Transactions of the Kansas Academy of Science
Vol. 119, no. 1
p. 33-48 (2016)

Rapid environmental changes in The Nature Conservancy wetland at Cheyenne Bottoms, Kansas: A review 2002-2015

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Cheyenne Bottoms is the premier wetland of Kansas; it consists of marshes, meadows, mud flats, channels, and pools within an oval-shaped closed depression. Cheyenne Bottoms has suffered a series of droughts and floods during the past century. During extended droughts, the bottoms may dry up completely. Conversely flooding may fill much of the basin with shallow, ephemeral lakes. Since 2002, we have conducted annual surveys during the growing season using various forms of remote sensing and ground observations. In particular, we have utilized low-height kite and blimp aerial photography to document changing conditions in The Nature Conservancy (TNC) marsh-complex environments.

During the early twenty-first century, a series of drought-flood cycles took place; dry intervals culminated in late 2006 and early 2013 and were followed soon after by major floods. Wet intervals are characterized by abundant surface water, influx of sediment and nutrients, numerous migrating shorebirds and waterfowl, expansion of emergent wetland vegetation, and abundant aquatic wildlife. During drought phases, surface water disappears, soil moisture declines, wetland vegetation dies or becomes dormant, migrating birds bypass the vicinity, and bare mud flats are subjected to wind erosion. The transformation from drought to flood conditions may take place quite abruptly. Wetland vegetation responds rapidly, invertebrate wildlife begins to recover quickly, and migrating shorebirds and waterfowl return. This scenario suggests a dynamic environment that may exhibit large short-term variations, but which is resilient and has long-term stability.

Introduction

Cheyenne Bottoms is the premier wetland of Kansas. Located in the center of the state, the "bottoms" is considered to be among the most important sites for migrating shorebirds in North America (Zimmerman 1990). To date, 340 bird species have been spotted at Cheyenne Bottoms, some of which are threatened or endangered—whooping crane, peregrine falcon, piping plover and least tern (Penner 2010). Nearly 11,000 ha (~27,000 acres) of the bottoms are designated as a Ramsar wetland of international importance (Ramsar 2014). Cheyenne Bottoms is divided between the state-owned Cheyenne Bottoms Wildlife Area (~8000 ha) in the downstream (sump) portion, The Nature Conservancy (TNC) land (~3200 ha) in the upstream (delta) portion, and various private land parcels (Fig. 1).

Cheyenne Bottoms is a closed depression at the terminal point for Blood Creek and Deception Creek drainage basins (Fig. 2). This topographic depression has existed for at least 100,000 years (Zimmerman 1990), but its origin remains uncertain. It may be related to basement structures, ancient meteorite impact, subsurface salt solution and flowage, as well as surficial wind and stream action (Aber and Aber 2009; Merriam 2011). The oval-shaped depression is surrounded on northern, western, and southern margins by bedrock upland, and the eastern side is blocked by unconsolidated alluvial sediment and aeolian sand.

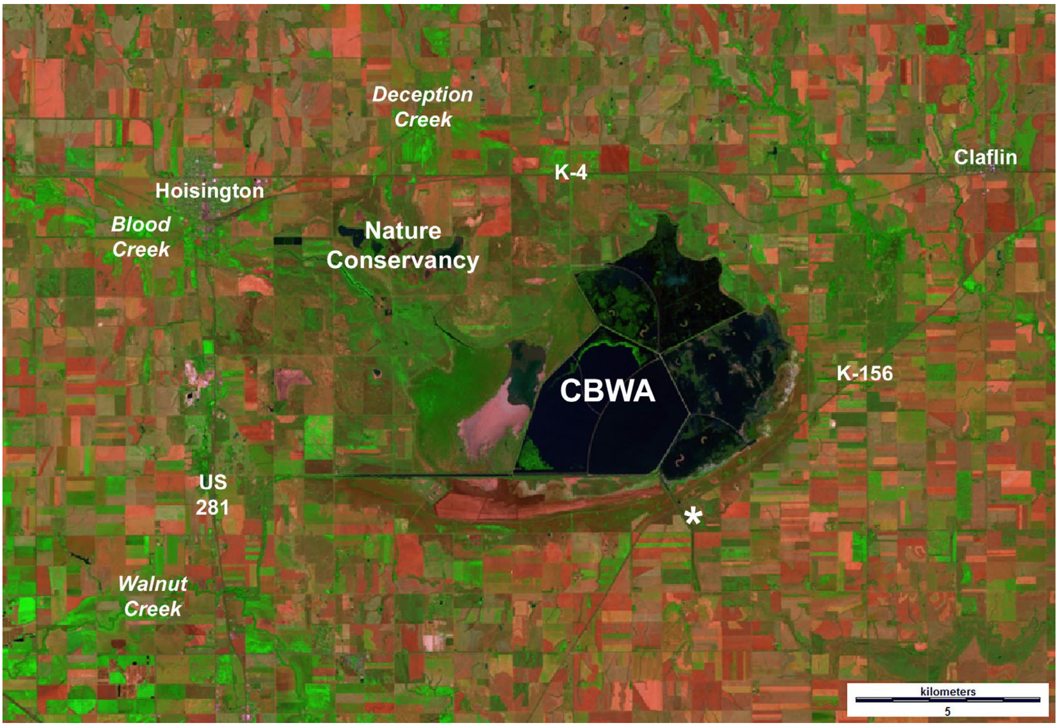

Figure 1. Early summer satellite image of the Cheyenne Bottoms vicinity at the beginning of our study. Active vegetation is green, fallow and harvested fields are red-brown, dry mud flats are pale purple, and water bodies are black. CBWA – Cheyenne Bottoms Wildlife Area; asterisk (*) shows location of the Kansas Wetland Education Center. Landsat TM bands 2, 4 and 7 color coded as blue, green and red; 28 June 2002.

