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RIVER FLOODPLAIN RESTORATION

Review Paper

Why experiment with success? Opportunities and risks in applying assessment and adaptive management to the Emiquon floodplain restoration project

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Abstract The Nature Conservancy's wetland restoration at the Emiquon Preserve has been a success to date, but there are warning signs of undesirable change if left unmanaged. A water control structure built in 2016 will increase management capabilities, but periodic connection to the river, which has experienced human alterations typical of rivers in eastern North America and Europe, also introduces risks. The Conservancy's planning process has identified (1) management targets (e.g., diverse native fish populations); (2) Key Ecological Attributes (KEAs) that maintain the targets (e.g., relatively deep overwintering habitats for fishes); (3) measurable indicators for the KEAs (e.g., depth in winter); and (4) desirable ranges for the indicators (e.g., 10% of the aquatic area has depths of 2–3 m and dissolved oxygen levels of 4–6 mg/l). Assessments and experiments completed to date have focused on documenting the restoration, evaluating effects of the record flood of 2013, and predicting outcomes of management actions. Simulation models of hydrology, hydraulics, and vegetation response developed during the planning process allayed some concerns of stakeholders, but not all outcomes are predictable from either current theory or management experience. Therefore, each action can be considered not only as

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an adaptive management experiment focused on sustaining targets, but also contributing to ecological theory and restoration practice on a broader scale.

Keywords Adaptive management · Floodplain · Large river · Restoration · Uncertainty · Conflict

Introduction

For centuries, the site of the current Emiquon Preserve on the Illinois River had been an important and highly productive floodplain with extensive wetlands and two permanent, shallow lakes, Thompson and Flag lakes (Walk et al., 2016). In 1924, this area, including the lakes, was drained and disconnected from the Illinois River by levees to form the Thompson Drainage and Levee District for row crop agriculture (Havera et al., 2003). In 2000, the Illinois Chapter of The Nature Conservancy (hereafter, the Conservancy) acquired the drainage and levee district and renamed the area "Emiquon," a place name used by the native people whom Europeans first encountered (Esarey, 1998).

The Conservancy planned to restore the wetlands, lakes, prairies and bottomland and upland forests, and the natural hydrologic regime, including the periodic floods that had once connected the river to its floodplain (Walk et al., 2016). Restoration is the acid test of ecological understanding, as described by Bradshaw (1983): *The acid test of our understanding is not whether we can take ecosystems to bits on pieces of paper, however scientifically, but whether we can put them together in practice and make them work.* With little or no intervention by humans, the Illinois Floodplain-River Ecosystem once "worked" as a clear water, scenic system that supported an extraordinary number of species and phenomenal harvests of fur-bearing mammals, turtles, waterfowl, fishes, and mussels (Walk et al., 2016). Today, in contrast, it seems that habitat requirements for different groups of organisms (each with its own human advocates) cannot be met simultaneously in the protected parts of the ecosystem that remain. For instance, annual water drawdowns would produce moist-soil plants used by migrating ducks but could also lead to winter or summer kills of sport fishes due to stranding or low oxygen levels. When reflooded, these same moist-soil plants could benefit fishes by providing important habitat and food (invertebrates). By extension, optimizing management for one resource on a continual basis poses a real risk of inhibiting or degrading other attributes over a span of years. While many stakeholders understand this management conundrum, building public patience and trust in both the science and the management needed for long-term recovery of a functional floodplain-river ecosystem that supports a diversity of species and human uses continues to be a challenge.

A particularly contentious issue is whether the Illinois River should ever be allowed to enter Emiquon, given the altered hydrological regime of the modern river, which could degrade, rather than maintain the Key Ecological Attributes needed for restoration (Walk et al., 2016). The very success of the restoration to date, as measured by fish and waterbirds that are valued by humans (Fig. 1), has created a public constituency that appreciates the present condition and opposes reconnection. Other risks from reconnecting altered rivers to their floodplains include introduction of excessive sediment, pollutants (including excessive nutrients), and invasive species (Jackson & Pringle, 2010; Walk et al., 2016).

Documentation and data

Having high quality data on Key Ecological Attributes provides the foundation for good decision making in restoration. Fortunately, the Conservancy and its partners (see the list at the bottom of Table 1) had the foresight to develop an extensive cooperative research and monitoring program prior to restoration of Emiquon. Some of the partners (e.g., the Illinois Natural History Survey) are contracted by the Conservancy for specific monitoring; others monitor because they want to follow the outcomes of services they provided, such as stocking of native fishes (e.g., the Illinois Department of Natural Resources); and still others have independent grants from the National Science Foundation and other sources to support basic research (University of Illinois at Springfield and at Urbana-Champaign). With these partners, the Conservancy contributes to basic research and monitors a suite of up to 52 metrics annually to assess 26 Key Ecological Attributes for 11 identified conservation targets. The information is used to assess restoration progress and provide guidance for management in an adaptive framework (Illinois Field Office of the

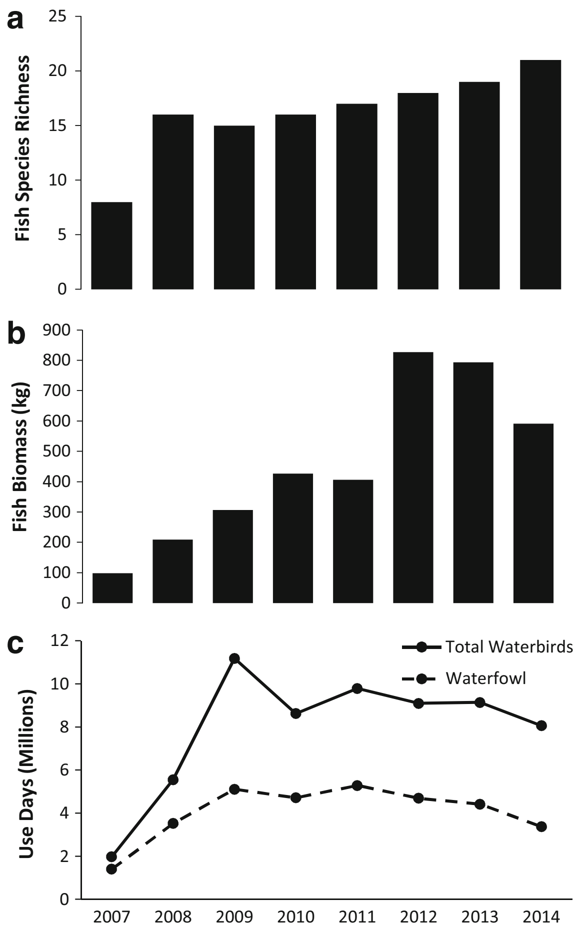


Fig. 1 Responses of native fishes and ducks to Emiquon restoration. **a** Number of native fish species collected per year. **b** Biomass (kg) of native fishes collected per year. **c** Use (millions of waterbird usedays) of Emiquon by waterfowl (ducks, geese, and swans) and all waterbirds (including waterfowl, herons, egrets, and others)

Nature Conservancy, 2009, 2013). Additionally, the Conservancy allows and tracks restoration-oriented research through a permitting system. During 2006–2015, over 100 permits were issued to researchers from 21 different institutions on three continents to conduct research and monitoring activities at Emiquon (Table 1). Approximately 50% of the permits have been issued for bird and fish research, but the rest have been issued for projects ranging from economics to archeology.

Through this process, the management actions and results at the Emiquon Preserve have been exceptionally well documented. Each year, researchers present results from their activities at an annual conference where ideas are shared and adaptive management processes evaluated by a diverse set of stakeholders. In this paper, we use the available data and published information to examine the major risks of reconnecting Emiquon to the Illinois River and offer recommendations for managing each of the risks. We use “Emiquon” to refer mostly to the aquatic and wetland areas within the levees marked by a dotted line in Fig. 1 of the Introduction (Walk et al., 2016). During low water, two original lakes within the Preserve, Thompson and Flag, are separate, but during high water these lakes join into one body of water (Fig. 2a). In addition to analyzing risks, we will examine the premises that: (1) Emiquon has been successfully restored, and (2) can be maintained indefinitely in its current, highly desirable condition, provided it is not connected to the river. Lastly, we suggest some strategies for this and similar high-profile restoration projects in the future.

Risks and recommendations

Excessive sedimentation

The Illinois River and its associated floodplain lakes and backwaters were once clear water habitats with luxuriant submergent aquatic vegetation (Kofoid, 1908; Bellrose et al., 1983). During the last several thousand years, the channel position has been relatively stable, and the floodplain lakes and backwaters have been relatively long-lived, in contrast to the more dynamic reaches of the Missouri and Mississippi Rivers (Butzer, 1977; Hajic, 1990). Over the last 120 years, however, sedimentation rates in mainstem fluvial lakes (e.g., Upper and Lower Peoria Lakes) and floodplain lakes have accelerated to 2–78 mm per year (Demissie et al., 1992). The flocculent bottom sediments never dry out and consolidate due to increased water levels from navigation dams and other hydrologic alterations. The combination of a poor rooting medium, highly variable water depths during the growing season, wind-driven waves, and the uprooting activity of common carp (*Cyprinus carpio*), has caused aquatic plants to die out in the river and connected waters (Garvey et al., 2007; Moore et al., 2010; Stafford et al., 2010).

