



Conservation significantly improves wetland conditions: evaluation of playa wetlands in different conservation status

Hong Zhang · Zhenghong Tang · Andy Bishop · Jeff Drahota · Ted LaGrange · Dana Varner

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Abstract This study assessed the conditions of wetland hydrology, hydrophyte and soil under different state and federal conservation programs, 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 in Nebraska, USA during 2004–2015. The results show that the historical hydric soil footprints with the conservation programs had significantly better performance in 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's conservation easements (WRPs), and 1.86% for non-conserved wetlands, respectively. The yearly average of hydrophyte plant community coverage within footprints reaches at 77.51% for WPAs, 79.28% for WMAs, and 66.53% for WRPs, and 8.82% for non-conserved hydric footprints. 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 ponding water frequency increased. The areas, with high likelihood to be restored, are the places between annual ponding/hydrophyte covered areas and 11 years' maximized ponding/hydrophyte areas.

H. Zhang · Z. Tang
University of Nebraska-Lincoln, Lincoln, NE 68588, USA

A. Bishop · D. Varner
Rainwater Basin Joint Venture, Grand Island, NE 68803, USA

J. Drahota
Rainwater Basin Wetland Management District, U.S. Fish and Wildlife Services, Funk, NE 68940, USA

T. LaGrange
Nebraska Game and Parks Commission, Lincoln, NE 68503, USA

Z. Tang (✉)
Community and Regional Planning Program, College of Architecture, University of Nebraska-Lincoln, 313 Architecture Hall, Lincoln, NE 68588-0105, USA
e-mail: ztang2@unl.edu

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Introduction

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 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 footprints having their own watersheds 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 and Smith 2014). The size of individual playa footprints ranges from less than one acre to more than one thousand acres (LaGrange 2005). Playa wetlands cycle through a wet/dry period that support diverse vegetation communities ensures providing the unique environments for physical, chemical, and biological processes to maintain productivity and biodiversity of wetland dependent plants and wildlife (LaGrange 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, and preserving biodiversity (Bolen et al. 1989; LaGrange 2005). Recently, the primary research focus of playa function has been on their ability to provide forage for millions of waterfowl during their migrations, particularly during spring migration. Yet, studies have found playas are being lost and degraded at a substantial rate reducing the amount of available forage (LaGrange 2005). The playas are still negatively impacted by conversion to improve croplands, and by excessive sediment accumulation, spread of invasive plant communities, hydrologic alteration resulting from runoff diversion and prevalence of drainage, filling, pits, and other factors (LaGrange 2005). Johnson et al. (2011) estimated that in the Southern High Plains, the number of playas decreased from 6122 to 2135 (65.1% decline), based on a hydric soil analysis. Nugent et al. (2015) reported that historical hydric footprints originally covered 830 km² based on historical soil survey (hydric footprints) in the Rainwater Basin (RWB) has been reduced by 90% in terms of complete or partial degradation. 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 anthropogenic

influences such as agricultural development and road system improvements. Tang et al. (2018) estimated that two-thirds of the historical hydric footprints in the RWB were no longer ponding water in any given spring, and 83.2% of the total footprints were observed without any hydrophytes in the past decade. All of these decreases playa functionality, and have caused declines in many ecological services. These wetlands can provide including migratory stopover habitat that supports refueling for millions of migratory birds energetic. With numerous losses and current 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 have had a profound effect including increase in the number and area functioning wetlands as well as the distribution of wetlands across the landscape.

Many studies have investigated the effects of conservation strategies on wetland, 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 an increased understanding of ecological function of restored playas with conservation programs. Smith and Haukos (2002) found that conservation efforts play a critical role in preserving native flora diversity on playas. They found playas with conservation efforts had fewer exotic species and lower perennial diversity than the playas within cropland watersheds. Moreover, Smith et al. (2011) found that conservation strategies have greatly improved playa hydrological performance, which are heavily affected by accumulated sediments. Beas and Smith (2014) found restored playa wetlands in the RWB provide more reliable habitat for amphibians. Amphibian species richness was almost two times greater in restored playas in a drier than average year. Braza (2017) established a spatial econometric method using 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 (Conservation Reserve Program) 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 (Wetlands Reserve Program) have the greatest potential to restore playa hydrology because the program encourages sediment removal which has been an extremely successful strategy. 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 success of conservation programs and practices on ponding and hydrophytic performance of playa wetlands.

