetland modifications including surface drains, tile drains, excavation of concentration pits, and placement of fill material (upland soils) in the hydric soils footprints have been extensively used to increase farmable acres and therefore reduce wetland function. McMurtrey et al. (1972) estimated that 82% of the wetlands had changed to agricultural land. It is estimated that currently less than 1% of the RWB landscape is playa wetlands (RWBJV 2013).

The rapid loss of wetlands did not slow until 1985 when the Food Security Act (Farm Bill) was passed. Even before the Farm Bill provisions, the USFWS had already began recognizing the value of playa in this region and started acquiring wetlands in fee title (LaGrange et al. 2011; Nugent et al. 2015). In 1963, the first Waterfowl Production Area (WPA) was acquired by USFWS (Nugent et al. 2015). Fee title acquisition by State and Federal has been pursued. To date, the USFWS owns permanent secure habitats through 58 WPAs with 94.43 km2 in the RWB, and there are 35 Wildlife Management Areas (WMAs) with 35.59 km2 managed by Nebraska Game and Parks Commission (NGPC). Playas in the RWB were then given the highest priority in NGPC's Nebraska Wetlands Priority Plan (LaGrange et al. 2005). Both WPAs and WMAs are public lands purchased by government agencies, they are critical habitats set aside for fish, wildlife and some native plants that heavily rely on wetlands to survive.

Since the North American Waterfowl Management Plan was initiated in 1986, conservation strategies and practices have been undertaken by the Migratory Bird Joint Ventures. These Joint Ventures are partnerships of federal, state, local governments, non-governmental organizations and individuals (Smith 2003).

In 1990, Farm Bill was reauthorized and contained a new conservation easement program focused on wetland restoration and protection. The Agricultural Conservation Easement Program managed by U.S. Department of Agriculture - Natural Resources Conservation Service (USDA-NRCS) provides technical and financial support to landowners to protect, restore and enhance wetlands, grassland and agricultural lands through long-term conservation easement programs, such as the Wetlands Reserve Program (WRP) and short-term conservation programs, such as the Conservation Reserve Program (CRP). In the RWB, there are 103 enrolled easements that contained 26.95 km2 land. Unfortunately, even lots of conservation efforts have been made, most playas in the RWB are still facing with multiple challenges, including highly physical modifications, sediments input from cultivation activities, especially those wetlands with cultivated surroundings.

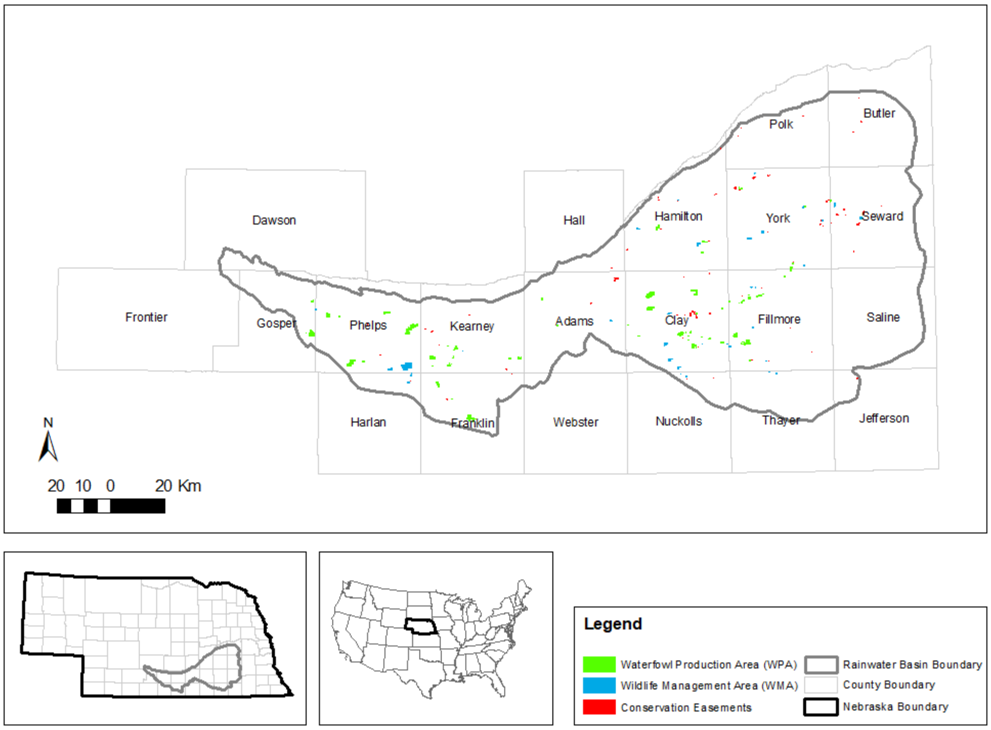


Figure 1: Location Map of the Rainwater Basin in Nebraska

2.2 Data Source

2.2.1 Wetland Historical Footprints Data

The RWB playa wetland historical footprints dataset was provided by the Rainwater Basin Joint Venture in 2016. This dataset was generated from multiple data sources, including the historic soil surveys, National Wetland Inventory (NWI) during 1980-2008, Soil Survey Geographic Database (SSURGO), satellite imagery and added area by field survey (Tang et al. 2016a). This dataset identified 8,979 historical playa footprints in the RWB, covering 764.75 km2. According to the historical hydric soil footprint layer, it has been estimated that there is 183.48 km2 (24.0%) of semi-permanent wetlands, 137.67 km2 (18.0%) of seasonal wetlands, and 443.59 km2 (58.0%) of temporary wetlands.

