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Using remote sensing to monitor cattail invasion, Cheyenne Bottoms Preserve, Kansas

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Cattail (*Typha* sp.) has become invasive since the mid-twentieth century in the central Great Plains region. Our long-term study site is the Cheyenne Bottoms Preserve marsh-pool complex, which is owned and managed by The Nature Conservancy (TNC). We employed various types of remote sensing and made ground observations, which we have conducted during the growing season every year since 2002. The goal has been to assist TNC management for cattail monitoring and control based on a pictorial and qualitative approach. During the past two decades, TNC was successful on two occasions in slowing or turning back cattail invasion of its marsh-pool complex. Both involved favorable combinations of climatic events and human actions. Surviving cattail is able to revive quickly and expand rapidly by clonal growth during wet periods, although prolonged high water of floods may arrest cattail growth. Under such variable and dynamic conditions, cattail expansion may regain or surpass previous limits in less than a decade. The long sequence of annual and multi-seasonal small-format aerial photography has proven invaluable for planning habitat work at Cheyenne Bottoms Preserve.

Keywords: aquicide, biodiversity, cattail dominance, drought, flood, glyphosate, small-format aerial photography (SFAP), The Nature Conservancy (TNC), Typha latifolia, Typha angustifolia, Typha x glauca

CATTAIL OVERVIEW

Cattail invasion: Nearly 40 species comprise the genus *Typha* around the world, of which four are common in North America, namely *T. latifolia* L. (broadleaf cattail), *T. angustifolia* L. (narrowleaf cattail), *T. domingensis* Persoon (southern cattail), *and T. x glauca* Godr. (cross of *T. latifolia* and *T. angustifolia*). All four occur in the Great Plains region, and *Typha* has become invasive since the mid-twentieth century (Bansal et al. 2019).

Cattails possess several traits that lead to dominance among emergent vegetation in palustrine wetland environments. These include self-pollination, wind-dispersed seeds, aggressive clonal spread via extensive rhizomes, rapid growth rate and uptake of nutrients, efficient root aeration and storage of carbohydrates in rhizomes, tall mature stature, and production of copious litter as well as suppression of seed germination and growth of other emergent plants (Linde et al. 1976; Gucker 2008; Larkin et al. 2011). These characteristics, taken together, give *Typha* a competitive advantage over other typical emergent wetland plants, such as sedges and rushes (Bansal et al. 2019). As a consequence, cattail is able to establish dense, nearly monotypic stands that cover many hectares in extent (Larkin et al. 2011).

Typha x glauca has proven more successful, in fact, than its parent species. *T. x glauca* grows taller than either parent, achieves larger clone size, and produces copious litter. The latter reduces growth of competing plants and inhibits germination of seeds from *T. latifolia* and *T. angustifolia.* The hybrid vigor displayed by *T. x glauca* may explain its invasive success (Bansal et al. 2019).

Typha abundance has increased across North America since the beginning of settlement due mainly to human activity. The most important factors for spread of cattail are nutrient enrichment from agricultural runoff and disruption of hydrologic regimes from alterations of drainage (Bansal et al. 2019). These factors accelerated since the mid-twentieth century with the introduction and widespread use of artificial fertilizers and drainage projects to increase cropland acreage.

A detailed study of *T. latifolia* in Michigan revealed that growth of shoots from rhizomes takes place in three distinct pulses or phases during the growing season resulting in three major cohorts (Dickerman and Wetzel 1985). The first cohort emerges in early spring, and all die in late autumn. The second cohort grows in mid-summer, and most die in autumn, but some survive the winter and grow again the following spring. The third cohort emerges in late summer/early fall, and most shoots survive the winter and resume growing the following spring.

Invasion and dominance of cattail lead to many deleterious impacts on wetland vegetation and wildlife resulting in reduced biodiversity (Larkin et al. 2011; Bansal et al. 2019). The main impact of *Typha* on waterbirds is by displacing those plants and animals that provide their food. Furthermore, cattail may fill wetlands and preclude most waterbird usage, which depends on shallow pools and bare mudflats. *Typha* invasion also enhances sediment accumulation, which provides further N and P nutrients in the soil.

Clonal growth: Cattail is extensively clonal which results in highly productive growth rates; a clone may expand to >50 m^2 just two years after germination with total rhizome length of nearly 500 m (Gucker 2008). Clonal growth is so prevalent for *Typha*, in fact, that nearly all scholarly articles comment on this phenomenon (e.g. Larkin et al. 2011; Travis et al. 2011; Bansal et al. 2019).

In spite of cattail's proclivity for clonal growth, few studies have documented or analyzed the spatial or temporal patterns of this phenomenon in detail. Linde et al. (1976) presented a low-height aerial photograph from Eldorado Marsh in Michigan. The small image depicts cattail clones in circular patterns that are tied together by rhizomes. Clones vary in size from only a few plants to 0.4 ha or more.

Cattail management: The cattail invasion across North America has led to management concerns and many attempts to control the infestation (Bansal et al. 2019). The most common techniques involve manipulating water level and use of herbicides. *Typha* favors water conditions ranging from saturated soil to water about 1 m deep. Thus, flooding a site to >1 m depth or, conversely, drying out a site inhibit cattail growth. Such manipulation of water level appears to be even more effective when combined with other techniques such as burning or cutting. Burning is widely practiced to control biomass, but cattail recovers quickly, just as fire-adapted grasses do in the prairie, and burning is effective only if the site is thoroughly dry.