Kansas historically has experienced repeated dry and wet climatic cycles (Fig. 3). The most serious droughts took place during the 1930s and 1950s, and lesser drought episodes have happened since. Meanwhile, the early 1970s, mid-1980s, most of the 1990s, and mid-2000s were wet intervals with frequent flooding. Cheyenne Bottoms likewise has suffered a series of droughts and floods during the past century. Annual precipitation in the Cheyenne Bottoms vicinity averages 60-65 cm, but is highly variable from year to year (Table 1). This leads to large fluctuations in surface runoff of local streams. The period 1990 to 2001 was generally wet for central Kansas; all but two years had positive PDSI values with an overall average of 1.59 (Table 2). The interval 2002-2014, in contrast, experienced marked fluctuations between dry and wet conditions with an overall PDSI of just 0.38.

During extended droughts, the bottoms may dry up completely. Conversely flooding has happened several times during the past century. Major floods fill much of the basin with shallow lakes that in extreme cases cover >9000 ha and may persist for many months. Over the long term, the region has a net water deficit, and the bottoms is dry more often than wet (Owens et al. 2011). In order to deal with these fluctuations in water supply, the state wildlife area is managed actively with an extensive system of levees, pools, pumps, gates, and other water-control structures. Furthermore, the state wildlife area receives additional water diverted from Walnut Creek via a canal across the drainage divide into the southern portion of the bottoms. When available, water may be transferred from the Arkansas River to Walnut Creek to supplement diversion from the creek. Management

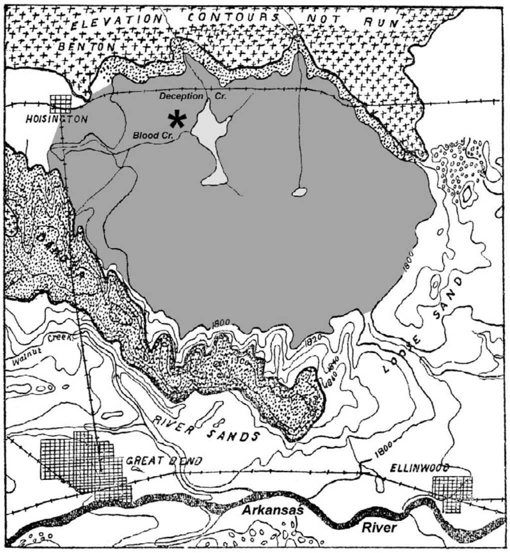

Figure 2. Early sketch map of Cheyenne Bottoms near Great Bend, central Kansas. The oval shape of the bottoms is shown in gray. Deception and Blood creeks are the natural tributaries, which have built a delta complex in the northwestern portion of the bottoms near Hoisington. TNC study site indicated by the asterisk (*). Elevation contours in feet; 1800 feet is ~550 m. Modified from Haworth (1897, fig. 1).

is primarily for migratory waterfowl and shorebirds (Penner 2010), and hunting provides a substantial source of income.

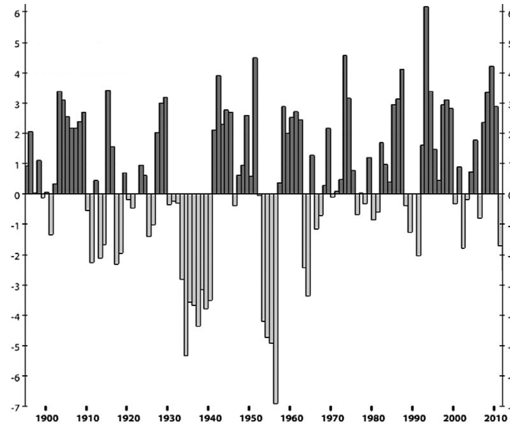

Figure 3. Kansas historical record of the statewide annual Palmer Drought Severity Index (PDSI). Negative values (light gray) indicate drought, and positive values (dark gray) show wet conditions. Adapted from NOAA (2013).

The Nature Conservancy, on the other hand, has adopted a largely passive management approach for waterfowl and shorebirds as well as upland prairie birds (Penner 2010; Aber et al. 2012). Wet meadows and marshes are dependent on natural flows and floods from Blood and Deception creeks. Upstream drainage basins are comprised overwhelmingly of agricultural land use, of which non-irrigated winter wheat is the main crop (KNRP 2015). Other non-irrigated crops

Table 1. Long-term yearly precipitation data (cm) for sites near Cheyenne Bottoms, central Kansas. Years of highest precipitation represent floods mostly in 1973 and 2007; lowest precipitation years are droughts in 1936, 1956, and 1988. Data adapted from HPRCC (2014).

Site	Period of record	Location	Mean annual	Highest (year)	Lowest (year)
Great Bend	1909-2012	12 km to SW	64	110 (1973)	36 (1956)
Claflin	1930-2012	12 km to NE	65	132 (2007)	31 (1988)
Hudson	1922-2012	40 km to south	64	108 (2007)	36 (1936)
Geneseo	1939-2012	44 km to east	67	146 (1973)	34 (1956)
Bison	1923-2012	48 km to west	60	98 (1973)	32 (1956)
Larned	1903-2011	50 km to SW	61	101 (1915)	31 (1988)