2.2.2 Hydrology and Hydrophyte Data

The playa ponding area data was drawn from the Annual Habitat Survey (AHS) which was conducted to measure the ponded area at the peak of every spring migration season in 2004, 2006-2015 (RWBJV 2015). This survey used acquired color infrared aerial photos and field survey data which were processed to generate shapefile data of ponding/hydrophyte covered wetlands. This acquired information was used to identify the distribution of ponded areas, hydrophyte, and wetlands without ponding/hydrophyte (Nugent et al. 2015).

Wetland vegetation survey data collected in 2012 was also provided by the Rainwater Basin Joint Venture. This data indicates the distribution and classification of hydrophytic plant communities. Wetland ponding presence and functional hydrophyte condition can serve as fact base to identify functional wetlands, as well as their functionality level. Highly functional habitats are comprised of early successional vegetative communities, which yield the greatest accessible energetic resource per acre for wetland dependent birds. These early successional habitats in playas typically contain bare soil/mudflat, moist-soil species, standing water, or wet meadow species (RWBJV 2015). Partially functional habitats are either those cropped wetlands with ponding water or partially degraded late successional plants, including invasive species such as narrow leaf cattail (Typha angustifolia), reed canary grass (Phalaris arundinacea), and river bulrush (Bolboschoenus fluviatilis) (Tang et al. 2016b). Some wetlands are more likely to be utilized as cropped land because of hydrological modifications. Cropped wetlands are often-ponded, cultivated lands on historical wetlands footprints. Nonfunctional wetlands are the most significantly impacted areas that never contain ponded water or hydrophyte. They virtually have little to no wetland function (RWBJV 2015).

2.2.3 Conservation Lands Data

The USDA-NRCS provided detailed information for existing conservation lands in 2016, including 93 public lands (58 federal WPAs, 35 state WMAs) and 103 conservation easement lands. This study only focuses on 99 WRP easements, because four easements do not have historical hydric soil footprints. In the RWB region, all the footprints (764.75 km2) were assessed, of which 56.85 km2 (7.43%) were on WPAs; 23.69 km2 (3.10%) were on WMAs; 17.93 km2 (2.34%) were on WRP easements. In addition, there were 669.74 km2 (87.58%) footprints that were not currently enrolled in conservation programs, which are defined as non-conserved wetlands (footprints) in this study.

2.2.4 Soil Data

The soil data was collected from the Soil Survey Geographic Database (SSURGO 2017), provided by USDA-NRCS. This digital soil shapefile provides informative details, such as land slope, flooding frequency, soil types, etc. According to general ponding frequency, the semi-permanent playa wetlands are primarily dominated by the Massie/Water soil. The Massie soil type is in the deepest poorly drained soils in the loess, with very low saturated hydraulic conductivity, it thus usually holds visible ponded water on the surface even in dry seasons. The Water soil type keeps standing water permanently. The seasonal ponded soil refers to Scott soil series, which is located above the layer of Massie soil and is also very poorly drained with frequent ponding. For the temporary ponded soil types, Fillmore, Butler, Rusco were analyzed in this study.

Fillmore is somewhat poorly drained in siltloams above Massie soil series and is ponded frequently for several days to a month. Butler soil type is also somewhat poorly drained in siltloams, with ponded water for a period in growing seasons. Rusco soil series consist of moderate well drained soils in siltloams, and it is rarely or occasionally ponded (SSURGO 2017).

2.3 Analysis Method

2.3.1 Assessment of Hydrology Performance (Ponding Presence)

This study primarily relied on ArcGIS 10.5 (ESRI Inc., Redlands, CA) to conduct the geospatial analysis on historical wetlands footprints.

To identify the ponded areas in each year, we firstly intersected the historical wetland footprint layer with conservation property layers (WMAs, WPAs and WRP easements), then dissolved by the same site name to map the conserved footprints on site level. We next intersected the resulting conserved footprints with ponding layers in each AHS year respectively to get the annual ponded area on each site of conserved footprints.

To determine the ponding frequency of conserved footprints, the acquired eleven annual ponding layers of conserved footprints were overlaid and processed by "Union" function to get a multi-years' maximized ponded area at least once was ponded during 2004-2015, which indicates the ponding frequency of conserved footprints in the observed years. We then edited the layer's attribute table to calculate the "ponding frequency" (ranging from 1 to 11) for all the ponded footprints. By comparing the eleven-year maximized ponded area with mean ponded area, we can identify the hydrology restorable potential for each kind of conservation program. Because the locations once were observed with ponded water theoretically had the ability of holding ponding water and could be maximized to realize the hydrology restorable potential.

Identification of non-conserved footprint area required several steps. First, we identified those conserved footprints, which are located both within WRPs and public lands (WPAs or WMAs). To do this, we developed the footprints of public lands and WRPs by “Union” function to obtain the overlapped footprints. Secondly, we intersected annual ponding layer with the overlapped footprints and the entire footprints layer respectively to get the ponded area on overlapped footprints and on entire footprints in each AHS year. Thirdly, the ponded area of non-conserved footprints in each AHS year equals to the ponded area of the entire RWB minus the ponded footprints within conserved lands, and then add the ponded area of overlapped footprints.

2.3.2 Assessment of Hydrophytes Performance (Presence and Types)

To determine the annual hydrophyte performance on footprints under different conservation status, we followed the same steps as processing method of annual ponded water to get the annual hydrophyte covered area both on conserved footprints and on non-conserved footprints. Moreover, get the eleven-year maximized area once was with hydrophyte on site-level of conserved footprints, after that we could identify the hydrophyte restorable potential for each kind of conservation program.

Furthermore, to assess the functionality level of hydrophyte within conservation lands, we took 2012 vegetation survey data as a contemporary snapshot of wetland hydrophytic plant community and intersected it with conserved footprint layers to get the information of vegetation types and distribution on conserved footprints.