Physical disturbances are aimed at reducing the above-ground biomass. Grazing, mowing, disking, and other mechanical cutting are commonly applied to cattail. Cattail provides low-quality forage for livestock including cattle and goats. Like burning, the effect is temporary; multiple treatments during the growing season may be necessary to draw down carbohydrate reserves in the rhizomes and, thus, reduce cattail. *Typha* responds strongly to nutrient enrichment; thus, reducing nutrient input could be effective for controlling cattail dominance. However, reducing the inflow of nonpoint-source runoff in agricultural settings is quite difficult in practice.

Glyphosate and other herbicides used for cattail are systemic and nonselective. The most effective control is achieved in late summer. Herbicide provides effective short-term control

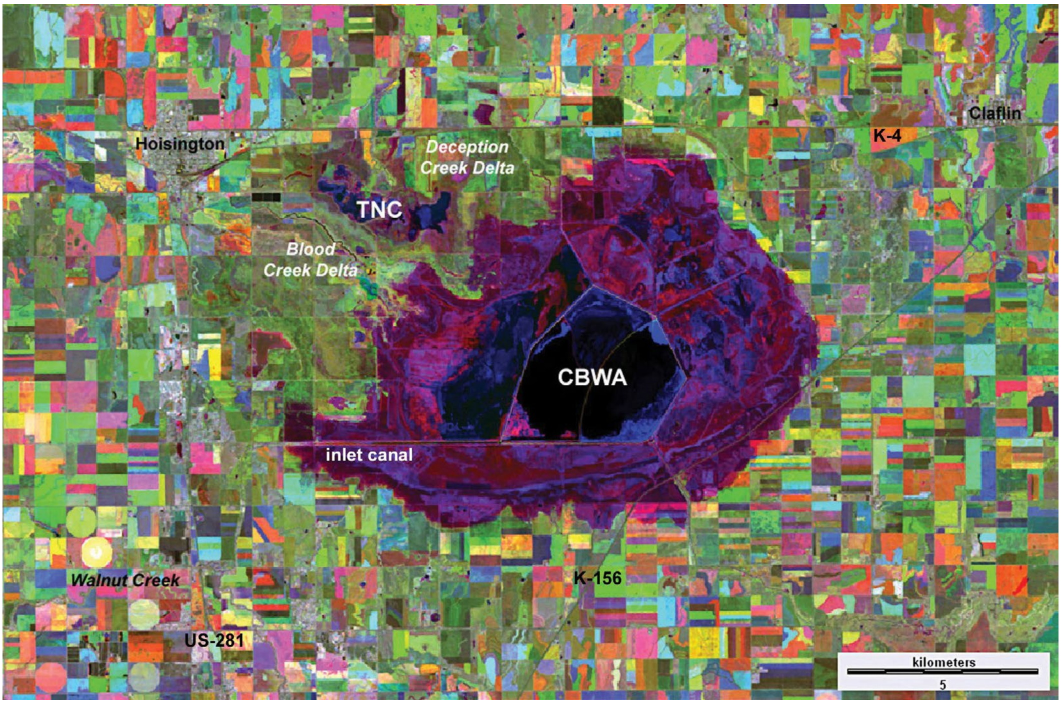

Figure 1. Multi-year, Landsat 5 TM, near-infrared satellite image of Cheyenne Bottoms vicinity for summers 2006, 2007, and 2009. Bright colors represent significant changes in land cover from year to year; dull-gray colors indicate little change in land cover. The broad maroon-purple zone shows the extent of flooding in 2007; black and dark blue show perennial water bodies. CBWA – Cheyenne Bottoms Wildlife Area; TCN – The Nature Conservancy. The inlet canal carries water from Walnut Creek across a drainage divide into CBWA. Datasets from EarthExplorer, U.S. Geological Survey <https://earthexplorer.usgs.gov/>.

of *Typha*, but may create soil-nutrient conditions that allow aggressive re-invasion. Furthermore, repeated use of herbicide or low application rates may lead to herbicide resistance in hybrid cattail. Integrated management schemes based on holistic principles may allow for better control of cattail with less use of herbicides. In this regard, Bansal et al. (2019) recommended long-term studies that employ historical aerial photography in combination with continued monitoring.

Cheyenne Bottoms: Cheyenne Bottoms is the premier wetland of Kansas, located in the central Great Plains region of the United States. It is considered to be among the most significant sites for shorebird and waterfowl migration in the United States, and many regard it as the single most important wetland for migrating shorebirds in North America (Zimmerman 1990, Penner 2010). At latest count, 356 bird species have been recorded at Cheyenne Bottoms, including several rare and endangered species.

Cheyenne Bottoms is a large natural depression, covering about 165 km^2; it is the terminal point of the enclosed drainage basin of Blood and Deception creeks (Fig. 1). Cheyenne Bottoms is divided between the state-owned Cheyenne Bottoms Wildlife Area (nearly 8000 ha) in the downstream (sump) portion and The Nature Conservancy (TNC) Cheyenne Bottoms Preserve in the upstream (delta) portion as well as various private land parcels.

No cattails were recorded at Cheyenne Bottoms in an early 20th century survey (Zimmerman 1990). By mid-century, both *T. latifolia* and *T. angustifolia* were present,

Figure 2. Nature Conservancy wetland complex in the northwestern portion of Cheyenne Bottoms. Asterisk (*) marks the nature trail. Black box outlines the approximate area of detailed study for small-format aerial photography. Water bodies appear silver-gray due to sun glint. Image extracted and adapted from NAIP, Redwing SW, DOQQ, July 14, 2008, a year in which pools remained full following flooding in 2007.

but only as minor constituents of the wetland vegetation community. Invasion of *T. angustifolia* began in the 1970s, which took place largely at the expense of bulrushes. *T. angustifolia* is now the dominant primary producer, although *T. latifolia* still remains. It seems probable that hybridization has taken place, but *T. x glauca* has not been documented to our knowledge.