However, there have been few studies systematically investigating the contemporary playa conditions with different conservation programs. Measuring variations in playa ponding and hydrophytic performance 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) on historical hydric soil footprints is a necessary step to understand the effectiveness of conservation programs. The assumption is that historic hydric footprints were once designated as such because of frequent ponding and hydrophyte presence, those places theoretically have the ability to be ponding/hydrophytes covered wetlands and could be fully retorted. Hydric soils with the greatest restoration potential can be identified by evaluating the degradation that has taken place and comparing the contemporary functional areas over a timespan of several years. Thus, the temporal-spatial patterns of playa condition in terms of ponding and hydrophytes presence, which indicate the delivered effects of each type of conservation program.

Many recent studies have evaluated and prioritized wetland restorable potential in different areas (O'Neill et al. 1997; Galatowitsh et al. 1998; Flanagan and Richardson 2010; Kauffman-Axlrod and Steinberg 2010; Stein et al. 2010; Tang et al. 2012). Wetland

restoration refers to reverse wetland loss and improve wetland function and integrity (LaGrange et al. 2011; Flanagan and Richardson 2010). Wetland restoration needs to recover the three key elements which are widely used for wetland definition: wetland hydrology, wetland vegetation, and wetland soils. According to the wetland definition, the functional playa wetland depends on ponding/hydrophytes and hydric soil presence. Therefore, the playa wetland restoration potential mainly refers to the restoration of ponding/hydrophytes in hydric soils (LaGrange et al. 2011; Tang et al. 2012).

To identify the current playa wetland conditions as well as restoration potential of conserved playa wetlands, this study used ponding and hydrophytes status, along with hydric soils, as multi-indicators to assess the associated wetland within each conserved wetlands footprints. Three specific objectives are addressed in this study: (1) evaluate the annual ponding performance of historical hydric soil footprints of conserved lands and non-conserved lands, and identify the ponding restorable potential on conserved playas; (2) investigate the hydrophyte presence on historical hydric footprints and determine the current hydrophyte coverage and identify restorable potential for restoration of hydrophytes on conserved playas; (3) understand the relationship of soil types and playas ponding/hydrophytic performance by analyzing dominant soil series on ponded footprints and the differences in ponding frequency, as well as in ponding/hydrophyte covered footprints on each type of conservation property.

Method

Study area

This study focused on the playa wetland complex in the RWB in south-central Nebraska, covering 15,907 km² of land across 21 counties. This region is globally well-known as the crucial staging habitats for millions of waterfowl and thousands of shorebirds each spring (RWBJV 2013). However, since European Americans settlement in the region, playa wetlands have experienced significant alterations. Wetland modifications including surface drains, tile drains, concentration pits, sediment deposition, land leveling and filling wetlands (with upland soils) have been the

primary practices used to increase farmable acres and therefore reduce wetland ponding and hydrophytes presence. McMurtrey et al. (1972) estimated that 82% of the wetlands had changed to agricultural land. It is estimated that currently < 1% of the RWB landscape is playa wetlands (RWBJV 2013). Unfortunately, even lots of conservation efforts have been made, most playas in the RWB are still facing with multiple challenges, including physical modifications, sediments deposition influenced by cultivation activities.

The rapid loss of wetlands did not slow down 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 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. The terms of WRP easements are not the same because the WRP easements is privately owned. For these 103 conservation easements, there are 94 of them as permanent easements and 8 of them as 30-year easements. This flexible management method can provide a level of certainty about the management options and maximize their engagement in management of conservation easements.

In Fig. 1, the lower maps show the location of RWB in the state of Nebraska and the state location in the US. The upper map shows the playa wetland complex in the RWB in south-central Nebraska. The areas with green, blue, and red colors indicate the 58 WPAs, the 35 WMAs, the 103 conservation easements.

Data source

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 8979 historical playa footprints in the RWB, covering 764.75 km². According to the historical hydric soil footprint layer, it has been estimated that there were 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.

Hydrology and hydrophyte data

The playa ponding area data were 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).