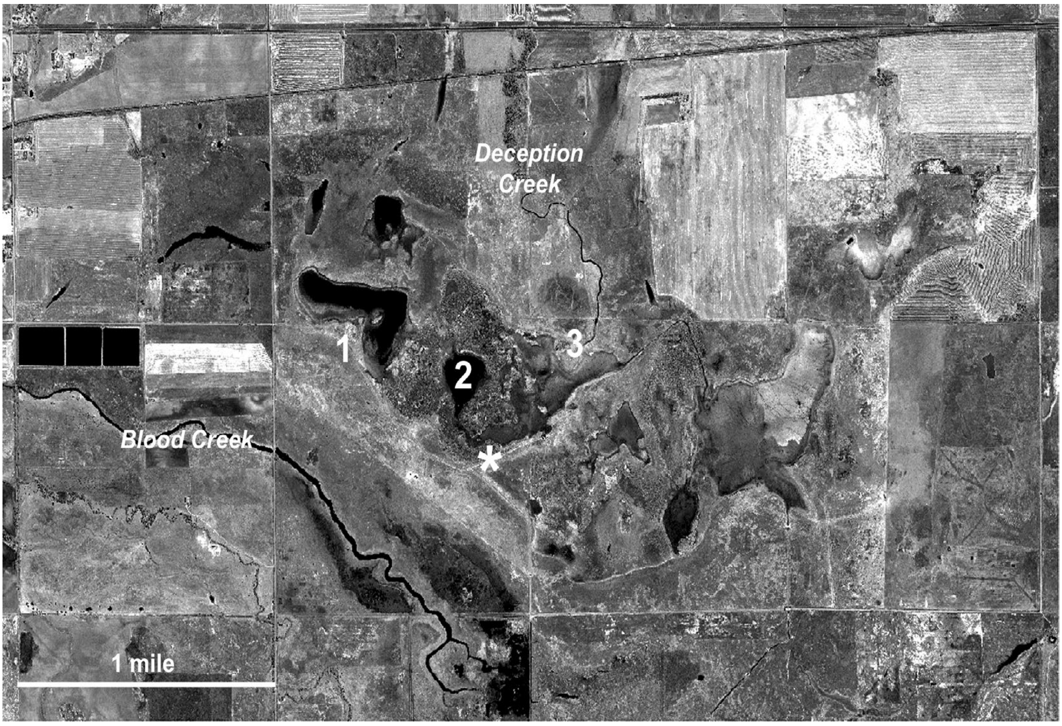

Figure 4. Close-up satellite image of TNC vicinity, northwestern portion of Cheyenne Bottoms. Long-term study site marked by asterisk (*). Black indicates surface water bodies of near-normal summer conditions. Reference points: 1 – access road from west, 2 – central pool, 3 – delta of Deception Creek. Ikonos panchromatic band, July 2003.

include corn and sorghum as well as grassland. Irrigation is limited within the drainage basins to a few fields of soybeans, sorghum, and alfalfa. Deception and Blood creeks are largely uncontrolled streams; however, many agricultural fields are terraced to reduce water and sediment runoff.

Within the wetland complex at TNC, barriers and artificial drainage have been removed, as much as possible, to restore natural water supply, which is highly variable seasonally and annually. Excess overflow from TNC land drains into the state wildlife area. TNC has ended crop agriculture and removed most trees. Meadows are subject to limited rotational grazing, which provides a source of income to pay expenses and property taxes. The public is welcome to visit TNC land, but no hunting or off-road vehicles are allowed.

Methodology

Beginning in 2002, we have conducted annual observations during the growing season (spring, summer and autumn) at the main TNC marsh complex (Fig. 4). Our primary methods are various forms of remote sensing, and our goals are to document, analyze, and understand climatic and human impacts on this dynamic wetland environment.

Specifically we have developed techniques for small-format aerial photography (SFAP). We have utilized low-height kite and blimp SFAP to acquire vertical and oblique views (Fig. 5). These images have high spatial (2-5 cm) and temporal resolutions that depict the landscape in great detail through the seasons. SFAP is supplemented with satellite imagery, historical aerial photographs, digital orthophoto quadrangle (DOQ) images, as well as ground

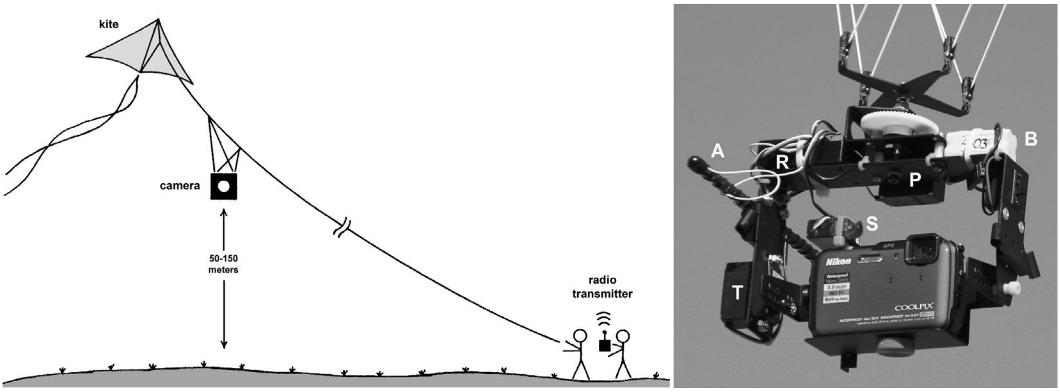

Figure 5. Small-format aerial photography. Left – cartoon showing the typical setup for kite aerial photography. The camera rig is attached to the kite line, and a radio transmitter on the ground controls operation of the camera rig. Not to scale (Aber, Marzolff and Ries 2010, fig. 8-22). Right – typical camera rig for kite or blimp aerial photography. A – antenna, R – radio receiver, P – pan servo, B – battery pack, T – tilt servo, and S – shutter microservo. This *Nikon* camera is waterproof and equipped with built-in GPS and directional functions.

observations. We have reported our preliminary efforts (Aber et al. 2006; Owens et al. 2011), and we continue to observe habitat conditions.