Wetland management strategy differs substantially between the state wildlife area and TNC Cheyenne Bottoms Preserve. The state wildlife area receives some water via direct precipitation and runoff from Blood and Deception creeks. It also obtains water from outside the drainage basin via a canal from Walnut Creek. Water levels are manipulated in several artificial pools and marshes in order to control cattail infestation and optimize environments for migrating waterbirds.

The Nature Conservancy, on the other hand, makes no attempt to control water levels on the Cheyenne Bottoms Preserve (>3200 ha), which is managed for shorebirds and waterfowl as well as grassland birds. Since the 1990s, in fact, TNC has removed barriers or artificial controls, where possible, in order to restore natural water flow from Deception and Blood creeks and maintain wetland habitats. As a result of this policy, TNC wetlands display marked environmental changes during drought and flood episodes.

TNC has attempted several means to control cattail, based on natural flood and drought cycles, including burning, mowing, and disking during dry periods, as well as haying and cattle grazing during the growing season. For many years, TNC rejected the use of herbicide because of the sensitive nature of the wetland environment. In 2017, 2018 and 2019, however, selected portions of the marsh-pool complex were treated with glyphosate via aerial spraying.

Study site and methods

Our long-term study site is the Cheyenne Bottoms Preserve marsh-pool complex that is fed normally by Deception Creek and also receives overflow flood input from Blood Creek (Fig. 2). As Zimmerman (1990) noted, the densely packed curtain of leaves hampers ground observations of the cattail community. Thus, an aerial view is imperative to visualize the structure and spatial pattern of cattail distribution and clonal growth.

Our primary method is remote sensing based on Landsat satellite imagery (see Fig. 1), conventional aerial photographs, and low-height small-format aerial photography (SFAP) as well as ground observations. We began our study in 2002, and we have acquired SFAP and ground observations for many portions of TNC land every year since (Pavri and Aber 2004, Aber et al. 2006, Owens et al. 2011, Aber et al. 2016). In this article, we take a pictorial approach and present a qualitative assessment of cattail during the 15-year period from 2006 through 2020.

Conventional high-altitude, large-format aerial photography is conducted routinely over the United States for many purposes, and such photographs have been utilized for many wetland applications (Tiner 1997). For example, Mitchell et al. (2011) documented the spread and age progression of cattail stands in a large Lake Michigan wetland complex based on historical aerial photographs spanning more than 80 years.

In particular, the National Agriculture Imagery Program (NAIP) of the U.S. Department of Agriculture's Farm Service Agency acquires color-visible images during the summer growing season, typically in early July. These images are rectified into DOQQ (digital orthophoto quarter quadrangle) format equivalent to one-quarter of a standard 7½-minute topographic map quadrangle. The nominal (pixel) resolution is 1 m^2, and ground positional accuracy is ±6 meters. New images are available approximately every other year. NAIP imagery is provided to the public online via EarthExplorer, U.S. Geological Survey. For the purpose of this study, available NAIP imagery for the Redwing SW quarter quadrangle was downloaded for the years 2006, 2008, 2010, 2012, 2014, 2015, 2017 and 2019. TNC study area and surroundings were extracted for further analysis (see Fig. 2). As a general rule of thumb, identification of objects depicted in vertical aerial images requires a ground sample distance (GSD) or pixel size three to five times smaller than the object itself (Hall 1997). Given a pixel size of 1 m^2 for NAIP imagery, the smallest object that could be identified would be approximately 3 x 3 m.

Small-format aerial photography (SFAP), in contrast, is a technique to acquire low-height, high-resolution, bird's-eye views from manned or unmanned platforms (Warner et al. 1996). SFAP has been employed since the late 20th century for documenting all manner of natural and human resources (Bauer et al. 1997). We fly kites to collect aerial photographs from 30-150 m above the ground using light-weight digital camera rigs. We also have used a helium blimp as the lifting platform for days with calm to light wind. These lifting platforms have minimal impact on birds or other wildlife in the wetland complex (Aber et al. 2019).

SFAP allows us to monitor TNC wetlands at frequent intervals and target specific features and ephemeral events, which we have done on an annual basis during the growing season usually in late spring and/or early autumn. Late spring represents the first cohort of cattail growth, and early autumn is the beginning of cattail senescence before first frost.

Over the years, we have utilized slightly different ground localities to launch our kites or blimp from the nature trail next to our study area. Wind direction and weather conditions varied, and digital cameras and lenses have evolved substantially. As a result, we do not have identical annual views for every portion

Figure 3. NAIP image for study area, July 13, 2006. In this early summer view, some mudflats are dry and partly covered by green weeds. Some mudflats are still moist and appear dark brown to black. Asterisk (*) indicates nature trail site for SFAP; see Fig. 2 for location and scale.

of the study area, which limits the potential for quantitative comparisons. In vertical shots, SFAP has GSD of 1-2 cm, depending on height of the camera and types of lens and sensor. Following the rule of thumb given above, the smallest object that could be identified would have dimensions of <10 cm.