2.3.3 Assessment of Hydric Soil Condition

In this study, we selected six types of aquatic soil to analyze, and we categorized them into four groups according to ponded water frequency: Massie/Water; Scott; Fillmore, Rusco or Butler and others. We intersected the soil map layer with the eleven-year ponding layer and eleven-year ponding/hydrophyte covered area on conserved footprints to identify the distribution and types of dominant soil for each kind of conservation property, in addition to present the relationship of ponding frequency and proportion of dominant soil types. Then the soil assessment on ponded footprints and ponding/hydrophyte covered footprints during 2004-2015 within conserved lands was completed.

CHAPTER 3 RESULTS

3.1 Assessment of Hydrology Performance (Ponding Presence)

Table 1 illustrates areas covered by ponding, hydrophyte or ponding/hydrophyte within footprints of WPAs, WMAs and WRP easements in every AHS year. Ponded area erratically varied from one year to the next. The wetland footprints demonstrated apparent wet or dry years. In wet years, the largest ponded area was recorded in 2010, followed by 2007 and 2004. While in dry years, the smallest ponded water area on footprints occurred in 2013, followed by 2014 and 2006.

Table 1 : Annual conditions of hydrology, hydrophyte and ponding/hydrophyte covered footprints under each type of conserved status

Year	2004	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Ponding area in footprint of WPA (ha)	915.70	441.33	1572.01	781.43	851.35	1540.79	444.71	439.45	166.53	329.01	394.07
Ponding area in footprint of WMA (ha)	385.70	138.80	628.07	532.51	496.79	883.38	170.19	143.72	118.24	123.55	230.44
Ponding area in footprint of WRP easement (ha)	350.83	70.44	469.42	371.53	330.68	727.47	66.51	70.65	20.45	28.55	88.47
Ponding area in non-conserved footprint (ha)	1861.48	462.92	2744.59	1653.53	1230.71	3482.20	554.59	555.83	304.58	337.98	460.16
Hydrophyte area in footprint of WPA (ha)	3998.18	4737.53	3648.57	4443.13	4343.42	3375.07	4360.10	4773.39	5056.91	4907.00	4834.34
Hydrophyte area in footprint of WMA (ha)	1726.63	2065.40	1603.01	1695.71	1757.45	1376.48	2077.62	2070.92	2134.87	2132.23	2022.26
Hydrophyte area in footprint of WRP easement (ha)	708.17	1134.90	924.50	881.52	932.64	835.05	1368.79	1370.61	1675.20	1678.01	1614.47
Hydrophyte area in non-conserved footprint (ha)	5420.73	6267.01	4933.29	5573.98	5773.68	4927.84	5866.99	6135.74	6635.00	6619.82	6658.31
Ponding/hydrophyte covered area in footprint of WPA (ha)	4913.53	5178.69	5219.14	5224.41	5194.59	4915.71	4804.66	5212.72	5223.44	5236.01	5228.41
Ponding/hydrophyte covered area in footprint of WMA (ha)	2112.18	2204.12	2230.74	2228.14	2254.20	2259.78	2247.77	2214.59	2253.12	2255.79	2252.70
Ponding/hydrophyte covered area in footprint of WRP easement (ha)	1059.00	1205.34	1393.92	1253.06	1263.32	1562.52	1435.30	1441.25	1695.65	1706.55	1702.94
Ponding/hydrophyte covered area in non-conserved footprint (ha)	7312.43	6730.19	7679.65	7227.74	7004.62	8410.26	6421.76	6691.74	6939.59	6957.80	7118.47

Percentage of ponding and hydrophyte area within conserved footprints are shown in Figure 2. In every AHS year during 2004-2015, we found each type of conserved wetlands contained a much higher percentage of ponded water area than non-conserved wetlands. The mean percentage of ponding area in conserved footprint (12.59% of WPAs; 14.78% of WMAs; 27.37% of WRP easements) is largely greater than the non-conserved footprints with yearly averaging at 1.86% (Figure 2).