Table 2. Annual average Palmer Drought Severity Index (PDSI) for Kansas climatic division 5 (central Kansas, including Cheyenne Bottoms). High (>1.8) and low (<-1.8) values are highlighted in blue (wet) and red (dry). Derived from data obtained from NOAA, National Climatic Data Center: http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp March 2015.

Year	PDSI		Year	PDSI
1990	-0.48		2002	-1.43
1991	-1.99		2003	0.11
1992	1.84		2004	-0.39
1993	6.89		2005	0.13
1994	0.22		2006	-2.11
1995	1.08		2007	2.25
1996	0.45		2008	3.50
1997	2.44		2009	3.32
1998	3.13		2010	1.89
1999	3.44		2011	-1.10
2000	1.12		2012	-1.96
2001	0.90		2013	0.18
Subtoal	1.59		2014	0.50
Grand total	0.96		Subtotal	0.38

During our investigations we have identified three key emergent wetland plants that are indicators for wildlife habitat conditions in TNC marshes, namely bulrush, spike rush, and cattail. These plants thrive or diminish with climatic variations, particularly drought and flood cycles. Great bulrush (*Scirpus validus*) and blunt spike rush (*Eleocharis obtusa*) are considered beneficial for wildlife habitat, food, and shelter. Common cattail (*Typha latifolia*) and narrow-leafed cattail (*T. angustfolia*) have hybridized in the Cheyenne Bottoms vicinity. Cattails are generally regarded as undesirable for wetland marshes in the central Great Plains. Cattail expansion converts open marsh and mud-flat habitats into dense overgrown thickets that are unattractive for most migrating shorebirds and waterfowl.

Summary of environmental events

At the beginning of our study, cattail thickets had spread over much of TNC marshes (Fig. 6). This was a consequence of relatively cool and wet climate during the previous decade with significant runoff (see Table 2). Cattail expansion was quite dramatic during the 1990s, as documented by multitemporal Landsat imagery (Pavri and Aber 2004). During the next few years, a series of minor droughts and floods

Figure 6. Cattail thickets (dark green) occupied substantial portions of TNC marsh in the spring of 2002. 1 – access road from west, 2 – central pool. View toward northwest with Hoisington in the distant background.

impacted TNC marshes, and cattail coverage was reduced as a result (Fig. 7). This interval culminated with a severe drought and complete drying of TNC marshes in 2006 (see Table 2). At this time, TNC undertook an experiment in which dry mud flats were disked, and emergent thatch was mowed down (Fig. 8). The intent was to mimic heavy bison grazing and soil trampling.

The drought phase ended abruptly in 2007 with extensive winter snowfall followed by repeated spring rains that led to widespread flooding of the region (see Tables 1 and 2). Cheyenne Bottoms experienced flooding of historic proportion begining in May (Fig. 9A). Thereafter much of the bottoms was inundated through the summer; water coverage expanded to >80 km^2 (Owens

Figure 7. Extensive pools and a mosaic of emergent wetland vegetation are evident in May 2005; darkest green patches in marsh are bulrush. Panoramic overview assembled from two wide-angle shots looking northward with Hoisington in the left background. 1 – access road from west, 2 – central pool.

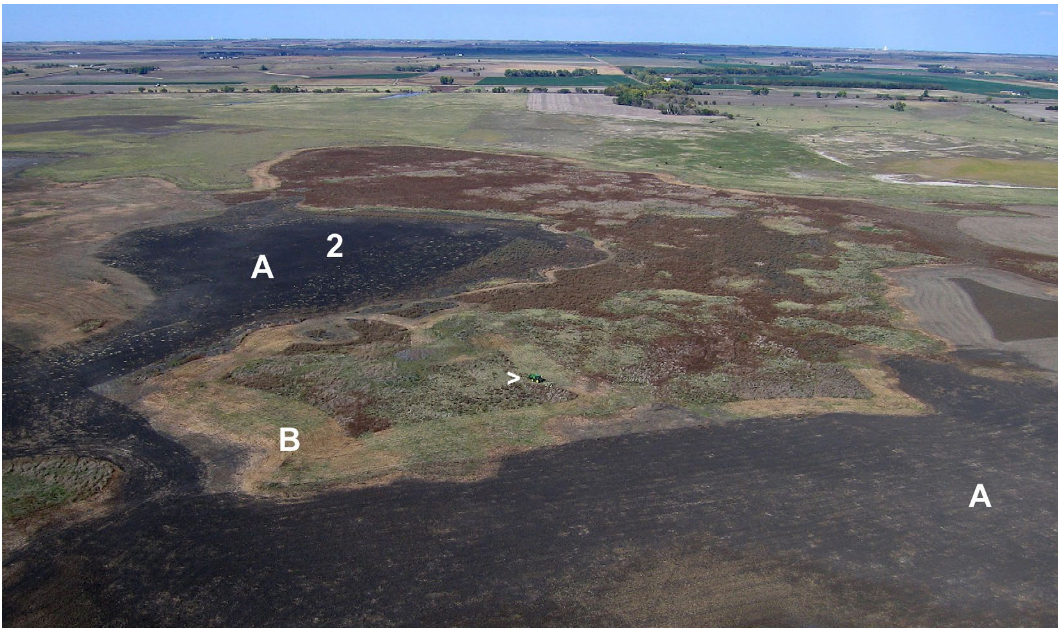

Figure 8. TNC mud flats were disked (A) and emergent thatch mowed down (B) in October 2006 under completely dry conditions. Note large tractor (>) near scene center; 2 – central pool (dry).

et al. 2011), and flood status continued well into the autumn. Flood water finally began to recede during the winter and spring in 2008. The TNC experiment to simulate heavy buffalo grazing appeared to be successful for creating open marsh conditions with extensive shallow pools (Fig. 9B).