Seasonal and year-to-year variations in weather and climate lead to cycles of drought and flooding that strongly impact water level and environmental conditions in Cheyenne Bottoms Preserve wetlands. To understand the climatic history, we accessed the U.S. Drought Portal <https://www.drought.gov/drought/states/kansas> for a summary of droughts in Kansas for the past two decades. Following are significant climatic events that impacted TNC wetlands and the cattail population.

2006 – culmination of a major drought in which the marsh-pool complex completely dried out.
2007 – flooding of historic proportion; much of Cheyenne Bottoms became a lake for several months.
2008-2010 – interval of generally wet conditions and high water levels in pools.
2011-2015 – extended drought conditions; interrupted by flooding of TNC wetlands in 2013.
2016-2017 – interval of generally wet conditions and high water levels in pools.
2018 – short-lived drought episode.
2019 – extremely wet year with flooding and high water levels in pools.
2020 – return of drought conditions.

Figure 4. SFAP looking toward the delta of Deception Creek, October 19, 2006. Disked mudflats and mowing in progress for senescent cattail thatch (tractor on left). Nature trail (*) is visible at lower right; concrete tank at end of nature trail is 3.5 m in diameter.

Results

In the following scenario, selected NAIP images are presented along with SFAP to demonstrate key events in the changing environmental conditions for the study area. NAIP are vertical views acquired in summer and depicting overall conditions of the entire marsh-pool complex. SFAP are oblique views mostly in late spring or early autumn looking north-northeast toward the small delta where Deception Creek enters the pool.

TNC wetlands experienced a drought in 2006 that led to complete drying of the marsh-pool complex (Fig. 3). TNC conducted an experiment for cattail control in the autumn. Dry mudflats were disked and senescent cattail thatch was mowed down to simulate an episode of heavy *Bison* grazing (Fig. 4). The following year flooding of historic proportion took place, and Cheyenne Bottoms was converted into a huge lake that persisted for several months (see Fig. 1). This sequence of drying, mechanical treatment, and flooding was effective in reducing the cattail population to a minimal role in TNC marshes (Fig. 5).

As flood water began to recede in 2008, cattail likewise began to recover and spread in the marsh-pool complex. The following year, a bloom of mosquito fern (*Azolla* sp.) took place on open-water surfaces (Fig. 6). *Azolla* is considered a good food source for waterfowl and provides cover for small invertebrates (Whitley et al. 1999). Cattail expansion continued into 2010 (Fig. 7). At that time, the circular pattern of older and well-established cattail clones became quite evident in the autumn, and new clones could be seen expanding into shallow water (Fig. 8).

An extended drought began in 2011, and by 2012 most of TNC marsh-pool complex was dry (Fig. 9). Once again, TNC attempted to disk mudflats and mow senescent cattail thatch in the autumn,

Figure 5. SFAP looking toward the delta of Deception Creek, May 17, 2007. Waxing flood of silty (brown) water has inundated the wetland complex. Only a few stands of cattail are active in small islands. This high-water condition lasted for several months.

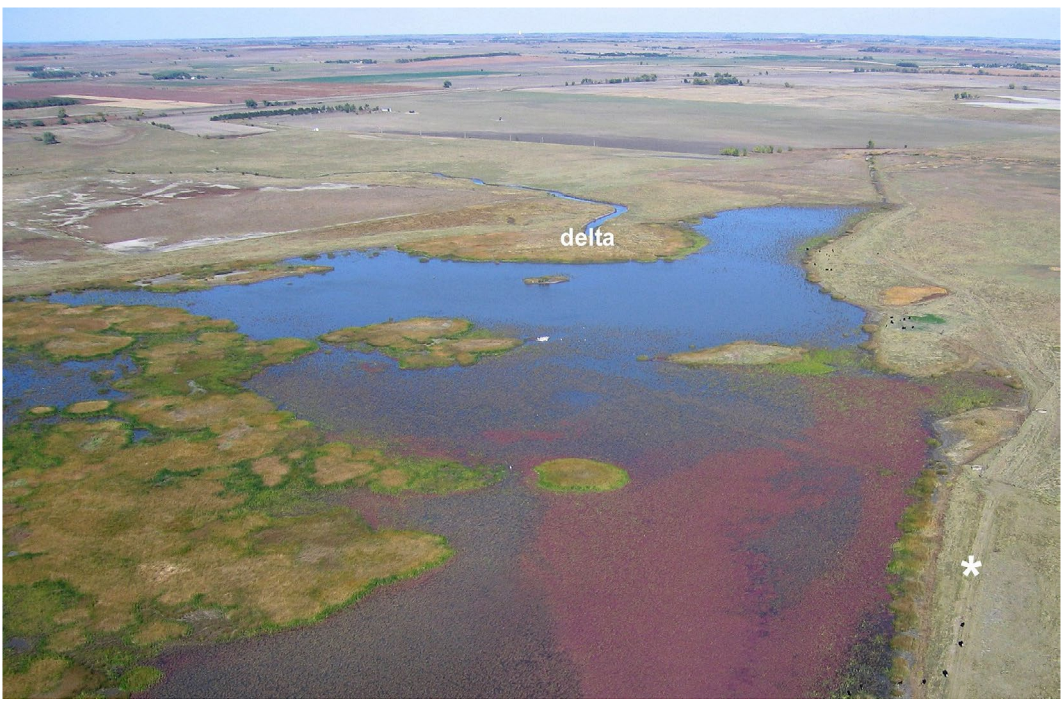

Figure 6. SFAP looking toward the delta of Deception Creek, October 9, 2009. The maroon-purple zone is *Azolla* floating on water surface. Cattle grazing on the nature trail (*), and white birds on water near scene center.