Table 1 Research subject areas and number of research permits issued by The Nature Conservancy to 21 institutions[a] for research on the Emiquon Preserve, 2007–2015

	2007	2008	2009	2010	2011	2012	2013	2014	2015	Subtotals
Number of permits	11	17	28	19	19	16	17	17	19	163
Subject areas										
Birds	3	5	7	7	5	5	4	6	5	47
Vegetation	4	7	8	2	6	3	2	3	3	38
Fish	1	2	5	3	4	5	5	4	5	34
Energy/material fluxes	1	2	3	5	2	2	2	2	1	20
Water quality[b]	1	1	4	3	2	1	2	1	1	16
Microbes	1	2	2	3	2	1	1	0	1	13
Hydrology	1	2	2	2	1	1	1	1	1	12
Sediment	1	2	3	1	1	1	1	1	1	12
Macroinvertebrates	1	1	3	0	1	1	0	1	2	10
Archaeology	0	0	1	1	1	1	2	1	1	8
Plankton	1	1	2	2	0	0	1	1	0	8
Economics	0	0	0	1	1	2	1	1	1	7
Mammals	1	0	0	0	2	1	2	0	1	7
Other	0	0	0	0	0	1	0	1	0	2
Subtotals	16	25	40	30	28	25	24	23	23	234

Some permits were for research in more than one subject area.

[a] Indian Statistical Institute, Kolkata, India; Bradley University; Dickson Mounds Museum; Havana Junior High School; Illinois Department of Natural Resources; Illinois Natural History Survey; Keystone Aerial Surveys, Inc; Lindenwood University; Michigan State University; National Great Rivers Research & Education Center; Ohio State University; Sanborn Map Company, Inc.; Southern Illinois University Edwardsville; The Nature Conservancy; U.S. Army Corps of Engineers Environmental Research and Development Center; U.S. Geological Survey Columbia Environmental Research Center; U.S. Geological Survey Upper Midwest Environmental Science Center; University of Illinois Springfield; University of Illinois Urbana-Champaign; Western Illinois University; Montpellier Sup Agro (National Institute of Further Education in Agricultural Science), Montpellier, France

[b] Water Quality includes parameters such as dissolved oxygen, pH, turbidity, temperature, total suspended solids, nutrients, and contaminants.

To assess likely rates of sedimentation in Emiquon if it were connected to the river, Demissie et al. (2005) used a hydrologic model to examine three scenarios: (1) no connection to the Illinois River; (2) complete connection to the river assuming the levees would be opened at both the upstream and downstream ends and river water would flow through Emiquon; and (3) a managed partial connection to the Illinois River using a single water control structure. The gates were assumed to be open from 1 February to 15 May (the typical flood season), then closed for two subsequent years, except when the river was low enough that water would drain from Emiquon. This three-year cycle then repeated for a total of 30 years (Demissie et al., 2005).

All three scenarios used historical water flow and sediment data (1971–2000) and hydraulic and sedimentation models to calculate the sediment that would be deposited in Emiquon during the 30-year period, which included major floods and droughts. Only *inorganic* sediment (silt and sand) was modeled. Under scenario 1, with no connection to the river, the model indicated there would be immeasurably small amounts of inorganic sediment accumulation because the drainage area within the levees is small in relation to the area and volume of the lake (Demissie et al., 2005). In model scenario 2, an unmanaged connection to the river with separate inflow and outflow structures, would result in sedimentation rates equivalent to observed rates in adjacent bottomland lakes that are

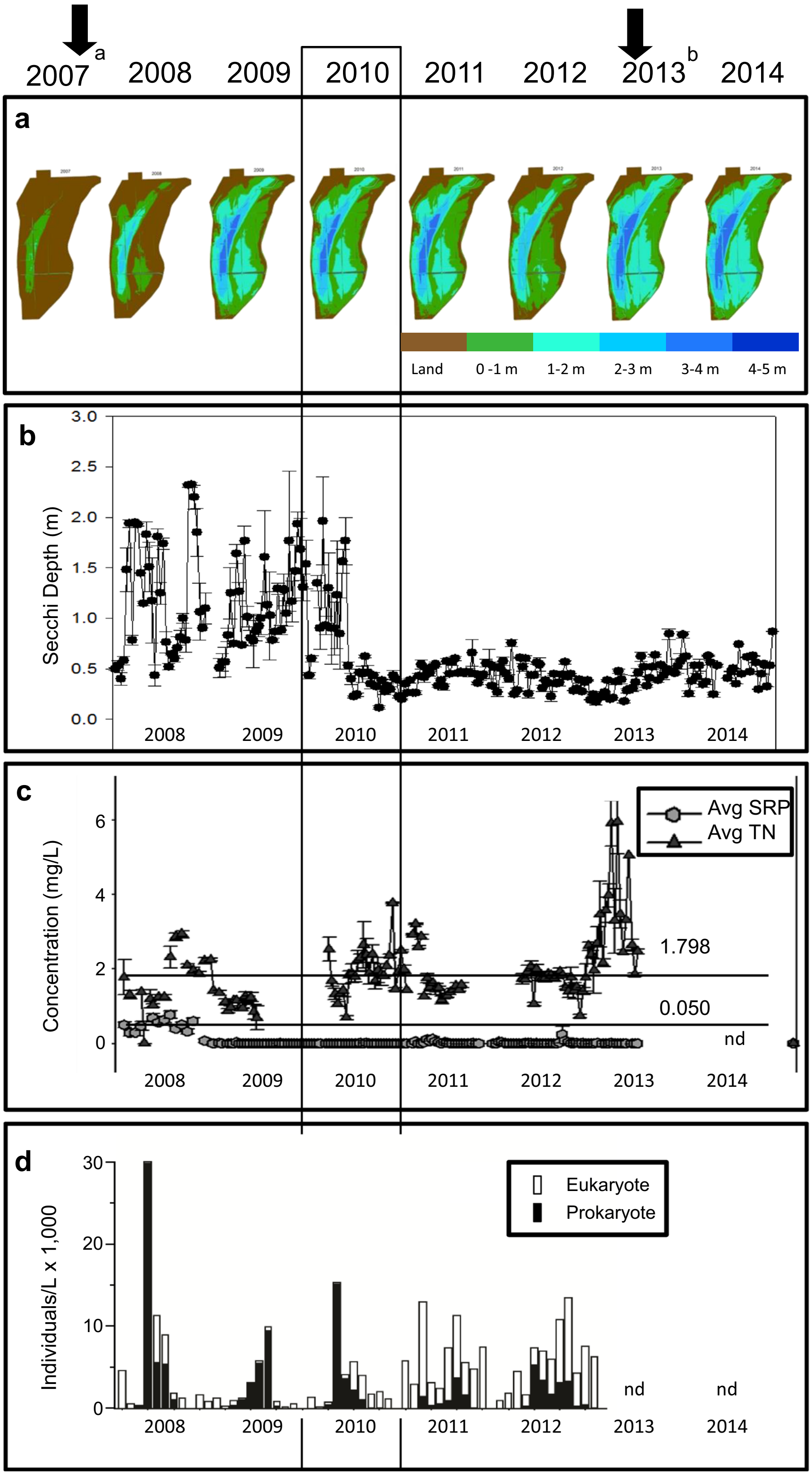


Fig. 2 Response of Emiquon to flooding. The *black arrows* at the top denote two events: **a** cessation of farming, drawdown of water, and fish rehabilitation; **b** flood of record that overtopped Emiquon levees. **a** Area and depth of water in mid July, 2007–2014. **b** Secchi depths (m). **c** Average soluble reactive phosphorous, SRP (mg/l) and average total nitrogen, TN (mg/l). 1.798 mg/l is the guideline for TN established by the Illinois Environmental Protection Agency to prevent excessive algal blooms. 0.050 mg/l is the guideline for SRP. **d** Autotrophs (number of individuals per liter × 1,000) in Thompson Lake, a part of Emiquon. Prokaryotes are N-fixing cyanobacteria. Eukaryotic algae include chlorophyceans, cryptophyceans, and diatoms

open to the river: 8 mm/year, or 240 mm in 30 years (Demissie et al., 1992).

In scenario 3, a managed connection to the river, there would be significant flow into Emiquon every 3 years and some flow out of Emiquon almost every year. Assuming no sediment would flow out of Emiquon through the water control structure and that the sediment would be uniformly deposited throughout the wetland, the estimated inorganic sedimentation rate was 0.16 mm/year, or a total deposition of 4.8 mm in 30 years. The main reason for lower inorganic sedimentation rates inside Emiquon is that the operating scenario did not allow as much sediment-laden river water to enter as in adjacent lakes with unmanaged connections. In all three scenarios, river water would only enter when the river level was higher than the water level in Emiquon, but under the managed scenario, the river entered Emiquon less frequently (once every 3 years, and only during a 105-day period in the Spring).

Although the simulations indicated that a managed connection would introduce very little inorganic sediment into Emiquon, and that there would be plenty of time to take corrective action if necessary, actual measurements raise concerns. For comparison, nearly 0.5 m of *organic* sediment has accumulated in Emiquon over the last 7 years, presumably because of the high levels of primary production within Emiquon.[1] This means wind-driven waves could resuspend the internally generated sediments—an effect not considered in the simulations.

Recommendations (1) Continue monitoring and characterizing sediment to assess its sources (inorganic vs. organic; within Emiquon vs. introduced from the river) and rates of sedimentation. (2) Use sedimentation rates and published criteria for sediment density, turbidity, and water transparency to help determine whether and when drawdowns are necessary to dry and compact sediments (Buck, 1956; Barko & Smart, 1986; Weber & Brown, 2011). (3) Use simulation models and cost analysis to evaluate whether island windbreaks, drawdowns, some combination of both, or no action are likely to be most effective in maintaining target water depths and water clarity.

[1] Personal communication, 14 September 2015, Prof. Michael Lemke, Biology Department, University of Illinois at Springfield, Illinois.

Altered hydrology

Prior to 1900, the Illinois Floodplain-River Ecosystem was characterized by a spring flood that inundated formerly dry land and expanded floodplain lakes and backwaters, thereby maintaining biodiversity and increasing biological productivity (sensu Van der Valk & Davis, 1979; Junk et al., 1989). The summer low stage was just as important, with the full natural range of seasonal variability serving to maintain the structure and function of the floodplain-river ecosystem (Bayley, 1995; Sparks, 1995; Poff et al., 1997; King et al., 2010). The Illinois River today does not fall to the same low water elevations as it did prior to regulation in the early twentieth century because of the man-made diversion of Lake Michigan water into the Illinois River drainage at Chicago and dams that maintain water depths for commercial navigation during the low water season (Lian et al., 2012).