Wet conditions and high water levels continued through the remainder of 2008 and all of 2009. This remarkable series of events is displayed in a multitemporal satellite image that includes 2006, 2007 and 2009 (Fig. 10). In the autumn of 2009, a bloom of mosquito fern (*Azolla* sp.) took place (Fig. 11). How *Azolla* entered TNC marshes is unknown, but several means of dispersal are possible including the flood of 2007, migrating waterfowl or shorebirds, boats or equipment, etc. (Aber et al. 2010). In any case, *Azolla* had almost disappeared by the following year.

A transition from wet-to-dry conditions took place during 2011 and represented the finale of the wet phase that began in 2007. Greenup in the spring of 2012 was exceptionally early, as marked by the earliest wheat harvest on record in Kansas (Fig. 12A; Salina 2012). Emergent wetland vegetation was active about one month ahead of usual, and it became clear that cattail had re-established over substantial portions of the marsh; drought conditions intensified, and by the autumn of 2012 TNC marshes were completely dry (Fig. 12B).

Drought status for TNC at Cheyenne Bottoms continued into 2013, culminated in early July, and then ended suddenly with heavy rains that led to flooding (Fig. 13). Most of TNC marshes and wet meadows were inundated by late August, and within a few weeks wetland vegetation began to recover quickly (Fig. 14). Ground inspection at this time revealed diverse hydrophytic vegetation along the marsh margin including water smartweed (*Polygonum amphibium* L.), great bulrush, blunt spike rush, mosquito fern, lesser duckweed (*Lemna minor*), and algae growing amid the remains of drought weeds, especially spiny cocklebur (*Xanthium spinosum* L.).

By the spring of 2014, TNC marshes again supported many migrating and nesting shorebirds,

Figure 9. High water in TNC marsh. A – waxing flood in May 2007. View toward the northeast. Deception Creek enters the marsh from the upper left side (3). Note high content of suspended sediment (muddy water) in foreground and extensive pools in the background. B – June 2008. Small patches of emergent wetland vegetation are scattered within extensive shallow pools. View toward northwest with Hoisington in left background; 1 – access road from west, 2 – central pool.

and repeated rains in June refilled the marsh pools (Fig. 15A). Wet conditions extended into 2015; spring rains already filled the marsh pools and emergent vegetation was well developed by mid-May (Fig. 15B). During the past two years, drought conditions in central Kansas diminished from extreme and exceptional categories. By the beginning of June 2015, drought was completely gone in the Cheyenne Bottoms vicinity (Miskus 2015). May of 2015 was exceptionally wet across

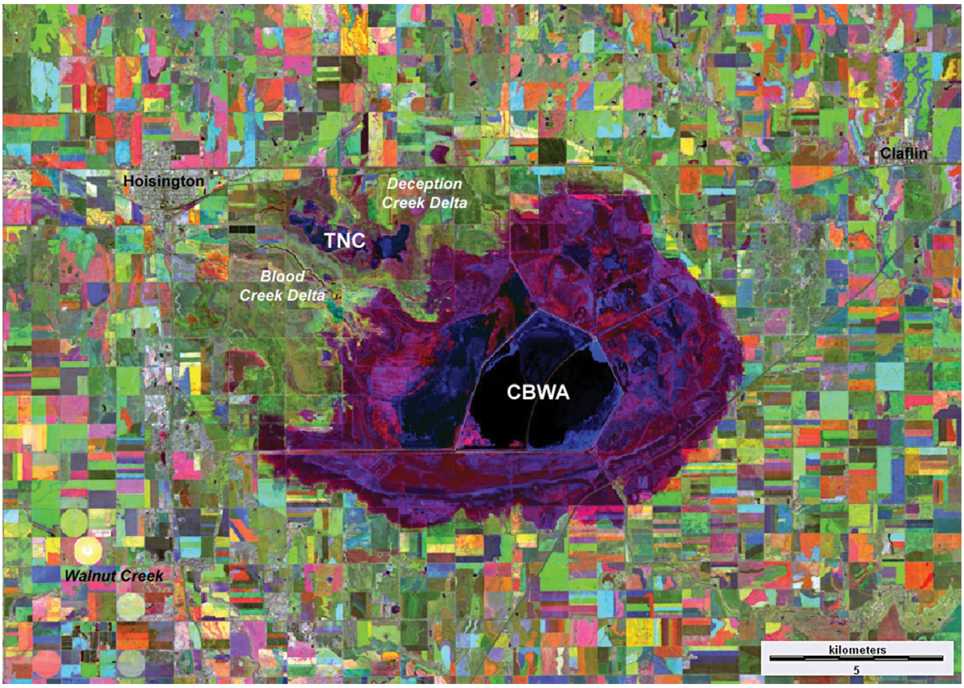

Figure 10. Multitemporal, near-infrared satellite image shows vegetation and water bodies for 2006, 2007 and 2009, color coded respectively as blue, green and red. Bright colors represent significant changes in land cover from year to year; dull-gray colors indicate little change in land cover. The broad maroon-purple zone shows the extent of high water in 2007; black and dark blue are perennial water bodies; compare with Fig. 1. Adapted from Aber, Pavri and Aber (2012).