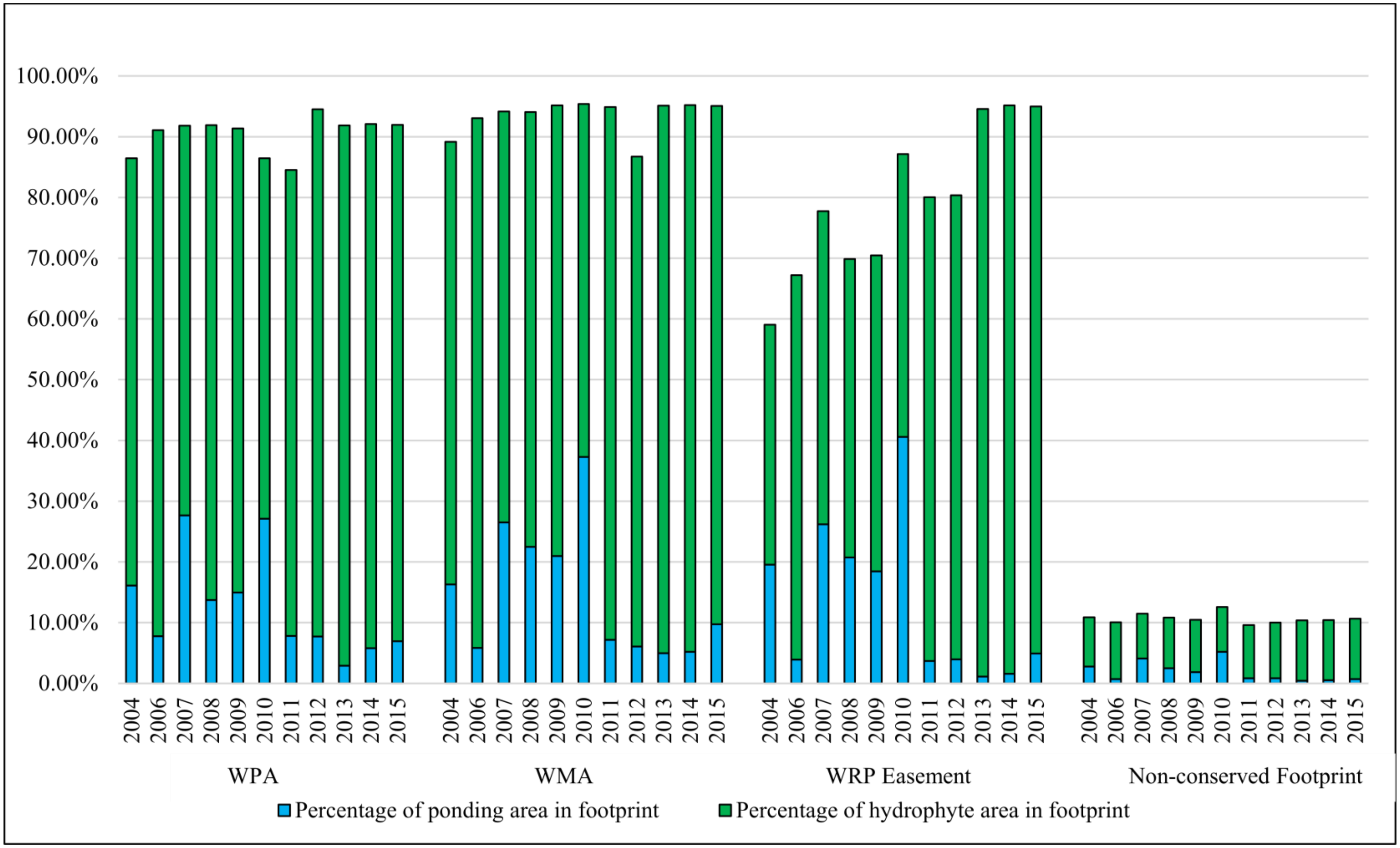


Figure 2 Percentage of ponding and hydrophyte area in footprints under different conserved status

When we overlaid the eleven years' data together, we obtained the maximized area of ponding, hydrophyte and ponding/hydrophyte area in footprints of each conserved site. Figure 3 presents descriptive statistics about percentage of ponding, hydrophyte, and ponding/hydrophyte within footprints on site level of conserved lands during 2004-2015. We found that site-level footprints of WMAs show an overall better performance of ponding water area than footprints of WPAs and WRP easements, with a smaller range and a greater mean and median.

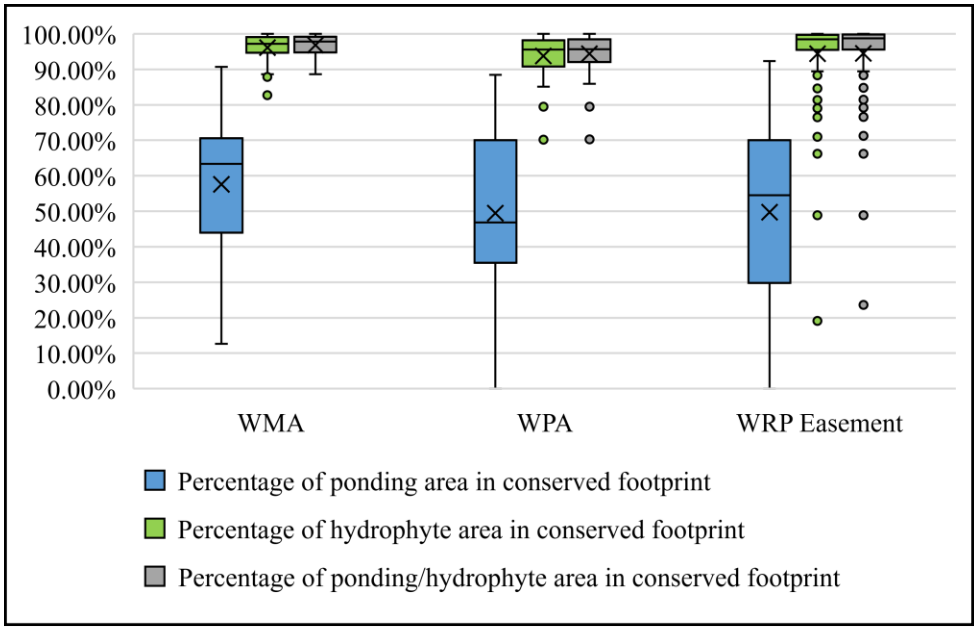


Figure 3: Percentage of ponding, hydrophyte and ponding/hydrophyte covered area in conserved footprints during 2004 to 2015 (site level)

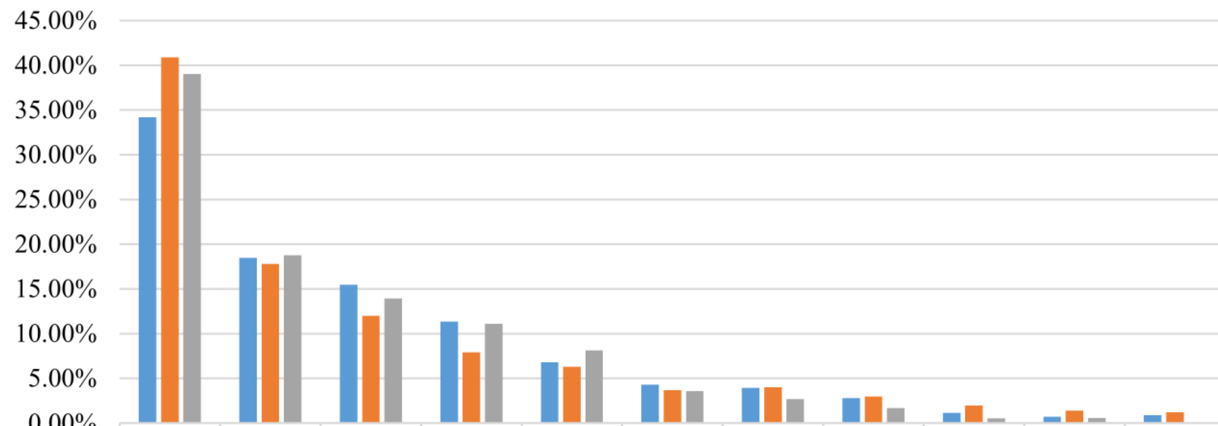
(The "X" in the boxplot indicates the Mean, the "–" in the boxplot indicates the Median)