If the levees around Emiquon were simply opened to the river, the entire area would become one large lake for most of the year. The increased wind fetch would generate waves that would resuspend the organic sediments mentioned above and also erode the shorelines and the levees, thereby adding inorganic sediment to the large lake. The topographic diversity (and hence, the habitat diversity) of the lake would decline as islands eroded and deep areas filled with sediment. Submerged and emergent aquatic vegetation would be extirpated due to flocculent sediments, increased turbidity, and unnaturally higher and more variable water levels during the growing season (Jackson & Starrett, 1959; Bellrose et al., 1983; Garvey et al., 2007; Stafford et al., 2010).

The contemporary Illinois River is characterized by unnaturally frequent water level fluctuations during the summer growing season (Sparks 1995). These fluctuations inhibit the germination and growth of submersed and emergent macrophytes and moist-soil vegetation. This vegetation provides critical food and structural habitat for migratory birds, reduces wave action (leaves and stems dampen waves), increases water clarity, and stabilizes shorelines (Bellrose et al., 1983; Sparks et al., 1998; Stafford et al., 2010). Because moist-soil plants depend on a natural flood cycle that drowns competitors in the spring, but exposes mud flats during the summer low flow, they are excellent indicators of how closely the annual water regime reflects the pre-modification regime to which most of the plants and animals are adapted (Ahn et al., 2004a). Previous work with models that simulate germination and growth of moist-soil plants in response to water levels showed that active water management would likely increase moist-soil plant biomass and abundance within Emiquon (Fig. 3). If water control structures had been used to keep out small floods during the growing season, moist-soil plants would probably have occurred in 24 of 30 years (1971–2000, the same period of record used for the sedimentation simulations). Even during the years when river conditions would have permitted moist-soil plants to grow, the production would have been greater with a water control structure in place in 6 of those 9 years (Fig. 3). Hagy et al. (2015) modeled hydrologic conditions beneficial to moist-soil plant development at a nearby restored floodplain with a partial river connection; i.e., the backwater lake and floodplain are disconnected from the Illinois River at low water levels, but connected at moderate and higher flood levels through an uncontrolled levee breach. These authors indicated that moist-soil plants would be produced in 22 of the last 35 years at this site or 63% of the years, but the site would be rarely inundated for fall-migrating waterbirds and inundated in only 43% of years for spring-migrating waterfowl. Moore et al. (2010) and Stafford et al. (2010) found that under existing conditions persistent submersed aquatic vegetation is incompatible with open or partial river connectivity throughout the lower Illinois and Mississippi rivers.

Recommendations (1) Learn from other floodplain backwaters along the Illinois River which are connected at different water elevations and for differing lengths of time (Garvey et al., 2007; O'Hara et al., 2008). There are a number of backwater lakes that are connected at minimum river stage and many others that are isolated most of the year, but become connected at higher river levels (i.e., 2–4 m above the minimum level). During autumn, total waterfowl use in the Illinois River Valley is greater in the water bodies that are not connected or only partially connected to the river (Fig. 4a). For some guilds of ducks, such as diving ducks, connectivity may provide additional habitat and access to food resources during the spring migration (Fig. 4b; Hagy et al., 2016). (2) Test the ability of the moist-soil plant model (Ahn et al., 2004a) to predict the success of the moist-soil vegetation within areas where data on moist-soil cover and quality are now available. A retrospective analysis will indicate whether the model is accurate enough to guide future water level management (Hine et al., 2016). (3) Test the hypothesis that moist-soil plant success stabilizes shorelines and benefits higher level consumers, including macroinvertebrates, fish, and waterfowl. (4) Test the predictive capability of other

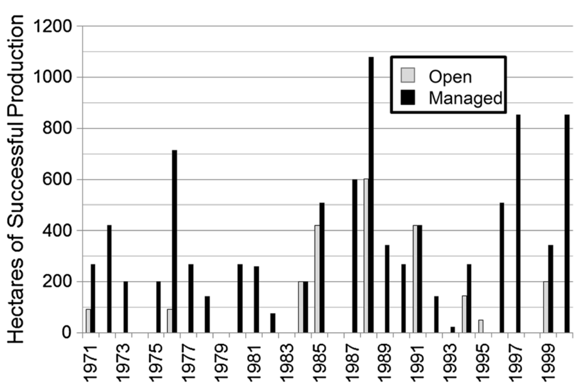


Fig. 3 Simulated annual area of moist-soil plant production in Emiquon, 1971–2001. Daily water level elevations in Emiquon from a hydraulic model (Demissie et al., 2006) were used as input to a moist-soil plant model (Ahn et al., 2004b). "Open" means that Emiquon was open to the Illinois River so that water flowed in and out of Emiquon according to the relative water surface elevations in Emiquon and the River. "Managed" means that water flowed into and out of Emiquon through a water control structure that was operated to exclude unnatural floods during the summer growing season

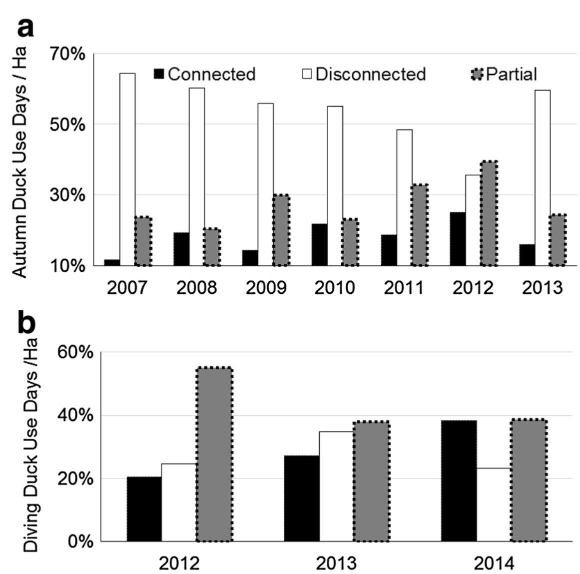


Fig. 4 Duck use (percent of duck use days/ha) of water bodies in the Illinois River Valley that are connected, disconnected, or sometimes connected (partial, depending on water levels) to the Illinois River. **a** All ducks. **b** Guild of diving ducks

models for invasive native and introduced plants (e.g., Ahn et al., 2007) using similar retrospective analyses. (5) Develop and use the verified predictive models for invasive species, indicator species, and desired species as tools to support water management decisions at Emiquon.

Water quality 1: oxygen, temperature, toxicants

The Illinois Environmental Protection Agency (IEPA) considers the Illinois River to be fully supportive of aquatic life, based on physical–chemical factors, including dissolved oxygen concentrations, temperature, and concentrations of toxic substances (e.g., ammonia) in the water (IEPA, 1992). However water quality standards, including those used by IEPA, are usually based on laboratory bioassays where factors are tested one at a time on reference organisms. Thus the question remains whether the combination of factors in the Illinois River poses a risk to organisms in Emiquon if river water is introduced. The most direct way to answer this question is to examine the status of organisms in the river, including small benthic macroinvertebrates, freshwater mussels, and fishes.

Several formerly abundant species of aquatic insects, snails, and fingernail clams practically disappeared from the Illinois River in just 3 years, 1955–1958, and began reappearing sporadically only in the 1980s (Starrett, 1972; Sparks et al., 1993). The declines had drastic repercussions on fishes and waterfowl that fed on these invertebrates. The lesser scaup duck, or bluebill (*Aythya affinis*), virtually stopped using the Illinois River as a major migration route, and there was a decline in the condition and growth rates of bottom-feeding fishes, including the common carp (Mills et al., 1966). In just the last few years, fingernail clams have been obtained in a few benthic samples and in the crops and stomachs of lesser scaup collected from the Illinois River upstream of Emiquon near the city of Peoria.[2] Then in October 2015, windrows of large adult fingernail clams (*Musculium transversum*) washed up on shore in the same locations. This large die-off is probably good news rather than bad, because fingernail clams are short-lived and adults die off with the onset of cold water temperatures, leaving juveniles to overwinter in the sediments.

Freshwater mussels (Order Unionoida) differ from fingernail clams (Order Veneroida) in their life histories and anatomy and are regarded as sensitive indicators of environmental conditions, for several reasons: (1) the adults are relatively sessile and cannot swim or fly away from toxic effluents and spills, hypoxic conditions, excessive sedimentation, or physical disturbance by boat traffic; (2) they burrow in bottom sediments and are therefore exposed to contaminants in both sediment and water; (3) several species are long-lived, in contrast to fingernail clams, so they can bioaccumulate contaminants over decades (e.g., life spans of 14–26 years; Starrett, 1971), and (4) their life histories are complex, with several steps in reproduction that are sensitive to environmental conditions and to low populations of reproductive adults. Gravid females must attract fish hosts for their larvae, usually using visual lures that may not be seen by the fish if the water is too turbid. Attachment to a fish host is required for the larvae to transform into the free-living life stage and be dispersed into existing mussel beds or new habitats.

The mussel fauna of the Illinois River was abundant and diverse prior to 1900, underwent severe depletion due to over-harvesting and pollution from 1900 through the 1960s, and has partially recovered since then (Danglade, 1914, 8; Forbes & Richardson, 1913; Starrett, 1971). As late as 1966, there still were no living mussels collected in the upper river, the most polluted section of the entire river (Starrett, 1971). It is therefore gratifying that recent surveys (1990–1999) have documented a recovery of 18 species of mussels in the upper river (Sietman et al., 2001). The recovery includes the return of the scale shell mussel, *Leptodea leptodon* (Rafinesque, 1820), which had not been seen in Illinois in 100 years, until collected from the upper Illinois River in 2013 (Illinois Natural History Survey Mollusk Collection Catalog #44305). The recovery is linked to source populations that include tributaries of the upper Illinois River and the channel and associated lakes of the lower river, via dispersal of mussel larvae on fishes, which themselves have exhibited a remarkable recovery in the upper river as described next.