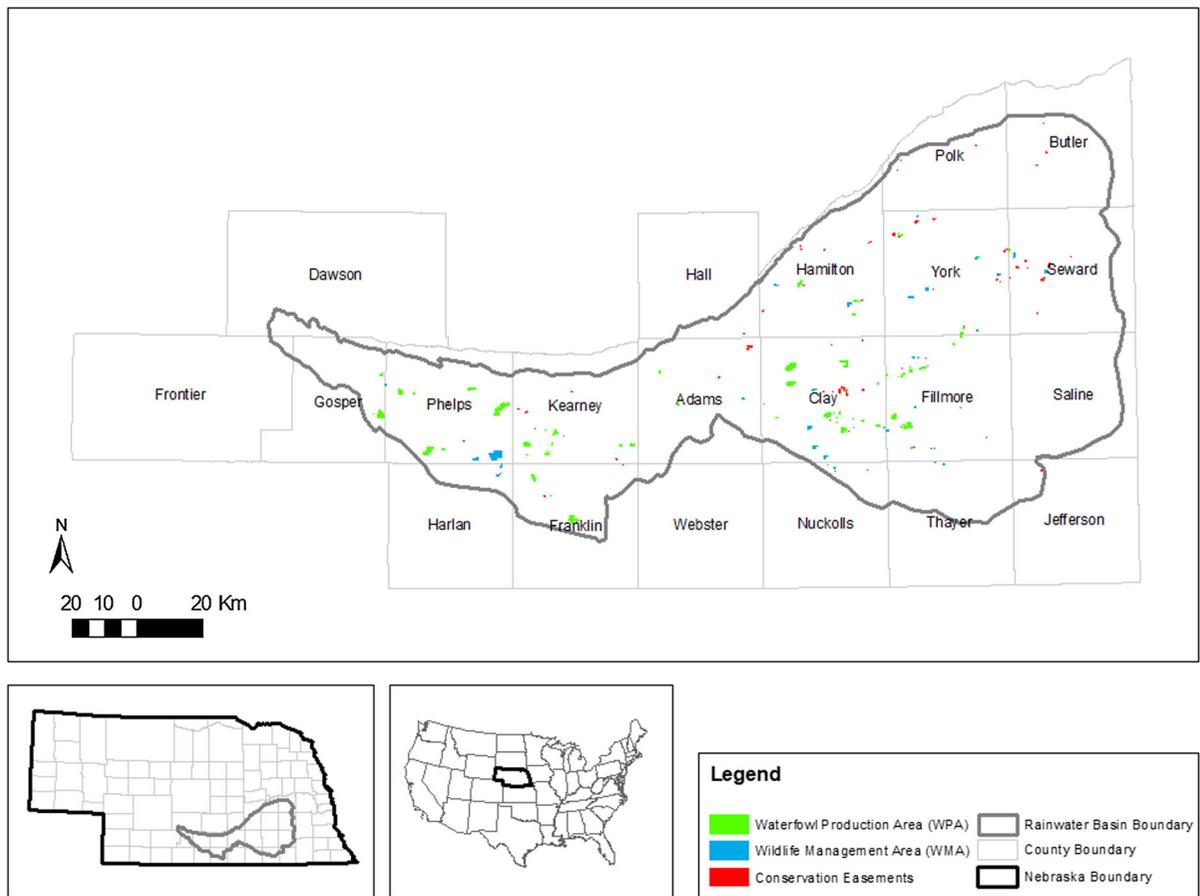


Fig. 1 Location map of the Rainwater Basin (RWB) in Nebraska

Wetland vegetation survey data collected in 2012 were also provided by the Rainwater Basin Joint Venture. This data indicates the distribution and associated plant community alliance. Wetland ponding and presence of hydrophytes can serve as good proxy for identifying 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 (RWB JV 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 (RWB JV 2015).

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.

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).

Analysis method

Flowchart of analysis method

This study primarily relied on ArcGIS 10.5 (ESRI Inc., Redlands, CA) to conduct the geospatial analysis on historical wetlands footprints. The flowchart is shown in Fig. 2. This flowchart shows how we evaluate the ponding/hydrophyte and hydric soil conditions on the playas with conservation programs in the RWB. First, we evaluated the annual performance of ponding and hydrophyte areas based on the Annual Habitat Survey Data from 2004, 2006–2015. Second, we evaluated the hydrophyte quality level by the types of hydrophytic vegetation of 2012 on the conserved playas in RWB,

and classified the hydrophytic vegetation into highly functional wetland vegetation, partially functional wetland vegetation, and non-functional wetland vegetation. Third, we assessed hydric soil conditions on the conserved footprints based on the data of Soil Survey Geographic Data in 2007, we classified the conserved footprints into semi-permanent wetland, seasonal wetland and temporary wetland according to the soil types.

Assessment of hydrology performance (ponding presence)

To identify the ponded areas in each year, we first 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 on conserved footprints, the acquired 11 annual ponding layers of conserved footprints were overlaid and processed using the “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 11-year maximized ponded area with yearly averaged ponded area, we can identify the ponding restorable potential for conserved playas. Because the locations once were observed with ponded water, they theoretically had the ability to pond water and could be restored to the maximum extent to reach full potential with least efforts compared with those locations that never with ponding water. The areas between the yearly averaged area and the maximum area are the most feasible places to improve wetland performance and functionality.