Figure 7. NAIP image for study area, July 14, 2010. Dark green patches within the marsh-pool complex are mature cattail clones that have recovered from drought in 2006 and flooding in 2007. New cattail clones in shallow water are barely discernible (see next figure). Asterisk (*) indicates nature trail site for SFAP; see Fig. 2 for location and scale.

but the mudflats were still too soft below the surface to support the tractor, so the effort was abandoned. Deep roots and dense rhizomes of cattail allowed it to survive and revive quickly following a short-lived flood of the marsh-pool complex in August of 2013. Cattail persevered through renewed drought conditions (2014 and 2015) into a wet phase that began in 2016. By this time, mature cattail clones were encroaching on the pool that remained around the delta of Deception Creek (Fig. 10).

The NAIP image from the summer of 2017 reveals that cattail clones had taken over much of the former open-water and mudflat areas resulting in a small, isolated pool at the mouth of Deception Creek (Fig. 11). TNC's primary mission is to provide stopover habitat for migratory birds, nesting habitat during the season, and wintering habitat, but the spread of cattail had considerably reduced suitable habitat. At this time, TNC reached a difficult decision to use aerial spraying of herbicide for selected portions of the marsh-pool complex.

Aqua Neat® is an aquicide designed for control of emergent weeds and brush in wetland settings, including flowing or stagnant, fresh or brackish water. It specifically targets cattail, reed, saltcedar and willow. Its active ingredient is glyphosate. This aquicide was sprayed over the southern portion of the study marsh-pool complex in July 2018, a drought year, and the results were quickly visible (Fig. 12).

Figure 8. SFAP looking toward the delta of Deception Creek, October 14, 2010. Older cattail clones on left side display circular patterns; new cattail clones at lower center are growing in shallow water. They display irregular and linear patterns. Nature trail (*) is visible at lower right; concrete tank at end of nature trail is 3.5 m in diameter.

May of 2019 was the wettest May of historical record in Kansas since 1895 (NOAA 2019). TNC marsh-pool complex flooded, and water level remained high into the next year. The impact of aerial spraying continued to be quite evident under high-water conditions (Fig. 13). Flooding also affected active cattail clones that had not been sprayed in 2018. These clones suffered die back in zones of deeper water, which became apparent in the spring of 2020 (Fig. 14). The zones of shallow water in and around dead cattail stands were densely covered by common duckweed (*Lemna minor* L.), which is an important food resource for birds and other wetland wildlife.

Discussion

Remote sensing: Landsat, NAIP, and SFAP images were primary sources of spatial and temporal information for this study of cattail at Cheyenne Bottoms Preserve. Landsat image spatial resolution, 15-30 m, restricts its usefulness to the larger drought and flood events. With an approximate 2-week repeat interval, however, it has the potential to document ephemeral events, such as the flood in August 2013, but cloud cover and atmospheric effects often degrade many datasets.

NAIP provides overall coverage of the study area and surroundings, but its spatial resolution limits interpretability of small features. For example, new cattail clones are barely discernible (compare Figs. 7 and 8).

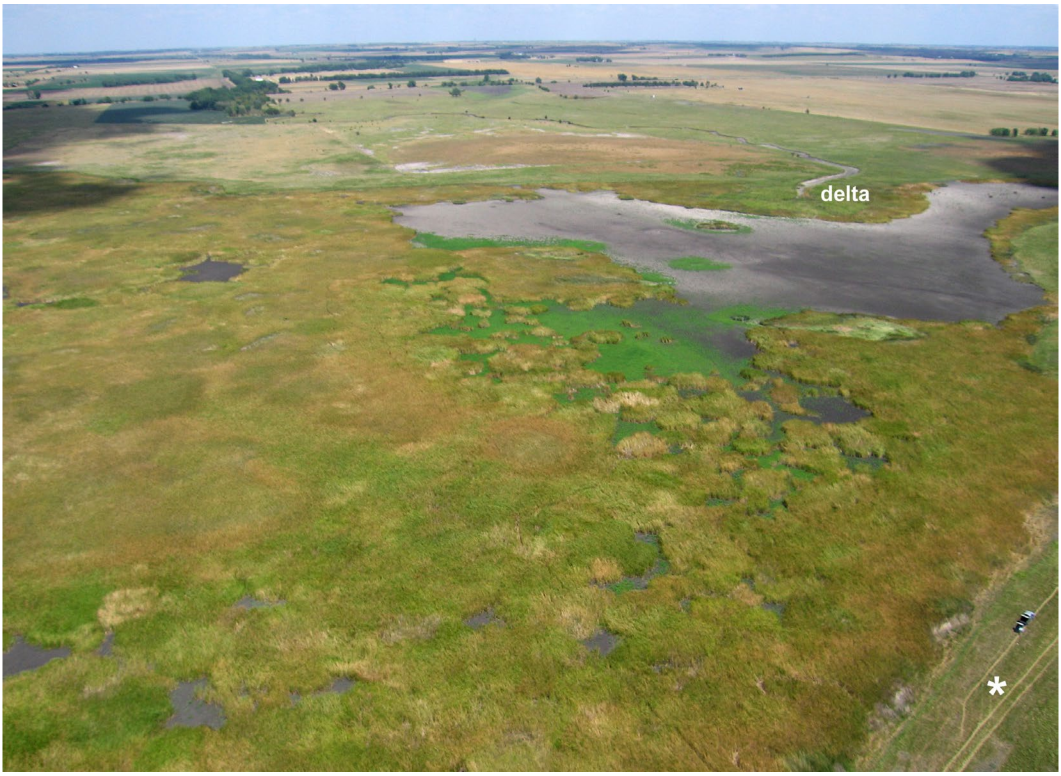

Figure 9. SFAP looking toward the delta of Deception Creek, July 10, 2012. Marsh-pool complex is completely dry, and cattail now occupies much of the former pool area. Bright green at scene center are weeds (i.e. yellow velvetleaf, *Limnocharis flava* L.) growing on dry mudflat. Nature trail (*) and kite flyers are visible at lower right.