The diversity, abundance and biomass of the fish assemblage in the river has shifted markedly since its low point before the 1950s. As late as the late 1920s, Thompson (1928) thought the polluted upper river was

[2] Personal communication, 26 October 2015, Dr. Heath Hagy, Director, Stephen A. Forbes Biological Station, Havana, Illinois.

devoid of fish. While fish had returned to the upper river by the early 1960s the assemblage was dominated by just four hardy species: goldfish (*Carassius auratus*, 32% of the catch), followed by common carp (*Cyprinus carpio*, 29%), emerald shiners (*Notropis atherinoides*, 27%) and gizzard shad (*Dorosoma cepedianum*, 8%). During this same period the lower river where Emiquon is located, though further from the pollution originating in Chicago, still was dominated by the invasive common carp along with largemouth and smallmouth buffalo. Following improvements in the water quality in the upper river associated with the Clean Water Act of 1972 (CWA), goldfish practically disappeared, basses and sunfishes (Family Centrarchidae) were resurgent, composing 21% of the catch, and common carp became a minor component at 5% (Lerczak & Sparks, 1995, p. 241). Since implementation of the CWA fish diversity, total abundance, and total biomass have continued to improve steadily (McClelland et al., 2012). Due to underlying geomorphological attributes, the river is currently made up of two different assemblages: the clear water, higher gradient upper river has a large number of cyprinids and centrarchids while the low-gradient, warmer and more turbid lower river has more large river taxa such as ictalurids (catfishes), lepisosteids (gars), moronids (white and yellow basses), and hiodontids (mooneyes) (McClelland et al., 2006). While water quality is sufficient to support native fish in the lower river, access to more spawning, nursery, and wintering habitat in places such as Emiquon, through periodic connection of the Preserve to the river, should increase populations of these fishes (Pegg et al., 2006).

Water quality 2: excess nutrients

In the summer of 2011 experiments were conducted in 19-l containers that were floated in Thompson Lake to test the hypothesis that addition of water and/or sediment from the Illinois River to Thompson Lake water would stimulate algal blooms. The introduction of river water stimulated the growth of phytoplankton, as measured by chlorophyll a (Fig. 5). In addition, when Illinois River water flowed over the levee and into Emiquon for 6 days during the record flood of April 2013, the total nitrogen and chlorophyll a in Emiquon increased (Fig. 2c). The intentional or accidental introduction into Emiquon of Illinois River water with substantially different stoichiometric ratios of nutrients could either have the beneficial effect of stimulating phytoplankton that would fuel higher trophic levels or cause harmful algal blooms that would shade out submersed aquatic vegetation, cause daily extremes in oxygen concentrations, or produce toxins that could harm aquatic animals (Vinyard & O'Brien, 1976). Initial flooding of the soils in Emiquon that had been in row crop agriculture for 80 years resulted in an initial release of soluble reactive phosphate (Fig. 2c) in 2008. The water came from precipitation, not directly or indirectly from the river, and presumably contained almost no nutrients. By 2009, phosphate concentrations declined to nearly zero. Total nitrogen concentrations have been variable, sometimes exceeding the guideline of 1.798 mg/l set by the Illinois Environmental Protection Agency, particularly after 2010 (Fig. 2c). On occasion in 2008, nitrogen concentrations were very low. Dominance of the phytoplankton community by N-fixing, prokaryotic cyanobacteria (e.g., *Aphanizomenon*) through the first half of 2010 is probably attributable to initial availability of soluble phosphorous, occasional low nitrogen availability, and clear water with good light penetration. Beginning in late 2008 and continuing into 2010, slicks of blue-green pigment "paint" were observed coating the shores of Thompson Lake, presumably from die-offs of blooms of the cyanobacteria.[3] The exact cause of the die-offs is unknown, but could be related to the decline in available phosphorous and a higher, less variable concentration of nitrogen (Fig. 2c). Thereafter, the eukaryotic algae (chlorophyceans, cryptophyceans, and diatoms), which support higher level consumers (e.g., zooplankton) to a much greater degree than the prokaryotes, became dominant and persistent. Under this interpretation, the shift in the phytoplankton community was probably due to physical–chemical conditions and coincidental with the marked decline in average Secchi depth, not the cause of the decline in visibility. Whatever the causes, the water transparency has become stable at lower than initial values and the phytoplankton community continues to be dominated by eukaryotes (Fig. 2c, d).

[3] Personal communication, 12 November 2015, Prof. Michael Lemke, Biology Department, University of Illinois at Springfield, Illinois.

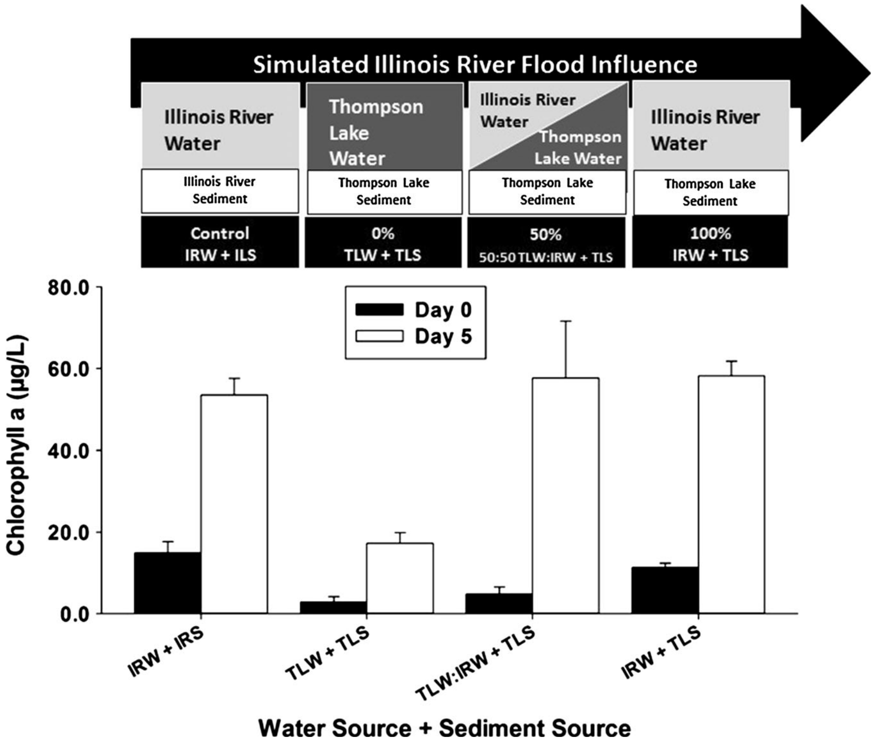


Fig. 5 Chlorophyll a (mg/l) in 19-l mesocosms in Thompson Lake, a part of Emiquon, following additions of water and sediment from Thompson Lake and/or the Illinois River in the summer of 2011. Chlorophyll a was measured at the beginning of each experiment and after 5 days. The addition of Illinois River water more than doubled chlorophyll a, in comparison to Thompson Lake water

Recommendations (1) Assess and characterize the nutrient fluxes (dissolved and sediment-bound) in the Illinois River and Emiquon in order to better model nutrient dynamics. (2) Include nutrient fluxes attributable to the millions of waterbirds that utilize Emiquon during their annual migrations. Snow geese (*Chen caerulescens*) feed in corn fields adjacent to the Illinois River, then seek overnight refuge in places like Emiquon, so they presumably transfer large quantities of nitrogen and phosphorus to the Preserve. (3) Repeat the microcosm experiments, with Illinois River water added at different times of the year, to account for seasonal differences in nutrient concentrations and plankton populations. (4) Use the data to develop and test nutrient dynamics models for Emiquon that can predict the risk of harmful algal blooms resulting from introduction of Illinois River water. (5) Alternatively, conduct bioassays with additions of Illinois River water to microcosms containing Emiquon water and plankton before deciding to connect Emiquon to the river. (6) Advantage should be taken of natural experiments provided by additions of river water during major floods that overtop or breach the levees, so that a post-flood recovery plan can be developed (sensu Lemke et al., 2014). (6) The Conservancy should continue supporting annual fish surveys (e.g., VanMiddlesworth et al., 2013) and add periodic mussel surveys in Emiquon. (7) The Conservancy should also advocate continued funding of current water quality and biological monitoring programs on the Illinois River that are conducted by federal and state agencies in order to compare results from Emiquon over the long term.

Toxic contaminants

Although the Illinois River in the vicinity of Emiquon currently meets the standards for aquatic life, including fishes, (IEPA, 1992), the Illinois Department of Public Health (IDPH, 2014a) advises people to limit their consumption of channel catfish (*Ictalurus punctatus*) longer than 16 inches and “carp,” which includes common, bighead and silver carps, to one meal a week because they contain elevated levels of polychlorinated biphenyls (PCBs). Also, there is a statewide consumption advisory for methylmercury for all predatory fish (e.g., basses and other fishes sought by sport fishermen, IDPH, 2014b). Despite improvements in water quality following implementation of the Clean Water Act, there remained a legacy of toxicants in some of the sediments in the upper river (IEPA, 1992) that probably explain the higher incidence of tumors and other external abnormalities observed in bottom-dwelling fish compared to pelagic fishes (Lerczak & Sparks, 1995, p. 241).