Identification of non-conserved footprint area required several steps. First, we identified those conserved footprints including, 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.

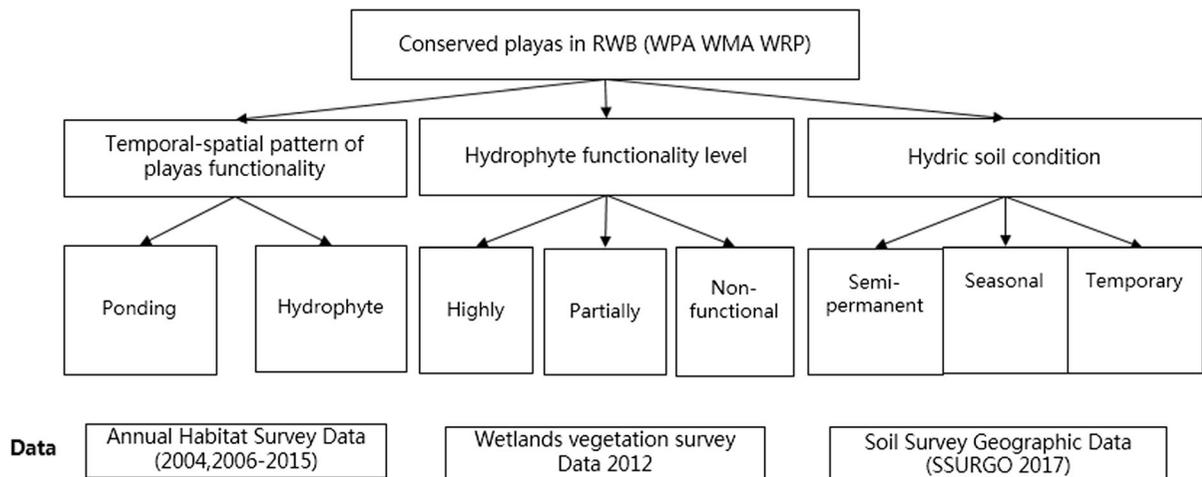


Fig. 2 Flowchart of analysis method

Second, we intersected the 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 for each survey year. Third, the ponded area of non-conserved footprints in each AHS year was equal to the ponded area of the entire RWB minus the ponded footprints within conserved lands, and then we add the ponded area of overlapped footprints.

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, to get the 11-year maximized area that once was occupied with hydrophytes at the site-level of conserved footprints, after that we could identify the hydrophyte restorable potential for each kind of conservation program.

Furthermore, to assess the quality 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.

Assessment of hydric soil condition

In this study, we selected six types of hydric 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 11-year ponding layer and 11-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.

Results

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 1 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

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

2006. Since the Annual Habitat Surveys were conducted in separate times in each year, therefore, in some cases, there were a little bit differences of the ponding/hydrophyte covered areas and the sum of ponding and hydrophyte covered areas. Ponding/hydrophyte covered area in non-conserved footprints mean that those areas were covered by either ponding or hydrophyte within the hydric footprints, but not in the conserved land (WPA, WMA, WRP conservation easements).

This study analyzed the footprints in the RWB, including the conserved footprints with either WPA, WMA or WRP conservation easements and the non-conserved footprints beyond the conserved properties boundary. Percentage of ponding and hydrophyte area within conserved footprints are shown in Fig. 3. The blue bar shows the percentage of ponding area in footprints in the RWB, it contains those footprints with different conservations status, including the conserved footprints (with WMA, WPA and WRP conservation easements) and non-conserved footprints. So does the green bars. 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

conservation easements) is largely greater than the non-conserved footprints with yearly averaging at 1.86%. Figure 3 not only shows the percentage of ponding and hydrophyte area within conserved footprints, but also the percentage of ponding and hydrophyte area in non-conserved footprints.

When we overlaid the 11 years' data together, we obtained the maximum ponded area, hydrophyte and ponding/hydrophyte area in footprints of each conserved site. Figure 4 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 4 only compares between the footprints with WMA, WPA or WRP conservation easements program, which did not refer to any non-conserved footprints.