Table 2 presents the actual hectares and percentage of eleven-year maximized area and mean area of ponding, hydrophyte, and ponding/hydrophyte. The percentage difference between maximized area and mean area implicates the restorable potential for each kind of conservation program. We found approximately half of the conserved footprints demonstrated ponding water at least one time during 2004-2015, but the average yearly ponding area percentage ranged from 12.59% for WPAs to 27.37% for WRP easements. The WMAs show the highest hydrology restorable potential, with 39.49% of the footprints once was ponded should have the ability of ponding water, however did not demonstrate every year.

Table 2 Hydrology, hydrophyte and ponding/hydrophyte covered footprints under each type of conserved status

	WPA		WMA		WRP easement	
	2004-2015	Average yearly	2004-2015	Average yearly	2004-2015	Average yearly
Ponding area on conserved footprints (ha)	2680.34	716.04	1285.91	350.13	968.60	235.91
Percentage of ponding area on conserved footprints (%)	47.14%	12.59%	54.27%	14.78%	54.01%	27.37%
Difference between eleven years' maximum and yearly averaged area	**34.55%**		**<u>39.49%</u>**		**26.64%**	
Hydrophyte area on conserved footprints (ha)	5266.06	4407.06	2284.53	1878.42	1724.91	1193.08
Percentage of hydrophyte area on conserved footprints (%)	92.62%	77.51%	96.42%	79.28%	96.18%	66.53%
Difference between eleven years' maximum and yearly averaged area	**15.11%**		**17.14%**		**<u>29.65%</u>**	
Ponding/hydrophyte covered area on conserved footprint (ha)	5302.36	5122.85	2298.11	2228.47	1726.21	1428.99
Percentage of ponding/hydrophyte covered area on conserved footprints (%)	93.26%	90.10%	96.99%	94.05%	96.26%	79.68%
Difference between eleven years' maximum and yearly averaged area	**3.16%**		**2.94%**		**<u>16.58%</u>**	

In ponded footprints within conserved lands, Figure 4 summarizes the percentage of ponded footprints with different ponding frequency in each kind of conserved lands. For those conserved footprints once were with ponding during 2004-2015, around one-third to forty percent were only ponded for one time. Less than half of those ponded footprints were ponded more than two times (WPA 41.35%; WMA 47.34%; WRP easement 42.21%). Moreover, around 1% or less of ponded footprints presented ponding water for 11 times in every AHS year, indicating most of those ponded wetlands have lost the ability of frequent ponding.



	1 time	2 times	3 times	4 times	5 times	6 times	7 times	8 times	9 times	10 times	11 times
WMA	34.18%	18.48%	15.46%	11.35%	6.78%	4.29%	3.93%	2.77%	1.15%	0.70%	0.90%
WPA	40.87%	17.78%	11.97%	7.89%	6.28%	3.69%	4.01%	2.95%	1.95%	1.39%	1.21%
WRP Easement	39.02%	18.77%	13.92%	11.09%	8.11%	3.56%	2.70%	1.69%	0.53%	0.57%	0.04%

WMA WPA WRP Easement

Figure 4: Percentage of ponding area with different ponding frequency in ponded footprints during 2004 to 2015

3.2 Assessment of Hydrophyte Performance (Presence and Types)

The actual hydrophyte hectares on conserved footprints did not change too much from year to year (Table 1). Within each type of conserved footprints, the hydrophyte area (which is expressed as a percentage) maintained at a very high level with larger coverage compared to ponding presence (Figure 2). The percentage of hydrophyte area ranged from a low of 39.49% in 2004 in WRP easements to a high of 93.57% in 2014 also in WRP easements. From Figure 3, we found all the conserved sites were covered by large presence of hydrophyte or ponding/hydrophyte in every AHS year, with the hydrophyte or ponding/hydrophyte percentage of almost every site greater than ninety percent.

According to Table 2, the vast majority of the conserved footprints demonstrated the hydrophyte feature during 2004-2015, with a large number of mean percentage (77.51% of the WPAs' footprints; 79.28% of the WMAs' footprints; 66.53% of the WRPs' footprints). However, only 8.82% of the non-conserved footprint averagely displayed hydrophyte every year, with a Min of 7.38% in 2010 and Max of 9.97% in 2015 (Figure2). We also found the WRPs have the greatest hydrophyte restorable potential, specifically, 29.65% of hydrophyte covered footprints within WRP easements should have displayed hydrophyte every year.

The hydrophyte area was primarily dominated by early/late successional vegetative communities. Table 3 describes the hydrophyte functionality level according to vegetation types for different conservation programs in 2012. Highly functional hydrophyte is comprised by early successional vegetation communities. Partially functional hydrophyte refers to the undesired vegetation communities include cropped wetlands with ponded water and late successional hydrophyte (*Cattail, Reed Canary grass, River Bulrush*). Results show 73.29% of hydrophyte on WPA footprints is either highly functional (51.80%) or partially functional habitat (21.49 %). For WMAs, there is 34.01% of hydrophyte in highly functional vegetation communities and 34.26% undesired species. In WRP easements, 1055.36 ha (61.01%) is covered by highly functional vegetation communities, and 317.1 ha (18.33 %) of partially functional hydrophyte.