Selected species and sizes of fish from Emiquon were sampled for contaminants in 2009, 2011, and 2015. Partial results from 2009 and 2011 indicate mercury levels high enough to trigger a more restrictive consumption advisory for some species and sizes of fish from Emiquon (Email, 26 October 2015, Rob Hilsabeck, Illinois Department of Natural Resources, with IEPA data attached).[4] The primary sources of mercury in the waters of Illinois are atmospheric inputs from burning coal and trash that subsequently settle or wash out in rain into lakes and rivers (IDPH, 2014b). Since the delivery of mercury is ubiquitous, it is likely that water and sediment in Emiquon are subjected to mercury deposition rates similar to the river, and water input from the river would have little effect on current levels. Whether the deposited mercury is converted into the methyl form that bioaccumulates depends on the microbial communities and chemical conditions in the sediments, for which we have no information. In the case of polychlorinated biphenyls (PCBs), there may be less in Emiquon than in the river because Emiquon was isolated behind levees during the period when PCBs came into widespread use upstream. Agricultural pesticides were used while Emiquon was farmed, and slightly elevated levels of dieldrin have been reported for some fish sampled in 2009 and 2011, although those levels are not high enough to trigger an advisory.[5] Judging by the success of the restoration to date, it does not appear that biota using Emiquon (native, resident fishes and migratory ducks) have been affected by any residual pesticides (Fig. 1).

One concern is the presence of intersex males among largemouth bass populations in the upper Illinois Waterway downstream of the Chicago Metropolitan Area. Oocytes, reproductive cells of females, were found in the testes of 21 of 51 largemouth bass captured in this reach of the river in 2014 (Fritts et al., in review). The presence of intersex fish downstream of large sewage treatment plants is a common phenomenon in the U.S. and is attributable to hormone-disrupting chemicals that are not removed by conventional waste treatment (Tetreault et al., 2011). Some agricultural chemicals are also hormone disruptors and may contribute to the problem. There is currently no information on the incidence of intersex fish in the Illinois River at Emiquon, or within Emiquon. It is also not known whether the current incidence of intersex males in the upper Illinois River is having a measurable effect on largemouth bass population dynamics; however, negative effects have been reported elsewhere (Kidd et al., 2007).

Recommendations (1) Additional tissue samples from fishes in Emiquon should be analyzed following protocols used by the Illinois Department of Public Health to provide a benchmark for contaminant levels prior to connection with the Illinois River. Samples should be submitted periodically after connection to the river to detect any changes. Blood samples from fish-eating birds that nest at Emiquon (e.g., cormorants) should also be sampled before and after connection. (2) The on-going survey of intersex fish in the Illinois River (Fritts et al., in review) should include samples from Emiquon, before and after connection to the Illinois River, and other backwater lakes along a continuum of connectivity with the river. (3) Since mussels are both a management target and sensitive indicator of environmental conditions, including presence of contaminants, mussel populations in Emiquon should be periodically surveyed and sampled for contaminants.

Harmful, invasive species

Non-native, invasive species are an on-going problem in rivers around the world and particularly confounding when their arrival changes the restoration potential that is a management goal (MacDougall & Turkington, 2005). Common carp, in particular, are ecological engineers in the sense that they alter shallow habitats by uprooting aquatic plants and increasing turbidity (Bajer et al., 2009; Weber & Brown, 2009). The resulting poor light penetration can have profound effects on photosynthetic organisms, visual predators, and mussels that use visual lures to attract their host fishes (Scheffer, 2004). Common carp also work from

[4] Email, 26 October 2015, Rob Hilsabeck, Illinois Department of Natural Resources, with IEPA data attached.

[5] Email, 26 October 2015, Rob Hilsabeck, Illinois Department of Natural Resources, with IEPA data attached.

"the middle out" in food chains and food webs because they can affect both lower and higher trophic levels, not only by altering the physical habitat, but also by competing for food (invertebrates and seeds) required by adults or young of native species (Weber & Brown, 2009). Common carp are abundant throughout the Illinois River basin and have the potential, in large numbers, to disrupt restoration projects and degrade wetlands (Bajer et al., 2009).

Despite attempts to eradicate common carp with rotenone prior to restoration and despite the stocking of several species of piscivores that were believed to feed on young carp (VanMiddlesworth et al., 2016), carp are still regularly collected during monitoring efforts (Table 2). The number of common carp captured in the long-term sampling program has generally increased since 2007, with substantial year-to-year variations since 2009. These data reinforce the importance of consistent long-term monitoring–at the end of 2008, the carp eradication efforts could have been judged a success, but the extended monitoring shows that was not the case (Table 2).

Despite the presence of common carp, the amount of submersed aquatic vegetation and diversity and density of native fish species have steadily increased at Emiquon to date, though the system may be approaching thresholds for change (Hine et al., 2016). Evidence of a potential threshold can be seen in the sudden decline in Secchi disk transparencies during the growing season in 2010 (Fig. 1d). Weber & Brown (2011) found that the abundance of native fishes was low when catches of common carp exceeded 0.6 carp per net-night in 81 lakes in eastern South Dakota and they only observed a high abundance of native fishes when the common carp catch was below this threshold. While common carp catches in Emiquon were initially very low, the catches have equaled or exceeded this threshold (0.6 per net-night) in recent years (in 2009, 2012, 2013, and 2014, Table 2). Similarly, Bajer et al., (2009) reported that when biomass of common carp remained below $\sim$ 30 kg/ha, they had no discernible effect on submersed aquatic vegetation or waterfowl use of a similarly restored and isolated floodplain lake along the Illinois River. When this threshold was exceeded, carp biomass increased exponentially and was quickly followed by a dramatic decrease in submersed and floating-leaf aquatic plant cover and waterfowl abundance during the autumn migration. Apart from declines in food supply associated with loss of plant-inhabiting invertebrates and the plants themselves, declines in water transparency disadvantage fishes and birds that rely on sight to find their prey (Vinyard & O'Brien, 1976; Scheffer, 2004; Bajer et al., 2009).

Other factors associated with high carp abundance ($>$0.6 per net-night, biomass $>\sim$30 kg/ha) were higher total dissolved solids, lower Secchi disk transparency, higher chlorophyll a concentrations, larger watershed/lake surface area ratios, and larger surface water areas (Weber & Brown, 2011). The positive association between larger watersheds, larger water surfaces, and common carp abundance might be due to indirect effects. Larger water surfaces have greater wind fetch than smaller surfaces, so wind-driven waves are bigger and have more power to disturb bottom sediments and uproot aquatic plants. In the turbid conditions that result, scent-feeding omnivores like common carp do better than sight-feeding predators such as basses and sunfishes. In addition, common carp are able to spawn over relatively soft substrates like submersed plants and algae where native species cannot (Panek, 1987). Clearly, preventing or mitigating the expansion of common carp numbers and biomass will be an important step in maintaining the desirable conditions observed at Emiquon since 2007.

Unfortunately, there is little evidence from diet analysis to suggest that common carp populations can be controlled by the native piscivorous fish stocked into Emiquon or in the Dixon Refuge at the former Hennepin Drainage District located upriver from Emiquon (Bajer et al., 2009; VanMiddlesworth et al., 2016). Piscivorous birds have also been advocated as a potential control mechanism for undesirable fish and Emiquon supports a robust population (Hine et al., 2013; Hagy et al., 2016), but Engstrom (2001) failed to show any effect attributable to cormorants in a freshwater lake. Moreover wading birds have been shown to consume mostly diseased or unhealthy fish suggesting the birds are not likely to have a large effect on carp recruitment and growth (Glahn et al., 2002). From this limited set of field experiments in restoration it seems that piscivore pressure on young or adult carp alone is not enough to suppress common carp. The next step in experiments to control common carp will be to test the combined effects of piscivore management *and* water level manipulations. For example, it might be possible

Table 2 Measures of common carp (CCarp), *Cyprinus carpio*, abundance from fyke net sets at fixed sites (catch per unit effort, CPUE), total common carp biomass (based on multiple gears from randomized sites), and common carp biomass per hectare (total biomass/aquatic surface area), Emiquon, 2007-2014

Year	Mean Annual CCarp CPUE from fyke nets only	CCarp Biomass (kg) from all gears	Aquatic area (ha) based on MWL[a]	CCarp Biomass (kg/ha)
2007	0	0	0	0
2008	0	0	0	0
2009	**1.9**	27	1662	1.6
2010	0.3	53	1662	3.2
2011	0.4	27	1662	1.6
2012	**0.7**	108	1528	7.1
2013	**1.0**	149	2153	6.9
2014	**0.6**	111	2153	5.1

Years where CPUE equaled or exceeded 0.6 per net set are in bold. This was the critical threshold for harmful effects noted by Weber & Brown (2011)

[a] *MWL* annual mean water level

to defeat the ability of common carp to rapidly outgrow their predators by drawing water levels down in order to force small carp out of shallow water refugia and macrophyte beds. Timing may be the key, otherwise recruitment of native species could also be substantially reduced.

Planktivorous Asian silver (*Hypophthalmichthys molitrix*) and bighead (*H. nobilis*) carps invaded the Illinois River in the mid 1990s and have shifted the native fish assemblage as well as reduced plankton populations and the nutritional status of native planktivores with which they compete (Irons et al., 2007; Sampson et al., 2009; Sass et al., 2014; Solomon et al., 2016). There is growing suspicion, based on their reproductive life history (Mills, 1991), that connected floodplain backwaters may serve as nurseries for the vulnerable larval and juvenile stages of silver and bighead carps (DeGrandchamp et al., 2007, 2008). Like the common carp, these carps also tend to outgrow their potential predators. Emiquon's water control structure for river connectivity is designed to test whether a managed connection (e.g., open only under certain river conditions or at certain times of the year or diel cycle) will allow the desired floodplain-river interaction without increasing silver and bighead carp populations. It may be possible to develop an operations schedule that benefits native fishes without encouraging invasive fishes, similar to those used at hydroelectric and reservoir systems around the country (Richter & Thomas, 2007).

Other non-native fishes that occur in the Illinois River but have not undergone population explosions or had observable impacts include the grass carp (*Ctenopharyngodon idella*), black carp (*Mylopharyngodon piceus*), white perch (*Morone americana*), and round goby (*Neogobius melanostomus*) (McClelland et al., 2012).