Table 2 presents the actual hectares and percentage of 11-year maximized area and mean area of ponding, hydrophyte, and ponding/hydrophyte. The percentage difference between maximum ponded and mean ponded area implicates the restorable potential for each kind of conservation program. We found approximately half of the conserved footprints demonstrated

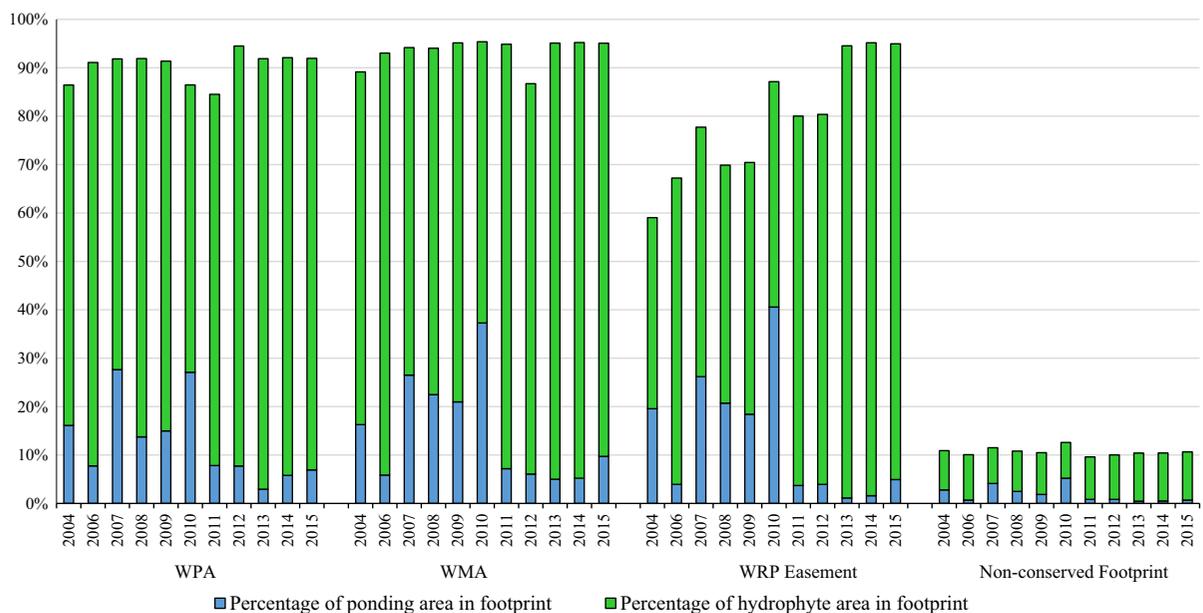


Fig. 3 Percentage of ponding and hydrophyte area in footprints under different conserved status

Fig. 4 Percentage of ponding, hydrophyte and ponding/hydrophyte covered area in conserved footprints during 2004 to 2015 (site level)

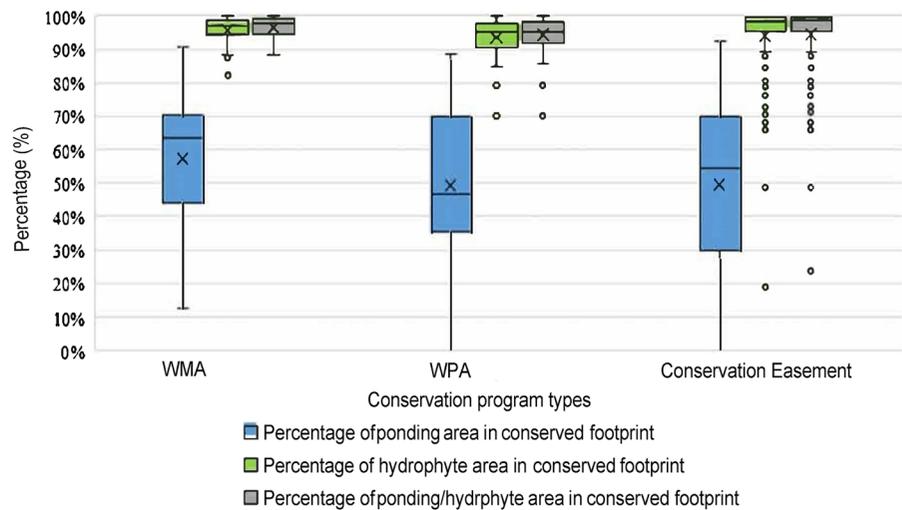


Table 2 Hydrology, hydrophyte and ponding/hydrophyte covered footprints under each type of conserved status

	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 11-year maximized and yearly averaged area	34.55%		39.49%		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 11-year maximized and yearly averaged area	15.11%		17.14%		29.65%	
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 11-year maximized and yearly averaged area	3.16%		2.94%		16.58%	

ponding 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.