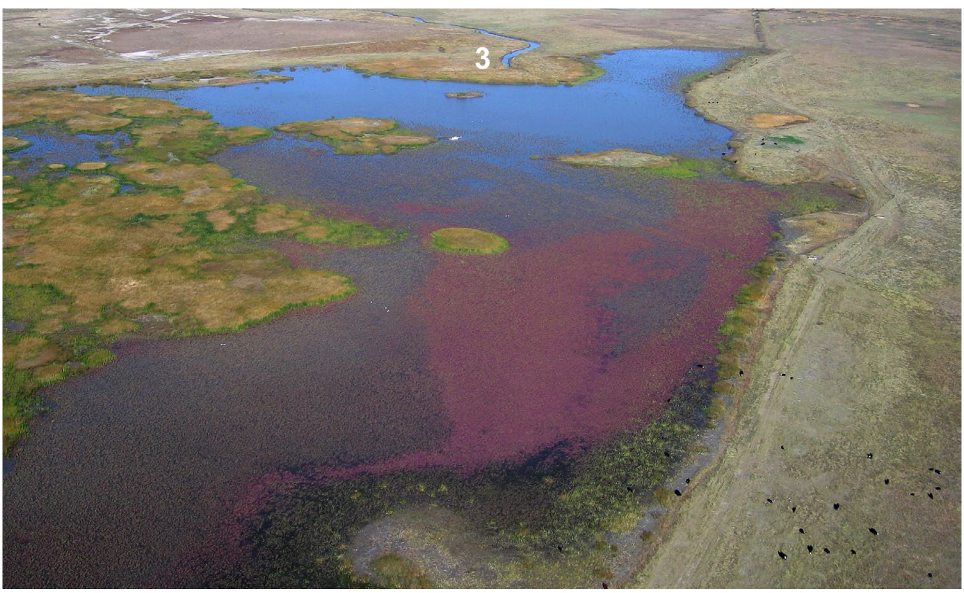

Figure 11. View toward northeast over TNC marsh in October 2009. Deception Creek enters the marsh at top center of scene (3), and cattle graze on meadows beside pools. The maroon color at scene center is a bloom of *Azolla* sp. (mosquito fern).

Figure 12. Transition during 2012. A – extensive coverage of cattail, bulrush, and other emergent vegetation in TNC marsh. Early spring greenup, April 2012. View toward northwest with Hoisington in left background; kite flyers at bottom right; 1 – access road from west, 2 – central pool. Compare with Fig. 6. B – full-drought conditions. Tracks in dry mud flats were made by local youth riding off-road vehicles without permission. View northward, November 2012; 2 – central pool (dry).