Invasive plants that are already in Emiquon include Eurasian water milfoil (*Myriophyllum spicatum*), purple loosestrife (*Lythrum salicaria*), and the introduced species of common reed (*Phragmites australis australis*). Hagy et al. (2014) ranked the non-native common reed as one of the most significant threats to waterfowl habitats throughout the United States. Several species of native cattail (*Typha*) are now abundant in Emiquon and could potentially dominate shallow water habitats and crowd out other native plants.

Non-native, invasive invertebrates known to occur in Emiquon or in the Illinois River adjacent to Emiquon include the zebra mussel (*Dreissena polymorpha*), quagga mussel (*Dreissena bugensis*), Asiatic clam (*Corbicula fluminea*), and the spiny water flea (*Daphnia lumholtzi*). (Thompson & Sparks, 1977; Stoeckel et al., 1996). All of these invertebrates filter seston from the water, so they have the potential to compete with native filter feeders, although there is no evidence to date of declines in populations or growth of native species due to food competition. The zebra mussel and quagga mussels produce byssal threads which enable them to attach to water intakes, boat hulls, and native mussels, where they block or interfere with normal water movement and exchange. During their initial population explosion during the protracted flood of 1993, zebra mussels appeared throughout the river and adjacent flooded areas and some native mussels were found that had been overgrown by zebra mussels (Tucker, 1994). Others could not burrow into gravel bars that were covered by mats of zebra mussels and subsequently died when they were exposed during low water (Tucker, 1994). At present, zebra mussels appear sporadically in the river, rather than densely throughout the river and its contiguous waters as they did in 1993. Moreover, native freshwater mussels shed their attached pests when they burrow into sediments (Lucy et al., 2014). Zebra mussel larvae drift downstream from upstream populations in the river or southern Lake Michigan. Unless currents and development rates of the larvae happen to be exactly the same every year, existing populations die out in 2–3 years when the adults reach the end of their life spans (Stoeckel et al., 1997). In summary, invasive invertebrates are present in the river, but do not seem to be endangering native species or acting as "ecological engineers" that pose as great a threat to ecosystem recovery efforts as do the common carp.

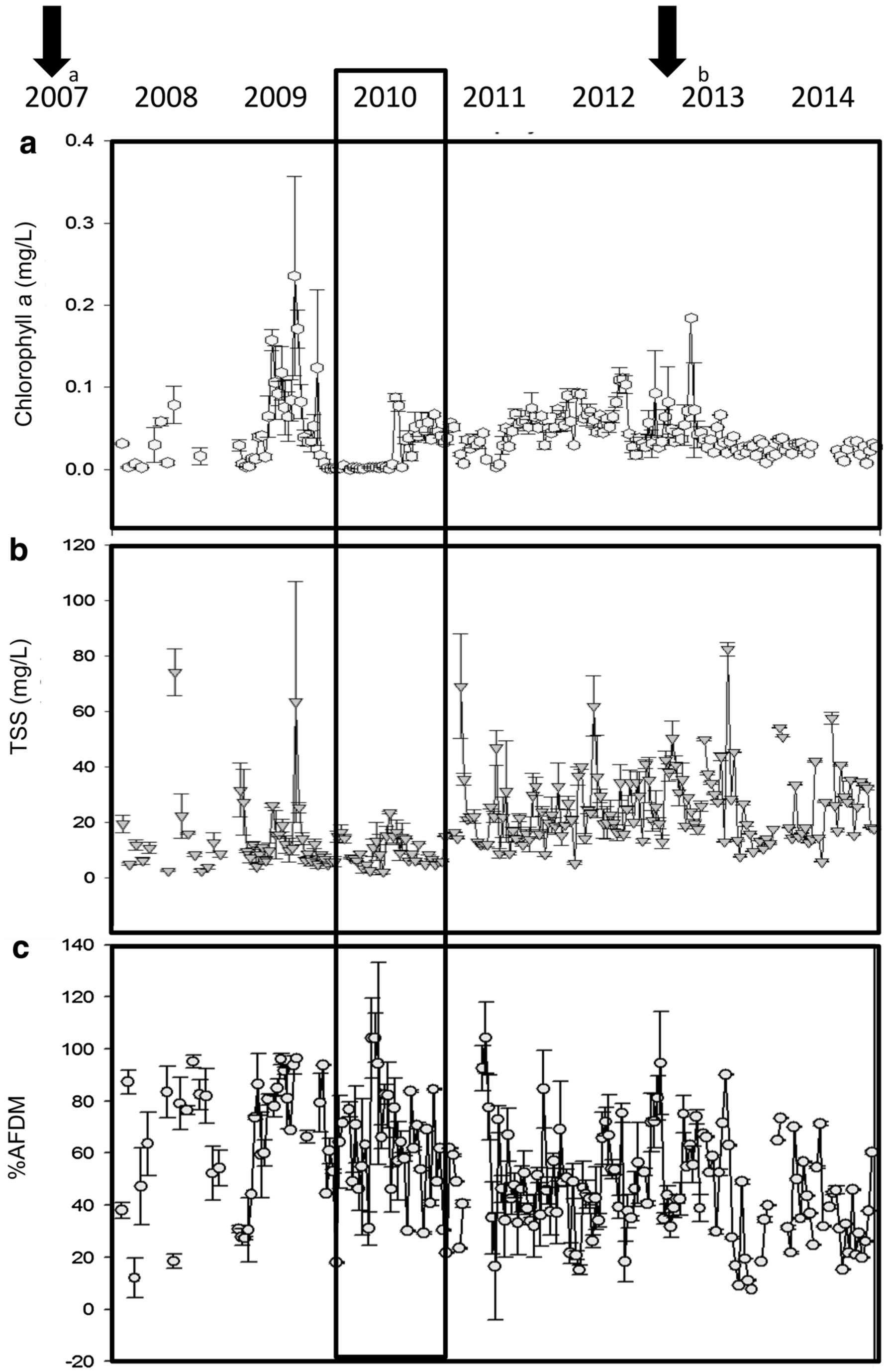
Recommendations (1) Develop a systematic monitoring program for invasive species, including plants and invertebrates. Sample water from the Illinois River for fish, invertebrates and plants whenever it is being introduced to Emiquon through the water control structures. The results will help determine whether there are patterns in invasive species abundances and sizes that can be associated with conditions in Emiquon and the river and with gate operations. (2) Based on the results, develop and test an operating plan to minimize import of undesirable species while maintaining export to the river of desirable native species, such as paddlefish (*Polyodon spathula*). (3) Evaluate the effectiveness of sound, bubble curtains, and electric fields to block or guide fish. (4) Experimental water level manipulations to reduce common carp reproduction and recruitment should be attempted soon, based on the fact that the carp catch rate has already exceeded one threshold for harmful effects (Weber & Brown, 2011).

Reduction in water transparency

Water transparency is a Key Ecological Attribute for Emiquon because of its potential to limit vegetative cover and productivity of multiple trophic levels (sensu Scheffer, 2004). The submersed and emergent vegetation that was once dense and widespread in the Illinois River and its associated backwaters and lakes was long considered a key factor in its productivity and biodiversity (Kofoid, 1908). However, conversion of over half the original floodplain and floodplain lakes to row crop agriculture by the 1920s and increased sediment loads in the river resulting from further intensification of agriculture and water level management in the basin in the 1950s subsequently caused loss of aquatic vegetation. Without the rooted vegetation that had anchored bottom sediments and the leaves and stems that dampened waves, bottom sediments were easily suspended and shorelines eroded, thereby adding and recycling sediments (Sparks et al., 1990). The end result was a virtual absence of clear water habitats and extensive aquatic vegetation by the 1960s (Starrett et al., 1971; Walk et al., 2016).

The dramatic decline in transparency in Emiquon observed in mid-2010 (Fig. 2b) is a major concern, because of the biological effects of decreased visibility and because a change in state appears to have occurred (i.e., Secchi disk readings have remained low since 2010). The exact causes of this change are not known. There was a slight increase in total suspended solids in the middle of 2010, followed by a decline, but the concentration of total suspended solids (mg/l) has been higher and more variable since 2010 (Fig. 6b). Water transparency may have remained low for the remainder of 2010 because phytoplankton (measured as chlorophyll a) increased (Fig. 6a). Another factor is that starting in 2009 the water was right up against the levees (Fig. 2a), so instead of the waves dissipating their energy in breaking and then running up the very shallow slopes that characterize the shores of this shallow, saucer-shaped basin, the waves were eroding the much steeper slopes of the levees and possibly contributing more sediment to the basin. The percent contribution of organic matter to the total suspended particulate matter appears to be trending downward since 2009 (Fig. 6c), suggesting an increasing contribution of inorganic sediment to the total suspended solids (Fig. 6b).

Fig. 6 Chlorophyll a (mg/l), total suspended solids (mg/l), and percent ash-free dry matter in Thompson Lake, a part of Emiquon, 2008–2014. *Black arrows* at *top* denote events: **a** cessation of farming, drawdown of water, and fish rehabilitation; **b** flood of record that overtopped Emiquon levees



Both chlorophyll a and suspended solids concentrations have remained higher and more variable than in the first half of 2010 (Fig. 6a, b). The reduced visibility and lower light penetration that results from suspended particles could have deleterious effects on macrophytes and fish. Successful recruitment of species like basses and sunfishes depends not only on their ability to see prey, but also on their ability to see mates and defend their nests against egg predators. It is possible that organic sediment generated by plankton and macrophytes within Emiquon had accumulated to the point by 2010 where it began contributing to turbidity. Jackson and Starrett (1959) found that it took an average of 11 days for turbidity levels to return to baseline following wind events at similar floodplain and backwater lakes in a former levee district across the Illinois River from Emiquon. Since wind events that generate waves typically occur more frequently than once every 11 days, sporadic wind events may suffice to maintain consistently low water transparency (Jackson & Starrett, 1959).