Table 3Vegetation condition of 2012 in footprints under each type of conserved status

Functionality condition	Vegetation type	Footprint area of WPA(ha)	Footprint area of WMA (ha)	Footprint area of WRP easement (ha)
Highly functional (Early successional habitat)	Bare soil/mudflat	276.07	105.10	82.32
	Moist soil species	1881.43	103.25	798.72
	Water	81.20	43.66	2.97
	Wet meadow species	494.38	151.67	171.35
	Subtotal	2733.08 **(51.80%)**	403.68 **(34.01%)**	1055.36 **(61.01%)**
Partially functional (Late successional habitat)	Cattail	161.88	59.19	39.13
	Reed canary grass	572.19	282.00	218.08
	River bulrush	398.11	65.40	59.04
	Subtotal	1132.18 **(21.46%)**	406.59 **(34.25%)**	316.25 **(18.28%)**
Partially functional (Ponded historical soil footprints that are being cropped)	Cropped wetlands	1.42	0.14	0.85
	Subtotal	1.42 (0.03%)	0.14 (0.01%)	0.85 (0.05%)
Non-functional (No hydrophyte or ponding)	Agriculture	9.35	4.94	30.02
	Grass	1368.84	345.94	320.54
	Woody species	31.13	25.75	6.92
	Subtotal	1409.32 (26.71%)	376.63 (31.73%)	357.48 (20.66%)

3.3 Assessment of Hydric Soil Condition

Figure 5 displays the dominant soil types and associated percentage in ponded footprints and ponding/hydrophyte covered footprints with conservation programs during 2004-2015. In the conserved footprints with ponding/hydrophyte, the Massie/Water soil type accounts for a large portion, 798.70 ha (34.75%) in WMAs footprints, 1075.56 ha (20.28%) in WPAs footprints, 188.80 ha (10.94%) in footprints of WRP easements. This is consistent with the deeper nature of these wetlands and larger associated watersheds.

Scott soil type also accounts for a large percentage in the footprints with ponding/hydrophyte. WRP easements demonstrated a particularly high proportion (45.91%) of Fillmore, Rusco or Butler soil type, followed by WMAs (21.87%) and WPAs (20.58%). A similar pattern of dominant soil types is observed in eleven-year maximized ponded footprints during 2004-2015. Footprints that once was ponded contained a higher percentage of Massie/Water soil type and a lower percentage of Fillmore, Rusco or Butler soils, compared to footprints with ponding/hydrophyte.

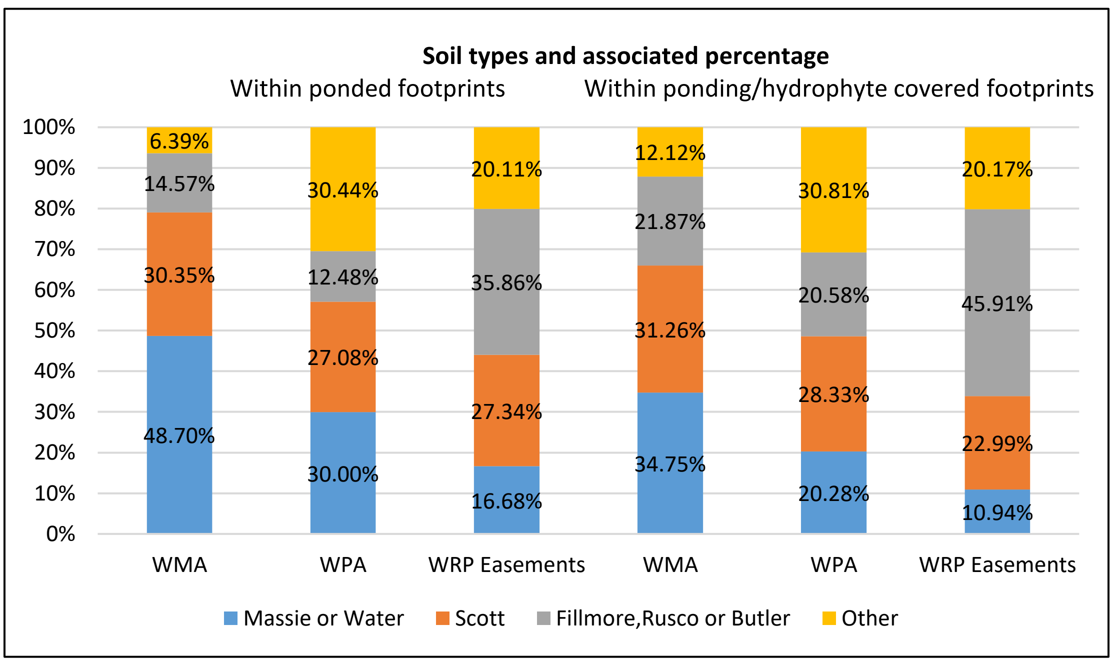


Figure 5: Soil types and associated percentage in ponded footprints and ponding/hydrophyte covered footprints (2004-2015)

Table 4 summarizes the ponding frequency and associated proportion of dominant soil types. The conserved footprints with higher ponding frequency obviously presented a higher percentage of Massie/Water soil series. Nevertheless, the share of Fillmore, Rusco or Butler soil series roughly decreased when the frequency of ponding water increased. This is consistent with the saturated hydraulic conductivity and drainage characteristics of different soil types and their ability of holding ponded water.

Table 4 Ponding frequency of each soil type under each type of conserved status

(The times in the table indicates the ponding frequency during 2004-2015.)