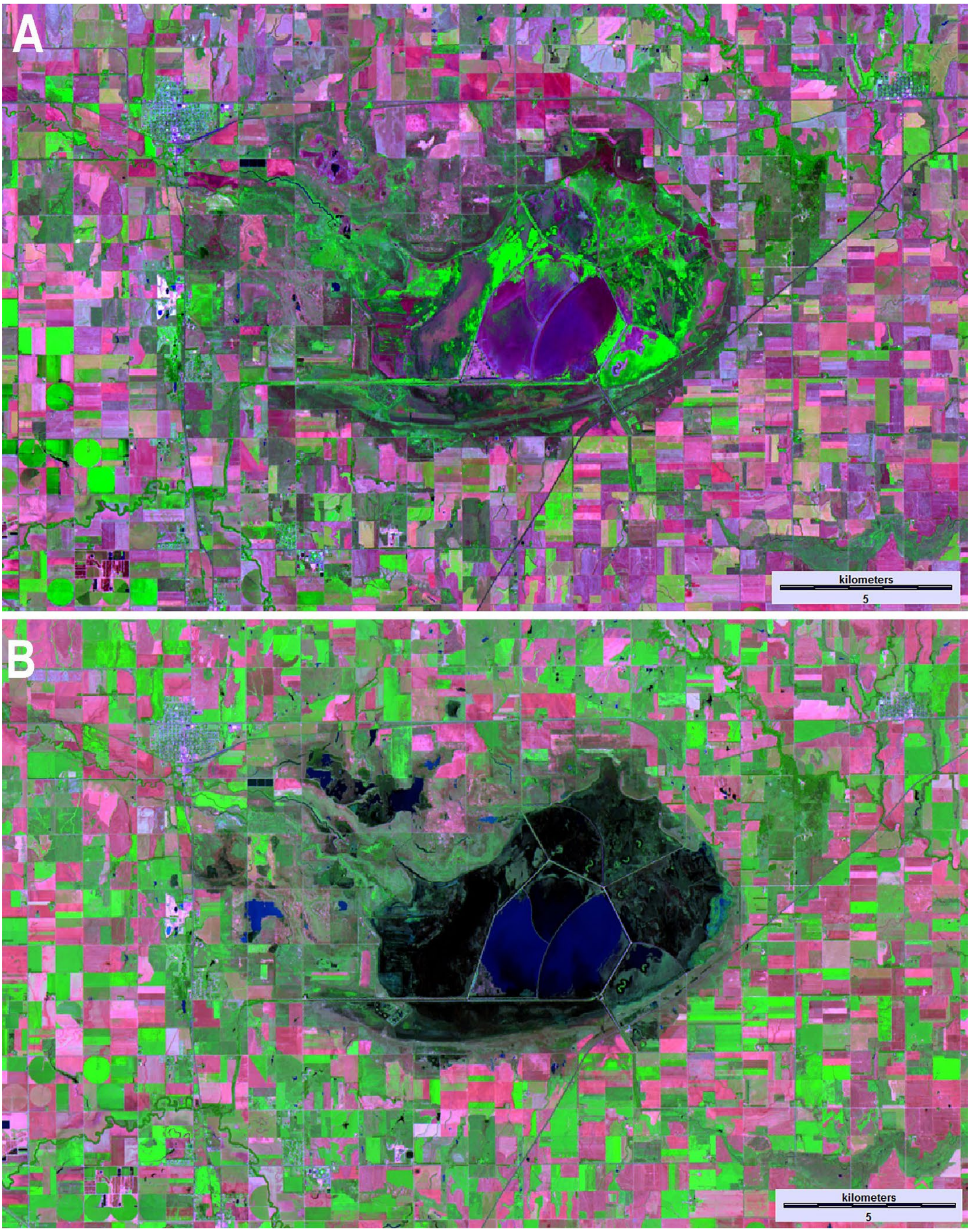

Figure 13. False-color Landsat images in which active vegetation appears green, fallow fields and mud flats are pink-maroon-purple, and water bodies are dark blue to black. July 12, 2013 (A) and August 29, 2013 (B). In July, active vegetation is mainly irrigated crops and weeds growing on mud flats, especially in the state wildlife area, which displays minimal surface water. In August, water fills most of the state wildlife area pools and TNC marshes, and vegetation is more active throughout the scene. Compare with Fig. 1.

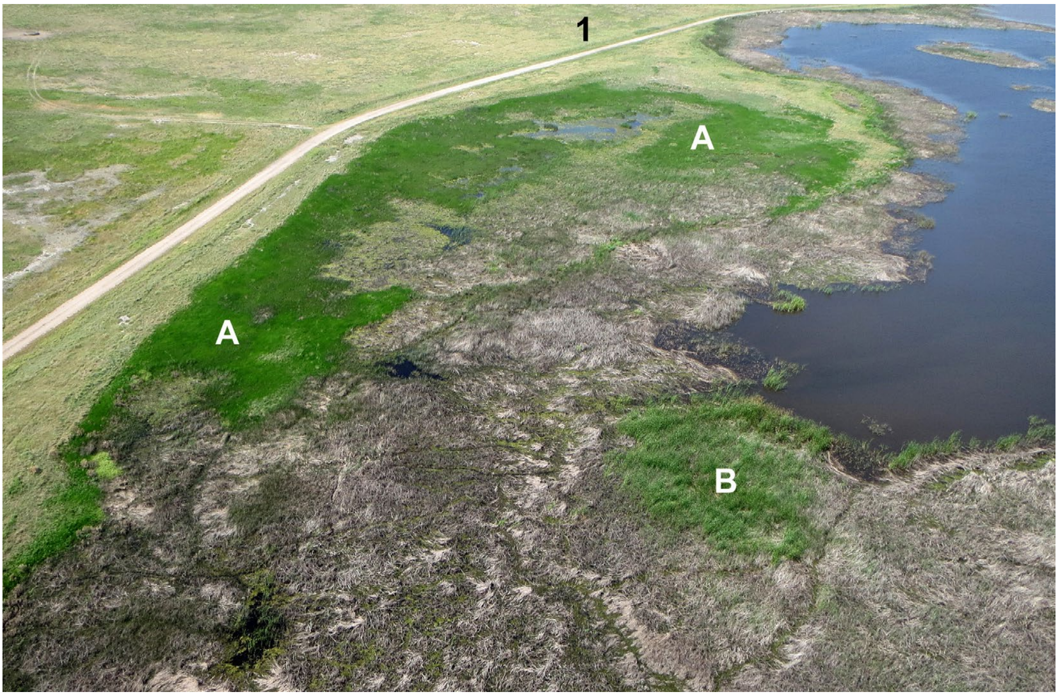

Figure 14. Close-up view of TNC marsh margin showing rapid recovery of emergent vegetation in early September 2013, a few weeks after flooding. Newly emergent bulrush and spike rush (A) and cattails (B). 1 – access road from west.

the southern Great Plains and Rocky Mountain regions. In fact, May 2015 was the wettest month for the whole United States since records began in 1895 (NOAA 2015).

Response of TNC marshes for drought-flood cycles

TNC marshes undergo substantial changes in surface water, soil moisture, and vegetation coverage as consequences of repeated droughts and floods. During the early twenty-first century, a series of drought-flood cycles took place; dry intervals culminated in autumn 2006 and early summer 2013 and were followed soon thereafter by major floods in 2007 and 2013. The environmental regime is, thus, one of frequent fluctuations, as determined by available surface water.

Wet intervals are characterized by abundant surface water, expansion of emergent wetland vegetation, numerous migrating shorebirds and waterfowl, abundant aquatic wildlife, and an influx of sediment and nutrients (see Figs. 9 and 15). Were such conditions to continue indefinitely, the shallow pools and mud flats eventually would become infilled with sediment and overspread by thickets of emergent vegetation and, thus, become less attractive for many species of migrating shorebirds and waterfowl. This tendency is especially evident toward the ends of wet intervals (see Figs. 6 and 12A).

During drought phases, surface water gradually disappears and soil moisture declines. Wetland vegetation begins to die down or become dormant. Early in the drought, well-established emergent wetland plants may draw on deep soil moisture, but eventually they will exhaust the available water. This has dire consequences for aquatic invertebrates living in the pools. Burrowing crayfish, for example, breathe with gills and must have some contact with water. During droughts, they may dig complex tunnel

Figure 15. High water in TNC marsh. A – pools were full of water, and emergent wetland vegetation was recovering from the previous drought in June 2014. Note the muddy brown water in foreground. Panoramic overview assembled from two wide-angle shots looking toward the northwest with Hoisington in the left background; 1 – access road from west, 2 – central pool. Compare with Fig. 9B. B – full pools in May of 2015. Panoramic overview assembled from two wide-angle shots looking toward the northeast showing the delta of Deception Creek (3).

systems extending meters deep to reach ground water and, thus, survive eating plant and animal detritus in the soil (EOL 2014).