Recommendations (1) Install at least one, preferably two, weather stations capable of recording wind speed and direction, temperature, and precipitation and at least one wave recorder that can be moved to several locations during wind events. Two weather stations would indicate whether there is fine-scale variability in rainfall and wind within Emiquon and would also provide redundancy in case of instrument failure. A recording turbidimeter should also be employed to measure turbidity before, during, and following wind events. (2) Use additional sensors and recorders to measure the effects of wind events on wave heights and turbidity in open water and within plant beds. (3) Test whether lowered water levels will increase water transparency in both the short term and longer term by reducing fetch and allowing exposed sediments to dry and compact. The beneficial effects of sediment compaction may persist after the sediments are reflooded. (4) Collect water samples before and during wind events to determine how organic/inorganic ratios in suspended sediments vary in response to wind and wave events. Effective actions to improve transparency depend on knowing the relative contribution of plankton versus resuspended sediment to the problem.

Loss of wildlife and fish habitat

The rapid, post-2007 success of Emiquon in providing high quality fish and wildlife habitat that is now scarce elsewhere in the Illinois River Valley, as well as providing public access for hunting, fishing, birdwatching and other outdoor recreation, has inadvertently created a risk-adverse group of stakeholders who are concerned that reconnection to the Illinois River will degrade the habitat. Currently, more than 260 species of birds and 26 species of popular sportfish such as bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), and black crappie (*Pomoxis nigromaculatus*) have been documented in Emiquon (VanMiddlesworth et al., 2014; VanMiddlesworth & Casper, 2014). Several million waterfowl and other waterbirds use Emiquon during the annual migrations (Fig. 1c; Hagy et al., 2016). Floating leaf, submersed, and emergent aquatic vegetation communities often attract more northern pintail (*Anas acuta*), gadwall (*A. strepera*), American green winged teal (*A. carolinensis*), and American coot (*Fulica americana*) than any other wetland or lake in the region (Hagy et al., 2016). The amount of emergent vegetation used for nesting by secretive marsh birds is unmatched within the Illinois River Valley and likely within the broader region (Hagy et al., 2016). Emiquon also serves as a hotspot for threatened and endangered species such as the federally listed decurrent false aster (*Boltonia decurrens*), the starhead topminnow (*Fundulus dispar*), migrating least tern (*Sterna antillarum*), and nesting black-crowned night herons (*Nycticorax nycticorax*).

Recommendations. (1) Continue annual cover mapping of habitat (Hine et al., 2016) and censuses of fishes (VanMiddlesworth et al., 2014) and birds (Hagy et al., 2016). (2) Develop criteria for management actions, based on changes in habitat, fish populations, and bird use. For example, if the extent of submersed aquatic vegetation drops below long-term averages, initiate drawdowns and investigate possible causes, including expansion of common carp populations, decreased light penetration due to plankton blooms or sediment resuspension by wind-generated waves, or herbivory by muskrats (*Ondatra zibethicus*) or grass carp (*Ctenopharyngodon idella*).

Climate change

Historic data, prehistoric data, and regional climate models all indicate that precipitation, runoff, and flood and drought frequencies in the Upper Midwest of the U.S. have changed in the past and could change markedly in the next several decades (Sparks, 2010). Recent experience at Emiquon suggests that a period of rapid change is already underway: the highest and second-highest floods on the Illinois River near Emiquon in the 137-year period of record have occurred in 2013 and 2015, respectively (USACE

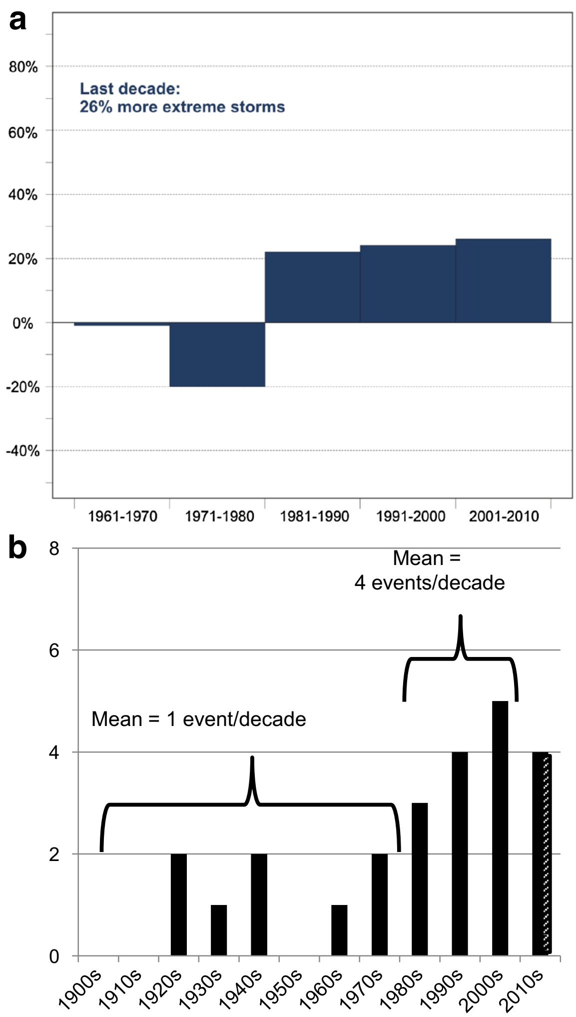


Fig. 7 **a** Intense rainfall events (>3 inches, 7.6 cm per event) by decade, in Illinois. Source: The Rocky Mountain Climate Organization: http://www.rockymountainclimate.org/images/Illinois%20data.pdf **b** The 24 largest flood stages on the Illinois River by decade, 1920s–2010s. There have already been four floods in the 2010s that rank in the top 24. Only floods separated by >30 days are included to differentiate distinct flood events. Observations by US Army Corps of Engineers accessed at: http://water.weather.gov/ahps2/hydrograph.php?wfo=ilx&gage=HAVI2

2015). Intense precipitation events and high river stages now occur more frequently than in the past (Fig. 7). Changes in the water and temperature regimes will interact with all the risks identified above and could have profound effects on biota (Sparks, 2010). The 2013 and 2015 floods overtopped the Emiquon levees for several days, causing only a slight rise in the water level and volume in Emiquon, but introducing nitrogen (Fig. 2c) and silver carp.[6] The 2013 water introduction did not cause a persistent change in nutrient concentrations, water transparency, or phytoplankton communities, which have been relatively stable since 2010 (Fig. 2), so it is unlikely that the shorter period of overtopping in 2015 had an effect, although a final assessment must wait until additional data are collected.

Species will need to adjust their ranges as climate changes, which will be a problem wherever suitable habitat is no longer continuous, but fragmented by human development (NRC, 2008). Fragmentation can also reduce the availability of stopover sites and corridors needed by migratory species (Runge et al., 2014). Preserves such as Emiquon will need to adjust their management targets as species respond to changing local conditions. If preserves cannot be connected along floodplain corridors in a way that allows natural north–south adjustment of the ranges of species and perhaps entire ecosystems, stocking might become necessary. Also, as the frequency of damaging floods increases, there may be increasing public pressure for utilization of Emiquon and other preserves for flood crest reduction, by storing or providing conveyance pathways for flood water.

Recommendations The actions recommended above to address other risks will also contribute to climate adaptation. For example, biological monitoring may detect early shifts in species abundances that presage more drastic changes in community composition and ecosystem function (Pace et al., 2015). The recommended weather and water quality monitoring should help explain why shifts occur. Beyond preparing Emiquon for changes in water and temperature regimes, the Conservancy should participate in regional coordination to fill gaps in floodplain corridors that would enable species to adjust their ranges and maintain their migrations.

Discussion

There has been public support, but also vociferous public opposition, not only from hunters and fishers, but also from fishery and wildlife professionals (e.g.,

[6] Personal communication, 30 June 2015, K. Douglas Blodgett, Director of River Conservation, Illinois Chapter of the Nature Conservancy.

Manning, 2014) to the next step in restoration of Emiquon (a managed connection to the Illinois River) which is understandable in view of the success of the restoration and the desire to maintain the existing high quality habitats and recreational values. The risks associated with a managed connection are real, but so are the risks of not connecting. Emiquon has an important role to play in demonstrating how restoration can proceed in the face of uncertainty. Integration of science, monitoring and management will be essential. Ecological concepts and theories, such as the role of disturbance in maintaining ecosystems, community assembly rules, and biotic regulation of food webs and processes, will be important in designing management plans that will necessarily be experimental because some outcomes, including abrupt changes, are uncertain given the present state of knowledge (Pace et al., 2015). The results of these management experiments should not only improve management, but contribute to scientific understanding.

Eight years of monitoring have documented a remarkably successful floodplain wetland restoration at Emiquon despite limited connection with the Illinois River. An ecological interpretation of the results is that it took approximately 2.5 years for the lakes to recover from being drained and farmed for 80 years. Perhaps the rapid recovery is associated with adaptation of floodplain-river ecosystems to frequent disturbance (floods and droughts). Nutrient (nitrogen and phosphate) concentrations initially varied greatly, including very low nitrogen levels (Fig. 2c); the water clarity was highly variable but often exceptionally clear (Fig. 2b); and the phytoplankton community was dominated by prokaryote blue-green nitrogen-fixers (Fig. 2d). The soluble reactive phosphate was largely gone by the end of the first year of restoration (2008), eukaryotic green algae largely replaced the prokaryotes by 2010, and physical–chemical conditions became relatively stable (Fig. 2).