In ponded footprints within conserved lands, the percentage of ponded footprints with different

ponding frequency in each kind of conserved lands can be found in Fig. 5. For those conserved footprints once were with ponding during 2004–2015, around one-third to forty percent were only ponded once. 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

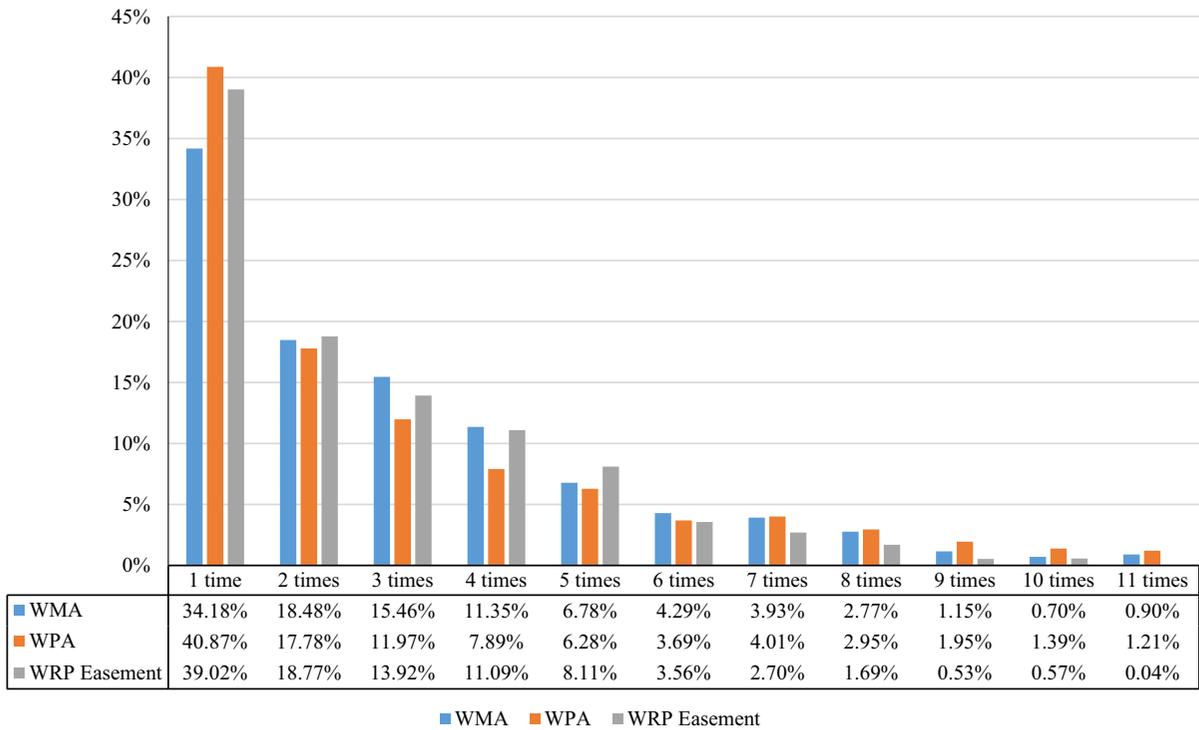


Fig. 5 Percentage of ponding area with different ponding frequency in ponded footprints during 2004 to 2015

times in every AHS year, indicating most of these wetlands have lost the ability of frequent ponding.

Assessment of hydrophyte performance (presence and types)

Hydrophyte coverage 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 (Fig. 3). 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 Fig. 4, we found all the conserved sites were covered by hydrophytes or ponding/hydrophytes 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 on average displayed hydrophyte every year, with a Min of 7.38% in 2010 and Max of 9.97% in 2015 (Fig. 3). 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 quality level according to vegetation types for different conservation programs in 2012. Highly functional wetland plant communities are comprised by early successional annual and perennial 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

Table 3 Vegetation and land coverage of 2012 in footprints under each type of conserved status

Functionality condition	Vegetation and land coverage	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
	Standing 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%)

easements, 10.55 km² (61.01%) is covered by highly functional vegetation communities, and 3.17 km² (18.33%) of partially functional hydrophyte.

Assessment of hydric soil condition

The dominant soil types and associated percentage in ponded footprints and ponding/hydrophyte covered footprints with conservation programs during 2004–2015 can be found in Fig. 6. In the conserved footprints with ponding/hydrophyte, the Massie/Water soil type accounts for a large portion, 7.99 km² (34.75%) in WMAs footprints, 10.76 km² (20.28%) in WPAs footprints, 1.89 km² (10.94%) in WRP easement footprints. This is consistent with the deeper nature of semi-permanent wetlands and larger associated watersheds. Scott soil type also accounts for a large percentage of the hydric soil 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 11-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.