Likewise, the concrete tanks that appear as scale factors in some SFAP (see Fig. 8), are barely visible and certainly are not identifiable in NAIP images. The mid-summer, every-other-year acquisition schedule of NAIP further limits documentation of seasonal or ephemeral events, such as the floods in 2007 and 2013.

SFAP, on the other hand, provides highly detailed resolution for identifying small objects, and allows frequent repeat intervals for seasonal features or ephemeral events. The oblique vantage possible with SFAP is often easier for most people to visualize, as it conforms to their personal experience, for example viewing from the observation tower. However, SFAP lacks the broad coverage and geometric fidelity that Landsat and NAIP images provide.

For most of the examples presented here, color rendition is generally brighter and more distinct in SFAP than in NAIP images, which further improves the interpretability of the former. This color effect results from the height NAIP is acquired above ground, typically 6000 m to 8000 m. At this height, atmospheric dust, haze, and scattering of blue light become factors that degrade color quality compared with SFAP taken less than 150 m above the surface. The same atmospheric effects are present in Landsat imagery.

Cattail clones: The spread of cattail was accomplished by new clones establishing in shallow water around mature clones and then gradually infilling for complete coverage. New clones appeared in the pool south of the delta of Deception Creek in 2010; no cattail clones were

Figure 10. SFAP looking toward the delta of Deception Creek, October 5, 2016. Cattail clones are distinct circular patches that have closed off the pool around the delta of Deception Creek. Concrete tank in lower right corner is 4.3 m in diameter.

present in this zone the previous year. The new clones have a somewhat ragged appearance, that is, without a clearly established shape or pattern of distribution (Fig. 15A). By 2016, this zone was completely covered by mature cattail clones in well-defined circular patches with almost no open water remaining (Fig. 15B).

The circular patches of cattail clones are most obvious in early autumn when senescence is underway. Diameters of mature clones that began growing in 2010 were in the range of about 7 to 14 m, or ~40 m^2 to 154 m^2 by 2016. This compares reasonably to >50 m^2 just two years after germination reported by Gucker (2008). The variations in clone size could reflect drought episodes during the interval 2010-2016, which may have interrupted or slowed cattail growth, or could be results of crowding as clones began to encroach on each other.

Cattail management: Given its goal to mimic natural conditions as closely as possible, TNC has limited options for controlling invasive cattail in its wetland complex at Cheyenne Bottoms Preserve. Water level responds to weather events and climatic cycles, and inflow of nutrients from surrounding cropland cannot be regulated. Twice during the past two decades, nonetheless, TNC was successful in slowing or turning back cattail invasion of its marsh-pool complex. Both involved combinations of climatic events and human actions.

- 2006-2007 – Drought and complete drying allowed disking and mowing in the autumn of 2006, followed by historic flooding in 2007.
- 2018-2019 – Aerial spraying of aquicide in the summer of 2018, followed by flooding during the growing season of 2019.