WPA											
Soil type	**1 time**	**2 times**	**3 times**	**4 times**	**5 times**	**6 times**	**7 times**	**8 times**	**9 times**	**10 times**	**11 times**
Massie/Water	21.30%	35.32%	33.37%	32.17%	38.15%	49.28%	40.60%	31.97%	27.20%	36.81%	53.49%
Scott	30.66%	24.77%	27.26%	33.51%	28.66%	16.76%	13.28%	13.74%	19.83%	24.31%	12.64%
Fillmore, Rusco or Butler	12.80%	8.54%	3.82%	7.68%	13.96%	7.69%	8.93%	44.75%	48.23%	35.50%	32.54%
Other	35.23%	31.37%	35.54%	26.64%	19.23%	26.27%	37.19%	9.53%	4.74%	3.37%	1.34%
WMA											
Soil type	**1 time**	**2 times**	**3 times**	**4 times**	**5 times**	**6 times**	**7 times**	**8 times**	**9 times**	**10 times**	**11 times**
Massie/Water	49.23%	44.89%	51.63%	38.88%	38.33%	44.48%	61.65%	75.04%	78.98%	68.17%	86.65%
Scott	27.38%	29.40%	29.69%	37.28%	40.72%	39.22%	30.53%	20.62%	17.94%	27.23%	13.35%
Fillmore, Rusco or Butler	16.29%	18.85%	14.52%	18.67%	11.76%	5.48%	2.35%	0.66%	0.44%	0.45%	0.00%
Other	7.10%	6.85%	4.17%	5.17%	9.19%	10.82%	5.48%	3.68%	2.64%	4.16%	0.00%
WRP Easements											
Soil type	**1 time**	**2 times**	**3 times**	**4 times**	**5 times**	**6 times**	**7 times**	**8 times**	**9 times**	**10 times**	**11 times**
Massie/Water	3.88%	14.17%	15.38%	20.13%	41.54%	49.57%	53.09%	53.45%	51.98%	67.03%	19.81%
Scott	29.09%	24.51%	24.13%	33.15%	23.42%	25.32%	31.78%	35.40%	6.71%	9.40%	34.00%
Fillmore, Rusco or Butler	45.90%	37.55%	32.29%	26.33%	25.57%	19.83%	12.51%	7.47%	31.20%	14.23%	0.00%
Other	21.13%	23.76%	28.20%	20.39%	9.47%	5.28%	2.62%	3.69%	10.11%	9.34%	46.18%

CHAPTER 4 DISCUSSION

4.1 Research Findings Discussion

The findings from this study indicate playa wetlands varying degrees of functionality under different conservation status. This study supports the previous findings that conservation efforts have greatly improved wetland functions (Smith et al. 2011; Bartuszevige at al. 2012; O' Connell et al. 2012; Daniel et al. 2014; Tang et al. 2016a; Tang et al. 2016b). The playas in the RWB with conservation programs showed a better performance in hydrology function and hydrophyte presence than the non-conserved wetlands. The results confirm the effectiveness of each type of conservation program by qualitative descriptions of annual functionality of WPAs, WMAs, and WRP easements. Public lands (WPAs and WMAs) generally showed a higher level of functionality than the private lands enrolled in WRP easements, with less variations of ponding, hydrophyte, and ponding/hydrophyte presence from one year to the next.

The annual ponded water data demonstrated distinct wet/dry years on site level. Ponded water amount is heavily dependent on regional precipitation as well as surface runoff. The collected water volume is also positively correlated to wetland size and watershed size (Tang et al. 2018). In every AHS year, the conserved wetlands maintained a relative similar area of hydrophyte, which was consistent with the results presented by Tang et al. (2016b). This study also found the majority of hydrophyte area within conserved wetlands was highly/partially functioning with large amount of desired plant species.

The results show that Massie/Water soil series demonstrated the prominent ability to hold ponding water compared to the other soil types. WMAs contained the highest proportion of Massie/Water soil series, followed by WPAs and WRP easements. Around one quarter to one third of the ponding/hydrophyte covered area or ponded area were Scott soil series protected by conservation programs. These seasonal ponded soil series are more prone to culturally-accelerated sedimentations (Tang et. al 2018). The temporary ponding soil series (Butler, Fillmore and Rusco) exhibited a very large proportion in WRP wetlands. This study also revealed the discrepancy between hydric soil condition and wetland function. The hydric soil condition reflected historical ponded water status in a long-time scale, which typically did not change in a short period. However, the areas with ponded water or hydrophyte were in highly dynamic process resulting from the interaction of natural hydrology cycles and anthropogenic factors.

This study also verified that the wetland natural hydro-period has been significantly altered due to agricultural activities, which is consistent with previous research that indicates agricultural activities directly or indirectly impact playa hydrology function (Smith et, al 2011; Bartuszevige at al. 2012; Tang et al. 2012; Collins et al. 2014; Daniel et al. 2014; Tang et al. 2016b). During the survey period, most non-conserved playas did not demonstrate standing water or hydrophyte largely due to the absence of conservation programs (Tang et al. 2015a; Tang et al. 2015b; Tang et al. 2016a). Non-conserved playas account for 87% of the total playa wetlands and only just about 10% of the non-conserved playas demonstrated ponding/hydrophyte in this study. Playas located in extensive agricultural land may have more chances to be contaminated by fertilizers or other sediments from the runoff passed by the immediate surroundings. Particularly, the cropped wetlands may be more vulnerable to sediment accumulation, hydrology degradation and adverse land conversion (LaGrange TG et al. 2005). This study also further assesses the hydrology function by precisely calculating actual ponded water hectares every year. In fact, the eleven-year ponded water map largely overestimated the wetlands' ability to being ponded, because one-fourth to one third of the ponded footprints did not present ponding every year. Annual dynamic ponded water descriptions are essential to provide updated field data for inferential results and policy insights for prioritization of hydrology restoration.