As food resources diminish, migrating birds and other wildlife bypass this vicinity for better resources elsewhere, such as the Nebraska Sand Hills. The bottoms gradually settles into a low level of apparent activity that may temporarily favor certain opportunistic plants (weeds), such as velvetleaf (*Abutilon theophrasti*) and spiny cocklebur. Bare mud flats are subjected to wind erosion as fine-grained soil (dust) is blown away from shallow depressions.

The transformation from drought to flood conditions may take place abruptly and without prior notice that a change is about to happen. Neither of the floods in 2007 and 2013 and subsequent wet cycles were predicted. Wetland vegetation responds rapidly, and insects proliferate in wet meadows. Saturation of soil allows seeds, roots, and eggs that may have lain dormant for months or even years to sprout or hatch and grow quickly. Invertebrate wildlife begins to recover, and migrating shorebirds and waterfowl return. After the flood in 2007 and high water in 2008, a bloom of mosquito fern took place in 2009 (see Fig. 11). Another bloom developed in 2014 following the flood of 2013 (Fig. 16). This scenario suggests a dynamic

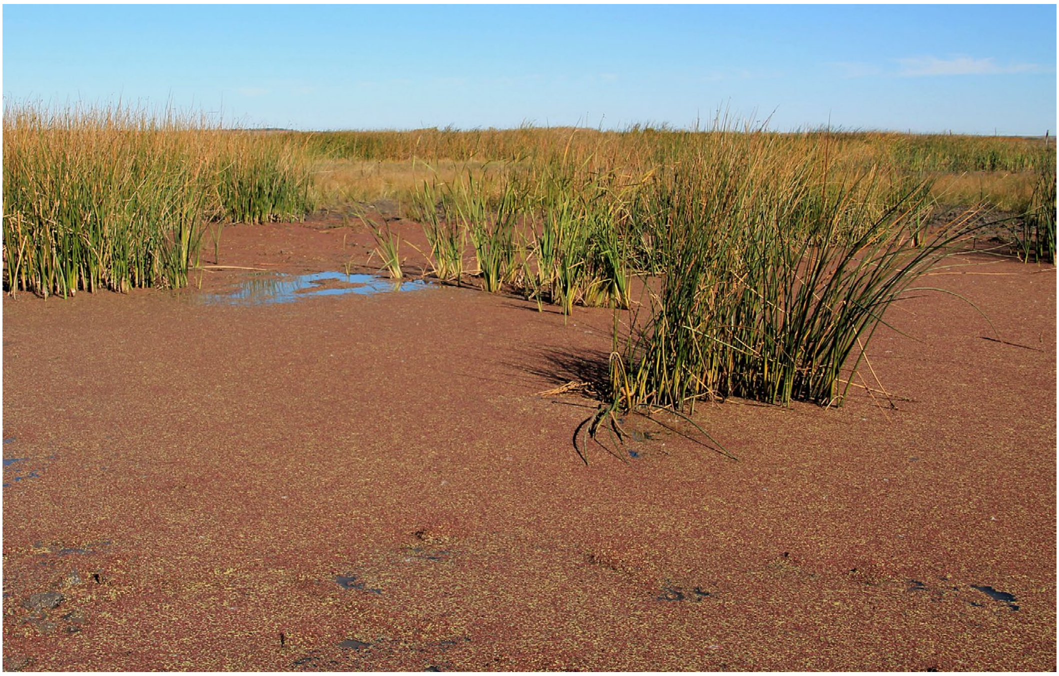

Figure 16. Mosquito fern (*Azolla* sp.) appears maroon along with duck weed (green) floating on a shallow pool in TNC marsh, October 2014.

environment that may exhibit cycles with large short-term variations, but which is resilient and has long-term stability. Plant and animal populations are well adapted to survive during droughts and to flourish during wet phases.

Wetland conditions in TNC marshes resemble the hydroperiods of playas on the High Plains. Playas are subject to cyclical wetting and drying, which is highly variable from year to year (Steiert and Meinzer 1995). The Cheyenne Bottoms Wildlife Area, in contrast, is regulated and draws on supplemental water from outside drainage basins in order to provide more constant environmental conditions. For example, in August of 2006, heavy thunderstorms rumbled across central Kansas, resulting in significant runoff in the vicinity of Great Bend. Flood water was directed via canals and ditches into the state wildlife area, but no recharge happened for marshes in the Nature Conservancy portion of the bottoms (see Fig. 8).

The attempt to manage cattail by disking and mowing during the drought in 2006 seems to have affected only a short-term change in vegetation and water cover. Thickets of emergent vegetation became established again during the following wet phase. TNC did not conduct mowing and disking during the subsequent drought (2012-13), however, and a noticeable difference was evident following the 2013 flood. Standing dead thatch and flood-washed wrack were much more abundant in the marsh complex. Otherwise, passive management by TNC facilitates natural fluctuations in wetland conditions dependent on drought-flood cycles. As long as Blood and Deception creeks continue to flow and flood more-or-less unimpeded, this dynamic situation should persist.

Acknowledgments

Gayla Corley, Tamara Korenman, Lida Owens, Firooza Pavri, and Brenda Zabriskie assisted with small-format aerial photography. D. Whittemore and D. Kettle provided early reviews that strengthened climatic aspects of the article, and an anonymous reviewer suggested further improvements. Our initial research was funded by a Kansas NASA EPSCoR grant (2002-04). The study has continued with support from the Kansas Space Grant Consortium, Emporia State University, The Nature Conservancy and other sources.

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