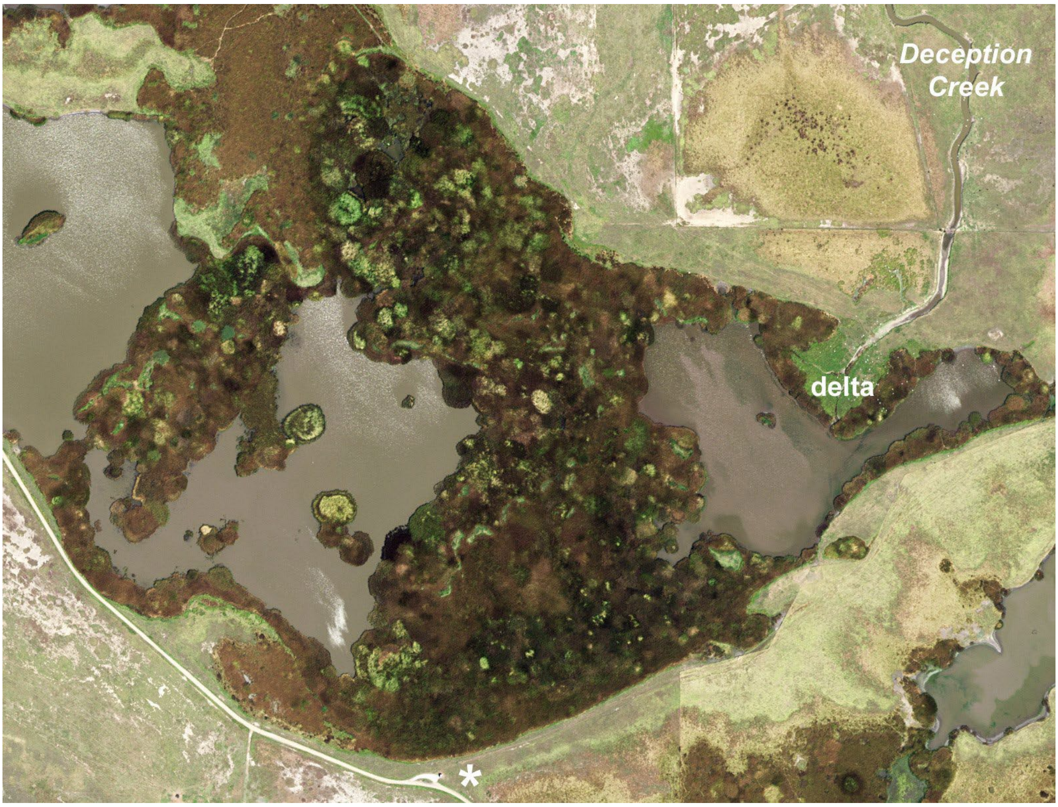

Figure 11. NAIP image for study area, July 10, 2017. Dark green patches within the marsh-pool complex consist of large, mature cattail clones. Once-continuous open water is now broken into small, isolated pools (compare Fig. 2). Asterisk (*) indicates nature trail site for SFAP.

These episodes of flooding after mechanical or chemical treatment could not have been predicted; yet, high water served to reinforce the previous treatments for limiting cattail. On the other hand, flooding in 2013 had minimal effect for limiting cattail as no prior treatment had been performed and the flood was short lived. Based on these outcomes, it would seem that treatments should be carried out whenever possible during drought episodes, but predicting when such droughts might end is all but impossible.

Surviving cattail is able to revive quickly and expand rapidly during wet periods, following droughts, although prolonged high water of floods may arrest cattail growth and favor blooms of *Azolla* or *Lemna*, which are valuable food sources for wetland wildlife. Under such variable and dynamic conditions, cattail expansion may regain or surpass previous limits in less than a decade. Thus, changes in climate and short-term weather events are the primary driving factors for cattail invasion in the marsh-pool complex.

Conclusions

The long sequence of annual and multi-seasonal small-format aerial photography has provided a valuable guide for planning and evaluating habitat work in TNC wetlands at Cheyenne Bottoms Preserve. When SFAP is combined with satellite and NAIP imagery for broad areal coverage, as well as climatic data, long time-series interpretations become feasible. Given the typical decadal timespan of drought-flood cycles in the central Great Plains

Figure 12. SFAP looking toward the delta of Deception Creek, September 28, 2018. Stripes in foreground were sprayed with aquicide in July, and emergent vegetation is now dead. Cattail clones to the north (behind) were not sprayed.

region, such long time series are essential to understand the dynamics of cattail invasion and consequences of management practices.

Long-term effective management for cattail invasion requires multiple techniques plus repeated applications, and involves trade-offs between effective methods and consequences for other vegetation and wildlife. The combination of ground management methods and aerial spraying of aquicide proved most effective when reinforced by climatic events, namely droughts and floods.

Future research

The program of annual and multi-seasonal small-format aerial photography will continue for the foreseeable future in order to document changing environmental conditions, status of cattail invasion, and results of management practices in the wetland complex at Cheyenne Bottoms Preserve. In particular, we plan to follow the effects of aerial spraying that took place in 2018; however, further aerial spraying is unlikely due to budget restrictions. We anticipate that kite aerial photography will be our primary tool, and unmanned aerial systems (UAS), commonly known as drones, may come to play a role for SFAP. As digital cameras and lenses evolve, still higher spatial resolution and better image quality may further improve interpretability of SFAP images.

Figure 14 (RIGHT). SFAP looking toward the delta of Deception Creek, June 12, 2020. Zone of aerial spraying in foreground and unsprayed portion behind. The pale yellow-green zones are floating masses of common duckweed (*Lemna minor* L.) within stands of dead cattail thatch. Open-water pool has expanded considerably (compare Fig. 10).