Ponding frequency for each soil type varies between conservation status (Table 4). The times in the Table 4 indicate the ponding frequency during 2004–2015. 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 in ponding area decreased when the frequency of ponding water increased in given multiple years. This is consistent with the saturated hydraulic conductivity and drainage characteristics of different soil types and their ability of holding ponded water.

Discussions

Conservation programs effectiveness

The findings from this study indicate playa wetlands varying degrees of ponding/hydrophytes performance

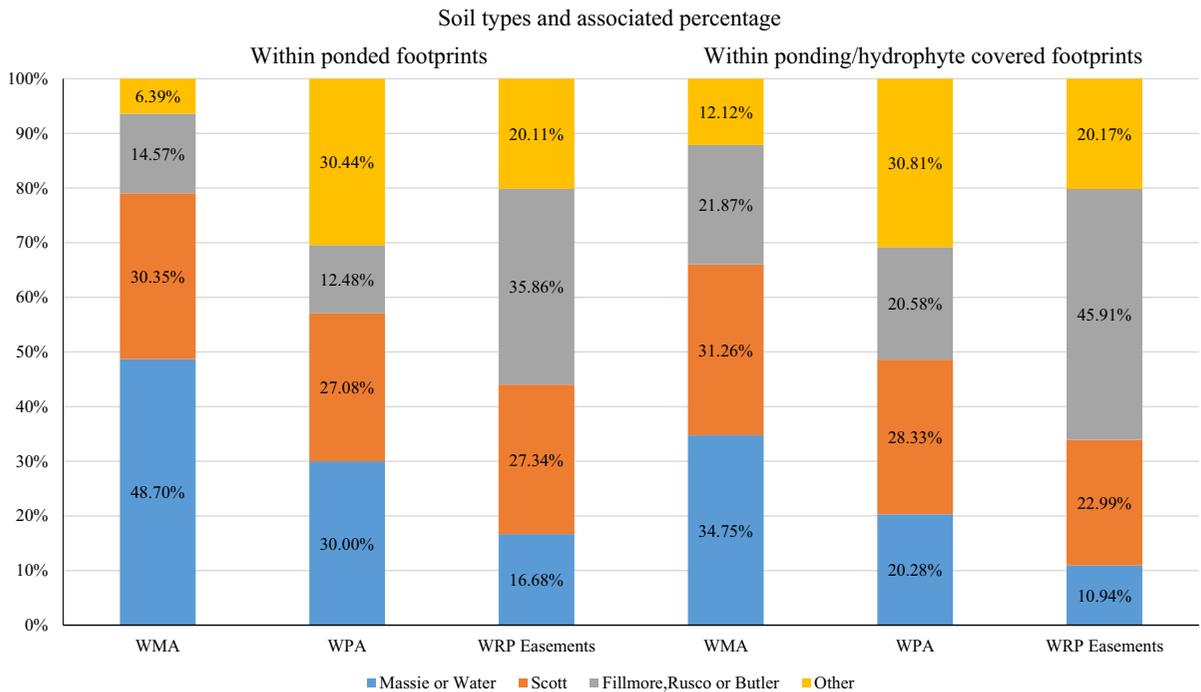


Fig. 6 Soil types and associated percentage in ponded footprints and ponding/hydrophyte covered footprints (2004–2015)

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

Soil type	1 time (%)	2 times (%)	3 times (%)	4 times (%)	5 times (%)	6 times (%)	7 times (%)	8 times (%)	9 times (%)	10 times (%)	11 times (%)
WPA											
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											
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											
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

under different conservation status. This study supports the previous findings that conservation efforts have greatly improved wetland ponding/hydrophytes performance (Smith et al. 2011; Bartuszevige et al. 2012; O'Connell et al. 2012; Daniel et al. 2014; Tang et al. 2016a, b). The playas in the RWB with conservation programs showed a better performance in hydrology performance and hydrophyte presence than the non-conserved wetlands. The results confirm the effectiveness of each type of conservation program by qualitative descriptions of annual ponding/hydrophytes performance of WPAs, WMAs, and WRP easements. Public lands (WPAs and WMAs) generally showed a higher level of ponding/hydrophytes performance than the private lands enrolled in WRP easements, with less variation of ponding, hydrophyte, and ponding/hydrophyte presence from 1 year to the next.