This means most playas were only supporting hydrophyte growth, which results in enhanced fully hydrology restoration of playas at a watershed scale. In addition, our results also reveal that the areas with ponding were largely smaller than areas with hydrophyte on playa wetlands. In each type of conserved footprints, two-thirds to four-fifths of footprints demonstrated hydrophyte coverage, while of one-seventh to two-sevenths presented ponding water. The ponded areas decreased when ponding frequency increased and only a very small proportion of ponded playas had the ability to be ponded frequently, which supports the research of Tang et al. (2016a). In agricultural lands of the RWB, playas exhibited lots man-made hydrological modifications, such as pits, channels, drainage systems etc (Tang et al. 2016b). These transformations of land surface dramatically decrease the water volume that should have reached the wetlands. The culturally accelerated sediments further deteriorate ponding ability by changing the depressions into flat or even high lands. This micro-topographical change of playas could cause the natural depressions to gradually lose the capacity of holding ponded water and lead to declining hydrology function.

We also found that there were a certain proportion of late successional plants in conserved lands in 2012, which were primarily some types of invasive plants in hydrophyte areas. It supports previous studies that indicate playa wetlands with cultivated surroundings are more likely to be colonized by invasive plants (Smith et al, 2003; Smith et al, 2011; Tsai et al. 2012). Among the conservation programs, WMAs had the highest proportion (34.25%) of invasive plants along with highest proportion of woody species, which was consistent with the research of Tang et al. (2016b). Wetlands with physical modifications of land surface became more prone to be filled with silt or to be leveled, which provides advantageous conditions for growth of invasive plants, such as cattail and reed canary grass. Sediments accumulated in depressions could absorb ponded water, topographically altered low lands to high lands and decreased the habitat availability of native plants, thus, promoted the colonization of invasive plants.

We should recognize this study only evaluated a snapshot of the functional condition of playas in the spring migratory season due to the timing of the AHS. But wetland definition is based on functional features in growing seasons, which did not concur with the AHS time. Therefore, it is very likely that some un-functional playas in this study should be classified as functional playas, because they may actually have functional features in the un-surveyed time (growing seasons). In addition, for hydrological function, some sites were observed with visible standing water, however, they were created for agriculture intentions, such as excavated pits, stock ponds, etc. Those sites were counted as wetlands with hydrology function, but they did not provide quality habitat for plants and animals by natural shallows. Besides, the hydrophyte area in the AHS contained some lands covered by grass, wood species, or agricultural lands. Those sites literally had no wetland function in energy replenishment for wetland birds. Therefore, more field surveys with accurate data during summer and fall seasons will be helpful to have a comprehensive understanding on playa hydrological performance.

4.2 Policy Implications for Conservation Planning

Playa wetlands in the RWB require a holistic restoration strategy within conservation programs. A combination of on-site wetland restoration and off-site watershed restoration is needed to upgrade wetlands function in public lands and private wetlands enrolled in conservation easements. Sediments removal should be prioritized, because they accumulated in depressions could absorb ponded water, topographically altered low lands to high lands and decreased the habitat availability.

Based on ponding frequency, restoration of large wetlands with Massie/water soil series should be prioritized, because they have more opportunities to be ponded due to large catchments even in dry seasons. The Scott soil series restoration should be prioritized in the agriculture surrounding, because they are more prone to culturally-accelerated sedimentations. The Butler, Fillmore and Rusco soil types may require additional hydrological restoration activities in order to maintain an ideally natural wet/dry cycle.

Full hydrological restoration requires water control management with rehabilitation of hydrological alterations, potentially including filling irrigation reuse pits, drain closure, sediment removal and culvert replacement (Grill 1996). Full restoration of wetland natural wet/dry cycles is the sound foundation of hydrophyte restoration, as it will provide optimal environments for animal and native plant communities which are adapted to the unique hydrological conditions. Replacement of invasive plants by desired plant species along with management of at-risk plant species should also be prioritized in conservation strategies. To decrease encroachments of the invasive plants, conservation practices also need to increase plant species richness and structural diversity combined with mimicry of natural disturbance, including seasonal grazing and fire interactions (RWBJV 2013).

CHAPTER 5 CONCLUTION

This study systematically mapped the annual temporal-spatial pattern of playa wetlands functionality in the RWB with WPAs, WMAs and WRP conservation programs in terms of ponding and hydrophyte based on the AHS during 2004 to 2015.

For research question, "(1) What is the temporal-spatial pattern of the playa functionality? And restorable potential?", we concluded the playas with conservation strategies exhibited a higher level of functionality in hydrology and hydrophyte presence than the non-conserved playas. The hydrology performance was not as good as hydrophyte performance, presenting a large hydrophyte coverage and small ponded water area within conserved wetlands, which suggests that hydrological restoration at the watershed level is needed. By comparing the yearly averaged and eleven-year maximized area of ponding/hydrophyte, we identified the WMAs have highest hydrological restoration potential and WRP easements have highest hydrophyte and ponding/hydrophyte restoration potential.

For research question, "(2)What is the functionality level of hydrophyte and hydric soil?", we found the hydrophyte assessment within conserved playas demonstrated almost the same amount of area every year with a favorable proportion of highly functional or partially function hydrophyte. Analysis of hydric soil condition showed the ponded footprints contained a higher percentage of Massie/Water soil types and a lower percentage of Fillmore Rusco or Butler soils, compared to ponding/hydrophyte covered footprints within conserved lands. In addition, with the ponding frequency increases, the proportion of Massie/Water soil type increases accordingly, with a decreased percentage of Fillmore, Rusco or Butler soil type.

For research question, “(3) What insights do the findings have into policy recommendation?”, we recommend playa wetlands in the RWB need long-term fully hydrological restoration at the watershed level to mitigate rapid loss, which calls for hydrologic restoration primarily in terms of filling the pits and reducing sediment inputs, as well as enhancing vegetation management with more desirable plant species.

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