Native plant coverage, waterbird use days, and diversity and biomass of fish all increased rapidly after restoration began and a native fish community was re-established by stocking—all continue within desirable ranges as indicators of restoration success (Hagy et al., 2016; Hine et al., 2016; VanMiddlesworth et al., 2014). Predictive models for sedimentation after connecting Emiquon to the Illinois River indicated that excessive inorganic sediment in Emiquon is not likely to be a problem and could be easily arrested simply by shutting the water control structures. The pumps and water control structures will also facilitate drying and compaction of sediments that do enter or that are generated within Emiquon. The segment of the Illinois River that borders Emiquon meets the standards for full support of aquatic life set by the Illinois Environmental Protection Agency (IEPA, 2014), and the recovery of mussels (regarded as a sensitive indicator of water quality) indicate that water quality should not be a problem (Sietman et al., 2001). However, the causes of intersex male largemouth bass and external abnormalities in benthic fishes in the upper river should be investigated and the downriver extent of the problems determined (Lerczak & Sparks, 1995; Fritts et al., in review).

Warning signs

Despite the success to date, the monitoring has also revealed warning signs that conditions could change in the near future unless the Conservancy takes corrective action. Common carp are present at a critical population threshold that, when exceeded in lakes in South Dakota, led to losses in water transparency and desirable fish populations (Weber & Brown, 2011). However, common carp have not exceeded the threshold of 30 kg/ha reported by Bayer et al. (2009) for loss of transparency and aquatic vegetation in a lake along the Illinois River that is similar to Emiquon (Table 2). The importance of site-specific data is evident when there are such contrasting thresholds for harmful effects reported for different water bodies in the literature. Additionally, average water transparency in Emiquon did shift suddenly in 2010 to half its former value and has remained low since then (Fig. 2b). Additional information (wind speed and direction, wave heights, sediment resuspension) and continued monitoring of carp, plankton, and suspended sediment will be needed to determine whether the current state of reduced transparency in the main body of water (Thompson Lake) is maintained by bioturbation, plankton, abiotic factors, or some combination, and whether any corrective action is necessary.

Trade-offs

One management option to deal simultaneously with both sediment resuspension and common carp would be a complete drawdown during spring and summer.

The Conservancy will be able to control water area and volume once the water control structure and electric pumps are in place. Construction began in 2015 and proceeded behind coffer dams to isolate the site from the river and to avoid draining Emiquon. Subsequently, a whole or partial drawdown would expose substrates to air and dry and compact them, reducing their susceptibility to suspension by waves when reflooded. Carp could also be more easily removed or killed when confined to the old drainage ditches and other low-lying areas during such a drawdown. A drawdown would also allow expansion of moist-soil plants and other emergent macrophytes (e.g., *Typha* spp.) which would reduce waves, further stabilize sediments, and provide extensive habitat for nesting waterbirds, aquatic mammals, and fish when reflooded. Declines in hemi-marsh vegetation and moist-soil plant communities in recent years could likely be ameliorated with an extended drawdown (>1 year) and a slow reflooding period.

However an extreme drawdown would also introduce risks, including temporary loss of recreational values. Depending on the time of year and environmental conditions, native fishes as well as carp could die because of stranding or low oxygen levels. If native species did not survive and recover on their own, it might be necessary to restock from hatcheries or the river. Rotting fish are a suitable substrate for bacteria growth and fly larvae, potentially contributing to outbreaks of botulism in insectivores (including birds) and scavengers. If the drawdown were done when air-borne seeds of native invasive species, such as black willow (*Salix niger*) and cottonwood (*Populus deltoides*), are actively dispersing, the moist-soil zone could be colonized by trees that would eventually exclude grasses and forbs, including the threatened *Boltonia decurrens*. A corrective response to either of these scenarios could be rapid reflooding to increase oxygen levels in the case of a botulism outbreak and protracted reflooding to drown the water-tolerant woody species before they grew so tall that they could survive extended flooding at the maximum depth that could be maintained in Emiquon.

Limits

There are practical and environmental limits to the range of water surface elevations that can be maintained in Emiquon. The height of the levees is 137.3 m msl, but at water levels above 131.6 m msl, the inside toes of the levees begin to erode from wave action.[7] The U.S. Army Corps of Engineers uses the La Grange Dam on the Illinois River downstream of Emiquon to maintain the low water elevation in the river at 130.8 m msl on the gage at Havana, which is equivalent to 130.9 m msl upstream at Emiquon. Water levels can fall below this threshold from evapotranspiration or the electric pumps could be used. In fact, pumps would probably have to be used to supplement gravity drainage when the water levels in Emiquon began to equilibrate with the water levels in the river because the flow velocity would decrease toward zero. Considering the above constraints, the operating range for gravity filling or draining of Emiquon is 130.9–131.6 m msl, or 0.7 m, considerably less than the 2.2-m range between the median 30-day minimum (131.70 m msl) and maximum (133.9 m msl) water levels in the historical reference hydrographs of 1879–1899 for the Illinois River (Koel & Sparks, 2002, p. 10, Table II).

Decision support models

One approach to determining whether a seasonal 0.7-m range in water elevation would be sufficient to achieve the objectives the Conservancy has for Emiquon would be to try it and monitor what happens. However, if a trial management regime creates problems (e.g., an invasion of the moist-soil plant zone by woody species), fixing the problem might be expensive and cause unwanted side effects (e.g., killing desirable species if herbicides were used to kill invasive woody species in the moist-soil zone). It would probably be more cost efficient and less risky to develop the information and predictive capability needed to determine what range of variation would achieve most of the management objectives most of the time. Some of the simulation models used during the planning stages of Emiquon could be developed into predictive models to assess the outcomes of alternative management actions before the actions are taken. In addition to the moist-soil plant model described previously, there are newer models available to predict the response of invasive species, such

[7] Personal communication, 27 March 2015, K. Douglas Blodgett, Director of River Conservation, Illinois Chapter of The Nature Conservancy.

as the black willow (Ahn et al., 2007). The predictive models could also be used to evaluate alternative water management responses (using the water control structure and pumps) to events such as extreme floods, droughts, excessive common carp populations, excessive accumulation of easily disturbed organic sediments, etc.

Emiquon as part of a larger wetland complex

The Conservancy should also consider integrating management of Emiquon with other nearby wetland areas. Conservation and coordinated management of wetland complexes or even landscapes is becoming increasingly important as the frequency and intensity of floods and droughts increases; as habitat becomes more limited; and as continued urbanization and agricultural intensification puts more pressure on wetlands and floodplains for ecological services. The Conservancy should consider Emiquon an integral part of a larger landscape that includes floodplain corridors that species could use to adjust their ranges as the climate changes. Although private waterfowl hunting clubs, the nearby Chautauqua National Wildlife Refuge, and state fish and wildlife areas attempt to provide extensive moist-soil vegetation for ducks during autumn migration, these resources are probably limited during the spring migration—a shortage that Emiquon could help alleviate. Few wetlands within the Illinois River Valley provide submersed aquatic vegetation comparable to Emiquon because they lack levees high enough to prevent the unnatural summer floods that kill vegetation. The unnatural, small floods also prevent sediments from drying out and compacting. A multi-agency, coordinated management program could ensure that needs of migratory birds and fishes would be met in most years in the Illinois River Valley, although not at every site every year.

Experiments

Monitoring before, during and after water level adjustments can record *what* happens, but may not be sufficient to explain *why* the observed responses occurred. Despite monitoring carp populations, suspended solids, water transparency, vegetation, and other biotic communities, the exact causes of the sudden and persistent drop in water transparency in Emiquon since mid-2010 remain obscure (Fig. 1b). It is likely that changing nutrient availability shifted phytoplankton communities and established a new transparency level. Further experiments with the mesocosms that were described previously could test this hypothesis. Mesocosms could also be used to test whether letting river water into Emiquon in the future would trigger harmful algal blooms. Answers would be obtained quickly and without risking the entire Preserve.

The observed decline in water transparency was insufficient to cause a loss of submersed and rooted, floating-leaved aquatic vegetation similar to declines noted by Bajer et al. (2009) and may not require a drastic water level drawdown. Moreover, transparency in the littoral zones during the growing season is still greater than 1 m where rooted aquatic vegetation beds form. The trade-offs of completing a drawdown could be better evaluated if one or more experimental compartments within Emiquon could be created to try a drawdown. If results of the small experimental drawdowns in compartments were favorable, the compartments could be used subsequently to retain brood stocks of native fishes during a large drawdown.

Every time a decision is made to move water either into or out of Emiquon, experiments and measurements should be conducted to answer management questions and evaluate trade-offs relative to the desired KEAs (Illinois Field Office of The Nature Conservancy 2009, 2013). For example, fish exclusion devices in the water control structures should be evaluated relative to passage of invasive Asian carps. Nutrient fluxes should be monitored before, during and after operation of the water control structures to calculate a nutrient budget for Emiquon and determine whether it might qualify in the future for nutrient removal credits.

Why experiment with success?

Apart from the warning signs mentioned above that the apparent success of Emiquon is not likely to continue without water management, reconnection of Emiquon to the Illinois River is essential to achieve the Conservancy's broader objective of restoring the greater Illinois River floodplain-ecosystem and recovering more of its historically documented biodiversity and productivity. The Conservancy is also interested in restoring other floodplain functions (e.g., nutrient retention) and setting an example that would be emulated by federal, state, and non-governmental organizations that have also acquired levee districts but have so far kept them disconnected from the river. This paper has addressed every credible risk identified by stakeholders who oppose reconnection and has recommended ways to lessen the risks of serious or lasting damage to Emiquon. The Conservancy will need to prioritize which risks are most serious and which recommendations can be implemented. By selecting a combination of monitoring; careful experimentation at the scale of mesocosms, compartments within Emiquon, and the entire Preserve; information sharing with partners who manage floodplain wetlands, backwaters, and lakes along the Illinois River; and use of predictive models to choose among management alternatives, the Conservancy should be able to achieve its goals and set an example that informs approaches to river management in North America and the world. Emiquon and other restoration projects also provide opportunities to test our basic ecological understanding of assembly rules for communities, importance and pattern of development of biotic vs. abiotic controls following disturbance, and factors that influence the resistance and resilience of ecosystem structure and function to natural and man-made disturbances.

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