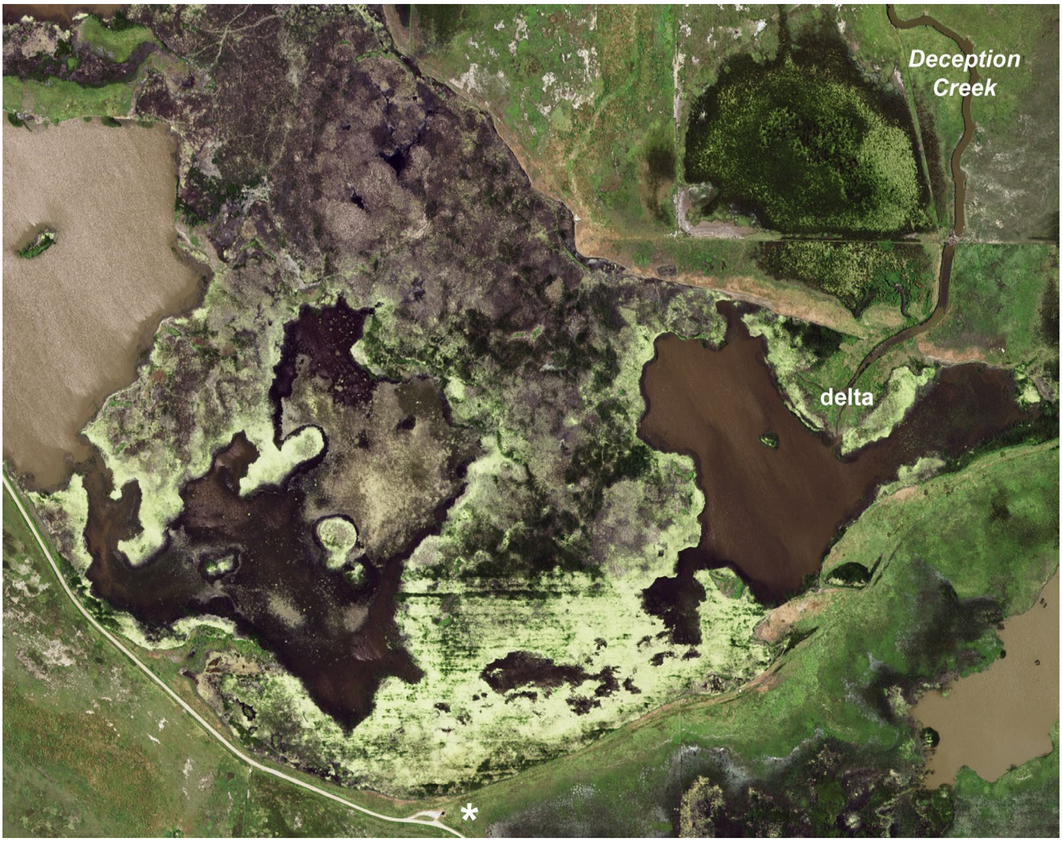

Figure 13. NAIP image for study area, July 12, 2019. Pale green linear stripes resulted from aerial spraying the previous year and are apparent in the southern portion of the marsh-pool complex. Asterisk (*) indicates nature trail site for SFAP; see Fig. 2 for location and scale.

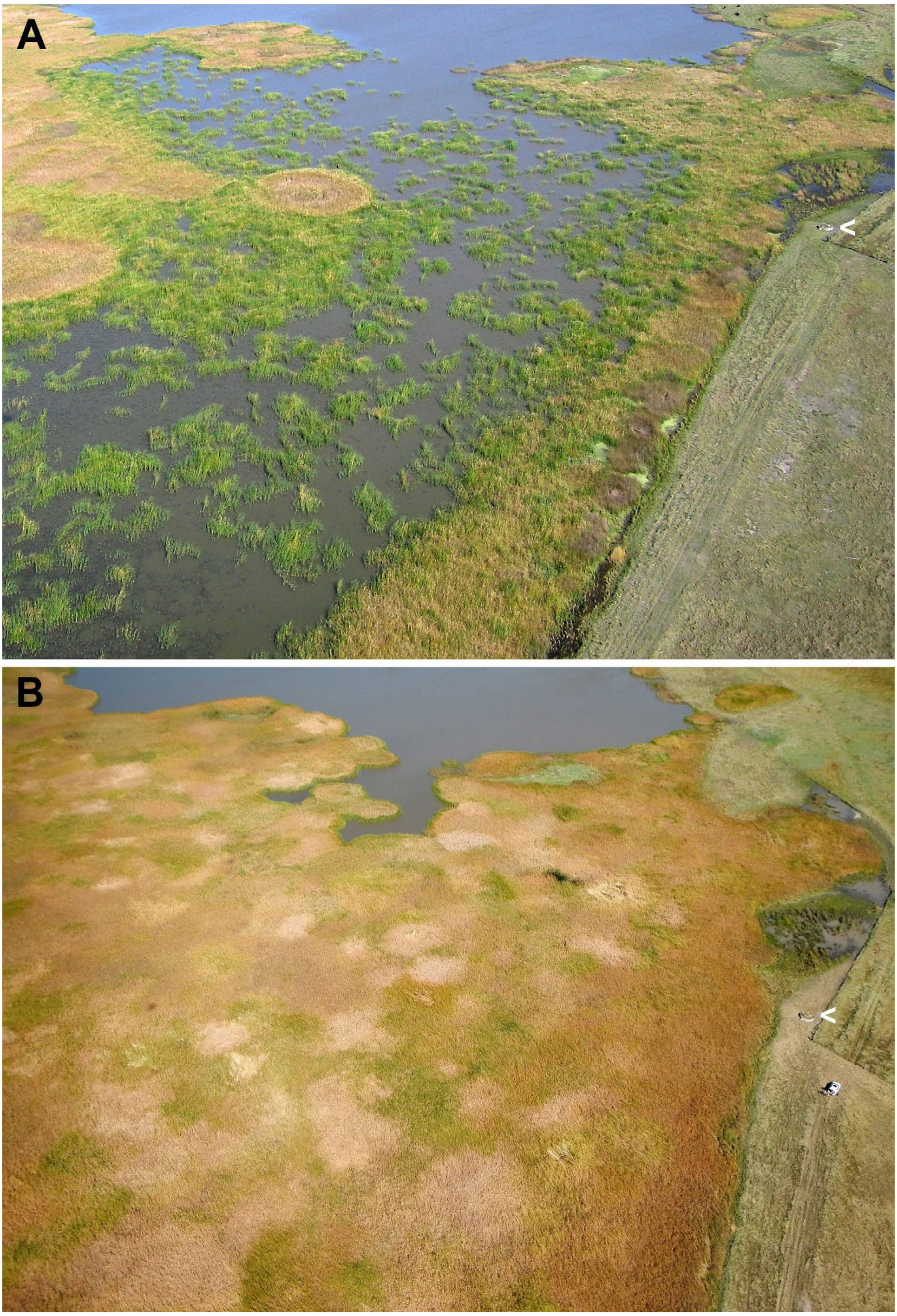

Figure 15. Close-up, low-oblique SFAP of the zone south of the delta of Deception Creek. A – new cattail clones in their first year of growth, October 14, 2010. B – mature cattail clones have completely covered the foreground, October 5, 2016. Concrete tank (<) at end of nature trail is 3.5 m in diameter.

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