Hydrology and hydrophyte conditions for restoration consideration

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). Therefore, a combination of on-site wetland restoration and off-site watershed restoration is needed to restore wetlands function on public and private wetlands enrolled in conservation easements. 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 conserved wetlands maintained a relative similar area of hydrophyte, and 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. It is hard to define an ideal balance between ponding and hydrophyte areas. Because the areas with ponded water or hydrophytes were in highly dynamic process resulting from the interaction of natural hydrology cycles and anthropogenic factors that are likely have compound effects on wetland hydric function. In general, the more ponding areas and hydrophyte areas in historical hydric soil footprints, the better function the wetland

will perform. The actual performance may still depend on many factors, such as topographic conditions, the vegetation management needs (burning, chemical treatment, grazing, etc.) and other conservation efforts (pumping, sediment removing, etc.). These practices could quickly change the balance between ponding and hydrophyte areas.

Soil conditions for restoration consideration

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 25% to 33% 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) covered a large proportion of the WRP wetlands. These soil types may require additional hydrological restoration activities in order to maintain an ideally natural wet/dry cycle. This study also revealed the discrepancy between hydric soil condition and wetland ponding and hydrophytes performance. The hydric soil condition reflected historical ponded water status in a long-time scale, yet this did not change in a short period. However, the areas with ponded water or hydrophytes were in highly dynamic process resulting from the interaction of natural hydrology cycles and anthropogenic factors that are likely causing reduced wetland hydric function.

Challenges and opportunities for restoration of playa hydrology

This study also verified that RWB 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 performance (Smith et al. 2011; Bartuszevige et 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 any evidence of hydrophytes largely due to cropping activities and the absence of conservation

programs (Tang et al. 2015a, b, 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 2005). This study also further assesses the hydrology performance by precisely calculating actual ponded water hectares every year. In fact, the AHS-11-year data layer largely overestimated the wetlands' ability to pond, because one-fourth to one-third of the ponded footprints did not present ponding every year. Yet, annual dynamic ponding descriptions are essential to provide the necessary feedback for inferential results and policy insights for prioritization of hydrology restoration, contemporary ponding frequencies, and to measure the success of previous restoration strategies. In addition, our results also reveal that the areas with ponding were largely smaller than areas with hydrophyte on playa wetlands. This means most playas were only supporting hydrophyte growth, and have unrealized restorable potential, including full hydrologic restoration at a watershed scale. In each type of conserved footprints, two-thirds to four-fifths of footprints demonstrated hydrophyte coverage, while of 14% to 28% 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, also identifies by Tang et al. (2016a) research. In agricultural lands of the RWB, playas exhibited many man-made hydrological modifications, such as pits, channels, drainage systems etc. (Tang et al. 2016b). These transformations impede runoff in many ways but ultimately decrease the water volume that should reach the wetlands. The accelerated sediments further deteriorate ponding capabilities 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 performance.

Challenges and opportunities for restoration of playa plant community

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 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.

Policy recommendations for playa wetland restoration

Playa wetlands in the RWB require a holistic restoration strategy within conservation programs. It involves full hydrological restoration and reestablishment of desired vegetation species. Hydrology 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 (RWBVJ 2013).

Conclusion

This study systematically assessed the ponding/hydrophyte performance of playa wetlands in the RWB with WPAs, WMAs and WRP conservation programs in terms of ponding/hydrophyte presence and types, and hydric soil condition based on the AHS during 2004 to 2015. It also identified the restorable potential of playas in terms of hydrology, hydrophyte and overall presence of ponding/hydrophyte based on differences between yearly averaged area and the maximum area of ponding. The playas with conservation strategies exhibited a higher level performance of 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. The hydrophyte condition within conserved playas demonstrated almost the same amount of area every year with a favorable proportion of desired plant species. Conserved footprints with ponding water contained a higher percentage of Massie/Water soil types and a lower percentage of Fillmore Rusco or Butler soils, compared to conserved footprints with ponding/hydrophyte coverage. 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. We also found WMAs have highest hydrological restoration potential and WRP easement have highest hydrophyte restoration potential. Playa wetlands in the RWB need long-term full 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. Focusing on increasing ponding frequency and ponded area seem to be in line with supporting migratory waterfowl refueling because of the increased habitat available after restoration work is completed. This work should focus on the watersheds of each wetland and remove or improve water delivery down to each wetland footprint, however, the basin restoration work should focus on treatments that increase ponding and decrease the invasiveness of each wetland footprint.

We should recognize this study only evaluated a snapshot of playas condition in the spring migratory season due to the timing of the AHS. But wetland definition is based on functional features (ponding/hydrophyte presence and hydric soils) 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 performance, some sites were observed with visible standing water, however, they were created for agriculture use, 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.

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